

Niels Ole Finnemann:
Thought, Sign and Machine -
the Idea of the Computer Reconsidered

Translated by Gary L. Puckering

"Thought, Sign and Machine - The Computer Reconsidered" is translated from "Tanke, Sprog og Maskine", Akademisk Forlag, Kbh. 1994 by Gary Puckering.

The English e-text edition has been revised and slightly abridged by the author. The translation is made possible by a grant from The Danish National Research Council for the Humanities.

Date of publication of the e-text edition on the Web: February 15, 1999.

Address of this e-text: <http://www.au.dk/ckultur/f/pages/publications/nof/tsm/abstract.html>

Link to Niels Ole Finnemann's Homepage at: <http://www.au.dk/cfk/pages/php/finnemann.html>

©Niels Ole Finnemann 1999. All rights reserved. This text may be copied freely and distributed either electronically or in printed form under the following conditions. You may not copy or distribute it in any other fashion without express written permission from me. Otherwise I encourage you to share this work widely and to link freely to it.

CONDITIONS

1. You keep this copyright notice and list of conditions with any copy you make of the text.
2. You keep the Preface and all chapters intact.
3. You do not charge money for the text or for access to reading or copying it. That is, you may not include it in any collection, compendium, database, ftp site, CD ROM, etc. which requires payment or any world wide web site which requires payment or registration.
4. You may not charge money for shipping the text or distributing it. That is, you must give it away with these conditions intact. For permission to copy or distribute in any other fashion, contact me via email at: <finnemann@hum.au.dk>

Everything really moves continuously

Alan M. Turing

Author's note

The manuscript of this book was written during the years 1988-1993 and published in Danish in 1994 under the title, »Tanke, Sprog og Maskine - en teoretisk analyse af computerens symbolske egenskaber«. The manuscript has been revised and slightly abridged in connection with the translation. References to sources only available in Danish have been kept to a minimum. In addition, a number of clarifications of chief points of view have been carried out and, with regard to some points - particularly in connection with the concept of redundancy - the analysis has been elaborated.

Aarhus, June 1996
Niels Ole Finnemann

Table of Contents

Table of Contents.....	4
1. Overview.....	7
1.1 Framing the question.....	7
1.2 Earlier theories.....	12
1.3 The structure of the book.....	18
2. The origin of a new concept of information.....	31
2.1 Missing information - the thermodynamic demon.....	31
<i>Boltzmann's presentation of the problem.....</i>	<i>33</i>
2.2 The price of information - Boltzmann's dilemma.....	38
2.3 The sign and the designatum.....	41
2.4 The physics of thought.....	43
2.5 Thermodynamic biology?.....	49
2.6 Mathematics as an approximative model.....	53
2.7 Summing up.....	56
3. Missing information.....	63
3.1 Information as a function of energy.....	63
3.2 The problem of observation in 20th century physics.....	66
3.3 Energy and information.....	69
4. The language of logic and the logic of language.....	74
4.1 The truth of a sentence.....	74
4.2 The logic and the life of the sign.....	77
4.3 The idea of a mechanical decision procedure.....	85
5. The universal computer.....	91
5.1 The demand for physically defined symbolic forms.....	91
5.2 The demand for universality and the dissolution of mechanical and symbolic procedures.....	96
5.3 Formal and informational notation.....	106
5.4 The automatic, the circular and the choice machine.....	110
5.5 The universal computer as an innovation in the history of the machine and of mechanical theory.....	114
5.6 Written down by a machine.....	119
5.7 Turing's machine, consciousness and the Turing test.....	128
5.8 Consciousness in Turing's hall of mirrors.....	132
5.9 Symbol generative competence as a criterion of intelligence.....	139

6. The breakthrough of information theory.....	156
6.1 Informational notation.....	156
6.2 Information as random variation.....	163
6.3 Information and noise.....	175
6.4 A generalization of the physical information concept?.....	180
<i>Not the mathematical theory.....</i>	<i>181</i>
<i>Not a purely mathematical theory.....</i>	<i>183</i>
<i>The problem of noise and the ability to generate symbols.....</i>	<i>185</i>
... <i>nor a communication theory</i>	<i>188</i>
6.5 The semantic ghost.....	191
7. The semantics of notation forms.....	197
7.1 The expression substance and the semantic potential of informational notation.....	197
7.2 The expression substance and the sign function.....	199
7.3 Signal, sign and code - Umberto Eco.....	204
7.4 Eco's sign concept - »Signals« and »signs«.....	210
7.5 The redundancy concept.....	214
7.6. Redundancy in notation systems with limited inventories.....	227
7.7 Linguistic redundancy structures.....	248
<i>Writing - a system of expression and/or a language?.....</i>	<i>252</i>
<i>Redundancy and regularity.....</i>	<i>258</i>
7.8 The redundancy structure as a criterion for distinguishing between semantic regimes.....	261
8. Informational notation and the algorithmic revolution.....	272
8.1 The problem of noise theory.....	272
8.2 The redundancy concept in information theory.....	274
8.3 Linguistic, formal and informational mediation between the expression substance and meaning.....	277
8.4 The unique characteristics of informational notation.....	286
8.5 A notation that is not accessible to sense perception.....	290
8.6. The algorithmic thread.....	293
8.7 The multisemantic potential of the algorithmic structure.....	294
8.8 The algorithmic revolution.....	301
9. The informational sign function.....	309
9.1 The algorithm in the machine.....	309
9.2 The informational sign system.....	322
9.3 The computer-based sign.....	330
9.4 The properties of computer-based signs.....	341

9.5 The interface between the internal and the external.....	344
10. Epilogue.....	352
10.1 What is a computer?.....	352
10.2 A new technology for textual representation.....	366
10.3 Computerization of visual representation as a triumph of modern textual culture.....	368
10.4 One world, one archive.....	372
10.5 Modernity modernized.....	373
Literature.....	379

1. Overview

1.1 Framing the question

Throughout what is now the more than 50-year history of the computer a great number of theories have been advanced regarding the contribution this machine would make to changes both in the structure of society and in ways of thinking.

Like other theories regarding the future, these should also be taken with a pinch of salt. The history of the development of computer technology contains many predictions which have failed to come true and many applications which have not been foreseen.

While we must reserve judgement as to the question of the impact on the structure of society and human thought, there is no reason to wait for history when it comes to the question: what are the properties which could give the computer such far-reaching importance?

The present book is intended as an answer to this question.

The fact that this is a theoretical analysis is due to the nature of the subject. No other possibilities are available because such a description of the properties of the computer must be valid for any kind of application. An additional demand is that the description should be capable of providing an account of the properties which permit and limit these possible applications, just as it must make it possible to characterize a computer as distinct from a) other machines whether clocks, steam engines, thermostats, or mechanical and automatic calculating machines, b) other symbolic media whether printed, mechanical, or electronic and c) other symbolic languages whether ordinary languages, spoken or written, or formal languages.

This triple limitation, however, (with regard to other machines, symbolic media and symbolic languages) raises a theoretical question as it implies a meeting between concepts of mechanical-deterministic systems, which stem from mathematical physics, and concepts of symbolic systems which stem from the description of symbolic activities common to the humanities. The relationship between science and the humanities has traditionally been seen from a dualistic perspective, as a relationship between two clearly separate subject areas, each studied on its own set of premises and using its own methods. In the present case, however, this perspective cannot be maintained

since there is both a common subject area and a new - and specific - kind of interaction between physical and symbolic processes.

It immediately becomes obvious that such a description of an interaction between physical and symbolic processes *can* be of significance for theories of consciousness and the way this problem presents itself in existing research has also given rise to the formulation of hypotheses regarding cognition and consciousness. The question as to the significance of theories of consciousness, however, is not simply whether we are considering a form of interaction which can be regarded as a model of human consciousness - or the other way around, whether the machine can think. It is also a question of the conceptualization of physical and symbolic phenomena which have been of significance as preconditions for the discovery and development of computer technology and, perhaps most decisively with regard to the result, of the conceptualizations used in the hypotheses on consciousness and thereby in the definition of what is interacting. The description must therefore also include a theoretical and historical account of the concepts used in describing the physical, symbolic and conscious.

In consequence the book takes its point of departure in a description of the theoretical preconditions for the modern computer with emphasis on two separate, yet parallel tracks.

One of them runs from Ludwig Boltzmann's statistical thermodynamics from the latter part of the last century to Claude Shannon's definition of the information concept in his mathematical communication theory from 1948. The other originates in mathematical logic from the first third of this century with Gödel's proof as the theoretical turning point from which the English mathematician Alan Turing started in 1936 when he described the principles of a universal computing machine by showing how any finite formal procedure can be carried out as a sequence of very few and simple, mechanical processes.

While these innovations in the history of mechanical theory are remarkable in themselves and are regarded as necessary preconditions for the development of the modern computer, the analysis leads to the conclusion that mechanically based symbol theories are neither adequate to describe the symbolic properties of consciousness nor those of the machine.

The basic argument for this position - as far as consciousness is concerned - is to be found in the fact that the concept of human consciousness and intelligence must at least include the ability to generate its own symbolic units of expression, while the precondition for mechanical theory is an already given set of invariant units.

If there is a similarity between the computer and human consciousness, it will thus consist in the fact that neither of them are subject to a definite, invariant set of rules for the representation of meaning.

While consciousness can be described as a rule *creating* system possessing the ability to produce symbolic rules, the computer can be described as a *rule free* system which, by virtue of this, can be used to represent and process an indeterminately large number of symbolic representations and a certain class of rules.

Where the machine is concerned the basic argument can be found in the condition that any rule whatsoever which must be carried out by a computer must appear in the same notational form and be treated in exactly the same way as all other data. It is therefore not possible - as is a precondition in mechanical theory - to define any invariant borderline between the machine and the material processed in the machine, between the rule and the regulated, between programme and data and between the knowledge implemented in the functional architecture of the machine and the knowledge processed in this architecture.

As a description of these characteristics cannot be carried out on a mechanical or formal basis the point of departure will be taken in sign theoretical concepts.

As sign theories - just like mechanical theories - are anchored in a dualistic thesis regarding the relationship between the physical and the symbolic, they do not provide a complete conceptual basis either. They have, however, two advantages which appear incompatible with a mechanical theory. First, because the existence of a once-and-for-all given set of rules for creating signs is not a precondition for the sign concept, whereas a mechanical system can only be imagined with the precondition of an invariant and preordained system of rules. Second, because a definite a priori assumption of the relationship between the physical and the symbolic is not a precondition for the sign concept either, whereas a given mechanical theory cannot be imagined without some sort of a priori assumption regarding this. In other words, by taking the point of departure in sign theories it becomes possible to include in the analysis the axioms which are a precondition for a mechanical theory. As sign theories on the other hand do not exclude the description of mechanical and other formal symbol systems in advance, they allow the theoretical openness which the subject demands.

The main thesis of this book is that the properties which characterize any use of computers and also characterize the computer as distinct from other mechanical technologies, other symbolic media and other symbolic languages, are determined by the symbolic notation form. This is primarily defined by the demand for mechanical execution, but - by virtue of this - it acquires a number of properties which justify referring to it as a new, independent notation system - called informational notation in the following - which differs both from formal and common language notation systems.

As this thesis implies an assertion to the effect that a computer is defined by this - unique - notation system, it also implies a negative assertion to the effect that it is impossible to provide a description of the computer's properties at a higher logical or semantic level (e.g. as a logical or thinking machine), if the description must both be valid for any application and be capable of characterizing this machine as distinct from other machines, media and languages.

I am thus claiming that a description of the computer as a logical machine is a description of a dedicated machine without the property of universality, while a description of a computer as a thinking machine is rejected because a computer - unlike a human being - does not possess the ability, so decisive for human intelligence, to produce its own notation system.

On the other hand I am claiming that a computer can be defined as a multi-semantic machine, by which I mean:

- That it is possible to use this machine to *process* symbolic expressions which belong to different semantic regimes - whether these are linguistic, formal, visual or auditive - with one restriction, that the expression processed can be represented in a notation system comprising a finite number of semantically empty notation units.
- That it is possible to *control* this machine with various semantic regimes subject to the same restriction, as this control can only be effectuated automatically for a limited class of procedures, while for others the precondition is continuous human intervention.
- That every process *performed* by the machine is carried out as a relationship between *at least two* semantic regimes, namely those which are laid down in the system and those which are contained in its use.

In continuation of this definition the conclusion will be drawn that the computer represents a new, general medium for representing knowledge, as it:

- is both a medium for the *production, editing/rewriting, processing, storing, reproduction, distribution and retrieval* of knowledge. It is thus possible to integrate the means of the production of knowledge (pen, paper, typewriter, calculating devices etc.), copy machines, books, book sales, libraries and postal services into a single and integrated physical and symbolic system.
- that it is both a medium for the *representation of auditive and visual forms of knowledge*, whether these belong to common languages, are formal, pictorial or auditive (e.g. music). It is thus also possible to incorporate in it modern society's most important symbolic languages and forms of knowledge in one single symbolic system.
- it is a medium for *communication*.

As a new, general medium for representing knowledge the computer is characterized by - what is in itself - an epoch-making integration of physical, social and symbolic functions which were formerly distributed among separate machines, institutions, media and symbolic languages. As this is not just a question of integration in one and the same medium (such as television, for example), but in one and the same notation form, which is defined by the demand for mechanical execution, this medium for knowledge representation has in addition a set of independent properties which also change the conditions and possibilities in each of the possible areas of use. These conditions and possibilities cannot be described under one heading and are therefore outside the framework of this book, but it is possible to point out at least four aspects of significance in all areas, namely:

- That a computer operates with an independent symbolic language which may also contain other symbolic languages.
- That there is no invariant borderline between the knowledge contained in the machine's symbolic architecture and the knowledge processed.
- That the symbolic control of the mechanical process allows a multiplicity of new forms for processing, organizing and retrieving knowledge.
- That a number of restrictions which were formerly attached to the invariant physical forms of symbolic media are here transformed into - free - facultative, symbolic restrictions, because the symbolic representation is available in a permanently editable form.

The following pages contain a presentation of the relationship of this thesis to previous theories, a broader description of the content of the thesis and an account of the construction of the book.

1.2 Earlier theories

If the existing scientific literature is grouped in accordance with its approach, it is possible to point out four different main sources which have made their mark on the understanding of computer technology.

First, there is a large group of *sociological theories* concerned with the transition from the industrial society to the post-industrial information and knowledge society. While the term information society itself appears to have been used for the first time in a Japanese futurological study,¹ the basic conceptualization stems from Daniel Bell, 1973, who emphasizes three overall features in the development: first, the growing extent of information work, second, the use of theoretical knowledge as a »strategic resource« and third, the development of new »intellectual technologies« such as the computer, the two last features, according to Bell, make a social diagnostics possible which can also be used to predict and hence prevent crises.

Where Bell in 1973 wrote cautiously of »axial principles« for future developments, only 13 years later James R. Beniger could show that it had now become almost trivial to refer to existing society as an information society (Beniger, 1986). Unlike Bell, who defined the new society in contrast to the industrial society, Beniger also stresses continuity, in that he sees computer technology as the latest step in the series of - energy-based - control technologies which have been created as a part of the establishment and stabilization of the modern industrial societies.²

¹ *The Plan for Information Society - a National Goal toward the Year 2000*. Japan Computer Usage Development Institute, Tokyo 1972. Source: Göranson & Josefson (eds.) 1988: 5.

² A great number of corresponding works could be mentioned. In a list of this literature Beniger, 1985: 4-5, mentions more than 80 different suggested descriptions for that state of society which is now generally referred to as the information society. A few examples will illustrate common features and breadth: *Posthistoric Man* (R. Seidenburg 1950); *Postcapitalist Society* (Dahrendorf, 1959); *End of Ideology* (Bell 1960); *Computer Revolution* (Edmund C. Berkeley, 1962); *Knowledge Economy* (Machlup, 1962); *Postbourgeois Society* (Lichtheim 1963); *The Global Village* (McLuhan, 1964); *The Scientific-technological Revolution* (Radovan Richta et al., 1967); *Neocapitalism* (Gorz, 1968); *The Age of Information* (Helvey, 1971); *Limits to Growth* (Meadows et al., 1972); *Post-industrial Society* (Touraine, 1971, Bell, 1973); *The Third Industrial Revolution* (Stine, 1975, Stonier 1979); *Telematic Society* (Nora & Minc, 1978); *The Gene Age* (Sylvester & Klotz, 1983).

Second, there is a group of *cultural and philosophical analyses*, partly linked to the concept of the postmodern, partly to concepts of thinking machines. As an exponent of postmodern theory, mention can be made of Francois Lyotard's description (Lyotard, 1979) of information as a radical break-up of the conditions for knowledge structures - a new, postmodern scene where hope is linked to the sublime, beyond the rational, deterministic islands in the postmodern ocean.

Where the postmodern understanding alludes to a contrast between controlling, mechanizeable rationalism and human thought, the theories of thinking machines are built up around the idea that it is also possible to describe consciousness as a finite, reproducible information or symbol system. There is thus clear agreement regarding the understanding of the machine, but of the opposite with regard to human thought.

The theories of thinking machines can be traced back to Turing, 1950, but are given a more elaborate and ambitious formulation by Newell, Shaw & Simon, 1961, and Newell & Simon, (1976) 1989. The philosophical aspects are discussed on the basis of different perspectives by such authors as Bruce Mazlish (1967) 1989, Hubert Dreyfus, (1972) 1979, H. & S. Dreyfus, 1986, Pamela McCorduck, 1979, Douglas Hofstadter, 1979, John Searle, 1980, David J. Bolter, 1984, John Haugeland, 1985 and Theodore Roszak, 1986.

A third approach to the computer can be found in *the literature on the history of technology*, but this is particularly concerned with the development of hardware and consists largely of descriptions in which the computer is seen as a further development of the automatic calculating machine, such as in Herman Goldstine, 1972, N. Metropolis et al. (eds.), 1980 (with a number of contributions from computer pioneers), René Moreau (1981) 1984, Bryan Randell, 1983, Michael R. Williams, 1985.

Although this literature provides widely differing descriptions and evaluations of the significance of the computer, there is a general consensus in seeing it as a key technology which - for better and/or worse - allows an epoch-making leap forward concerning the possibilities for social regulation and control. Despite all other disagreement, the computer appears as the almost perfect - perhaps not fully developed - automatic calculation, control and prediction machine.

This common, and basically control-theoretical understanding of the computer is not completely unfounded, on the contrary, it is clearly in harmony with the ideas which dominated the fourth group of main sources re-

garding the understanding of the computer up to the 1980's, namely those theories which created the basis for *computer development research*.

Among the earliest exponents, mention can be made of Alan Turing's theoretical description of the universal computer (1936) and John von Neumann's and others' description of what has since become known as the von Neumann machine (Neumann 1945), (Goldstine & Neumann, 1947-48). But the first general formulation of a control-theoretical understanding makes its appearance in Norbert Wiener's interpretation of the computer as a cybernetic system, (Wiener, 1948 and 1950). Wiener also laid the foundation for the later discussion regarding social implications in raising the question as to whether the machine could be used as a centralistic, bureaucratic administration instrument which would make Thomas Hobbes' *Leviathan* look like a pleasant joke.

The control-theoretical understanding can be rediscovered in new forms in the classic AI description (Allan Newell, Cliff Shaw & Herbert A. Simon, 1961), in the reformulated AI descriptions which appear in Cognitive Science (e.g. Zenon Pylyshyn, 1984) and a number of accounts on information theory, (e.g. Børje Langefors, 1966) where the machine is defined by its computational process which is described as an independent, finite, mechanically performed symbolic procedure which operates on the basis of a previously established rule structure.

The core of this literature was created around the basic symbol-theoretical thesis of classic AI, according to which a »physical symbol system« comprises a set of physical units of expression which can be joined together in sequences and of a set of rules which can transform a given sequence to another.³ But the group also includes theories which transfer concepts which were developed to describe other linguistic media (whether general or formal languages) to the description of the computer and theories which consider concepts developed to describe computational processes as general symbol concepts. All these theories assume, implicitly or explicitly, that informational notation builds upon the principles of formal notation.

Loosely speaking, the control-theoretical descriptions cover what happens in the time that elapses from the moment a programme is started until it has been carried out as an automatic - and here that also means mechanical - procedure. They are founded upon the basic assumption that the programmer

³ Newell & Simon, (1976) 1989: 112-113. The thesis is quoted and discussed in chapter 5, 9 and the epilogue.

and the user can be ignored in the description of the symbolic properties and thus see the machine as an autonomous, linguistic or cognitive agent.

In this respect the control-theoretical understanding also includes the »connectionist« theories of Cognitive Science (e.g. J.L. McClelland, & D.E. Rumelhardt (eds.) 1986) as the symbolic process is also described here as a finite, mechanically performed procedure. But as these relinquish the essential control-theoretical demand for a rational description of the symbolic rule structure, the latter group of theories can also be seen as a phase in the break with the control-theoretical understanding which, for the past ten years, has also been the subject of growing criticism from other quarters.

In continuation of this a number of other theoretical descriptions of the computer have emerged in which the idea of describing the machine as an independent and automatic manipulator of symbols has been abandoned in favour of a description of various forms of relationships between system and use. Where the machine was formerly understood as an automatic calculating machine, a mathematical and/or logical manipulator of symbols, or literally as a thinking machine, it is now also understood as a tool, as a plastic, freely designable material or as a (communicative and interactive) medium. Exponents of these views include Alan Kay & Adele Goldberg, 1977, the American Human Computer Interaction tradition, such as Norman & Draper, 1986, Terry Winograd & Fernando Flores, 1986, Scandinavian system development theory, for example Pelle Ehn, 1988, while P. Bøgh Andersen, 1991 and Andersen, Holmqvist and Jensen (eds.) 1993, describe the computer, on a semiotic basis, as a medium.

This development in the theoretical description of the computer can be regarded as a differentiation between an increasing number of competing descriptions, but can also be seen as a theoretical expression of a differentiation of possible kinds of use, not least promoted by the appearance of small, inexpensive personal computers which at one blow made a broad range of previously poorly exploited applications accessible to a much greater group of potential users.

While the control-theoretical approaches correspond to uses which emphasize automatic procedures (numerical control of other machines, the performance of complex calculation and control tasks, mechanical pattern recognition etc.), the tool and medium-oriented approaches correspond rather to uses based on continuous human interaction (whether text and image processing, database retrieval, the use of decision supporting systems, virtual reality etc.).

Both points of view imply, however, that it is a question of a differentiation in the understanding of the computer which raises doubts regarding that understanding of the machine on which the analysis of its social and cultural implications have been based.

In recent years a number of analyses have appeared which place considerably more emphasis on the many human choices which can have a significant influence on these implications - thus, for example, Shoshana Zuboff, 1990, who in addition to the automatic perspective emphasizes the informative perspective, as well as Andrew Feenberg, 1991. A similar tendency is evident in a number of detailed studies of the use of computers in companies, including analyses which stress the social and constructive elements in technological development.

By stressing human choice, the understanding of computer technology becomes linked to the question of the relationship between the respective competence of machines and humans and the relationship between control and democracy in the business community and in society.

Even if we subscribe to the - good - intentions in these confrontations with a deterministic understanding of technology, we still lack a description of the computer which will account for the properties which are common to every possible type of use and will explain how these properties can be exploited for the many - both good and less good - possible applications. The machine cannot simply be understood on the basis of the intentions implied in its use, it is also necessary to take into account the form these intentions will receive when implemented in this machine.

In other words we need a description that provides an account of the common platform which is the condition for the use of the computer, both as an automatic control and calculating machine, as a logical manipulator of symbols, as a tool, as a plastic, freely designable material, as a communicative and/or interactive medium (whether for word processing or virtual reality) and also describes the characteristic differences between these uses.

In its simplest form the problem is to explain how it is possible to use this machine both as a calculator and a typewriter. But the question must be treated subject to the condition that we can also use the machine to re-present an indeterminately large number of other both symbolic and non-symbolic processes. The description can therefore not take its point of departure in one or another specific use. Although the computer was created as a further development of the automatic calculating machine, it can no longer be understood by using the calculating machine as a model. We must rather say

the opposite, because that which separates the computer from the automatic calculating machine is precisely that which also makes it possible to use it as a typewriter.

While the computer and the calculating machine are both machines which can be used for calculation purposes, the computer can also be used to represent and perform other symbolic processes and a great number of non-symbolic processes. It is therefore necessary to describe how this machine differs both from automatic calculating machines and how it differs from other symbolic media and languages.

Mechanical procedures have also formerly been used for symbolic purposes (e.g. in the form of machines such as the calculating machine and the clock, or in the form of organized energy processes such as the telegraph, telephone and television). In all these cases, however, we are considering applications which are characterized by a single - or a limited set of - finite, invariant mechanical procedure(s) which establish the functional structure of the machine or tool in a repetitive process. The individual machines and tools can correspondingly be characterized on the basis of these finite procedures and these are again linked to a limited set of possible applications. A calculating machine cannot be used as a typewriter, a clock as a telephone and so on. Where the telephone, the telegraph, the typewriter, the clock and the television are concerned the mechanical procedure is completely independent of the symbolic content, whether this be the meaning or the symbolic rules. Where the calculating machine is concerned the symbolic rules (rules of arithmetic) are implemented in the invariant physical structure of the machine. In all these cases we can therefore speak of a clear, invariant division between the mechanical and the symbolic, between the physical apparatus and the symbolic material which is handled by this apparatus. In the computer, on the other hand, the mechanical procedure which establishes the machine's functionality is defined by the symbolic material which is processed.

This difference has sometimes been cited as a reason for describing the computer as a machine which is not defined by its physical organization but on the contrary by its - symbolic - programmability. Although this definition is both suitable and perhaps even necessary, it is inadequate for many constructive purposes. As a description of the machine's basic features it is also misleading, because the computer as mentioned can *only* carry out a programme by representing and treating it in exactly the same way as all other data.

While a decisive factor in the use of other mechanical technologies has been to avoid or minimize the material's effect on the machine's organization and mode of operation - or in some cases - to define invariant physical limits for such effects - the use of computers is based on continuous interference between material and machine.

It has sometimes been claimed that this property is not peculiar to the computer and reference has been made to such areas as the cybernetic feedback procedure used in physical thermostats. The comparison is excellent because it can contribute to a more precise definition of the difference. While a precondition for informational feedback in a thermostat is that the same physical state - for example the temperature - always has the same informational meaning and mechanical effect, the computer on the contrary is characterized by the fact that the same physical state - in the electronic circuit - can have changing informational meaning and be connected with changing effects. While the thermostat is defined by an invariant and closed body of information which has been implemented once and for all, the computer is defined by a variable and open body of information as there is no invariant borderline for interference between the knowledge which is part of the machine's construction and the knowledge which is part of its use.

The computer, however, is not the only tool which is characterized by this type of interference between tool and material. The same is also true of common languages and this characteristic thereby links these two media for the expression of knowledge.

1.3 The structure of the book

The general sequence of this book moves from a description of the development of mechanical theory on local, finite systems, partly in mechanical physics (chapters 2-3 and 6) and partly in mathematical logic (chapters 4-5) to a description of the informational sign's physical, notational, algorithmic-syntactic and semantic levels (chapters 6-9). In the book's penultimate chapter (chapter 9) the analysis is outlined in relationship to more recent, semiotically-based descriptions of the computer, one an American, Peirce inspired, the other a European, Hjelmslev inspired description, namely those of James H. Fetzer (1990) and Peter Bøgh Andersen (1990). The final chapter, the epilogue, contains an account of the theoretical considerations on the nature of symbolization which have been of significance for the present analysis.

As the book concerns subjects which are traditionally classed as mutually separate areas the following contains a short summary intended to provide an overall perspective of its sequence.

It has generally been accepted that the various post-war information theories have their roots in theories of physics and particularly in the German-Austrian physicist Ludwig Boltzmann's statistical formulation of thermodynamics from the end of the last century. In interpreting this connection authors have often been content to supply a rather short summary of Boltzmann's work emphasizing his mathematical-statistical definition of entropy as a yardstick for the degree of »disorganization« in a closed physical system. The many references to, but few expositions of, Boltzmann's deliberations have motivated a more extensive treatment. This treatment led my attention to another area which has been overlooked in discussions of information theories, namely the break-up of the physical theories on mechanical processes, which is a central theme in Boltzmann's theoretical and philosophical considerations regarding mechanical theory. Although Boltzmann has had no influence on the reinterpretation of the mechanical theory contained in Alan Turing's theory on the universal computer, (which is discussed in chapter 5) he nevertheless anticipated many of the questions that arise in this connection, just as he established a theoretical model for describing local and closed systems based on an arbitrary subdivision of an - imaginary - finite space.

Where nature was understood in classical physics as a huge, coherent machine, Boltzmann's view is rather a question of an understanding of nature as a number of small, finite machines and, as perhaps the most far-reaching point considered in retrospect, of the germ of a break with classical physics' definition of matter on the basis of its - outer - extent and form. While this definition binds form to its material substratum, (expressed, among other things, in the demand that physics should supply a mathematical abstraction corresponding to physical reality), Boltzmann's statistical description model paved the way for an emancipation of the form concept which would become the point of departure for what - considered as a whole - can be described as a neo-Cartesian paradigm of information theory.

The paradigm of information theory, which has been of decisive importance for the emergence and development of computer technology, takes over the mechanical and dynamic process perspective formulated in the energy theories of 19th century physics, but at the same time releases the understanding of the mechanical process from the physical binding to matter with the resulting

development of an abstract, mechanical description model which can be applied to an arbitrary area of matter - whether physical, biological or psychological.

Whereas the mechanically based information theory follows Descartes in the sense that it describes informational processes in the way Descartes would describe the external, physically extended world, for the same reason it breaks with the Cartesian construction because it now includes the - for Descartes detached - consciousness in the same world of time and space.

Chapter 3 provides an overview of the development of the physically-based information concept - from the physical to the symbolic - up to Claude Shannon, while in chapter 4 there is an overview of a parallel line of development - but now from the symbolic to the mechanical - in mathematical logic which leads to Alan Turing's theory of the universal computer - with a glance at the almost contemporary sign theories of Ferdinand Saussure and Charles Peirce.

Turing's theoretical description of the principles of an universal computer are discussed in chapter 5. This theory, which occupies a central position in any discussion of the theory of computers, is treated here with particular emphasis on its new interpretation of 1) mechanical theory, 2) the informational notation form and 3) the use of algorithmic procedures for the mechanical linking of mutually separate physical-mechanical individual states, in that his contribution regarding these three points is central to the description of the physical and algorithmic levels of the informational sign system. The point of view taken gives rise to a partial reinterpretation of the theory as emphasis is placed on features which Turing himself did not accord the same weight and because the conclusions which are drawn are of a nature he would hardly have been able to imagine. This is first and foremost true of the description of the notation form which is necessary for mechanical performance and of the character of the universality of the machine.

This re-reading of Turing can naturally be discussed. But the choice of Turing's theory as a point of departure for the description of the physical basis of the informational sign system can also be discussed - a) because the »Turing machine« is not subject to the same finite conditions as actual, physical computers - b) because Turing did not exploit the properties connected with the separation of programme from control unit - c) because he was unable to take into consideration the later developed random access memory - d) because he worked within the image of a traditional, physical-mechanical machine - and e) because he worked on the presupposition that all symbols were perceptually

identifiable. The analysis of Turing's work, however, provides several important results; among them:

- That on the basis of his understanding of a mechanical procedure as a local determination between two and only two steps, he laid the foundation for a radical dissolution of the physical-mechanical machine into its smallest »atomic« components.
- That with his description of how a formal expression could (and should) be converted to a mechanically active notation form, he laid the foundation for the informational notation system although he failed to notice the decisive distinction between formal and informational notation.
- That he found the syntactic means - namely algorithmic organization - which could be used for organizing both the physical process and the mechanical handling of semantic values. While Turing believed that algorithmic organization itself must be controlled by an integrated mathematical or logical semantics, later developments have shown that the algorithmic organization of a »Turing machine« is open to a multiplicity of semantic regimes whether mathematical, logical, linguistic or pictorial.
- That his theory, although he and many who came after him understood it as a theory of a universal automaton, nevertheless contains a more comprehensive description of computers, as the automatic function alone is linked to the performance of a certain - comprehensive, but not universal - class of calculation tasks. Confronted with other tasks, Turing characterizes the same machine as a choice machine. Whether we wish to use this term or not, it does indicate a more comprehensive functionality.

In later chapters it will be claimed that the possibility of choice is decisive for an understanding of what is called here the computer's multisemantic potential.

Turing's description of the computer, however, lacks two significant features. One is a description of the properties related to the separation of programme and control unit. This separation was explicitly described for the first time in 1945 by John von Neumann and Herman Goldstine and implies that any part of a programme whatsoever can become an object for processing, just as any data element can be utilized in a programme function. That a programme can only be carried out when it functions as data, however, was first clearly formulated at the end of the 1950's by John McCarthy in his description of a programme as a simple list of instructions and his creation of

the programming language, LISP, on this basis. In the present work the theme is treated in connection with the more general development of algorithmic handling competence which is described as a transition to a second-order handling or algorithmic handling of algorithms.

The second feature lacking in Turing's theory is the physical definition of the machine's notation system which is independent of human perception. Although Turing mentions this aspect in a footnote - and makes it clear that mechanical »reading« depends entirely on the definition of the symbols' physical form - he fails to take into account the possibility of completely ignoring the demand for perceptual recognition and the possibility of utilizing an entirely arbitrary definition of physical values and, as already mentioned, failed to note any qualitative difference between formal and informational notation either.

The definition of notation units independent of perceptual recognition, on the other hand, were familiar in the technical sphere, where for half a century work had been performed on invisible information *transport* in connection with such media as the telephone, radio and television. It was also an engineer, Claude Shannon of Bell Telephone Laboratories, who formulated the first theory on invisible informational entities, defined solely on mathematical-physical criteria. Shannon's theory has also had great influence in other ways, both on later information and computer theory, but is used in the present context particularly as a primary source for describing the informational notation system and the redundancy functions which belong to it.

This understanding of Shannon's information concept as a theoretical definition of a - new - informational notation system breaks with Shannon's own, more general understanding of the information concept, but it also differs from much - not least - linguistic criticism of Shannon's a-semantic information concept because the concept, seen as a contribution to the construction of a new notation system, is maintained here as an extremely useful theoretical and operational asset.

These deviations from former interpretations of Shannon's information theory have set their stamp on the following part of this account because they raise several questions regarding the theoretical basis for describing informational signs. This is true with regard to Ferdinand Saussure's and Louis Hjelmslev's distinction between the concepts of expression substance and expression form and the relationship of the expression substance to the sign function, as well as with regard to Umberto Eco's distinction between »signals« and »signs«.

From a linguistic point of view it would perhaps be tempting to keep to an established, theoretical foundation for as long as possible and thereby make a point of maintaining or adjusting the individual concept in rigorous accordance with the existing conceptual inventory. But with the point of departure given here it might be more appropriate to see the relationship between the informational sign system and existing linguistic theory as a contrapuntal relationship where the concepts used to describe the informational sign system have, on the one hand, roots in linguistic theory, but on the other have their meaning established in relative freedom in order to prevent that which is new from drowning in old meanings.

The problems which emerge in connection with a linguistic description of the computer can hardly be collected in a general form as they not only depend on the computer's properties, but also on the linguistic theory chosen. The only practicable course has therefore been to include the linguistic theory on the basis of its relevance to the description of the informational sign system.

These sources (primarily Ferdinand Saussure, 1916, Louis Hjelmslev, 1943, Umberto Eco, 1968 and 1976 and Eric A. Havelock, 1982) were not chosen to ensure linguistic representativeness, but because they were considered suitable for illustrating various aspects of the relationship between common language, speech and writing, and the informational sign system.

The linguistic material is primarily included as part of a comparative analysis of various forms of the use of notation systems (spoken and written language and formal language) and the relationship between various forms of redundancy used in these systems.

Redundancy is understood in a broad sense as a sounding board which makes distinctive expressions possible. The concept is used in music theory to describe such things as recurrent patterns which are varied. It is evident from this that the sounding board itself is part of the musical expression manifested which can be separated from the physical background noise. While the concept on the one hand is thus defined by the demarcation between the symbolic sounds (of music) and other sounds, on the other it is defined by the demarcation between the »more« distinctive from the »less« distinctive musical symbols.

In a sense, the two definitions are circular because the musicality as such is manifested in distinctive musical symbols. A given musical sequence can in one sense belong to the redundant sounding board for other distinct musical expressions, while in the other sense it manifests itself as such a distinct

expression. Due to this structure a given element in an expression system *can* therefore also manifest itself as redundant and distinctive at one and the same time.

Although - or precisely because - it is impossible to define redundancy as a concept with an invariant feature it may well fill the bill in the description of all symbolic expression forms. However, as redundancy is regarded as a key concept in describing structural differences between expression systems, a more precise definition is also given according to which redundancy is understood as repeatable patterns, structures or systems which:

- are characterized by the possibility for optional variation in the strength of meaning of a given pattern and/or variation in the meaning content of a given pattern
- allows - or depends on - optional use of pattern deviation and pattern variation as a means of content variation.

The concept of redundancy is used here as an alternative to the concept of linguistic structure. At a theoretical level the most important purpose is to dissolve the conceptual borderline between the concept of linguistic structure and usage which has had axiomatic status in many areas of linguistics in the 20th century. This dissolution is first and foremost motivated by the fact that the rule structure of language can itself become the object of semantically motivated changes, including in addition the creation of new rules which are not defined by the established rule structure, but also by the relationship to the non-linguistic substances - whether the expression substance or the meaning.

It may be possible to claim that this loss of conceptual precision, which will necessarily be transmitted to other concepts, is an expression of a more precise picture of the relationship between language rules and usage, but in any case the redundancy concept allows a better understanding of the relationship between the different levels of the symbolic expression, from the physical, through notation, to the syntactic and semantic, as the common question at all of these levels is how to bring about expression distinctiveness in a given symbolic language, partly relative to the underlying level and partly relative to other distinct expressions at the same level.

As the primary aim has been the analysis of the informational sign system, emphasis has been placed on a comparative description of structural differences to other symbolic redundancy structures at the level of notation

forms. The intention was thus not to fulfil the need for a more exhaustive analysis of the redundancy structures of different symbolic languages.

The overall result of this analysis is that the different symbolic expression media, spoken and written language, figurative and formal representation, are characterized by the differences in redundancy structure at all levels, in the physical articulation, in the notation system, at the »syntactic« and semantic levels.

Although there are considerable differences between the redundancy structures of spoken and written language, they do have a common feature which both separates these symbolic expression formats from both figurative and formal formats, as the smallest expression units in the former languages manifest themselves as redundant and distinctive expressions at the same time. This double articulation is closely connected with the fact that the smallest expression units, which are also the smallest semantic variation mechanisms, are smaller than the smallest content units.

On the other hand figurative and formal expressions are characterized by the absence of specific, redundant expression manifestations.

Where pictures are concerned this absence is described as a consequence of the fact that there is no fixed, pictorial notation structure in the form of a limited set of expression units, as the creation of pictures depends on the creation of form through an indeterminately large number of possible colour variations.

Where the formal expression is concerned, on the other hand, the absence is described as the result of a semantic operation: The formal expression depends on the declaration of prescriptive rules or values which establish invariant, semantically distinctive values for each individual expression unit. The formal expression has a fixed notation structure and an arbitrary number of expression units each demanding a specific declaration as a member of the notation system. The smallest unit of the formal expression cannot be manifested as redundant and distinctive at the same time. The prescriptive declaration thereby allows the intended elimination of the linguistic redundancy structure and takes the place of the linguistic redundancy by manifesting itself as a stabilizer of meaning.

The meaning of the redundancy concept in the informational notation was demonstrated for the first time in Shannon's theoretical analysis of physical information transport, as the physical definition of informational entities includes both a definition of the informational entity relative to the physical medium and relative to other informational entities.

Shannon, however, confined himself to an analysis of redundancy at the notation level with the result that while he could certainly define a physical scale for informational entities in the form of fixed, recurrent physical signals which appeared with a calculable, statistical probability, he could not separate distinct, meaning-carrying physical notation forms from the occurrence of *noise in the same physical form*.

Although his intention was to formulate an a-semantic theory Shannon assumed - apparently unconsciously - that this distinction would be carried out on semantic lines.

He thereby overlooked the fact that the semantic level is not only of significance for the choice of distinctive notation elements, but also for the redundancy structure which is a condition for semantic distinctiveness. Shannon's redundancy concept can not therefore be used in the analysis of the syntactic and semantic structures which characterize different uses of a given notation system. Nevertheless he indicates a method by which the semantic legitimacy of informational notation can be ensured by adding an extra coding, which is independent of (and has no disturbing effect on) the semantic content of the message, to the informational expression. Shannon therefore refers to this procedure as a means of ensuring the content of the message by increasing the redundancy.

Shannon's analysis thus shows not only that the redundancy function plays a central role for the stability of the informational notation system - which is not the case with formal notation - but also that the redundancy function is completely different to linguistic redundancy functions because informational redundancy can, on the one hand, be defined independently of the semantic regime in which the message appears and, on the other, must be expressed as an independent sequence of notation units which is added to the given message. This is thus also solely a question of redundancy in relationship to the meaning content of the message and not in relationship to the notational expression. This use of a formal semantic as a redundancy function is unique to informational notation. As the formal coding which is added does not change the meaning of the message, Shannon's analysis shows in addition that the content of a formal procedure can be a function - variable to the point of weakness of content - of other semantic regimes.

While the mechanical performance of the algorithmic procedure presupposes informational notation, the algorithmic procedure is itself a precondition for the simultaneous, mechanical and symbolic use of informational notation. It is this relationship between informational notation

and algorithmic syntax which differentiates the computer from other dynamic media such as the telephone, radio and television and gives the machine its unique symbolic properties. Implemented in this machine, however, the algorithm takes on new properties at the same time because - due to the synchronically manifested representation - it becomes possible to work systematically with the algorithmic handling of algorithms.

The description of algorithmic syntax therefore includes a general description of the dynamic and arbitrary second-order handling of algorithms and a description of the linguistic dependency of the algorithmic structure.

The fact that the term algorithmic second order handling is used here instead of the commonly used notion of algorithmic complexity, is due to three factors in particular.

First, the term points directly towards the new qualitative moment which is linked to the self-referential aspect: the algorithmic expression is handled with the help of - other - algorithmic expressions, while the notion of complexity primarily refers to a more complicated algorithmic handling of something which is non-algorithmic.

Second, the term points, albeit indirectly, towards an underlying connection to more comprehensive developments within the history of ideas, often referred to as »the linguistic turn« characterized by the assimilation of linguistic representation in the subject area of a number of disciplines.

Third, the term »second-order handling« is a more precise expression for the dynamic procedure as it is realized in the computer, as every step here is defined as a relationship between two elements. Although each of these elements is related to a multiple of algorithmic structures, there can be only one relationship at each step, where one element from one informational sequence appears in one relationship to one element from another.

This definition of the algorithmic second-order procedure is not exhaustive, but makes it possible to point out two invariant features which differentiate it from the algorithmic first-order procedure.

- While the algorithmic first-order procedure can be characterized by the possibility of uninterrupted execution, the algorithmic second-order procedure is characterized by the possibility of an arbitrary interruption. As such an interruption allows a facultative continuation, the algorithmic second-order procedure is described as a semantically open, syntactic structure. Chapter 9 contains an argument that this openness, which creates the foundation for multi-semantic potential, not only includes different formal semantic regimes,

but also informal regimes, *in so far* as they can be articulated in a notation system with a finite number of expression elements.

- While the uninterrupted execution of first-order procedures is based on an established sequentially progressing regularity, where a given element is either defined by the preceding step in the algorithmic procedure or by previously established rules and definitions, the individual element in a computational algorithm is exclusively defined by the actual state of the total system. To the extent that previous states have not been deleted, the synchronic structure therefore allows an arbitrary use of previous states. The previous states, on the other hand, have no influence on the later which cannot be suspended or ignored.

As the synchronically manifested expression contains all rules, any rule can become the object of a semantically motivated modification, alteration or suspension. The synchronic structure, however, can only be handled through a diachronically organized process which is subject to the demand for step-by-step transition which is defined by the relationship between the total system's actual state and the next - binary - notation unit.

We can therefore conclude that the informational sign system at the syntactic level is characterized both by a synchronic and a diachronic redundancy structure. The synchronic redundancy structure comprises the total system as manifested in a given state, excluding the notation which defines the next step. Nor, as this notation can consist in a new input, does the diachronic »syntax« only include the internal computational structure, but also the chosen input structure. Within the diachronic structure, the synchronic structure does not therefore appear as an ordinary syntactic structure either, but rather as a - complexly composed - singular notation unit which can be subordinated to another, complexly organized input structure, which again can be an expression of different semantic regimes or purposes because the input structure not only allows formally finite - calculative or logical - regimes, but also informal regimes. In the diachronic sequence the smallest expression unit (and smallest semantic variation mechanism) consists of the actual state of the total system plus the next notation unit.

In continuation of this description, I claim finally that the semantic restrictions of the informational sign system alone are contained in the demand that a given semantic expression be present in a notation system with a finalized, established number of expression units.

In addition to the general restriction there is also a technological and historical restriction, as there is a semantic restriction in the relationship between the time taken by physical processing and the time taken by human perception, because different semantic articulation forms demand a different degree of dissolution and rebuilding in order to be represented in a discrete notation system. It is thus insufficient to subdivide a picture into informational entities. Pictorial representations also presuppose that the machine can operate sufficiently rapidly to transpose the serial representation in what is to us a simultaneous, visually recognizable form. As the time occupied by physical processing is not restricted by the speed of human perception, this restriction is relative to technological competence and not to that of the speed of human perception.

The informational sign system can therefore not only be subordinated to all the semantic regimes which already use fixed notation systems, but also - through a suitable subdivision of the expression form - semantic systems which do not. It is thus characterized by the fact that not only the notation system, but also the syntactic structure have a multi-semantic potential.

Finally I claim that the multi-semantic potential of the syntactic structure differentiates the computer from other machines and expression media and confers on it its far-reaching civilizing significance, just as this structure also guarantees that the medium always retains that form of unpredictability which holds good for speech, writing, arithmetic and pictorial art. Although it is possible to describe the properties of these symbolic media and describe certain restrictions on the type of knowledge which can be expressed through them, it is impossible to predict the knowledge content expressed. Unlike other mechanical media it is true of the computer, as also previously mentioned, that there is no invariant borderline between the knowledge which is included in the functional architecture of the medium and the knowledge which can be expressed.

In the penultimate chapter there is a more detailed description of the informational sign system compared to James H. Fetzer's Peirce-inspired description of the computational process as a formal symbol process, characterized by the absence of the referential and interpretational functions in Peirce's sign concept and Peter Bøgh Andersen's Hjelmslev-inspired theory of computer-based signs.

With regard to Fetzer's theory, which was formulated in opposition to the classic AI concept, the central objection is that with his acceptance of Newell

and Simon's symbol definition as an adequate definition of the computational processes (but not of the semiotic) he has in fact excluded a semiotic understanding of the computer medium.

Where Fetzer's theory is formulated in opposition to consciousness-theoretical elements in the classical AI concept, but not with the idea of the computer as an autonomous symbol machine, Bøgh Andersen's theory is formulated as a contribution to the development of new areas of application (e.g. »narrative systems«) based on a semiotic analysis, as he takes his point of departure in the interaction between the programmer, the machine and its user. Although the latter work was an important source of inspiration for the present work, the emphasis has been placed on differences and deviations.

In relationship to the description provided here, the most important divergence is that Bøgh Andersen (with reference to the linguistic definition of the expression form as the perceptible expression) assumes that the computer-based sign can be described at the interface level, while the underlying processes are regarded as expression substance or sign candidates which can be utilized in sign production. While this emphasis contributes to the development and analysis of the visually expressed semantic potentialities, it also creates an obstacle to the utilization of the non-visually expressed aspect of the informational sign.

The theoretical criticism of this definition of the borderline between sign and non-sign is based on the fact that the borderline between »system« and »interface« itself is manifested as a result of sign work, namely the programmer's. As the programmer, who creates the system and selects an interface, is himself a user and any sufficiently competent user can also take the programmer's place and alter the programme, the entire existing system must be regarded as part of the informational sign. The relationship between the programmer and the user must correspondingly be regarded as a relationship between several different - and always at least two - semantic relationships - for the same expression form and this expression form is, unlike other familiar symbolic languages, not defined by the demand for perceptibility, but by the demand for mechanical execution.

2. The origin of a new concept of information

2.1 Missing information - the thermodynamic demon

Modern information theories are in agreement concerning their origin in thermodynamics in the last part of the 19th century, more precisely the statistical thermodynamics of the Austrian physicist, Ludwig Boltzmann in 1872.¹

In spite of many references, however, most are more than sparing, often restricted to quoting Warren Weaver's remark that:

*Boltzmann's observation in some of his work on statistical physics (1894) that entropy is related to »missing information« inasmuch as it is related to the number of alternatives which remain possible to a physical system after all the macroscopically observable information concerning it has been recorded.*²

A laconic, but apposite clue. Information theory takes its point of departure in considerations of the way in which it is possible to calculate the indeterminate by describing indeterminacy as a quantity of a finite number of alternative, not yet decided possibilities. The hunt for the thus more narrowly defined, missing information became a central theme within both physics and the later information theory.

What is missing, however, and what more precisely takes its starting point here, is in dispute. The dispute is not simply concerned with the localization of a definite body of missing knowledge, but also with the interpretation of the epistemological implications. This is the reason why one and the same problem has given rise to different interpretations within physics and created the starting point for the paradigm of information theory. It is the latter clue which is central in this connection, but it cannot be pursued without a glance at physics, because the paradigm of information theory is not only derived from

¹ Boltzmann, 1872. Both Kronig, Clausius and Maxwell had anticipated the statistical point of view in thermodynamics during the 1850's, but it was Boltzmann who was the first to give it a precise mathematical form. Cf. P. & T. Ehrenfest (1912) 1959: 1-2, Prigogine, 1983: 405, Cohen & Thirring, 1983: V.

² Warren Weaver, (1949) 1969: 3. Despite a certain amount of work, I have not succeeded in verifying the term »missing information« in Boltzmann.

the concept of missing information in physics, but also appropriates other concepts from the thermodynamic reformulation of mechanical theory.

This chapter contains an account of Boltzmann's contribution to this reformulation, as he not only identified missing information with his foundation of statistical thermodynamics, but also established the conceptual framework which is the starting point for the paradigm of information theory. This is first and foremost true of his description of the physical problem of observation which is connected with the discrepancy between macro-physical order and micro-physical (molecular) »disorder«, his use and interpretation of statistical methods and his contribution to the development of the concept of finite space as an abstract and arbitrary system.

Together, these elements contain a basic renewal of the mechanical paradigm, because the mathematical description is developed here as an abstract model which can be applied to both physical and non-physical phenomena and processes. Thermodynamics hereby breaks with the understanding of the relationship between matter and form in classical mechanics and at the same time opens the way for the emancipation of mechanical theory from physics.

In classical mechanics physical matter is defined on the basis of form and extent, the form is understood as the defining property of matter and difference in form is interpreted as material difference. In statistical thermodynamics, on the other hand, form is defined as an independent structure which can organize an arbitrary material and the material is regarded - in Boltzmann still only latently - as amorphous and without structure. The same forms and structures can thus also be imagined as being incorporated in different domains/substances. Mechanical theory can now be thought of as a purely formal system of mathematical relationships which can be applied to an arbitrary physical, biological or mental substance. It is true that the demand of classical physics for a mathematical abstraction which corresponds to physical reality is not abandoned, but the demand is manifested as a descriptive ideal which cannot be fulfilled within the framework of classical physics.

The abandonment of a materially bound form concept, which opens the way for the development of mechanical theories in a number of new domains, also gives rise to another difficult problem, however, because the concept of amorphous matter removes the justification for a distinction between different domains - such as between the physical, the biological and the mental.

Given these far-reaching innovations, it is hardly surprising that several mutually different interpretations and answers are given. There are also two different paths which lead from Boltzmann's thermodynamics to the later

information theories. One takes its point of departure in the concepts of missing information and entropy and leads - as Weaver pointed out - directly to Shannon's mathematical theory of communication. The concept of finite space is here interpreted as physical space. The second path takes its point of departure in the concept of formally defined, finite space and passes, via mathematical logic, to Alan Turing's theoretical description of a universal computer. The concept of finite space is interpreted here as logical space.

The two different paths from the problem of observation in physics would later meet again, as both arrived at the idea that it must be possible to describe both biological, perceptual and conscious processes, as well as the content of consciousness as local, finite physically-mechanically performed processes which take place in time and space. The two paths together thus comprise a significant - although not the only - precondition for post-war information theories, cybernetics, theories of artificial intelligence, cognitive science and artificial life. As Boltzmann's theoretical deliberations took the same direction, his work also provides an early account of the epistemological problems which arise in the later efforts to use one and the same mechanical paradigm in the description of physical and biological processes, of the processes of the brain and consciousness and of the content of consciousness.

Boltzmann's presentation of the problem

Boltzmann's work as a physicist took its point of departure in thermodynamic theory as it had been formulated in the middle of the last century. According to the first law of thermodynamics the amount of energy in the world is constant and, according to the second law - the law of increasing entropy - nature is subject to a law of irreversible development which will gradually lead to the so-called »heat death«, where all differences in energy - and hence all kinds of organization - have been neutralized.³

³ The entropy concept (»transformation content« Greek: en + tropein) was formulated in 1865 by Rudolf Clausius, roughly at the same time as the energy concept (»work content« Greek: en + ergon). Both concepts were created as part of the recognition of the connection between the material forces of nature: mechanical, electrical, magnetic force and heat. Entropy is defined as a reduction of available energy as it degrades into unavailable (heat) energy. The relationship between the different types of energy was described as a relationship between higher and lower forms of energy. The idea was first formulated by Carnot who established a utility principle on the criterion of accessibility or inaccessibility, but this was gradually reformulated to a distinction between forms of energy of different ranks and quality by Lord Kelvin - alias William Thomson - and Clausius. Mechanical energy can be transformed into heat energy, while heat energy cannot be fully transformed into mechanical energy, which has a higher rank. The same is true of electricity, while chemical energy (e.g. combustion) occupies an intermediate position. The first formulation of the law of entropy as »heat death« stems from physicist Helmholtz in 1854.

The theory, however, could only be confirmed at a macro-physical level through a measurement of temperature and pressure conditions, it was impossible to account for the order of the individual particles in the thermodynamic system. Here, spectroscopic analyses had on the contrary provided evidence of a complicated micro-physical structure that could not be described on the basis of ordinary theoretical assumptions.

It was James Clerk Maxwell who had formulated the problem. Although it was not possible to observe the micro-physical processes, it was possible, noted Maxwell, to imagine an ideal observer, a »demon«, equipped with such refined, but scientifically describable means of observation that this, unlike the physicist, could observe each, individual molecule which moved within a closed physical system. He then demonstrated how such a demon could work as a kind of perpetual motion machine as it could move energy from a colder to a warmer place without performing any work, thereby undermining the second law of thermodynamics - on the degradation of energy. This does not, however, undermine the law of the constancy of energy, which means that there can be no question of a perpetual motion machine which is capable of producing energy from nothing.⁴

The talent of the hypothetical demon not only raised the question of micro-physical order, but also of how the micro-physical system, comprising a very large number of molecules moving in mutually uncoordinated paths and unceasingly colliding with one another, can still, at the observable, macro-physical level, show unchanged, constant properties.

Molecular thermal motions are most probably such that a given state of motion is not shared by a large group of neighbouring molecules, but that in spite of constant mutual influence each molecule pursues its own independent path, appearing as it were as an autonomously acting individual. One might therefore think that this autonomy of the parts would at once have to show itself in the external properties of bodies for example

⁴ Maxwell illustrated his argument with a suggested experiment: The starting point is the experimental knowledge that gas molecules in a closed container at a uniform temperature move at unequal speeds. The container is divided into two parts, A and B with a divider in which there is a small hole and it is assumed there is an observer (the demon) who can see the molecules and open and close the hole. If the observer opens and closes the hole so that the faster molecules are able to pass from A to B and the slower molecules from B to A, the temperature in B will rise, while it will fall in A. He has moved energy from a colder to a warmer place without performing any work, which is at variance with the second law of thermodynamics on the irreversible growth of entropy (in that his own operations are not seen as part of the system): Maxwell, (1871) 1970: 308-309. Cf. Goldmann, 1983: 122 ff. and Klein, 1973: 74-77.

*that in a horizontal metal bar the right and now the left end must become spontaneously hotter according as the molecules happen to vibrate more intensely at one or the other place, or that if in a gas a large number of molecules happen to be moving towards the same point at the same time, a sudden increase in density must occur there. However, we observe none of this, and the reason why this is so is nothing other than the so-called law of large numbers.*⁵

In another, more recent formulation, the question is posed as follows: how can a system made up of particles which obey mechanical laws that are invariant with regard to the direction of time nevertheless develop in a certain direction?⁶

Boltzmann's thesis was that it was necessary to give up traditional methods of description for the benefit of statistical methods designed to calculate the probability of a molecular system being in one or other of its possible states and then explain why a system could not move from a probable state to another, equally probable, state, but only to a more probable state.

Boltzmann assumed that there was a corresponding number of different combinations (imagined micro-physical states) for every macro-physical state. He hereby describes a given macro-physical state as a closed - spatial - system which is subdivided into an - arbitrary - number of smaller »phase spaces« so that it would be possible to describe the micro-physical (molecular) state on the basis of the distribution of the molecules in these phase spaces.

In the micro-physical system the most improbable state is characterized by the highest degree of order. This state corresponds to a situation where all molecules are concentrated in a single phase space. Entropy here is zero and the number of possible combinations assumes the minimum value 1.⁷ The most probable state is the opposite and characterized by maximum disorder, the energy has degraded to heat energy, the molecules are »spread throughout the system« and the number of possible combinations here assumes the maximum value for a given system depending on the number of molecules in the system.

⁵ Boltzmann, (1886) 1905: 33-34. English translation: Boltzmann, 1974: 19-20.

⁶ S.R. Groot, Boltzmann, 1974: 3.

⁷ The salient point here is that this description does not emphasize the question as to where molecules are gathered in the space - in which of the imagined phase spaces - but only as to the combinatory or structural distribution of the molecules relative to the phase space. It is also a precondition that the molecules move in discrete and instantaneous transitions between states, so that each particle at all times is in a certain phase space.

Boltzmann thus abandons a classic, fully deterministic prediction. But, he claims, entropy can be regarded as proportional to the number of possible combinatory states, expressed in the formula:

$$S = k \log W$$

where S is entropy, k a mathematical constant (later designated Boltzmann's constant) and W the thermodynamic probability which expresses the possible number of molecular combinations with the same macro-physical properties (same distribution structure).⁸

With this description of the system »as though« it comprised a large number of independent particles, each behaving individually in accordance with mechanical principles, Boltzmann had indicated a method for predicting the total state of the system with exactly the degree of statistical precision required, even though it was not possible to describe the behaviour of the individual particle.

The system was characterized by increasing molecular disorder (equal distribution of molecules throughout the system) or »progressive elimination of all original asymmetry«⁹ and it behaved, in spite of the molecular chaos, in accordance with the law of increasing entropy.

Hereby, Boltzmann believed, the problem of missing information in thermodynamics had been solved. The statistical and probabilistic description of the state of the thermodynamic system was a complete, exact description which could also reconcile the law of entropy with a classical, mechanistic and deterministic theory of motion.

The means to this was a new method where a number of - atomic - particles was described in relation to a finite physical space which was divided into smaller units and included all possible spatial positions. The idea of the finite space itself was presumably quite obvious as it is the epitome of the containers which were used to store various gases. Similarly, the purely formal or arbitrary subdivision of the space resembles a simple reference to the three-dimensional, spatial system of co-ordinates. But it nevertheless implies a break with the classical conception of nature as one - infinite - cohesive mechanical universe in favour of a conception of nature as a number of locally limited, finite

⁸ The - final - notation given here is from Max Planck. Thermodynamic probability is calculated as the possible distribution of molecules in a three-dimensional, geometric model of a given system which is imagined as divided into cells in which a given number of molecules can be placed. In the improbable state the molecules are gathered in one cell (thereby giving only one possible state). In the most probable state they are equally distributed in all cells (which would be the case for the maximum number of possible states of the system). Cf. Witt-Hansen, 1985: 49-50. Flamm, 1983: 265.

⁹ Witt-Hansen, 1985: 50.

systems. The break occurred as Boltzmann abandoned the description of the individual molecule's individual state in favour of the probable distribution state of the total system relative to a formal lattice structure in a closed space with a finite number of possible positions.

With this break the method of analytical subdivision becomes a completely arbitrary method, *as the analytical procedure is no longer a means to dissolve a phenomenon into its component parts, but on the contrary, a means to structure a formal reference system for describing - statistical properties of - phenomena independently of individual variations.*

But the solution had its price. The statistical description of molecular »chaos« could not be understood as a phenomenological description of molecular nature. Boltzmann's answer to the information that was missing on the individual particles meant that the door opened up on another area of missing information of a more fundamental, epistemological character. Namely the missing information which manifests itself as a difference between a deterministic, physical description and a statistical and probabilistic description.

There were two areas in particular which - notwithstanding the interpretation - were difficult to handle on the basis of the classical Newtonian paradigm in which force was described as an - in itself immaterial - function of discrete particles' mass and speed (or distance). One was the discovery and description of the many different types of energy. It was impossible to reconcile the Newtonian laws of motion, that described the meeting of particles as a collision, with the experimental examples of wave interference and transformations between the different energy forms. The second was the transition from a description of physically visible or perceptible phenomena to the description of physical micro-processes which could not become the object of directly perceived observations, but only be studied indirectly through macro-physical, recordable effects.

Both of these problems were generally acknowledged, the dispute was about - and is about - their implications. The most obvious - and at the time most common - starting point would have been a reformulation of physics based on wave theory, because thermodynamic theory pointed to energy as the basic physical substance. But Boltzmann, starting with a statistical description of the micro-physical system on an atomic basis, chose a different path.

His solution to the specific problem of description therefore necessarily brought about a re-interpretation of scientific epistemology and during the

1880's he turned increasingly away from the work on thermodynamics to questions connected with the epistemology of physics in general. This change of direction meant that he absented himself from the history of physics for a very long period. During this period his deliberations are seldom referred to and when they are, they are treated rather as an expression of a more outgoing personal and philosophical interest which had little relevance to physics.¹⁰ It is hardly possible to decide whether this was also the reason why he became tired of life, but a certain bitterness in his latest work indicates something of the sort. Boltzmann committed suicide in 1906.¹¹

2.2 The price of information - Boltzmann's dilemma

If Boltzmann experienced problems in gaining a deserved hearing for his theoretical deliberations, this was not least due to the fact that he was unable to accept the inability to solve a problem which - still unsolved - would become central to 20th century physics, namely the relationship between the descriptions of inorganic, micro-physical nature based on the wave and particle theories respectively and the relationship between the micro-physical and macro-physical levels.¹²

In his attempts to solve this problem Boltzmann started with the successful statistical description of molecular systems. This description was based on classical atomistic premises which now, however, had to be formulated as a statistical and probabilistic description. The mechanical procedures which were part of the description could not be understood as mechanisms which existed in nature:

If the molecules and atoms of the old theory [Newton's] were not to be conceived of as exact mathematical points in the abstract sense, then their

¹⁰ A large part of this work was published under the not particularly apposite title *Populäre Schriften* in 1905. According to Klein, 1973, Boltzmann's difficulties in making himself understood were due to the fact that he reformulated his position several times without explanation. Another of Boltzmann's problems, however, was that many physicists - including Maxwell, who was otherwise concerned with similar questions - considered him prolix and quasi-metaphysical.

¹¹ Flamm 1973: 13 and 1983: 274.

¹² The problem had already manifested itself in the divergence between Newton's and Huygen's understanding of light as respectively a particle or wave phenomenon. It became more urgent, however, because no progress had been made in clearing it up in spite of an increase in knowledge. It was no longer enough to »simply« differentiate between what was known and what was not yet known. The problem now lay in the relationship between the acknowledged laws of physics.

*true nature and form must be regarded as absolutely unknown, and their groupings and motions, required by theory, looked upon as simply a process having more or less resemblance to the workings of nature, and representing more or less exactly certain aspects incidental to them. With this in mind, Maxwell propounded certain physical theories which were purely mechanical so far as they proceeded from a conception of purely mechanical processes. But he explicitly stated that he did not believe in the existence in nature of mechanical agents so constituted, and that he regarded them merely as means by which phenomena could be reproduced, bearing a certain similarity to those actually existing... Maxwell himself and his followers [continued Boltzmann, thinking not least of himself] devised many kinematic models, designed to afford a representation of the mechanical construction of the ether as a whole as well as of the separate mechanisms at work in it: these resemble the old wave mechanisms, so far as they represent the movements of a purely hypothetical mechanism. But while it was formerly believed that it was allowable to assume with a great show of probability the actual existence of such mechanisms in nature, yet nowadays philosophers postulate no more than a partial resemblance between the phenomena visible in such mechanisms and those which appear in nature.*¹³

By looking at mechanical theory as a mental model which always and in principle only expressed an approximation *»bearing a certain similarity«*, according to Boltzmann a number of old questions disappeared of their own accord.

As we know that both material *»points«* and *»forces«* are simple mental images, we no longer need to speculate about how it is possible for a force to be emitted from a point which is simply a mental construction, or how points can be united and become extended. As it was also possible to refine the description of points and forces *»as closely as we please«* to an image of the spatial world, this re-interpretation could be depicted as a practical expansion - rather than a theoretical loss - of possible cognitions. This bore a similarity to the old dispute on the relationship between matter and energy. By looking at the theoretical concepts as mental images it was possible to avoid falling back on the old metaphysical debates as to whether matter or energy is *»truly existent«*.¹⁴

¹³ L. Boltzmann, (1902) 1974: 217-218.

¹⁴ L. Boltzmann (1899a), 1905: 216, 219. English translation, Boltzmann 1974: 91, 93.

Correspondingly, from another article:

All our ideas and concepts are only internal pictures, or if spoken, combinations of sounds. The task of our thinking is so to use and combine them that by their means we always most readily hit upon the correct actions and guide others likewise. In this, metaphysics follows the most down-to-earth and practical point of view, so that extremes meet. The conceptual signs that we form thus exist only within us, we cannot measure external phenomena by the standard of our ideas. We can therefore pose such formal questions as whether only matter exists and force is a property of it, or whether force exists independently of matter or conversely whether matter is a product of force but none of these questions are significant since all these concepts are only mental pictures whose purpose is to represent phenomena correctly.¹⁵

The theory thus allowed the Newtonian model to be preserved by understanding the concepts of both energy and matter as mental pictures which, in principle, were only capable of providing an approximative expression of certain traits in nature's organization.

The idea of the mental, pictorial character of mathematical physics itself is reminiscent of Descartes' theory of consciousness, but with the difference that the mathematical picture is now understood as a hypothetical approximation, the legitimacy of which depends on its appropriateness. Mathematical consistency is no longer a secure basis for a correspondence between concept and the conceived.

It can be mentioned in passing here that Descartes saw this correspondence as divinely given and certain. Boltzmann was also very much aware of the religious foundation of the epistemology of science, but attempted to eliminate its significance by pointing to the common - and inadequate - anthropocentric basis of all the different ideas of god inherent in epistemological considerations.

Here, too, belongs the question of the existence of God. It is certainly true that only a madman will deny God's existence, but it is equally the case that all our ideas of God are mere inadequate anthropomorphisms, so that what we thus imagine as God does not exist in the way we imagine it. If therefore one person says that he is convinced that God exists and another that he

¹⁵ L. Boltzmann (1899b), 1905: 257- 258. English translation, Boltzmann 1974: 104.

*does not believe in God, in so saying both may well think the same thoughts without even suspecting it. We must not ask whether God exists unless we can imagine something definite in saying so rather we must ask by what ideas we can come closer to the highest concept which encompasses everything.*¹⁶

There is no direct connection between the truth and the mental representation - human consciousness - but it is possible to draw them closer together with the help of an increasingly sophisticated and complex model construction and the experimental experience of »facts«.

This was true both of classical mechanics and statistical thermodynamics and Boltzmann took an emphatic stance as one of the few advocates of a classical atomistic physical theory of his period, but re-interpreted as a suitable mental model which could not be abandoned for the present. At the same time it should also be mentioned that he often emphasized the great probability that the mechanical model might have to be rejected - or radically changed - at some future date. The postulate was simply that at the time there was no basis for doing so.

2.3 The sign and the designatum

It is still a matter of debate whether Boltzmann represented a realistic/materialistic theory or broke with the idea of a mimetic/realistic correspondence between the description and the described.¹⁷ A decision regarding this discussion can hardly be made because he expressed himself as an adherent of both positions. We will probably not be much mistaken if we assume that his original point of departure was within the realistic tradition, but it is equally clear that he was in favour of retaining the atomistic model even though it could no longer be seen as a realistic theory. This is the schism which is at the heart of his theoretical work and it increasingly forced him to exchange the choice between two different theoretical ideas of nature for a transition from a classical idea of direct representation (mimetic reflection or Cartesian correspondence) in the relationship between the world and the scientific

¹⁶ L. Boltzmann (1897b), 1905: 187. English translation, Boltzmann 1974: 75.

¹⁷ The two points of view are represented by respectively Broda's and Klein's contributions in Cohen and Thirring, 1973.

description to a new idea of the approximative description as a principle and unavoidable epistemological condition.

*... it cannot be our task to find an absolutely correct theory but rather a picture that is as simple as possible and that represents phenomena as accurately as possible. One might even conceive of two quite different theories both equally simple and equally congruent with phenomena, which therefore in spite of their difference are equally correct.*¹⁸

Furthermore, Boltzmann is almost prepared to desert the idea of analogical representation in favour of a semiotic description where scientific concepts are seen as an independent sign system (where the greatest possible mathematical determinism must be attempted) which does not represent, but refers to another - natural - system.

*Hertz makes physicists properly aware of something philosophers had no doubt long since stated, namely that no theory can be objective, actually coinciding with nature, but rather that each theory is only a mental picture of phenomena, related to them as sign is to designatum.*¹⁹

He had, however, at best only a vague idea that there was a great deal of slippery material in the matter he had taken up. Even though, for example, in introducing his lectures on mechanical principles he carefully corrected himself and suggested the sign concept rather than the concept of mental pictures, he failed to go into further detail regarding the implications of sign theory.

*Nobody surely every doubted what Hertz emphasizes... namely that our thoughts are mere pictures of objects (or better, signs for them), which at most have some sort of affinity with them but never coincide with them but are related to them as letters to spoken sounds or written notes to musical sounds.*²⁰

He was not aware that the relationship between the sign and the designatum, far from being given, would on the contrary become a main theme of the 20th century. He was by inclination a realist and appears, in spite of his emphasis on

¹⁸ L. Boltzmann (1899a), 1905: 216. English translation, Boltzmann, 1974: 91.

¹⁹ Ibid: 215-216. Respectively: 90-91.

²⁰ L. Boltzmann, (1897a), 1974: 225.

the figurativeness of mental representation, to have regarded the character of figurative and verbal representation as an already clarified, obvious matter.

The comparison of the relationship between the spoken sound and written letter was not simply intended as a pedagogical reference to an assumedly well-known matter from a different area of experience. It was a direct expression of the fundamental idea in his understanding of the character of mental construction of all theoretical and particularly mathematical-physical thinking. That he did not - like Charles Peirce, similarly prompted by thermodynamics - take the further step towards a general sign theory is connected with the fact that he had a different view of the way in which it might be possible to negotiate the gulf which opened up between the sign and the designatum. The mental picture which pointed the way to physical nature was not simply a sign, it was also itself physically manifested in time and space.

2.4 The physics of thought

It appears as though this idea grew out of his deliberations on mechanical principles, which did not simply exist as conceptual, mental pictures, but in the form of independent mechanical apparatuses. Boltzmann saw these apparatuses (machines, instruments etc.) as materializations of our mental representations which not only - as for Descartes - included the inner representations, but also the physical models and tools we surround ourselves with and use:

When therefore we endeavour to assist our conceptions of space by figures, by the methods of descriptive geometry, and by various thread and object models our topography by plans, charts and globes and mechanical and physical ideas by kinematic models - we are simply extending and continuing the principle by means of which we comprehend objects in thought and represent them in language or writing. In precisely the same way the microscope or telescope forms a continuation and multiplication of the lenses of the eye and the notebook represents an external expansion of the same process which the memory brings about by purely internal means.²¹

²¹ L. Boltzmann, (1902) 1974: 214. My emphasis.

This is remarkable because here Boltzmann expresses the opinion that there is no path from the one »great machine«, nature, to the small machines, except through human consciousness and sign creating competence. This also explains why a universal mechanical paradigm must regard consciousness as a function of the »great machine« in order to allow the existence of the small, while a »local« mechanical paradigm for well-defined finite spaces both provides the space for a finite consciousness and for a finite machine. On the other hand, this point of view provides no answer to the question of how a finite mechanical system can create an extension of itself which is at the same time an independent, closed system.

Boltzmann insisted, however, on the mechanical idea and would not himself describe it as a semiotic understanding of technology either. Rather, he regarded the possibility of externalizing mental pictures as experimental confirmation of the utility of the mental picture and - something that certainly had a far-reaching perspective - as an expression of continuity behind the distinction between the concept and the conceived. The technological materialization of mental ideas was a kind of confirmation of the validity of these ideas. That the familiar mechanical technologies had no obvious similarity to other visible phenomena in the surroundings produced no further deliberations.

In regarding models and mechanical apparatuses as implemented consciousness Boltzmann exceeded the bounds of the Cartesian distinction between the inner, which has no extension, and the outer, which has, precisely in keeping with his repeated insistence that behind the apparent jumps in nature there are gradual or continuous transitions, »*nature knows no jumps*«. ²² This had, he claimed, been confirmed experimentally time after time both in physics and chemistry. Now, however, the question arose as to whether the same also held true of the relationship between physics, biology and consciousness?

Descartes' idea that human consciousness, although it belongs to the natural world, but floats freely in a separate substance, had not only been contested by Thomas Hobbes in the 17th century, but also early on in the 19th. Hobbes believed that thinking was a purely mechanical system like all other phenomena in the world. He therefore saw no problem in the relationship between the physical and mental aspects of thought processes. This theme was raised, however, in the 19th century. While both Goethe, Romantic philosophy and scientifically-oriented sensory physiology, as well

²² L. Boltzmann, (1886) 1905: 47. English translation. Boltzmann 1974: 29.

as physicists such as Müller and Helmholtz attempted to describe the physics of sense perception,²³ Boltzmann, inspired by Darwin's biological theory of development, goes a considerable step further and claims that not only sensation, but also consciousness and the thinking process can be understood as physical processes:

The intimate connection of the mental with the physical is in the end given to us by experience. By means of this connection it is very likely that to every mental process there corresponds a physical process in the brain, that is, there is an unambiguous correlation and that the brain processes are all genuinely material, that is, are representable by the same pictures and laws as processes in inanimate nature. In that event, however, it would have to be possible to predict all mental processes from the pictures that serve to represent brain processes. Thus all mental processes must be predictable from the pictures used for representing inanimate nature without change of the laws that govern it... All these circumstances make it extremely likely that an (objective) world picture is possible in which the processes in inanimate nature play not only the same but even a much more comprehensive role than mental processes, which latter are then related to the former only as special cases to general ones. Our aim will not be to establish the truth or falsehood of one or the other world picture, but we shall ask whether either is appropriate for this or that purpose while we allow both pictures to continue alongside each other...

The brain we view as the apparatus or organ for producing word pictures, an organ which because of the pictures' great utility for the preservation of the species has, conformably with Darwin's theory, developed in man to a degree of particular perfection, just as the neck in the giraffe and the bill in the stork have developed to an unusual length. By means of the pictures by which we have represented matter (no matter whether the most suitable pictures will turn out to be those of current atomism or some others) we now try to represent material brain processes and so to obtain at the same time a better view of the mental and a representation of the mechanism that has here developed in the human head, making it possible to represent such complicated and apposite pictures.²⁴

²³ Cf. Jonathan Crary, 1988.

²⁴ L. Boltzmann (1897b) 1905: 178-179, English translation. Boltzmann, 1974: 68-69. The English translation, probably correctly, regards the German edition's »automistik« as a printer's error for

The idea of technology as an externalized materialization of mental pictures is thus closely connected with the idea that mental processes are not only physically materialized, but can also be described with the concepts of physics. That he ventured upon such deliberations was not least due to the fact that the thermodynamic description of physical systems had reached a new stage of higher complexity which better allowed ideas on complex or hierarchic physical systems in which the higher levels possessed other - more well organized - properties than the simpler, but less organized systems. If such a description of biological phenomena could be given it also implied that it would be possible in principle to construct artificial organisms, including organisms which think like people.

Imagine there could be a machine²⁵ that looked like a human body and also behaved and moved like one. Inside it let there be a component that receives impressions of light, sound and so on, by means of organs that are exactly built like our sense organs and the nerves linked with them. This component is further to have the ability of storing pictures of these impressions and by means of the pictures so to stimulate the nerve fibres that they produce movements that are totally similar to those of the human body. Unconscious reflex movements would then naturally be those whose innervation did not penetrate so deeply into the central organ as to generate memory pictures there. It is said to be a priori clear that this machine behaves externally like a man but does not sense. It would indeed retract the burnt hand just as quickly as we do, but without feeling pain...

...In our fictitious machine every sensation would exist as something separate. Similar sensations would have much in common and dissimilar ones less. Their course in time would be that given by experience. Of course no sensation would be simple, each would be identical with a complicated material process, but for one who does not know how the machine is built, sensations would again not be measurable by length and measures, he could no more represent them by spatial and mechanical pictures than we can our own sensations. However nothing more is given by experience. Thus

»atomistik«.

²⁵ Boltzmann adds in a footnote: *By a machine I naturally mean merely a system built up from the same constituents according to the same laws of nature as inanimate nature, but not one that must be representable by the laws of current analytical mechanics; for we are by no means sure that the whole of inanimate nature can be represented by these latter. (1974: 76, note 12).*

*everything we are empirically given of the mental would be realised by our machine. The rest we arbitrarily add in thought or so it seems to me. Like any other person, our machine would say that it is aware of every existence (that is, it had thought pictures for the fact of its existence). Nobody could prove that it was less aware of itself than a human. Indeed, one could not define consciousness in some manner such that it applied less to a machine than to men...*²⁶

With this - hypothetical - idea of a reconstruction of a human being based on the complex laws of physical nature Boltzmann not only anticipated the theoretical and practical efforts of the 20th century to construct intelligent machines, he also formulated three central criteria for this project. First, that this would have to be built on the basis of the concepts we use in describing physical nature, because all mental and biological phenomena have a basic physical realization. Second, that such a reconstruction would necessarily include a reconstruction of the human sensory apparatus, because sensory and experimental experience are conditions for knowledge and thinking, and third, that the possibility of such a project is entirely dependent on the definition of consciousness.

The point that Boltzmann saw, however, was also that definitive arguments can never be produced against this possibility because any definitive argument would contain such a specific definition of consciousness that consciousness could be reconstructed with the help of the identical, testable specifications. We can never say never. As will appear in chapter 5, this is exactly the same consideration that Alan Turing uses as an argument for the future possibility of being able to refer to the modern computer as a thinking machine without expecting contradiction.

Whether it is possible to manufacture such a copy is still a question of belief, but it is quite legitimate to discuss the basis for doing it. Boltzmann's human machine implies the precondition that we are able to reconstruct human organs on the basis of their micro-physical parts and functions. However, not only do we not possess that knowledge, we do not possess the means to handle the necessary amount of knowledge either. On the other hand we know that we can only obtain these means if it is possible to carry out some kind of - mathematical, for example - synthesis of the necessary knowledge. This conflicts with two of Boltzmann's central premises. First, a mathematical

²⁶ Ibid: 183-184. English translation. Ibid: 72f.

synthesis would only be an approximation which expressed certain, limited aspects of what is described. Second, the very idea of a mathematical synthesis is incompatible with his demand for a precise correspondence between the thought and its physical manifestation. A mathematical synthesis could not have the same extent as the unsynthesized expression.

The condition for carrying out Boltzmann's project is thus that his precondition, the unambiguous correspondence between the physical and mental aspects of thought processes, is not valid. The project dissolves into a paradox, it is only possible if it is impossible and this is due to the fact that Boltzmann, in a circular fashion, ignores his own starting point: mental representation, even in the most rigorous mathematical synthesis, is only an approximation which in principle cannot reproduce all relevant physical properties. This understanding of approximation is incompatible with a deterministic theory.

In the final analysis, the paradoxical in Boltzmann's project was connected with the attempt to avoid the threatening indeterminism of the physical theories with the help of a deterministic theory of consciousness. Even if the physical restrictions are ignored, the idea of a deterministic theory of consciousness appears to be extremely difficult to reconcile with the idea that thinking has a content. As it can only refer to its own, previously known, determined preconditions the thought would not be able to produce anything. Prediction is reduced to a simple, meaningless articulation, a sign which is only capable of referring to its own preconditions - or in Boltzmann's case: its physical manifestation - is not a sign of anything at all.

Boltzmann's paradox, however, cannot simply be explained away as the result of a one-off blunder. It must rather be understood as an early formulation of an epistemological field of tension which has retained its paradoxicality in the 20th century. Behind the paradox lies also an extension of the scientific field of reflection which is still far from being thoroughly worked out. This is true both of his idea of a physics of thought, the idea of an artificial reconstruction of biological and mental systems, and a preliminary semiotic understanding of technological artefacts. It is also true of his draft for a dynamic ecology.

2.5 Thermodynamic biology?

Boltzmann built up his idea of a hypothetical machine-human on two central theoretical preconditions. One was the new, more complex picture of physical - especially micro-physical - nature and the thermodynamic theory of development in particular. The second was Darwin's theory of biological evolution. Also propounded in this hybrid is the idea of biological evolution as a function in and of the thermodynamic.

The basic idea is that, seen from a thermodynamic perspective, biological organisms can be described as highly-organized physical systems. The fact that this - from a cosmic point of view - extremely improbable situation actually exists and even, according to Darwin's theories, continues to develop towards still higher forms of organization, can be explained partly on the basis of the assumption that the universe as a whole is enormous and can therefore contain local, more highly developed systems, partly on the basis of the assumption that a continuing degradation of energy takes place within such locally existing systems. The energy which comprises the conditions of life for biological organisms is released through this process:

The general struggle for existence of animate beings is therefore not a struggle for raw materials - these, for organisms, are air, water and soil, all abundantly available - nor for energy which exists in plenty in any body in the form of heat (albeit unfortunately, not transformable), but a struggle for entropy, which becomes available through the transition of energy from the hot sun to the cold earth. In order to exploit this transition as much as possible, plants spread their immense surface of leaves and force the sun's energy, before it falls to the earth's temperature, to perform in ways as yet unexplored certain chemical syntheses of which no one in our laboratories has so far the least idea. The products of this chemical kitchen constitute the object of struggle of the animal world.²⁷

The idea that human intervention in the natural process of energy transformation could be of great significance for conditions of life must have been rather remote to Boltzmann. It is more remarkable that three-quarters of a century would elapse before the entropy-ecological clue he hints at here as a possibility would attract broader scientific interest, particularly because

²⁷ L. Boltzmann (1886) 1905: 40. English translation, Boltzmann, 1974: 24.

physics, during the course of this century, has produced a dramatic expansion of energy releasing technological potential.

Even without this development, which includes both a quantitative expansion of 19th century macro-physical energy releasing techniques and a qualitative expansion with the 20th century's micro-physical, Boltzmann's theory would have been far from adequate, however, and his premises are also doubtful. The inadequacy lies, among other things, in the physical approach. Universal heat death is irrelevant by comparison with the - much narrower - biological boundary conditions which are neither within the scope of Darwin's nor Boltzmann's ideas. The doubtful premises lie in the idea of development.

The idea of development is beset with two uncertainties - both in Darwin and Boltzmann. One is the lack of a possibility for pointing out or defining certain natural initial conditions. The other is lack of an explanation of how a cell, or a more complex organism, creates itself as a biological entity and how this type of physical condition can again produce mental phenomena. For example Darwin assumed in *On the Origin of Species*²⁸ that there was an original (divine) creation of a few biological species, (or perhaps only a single) while Boltzmann believed that it was sufficient to assume that very complex atomistic processes could reduplicate themselves

*...by forming similar ones around them. Of the larger masses so arising the most viable were those that could multiply by division, and those that had a tendency to move towards places where favourable conditions for life prevailed.*²⁹

This is the same idea of an already existing, mechanically executed »tendency« (»instinct« or »intentionality«), i.e. a force which motivates a complex of atoms to reproduce themselves as a whole which can then search for »the favourable conditions for life« - which is the prerequisite in Boltzmann's hypothesis on the origin of consciousness or intentionality:

Sensitivity led to the development of sensory nerves, mobility to motor nerves sensations that through inheritance led to constant strong compelling messages to the central agency to escape from them we call pain. Quite rough signs for external objects were left behind in the individual, they

²⁸ Charles Darwin, (1859) 1964: 484. Facsimile of the first edition.

²⁹ Boltzmann(1886) 1905: 49. English translation, *ibid*: 31.

*developed into complicated signs for complex situations and, if required, even to quite rough genuine internal imitations of the external, just as the algebraist can use arbitrary letters for magnitudes but usually prefers to choose the first letters of the corresponding words. If there is such a developed memory sign for the individual self, we define it as consciousness.*³⁰

The lack of a possibility for defining the initial conditions, however, not only implies what Boltzmann is quite aware of, that the theory is hypothetical, but also that the hypothesis takes as its point of departure that - biological or cognitive - phenomena which it will explain as the result of a physical development must already exist before this development takes place. Darwin assumed the existence of a few divinely created biological cells and simple organisms, while Boltzmann assumed that molecular systems of a certain physical complexity would receive the properties we describe as biological and mental, including a purpose-oriented autonomy. The only question the hypothesis fails to answer is that which motivated it, namely what can make a mechanical-physical system produce biological and mental properties which allow the system, among other things, to »escape« or avoid what we call »pain«?

This objection tells not only against Darwin's and Boltzmann's attempts to reformulate and expand a deterministic theory of nature, it also reveals the weakness which appears in any deterministic theory in the unavoidable meeting with consciousness. Not because any specific criticism can be made of determinism, but because any deterministic theory of consciousness is a contradiction in terms. If consciousness is determined by physical or congenital, hereditary or mutated biological processes, there is no sense in talking of human perception of the world's organization because no statement in such a case can be related to anything else, it is exclusively a passive function which is in rapport with the physical or biological system in which it is realized at a given - already disappeared - time in a certain place.

Haugeland makes a similar criticism of Thomas Hobbes' and David Hume's philosophical models of the mechanical structure of thought in pointing out that, each in his own way, they end precisely by not being able to explain the trait which makes thinking thinking, unlike the mechanical processes which are not.³¹

³⁰ Ibid: 49. English translation, *ibid*: 31.

³¹ Haugeland, (1985) 1987: 23-44. According to Haugeland the problem for Hobbes, who regarded con-

Haugeland calls this »the paradox of mechanical reason«, but apparently believes that it either is, or soon will be, capable of solution.

Perhaps the idea of automatic symbol manipulation is at last the key to unlocking the mind...

he says in his conclusion, but does admit that another possibility can be imagined

*Perhaps the programmable computer is as shallow an analogy as the trainable pigeon - the conditional branch as psychologically sterile as the conditioned reflex... after thirty years, the hard questions remain open.*³²

When Haugeland, who in all honesty acknowledges his dislike of what he calls the »intellectual anaemia« of scepticism, finds himself forced to come to such a sceptical conclusion, it is well founded. A theoretical determinism concerning consciousness cannot be saved by replacing the mechanical motor with a formal automaton, however many built-in conditional clauses it contains, because the formal procedure, unlike human consciousness, cannot describe the rule structure of the formal procedure or interpret its significance.

The cognitive void which manifests itself as a logical circularity - even an automatic circuit - at the same time makes deterministic theories of consciousness immune to criticism.

It is perhaps slightly more paradoxical in Boltzmann's case than in others because of the degree to which he directed his physical research precisely towards the questions which in particular undermine the classical deterministic assumptions of natural science and because, philosophically, he placed such

consciousness as part of the corpuscular world, is that in order to explain the mechanics of thought processes he must differentiate between the individual thought units (parcels) and the laws of motion which regulate the movement. These, however, have the character of thought themselves (rules of calculation) and their activity must therefore also be explained, which again demands an underlying motor whose activity must be explained so that this results in an endless recurrence or in an unexplained assumption of an inner homunculus which makes the system move. Hume attempts, says Haugeland, to avoid Hobbes' problem by denying that thinking refers to the surrounding world. He »simply« sees the mechanics of thought as an analogy to mechanical physics and thus ignores the question of what separates this mechanical system from other mechanical systems, but is still far from providing an answer to what gives this mechanics its content of thought. Where Hobbes has a homunculus, Hume has nothing.

³² Haugeland, (1985) 1987: 253-254.

emphasis on the freedom and fallibility of thought - also with regard to the perceptions of natural science.

Boltzmann takes great pains to emphasize that it is not only the senses, but also human thinking that is fallible, but claims that this can also be explained on mechanistic premises on the basis of Darwin's theory.³³ This is true both of fallibility and the surmounting of its limitation. The idea appears to be that this development, also within the realm of thinking, has the happy logic that the fittest will win. In mechanical theory, however, there is no room for any criterion of fitness. Another problem with Darwin's theory is that it is purely retrospective, it derives the prehistory of the later development which itself can only be explained on the basis of an even later development. As it thus contains no indicators for the future, it provides no means to decide what is valid in the present.

It is not easy to understand how it is possible to reconcile the idea of consciousness as an unambiguous function of physical laws with the idea of correct and incorrect scientific theories. But it is also remarkable because Boltzmann, as a corollary to Maxwell, so strongly emphasizes mathematical physics' character of mental pictures, which in the best case can represent an approximation of certain selective traits in the physical world. It was here more than anywhere that Boltzmann saw missing information of a more fundamental and unavoidable character than that missing information which is concerned with the number of alternative, micro-physical possible states.

2.6 Mathematics as an approximative model

Boltzmann gave several reasons for this schism. One lay in physical theory. Although the formulation of a number of mechanical models of physical energy processes had succeeded, it was clear that they should be interpreted as conceptual analogies, they did not express nature's actual »inner structure«. ³⁴ It is possible to express laws for both interference and collision in

³³ Boltzmann understood Darwin's theory as an - exhaustive - mechanical theory even though Darwin's evolutionary logic is filled with intentional and instinctual forces (both individual and with regard to species) and assumes a divine creation long after the origin of the physical universe.

³⁴ Paul Feyerabend draws a direct parallel between Boltzmann's and Maxwell's understanding of form analogies and Bohr's understanding of the "figurativeness" of wave and particle concepts. Feyerabend 1981, I: 12 (and note 29). It is perhaps more surprising that Einstein, in spite of his fundamental determinism, also expressed great scepticism of the »precision« of applied mathematics. *The differences between pure and applied mathematics are very great, indeed*, wrote James H. Fetzer and adds, *As*

mechanical models, but not join them together to a theoretical whole. This perhaps initially affected only the understanding of energy, but subsequently also the realistic understanding of mechanistic particle theory and the idea of nature as one great machine. The understanding of theory as no more than a model was a consequence of the thermodynamic description.

Another reason lay in the understanding of mathematical representation itself. Paradoxically, this limitation emerges from the success of mathematical description. It became evident that it was possible to describe many, quite different physical processes using the same mathematical formulas:

*It often happens that a series of natural processes - such as motion in liquids, internal frictions of gases, and the conduction of heat and electricity in metals - may be expressed by the same differential equations and it is frequently possible to follow by means of measurements one of the processes in question - e.g. the conduction of electricity just mentioned. If then there be shown in a model a particular case of electrical conduction in which the same conditions at the boundary hold as in a problem of the internal friction of gases, we are able by measuring the electrical conduction in the model to determine at once the numerical data which obtain for the analogous case of internal friction.*³⁵

Physics was later able to confirm, to a great extent, that this applicability also held true of the equations which in particular ensured Boltzmann a place in the history of physics.³⁶ But the advantage is connected with the fact that the mathematical procedures have no reference to what separates the represented systems. The same mathematical expression can only describe different physical processes because it does not describe all the significant physical aspects of any individual process. Connected therefore to each individual, specific use is a detailed explanation of the specific conditions for use. Here, Maxwell expressed himself more distinctly as - to a greater degree than Boltzmann - he emphasized that the analogies based on the mathematical equivalence between different physical processes were specific and that any extended generalization of this equivalence must be based on step-by-step

Einstein remarked, insofar as the laws of mathematics refer to reality, they are not certain, and insofar as they are certain, they do not refer to reality. Fetzer 1990: 259.

³⁵ L. Boltzmann, (1902) 1974: 220.

³⁶ Cf. Cohen and Thirring, 1973 and Groot in Boltzmann, 1974.

experimental instances.³⁷ The choice of which mathematical expression that expresses general laws of nature lies outside the scope of the mathematical description.

The use of the same mathematical expression in describing different physical processes thus does not indicate that these processes can be subsumed under one, general law. This multiple application is only possible because it is a question of different physical processes which, under certain conditions, can be regarded from the same reductive point of view. Conversely, a generalization of the mathematical description must represent the physical differences.

This is not only true of qualitatively different physical phenomena, but also of purely quantitative differences:

*...a mere alteration in dimensions is often sufficient to cause a material alteration in the action, since various capabilities depend in various ways on the linear dimensions. Thus the weight varies as the cube of the linear dimensions, the surface of any single part and the phenomena that depend on such surfaces are proportionate to the square, while other effects - such as friction, expansion and condition of heat etc. vary according to other laws.*³⁸

Mathematical precision for Boltzmann is neither a certain nor sufficient basis for physical knowledge. The mathematical formulas are rather excellent schemes or models for handling things because they are independent of both the conceptual ideas from which they are derived and of the specific physical processes which are handled with these models and with the calculative possibilities which are connected with them.³⁹

Boltzmann's deliberations on the approximative character of mathematical description - notwithstanding their preliminary and tentative form - are not far removed from the views of newer mathematics on the arbitrary, symbolic

³⁷ According to Feyerabend, Maxwell distinguished mathematical formulas from physical hypotheses and from form analogies. He believed that the mathematical formulas lacked heuristic potential. They can help to trace the consequence of given laws, but at the expense of the »visibility« and »context« (connections) of phenomena. Hypotheses are useful as guides, they keep sight of the physical subject, but also confuse because they are generalizations expressed in a conceptual, theoretical medium. The concept of form analogies serves to emphasize the need to test the constituent parts of all hypotheses, step by step. Feyerabend 1981, 1: 12.

³⁸ L. Boltzmann (1902) 1974: 220.

³⁹ Cf. Boltzmann (1897c) 1905: 158-162 and (1890) 1905: 80. English translation, Boltzmann, 1974, 54-56 and 1974, 36.

character of mathematical idealizations and it is possible to discern in them the beginnings of a thematization of the epistemological problems which lie in the application of mathematics to physics.

2.7 Summing up

When we read Boltzmann today it is almost impossible not to be struck by the consistency with which he formulated and pursued the epistemological questions which are still under discussion in relationship to the interpretation of the physics of thermodynamics. It is not only Boltzmann's still discussed, specific results and answers, but also the methodical procedure and a broad range of the problems discussed that have retained their topicality.

If we join Warren Weaver in claiming that Boltzmann was the first to point out a specified relationship between missing information and physical entropy, we can also add that he thereby not only laid the foundation for an understanding of the indefinite as a number of alternative possibilities which could be calculated with the help of statistical probability methods;⁴⁰ with his concept of the formal, arbitrary variable and finite reference system, he also laid the foundation for a new mechanistic model of description and raised many of the epistemological problems which were attendant on this method, although not all.

Statistical description meant that he had to refrain from describing the individual particles. He thereby left unsolved the main question, the relationship between micro and macro-physical order, but also added a new, namely that of the epistemological status of statistical description. Boltzmann attempted to answer this question in several ways. First, by claiming that statistical description was just as precise and deterministic as classical atomistic description, but the price was that neither of them could be considered as phenomenologically valid. He continued to accept mathematical description as explicatively valid, but still maintained that it could only be approximative. He hereby conferred a new form on the epistemological problem, namely that of a general problem of observation and description.

It was as an answer to this that he formulated his draft of a physics of thought. Although he formulated this idea on the basis of deterministic and physical thinking and therefore ran into the problem of deterministic description in the form of mutually conflicting premises, he still paved the way for the

⁴⁰ Warren Weaver (1949) 1969. See chapter 6.

scientific use of the philosophical idea of consciousness as a dynamic system which would later give rise to distinctive theoretical innovations.

What he thus attempted to make cohesive can be summed up in the following themes, each of which has attained central significance as an area of discussion in the 20th century, but seldom in a similar, collected form:

- The relationship between the micro and macro-physical levels.
- The problem of observation in mechanical theories.
- The status of mathematical representation as a schism between the approximative character and explicative validity.
- The idea of the formal, arbitrarily variable, finite system of reference for describing mechanical processes.
- The separation of the concepts of matter and form and thereby the break with classical mechanics' definition of matter through form.
- The relationship between information, energy and entropy.
- The relationship between the physical and mental order of consciousness.

In the clue pointed out by Warren Weaver, the connection between thermodynamics and information theory lies first and foremost in the connection between the concepts of entropy and information. This connection, however, is not quite as simple as Weaver appeared to assume and for Boltzmann it already implied a number of more far-reaching considerations on the epistemology of physics and the possibility of describing biological and mental processes (including the content of the latter), as well as the physical execution of these processes on a physical basis.

Although both Boltzmann and Weaver believed that the problem of missing information had been solved, they had completely different ideas both of the problem and its solution. For Boltzmann this involved finding a mathematical expression for an (invisible) physical process, which could not be described exhaustively. He sought a method for extracting knowledge on the way in which such physically indefinite micro-processes could manifest themselves as a physical whole with well-defined physical properties and believed that he had found this with the statistical and probabilistic description.

For Weaver, who interpreted Claude Shannon's mathematical information theory, it involved on the contrary defining a general mathematical goal for the frequency of occurrence of physically well-defined informational entities.

Here the problem was not the extraction of knowledge either, but the stable transport of knowledge.

Both Shannon and Weaver appeared - as will be shown in chapter 6 - to understand mathematical information theory as a generalization of Boltzmann's thermodynamic definition of entropy, as Shannon »simply« eliminated the physical constant (Boltzmann's constant) in the formula. It was precisely this constant, however, that contained the connection to the entropy concept. The mathematical formula which the two theories had in common has nothing to do with the entropy concept, but is exclusively a - relative - yardstick for a statistical (im)probability, the calculative result of which incidentally rests entirely on and varies with the chosen area of application. The mathematical yardstick itself has no content.⁴¹

Where »missing information« in thermodynamics stems from the lack of a possibility for establishing the initial conditions for a physical system - and thereby also the lack of possibility for predicting the movements of the individual molecules - mathematical theory is interested solely in physically well-defined quantities. These quantities, however, are not concerned with the organization of nature, but with - physically defined - symbolic notation forms. The question of physical-phenomenological precision and the question of the validity of knowledge, are not included in the mathematical information theory.

The path from Boltzmann's to Shannon's theory thus traverses a gulf which involves both the missing information and the problem of observation in physics. That Shannon did not become involved with these questions can first and foremost be explained by the fact that his own path back to Boltzmann went via the Hungarian physicist, Leo Szilard, who at the end of the 1920's had proposed a theoretical analysis which was intended to explain how it would be possible to maintain thermodynamic principles if the analysis included a measurement of the energy used to transfer information from the system to the observer.

Szilard proposed the theory with a - debatable - postulate to the effect that it contained a solution to the theoretical problem of observation. But it also contained a more precisely - and narrowly - defined concept of physically defined information, as information is defined as a measurable amount of energy.

⁴¹ Cf. Donald McKay, 1983: 489.

As the information concept with this definition becomes a synonym for a physical phenomenon, it has no place as an independent concept in physics. On the other hand the definition contains the conceptual basis for a description of physical and informational systems as parallel mechanical systems because the physical and informational entities are joined like two sides of a coin.

As Szilard's theory thereby becomes an important link in the transformation of the mechanical paradigm from a physically to a mechanically founded informational paradigm, it will be returned to in chapter 3, while Shannon's theory will be gone into in greater detail, but in chapter 6, as the intervening chapters concern the - simultaneous - theoretical development of the idea of the finite, mechanical symbol procedure towards the symbiosis of mechanical and symbolic thinking in modern information theory.

Prior to this, the discussion of Boltzmann will be rounded off with a glance at a couple of the other clues which, during the course of this century, have secured him continued - and for the past 25 years growing - attention both in and outside physics.

While the English physicist, J.D. Bernal, completely ignored Boltzmann in his voluminous history of science from the 1950's,⁴² there is widespread agreement today that the honour of having introduced statistical-mechanical description into the history of physics should be ascribed to him. Since then, statistical thermodynamics has pursued another path, laid out almost at the same time, independently of Boltzmann, by the American physicist, J.W. Gibbs, who instead of describing a single system with many interacting molecules, described a number of such systems with the whole system as an entity.⁴³

But a lasting significance is ascribed to Boltzmann for his two more specific contributions to thermodynamic theory, namely his description of the entropy concept as a mathematically well-defined yardstick for the disorder, or probable state, of a molecular system and his formulation of the so-called Boltzmann equation, a mathematical expression of the state of equilibrium of a system comprising a great number of particles.⁴⁴ Certain mathematical equations accompany both of these more durable results, which have since

⁴² J.D. Bernal, (1954). Norwegian edition, 1978.

⁴³ Cf. P. and T. Ehrenfest (1912) 1959, which contains a detailed discussion of Boltzmann's and Gibbs' works, John von Neumann (1932) 1955: 360.

⁴⁴ The formulation given here summarizes S.R. Groot's characteristic in Boltzmann, 1974: IX-X. In E.D.G. Cohen and W. Thirring, 1973, the editors emphasize in the introduction that the Boltzmann equation provided the first-ever precise, mathematical basis for a discussion of the conditions for a state of equilibrium.

acquired - and are still acquiring - many new areas of use. Shannon's theory is an example of such use.

There can be little doubt that these - rather tardily recognized - results will secure a more visible place in the history of physics for Boltzmann, but his rehabilitation is less interesting than the discussion and disagreement that have emerged in the discussion of the implications of these results, which concern both the understanding of thermodynamic irreversibility and the relationship between mechanistic and statistical methods of description. The thermodynamic entropy theorem as it was formulated by Boltzmann is still an object of discussion, as he showed how macro-physical irreversibility could appear as a - statistical - result of a mechanical (and thereby reversible) description of molecular processes.

Boltzmann thereby synthesized, says Ilya Prigogine, three forms of description which had arisen separately, namely the dynamic description based on the laws of mechanics, the probabilistic and the thermodynamic descriptions.⁴⁵ But that synthesis which was the answer to the problem for Boltzmann was rather the new question itself.

Boltzmann's influence can be traced not only in statistical mechanics in physics and in Shannon's and Weaver's mathematical communication theory, but also in Ilya Prigogine's thermodynamic theory, which is a new attempt to surmount the conflict between the reversible chronological symmetry of mechanics and the asymmetry of thermodynamic chronology.

According to Prigogine the concept of dissipative structures makes it possible to eliminate the stochastic, probabilistic element in Boltzmann's theory.⁴⁶ Thermodynamic entropy, irreversibility, is explained here on a causal-dynamic, mechanistic basis which presumably contains an asymmetric time concept. Mechanical reversibility is hereafter a borderline case.

Another, far-reaching actualization of Boltzmann's work can be found outside the realm of physics and information theory - in a comprehensive treatise, *Filosofi*, by Danish philosopher Johs. Witt-Hansen. Boltzmann's statistical thermodynamics is described here as a radical break with classical dynamics, as the statistical point of view - used as an explanatory principle - implies a new understanding of the concept of order. According to Witt-

⁴⁵ Prigogine, 1973: 407.

⁴⁶ Prigogine, 1973: 443-445. Prigogine's theory is also statistical, as the molecular processes are described as »ensembles« and not as the movements of singular molecules. The phenomenological or realistic interpretation of the statistical foundation is also disputed. Cf. Danish physicist Torben Smith Sørensen, who points out that it is impossible to ignore the lower limit of description in quantum mechanics. Sørensen, 1987: 48.

Hansen, order is understood here as a combinatory phenomenon which can be described on the basis of statistical probability, while classical Newtonian mechanics was founded on a causal deterministic idea of order where every phenomenon can be localized in a well-defined time-space connection.

Witt-Hansen sees Boltzmann's statistical description of the thermodynamic principle of irreversibility - today often called »the arrow of time«, after Arthur Eddington⁴⁷ - as a first and prototypical example of what he calls »mathematical generalization«, or logically based extension of the conceptual framework. He sees herein a general principle for transcending the explanatory limitations of a given scientific paradigm. In Boltzmann's case the limitations of classical, mechanical description.

Although Witt-Hansen refers directly to Prigogine as a precondition, he draws a different - less realistic - conclusion in that he sees the value of Boltzmann's efforts in another area, namely in his contribution to the development of the principle of mathematical generalization, which according to Witt-Hansen constitutes the only stable foundation for science and today is becoming »fruitful in biology, sociology and futurology«.⁴⁸

That he thereby presents a less critical interpretation of Boltzmann than we otherwise find in present-day discussions, does not necessarily affect his argumentation for regarding the principle of mathematical generalization as the proper answer to explanatory limitations of a scientific theory, but it does indicate a problem. Boltzmann's statistical explanation of thermodynamic irreversibility was later rejected as inadequate, the status of statistical description is still an object of discussion and the law of thermodynamic entropy cannot be regarded as definitively proven. Like Boltzmann, Witt-Hansen also glides from purely epistemological to ontological reasons because, among other things, he places so much emphasis on the concept of natural constants.

When considered together these theories first and foremost indicate that even more recent research has failed to lead to any final evaluation either of Boltzmann's results, or of his own interpretations. Boltzmann's topicality lies not only in some of the answers he provided, but also in the questions and

⁴⁷ Arthur Eddington (1928) 1930.

⁴⁸ Johs. Witt-Hansen, 1985: 44-52. Witt-Hansen's theory stems from a discussion of thermodynamics which intensified within physics and in the area between physics and biology, among other things due to the fact that many physicists, especially after World War II, began to take an interest in biology. Cf. S.B. Dev, 1990. Flamm, 1983, believes he can demonstrate that there is a direct line from Boltzmann to quantum physicist Erwin Schrödinger who published his famous *What is Life?* in 1943, which provided inspiration in such areas as the development of information-theoretical molecular biology.

new points of view he formulated. The reach and character of these questions explain why he himself increasingly moved from scientific to epistemological and theoretical problems.

3. Missing information

3.1 Information as a function of energy

When we consider the conceptual tensions in Boltzmann's reflections on thermodynamics, it will hardly be surprising that he was later evaluated in many different ways, that he did not found a school and, that his work has only become the object of more comprehensive consideration within the past 20-25 years. It is more remarkable that there has been no clarification either of the interpretation of what he meant himself, or of the answers to the questions he discussed.

It is the ghost of the missing information and the proper interpretation (of this) which still has not been laid. Boltzmann believed that the statistical description of molecular chaos was sufficient because it made it possible to predict the general behaviour of the system with great mathematical precision, although very little was known about »molecular chaos«, not even the fact that it was molecular. Until the last years of Boltzmann's life the concepts of molecules and atoms were doubtful and of an extremely speculative character.

With the breakthrough of atomic theory, however, it also became necessary to be able to predict the behaviour of the individual particles in the molecular system.¹ Although Boltzmann's theory could describe how the micro-physical system could affect the macro-physical level it was not adequate to describe - and manipulate - the micro-physical system itself. The statistical description had to be adjusted in such a way as to make it phenomenologically precise. Lying in wait behind this was Maxwell's demon. If Boltzmann's description of molecular disorder was exhaustive it would still, at the micro-physical level, be possible for the demon to construct a perpetual motion machine - albeit bogus - which would imply that the second law of thermodynamics would have to be rejected. As atomic theory in addition made it impossible to simply desert the mechanical description, a way had to be found to explain why Maxwell's demon still could not realize the utopia of work which cost nothing.

¹ Later there was also a need to describe thermodynamic systems of greater density. Boltzmann, who worked with gases, assumed that the individual molecules could move freely with relatively long periods elapsing between collisions and that collisions occurred »instantaneously« as collisions between only two molecules »at a time«.

An answer to this was first provided in 1929 by the Hungarian physicist Leo Szilard who claimed that it would be possible to maintain the thermodynamic maximum if the energy used to transfer the information from the system to the observer were included. The energy used would compensate for the increase in the system's organization which was supposed to be achievable through the activity of the demon.²

According to Szilard it should thus be possible to solve the observation problem of mechanical physics by regarding the process of observation as a physical process. Where the problem of observation had formerly been a threat to the concept of a mechanical-deterministic system, it now became part of the foundation of this concept instead. Observation could be included in a fully deterministic manner in what was still a well-delimited system.

Although Szilard uses the information concept and talks about a physical system which possesses a kind of »memory«, as a given piece of information from the system also contains information on former states,³ his conclusion was that the concepts of information and memory had no independent content. The question as to whether there could be any sense at all in working with the idea of a local, closed physical system belonged to a later date,⁴ but the question of the relationship between the observer and the observed did not.

Szilard assumed that this problem had been solved insofar as it concerned observation with the help of mechanical instruments which allowed a

² That is, the energy which was necessary to inform the demon when it should perform its operations, corresponding to the light energy which must be transferred from the system to the observer in order to make observation possible, whether this be energy transferred to the human sensory apparatus or to a physical measuring apparatus.

³ ...so behält der Parameter y zunächst seinem Wert 1 unverändert bei, so dass sich das »Molekül« vermöge des Parameters y während des ganzen späteren Prozesses daran »erinnert«, dass x ursprünglich in das hervorgehobene Intervall fiel. Szilard, 1929: 848. The postulate is that one parameter (x) can be measured indirectly through the other because they are »indissolubly« connected through a measurable entropy production. Later in the article Szilard talks of a connection endowed with a memory - without inverted commas. Goldmann rejects Szilard's phenomenological and deterministic interpretation (without mentioning it) as he claims with arguments derived from quantum mechanics that the premise assumed by Szilard, that the system contains memories of a former state, cannot be maintained. *The generally held opinion now is that the demon cannot work; to see the fast and slow molecules arriving he would have to receive light from them, and, by the precepts of quantum mechanics, bouncing a photon of light off a molecule alters its velocity, so the demon could no longer tell if it was fast or slow.* Goldmann, 1983: 123.

⁴ *The truth is that isolated systems are not found at the microscopic level. The effect of the weak disturbances coming from outside would be such that the newly-formed speed correlations would be continuously destroyed and the finely-drawn trajectories would be smeared as though by a big eraser,* wrote thermodynamician Torben Smith Sørensen, but here in a criticism of Ilya Prigogine. Sørensen 1987: 50. Boltzmann incidentally had also more speculatively pointed out that no sharp borderline could be drawn between a local system and the total cosmic system.

complete observation of all desired, quantifiable relationships, but his argument was based on two dubious premises. First, the theory presupposed that this was a question of a simple mechanical transfer of energy from an object to - a passive - means of observation. That is, classical conditions which cannot be fulfilled within quantum physics, for example. Second, the theory presupposed that it was possible to describe the *use* of a mechanical measuring apparatus as a physical-mechanical process. A measuring apparatus, however, can only measure something if it contains a symbolically defined yardstick which establishes the legitimate scale of physical sensitivity. Nor can the measuring apparatus simply receive signals. It must also be possible to read it, as it cannot read itself.

The description of the physically organized transfer of information must therefore, claimed the Hungarian born quantum physicist and mathematician, John von Neumann, also be capable of following the energy process through the human sensory apparatus:

First, it is inherently entirely correct that the measurement or the related process of the subjective perception is a new entity relative to the physical environment and is not reducible to the latter. Indeed, subjective perception leads us into the intellectual inner life of the individual, which is extra-observational by its very nature (since it must be taken for granted by any conceivable observation or experiment)... Nevertheless, it is a fundamental requirement of the scientific viewpoint - the so-called principle of the psycho-physical parallelism - that it must be possible so to describe the extra-physical process of the subjective perception, as if it were in reality in the physical world - i.e., to assign to its parts equivalent physical processes in the objective environment, in ordinary space.⁵

von Neumann visualized a situation in which taking a temperature reading would therefore in principle first involve taking the reading, then giving an account of the heating of the mercury column, its expansion and the resultant length registered by the observer and then, by taking the reflection of light into account, measuring the quantity of light which reached the eye, the refraction in the lens of the eye and describing the picture on the retina. If

⁵ John von Neumann, (1932) 1955: 418-419. von Neumann, who later became a main figure in the development of American computer technology, was born in Budapest in 1903. He studied in Berlin, Zürich and Budapest. Taught at the universities of Berlin and Hamburg respectively 1927-1930, then at Princeton University. He later became an American citizen.

physiological knowledge had not been so limited, it would then also be possible to trace the chemical reactions which produce the picture impression in the brain.

The point, however, was not that it would be possible in this way, without further ado, to substitute the concept of an observer with a description of the sequence of physical laws in the observation process. The point was that in possessing these possibilities for describing the various parts of the process, we make it possible to freely establish several different limitations between the observer and the system. He therefore sought to solve the problem with the mathematical proof that by choosing several different limitations it would be possible to arrive at the same result.⁶

Both Szilard and von Neumann placed great emphasis on the demand for a phenomenologically valid description, but their demonstrations were of a mathematical-logical and theoretical character. Their answer to the problem of observation bequeathed by Maxwell and Boltzmann presupposed that the acceptance of the mathematical description be understood as a phenomenologically valid representation, in von Neumann's case supported by the idea of psycho-physical parallelism, which presented the demand for representation as fulfilled if, in principle, it was possible to take into account the physical dimension of human observation.

This, however, is not easy. The problem of observation had come to stay.

3.2 The problem of observation in 20th century physics

It is undoubtedly irreversibility that has dominated the idea of thermodynamics during the 20th century, not least outside physics, but the interpretation of irreversibility is not the only epistemological problem which has been raised.

Thus nobody has yet succeeded in connecting the irreversibility of thermodynamics with the physics of quantum mechanics in which a description related to classical assumptions of reversibility has been maintained, but which at the same time relinquishes the idea of a complete description, understood as a simultaneous description of the speed and position of subatomic particles.

⁶ Ibid: 420-445.

The two theories, however, concur in according a central position to the problem of observation and share this concurrence with a third new energy paradigm of the period, the theories of relativity.

There is nothing new or strange in the fact that these theories also take up the problem of observation, all theories which aim at reaching a generalized statement do so. The remarkable lies rather in the fact that physical research into micro-physical energy processes gave rise to a treatment of the problem of observation in three very different - and still incompatible - ways.

All three theories agree - as something new in physics - in regarding the observation situation as an integrated component of that phenomenon or the phenomena which are observed and all three theories identify the observer with the physical measuring apparatus without »subjectivistic« implications, as the observer is seen as an equally »pure« physical category as the phenomena. The theory of relativity and quantum physics also assume the same - synonymous - relationship between information and energy that was formulated in thermodynamics, because in both cases the problem of observation is treated as a question which exclusively concerns acquiring a knowledge of the energy process between the means of observation and the system. But here the agreement ends and the information concept only appears within thermodynamics.⁷

Einstein had no need of an information concept, but could stick to a reinterpretation and extension of the energy concept because he maintained the classical assumption of realistic theory that a complete physical description of a system was possible. The concept was also out of the question in quantum mechanics because here it was maintained that it was impossible in principle to

⁷ The formulation in quantum mechanics of the problem of observation »the difficulty of differentiating between subject and object« (Niels Bohr) has often been described as unsatisfactory due to its »subjectivistic implications«. But if there are subjectivistic elements in Bohr, they do not lie in his view of the observation situation (where the problem is one of giving an account of the micro-physical processes/phenomena, which are inextricably bound up with the observation). They lie rather in his constant emphasis on the fundamental border of knowledge and the provisional character of scientific theories. Cf. Paul Feyerabend, 1981, 1: chapters 16-17. The border which disappears, says Feyerabend, taking his example from Bohr's formulations and as a criticism of Karl Popper's positivistic criticism of Bohr's subjectivism, is not between the observer and the »world«, but between the atomic phenomena and the physical means of observation: *There is no 'ghost' to be exorcized from quantum mechanics*. Feyerabend, 1981, 1: 280. That there is no ghost is due, according to Feyerabend, to the fact that the indefinable border between subject and object does not involve the observer's consciousness, but only the physical arrangement of the observation. In the meantime, however, it has become more difficult to talk of a well-defined border between cognitive, sensory and physical processes. Psycho-physical parallelism is still unable to give an account of how it could be possible for a physical-mechanical system to come into possession of mental properties.

obtain any other knowledge of the system than that which could be obtained through measurements of those energy states which could be measured.

Although the problem of observation is thus treated as a purely physical problem of energy measurement in all three theories, the physical observer (synonymously termed the experimental test set-up, or the observation situation) is included in three completely different ways.

In thermodynamics the observer is understood as a receiver to which the system gives off a certain amount of energy in a manner that can be described in ordinary deterministic terms. The thermodynamic system from which the energy is given off must, however, be described in statistical terms and the system is characterized by a non-classical irreversibility.

In theories of relativity the observer is understood as a physical body with a determinable velocity and position which must be taken into account in its relationship to the velocity and position of the observed phenomena. Here it is not the observation process, but the observer, that is included in the physical system which is described on the basis of a classical deterministic representation theory.

In quantum mechanics, on the other hand, the observer is included in such a significant interchange with that which is observed, that it is regarded as impossible to speak of a phenomenon which exists independently of the observation, just as it is regarded as impossible to provide a total description of the observation situation's effect on the observed surroundings. In quantum mechanics the observer can no longer be reduced to a passive or well-defined receiver. Quantum mechanical theory also further assumes that there is a lower border threshold for the validity of scientific concepts and thereby turns the relationship between the language of description and the described into a chronic epistemological problem.⁸

The problem that motivates the use of the information concept, is thus included in all three theories as an important interpretation theme, but the

⁸ The assumption by quantum mechanics of such a lower border threshold is defined by the lack of possibility for simultaneous determination of a particle's position and momentum while observation rests on the use of traditional measuring apparatuses which depend on »classical« assumptions. This limit for description indicates that the »classical« concepts of particles and energy cannot be applied to subatomic nature. This is expressed in Bohr's warning that there seems to be »an essential failure of the pictures in space and time on which the description of natural phenomena has hitherto been based«. (Here quoted from Feyerabend, 1981:283). This limitation is thus not identical to the conceptual limit Boltzmann touches on with his concept of the approximative character of mathematical description, which on the one hand was a general trait of any mathematical application, but on the other a trait whose significance could be reduced to the verge of disappearance through an increasingly refined »approximation«.

theories look at the problem on the basis of different epistemologies. A divergence that can initially be justified because this is a question of descriptions of different aspects and levels of physical nature.

We hereby obtain an explanation of why the information concept remained rudimentary in physics even though the problem of observation which underlies it became central both to relativity theories and to quantum physics. And we also obtain an equally clear expression of the fact that the use of the information concept within the world of theoretical physics requires a non-deterministic theory.

But as the theory of relativity and quantum mechanics eliminate the information concept - and the threat of indeterminism - in two mutually contradictory ways, together they provide a reason to maintain that the problem which brought about the use of the information concept still exists. The general validity of their respective solutions of the problem of observation must therefore also still be disputed.⁹

The information concept disappeared again from the history of physics, but the problem of observation remained in physical theory, where it had been left behind when the physically defined information concept was later taken up in an information theoretical context.

3.3 Energy and information

Notwithstanding the explanatory value accorded to mathematical demonstration, there was a new accentuation in Szilard's use of the information concept. Although Boltzmann had pointed to a connection between the physical system and the possibility of obtaining information on the system and in spite of his attempts to sketch a general physicalistic theory of consciousness, he failed to make a connection between certain physical and informational entities. This was not a question of a break with more traditional views of information as a concept for general - e.g. physically relevant - knowledge. In Szilard the beginning of such a break is hinted at both in the sense that here only information as a measured expression for a quantity of energy is being considered and in the sense that there is a reference to a description of the

⁹ This also appears to create problems for the suitability of the mathematical generalization procedure to solve epistemological problems. Witt-Hansen, op. cit. describes both Einstein's and Bohr's theories as examples of this procedure, which implies that the fulfilment of its criteria, even within two such closely related areas, may well have inconsistency as its product.

transference of information as a physical process, subject to - and therefore calculable on the basis of - the laws of physics. This, however, requires a more explicit thematization of the problem of observation, which in Boltzmann was described as a general epistemological problem connected with the creation of mental pictures as a cognitive precondition.

Szilard's emphasis on the observer's significance for the observation is far greater than Boltzmann's, which is hardly surprising, as the way this problem presents itself had in the meantime merged into the foreground of physics. In Szilard this is a question of a growing clarification won at the expense of a considerable narrowing of the information concept.

This exclusively concerns the information on a physical system's energy state which is contained in the system in the form of energy. The question was the extent to which the information could be measured. A precondition for this, on the one hand, is that the energy which is released as information from a system is the only exchange of energy between the system and the surrounding world and, on the other, that the sought-after information on the state of the system is an exhaustive fund of information on the system. The information concept is thus defined solely on the basis of the parameters which are included in the given measurement of physical energy processes.

That it was assumed that a certain amount of released energy is synonymous with a certain quantity of information is due to the fact that the search was for information on the released energy and the system it was released from, but this assumption also implies a limitation in the way the information concept is regarded, as it excludes all considerations of information which are not information on the physical entity which bears the information. The information concept is thus only the other aspect of the energy concept, the concept of what we can discover about energy by measuring it. When information is understood as information on the quantity of energy, it can therefore also be measured and treated as energy.

If the concept of information is defined as a mimetic reflection of the energy which transports the information, there is no obvious reason at all to introduce the concept as an independent concept in physics either.¹⁰

According to this definition a physical information concept only has an independent content in physics if - as was the case of thermodynamics after

¹⁰ The degree to which a more comprehensive physical information theory is possible, or has meaning, can be discussed. But as we know, on the one hand, that the same information can have different physical representations and that the same physical quantity of energy can transfer different quantities of information as well as information with different contents, it is clear that a theory based on the synonymy of energy and information can at best only concern a borderline case.

Maxwell - we have a problem of observation which concerns the possibility of maintaining a deterministic understanding of physical nature itself, which in a different light means that the use of the information concept was an indication of an epistemological conflict in relationship to classical physical theory.

The justification of the concept (or the meaning of its use) lay in the fact that it expressed this problem in discourse. In responding to this no attempt was made to extend physics by introducing a new concept, on the contrary, efforts were directed towards making it superfluous by reducing its possible content in such a way that it could be expressed by establishing a measurement of physical energy. The problem of description could be solved by allowing the information concept to disappear. It was thus a concept which at once cloaked and kept open a place for a problem which is concerned with establishing a connection between a certain physical form and a certain meaning. In this sense the apparently paradoxical idea of »missing information« was rather a pleonasm. The concept of information only had meaning as a concept of something that was missing.

The physical information concept thus becomes established in a tension between that which motivates the concept: the indefinable with regard to the physical as well as to knowledge and that which defines the concept: the definite physical form. It is therefore hardly surprising that this duality reappears later in Shannon's theory. The surprise lies rather in the way Shannon exploits this duality to describe an informational process without regard to its content. While Shannon thereby retains Szilard's equivalence between the physical and informational entities, he at the same time emancipates the physically defined information concept from the restriction which lay in Szilard's idea that the content of information was a statement of its own physical value. It is thus only from Shannon's engineer's point of view that the physically defined information concept exists in a general form in the sense that it is not defined by a determinable knowledge content.

Although Maxwell's demon is a brilliant observer that can see the individual molecule's movements in a closed molecular system, it cannot at the same time see itself and thermodynamics introduced not only a new model for a physical determinism, it also raised the germ of two other epistemological problems which contest the validity of the same determinism. This was not only the first time the concept of time in physics was given a direction, it was also the first time the information concept was described as a concept which could be determined by its physical form and the first time the observation situation was

included as an integral part of the object field with the fall of the idea of the detached, ideal observer as a consequence.

Although the physical approach to a description of the information concept is based on a very narrow and specific concept, which exclusively concerns a very special type of information (on physical energy) which is far removed in meaning from the older, general concept of information (as determinable knowledge which can be about anything at all) at the same time the physical information concept indicated a completely new, general dimension which is valid for any information concept, namely that all information is manifested in a physical expression. In physical information theory interest was focused on the special cases where information was the evidence energy gave about itself. Energy, so to speak, bore the information. The classical dualistic assumption that there is a clear distinction between information and energy, based on the belief that there is a well-established order of representation, now expressed in the idea of psycho-physical parallelism, was maintained.

As soon as it is no longer possible to maintain that the relationship between meaning and physical expression is a fixed, simple representational relationship, the dualistic conceptualization of the relationship between spirit and matter is brought into play as an object for exploring a connection in a place where in thought we assume there is a dividing line.

With thermodynamics, modern European physics therefore came a step closer to contesting the validity of the idea of a fully causal or logically ordered and describable nature.¹¹

The core of the way in which this problem presents itself is the question of the implications of the observation situation for our understanding of the character of and conditions for the representation of knowledge. Included here are questions of a) the epistemological interpretation of the subject-object relationship, or of the relationship of cognition to the cognized, b) the idea that finite systems can be characterized on the basis of their internal structure and c) the possibility of a complete description of both locally limited systems and the cosmological-universal world »system« and d) the impact of linguistic structures on the representation of knowledge about the world and e) the question of the relationship between the content of human cognition and its physical manifestation.

¹¹ Cf. physicist Peder Voetmann Christiansen (1988) who pleads that thermodynamics' acknowledgement of the impact of measuring procedures on the result of the measurement must be regarded as a precondition for the indeterminism of quantum mechanics, in that he refers to Charles Peirce's criticism of »necessitarianism« which, prompted among other things by thermodynamics, was formulated by Charles S. Peirce (1892).

All these questions far exceed the bounds of the physical information theory which helped to move the presentation of the problem from philosophy to science, but did not solve it.

The thesis here is that this establishment of the information concept as an indicator for a problem of determinism connected with the discovery of certain limits to knowledge in thermodynamic physics at the end of the previous century is a prototype of the later, far more comprehensive use of the concept. The thematization of the epistemological dilemma between form and meaning is released from its narrow bondage to the relationship between energy and information and is reformulated in many other areas of research. It is, runs the viewpoint, the acknowledgement of a similar, basic disruption of the balance of meaning which lies behind the breakthrough of information theory.

While the preceding chapters have followed the clues which lead to here from mechanical physics, in the next two chapters our attention will be concentrated on the clues which lead to here from formal symbol theory.

4. The language of logic and the logic of language

4.1 The truth of a sentence

With the invention of arithmetic, which cannot be dated, it became clear that mechanical procedures could be incorporated in human thinking. With the invention of the counting-board, which was known in such countries as ancient Babylon, now Iraq, approximately 5000 years ago, it also became clear that we are able to implement such mechanical thought procedures in physical instruments to our own advantage - but without finding it necessary because of this to refer to these or other mechanical apparatuses as capable of thought.

The reason for this may be philosophical or religious, human thought has always been seen in an eternal, spiritual light and thus superior to the finite world. But it may also be for practical and experientially conditioned reasons. Throughout the history of arithmetic people have handled mechanical procedures with the help of different, non-mechanical thinking - whether they were carried out mentally, manually or with the help of artefacts.

This is still the case. A mechanical procedure or calculation is always preceded by an analytical explanation which must at least include a definition of the components of the calculation and a motivated choice of compositional structure. Similarly, after a mechanical procedure there follows a non-mechanical handling of the result.

Confronted with this massive historical experience there would appear to be little room for the idea that all human thinking is mechanical or calculative. Nevertheless it was precisely this idea that was to become a main theme in much of 20th century science and philosophy.

In a peculiar way the breakthrough of this idea was based on mathematical physics. It is from here, on the one hand, that the idea arises that human consciousness can be regarded as a - complicated - physical system, that every mental process has a physical manifestation which should consequently be describable in mechanical terms. On the other hand, there is a manifest destabilization of the mechanical description of physical nature which also stems from here. Mathematical physics loses its ontological foundation while the question of truth is transformed from a question of nature's order to that of language.

On the face of things, these two traits would appear to contradict one another and in themselves provide no reason for regarding language - and un-

derlying this, thinking - as a mechanical calculation procedure. However, they did actually occasion a dialectical effort to resolve the contradiction by formulating it at a higher level.

The epistemological problems in physics had arisen as a new uncertainty concerning the interpretation of mathematical formulas as models of physical phenomena. Rejecting the mathematical description of physical processes was out of the question. On the other hand it was conceivable to imagine that it might be possible to solve not only the problem of mathematical physics, but all epistemological problems by constructing a more comprehensive and independent mathematical or logical language.

With this idea in mind a number of philosophers and mathematicians including Charles S. Peirce, Gottlob Frege, Bertrand Russell, David Hilbert, the logical positivists and the young Ludwig Wittgenstein took up an idea which had been previously taken up by Leibniz, but whose roots are lost in Arabian mathematics and medieval alchemy.

Although both the German Orientalist, Wilhelm Schickard, and the French mathematician and philosopher, Blaise Pascal, anticipated Leibniz with their calculating machines, Leibniz was the first to see in the calculating machine the fundamental form of the thinking machine. Although his own computer was only able to handle the four basic arithmetical operations, his philosophical system contained the idea that human consciousness was pre-programmed - like the mechanism of a clock - and that it should be possible to formulate the logic of this mechanism in a language characterized by the precision of mathematics.¹

Leibniz imagined that with such a reduction of logic to mathematics it would be possible to solve all conceivable problems, from the proof of God's existence and world order to the clearing up of any moral dispute. This depended, however, on the paradoxical precondition that all these and other relationships had been decided in advance, as Leibniz assumed that God had created a precisely co-ordinated synchronism between an external, physical

¹ C.f. Bolter, 1984: 143 and Davis, 1988: 150. Leibniz was one of the first European philosophers to take the binary system into consideration. Among other things, he believed that it provided an almost exemplary proof of the existence of God as it was a system which allowed the Almighty to create everything out of nothing. Augarten, 1984: 34. The idea of using the binary system in a calculating machine should perhaps have occurred to him, but would hardly have been possible to utilize at the time. The binary system is almost impossible to handle without the help of extremely complex mechanical or electronic apparatuses, its use as notation in a universal calculating machine also demands - as will be shown in chapters 5 and 7 - a conceptual break with the understanding of the binary form as a system of notation with fixed relationships between the notation unit and its value (as number or rule).

world clock and a clock of consciousness. Thus, if we feel pain when we cut a finger this is not due to any causal connection between the external event and the inner experience, but on the contrary to the divinely instituted synchronization of the two clocks which each controls its own domain. For Leibniz there was no other connection between the external and internal than this pre-ordained synchronization.

But this idea did not originate solely with Leibniz. He refers to the Spanish mystic, Ramon Lull, also called Doctor Illuminatus, as the first to broach the idea of a universal algebra. It was the goal of Doctor Illuminatus - long before Descartes - to emancipate philosophy from theology, because reason should be founded on doubt, not faith. For this purpose he built an apparatus - *Ars Magna* - comprising a number of concentric circles to which were attached a series of words and ideas in accordance with a specified order. By arranging these words in different ways it was possible to form questions and, by so doing, produce another series of words which presumably expressed a more precise delimitation of the logical character of the problem.²

This logic - referred to disrespectfully by Descartes as »the art of Lully«³ - which was ostensibly thought up as a defence for sceptical reason against the illusions of faith, had thus as automatic logic also the property of freeing the individual from a significant amount of difficult thinking. In this perspective the picture of the complete refinement of thought appears as the cessation of thinking.

However we balance the inherited accounts there is - for us at least - one immediately obvious difference between the ideas of Doctor Illuminatus and Leibniz on the one hand and mathematical logic, which makes its breakthrough at the beginning of the 20th century, on the other. What was once a theme for quaint alchemistic and philosophical excursions becomes - refracted through the prism of mathematical physics - the axis of a technological scientific revolution, which since World War II has assumed the character of a permanent revolution.

Regarded as a change in the history of scientific-utopian thinking this is not simply a question of a leap from utopia to reality, but also of a conceptual change-over. While the utopian dream has ancient roots, it assumes a new

² Cohen, 1966: 33.

³ »But on further examination I observed with regard to logic that syllogisms and most of its other techniques are of less use for learning things than for explaining to others things one already knows or even, as in the art of Lully, for speaking without judgement about matters of which one is ignorant.« Descartes (1637) 1985: 119.

shape expressed in particular as new, more rigorous demands on demonstration. The result of this was not only the loss of the dream, but also the first description of the principles of a real universal calculating machine.

4.2 The logic and the life of the sign

Attempts to construct a complete mathematical-logical language constituted only one of the new symbol theories which came into being around the turn of the century. During the same period Ferdinand Saussure presented the idea of a general semiology which also laid the foundation for structuralist theories of language while Charles S. Peirce presented his ideas of a general semiotics.

All three projects have a common and general theoretical ambition, but are mutually very distinct. The mathematical-logical project differs partly in its marked constructive and innovative aim, partly in the peculiarity that it hardly concerns itself with language as its subject area. The real subject is logic, which is also the basis of reflections on common language, to the extent that this is taken up at all, as in Rudolf Carnap. The same is perhaps true of Peirce who does not, however, see his draft of a sign-theoretical relational logic as the construction of a new language, but rather as an inherent principle in all symbolic activities.

While mathematical logic became of direct significance for the development of information theories, Saussure's and Peirce's theories have only been of a less direct and later significance. As they were formulated within the same scientific-historical context and play a part in the present description of both information theory and computer technology, it will be appropriate to define the different approaches more closely.

In Peirce's general model of cognition the classical subject-object figure is replaced by a so-called triadic sign concept. The established understanding of a sign as an expression which stands for something else is replaced by a tripartite relationship between *firstness*, »the signal« or quality as it is, *secondness*, the relationship of the signal to an object and *thirdness*, the interpreter that defines the connection between the signal and the phenomenon. As the interpreter comprises all the ideas included in the understanding of the sign, it resembles a colossal scrap-bin with a completely arbitrary content. But not for Peirce, who claimed that it was possible to define all imaginable logical relationships between the three sign aspects, which only together

comprised what Peirce called »genuine signs« as opposed to »degenerate signs«. Underlying this is again the thesis that all sign relationships can be described as more or less complex combinations of triads. Corresponding to the genuine sign's general triadity there is therefore also a triad of possibilities for each of the parts. There are three possible types of signal (qualisign, sinsign and legisign), three possible referential relationships to objects (icons, indexes and symbols) and three possible types of interpreter (rhemes, dicisigns and arguments/argusigns).⁴

As all we are concerned with here is representing the general sign model it is not appropriate to run the scholastic risk of giving a more detailed account of the individual categories. For the moment it is sufficient to note the new epistemological emphasis on the interpreter function which can be understood as a reflection of - and an attempt to solve - the problem of observation in physics. The interpretation of the sign is included in the definition of the concept of observation.

Given Peirce's interest in the logical relationships of signs it is hardly surprising that he - who was characterized by Cohen as a reincarnation of Dr. Illuminatus - was also interested in the idea of a logical, thinking machine.

*The secret of all reasoning machines is after all very simple. It is that whatever relation among the objects reasoned about is destined to be the hinge of a ratiocination, that the same general relation must be capable of being introduced between certain parts of the machine.*⁵

Peirce understood - like all his predecessors - the logical machine as a mimetic reconstruction of the structure of logical thought, but had, on the other hand, no illusions that human thinking as such could thereby be reproduced:

Every reasoning machine, that is to say, every machine, has two inherent impotencies. In the first place, it is destitute of all originality, of all initiative; it cannot find its own problems; it cannot feed itself. It cannot

⁴ Both in Peirce and later, changing terminology is used in referring to the individual components of the so-called sign trichotomy. The terminology here is from a number of manuscript fragments printed in Peirce: *Collected Papers*, volume 2. The fragments were collected by Justus Buchler under the title *Logic as Semiotic: The Theory of Signs* and printed in his selection of Peirce texts in Buchler, 1940: 98-119. C.f. also Gorié, 1990, who describes the development of terminology and meaning in Peirce's view of monadic and dyadic (»degenerate«) signs which include such things as biological and bodily signs and mental signs in which the triadic element is missing.

⁵ Peirce, 1887: 168. Cohen's characterization is from Cohen 1966: 112.

*direct itself between two different possible procedures... And even if we succeed [in the latter] it would still remain true that the machine would be utterly devoid of original initiative... In the second place, the capacity of the machine has absolute limitations; it has been contrived to do a certain thing, and it can do nothing else.*⁶

This is indeed also true, adds Peirce, of consciousness, but in a different way, which is illustrated by our ability to continue to develop algorithmic calculations indefinitely. As will appear in the next section Gödel incidentally used very similar reasoning in his argumentation regarding the incompleteness of formal description.

As a consequence of these limitations, which were related to analogue machines, the point lay not in the possibility of replacing human thinking, but in the possibility of freeing us from boring routine work and particularly in the possibility of obtaining new knowledge of logical thinking by studying such machines. The question was, how great a part of thinking could such a machine carry out?⁷

According to Peirce, however, mechanical procedure also possesses a property which means that it cannot solely be seen as a simple, repetitive procedure. When the various parts of a machine interact, relationships also arise which have not necessarily been intended or anticipated. Peirce sees these relationships as »reasonings« which express a law which has thus been formulated by the machine. This argument goes not only for the logical machine, where laws are of a logical character, but, says Peirce, also for many physical machines where the interaction is an expression of physical or chemical laws:

*In this point of view, too, every machine is a reasoning machine, in so much as there are certain relations between its parts, which relations involve other relations that were not expressly intended. A piece of apparatus for performing a physical or chemical experiment is also a reasoning machine, with this difference, that it does not depend on the laws of the human mind, but on the objective reason embodied in the laws of nature.*⁸

⁶ Peirce, 1887: 168-169.

⁷ Peirce, 1887: 169 and 165.

⁸ Peirce, 1887: 168.

In a narrower linguistic sense the new sign theoretical clues are laid down rather by Ferdinand Saussure's draft of a structuralistic sign theory which, in spite of its general aim to be a »a science which studies the role of signs as part of social life«⁹ was constructed around an investigation of linguistic signs with the definition of the sign as an - arbitrary - unit of expression and content: »A linguistic sign is not a link between a thing and a name, but between a concept and a sound pattern.«¹⁰ This definition of the sign concept contains the entire basis of Saussure's theory of language: No matter how we look at a linguistic phenomenon it always contains two complementary facets. There is thus not only an indissoluble - but also variable - bond between a concept and a sound pattern, as well as between articulation and acoustic impressions, between the auditory-articulatory unit and the idea, between physiological and psychological, between the individual and social aspects of language, between language as ever ongoing evolutionary process (diachrony) and as institutional system (synchrony) and between language as an invariant structure or system (langue) and use (parole).¹¹ As language use is understood on the one hand as the sole manifestation of the invariant linguistic structure and also, on the other, as the sole manifestation of meaning-giving variation, the different interpretations of the meeting between system and meaning constitute an important dividing line between different linguistic theories.

Where Peirce introduced an interpretant as a kind of bridge builder between the expression and the content, Saussure saw the sign relationship as a series of units between the two sides. Both theories implied that any study of signification and meaning should be based on a study of the structural representation of the content. But they did so in two different ways. Where Saussure's theory directs attention towards the specific linguistic sign function, Peirce attempted - as pointed out by Linda Gorfée - to formulate a universal symbolic logic on the basis of the assumption that it is possible to identify thought content with the symbolic expressions.

*Logic needs no distinction between the symbol and the thought for every thought is a symbol and the laws of logic are true of all symbols.*¹²

⁹ Saussure (1916) 1983: 15 (33).

¹⁰ Saussure (1916) 1983: 66 (98).

¹¹ After Saussure (1916) 1983: 8-8 (23-24). The most common translation of parole seems to be »speech«, which accords with Saussure's concept of language as spoken, not written. But since it is sometimes necessary to include or refer to the manifestation of written language, it will also be translated - in agreement with Hjelmslev's terminology - as language use or usage.

¹² Peirce (1865, Writings. 1.166) quoted here after Gorfée, 1990: 72.

For Peirce the linguistic form of expression therefore simply becomes in itself a less significant manifestation of an underlying, universal logic of sign relationships, while Saussure viewed linguistics as a beginning and contribution to a general theory of signs - a semiology - including *different* sign systems whose respective places in human consciousness would later have to be determined by psychology.¹³

To do this, however, the psychologist would have to have both a theory of signs and a sign system with which to express his analysis. In spite of all caution Saussure also paved the way - with his draft of a more precise definition of language as a distinct subject area - for an acknowledgement of the central place of the sign system in epistemology. The delimitation of the concept of language as a phenomenon with its own separate structure at the same time instates this structure as a condition for human cognition of the non-linguistic.

Saussure formulated his theory in a break with the comparative linguistics of the 19th century, because »they never took very great care to define exactly what it was they were studying«¹⁴ and they were therefore unable to develop a systematic method. But the definition of language as a stockpile of sound patterns, signs which are composed of a connection between expression and content is not only a new, improved foundation for the same linguistic science, it also becomes the starting point for a methodological polarization which, in its general form, results in a distinction between a synchronic and diachronic description of language, each covering its own point of view with the sign concept as the only connection.

For Saussure the distinction is primarily methodological, a necessity which makes it possible to carry out a more precise description and the choice of point of view is in principle only a question of what we are interested in. If we study a slowly evolving language, we will take note of the synchronic traits, but if the language evolves rapidly, a diachronic approach will not only be more obvious, it will also be considerably more difficult to separate an area for a synchronic description:

Of two contemporary languages, one may evolve considerably and other hardly at all over the same period. In the latter case, any study will ne-

¹³ Saussure (1916) 1983: 16 (33).

¹⁴ Saussure (1916) 1983: 3 (16).

*cessarily be synchronic, but in the former case diachronic. An absolute state is defined by lack of change.*¹⁵

This simply shows how difficult operating with an isolated synchronic description is. Saussure also supports the distinction by allocating the diachronic and synchronic perspectives to two different domains of language. The synchronic is anchored primarily in grammar, while the diachronic is anchored in phonology.¹⁶ In the later structuralist interpretation the diachronic perspective has, as a general rule, been completely abandoned or regarded as a less decisive, modifying factor.

Saussure himself set the stage for this consequence in that he assumed that diachronic changes - sound shifts, for example - primarily involve individual elements in the language system. Although such changes undoubtedly affected the entire system there was no »inner« connection between the partial, diachronic changes and the total system. The two aspects could not be studied simultaneously and language was primarily understood as a system with emphasis on the synchronic connections between its components.

The central, still unsolved problem on both sides of this polarity, however, turns out to be the same, namely the relationship between a language as a system and the manifested use of language. The synchronic language system must not only be separated from the diachronic time axis of the phonological expression variation, it must also be separated from the semantic variation which is manifested in the same usage as the language system. Unlike phonological variation, semantic variation cannot be described as a particular, delimited variation of a single link in a language system. Semantic variation is not only manifested as individual variations, but is also expressed as a trait of genre and style. Hence, it is difficult to see why semantic variation should not occupy a place at the level Saussure delimited as language system or language construction. In other words, there is no basis for the concept of an invariant language system.

¹⁵ Saussure (1916) 1983: 99-100 (142).

¹⁶ Saussure (1916) 1983: 99 (141), 133-142 (185-197). It should also be mentioned that Saussure also expanded and re-interpreted grammar by adding lexicology to morphology and syntax and by describing these - mutually overlapping - aspects on the basis of what he believed was a more basic distinction between syntagmatic and associative relations. Syntagmatic relations exist in relationship to the surrounding signs in the speech chain. Associative relations are concerned with the relationship to other possible candidates for the same place.

Saussure also concedes that the diachronic perspective cannot be reduced to phonological or other subordinate changes regarding the synchronic description.

When the phonetic factor has been given its due, there still remains a residue which appears to justify the notion that there is a »history of grammar«. That is where the real difficulty lies. The distinction - which must be upheld - between diachronic and synchronic calls for detailed explanations which cannot be given here.¹⁷

A more detailed explanation along these lines has still not appeared and we could therefore ask whether this indeterminacy in the relationship between language system and language use, which appears to be valid for all languages sometimes referred to as »natural« languages, is not a - perhaps even very central - property which at the same time separates them from mathematical, algorithmic and logical languages?

This question will be taken up for further discussion in chapters 6-9, where it will be claimed that the concept of an invariant language system cannot be valid for languages that allow an indeterminate semantic variation of the utilized notation system's smallest units of expression because in this case, such a semantic variation would also be able to include the established rules of the system.

The relationship between the diachronic and synchronic description was neither included as a problem in mathematical logic nor in Peirce's semiotics. But according to Saussure the problem is manifested in disciplines which, like linguistics and economy are concerned with »a system of equivalence between things belonging to different orders. In one case, work and wages in the other signification and signal«. Such systems are characterized by simultaneously manifested, different 'values' which together comprise the system at a given stage, while the individual components vary individually over time.¹⁸

The three sign theories were in many ways extremely different mutually. Mathematical-logical symbol theory is concerned with the relationship between mathematical and logical representation, each of which is understood as

¹⁷ Saussure (1916) 1983: 141 (196-197).

¹⁸ Saussure (1916) 1983: 79-86 (114-123).

a well-established and consistent symbol system that, in one or another combination can comprise a general sign theoretical foundation. Peirce's theory contains a draft of a new sign theoretical logic, while in this connection Saussure sets his sights - rather uncharacteristically - on a more modest goal, a narrower definition of a new starting point for a later general sign theory.

Although these theories emerged independently of one another and are mutually incompatible in their original form, their direction was the same: The attempt to describe language as an independent system with immanent laws which were either independent of or actually controlled the semantic reference. Sign production came to be regarded as a result of sign relationships contained in the language system. Semantics was regarded either as invariant in relationship to the language system, or as a function of language use and language system.

Herein lies the implicit and - it will be claimed in a later chapter - also dubious postulate: that the semantic dimension of language is completely manifested in the symbolic expression system - wholly contained or expressed in language use and surrounded by the language system which, conversely, is postulated as inaccessible to semantically motivated variation. The common goal was thus to describe an independent, closed system of rules for the articulation of meaning.

Saussure's theory was formulated against the background of the »pre-scientific foundation« of historical linguistics where although language had been regarded as a form, the form was seen as an external vehicle for the articulation of meaning. Instead, he claimed, that thought, before it is expressed in the distinctions of language, must be understood as an amorphous mass, »chaotic by nature«. The semantic content can therefore only exist through the linguistic oppositions, »the contact between [sound and thought] gives rise to a form, not a substance« which again implies that the semantic level is allocated to the individual signs.¹⁹

For Peirce and the formal, mathematical-logical symbol theory, the background was a destabilization of the representational validity of the mechanical description of nature.

There were apparently two equally disagreeable alternatives. If the aim was to maintain a systematic or mechanical model, a loss of referential validity would have to be accepted. If the aim was to maintain the demand for

¹⁹ Saussure (1916) 1983: 110 ff. (155 ff.). Here there is a parallel with the movement of physics from the idea of matter defined by form to the idea of amorphous matter and pure form.

referential validity, the method of systematic or mechanical description would have to be abandoned.

The main currents of 20th century linguistics thus take on the appearance of an emancipation from an understanding of language as submerged in the pre-ordained meaning content of history and nature. Hume's philosophical critique of the concept of causality had, so to speak, caught up with linguistics, the semantic bond to the described world was broken.

When a fixed correspondence between the concept and the conceived is no longer regarded as given, conceptualization, linguistic representation, emerges as a separate substance and as the place where the question of truth is decided. With the transformation of ontology to epistemology the reference of language to the world outside language becomes woven into the reference of language to itself. Referentiality no longer exists as an assumed or obvious possibility, instead it becomes an object for linguistic reflection, while at the same time language emerges more clearly as an independent, autonomous system of pure forms.

In spite of the mutual divergences, which will appear again in later chapters, together they represent the first marked - as yet only theoretical - expressions of a secularization of the relationship of science to language. This secularization has traits in common with older, nominalistic assumptions which similarly doubted that language refers to an order outside language, but it is distinguished by the objectivizing view of language as a self-reliant phenomenon that *can* be described.

While Saussure aimed at a systematic description of the mechanisms of common language, the logical and mathematical symbol theories attempt to respond to the lost referentiality by formulating a new, formal and consistent symbolic language. Hereby the idea itself of an abstract and formally defined symbolic system became firmly anchored in many other disciplines beside mathematical physics.

4.3 The idea of a mechanical decision procedure

It might be thought that logically oriented philosophers would be the first to cast doubt on the idea of a mechanical logic which makes the logician superfluous, robs his previous efforts of any connection with the more elevated mental occupations and relegates philosophical logic to civilization's prehistoric archive for happily done with, now superfluous business. But this

is far from being the case. Nobody else has proposed - let alone attempted to develop - the idea of a mechanical logic with the same disinterested fervour and perseverance as can be found in the history of logical philosophy. In addition, the most ambitious and powerful expression of these efforts is to be found precisely at the point where the mechanical paradigm, with its background in physics, really got into difficulties. There can be little doubt that inspiration was to a great degree derived from the speculative daring which in its time led to the successful formulation of the basis of mathematical physics. Galileo's »measure what can be measured«, Descartes' analytical geometry and formulation of mathematics as the critical, sceptical weapon of reason against ignorance and Newton's largely successful application of a relatively simple system of axioms to a description of the planetary system, which was in itself an expression of the fact that it was possible to develop general methods of description which must clearly take precedence over questions of empirical evidence.²⁰ The problems of mechanical physics had to be regarded in this perspective and the central theme of philosophical logic therefore became the relationship between logic and mathematics itself. The overall goal was to provide a proof theory, that is, a general, formal proof that it was possible to decide whether a procedure carried out in a formal, symbolic logical language was correct or incorrect.

The meta-mathematical programme - of David Hilbert - resulted in a number of precisely formulated questions proposed at two international mathematical congresses in 1928 and 1930. Among the questions raised there were three in particular which came to occupy people: Can mathematics be regarded as complete in the sense that every mathematical statement can either be proved or disproved? Can mathematics be regarded as consistent in the sense that a valid operational sequence will never lead to incorrect statements (such as, for example, that it will never be possible on arithmetical lines to arrive at results such as $2 + 2 = 5$)? And can mathematics be regarded as decidable or provable, i.e. is there a finite method which in principle can be used on every assumption with the guarantee of a correct decision as to the truth of the assumption? The last problem is the so-called *Entscheidungsproblem*.²¹

Hilbert himself was convinced that all these questions could be answered in such a way as to make it possible to declare that it had been proved that

²⁰ Empiricism too assumed (and developed on the basis of) such a theoretical-constructive epistemological foundation, necessitated by the attempt to penetrate the prejudices of immediate experience.

²¹ C.f. Hodges 1983: 90-92.

mathematical logic was a complete and consistent descriptive language. At the 1930 congress he rounded off his lecture by declaring that *ein unlösbares Problem überhaupt nicht gibt*.²²

But far from everyone shared Hilbert's optimistic expectations regarding formal mathematical description. Mathematician E. L. Post had thus as early as the 20's been on the trail of formal problems which could not be decided with the help of any finite method. Others - such as John von Neumann - had, similarly in the 20's, argued that there was not only no known proof that all mathematical problems in principle had a finite solution, there was no reason at all to believe that such could be found. On the contrary, the lack of such proof was the *raison d'être* of mathematical thinking:

*...the contemporary practice of mathematics, using as it does heuristic methods, only makes sense because of this undecidability. When the undecidability fails then mathematics, as we now understand it, will cease to exist; in its place there will be a mechanical prescription for deciding whether a given sentence is provable or not.*²³

Even before Hilbert had been able to present his whole programme at the 1930 congress, the two first of the three questions mentioned had found a clear and equally surprising answer.

On the previous day, mathematician Kurt Gödel presented one of the 20th century's most epoch-making mathematical proofs, Gödel's theorem, which in a nutshell states that arithmetic is either inconsistent or incomplete, as he showed that there are »relatively simple« arithmetical sets which contain at least one assumption the validity of which cannot be decided within the premises of the given formal system.²⁴

With Gödel's proof culminated the idea of a mathematical-logical epistemology and logical positivism lost its philosophical foundation. Instead of a general truth function there was now a formal proof that there was a problem

²² Quoted after Robin Gandy, 1988: 63.

²³ Von Neumann, 1961: 265-266. Quoted here from Robin Gandy's translation, 1988: 66. The original quotation is as follows: ...die Unentscheidbarkeit ist sogar die *Conditio sine qua non* dafür, daß es überhaupt einen Sinn habe, mit den heutigen heuristischen Methoden Mathematik zu treiben. An dem Tage, an dem die Unentscheidbarkeit aufhörte, würde die Mathematik im heutigen Sinne aufhören zu existieren an ihre Stelle würde eine absolut mechanische Vorschrift treten, mit deren Hilfe jedermann von jeder gegebene Aussage entscheiden könnte, ob diese bewiesen werden kann oder nicht.

²⁴ Gödel, (1931) 1965: 6 and Hodges, 1983: 91 ff. Gandy, 1988: 68. Gödel's proof was printed in 1931 and expanded in 1935. Quoted here from a reprint in Davis, 1965.

of description and decision which could not be solved within the framework of formal logic - as Gödel wrote:

*The true reason for the incompleteness which attaches to all formal systems of mathematics lies... in the fact that the formation of higher and higher types can be continued into the transfinite... while, in every formal system, only countably many are available.*²⁵

While Gödel closed one door with this conclusion, he opened another with his method, the formal treatment of formal systems.

As such this method had already been developed in the various attempts to connect the mathematical and logical descriptions. The assumption here, however, was that there was a logical relationship: that mathematics *is* logic (Frege-Russell) or that mathematical problems could be handled with a meta-mathematical logic (Hilbert). In both cases the method was deductive, an attempt to reach the mathematical expression through analytical reduction. Gödel took a different path as he simply numbered the individual sentences in a formal system: »we now set up a one-to-one correspondence of natural numbers to the primitive symbols of the system«²⁶ and then proceeded to handle the demonstration process on the basis of number theory. Gödel thus demonstrated how it was possible, with a simple and arbitrary coding or addressing procedure - »Gödel-numbering« to handle a logical-symbolic system in a numeric system, where the first system was represented only by an address. As a whole the demonstration was extraordinarily complicated, but the coding procedure itself was almost hair-raisingly simple.

The methodical principle, arbitrary re-coding, contains at least in germ a number of formal procedures which have since found widespread use. In the present connection it is particularly interesting that the method contains a general model for the algorithmic handling of formal procedures, among them also other algorithms - second-order handling - and that it exploits a »scanning principle« as a coding procedure.²⁷

²⁵ Gödel, (1931) 1965: 28-29.

²⁶ Ibid: 13.

²⁷ By scanning I mean here that a phenomenon is represented or handled via an arbitrary symbol - just as a wardrobe number represents a coat. The scanning concept has since spread together with the information concept and is used both of cognitive and visual processes and as a term for certain investigation procedures (such as search procedures in computer science, the eye's search procedure in perceptual psychology, by among others, Gregory and Gibson, each with his own interpretation, and ultra-sound scanning in medicine). It could be said that the scanning perspective, which is a principle of fragmentary representation, today plays a role as a cognitive and visual paradigm, which resembles the

The method, however has - still - not been emancipated from that limitation which was the first result of its use. It is impossible to formulate a general, formal demonstration procedure for the completeness of a formal description.

In this way Gödel's theorem is part of 20th century mathematical logic in the same paradoxical way as quantum physics is of 20th century physics, as a method of description which extends the descriptive potential by limiting the validity of the description.

Gödel, however, answered Hilbert's two first questions with his method. The third remained. Gödel had introduced a distinction between formally correct, demonstrable sentences on the one hand and non-demonstrable sentences on the other and presented a new method of demonstration which extended the area of use for formal demonstrations, which depended on the performance of a finite number of formal, step-by-step operations with fully deterministic rules of arithmetic. But he had only shown that any known formal system was incomplete because it must contain at least one sentence which could not be demonstrated within the system's own framework. He had not invalidated the possibility that there could be a general, finite method to decide *whether* an arbitrary mathematical sentence could be demonstrated or not. But this problem too - Hilbert's *Entscheidungsproblem* - was now coming close to solution.

If it were possible to confirm Hilbert's thesis, it must be assumed that it should be possible to perform any logical procedure along mathematical-algorithmic lines with the help of mechanical procedures. »It is well known«, wrote Gödel in 1931,

*... that the development of mathematics in the direction of greater precision has led to the formalization of extensive mathematical domains, in the sense that proofs can be carried out according to a few mechanical rules.*²⁸

But, it appeared, a confirmation of Hilbert's thesis required not only the description of a mechanical demonstration procedure, it must also be shown that this procedure could be performed with a finite number of operations. It must be possible to decide when it could conceivably be stated that there *never* would be a decision. This again required a precise definition of what was understood by a finite mechanical procedure.

role of system perspective in the 19th century and that of central perspective in the 17th and 18th centuries. C.f. Finnemann, 1989: 163-172 and 1991: 170-172.

²⁸ Gödel (1931) 1965: 5.

In the middle of the 30's no fewer than three different suggestions for such a definition emerged. It could quickly be shown that the three suggestions were equivalent even though they had been worked out in different ways and that they implied that it was not possible to formulate a general method to decide whether an arbitrary sentence could be proved. One of these definitions distinguished itself, however, by being formulated on the basis of an arbitrary theory of numbers.

It was with this definition of a finite mechanical procedure based on the theory of numbers - developed in an attempt to answer Hilbert's third question - that, in 1936, the then 24 year-old English mathematician Alan Turing supplied the first theoretical formulation of the principles of the »universal« computer.²⁹

²⁹ The three definitions are Church-Kleene's, Gödel-Herbrand's and Alan Turing's. C.f. Kleene, 1988: 34-36. Gandy, 1988: 69-88 and other contributions in Herken, 1988. The coincidence of time has given rise to much speculation regarding the possible direct and indirect lines of inspiration. It has, however, been reasonably well established that Turing formulated his proof without knowledge of the others. Turing came last, but his article was published because his method was different to Church's.

5. The universal computer

5.1 The demand for physically defined symbolic forms

Turing presented his answer to Hilbert's Entscheidungsproblem in the article *On Computable Numbers, with an Application to the Entscheidungsproblem* in 1936.¹ The answer was negative. It could be demonstrated that there is no general calculation procedure which can decide whether an arbitrary, well-defined arithmetical or formal logical problem can be solved in a finite number of operations. It is true that this piece of news was already a month old, as Alonzo Church had shortly before published a similar demonstration. Turing's demonstration, however, was formulated in a different way and contained two original results.

One was that Turing's definition of finite, formal procedures did not - like Church/Kleene's and Gödel/Herbrand's - depend on a specific set of formal axioms. This meant, maintained Alonzo Church in 1937, that Turing's definition had...

*...the advantage of making the identification with effectiveness in the ordinary (not explicitly defined) sense evident immediately - i.e. without the necessity of proving preliminary theorems.*²

Church therefore viewed his own thesis as a theoretical definition which was proved by Turing's analysis. It was ostensibly also this independence of specific formal axioms which convinced Gödel that his own and Church's definitions were not simply heuristic theorems.³ He certainly emphasized a number of years later that Turing's definition had a distinct epistemological value.

*With this concept, one has for the first time succeeded in giving an absolute definition of an interesting epistemological notion, i.e. one not depending on the formalism chosen.*⁴

¹ Turing, (1936) 1965: 115-154.

² Quoted here after Gandy, 1988: 85.

³ Feferman, 1988: 117 f.

⁴ Kurt Gödel, (1946) 1965: 84.

This theoretical gain and the evaluation of its implications belong to mathematical logic.⁵

The second main result in Turing's article was contained in the tool he developed to carry out his demonstration. This tool comprised a description of what he called himself »the universal computing machine«, later often referred to as a Turing machine. The key to this also lay in his definition of the finite, formal procedure in that he showed that any such procedure could be divided into a series of step-by-step operations which could be performed mechanically.

Turing himself understood the two results as being mutually connected, just as the later literature also exhibits a tendency to view the Turing machine solely in a mathematical-logical perspective.

Although the tool was developed as part of a mathematical-logical demonstration, it has an independent character, however, which can be described - and used - independently of mathematical logic.

This postulate implies on the one hand that mathematical-logical interpretations are regarded as valid descriptions of certain delimited classes of computational processes. On the other, the thesis implies that Turing's - and later others' - mathematical-logical descriptions of the computer contain restrictions which are not conditioned by the properties of the tool, but on the contrary by the mathematical-logical interpretation, which can consequently only be seen as a special case within a more general description.

Mathematical-logical descriptions of the Turing machine can thus be understood as descriptions of dedicated machines where the mechanical procedure is subordinated to a closed, formal - mathematical or logical - semantics. The Turing machine, however, is not defined by any demand on a formal semantics. It is, on the contrary, defined by the demand that the symbolic expression must be available in a physically and mechanically executable form.

⁵ C.F. Michael J. Beeson, 1988: 194-198. There appears to be agreement that Turing's result accords with Church's thesis: that effectively calculable functions in general are recursive. The thesis is sometimes referred to as Church's and sometimes as Church-Turing's thesis. C.f. Kleene, 1988. Haugeland, (1985) 1987 assumes that the two analyses are equivalent. Church, as mentioned, believed that his thesis had been demonstrated by Turing's analysis, but its status is still under discussion. Gandy thus objects that it cannot be excluded that it may be possible in the future to formulate non-recursive mathematical-logical algorithms and demonstrations and that the thesis can therefore not be regarded as having been proved. Gandy, 1988: 78-79. Gandy also emphasizes that Turing's analysis also contains another independent thesis, usually called Turing's theorem: Any calculable function (in Church's sense) which can be performed by a human, can also be performed by a machine.

The demands made on the physical form are, as will become evident, not only independent of the meaning and semantic organization of the expression, they also imply that any symbolic expression which is to be handled must be available in a notation system which is not subordinated to the semantic restrictions which hold true for formal notation systems.

The analysis which follows in sections 5.2-5.4 will thus result in three connected conclusions, namely that:

- A Turing machine is distinct from other known machines because the rules which establish its functional architecture are not defined as part of the machine, but on the contrary are included and defined in the description of the task. A Turing machine can thus only be used as a calculating machine (or to carry out a formal procedure) because it is not itself subordinated to the restrictions which are contained in the rules of arithmetic (or in the formal procedure).
- The physical demand for mechanical performance implies that both the rules which define the functional architecture of the Turing machine and the data that are to be processed must be represented in a notation system comprising an invariant, finite number of notation units, each of which is individually semantically empty. The central leap from the automatic calculating machine to the universal computer is brought about in and by the construction of a notation system which is principally different to formal notation systems. This notation system will be designated informational notation in the following.
- Informational notation, which makes it possible to use a Turing machine to simulate an automatic calculating machine, also makes it possible to use this machine to simulate an indeterminately large quantity of both formal and informal symbolic expressions, as well as a multiplicity of non-symbolic processes and phenomena.

As will be shown, the unique properties of the Turing machine are founded on a new form of exchange between physical-mechanical and symbolic procedures. As Turing discovered the foundation for this construction in a number of assumptions connected with human cognition, which have also played a central part in later interpretations, they will be discussed in sections 5.6-5.9.

The Turing machine in its basic form is a quite simple model for performing mechanical calculation procedures. The leading idea is that any such calculation subsists in running through one or another, possibly large, but for a given task, finite, number of repetitions of very few and individually simple operations. The demands on such a machine can be specified in the following points:

- It must perform its operations *step by step*.
- It must be able to *receive instructions in the form of symbols* on a *tape* divided into a number of *squares* where a given square can contain *one symbol* (or be empty). This tape should in principle be endless, but it will at all times contain only a finite number of squares and symbols.
- Each symbol must have a physically well-defined form, as it must be able to produce a physical-mechanical effect. The number of permissible symbolic units must be finite as they must comprise an invariant part of the machine.
- It must be able to »scan« the squares on the tape one by one, either by *moving forwards or backwards*, but always only one step at a time.
- A scanning must result in - similarly very few - different effects, either on the tape or on the state of the machine:
 - It must be able to write symbols in empty squares, delete a symbol which has been read in, leave it there, or change it.
 - It must be able to move the tape forwards or backwards to the next square.
 - It must be able to change the machine's »figuration«.
- Finally, in addition, it must also be possible to describe the machine - not the tape - using a finite number of distinct states and each individual state, »machine figuration«, must be addressable.⁶

The description can be compressed, as any Turing machine can be described as a finite set of sequences, each with the form:

F MG

as the form expresses that a machine in a given figuration, F, with in the actually scanned square will replace this with a , move the tape, marked by

⁶ C.F. Kleene, 1988: 23 and Gandy, 1988: 81 for slightly varied specifications of the operational structure of the Turing machine. On practical grounds, Turing introduced on the way several operational mechanisms, among them a division of the tape so that every other square was reserved for auxiliary signs which could be deleted and which were used during the operations.

M, one place to the left, right, or remain in the same place and change its figuration to G.⁷

As the machine's behaviour is in this way determined by its actual state (machine figuration) and the actual scanned symbol, this specification is adequate to describe the behaviour of the total system (the configuration) at any given moment.

Using this inventory, Turing then went on to show how it was possible to draw up a table for any arbitrary computable sequence which would indicate the necessary configuration in a standard form so that the calculation could be performed solely with the help of the operations indicated by the table. As the machine can begin by reading a description of the standard form for a given computable sequence, there lies in this a new possibility, since referred to as Turing's thesis or theorem:

*It is possible to invent a single machine which can be used to compute any computable sequence.*⁸

The idea is thus not only that any - possible - calculating procedure can be performed mechanically, but that with suitable programming it can be performed by one and the same machine »the universal computing machine«.⁹

Looked at from Turing's - and mathematical logic's - point of view this description of the machine is exhaustive. What remained was to give an account of its possible uses which, as far as Turing was concerned, primarily involved two questions. One was the question of which calculation tasks such a machine could carry out. The other was the meta-theoretical question of how the theoretical model could be exploited to clear up Hilbert's Entscheidungsproblem and eventually other meta-theoretical problems in mathematical logic as well.

Neither of these questions gave occasion to regard the machine's physical method of functioning as a central element in understanding its basic form. In later literature it has often been claimed that, among its other merits, the purely

⁷ This specification is from Martin Davis, 1988: 155, who presents it in three variants - one for each of the three possible movements. It should be noted that \rightarrow and \leftarrow can have the same value, so that the result of the operation will be that the value remains unchanged, corresponding to nothing being written. In this form \rightarrow and \leftarrow cannot be replaced by 0 and 1. Turing uses the form as a starting point for a conversion of the programme to »machine language«, Turing (1936): 126-127.

⁸ Turing, (1936) 1965: 127.

⁹ Turing uses the term computer of a person who performs calculations, in accordance with its then ordinary meaning. The machine is called a »computing machine«.

formal description of the machine was that it was not determined by specific physical properties. In general it is acknowledged, however, that a physical realization contains certain restrictions, among them that which lies in the difference between Turing's infinite tape and the finite capacity which characterizes any real machine, just as formal procedures in real machines are subject to the restrictions of time.

But the physical realization not only plays a central role for an understanding of modern computers, it also plays a somewhat overlooked, but nevertheless fundamental role for an understanding of the functionality of the Turing machine.

5.2 The demand for universality and the dissolution of mechanical and symbolic procedures

If Turing had been asked how he would describe the relationship between the symbolic and the physical process, he might have answered that the physical-mechanical processes were simply divided into a series of individual steps which were regulated by a finite and deterministic symbolic procedure. Such an answer would be in agreement both with the classical understanding of physical-mechanical processes and fulfil the purpose to use the machine to solve finite calculation tasks, just as it incidentally places the Turing machine in the company of other, already familiar calculating machines.

There can be little doubt either that Turing himself saw the universal computer as a calculating machine and considered the main point to be the arithmetical analysis of finite procedures, as this analysis implied a considerable increase in the types of problem which could be made the object of automatic calculation. With this overstepping of the hitherto known limits for calculating machines, Turing took the idea of the automatic calculating machine to its theoretical completion.

There were others who were going in a similar direction. The German engineer, Konrad Zuse, thus built the first automatic calculating machine (with memory, control unit and a punched tape as input medium) during the years 1936-1938, while the American engineer, Claude Shannon, published a thesis in 1938 in which he used George Boole's logical algebra to describe and organize physical relay systems as logical functions.¹⁰

¹⁰ Zuse's first and subsequent machines are described in Williams, 1985: 216-224.

Turing's description, however, contained a far more radical innovation, as he not only described how to construct an automatic calculating machine, or a logically controlled relay system, but also how *any* finite formal procedure could be performed by *one and the same machine*. He thereby also took the fundamental theoretical step which led from the automatic calculating machine to the universal computer.

The principle difference between these machines stems from the demand for universality, as this implies that the operational rules of the machine are described together with the task. They can therefore not be built into the machine's invariant physical architecture which, on the contrary, must function completely independently of any definite calculational rule of arithmetic as, if it does not, the machine will be limited to a finite set of built-in rules/formal axioms.

It is precisely at this point that Turing's theoretical machine differs from Zuse's, which used a built-in mechanical calculator while the punched tape only contained the calculating task itself.

Now this was not simply a question of separating the definition of the machine from the definition of the rules of calculation it was to follow. Or rather, this separation immediately raises a very radical question, namely whether and how any finite formal procedure can be described in such a way that it can be carried out by a machine which is only capable of repeating the same few, very simple mechanical operations again and again?

The answer to this can be obtained by looking more closely at the tape where the dividing line is drawn between machine and task and where the transition from the formal expression to the physical-mechanical performance takes place. It appears from this that the mechanical performance of a finite formal procedure requires that the formal expression - the task as well as the rules which are to be effectuated - be converted to a notation system which consists of a finite number of notation units individually empty of meaning.

That Turing himself understood the mechanically executable notation form as absolutely equivalent to formal notation, makes it necessary to look more closely at his conversion procedure and the »machine language« which is produced as a result.¹¹

In the examples he provides he uses a quite arbitrary notation. In some cases he uses the two symbols (0-1) of the binary number system as a notation for the number system (and only for that), the letters L (left), R (right), N (none)

¹¹ The relationship between Turing's notation and binary notation as used in modern computers will be discussed later in this chapter.

for rules of movement, P (print) for the writing operation, E (erase) for a deletion operation and a number of auxiliary signs for addressing and other functions. In other cases both number values and functions are expressed by letters - all in accordance with the principles of formal notation. The quantity and types of sign are directly derived from what is necessary for the given calculation procedure and each symbol has its own semantic value. As the symbols and functions can also be described physically, they can as such perfectly well be implemented in a machine.

This machine, however, is not a Turing machine, but a calculating machine, as it operates with a limited number of functions/rules and with a specific semantic content connected to the individual physical units of expression. The universal machine, on the other hand, demands that this formal notation be converted to a standard notation which, in its form, is quite independent of the rules of calculation and the meaning of the symbols.

Turing described the conversion with a starting point in the previously mentioned description of finite calculation procedures as a list of the total number of operations of the form $F_i \rightarrow M_j G_k$, as each of these is given a number which indicates the sequence so that the complete list comprises a set in the form of

$$F_i \rightarrow M_j G_k$$

to which is added a punctuation mark between the individual sequences.¹²

To enable the machine to identify a given figuration (sequence no. i) the expression is converted to a new form. The machine figuration (before = F and G) is represented by the letter D, while the figuration's number in the list (i) is represented by another letter, A, appearing i times.

The actual symbol is similarly defined partly by the same letter, D, partly by a number (j) which is similarly represented by allowing another letter, C, to appear (j) times. There is a differentiation between (i) and (j) because the symbol in a given square can change during the procedure. The combination DA...A thus indicates the actual figuration, while the following DC...C indicates the actually scanned symbol which is again followed by a new sequence DC...C, which indicates the new symbol value in the actual square.

Then follows one of the symbols for the next movement (L, R, N) and finally a new DA...A sequence which contains the address of the next figuration to be processed. To differentiate between the two functions covered by DA...A

¹² In Turing the expression is given in the form $q_i S_j S_k R q_m$, where R (right) can be replaced by L (left) or N (none).

sequences (which partly mark the beginning of a figuration, partly the next actual figuration) a punctuation mark? is introduced to the left of the first and to the right of the second DA...D.

This produces an unambiguous and serial representation which can be performed mechanically step by step in the form of a long list with very few different letters (A, C, D, L, R, N) and the separating character which indicates the beginning of a new figuration. As an example he presents the standard form

DADDCRDAA;DAADDRDAAA;DAAADDCCRDAAAA;DAAAADDRDA;

which can produce the expression 0 1 0 1 as a result.

By converting the letters to numbers in accordance with an established code (1 for A, 2 for C... and 7 for the separating character) a corresponding description number is produced which can stand as an unambiguous description of the sequence of machine figurations which can perform a given calculation task.

Turing's point with this description is to show that it will always be possible to express a given calculation procedure in (at least) one such standard form with an accompanying, unambiguous description number which, conversely, will also correspond to only one given calculation procedure:

*To each computable sequence there corresponds at least one description number, while to no description number does there correspond more than one computable sequence.*¹³

This is a truth which must be modified because it presupposes that the sequence is seen from the point of view of the given formal task. Turing thereby overlooked the principle difference between the notation units of the standard form which are defined on the basis of their mechanically effective, physical form and the formal notation units which are defined by a semantic value determined in relationship to the task.

The explanation is naturally that this difference played no part in the mathematical-logical perspective, where the whole point was to show that the formal expression could be converted to the mechanically executable form.

¹³ Turing, (1936) 1965: 127.

The demands the mechanical performance makes on notation, however, imply that the expression appears in a form which can be processed independently of the semantic content and this provides the universal computer with a number of properties which are beyond the scope of even the most sophisticated automatic calculating machine. These demands constitute the only principle restriction on the universal computer and they can be described by taking yet another look at Turing's tape.

Now looking at this tape is not exactly a straightforward matter, as Turing claimed that it had to be infinite and thereby possess an abstract, physically unrealizable property. He did this because it is impossible to define an upper limit to the number of squares which may be necessary in order to construct a machine that must be able to perform all imaginable finite calculation tasks. But he also made the provision that the tape is a thoroughly concrete and mechanically effective physical entity.

Turing defended this dualism in the conceptualization of the tape by saying that the machine would always only carry out a finite number of operations and therefore also only needs a finite number of squares on the tape. The infinite tape simply indicated that the necessary number of squares varied with the given task. Since a finite formal procedure is defined as one that can be performed through a finite number of steps, it would be possible to do so with a machine equipped with the corresponding number of squares.

The answer implied that, as such, there is no demand for an infinite tape, but only for a tape with an indefinitely large number of squares. It is therefore rather surprising that Turing raised the theoretical problem of the infinite tape at all.

He does so, however, because the problem exists, even though it has no significance for the machine's construction and mode of operation. The reason for this is that it was impossible to determine beforehand whether an arbitrary task could actually be performed through a finite number of steps and therefore impossible to decide how long it would be necessary to continue to supply the machine with more squares.

Mechanical theory offers no solution to Turing's problem as it does not allow a material representation of the infinite, or physically active bodies to have an infinite extent. Turing's tape cannot be imagined on the basis of classical mechanical physics and his re-interpretation of mechanical procedures would hardly have a purpose if it merely concerned building ordinary physical machines. The reward, on the contrary, was the possibility of building

a machine which could be regulated through mechanical procedures which were not built into the invariant physical structure of the machine.

Nor did he derive the unique ideas of the tape and the step-by-step procedure from mechanical physics. They were derived as a result of a phenomenological analysis of a certain type of human symbol manipulation, namely practical arithmetic as carried out with a pencil and paper.

Here he also found another theoretical argument which it is true did not solve the problem of the infinite tape, but which provided a completely new dimension, as he used the physical image of a closed, finite world to describe consciousness as a closed, finite system. He then concluded that the universal computer would be capable of performing any calculation which could be performed mechanically by man. The problem of the infinite tape fades behind the limitations of human consciousness. It first emerges beyond our own reach.

Turing used not only the contemporary - human - computers as an illustrative analogy, but also as a starting point for a more detailed analysis of the arithmetical process.

The argument regarding theories of consciousness, which will be taken up in section 5.6-5.9, thus plays a central role for Turing, but none at all for the Turing machine's actual mode of operation. Turing uses the hypothetical assumptions regarding human calculation as a source of inspiration - and draws a veil across the problem of the impossible tape.

What remains is the activity carried out on the physical and finite part of the tape. Looked at from a physical perspective this is a question of two process levels. First, the tape as a whole is moved step by step as it leads a new square into the reading mechanism. The movement halts here while the reading mechanism reacts - mechanically - to the physical form, a symbol which is manifested in the given square. A mechanical effect is now produced, as the physical form may remain unaltered, be deleted or replaced by another symbol, after which the tape is moved another step so that a new square reaches the reading mechanism.

In any given state the relationship between a given square and the symbol it contains is bound and fixed, but the bond is only local. The next step may be an alteration of the symbol in a given square, or an alteration of the square and thereby also the, in this case, invariant symbol's place. The relationship between the square and the symbol itself is variable whether the symbol is actually altered or not. This functional property is possible because the square and the symbol comprise two separate physical levels which are not part of a

physically bound determination, even though the symbol can only exist as a physical manifestation in a square. The connection is subject to an optional regulation which makes it possible to make a symbol in a given place change itself into another.

It is evident that all these mechanical procedures depend on physical forms we ourselves understand as symbols, but appearing here and working as purely physical-mechanical entities and that these symbols therefore belong to the physical, invariant part of the Turing machine. The physical symbol forms must therefore be defined prior to and independently of the task to be performed. It is also clear for the same reasons that there must be a predetermined finite number of permissible physical symbolic units - which are independent of the task to be performed.

The mechanical process is thus independent of the symbolic interpretation of the physical forms and depends entirely on the effects created by the physical form of these symbols. Whether the symbol symbolizes something outside the system (and if so, how) is of no importance for the machine's physical mode of operation.

It is also at the same time clear that not all these mechanical parts of the machine can be included in its construction, as the individual mechanically effective symbol's - changing - location, sequence and mechanical effects on the tape and on other symbols is first defined by the task the machine is to perform. The tape and the symbols on it are at all stages both part of the machine and part of the material that is to be processed. As far as the tape is concerned the necessary number of squares is determined by the task while as far as the symbols are concerned it is the task which determines their sequence and the semantic value of the total procedure. The machine, on the other hand, determines the structural division of the tape into squares and the permissible number of physically determined, semantically empty symbols.

The central point is thus the distinction between the definition of the physical and semantic value of the symbols, as the one definition is part of the machine and the other part of the task.

The physical symbol definition was not in itself a theoretical innovation. This type of definition had long been familiar in such areas as the Morse alphabet used in telegraphy. Here, however, the physical definition still went hand in hand with the declaration of unambiguous and invariant semantic values. Nor did the physical definition particularly interest Turing. He touches upon it only in a footnote where he remarks that it is possible to describe the symbol as a -

measurable - set of points corresponding to the form of the ink within each square and thereby defines the necessary criteria which make the machine capable of differentiating between the individual symbols.¹⁴ This definition indicated not only a general theoretical solution of the problem of mechanical reading for a few chosen symbols, it allowed the use of an arbitrarily large number of symbols with a single restriction, that it had to be a finite number, because the difference between symbols approaches zero in step with increasing numbers.

Turing thus appears to have imagined that a very large number of notation units might be necessary for solving complicated tasks. The decisive point for him was that there must be a finite number because the permissible symbols had to be included in the building of the physically invariant machine. This is also a reflection of the fact that he still understood the number of notation units as a function of the task and the individual notation unit as loaded with a semantic content of its own.

Notwithstanding this he could not avoid the conversion from formally and semantically defined to physically defined symbol sequences, as the conversion to »machine language« is the condition for mechanical, step-by-step performance and thereby also the Turing machine's *conditio sine qua non*.

The demand for universality not only implies that there must be a predetermined and therefore limited number of notation units defined by the mechanically effective form, the same - few or many - units must also be capable of manifesting themselves as expressions with different meanings as they must both be able to represent an arbitrary quantity of changing data and an arbitrary number of changing rules. As no distinct limits can be defined for this demand on the possible semantic variation of the notation units, there can consequently be no definite semantic value in the definition of the individual notation unit. This cannot represent anything definite as it must be able to successively play a part in representing everything.

Turing thus passes over the crucial point in the conversion of the deterministic symbol procedure to the mechanically executable form, as he reads the two forms as equivalent. At the same moment a given formal procedure is available in the standard form it is available in a form where the individual notation unit is accessible to manipulation and where its meaning is solely determined by the - optional - preceding and succeeding units.

¹⁴ Turing, (1936) 1965: 135 (footnote).

The universal computer not only requires the mechanical procedure to be carried out as a series of semantically empty single steps, it also requires a corresponding subdivision of the task as well as of the rules of calculation that are to be used.

Turing's theoretical description thus shows not only that it is an advantage to specify the rules of calculation together with the task rather than to incorporate them into the machine, it also shows that this advantage, which is a necessary precondition for the universality of the machine, implies that these rules must be expressed in a form in which they can be processed independently of their semantic content. This means that the rules of calculation can become an object of calculation in themselves and that at each stage of the process they can be modified or suspended independently of the previous steps and of the original rule structure.

The universal computer can only be universal because it is not defined by the symbolic logic of the task it is to perform. The universal properties of the machine are on the contrary contained in and determined by the demand that it must be possible to re-present the task in a notation system which is defined by the notation's physical - mechanically effective - form, independent of the symbolic meaning and logical structure of the notation.

Where the automatic calculating machine builds on the mechanical execution of deterministic arithmetical rules, the Turing machine builds on a dissolution or breakdown of the deterministic rule structure into separate mechanical steps.

While the machine is subordinated to the demand for a well-defined alphabet, it is not subordinated to any demand for a specific syntax, or semantic. It thereby allows a treatment of symbols which completely lacks the determination which defines the calculation procedure.

This difference also appears when we look at what Turing calls the machine's memory, as the total memory, whose content can be described and calculated on the basis of the symbolic description, cannot be contained in the Turing machine because it continuously erases or changes some of the symbols and continuously increases the number of used squares.

Although it is true that the system's memory at any given time can be described on the basis of the machine's (i.e. the tape's) total state at a given stage in the process, this definition does not contain all the existing and erased information which has been or will be on the tape's other squares. Thus no finite representation of the whole system's total memory exists. The

deterministic character of the system is only local.¹⁵ As erased and changed symbols are also included, the determination is at the same time irreversible.

The point is naturally that the machine has no use for such a memory, as long as the necessary instructions are present at the time they are to be used. What this demand implies can only be established, however, through a symbolic reading, it cannot be decided through reading in the - mechanical form - the machine is bound to.

The paradoxical result of Turing's analysis is therefore that the symbolic rule determination he used to dissolve the physical-mechanical process into facultative individual steps must itself be dissolved before it can be performed mechanically. This reduction at the same time constitutes the decisive dividing line which separates it from all earlier attempts to create a universal calculating machine or logical symbol manipulator - from Raymond Lull through Leibniz to Charles Babbage.

The independent physical definition of the form of symbols is thus not simply a technical detail which is only connected with the mechanical performance either, it is also the foundation of the previously mentioned principle difference which separates the universal computer from all calculating machines, as it determines:

- That any given sequence of individual steps can be performed independently of its symbolic meaning.
- That one and the same sequence of notation units can, in principle, represent facultative variable symbolic values and/or logical structures.
- That the symbolic procedure »the programme«, which is used to control the mechanical process, must be an explicit expression and converted to the standard description's form as a series of individually manipulable notation units similarly to all other kinds of data.

Turing's postulate that a given sequence which is available in a standard form can only correspond to one definite computational process thus primarily reflects the fact that he interpreted the universal machine on the basis of a deterministic (mathematical-logical) understanding of symbols which allowed no room for describing these three properties. These properties are, conversely, necessary preconditions for the ability of a computer to solve a multiplicity of

¹⁵ C.f. Kleene, 1988: 30. Turing, (1936) 1965: 118.

tasks, such as word processing, represented by the present work, for example, although there is no formal mathematical-logical description of these tasks.

5.3 Formal and informational notation

As will be evident from the preceding, the demand for computational universality implies that the machine must work independently of any specific rule of arithmetic or formal procedure. The price for this necessary freedom is that the formal expression must be converted to a mechanically executable form which demands a notation with a predetermined, finite set of physically defined notation units which are individually empty of meaning.

With these two demands the conversion of a given task to the mechanically executable form becomes identical with a complete conversion from a formally-defined to a physically-defined notation system, which depends upon other principles for meaning attribution and allows several forms of meaning representation, as this notation is not subordinated to the demand for a complete formal description of the meaning represented.

Turing provides no complete description of these notation conditions as he only makes explicit the demand for a finite number of physically defined notation units, but not the demand that the individual notation units be defined without any intrinsic semantic value. This demand is only an implicit, not explicit, but necessary precondition in Turing's analysis.

Together, however, these two demands imply the use of a notation system which does not build upon formal notation principles. As this also - as will appear from chapters 7-8 - differs from linguistic and other previously described notation systems, it will be regarded in the following as a new, independent notation system.

As Turing's notation is distinct from the - binary - notation which is used in modern computers, there are reasons to include the latter already at this point. This will also provide the opportunity to illustrate the difference between formal and informational notation principles with the same (binary) notation set as an example.

In the binary number system both notation units always have a definite numerical value determined by their position in the expression. If the same unit appears in another position it has a correspondingly, different predetermined numerical value. A set of general, invariant rules is a prerequisite of all

arithmetical notation systems for attributing values to each individual notation, just as it is a prerequisite of formal notation that the individual notation units are connected with a definite value which is either a data value or a rule value. Rule and data values are thus each expressed through their own distinct set of notation units (or rules of positioning) and any change of a single notation unit is connected with a change - determined by the semantic value of the new notation - in the total content of the expression.

There are only two notation units in the binary number system, but as it is also necessary to use an - arbitrary - number of rule notations, binary number notation can only be used in connection with a more comprehensive notation system where, in principle, new notation units for operators can be introduced arbitrarily on the single condition that each individual notation unit is ascribed a certain content value at the same moment as it is introduced. There is no definite invariant limit to the number of notation units in formal notation systems, on the other hand a notation can only become a member of a formal notation system through a declaration of its semantic value.

This also holds true of formal expressions which use notations with variable values, as this makes it necessary to indicate well-defined, formal rules for value variation. A variable value, x , can only appear in connection with a declaration of variation thresholds and it cannot at one moment appear as a variable numerical value and at the next as a rule of arithmetic.

Arithmetical notation systems are, like all mathematical and formal notation systems, based on explicit and unambiguous declarations of the individual content value of the notation units. These values are again determined in relationship to an overall set of rules for semantic variation within the given formal system.

None of these conditions is valid for the use of binary notation as informational notation used in computers. On the contrary, here, as previously shown, it is a question of a notation system comprising semantically empty notation units without general rules for the values which can be attributed to the individual units. In the binary version only two notation units are used, which is not, however, a necessary condition, as long as their number has been predetermined. Nor can any differentiation be made between separate rule and data notations. The same two units must represent both parts of numbers, parts of arithmetical rules, or logical relationships. In some cases they must act as parts of an address in the system, at others as parts of a procedure for producing an output. In other words, they appear with changing values in the same sequence. These values are never bound to the individual notation unit,

but only to the given sequence as a whole. Thus no separate rule notations appear, nor can new notation units be introduced during a given procedure. Rule and data must on the contrary be expressed with the same notation units and the rule can only be effectuated through a sequence of individual steps carried out at the level of the notation units, which means that the rule can only be effectuated by being represented and processed exactly as all other data.

It is also evident from this that the concept 'data' is not an adequate concept for the operationally active notation unit, if we thereby infer that there is an equivalence between the minimum unit of expression and the minimum content value.

While such an equivalence is the foundation of formal notation, informational notation is defined by non-equivalence which - as will appear from chapter 7 - is a property informational notation shares with common language notation. The principle of such notation systems is expressed by the concept 'double articulation', by which is understood notation systems where the minimum expression unit is a semantic variation mechanism which is smaller than the minimum content value.

It is natural to illustrate this relationship by starting with a well-established representation standard such as the ASCII code which establishes a convention-determined (freely chosen) binary representation of up to 256 notations derived from other notation systems in a constellation of 8 bits, which can each assume one of the two values 0-1 corresponding to 2^8 bit patterns. As long as we concentrate solely on the ASCII code itself there is a clear equivalence: each individual represented notation unit has an unambiguous binary equivalent. The point of informational notation, however, is that it must not only be possible to represent letters, numbers and operators, but also to effectuate the operations mentioned. Where *we* can simply write $1+1$, the *machine* must express both the two numerical values and the operator as well as effectuate a mechanical process which produces the ASCII value for a total with the help of two and only two notation units. These thus appear in this process both as partial elements in the binary expression of the number /1/, the letter /a/ and the notation /+/ and the arithmetical rule of addition. The ASCII code also shows that the individual notation unit never has an intrinsic semantic value. The meaning is only connected with the total constellation - in this case by 8 bits - but the meaning variation is nevertheless manifested through the variation of a single bit.

This difference between formal and informational notation also holds true in the cases where binary notation is interpreted as a logical relationship between two possible alternatives. Although the alteration of a single bit in the informational notation sequence can have semantic effects, these cannot be described by interpreting the binarity as an alternative between the two semantic content values, yes or no. The individual bit is a unit of expression which is smaller than the smallest content value, as the smallest content value (a numerical value or a logical yes, for example) always requires a sequence of bits before it can be performed in the machine. While the rules in a formal system are always defined outside the system, the rules must be explicitly contained in an informational expression and they can only work as rules if they appear themselves through a number of step-by-step, mechanical stages. The rule effects appear here as an integral part of that process we say that they regulate.

While it is thus possible to describe formal, (symbolic or mechanical) processes as rule determined processes where the rules are predetermined and given outside the regulated system, the process in the Turing machine must be described as a process in which rule formation and execution is an integral part of the result of the process.

The difference between formal and informational notation is finally emphasized by the fact that it is not the physical form of the formal notations, e.g. the binary numbers, but their numerical value which determines the effect on the calculation process, whereas informational, e.g. binary, notation works solely by virtue of the physical form of the notation, no matter whether the entire sequence has been imagined as a logical value, a rule structure, or a numerical value.

When we take these differences into account there appears to be no possibility of understanding informational notation within the framework of formal notation principles. The conversion of the formal expression to a mechanically executable form implies that the structure of the formal expression can only be retained in a form in which the determination of the structure assumes a resolvable, freely editable and variable form in line with the material that is structured.

It is also evident that this structural dissolution of the expression form not only goes much further than the aims which motivated it, but also exceeds the understanding of formal notation. It was not by chance that Turing overlooked the demand for semantically empty notation units and that he failed to arrive at the binary notation form.

It is therefore doubtful whether Gandy is right in presuming that Turing relinquished the idea of suggesting a purely binary notation out of regard for the reader.¹⁶ It is true that nobody can be certain what unspoken considerations Turing may have taken into account, but there is no indication that in 1936 he would have been able to imagine such a complete binary representation.

If he had, it would have complicated the explanation and produced problems in the description of the machine. This is because he would not only have had to specify how it could decide which were numbers, which were arithmetical rules and which were rules for movement, instead of sticking to the intuitive advantage which lay in the use of a more arbitrary choice of easily recognizable symbols where the physical form was still directly connected with functional semantic values, it would also have created a conceptual break for which there was, at the time, no motive.

5.4 The automatic, the circular and the choice machine

The lack of a distinction between formal and informational notation principles was of no direct significance to Turing's project and reflects his formal perspective regarding the machine.

The limitations of the perspective, however, became evident in his formal definition of the mechanical procedure, as he introduced here two central modifications which, each in its own way, showed that he was unable to demonstrate the necessary theoretical distinction between the universal machine and the specific tasks.

The first modification comes to expression in his distinction between what he refers to as the automatic machine - which in his eyes was the genuine universal machine - and what he called »the choice machine«. While the automatic machine is presumably determined completely by the given figuration, the choice machine is characterized by the fact that in certain states there is a need for a choice made by an external operator.

¹⁶ Gandy, 1988: 90 note 38.

*When such a machine reaches one of these ambiguous configurations, it cannot go on until some arbitrary choice has been made by an external operator.*¹⁷

States thus occur in this machine where the next step is not determined by the actual configuration.

Turing clearly understood the choice machine as a less interesting and more limited version of the automatic machine. The choice machine is dealt with only in a single footnote which mentions that it can be simulated on the automatic machine.

The interesting point here, however, is that Turing's distinction between the automatic machine and the choice machine has nothing whatever to do with the properties of the universal computer.

His introduction of the distinction is not due to the fact that this is a case of machines which work in different ways, but on the contrary that there are different tasks. The two machines are identical. The introduction of the distinction rested on a theoretical problem connected with the question of whether all formal systems could be represented in a set of distinct, finite operations.

For Turing the potential of the choice machine lay exclusively in the need for the intervention of an external operator in the handling of certain formal systems. Although he described the necessity of the choice as a consequence of the fact that the next step was not determined, he quite naturally assumed that the possibility of choice alone was of relevance for the handling of - a certain group - of formal symbol systems.

As this possibility of choice is not connected with a machine which differs in any way from the automatic machine and as the possible choices are solely limited by the demand that the symbolic meaning must be expressed in a finite notation system, it becomes clear that Turing is only capable of defining the universal computer as an automaton by defining the machine on the basis of a certain class of task. He thereby draws a veil across the properties which make the machine universal, whether this universality is seen in its specific mathematical-logical meaning, or in a more general symbolic way.

Turing saw the difference between the automatic machine and the choice machine in the light of different classes of deterministic symbol processes, but the potential of the choice machine goes further than this difference, because

¹⁷ Turing (1936) 1965: 118.

the machine itself makes no demand that the formal expression must represent a closed or unambiguous semantic message.¹⁸ It only makes a demand on the form of the notation. The potential of the choice machine is therefore only limited by the external operator's ability to express a message in a finite set of distinct expression elements. It is also perfectly possible - as is shown by any word-processing programme today - to control the computational process with a symbol system where no unambiguous deterministic relations exist between the individual symbols used by the external operator.

The automatic Turing machine represents only a special case of a more universal symbol manipulating machine. It realizes only a limited spectrum of the machine's potential. This spectrum is characterized by the operator allowing the mechanical procedure to be controlled by a precept which contains a deterministic description of a given problem area. In other words the automatic machine is a dedicated machine devoted to a previously limited set of tasks which determine all its operations. In this form it approaches the classical machine, but also in this case there is a basic difference, as the automatic procedure's determination is symbolic - not physical - and thereby accessible to new choices.

Turing's distinction between the choice machine and the automatic machine emerged as a consequence of the theoretical problem which was his starting point, namely the question of whether it is possible to break down formal procedures into a finite number of distinct mechanical steps. It was possible in many cases, but not all.

The other central modification came, on the other hand, from the result. Turing decided the Entscheidungsproblem by demonstrating that there is no algorithm which can determine whether an arbitrary formal procedure fulfils the demand that it can reach a conclusion with the help of a finite number of operations. This proof of what later became known as »the stop problem« not only demonstrated that there are formal procedures which cannot be carried out with finite means, it also demonstrated that there is no general method for determining whether an arbitrary, given procedure has such a finite solution.

Turing himself hereby supplied a theoretical proof that there it is not possible to limit a universal calculating machine to the status of an automatic calculating machine.

¹⁸ Turing's view of the choice machine is incidentally too narrow, even if only the machine's ability to simulate calculations is taken into account. By allowing the operator to provide new input it also becomes possible to use new or unforeseen information. It may not only be difficult or impossible to realize the ideal dream of including these possibilities in an automatic process, it may also be inappropriate.

If it is not possible to determine in advance whether an arbitrary formal procedure has a finite solution, a machine capable of carrying out any finite calculating procedure must work independently of this criterion. The stop condition cannot be built into the machine. This also explains how Turing »happened to« break down the concept of mechanical and symbolic determination into facultative decisions which can be made step by step, in conflict with his own basic theoretical assumptions.

He bypassed this problem by introducing a distinction between what he called respectively »circular« and »circle-free« machines. These machines are also identical, however, the difference lies exclusively in the character of the task presented. If the task can be carried out with a finite number of operations, it is a circle-free machine, if not, it is a circular machine which either comes to a standstill, runs in a circle or continues without yielding new information.

From Turing's mathematical-logical perspective such a »circular machine« would have no purpose, but this is solely due to the mathematical-logical perspective, as he understood circularity as an expression of the fact that the machine had come to a standstill (ran in a circle) in a calculating process. That a circular Turing machine could be used to simulate other machines was entirely outside the sphere of his attention and interest. Furthermore, the term circular is used - rather confusingly - both of the sequences where the machine runs indefinitely in a circle without yielding new information and of the sequences where it comes to a standstill and demands new input (as a variant of the choice machine).

That the Turing machine can simulate the structure of the classical machine, including that of the calculating machine, does not reduce the difference between them. It increases it, as the possibility of simulating the classical machine depends on a property which the classical machine does not possess. The property which makes the simulation possible must thus also be regarded as more basic than the phenomenon simulated, whether this be a machine, or in Turing's case, a formal calculation procedure processed in the circle-free machine, which is defined by procedures which bring the machine to a stop when it has reached the result of the calculation.

Turing's distinction between the circular and the circle-free machine is still justified when seen in the light of his purpose and in connection with the performance of automatic calculating procedures. It has considerable mathematical-logical relevance, but is also central because Turing demonstrates that it is incapable of playing any part in the construction of his ma-

chine. As there is no general method for deciding whether a calculation can actually be completed, the demand for non-circularity cannot be built into the physical layout of the machine. On the contrary, the physical layout must be independent of this criterion.

Turing saw the circle-free machine as the genuine universal computer, once again because of his interests and aims. But he overlooked the fact that the freedom of the circle-free machine from circularity depends on the character of the task and not of the machine, by which he robs the machine of its universal properties. He also overlooked the fact that his own definition of the formal procedure implies that it can only be described as a finite, deterministic procedure if a purposeful task is included in the description. Without such a specified purpose the procedure breaks down into random steps which are devoid of meaning. The Turing machine can only function as an intentional machine. Its prerequisite condition is an intention, but if the task is included in the definition of the machine it is no longer universal. If instead the symbolic level is left out entirely, it will hardly be a machine at all, but simply an imperfect radiator.

It is not the purposefulness itself which separates this machine from other physical machines, as they are similarly characterized by the fact that their finite character is brought about through the implementation of a purpose. The difference appears on the contrary because the Turing machine does not demand - nor allow - these purposes to be built into the invariant structure of the machine. It is thus not only the stop conditions which are not incorporated, the starting conditions are not incorporated either.

As the machine itself can neither define the starting conditions nor the stop conditions, in its general form it is always a choice machine and never an automaton. The closest that this machine can come to a completely automatic procedure is when it runs in a closed loop where it never encounters any stop condition.

5.5 The universal computer as an innovation in the history of the machine and of mechanical theory

Turing's theoretical description of mechanical procedure as a step-by-step procedure where the physical determination is limited to the relationship between two steps, together with his description of the way in which the individual steps could be connected by linking them to corresponding, step-by-

step symbolic choices, represents a far-reaching innovation in mechanical theory.

This appears directly from Turing's own account, but the reach appears with even greater clarity if we look at Turing's description in relationship to a physical-mechanical process which prior to Turing existed in one of two basic forms. A mechanical process could either be understood as a regular, universal and deterministic natural process (first clearly and generally formulated by Pierre Laplace) or as a sequence of a definite number of finite physical operations which comprise a mutually connected and outwardly delimited whole, such as exists in the form of actual, physical machines in well-defined laboratory experiment arrangements and in the concept of Ludwig Boltzmann and that of later physics of local, completely delimited finite space.

The two points of view were usually interwoven to a greater or lesser degree in spite of the theoretical contradiction between the image of the universal, deterministic system (nature as a whole) which permits no kind of intervention (man is smaller than the system and is within it) and the image of the finite, local system which can both be interrupted and produced as a selective and constructive choice and combination of mechanical processes with limited and local effect (man is greater than the system and stands - as before God in front of the huge machine - outside it).

The Turing machine partly represents a polarization between and partly a break with these conceptualizations.

In classical mechanical theory the determination between the individual steps is seen as an effect of the general laws which operate throughout the system. The difference between two steps is a simple function of a time variation in a system where each possible state is established on the basis of a set of predetermined, well-defined starting conditions. The relationship between the individual steps in the process is such that they are bound together so that the individual step is only an intermediate link with the next and whose effect on the following step is completely determined by the starting conditions. The individual step cannot itself influence the previous and following steps.

In the Turing machine the mechanical determination is clearly of a different character, as its physical movement is defined solely by the relationship between the actual state and the actual symbol. The physical determination is local and never includes more than one step at a time. A *new* instruction *can* be called for at each step and the transition to the next step *must* be specified for each individual step.

Turing's contribution to mechanical theory thereby comprises a proof that it is possible to break down any finite mechanical system into a sequence of step-by-step, facultative operations in which physical determination is limited to the relationship between one step and the next and, conversely, that every further step can be made accessible to a free choice.

The Turing machine, however, cannot be described within the framework expressed in the description of classical machines as a sequence of a finite number of delimited physical operations which comprise a mutually connected and outwardly delimited whole.

Although traditional machines are often based on the use of many different - physical - laws, each governing a fraction of the operations, the functionality depends at the same time on the fact that the various mechanical effects on the individual steps are connected in a repetitive system in a pre-established and physically bound way.

It is quite true that it is theoretically possible to describe the Turing machine's repetitive physical operations step by step, but this description only includes movement from square to square and the mechanical operation on the actual physical notation. Such a description, however, is not a description of a Turing machine as it does not include the continuous changes in the physical notation units and thereby the effect of the mechanical operation on the individual square. At the same moment the notation units and their mechanical effect are included, the limit to the description of the invariant mechanical process has been reached, because this is a machine in which the sequence of steps has not been pre-established, is not repetitive and not unambiguously bound by the physical layout of the machine.

The physical process of the machine - the number of steps and the continuous mechanical changes in the location and sequencing of the physical notation units - depends on and varies with the task to be performed.

Rules are not simply allocated step by step in the Turing machine, they are also allocated in another way which appears from the fact that the - symbolic - rules which determine the individual steps can not only be made conditional - as is familiar from such equipment as the thermostat - they can also be modified. The - mechanically effective - instruction which controls a given step must thus either be produced by a previous step or a new input, but can also be re-activated and thereby altered by a subsequent step.

The key to the machine lies in the double character of the tape, which is at one and the same time part of the machine and the material and the place of exchange between the physical-mechanical and the symbolic procedures.

As a consequence of this the invariant borderline between the machine and the material processed, which constitutes classical physical machines, is broken down. As the material not only *can* but *must* contain the rules which control the machine's operations, this is a radical extension of the concept of machine.

The Turing machine thus differs from previously known physical machines at two central points. One point is contained in the step-by-step procedure which limits physical determination to a simple relationship between two steps, by which the classical machine is broken down into its »atomistic« components. The other point is contained in the breaking down of the borderline between machine and material, as the machine not only demands that the rules governing the sequencing of the physical steps must be contained in the material, but also that they must be contained in a form in which they can be effectuated as a chain of - variable and facultative - individual steps in the course of the process they regulate.

The two machines, therefore, do not differ because the rules which are incorporated in the classical physical machine originate in physics, while the rules governing the symbolic machine originate in mathematics or logic, they differ because the rules are implemented in two different ways. While a traditional machine can be described as a machine in which a number of causal processes are collected and ordered under a single, overall final intention which is implemented in the machine's invariant physical architecture, the Turing machine can be described as a mechanical apparatus in which an arbitrarily large number of different final intentions can be implemented continuously in arbitrarily small portions.

Turing's theoretical analysis of the principles for a universal computer thus contains marked renewals of mechanical theory and of the history of the machine and leads finally to a radically new way of presenting the problems regarding the concepts of rules and regularity.

The renewals appear in direct connection to the description of the machine, as this description assumes 1) that mechanical theory is understood and formulated as an abstract, theoretical model and not as a model of the physical world and 2) that the abstract rules of procedure are effectuated through a physically performed process. Where mechanical theory previously represented physical nature, it is now seen as a model for the physical execution of formal, symbolic procedures.

The first link in this conversion consisted of emancipating mechanical theory from physics and it appeared, when Turing simply transferred the mechanical model of nature as a universal and deterministic system to the understand-

ding of the computer as a deterministic, finite, formal system. In a later article he draws a direct parallel to Laplace's formulation of the ideal ambition of mechanical theory: to predict all previous and later states on the basis of a single, given state, in remarking that this ambition is closer to fulfilment in the computer than in the physical world where infinitesimal inaccuracies in the starting conditions create huge disturbances.¹⁹

With the abstract re-interpretation of mechanical theory the conflict between universal and local mechanical theory assumes a less contradictory character, as it is now expressed in the distinction between infinite and finite procedures, of which only the last can be performed mechanically, as it is only here that it is possible to speak of a complete establishment of the conditions for starting and stopping. In return for this freedom from contradiction, however, the theory only concerns formal systems which are defined on the basis of axiomatic criteria of validity. The inner consistency with regard to meaning and validity is thus achieved by abandoning all demands on referential validity.

The second renewal lies in the demand for physical execution of the formal rules, as this demand implies that the rules must be made explicit in a form in which they become regulable themselves. In other words, here the rules assume the character of freely defined, chosen and variable laws or conventions. They no longer stand outside the regulated system as transcendently preordained and invariant laws, but are included on the contrary as step-by-step performed sequences which can be influenced through intervention at the - lower - level of physical notation, i.e. independently of the content of the given rules.

In this respect the Turing machine represents a model of a mechanical system in which at any moment outside impulses, which are not only capable of changing the further sequence, but also any previously given rule, can make an appearance.

While formal, deterministic symbol theory was a necessary prerequisite for constructing an idea - and the first description - of the universal computer, it not only fails in describing the result, it is also undermined because mechanical performance implies that the symbolic procedure is emancipated from the concept of determination, so that the connection alone expresses a semantic choice which is connected to specific tasks and purposes.

¹⁹ Turing 1950: 440. This equally pioneering article is discussed in greater detail in sections 5.6-5.8.

There are several reasons why Turing did not pay attention to these aspects. The most obvious lay in his mathematical approach and the mathematical-logical purposes he had in view. These purposes meant that he had to overlook this aspect because the whole point of his work was to show how it would be possible to carry out any finite and deterministic symbolic procedure with an »ordinary« mechanical machine. This meant, so to speak, that he had cut himself off in advance from concerning himself with the dissolution of the fusion of the concepts of mechanics and determination.

5.6 Written down by a machine

In the previous sections the Turing machine has been described with the emphasis on the new type of exchange between physical-mechanical and symbolic procedures and it has been demonstrated that the notation Turing used to provide the formal expression with a mechanically executable form was not simply - as he believed - a practical notation technique, but comprised an independent notation system with properties that separated it from formal notation systems.

While Turing saw the new notation technique as an - almost trivial - equivalent to formal notation because it was possible to derive the informational form of the formal expression from simple, unambiguous procedures, on the other hand he used some less trivial assumptions from theories of consciousness as a starting point for the new construction of the relationship between mechanical and symbolic procedures. Although Turing's universal calculating machine worked because

of its mechanical properties and therefore quite independently of our understanding of the organization of human consciousness, certain ideas on this are included in the theoretical assumptions Turing used as a precondition for the construction of the machine. As these assumptions also played a central role both in Turing's and others' later interpretations of the machine, they will be discussed in the following sections before the analysis of informational notation is continued in chapters 6-9.²⁰

One thing can be established immediately however. The universal Turing machine does not work in the same way as Turing's consciousness did. His article from 1936 provides excellent documentation of this, as it unites

²⁰ Among them, cybernetics, classical AI research and Cognitive Science research.

stringent theoretical analysis with a presentation containing a number of errors due to sheer carelessness in the details. Martin Davis thus introduces his 1965 reprint of Turing's article with a well-meant warning:

*This is a brilliant paper, but the reader should be warned that many of the technical details are incorrect as given.*²¹

A few years later Gandy supplements this with more imagery and greater tolerance:

*The approach is novel, the style refreshing in its directness and simplicity. The bare-hands, do-it-yourself approach does lead to clumsiness and error. But the way in which he uses concrete objects such as exercise books and printer's ink to illustrate and control the argument is typical of his insight and originality.*²²

It is only reasonable that well-informed colleagues are ready to make such allowances. It shows not only that the erroneous, mechanical procedure is regarded as a far less significant part of human thinking than the originality, brilliance, simplicity and imagination necessary to transcend the previous conceptual frameworks, it also shows that human consciousness is capable of working in ways which would bring any Turing machine to a standstill.

Although later analyses based on theories of consciousness are mistaken in ignoring or underrating this difference, they are correct in placing the theories of consciousness on the agenda in connection with the Turing machine. This is the case because Turing's theory confirms that there is no path from classical, universal mechanical theory regarding the organization of nature to the machine which does not pass through human consciousness.

It was therefore not by chance that Turing himself - in the middle of the busy road between mathematics and physics - had to make an epistemological leap by initially using mechanical theory in the area occupied by theories of consciousness.

It was the problem of the stop condition which made this leap necessary, as he showed that it was impossible to determine in advance whether a formal or mechanical procedure would reach a conclusion. As any classical machine is

²¹ Davis, 1965: 115.

²² Gandy, 1988: 85.

characterized by the fact that it constitutes a delimited and closed system it was not possible to find a solution to this stop problem within the world of the machine. Nor, conversely, was it possible to derive the construction of the machine directly from universal mechanical theory which, it is true, contains no precondition regarding a stop condition, but which for the same reason represents a system which it is completely impossible to delimit and which is infinite, whether we believe that it reflects the order of the universe or simply a mental picture.

A theoretical leap was necessary in order to find a solution which was possible in practice.

The reader first receives notice of this when Turing, almost in passing, concludes the introductory survey of the general content of the article with his definition of computable numbers which can be written down by a machine. The article begins:

*The »computable« numbers may be described briefly as the real numbers whose expressions as a decimal are calculable by finite means. Although the subject matter of this paper is ostensibly the computable numbers, it is almost equally easy to define and investigate computable functions of an integral variable or a real or computable variable, computable predicates, and so forth. The fundamental problems involved are, however, the same in each case, and I have chosen the computable numbers for explicit treatment as involving the least cumbersome technique. I hope shortly to give an account of the relations of the computable numbers, functions and so forth to one another. This will include a development of the theory of functions of a real variable expressed in terms of computable numbers. According to my definition, a number is computable if its decimal can be written down by a machine.*²³

Simple and neat. Everybody knows how a machine works. But the abrupt introduction of the machine is not due to the familiarity of the image and its obvious pedagogical advantages. What Turing is introducing here with the concept of a machine is not the mechanical writing function, but the demand that through mechanical means a result of a calculation must be produced in the course of a finite number of procedures, the stop condition, which separates the finite from the infinite formal procedure.

²³ Turing, (1936) 1965: 116.

This is not exactly the first evocation given of the idea of a machine, nor is it the physical proficiency in writing, but the mental mechanics of the proficiency in arithmetic which is the source.

As with the last sentence of the introduction, so with the first, apparently even more trustworthy sentence where the computable numbers are defined as numbers which can be calculated through finite means.

Underlying this idea are two assumptions derived from theories of consciousness, one a general theory of human memory as a finite system and the other a more detailed and specific idea of how humans calculate.

Turing does not appear to have paid any great attention to this not very obvious introduction of the machine, but when it comes to the unusual assumptions derived from theories of consciousness, he is perfectly clear. It is from here that he takes his point of departure:

*We have said that the computable numbers are those whose decimals are calculable by finite means. This requires a rather more explicit definition. No real attempt will be made to justify the definitions given until we reach § 9. For the present I shall only say that the justification lies in the fact that the human memory is necessarily limited.*²⁴

Turing has thus, in the first and last sentences of the introduction, carefully placed, but not developed, the two conceptual frames from which he obtains the ingredients for his definition of the finite, formal procedure, namely classical, universal mechanics as formulated by Laplace and human proficiency in calculation as analysed by - Turing.

In his introductory resumé, for some reason, Turing introduces the two images, the mental and the physical-mechanical, as though they were two poles which delimit the article's space. In the continuation they become completely fused:

*We may compare a man in the process of computing a real number to a machine which is only capable of a finite number of conditions.*²⁵

There is a paradoxical point in this construction, as it is not possible to derive the idea of human consciousness as a finitely delimited system from universal

²⁴ Turing, (1936) 1965: 117.

²⁵ Ibid: 117.

mechanical theory (whose preconditions are that the universe is one great, cohesive machine and that a given system which is left to itself can continue indefinitely) or from an analysis of formal arithmetical procedures (as Turing's own analysis showed that infinite, formal procedures did exist).

Nor does the structure of the classical machine correspond to a fungible Turing machine, but rather to Turing's circular machine which runs in a circle without yielding any output.

Turing also equipped his machine with an infinite tape and limited the use of the idea of finite consciousness to the finite arithmetical procedures. The infinite tape is not part of Turing's model of consciousness, which is more reminiscent of Boltzmann's theoretical model of finite, thermodynamic space and of Hilbert's idea of a completely closed, formal system.

Paradoxical or not, by transferring mechanical theory's tension-filled combination of the idea of the single, great universal machine and the many small, specific machines from the domain of physics to that of consciousness, Alan Turing got the idea that it must be possible to construct a machine which would be capable of carrying out any finite mathematical symbol manipulation.

Taking into account the result - this must be considered an extremely productive exploitation of the theoretical contradiction, but there is no marked confirmation of its relevance to theories of consciousness. On the contrary, the idea of a finite, step-by-step operating consciousness is a less plausible part of Turing's theory. As it is also an idea which has in particular given rise to later schools of theories of consciousness, his formulation and exploitation of the idea deserve a more detailed investigation.

Turing's idea of finite consciousness served two more specific purposes - over and above the possible motifs of theories of cognition. One was to create a basis for the idea that it might be possible to reduce a large part of logic and mathematics to the premises of mechanical physics. It is highly probable that this idea played a pioneering and necessary role in the development of his theoretical description, just as it is also clear that he did not maintain the idea in this form, as he equipped his machine with an infinite tape.

As will be evident from the following, Turing never, neither in 1936 nor in his later work, subscribed to the idea that his own theoretical machine or the later computers worked similarly to human consciousness. On the contrary, he distances himself increasingly from the idea of describing consciousness as a closed system characterized by a finite set of discrete states.

Nevertheless, this idea serves yet another important purpose in Turing's theory, as he also uses it in his phenomenological analysis of arithmetical procedure. He thereby made the theoretical leap which definitively and rightfully takes the use of mechanical thinking into the area of theories of consciousness.

In Turing's analysis of arithmetical procedure the idea of finite - calculating - consciousness is utilized in five different elements, which comprise:

- The idea of consciousness as physically processed in time and space.
- The idea of finite consciousness as a set of distinct, mechanically connected states.
- The idea of step-by-step, locally determined procedure.
- The criterion of readability, i.e. the demand for breaking down into simple expressions which can be recognized »immediately« and the demand for a limited number of actually possible »readable« squares.
- The idea of a completely explicit representation of the contents of the calculation which is developed on the basis of the observation that an arithmetical procedure can be interrupted and notes taken which contain all the information necessary for a later continuation.

The question now is whether this model of conscious processes can be seen as a general model of the way in which consciousness works, or as a model for certain types of conscious processes, such as arithmetical processes and other mechanical conclusion procedures, or whether it is rather a question of a model which describes how, with the help of outside aids, we can arrive at the same results which we could arrive at ourselves in other ways?

It is reasonable to take our point of departure in the arithmetical procedure itself, as we can both perform many arithmetical procedures with a calculating machine, a Turing machine and without outside aids. And it is also here in particular that Turing utilizes the assumptions of theories of consciousness in more specific criteria which are especially connected with the concept of memory and concrete arithmetical procedure.

The question is not yet whether *all* forms of thinking can be broken down into simple, step-by-step sequences, but conversely whether human consciousness performs *some* of its activities by breaking down complex, formal expressions in the same way that they are broken down in a Turing machine.

There is no doubt that certainly in 1936 Turing believed that there was a clear relationship here, as he simply gives the grounds for the breaking down procedure by referring to the empirical experience that we are unable to differentiate large numbers which resemble one another without breaking them down into smaller units.

*The differences from our point of view between the single and compound symbols is that the compound symbols, if they are too lengthy, cannot be observed at one glance. This is in accordance with experience. We cannot tell at a glance whether 9999999999999999 and 9999999999999999 are the same.*²⁶

When we make a calculation we work serially and step-by-step forward through a number of discrete states and must therefore break down any more complex symbol into a finite sequence through subdivision. The fact that we do not lose our way in this process may similarly be because the individual step is determined by the relationship between the actual memory state and the single symbol observed at the given stage:

*The behaviour of the [human] computer at any moment is determined by the symbols which he is observing, and his »state of mind« at that moment. We may suppose that there is a bound B to the number of symbols... which the computer can observe at one moment. If he wishes to observe more, he must use successive observations. We will also suppose that the number of states of mind which need be taken into account is finite. The reasons for this are of the same character as those which restrict the number of symbols. If we admitted an infinity of states of mind, some of them will be »arbitrarily close« and will be confused. Again, the restriction is not one which seriously affects computation, since the use of more complicated states of mind can be avoided by writing more symbols on the tape.*²⁷

That this description of arithmetical procedure can actually create a basis for the performance of calculations is not in doubt. If we accept that what is referred to here as »state of mind« only includes the relevant information for

²⁶ Turing, (1936) 1965: 136.

²⁷ Turing, (1936) 1965: 136.

the specific arithmetical procedure, it also appears, on the face of it, as a quite plausible model for a description of how human beings *can* do arithmetic.

A more detailed consideration, however, gives rise to considerable doubt. It is not only improbable that the description corresponds to the way in which we perform calculations ourselves, it is also doubtful whether we will be able to perform many calculations in this way.

The central point in Turing's description of the arithmetical process consists in breaking down the task to its smallest components, as such, a classical and familiar analytical procedure which could hardly find a more suitable area of use.

The critical points in this procedure are similarly familiar. They lie partly - as mentioned previously - in the establishment of premises, i.e. the starting conditions, and partly in the question of how we can define the optimum or maximum degree of breaking down.

It is also at these two points that Turing's model of the arithmetical process differs most markedly - but from both human calculation and from the way in which the Turing machine works.

With regard to arithmetical procedure carried out by a human being, the most striking difference is that Turing's ideal model can *only* function if the task is actually broken down into its smallest expression components. This condition is not ultimately binding on human calculation. Even though we *can* break down large numbers into smaller components, there is no evidence that we break down these numbers into their *smallest* expression components. On the contrary, it is far more characteristic - normally - that we find it both difficult to handle large numbers and to reduce them to their smallest expression components. While many people for the same - or other - reasons completely give up doing arithmetic, others, at precisely this point, begin to use external aids such as counting boards, abacuses, pencils and paper.

Turing's analysis actually helps to illustrate one of the reasons, as it is evident that the radical breaking down of the expression into its individual components requires a dramatic expansion of a stable and reliable memory. The number of symbols which must be remembered is not only increased, they must also be located in precisely defined places on a tape where the access to each square is unambiguously established as a mechanical procedure and where the values in the individual places can be varied.

We are quite simply incapable of handling the simple, serial manifestations of the complex expression which comprise the core of Turing's model. Not only do we find it extremely difficult to reduce an arithmetical task into its

smallest components - with the exception of quite simple operations involving whole numerical values from perhaps -100 to +100, or thereabouts - we are not bound to do so either.

Turing's model does not reveal much - if anything at all - about mental arithmetical processes. Nor is his model a model of a human being doing mental arithmetic, but of someone working with paper and pencil and, moreover, he immediately replaces ordinary squared - two-dimensional - paper and the decimal system with a one-dimensional tape and the binary representation of numbers, while the other symbols and rules of arithmetic are not made explicit at all. He assumes that we have them in our heads.

What he showed in this respect was that it was possible to arrive at the same results in other ways and particularly that it was possible in this way to perform calculations which we can only perform ourselves with the greatest difficulty - if at all - with other aids.

Nor has it subsequently been possible to identify an equivalent to the Turing tape and a mechanical reading unit, neither in the human brain nor in the mind.

The human arithmetical procedure thus approaches the Turing model in the area of very simple tasks where the model is least relevant, while Turing's model comes into its own exactly in connection with arithmetical tasks we are unable to perform without the use of aids, of which Turing's machine is undoubtedly the most perfect hitherto.

That this is the case, however, is due to the fact that it does not work in the way Turing describes in his model either.

While Turing's arithmetical model is based on the breaking down of the arithmetical procedure into its smallest components of formal notation units, the Turing machine is based on this expression being further broken down and subdivided into components which no longer possess any intrinsic semantic value.

As will be evident from the preceding sections in this chapter, this state is closely connected with the demand that both the description of the task and of the rules for its performance must be contained in the same notation, which must itself have a form that is independent of the task. As will also be evident, this demand was fulfilled by separating the physical definition of the symbols from the definition of their value.

That this is far from being a banal condition, however, appears not only from its significance for an understanding of the Turing machine, but also from the fact *that the ability to construct such definitions of the physical forms of*

*symbols is a unique human ability, beyond any computational competence, as this competence itself assumes one or another minimum number of such previous definitions.*²⁸

The demand for a definition of the physical form of the symbol, independent of its function and value, can also be seen as a distinctive criterion in understanding the relationship between the Turing machine's processes and human intelligence. As human intelligence includes the ability to create and define delimited, physically-defined symbolic forms, we possess a mental competence which the Turing machine cannot possess.

As this more far-reaching conclusion affects both Turing's point of view and a general main assumption in later theories of information and cognition, it will be considered in more detail in the following section.

5.7 Turing's machine, consciousness and the Turing test

According to Turing's biographer, Andrew Hodges, it was Gödel's demonstration in particular and the problem of description in quantum mechanics which inspired Turing to describe consciousness as a finite system, because he saw both elements as a manifestation of the fact that human consciousness was subject to decisive limitations: Although humans are living organisms, which apparently possess free will, they must, at a more fundamental level, be subjected to deterministic restrictions. Consciousness itself must be a »machine«, although much more complex than other physical, chemical or biological »machines«.²⁹

Hodges thus understood Turing's description of human consciousness as an abstract generalization of the deterministic limitations common to mechanical physics, formal logic and effective calculation procedure - or what Turing calls computability.

It can certainly be taken for granted that Turing gave a new turn to the old dream of reproducing the human thinking process in an appliance by starting with the idea of a limited, finite consciousness, rather than with its sovereignty and that a radical expansion of mechanical handling competence lay in his

²⁸ The separation of the definition of physical form from the definition of the symbolic value also has linguistic implications, as it appears difficult to reconcile with the linguistic description of the sign relationship as a unity of expression and content. C.f. chapters 7-9.

²⁹ Hodges, 1983: 96 ff.

proof that it was possible to reduce all finite logical, formal and mathematical procedures to pure mechanics.

With this new turn he became the first person capable of showing how it was possible to construct a machine which could perform all the finite arithmetical and logical procedures which humans can perform with the brain.³⁰

If the machine were able to carry out this reduction itself, we would be able to use it to free humankind from a great civilizing burden, as it would immediately become possible to remove arithmetic, a large part of mathematics and logic from the necessary repertoire of human competence and therefore also from the obligatory curriculum in schools.

What we might otherwise think about such a possibility, it will never under any circumstances be furthered by Turing's machine which, on the contrary, produces a growing need for increased human competence in interpreting, handling and producing algorithmic procedures. The explanation is naturally that the machine is not subject to the same limitations as is human consciousness.

What Turing himself thought about these questions in 1936 is not clear, but it is absolutely clear that his view of thinking, including mathematical thinking, took exactly the same direction in 1939 when he wrote:

Mathematical reasoning may be regarded rather schematically as the exercise of a combination of two faculties, which we may call intuition and ingenuity. The activity of the intuition consists in making spontaneous judgments which are not the result of conscious trains of reasoning... I shall not attempt to explain this idea of »intuition« any more explicitly.

*The exercise of ingenuity in mathematics consists in aiding the intuition through suitable arrangements of propositions, and perhaps geometrical figures and drawings.*³¹

For Turing, »intuition« and »ingenuity« are the two typical mathematical tools. The fact that he mentions them is not because he believes that thinking can be reduced - nor mathematical thinking either - to these two concepts, it is rather because he is taking stock of the programme of logical formalism.

³⁰ Hodges, 1983: 96.

³¹ Turing, (1936) 1965: 208-209.

Where, *in pre-Gödel times*, as he writes, the goal had been to replace all the intuitive judgements of mathematics with a limited set of formal rules of inference thereby making intuition superfluous, great progress had now been made in the direction of the diametrically opposite result. It was not intuition, but organizing reason, ingenuity, that was being replaced, as it was the reasoning, systematic endeavour which now, to a great degree, could be reduced to a mechanical procedure:

*We are always able to obtain from the rules of formal logic a method of enumerating the propositions proved by its means. We then imagine that all proofs take the form of a search through this enumeration for the theorem for which a proof is desired. In this way ingenuity is replaced by patience. In... heuristic discussions, however, it is better not to make this reduction.*³²

There is nothing here to provide any indication that Turing had mistaken the Turing machine's formal procedure for the general form of human thinking. Mechanical symbol procedure is a specific thinking (and proof) procedure derived from formal logic. Not only does intuition remain unchallenged, Turing also indicates - in an introductory footnote - that here he is completely ignoring »*that most important faculty which distinguishes topics of interest from others*«.

Here, in the description of mathematical thinking, Turing establishes a - quite traditional - concept of consciousness with no visible trace of the model he used in 1936. It might appear as though he had completely abandoned the question of the relationship between the Turing machine and human intelligence.

He had undeniably abandoned one thing, namely the idea that human beings and machines think in the same *way*. When, some years later, he returned to the question in his now classical article *Computing Machinery and Intelligence*,³³ he begins by rejecting the question because it is impossible to provide a precise definition of the concepts »intelligence« and »machine«. Instead he suggests that the question: can a machine think? should be replaced by the question: can a human being differentiate between an answer he receives from a machine and one received from another human being? - as he establishes the precondition that the subject of the experiment be kept in

³² Turing, (1939) 1965: 209.

³³ Turing, 1950: 433-460.

ignorance of everything except the content of the answer which is passed on in a neutral, technical form.

Although Turing proposed his experimental test criterion because there was no clear definition of the concepts of intelligence and machine, the test itself relied on such definitions. The most decisive definition of human intelligence lay in the assumption that it is an advantage to differentiate between a human being's physical and intellectual capacities:

*The new problem has the advantage of drawing a fairly sharp line between the physical and the intellectual capacities of a man.*³⁴

This definition provided Turing with a reason for placing the subject in another room without direct sensory contact with the test arrangement. Turing also admitted that the machine could possibly perform something which must be described as thinking, even though performed differently to human thinking. He claimed that such limitations, however, were only problematical if the machine failed to live up to the demand on intelligence presented by the test. If it could pass the test, i.e. produce the impression in the subject that he was communicating with another person, there would be no need to take these differences into consideration.

As far as concerns the machine the most important definitions are that it can be constructed using any technique, that the constructors need not necessarily be able to describe its mode of operation, as they must be allowed to use experimental methods and, finally, that the concept 'machine' does not include humans »born in the usual manner«. The three criteria cannot all be completely fulfilled because the possibility of constructing a human being from a single cell cannot be ruled out. As in this case it would not be possible to claim that a thinking machine had been constructed, as the thinking mechanism would perhaps already be contained in the cell, Turing only accepts digital computers.

The Turing test has no meaning, however, if we assume that the relationship between the computer and human thinking is connected with a more or less common way of functioning. The test is exclusively based on the result, the process is regarded as an irrelevant black box.

There is thus no support for the assumption that Turing believed that the structure of human thinking could be described in terms of computational

³⁴ Turing, 1950: 434.

processes. On the contrary, in 1950 he only stated that it was possible to imagine a machine which would be capable of producing the same results that humans could arrive at and that this could be taken as an argument for saying that it could think »like« a human.

As the Turing test assumes that there is someone withholding relevant information from the subject of the test, it is first and foremost suitable for testing the human art of illusion.

5.8 Consciousness in Turing's hall of mirrors

Turing's purpose with the experimental test was not to produce a new theory of human consciousness or intelligence in the form of a philosophically consistent summary of an empirical material. His purpose was to ask the question as to whether a machine could think in such a way that it could create a basis for a new research project or programme in which it would be possible to use human consciousness as a model from which ideas regarding the mechanical imitation of human thought processes could be extracted.

He did not imagine, however, that this programme would lead to any serious answer to the question of whether machines could think. He believed, on the contrary, that in the course of fifty years it would be possible to design machines which - in the given test arrangement - would often be confused with humans and that this would imply such a change in the ordinary use of language that a contradiction would seldom follow the assertion that machines think. This clearly formulated, but often overlooked, perspective deserves to be given in his own words:

I believe that in about fifty years' time it will be possible to programme computers, with a storage capacity of about 10^9 , to make them play the imitation game so well that an average interrogator will not have more than 70 per cent. chance of making the right identification after five minutes of questioning. The original question, »Can machines think?« I believe to be too meaningless to deserve discussion. Nevertheless I believe that at the end of the century the use of words and general educated opinion will have altered so much that one will be able to speak of machines thinking without expecting to be contradicted. I believe further that no useful purpose is served by concealing these beliefs. The popular view that scientists proceed inexorably from well-established fact to well-established fact, never being

*influenced by any unproved conjecture, is quite mistaken. Provided it is made clear which are proved facts and which are conjectures, no harm can result. Conjectures are of the greatest importance since they suggest useful lines of research.*³⁵

It is remarkable that Turing completely rejected the possibility of - seriously - discussing the relationship between the computer and human intelligence, but also that he formulated the much vaguer cultural expectation that the computers of the future would bring about a state of affairs in which this distinction would simply disappear from the language. He thus did not possess the imagination necessary to conceive that the attempt to imitate human thinking could possibly lead to new arguments for differentiating between the computational process and human thinking. The explanation may be that he would not have dreamt of claiming that humans think in the same way as machines.

It is certainly striking that in the same passage Turing reveals a characteristic of scientific thinking containing an aspect which cannot be accommodated in his picture of the computational process. The latter corresponds exactly to the popular, but according to Turing inaccurate, view of scientific processes as systematic, step-by-step procedures.

Turing also utilized this difference in a specific criterion connected with human intelligence, as he claimed that this included the ability to differentiate between surmise and fact. But he failed to formulate any criterion by which it would be possible to decide whether the computer possessed such a discriminative competence, just as he also failed to consider »that most important faculty which distinguishes topics of interest from others«, to which he had called attention in 1939. It is quite true that the test concerns the ability to differentiate, but it is not the computer's ability which is being tested, it is that of the test person. The result of the test shows exclusively the degree to which he can decide whether he is talking to a man or a machine.

It is not difficult to find a pattern in this picture. That intelligence which Turing makes the object is different from that intelligence which makes the intelligence the object. It is neither his own intelligence, scientific thinking in a broader sense, or the ability to formulate new thoughts and pose questions which is produced here as a model for imitation, it is a much more narrowly

³⁵ Turing, 1950: 442.

conceived intelligence. There is no demand here to differentiate between surmise and fact.

It was therefore on good grounds that Turing formulated his expectations for a development in common-sense understanding which lay fifty years in the future as a matter of personal belief. The question, however, is what justified the inclusion of such a declaration in a highly esteemed scientific journal and its later incorporation in the basic documents of an entire field of research.

The most obvious reason would probably be - taking the scientific context into account - to provide a well-formulated research programme which, on the basis of a relatively consolidated or clear theoretical basis, defined a number of more distinct ways of presenting the problem which could become the objects of investigation. But here too, Turing is remarkably clear. There are no particularly convincing arguments for the idea:

*The reader will have anticipated that I have no very convincing arguments of a positive nature to support my views. If I had I should not have taken such pains to point out the fallacies in contrary views.*³⁶

Another obvious possibility might be that his expectations corresponded so closely to general contemporary expectations with regard to science. But this is not the case either. The idea was epoch-making and contrary to time-honoured scientific trains of thought. Turing himself introduced a great many of the objections which presented themselves from various philosophical, theological and scientific points of view and - in under 12 pages - he touched upon as good as all the themes which have since been included in the discussion. There is one central point in particular which is repeated in Turing's answers to these objections, as his general argument is not - as it is in almost all later discussions - that there may be an answer to the question of whether a computer can think, but on the contrary that the objections to this possibility are just as illusory as the postulate.

The identification of this wide-open, undecidable question undoubtedly comprises one of the two reasons for the later significance of the article. Turing hereby staked out a new research-political Utopia where the dream of reproducing human thinking ability was connected with - it appears - a correspondingly open technological potential. The second reason lay in the rather more prosaic suggestion for the first steps. In the final section of the

³⁶ Turing, 1950: 454.

article Turing described two possible strategies, namely the reproduction of the logical-deductive procedure, the logic of chess, and the reproduction of human perceptual and learning competence.

Here, on the other hand, all the problems which were ignored in the Turing test make an appearance.³⁷ First and foremost that any step which can be taken as a facet of the construction of a machine capable of fulfilling the Turing test contains a specification of human thinking which is in conflict with the point of departure: that no well-defined and meaningful description of the concept 'intelligence' as opposed to the concept 'machine' can be given. This paradox is not due to a careless mistake which can easily be corrected. If the latter postulate is abandoned we are faced with the demand that we must make the concept of intelligence explicit, so that we can no longer simply point out that the concept of intelligence is unclear and we can therefore not content ourselves with the Turing test of human illusion. If, instead, we abandon the first, we have on the other hand no possibility of pointing out any specific step as a step towards such a machine.

Turing's suggestion for a strategy, however, contains not a single - consistent in itself - view of human intelligence, it contains several mutually incompatible models which individually have their roots in older, more traditional and therefore, on the face of it, reasonably plausible assumptions. The three most important models are 1) the description of consciousness as a result of a Darwinian process of development, 2) the description of - the child's - consciousness as a well-delimited and blank page and 3) the description of consciousness as a logical-deductive symbol machine.

There is no discussion in Turing's article of the connection between these three different models. They are referred to individually only in different connections, but it should be noted that Turing clearly separates the logical-deductive procedure as the object of a specific development project, while the learning project is built up around the two other models. This line of demarcation has since been maintained and further developed in two different and - especially in the 1980's - competing research strategies within Cognitive Science.

That Turing with no further ado could juxtapose the two strategies as equally reasonable and explicitly refrain from weighing them mutually was not

³⁷ This last section of Turing's article from 1950, which according to Turing contained the positive, concrete and debatable evidence is omitted from the reprint in Hofstadter and Dennett, 1981: 53-67. The whole article (apart from some cross-references) has been reprinted in Bannon and Pylyshyn, 1989: 85-109.

an expression of a later misplaced clarity, it was rather an expression of the fact that he failed to see that they were based on incompatible premises. That this holds true of the relationship between the logical-deductive strategy and the learning process strategy is documented in the later development. But there is a corresponding conflict hidden in the two models Turing suggests as starting points for the development of the learning machine. The Darwinian model cannot easily be reconciled with the image of the individual organism's consciousness as a blank page.

The image of the - child's - consciousness as a blank page at birth serves in Turing's argument as an instance of a differentiation between a very simple, innate mechanism, the programme, and the subsequent experience, data. But the page is not completely blank. While learning and other experience is assumed capable of producing a more complex programme structure, the basic programme is given in advance, it is invariant and independent of data.

Presumably the child brain is something like a note-book as one buys it from the stationers. Rather little mechanism, and lots of blank sheets. ... Our hope is that there is so little mechanism in the child-brain that something like it can easily be programmed. The amount of work in the education we can assume, as a first approximation, to be much the same as for the human child.³⁸

The background is naturally that the computer requires such a programme. Turing overlooks the fact that precisely this programme cannot be an »inborn« part of the machine, if the machine is to have universal properties. He also overlooks the fact that the programme in the computer must be available in exactly the same form as all other data.

The distinction between a preordained programme and data is incidentally not reconcilable with the Darwinian model either. It is quite true that we can imagine that the individual child has an inborn mental capacity, but it also has parents who have parents who, at some stage or another of prehistory, descended from organisms without this inborn capacity. The Darwinian theory not only requires that we allow the development of increasingly complex organizations of elements which already exist, it also requires that we assume that biological and mental processes have their origins in a physical universe in which these processes were not found before these origins. If there is

³⁸ Turing, 1950: 456.

anything that can be described as a mental programme, it must not only have the property of developing into a more comprehensive and complex programme, it must also have the »property« that it has originated from something which is not a mental programme.

It will be of no help here to supplement with a description of reality as a realization of a potential which has existed since the dawn of time, because in such a case the potential will be more comprehensive than the realization, which will not become more invariant on these grounds. The possible genetic potential for consciousness must also have a history of origin and development if we refuse to explain its existence as the result of divine creation.

Turing side-steps this problem, as he only uses the Darwinian model as a metaphorical analogy without asking himself the question regarding the relationship between the biological and the mental. The child's mental programme is equated with the hereditary material, the changes in the programme made by scientists are equated with mutations and their evaluation of which improvements in the programme they will use are equated with natural selection.³⁹ With one exception:

*The survival of the fittest is a slow method for measuring advantages. The experimenter, by the exercise of intelligence, should be able to speed it up. Equally important is the fact that he is not restricted to random mutations. If he can trace a cause for some weakness he can probably think of the kind of mutation which will improve it.*⁴⁰

It is no longer the ideal observer who is here attempting to fill the position once assigned to the divine creator, but nor is it - as for Niels Bohr - the participating observer who appears, it is the ideal constructor. The paradox, however, resides in the fact that he can only appear in this place because he at the same time assumes that it is, and will remain, empty.

*I do not wish to give the impression that I think there is no mystery about consciousness. There is, for instance, something of a paradox connected with any attempt to localise it.*⁴¹

³⁹ Turing, 1950: 456.

⁴⁰ Turing, 1950: 456.

⁴¹ Turing, 1950: 447.

As with consciousness, so with an onion, wrote Turing. We can peel off one (mechanically functioning) layer after another until we possibly have nothing left in our hand,⁴² but he does not draw the conclusion that this emptiness is the result of analytical subdivision and that what the onion and consciousness have in common is their joint - but mutually different - corporeality.

To the conventional and problematic distinction between the biological and mental processes corresponds a strikingly loose treatment of the human perceptual apparatus. Turing assumes without further consideration that the perceptual processes can be replaced by learning through a symbolic language. This implies a postulate to the effect that the biological and neurophysiological level has no independent significance for the understanding of intelligence. This can naturally be discussed, but in the given case it challenges his own use of biological theories in his definition of the mental machine. Turing also claims elsewhere in the article that the human nerve system is definitely not a digital computer, but rather a continuous machine.

This highly contradictory account rests on an underlying assumption which Turing never explicitly discussed, namely that it is possible to produce a description of all natural phenomena in a mathematical-algorithmic form. The problem he raised with the continuous nerve machine can therefore be reduced to the relationship between continuous and discontinuous mathematical functions.

Turing does not, however, claim that the digital computer can provide exactly the same answer as a continuous calculation, he simply claims that it can provide an answer which is so similar that a test person would not be able to decide what kind of a machine had calculated the result.⁴³

He once again uses the limitation of human consciousness as an argument for ignoring a difference he acknowledges as valid himself.

We may, but need not, wait for the future results of biological science. Although Turing's thesis in its general form consists of a debatable postulate on the immateriality of consciousness, the elimination of the biological and perceptual dimensions can be accepted. If they mean anything, this meaning must also be manifested at the symbolic level.

As symbolic representation is at the same time an indispensable condition for computational processes, this level comprises not only a necessary, but also

⁴² Turing, 1950: 454-455.

⁴³ Turing, 1950: 451-452.

an adequate basis for an understanding of both intelligence and machine, given that we accept the idea that we can think ourselves.

5.9 Symbol generative competence as a criterion of intelligence

There can be no doubt that the »consciousness machine« that Turing modelled in 1936 can contain a deterministic calculating machine. Nor can there be any doubt that this machine, thanks to its memory function, the division of its mechanical procedure into single steps and the possibility of programming (and mechanical exchange of) mechanical instructions represented a machine of a new type, both with regard to mechanical functionality and areas of use. Although it can hardly be claimed that Turing played a decisive role in the development of the early computers, he was the first to provide a theoretical description and definition of this type of machine and this description did have considerable influence on later developments.

Some of his predictions have also been fulfilled. It would be unreasonable not to acknowledge that it is possible today to build computers which can compete with humans, when it comes to chess, and it would be equally unreasonable to claim that it is not possible to build computers which can be trained to carry out many other thinking procedures which are very much in keeping with the perspectives he drew in 1950.

There are also strong indications in favour of accepting Turing's break with the Cartesian construction of consciousness and its many unreasonable dualistic implications. We do not *know* of any mental, spiritual or psychic processes which are not corporeally realized in the physically extended world. This is true of all experiences of timelessness, weightlessness, all perceptual experiences, all hallucinations, all revelations, exactly as it is true of any articulation of the idea of a god, of eternity, immateriality and immortality. We are always able to give a time and date to any human experience.

Finally, there are also strong indications - along with Turing - that we cannot draw the conclusion from this that human consciousness and thinking can be described solely through a description of consciousness as a physical or physiological system. A theory of consciousness must include a dimension which attempts to provide an account of the course of the thought process as a process of thought.

The remaining question, however, if we follow Turing this far, is whether human consciousness under these preconditions can be described as a finite

system with a finite number of distinct possible states and whether the relationship between these possible states can be described with the help of the concept of a mechanical process.

Turing's answer to this question comprises an ingenious combination of two arguments. On the one hand, he claims that we cannot exclude that there is a basic equivalence between consciousness and the universal computer, because the question cannot be formulated in a meaningful, i.e. precise form. On the other, he claims that it seems possible to design machines which can answer questions in such a way as to make it impossible for people normally to decide whether they are receiving an answer from a machine or from a human being. Among the arguments for this view, he mentions that it is possible to make the machine capable of answering incorrectly and thereby increasing the similarity to a human answer.

It may well be the case that Turing is correct, both in claiming that it is impossible to provide a precise description of consciousness and that it is possible to build machines which can pass the Turing test. But he cannot be correct when he claims that these two states are compatible with the postulate that it is impossible to exclude an equivalence between consciousness and a Turing machine. He hints at this himself when he maintains that it is necessary to allow the constructor to work with experimental methods which are not predefined, which simply means that the idea of equivalence is an idea of equivalence between two completely unknown entities.

The Turing test, however, can only be carried out when a machine has been built, which again implies that we can give an account of the way in which it is built. The question is therefore not one of a relationship between two quite indefinite phenomena, but of a relationship between the non-defined consciousness and a definite, specific machine which works on the basis of a finite number of discrete states. Any equivalence is thereby excluded, as it is possible to provide a precise description of how such a machine works, while it is impossible to describe consciousness with the same precision.

The objection could now be raised that a description of the machine which can pass the Turing test will therefore also provide a description of consciousness and thereby solve the original problem. This objection will not hold, however, as the Turing test can only reveal whether we can confuse the content of the answers, not the way in which they are produced. It was precisely because it is impossible to conclude from the result to the sequence which produced the result that Turing constructed the test as he did.

This is the reason why he did not predict that machines would be built which would work in the same way as humans think, but only that it would be possible to build machines which produced results which resembled the results of human thinking to the point where the two were indistinguishable and that he believed this would encourage people to accept the idea of thinking machines as a natural part of common sense and common language usage.

The greatest problem in Turing's construction, however, is not that equivalence between consciousness and the discrete-state-machine must be abandoned because we do not know how consciousness works, but do know how the machine works. The greatest problem is that his own description of the universal computer also makes it possible to describe the difference between the machine and consciousness with a hitherto unknown precision, which shows that consciousness quite simply cannot function as a Turing machine.

While Turing uses the idea of the indescribable consciousness to keep open a place for the idea that it can be described as a finite, discrete system, his definition of mechanical procedure provides the possibility of drawing the opposite conclusion.

It is not only possible with this definition to 1) exclude any possibility that consciousness can only operate as a discrete, mechanical symbol system, it is also possible 2) to exclude the idea that there may be a single, even if tiny or bizarre mechanical procedure which itself can produce some form of symbolic activity, if it falls within Turing's definition. It is finally also possible with this definition to prove 3) that human consciousness cannot be completely manifested in a discrete physical system.

The first proof follows immediately if, instead of starting with the mystic consciousness and the human art of illusion, we start with Turing's description of mechanical procedure.

It is evident from this definition that human beings can both formulate procedures which can be executed - and produced - as a result of a finite number of step-by-step operations, and procedures which cannot be executed - and therefore cannot be formulated through - a finite number of step-by-step mechanical operations either. If an attempt were made to get the machine to execute these incomplete procedures mechanically, it would be unable to conclude the process, as it cannot itself produce a stop condition independently of the process. The machine is thus incapable of formulating both the start and stop conditions of the formal procedure. These limitations are not applicable to human consciousness which, on the contrary, also has

the ability to formulate such conditions, just as we are capable of working with undetermined conditions, undecidable questions and of interrupting a process which has no built-in stop conditions.

These abilities are explained in mechanical symbol theories by looking at consciousness as a more comprehensive system, where a procedure at one level can be interrupted by a procedure at a higher symbolic level. If we take into account the capacity of consciousness, it is also possible for us to imagine a very great number of finite states.

Turing's analysis, however, also provides the possibility of rejecting this model with greater certainty, as he shows that any mechanical execution of symbolic procedures depends on a physical definition of the individual symbols which are included in the process.

This definition cannot be carried out by the machine itself and cannot in general be produced as a result of a mechanical symbol procedure because any such procedure is based on a previous definition of the symbols in which the procedure is expressed and through which it is carried out.

It is obvious that the physical symbol cannot be explained as the result of a process which presupposes that it already exists.

In other words, any mechanically performed symbolic procedure depends on a symbolic activity which cannot be explained on the basis of a mechanical symbol theory.

The physical definition must therefore be the result of a symbolic process which is not itself bound to the use of discrete symbols, it must be produced by a physical system which possesses the ability to create discrete symbols. This system cannot, in the given case, be a mechanical system which works step by step because such a system is bound to and limited by the precondition that all effects can be derived mechanically from the given start conditions.

If the system is defined as a mechanical system it is thus bound to comprise a given set of physical entities and a certain set of rules regarding movement. It cannot, at some later step in the process, move in such a way as to make it capable of distinguishing some of the physical entities as symbolic, as the rules governing its movement cannot provide the individual physical entities with new qualities. Nor does the concept of the finite mechanical system allow the introduction of new, physically effective symbols during the process.

If physical-mechanical systems possess a symbolic content this is because it is given outside the system and if this symbolic content manifests itself as an

independently operating force which can be distinguished from the given physical rules of movement, the system is no longer mechanical.

No matter whether we explain the ability to define the distinct symbols on the basis of a symbolic competence which is not itself bound to operate with distinct symbols, or as a property of the physical system in which the symbol is created, the result will be that the symbol-creating activity is rooted in a system which is not itself limited to working in distinct, mechanical steps.

This hereby completely excludes the possibility that a Turing machine or any other machine, which only operates with distinct symbolic entities and step-by-step defined, physical movements, itself can possess symbol-creating competence.

As, on the other hand, we know that human consciousness exists in a physical system which can distinguish certain physical forms as symbolic from other, non-symbolic, physical forms in the same system, it is impossible for symbolic competence, consciousness or human intelligence to be contained in a discrete mechanical system, notwithstanding the incalculable number of physical and symbolic possible states in this system.⁴⁴

If we therefore wish to maintain the idea that consciousness is a finitely extended system, we must abandon the demand that it can only operate in distinct, mechanical steps and if, on the other hand, we wish to maintain this demand we must - just as Turing allowed the infinite tape - accept that consciousness is not subject to the finiteness of the physical world, while at the same time admitting the ability of this transcendental force to continually intervene in the physical world.

The attempt to use mechanical description on human consciousness thus leads unavoidably to a complete dissolution of the constitutional premises of this thinking. The explanation is, in fact, not particularly surprising, as mechanical thinking both assumes the concept of infinite consciousness and the divine creation of immaterial force as well as of material particles.

While it is easy to explain how it is possible to perform calculation processes on a machine, namely by referring to our consciousness which is capable of defining both the physical and semantic value of symbols, it is more difficult - or as Turing claimed perhaps quite impossible - to explain how we ourselves are capable of carrying out these symbolic operations. But it is not

⁴⁴ This conclusion is strengthened as it can also be shown - as will appear from chapter 6 - that a conscious system must necessarily possess the ability to decide whether a given physical form in an arbitrary situation is only a physical form or whether it is also a symbolic form. In other words, it is not possible to provide a purely physical or mechanical definition of the concepts (and distinction between) 'noise' and 'information'.

particularly difficult to see that a mechanical description of physical systems, which are capable of creating symbols, must describe this ability as a transcendently given, metaphysical precondition by which the entire mechanical point is dissolved.

Even the simplest step-by-step symbol procedure presupposes a symbolic competence the machine cannot possess, whereas human consciousness possesses the ability to both 1) establish symbols in its own physical system and in the physical surroundings, 2) formulate start and stop conditions for finite procedures, 3) handle undecided and undecidable states, 4) formulate expressions which cannot be produced through a finite number of simple mechanical steps, and 5) possibly not work at all, but certainly not exclusively, with a single, delimited and physically-defined notation system in its brain.

As Turing's machine cannot describe its own physical system, it cannot itself produce any distinction between physical forms which are symbolic and physical forms which are not, either.

This competence must conversely be seen as a basic condition for intelligence and must therefore necessarily be included in a theory of human consciousness and thinking.

Exactly the same holds true of the relationship of the Turing machine to the content of thought. It cannot itself formulate the concepts which must be defined in order to make it fungible. His model does not include the ability to establish the symbolic meaning of a symbol, just as any attribution of functional, syntactic or semantic content depends on a symbol activity produced by a human.

As the ability to create symbols depends on distinguishing between physical processes which are not symbolic, relative to physical processes which are manifested as symbolic, it is tempting to propose the thesis that the human ability to make such distinctions is connected with the fact that our conceptual competence is not bound to a well-defined relationship between the corporeal realization and a certain symbolic structure. It appears as if the human brain - the physical, neurophysiological and mental system - can only possess symbolic competence because the symbolic structure does not coincide, or is not congruent with the physical structure in which it is embodied.

The informational, mental or conscious level cannot, however, be completely separated from the physical-physiological as an absolutely separate level with its own delimited, stable structure, because consciousness must also be understood as the process in which the definition of symbols as symbols takes

place. Such a definition can in many cases be derived from already established symbols, but it cannot hold for all symbols. We must also include in the concept of consciousness the physical-physiological »system's« ability to crystallize symbolic forms as well as symbolic meaning.

While it is true of human cognition that it takes place in a physical system which in one or another - unknown - way has become capable of producing a critical threshold for creating symbols itself, it is true of all known physical machines, including the computer, that they cannot of themselves produce such a critical threshold.

Which physical explanation is necessary in order to introduce human consciousness into the extended world can hardly be decided at present, but it is difficult to see how it is possible to avoid concepts of indefinite transitions and other non-mechanical concepts.

The demand on both formal and physically well-defined symbols comprises the computational start condition, but not that of the consciousness. In itself it comprises an irreducible and distinctive criterion for distinguishing between human consciousness and all types of mechanical calculation procedures.

Turing incidentally also had the idea of transferring the concept of a critical threshold from quantum physics to an understanding of consciousness. While the consciousness of animals appears to be sub-critical, he writes, it is perhaps possible to assume that human consciousness contains a special super-critical threshold where a certain mental input produces an »explosive« chain reaction which takes the form of a production of new ideas.⁴⁵

He limited himself, however, to discussing the critical threshold as an analogy between the physical and the conscious planes. He overlooked the fact that the first critical threshold which characterizes human consciousness is that threshold which enabled the physiological system to create symbols by itself at one stage or another in the history of development.

Although we cannot provide an exhaustive description of consciousness, we are perfectly able to localize symbol creating competence as the common minimum condition of consciousness, thinking and language.

It is therefore not only obvious or necessary to reject the intelligence criterion of the Turing test (that which resembles something else is probably the same as that which it resembles). It is also possible to formulate a more precise test criterion, as we can make this - as yet unexplained - but evident physiological property a central test criterion for a scientifically well-defined

⁴⁵ Turing, 1950: 454.

use of the term ‘thinking machine’. No ingenious experimental arrangement is necessary to carry out the test. The demand is solely that we build a physical apparatus which possesses the ability to develop symbol generative competence with the help of components which do not possess such competence.

With this criterion we not only avoid the unbecoming reference to a more or less widespread terminological confusion, we can also emancipate the understanding of the immanent character of symbolic processes from mechanical reductionism.

We may wonder that Turing himself did not discover this criterion, as he was perfectly at home in the borderland between the physical, biological and psychological. The explanation can perhaps be found in the conceptual tradition which is based on the development of separate conceptual apparatuses for each area and discipline, which thereby become jointly responsible for placing the borderlines between areas and disciplines as a given precondition which thereby falls outside the area and scope of each individual discipline.

Turing did not actually consider the physical manifestation of consciousness, on the contrary he used - and reinterpreted - the mechanical model of physics because it turned out that it was possible to exploit this model to represent a considerable part of mathematical logic, which undeniably has its place within the concept of human intelligence.

A similar - rather less subtle - figure can be found later in Newell and Simon’s formulation of the theoretical basis for the idea of artificial intelligence, although they actually describe their, possibly universal, symbol theory as a theory of *physical* symbol systems, because:

*... such systems clearly obey the laws of physics - they are realizable by engineered systems made of engineered components... A physical symbol system consists of a set of entities called symbols, which are physical patterns that can occur as components of another type of entity called an expression (or symbol structure). Thus a symbol structure is composed of a number of instances (or tokens) of symbols related in some physical way. Besides... the system also contains a collection of processes that operate on expressions to produce other expressions.*⁴⁶

⁴⁶ Newell and Simon (1976) 1989: 112-113.

A physical symbol system is thus defined here as

- A given set of symbolic entities, each with a well-defined, finite physical manifestation.
- A given set of sentences created by a constellation of such entities and
- A given set of rules for how one sentence can be transformed into another.

This model is generally consistent with formal logic and the basic theses of formal linguistic theories, with the single addition that Newell and Simon assume that the symbols are also physically manifested and that the entire system obeys physical-mechanical laws. It can also be noted that its structure is completely equivalent to Newtonian mechanics, as it is a system of physical entities corresponding to Newton's particles which are moved by an immaterial or transcendental set of rules without a physical manifestation and not themselves processed in time and space, corresponding to his transcendental concept of force.

It is only the first two points, however, which are understood as physically manifest, whereas the governing rules are understood as given outside the system.

Newell and Simon clearly attempt to bridge the gap between physical process and mechanical theory by defining the symbols as physical »atoms«, which together create »sentences« which again can be transformed with the help of a number of »processes« which are apparently elevated above the physical system as a Newtonian transcendental force that regulates the physical symbol particles. Although they - naturally - consider which properties are also necessary for such a system to be regarded as intelligent, they take as little trouble as Turing to explain why certain symbolic entities are physical while others are not and why certain physical entities are symbolic and others are not.

The quasi-physical symbol theory which was the basis of classical AI research thus begins by ignoring exactly that which delimits its subject area from other areas, namely the symbol generative competence which separates certain physical systems, including human consciousness, from others - among them all known machines.

That Newell and Simon formulate their physical symbol theory in the image of formal notation is not only inadequate, because it identifies the physically defined expression form with an equivalent content form, it also gives a completely incorrect description of how the symbolic rule structure is

produced as the result of a physical-mechanical process in a Turing machine as well as in an electronic computer. Like Turing they overlook the fact that rules can only be effectuated if they are themselves represented as a sequence of individually and freely editable, physically manifested notation units - in exactly the same form as all other data.

These inadequacies and errors presumably partially explain the discrepancy between the many proclamations on the theoretical explanatory force and the actual results which have since been arrived at. But they do not explain the considerable impact of the theory, which is surprising when we take into consideration that far into the 1970's and 1980's - classical mechanics in the manner of Laplace was

understood, in these theories, as a universal physical paradigm simply utilized as though the great machine were the sum of many small machines.

Turing was not only more cautious, he was more precise because he maintained a distinction between the indefinable basic category 'consciousness' (or intelligence) and the definite machine. Although he therefore had no illusions that the Turing test could be used to draw conclusions regarding the way in which humans think - the inability to distinguish between, or the similarity of two phenomena does not mean that they are produced in the same way - he still became enmeshed in his own net. There is no room in the world of mechanical concepts, neither in Turing's nor Simon's version, to describe how symbol generative competence can arise in a physical system. In fact, there is no room at all for events of this character. But it nevertheless explicitly assumes such human symbol activity, without which there is no machine.

Formerly, there was much criticism both of the Turing test and the implications for theories of consciousness which were formulated as a corollary to this. The criticism can be divided into three main positions.

First there are objections which start with a traditional, idealistic understanding of consciousness. These oppose the idea of describing the content of consciousness as processes which are expressed in time and space, as this presentation is understood as a mechanical-reductionist and materialistic idea which cannot give an account of values and content. It is characteristic that from this point of view there is no concern with the creation and development of consciousness, but consciousness is taken as axiomatically given - usually from an introspective viewpoint.⁴⁷

⁴⁷ Theodor Roszak can be mentioned as an exponent of this view, (1986). 1988.

Second come the objections which accept the idea that the brain's physiological activities can be described on the basis of mechanics, whereas the possibility of deriving a description of consciousness - intentionality - from the physiological description is contested. An exponent of this view is John Searle, who formulated it briefly and clearly:

*The brain, as far as its intrinsic operations are concerned, does not do information processing. It is a specific biological organ, and its specific, neurobiological processes cause specific forms of intentionality. In the brain, intrinsically, there are neurobiological processes and sometimes they cause consciousness. But that is the end of the story.*⁴⁸

It is characteristic here that the biological anchoring of consciousness is acknowledged, but that the relationship between the biological and the conscious is accessible (or necessary to take into account) is rejected.

Third come the objections which accept the idea that the brain and consciousness both operate as a physically realized, finite system, but which dispute that the - informational - processes of consciousness are rule determined.⁴⁹ It is characteristic that here it is accepted that the processes of both the brain and consciousness are realized either in a single system, or in two homologous systems which operate exclusively with a finite number of discrete - physically definable - states.

The following criticism has connections with elements from all three positions.

From the first and second positions I accept that there is no possibility of deriving the content of consciousness from the underlying neurophysiological processes, or of describing it as homologous or homomorphic to the physical realization, certainly not if this realization is identical or analogous to computational processes.

From the third position I accept that the content of consciousness is always processed in a physical form manifested in time and space, but not the idea that consciousness can be regarded as a system which operates exclusively with discrete and finite states.

The decisive difference to previous criticisms comes when we accept the idea that consciousness is physically processed and manifested in time and

⁴⁸ John Searle, 1990: 19.

⁴⁹ Exponents of this view can be represented by Hubert and Stuart Dreyfus, (1986), 1991.

space, as a consistent implementation of this idea leads to the conclusion that consciousness must possess symbol generative competence, which includes the ability to produce the symbolic forms that are taken as axiomatically given in the view of consciousness as a finite and discrete system.

Although it is not possible on the basis of our present knowledge to give an account of the origin of this property in the physical and biological universe, it has a character which implies that it is possible to draw the conclusion that consciousness must necessarily possess at least one property which is incompatible with the idea of a discrete, finite formal or physical system.

But this is not a question of rejecting the formal theories of cognition on the basis of older assumptions of theories of consciousness. On the contrary, it is a question of a criticism which appears when we take up the consideration of Cognitive Science and follow it to its conclusion, which here means back to the problem of the indefinite beginning.

While the models of Cognitive Science fall short as models of consciousness, the attempt to use the conceptual world of mechanical physics on consciousness gave rise to a remarkable transformation in the understanding of the mechanical system itself, as we replace the reference of classical mechanics to the physical universe with a functionalistic idea of a separate, distinctly delimited symbolic world which is realized (in different or similar) human and mechanical forms.

While the mechanical procedure in Newtonian theory is controlled by an immaterial force, its effects are purely material. Conditions are reversed in the symbolic interpretation of mechanical theory, as the relationship between material entities is seen as the cause of symbolic effects. Although the mechanical symbol theories do not provide an account of the force concept, they apparently allow it to be understood both as an immaterial Newtonian concept (as a kind of symbolic force) and as a concept of physical energy, as long as the physical energy is described as pure form.

It was Boltzmann who took the first step in this transformation by interpreting mechanical theory as an abstract, finite model of description. While he still viewed the mechanical model as a physical model, however, it was interpreted in other disciplines as a model of the their respective domains. The idea of the finite space is thus interpreted in mathematical logic as a logical space and from here Turing could take the final step in this transformation as he brought the logical space back into a mechanical-physical form, by showing that it is possible to reduce all finite mathematical and logical procedures to simple, mechanically executed steps. On this footbridge be-

tween logic and physics mechanical procedure apparently becomes equipped with a built-in symbolic meaning and the way is paved to the opposite movement: from symbolic mechanics, where physical materiality no longer means anything, to logic which, as the highest expression of human intelligence, perhaps also contains its essence.

The result was a neo-Cartesian research paradigm which supplies the Cartesian subject with finite and delimited physical-dynamic properties derived from 18th century materialistic theories of energy and instinct, as the concept of physical and/or biological forces is replaced by an immaterial process concept.

This abstraction results in a new version of the Cartesian dualism between consciousness and corporeality, as corporeality is removed from the room under consideration and the form concepts derived from the study of corporeality are used on consciousness. In this way the concept of the mental subject and the physical object disappear into a formal - often mathematical or information theoretical - transcendence. The relationship to the Cartesian tradition is thus not characterized by a confrontation with its dualism, but on the contrary by a confrontation with the use of this dualism in the polarization between an immaterial, non-extended subject and a material, extended object.

In the neo-Cartesian paradigm everything is extended in time and space and nothing is material. Matter is no longer accepted as a source of meaning, it is manifested only as a tiresome restriction or a completely passive and arbitrary medium. The system is at the same time deterministic and allows no room for either will or instinct as potential sources of disturbance of a given structure. But it is itself a theoretical system and was thought of in opposition to other theories. In other words it is itself a product of tension and will. But its existence must still be taken into account, just as for some time yet we must probably come to terms with the fact that the source of this will is not only reason, but also instinct.

The fact that this paradigm can provide new knowledge, and there is no reason to deny this, is connected both with the theoretical, levelling one-sidedness, which contributes to making a number of problems of cognitive theory more acute, and with the well-documented circumstance that it is far from the case that only valid theories are capable of providing knowledge of the world.

It is hardly by chance that the neo-Cartesian paradigm takes the shape of a highly speculative cognitive paradigm, as human cognition, unlike all other areas of research, occupies a doubly exceptional position. First, the process of

cognition is invisible and therefore inaccessible to direct observation. In this it resembles much of modern physics which must also use instrumentally mediated measurement procedures, the meaning of which can hardly be separated from the phenomena measured. In both cases they are areas where any type of observation is determined by complex, hypothetical assumptions which are implemented in experimental arrangements, measuring and testing apparatuses. And, as far as cognitive science goes, also that it is by definition self-referential. The extent and properties of the research subject are identical with those of the object.

The study of cognitive processes perhaps resembles, as Zenon Pylyshyn wrote, the attempt of a blind man to study elephants, but more closely resembles a blind man's attempt to study blindness.⁵⁰

These circumstances not only make the circular conclusion of neo-Cartesianism understandable, they also show that cognitive science could only achieve its modern breakthrough from the moment that an advanced set of theoretical and hypothetical assumptions became available which would make the necessary objectivization possible through externalized test apparatuses.

While the idea of utilizing the description of conscious processes in the construction of computers together with the idea of using computer models to test empirical and theoretical material on mental processes may be two individually well-reasoned, scientific paths, the interweaving of these ideas in the idea of a constitutive similarity is a blind alley which creates an obstacle for an understanding of the properties of consciousness and the computer alike. A scientifically responsible comparison must start by conceptualizing the differences which are the precondition for a comparison.

Turing's mistake was not that he suggested a strategy for constructing an apparatus which could serve as a tool for human thinking and also as a tool for research into human thinking, in which case civilization as such is an error; it was that he made the symbolic start and stop conditions, which are a precondition for the machine, a precondition for that consciousness which is the only known producer of such conditions. It is with this constitutive mistake that the information theoretical paradigms of the 20th century - with all due respect to the other many merits - take leave of the energy-theoretical paradigms of the 19th century.

⁵⁰ Pylyshyn, (1984) 1985. *Computation and Cognition: Toward a Foundation for Cognitive Science*.

Turing was perfectly aware of this. There are, he wrote, no systems which are characterized by discrete states:

*(The discrete state machines) are the machines which move by sudden jumps or clicks from one quite definite state to another. These states are sufficiently different for the possibility of confusion between them to be ignored. Strictly speaking there are no such machines. Everything really moves continuously. But there are many kinds of machines which can profitably be thought of as being discrete state machines.*⁵¹

Everything moves continuously.

The discrete state is only a - rewarding - mental idea. For exactly the same reason the double reflection of the idea of the discrete consciousness and the discrete machine is a circular short-circuit which by definition ignores the insoluble, research motivating basic problem - the relationship of the discrete representation to the continuous phenomenon.

We could say that this is particularly an ecological error, but the correction of this error must be located in symbolic theory.

A related conclusion, which however, is limited to providing an account of the difference between the physical-mechanical and the formal logical procedure, has also been presented by Robert Rosen in pointing out that there is no formal method which can produce a statement on the congruence between causal relationships in physical systems and the logical conclusion procedures which define any formal simulation of a physical system:

*Thus in formal systems, we already find that a purely syntactical encoding will in some sense lose information. The information lost must then pertain to an irreducible, unformalizable semantic component in the original inferential structure. By changing the encodings, we can shift to some extent where this semantic information resides, but we cannot eliminate it.*⁵²

Rosen's objection is thus not simply that the physical »causation« and the logical »implication« represent two different logical structures, but also that the formal procedure is of a syntactic nature and is produced by an elimination of the information on the system which is to be simulated (or represented).

⁵¹ Turing, 1950: 439.

⁵² Rosen, 1988: 533.

As will be shown in chapters 6 and 7 it is possible to provide an even more precise definition of the information which is lost, as the formal procedure is not produced as a selective choice (disposal) of more relevant information from less relevant, but as a principle and constitutive elimination of referentiality to the non-symbolic.

The general theme of Turing's thinking is the relationship between matter and consciousness. To this he added two fine distinctions, both closely connected with the inversion which lay in the understanding of consciousness in the image of matter.

The first distinction - clearest in its difference from a classical physical-mechanical understanding - was that his materialistic model included both memory, self-control and development mechanisms. At this point he was completely in line with the contemporary efforts of behaviourist psychologist, Clark L. Hull, to design mechanical robots.⁵³ Unlike these, Turing's machine, however, was not simply characterized by containing a memory function, a control unit and a feedback mechanism - the three elements then considered as the decisive obstacles to providing a mechanical description of biological and mental processes - Turing's machine was also characterized by a complete dissolution of both mechanical determination and the invariant bond between the mechanical function and its symbolic meaning.

The second distinction - clearest in relationship to classical mentalism - was the use of the condition of finiteness as a question of physical-mechanical execution. Turing believed that through a combination of these two trains of thought it would be possible to place the significance of physical corporeality in - a mathematical - parenthesis. Corporeality itself becomes an external, arbitrary and replaceable vehicle.

In this way Turing eliminated the materialistic dimension from materialistic thinking and thereby concluded an epoch in the history of materialistic thinking, as he also opened the way for a new, at once »symbolic« and practical technological epoch in the mentalist tradition.

He led the old dream of a mathematically perfect solution to the enigmatic relationship between matter and consciousness to new limits - as a mathematician, as one of the leading English cryptographers during and after

⁵³ C.f. Roberto Cordeschi, 1991, who discusses Hull's work in relation to Cognitive Science.

World War II, with access to knowledge so secret that even its existence was a secret - subject to military regulations of secrecy, sentenced to hormone treatment for a homosexual relationship with a young man of proletarian background at a time when the cold war was breeding a paranoid fear of sexual perversion and communism, finally it is believed - perhaps, perhaps not in accordance with his own basic beliefs - that he committed suicide on 7 June 1954.⁵⁴

⁵⁴ Hodges, 1983.

6. The breakthrough of information theory

6.1 Informational notation

The thread which runs from the physical to the later information concepts is not continuous. One of the breaks in it is expressed by the lack of interest in this area in the years up to World War II. In 1949, Warren Weaver in his interpretation of Claude Shannon's mathematical information theory in addition to Leo Szilard, who *extended [Boltzmann's] idea to a general discussion of information in physics*, only mentioned one other work on information theory, namely that of John von Neumann on the information concept in quantum mechanics and particle physics.¹

A lack of interest is in itself a kind of break, but Shannon's interest in the information concept led to another, namely a break with the view of information as a mere function of energy. He took the first step towards this in 1938 when he introduced the idea of using mathematical-logical principles (symbolic analysis based on Boolean logic) in the construction of electrical circuits.² Although no theory proper was presented here, there was an implicit view of electrical circuits as functions of a logical - and not physical - order.

It had long been known that it was possible to use electricity to transfer messages in a not directly perceptible form, which could both be analogue, such as in the telephone and the radio or handled with a discrete notation system such as in telegraphy where the Morse alphabet was used. But Shannon's idea of describing the electrical circuit as a logical mechanism paved the way for a new, more complex use of electricity for symbolic purposes. Whereas the Morse alphabet transferred messages as a sequence of individual signals one by one, the logical description of the relay makes it possible to introduce conditional relationships between the individual signals. A given signal can thus produce a change in the following signals and the following signals can produce a change in the effect of previous signals before the total transport has been completed.

¹ Shannon and Weaver (1949). Weaver refers to Szilard, 1929, but incorrectly gives the year 1925, where Szilard had published another article in which he gave a phenomenological interpretation of statistical thermodynamics where he ignored that information which could reside in the individual, arbitrary deviations. Szilard, 1925: 757, note. John von Neumann, (1932) especially chapter 5.

² Shannon, (1938) 1976. Davis, 1988b: 319.

Shannon's description involved a leap to higher level in the symbolic utilization of electricity. Where this utilization had formerly been based on a definition of physical threshold values for symbolic notation units, Shannon's description contained the basis for a formal, syntactic organization of electrical circuits.

In itself, the linking of the mechanical and logical is related to the link Turing had made in his description of the universal computer. But Shannon did not have the same acute sense of theoretical reach and was also far more concerned with the practical use of logic for handling electricity. Nevertheless - or precisely because of this - his contribution contained a theoretical element which is not found in Turing, but which would be of great importance to the later computer technology.

Where Turing had worked on the basis of a traditional physical machine which was controlled by a logical description, Shannon's description contained the elements of a machine with a built-in syntactic structure. Such a machine is a far more complex physical construction than the Turing machine. Nor is it immediately obvious that it can possess the same universal properties, as the syntactic structure contains a set of restrictions which are not contained in the physical construction of the Turing machine.

There is another difference, however, as the syntactic structure which is incorporated in the machine prepares the ground for a conceptual distinction between the syntactic and semantic levels, whereas Turing's implicit precondition was that the syntactic and semantic levels coincided and were expressed in the programme.

While Turing's point lay in the description of how an entire class of mathematical and logical operations could be performed by traditional mechanical means, Shannon's point lay in the description of the way in which mechanical processes could be subordinated to a symbolic organization at a formal syntactic level. He thereby paved the way for the complex physical construction which is now found in modern computers.

That his description also contained one of the germs of a new information theory first became evident when a group of American scientists, with mathematical, technical and biological backgrounds - urged on by the advent of World War II - discussed the more long-term scientific perspectives which would be connected with the new computer technology.

After some more informal contacts during the first war years, on the initiative of mathematician Norbert Wiener, a number of scientists gathered in the winter of 1943-44 at a seminar, where Wiener himself tried out his ideas for

describing intentional systems as based on feedback mechanisms. On the same occasion J.W. Tukey introduced the term a »bit« (binary digit) for the smallest informational unit, corresponding to the idea of a quantity of information as a quantity of yes-or-no answers.³ In continuation of this meeting, *The Teleological Society*⁴ was formed in 1944, the name of which was changed after the war, to the *Cybernetics Group*. Among its members were such figures as anthropologists Gregory Bateson and Margaret Mead, engineer Julian H. Bigelow, neuro-psychiatrist Warren McCulloch, physiologist Arthur Rosenblueth, mathematicians Walter Pitts, John von Neumann and Norbert Wiener.

Through discussions in this society the cybernetic paradigm, named by Norbert Wiener, and - in a relatively vague and general form - the idea of information as an abstract, quantifiable entity became crystallized.

According to Wiener's formulation of the cybernetic paradigm, it should be understood as a joint, basic paradigm for describing physical, biological, psychological and sociological »systems«. It was believed that mathematical description, which had been of such use in physics, could now be used in a similar way to describe living systems. The central point lay in mathematical description, but the decisive innovation lay in the idea that with the feedback mechanism there was now finally a general (neo)mechanical basis for describing self-regulating systems, including consciousness - which did not lead back to the old reductionist rut.

As far as can be seen, there are only sporadic discussions of the epistemological problems inherent in the application of mathematics to energy physics. Norbert Wiener thus saw Werner Heisenberg's statistical quantum mechanics as a realistic and exhaustive synthesis of Newtonian particle mechanics and Planck-Bohr's quantum mechanics. But that he contented himself with the statistical and non-phenomenological character of this description is exclusively due to the technical utility of the statistical description which is bound to specific communication systems.

³ C.f. Shannon, 1949: 32 and Wiener, 1962: 6 ff. and 1964: 269. The idea of using binary representation is older. It is not clear who originated it. Wiener 1962: 4, writes that the idea was accepted in accordance with a practice used by Bell Telephone Laboratories in another technical area. H. Goldstine, 1972: 123 wrote that John Atanasoff used binary representation in a calculating machine from 1940 and later claimed to be its originator. It was the German computer pioneer, Konrad Zuse, however, who came first. Zuse used binary representation in his first computer (Z1), which he developed during the years 1936-1938, but only for numerical notation. C.f. Williams, 1985: 216 ff. Zuse's work, incidentally, was not known outside - and received little attention in - Germany until much later.

⁴ H. Goldstine, 1972: 275.

*The relation of these mechanisms to time demands careful study. It is clear, of course, that the relation in-output is a consecutive one in time and involves a definite past-future order. What is perhaps not so clear is that the theory of the sensitive automata is a statistical one. We are scarcely ever interested in the performance of a communication-engineering machine for a single input. To function adequately, it must give a satisfactory performance for a whole class of inputs, and this means a statistically satisfactory performance for the class of input which it is statistically expected to receive. Thus its theory belongs to the Gibbsian statistical mechanics rather than to the classical Newtonian mechanics.*⁵

The epistemological problems are limited to a criticism of Bergson's vitalistic objections to classical mechanics. Although it is true that the vitalists, according to Wiener, correctly claimed that the reversible time of classical mechanics was not suitable as a basis for a mechanical description of living organisms, the thermodynamic and quantum mechanical descriptions offered new images of irreversible and self-regulating mechanisms:

*Thus the modern automaton exists in the same sort of Bergsonian time as the living organisms and hence there is no reason in Bergson's considerations why the essential mode of functioning of the living organism should not be the same as that of the automaton of this type. Vitalism has won to the extent that even mechanisms correspond to the time structure of vitalism but as we have said, the victory is a complete defeat, for from every point of view which has the slightest relation to morality or religion, the new mechanics is fully as mechanistic as the old.*⁶

Wiener was correct in claiming that the new feedback mechanism on the one hand was equally as mechanistic as the old, while on the other hand it contained a considerable expansion of the concept of mechanical procedures. But he was not aware that the growth in the number of mutually disunited mechanical paradigms in physics had at the same time raised other completely different problems for a realistic interpretation of any form of mechanical description. He thus completely avoided the question - so critical for Boltzmann and other physicists - of how it could be possible to connect a

⁵ Wiener, (1948) 1962: 37-44. Quotation: 43.

⁶ Wiener, (1948) 1962: 44.

mechanical description of a closed, local system to a realistic and universalistic interpretation of the mechanical paradigm.

A partial explanation probably lies in the pragmatic and technological perspective, but the fact that the cybernetic theory was presented as a universally realistic description model is probably to an equal degree due to the underlying idea of a unified science which, however, rapidly proved a failure.

The cybernetic society held ten conferences with invited guests during the years 1946-1953, after which it was dissolved. After the eighth meeting Wiener and von Neumann left and, at the tenth meeting, writes Steve J. Heims, the participants had nothing new to say to each other.⁷

The reason for this is obvious today. If we wish to describe different domains with the same conceptual apparatus, we must either ignore the differences or modify the conceptual apparatus so that it becomes capable of representing the differences. If we use the same procedure, such as the feedback mechanism, to describe both physical and psychological processes, we avoid the risk of taking one kind of phenomenon as a model for another by identifying the two with each other. The procedure simply ignores the difference which makes the comparison possible and the failure to make a distinction erroneous.

The history of the cybernetic society also appears as the history of a convergence, which immediately changes to a divergence. It was, as von Neumann expressed it at one of the meetings, far from given that it was possible to describe consciousness within the same logical categories as those used to describe other, less complex phenomena. On the contrary, it could be imagined that the phenomena of consciousness possessed an analytical irreducibility, that an object of consciousness comprised its own smallest description.⁸

The ambition of cybernetics to be the unifying science undoubtedly contributed to an overestimation of the explanatory force of the feedback mechanism, but the idea of a new - almost cosmological - world description influenced a number of sciences, with the creation of information theoretical

⁷ Steve J. Heims, 1988: 75.

⁸ Quoted here after Heims, 1988: 73. In a later discussion, (an incomplete, posthumously published manuscript) von Neumann emphasizes a number of differences between the digital computer and consciousness (understood as the neurophysiological system) and concludes, »the Language of the Brain [is] not the Language of Mathematics« J. von Neumann, 1958:80. Among his reasons for this conclusion are that the neurophysiological system consists of an interplay between digitalized and analogue processes. It can therefore not operate with the same numerical precision and is not subject to the same vulnerability to singular signal disturbances as digital computers. Ibid. 68-78.

paradigms in such areas as mathematics, biology, psychology, anthropology and linguistics as a consequence. In spite of its short history, cybernetic thinking thus comprises one of the central points of departure for the still ongoing technical-scientific revolution which began around World War II. It is therefore not surprising that this conceptual framework has also played a central role in the description of the symbolic properties of digital computers.

It is not only true in a general sense that the computer has been seen as the incarnation of a cybernetic system based on the use of the feedback mechanism as a conditional clause, but also in the sense that the symbolic processes which are performed in the computer have been described as formal procedures in line with other forms of algorithmic, mathematical and logical procedures.

While such a description is adequate for any single, finite procedure which can be performed automatically, it is not adequate to describe the way such procedures are performed in the computer, as the formal procedure, as shown in chapter 5, can only be performed in a computer if it is represented in a notation system which is *not* subject to the semantic restrictions which characterize a formal notation system.

At the time, nobody seems to have attached much importance to the principle difference between formal and informational notation, much less to have seen the new notation system as the most far-reaching or general innovation. The most important reason for this seems to lie in the widespread idea that the central point of this project was to perfect control theory, as this idea assumes that the innovation lay in a more comprehensive and perfect representation of the »world« rather than in the development of a new system of representation, which contained a number of questions regarding the relationship between what was represented and the forms of the representation.

The decisive point, however, is that it is neither possible to maintain the idea of a direct equivalence in the relationship between formal and informational notation, nor in the relationship between the symbolic and the physical process. On the contrary, informational notation comprises an independent link between the symbolic and the physical-mechanical.

The fact that this link - the informational notation system - was actually a new alphabet which formed the basis for a new sign structure different to any previously known sign structure - as will be explained in the following chapters - only emerged during the course of later developments. The same goes for the understanding of the new semantic potentialities and constraints of this sign system compared to any other hitherto known systems.

Although the acknowledgement of these aspects has only occurred slowly compared with the speed of technical innovations, there are sound reasons for assuming that they will represent the most far-reaching historical innovations prompted by the appearance of computers. First, while the development of a sign system is not subject to that technological obsolescence which affects specific technical innovations (such as individual articulations in a sign system compared to the system as such). Second, the properties of the new sign system are more general and inclusive than those of any other known system, which implies, among other things, that the latter can be represented in the former.

Since anything represented in a computer is represented in a sequential form and in the very same alphabet and sign structure, we can speak of a new kind of textual technology.

And since we can represent knowledge in any known form, whether expressed in common language, formal languages or in pictorial or auditive forms and integrate the basic functions in the handling of knowledge, such as production, editing, processing, retrieving, copying, validating, distribution and communication, we can also state that the computer has the capacity to become a new general or universal medium for the representation of knowledge.

Even if we cannot predict much regarding the knowledge content which will be expressed in this medium in the future, we can predict that the expression of knowledge in this medium will have a cultural and social impact of the same reach as the invention of modern printing technology, i.e. that computerization implies a change in the basic means of knowledge representation in modern societies, that is a - slowly but steadily developing - change in the very infrastructure of society

Although the informational notation system possesses properties which distinguish it from formal notation systems, it is nevertheless a product of the efforts to extend the area of use of formal representation and to bring about a generalized, universal system for formal representation, just as it is also such efforts which have produced the most important methods for using the new notation system.

These methods have primarily been developed at two levels: An algorithmic level, where there is both a quantitative and qualitative development of new, arbitrary syntactic methods of treatment and at the level of notation, where there are new methods for handling informational notation.

As these notation handling methods are themselves algorithmic, they can as such be regarded as a special branch of development at the algorithmic level, which will be discussed in chapter 8. They are also interesting because they can help to reveal the characteristic properties of informational notation.

6.2 Information as random variation

A pioneering work within this area appeared in 1948 in the form of an article by Claude Shannon under the ambitious title: *The Mathematical Theory of Communication*. The article aroused a great deal of interest and was reprinted in the following year together with Warren Weaver's comprehensive comments and his views of its perspectives.⁹

In essence the article was of a purely mathematical and technical character. Shannon's ambition was to demonstrate that it would always be possible to find a mathematical method for carrying out the optimum compression of a given message on the basis of a statistical knowledge of the system in which the message was expressed.

*The main point at issue is the effect of statistical knowledge about the source in reducing the required capacity of the channel, by the use of proper encoding of the information.*¹⁰

If the source is a linguistic message, in alphabetical or Morse alphabetical form, the question would then be whether there was a mathematical method for performing an optimum compression of the expression so that it would be possible to omit the transferral of as many individual symbols as possible, without the content being lost.

This, neither more nor less, is the subject of Shannon's theory and it thus appears quite directly, although it has often been passed over, that it is a theory of the compression of symbolic *notation* systems. The background for the theory included the well known fact that the different symbols in a notation system, such as the letters in the alphabet, occur with irregular frequency and that many sequences of letters are defined by the structure of the given

⁹ Shannon and Weaver (1949) 1969.

¹⁰ Shannon, (1949) 1969: 39.

language, while others are »freely chosen«, i.e. defined by the specific message.

The postulate was that expressions in a notation system can be regarded as the result of a stochastic process where a given, discrete symbol is handled as a unit which appears with a statistical probability characteristic of the chosen notation system as a whole, notwithstanding the symbol sequence which comprises the specific message.

No particularly precise description of the statistical structure as such is required. For instance, it can very well be assumed that the individual figures appear with equally great statistical probability, although the optimization of the compression will increase proportionally with the statistical knowledge of varying frequency

Now it is also true of common language that many individual symbols frequently appear in fixed constellations with surrounding symbols, such as »wh« and »th« and many suffixes in English. In these cases the probability of a given symbol occurrence is thus determined by the preceding symbol occurrence(s). In order to exploit the possibility for compression here, Shannon used a special series of stochastic processes, Markoff processes, which calculate probability with regard to the preceding »events«.

It is thus possible, writes Shannon, to regard any message, any source which appears in a discrete form, as a stochastic process and any stochastic process can conversely be regarded as a source which generates a message, as every step in the process can be regarded as the production of a new symbol - by which is meant here a notation unit.

Shannon believed that it would be possible to arrive at such a comprehensive description of language on a probabilistic basis that it could be claimed that language was actually governed by a stochastic process.

He carried out a number of calculations which were intended to show that a relatively simple stochastic model (where first, letter frequency was taken into account, then dependency between two and then three succeeding symbols, then word frequency and finally the dependency between two immediately succeeding words in ordinary English) could produce linguistically plausible symbol sequences to an extent that was twice as great as the statistical basis of calculation. If, for example, the statistical bond between up to three succeeding symbols was taken into account, linguistically plausible symbol sequences of up to six letters could be produced and if the statistical bond between two immediately succeeding words was taken into account, it was possible to produce linguistically plausible expressions of up to four words.

The idea of a complete approximation of the linguistically plausible has given rise to many subsequent works, but as Shannon remarked, the work on the next step would be colossal and he refrained from continuing the series of approximations himself.¹¹

This experiment in linguistic analysis, however, also served another, more specific purpose. It would show that it was also possible to increase the precision of a statistical analysis of apparently indeterministic systems by using a special series of Markoff processes, namely ergodic processes, in which the statistical structure of a - reasonably large - sample of a sequence is the same as for the entire sequence. It follows from this that all the sequences which can be produced in an ergodic system have the same statistical properties.

If we can thus - through a series of approximations - describe a given message with the help of an ergodic process, we can also describe a complete set of possible messages which can be handled in the same way. The question then is whether it is possible to exploit this statistical knowledge to compress - or re-code - all the messages which belong to the given set.

In its simplest form this is a question of finding a standard formula for the certainty with which we can predict what the next symbol will be, purely on the basis of the probability with which each symbol occurs in a given set.

It is reasonable, writes Shannon, to claim that such a standard in the given case must fulfil three demands:

- The measure of uncertainty (H) should be a continuous function of the probabilities of the occurrence, (p_i).
- If all p_i are equal, then H should be a monotonic increasing function of the number of symbols. With equally likely events there is more choice, or uncertainty, when there are more possible events.
- If a choice be broken down into successive choices, the original H should be the weighted sum of the individual values of H.

The only H satisfying the above assumptions is of the form

$$H = -K \sum_{i=1}^n p_i \log p_i$$

Where K is a constant related to the choice of the unit of measurement and p_i is the calculated probability for the occurrence of a given symbol.¹² The

¹¹ Shannon, 1951, Burton and Licklider, 1955, Mandler, 1955.

¹² Ibid. 49-50.

formula describes the uncertainty, »the entropy«, of the total system as a function of the uncertainty valid for each occurrence. The fact that it is the logarithmic value of the probability which appears as a factor is because of an arbitrary choice, intuitively motivated by engineering and practical considerations, as a great number of functions vary linearly with the logarithm of the number of possibilities, just as the use of logarithmic values simplifies the mathematical calculation.

An illustration of the usefulness of the choice is that by using the logarithmic function with base 2 we get a binary unit of measurement corresponding to a relay with two stable positions which can contain one bit of information, while a system with N relays, which thus has 2^N possible states, can correspondingly contain N bits, as \log (base 2) of $2^N = N$. By using the logarithm for base 2 as a factor, we thereby obtain uncertainty expressed in bits.

In its mathematical structure Shannon's formula is equivalent to Boltzmann's measure of physical entropy, as the constant in Boltzmann, however, is a physical constant. Shannon provides no proof of this theorem:

*It is chiefly given to lend a certain plausibility to some of our later definitions. The real justification of the definitions, however, will reside in their implications.*¹³

The value of the formula is thus connected with its intuitively relevant properties: H becomes zero if all signals except one appear with probability zero and that one with 100% probability (or probability 1, when uncertainty is expressed as a positive value between 0 and 1). In all other cases, H is positive. H is conversely maximum in the case where all symbols occur with equally great probability and H increases in this case linearly with the logarithm of the number of symbols.

It can further be demonstrated that the formula accords with the intuitive supposition that the probability of the occurrence of two given symbols in a sequence is less than or equal to the probability of the individual occurrence of the two symbols.

In the remainder of the article Shannon demonstrates how to apply the general mathematical measurement for uncertainty, entropy, or what is identical here: the amount of information in a given message, *where the*

¹³ Ibid. 50.

information concept is identified with the relative improbability which is valid for a decision as to what can occur as the next symbol. If we use base 2 for the logarithmic value, this corresponds to expressing uncertainty as the number of bits necessary to identify a signal.

If we define the uncertainty of a given set of messages as an average of the uncertainties that are valid step by step for the next symbol, weighed with regard to the probabilities which are valid for the occurrence of the individual permissible symbols, it is also possible to show that, through a series of approximations, the uncertainty of the total system can be calculated with as great an approximate precision as desired, simply on the basis of the total statistical structure of the message, i.e. without taking into account the variations which are connected with the transitions between the individual steps.

If a given message thus contains a given, large number of signals, the permissible symbols will occur individually with a probability which approaches that probability valid for its occurrence in the total set of possible messages.

That uncertainty which is valid for a specific message will always be less than that uncertainty which is valid for the entire set of possible messages in the same stochastic structure and the relationship between these uncertainties comprises what Shannon calls relative entropy.

This standard defines the amount of information contained in a given message relative to the degree of freedom which is valid for the total expression system. If a given message uses 80%, for example, of the free choices which are permitted in a given system, the relative entropy is 0.8 and, at the same time, comprises the maximum compression of the amount of information contained.

Correspondingly, the system's redundancy, i.e. that amount which is not available to free choice, is determined as a residual factor of the *relative entropy*.

This definition, however, does not appear to be quite clear, as relative entropy expresses a relationship between the maximum possible and actually utilized freedom of choice. Redundancy is thus defined here as a measure of the freedom of choice not utilized and not as a measure of the number of occurrences which are not accessible to choice.

Shannon's exemplification fails to clear up the problem, as he refers to a number of investigations into the statistical structure of the English language, from which it appears that redundancy in »ordinary English« is around 50%

and the amount of information therefore also 50%. Compared with this, Basic English, which is characterized by a limitation of the vocabulary to 850 words, has very high redundancy, while James Joyce is chosen to represent the linguistic contrast with very low redundancy. In all these examples, the redundancy concept is used of the number of symbol sequences that are determined by the language structure and not of the maximum number of free choices utilized.

That there are two different standards becomes clear if we consider a message in ordinary English, where relative entropy approaches 1, i.e. the amount of information approaches the maximum possible for the set of messages which belong to ordinary English. While redundancy as residual between the eligible and ineligible signals is, according to Shannon's statement, constant, equal to 0.5, when seen as residual to the relative entropy, it becomes very low, approaching 0 as the relative entropy approaches 1. If, conversely, we compare the possible choices used in ordinary English to the maximum number of choices the English language permits as a whole, the result will be that the relative entropy, the relationship between the possible choices utilized and not utilized, approaches 0, while the relationship between eligible and ineligible signals in the message remains 1:1 and the relative entropy is 0.5.

The relationship between the potential amount of information and the amount used is not included in Shannon's (nor in Weaver's) examples, but it is not possible on the basis of Shannon's definition to speak of higher or lower redundancy without placing it in relationship to a common - and maximum - standard for the possible free choices, of which any given text only utilizes some part or other.

If we therefore look at the different variants of English as different degrees of approximation of the maximum number of possible choices in the total system, the redundancy, which is expressed as residual to the relative entropy, would be low for Basic English because Basic English only uses a small number of the possible choices, while Joyce uses a greater number with a correspondingly higher redundancy. In order to ascertain this portion, however, we must take our point of departure in the maximum number of possible choices the English language allows for symbol sequences, which far exceeds any usage and has nothing to do with the 50-50 ratio which is considered typical for the relationship between redundancy and information in ordinary English, as in ordinary English nobody uses 50% of the maximum number of free choices in the English language as a whole.

So we have here two different definitions of the concept of redundancy. On the one hand, redundancy is defined as that part of the expression which is determined by the structure of the language, as Shannon assumes that a message can be divided into two portions, one of which is determined by the language system while the other is the part that is accessible to a free, meaning-bearing choice. This redundancy is defined in direct contrast to the meaning. The definition leads to a paradox, as Shannon here identifies redundancy with the system and rule determined part of an expression.

On the other hand, redundancy is defined as the unused possible choices in a given text. Here, redundancy is also defined in contrast to the meaning of the text, but where, in the first definition, this contrast was between the system determined and the freely chosen parts, in the second definition it is drawn between the freely chosen part and the unused, alternative possible choices in the given language.

In order to arrive at this result Shannon first had to use a third definition, as he could only determine the unused possible choices which characterize a given text by first carrying out a statistical analysis of the relationship between regularly occurring and irregularly occurring signals in a - representative section - of texts from the given language.

This - statistically expressed - redundancy differs from the two preceding definitions as it is not defined in contrast to, but completely without regard to the meaning of the text. The statistical standard is carried out on the entire set of messages no matter whether the individual notations occur because they are determined by the rule structure or belong to the specific, eligible content of the message. This determination also allows Shannon to avoid the question of how it is possible to differentiate between rule and meaning determined letters in a perfectly ordinary word.

Where redundancy in the two first definitions is defined in contrast to the meaning, redundancy in the third definition is defined quite independently of meaning. And while redundancy in the first definition is defined as the system determined part of the expression - in the two others it is defined as the used and unused parts respectively which are accessible to a free choice.

It is the first definition which comes closest to the traditional definition of redundancy as repetitively occurring, superfluous, structures which are of no importance for the content of the message. But this definition too is distorted by Shannon, as in this connection he simply defines the superfluous, meaningless structures as the regular occurrences, whereby they also come to

include the occurrences determined by the rules of the system in which the message is expressed.

To the traditional definition of redundancy

- as a repetitively occurring, superfluous structure which is of no importance for the content of the message,

Shannon thus adds three new definitions:

- as the regularly occurring, system determined parts (in contrast to meaning)
- as the eligible, but unused parts (the alternative possible meanings - in another contrast to meaning)
- as the statistically determined parts (without regard to meaning at all)

The relationship between these different definitions gives occasion for a more detailed analysis of the redundancy concept which will be taken up in section 7.5.

We are also left, however, with the first part of a new definition of informational quantities, as these quantities are determined as residuals to quantities which are established in a statistical structure. The smallest informational unit is defined here by its degree of unexpectedness in relationship to a specified expectancy structure which, in its stringent form, can be described as a stochastic procedure.

The paradox in this definition appears when we become aware that the informational quantity is a statistical function which itself has no specific manifestation. Uncertainty is concerned with the degree of unpredictability whereby a symbol occurs at a given time, or the degree of unpredictability whereby the total number of symbols occurs in a sequence, or is concerned with the average number of units necessary to specify a symbol within a class of possible symbols. The smallest amount of information here is thus not the same as the smallest expression unit in a notation system.

The amount of information is, on the contrary, a specific attribute, or property, of individual symbols or of sequences of symbols, as the amount indicates the degree of unexpectedness in the occurrence of a given form. But this is a peculiar property which only appears occasionally and, in principle, independently of the existing message, as the degree of unexpectedness is not a property of the message, but a function of the stochastic procedure which is chosen to characterize the message. The same message thus contains different

amounts of information if it is described or calculated on the basis of two different stochastic procedures. Other things being equal, the more complicated the procedure it is handled with the less information is contained in the source.

Characteristically, this is an almost diametrically opposite result of a semantic treatment in which the main rule would be that the more complicated interpreter yields more information than the less complicated.

There is nothing surprising in the fact that the statistically defined amount of information is independent of the semantic content, as this was the aim itself. The interesting thing is rather that, quite contrary to his own expectations, Shannon shows that the information which can be produced by a stochastic interpreter is not only independent of the meaning content of the message, but also of its notation structure, as the amount of information depends solely on the interpreter. The less the interpreter is capable of specifying the statistical properties of a message, the more information.

Of course it is correct that we can speak, in a certain vague manner, of such a connection at the semantic level. The less we know, the more, in a sense, we have the opportunity to learn. But this vague analogy obscures a significant discrepancy because more knowledge in the statistical theory is identical with less information. The knowledge which is absorbed in the statistical procedure is thus for the very same reason no longer possible information. There is only information in so far as it is missing.

Shannon's problem here is that signals which occur with great statistical regularity may well occur as the consequence of a free choice. Statistical regularity, which is not information, can therefore both be the result of a system determined order and of a semantic choice.

It is the definition of information as - the degree of - uncertainty which is the source of these paradoxical implications. In her book, *Chaos Bound*, N. Katherine Hayles writes of Shannon's conceptualization that it contains a transformation of the thermodynamic concept of uncertainty. While uncertainty in the thermodynamic description is seen as an actual micro-physical disorder, i.e. a state which cannot be known and where it is only possible to describe the statistical probabilities of possible states, uncertainty in Shannon's theory is understood as a degree of the »unexpectedness« of an actual event.¹⁴ In Shannon's theory the micro-state is completely unambiguous and given. There is a message in the form of a fixed sequence of given,

¹⁴ N. Katherine Hayles, 1990: 37, 54.

individual signals. Here, it could be added, the result of the measurement varies solely with the measurement procedure.

For the same reason Shannon's conceptualization of the information concept is only directly justified as part of the description of statistical properties in connection with the occurrence of symbols in different notation systems. The stochastic interpreter contains neither a description of the syntactic structure of the message nor of its informational content and can, precisely for this reason, be used on any set of physical forms, including physical notation forms.

As mentioned, there is no doubt that Shannon himself imagined that it was possible to design complicated stochastic models which could describe the syntactical structure of a common language, for example, as such a model would also make it possible to define a standard for the possible content of a message expressed as the degree of freedom in the choice of any succeeding symbol. The consequence of this, however, would be that the ability of a language to express a content decreases with the increasing complexity of linguistic rules.

As Shannon's paper indicates that he believed that we can always discriminate between rule determined and meaning determined notation occurrences, it would have been more obvious to use the model on formal languages in which such discrimination is obligatory, but this would have provided no confirmation. Although any notation in formal systems occurs as a consequence of a free - and semantically meaning-bearing - choice, the individual notations can nevertheless appear in a multiplicity of repetitive patterns.

It would not be difficult to construct a stochastic procedure which could produce plausible formal expressions, but it would be difficult to convince anybody that such a procedure thereby had any descriptive validity at all.

We need not, however, go down these blind alleys in order to derive some benefit from Shannon's theory and they were only of esoteric significance for his main purpose, which was to formulate mathematical means of optimizing transmission capacity in energy-based information media.

The definition of information as the degree of uncertainty of the occurrence of a signal comprised, in this connection, only one of the interesting new features.

Another lay in his account of how entropy per symbol in a text could be converted to an expression of the frequency with which a source produces entropy per unit of time. This conversion follows almost of its own accord

providing that the stochastic procedure is seen as a generator which produces symbols *at a given speed*.

By looking at statistical uncertainty, the information, as a function which can be expressed in physical duration, measured in time, in addition Shannon incorporates the information concept into a general physical scale. *The purely formal, statistical definition of the informational amount is thereby transformed into a definition of the informational amount as a physically determined entity.*

This means that informational entropy can be measured on the same scale as any other physical signal defined by a time function, whether it occurs with complete certainty or with some statistical (im)probability, as time is a general measure of duration. The concept of informational entropy thereby becomes a common unit of measure for a comparison of the degree of uncertainty of different stochastic procedures.

There was nothing new in describing a physical symbol structure on the basis of the duration of the signals. On the contrary, this had been taken up by many engineers since the introduction of the Morse alphabet for telegraphic purposes, because the duration of the signals was a decisive factor for the capacity of the transmission channel. The Morse alphabet was itself an example of how a discrete notation system, such as the alphabet, where duration is not distinctive, could be advantageously converted to a system which uses only duration as a distinctive element. This is probably also the reason why Shannon himself introduced the measure of time for informational entropy without noting that this implies a reinterpretation of the concept, as it now becomes an expression of that frequency (measured in time) whereby a more or less unexpected, but distinct, *physical* phenomenon (which can also be measured in time) occurs.

Informational entropy can, as a physical time function, only be determined on the precondition that the time scale which defines the signals as physically distinct signals is unambiguously connected with the time scale which defines the frequency of unexpected occurrences.

This connection is guaranteed by the chosen stochastic procedure when it is regarded as a product of a mechanical generator which operates at a known speed. The generator thereby establishes both the code which separates the signals as distinct physical values and the code which defines the average frequency of the unexpected occurrences of such distinct signals.¹⁵

¹⁵ It is incidentally also worth recalling these principles in connection with the discussion of informational theories of cognition, as they give occasion to ask the question of the degree to which -

By utilizing the time scale established by the generator, informational entropy can both be measured 1) at the level which is concerned with omitting the signals determined by the statistical structure, 2) at the level concerned with minimizing the time taken to transfer the symbols which are not determined by the structure, and 3) at the level which is concerned with specifying the individual symbols in the most economical form with regard to transport, for example by calculating the average necessary number of bits which are needed for unambiguous identification (which makes subsequent re-coding possible).

With the definition of informational entropy as the optimum, i.e. least possible, physical duration, Shannon arrived at an expression for the entropy of a given source which could be made operational in relationship to the transmission capacity of the channel, as this could also be expressed as a function of the possible messages per time unit.

Shannon then attempted to demonstrate that there is always at least one mathematical method to calculate the optimum compression of messages which are manifested in a discrete notation system. The demonstration is carried out partly by showing that the average transmission speed cannot be greater than *the relationship between the channel's capacity per time unit and the source's entropy per symbol*, while it can conversely be optimized so that it coincides with this - calculable - value with an uncertainty that is almost non-existent.

Shannon mentions two different methods of carrying out such an optimization. One method involves a division between the more probable messages which are transmitted as they are, while the less probable messages are separated and sent in a different code. In the other method the messages are organized according to their degree of probability, after which they are re-coded in binary form, where the more probable messages are represented by a short code and the less probable by a long code. In both cases it can be shown that for messages of a certain greater length, the upper limit for average transmission speed will be determined by the relationship between the channel's capacity and the uncertainty of the source.

In practice the result must be modified, however, because the code procedure itself, which elapses in time, builds upon a calculation of probabilities. Coding requires an analysis of the structure of the message. The code me-

parts of - the brain or consciousness operate with criteria of this sort, as a - hitherto unanswered - empirical question.

chanism must thus contain a store with a certain capacity. As a consequence of this the optimization of coding is always carried out at the expense of a certain delay in transmission. The same effect is produced at the other end of the channel as well, where the transmitted signals must be coded back to their original form.

In addition to this, there is yet another problem. As the theory is formulated up to this point, it is concerned with transmission through an idealized channel where the signals transmitted are supposed to move undisturbed through empty space. In this case, no transmission at all is possible because all signals are defined on the basis of some kind of physical manifestation in a medium - if nothing else then in the apparatus that registers the signal. It is therefore necessary to investigate how the determination of the optimum compression is influenced by physical noise in the channel.

This problem in itself would be of a purely technical nature if it were not precisely that the technical definition of informational entropy is identical with the technical definition of physical noise. As a consequence of this coincidence in the technical definitions, the technical possibility of distinguishing between information and noise depends upon conditions which lie outside the definition. The question is which?

6.3 Information and noise

With his definition of information as a random variation that can be described relative to an order defined by an arbitrary stochastic procedure, Shannon laid the foundation of a conceptual pattern which has since been the object of considerable attention. The heart of this conceptual pattern can be summarized as the thesis that it is possible to regard random variation as the basis of an order at a higher level. In Shannon this idea comes to direct expression, as without any detailed account, he assumes that the relative randomness which can be observed in the occurrence of a symbol sequence in a given message is a direct manifestation of the distinct content of the message. The disorganization which exists when the message is regarded as a sequence of individual symbols thus creates the basis for its meaning at the higher, semantic level of observation.

There is therefore a partial justification for this interpretation in what Shannon writes, but no reason is provided and his own analysis gives, on the contrary, several indications that it is a wrong approach.

One of these indications lies, as has already been discussed, in the description of informational entropy as a function of an arbitrarily chosen stochastic process, according to which the amount of information decreases with the increasing precision of the description of the message. It is immediately obvious that this relationship in itself prohibits any reference to the semantic content of the expression from being ascribed to the concept of informational entropy. Informational entropy can either be regarded as an arbitrary statistical function, such as is the case with the description of the source of the message, or as a function of time in a temporally defined signal system, such as is the case with both the description of the transmission channel and of the stochastic procedure as a mechanical signal generator.

Another indication appears from a more detailed observation of the coincidence in the definition of information and noise. The reason why Shannon uses the same definition of both phenomena is due to the circumstance that he is particularly interested in the mechanical transport of information, where doubt can arise as to whether a signal appears because it has been transmitted, or is a consequence of noise in the transmission channel. He is thus - in this connection - not interested in irregular noise which does not distort the signal transferred to such an extent that the receiving mechanism cannot distinguish the transmitted signal, nor is he interested in regular noise which always produces a certain distortion, except in those cases where this distortion can result in two different signals being received as the same.

On the other hand, he is particularly interested in how to determine with the greatest efficiency whether a received signal, with a legitimate physical form, stems from the transmitter or is due to noise during transmission.

In these cases, writes Shannon, it is reasonable to assume that the signal received can be understood as a function of two transmitted signals, one being the transmitted signal, the other being the noise signal. As both these signals can be understood as random variables, it can also be assumed in continuation of the preceding analysis, that they can be individually represented by appropriate stochastic processes.

This train of thought can be illustrated by imagining that the transmission is sent in binary code where the question is how it is possible to be certain that a transmitted 0 or 1 is also received as 0 or 1, if the physical noise in the channel sometimes means that a 0 is actually received for a transmitted 1. The idea therefore is to regard the transmitter and the noise source as two generators each operating with a measurable entropy.

This idea assumes that both the »informational entropy« and the noise are manifested in the same physical form as the physical signal - namely expressed in duration or amperage, conceived of as bits, for example.

The theoretical identification of noise and information has thus special relevance for the mechanical handling of notation systems where it is not immediately possible to use semantic criteria in the interpretation of the legitimacy of the notation unit and where the individual members of the notation system are defined on a common physical scale of values, because the relevant noise for the receiver occurs as though it came from the transmitter, completely on a par with and inseparable from the legitimate signals which comprise part of the message.

In noisy channels of this type a completely correct transmission is impossible and the question therefore was whether a coding procedure could be found which would enable a reduction in the frequency of errors or ambiguities in the received result to as great a degree as desired. A possibility would be to send the same message a great number of times and let the receiving apparatus carry out a statistical analysis of the individual messages in order to separate the most probable, correct version. The principles of the method are simply to increase redundancy in the total set of transmitted, identical signals which would imply a correspondingly great reduction of the effective capacity of the channel. Shannon could show, however, that it was possible to code the transmitted message in such a way as to minimize the limitation which lay in this increased redundancy by introducing a correction mechanism.

This mechanism was conceived of as an extra coding which would be added to or incorporated into the original message and the question therefore was whether it would be possible to determine the optimum reduction of the channel capacity which this extra coding would bring about.

For this purpose Shannon defined the effective transmission rate as the difference between the information transmitted and the information lacking at the receiver - due to noise. This missing information thus expressed the average uncertainty (»the equivocation«) which obtained for the signals received. It therefore also expressed, wrote Shannon, »the additional information« necessary to correct the message and this measure consequently indicated the necessary capacity for correction.

According to this, it is possible to carry out a coding which ensures as close an approximation of the correct transmission as desired and which only limits

the capacity of the channel with that uncertainty whereby noise is produced in the system.

At this point Shannon's analysis has a theoretical character, as he only supplies proof that on the basis of the given premises it is theoretically possible to find a coding procedure which can optimize the transmission. The procedure which can fulfil this condition, however, depends on the specific message.

This also appears from Shannon's own example of such an efficient re-coding, as he shows how a sequence of seven binary signals can be coded, x_1, x_2, \dots, x_7 (where the individual signal has one of two possible values). Of the seven signals, four (x_3, x_5, x_6, x_7) comprise the content of the message, while three (x_1, x_2, x_4) - in Shannon's terminology, redundant signals - comprise the necessary number of signals which are used to correct the message, if it is assumed that this block has either been transmitted free of error or with one error and that these eight possibilities are equally probable.

The value of the redundant signals is determined by a simple addition of the binary numerical values, as

x_1 is defined so that $x_1 + x_3 + x_5 + x_7 = 0$

x_2 is defined so that $x_2 + x_3 + x_6 + x_7 = 0$

x_4 is defined so that $x_4 + x_5 + x_6 + x_7 = 0$

If one (and only one) error occurs during transmission this will appear from the fact that either one, two or three of the redundant signals has become a 1 when the same test procedure is carried out by the receiver. If one of the redundant signals has been distorted, there will be *one* 1 value, if x_3, x_5 or x_6 has been distorted, there will be *two*, (different in each case) if x_7 has been distorted, there will be *three* 1 values.

As this is a question of a binary system, the wrong signal can therefore be corrected automatically.¹⁶

Even though coding can be carried out mechanically, it is nevertheless based on a semantic description of the message, as the binary signal values are interpreted as numerical values which can be added to each other. In other words, coding is brought about by ascribing a certain semantic value to the individual notation units. Although the message is interpreted through a formal semantics which is independent of the language in which the message

¹⁶ Shannon, (1949) 1969: 80.

appears, a semantic interpretation is still necessary to ensure the legitimacy of the notation unit. This is thus not a question of an asemantic coding, but on the contrary of the use of a formal semantics in the coding of the necessary notational redundancy. The redundant notations are then also redundant when regarded in relationship to the meaning content of the message itself, while both as transmitted physical signals and as notations in the formal code they are equally as distinctive notation units as the others.

Here, Shannon formulated a fifth definition of the redundancy concept where redundancy is determined as:

- a formal control code which can be defined by subjecting the message to a formal calculation, the result of which is added during transmission and removed after reception.

The - calculated - redundancy is thus not contained in the original message's expression and has no relation to the meaning or rule structure of the message. Whether the individual x's in the example above represent the letters in a word, an arithmetical problem or the result of a physical measurement of the temperature of sea water, or something completely different, is of no significance whatsoever for the determination of the formal control code. This is precisely where the advantage lies, because the method hereby becomes generally usable.

The fact that Shannon understood this solution as an asemantic solution to the problem of noise is first and foremost because of a confusion in his information concept, as he uses the concept both of a mathematically quantified expression for a meaning content and of a simple physically defined notation unit. Both views aim at an asemantic description of semantic phenomena. But in the first case the information concept is defined as the specific meaning-bearing part of the expression seen in contrast to the rule determined part. In the second case the information concept is defined quite independently of the meaning content, as the physical view is valid for any notation, whether it belongs to a repetitive redundancy structure or not.

In other words this is a question of two different definitions of the superfluous or »meaningless«. In the first case it is determined as the repetitive structure which, for the same reason, can be omitted from the transmission. In the second case it is determined as the unintended occurrence of one of the physically defined notation forms used. In the first case the noise is thus

identical with the rule-determined, in the second with signals occurring at random which are only distinct from legitimate signals by not being intended.

On the other hand, there is also a certain inner connection between the two definitions, as the use of the first definition as a means for eliminating the redundant notations becomes definitively limited by the second noise problem concerning the question of how to decide whether the occurrence of a legitimate physical form is intended or not.

While Shannon's idea that redundant notation sequences are an expression of the rule-determined structure of the given symbol language must be rejected, because it - as will be considered in greater detail in chapter 7 - is neither valid for formal nor written language expression forms, his noise theoretical analysis shows that the occurrence of redundant notations is necessary to stabilize the recognition of the legitimacy of the physical form as notation form.

There is also a reason to attach importance to the fact that Shannon's physical noise problem also has a general background, because each notation can only manifest itself in a physically possible form. The specific coincidence between noise and information which is treated in the theory is thus also a specific manifestation of the fact that any notation form can coincide with a physical form which is not intended. From this it appears indirectly that there is always an intentional and symbolic element in the definition of a physical form as a legitimate notation unit, despite the precision in the definition of the physical form. In other words, it is not possible to maintain Shannon's idea of a purely physically defined, asemantic notation.

6.4 A generalization of the physical information concept?

Warren Weaver's comments on Shannon's theory give it the appearance of a generalization of Boltzmann-Szilard's physical information theory, because Shannon defined »informational entropy« in the same mathematical form, but independently of the physical medium in which the information was embedded. The same formula, however, describes two completely different relationships. While thermodynamic entropy describes how a number of molecules, whose individual motions are unknown, can be expected to act as a whole, informational entropy is a measure for the irregular recurrence, but actual occurrence, of individually identifiable single signals.

Shannon's definition of information as entropy, a degree of uncertainty, is not a more general definition of the thermodynamic entropy concept, but another specific use of the same mathematical expression. It does not differ, however, by being a mathematical definition instead of a physical definition, as informational entropy is a yardstick which is only used on - certain types - of physically manifested signals.

Shannon could not have found a more inappropriate title for his work if he had tried. It is not *the* mathematical theory, nor is it a purely *mathematical* theory and it only concerns *communication* in the very special sense of mechanical transmission.

Not the mathematical theory

That it is not *the* mathematical theory appears from the later mathematical-physical discussion, in which two different limitations were introduced. First, the theory contains no definition of the phenomenon it can express in quantified form, namely the concept of information and second, it has not made the need for other quantified information measures superfluous.¹⁷

Donald Mackay describes this limitation by differentiating between quantifications based on *selection* from a set of preconstructed forms such as Shannon's and quantifications based on *form construction*, exemplified by the construction of the form of a TV picture with the help of spots of light.¹⁸ The decisive point in Mackay's argument is that the question »how much information« must be answered in different ways depending on the given forms of the information which are relevant in a given context. Constructive and selective information measures - among which Shannon's is just one of many possible - do not therefore represent competing theories of information either. On the contrary, they represent quantifications of an information concept which cannot be defined by one or the other quantified measures for an amount of information.

It would be clearly absurd to regard these various measures of amount of information as rivals. They are no more rivals than are length, area and

¹⁷ Shannon's theory has given rise to what are still continuing discussions. A resume - with summaries of various main viewpoints - can be found in Machlup and Mansfield, 1983 and Hayles, 1990, among others.

¹⁸ Such measures were developed by, among others, Ronald A. Fischer in 1935 and Dennis Gabor in 1946. Gabor, who was later awarded the Nobel prize for his work on holography, used the concept a »logon« as a measure of an amount of information, as the number of logons in a signal represented the amount of freedom in the structure, or the smallest number of independent measures mathematically necessary for defining the form of the signal under the limiting conditions of frequencies, band widths and duration. Mackay, 1983: 487.

*volume as measures of size. By the same token, it would be manifestly inept to take any of them as definitions of the concept of information itself.*¹⁹

Even though these quantifications can be regarded as complementary, continues Mackay, it is not possible as a matter of course to define an information concept through an abstraction based on the complementarity between different quantified information measures. The quantified theories also have in common the fact that they work with an operationally defined information concept which only allows a definition of information as »that which determines form«. Common to these theories is thus that they refer to processes in which the time-spatial form of one set of events (a place) determines the form of another set without taking into account the energy process involved. Information is thus defined only as »something« which flows from one place to another.

According to Mackay, this view builds upon a false analogy, as by determining information through what it does (determines form) we look at information in the same way as we look at energy in physics, namely through what it does (produces acceleration) and not through what it is, namely some kind of specific physical energy process.

Mackay bases his criticism of this analogy by pointing out the difference between what energy is said to do: perform work of a physical character and what information is said to do: perform work of a logical character.

*In talking about information, there is always a suppressed reference to a third party, as in the physical theory of relativity we have to relate our definitions to an observer, actual or potential, before they become operationally precise.*²⁰

The third party not overtly referred to which is waiting here in the wings, pops up precisely because the information concept, as will be discussed in more detail in the following section, must necessarily contain a semantic dimension connected to the choice of the viewpoint of the process.

While Mackay - on a par with George A. Miller²¹ in this question - takes his point of departure in the need for other quantitative information measures, Peter Elias adds that the many different uses of Shannon's information

¹⁹ Mackay, 1983: 488.

²⁰ Mackay, 1983: 486.

²¹ George A. Miller, 1983: 493-497.

measure depend on specific conditions, purposes and connections in each case. Validity does not depend on the mathematical measure, but on the character of the given way the problem presents itself and the theory can only hold true of transformations in which the reversible coding of a set of sequences to another occurs.²²

This is a central limitation. The theory not only lacks a definition of the information concept, it concerns only a *re-coding* of an already physically defined message.

Myron Tribus can also refer to a private conversation where Shannon in 1961 was supposed to have expressed scepticism regarding the use of the theory outside the context of communication theory and acknowledged that it does not contain a definition of the information concept.²³ The contribution that the theory makes to this does not lie at a mathematical level at all, but at a physical level, as it is solely concerned with the physical dimension of the symbolic expression form. That Shannon assumed there was an unambiguous equivalence between the individual physical notation and the content of the message was perhaps due to the fact that he regarded the formal notation form as typical.

Not a purely mathematical theory

Shannon's theory is not *the* mathematical theory, but nor is it a purely *mathematical* theory. It is a mathematical-physical theory. Seen in comparison to thermodynamic theory it is a matter of a different description of the relationship between energy and information, as the new theory not only refers to the special case where a certain amount of energy »contains« a certain amount of information (on the same amount of energy) but on the contrary to all cases where an arbitrary meaning content has been manifested in a physically well-defined notation system. Considered in the light of Szilard's »narrow« information concept this represents a great expansion, as the informational notation unit is not only emancipated from a certain meaning content, but also from the physical, natural form. Although Shannon defines informational notation through certain physical values, this physical form is distinct from the physical, natural forms in two ways, as the informational entity is limited both in relationship to physical forms which are not identical and in relationship to physical forms which are identical, but not intended. Each of the two definitions is thus connected with its own noise problem. One

²² Peter Elias, 1983: 500-502.

²³ Myron Tribus, 1983: 475.

that concerns the physical form and one that concerns the legitimacy of the physical form as a valid member of the message.

The mathematical definition is thus valid only for physical systems in which it is possible, on the basis of rules, that is instrumentally, to install the lower noise limit which will ensure a stable distinctiveness between non-informational physical noise variation and informationally significant, physical variation.

In this sense, Shannon's theory is only valid in connection with symbolic systems which operate with a well-defined and invariant noise limit. The quantified amount of information is at all stages determined relative to a controlled quantity of energy, where the noise which does not exceed the critical threshold separating the symbol from the medium can be ignored.

The physical character of the theory therefore manifests itself not only as a physically determined limitation of the possible applications, it also manifests itself in the sense that the theory only concerns informational entities which are available in a *physically defined* form, because the critical threshold which is the basis of the distinction between noise and information is brought about as a definition of physical threshold values. The physical definition of the informational entity comprises - as was also the case with the Turing machine - a necessary, but not complete, condition for carrying out the - presumably asemantic - re-codings, which at the time constituted a highly dramatic innovation.

That this is a mathematical-physical and not a purely mathematical theory follows for the same reasons, which meant that it was not *the* mathematical theory, but one among many possible mathematical information measures. That different forms of mathematical quantification can exist is due to the fact that the individual methods each measure different physical features of the symbolic expression units.

The whole point of mathematical theories of information is connected with the circumstance that they allow a mathematical handling of symbol systems solely on the basis of the physical properties which are used to define the physical form of the symbols. On the one hand, this justifies distinguishing between those theories of physically defined symbols and physical theories which describe physical distinctions independently of whether they are used for symbolic purposes. But, on the other hand, it does not justify ignoring the fact that the theories do handle the physical properties of symbols with mathematical methods.

Shannon's quantified information entities are bound by the physical definition. But it is also a question of a new determination of this bond. The bond is no longer, as in Szilard, naturally given as a causal connection or isomorphic combination. Within certain limits it is an open, arbitrary bond. Information is no longer seen as a simple, mathematically expressed function of energy, energy is seen, on the contrary, as a function of notation. This also implies that informational notation is subject to the demand that the notation units used be defined on the same scale of physical value. This is thus a question of a far more rigorous demand on the definition of the notation's physical form than the demand which obtains for written and formal notation, where the demand on the physical form is related to sensory recognizability, while informational notation is subject to the demand that it function as a mechanically effective entity. The relationship between the different notation systems is discussed in greater detail in chapter 7 and sections 8.1-8.3.

Shannon himself perhaps passed over the physical features of the theory because, in all essentials, the first physical noise problem was concerned with practical problems which were of no significance to engineering, as they could be solved with familiar mathematical-physical methods, while the remaining questions concerned the optimization of time consumption and the handling of the second noise problem which has no physical solution.

The problem of noise and the ability to generate symbols

The basic demand on a physical expression form is the well-defined lower physical limitation of the informational entities relative to the variability of the physical medium.

The demand for such a lower limit is true in principle of all symbol systems. For digital systems it is thus true that there is no isomorphism between the informational process and the physical process through which the former is performed. Turing touched on the same when he pointed out in his article in 1950 that certain mechanical systems could advantageously be regarded *as though* they were discrete-state-systems, although physically considered they are continuous.

On the face of it, it might appear as though the demand for a lower noise limit does not have the same validity for analogue systems, which are characterized by equivalence or isomorphism between physical and informational variability. But this equivalence can only be brought about at a certain macro-level. That isomorphism between an analogue symbol and the supporting physical structure depends on a previous coding of the physical structure

appears from the fact that the same physical structure can be described independently of the sign bearing structure. As any symbol formation is bound to a physical manifestation, the smallest symbol unit cannot be smaller than the smallest organized physical variability, but it cannot - according to existing physical knowledge - be equal to the smallest physical variability either, as the micro-physical description here assumes the existence of irreducible noise.

The demand for a lower noise limit is thus valid not only for digital, but also for analogue symbol systems, nor does it appear possible to limit this demand to a demand which is only valid for certain technical information systems. We can assume that it is also valid for human perception and information processing. On this point Shannon's noise theoretical results therefore appear to be general. Symbolic activity assumes both the ability to separate the symbolic expression forms from the physical noise in the physical (or physiological) medium used and from identical physical forms. The question then is, how the critical threshold can be brought about and work in different biological, human and artificial information systems.

Here, a fundamental difference between the artificial systems covered by Shannon's theory and human information systems makes its appearance, as the latter possess the ability to produce codes of both the first and second orders (and many more), while the former are characterized by only being able to perform re-codings to the second order, if a model in the form of codes of the first order already exists. The most significant point is not that the one system can produce several types of code, but that it also possesses the ability to *produce* the critical thresholds which are a condition for symbol systems of both the first and second order. In Shannon's theory, the critical threshold is defined prior to and independently of the system. Artifactitious systems assume that there is already a coding of the first order *and* a defined critical threshold which makes re-coding to another order system possible.

To all appearances, only certain types of physical information systems possess the ability to produce codes of the first order themselves, namely those systems which are traditionally described as biological. As - some of - these systems have the ability to bring about the critical threshold itself, which is a condition for the first symbol formation, it is difficult to imagine that these systems should not retain this ability.

In that case the biological systems which possess the ability to create consciousness are characterized by the fact that they are not subject to the demand for a preceding, once-and-for-all established threshold for a given

system which determines the condition for the distinction between physical noise and information as a functional condition for the artifactitious systems. It is therefore more plausible to assume that the conscious systems not only retain the ability to produce symbols of the first order, but that they also, at some stage of biological history, have generated an ability to release themselves from the established noise thresholds, for example in the form of a semantic re-interpretation or exploitation of »noise«.

There can be little doubt that many biological information systems are capable of maintaining a given critical threshold for a certain period. Human beings can certainly maintain similarly critical mental thresholds, when we calculate, perform deductive conclusions and other systematic thought processes. In such cases, however, we usually prefer to use externalized aids precisely because they help to stabilize or maintain invariant thresholds for defining valid informational entities during the performance of well-delimited tasks. The concentration required and the difficulty involved in maintaining these thresholds for a certain time shows, however, that for consciousness to have defined thresholds as a characteristic, its constitutive properties must be the ability to vary and even create thresholds.

The human system has thereby a symbol producing property that computers do not have, namely the ability itself to establish the critical threshold which makes it possible to separate informational physical variations from physical noise variation.

The exact delimitation of what noise is, relative to a critical threshold defined outside the system, can therefore not be transferred to human consciousness. An analysis of Shannon's noise theoretical results thus confirms the relevance of the symbol generative test criterion for an understanding of consciousness and intelligence, as discussed in sections 5.8-5.9.

The reach of this appears, among other things, from the fact that it is incompatible with a main assumption in the later theories of cognition based on information theory, namely the idea that cognitive activity can be described as a closed informational system which can either be understood as isomorphic in relation to the neuro-physiological system, or as a self-supporting, learned or inherent, *logos* which organizes the underlying biological and physical components. These assumptions not only ignore that the biological theory of the origin of the higher organisms also includes consciousness, but also that the restrictions which apply to physical information systems of Shannon's type cannot be reconciled with our knowledge of our own ability to produce codes and symbols.

The mathematical-physical determination of the critical threshold first arose as a relevant theme - both in the understanding of analogue and digital systems - in connection with the appearance of a physical-technical potential for - invisible - symbol handling based on the technical mastery of micro-physical energy processes. This concerns performing symbol handling independently of the perceptual and cognitive potential which provides the basis for human symbol production.

It was this difference which gave Shannon's 'choice theoretical' information considerations far-reaching practical and thereby also cultural and theoretical significance, as it pointed out the possibility of compensating for physical noise by increasing redundancy in the transferral of messages in not completely reliable electronic systems. The benefit lay in going beyond the direct equivalence between energy and information amount.

With the mathematical measure for technical compression, Shannon created an obvious technical advance within the area of information transport. But looked at from the point of view of information theory it has a grave defect because this solution assumes that the theory can only concern re-coding of already coded messages. It is also one of the two reasons which mean that it is not a theory of *communication* either.

... *nor a communication theory*

A reasonable demand on a communication theory is naturally that it concerns an exchange of meaning or signification. Meaning is also included in Shannon's theory in the sense that it is concerned with discovering an economical method of transferring messages without loss of meaning. Meaning is included, however, only as the ultimate test criterion of the success of the communication and the heart of the theory did not lie in the exchange of meaning between the producer and the interpreter, but in the transfer of already formed messages, as Shannon took his point of departure in the manifest expression form of the message.

Frequently the messages have meaning that is they refer to or are correlated according to some system with certain physical or conceptual entities. These semantic aspects of communication are irrelevant to the engineering problem. The significant aspect is that the actual message is one selected from a set of possible messages. The system must be designed to operate for

*each possible selection, not just the one which will actually be chosen since this is unknown at the time of design.*²⁴

That Shannon in spite of this - with regard to engineering, well-founded - motivation of semantic irrelevance still concerns a communication theory is not only due to the ultimate criterion of understanding (in the final analysis the message must be recognized by a human interpreter), but also that he actually uses a theoretical model of communication as a point of departure for his engineer's perspective.

That he again here - and now tacitly - can ignore the semantic dimension is because he is only concerned with the reversible re-coding of existing codings.

The model comprises a functional unit which includes five components: 1) a source of information, 2) a transmitter with a built-in code set, 3) a channel, 4) a receiving apparatus with a de-coder and 5) a receiver. As we have seen, the weight of the theory lies in the effectivization of transport, i.e. the movement from the second to the fourth component. The fifth component, the final receiver, is included because all processes from 1 to 5 must operate in such a way as to ensure that not only the signals, but also the meaning reaches the receiver. The central operations, the establishment of the stochastic procedure which must be used in the re-coding procedure, is carried out, however, before the first step.

Shannon indicates that the theory includes a number of different types of message, namely:

- Sequences of letters (such as in the telegraph and teleprinter).
- Sequences expressed in a single time function (such as the radio and telephone).
- Sequences expressed in a time function and other variables (such as black and white television with two spatial co-ordinates).
- Sequences expressed in two or more time functions («three-dimensional sound transmission» and multiplex).
- Sequences with several functions of several variables (such as colour television).
- Various combinations (such as television coupled with sound).²⁵

²⁴ Shannon (1948) 1969: 31.

²⁵ Shannon (1948): 33.

It is true of all these examples that the communicative process occurs as a sequential, linear physical process through one or more separate channels. It is thus not only assumed that the message is available in a fully formulated state before it is transmitted, but also that there must be no meaning exchange or informational interference between the transmitter and the receiver during the process. There is no room here for confidential conversations, or telling glances and gesticulatory articulations of meaning.

These limitations are not of a temporary character. It is not the case that they could be modified through an extension of the theory. They comprise its constitutive basis, as they are contained in the demand this type of system makes on the physical definition of informational entities. That these demands do not apply to all systems and especially not to human communication, appears, for example, from the fact that we cannot mistake what we can see on a television screen, namely physically defined symbols with well-defined critical thresholds, with what we can see on the spot, where the definition is left entirely to the observer. What we can see on the spot has not been filtered by the coding the transmitter must carry out in order to transmit a television picture. There is thus a difference, because in the one case something is being communicated which is not being communicated in the other.

Although some of this missing »information« could perhaps be analysed and brought into a formal description, it would not remove the difference. Touch, for example, implies something other than a symbolic representation communicated through an electronic medium. The difference exists, among other things, because in spite of all general definitions, any information system is always a specific physical system implemented in a definite form.²⁶

The artifactitious system does not cover the entire human perceptual potential because it depends on the establishment of a well defined critical threshold. Human perception is not subject to the same demands for a well-defined lower limit between noise and information. The lack of such a definition is, on the contrary, rather a constitutive condition for meaning production.

²⁶ This difference also holds true of virtual reality systems which offer a symbolically mediated, mechanical sensory effect on an arbitrary part of the body. The mechanical effect, it is true, will also be accompanied by physical noise, but this noise is relative to the influencing medium and therefore different for different sensory media.

Shannon conceals the problem of the first coding behind the second problem, that of re-coding by simply filling up the box of information sources with a list of different means of information transport.

As the theory with regard to definition ignores the meaning dimension both in connection with production and exchange, it is impossible to consider it a legitimate candidate within the area of communication theory.

But it would be equally misleading to simply dismiss the theory with reference to Shannon's asemantic symbol concept. Although the theory neither includes meaning production nor oral communication, to a great degree it sheds light on the understanding of the physical dimensions of both alphabetical and pictorial symbol manifestations. And, although not formulated as such, Shannon's theory also presents the first theoretical attempt to describe a notation system independent of the senses, where the relationship between the individual notations is mutually conditioned. Whether this could have been done on the basis of a semantic approach cannot be decided. Shannon showed, apparently unwittingly, that it could be done with the point of departure in a physical symbol definition.

6.5 The semantic ghost

If Shannon's information concept is seen as a quantified measure of the meaning-bearing parts of an expression, the problem arises that the amount of information in the message grows in inverse proportion to the organization of the expression and that the most meaning-bearing expressions are identical with the least structured. Or in Katherine Hayles' words, the most muddled expression contains the maximum possible information.²⁷

Nevertheless, in a considerable part of the later literature, the conceptual connection between noise and information has been maintained, as this has been joined to Shannon's definition and the information content of the received message described as the sum of two messages. But where Shannon distinguishes between these two messages by operating with two mechanical generators working within the same physical system, a distinction has been introduced between that part of the received message which is intended by the transmitter and that part which is not. Shannon's distinction is thus ascribed a semantic foundation joined to an intention.²⁸ As Hayles remarks,

²⁷ Hayles, 1990: 55.

²⁸ Hayles, 1990: 56, where the later paradigmatic transformation of Shannon's theory is described as an extension of the significance of the noise concept, as noise is not simply seen as a potential destruction

this re-interpretation assumes the introduction of an interpreter, who can see the system from outside. As the transmitter and the receiver in Shannon's theory do not enter into a semantic relationship (the receiver is not aware of the transmitter's intention, but only of the message received), this description can only be carried out by introducing an outside observer of the total system.

This observer is the only one capable of making the distinction. On the other hand, he can therefore see both the information which is not intended as »destructive« noise or as »constructive« additional information, not measured in relationship to the message, but in relationship to the total system.

Within this idea lies a real emphasis of the fact that Shannon's theory assumes both a tacit semantic interpretation and an outside observer.

The semantic interpretation is assumed because there must be a valid, noise-free message as a starting point and because no asemantic criterion can be formulated for deciding the legitimacy of the received signal. This distinction can be ensured, as we have seen, with the help of the redundancy function, as the message can either be sent a great number of times, or be analysed and a set of control codes prepared through which the legitimacy of the individual signal can be determined by the surrounding signals. These codes cannot be prepared without some kind of semantic analysis of the message.

The outside observer is assumed in the sense that there is not only a transmitter and a receiver at each end of the system, but also a proof-reader, who can observe both the total system and describe the noise structure of the channel.

These descriptions mean that the signal process must be observed from several places. The informational entropy, which is measured at the message source, is thus distinct from the informational entropy which is transmitted from the noise source and both are distinct from the informational entropy in the received message. It is also evident from this that informational entropy varies exclusively with the interpreter and they can only be connected on the condition that the system is seen from outside, that a meta-interpreter also exists.

It is also only this meta-interpreter who is capable of differentiating between information and noise, as this distinction is only relevant because the two elements are identical in the system itself. Although this reading of Shannon's theory takes its point of departure in a demonstration that a meta-interpreter is also assumed in Shannon, it still contains a semantic short-circuit

of the message, but also as a potential source for the reorganization of the system.

which obscures the point which lay in considering the signal independently of its semantic content. Instead of limiting the reach of the theory by maintaining this, constructively seen, rational point, Shannon's noise concept is interpreted as though it did *not* depend on an outside interpreter.

The whole point of Shannon's theory, however, lay in the fact that the concept of noise and information coincided inasmuch as only the physical properties which characterized the signal as a member of a symbolic notation system should be taken into account. If the interpreter observes the noise as a source of a new organization, he is actually looking at another system, in which Shannon's problem is not of importance. Shannon only had a problem *if there was noise which had no potential meaning at all*.

Although Shannon was incorrect in his postulate that the meaning of the message was irrelevant from the point of view of engineering, it is not tenable to re-interpret his definition of the noise concept as a potential meaning-bearing phenomenon. Shannon was not wrong because he ignored the fact that both noise and information were meaning-bearing, but because he overlooked the fact that the dividing line itself between information and noise can only be a *semantic* distinction in the - relevant - case where noise is manifested in the same physical form as the information. Here, on the other hand, it is indispensable.

Shannon's theory concerns separating those elements which physically seen manifest themselves exactly like the intended information, but which do not constitute information. In Shannon, therefore, noise is not something which can be added *to* the original message, but exactly »something« which is lacking, namely the knowledge of the legitimacy of the physical form.

However, Shannon not only contributed to a confusion of his own concepts with the postulate that it was possible to establish an asemantic point of view, he created just as much confusion by describing the information concept as though it were a physically indefinite element. The theory exclusively concerns how to handle symbols which are defined on the basis of their physical form. This is also the only reason why the theory need concern itself with transmission efficiency and noise, just as it is the explanation why the theory distinguishes between discrete and continuous transmission systems.

Strangely, Shannon claimed not only that he could ignore the semantic content, but also that he could compress a message so that it *only* contained those symbols which contained the semantic content. He thus spoke both for and against the idea that there was a connection between his definition of the information in the message and its meaning.

This ambiguity has manifested itself in two different directions in the reception of his theory. On the one hand, as mentioned, an interpretation which sought to maintain that there is a connection, which not only interpreted the information concept, but also the noise concept as signals which contain a meaning in themselves. On the other hand, there has been a widespread tendency, especially within linguistics, to take the asemantic postulate at face value, as here - contrary to the idea of viewing randomness as order at a higher level - the inclination has rather been to say that the engineering point of view is irrelevant precisely because it ignores the semantic aspect. This view is discussed in more detail in chapter 7.

On the face of it, neither of these two directions seem satisfactory. It is not satisfactory to regard the most arrant nonsense as the optimum achievable information. But nor is it satisfactory to assume that a mathematical theory on the treatment of physically defined notation systems should have no relevance to an understanding of notation systems.

A third possibility is to regard the engineering point of view as a contribution to an understanding of the notation concept and, in this case especially informational notation, through an approach which, as a starting point, places semantic coding in parenthesis.

The motivation for this point of view cannot simply be that it is a more moderate middle path between over-interpretation and under-interpretation, it is also motivated by Shannon's actual results.

Although, in the preceding analysis of Shannon's theory, it has been argued that its validity should be greatly limited and re-interpreted, it has also been claimed that the theory still has general implications for an understanding of notation systems as a »meeting place« between the physical and the symbolic. There are reasons to emphasize three points in particular here.

The first is his demonstration of the specific noise theoretical problem which is connected with the possible occurrence of legitimate, but unintended physical forms. While the precise physical definition of the signal contains a solution to what could be called the general noise problem (namely the separation of physical forms, which can be included as legitimate signal values, from illegitimate physical forms) it also produces another specific noise problem in connection with the legitimate physical forms, as all physically defined signals necessarily have a physical form which can exist without having a symbolic value. In other words, the physical definition excludes in principle the possibility of deciding whether a given, legitimate physical form is noise or information, which again implies that we can draw the conclusion

that it is impossible in principle to formulate a purely physical theory of symbolic expression forms.

Although Shannon supplied all the premises for this conclusion, it also went against his own efforts to formulate an asemantic information concept. But the noise theoretical problem also has a more general character which holds true of all physically manifested signals. The question thereby arises as to how this noise problem manifests itself and is solved in different notation systems.

The second is his demonstration of the significance of the redundancy function for ensuring the stability of the message. In spite of the fact that Shannon uses the redundancy concept with several mutually unconnected meanings, his analysis shows that, as far as informational notation is concerned, it is possible to work with different forms of redundancy, as some of them can substitute each other and perform the same stabilizing function. The analysis thus produces both a need for a more consistent definition of the redundancy concept and a closer analysis of the significance of the redundancy function for the stability of notation systems.

The third is his demonstration that it is possible to stabilize informational notation with the help of a formal semantics which is independent of that semantics in which the original message is presented and which therefore does not depend on the content of the message either. His analysis hereby shows that it is possible to stabilize informational notation with a semantic component which is quite independent of the semantic content represented. It also shows that it is possible to use formal procedures as a redundancy function that is equivalent to other forms of redundancy, which again implies that the formal procedure in informational notation can act as a semantically empty or a meaning indifferent procedure relative to the message contained in the informational expression.

Although the asemantic view of the notation system thus ends by allowing the return of semantics, it does not return as it was when abandoned. Shannon's analysis makes it clear that there is a semantic component in the expression substance of informational notation and that the description of this notation form must therefore be concerned with semantic properties on at least three levels: 1) the level which establishes the notation system as notation system, 2) the level which establishes the syntactic structure of the notation and 3) the level which is concerned with the semantic interpretation of the content of the informational notation. While the last level concerns definite messages, the two first have to do with the general properties of the notation system and thereby its semantic potential.

Together, these two levels of the description of notation systems indicate the curious circumstance that a given semantic potential always builds upon a semantic restriction at another, underlying level. That we can ignore the content of the expression is due to the fact that the form itself has meaning on another level. That meaning which makes it possible to distinguish any piece of information from any other, identical physical form.

Rather than claim that Shannon was mistaken in one or another of his two contradictory postulates, there is thus a reason to claim that he was partly right because he was partly mistaken in both.

7. The semantics of notation forms

7.1 The expression substance and the semantic potential of informational notation

Shannon's theory left a certain terminological confusion behind it. The concept of information merges with the concepts of noise and signal. This is because Shannon measured these phenomena with the same yardstick, which relates solely to the temporal dimension of the physical form. The confusion, however, is understandable because the theory concerns signal systems in which noise signals with *the same physical form* as the intended signals occur frequently. The interpretation of the theory must therefore take its point of departure in the fact that there are no physical criteria for distinguishing between the symbolic notation form (whether this is called information, signal, notation or symbol) on the one hand, and the concept 'noise' in the same physical form, on the other. This distinction is of a semantic nature and can only be made through an interpretation which assumes an interpreter capable of deciding whether a given physical form should be understood as an intended symbolic notation or not.

As all physical forms which can be used as symbolic expression units can also occur without being symbolic expression units, this is a question of presenting the problem in terms of a general noise theory valid for all symbolic expression forms. In other words, a symbolic component is included in the definition of any symbolic expression form.

The question now is, whether the semantic procedure through which a signal is distinguished as a signal, i.e. as a valid member of a message, always has the same character no matter which notation system and no matter what the semantic exploitation of the notation system. Is an /a/ which occurs in a written message, for example, defined in the same way as a /+ / or an /a/ which occur in a mathematical expression?

If this is the case, this special semantic operation can reasonably be regarded as a general precondition for all symbol formation and this level can be omitted from the description of differences between symbol systems.

If, on the other hand, we can distinguish between different forms of semantic separation of notation elements it becomes necessary to include the semantics of notation forms in the description of the languages which use notation systems.

The following two chapters contain my arguments for the second of these two possibilities, as it will be demonstrated that informational notation is a new, independent notation system, *which by virtue of its definition possesses a peculiar set of semantic potentialities which both separate themselves from the semantic potentialities of common language and formal languages.*

In writing at this point of linguistic, formal and informational semantics (or semantic regimes) the term semantics is used in a more general sense than is usual within linguistics, where it is used of a special discipline, the study of linguistic meaning structures, as distinct from other linguistic disciplines. What I mean by a semantic regime in the following is a set of (implicit or explicit) codes which we use to produce or read a given symbolic expression, no matter whether we are capable of providing a consistent description of these codes or not. Over and above this, the concept of semantics will also be used in a number of more limited senses, as a distinction is made between semantic levels within the individual semantic regimes: those of the notation forms, those of the syntactic structures and those of the content forms. This differentiation in the use of the term specifies that the meaning dimension indicated by the term is valid at all these levels and has therefore an unlimited, but not unstructured character.

It will be shown in the following that the difference between the semantic potentialities of common language, formal languages and informational representation is rooted in two relationships, partly the relationship between expression substance and expression form and partly the relationship between notation, syntax and the general semantic regime.¹

A short outline of the content of this thesis as it applies to informational notation follows.

The significance of the expression substance for semantic potential is first and foremost connected with the demand for mechanical execution, as this demand 1) releases the notation system from a function which is essential - and common - to both formal and linguistic notation systems, namely to serve as a means for human sensory recognition and 2) determines that a limited number of notation units, each of which is semantically empty, are used.

In both these respects, I claim that the semantic potential of the expression form is directly related to the properties of the expression substance, as these

¹ The distinction between expression substance and expression form is Hjelmslev's. He viewed phonetics as the study of the spoken language's expression substance and phonology as the study of the spoken language's expression form. Unlike Hjelmslev's understanding of the »linguistic« as independent of the expression substance, the relationship between expression substance and expression form is interpreted here as a semantic relationship which differs in different symbolic languages.

properties allow a number of previously unknown possible expressions, including new possibilities and types of relationship between expression forms and content forms. The postulate, in other words, is that the expression substance provides the expression form with a semantic potential it would not have in an expression substance with other properties.² The most far-reaching new possible variation is included in the demand that rules must be represented in exactly the same form - and therefore with exactly the same possibilities for variation and editability - as all other forms of data.

The potential for semantic variation, which is rooted in the relationship between expression substance and expression form, provides not only the possibility of the mechanical execution of a delimited class of formal, closed semantic operations (the properties of the universal calculating machine), it is also the precondition for what will be described (in chapters 8 and 9) as the *multisemantic potential* of informational notation, as informational notation, unlike linguistic and formally defined notation systems, can be subjected to a multiplicity of semantic regimes, including both linguistic and formal, but also pictorial regimes. While linguistic and formal notation systems are characterized as mono-semantic with a fixed - but mutually different - bond between the notation system and the semantic regime, informational notation is characterized by multisemantic potential. A more precise description of the concept, multisemantic potential, is given in chapter 9. It should, however, be noted in advance that the concept 'multisemantic' differs from the concept 'polysemy', which describes the circumstance that an expression can have several interpretations within a given semantic regime. Both linguistic, formal and informational expression forms can thus be polysemic - each in its own way - but only the informational expression has multisemantic potential.

7.2 The expression substance and the sign function

The first problem in carrying out a comparative analysis of different symbolic expression systems concerns the terminological starting point where, there is a general choice between semiotic and formal symbol theories. As the formal symbol theories assume full equivalence between expression form and content form, they do not provide the necessary concepts for describing the

² There is a similar argument in sections 7.6 and 7.7 regarding the difference between spoken and written language, which are thus regarded as common languages with partially different semantic potentialities.

differences between formal and linguistic expressions. They lack - as was shown by the description of Simon's symbol theory (section 5.9) and Shannon's description of informational notation (chapter 6) - in particular the concepts for describing the possibilities of semantic variation in the relationship between expression and content forms.³

I will therefore take my point of departure in semiotic concepts. As the semiotic understanding of signs was developed, on historical grounds, with the emphasis on the description of spoken and/or written common language, there is also a risk here of turning a given symbolic language (in this case the spoken/written language) into a norm for describing other symbolic languages. This risk, however, can be averted because the semiotic point of departure has been chosen as a means for a comparative analysis of the differences between informational, formal and linguistic expressions.

The choice of the semiotic approach thus implies no postulate that it is possible to fit the description of the informational and formal symbolic languages into the sign function which characterizes common languages. On the contrary, the choice has been made for the purpose of describing the sign theoretical differences between these languages.

It will be evident from the following that the linguistic sign description is inadequate with regard to an important point in the present connection, as it will become necessary to include the expression substance in the understanding of the sign function.

The fact that it is necessary to take this step - in spite of the conceptual problems consequent on it, because the sign function is defined in modern linguistic theory as a relationship between expression form and content form (independent of expression and content substances) - is first and foremost due to the semantic potential inherent in the relationship between expression substance and expression form in the informational notation system.

As a consequence of this there are two possibilities. One is that the expression substance has a semantically significant meaning for the informational sign function, but not for the linguistic function. The second is that the relationship between expression substance and expression form can also be included in the linguistic sign function.

The first possibility appears most attractive because it allows a greater degree of correspondence to and exploitation of existing linguistic theories. But it is the second possibility which gained the upper hand, because a

³ C.f. also L. Hjelmslev, (1943) 1961: 110 ff., where a similar criticism - but in other terms - is advanced against Rudolf Carnap's »monoplanar semiotic«.

comparison of informational and linguistic notation will have a different result depending on whether the starting point is spoken or written language.

The crux of the matter here is whether it can be claimed that the difference between the expression substance of spoken and written language can create a basis for a distinction between the semantic potentialities of spoken and written language. If this is the case, the relationship of the expression form to the expression substance must also be included in the linguistic sign concepts.

Although this question has general sign theoretical implications, it can be decided through a more limited analysis of the expression forms of spoken and written language.

There is no demand for a complete description of the general implications, all that is demanded is proof that the different expression substances of spoken and written language determine that there is no complete semantic compatibility between the two, that - in spite of a large semantic intersection of sets - they each have a semantic marginal zone connected to the dissimilarity of the expression substances.

The normal argument for the external and arbitrary (semantically irrelevant) relationship of the expression substance to the linguistic expression form builds upon the observation that the phonetic sound, or the physical form of the grapheme, provides no information on the linguistic utilization which, on the contrary, is assumed to be based on an »internal« linguistic system of sound patterns (Saussure) or relationships between *figurae* (Hjelmslev) that are of a psychological (or in Hjelmslev's terminology, »immanent« linguistic) and not physical nature. This point of view makes it possible to explain how the same language can be manifested in different expression substances. This last view will also be maintained here, as the analysis of Shannon's information concept confirmed that it is not possible to provide purely physical criteria for the decision as to whether a given physical form is a valid member of an expression.

None of these arguments, however, provides any reason to conclude - with Hjelmslev - that linguistic or other symbolic expression forms are independent of the properties of the expression substance. Although a language may use many different expression substances, it obviously cannot use them all. But language cannot exist without substance either, and there is nothing to prevent different expression substances from creating different restrictions - and possibilities - for its symbolic use. The relationship between substance and form cannot, in other words, create a basis for an axiomatic delimitation

between the non-linguistic and the linguistic, but must be made the object of investigation.

The point of departure here (in section 7.3) will be taken in Umberto Eco's theoretical delimitation of the sign theory towards its »lower threshold« - attached to his distinction between »signals« and »signs« - as Eco at the same time attempts to describe a sign concept which is not only valid for (or formed around) the linguistic sign function.

This attempt leads Eco to a dissolution of the concept of a well-delimited language system which is outside (as a precondition of) the sign function. He therefore defines the sign function independently of the expression form connected with a multiplicity of possible codings, while the language system, the structure, becomes a conceptual entity, we »pretend« exists, just as the sign function itself is defined as a purely mental correlation of mutually different - mental - code procedures.

If the sign function is connected with - and manifested through - different codings, the transition between these code procedures cannot be explained at the level of the code procedures. The way the problem presents itself therefore gives rise - as a corollary to the noise theoretical conclusions extracted from Shannon's information theory - to the assumption that the formation of the code procedure occurs through a semantic exploitation of the forms inherited by the expression substance.

It is hardly possible to describe the complete repertoire of possibilities for the semantic exploitation of expression substance forms, possible signals, but, as we saw in chapter 6, any identification of a signal will depend on a concatenation in which a physical form is linked to a symbolic legitimacy, even in the cases where the physical signal manifests itself without any determinable content.

Where Eco attempted to determine the general sign function by defining it independently of expression substance and expression form, it is claimed here that it is necessary to include the relationship to the expression substance in the understanding of any sign relationship and that it is possible to describe central differences between different sign functions as differences which are rooted in different ways of coding expression substance forms.

The central point here is that the two criteria included in any definition of signals or physical notation forms are mutually dependent, but at the same time comprise two independently variable axes. It is possible to carry out the definition on the »physical« axis independently of the definition on the

semantic axis. It is therefore also possible to connect the two axes in different ways.

The ambiguity explains, for example, the fact that we can recognize a multiplicity of different physical forms (variations of the substance form) as one and the same letter, as the recognition can both rely on the knowledge of the symbolic expression form and the expression's meaning. This also explains how it is possible to establish a notation system which - released from the demand for recognition - can be based primarily on an unambiguous definition of the physical form of the expression substance - with the modifications which follow from the problem of noise theory. It will be evident from the analysis (chapter 7 and sections 8.1 - 8.3) that in certain respects informational notation is more closely related to alphabetical notation than to formal notation (the first two use a limited number of notation units and the individual notation units have no independent meaning). Whereas written language notation, however, allows variation on both the physical and semantic axes, informational notation allows only variation on the semantic, while formal notation only allows variation on the physical axis (as a given notation unit is defined on the basis of a semantic - fixed or variable - value of its own). The definitions of physical form and semantic legitimacy therefore become connected in three different ways, of which only the latter brings about an unambiguous relationship between the expression form and its content, while the two others allow the same physical form to manifest itself with changing functions and values. These two, however, are also mutually distinguished. Informational notation is based on an unambiguous relationship between the form of the expression substance and the expression form, while written language notation not only generally allows a variation in the physical substantiation of the individual expression form, but also exploits certain substance variations - such as italicization - for semantic purposes.

What is lacking therefore is a concept which describes the semantic variation possibilities which are connected with the various forms of relationship between expression substance, expression form and content form.

In the following this relationship will be referred to with the concept 'redundancy structure'. Section 7.5 contains a theoretical definition of the redundancy concept, while the relevance of the concept for a description of linguistic expression forms is discussed with the starting point in a critical analysis of Hjelmslev's concept of *figurae* in section 7.6.

With this analysis as a starting point, the significance of the redundancy function for linguistic sign formation is discussed in section 7.7. Unlike

Hjelmslev, I claim that the different expression substances in spoken and written language create a basis for two partially different forms of redundancy structure, which again determine differences in semantic potential. Further to this, I argue that redundancy structures should be understood as a precondition for the stabilization of linguistic rule structures, as this enables an explanation of the possibility of rule weakening, rule deviation and rule suspension and of co-existence between mutually overlapping, but not clearly delimited rule structures relative to the intended meanings expressed in the sign function. As different forms of redundancy can at the same time be semantically significant, it is correspondingly necessary - dissimilarly to ordinary linguistic assumptions - to include the redundancy function in the sign concept.

Section 7.8 includes a summary of the comparative analysis of the different semantic potentialities which are connected with the use of notation systems in common languages (written and spoken) and formal languages. Finally, pictorial representation, which does not assume a finite set of notation units, is included with regard to the analysis of the informational sign potential which also embraces the possibility of pictorial representation.

A further analysis of the significance of redundancy in informational notation is the subject of sections 8.1 - 8.3. A schematic survey of the relationship between linguistic, formal and informational notation systems appears in section 8.3, page 276.

As the use of informational notation is based on algorithmic organization, it also becomes necessary to investigate whether algorithmic »syntax« places semantic limitations on the use of informational notation. At this point, the comparative analysis must be taken a step further to include the relationship between the formal and informational representation of algorithmic procedures (sections 8.4 - 8.6).

7.3 Signal, sign and code - Umberto Eco

It is symptomatic that within linguistics, information theory is often seen as a theory of - physical - signals, which are either completely outside the domain of linguistics or constitute a borderline area. Eco, (1976), who defines semiotics in relationship to the subjects which are not those of semiotics, the signals of information theory, together with physical stimuli thus comprise a »lower threshold« which should properly be studied separately, although it

can also be regarded as a »missing link« between »the universe of signals and the universe of signs«. ⁴

On the face of it, the reason for this distinction appears reliable:

The proper objects of a theory of information are not signs but rather units of transmission which can be computed quantitatively irrespective of their possible meaning, and which therefore must properly be called 'signals' and not 'signs'.⁵

Although well-established, this conceptual convention contains a number of difficulties, first and foremost that the physically defined signals which comprise information theory's »proper objects« are only available by virtue of a theoretical definition, an attribution of meaning. They are thus brought about by a semiotic activity.

Eco can also show that the relationship between this type of signal and other signs must rather be described as the relationship between expressions based on *different* coding procedures. The central distinction is therefore not the distinction between signal and sign, although Eco maintains this, but on the contrary between:

I: *Formal code procedures* such as

- a) Sets of *signals* ruled by internal combinatory laws, i.e. *syntactic systems*.
- b) Sets of *semantic systems*, consisting of sets of (possible) semantic contents.
- c) A set of possible *behavioural responses*, on the part of the destination and which can be independent of b)

II: *A superior code* or

- A *rule* coupling some items from the a) system with some from the b) or c) system.

While the signal system, semantic system and response system are all formal code systems (designated s-codes, where s stands for system), the last coding comprises the semiotic code procedures which, unlike the s-codes, are not characterized by a definable structure, but on the contrary by bringing about

⁴ Umberto Eco, (1976) 1979: 21.

⁵ Umberto Eco, (1976) 1979: 20.

the unity between signal code and content code (either a semantic set or a behavioural response), which can constitute a sign.⁶

Although we may accept Eco's concept of the missing structure as a basic characteristic of semiotic processes, his description leaves the problem that s-codes, which are assumed to be able to exist independently of any form of meaning or communicative purpose, are themselves based on signals or possible content entities which have been produced by a semiotic activity. They can thus not simply occupy a place in sign theory as an underlying material which creates the basis for a semiotic process.

Traffic lights have often been used to illustrate the theoretical difference between a signal system and a sign system, as importance is attached to the fact that the motorist need not subject the light picture to any interpretation. Signals are regarded in these examples as stimuli which produce a mechanical response. Although for the sake of the example we can ignore the fact that it would be extremely dangerous to react completely mechanically to traffic lights, the example provides no basis for the theoretical distinction. If the motorist can react mechanically to the light signals, it will depend on two things. First, that there is an exhaustive set of rules which prescribe an unambiguous interpretation of the total signal system. Second, the motorist is familiar with this total system and willing to accept the received interpretation. He asks no questions, is not in doubt, proposes no alternative possible interpretations. His behaviour is exactly the same as that of a man who receives a letter containing a message of which he takes note and then complies with any instructions it may contain. The acceptance is a semiotic process.

Whether this acceptance is established in seconds or through years of anxious consideration for and against with the participation of a larger or smaller number of people, it cannot motivate a theoretical distinction between signal and sign. The traffic lights are part of a sign function both for the motorist and for the authorities that have established the signal system.

One of the reasons that traffic lights have been considered as a signal system of a lower rank and outside the domain of sign theory is presumably because the message of the traffic lights is presented in a monotonous circularity and within an unambiguous rule system characteristic of commands. Although the messages change with high frequency, nothing very novel is communicated.

⁶ Umberto Eco, (1976) 1979: 36-47.

That an expression does not provide the receiver with anything new, however, does not mean that it has no semantic content, but simply that its content is already familiar. Familiarity - which in the case of the traffic lights does not, however, include the highly meaningful time of the message - cannot motivate any theoretical distinction between signal and sign, among other things because it would then be necessary to assert that a message only contains signs when read for the first time, but not the second or third.

It would therefore be more apt to describe the traffic signal system's notation as a notation where each individual expression unit is connected with a specific content meaning.

The semantic coding which indicates a physical entity (e.g. represented by the colours red, amber and green) as members of a notation system is connected with a semantic coding which connects each expression unit with a content form that in this system has a definitory and unambiguous character. The coding of this system at the same time includes a declaration of a set of rules which establish the legal relationships between the individual notation unit's content forms. These rules are not expressed in the system itself, but are necessary for coding and de-coding it.

Now the signal structure, as Eco points out, can also be described by itself and possibly used in completely different meaning contexts - the signal structure can be polysemic. It is apparently available as an independent, purely syntactic structure which is not itself based on a sign function. But this is only apparently, as the structure depends both on the definition of the units' physical value and legitimacy and on the mutual relational connections - in this case the choice of the opposition, red-green, the combination of red-amber as respectively both-and (warning) and either-or (the state between green and red) etc.

The simple - or »lower« - signal system (the s-codes) thus requires that the notation system is subject to *two simultaneous, but different codings*, in which the individual notation unit is defined as a notation unit and connected with other notation units through a more general, preordained rule system. In other words, this is a question of a genuine sign function and this coding procedure, as will be discussed in greater detail in section 7.8 and chapter 8, is at the same time also the common and characteristic, basic form of all formal symbolic languages.

The double code procedure is thus included not only in the relationship between a syntactic and a semantic coding, but also in the coding of each of the two forms of s-codes. Eco touches on the problem when he concludes this

part of the analysis by demonstrating that, ultimately, it is impossible to decide whether one or the other type of coding comes first and that:

*Signification encompasses the whole of cultural life, even at the lower threshold of semiotics.*⁷

This also expresses one of the reasons why Eco more generally argues against the idea that scientific knowledge is a definite knowledge of phenomena.

The question is whether this reference to the chicken and the egg can simply remain for ever as a final reference, or whether the uncertainty in the conceptual foundation, which is connected here with the insoluble problem of origins (where and how did semiotics begin), perhaps also has its price for the ability of the semiotic theory to describe the difference between sign systems.

As we have seen, Eco uses the dubious distinction between sign and signal as a foundation for the semiotic theory in opposition to the mathematical »signal theory«, (information theory in Shannon's sense) as a definition of a lower threshold for the subject area of semiotic description. It even appears as though Eco is closer to allowing traffic lights and other signal systems a place in human sign activity than the informational signals, because the informational signals can be studied independently of their content:

*We are now in a position to recognize the difference between a signal and a sign. A signal is a pertinent unit of a system that may be an expression system ordered to a content, but could also be a physical system without any semiotic purpose; as such it is studied by information theory in the stricter sense of the term. A signal can be a stimulus that does not mean anything but causes or elicits something; however, when used as the recognized antecedent of a foreseen consequent it may be viewed as a sign, inasmuch as it stands for its consequent (as far as the sender is concerned). On the other hand a sign is always an element of an expression plane conventionally correlated to one (or several) elements of a content plane.*⁸

Even if we now - erroneously - accept that information theory can describe informational notation independently of semantic content, it is not a well chosen criterion for separating informational signals from other signals, because we can also establish a corresponding signal consideration in all other

⁷ Umberto Eco, (1976) 1979: 48

⁸ Umberto Eco, (1976) 1979: 48.

expression systems. But nor is information theory concerned, as we have seen, solely with expression systems, it is also concerned with the development of a special - and new - type of relationship between expression and content forms.

Whereas the traffic light system and all other formal notation systems are characterized by the simultaneous declaration of the individual notation units' membership and establishment of internal, syntactic and semantic relationships respectively, informational notation is characterized by a systematic distinction between the declaration of membership and the establishment of syntactic and semantic relationships respectively. While formal systems connect syntactic and semantic codes by attributing a semantic value to the individual notation, syntactic and semantic codes in informational notation are only attributed to a cohesive sequence of units.

As the use of formal and informational notation thus builds upon two different principles for the formation and connection of expression and content forms, this is not a question of two different kinds of signal, some of which are connected with a content meaning and some of which are not, but of two different sign functions, as expression form and content form are connected in two different ways.

While these differences can be described within the framework of the semiotic/linguistic sign concept, i.e. without regard to expression substance, the picture changes when the mechanical properties of informational notation are also included. Where the formal expression form allows variation in relationship to the expression substance, the informational expression form is defined by an unambiguous bond. It was, as we saw in chapter 5, precisely this demand which - combined with the demand for universality - made it necessary to convert formal notation to informational notation with the result that the informational expression is available in a form with other semantic variation possibilities, even in the cases where it is derived completely mechanically from a formal notation.

The physical definition of the expression form - the binding of the expression form to the expression substance - thus gives informational notation a special semantic potential which is directly connected with the physical-mechanical form of the expression substance and the properties of this form. The substance of the expression form is thereby included as a specific and constitutive part of the informational sign function in a way which separates this both from the sign functions of formal and common languages.

No matter what significance the expression substance has for common language and formal sign relationships, its significance for the informational sign relationship must lead to a re-interpretation of the structuralist sign concept.

7.4 Eco's sign concept - »Signals« and »signs«

The demand for a re-interpretation of Saussure-Hjelmslev's structuralist sign theory is not new nor in any way original. On the contrary, similar demands - and suggestions for such re-interpretations - appear repeatedly as a kind of lowest common denominator for post-structuralist semiotics, represented, for example, by Jacques Derrida and Umberto Eco, where the criticism in both cases finds a partial motif in developments within information technology and information theory, just as post-structuralist criticism also more generally aims at a formulation of sign concepts which include all forms of human (and possibly other biological) sign functions.⁹

None of these theories, however, have made the informational sign function the object of closer analysis and they are therefore included only to the extent that the more general considerations of the sign concept also apply to the significance of the expression substance for the informational sign relationship.

Although Eco's reformulation of the sign concept takes its point of departure in a discussion of a lower threshold of semiotics, he finds no basis for including the expression substance in the sign concept. On the contrary, he separates the sign concept from the expression form: What is left as a possible distinction between the signal and the sign, when we look more closely at the definition quoted above, does not find expression at all:

We are now in a position to recognize the difference between a signal and a sign. A signal is a pertinent unit of a system that may be an expression system ordered to a content, but could also be a physical system without any

⁹ In Derrida, among other things, as part of the considerations of the alphabetical script's linearization of the structure of thought and regarding the conclusion of the alphabetical script's period. Derrida (1967) 1976: chapter 3, p. 74 ff. The idea of a general sign theory, however, is far older and is also found in both Saussure, Hjelmslev and Peirce. It is therefore rather more appropriate to speak of yet another unclarified borderline - or an inner tension - between the attempts to formulate a single, overall sign concept which characterizes all forms of sign formation and attempts to differentiate the sign concept.

semiotic purpose; as such it is studied by information theory in the stricter sense of the term. A signal can be a stimulus that does not mean anything but causes or elicits something; however, when used as the recognized antecedent of a foreseen consequent it may be viewed as a sign, inasmuch as it stands for its consequent (as far as the sender is concerned). On the other hand a sign is always an element of an expression plane conventionally correlated to one (or several) elements of a content plane.

Every time there is a correlation of this kind, recognized by a human society, there is a sign. Only in this sense is it possible to accept Saussure's definition according to which a sign is the correspondence between a signifier and a signified. This assumption entails some consequences: a) a sign is not a physical entity, the physical entity being at most the concrete occurrence of the expressive pertinent elements b) a sign is not a fixed semiotic entity but rather the meeting ground for independent elements (coming from two different systems of two different planes and meeting on the basis of a coding correlation).¹⁰

With this definition the sign concept becomes wholly a concept of an inner, mental procedure which is both imagined independently of the external physical and perceptible manifestations and of the internal physiological realization. It is impossible to decide whether a manifest expression is a signal or a sign. The distinction depends exclusively on the question whether a given signal - an expression system - is mentally interpreted or not. Eco expresses this more indirectly in phrases such as »recognized by a human society« instead of »a human mind« and in a subsequent remark that, strictly speaking, signs do not exist, but only sign functions.

That this is the case can be confirmed through analyses of manifest expressions. At the same moment we begin to reflect about the borderline between signal and sign, the distinction disappears. We *only* have access to signals through interpretation, which immediately transforms them into signs. There is no divergence here from Eco's general sign definition »A sign is everything which can be taken as significantly substituting for something else«,¹¹ but on the contrary it points out that it not only undermines the lower threshold Eco proposes for semiotics, but also transgresses that threshold which connects the general sign concept with a manifest expression. The sign

¹⁰ Eco (1976) 1979: 48-49.

¹¹ Eco, (1976) 1979: 7.

concept thereby, as Eco mentions in a note, coincides wholly with the meaning »intelligence«.¹²

This sign definition is so general that it includes every articulatory design, but this has its price, which is not willingly accepted in semiotic theory, namely that this sign concept provides little help in the analysis of the different semantic potentialities of expression systems.

Linguistic literature also contains many examples of spoken and written language being understood as one - often both natural and national (!) - language - even though the two expression forms can enter into very different communicative connections with different demands on the expressions which must be manifested in order to make an exchange of meaning possible.¹³

In Eco's theory the problem is proposed differently because he replaces the universal rules of language (Saussure's »langue« or Hjelmslev's »language system«, or »scheme« or »building«) with a multiplicity of different - underlying codes - which do not comprise one system and are therefore not affected by the many exceptions in the use of language. The ghost of linguistic theory is thereby moved from the expression system into the code which resides in consciousness.

But it pops up again, because the code, according to Eco's universal definition of the sign as a non-physical, conceptual definition, is itself a sign, although we cannot see and do not know how it - or other traits of consciousness - are manifested in the physiological system. Like all signs, the code is also a cultural convention and the hidden codes are subject to the same problem of meaning balance as other signs:

¹² Eco, (1976) 1979: 31, note 5. The transition from Hjelmslev to Eco at this point is not as great as it may appear on the face of it, because Hjelmslev's concept of the expression form is also a concept of a mental content. The concept designates a set of mental »codes« for using the phonetic or graphic expression substance. Hjelmslev, however, assumed that these mental codes comprised a closed linguistic system which could be described »immanently«, i.e. without including the mental environment. In his argumentation for this view, Hjelmslev claims, among other things, that it is not a question of individual, and thereby psychological, but social, common codes, that language is a social institution. But we are forced to ask - in spite of Luhmann - where this social institution is located, if not in consciousness?

¹³ Havelock, 1982: 48, who views the alphabetical signs as visual representations of sounds, actually claims that it is as good as impossible to obtain a clear distinction »between speech and the visible symbols of speech« from linguistic theory. After Derrida, (1967) 1976, who sees the idea of oral primacy as a logocentric illusion, Saussure has been given the main responsibility for this weakness. Saussure saw written language as a distortion of 'natural' or 'genuine' spoken language: *These phonetic distortions do indeed belong to the language but they are not the result of its natural evolution*, Saussure, (1916) 1983: 31 (54).

*every time a structure is described something occurs within the universe of signification which no longer makes it completely reliable.*¹⁴

For semiotics as a science, the consequence for Eco is therefore that »semiotics must proceed to isolate structures *as if* a definitive, general structure existed«. When we only pretend that a definitive language structure exists, we naturally have a great deal of latitude, as we can pretend that this structure has a host of different forms. It is more difficult to find an appurtenant criterion for choosing among the many possibilities.

As will appear from the next section, it is impossible to carry through this »proceeding as if« without paying a price. The idea of a general structure is - in spite of its fascinating character and although this idea has often led to new insights - no longer tenable. It creates difficulties in linguistics because, among other things, it reduces the relationship between language and the non-linguistic to a marginal phenomenon both in connection with the relationship between expression substance and expression form as well as the relationship between language form, meaning form and meaning content.

The relationship to the non-linguistic is a many-headed monster which includes both the referential dimensions (to the contents of consciousness, patterns of thought, the outside world and meaning relationships between different linguistic entities) the expression form and the substance of articulation. The form-substance relationship reappears in all areas, but in the following the presentation is concentrated on the relationship between the linguistic and non-linguistic as manifested at the level of notation.

As will be evident, different notation systems can both distinguish themselves by using different expression substances and by using the properties of the expression substances in different ways, as this can both be a question of using the different properties of the same expression substance and of using the same property in different ways, just as, finally, different properties of substance can be used in the same way. As the notation units in all notation systems can act as semantic variation mechanisms, the relationship to the expression substance can consequently also be included in the description of the semantic potential connected with a given notation system.

Conversely, this connection implies that the functions which are handled by the notation system in some symbolic languages can also be handled through other means. Notational distinctiveness, which belongs to the

¹⁴ Eco (1976) 1979: 129.

expression form, can thus sometimes be replaced by semantic distinctiveness at the level of content form or content meaning. Notation systems do not therefore comprise an independent, closed level, subject to an invariant rule structure, on the contrary, they are included in the different symbolic languages as a facultative semantic variation potential.

Although the semantic choices can embrace the suspension of underlying notation rules and conventions, there are considerable differences between the different notation systems, as they use different forms of rule determination and rule suspension. As the possibilities of rule suspension and rule variation differ in the different notation systems, these differences must also be included, which again implies that it is not possible to provide a wholly rule based delimitation of the individual notation systems.

As semantic use is not wholly rule based, the notation systems will instead be regarded as redundancy systems and the different uses will be described as different ways of using notational redundancy. This point of view therefore makes it necessary to provide a clarification of what is understood by redundancy and by the relationship between the redundancy and rule concept.

7.5 The redundancy concept

Although the concept of redundancy is used in a number of disciplines, it is a controversial concept which people often try to avoid. While most scientists and scholars appear to agree in acknowledging the existence of redundancy forms, many are sceptical that the concept can be used with the necessary precision. The concept appears only sporadically in the older structuralist linguistics because redundancy is seen here as a peripheral phenomenon on the borders of, or outside, language structure. This use is, as such, consistent because the concept is used with the meaning *recurring structures with weak or negligible meaning*, bordering on the superfluous, while the repetitive structures which are necessary in the linguistic expression are described by the concept 'language system'.

The distinction between the concept of redundancy and that of a language system thus has nothing to do with the occurrence of a structure or a pattern, nor with the form of the structure. Both concepts are used of recurring structures, patterns or regularities which thus constitute a common core of meaning. The distinction between the two, however, builds upon *the function* of the structure, as a distinction is made here between necessary structures,

which do have a function, and superfluous or random structures, which do not.

While the concept of a language system rests on the connection between structure and necessity, an almost scientifically obvious idea, the redundancy concept builds on a far less obvious idea, as regularity - the recurring pattern - is described here as something meaningless, superfluous and random. It is apparent that such an idea can only with difficulty be reconciled with a stringent scientific description which, almost by definition, must ascribe meaning to any kind of pattern formation and regularity in the phenomena described. In older structuralist linguistics the answer to the way this problem presents itself was provided through the distinction between language system and language use, as redundancy phenomena were applied to the latter category.

In more recent structuralist - and post-structuralist - linguistics, which have objected to the sharp distinction between a synchronic language system and diachronic sequences, attempts have also been made to modify the sharp contrast between the redundancy concept and the concept of a language system as - in a formulation from Greimas and Courtes - it has been acknowledged that redundancy, defined as »the iteration of given elements in the same discourse seems significant, for it manifests the regularities which serve its internal organization«.¹⁵

Although Greimas and Courtes do not explicitly discuss the relationship between the concepts of redundancy and language system, they are working towards an approximation, as they not only ascribe a more central role to the redundancy function in the description of the structure of sentences, but also - as appears from their treatment of the concept »natural language« (Saussure: *langue*, Hjelmslev: *schema*) - find it necessary to view syntactic sentence structures as part of this construction.¹⁶

As the syntactic structures, similarly to the structures described by the concept of a language system are repeatable patterns, it is difficult to see how it is possible to differentiate this concept of the redundancy function from the concepts of syntax and language system. There are indications, however, that they only have a more limited, perhaps stylistic definition in mind.

¹⁵ Greimas and Courtes, (1979) 1982: 259.

¹⁶ »It is becoming necessary today to bring the concepts of natural language [as a pure taxonomy or schema] and of competence together. This rapprochement seems to demand an explicit integration of syntactic structures in the definition of natural language [or in the terms of Saussure: *langue*, and Hjelmslev: *language system/schema*]. Ibid: 170.

That Greimas and Courtes still recommend that the redundancy concept should be avoided - and suggest instead »the more natural term, recurrence« - can hardly be due to this vagueness, but rather to their wish to mark a distinction from Shannon's - statistical - redundancy concept, which does not acknowledge the significance of redundancy for the internal organization of the message, as Shannon identifies redundancy with the superfluity of the signals. In Shannon's interpretation the superfluous signals were precisely those which occurred with fixed regularity because they represented the statistical structure of the language system, while those signals which occurred irregularly, conversely represented the meaning of the message.

While Shannon in his definition takes the point of departure in one of the two senses of the concept, namely the *superfluity* of the recurring structures, as this concept is extended to include all types of recurring pattern, and this means the total language system, Greimas and Courtes, on the other hand, take their point of departure in the other, namely the *meaning* of these structures. In this connection there is no criterion for distinguishing between redundancy structures from the recurring patterns which are regarded as part of the language system. Nor is any answer given to the question whether and possibly how a recurring structure can be connected with a changing meaning content. A possible explanation may be that the particular purpose only is to describe how a simple - for example, stylistic - repetition of a form can contribute to expressing a meaning content which would not be present without the repetition.

Although the information theoretical definition falls short, because in opposition to the theoretical definition it becomes necessary to acknowledge the significance of the redundancy function for the reception of the message, it nevertheless also points out - with the concept of the significance of the random occurrence - a problem for the semiotic definition, where meaning is connected to variations of fixed, recurring structures.

While the redundancy concept in both definitions is a concept of fixed, recurring patterns, they differ in their description of the significance and necessity of these patterns. The two viewpoints form here extremities in a semantic field which applies to the redundancy function's *strength of signification*. The two definitions can therefore only be reconciled if by redundancy we understand repetitive structures which can appear with a variable - and thereby generally indefinite, not pre-established - strength of signification. Although they individually fix themselves in a certain position in this field, (information theory views redundancy as having a meaning which is weak to

the point of non-existence, while semiotic theory views it as meaning bearing), we must see this divergence as an expression of a property of the redundancy function itself and assume that redundancy phenomena can both be manifested with variable strength of signification and/or changing content of signification.

This is indirectly confirmed by Shannon's use of the 5 previously mentioned definitions of the redundancy concept, as these definitions refer to different variation axes (two axes for meaning, namely respectively *independently of* and *in opposition to*, one axis for the rule structure, namely the system determined part and one axis for the expression form, namely the statistically determined part).

Such variations are a well known linguistic phenomenon and there are hosts of examples in the stylistic and rhetorical literature. This reformulation of the redundancy concept therefore creates no great problems.

The difficulty is rather greater when it comes to the second component of the redundancy concept which is formed around the relationship between the necessary and the random. As a consequence of linking the redundancy structure and meaninglessness, information theory is forced to identify the concept 'meaning' with the concept of random, non-patterned - and therefore facultative - occurrences. Semiotics, on the other hand, connects meaning with (variations in the relationship between) regular occurrences, as here the random and non-patterned is connected with the meaningless and not the meaning bearing.

None of these conceptualizations, which conflict with each other, appears convincing, but they each point out a weak spot in the other view. While information theory points to the possibility of free choice as a necessary element, something which is allowed no place in the structuralist definition, the latter, on the other hand, points to the possibility of ascribing meaning to the recurring patterns.

This mutual contradiction is manifested as a consequence of using the same theoretical thought structure, as in both cases an absolute opposition is assumed between the invariant - preordained - pattern, repetition, and the random occurrence, deviation. The conflict can therefore only be resolved by abandoning the idea of an invariant border between the repeatable-regular and the facultative, random deviation.

This abandonment has already been anticipated here by connecting the concept of the random, facultative occurrence with the concept of deviation, as the latter concept, unlike the concept of the random, not only covers the

free - meaning-bearing - choice as a variation *in relationship to a pattern*, but also the free choice as a variation *in or of a pattern, in or of its meaning respectively*. The clarification at the same time makes it possible to provide a definition of the redundancy concept which clearly distinguishes the concept of redundancy systems from the concept of rule based symbol systems, as redundancy systems can be understood as repeatable patterns, structures or systems which

- are characterized by the possibility of facultative variation in the signification strength of the patterns and/or signification content and
- allows - or depends on - facultative, meaning-bearing uses of pattern deviation and pattern variation.

The definition maintains the concept's two semantic components as two connected, but individually variable, axes of signification, as the one axis allows variation in signification strength, while the other allows variation and deviation in pattern formation. Variation on both axes can at the same time be connected with variation in signification content. As variation of signification content can both be produced through variation of signification strength and/or pattern and as the pattern variation conversely is not always connected with (a certain or any) meaning variation, variation of signification content must be regarded as a third, independent, variation axis. While variation of signification strength depends solely on the reinforcement or weakening of an existing meaning, variation in content can also concern discontinuation and new meaning.

That it is the connection between these independent axes which is central appears if we attempt to clarify the definition by focusing on one aspect or the other. If - like Greimas and Courtes - we emphasize repeatability alone, the meaning paradoxically coincides with the concept of regularity - with the Shannonian consequence that the system thereby becomes empty of meaning because it is completely rule defined and inaccessible to meaning determined choice. If, on the other hand - like Shannon - we emphasize weakness of meaning or the superfluous, the meaning conversely coincides with the conceptual contrast: random and meaningless background noise.

Together, these two poles indicate the extremes in a three-dimensional meaning structure formed around the variation in strength of signification, content of signification and pattern variation. In connection with strongly significant and invariant pattern occurrences the concept coincides with the

concept of regularity, structure and/or a new content of signification. In connection with occurrences of incomplete repetitions characterized by weak meaning - deviations from or variations of patterns - the concept approaches the meaning 'noise'.

Although this determination of the redundancy concept has its point of departure in - and has been kept within the framework of - the ordinary scope of the term's meaning, i.e. the connection of repeatable structures with indefinite meaning, it has implications which can hardly be considered obvious on the face of things. It is thus not immediately clear that the concept can be used to describe certain phenomena at all, because it apparently suspends any possibility of speaking of invariance.

It is perhaps also the fear of this slippery conceptual slope, which weakens the concept of regularity, that lies behind the widespread scepticism regarding its use and which prompts Greimas and Courtes to accentuate the rigorous form repeatability in their - cautious - rehabilitation of the concept.

But if the need is greatest for semiotics, it is also the first to offer the help which can be found in the biplanar sign concept. Where information theory falls short, because it operates with equivalence between the expression form and content form and assumes that the symbolic expression is subject to a single - or several completely distinct and thereby parallel - rule systems, the semiotic understanding of the sign implies that expression form and content form be regarded as two different, interfering pattern formations or rule systems. It follows from this that a pattern deviation and/or suspension and/or meaning variation on the one plane can occur on the basis of a stabilization of patterns on the other. As it is the sign function itself which - alone - creates the connection between the two planes, pattern deviation on the one plane, however, can also produce pattern deviation on the other.,

Where »monoplanar« symbol theories can only operate with rule based stability, the biplanar understanding of signs allows rule deviation to occur without stability being broken down, just as this understanding allows the existence of several stable meaning hierarchies in the same expression which are not unambiguously connected because they are not subject to clearly separate rule sets.

Perhaps a metaphor can help to illustrate this kind of relationship. Imagine for instance the interaction between our legs when walking. The movement of the legs is well co-ordinated but in such a way as to allow the movements of each leg to be varied with a certain degree of freedom, which is basically

constrained by the use of the other leg as the stable - and in the actual situation »redundant« part - of the system, while at the next moment the redundant part becomes distinct.

Some of these variations might cause a change (whether intended or not) both in speed, rhythm or even direction. Others will effect only the rhythm, or speed or direction and some changes might not result in any changes in these respects at all. It is also possible to use such variations for semiotic purposes, e.g. simulations (walking with a limp to draw attention to ourselves).

There are different kinds of constraints on these variations. While some variations may make us stagger or fall, others will make us stop walking and others make us run, or jump on the spot etc.

The metaphor illustrates a system consisting of two co-ordinated axes in which stability can be obtained in - at least three - different ways: based on the stability of one of the two legs, based on the stability of the co-ordinated movements of both legs at the same time. As a metaphor, however, it also illustrates a difference, in that the system consists of two axes of the same category (since both legs are legs) while in symbolic systems there will always be at least two axes of different kinds, since there must necessarily be both an expression system and a content system, resulting in a more complex set of possible interferences between the two axes of variation.

While sign theory thus provides a theoretical justification that it is possible to connect the definition of the redundancy concept given here with the necessary stability, it makes no contribution to clearing up the meaning of the redundancy function.

This meaning can be illuminated in the relationship between the redundancy concept and the concept of language system.

While, on the one hand, it is possible to describe any kind of rule formation as a stable pattern which is maintained for a shorter or longer period in a redundant system, on the other it is impossible to fit the redundancy function into a rule system based on pre-established, invariant rules or patterns.

This definition of the redundancy concept can thus contain all the form elements and rule structures which are included in the concept of a language system, whereas the concept of a language system cannot contain the possibilities of rule variation, suspension and variation in strength of signification which characterize a redundancy system. The redundancy concept can thus be seen as a more basic - and comprehensive - concept than that of a language system. The rules of a language system are at the same time

manifested as a system which - contained in a redundancy system - comprise a set of facultative and variable pattern formations which can both serve as a stabilizing background structure and be made the object of distinct meaning articulation through variations in the strength of signification and/or in pattern variation. A repetition structure of this kind can both act as a regulatory stabilizer, as an expression for a specific meaning content and is also accessible to variation in the content of signification, strength of signification and facultative pattern variations.

The central difference between a description of language as a rule based, as opposed to a redundant, system thus lies in the circumstance that rule structures in redundant systems become facultative, accessible to variation, suspension and non-rule determined interlacement, as the maintenance and use of rules becomes connected with the formation of meaning.

These properties have an intuitive relevance for an understanding of language, as they reproduce the infrangible connection between rule generation and meaning articulation which characterizes all linguistic articulation. Through this, the redundancy concept also makes it possible to re-establish a bridge between the concept of a synchronic language system and diachronic language use, as the synchronic structures can no longer be understood as once-and-for-all established, invariant structures which exist independently of usage, but on the contrary as more stable patterns and language norms.

If it is possible to distinguish structures with completely stable, invariant patterns, the concept of redundancy will coincide with the concept of structure, form or system. Any identification of a redundancy structure, however, assumes an interpreter and the same is true of the identification of an invariant system. *An invariant system thus only exists if the interpreter cannot imagine any instability.*

The extent to which we can do without the idea of instability in the description of »monoplanar« systems will not be discussed in this connection, but the fact that it is difficult to do without in the description of biplanar or multiplanar systems such as the linguistic, for example, appears not only to be confirmed by our ordinary understanding of the unruliness of language, but also by the noise problem of information theory.

This intuitive relevance, however, is supported by the circumstance that we must assume that any linguistic rule structure has a history both of origin and development. Although many language patterns and norms have been maintained for long periods of time, they must nevertheless have originated at some stage. As we are not familiar with their genesis we cannot derive later

language development from them, nor can we therefore base language theory on the assumption that the total set of linguistic rule structures was formed as a total and invariant language system which is available as a preordained condition for language use. Of the possible explanations, this appears the least probable.

The redundancy concept is equally as incapable as the concept of form, rule or system of providing any clarification of how the phenomenon itself originated. It is not claimed that there is a genetic explanation, but on the contrary that the indefiniteness which is connected to the genesis of language implies that the linguistic rule structures cannot be understood on the basis of themselves, but must be understood as (new) formations which occur in relationship to other, linguistic or non-linguistic, structures.

As any repetition, in the nature of the case, is a repetition of something, repetition implies that a repeatable form exists prior to the repetition. The rule is distinct, however, from simple repetition, as regularity only becomes regulatory when it is connected with or used for a purpose. This purpose is not contained in the form repeated nor in the repetition itself, on the contrary, it lies in the use of the repetition. The form that is repeated can therefore best be described as an available expression form which, with the intentional repetition, is connected with a - regulatory - content form. In other words, the repetition of the form gives this a new meaning dimension as an available pattern which can be connected with a regulatory purpose. It is thus not the rule concept that is a precondition for the sign function, but the sign function which is a precondition for the rule formation.

While a rule system assumes a fixed connection between the occurrence of a form, the repetition of this and the connection of the repetition to a regulatory content, a redundancy system, on the contrary, is characterized by the possibility of varying these relationships. Redundancy systems have therefore not only the three previously determined variation axes (1: strength of signification, 2: pattern and 3: content of signification), but also a fourth which ranges from the first, possibly random occurrence of a form, through the repetition of the form to the connection of the repetition with some other kind of regulatory function which again can be connected with further meaning variations. See section 7.7 for an exemplification and further elaboration.

That the sign function is a precondition for and thereby independent of rule formation is not only supported by the circumstance that we have symbolic languages with different rule structures - in other words, the symbolic forms can be connected with different regulatory content forms - but also because

we can only unambiguously distinguish between rule structure and that which is regulated when confronted with formal languages. *As far as common languages are concerned this relationship can only be registered as a difference in perspective of the view of the same expression.* It is not possible here to distinguish between that part of the expression which represents »the programme« and that part which represents »data«.

Put another way, the regulatory structures in common languages are different to the regulatory structures which characterize formal languages. As formal languages assume that both the expression form and its meaning are entirely rule based and mutually connected, these languages allow only rule based variation, just as the mutual relationship of the rules in the form of extent, grouping or co-ordination are fixed. The formal sentence is in principle a general statement which connects the situationally determined content (data) with a general, invariant rule structure. In formal languages the rule structure thus has its own distinctive notation form and each individual expression unit has an independently defined semantic content which represents either a rule or a regulated value.

In common languages the same - sequences of - notation units can both represent the rule structure and the meaning content, which not only means that the same expression form has at least two overlapping determinations, but also that the rule formation can be modified, weakened or strengthened relative to the concrete situational and meaning determined content of the message. The regulatory is not bound to the expression form itself, but to its semantic use. The common languages thus allow all legitimate expression forms, including those of the rules, to be subjected to variation in strength of signification, extent and content of signification - such as for example is the case with the use of tense (as respectively a neutral narrative form or distinct indicator of time) and gender (as respectively a purely grammatical or biological indicator) in common languages.

While the formal languages operate with a rule based expression system, the expression system is used in common languages as a redundancy system in which the individual expression forms are subject to several simultaneous, mutually different and variable semantic purposes. Any rule structure can therefore also be subjected to meaning variations through inclusion in new sign functions.

Unlike the rule concept, the redundancy concept allows a necessary openness in the conceptualization of the relationship between the unique and

the general and of the unsolved problem of the origin of and transition between levels, as it allows:

- A rule to be formed through the purposeful repetition of something which was not a rule prior to the repetition. This may be a newly created form or a regularly occurring, but not previously used form, or a change in a regularly occurring form and/or its function.
- New rule and meaning levels to be formed by using established rule and meaning levels as redundancy potentialities, as the new level is neither completely independent of nor entirely bound to the rule structure of the underlying level.
- Any element in a sign function - a rule structure or a meaning content - to become an expression form for a new sign function which possibly modifies/changes the rule structure and/or the meaning content which is the starting point.
- A meaning expression to become a rule structure and a repetition structure to become both a rule structure with a weak meaning and/or with a distinctive meaning.
- A rule structure to be suspended or modified through rule deviation - partly for semantic purposes, partly for regulating mutually overlapping rule systems without fixed rules for »giving way«. For example, the sign sequences of languages are subject to conventions for consonant groups, syllable formation, word formation, syntax and semantics.

Redundancy structures are thus characterized by the possibility of distinguishing (and perhaps modifying) elements from a subordinate level as members of a superior level and by placing *partially* stabilizing elements between these elements, which again allows the establishment of a new level. The description of the basic structure of language as a redundancy structure also provides the advantage of allowing a continuous formation of new rule structures at new, higher levels through the modifying variation of the subordinate levels.

As rule formation is described as part of language use and meaning production, it cannot be excluded from the sign function either, which also appeared as a consequence of Umberto Eco's analysis (7.3) just as it is in accordance with stylistics' many examples of different forms of semantic exploitation of repetitive language patterns.¹⁷

¹⁷ In a 1960 »Danish stylistics« it is said of »repetition« that it 1) is the primitive expression of po-

The concept of style is incidentally - and not surprisingly - one of the concepts which forces Hjelmslev to the - in his theory, surprising - admission that it may well be - perhaps almost always is - necessary to encatalyze several mutually different language systems in the analysis of the same text.

*In other words, in order to establish a simple model situation we have worked with the premiss that the given text displays structural homogeneity, that we are justified in encatalyzing one and only one semiotic system to the text. This premiss, however, does not hold good in practice. On the contrary, any text that is not of so small extension that it fails to yield a sufficient basis for deducing a system generalizable to other texts usually contains derivatives that rest on different systems.*¹⁸

While the style of the text prevents it from being accommodated in the house, the house itself becomes an element of the style, as it is the style which determines how many houses are necessary, how they are used and how they are connected with each other.

While Hjelmslev's language theory demonstrates how his own monoplanar calculus understanding of the language system entails that when analysing an arbitrary text we must assume that there is an unarranged quantity of mutually unconnected systems, it thereby indirectly reveals the existence of an underlying language potential which makes any rule formation and language norm accessible to stylistic exploitation and semantic choice. It is the existence of this potential which justifies the redundancy concept as the most suitable, most adequate concept for the basic structure of language formation.

The concept of style hardly plays the same role in all symbol systems, but it always plays a certain role. The style concept is sometimes used in formal symbol theories as an argument for preferring one - more elegant solution - to another. There is a long-standing tradition in mathematics for supporting the

werful emotional agitation, 2) produces a stronger effect if it does not 3) conversely weaken the effect, that it 4) is related to gradation, that it can be 5) lulling in its monotony, or actually 6) platitudinous. The work also contains a syntactically based classification of a number of classical repetitive figures based on the repetition of the same figure (epizeuxis, anaphora, symploce, epanastrophe, antimetabole, polyptoton, as well as »several other types«, to which can be added repetitions based on variations of the thus only partially repeated figures. Albeck, 1960: 155-179.

¹⁸ Hjelmslev, (1943) 1966: 101-102. English translation: (1953) 1961: 115. After the above quotation, Hjelmslev introduces a number of largely stylistic examples, but also those features which distinguish various national languages. He responds to the problem by describing these features as connotative features which can be omitted from the elementary description of »everyday language« which are conversely - and rather surprisingly - defined as purely denotative language.

argumentation for the truth of a mathematical proof with its beauty. Probably not all mathematicians would claim that this, in itself appealing, idea of the importance of style can be ascribed an independent - or basic - status in understanding formal languages, but we can certainly note that there is an inner relationship between the formal languages and a certain style concept, namely the concept of the pure and simple, non-contradictory expression.

With our point of departure in Hjelmslev's description of formal languages as »monoplanar«, we find here a further indication of the assumption that the transition from multiplanar to »monoplanar« symbol systems - with full equivalence between expression form and content form - is closely connected with a reduction or elimination of that redundancy structure which is the basis of the multiplanar symbol system. Such a reduction (also including the elimination of the linguistic gender and tense functions, for example) is also a central element in the operative procedure for producing formal expressions.

If this assumption is correct, it can explain why Hjelmslev, who attached himself to this ideal of style, could overlook the paradoxical contradiction between this monoplanar stylistic ideal and the biplanar phenomenon of language he wished to describe. Moreover, it can also create the basis for a description of the difference between common languages and formal languages, as formal languages' identification of the expression form and content form builds upon a freezing up of the four variation axes of the common languages' redundancy systems (strength of signification, pattern formation, content of signification and the axis from the first, random occurrence through repetition of the form to the connection of the repetition with regulatory function and possible further meaning). Formal languages only allow rule based variation - which has been declared in advance. As these declarations are carried out at the level of notation, any notation variation is thereby connected with a rule based meaning variation. While the use of notational redundancy is a precondition for common languages (and other informal uses of notation systems) formal languages are based on wholly rule based notation, in which redundancy forms, however, can appear at higher semantic stages.¹⁹

This difference also explains - the generally accepted assumption - that all formal expressions can be translated into common language expressions,

¹⁹ The concept of monoplanar symbol systems is actually imprecise, as this is rather a question of symbol systems where any given expression form always only corresponds to a single, given content form, or several mutual, but clearly distinct forms. It is used here to distinguish this system from other multiplanar symbol systems which operate with variation in the relationship between expression and content form.

whereas the opposite is not possible. Common languages have a variation potential which cannot be represented in formal languages.

As it is thus reasonable to assume that the redundancy concept can be regarded as a key concept in the description of structural differences between expression systems, the theoretical definition of it given here will be used in the following sections to describe the different redundancy structures which characterize the linguistic, formal and informational uses of notation systems.

7.6. Redundancy in notation systems with limited inventories

The difference between common and formal language notation was described in the preceding section as a relationship between the use of the notation system as a redundancy system based on the use of a limited inventory of notation units, each of which is empty of meaning, and as a rule determined system based on the use of an unlimited inventory of individually meaning-defined units. This difference was described as a difference between a symbol system, in which rule set and meaning content are connected with the same expression constellations, and as a symbol system which builds upon a systematic distinction between rule expression and the expression of that which is regulated.

While this description is adequate for distinguishing between common languages and formal languages, it is not adequate for describing the relationship between linguistic and informational notation, as in both cases they use a limited set of notation units which are empty of meaning, so that meaning is only connected with sequences of expression units. In both these uses, meaning variation can still also be produced through the variation of an individual expression unit. In other words, the individual notation must be able to represent a meaning distinction without itself containing any meaning. In both cases, the limited inventory of legitimate figurae comprises a set of semantically empty, semantic variation mechanisms.

To these similar features yet another can be added, as the variation potential of the notation system is not only concerned with meaning content, but also, as will be discussed in greater detail in chapter 8, the rule structures.

These very striking and comprehensive similarities appear on the face of it to confirm one of the assumptions on which efforts to artificially simulate

»natural« languages (designated common languages in the present work)²⁰ have been based. It must therefore immediately be noted that the similar features mentioned here will not bear such a far-reaching interpretation. The relationship is rather the contrary, as simulation theories operate with formal notation, while it is precisely the similarities between linguistic and informational notation indicated here that distinguish these from formal notation. The way this problem presents itself therefore gives occasion for a more detailed analysis of the relationship between common languages and the use of informational notation.

Here it is most appropriate to take our point of departure in Hjelmslev's commutation test. Hjelmslev formulated the commutation principle as a method for deciding whether an expression unit is semantically distinctive, as what is tested is whether a change in the expression also changes the meaning of the expression. The method is a suitable means of delimiting the smallest units of the semantic variation potential and it becomes possible in this way not only to indicate the phonemic and graphemic expression units, but in the case of -spoken - language also a number of other semantic variation mechanisms such as intonation, stress, glottal stops and hesitation, at the same time as the method makes it possible to separate semantically empty expression variations such as individual differences in the articulation of the »same« sound. At this level the commutation test can be used to distinguish the variation potential used for semantic purposes from the - more comprehensive - variation potential offered by the expression substance.

Hjelmslev used the test himself to distinguish the »figurae« at the disposal of sign formation, as in his formulation of the law of the relationship between the sign and the figura he states:

*the transition from sign to non-sign never occurs later than the transition from unlimited to limited inventories... Language is thus so organized that with the help of a handful of figurae and through continuously new juxtapositions of them, a host of new signs can be constructed.*²¹

²⁰ The terminological pedantry in this connection is not only due to the difficulty of accepting the concept 'natural' in connection with certain cultural phenomena as opposed to others, but also to the fact that the use of the concept as a designation for language appears to be based on a scientific understanding of rules, in accordance with which the observance of the rule is given by the rule itself. Although this holds true as a condition of formal languages, it is not true of most other cultural phenomena, if any, because the execution of a rule assumes the overcoming of »noise«.

²¹ Hjelmslev, (1943) 1966: 42-43. This passage - in fact nearly a whole page - has been omitted from the English translation. In Hjelmslev's terminology, a figura can both be a phoneme and a syllable. The phoneme and the grapheme are also described as 'functives', where Hjelmslev differentiates between

The definition implies, continues Hjelmslev, that language should not first and foremost be understood as a sign system, but as a figura system which is built up around a limited number of figurae and used for sign formation, as the figura system comprises the foundation for the immanent functions of language.

Hjelmslev thus saw the figurae as the material of sign formation, as at the same time he defined the concept of a language system as a set of invariant rules for the mutual organization of the figurae. As mentioned in section 7.5, he was thereby forced to draw the conclusion that any, even slightly longer text, must presumably be described as a conglomerate of elements from several language systems, whereby an important part of his point is lost.

We can naturally - like Hjelmslev - refer any deviation from a delimited, invariant system to another system. The consequence will be that the described phenomenon »everyday language« in such a case becomes an aggregate of a very large number of mutually unconnected language systems, while the ability of everyday language to contain these mutually unconnected constructions remains undescribed. An obvious example is variation in pronunciation.

It is a well known fact that many individual pronunciation variations in spoken language are precisely only pronunciation variations which are not used as semantic variation mechanisms. It is far more difficult to draw a clear borderline between dialectal and sociolectal pronunciation variations (as well as those characterized by age and gender), which can both form part of spoken language as messages with weak meanings connected with the speaker's background and as an emphasis with a less strong meaning of this background (perhaps intentional in the situation), or as a central aspect of the point of the message (such as in jokes).

The circumstance that everyday language contains individual dialectal and sociolectal pronunciation variations, which are sometimes manifested as semantic variation mechanisms with a positive result in a commutation test, is seen by Hjelmslev as a less essential feature of language.

their occurrence in a process, in which the various letters co-exist in a »both-and« relationship (a function Hjelmslev calls a *relation*) and their occurrence in a system, in which they enter into an »either-or« relationship with each other (a function Hjelmslev calls a *correlation*). Ibid. pp. 34-44, English translation: 36-48. These definitions apply at the starting point of the analysis, where an approach is made to a definition of a formal language theory. At the other end - where the formal theory is applied to language - the phoneme is identified with the term a 'taxem', i.e. the possible (virtual) expression inventory.

The occurrence of dialectal and sociolectal sound variations, however, leads directly to a basic question of linguistic rule formation because this is a question of a non-rule determined, semantically facultative break between different dialectal or sociolectal rule structures (for the use of phonemes). Such breaks are not only general occurrences in the individual use of language, they also create a foundation for comprehensive and far-reaching cultural struggles for the upholding of some rules rather than others. While the struggle regarding linguistic rules is also carried on *in* language, such struggles cannot be fought in formal languages. That such a struggle can take place is in itself a good example of the importance of the redundancy function for the use of linguistic rule structures, as it is a question of variation in the rules' strength of signification, extent and content of signification, just as these features assume the possibility of semantically motivated rule suspension.

In Hjelmslev such features create a foundation for the concept of language norms, which on the one hand fulfil regulative purposes on a par with the invariant language system, but on the other are accessible to variation. Although the normative rules also regulate language use, they are not included in Hjelmslev's concept of a language system, but on the contrary are included in the use of the language they regulate. In other words, the language norm is a significant property of language which is not incorporated into Hjelmslev's concept of a language system. As this property can not only fulfil the same - regulatory - purpose, but can also create a foundation for rule deviation and rule suspension, it not only gives occasion to ask whether there is a need for a concept of an invariant language system at all, it also raises the question as to which criteria create the basis for separating a set of invariant rules from the variant norms.

In Hjelmslev the distinction between variants and *figurae*, which creates an invariant system that is independent of norm changes and variations in use, appears solely as a consequence of the theoretical model. Hjelmslev, however, can only identify the elements of the system with the help of the commutation test, which is empirically bound. It cannot thus be used to distinguish an invariant set of *figurae*, as it contains no criterion which can determine whether a given, unused variant *could* be used in another case.

While Hjelmslev believed that the test could be used as a means to distinguish a delimited set of linguistic *figurae* which could be utilized for sign formation, it is, on the contrary, a means for distinguishing a set of actually used *figurae* from a set of possible substance forms.

Hjelmslev's use of the commutation test to distinguish the elements of the system is not only problematical because it is empirically limited, it is also problematical because he overlooks the fact that the commutation principle he is forced to use to distinguish the invariant system *figurae* only works on the condition that these *figurae* actually occur as semantically facultative variation mechanisms.

Where Hjelmslev claims that the *figura* system is invariant, as the used *figurae* form a closed, delimited system, the test shows on the contrary that the border between used and unused *figurae* depends solely upon the question as to whether a given *figura* is actually used as a semantic variation mechanism.

The figurae of a language system are in other words not themselves defined by the language system, they - and thereby also the system - are on the contrary defined as the semantically used parts of the figura variation possibilities which are contained in the expression substance.

It could now be objected that the commutation principle is only a - necessary and sole - analytical means of discriminating the *figurae* theoretically and that the analytical procedure provides no information on how the *figurae* are used in language. Although the commutation principle prescribes that we regard the graphemes /h/ and /c/ as semantically distinctive graphemes which are incorporated in the language system's *figura* set, as we for example can differentiate between /hat/ and /cat/, the respective meaning content of the two words is not connected with the two distinct *figurae*, but to the total constellation.

We are also only able to point out the graphemes /h/ and /c/ as semantically distinctive because this distinctiveness is relative to the subsequent - in this analytical context, semantically non-distinctive - graphemes -at.

The result of the test is independent of whether the chosen words occur in contexts where they can be confused. It therefore provides no information on the individual grapheme's function in a given use. The grapheme, however, has a more distinctive value when it occurs in contexts where the mistake of a single grapheme also changes the meaning.

As an example, we can take a not unusual error in writing the word intention as /intension/. If the word appears in a text, whose subject has not yet been revealed, the reader will be in doubt as to whether the writer was thinking of the concept of intension (as distinct from extension), or whether it is rather an error for the more widespread concept intention (which has no definite opposite concept). In this case the 's' is manifested as a grapheme with strong meaning - so strong that it causes doubt. If the word, on the other

hand, appears in a text whose subject has been revealed, the reader will not experience a problem of understanding - or will easily 'skip' the error. In this situation the 's' is manifested as a grapheme with weak meaning - so weak that doubt does not arise or can easily be ignored.

The difference between the analytical procedure which is independent of the actual context and the way in which we use language ourselves does not alter the fact that we can *only* use this procedure (and have no other) *because* the figurae of language *are* semantic variation mechanisms. It is the possibility of *semantic* variation which decides which parts of the variation possibilities of the expression substance that are used in language. If we do not use this criterion we cannot distinguish the figurae which can be included in the language system from the figura possibilities of the expression substance. If we do use this criterion we must also draw the conclusion that the rule structure of a language system is rooted in a figura system in which each individual element is defined through the possibility of semantically motivated variation which depends both on strength of signification, pattern variation and content of signification, not only for the individual figura, but for the total expression.

The problem with Hjelmslev's theory is thus that the means he uses to provide the theoretical construction with an empirical foundation itself assumes the semantic bond the theory denies.

It is not difficult to see that the contrast between /h/ and /c/ may be decisive for an understanding of the content of the sentence, while in other situations it may be the surrounding graphemes (a or t) which handle the more distinctive function relative to the distinctions between *hat-hit*, *cat-cut*, *hat-ham*, *cat-cab*, for example.

The individual grapheme is thus manifested at one and the same time as semantically distinctive relative to the surrounding graphemes and relative to other possible graphemes in the same place. But it is manifested as less distinctive or redundant in relationship to the surrounding, more distinctive graphemes, as we distinguish *hat* from *hit*, *cat*, as well as *ham*.

In other words, it is only in the test situation itself that we can isolate the distinct from the redundant. What distinguishes /hat/ and /cat/ unites /hat/ with /hit/ and these are distinguished by one of the elements which unite /hat/ and /cat/. As the examples can be supplemented with /cat/cab/ and /hat/ham/ we have an example here in which commutation is positive for all graphemes in the words *cat* and *hat*.

The individual grapheme is manifested as distinctive in contrast to other graphemes, which are manifested as redundant through the same contrast. But at the same time it acts itself as a redundant background for each of the others. The graphemes enter into a simultaneous reciprocity as each others' foreground and background.

It is the surroundings, and not the grapheme itself, which make it possible to define the individual grapheme's semantic distinctiveness in the actual figuration. Semantic distinctiveness is therefore also manifested as a variable relative to the grapheme's own possible occurrence in other surroundings (including the possible occurrence at another place in the same expression).

Although the meaning is connected with the whole word and although the different meanings do not necessarily have any graphemic representation at all - words with different meanings can be spelt similarly (such as bow, for example = a knot with two loops, the front of a ship, a lowering of the head etc.) - the marking of the difference in meaning *relative to the context* (which here both includes the meaning and the actual surrounding graphemic expression forms) is clearly one of the important functions of the grapheme.

The commutative test shows just as little as other methods that certain graphemes are always and only distinctive, on the contrary, it shows that it is true of any semantically distinctive grapheme that it can only be semantically distinctive because it can act less distinctively in other surroundings and, at the same time, act as a redundant background for the distinctiveness of the surrounding graphemes. The individual grapheme's distinctiveness is thus manifested in a double redundancy structure where on the one hand it is determined in relationship to its own possible occurrence as more or less distinctive in other circumstances and, on the other, as both distinctive and redundant relative to the surrounding graphemes.

That it is redundant does not mean, however, that it can simply be omitted from the expression, although this may be possible in some cases. But this can only be determined by finding out whether meaning is lost by omitting it. Although a certain grapheme is superfluous in one context, it is not given that it is in another. The same figura constellations, even in the same word, can act with a variable strength of significance - as more or less necessary for maintaining the meaning content and/or rule structure in different occurrences.

The distinctive unit in common language can only appear with the meaning »more« distinctive and a more distinctive unit can also appear as »less distinctive«. If a given grapheme could only act distinctively, it need not be manifested relative to redundant surroundings.

Moreover, as will be described in more detail in chapter 8, it is precisely this second possibility which is the foundation of the formal notation systems, where the individual figure's semantic distinctiveness is ensured by definitory precepts which are outside the expression. The formal and informational notation systems do not operate with the same more-less polarity and the thereby connected variation potential.

Conversely, in linguistic notation, external definitions of the individual figures' distinctive meaning are not used, here distinctiveness appears, on the other hand, in a double redundancy structure.

The redundant occurrence is the condition for the distinctive occurrence, as this both assumes redundant graphemes in the surroundings, (redundancy in usage) and redundant occurrences of the same grapheme in other expression contexts (which in Hjelmslev's terminology should mean that redundancy is also constitutive in the language system).

For Hjelmslev it is only the distinctive function which is included in the language system. The redundant function is not recognized as an important feature of the structure of the language system. Redundant figurae are treated as unused figurae - although they are actually used as conditions for the manifestation of the semantically distinctive figurations and as semantic variation potential.²²

In a given context, as far as speech is concerned, it is also possible to use expression substance variations in the form of dialectal and sociolectal variants. Where writing is concerned there are fewer possibilities for using substance variation, and in printing still fewer, but they are found, for example, in the form of italicization and certainly in some choices of type faces, typographic styles and page layouts. It could also finally be discussed whether spaces and division into sections should be regarded as blank signs, i.e. as independent figurae, or as variations in substance similar to the choice of type face and typographic style.

There is thus no definite rule structure which determines how the smallest semantic variation mechanism of language can be connected with meaning variation. The linguistic notation figurae are each determined by their potential use as semantic variation mechanisms and the use of them in language is characterized by the possibility of variation along several axes:

²² As Hjelmslev, in continuation of Saussure, defines the sign concept on the basis of semantic distinctiveness, the inner composition of the sign is subordinate. Whether the sign is manifested through one distinctive grapheme, or a root which is manifested in many graphemes, is considered secondary. Behind the terms, non-sign, part sign or figura lies a mixture of figurae and some of the functions the figurae can occupy in the sign's composition.

- more-less distinctive compared to the occurrence of the same figura in other contexts.
- more-less distinctive compared to the meaning of the context.
- more-less distinctive compared to the surrounding figurae within a delimited semantic entity such as the word.

The semantic variation potential connected with this includes, finally, not only semantic variations within the framework of the language system, but also this system, as - exactly like meaning - it is itself manifested as an organization of notation units which are defined by their use as semantic variation mechanisms. It is quite true that there are several different forms of rule based notation sequences with rules of inflection as the most rule determined, while the notation sequences of words are subject to the syllable criterion.

The syllable criterion implies that there must be a vowel (although vowels need not be manifested in all written languages) and very little else. To this, the national languages each add their rather arbitrarily delimited set of customs for legitimate and illegitimate syllable forms.

Roots and inflection forms are thereby subject to different types of regulation of notation sequences and the two forms largely act independently of each other. But not completely, as there may be interference from inflection form to root. It appears moreover that every rule has a least one exception. While the individual notation units are in principle semantically empty, the vowels /i/ and /a/ (i, ø and å, in Danish) are also used as meaning bearing words.

Unlike the graphemes of the roots, the graphemes which present the rules of inflection have been given a further semantic determination as rule notation. But although they are regulatory they are not regulatory in the same way as the operators of formal languages. The graphemes of the inflection system do not represent a programme which transforms one set of data to another. On the contrary, they represent a supplementary semantic determination which can also occur with variable semantic values, such as is true of the use of the present tense, for example. It can hardly be by chance - and is certainly not without significance - that the inflection system is manifested with the help of - a selection of - the notations which are also used to manifest the roots, whereas formal languages systematically distinguish between rule and data notation units. In the latter case, a line is drawn between two separate semantic rooms, where in the first there is an interference.

The rules of language are similar to many other social rule systems, they are not rules which carry out themselves, but rules which are - perhaps - respected and which can be respected to a greater or lesser extent, and rule formation often has the character of analogy - sometimes almost on the principle, if you can get away with it, all well and good. This is impossible to get away with in a formal system.

Although the separation between root and inflection form is unavoidable and invariant, it is not unavoidable in the expression system. For a great number of words (some) inflection forms are identical with the root. The inflection form can thus also occur as a purely semantic determination as regards content which, among other things, allows an inflection category such as the dative case almost to disappear from a language, such as has happened with modern Danish, for example.

The same expression form can in these cases therefore also occur with variable semantic values. The semantic distinction is not stabilized through the inflection system, but solely through the actual syntactic and/or semantic context, which is thus sometimes used as a means to suspend the use of the inflection system's notation rules.

Under any circumstances the linguistic use of the notation system is characterized by a set of possibilities for exchange between rule distinctiveness, custom distinctiveness and semantic distinctiveness, as all notations can serve on all three sides, often simultaneously, although in several different ways and with more or less weight.

In other words, there is an indissoluble discrepancy - and structural difference - between expression form and content form which cannot thus be described as homologous. The variation potential of the expression form is not bound to the content forms. The change of a single expression unit can dissolve a content form which includes a word, a sentence or a rule.

As the relationship between rule structure and meaning content can neither be wholly rule based nor wholly unconnected, the two levels can be regarded as reciprocal redundancy structures, i.e. as a system of variation axes in which each axis has its own variation criteria and where the relationship between the individual axes constitutes an independent variation axis which establishes the meaning and function of the variations.

Double redundancy and the simultaneously redundant and distinctive occurrence comprises one of the specific characteristics of alphabetical writing. It does not occur in formal notation systems which are characterized by the elimination of all redundant graphemes and it does not occur in

pictorial expression systems which neither use a delimited notation system such as the alphabet, nor in an unlimited system where the individual members must be declared, such as in formal notation.

It thus appears that the redundancy which must be included in linguistic theory's criterion for sign distinctiveness comprises an extremely central and characteristic *linguistic* feature which permits a conceptual distinction with regard to other semantic systems such as formal and pictorial systems.

Although Hjelmslev's description of linguistic notation as a use based variation of an invariant set of asemantic relations between a limited set of notation units provides a great deal of leeway for normatively established, but principally variable, structures and relationships, his theoretical interest in the normative is peripheral and he has no more detailed considerations regarding the relationship between the smallest semantic variation mechanisms, rule formation and meaning variation.

A comparison with informational notation shows, however, that there is a characteristic difference here. Linguistic notation shares the limitation of inventory and the demand for semantically empty, but semantically distinctive notation units with informational notation. The smallest semantic variation mechanisms are not only defined in different ways, however, they also allow different forms of semantic variation, because linguistic notation also depends on the use of notations and notation sequences which are indefinite or have weak meaning or open meaning. Thus phenomena such as syllables, relationships between vowels and consonants, the frequent occurrence of preferred consonant constellations and the absence of others, as well as the use of inflection forms are only of relevance for a description of linguistic notation.

It is possible to further isolate this difference with the help of the commutation test, as in this way we can ascertain that it is possible to eliminate quite a number of graphemes from a written text without the meaning being lost, whereas the omission of only a single informational notation unit can only be made without loss of meaning if a set of control codes has been added to the total message. This difference is again related to the circumstance *that informational notation in binary form always uses the entire expression inventory, where language, step by step, uses only a small selection*. The two different notation systems are in other words characterized by different stabilization structures.

Where language is concerned this stabilization is characterized by a limited use of rule determination which mainly only occurs in inflection systems, while most other notation sequences are determined by tradition or meaning. The notation system is used as a redundancy structure which allows the individual notation units to be manifested as determined by conventions, by purposes of meaning and by rule structure and where the individual notation's function can serve several purposes and vary with the contextually determined meaning.

Informational notation, on the other hand, is highly subject to rule determination, which includes both the unambiguous demands on the physical form and the formal semantics that is used to stabilize the notation's legitimacy. This semantics can be separated completely, however, from the semantic regime in which the message is produced. Formal semantics acts here as a redundancy structure with weak meaning seen in relationship to the meaning of the message, while it at the same time acts as a means, with strong meaning, of ensuring the notation's legitimacy. The separate part of the message can therefore not be used as a semantic variation potential in relationship to the meaning of the message either. Finally, informational notation is also subject to a rule based demand on the syntactic organization which stems from the demand for mechanical efficacy.

Hjelmslev's system theory therefore appears - curiously enough - to provide a far more apposite description of informational notation than it does of the linguistic, as in the first case we can clearly distinguish between the definition of legitimate figurae and the definition of their function and meaning. The definition of the figurae is at the same time a definition of their mutual - asemantic - and oppositional relationship. This definition determines notation at the physical-mechanical machine level, while the definition of their function and meaning is a subsequent semantic determination which establishes the function and meaning of the notations at the level of the protocol, programme and use. *The informational notation units can therefore neither be varied individually nor as a total system through use, whereas spoken language allows such variations*, which can act both as individual and dialectical and sociolectal variations, just as it is also possible to assimilate formal notation systems. The latter also holds true of written language, just as various diacritical notations can also be introduced here. In print, the individual variation of graphemes is limited to the choice of typefaces which are not semantically distinctive, whereas italicization and underlining, for example, can be used in a semantically distinctive way. Something of the same is also true of

handwriting where individual variation, however, can also be read as a personality trait.

Although both notation systems are bound to the use of a limited set of notation units, this restriction is manifested in two different ways. Informational notation does not use more or less superfluous notation units which are weak of meaning, whereas linguistic notation is characterized by frequent occurrences of more or less superfluous (but potentially meaning bearing) notation units. The informational use of notation units is rule based, each individual notation unit has a definite physical value and function - with regard to the mechanical procedure - while the linguistic utilization uses the notation system as a redundancy potential.

Excursus: In several of these respects the linguistic use of notation units is related to the function of notes in scale-based music, where the musical expression is bound to a sequence of notes although the expression is changed through variation of the individual note. Such variations can both have the effect of a deviation from a given scale, which is common to many works, or of a variation of the thematic structure which characterizes the individual work. While the scale establishes a sonar background structure (not necessarily explicitly manifested in the individual work) as an invariant basic pattern for the musical expression, the themes which characterize the individual work are expressed through the repetition of a limited and chosen set of the possible combinations. The relationship between these two repetition patterns is not, however, fixed. The thematic variation, which can include overlapping between themes and variations of the individual themes, can be carried through right up to the dissolution of the theme. It can also lift the musical expression out of the scale-based tonality (we could say over to another scale, although this is perhaps only represented by a single note) and both pattern structures (that of the scale, which is common to many works, and the choice which characterizes the individual work) can become the objects of corresponding variations in strength of significance.

In scale-based music the individual notes are defined by a certain frequency which additionally defines the musical borderline between noise and legitimate musical sounds. The unlimited possibility for varying the patterns which create music thus does not depend on a continuous, gliding sound transition, but on the circumstance that the pattern itself is produced as a compositional, facultative structure of distinct expression units. This holds true not only of the thematic patterns which characterize the individual work - and its relationship to other individual works - but also of the harmonic scale pattern which establishes a tone structure for a greater number of works.

Although the musical sound value of this music has a well-defined physical form and a well-defined relation to other sound values established by the scale, the musical expression cannot be described as monoplanar sound symbolism.

The individual notes are defined both by frequency, by scale and by thematically determined relationships to other notes. At all three - individually variable - levels this is a question of conventional pattern formations through which sounds are defined as music - i.e. legitimate - sounds.

The similarity between the symbolic systems of language and scale-based music lies in the circumstance that the linguistic and musical rule structures are established, on the one hand, in a subdivided layer of sequence structures, (those of the scale, the work's basic theme and the thematic variations) which on the other hand is realized in an expression form which makes it possible to arrange these structures in variations, ranging from complete regularity to complete dissolution, as all structures are produced through a combination of singular facultative or variable expression units.

Now it is difficult to imagine that it would be at all possible to create music or language if this should be done by selecting expression units one by one. But although neither language nor music appears conceivable without restrictive conventions for the composition of expression units, in both cases there is a need to limit and stabilize the potential choice and not for a set of rules which can define the musical or linguistic field. The rule structures which are included in the individual musical work or the linguistic expression respectively, do not circumscribe the musical and the linguistic, on the contrary, they are contained in the expression and manifested in the expression systems which in both cases are accessible to variation which transgresses the rules.

This possibility of varying and suspending rule structures, which holds true of all symbol systems that 1) use a finite number of expression units and 2) allow rule formation to be manifested in the same expression units as meaning content, is thus based on the circumstance that the smallest expression units are defined as semantic variation mechanisms, but have no definite semantic rule or meaning value.

Although the individual work will always use only a very limited number of the possible variations, it is not possible to establish definite limits to variation at any of these levels which are common to all music. The limits which appear through a description of a given body of works thus do not represent a description of the musical »essence«, they represent, on the contrary, the intentional, semantic considerations of the communicative purpose and ensure that the message can be understood and received.

The purpose of this parallel is not to emphasize the music of language, but to emphasize that kinship between language and music which lies in the central importance of the redundancy function for the symbolic use of what - in both cases - is a limited set of

expression units. The kinship is not, however, interesting solely because of the similarity, but also because of the differences.

No attempt will be made here to describe what can be understood by the meaning content of music, nor the content forms of the musical sign function; there can, however, hardly be any reason to deny that the musical expression is only musical because the expression is part of a sign function and must therefore be described as a biplanar or multiplanar symbol system. This is why John Cage could compose (and we can listen to) a piece of music by declaring only its duration (four minutes and some seconds) using no sounds at all. If nothing else, this work illustrates the ultimate and sole limit to musical expression, that of the substance. In the broadest sense of language, music is a language. The difference between speech and music, however, is not only a difference at the level of content meaning and content form, but also at the level of the expression form, although speech and music both use the same ethereal substance. We can therefore not speak of more or less superfluous occurrences of notes in scale-based music, each individual occurrence of a note is subject to the composer's choice and the musical expression is also bound to a far more rigorous demand on the physical definition of the notes. In other words, this is a question of two different criteria for distinguishing legitimate forms in the same expression substance.

Whereas it is possible in spoken language to use the forms of the expression substance as a semantic variation potential, the scale-based musical expression is bound to a sharply delimited set of legitimate substance forms. While the expression substance variation of the individual sounds is included in the redundancy structure of linguistic notation, it is not included in the scale-based musical redundancy structure - apart from that timbre which distinguishes the same sound when played on different instruments. In scale-based music all other variants and deviations from the rule based substance forms are, on the contrary, always defined as noise.

As a consequence of the precise tone definition, scale-based music can also be represented extremely precisely, note for note in the form of musical notation. The difference between the tone and the equivalent note is simply a difference in substance. Although there are probably people who can enjoy a comprehensive and lively musical experience by reading a musical score, music cannot normally be understood with the eye. The sensing of the form is conditioned by and bound to the substance in which the form is expressed.

In an article on musical notation as a means of knowledge representation (seen as a kind of »precedent« for binary notation) Henrik Sinding-Larsen notes that the musical information in the score »apparently as a paradox« grew in step with the development of a notation system in which the individual notation unit »contained less and less information« up to the point where the notes had become »exact digitalized symbols in a

well defined system«. This development, claims Sinding-Larsen, is typical of semiotic systems, as these develop in a continuous abstraction in which the semiotic and syntactic systems take on greater and greater importance, while the individual element correspondingly loses information content.²³

While this description is perhaps adequate for a possible line of development in a formal notation system such as the musical score, which is the formal re-presentation of a tonal system, it is inadequate as a general model. First, because it allows no room for the difference between notations which *have* independent semantic value and notations which do not. Second, because it connects the »falling information content« of the individual notation with less weight in relationship to the total system. The relationship is rather the opposite, as a notation without an independent information content has a potential use of far greater semantic reach. The less the value of the notation is preordained, the greater the potential for its use as a semantic variation mechanism. Third, the individual note's notation value is defined by its place on the line, which is part of the rule determining formal system.

It is exactly at these points that alphabetical writing and informational notation differentiate themselves, because they use semantically empty notation units, while the tone (and thereby also the note) is bound to a definite relationship in the tonal system. As musical note notation is bound to a scale - and not to its own expression substance - it cannot be regarded as an independent notation system. The relationship between the phoneme and the grapheme is different from the relationship between the tone and the note. Writing does not have the same relationship to speech as that of the score to the music.

The music of language clearly distinguishes itself from the language of music, but the language of music is also used for linguistic meaning articulation. We have no difficulty in distinguishing spoken language from song, song from other musical expressions or singing a song from song-like sounds such as humming, for example. The relationship between these symbolic expression forms is not a relationship between two different symbolic expression forms with clearly delimited rule systems which do not overlap. Not only can we break into song and thereby connect the musical and linguistic norms with the same physical sounds, we can also exploit musical structures as expression forms for linguistic meaning articulation.

That we can connect linguistic and musical norms with the same sounds is not quite so obvious as it - sounds, as the scale-based, musical sounds are defined by a precise frequency, while language works with both dialectal, sociolectal and individual variants of the »same« sound. Nevertheless the common expression substance allows an amount of

²³ Henrik Sinding-Larsen, 1988: 97.

interference between musical and linguistic sound symbolism. The exploitation of musical structures in linguistic meaning articulation, however, is even more interesting because it is a question of a linguistic use of a non-linguistic expression form.

If we wish to maintain the concept of an invariant language system, we must therefore introduce musical structures as part of this system and indicate invariant thresholds for their linguistic use. The question then is whether these thresholds, if they could be shown, would make the gateway to language systems so high and the door so broad that there will no longer be any room for a wall.

The comparison with scale-based music shows that the use of the expression substance by spoken language is not only different from that of music, but also that this special relationship to the expression substance can be used as a semantic variation mechanism.
End of excursus.

Hjelmslev does not eliminate expression substance and notational redundancy from the structure of language because redundancy is not part of the expression form. The explanation can rather be found in Saussure's sign concept, which propounds the opposition between expression and content as an overall, controlling perspective in considering the expression side. Through this perspective the relationship between semantic distinctiveness and redundant expression figurations is arranged in order of precedence on the basis of content distinctiveness which - in a short-circuit - is directly connected with the preferential position of expression distinctiveness as the exclusively semantic part of the expression. Content distinctiveness, however, becomes manifested in the polarization of redundant and distinctive manifestations.

If we wish to describe the specific linguistic utilization of alphabetical notation, we cannot omit this redundancy structure. Hjelmslev's omission of it is also closely connected with the fact that he saw notation as an insignificant expression material for language, except for the circumstance that the number of permissible figurae was limited. This limitation, however, is not invariant and not systematically determined.

It is also in the same - i.e. reversed - fashion with the content side, where Hjelmslev's system separates language system from meaning, as he simply writes off the importance of the linguistic redundancy structure for interference between language system and meaning.

If we maintain Saussure's terminology - and precisely from his assumptions - it becomes clear that the substance depends on the form to such a degree

*that it lives exclusively by its favor and can in no sense be said to have independent existence.*²⁴

In spite of this almost religious rhetoric,²⁵ which so appositely expresses the theological roots of his idea, Hjelmslev shows immediately after, with the sentence »I do not know« in Danish, English, French, Finnish and Eskimo, how the same meaning de facto exists in different languages, expressed in different content forms which »stress different factors within the amorphous “thoughtmass”«. ²⁶ There is a further discussion here on an arbitrary relationship, which must mean that the meaning exists in such a real sense that it both has different features - so that it is not completely amorphous - and can be included in various relationships with a content form.²⁷

The sign concept is thus formed through a double delimitation: on the expression side in relationship to the manifested redundancy, described as sign parts, non-signs, or *figurae* and on the content side in relationship to the complex meaning concept, described as an amorphous mass.

The semantic field, however, stretches across both these borders. Although meaning is understood as an amorphous mass, in Hjelmslev's theory structured meaning elements are included as a necessary precondition. It is such elements (and not content forms) which are used in the commutation test, which also only works because it uses meaning change as a form distinctive criterion. It is also structured, i.e. a specific, meaning content which is decisive for the sign definition itself, for the distinction between sign and non-sign and for any analytical segmentation of the language forms, both at the level of content and that of expression.

When all is said and done, it is only the meaning which distinguishes any kind of symbolic form from any other kind of form. It is also only the meaning in a form which turns it into in-formation. Hjelmslev's language theory does not include the semantic tools of analysis he uses to express his own theory in linguistic form.

Although Hjelmslev emphasized the linguistic form as the concern of linguistics in opposition to transcendental, meaning bound language descrip-

²⁴ Hjelmslev (1943) 1966: 46. English translation (1953) 1961: 50.

²⁵ »by its favor« is a translation of the Danish »af dens nåde«, which has reference to the grace of God.

²⁶ The amorphous “thoughtmass” is also referred to as »the meaning« or (content) »purport« - residing outside the language system, but totally dependent on it.

²⁷ See the examples with »børneren« (the kindergarten), »døgneren« (the 24-hour service kiosk), and »fritteren« (the day-care institution) in 7.7 for further explanation.

tions, he also used meaning as a means of deriving the language system, in spite of his claim that the system existed independently - and transcendently - of meaning.

The transcendental precondition is contained in the axiomatic postulate that it is possible to claim that any linguistic sequence can be understood as the manifestation of a language system.

While no linguistic sequence can exist without an underlying system, there may, it is said, be language systems which exist without there being a text constructed in that language, i.e. virtual texts without realization in the form of theoretically possible systems.

*It is thus impossible to have a text without a language [system] lying behind it. On the other hand, one can have a language [system] without a text constructed in that language [system]. This means that the language [system] in question is foreseen by linguistic theory as a possible system, but that no process belonging to it is present as **realized**. The textual process is **virtual**.*²⁸

It would now be highly appropriate to discuss how a mental language system without linguistic features could possibly exist. Under any circumstances, the idea of the primacy of the language system contains a residue of the same transcendental precondition that Hjelmslev wished to dismiss.

If, in accordance with Hjelmslev's intention, we wish to establish an immanent view of language, we cannot lay the foundation by declaring that there is a language system which exists in the form of a linguistically well-defined island which is completely delimited from the surrounding non-linguistic sea and prior to any linguistic articulation.

When we deny that the language system is produced by language usage, we are left with the question as to where, when, how and by whom it was created. Without an answer to these questions, the declaration lacks the foundation it assumes itself. That this lack has often been accepted is perhaps due to the fact that the idea of a fully created, closed system is ideally suited to the deep-lying cultural assumption expressed in the idea of a divine creation.

It was at this point that Chomsky (probably without knowing it) broke with Hjelmslev's theory in proposing the hypothesis that humans were equipped with a physiological »language motor« in the form of an innate, universal

²⁸ Hjelmslev (1943) 1966: 36-37. English translation, (1953) 1961: 40.

grammar.²⁹ By identifying the system with a motor Chomsky resolved the schism between the invariant, static system and the dynamic sequence. But the theory does not describe how the physiological system can produce a grammar. It fixes a long, unknown history of development in a single, giant leap from the physiological system to a physiologically rooted grammatical system in which it is no longer necessary to see the physiological process as a potential source of meaning which can work both with and against the grammatical motor.

Although Chomsky is a Darwinist in the sense that he places the innate grammar in the physiological system, he maintains a classical dualism with the idea of an autonomous, mental - in this case, grammatical - form which is elevated above (and conceived independently of) material substance. The form concept, however, is itself determined by a cognitive discrimination which distinguishes certain elements in the matter as part of a form, a structure or level.

If there is a grammatical motor in the physiological system - and this is still a speculative hypothesis - it does not represent the beginning of linguistic competence, but a late stage in its development. As the motor has not always existed, it cannot be particularly universal either, much less inaccessible to new, non-linguistically motivated change.

The immanent, scientific viewpoint must also go beyond this transcendental residue in the understanding of form and take steps to look at form creation, including that of language forms, in relation to the immanent, non-linguistic »surroundings«. The relationship between the linguistic and the non-linguistic is not only a question of how it is possible to use external matter to depict the external world in the form of language which is distinct from both matter and meaning, but rather a question of how linguistic forms are generated in the field of tension between matter and meaning.

Probably nobody would deny that it is possible to construct languages which follow a limited set of given rules, or that any linguistic expression can assume some kind of regularity. The problematical point in these assumptions lies, on the contrary, in the implicit precondition that any linguistic rule system always constitutes a coherent, theoretically reconstructable and, in this sense, closed system. It is the same problem which motivates Hjelmslev to suspend further analysis of linguistic redundancy with the term 'figura'. If a linguistic sign is created in the establishment of a distinction between semantically more

²⁹ Chomsky, 1957.

distinctive and more redundant figurations, it is impossible to maintain Hjelmslev's - transcendental - concept of a language system, as the minimum linguistic condition in such a case consists of the distinction between semantically distinctive and redundant figurae and not of any particular rule system. The redundancy structure thus appears to comprise the smallest identifiable condition of language.

This assumption is completely in accordance with the description of a sign as something that can stand for something else, as that which must stand for something else can only do so by standing slightly less for itself. It thereby conflicts with the idea that only signs can produce signs, in what Peirce described as an infinitely continuing, self-dependent semiotic process.

That we can only speak of the world through language and that any referentiality has a debatable quality, does not mean that the thus dubiously referred to and always only re-presented world around us can be eliminated or marginalized in linguistic theory. On the contrary, it means that the semantic meaning field stretches across the gulf between language and non-language also including, as is the case with informational notation, that of the lower threshold to the expression substance. The elimination of the non-linguistic is only made possible by the groundless claims on behalf of a sign concept based on transcendental, theoretical premises which legitimizes taking the sign as exclusively given as its own cause.

Whether we motivate the autonomy of the science of signs with the concept »langue«, »language system«, or »code« cannot change the fact that in all these cases, with these terms, we carry out a groundless separation of a special linguistic fragment of consciousness from the rest of the contents of consciousness - and also from the physiological manifestation form of consciousness which comprises the mental expression substance.

In the definition of the sign function as a relationship between two different levels, an expression and a content level, both seen as purely linguistic dimensions, linguistic theory eliminates its possibility of understanding the meaning of the non-linguistic for the way language works. This holds true at the internal, mental level and at the level of the expression and therefore also for the sign concept which is defined as the connection between them.

The idea is not in this way to be able to solve the problem of meaning in the form of a definition of the referential status of various sign systems, but on the contrary to investigate the ways in which the relationship to the non-linguistic is included as an element *in* the linguistic.

7.7 Linguistic redundancy structures

I have claimed in the preceding that redundant *figurae* are an irreducible part of the sign's expression form and of the semantic structure of language.

The redundant manifestation of *figurae* as a foundation for the manifestation of the more distinctive *figurae* is in itself an important functional property, but it also creates the foundation for other characteristic semantic features.

It is well known that an abundance of sign elements considerably aids readability. We are thus often able to ignore printer's errors, mispronunciations and speech variations (or ascribe meaning to them) and decipher indistinct signs, whereas notation systems without redundant sign elements - Morse signals for example, or binary notation - are much more vulnerable.

This meaning stabilizing effect can hardly be underestimated, but on the other hand, it is not of such importance that it can explain in itself why language has retained its redundant elements. If redundancy only served to support meaning recognition, it would be reasonable to expect redundant expression units to disappear in step with increasing reading proficiency - whether in the form of abbreviations or linguistic innovations which omit certain sign sequences. Words which are used in a group are often subject to this type of change in pronunciation or spelling, because the need for distinct marking declines as a given meaning expression becomes a custom. A good example is a Danish usage which apparently grew up among children of kindergarten age. Here, we not only encounter 'børnehaven' (the kindergarten) referred to as */'børneren'/* (literally 'the kinder'), but also 'fjernsynet' (the television) referred to as */'fjernereren'/* (the 'tele', or 'the telly' as it is usually spelt), 'døgnkiosken' (24-hour service kiosk) as */'døgneren'/* ('the 24-hour'er'), 'fritidsinstitution' (the recreation centre) as */'fritteren'/* (the 'rec') - and a number of other similar innovations.

The - Danish - example not only tells us something about the linguistic creativity of children - which is often seen by adults as vulgarization - but also something about the redundancy function. It is immediately obvious that these changes follow the same rule for the elimination of superfluous sign elements. But it is also clear that the familiarity which makes it possible to omit the entire second part of a number of compound nouns is not only a linguistic familiarity. The regularity which permits the elimination is, on the contrary, a regularity in the world of children, where the kindergarten, television, 24-hour

service kiosk and recreation centre in the same period have become common and basic areas of daily life experience.

The example thus shows that a distinctive expression can become redundant relative to the non-linguistic (in the actual a case a new lifestyle). But it also shows that expression redundancy is relative to the content form. The two different expression forms (the television/the telly) correspond to a semantic difference, although it may be difficult to define this difference. One possibility is to regard it as a - subjectively motivated - stylistic difference, but it could also be claimed that the stylistic difference represents a more comprehensive semantic distinction, /the telly/ indicates a relational experience, a familiarity, which is not contained in the concept of /television/.

A »sui generis« explanation could attach importance to the fact that the different examples are formed in accordance with the same rule, which could thus be regarded as part of the language system. The rule could be formulated as something like: the second part of compound nouns is subject to the same tendency towards loss of distinctiveness that we are familiar with in connection with many suffixes in Danish. There is, however, no rule for when this rule comes into force and when it does not, for which words it affects and which it does not and this is because it can only come into force as the consequence of a semantic choice made by a language user and then accepted by so many other users that it becomes adopted. *The semantic choice of the form, the first use, occurs under any circumstances before the formation of the rule, just as the establishment of this expression form as a rule structure contains yet another semantic choice.*

The use of the rule in the examples we have seen here can only be explained by referring to the specific context. The transition from distinctiveness to redundancy is not only fluid, it is determined by semantic decisions which are not solely subject to linguistic rules. The redundancy structure is conversely precisely a structure which permits such an interference between the linguistic rules and non-linguistic influence on rule structure and rule formation, because it permits both new and old expression forms to be manifested with semantically motivated, variable values.

The sign economy of the linguistic expression is thus closely connected with both meaning and the non-linguistic world in which and of which meaning is formed. Where there is great familiarity with regard to meaning between sender and receiver, distinctive sign sequences lose some distinctiveness. This does not necessarily mean that they are no longer manifested, but rather that they are manifested as redundant sign sequences which can

later be eliminated or retained with the possibility of becoming distinctive once again.

Expression redundancy thus constitutes an extremely important aspect of the plasticity of language relative to the highly variable consensus between the senders and receivers of language. That which is expressed is a semantic function of the non-expressed, not only on the content side, but also on the expression side.³⁰

Finally, herein lies the fact that the relationship between redundant and distinctive manifestations need not necessarily coincide for the sender and the receiver or for different receivers.

Complete coincidence, on the other hand, is an exception which rarely or never occurs. We never hear or read the precise meaning expressed, we hear or read it in more or less conformity with the sender's intention or explication. The question therefore arises as to how one and the same linguistic - and not least written - expression can contain this semantic openness at all, as the expression is produced in a completely closed form.

In answering this, reference has often been made to the fact that linguistic understanding depends on an interpretation community, which in some way permits meaning to be received as a copy of the message transmitted and then interpreted. But the reference to an interpretation community, which is not completely inaccurate in itself, provides no answer to the question of how language can contain several meanings in the same expression. The reference to an interpretation community, however, is not quite accurate either. If we already possess a common understanding, communication would only be a confirmation of this concord. In this case the only reason to communicate would be to confirm that there is no need to communicate at all. Conversely, we can state that a basic motive for communication is to establish common interpretations or to explore differences.

Nor will it help to regard the expression on the basis of the semantic-distinctive sign manifestations, because this view either implies a semantic unambiguousness or complete randomness in the relationship between the

³⁰ This function is also frequently manifested in the use of »empty places«, for example the omission of one part of the nexus relation often used in newspaper headlines: / [] Sends suggestion to committee/. / [] Died of drink/. /Peter Hansen [] court tomorrow/. Here it is left to the reader to encatalyze the missing parts. The reader's capability to do this is considered, in Hjelmslev's theory, as confirmation of the existence of the language system. It is not possible, however, to encatalyze the correct word without take meaning into account, just as the possibility itself of working with »empty places« provides language with a characteristic property. We could perhaps cautiously compare this to the meaning of the number 0, which is different to nothing.

expression and the content form, whereas the relationship between the sender and the receiver is neither unambiguous nor completely random. Polysemy must at once be made possible in and limited by the expression itself.

But nor is it adequate to simply add that redundant sign sequences are also included, if we thereby imply that a given expression is characterized by an - intentional or unintentional on the part of the sender - completely defined relationship between redundant and distinct manifestations. This would imply that all semantic variations permitted by the expression would be variations of an opposed character. Where the sender defined a distinctive relationship, the receiver would have to read this as redundant, with complete randomness as a consequence.

The only possibility which remains is to assume that the same notation sequence permits variation in reading the relationship between the more or less distinctive.

This variation is not limited to the circumstance that many words can be used with different meanings and that different shades of meaning can be manifested in certain uses. This form of polysemy, connected with semantic entities such as the word - or sentence - is well known and obvious. In these cases it is a question of a semantic content form which is connected with a (variable) register of possible content meanings (old meanings may disappear while new are created). This type of variable reading (polysemy) thus concerns variation in the relationship between content meaning and content form.

But in addition to this there is a possible polysemy which is connected with the smallest semantic variation mechanisms. It is well known that it is possible to change meaning in spoken language by changing tone or emphasis. In this case the change of content meaning is brought about by changing the expression form. The interesting point now is, that such a change need not necessarily be manifested in written language. While the difference between /en vis person/ (a certain person or a wise person) in spoken Danish is expressed by a phonemic distinction (the former is pronounced something like [vis] (as in 'this') while the latter is pronounced something like [vees] (unvoiced 's'), the two persons today usually have the same expression form in written language. The difference can be represented either by using the archaic /ii/ (en viis person, der er klog - a wise person who is clever) or by italicization (en *vis* person, der er bestemt - a certain person), but this is not necessary and not usual.

While meaning distinction in speech is represented here by an expression difference, in writing it is only borne by the meaning context. The phonemic marking of semantic distinctiveness in spoken language is substituted by a purely semantic distinction which has no explicit manifestation in writing. The individual grapheme can in other words have different semantically distinctive values in the same constellation. If we use the commutation test on this example the peculiar result is that in written language we have genuine commutation between the grapheme /i/ in *vis* (wise) and the grapheme /i/ in *vis*, (certain) which are thus both identical and different graphemes.

While such a case strains the idea of an asemantically defined graphemic system, it confirms the description of *figurae* as semantic variation mechanisms which are included in a redundancy system in which the individual *figurae* can occur with a variable content of significance and/or strength of significance and that notational distinctiveness can be replaced by semantically determined distinctiveness.

The example, however, also gives occasion for a closer look at the relationship between the spoken and written expression.

Writing - a system of expression and/or a language?

Hjelmslev's language theory concerns the description of what he refers to as the »so-called "natural" spoken language«. We could immediately ask, however, whether the spoken language, on the whole or solely, uses sign elements in the form of phonetic *figurae* in the sense that Hjelmslev assumes. Although it is true that it is possible to establish relatively clear phonetic inventories as typical, and the understanding of spoken language also presumably assumes a certain correspondence between the speaker's and the listener's phonetic inventories, spoken language equally indubitably permits a far greater (individual, group determined, dialectal, stylistic etc.) phonetic variation than is expressed in these inventories, just as at the same time it offers a number of other, corrective possibilities for distinguishing semantic distinctiveness (tone, facial expressions, gestures, pre-established social expectations in the communicative context) which are regarded as peripheral by Hjelmslev.

As spoken and written language not only use different substances, but also use substance forms in different ways, it is not possible to speak of an expression system common to both without further ado, nor to take either speech or writing as a model for »language«.

A more cautious interpretation therefore prompts us for the present to regard the graphemic redundancy structure as a redundancy connected with the alphabetically expressed language, where the manifestation of redundant sign elements is the necessary precondition for the manifestation of semantically distinctive signs.

That this is a characteristic of alphabetical writing does not necessarily imply that it is also a characteristic of spoken language or of language as such. Havelock, for example, claims that it is wrong to identify writing with language and suggests that the term »language« should be reserved for spoken language. Further to this he describes alphabetical writing as a translation of the phonemes of speech into a visual expression which depends on - compared to speech - a very recently developed civilizational competence.³¹

According to Havelock, a true alphabet can be defined by three requirements which must be fulfilled simultaneously: First, that all the phonemes of spoken language must be covered. Second, that the total number of graphemes (letter shapes) must be limited to between 20 and 30. And third, that a given grapheme need not handle more than one task, the individual grapheme must be connected with a fixed and invariable acoustic identity.³² The central point in this definition is that the visual representation of spoken language in the Greek-Roman alphabet is a re-presentation of the spoken language's phoneme system.

This translation depends on the one hand on a theoretical, analytical conceptualization of the basic acoustic components of spoken language, its »atomic structure«, with the deciphering of the vowels as the sonant element, to which are added con-sonant start and/or stop conditions and, on the other, on the written notation system being based on a set of distinctive forms which have no semantic content. The graphemes of writing, letters, must on the contrary be seen as visual signals which mechanically release an acoustic picture in the consciousness.

The bond, which can connect speech and writing, thus lies in the demand for a rigorous correspondence between phonetic and graphemic manifestation, a correspondence in the elementary particles of the expression system. According to Havelock, it is this asemantic relationship between speech and writing which makes it possible to represent many different spoken languages in the same written notation system. That the number of necessary graphemes

³¹ Havelock, 1982: 39-59, 316.

³² Havelock, 1982: 61, 77.

can be defined with such relative clarity as being between 20 and 30, finally depends on a combination of a mnemonic need to reduce the number of immediately recognizable basic forms as much as possible with the demand for complete representation of the possible number of phonemes, which again is determined by the biologically contingent, physiological articulation possibilities.

Havelock thus assumes that the expression elements of alphabetical writing »ideally« correspond to those of spoken language, but he also claims at the same time that acoustic recollection can hardly have the form of a - limited - phonetic inventory, as he sees the spoken language as a biologically handed down disposition comprising the mental ability to retain the enormous number of acoustic picture constellations of spoken language. But this view is not without its problems either, because it conceals the question of the spoken language's acoustic side in biology, even though the art of speaking has by definition, so to speak, artificial dimensions. This at the same time implies that the description of the limited phonetic inventory also in this theory is perhaps rather a projection of the much later developed alphabetical notation.

On the other hand, both Hjelmslev's and Havelock's theories create the, in this connection, regrettable problem that writing is not understood as language. In Hjelmslev this only appears implicitly from his repeated emphasis on the claim that the primary linguistic subject area is spoken language, although he otherwise appears to assume that linguistic theory is so general anyway that it includes all languages. The lack of clarity in his view of the relationship between spoken and written language is not only shown by his refusal to consider written language as a separate subject, but also by the fact that when referring to the physical material (usage) he is thinking of speech, but is mainly and perhaps exclusively writing about the »text«:

*The objects of interest to linguistic theory are texts. The aim of linguistic theory is to provide a procedural method by means of which a given text can be comprehended through a self-consistent and exhaustive description.*³³

³³ Hjelmslev (1943) 1966: 16. English translation: (1953) 1961: 16. The term 'text' is used throughout and naturally in *Prolegomena*, while when referring to the fact that it is the spoken language that is the subject, this appears in more emphatic connections. In the original Danish text, the two reference systems sometimes meet in one and the same sentence, thus towards the end we find: *a demand for a sure method of describing a given limited text composed in a previously defined »natural« [spoken] language, has, in the course of our presentation, with logical necessity, had to make way...* Hjelmslev (1943) 1966: 110. English translation (1953) 1961: 125. The English translation uses »language« for Hjelmslev's *sprog/ dagligsprog/talesprog* (language, ordinary or everyday language as well as for spoken language).

It is not difficult to understand the motive behind this textual reference to spoken language which proposes the description of language *sui generis* as a goal. While the written language, precisely on the expression side, appears *sui generis*, the spoken language has no such »existing« property as a manifest object. Writing exists, as a fixed manifestation, speech is unique and can only appear as an object in a mediated and reconstructed form.

That this is a question of a deeper confusion also appears from the quite informal and uncommented use of examples from Latin, just as all examples which are used in the book therefore appear as written representations, while there is a complete lack of any attempt at all to describe oral communication. This confusion cannot be explained as a careless lapse. It is, on the contrary, the result of the theoretical construction, as speech and writing are viewed as two different usages, i.e. as two, for language, external and random expression substances, or as Hjelmslev gradually defines them: as substances for an expression system of a linguistic schemata,

*Thus, various phonetic usages and various written usages can be ordered to the expression system of one and the same linguistic schema. A language can suffer a change of a purely phonetic nature without having the expression system of the linguistic schema affected, and similarly it can suffer a change of a purely semantic nature without having the content system affected.*³⁴

There is no basis for denying these possibilities which, according to Hjelmslev, explain, »that it is possible to distinguish between phonetic shifts and semantic shifts on the one hand, and formal shifts on the other«. On the other hand there are no possibilities either for denying that both phonetic shifts and semantic shifts *can also produce* formal shifts. In Hjelmslev's theory this can only happen as an external cause whose effect in the language system is exclusively determined by »the immanent algebra of language«. ³⁵ This abstraction, however, cannot be observed as there is no other way of studying the language form than through the study of notation and meaning changes.

By isolating the language form and reducing the physical medium to an amorphous substance, the central question as to whether it is possible to explain rules for which shifts at one level can produce shifts at one of the

³⁴ Hjelmslev, (1943) 1966: 93. English translation (1953) 1961: 105.

³⁵ Hjelmslev, (1943) 1966: 72. English translation (1953) 1961: 80.

other levels, disappears, partly because the relationship is seen as peripheral, but particularly because the idea of an amorphous substance implies that we must ignore the structural properties which characterize the relationship to the expression substance and provide speech and writing with different semantic potentialities.

Where Hjelmslev is silent (but does remark that written language has still not been studied at all and is perhaps just as »original« as speech), Havelock offers a number of conceptual - and historically motivated - distinctions, including the descriptions of the development and mutual relationship of the two expression systems in ancient Greece. For Havelock this distinction implies that we cannot use writing as a paradigm for the description of spoken language, but at the same time he also introduces the two systems into a mutual hierarchy where speech is seen as a biological invariant, while writing systems are seen as specific, artificial and external notation systems.

*A successful or developed writing system is one which does not think at all. It should be the purely passive instrument of the spoken word even if, to use a paradox, the word is spoken silently.*³⁶

As different articulation possibilities are attached to each of the systems, it is not obvious that writing is only a passive, external medium for speech and is not seen as language. No clear reason - over and above the biological background - is given and it is perhaps limited, ultimately, to a manifestation of that logocentrism which, according to Derrida, is expressed in a tacit preference for speech as against writing, an invocatory gesture intended to conceal the gulf between meaning and expression which is attached to the sign concept in which the presence of the sign is a manifestation of the absence of the thing. Whether the way the problem presents itself here can be clarified must remain unanswered in the present work. The problem, however, marks a possibility for regarding alphabetical writing as a specific language.

As far as the redundancy concept is concerned, it is therefore obvious to ask, moreover, how the sign organization of alphabetical writing relates to the spoken language. Does spoken language possess double redundancy parallel to that of written language, or is the redundancy structure of written language, on the contrary, a specific function which only corrects problems in

³⁶ Havelock, 1982: 55.

converting visual forms to the mental recollection of the spoken language's phonemes?

Probably both. It is well known that written language is far from capable of reproducing spoken language when read at the level of expression units. Linguists operate, on the contrary, with a special phonetic notation which is subject to a far higher variability than written language. In this respect Havelock's correspondence theory represents an idealization of limited durability, as any child who has learned to spell knows.

In some circumstances, redundant grapheme occurrences are undoubtedly connected with a need to correct the incomplete correspondence of written notation to acoustic recollection, but this does not imply that a similar redundancy does not also hold true for the phonetic inventory. The difficulty here is that there is no obvious symmetry between the concepts of phoneme and grapheme.

While graphemes, in their capacity of explicit and physically fixed forms, are constructed as distinctive and manifest forms, the concept 'phoneme' is perhaps only a theoretical abstraction whereby we make the acoustic aspect of spoken language accessible to analytical operations. There thus appears to be a question in both Hjelmslev and Havelock of a description of the phonetic structure on the basis of the alphabetical notation. While written notation is based on a sequential, single-stringed organization of discrete elements, spoken language is under any circumstances at least two-stringed. The distinction between consonants and vowels in writing is here parallel to a co-ordination of at least two simultaneous (and complex) physical processes: the production of acoustic waves and the modulation of variations which can be both continuous (sonant) and discontinuous (con-sonant). The speech situation at the same time contains a number of other, simultaneous and mutually interfering physical expression possibilities. A wink can influence the speaker's construction of a sentence, or be used to give expression to one or more meanings etc.

That we can still claim that redundancy is not simply a function of written notation, but is included as constitutive for language formation, is due to the fact that redundancy is a necessary precondition for any articulation in this world. The acoustic picture of the spoken language can - just as the musical picture - only be manifested as a choice of repetitive modulations in a sonant sounding board.

Redundancy and regularity

In the description given here of the notational redundancy structure, the emphasis has been placed on the functionality of redundancy seen in the relationship between the linguistic and the non-linguistic, on the one hand in relationship to Hjelmslev's »meaning« (intentions and references) and on the other in relationship to the physical manifestation of language. The relationship between the linguistic and the non-linguistic, however, cannot simply be understood as a »national border« between distinct territories such as has been done through the well-motivated attack on the view of language as a mimetic mirror, or as a means of perfectly reconstructing the world around us.

Hereby falls the idea of the possibility of a given language being described on the basis of the jurisdiction that is indicated by the concept of language system. The building itself is built, the rules are themselves subject to regulatory changes in a process which is at once produced by signs and non-signs which breed new signs. This affects not only Hjelmslev's dream of a language theory which would

*be of use for describing and predicting not only any possible text composed in a certain language, but, on the basis of the information that it gives about language in general, any possible text composed in any language whatsoever.*³⁷

it affects all theories which describe language systems as invariant, structural precepts for language use.

It is quite true that there are many linguistic features which have not changed much, if at all, for a period of 50, 100 and perhaps 1000 years, for example the nexus structure of the principal clause. This shows that to a very great degree language utilizes stabilizing rules. It does not, however, show that there is an precept which is independent of the manifest usage, nor that the functionality of the nexus relationship is only connected with the internal organization of the sentence.

As long as we only consider the repetitive use of the same rules, the choice between describing them as part of a language system, or as an expression of stabilization in a linguistic redundancy structure, is perhaps arbitrary, but the arbitrariness is dissolved when we consider the relationship between

³⁷ Hjelmslev, (1943) 1966: 17. (1953) 1961: 17.

redundancy and distinctiveness. If we see repetition as part of a transcendental language system, in relationship to usage, we create an unbridgeable gulf between the - in such a case redundant - part of the linguistic expression which represents the system and that part which represents meaning. To each part there must belong an individual set of sign sequences, as the rules of the language system cannot determine all sign sequences, if it is to be possible to read a meaning into the expression.

It is not possible, however, to carry out such a complete division of sign sequences, but it is possible, on the other hand, to show that the sign sequences of written language are subject to several simultaneously operating rules and that they are included in several simultaneous relationships. Distinctive occurrence goes hand in hand with redundant occurrence, linguistic certainty goes hand in hand with non-linguistic certainty and linguistic certainty can itself embrace several levels, from grammatical choice to that of genre and style.

Abandoning the idea of a transcendental language system does not therefore imply that it is impossible to speak of rules, but on the contrary, that the relationship between rules and the determination of their reach and use is itself part of the sign formation process and that linguistic rule formation takes its point of departure in the repertoire of existing forms whether they are already defined in one or several - possibly overlapping - ways or only exist as redundant or potential forms.

It could also be said that the common spoken and written languages are characterized by a semantic rule formation, that this is part of the practice it regulates and that rule formation occurs in the form of a shifting balance between several different, available linguistic rules and non-linguistic interferences.

The relationship between what is preconditioned and that which is expressed is not a relationship between a precept and an execution of the programme, but a semantic choice which delimits the expressed relative to an intention and a receiver. Further to this comes the fact that the concept of linguistic redundancy itself is, in an important sense, contrary to the distinction between a programme and an execution. On the one hand the redundancy function constitutes an alternative to precepts. Redundancy brings about a stability which, in its absence, would have to be filled in by a programme. On the other hand, it is not possible to speak of the concept of redundancy before there is a manifested expression, as redundancy can only be determined relative to physiological and semantic distinctiveness.

It is therefore not satisfactory, as Paul Ricoeur does, to simply supplement semiology, understood »as a science of signs in systems« with »a semantics, or a science of usage, of the use of signs in sentence position«. Ricoeur motivates his distinction with the point of departure in the poly-semantic character of language which

*in purely synchronic terms... signifies that at a given moment a word has more than one meaning, that its multiple meanings belong to the same state of system.*³⁸

while in diachronic terms polysemy is the actual result of an ongoing semantic exchange of meaning, which is again determined as follows »that the word is a cumulative entity, capable of acquiring new dimensions of meaning without losing the old ones«.

While the diachronic and semantic dimensions are thus characterized by »a factor of expansion, and, at the limit, of surcharge« the synchronic system dimension becomes »the mutual limitation of signs within the system« seen as a necessary brake which means »that the new meaning finds its place within the system«.

It is clear here that Ricoeur is wavering between the view of synchronic description as a description, with regard to meaning, of a transcendental form system »which can be treated without any reference to history« and as a »thumbnail sketch«, a certain stage in a process - and hence a history - in which the system is included as an acting force. He describes the relationship between the synchronic and the diachronic as a collision process between two completely separate systems, where the former changes the latter, but itself remains untouched.

The condition which allows the system to work limitationally in relationship to the semantic expansion, however, is that it is semantically sensitive itself. The meaning of the one word cannot fall into place unless the system permits continuous and unpredicted semantic changes in the linguistic surroundings, i.e. changes in the extent of the rules and/or changes in the content form and/or expression form without which a change in meaning cannot be manifested.

That language can contain this polysemy at all, which according to Ricoeur is the characteristic proper of language, is due to the fact that the regularity of

³⁸ Ricoeur, (1969) 1974: 93-94.

language is formed in continuous modulations and crystallizations in redundancy structures which permit the same expression elements to be both rule-bearing and meaning distinctive, often at the same time, but also in a mutually variable relationship. This implies that the entire structure, and not only meaning, is included in the semantic dimension. The synchronic description must therefore be seen as an idiomatic, photographically frozen picture of a specific state whose relationship to preceding and subsequent states is open to semantic variation and to the introduction of new rules and structures, or the suspension of old. Polysemy includes the rules of language, which only exist if they are accepted and are only accepted if they further a semantic relationship between a sender and a receiver.

If the rules of language were available in the form of an invariant rule structure, language would be highly suitable for presenting unambiguous messages, as there would be a declarative expression rule for each meaning entity. In such a - for example mathematical - language, an expression such as »goddag mand økseskaft« (»hello, man axe-handle«) cannot be articulated, although in Danish this phrase is actually used to tell people that they are talking nonsense. Nor would a critical reading of such a text be possible.

7.8 The redundancy structure as a criterion for distinguishing between semantic regimes

If we were asked to name the last 5-10 words - or the last sentence - we had read, we would generally have to think for a while, it is easier to reproduce a meaning than to repeat an expression we have read. If we were asked instead to name the last 5 or 10 letters, or to spell the last word, this would also require some thinking. The path to the recollection of the letter appears to go through the recollection of the word and the path to the recollection of the words to go through the recollection of the meaning. While the distance between word and meaning corresponds to great freedom to choose words to express a meaning, the distance between the word and the letter with regard to recollection is more striking, as there are fixed bonds between the word and its literal manifestation.

Things are different in spoken language. It is often possible to repeat without difficulty something which has just been said. On the other hand, we do not possess the same fixed codex for dissolving words into a phonetic inventory. Whether it is possible to carry out a phonetic or phonological

dissolution of words into sound components plays no important part in language competence. While spelling is a facet of the ordinary learning of written language, phonetic transcription is a purely professional accomplishment in spite of the colossal importance we attach, individually and collectively, to correct pronunciation.

It is clear that the phoneme does not play the same role in oral language competence as the grapheme does in writing, but where does this difference lie?

One possibility is that there is a structural difference between the auditive and the visual sensory apparatus. But it is difficult to see why visual mediation should demand closer ties between the written word and its graphemic representation than the auditive mediation demands between the spoken word and its phonemic representation, not least if, with Havelock, we see the alphabet as a visual representation of the phonemic structure of spoken language.

It is therefore more reasonable to view this difference in the light of the different communication structures of the spoken and written word. Whereas speech - with the air as its medium - is transient and the relationship between speaker and listener is contemporaneous, writing is fixed and the relationship between writer and reader is non-contemporaneous.

As contemporaneousness between speech and hearing implies physical closeness between speaker and listener, the speaker is also able to use other possibilities to express himself. The phonetic inventory does not exist alone, it is accompanied by accentuation, stress and gesticulatory signals as means of articulating meaning, just as the speaker can utilize the receiver's reactions as part of the stabilization and clarification of the message.

These structural differences determine a difference in the expression economy of speech and writing. While the speaker, in speaking, can *both* use multiple auditive, visual and possibly also tactile means of expression *and* economize with the expression under the impressions of the signals which are emitted by the receiver and the surroundings, the author of the text can only use graphemic means of expression and must himself, in advance, establish his interpretation of the necessary relationship between redundancy and distinctiveness in the expression.

It appears from this difference not only that the grapheme must handle many more tasks than the phoneme, the graphemic manifestation must also transpose the simultaneous manifestations of speech (and those which are not linguistically expressed, e.g. 'shown' meanings, gestures, for example) to

successive sequences. The fixed graphemic structure of words, which in writing is further emphasized by the blank sign which separates graphemic blocks from each other, are not equivalent to the phonemic structure of speech.

There is thus also an exceptionally good reason why the phoneme does not play the same role for spoken language competence as the grapheme does for competence in writing. The phonemic inventory is simply not the elementary particle of spoken language in the same way as the grapheme is for writing. There are three reasons for this.

First, the phoneme as a unit is larger than the smallest possible semantic expression unit. Different accentuation, (voicing, stress, the Danish glottal stop, strength and volume of voice), of the same phoneme can be semantically distinctive.

Second, the phonemic manifestation is subject to great individual and group variation. Handwriting too has its individual variations, but this variation appears to permit far from the same rich set of possibilities for semantically distinctive use. The individual variations of handwriting have also traditionally been seen as a stylistic phenomenon which may characterize the personality of the writer.

Third, consonant articulation, which in writing is represented by separate graphemes, is precisely a con-sonant modulation of vocalization. We simply cannot pronounce separate consonants without a minimum of a sonant resonator. Distinctions are always distinctions in something.

Whether phonemes actually exist at all as a clearly delimited, acoustic entity can be discussed, whereas the existence of graphemes as manifest, graphic entities is indisputable. The difference also appears indirectly from the difference between phonetic notation and written language, as phonetic notation produces many phonemic variants of the same word, while written language uses an almost complete - semantically - invariant graphemic manifestation.

It is clear that fixed spelling serves to make word recognition easier. As a consequence of the fact that this occurs in a different way in writing than in speech, the economic alleviation argument must be seen in the light of the written communication structure and not as a manifestation of a general economic law of language.

Where writing with the blank sign and the graphemic invariance of the individual word support the *word* as a far more invariant and distinctive entity than speech, it expresses a difference between the semantic potential which

lies in the different time structures of the two languages. This difference in time structures is given in and with the properties of the expression substance.

It is correct that, as a whole, speech, like writing and reading, can be regarded as a linear sequence in time, but it is not correct that the expression elements of speech are articulated (or understood) in a linear succession similar to that of writing.

The multi-dimensional time-space of speech is only possible because speech elapses in time, unlike writing which appears as a closed and simultaneous manifestation of the entire expression. Correspondingly, we can only understand speech at the time, place and in that order it is pronounced, whereas the reader can read at any time or place and is completely at liberty to turn the pages backwards and forwards, skip a page, put the book down or read it again.³⁹

Whereas the reader, however, must take note of what he reads, put away the text or make objections *post festum*, the listener has a broad range of possibilities for intervention: from the continuous confirmation of understanding, through quizzical facial expression, interruptions, supplements, amplification, dialogue, objections, contradictions, to argument, fighting, or departure - or bloodiest of all - murder. The solitude of writing, however, does offer the author the clemency of being able to exploit the distance of time - and thought - to correct or - perhaps - protect himself before the message is sent out into the world.

The graphemic freezing and sequencing of the contemporaneous field of speech thus constitutes a micro-structural difference in speech as a dialogic and writing as a monologic medium. This micro-structural difference remains, although speech can be monologic or writing dialogic. In speech the expression is not alone and is accessible to variation as it is produced. Writing, on the contrary, - in order to stand for itself - must use a certain expressional invariance speech does not need. As expression systems, speech and writing are separated by their semantic variation possibilities.

The difference between speech and writing is therefore basically a difference in the redundancy structures of the two expression forms, as the expression substance offers different semantic variation mechanisms. Although this structural difference can be modulated, the two expression forms drawn closer together, it is not so plastic that the one system can be made to cover the entire expression potential of the other. Many sentences can without further

³⁹ This difference can still be maintained in a modified form even though there are means (recitation, telephone, radio and tape recorder) to repeat and/or transmit speech at a later time and/or another place.

ado be produced in both systems, but both systems also permit meaning expressions which cannot be produced in the other. Here we are cut off from the possibility of providing genuine examples of spoken language which cannot be expressed in writing, but the present text is an excellent example of a written expression which cannot be produced in spoken language.

The difference reaches further that the difference in production potential. Not all expressions can be translated either, once they have been produced. It is quite true that it is possible to read any text aloud, but a number of texts have been written which could not be understood if they were read aloud, such as theoretical texts which operate with hierarchic sentence structures, highly specific concept formations and low meaning redundancy.⁴⁰ Conversely, written language can in many cases reproduce spoken language through a detailed linguistic (and sequentially ordered) account of the many non-linguistic (and simultaneously expressed) elements which are included in the meaning expression, but not in what is pronounced in language. In this case, it is not the complexity of the sentence structure which hinders representation, but the complex, non-linguistically expressed - meaning distinctive - situation, whether the meaning is given by an existing interpretation community or is only produced during the act of speaking.

Speech and writing have different relationships to Hjelmslev's »purport« and »substance«, both on the expression and the content side.

Where the clear meaning in spoken language builds upon a complicated, non-linguistic context, this context is not expressed in the spoken language even though it is semantically distinctive. The circumstantiality with which such a speech must be retold or written down for others reveals that contemporaneity, which determines a possible interaction between the event and the narrative and/or between the narrator and listener, also confers a chronological dimension on the spoken language's redundancy structure which is unknown in invariant writing, although it is both produced and read in a one dimensional, linear progression in time.

The difference which exists between the linguistic competence of writing and speech corresponds to a difference between their redundancy structures, which implies a difference between the distinctive potentialities of the two languages.

The two languages, however, are at the same time each other's subset. Seen in relationship to other sign systems this kinship appears characteristically as a

⁴⁰ This structural difference becomes very extreme if we also include in writing numerical-algorithmic and mathematical notation, which can only be handled to a limited extent without writing.

kinship in the same area, which mutually separates them, namely the redundancy structure.

While written language is distinguished from spoken language by the redundancy structure of graphemic notation, writing and speech have a simultaneous manifestation of redundancy and distinctiveness in common. These two languages thereby distinguish themselves from both pictorial and formal expression systems.

Written language shares the manifestation's spatial two-dimensionality with other pictures, but not the linear sequencing of space. All relationships are manifested at once in the picture, but are not bound by any succession sequence. Although the distinctive features - the forms - appear against a background and in relation to other forms, no fixed redundancy structure is included in the pictorial expression, as no delimited notation system exists.

It is true that colour in a certain sense constitutes a kind of equivalent to the linguistic redundancy structure, as forms can only be manifested as differences between colours. These differences possess a plastic variability, but the relationship between colour and form itself is invariant. Even though the form can be determined through the critical thresholds for colour transitions, the relationship between colour and form is different to the relationship between redundancy and distinctiveness. Colour cannot be manifested as form, nor form as colour, as the form always and only manifests itself as a difference between colours. The relationship is not open to semantically motivated change, whether the colour is seen as the form's - random - substance or colour variation is seen as the material structure of form.

In a certain sense it could be said that picture formation, similarly to language formation, is characterized by over-determination (overlapping rules), by the simultaneous effect of several norms and rules, but picture formation is also characterized by irregularity rather than the possible suspension and variation of the extent of the rules. While the individual picture constitutes a complete, closed and ordered entity, the picture as an abstraction has no definable order structure. No classification of the pictorial expression can be made on the same scale as for spoken and written language because the pictorial expression is not bound to well-delimited notation systems.

This does not mean that certain pictures cannot be classified on the basis of a notation structure. On the contrary, it is quite possible to classify certain types of picture in this way, as distinct from others, including groups of pictures which use other notation structures. A typical example in this connection is the difference between a television picture and a computer

generated picture on a monitor which are precisely and solely distinguished through the two different - invisible in themselves - underlying notation (or signal) structures.

Although the grapheme is a picture form which as such can become the object of aesthetic consideration and variation, it is at the same time subject to an acquired interpretation regime which includes the separation of the graphemic forms, for example in the form of an abecedarium and an established rule set for reading - for example in the form of a linear succession. It is not possible, on the other hand, to distinguish the letter from other pictorial forms simply by pointing out the letter's arbitrary, non-iconic character, as all pictorial forms can be dissolved into non-iconic form elements with division into individual points as the most radical subdivision.

The graphemic picture is thus determined by its belonging to an established inventory and by a chronologically defined, usually one-dimensional reading order. Herein also lies the fact that the grapheme is not defined by its invariant form. That this is the case is also shown by the way we can recognize with surprising certainty a great number of different A's as »A« and also distinguish many similar manifestations as »not A«, whether »not A« is another grapheme or a non-graphemic pictorial form.⁴¹

The continuity of possible pictorial forms constitutes the redundant background for the distinctive occurrence of the grapheme. Writing thus rests on a simultaneously redundant and distinctive utilization of pictorial forms. The recognition of the individual grapheme, however, is at the same time supported

⁴¹ Stjernfeldt, 1990, discusses this, taking as his point of departure Douglas Hofstadter's question, what is A and I? Hofstadter, 1985. With support from J. Petitot, Stjernfeldt suggests a topological description of graphemes, as he assumes that the topological categories have ontological status: »The categorical perception of writing and its base in a combinatorial of topologies seems to indicate that the reason for categorization of letters is the same as for the categorization of the phenomenal world - thereby suggesting an *interface* intermediating the two being topology«. Stjernfeldt does not explain, however, how topological mathematics - or simply J. Petitot's idea of a mathematically describable categorical perception - deserves such an ontologically privileged position rather than a number of other transcendental form concepts. As the human perception apparatus itself has a history of origin and development it is not easy to see how an invariant topological picture of perceptual structures can be applied. The difficulty is indicated by the use of the concept »combinatorial of topologies« because these combinations are not themselves contained in the topological description. But I must admit that as far as I know there is no other satisfactory explanation. However, it can hardly be unreasonable to assume that an explanation must, under any circumstances, operate with indefinite, critical - mental - thresholds for the transition between physical form and symbolic form, pictorial form and grapheme, between graphemes mutually and, as far as notation systems are concerned, indubitably also semantic components, as the distinction of notation systems assumes a significant competence in making symbolic abstractions which can hardly be explained without reference to pre-existing symbolic activity based on less established, »semi«-discrete means of expression.

by the manifestation of other graphemes, which in this connection act as a manifested graphemic redundancy.

While the notation system and the social bond between form elements distinguishes the graphemic picture from other pictures, the picture's contemporaneousness has a counterpart in spoken language. But where the picture's contemporaneousness is established by freezing the expression, (and separating the sender from the receiver) the contemporaneousness of spoken language exists between the sender and receiver who are related in a sequentially developed semiotic relationship which allows variation of the expression during the articulation.

On the face of it, it may be surprising that pictorial and formal expressions, which appear to be diametrical opposites, have in common that they distinguish themselves from language through one and the same circumstance, namely the absence of structural redundancy which is a characteristic of linguistic expressions. The absence of this redundancy at the level of physical manifestation also has a different - form.

While pictorial structures appear with no relation to the redundancy structure of language, (the redundancy structure of writing has, on the contrary, pictorial structure as a precondition) formal notation appears through the elimination of linguistic redundancy. The means to this elimination is a prescriptive declaration of unambiguous rules, the purpose of which is to overcome the polysemy of language.

While language on the one hand is characterized by the fact that any element in the language system can be subjected to variation - just as any rule in a computer programme can become data - on the other hand, unlike the programme, it is characterized by the fact that variation appears as a result of a semantic operation which is manifested as a shift in the relationship between redundancy and distinctiveness. This shift can, as will be evident, occur through variations on one or more axes: as a new utilization of a random form through repetition, as a variation of a pre-established pattern, through its strength of significance and/or through its content of significance. That this is a semantic shift implies that it need not - such as in the programme - be declared *prior* to its effectuation.

With the preceding unambiguous rule declaration the formal representation is given a redundancy structure which is distinct from that of language, as the rule simply defines the distinctive expression by distinguishing the indefinite redundancy potential as superfluous. While the formulation of the rule occurs as a semantic operation in linguistic form, the expression of the rule occurs in a

formal form through a replacement of the linguistic notation by a formal notation.

As both the redundant content and expression elements are thus distinguished from the formal expression, this expression does not have the same semantic variation potential. To the chronological distinction (the declaration of rules always precedes the execution) belongs a structural or logical distinction between the open, semantic operation and the formulation of the closed, formal expression. All transitions between redundant and distinct occurrences thereby become subject to a sequential time relationship where these transitions in language can be defined in a simultaneous relationship with the definition of redundant features.

Now the definition of any redundancy structure necessarily contains the definition of distinctiveness. It is the relationship which defines each of the features in the relationship. It might therefore also be tempting to regard the semantic potential of the formal expression solely on the basis of the programme which is rooted in the semantic structure of the language, as this can only be formulated with a linguistic articulation as a starting point and working means.

This, however, is not sound. Although the distinct formal expression - the operational procedure - is characterized by the fact that the semantic content, the establishment of the relationship between redundancy and distinctiveness, is defined in advance - and outside - the distinctive, formal expression, the expression appears as a distinct linguistic procedure subject to a delimited, specific to the expression, set of semantic variation rules. This set is not simply a chosen set of linguistic variation rules, it is a set of rules which as a whole is characterized by a different relationship to other rules than that between linguistic rules.

This different relationship to linguistic rules is manifested in a structural difference in the definition of graphemic expressions, rules for sign sequences and in the linguistic and formal sentence construction. In the formal expression it is necessary to declare the semantic value of each expression unit. Although the alphabetical notation units are often used, the individual notations do not appear with their alphabetical value or function, they no longer belong to alphabet of language. In the same way, the rules of language for notation sequences are also rejected in favour of the demand for a specific definition of the relationship between a given notation and the next. Finally, where a linguistic utterance can be a single sentence, a formal expression always requires at least two.

Even though, seen in isolation, the formal expression can be described as a defined relationship between defined entities, in the most literal sense the expression has the definition as a precondition. The semantic analysis of the formal expression is only possible if this precondition is taken into account.

The bipartite formal sentence structure is not equivalent to the principal clauses and subordinate clauses of language, as these are not subject to the same declarative definition of the redundancy structure. With the demand for declaration, the formal expression is connected with and part of language, but with this declaration an expression system based on non-linguistic rules is created.⁴²

While we thus in the relationship between language and picture have two separate expression forms where the structural connection - as far as written language is concerned - is limited to the notation level, in the relationship between linguistic and formal notation we have two separate expression forms which are both included in a historical and structural internal connection of a syntactical and semantic character. The formal expression form is an expression of a linguistic meaning content and the formal expression's content is specified through a linguistic expression form.

As the formal representation overcomes the polysemy of language through the elimination of the - for language - bearing redundancy structure, the relationship between the two expression systems necessarily contains a tense negation with comprehensive and often discussed epistemological implications.

The relationship between the *linguistic* structure of these two languages, however, has played a surprisingly modest role in these discussions, often subordinated to transcendental considerations of truth. The relationship between linguistic and formal representation has either been seen as a variant of the relationship between everyday language and scientific language, or as a difference between language and non-language, which, for example, could be described as the history of arithmetic or the use of signals, where a weak parallel to written language is only drawn in the introductory reference to the extent of this history.

⁴² In formal expressions at least one decision - as a condition - has been made which need not have been made in a linguistic expression, for example that two + two are four, while »two by two« in language can both be four, but also, for example, refer to a procession with an indefinite number of participants who move - two by two, or to phenomena which often occur between two, such as, for example a widespread and well known reproductive procedure where $1 + 1$ can both become 2, 3 or 4, or almost overwhelming.

The explanation of this circumstance should, however, hardly take the form of a criticism of tradition. That the formal representation - in spite of its thousands of years of history - only rarely gave rise to linguistic considerations shows first and foremost that it has been far from obvious - and perhaps not particularly relevant - to regard formal representation in its - semantic - relationship to language.

Whether formal representation creates a foundation for a special language can still not be taken as given. On the other hand, it is given that the dramatic expansion of formal representation competence over the past 50 years also includes in-depth changes in the relationship between linguistic and formal representation.

These changes, however, are based on the appearance of informational notation which, among other things, is distinct from both linguistic and formal notation because it can contain them both in the same expression form.

As this revolution marks a significant historical change in symbolic representation competence and has its centre of gravity in a new definition of the concept of information, the new symbolic competence will be treated here separately under the term informational representation competence.

Through a coincidence, which is perhaps more than a coincidence, a crossing of a historical and structural perspective in informational representation leads to one and the same starting point, namely the redundancy structure of informational representation. While the structural path to here starts with the relationship to language, the historical path starts with Shannon's theory which, with its establishment of a mathematical scale for measuring informational redundancy, became one of the theoretical starting points for the informational revolution.

8. Informational notation and the algorithmic revolution

8.1 The problem of noise theory

As appeared from chapter 6, Shannon used the information concept as a concept for an expression unit which could be defined independently of the language in which it was included, as the individual notation was primarily defined as a physical value. The exact definition of the physical form of the notation, however, was not sufficient to define the individual notation unit because any physically defined notation form can also exist as a physical form without being a notation. In other words, a semantic component is also included in the definition of informational notation.

As this holds true in general of all notation forms, the conclusion was drawn in chapter 7 that the use of notation systems assumes a double coding of the individual notation unit, as there must both be a coding of the physical form - relative to the physical background noise and to the physical forms of other notation units - and a coding relative to the occurrence of the same physical form as an unintentional, illegitimate form.

While the first coding appears as a solution to a purely physical noise problem, the second coding appears as the solution of a semantic noise problem. This appears, in other words, to be a question of two mutually independent code procedures which answer two clearly distinct noise problems.

The relationship, however, is more complicated, as Shannon's analysis also showed that it is possible to compensate for an elimination of redundancy in the physical notation structure with a semantically determined redundancy. There is thus an inner and variable relationship between the two codings.

This conclusion therefore gave rise in chapter 7 to a more detailed investigation of how noise problems are solved in other notation systems - primarily those of common language and formal language. It appeared from this that there is always an internal connection in the solution of the two noise problems in the individual notation system and that this internal connection differs in different notation systems.

While some differences are concerned with the use of the physical properties (i.e. some of the properties) of a given expression substance in different ways, other are concerned with utilizing different properties in the same expression substance and others again of differences connected with the mutual differences of expression substances. Finally comes the additional fact

that different properties (of the same or different expression substances) can be utilized to solve the same problem and that the different notation systems each have a set of possibilities for substituting the use of semantic content criteria for the use of physical form criteria.

At the same time, the criteria used to establish the limits of physical variation establish a set of conditions for the semantic exploitation of the physical forms. The solution to the two noise problems is thus always a solution which establishes a set of semantic variation possibilities which can be used in a given notation system.

Although the comparative analysis took its point of departure in Shannon's utilization of the redundancy function to solve the noise problem, it was not possible to use any of his mutually inconsistent notions of redundancy to describe the different redundancy structures of common language. Moreover, a general definition of the redundancy concept was given and it was shown that notational redundancy plays a central role for the properties of common languages, as different semantic potentialities are connected with the notational redundancy structures of written and spoken languages respectively, just as it was shown that the use of notational redundancy structures distinguishes the common languages from formal languages, which are characterized by the elimination of notational redundancy.

The intention now is to resume and pursue the analysis of informational notation with the point of departure in the results of the comparative analysis.

In section 8.2, I show that the redundancy functions used by Shannon contradict his own definition of the redundancy concept, whereas it is possible to describe these functions with the help of the definition given in chapter 7.

In 8.3 - 8.5 there is a description of the semantic variation mechanisms of informational notation relative to linguistic and formal notation. In 8.3 the emphasis is placed on the informational use of properties which are also used in other notation systems, while the emphasis in 8.4 and 8.5 is on properties which are only used in informational notation, namely 1) the notation's independence of the demand for sensory recognition, 2) its mechanical effect and 3) multisemantic potential.

As the treatment of informational notation is based on the use of algorithmic procedures, the significance of algorithmic procedures for the semantic properties of informational notation is treated in sections 8.6 - 8.8, while the synthetic description of the informational sign function as a whole is the subject of chapter 9.

8.2 The redundancy concept in information theory

The central problem of noise theory in Shannon's analysis, as we saw in chapter 6, was the question of how to decide whether a given physical form appears as part of a message or as a result of an unintentional noise effect.

It is obvious that the way this problem presents itself is of particular interest in connection with working on electrical signals, because here the signal values are expressed through threshold values between varying amperage and duration in a continuous medium and where notation - as the most decisive factor - is handled (transmitted) independently of the human interpreter.

Shannon thus had good reason to make the notation form the object of a separate consideration independent of human sensory and meaning recognition. He also had good reason to speak of the general character of the way the problem presents itself, just as he found the right means to handle the technical problem, in that he suggested that transmission could be stabilized by increasing the redundancy of the message.

If we consider Shannon's own redundancy concept here, however, the suggestion is meaningless, as he used the concept of all forms of repetitive structure which - due to the repetitive element - are regarded as superfluous and without meaning for the content of the message. In addition, he assumes that this concept also embraces the rule structures which are valid for the given symbolic language and that meaning alone is contained in the signals which occur quite arbitrarily as deviations from any form of repetitive structure. On the basis of this redundancy concept the idea of stabilizing the message by increasing its redundancy is a waste of time. If redundancy is completely superfluous, it will naturally not help to add more of it to the message.

While Shannon starts by defining redundancy as that which is *without importance for* the meaning, he continues with two mutually different definitions of redundancy *in contrast* to the meaning, (the one equal to the system-determined part, the other equal to the alternative, possible, but unused choices). The redundancy concept he uses *in* the statistical description, however, is a fourth, as redundancy is defined here *independently of* any regard to meaning. With this definition, redundancy is solely determined by the statistical procedures used.

This redundancy - in accordance with Shannon's asemantic approach, but contrary to his supposition that meaning content is only manifested in the random variations - is thus completely independent of the meaning content and rule structure of the message. For example, Shannon would not be able to decide, on the basis of the determination of this redundancy in a message, whether the message existed in a common language or in formal notation. The redundancy function is solely determined here in relationship to the physical manifestation of the expression - i.e. the form of the expression substance.

As a consequence of this any message contains redundancy of this form, simply if a given notation occurs more than once, or simply if a single notation comprises some quantity of repeatable, smaller physical units.

With this definition, the idea of increasing redundancy in order to stabilize the message immediately becomes more understandable, because the elimination of the thus determined redundancy will unavoidably come to affect the content. It is therefore all the more peculiar that the method Shannon proposes for increasing redundancy builds upon yet another, fifth, definition, as he suggests that redundancy can be increased by adding a set of control codes so that the validity of the individual signal or signal sequence is conditioned by preceding and subsequent signals. This condition could be fulfilled by describing the notation system with the help of a formal semantics in which a numerical value is ascribed to the individual notation units. He thereby showed that it was possible to solve the semantic noise problem independently of the language in which the message appeared - and in this sense without regard to meaning.

Here, it is no longer a question of a purely statistically determined redundancy structure which can be described at the level of notation, nor of a redundancy which can be defined relative to the physical form, but of a determination of redundancy relative to a - formal - semantic interpretation of the notation's value.

The codes Shannon used to increase redundancy can neither be derived from an analysis of the physical notation nor of the stochastic procedure used. They can only be derived from a semantic interpretation of the given message, because the asemantic consideration - whether this is founded on the notation's physical form or on the statistical repetition structure - contains no criterion for distinguishing the random variation which is emitted by the source of the message from the random variation which is emitted by the noise source. Shannon's use of the redundancy concept in connection with these control codes only has meaning if the codes are seen in relationship to the

original meaning of the message. They are only redundant in this relationship because when compared to the code procedure and the physical structure of the notation, they are equally as distinctive expression units as the »meaning bearing« signals.

That Shannon did not attach much importance to the difference between these concepts can probably be explained by the fact that he used a formal semantics which was independent of the semantic structure of the original message, but in addition to this comes the point that the semantic redundancy concept (in that form in which it was defined relative to the expression substance) could be used on any notation system, just as it was also this concept which provided the economical advantage in transmission, whereas the semantic concept was an economical liability - albeit very small.

Shannon, however, not only used semantically determined redundancy because it was possible or economical, but because it was necessary, as the asemantic approach was not sufficient. It was only possible to eliminate the one redundancy structure by establishing another. Shannon's analysis therefore provides yet another important result, as it demonstrates that a variation of redundancy at one level can be compensated for by a variation at the other.

Shannon's analysis thereby also confirms - constraintentionally - that the redundancy structure is necessary in order to establish the symbolic legitimacy of the notation units and that the physical and semantic determination of the notation units constitutes two mutually connected variation axes.

Shannon's demonstration of the importance of the redundancy structure for positive physical-mechanical recognition is therefore not connected with his mistaken idea that any form of redundancy can be described with the help of a stochastic procedure. His own analysis shows, on the contrary, that a semantic component is always included in the stabilization of the expression unit in the physical expression substance and that expression redundancy enters into an internal relationship with content redundancy.

While the description of redundancy as a meaning independent »system function« must be abandoned, Shannon's use of a meaning related redundancy structure confirms first that the redundancy function is a precondition for stabilizing the expression form in the expression substance and, second, that it is also a precondition for the establishment of the sign function as a link between the expression form and the content form.

8.3 Linguistic, formal and informational mediation between the expression substance and meaning

While Shannon's analysis on the one hand - directly contrary to its main purpose - leads to the conclusion that it is not possible to provide a purely physical or algorithmic - or other form of asemantic - description of notation forms, it also reveals on the other that the »physics« of notation forms, the manifestation of notation forms in the expression substance, plays an important role for the semantic use of the notation system.

This too only appears indirectly because Shannon uses the electrical signal as a prototype of the concept of notation. He thereby assumes, 1) that the informational form has an unambiguous physical value, 2) that a notation unit in an arbitrary notation system is defined by a set of - very few - invariant physical values (signal strength and duration), 3) that the same yardstick is used for the definition of the different notations, and 4) that the individual notations follow each other in a single-stringed serial order or in synchronized parallel series.

It appears to be possible to fulfil these four conditions with the necessary precision as far as energy-based mechanical transmission systems are concerned, where communication is understood solely as a question of reproducing the same physical manifestation:

The fundamental problem of communication is that of reproducing at one point either exactly or approximately a message selected at another point.¹

While these four assumptions on the one hand exhaust the possibilities of a precise physical definition - it is not possible, on the other, to solve the second problem of physical noise with more precise physical criteria for the definition of notation units - they give far too narrow a picture of the possibilities we have for utilizing the physical expression substance for symbolic purposes.

While all notation systems are based on critical thresholds which delimit the notation system relative to the physical medium and the other notation units, the distinction of physical forms can be brought about in several ways, each of which is connected with a set of semantic variation mechanisms, as the solution of the physical noise problem is connected with the solution of the semantic noise problem.

¹ Shannon, (1949) 1961: 31.

As appeared from chapter 7, spoken language, which uses far less precise physical criteria, contains such possibilities as sound variations, tonality, stress, dialectal and sociolectal characteristics etc., which can be used for distinctive purposes. Spoken language thus permits the physical values to be varied during use, while the demand of informational notation for an exact physical definition implies that the possibility of variation is excluded. The different relationship to the expression substance gives the two expression systems different semantic potentialities.

This is not only true in the sense that different stability criteria are connected with the different physical expression substances, but also in the sense that the same problem can be solved in different ways - also within the same notation system - as the semantic component which is included in the definition of the individual notation unit can be included in several ways.

Shannon's own analysis also provides examples of both, as he is concerned both with the differences between analogue and discrete signal systems which are based on different forms of the symbolic use of the »same« physical expression substance and - as we saw in 8.2 - both with expression and content determined redundancy as a means of stabilizing a message in a given notation system.

In these cases, the redundancy function serves first and foremost as a means of stabilizing the message's expression form in the expression substance, as the redundancy function helps to distinguish the legitimate physical forms from the identical - as well as the non-identical - illegitimate forms. But the effect relative to the expression substance can on the other hand only occur because the redundancy function also has a semantic component, so that the stabilization downward is connected with the stabilization of a superjacent level, whether this is the notation level or the semantic content level.

Redundancy thus also serves to distinguish and stabilize a level above an underlying level and to make possible the formation of new superjacent levels. The precondition for this duality is that the underlying notation system as a whole is included as a redundancy potential for a semantic utilization at a superjacent level.

There are examples of this in connection with linguistic notation in chapter 7, as we saw here that the legitimacy of the notations could be founded both on habitual conventions for notation sequences, syntactic rule structures and on the semantic context. In addition to this is the fact - compared with the number notation system, informational notation and the Morse alphabet - that a reasonably large number of different notation units are used, which make it

possible to use conventions for illegal, but possible combinations, while any combination of numbers, for example, can be legitimate. As examples of illegitimate combinations in Danish we can mention /dn/ in the same syllable, the occurrence of a number of consonants (e.g. - b, d, f, g, h,) before /s + vowel/ in the roots. Over and above illegitimate combinations there are also many combinations which are not used, but which are more legitimate.

Although the different methods for solving the noise problem of written language notation are often used simultaneously, with over-determination as a consequence, these provide no complete guarantee. Over-determination contributes to an increase in the stability of language, but does not exclude such things as the occurrence of printer's errors which completely alter the sense of what has been written.

The solution in written language of the problem of noise, however, is not only concerned with the establishment of criteria for legitimate occurrences. The methods used simultaneously establish a framework and possibilities for utilizing the notation units as semantic variation mechanisms.

The habitually established conventions, the semantic context and the syntactic rule structures not only each make their own contribution to a stabilization of linguistic notation, they also each provide their own set of conditions for the use of the smallest semantic variation mechanisms, while over-determination also provides considerable room for semantically motivated deviation from rules and conventions.

The linguistic solution of the noise problem is thus connected with 1) the use of semantically empty notation units, 2) the limited use of rule determined notation sequences, 3) a relatively large latitude for semantically motivated rule, norm and convention deviation.

The extent of the semantic variation potential was shown, among other things, by the fact that the rule structures play a much smaller role for the stability of the notation systems than the convention determined norms and the semantic context. The rule structure thus works mainly on the relationship between whole words (rules of word order) and suffixes (and possibly from there back to the root).

The use of rule determined notations plays a limited role in the linguistic solution to the noise problem and there are no overall rule structures for the use of the various means of stabilization either. The stability of linguistic notation depends on a plurality of different mechanisms, each of which is accessible to semantically motivated variation. Conversely, over-determination permits the notation forms to undergo change without meaning being

affected. Such changes, *which necessarily arise as - individual - variations*, can later emerge as new rules of expression.

Dissimilarly to this situation, formal notation systems operate only with semantically determined notation units, as the individual notations are either determined by a rule function or a content value.

While written language notation is stabilized through the use of a great number of conventional notation sequences, stable rule structures, over-determination and the meaning of the context, formal notation has few built-in stabilization mechanisms. Formal notation gains its precision by replacing the redundancy structure of written language with a semantic definition of the value of each notation unit. The content form is unambiguously connected with the expression form through this definition. The formal expression therefore not only has a different and greater vulnerability with regard to printer's errors - i.e. the occurrence of unintended, physically legitimate notation forms - it also has a different potential for semantic variation.

While the linguistic notation unit is a semantic variation mechanism which can only work through the context - having no independent semantic value - the formal notation unit is a semantic variation mechanism which only influences the context through (a change in) its own semantic value. As the declaration of the value of the individual notation (as a referent to a general rule or to the content which is regulated) is at the same time a declaration of the physically legitimate notations, formal language permits the use of an indeterminately large number of »local« notations, whereas common languages operate with a limited (although modifiable) number of general notation units. Formal notation substitutes linguistic notation redundancy with a rule determined notation, as the definition of semantic value is always connected with the definition of a certain physical form.

In spite of these differences, the notations in both systems are basically determined through their function as semantic variation mechanisms, while the physical definition is primarily based on criteria of identity and difference which can be registered by the senses. The sensory criterion is not distinctive in the relationship between these notation systems, but on the contrary, to a great extent determines the use of linguistic notation units in formal notation. While formal notation can use any linguistic notation unit for its own purposes, language, on the other hand, can express any formal content.

Informational notation has both a number of features in common with the common languages, a number of other features in common with formal lan-

guage and finally, a number of features which are unique to this notation system.

The kinship with written language notation comes first and foremost to expression in the fact that both notation systems are based on the use of semantically empty notation units, that no separate rule notations are used and that a limited set of notation units is used. But even in connection with these points, there is still no complete identity, partly because written language in some cases permits a notation unit to have an independent semantic value, which is never the case with informational notation, partly because written language permits the introduction of »locally valid« notation units, which is not possible in informational notation either.

The two notation systems, however, are also distinguished by a number of other points. First, written language notation is subject to the demand for sensory recognition, where informational notation is subject to the demand for mechanical efficacy. Second, written notation - as described in chapter 7 - uses a number of different forms of notational redundancy which cannot be used in informational notation, just as written language uses qualitatively different notation units (vowels versus consonants, punctuation marks etc.) while it is not possible to qualitatively determine the informational notation units. Third, the entire inventory is used in all informational expressions, no matter how short they are, whereas common language uses a variable range.

In addition to this come differences in the relationship between the notation system and the expression substance. Both spoken and written language and formal notation thus allow considerable latitude with regard to the physical form of the »same notation units«. Informational notation, on the other hand, is subject to the demand for an unambiguous, invariant definition of the physical form of the notation units and this form cannot be varied during use.

The unambiguous definition of the physical form permits the emancipation of the notation from the demand for direct, sensory recognition, while conversely we must say that this demand, which holds true of the human recognition of letters, is not based on an unambiguous invariance with regard to form. It is thus not possible to use the physical form of letters as the smallest physical expression units in energy based media, while it is conversely extremely difficult to use the human sensory apparatus to handle a notation which is defined by physical criteria that are not subject to the demand for sensory recognition.

Different discrimination procedures are thus used in distinguishing the physical features of notation systems. Distinguishing physical characteristics

occurs in different ways and these differences are of exceptionally far-reaching importance for the possible uses of the physical form for symbolic purposes.

The difference in the physical definition of different notations is not dissolved by the fact that it is possible to convert an expression which appears in one form to that of another. The different forms still provide the possibility of different kinds of use. The most striking difference is that the informational notations lack any kind of quality in the definition implying that any possible quality can therefore be ascribed to a constellation of the same two units.

In spite of these differences, the kinship between these notation systems is considerably stronger mutually than the kinship between informational and formal notation systems. First, there are simply fewer similarities between informational and formal notation. As shown in the table of the typical characteristics of chosen notation systems below, there are only two common features (namely single-stringed seriality and no utilization of redundant notation sequences), of which the first must still be modified, as we shall see in section 8.4. Second, the differences between informational and formal notation are of fundamental importance for the properties of the two notation systems. Whereas formal notation only operates with semantically determined notation qualities, as all notations are either rule or data notations, the ascription of meaning in informational notation is connected with sequences of notation units in which rule and data values - similarly to language - are manifested in the same notation units. The individual unit is used both as a notation unit in sequences which can represent a rule, and sequences which can represent a content value.

Finally, in addition, is the fact that formal and informational notation are also distinguished by the way the semantic value is bound to the physical manifestation. Although a semantic component is part of the definition of the physical form of informational notation, this semantic component can be expressed independently of the semantic content of the informational sequence because - as was evident from Shannon's analysis - it could be brought about through an appropriate code procedure which did not affect the semantic content of the sequence. Informational notation is thus characterized by the possibility of distinguishing the definition both of the individual notation unit as well as of the notation system from the ascription of semantic content value and can therefore also be used as an expression system for a plurality of semantic regimes.

In formal notation systems it is also possible to ascribe a new value to an already given notation, but the relationship between the notational expression form and the content form are wholly rule determined for each individual notation unit and there is always a direct equivalence between the physical form of the notation unit and its semantic value.

Table of characteristic features of notation systems

	Spoken language	Written language	Formal notation	Informational notation	Morse alphabet
SINGLE STRINGED SERIALITY	-	+	+	+	+
PHYSICAL STABILITY	LOW	HIGH	HIGH	LOW	(LOW)
NUMBER LIMITATION	+	+	-	+	+
	PARTIALLY				
DEMAND FOR PERCEPTUAL RECOGNITION	+	+	+	-	+
MEANING ASCRIPTIONS TO INDIVIDUAL NOTATIONS	-	-	+	-	-
	MAY OCCUR				
REDUNDANT NOTATION SEQUENCES	+	+	-	-	-
DISTINCT RULE NOTATIONS	-	-	+	-	-
QUALITATIVELY DIFFERENT NOTATIONS	+	+	+	-	-

[Grey background indicates the greatest kinship group for the individual features – read horizontally.]

Remarks on the table:

The Morse alphabet has been included for the sake of gradation, although it is a notation system for other notation systems and not an independent system.

As the schematic simplification increases both some similarities and differences, it is necessary to supplement it with some remarks.

Single-stringed seriality: Where informational notation is concerned, the demand for the serial single-stringed feature can be suspended through interactive operations. Informational notation thereby acquires a feature which is reminiscent of that of speech, but, as will appear later, with completely different implications. This demand on notation, on the other hand, is not suspended in parallel processing systems («neural networks»).

Physical stability: The parenthesis under the Morse alphabet indicates that it can also be used in written form.

Number limitation: For spoken and written language the limit to the number of notation units is variable, as contextual and explicitly declared expression units can be introduced, which is not possible in informational notation.

Demand for sensory recognition: Informational notation is distinct here, as it is subject to the demand for mechanical effect instead.

Meaning ascription: A /+/ indicates that the ascription of meaning to the individual notation is a necessary condition, a /-/ indicates that it is not. In spoken and written language the ascription of meaning to the individual notation is possible in certain cases. It is not possible in informational notation. On this point, the table thus exaggerates the similarity between linguistic and informational notation. In the Morse alphabet, the notation units have both a distinct value as notation units for a notation unit in written language and as expression elements for those sequences which represent the other notations. A short signal represents both an /e/ and part of a number of other notations (letters, numbers etc.).

Redundant notation sequences: Redundant sequences can occur in all notation sequences. A /+/ indicates that non-rule determined (customary) notation sequences **occur** as typical and integrated features, a /-/ indicates that all legitimate notation sequences are rule determined, whether they are redundant or not.

Distinct rule notations: In connection with this point the table shows the same kinship as for that of the criteria of meaning ascription. While this kinship must be modified for meaning ascription, (c.f. above) it is adequate for distinct rule notation.

Qualitatively different notations: Here too, the table exaggerates the similarities between, on the one hand, the common languages and, on the other, formal notation, as it is a question of two different forms of quality differentiation. The notation qualities of common languages are primarily concerned with the distinction between vowels and consonants, but also of the occurrence of function signs (punctuation marks etc.). In formal notation, quality is solely determined by the definition of the semantic value. Qualities can possibly be classified, for example in rule and data notation, variables and constants etc.

Formal notation systems mainly use the expression substance as a means of stabilizing the expression, whereas the properties of the expression substance, both in common languages and in informational notation, are used as semantic variation mechanisms, but in a mutually very different way.

In informational notation the exact physical definition is used as a basis for the notation's mechanical effect. In spoken language, which has physically weakly - or broadly - defined means of expression, the physical variation is used for a multiplicity of semantic purposes (dialectal and sociolectal characteristics, distortion, irony, stylistic choice etc.). In handwriting the physical variation has a mainly individual stamp, while physical variation in printed matter is mainly an aesthetic means, which, however, from time to time - such as with italicization - is also used semantically distinctively.

Although the schematic arrangement cannot contain any description of the meaning of these characteristics, either individually or as a whole, it nevertheless shows a number of interesting connections and differences. It thus appears - if we initially ignore the Morse alphabet - that:

- The kinship structure between the different notation systems is different for each of the eight criteria.
- That written notation - as the only system - always shares characteristics with at least one other notation system, whereas the others have at least one characteristic peculiar to themselves. The table is not exhaustive, but does show that written notation has fewer unique features and several affinities.
- Informational notation has three unique characteristic properties (invariable number limitation, independence of sensory recognition, and the absence of qualitatively different notations). Formal notation also has three (necessary meaning ascription, no number limitation, distinct rule notations). Spoken language has one (non-single-stringed seriality), as informational notation, however, has one feature which is reminiscent of this² - and
- Finally, the table demonstrates that the different notation systems together are included in a joint redundancy system in which the individual variation mechanisms are included in mutually different connections.

The table exaggerates the similarities in three respects.

First, those features which are reproduced as common features cover very different variants. This holds true, as mentioned, of the qualitative differences in formal and common language notation, the non-single-stringed seriality in speech and informational notation, the demand for sensory recognition in speech and writing, the - low - physical stability of speech and informational notation.

Second, the table does not reproduce the differences which may be connected with the function of the individual qualities in the respective notation systems, as the same quality cannot simply possess a different function in itself, but can also possess it through the relationship with the other features.

The different demands made on the physical definition (more or less exact, more or fewer different physical criteria etc.) thus simultaneously contain a set of restrictions for the use of the expression substance as a semantic variation potential. The notational rule system is included in a connection with the overall semantic regime which is characteristic for each notation system.

² If we include the Morse alphabet, the latter point is modified, as the Morse alphabet also possesses two of informational notation's otherwise unique properties (invariant number limitation and no qualitatively different notations). Finally, the Morse alphabet is related to written language in the sense that it too has no unique characteristics which are not shared with at least one other notation system.

Third, the table does not reproduce the different forms of definition of the relationship between and use of the properties of the expression substance. Where linguistic and formal notation are primarily subject to the demand for sensory recognition, informational notation is primarily subject to the demand that the individual notation unit must be able to appear as a mechanically effective entity in a machine.

With this definition of the informational form relative to the physical medium and other informational forms there appears - for the first time in history - a non-sensorily determined, discrete, mechanically effective and semantically open notation system.

8.4 The unique characteristics of informational notation

Although a semantic component is always contained in the definition of a notation system, there were two important historical innovations behind Shannon's idea of an asemantic, purely physically defined notation system. One of these concerned the exact physical definition which is conditioned by the demand for the mechanical effectiveness of the notation units. The other concerned the definition of the semantic component of the notation.

While the semantic component in linguistic and formal notation systems is defined through the semantic regime in which the message is produced, the semantic component which is included in the definition of the informational notation unit is produced with the help of a formal code procedure which is independent of the semantic regime of the message. This coding can take place no matter whether a given data sequence represents a rule, a set of data, a text, a sound, a picture, or a physical machine.

It is this circumstance which makes it possible to represent both formal and informal semantic regimes in the informational notation system, or **conversely**: that informational notation can be used both as a notation for a numerical expression, for a rule of calculation and for a logical expression - where it is a question of using informational notation to represent a formal semantic regime - or as an expression of a linguistic message where a given notation sequence can represent a - semantically empty - linguistic notation unit - or as an expression of a picture or a sound subject to pictorial or auditive semantic regimes. At the same time, it also appears from this that it is possible to represent both linguistically, formally, pictorially and auditive expressed

information, each of which was formerly represented in its own notation system (or in no notation at all) in one and the same notation system.

In other words, informational notation is not subject to one specific, overall semantic regime in the same way as other notation systems. Shannon's »asemantic« consideration thus contains a description of a notation system which is relative not to a single, but to several semantic regimes. Shannon himself also prepared a list - under the term »information sources« of the different semantic regimes which can utilize informational notation.³

Now it is quite true that it is also possible to use the letters of the alphabet, for example, in formal expressions, but this use assumes that the letters are subject to the criteria which are valid for formal notation. Only the physical form can be transferred, not the linguistic qualities and functions which are connected with the form - whether this be the distinction between vowel and consonant, or conventions for notation sequences - and thereby not the semantic variation mechanisms which are connected with the form and its quality either. When the grapheme is used in a formal expression it no longer belongs to the alphabet of common language.

That which thus characterizes informational notation as a special and unique feature is the complete lack of quality in the definition of the individual notation unit. This complete lack of quality in the definition distinguishes informational notation equally sharply from linguistic and formal notation, each of which operates with its own form of quality determination and this lack is identical with complete openness to contextual determination. Informational notation is the closest we can get to a perfect, »pure alphabet«, and it can contain any form of symbolic content with the single - but not unimportant - restriction that it must be possible for the symbolic content to be manifested in a sequence of notation units belonging to a notation system with a finite number of mutually different expression units. The decisive point being not the number itself, but the condition that the number is established in advance. Whether we use 2, 5, 27 or 117 notation units is theoretically of no importance, but we can only use a definite, previously established number if we wish to utilize the mechanical properties of the notation system.⁴

³ C.f. 6.4 where this list is given.

⁴ In the 1940's, the binary form was the object of much discussion and the choice was made on functional, pragmatic grounds which included such elements as the physical layout of the machine, process efficiency and simplicity, although von Neumann also referred to the binary character of logic as an argument for emphasizing the computer's logical rather than arithmetical functionality. Goldstine, 1972: 260.

Although any notation system has a built-in semantic dimension, the value of the reductive idea of asemantic notation which lay behind the establishment of informational notation should neither be rejected nor underestimated. That the reach of the idea is considerably expanded because its effect is increased by the semantic dimension can be illustrated by a related historical precedent.

It was thus precisely such an asemantic handling of the alphabetical figures as singular, physical entities which comprised the pioneering innovation in Johann Gutenberg's typographical revolution.

This is not only a convincing, but in this connection also a central historical example. Although opinion is divided as to the correct interpretation of Gutenberg's typographical revolution, nobody disputes that it has had far-reaching cultural and historical implications. Here, we will simply consider a couple of the aspects which are of particular interest in relation to an understanding of informational notation.⁵

In itself, Gutenberg's use of movable type first and foremost implied an effectivization of text reproduction with regard to time and money, as the individual type could be reused for producing texts with a different content. A direct consequence of this was that books became cheaper and it became possible to increase the extent of book distribution.

The new technique, however, also implied a considerable improvement in the reliability of the copied texts, as through proof-reading it became possible to emancipate the text from the semantic bond which lay in the manual copying techniques of the Middle Ages where the reproduction of texts was subject both to the individual writer's interpretations and errors. The technique permitted - at least in principle - an asemantic proof-reading. Proof-reading itself could also be reduced to the proof-reading of the original proof rather than of individual copies. This advantage had become partly available with the introduction of wooden block printing, but block printed books were roughly as expensive as hand-written copies and a single mistake could mean the loss of a whole block, whereas Gutenberg's technique permitted the making up of a single or a few lines.

At the same time the conditions for semantic control were changed. Where this control in the Middle Ages could be exercised directly in the semantically rooted copying process, and be done efficiently because the number of

⁵ See Eisenstein, 1979 for further details. Gutenberg's personal role in the development of the new method of printing is still unclear, but as the method was developed at a printing house under his management, his name can still reasonably be used as a code.

possible copies was limited, the faster and a-semantic reproduction technique implied that semantic control had to be exercised externally - through a separate and visibly censoring hand. The technical form thus contained a quite obvious secular potential for posterity.

Last, but not least, it can also be mentioned here that Gutenberg's technique made it possible to store and manage a great body of knowledge which could not be managed, or managed only with difficulty, using the existing technology. This holds true first and foremost of all technically, mathematically and numerically expressed knowledge, where the demand on accuracy of detail and the individual notation is particularly rigorous - and highly limiting for the validity and use of manual reproduction.

The technique involved a manual trade, but as a medium for the representation of knowledge it fulfilled one of the necessary conditions for the entire industrialization process which followed later.

It is difficult to indicate precisely when printed knowledge became decisive for the technical development of modern society. It was not a precondition for the development of the early mechanical technologies - including that of printing. An epoch-making effect can perhaps first be noticed in the energy technologies of the 17th and 18th centuries, which were founded on technical, physical and mathematical knowledge which could not be produced, verified and managed without the printed book.

As a general medium for representing knowledge the printed book not only released a new technological and theoretical potential, it also became - as a medium for stabilized, generally objectified and theoretical knowledge which is available without respect of persons and power - one of the preconditions for the development of modern society from enlightened absolutism and the Age of Enlightenment to democratic movements and the constitutional division of power. When we consider that the idea of a free market and modern man's personality emerged as results of a comprehensive theoretical work of construction which - again through the medium of written knowledge - brought about far-reaching strategic developments and educational initiatives, it becomes clear that the printed book as a common, typical and distinctive medium for representing knowledge in modern society forms an essential part of the infrastructure of these societies.

It is thus the book rather than the computer which has made possible the transition to a society based on the utilization of theoretical knowledge as a strategic resource nor, therefore, does this transition - as Daniel Bell claimed -

characterize the relationship between industrial and post-industrial society, but rather the transition to modern society.⁶

It is quite true that the printed book is not a condition for any production of theoretical and technical knowledge since it is only a means of reproduction, but it is to a great degree a condition for the articulation of some types of knowledge and for the dissemination and use of existing knowledge. It is difficult if not impossible to imagine that theoretical knowledge can become a strategic resource in society without this or another medium with similar properties.

While Gutenberg's typographical inventiveness lay in the asemantic consideration and handling of alphabetical notation, the cultural and historical significance of the invention is due to the fact that this consideration paved the way for a number of previously unknown or unexploited semantic potentialities.

Viewed from this perspective the question therefore is not only whether the asemantic consideration of the informational notation system was right or wrong, but also which potentialities are embraced by this revolution in the technology of textual representation.

8.5 A notation that is not accessible to sense perception

In using printing to emphasize the cultural and historical perspectives which may be connected with an asemantic view of notation, it is necessary to add that this is a question of effects which first emerged during the course of a long period of time and as part of other cultural processes. Gutenberg developed his technique in the 1430's, but the printed book only became the most important, socially supporting knowledge and script technology several hundred years later and this was naturally not because of the medium, but of the knowledge expressed in the medium. When we read a boring book it is not the handling of the alphabet we criticize, it is the meaning and style.

⁶ Bell, 1973. Beniger, 1985 traces the strategic use of theoretical knowledge as a foundation for the development of American society back to the building of new infrastructures around the beginning of the 19th century, but only sporadically touches upon the script-technological preconditions for the development strategies. It should perhaps be added that what has been written here should not be considered as a suggestion of any form of causality between the technical media and the exploitation of its potentialities. Many other circumstances are included in the same processes and the existence of a potential is not the cause of anything. The exploitation of technical potential has also, suprisingly often - perhaps almost as a rule - completely unforeseen and unforeseeable consequences.

Discussing informational notation in the same historical perspective is impermissible in the nature of the case. If informational notation permits new ways of expressing forms of knowledge (not to anticipate the question as to whether it could also permit the development of new forms of knowledge) to the same extent as Gutenberg's printing technique - and this is not an unreasonable expectation - an attempt to discount the cultural implications in advance would be a foolhardy undertaking.

On the other hand, it is not impossible to discuss whether informational notation contains new semantic potentialities, as in such a case they would be connected with those features which distinguish informational notation from alphabetical and other familiar sequential notation systems which, as we saw in 8.4, include the semantically empty, quality-less notation, the finite number limitation and the mechanical effect potential, as well as the special form of rule determination which will be considered in 8.6 - 8.9.

Another modification, however, must be introduced here, because informational notation does possess one quality common to all notation systems, as it has a physical value. But this quality is not only defined in another way, it also serves a different purpose.

While the physical manifestation in alphabetical writing and formal notation serve to ensure perceptual recognition, the informational entity is not bound to any criterion for perceptual recognition.

This independence is ensured by the precise physical value and implies *first* that it is possible to employ the mechanical processing of informational structures, *second*, that it is possible to work with semantically distinctive, physical entities of a completely different, small size and a correspondingly high process speed and, *third*, makes it possible to implement notation in energy substances.

It is quite true that there is nothing wrong in defining the smallest informational units with threshold values registrable by the senses, but this is not simply an unnecessary restriction, it is also a contra-functional restriction. It is only possible to utilize sensory registration if - as occurs in the alphabet and the Morse system - we have in advance bound any given perceived entity to an invariant - recognizable - place in the notation system. If we wish to utilize the perceivable manifestation, we must also abandon the advantages which lie in the unambiguous definition of the physical form of the symbols.

At the same moment an informational process is accessible to human understanding, it is therefore also accessible to another expression system where informational notation is also used as a means of mechanically producing an

output recognizable by the senses. As such a transformation is both a necessary starting and finishing point for any use of informational notation, this notation system will be limited, it can only exist as a means to a non-perceptible re-presentation of other perceptible expression systems. On the other hand, this mechanical transformation implies that informational notation can also *represent* - for example, pictorial - expressions which cannot themselves be expressed in the same sequential form.⁷

Informational notation has thus, as a distinct characteristic, the fact that due to its definition it can be realized in a machine in a form which is not accessible to the senses. Where Hjelmslev at the time was puzzled by his own statement that »it is in the nature of language to be overlooked«⁸, that is, was concealed behind the auditive or alphabetical clothing, we are puzzled today by the fact that, as far as informational notation is concerned, it is the clothing, the expression form, which *cannot* be seen. The little boy in the fairy-tale may still be right, but now the tailors are too.

That the form of the information cannot be seen does not mean that it cannot be made visible, or that it is of an immaterial or transcendental character, it means on the contrary that special demands are made on the threads which are used in sewing the clothes.

It is now already clear that informational notation possesses properties which are not only new, but also more profound than those of Gutenberg's invention. Where Gutenberg made a contribution to a new use of an existing notation system, informational notation, seen as a physical expression system, is a completely new system. It was - and could only be - developed in connection with the development of new technical and semantic handling methods.

Shannon developed his theory primarily with the aim of improving a number of existing communication technologies, but it rapidly became evident that informational notation came into its own particularly in connection with the realization of Turing's theory. Turing had already discovered the - algorithmic

⁷ The demand for re-presentation in a form recognizable by the senses is handled in modern computers by an interface. The same internal procedure can thus be transformed into an arbitrary quantity of different expression forms which depend solely on the organization of the chosen output medium. A »picture« transmitted to a loudspeaker will thus produce a sequence of sounds which will largely be completely meaningless. We can therefore draw the conclusion that the meaning of the informational procedure is formed in relation to the interface and is not immanent in the procedure.

⁸ Hjelmslev (1943) 1961: 5. The Danish original has »at sproget *vil* oversees«, that is: »language *insists* on being overlooked«, implying that language has a will of its own.

- thread which was necessary to utilize the new potentialities of the informational notation system.

8.6. The algorithmic thread

When the informational entity has no solid physical form there is naturally a great risk that the informational structure will collapse. In Turing's theory, the informational structure was supported by well-defined, permanent physical sign manifestations, where a physical-mechanical operation, which also stood for a symbolic operation, could be allocated to a given manifest form.

Turing did not use informational notation units, but notation units which could be recognized by the senses, as he regarded the - necessary - physical definition of the expressions of these entities as a purely technical question and saw the notation system as a formal notation system.

On the other hand he showed how - by regarding a physical-mechanical procedure as a relationship between one step and the next - it was possible to organize a physical-mechanical system in such a way that it could perform any symbolic operation which could be described step by step. Whether the next step was established in advance, or had to be defined during the process, made no decisive difference.

Although Turing worked with fixed, well-defined physical symbol manifestations, this input might well comprise new definitions of their value. The demand was only that any change should be carried out step by step as the result of an unambiguous declaration, whether this was given in advance in the form of a programme or in the form of a continuous input of new instructions.

The Turing machine was thus not only defined by physical mechanics, or through physically determined, symbolic expressions or given symbol values, but also through the algorithmic procedure which simultaneously organizes the physical and symbolic process.

While the ability to *maintain* an informational structure in a physically fluid substance depends on the definition of critical threshold values for the legitimate physical forms, the ability to *vary* the informational notation structure is based on the algorithmic treatment of the relationship between the physical and the symbolic structures.

Herewith, Turing had also discovered the means which could be used to utilize the properties of informational notation independently of human recognition.

As informational notation and the algorithmic procedure together constitute the necessary and sufficient foundation for the mechanical execution of computational processes, they are also included as distinctive basic elements in all informational signs.

As the connection between informational notation and the algorithmic procedure not only implies that it is now possible to “electrify” the algorithm, but also indicates a deep conceptual change in the understanding and handling of algorithmic processes, it becomes necessary to include this advance in algorithmic management before describing the informational signs.

8.7 The multisequantic potential of the algorithmic structure

In mathematics, the term algorithm is understood generally as any precise precept for the execution of a procedure. The algorithm defines a set of procedural rules through which it is possible to unambiguously transform a given set of numerical values to another, or in Trakhtenbrot’s formulation:

*A list of instructions specifying a sequence of operations which will give the answer to any problem of a given type.*⁹

In its basic form the algorithm thus represents a system of invariant rules for handling a set of variable data appropriate to the rules. The algorithmic structure ensures that a calculation involving the same data will always lead to the same result and that a calculation involving different data must be performed in accordance with the same rules of calculation, whereas a calculation involving different data does not necessarily lead to different results, as both $3 + 5$ and $4 + 4$ and $14 - 6$ all give 8. When there is only an algorithmic result there is thus no algorithmic path to return on, either to the process or the point of departure. The algorithmic result itself is empty.

The central part of the algorithmic procedure is connected with the distinction between rule and data. But the distinction is not absolute. Although the rule system is available independently of the data, it is not possible to handle any set of data with a given algorithm. The algorithmic structure makes demands on the structure of the data set and there may also sometimes be a demand on the permissible data values, which we are familiar with from the

⁹ Trakhtenbrot, (1960) 1989: 203.

rule that the value zero may not occupy the place of the denominator in a fraction, just as there is often an indication of upper and lower limits to the variation of data values included in the definition of an algorithm.

Although the algorithmic procedure is not limited to handling numerical values, but may often include symbolic and logical values and relationships which have the character of complex semantic structures, there is a fundamental demand that not only the procedure, but also the data structure must be available in the form of mono-semic values.

The algorithmic structure thus does not permit »the cumulative acquisition of new dimensions of meaning« which, according to Ricoeur, is a characteristic feature of linguistic expressions, nor the complementary and equally characteristic possibility of storing meaning for an unspecified period (including the risk that it will be forgotten if not actualized) which is also contained in the linguistic redundancy structure.

The algorithmic procedure's unambiguousness is connected with the demand for well-defined starting conditions and sequencing, including the demands:

- That the rules are individually unambiguous
- That the rules are used one by one, sequentially. The simultaneous use of several rules cannot occur. The individual rule's area of use must be defined in extent and be clearly delimited in relation to preceding and/or subsequent rules.
- That the transition from one rule to the next occurs immediately after an operation has been executed
- That all values, whether they are included in the rule structure or data structure and all relationships between them, must be specifically declared before they are used.
- And that all values must be mono-semic - or numerical in the broadest sense of this term.

As a consequence of this unambiguousness, the formulation of the algorithmic expression has often been seen as a goal for a scientific description of a given problem and scientific attention has then been directed towards other problems if this goal was achieved. The relationship between language and algorithmic representation is seen from this perspective as a relationship between a problem and its solution. From a linguistic point of view, however, there is a different result, as the relationship between problem and solution is

manifested as a relationship between polysemic and mono-semantic language - and not as a transition from a problem to a solution.

That it is a relationship between two linguistic articulation systems rather than a relationship between problem and solution appears experientially from the circumstance that even the purest mathematical exposition must both be introduced and concluded with a linguistic account. This familiar experience is not only due to a - good or bad - habit, it is on the contrary the unavoidable result of the fact that an algorithmic expression by definition assumes an establishment of start conditions and an interpretation of results which have no algorithmic expression.

As we saw in chapter 7, mono-semantic expressions are formed with a starting point in a definition of a specific linguistic redundancy structure. In the linguistic representation this bond is expressed in the declaration of unambiguous statements which again can create the starting point for an algorithmic procedure.

The transition from an unambiguous linguistic expression to an algorithmic procedure, however, is not a simple matter, as there is also a question of a complete transition from one - linguistic - rule system to another - algorithmic - rule system. This replacement of the rule system does not leave the mono-semantic expression untouched. At the same moment a mono-semantic expression is subjected to an algorithmic rule structure, it loses its referential meanings.¹⁰ Whether we multiply apples by pears, metres by kilograms, the height of the Eiffel tower by the sound of a thunderclap, makes no difference to an algorithmic sequence:

While the transition from polysemic to mono-semantic articulation depends on a fixed definition of the redundancy structure, the transition from mono-semantic, linguistic articulation to the algorithmic handling of mono-semantic values depends on the elimination of the expression's referent.

The elimination, however, only holds true during the algorithmic sequence, as it is only possible to refer to the procedure's result as a result if it is assumed that the mono-semantic expression's referent remains the same throughout the sequence. This is thus a question of an abstraction procedure where the referent is assumed or, more correctly: placed in parenthesis. This construction of the relationship to the referent is distinctive for algorithmic expressions and determines the relative autonomy of the algorithmic procedure, i.e.: its

¹⁰ The loss includes not only the reference to phenomena in the world, but also the linguistic meaning relationships between words and between sentences and - naturally also - the linguistic syntax.

existence as an expression system, which can stand for itself without standing for anything else.

But the same construction simultaneously places the algorithmic procedure in a position of semantic dependence on the linguistic expression. When the parenthesis is closed, the expression must again be handled in linguistic form. The algorithmic procedure cannot stand alone because the mono-semantic values lack their referent.

That which distinguishes the algorithmic from the linguistic procedure, at the same time places it in a one-sided relationship of dependency on this.¹¹

As the relationship to the linguistic referent is placed in parenthesis, however, it becomes possible to change the referent and transfer an algorithmic procedure from a linguistic reference system to another without, for this reason, bringing about any identity or connection between the referents (formal polysemy). It was this property that Boltzmann saw as a frequently used and characteristic feature in and of mathematical physics and this appears to support the view of the algorithmic procedure as an immanent, purely formally defined procedure which runs in accordance with its own rules. The relationship to the linguistic referent, however, is more complicated.

While there are rigorous demands on the definition of the individual rule, on the sequential linking of rules and on the relationship between rule structure and data structure, there are *no* general demands on the choice and combination of rules. Although any algorithmic expression is completely deterministic, there are no general syntactic rules for the composition of the algorithmic expression. We can multiply, divide, integrate and differentiate as much as we wish, as long as the sequence of each individual operation has been established. As the rules are individually established, the choice of rules is therefore a semantic choice which cannot be made without a linguistic referent.

This naturally does not mean that we have a free hand in the referential interpretation of any algorithm, but only that a given algorithmic procedure constitutes a compositional whole which does not itself have an algorithmic form. The composition is therefore not determined by the algorithmic functions either.

¹¹ In Hjelmslev's terminology, this relationship is called a determination, i.e. a relationship between a functive, (the linguistic antecedent) which is necessary for the occurrence of another functive (the algorithmic procedure). Hjelmslev (1943) 1961: 34-35. In Hjelmslev's rather awkward use of the term determination it would be expressed: that the algorithmic procedure determines the linguistic sentence.

The algorithmic function cannot motivate the choice of itself and the algorithmic procedure cannot motivate its own continuance. While all algorithmic procedures are completely deterministic, each procedure is based on a series of arbitrary, semantically motivated choices. The algorithmic procedure can therefore be described rather as a rule system for co-ordinating linguistically motivated entities where both the individual part alone and the total expression as a whole have placed the linguistic referents in parenthesis.

The algorithmic form's semantic bond, however, not only embraces the parenthetical relationship to the linguistic expression's referents, the form is also - seen as a detached expression form - subject to structural limitations of a semantic nature. Any algorithmic expression is both determined in its relation to one or more sets of general rules (here we can rightfully speak of a language system) and a specific realization in the form of a correspondingly distinct usage. As any algorithm can be described as a relationship between a precept and a data structure, and as a given precept also establishes the conditions for adequate data structures, it is evident that the relationship between precept and data (i.e. language use) is a semantically distinct relationship. The semantically motivated choice of precept is also a semantic choice of data structure. The same holds true of the relationship between a given precept and the established set of possible calculational or procedural rules, as the precept can be seen as a choice of calculational rules from a formal language.

The semantics of algorithms thus includes at least three levels. First, the individual expression unit is always defined as a unit which connects the notation's form with a mono-semantic value. Second, the specific relationship between precept and data structure is semantically distinctive in the sense that a given precept - a defined rule system - can only handle a certain amount of structurally uniform data sets. Third, the total composition of a given algorithmic expression is based on a semantically motivated choice of the possible rules of procedure which are contained in the »language system«. If this is a calculation algorithm, the language system is thus constituted by the existing rules of calculation. As the term language system here may remind us of Hjelmslev's terminology, it must be added that the rules of a language system are only included in an algorithmic expression *if they are declared as a referent for a specific notation unit*, such as is the case, for example, when we refer to the rules of addition with the notation +.

Unlike common languages, these different semantic choices are distinguished in a series of distinct semantic choices because all choices are subject

to the mono-semantic restriction and the demand for a delimited area of effect for chosen rules. The algorithmic procedure, unlike the linguistic expression, thus contains no semantic interference between expression elements, on the other hand the algorithmic language demands that rules are manifested as distinct expression elements.

The algorithmic language not only has a polynomial semantic structure relative to common language, but is also itself structured at several formal levels. Whereas the language system is constituted by the available set of procedural rules, usage is constituted partly by a precept and partly by a data structure. It is not difficult to distinguish the system from the usage, as the system is constituted by the legitimate rules of operation.

This clear distinction determines, on the one hand, that it is both possible to construct new general rules and freely choose rules for use with specific purposes. As the rules of formal language systems are fully deterministic, it is quite true that they place certain limitations on the possible combinations, but these limitations can be avoided through delimiting the areas of use of the individual rules.

While a formal language system as a whole can be described as an independent and total system of well-defined procedural rules, usage which is constituted by the chosen combination of rules and mono-semantic value sets is rather more difficult to describe.

Seen in relationship to a given data structure, it is not possible to choose any - but perhaps several - rule structures and seen in relationship to a given rule structure, it is not possible to handle any data structure. As the relationship between rule and data structure is thus characterized by a mutual bond of solidarity, it is not possible, on the face of it, to identify the rule structure, the precept, as a superior interpreter relative to the data structure and the data this permits. The relationship between rule and data certainly possesses certain features which could perhaps be seen as reminiscent of the linguistic relationship between expression and referent, as the relationship between rule and data is derived from the linguistic definition of the mono-semantic referents.¹²

In a certain sense, it might also be possible to claim that the solidarity between programme structure and data structure implies that the algorithmic expression - over and above the parenthetic relationship to the linguistic referent

¹² It might perhaps be possible to describe a definition as a specific linguistic form different to other linguistic expressions - as explicit designations of chosen referents, as the referent is normally taken as given and is therefore not included in the linguistic expression.

- also itself contains an immanent referential function between programme and data structure and that the linguistic referent is thus not the sole referent. On the other hand, the relationship between rule structure and data also possesses features which clearly distinguish themselves from the relationship between word and referent, as both parts are manifested. Together they comprise the basic syntactic structure, which is why they are rather equivalent to the nexus relationship of the sentence.

Where a sentence, however, produces a meaning, the algorithmic procedure instead produces the transformation of one expression to another. While both the construction as a whole and each individual element are semantically motivated, the transformation procedure which occurs from a given input to a given output, is asemantic, as the connection between input and output is accessible to - and completely dependent on - an interpretation which is independent of the procedure. The procedure guarantees that there can be a connection, but says nothing regarding in what it consists.

As the choice of referent and semantic regime can thus be distinguished from algorithmic syntax, the syntactic structure itself is open to several semantic regimes.¹³

This multisemantic property not only makes it possible to develop different algorithmic procedures for different semantic regimes (whether logical, numerical, linguistic, pictorial or auditive), it also permits one and the same algorithmic structure to serve as a basis for any semantic regime.

The description given here of the algorithmic expression can be summarized as follows:

- While each individual notation unit in an algorithmic expression has a well-defined value (a referent which is either a data or a rule value), the total algorithmic expression has no definite referent. The same algorithmic procedures can represent a plurality of significations, purposes or meanings and different algorithms can represent the same signification, purpose or meaning. The algorithmic procedure is also characterized by the fact that it can be executed quite independently of these meanings and the result of

¹³ Since an algorithm is a formal expression, it may appear that this contradicts the statement in chapter 7: that formal systems can be polysemic but not multisemantic systems. Only a modification, however, is necessary, since the multisemantic potential of algorithms presupposes that the algorithm is itself conceived as a purely syntactic structure, without any reference to or dependence on a semantic interpretation. But even so, there is still a significant difference between the multisemantic potential of algorithms expressed in formal and informational notation systems, since the latter, as will be described in chapter 9, allows a wider range of possible variations.

the procedure is semantically empty. The algorithmic procedure does not prevent us from comparing or multiplying the height of the Eiffel tower with or by the sound of a thunderclap.

- While any algorithmic expression is completely determined, there are no general rules for combining algorithmic sequences. All data can be multiplied, divided, integrated, differentiated and combined to our heart's content, as long as the sequence for each operation is described.
- The algorithm's start and stop conditions cannot themselves be expressed in algorithmic form. The algorithmic expression cannot contain its own interpretation. This must be interpreted in another language and the same goes for the algorithmic rules of procedure. The algorithmic expression contains references to formal rules, but the rules are not contained in the expression, they are, on the contrary, *re-presented* by a distinct and declared notation which refers to a rule outside the expression.
- The number of notation units used can be freely varied, depending on the task and purpose.

8.8 The algorithmic revolution

With his description of the mechanical process as an algorithmic sequence of local, step-by-step determinations, Turing was apparently the first to discover the unique syntactic properties of algorithms, just as he was also the first to see how it was possible to bring mechanical procedures into a logical regime by first reducing finite, formal procedures to mechanical procedures.

Although this was an epoch-making breakthrough, the construction contained a decisive obstacle to the description of the syntactic potential he had discovered.

Within the logical regime the dissolution of mechanical procedures into individual steps could immediately be interpreted on the basis of a classical understanding of determination, as the superior, general determination was now ensured by the logical and not the mechanical totality. He was not aware that the local determination could also form the basis of other and not least, non-deterministic semantic regimes - nor, apparently, did it interest him, as he saw the choice machine as a less successful version of the automatic machine.

This limitation is not particularly surprising and naturally does not detract from Turing's original efforts.

Turing's limitation on this point, however, cannot simply be explained by regarding it as due to the dominant currents of contemporary science, it can also be understood as a consequence of the fact that it only became possible to illustrate and handle the new syntactic potential once the machine Turing had thought out came into existence.

Although in many respects there are good reasons to regard the human brain as superior relative to any existing - conception of - computers, all computers are superior to the human brain when it comes to handling exactly this type of step-by-step process which creates the foundation for algorithmic syntax.

If the algorithmic handling of symbols created the basis for Turing's idea of the universal computer, the later computer technology also created the basis for a revolution in algorithmic management.

The concept of revolution may perhaps appear rather hackneyed and produce meagre descriptive associations, but in this connection it is an apposite concept, because it unites a reference to a definite, fundamental change with a reference to the change's equally fundamental indefiniteness and incalculability. It is thus hardly possible to provide a total picture of the course of this development as it is still an ongoing - and uncontrollable - process which runs along a multiplicity of mutually unconnected paths.

As far as I am aware, no general investigation of this development up to the present exists and naturally even less an informed opinion as to how it will develop further. How far it has progressed today and how it will develop tomorrow must remain open questions.

A picture of the point of departure and some of the lines of development which issue from here, however, have gradually begun to delineate themselves through a number of spread, sometimes sporadic, contributions in various available sources. As the subject, both in extent and with regard to the demand on insight, considerably exceeds my competence, the reader must be content with a more summary account based on a relatively limited choice of sources.

On the face of it, the most eye-catching feature is without doubt the tremendous explosion in the number of available, written algorithms itself. In a standard textbook on algorithms from 1983, Robert Sedgewick thus starts by stating that as good as all algorithms mentioned in the book are less than 25 years old, while a few have been known for a couple of thousand years - although under a different designation, as algorithms owe their name to

mathematician, Mohammed ibn Al-Khowarizimi, who published an - epoch-making - arithmetical textbook around the year 850.¹⁴

The quantitative growth in the production of new algorithms includes both the development of new algorithms for old purposes and the development of algorithms for new purposes. Among the new purposes the development of computer technology is one of the most important and advances within this area led during the 1950's to the introduction of computer science as an independent subject distinct from mathematics.

In addition, there is another remarkable new departure, as algorithmic models were developed in a number of new areas. Where the algorithmic procedure had hitherto only occupied a central place in mathematics, logic, physics and economics, it now began to occupy a central position in areas of biology, psychology and linguistic and a wider range of social sciences.¹⁵ Subject areas which still hesitate, such as a number of disciplines within the humanities, appear to be correspondingly losing esteem.

The technological potential of this expansion is immediately visible. Where mechanical manipulation had hitherto had its centre of gravity in the handling of knowledge extracted from studies of inorganic, physical nature, the way is now clear for a corresponding, algorithmically based mechanical handling of knowledge extracted from the study of living organisms, mental and social processes.¹⁶

There appears to be little doubt that the two new departures developed in close mutual interplay? The sources provide a multiplicity of examples of intersecting lines of inspiration and none of those involved appear to have any precise, not to mention concurrent, picture of these lines. Nevertheless, the two lines of development also contain an inner conflict.

One the one hand, the computationally oriented development of algorithms is necessarily and strongly bound to and determined by the way the technical problems present themselves and the understanding of algorithmic functions is

¹⁴ Sedgewick, 1983: 7. Williams, 1985, 21-24.

¹⁵ Where psychology is concerned the developments of the 1950's are described in Miller, Galanter and Pribram, 1960, among others, in an attempt to create a foundation for algorithmic psychology in a break with behaviourist psychology. Within linguistics, Hjelmslev is one of the pioneers of an algorithmically oriented theory, but the dynamic process perspective was first formulated in Chomsky's generative grammar. In the biological field, corresponding ways of presenting the problem are discussed by such authors as Emmeche, 1990 from a Peirce inspired viewpoint.

¹⁶ That there is also a great potential in this for an industrial expansion based on the development and use of industrial methods for handling biological and mental natural resources, is moreover often overlooked or underestimated in the many theories on »post-industrial« society.

characterized by the abstract and arbitrary functionalism of algorithms. The internal algorithmic functionality is central and the understanding of the algorithm is closely connected with its effectuation as a process which elapses in time. Algorithmic process time, which had played no role in mathematics and logic, has thus become a central element in computer science.

On the other hand, the use of algorithms in a growing number of disciplines is rather understood as a goal for scientific description in a more or less explicit analogy to classical mathematical physics, but naturally with the addition that it is now a question of handling algorithms at a higher, more complex level.

There are a number of reasons why this conflict in the conceptualization of the algorithmic procedure has been under-emphasized. First, the fact that there was a common root in the classical mathematical-physical tradition, so that the new departure was seen as an expansion of the potential of this tradition. Second, the fact that many of the divergences appeared as divergences between the special ways problems present themselves within different disciplines. Third, the fact that there was also common ground in a general automatization perspective and last, but not least, the fact that as a whole this was a question of a development where trying out the many new - immeasurable - possibilities necessarily came to occupy a dominant position as a guiding principle.

That it is reasonable to describe this expansion in quantity and areas of use as a revolution proper in algorithmic management competence, is also due to the fact that the quantitative growth of algorithmic procedures and areas of use are closely connected with a fundamental leap in the history of algorithmic methodology. This leap also has its centre of gravity in the new computer technology and began in the 1940's.

According to Wells¹⁷ this change is expressed as a growing clarification, structuring and abstraction in the formulation of algorithmic procedures. Where previously, algorithms had been seen and worked with as short sequences related to specific problems in a given context, they now became regarded as detached, independent expressions which could be utilized in long sequences, structured in blocks and released from the specific data connected with the given subjects.

The same view leads to a more systematic use of the distinction between procedure and data - manifested among other things in the introduction of

¹⁷ Wells, 1980: 276 ff.

such terms as data and data structures - as references to data are now (solely and completely) established as a definition of input parameters.

The mechanical execution of these procedures at the same time produced a number of other methodological innovations, among them the calculation of process times, problem-solving times and expression complexity.

An important fulcrum in this development, according to Knuth and Trabb Pardo, was the appearance of the assignment function as distinct from the mathematical »equal to« expression. The assignment function was first used by Konrad Zuse in 1945 in his »Plankalkül«, which at the same time was the first general programming language.¹⁸ The Plankalkül, however, was first published in its entirety in 1972. Although shorter excerpts appeared in 1948 and 1959, his work had no demonstrable significance for the new trend in algorithmic development.

According to Knuth and Trabb Pardo, the first significant step towards distinguishing the assignment function was taken instead by Herman Goldstine and John von Neumann with their suggestion of the - graphic - representation of algorithmic procedures as flow diagrams - or flow charts - from 1946-1947.¹⁹

Although Goldstine and von Neumann do not define the assignment function here, it was waiting - certainly in retrospect - say Knuth and Trabb Pardo - in the wings, as the block divided algorithmic sequence is connected with directional, irreversible transitions (marked in the diagrams by arrows), where the mathematical »equal-to« designates reversible transitions. The assignment function, however, is also distinct from the mathematical equal to function, as it replaces an automatic or determined connection with a semantic and facultative connection.

As a whole, flow diagrams represented under any circumstances a pioneering innovation with their procedural and functional view of the algorithmic sequence.

If the flow diagram - and Wiener's cybernetic feedback mechanism - represent the first step in the transformation of the concept of algorithms, the next step is the transition to an understanding of the algorithmic procedure as a programme which can be designed with arbitrary, formal-logical symbols.

¹⁸ Knuth and Trabb Pardo, (1977) 1980: 202 ff. According to Williams 1985: 225, the Plankalkül uses by far the greater number of basic programming functions, among them variable functions, conditional sentences, loops, subscripts and parameter determined procedures, but not recursive functions, i.e. procedures which contain themselves.

¹⁹ Published in H.H. Goldstine and John von Neumann (1947-1948).

Hamming describes this development as a conceptual transition from the 'number crushing' metaphor to an understanding of programming as a - logical - symbol manipulation and believes that this change made its breakthrough with those involved - himself among them - in 1952-1953, in this case coinciding with the appearance of the first compilers which gradually emancipated programming from the built-in machine language.

Hamming admits that Turing perhaps developed this symbol understanding rather earlier, but believes that it is still the idea of the number crusher that is the basis of Burks', Goldstine's and von Neumann's pioneering work on the logical construction of electronic computers from 1946, where they formulated the basic principles of the modern serial computer (von Neumann architecture) with a stored programme.²⁰ Hamming's view is indirectly confirmed by Goldstine who, in referring to the ideas of the 1940's exclusively mentions the mathematical perspectives for use, although both a logical description of the computer, the idea of the stored programme and a control system, which made it possible for the machine to alter its own programme structure, had been developed.²¹

While it is thus possible to date the emergence of a new perspective on algorithmic representation to the 1940's, the more systematic utilization in the form of fixed programme functions and a programming language proper stretches over a rather longer period. According to Wells it is only possible to speak of a general algorithmic language with the emergence of block structuring, structural control, data structuring, data abstraction - and two-dimensional notation and set theoretic notation in the 1960's. The programming language, ALGOL, which was completed by Peter Naur in 1960 is indicated by many sources as the first fully developed programming language with a general and consistent syntactic notation.²²

As the final part of this summary account of the algorithmic revolution we must also include the fact that the practical developments created the

²⁰ R.W. Hamming, 1980: 7-8. The work referred to is by Burks, Goldstine and von Neumann (1946) 1989. von Neumann had formulated the logical principles of a machine with a stored programme in *First Draft of a Report on the EDVAC* from June 1945 and in *Memorandum on the Program of the High-Speed Computer Project* from 8 November 1945. They contained, however, no description of the coding and programming process. C.f. Goldstine, 1972: 191-203, 242, 253, 266.

²¹ Goldstine, 1983. Especially chapter 2 and Beeson, 1988: 200.

²² Wells, 1980: 277-283. A more detailed account of various aspects of the development of programming language can be found in, among others, Goldstine, 1972, Simon and Newell, 1972, Metropolis et al, 1980, Herken (ed.), 1988 and, to a lesser extent also Williams, 1985, who mainly discusses the development of hardware.

foundation for the appearance of the first algorithmic theories proper with the Russian mathematician A. A. Markov's *Theory of Algorithms* from 1954 as the first. Here, Markov made a direct connection with Gödel's, Church's and Turing's work from the 1930's, but aimed at a more precise, mathematical analysis of the computability of various algorithmic systems. As, according to Markov, it was possible to show that there is a series of mathematical problems which demonstrably could not be solved through algorithmic means, he naturally also rejected the idea that it would be possible to design a machine capable of solving problems of the same type.

If an algorithm solving every isolated problem of a given class is impossible, then a machine solving every such problem is likewise impossible.

This deprives of their very foundations the stories published in foreign (especially American) literature concerning machines capable of solving any problem, and automata replacing the scholar... Therefore the conative research enterprise in mathematics (as well as in any other branch of learning) will never be transferred to machines, capable only of assisting man but not replacing him.²³

Against this it is often claimed, especially in areas of the American tradition, that it is not possible to generalize over and above the existing algorithmic competence - that we can never say never - and therefore cannot exclude the possibility of new algorithmic revolutions.²⁴ What remains is the fact that the algorithmic revolution up to the present has not brought about such an automated, general problem solving method, neither in mathematics nor any other area.

The control and automation perspective has played a central role as a motivating and driving force in the algorithmic revolution, but is not suitable for describing the result of the process. The explanation of this circumstance is of a linguistic character. The automatic procedure assumes that the semantic value of symbols is first frozen and then placed in parenthesis. As the automatic procedure therefore cannot contain its own preconditions, it cannot describe its own results either.

It can hardly be disputed that the algorithmic revolution implies a considerable expansion of the possibilities for designing and executing automatic

²³ Markov, (1954) 1961: 441.

²⁴ A view which is taken as a basis in Haugeland, (1985) 1987, among others.

processes. This automatization, however, includes only problems that have already been unambiguously formulated and automatization in addition describes only one part of the potential which lies in the transition from physically bound to programmed mechanical operation. At the same time, with programming comes a complete dissolution of the automatic bond, as each individual step in any sequence can be made the object of choice, because the stored programme is distinct from the machine's control unit which can thus be used to control and alter the stored instructions.²⁵ As the algorithmic expression is available in informational form these changes can be executed at the level of the individual notations, quite independently of the original algorithmic expression's rule and data structure.

This property appears to a great degree to contradict the properties normally ascribed to an algorithmic procedure and it also apparently contradicts another of the properties which motivated the use of the algorithmic procedure in computers, namely to guarantee the reliable, automatic handling of the - otherwise inaccessible and unmanageable - informational processes.

The explanation for this apparent paradox lies in the fact that the computational programme structure not only permits the algorithmically controlled, automatic handling of data, but also the algorithmic handling of algorithmic expressions which are available in the informational notation form. Although it may be possible to find older examples of such a second-order handling of algorithms, there has never previously been an operative procedure which was independent of the task, not to mention any mechanical apparatus by which such a second-order handling could be performed relative to any informational notation unit, whether this is included as part of the expression of a rule or a data value. The methodological leap from first to second order handling of algorithms is therefore the central element in the algorithmic revolution.

²⁵ This property was not clearly in evidence in Turing's theoretical model from 1936 although he actually allowed the machine to alter its instructions and moreover stored both the programme and data in the same medium. But this was a central element in von Neumann's logical description from 1945. Goldstine, 1972: 259.

9. The informational sign function

9.1 The algorithm in the machine

If the algorithmic revolution is characterized by abstraction, block structuring and hierarchical division with the centre of gravity in the distinction between code instruction and control unit, as well as programme and data structure with second-order handling of algorithms as a consequence, this is undoubtedly a far-reaching methodological break in the history of algorithmic management. But it is not immediately obvious that this should also occasion new linguistic considerations, as there is no element included in it which in itself touches on the relationship to the semantic surroundings. It is a revolution inside a concluded parenthesis.

At the same moment, however, as we take this second-order handling into account as it is performed in a computer, the picture changes, as was theoretically anticipated by Turing.

What has been changed is first and foremost the possibility of utilizing the access to the step-by-step choice of a new instruction at the notational level. While the algorithmic first-order procedure was formerly characterized by diachronic determination, which stretches from the beginning to the end, the algorithm in the computer is available in a form which dissolves the diachronic determination, as all determination in the computer is locally limited so that it is only valid for the transition from one step to the next.

The diachronic, algorithmic expression is not only available as a sequence of informational notation units. It is available in a synchronic form where an arbitrary notation unit can become the object of the next operation, independently of its position in the preceding diachronic sequence. As the synchronic manifestation is produced as a result of previous states, they can be contained in this manifestation, but they need not determine the next step.

It is difficult to decide whether the access to the step-by-step choice of new rules should be seen as a result of a new conceptualization of algorithmic procedures, or as a product of the new possibility for the mechanical handling of these procedures. Under any circumstances, both parts work in the same direction. With mechanical handling the algorithm appears in a secularized form, distinct from any specific overall semantics and accessible to a step-by-step handling with the help of other algorithms which themselves must be dissolved into individual steps at the level of informational notation.

In the following I shall argue that the step-by-step procedure and the synchronic representation of the algorithmic structure imply that the algorithmic revolution inside the concluded parenthesis stretches beyond this parenthesis with the formation of a new sign system, the informational sign system, as a consequence.

H. Goldstine and John von Neumann were the first to diagnose the crux of the matter in this process. They referred to it as a transition from a static to a dynamic decision procedure, but it was evident from their description that this was only a half-truth. The new procedure contained not one, but two dynamic agents. The dynamic procedure runs as an exchange between a coded instruction and the machine's control organ, which implies the possibility of continuous modification of codes during the process. It could not be assumed, they wrote, that the code's instructions simply stood for an actually defined content at a certain point in the process. A given code can obtain a changing content, as it can both be summoned for use on a content, which is modified during the process, or can itself be modified as a consequence of other instructions which can be similarly modified.

Hence, it will not be possible in general to foresee in advance and completely the actual course of C [the control organ], its character and the sequence of its omissions on one hand and of its multiple passages over the same place on the other as well as the actual instructions it finds along this course, and their changes through various successive occasions at the same place, if that place is multiply traversed by the course of C. These circumstances develop in their actually assumed forms only during the process (the calculation) itself, i.e. while C actually runs through its gradually unfolding course.¹

That the computational process, seen from the control organ's point of view, is manifested as an unpredictable process, follows from the fact that the control organ can change the codes which control its own operations. The decisive aspect is not the relationship between programme and data, but the division of the controlling function in code and control organ as two distinct features which control each other step by step.

Just as for Goldstine and von Neumann, for later computer architects it was an - easily understandable and well-founded - main motive to develop me-

¹ Goldstine and von Neumann, (1947-48), quoted here after the excerpt in Goldstine, 1972: 269.

thods which could control this unpredictable process. The computer has therefore often been defined on the basis of the programme emphasizing the overall logical structure as the basic characteristic of the automatic, computational procedure, whether they worked with arbitrary, imperative functions (such as the assignment function and the go-to function) or with syntactic or logical programming methodology, where the use of arbitrary steps is often described as »dirty tricks«.²

The very existence of these two conflicting views of programming not only reflects the fact that programming is a necessary condition for the use of a computer, but also that this necessity is not determined by the machine, but by the human use of it. The differences are not a question of what is possible, but of what is considered correct. The programme expresses a conceptualization at a semantic level which concerns human interpretation and use for specific purposes. The machine will work with any programme notwithstanding its semantic structure, as long as it is used in an informational notation system which is in accordance with the physical structure of the machine.

Nor does the programme therefore constitute the most basic conceptual frame for a description of the computer. The necessity of the programme stems on the contrary from the fact that the computer, due to local determination and the distinction between the stored programme and the control mechanism, possesses a more basic and anarchic property, where each next step is accessible - in principle - to a free choice.

We would not make much progress if we were to attempt to exploit this possibility of choice to its full extent. Any use depends on a semantically motivated choice which is utilized in regulating the diachronic sequence. Local determination is nevertheless of central importance because it implies that the former states exercise no determination on the subsequent states. Although the system's actual state is produced by a predetermined rule structure, the next step can not only be executed independently of these rules, the actual state can also create the starting point for new steps which build upon other semantic interpretations of the actual state. As a consequence of this, any rule can both be modified, suspended and/or have a new function and meaning ascribed to it.

This conflicts with the understanding of the computational process as a sequence determined by an algorithm or a programme.

² C.f. Trakhtenbrot, 1988: 620, who argues that certainly some of the imperative programming features can be contained in a structured programming language based on Church's calculation.

It also conflicts with the experience we have of handling linguistic and formal notations which build upon - mutually different sets of - stable syntactic rules for the sequential organization of notation units. The most incalculable element, however, is probably that this dissolution of the rule structure conflicts with the basic ideas of the relationship between the rules and that which is regulated. Whether we think here of the idea of natural laws or of social conventions, in both cases we employ the idea of a precept or inherent structure which cannot be influenced by the system the precept regulates.

As described in chapter 5, it was a similar idea which created the foundation for Allen Newell's and Herbert Simon's theory of »physical symbol systems«, where the rules are given outside the regulated (physical) system. Where the computer is concerned we know that the programmer can formulate such rules (including rule systems which can generate new rules), but also that they must be dissolved and converted to another notation system in which the rules are produced as the effect of a mechanical process which is not bound by the symbolic rules. The individual, mechanically effective symbolic entities, as described in chapters 7 and 8, have no definite content value and there is no directly compelling equivalence between a certain symbolic content and its mechanical execution.

In other words, Newell and Simon's symbol theory gives an incorrect description of the computational process, as the description ignores those features which characterize informational notation as distinct from formal notation systems.

The same idea of the rule system given from outside which controls the process also underlies the use of concepts such as operative systems and programmes. These concepts are often highly functional because they indicate a delimitation according to purpose and task, but at the same time also give a misleading idea of the semantic freedom of choice which is connected with the diachronic process, because they describe the sequence as a process in which the former states determine the following states. In the computer, however, every symbolic rule effect appears as the result of the process the rules are supposed to regulate.

In order to describe the diachronic process, it is also necessary to include another conceptual difficulty which appears in the implementation of the algorithmic procedures in the machine, as this implementation at the same time implies that the algorithmic expression (whether this is the prescribed programme or a given data structure) be converted from a sequentially

organized, diachronic structure to a synchronic manifestation of the total expression.

While the algorithmic expression - just like the alphabetical-linguistic expression - is manifested as sequences of successive notations in which the individual notations are defined relative to the preceding and subsequent notations in a linearly organized sequence of relationships, local determination in the computer implies that the functional value of each notation unit is exclusively defined by the total system's actual - simultaneous - state, or in Turing's words: by the relationship between the machine figuration q_n and the actual symbol (the instruction) - described by Turing as $S(r)$ - as the pair, $q_n, S(r)$ comprise the total figuration which determines the machine's possible behaviour.³

The concept of the synchronically manifested notation corresponds to Turing's concept of the system's actual state, the machine figuration, but with the emphasis on the fact that this figuration is available as a notation structure which is not subject to any specific diachronic determination.

The concept of a synchronic structure itself is derived from linguistics where, however, it creates great theoretical problems. On the other hand, it is an extremely apposite term for the circumstance that, at any given moment, informational notation is available as a simultaneously manifested whole. Its use in linguistics will be discussed in more detail in the next section, but there is a reason to point out that in linguistics the concept refers to an underlying, invariant rule structure such as in Saussure, for example, who uses it on a presumed stable linguistic state, or in Hjelmslev, who uses it of a language system, while it is used here of a manifest notation structure.

The circumstance that every next step is determined solely by the relationship between the actual state of the system and the actual notation implies that the informational expression has a unique character, because while the individual step only embraces the relationship between two bits, every individual step at the same time implies a change in the state of the total system.

While the smallest expression unit in the synchronic expression is constituted by the informational notation unit, there is no invariant, smallest expression unit which corresponds to the bit, the grapheme or phoneme in the diachronic sequence. The smallest expression unit here is constituted by a complex expression, namely the constellation of bits which comprises the total

³ Turing, (1936) 1965: 117.

system's actual state. *The relationship between the total system's actual state and the next individual step thus comprises the smallest semantic expression unit and it therefore represents the basic form of the informational sign.*

The circumstance that the smallest diachronic expression unit is itself a complex, synchronic notation structure which coincides with the smallest sign function distinguishes the informational sign system from other symbolic sign systems.

The expression form of this sign structure can be described with complete precision, but this can only be done by describing it as a sequence of successive system states which are not connected by a general, underlying rule structure. Although all computational procedures assume a specific syntactic and semantic composition of the sequence structure, there is no general syntax for the diachronic sequence. The semantic restrictions are determined solely by the demand on the notation form and not by the demand for a specific syntactic and semantic regime, as is the case with the linguistic utilization of the alphabet and the use of formal notation.

The choice of syntactic structure and the interpretation of its significance is on the contrary a semantically motivated choice. While other sign systems (among other things) are characterized by syntactic stabilization rules for the use of notation elements, the informational sign system is characterized by syntactic freedom. Here, the notation structure is the stable element for syntactic variation. For the same reason, the development of - new - syntactic structures is therefore a general - and inexhaustible - source of innovation. The rapidly growing number of different programming and system development theories could also be described as a huge reservoir of syntactic structures or models relative to different uses. Finally, the synchronically manifested notation implies that there is no invariant relationship between a certain syntactic structure and a certain semantic regime.

Compared with other notation systems, the risk structure of informational notation is also different with regard to semantic breakdown and correspondingly requires other control and redundancy structures. The smallest synchronic expression unit can thus bring about a more radical semantic variation than the smallest expression units in other notation systems, as a single incorrect bit can imply the complete dissolution of the expression. Conversely, it has a weaker intrinsic meaning because its notation value is completely fixed relative to the system's actual state. Informational notation

has, as we saw in chapter 8, no independent qualities over and above its physical value and notational legitimacy.

The synchronic manifestation creates the foundation for an incalculable expansion of the potential choice which is connected with the step-by-step procedure and syntactic freedom in the choice of the diachronic sequence.

There are certain cases where it would be quite correct to say that a synchronically manifested notation represents a programme for the execution of a process, namely those cases where we do not utilize the possibility of making new choices during the process, as we use a given synchronic starting state as a determinant for the following diachronic process.

In these cases we are not describing a universal Turing machine, but a dedicated machine for performing a limited set of tasks. Such a description is not a description of the computational procedure, it is on the contrary a description of a given step in the performance of a pre-established task where we do not utilize the potential choice. Here, all that is necessary is simply to turn on the machine.

In all other cases the synchronic states are on the contrary subject to a diachronic determination which is not bound to any definite rule structure. The diachronic sequence cannot be described through the concept of a programme which determines the process.

The objections to the view of the computer as a machine which is determined by a programme can be summarized in two points.

First, it is difficult, if not impossible, to provide a clear definition of the concept 'programme', as we have no criterion which can determine when a given data sequence can be referred to as a programme and when a sequence must be referred to as something else.

If, for example, by a programme we understand a collection of precepts which control a sequence from beginning to end, the concept will include neither operative systems nor application programmes, such as word-processing programmes. Using this definition we must say on the contrary that we start a programme when we open the system, a new programme when we open the word-processing programme and yet another when we strike a key in order to produce a letter, change a typeface or adjust a margin. The word-processing programme therefore does not contain a set of precepts which determine which data sequences are used in which order, just as this type of programme is not defined by any invariant set of functions either.

In practice, the programme concept is not used in any consistent sense. It is used, on the contrary, as a pragmatic, common name which covers different

forms of semantic organization of data sequences. Some programmes are based on a purely mathematical or logical, formal, closed semantic. Others are based on an informal semantic and the kind (or level) of semantic is determined by the user. The user is thus not bound to intervene at only one, e.g. logical or linguistic level. It is both possible to intervene at the level of the informational notation unit, at the level where we use a sequence of bits as a representation of a notation unit in another symbolic language (for example, in the form of the ASCII code) and at the syntactic level, as we can use a sequence of bits as a syntactic structure which performs a rule of calculation, and at a semantic level, as a sequence of bits can represent a mathematical or formal way of presenting a problem, a logical retrieval procedure, a text, a picture and so on.

That which is referred to as a programme is a freely selected number of notation sequences, but what makes these sequences a programme has nothing to do with the specific sequences, but on the contrary with the circumstance that there is some purpose which could, in general, be fulfilled by completely different sequences, just as the given sequences could well have been used for other purposes.

The second, and most decisive, objection to describing the computer as a machine which handles data with the help of a programme is that the computer can only execute a programme by treating it in exactly the same way as all other data and that it can only handle data which are represented in the informational notation system.

Here, every rule and all data values are present in the same notation and manifested in a synchronic form which makes it possible to handle each individual notation unit independently of the previous values, whether as part of a rule or of data.

The concept 'programme' can therefore only be distinguished from the concept 'algorithm' by connecting a given purpose to a given quantity of informational sequences. It is not the programme which organizes the notational structure, but the notational structure which creates the foundation for programmatic variation.

The synchronic structure not only permits an absolute division between the preceding and subsequent states, but also provides the possibility of a facultative utilization and interpretation of arbitrary elements which are produced through the previous states. This dividing line determines that it is both possible to implement the assignment and go-to functions with the arbitrary definition of the next step relative to the preceding steps and to change operation mode, for example, from process execution to programme changes.

Both can be seen as specific uses of the more general possibility of choosing the next step without taking the preceding diachronic sequence into account. As both the execution of the preceding steps and the result of the process are only available as a synchronically manifested notation structure, this independence holds true not only of the choice of new data or the possibility of switching between programmes, it also holds true of the choice of the semantic regime for further handling.

This arbitrariness is not limited to the free choice of the fragments we will use, it also includes the possibility of choosing the syntactic functions and semantic values of the fragments used, because all functions and values are only available as a set of synchronically manifested notation units. The synchronic expression constellation thereby constitutes a redundancy structure, as defined in chapter 7, for the diachronic use.

It is precisely this redundancy function which both makes it possible for a user to respect and/or modify or suspend the precepts the programmer has laid down in the system. From the programmer's point of view the informational expression form is an expression of a semantic purpose, i.e. an expression of a content form. The user can - hopefully - understand the message, but is only bound to take over the expression form and this bond is moreover only valid for the user's starting point, as the user can both change the expression form and/or its interpretation, because the expression is available in the informational notation structure.

The diachronic structure is thus a semantically open structure which is neither congruent with the idea of a programme which is executed, nor with the synchronic structure. A congruence between these structures only takes place when the machine is used as a dedicated automaton. For this purpose, it will moreover often be an advantage to exclude a number of symbolic choices by incorporating a number of procedures in the hardware. In all other cases, the programme, the synchronic manifestation and the diachronic sequence will require three different descriptions, of which the last is the superior.

The crux of the matter here is that the possible semantic regimes not only embrace formal and closed regimes, but also informal and open regimes, as the only semantic restriction on the process lies in the demand that it must be possible to represent the semantic content in a discrete notation system with a finite number of members.

It is this circumstance which explains how it is possible to use the machine both as a typewriter, where notation is subject to such elements as linguistic syntax and semantics, as a calculating machine, where it is subject to the

syntax of the rules of calculation, as a picture processing machine, where the notation is subject to a pictorial semantic regime, just as it is a precondition for the use of graphic interfaces⁴ as well as Virtual Reality systems in which the user can represent selected fragments of his or her own behavior and interact with symbols generated by a programme.⁵

This peculiar circumstance can be illustrated by comparing the letters of written notation with the corresponding informational representation of the letters we see on the screen. While a letter - for example an /a/ in writing constitutes the smallest notation unit, an /a/ on the monitor screen is the result of a - rapidly executed - but extremely large number of individual steps comprising a series of changing synchronic states.

This sequence in itself can be described as the execution of a closed algorithmic procedure, or a little programme, but it is clear at the same time that there is no fixed relationship between this programme and the diachronic sequence in which the programme is utilized. The programme for executing such an /a/ works as a - composite - notation unit when using a word-processor. In this case the diachronic process is linguistically defined. In other cases, such as when used for calculation, such computer programmes can act as syntactic structures and in yet others - for example for performing logical demonstrations - as semantic structures. In the case of Virtual Reality the diachronic process is a result of the interaction between a programme and the behavior of the user, which again may be determined by a variety of motives. The informational notation structure prescribes no interpretation plane. Nor does the algorithmic linking of the individual notations into longer sequences.

This special syntactic and semantic freedom when interpreting the binary, synchronic representation is determined by the physical definition of the notation system, which once again thus appears as a vital, central element in understanding the symbolic properties of the symbolic machine.

The facultative handling of the synchronic notation includes the possibility of replacing, re-interpreting or suspending the syntactic rules and/or semantic values. It is this structure which makes it possible to regulate computational processes with linguistic and pictorial semantics and/or bodily behaviour, even

⁴ A comprehensive sign theoretical analysis of graphic screen communication can be found in P. Bøgh Andersen, 1990, which is discussed in more detail in sections 9.3-9.5.

⁵ In spite of the name Virtual Reality, there is neither more »virtuality« nor »reality« in those systems than in any other symbolic system such as ordinary language, for instance. In both cases we use a part of our own body to produce symbols, whether as a symbolic expression of a movement we make in the actual situation or as an expression of something which is not present such as when we talk of cows, for instance, without having one at hand.

though we are not capable of formulating these semantic regimes in the form of programmes.

The use of a computer for word-processing which, during the course of less than ten years has changed from an almost unknown to an almost everyday occurrence, is a good example of how the computer's multise semantic potential can be used.

If we take our starting point in the image on the screen, it can be described as a combination of a pictorial semantic and linguistic control of the computational procedure. The pictorial semantic control, which is a precondition for the linguistic, (because it is the precondition for the visually simultaneous representation of a serial process), is at the same time subject to the linguistic semantic, which as mentioned above exploits a number of algorithmic sequences each of which corresponds to a single unit in alphabetical notation.

Word-processing is thus an excellent example of the fact that the semantic use of informational signs is not bound to formal, closed semantic regimes. The same goes for picture processing, as here, the formal procedure alone defines the elementary particles of the picture and a sequential procedure for constructing the picture in a given output medium. Here, there is only a physical-mechanical connection between the symbolic precept and the picture content it represents. While the formal picture construction elapses in time, the reading off of the picture is bound to the possibility of perceiving the whole picture simultaneously.

The semantic restriction lies neither in the binary form nor in the demand for finite algorithmic procedures, but solely in the demand that the semantic regime can be expressed in a discrete notation system with a finite number of members.

On the other hand, this demand implies a sharp restriction on the kind of *rule* structures which can be implemented as automatic procedures, as it only holds true of finite, formal rule systems. For symbols which are not expressed in a notation system - such as pictures - another restriction holds true, namely that they cannot be represented without loss of information since they can only be represented by the help of a coding which defines certain selected physical values as legitimate informational units, while other physical traits are ignored. The coding is irreversible, there is no path from the informational representation back to the original.

Although the user, in the case of word-processing, controls the computational process with a linguistically rooted semantic in a way similar to that in which a typewriter is used, there are also several important differences, since a

number of mechanical typewriter functions have been replaced by a series of small programmes, The use of a computer for word-processing not only requires that the letters are available as programmed notation sequences, the paper that is written on must also be available in a symbolic representation in the same notation system. This symbolic representation can either be a precept for the background of the screen image, or a precept for a printing routine. It is naturally preferable to have both.

The peculiar conceptual consequence of this circumstance is that here writing is represented in the same symbolic notation as its background and that both parts are available at all times in the same synchronically manifested form. The same goes for a number of other physical-mechanical typewriter functions, such as margin and correction functions which can be simulated with the help of iconographic control.

Whereas the word-processing programme can be described as a symbolic representation of the mechanical typewriter and regulated with the same semantic, the two apparatuses produce the »same« text in two different symbol systems with very different editing and handling possibilities. These differences are connected with the underlying informational notation, which is characterized partly by being independent of the demand for direct perceptual recognition, partly by the fact that all rules are contained in the same notation as that which is regulated, partly by the fact that the text - or any other simulated phenomenon/process - is represented in a synchronically manifested notation and thereby within another time structure and finally by the fact that the simulation of the typewriter presupposes a transformation of - at least some - physical constraints into symbolic constraints whereby the physically invariant constraints becomes optional.

Each of these elements constitutes a distinct and unique feature which, together with the dynamic properties, characterizes the informational sign system as distinct from other sign systems.

Word-processing programmes use only a small fraction of these options, but they show that it is possible to control the computational process with the help of several - co-ordinated - semantic regimes.

If the more user-oriented design architecture which made its breakthrough in the 1980's is a marked expression of the possibilities which lie in the use of the informational sign system's synchronic structure and the radical, step-by-step freedom of choice - as is claimed here - it must be added that this use also has a regressive character, as the algorithmic and formal semantics which were formerly dominant have been replaced by more traditional semantic regimes.

User orientation has generally been utilized in metaphorical imitation - whether in the form of the typewriter, keyboard, paper, pencil, drawing board, tape recorder, filing cabinet or some other more closely delimited area of the existing working processes. This conservatism has also been the object of increasing discussion and criticism in several of the design-theoretical reflections of recent years.⁶

Metaphors cannot and should not be avoided in developmental work. The arbitrary synchronism of the informational sign system is not only a basic structure, but also one that is difficult to handle and which can only be used through self-chosen semantic restrictions which are not only significant for the purpose, but also for the construction of the syntactic organization. As the informational system's syntax, however, is not related to a specific semantic regime, the user-oriented perspective, whether utilized in one or another metaphorical model, can hardly be understood as more than a first step in the direction of a more radical leap from the mono-semantic to the multisemantic machine.

One of the next steps is a question of releasing the user perspective from the visually bound handling of the informational signs at the interface level, because this understanding of the user perspective cuts the user off from the potentialities which lie in the non-visually represented, underlying notation structure. As this question, which will be discussed further in section 9.5, also concerns human competence, developments here will presumably be the result of a slow and insidious process of change which is far removed from the common idea of rapid technological changes in society.

The multisemantic potential is perhaps that element which, more than any other, can motivate a comparison with human consciousness, while at the same time it distinguishes the computer from other symbolic representation media because it is connected with the specific, arbitrary and synchronic structure which makes it possible to store any input and retrieve any stored element whatsoever.

It is nevertheless more relevant to regard the informational sign system on the basis of its differences to other expression systems because the combination of synchronic determination and diachronic freedom of choice assumes explicit, descriptive declarations.

⁶ Thus in Ehn, 1988, Bannon, 1990, Bannon and Schmidt, 1990 and P. Bøgh Andersen, 1990.

The multise semantic potential also exists exclusively as a human relationship to the system.

9.2 The informational sign system

As informational signs are based on a synchronically manifested structure, it might be imagined that the linguistic concept of the synchronic language system would come into its own precisely in the description of these signs, although - as claimed in chapter 7 - it is not suitable for describing the common languages.

In linguistic theory, the concept of the synchronic structure appears as a concept of the invariant language system at a given time which not only organizes the linguistic sequence (usage), it also creates the framework for diachronic changes in the language system itself. The synchronic structure is thus seen as the superior instance at all times. Basically, the concept serves to establish a sharp distinction between two forms of diachrony, namely that of usage and that diachrony manifested as changes in the language system.

Hjelmslev, who takes over and tightens up Saussure's concept of the synchronic structure, thus acknowledged at a very early stage that the concept assumes a postulate to the effect that changes in usage and language norms can never bring about any change in the system. He therefore proposes the thesis that changes in the language system can only occur as the result of (tensions in) the synchronic system's structure, as this can thereby be regarded »as a self-sufficient totality, a structure *sui generis*«, or what is called today a self-regulating or 'autopoietic' system.⁷ The dynamic forces which are incorporated in this system are not described further, but Hjelmslev presumes that they have an algebraic form.

The interesting point in the present connection is not the theory's lack of validity for linguistic analysis, but on the contrary, that Hjelmslev's idea of an invariant synchronic structure forces him to distinguish between two completely separate types of diachronic processes, those changing the synchronic structure itself and those manifested in the actual usage, although the rules for - or constraints on - both types are given in the synchronic structure.

⁷ Hjelmslev (1934) 1972: 38 and (1943) 1961: 6.

In the informational sign system, however, the synchronic structure contains no invariant rules for diachronic sequences. On the contrary, it is itself included as a redundancy structure through which the former states and sequences - taking in all rule structures - become accessible to change through use. It is not only that the system can be changed through use, it is also the fact that it is the only possibility for both constructing it and for changing what has already been constructed.

The informational sign structure, which is available in a distinct synchronic state at all times, is thus an excellent example of how synchronic structures can be included in a redundancy system in which the rules can be modified and changed through the use they regulate.

This example also shows how such a system can also contain algorithmic procedures.

It is not possible, however, to maintain the concept of an asemanic - algorithmic - structure in the description of the diachronic sequence. These structures act as stabilizing elements through semantic codings which include both the composition of the algorithmic sequence and the possibility of variation, suspension and/or dissolution of the algorithmic procedure and/or its meaning.

The diachronic sequence is established by separating an individual element (a notation unit or a synchronically manifested sequence of notations) step by step into a series of synchronic states. In the given state, the element which is separated constitutes the semantically distinctive element, whereas the actual figuration constitutes the actual redundancy structure in a given state. The diachronic redundancy structure does not, on the contrary, have the same unambiguous and delimited character. The individual bits in a sequence of states can alternately act as semantically distinctive and redundant and the function of each bit is determined by the total sequence. Here, there is no semantically independent, constant structure. Any element in the informational sign can act both as redundant and as semantically distinctive, but not - as in common languages - simultaneously.

It can thus be noted that the structuralistic interpretation of the concept of the synchronic structure falls short in the description of informational signs on exactly the point it fell short in the description of common languages, although the informational sign system is distinct from these. It is not possible to describe either the linguistic or the informational sign structure without taking the semantic content into account and this is manifested in both sign

systems in - mutually different - continuous modulations of a redundancy structure which, for the same reason, can have no delimited, distinct form.

As Hjelmslev assumes that the synchronic structure creates definite and restrictive rules for diachronic succession it is clear that using his theory to describe the informational sign requires the theory to be greatly modified, partly because the synchronic construction here is produced as a manifested notation structure, partly because the informational sign system is characterized by a free, arbitrary and step-by-step choice, precisely at the point Hjelmslev places all linguistic determination.

A modification of Hjelmslev's theory is thus also the starting point for Peter Bøgh Andersen's theory of computer semiotics which, together with James H. Fetzer's theory, constitute two significant attempts to analyse, on the basis of sign theory, what Peter Bøgh Andersen calls computer-based signs, while Fetzer, taking his starting point in a critique of the Cognitive Science/AI approaches to the analysis of informational symbol systems, dismisses the idea that informational symbol manipulation - with Newell and Simon's definition as a prototype - can be regarded as a semiotic process.⁸

While both theories formulate the semiotic approach as an alternative to the Cognitive Science computer paradigm, (in the classical version which Haugeland dubbed the GOFAI version),⁹ they thus lead to two diametrically opposed conclusions. Where Bøgh Andersen would introduce the sign concept, Fetzer would exclude it.

This disagreement becomes no less striking when we add that Bøgh Andersen takes his point of departure in the semiotics of Saussure-Hjelmslev, which contains no concept concerning the structural relationship between the sign system and human use, while his analysis has this use relationship as its cardinal point. Fetzer, on the other hand, takes his point of departure in Peirce's triadic semiotics, but completely ignores the relationship between the informational system and its human interpreter(s).

The difference between the two analyses leads to one of the central problems in the semiotic description of the informational sign system, namely the relationship between the (chosen) semiotic theory and the analytical results the theory can produce when brought into play in the analysis of a never previously described sign system which is radically different to the sign systems which created the foundation for the formulation of the theory.

⁸ Peter Bøgh Andersen, 1990 and James H. Fetzer, 1990.

⁹ Haugeland, 1985: 112. GOFAI is an acronym for Good Old-Fashioned Artificial Intelligence.

The two theses make a pointedly different response to this question. Fetzer's strength lies in his theoretical analysis of Newell and Simon's, in many respects well-defined, symbol-theoretical basis for the AI paradigm, in which he also admits that the problem presents itself in a number of new ways.¹⁰ Fetzer, however, completely avoids the question as to whether there is a new sign system at all. This - taking into account the semiotic starting point - must be considered as quite remarkable. On the face of it, the explanation is quite simple. Fetzer assumes in advance that the symbol-theoretical paradigm constitutes an adequate description of the informational sign system (or at least of the most advanced or »intelligent« forms).

This assumption is not only an expression of a praiseworthy effort to avoid misrepresenting the symbolic-theoretical paradigm, it is also motivated by Fetzer's more general enterprise, which is not concerned with the analysis of different sign systems, but on the contrary with replacing the symbol theory with semiotics as the rightful interpreter of human consciousness, as he disputes that the symbol theory can constitute a stable basis for an understanding of genuine semiotic processes, including the human sign production which, according to him, can be described on the basis of Peirce's triadic sign concept.

...the evidence that has been assembled here would appear to support the conclusion that the semiotic-system approach clarifies connections between mental activity as semiotic activity and behavioral tendencies as deliberate behavior - connections which, by virtue of its restricted range of applicability, the system-symbol approach cannot accommodate. By combining distinctions between different kinds (or types) of mental activity together with psychological criteria concerning the sorts of capacities distinctive of systems of the different kinds (or types), the semiotic approach provides a powerful combination of (explanatory and predictive) principles, an account that, at least in relation to human and non-human animals, the symbolic-system hypothesis cannot begin to rival. From this point of view, the semiotic system-conception, but not the symbol system conception, appears to qualify as a theory of mind.¹¹

¹⁰ Newell and Simon's symbol definition is quoted in chapter 5 and is also discussed in the epilogue.

¹¹ Fetzer, 1990: 52.

The first victim of the struggle for the right to occupy the place as the interpreter of consciousness is thus the analysis of that sign system which is the starting point for the struggle.

The next victim, however - with due respect to Fetzer's other merits - is the semiotic theory's demand that it is the adequate and general theory of human sign production, as the semiotic theory - certainly in Fetzer's Peircian form - does not include the sign production humans carry out with the computer.

The question is whether this omission is connected with Fetzer's interpretation of the theory as to whether all that is lacking is an application of the theory to the computer, or whether it is a necessary consequence of the theory's structure?

Under any circumstances it is remarkable that the semiotic theory can divert attention from its own subject area to such a degree and, apparently, completely lack concepts for delimiting different sign systems and guidelines for the way in which it can be applied to the analysis of specific sign systems.

The central argument for claiming semiotics' primacy as a paradigm for a theory of consciousness, according to Fetzer, is that semiotic theory provides the space for different forms of sign formation and sign production which cannot be described with the symbol-theoretical paradigm. This thereby raises the question as to what constitutes the common and constitutive feature of semiotic systems as distinct from other systems. Fetzer answers - with a slant in the direction of Eco's intriguing dictum that signs are »everything which can be used in order to lie«¹² - that the most apposite criterion for identifying a semiotic system is: »the capacity to make a mistake.«¹³

It would be wrong to deny that a theory of human consciousness must make room for the ability to make a mistake. But when precisely this ability is made the distinctive criterion of semiotic systems, it is no longer sufficient to refer to fallibility in general, what is required instead is a clear definition of what a mistake is. Fetzer also defines the possibility of a mistake as follows:

In order to make a mistake, something must take something to stand for something other than that for which it stands, a reliable evidential indica-

¹² »Semiotics is concerned with everything that can be taken as a sign. A sign is everything which can be taken as significantly substituting for something else. This something else does not necessarily have to exist or to actually be somewhere at the moment in which the sign stands in for it. Thus semiotics is in principle the discipline studying everything which can be used in order to lie. If something cannot be used to tell a lie, conversely it cannot be used to tell the truth: it cannot in fact be used 'to tell' at all.« Eco (1976) 1979: 7.

¹³ Fetzer, 1990: 40, with a discussion of the possible fallibility of purely syntactic systems, p. 56 ff.

*tor that something has the capacity to take something to stand for something, which is the right result... to mis-take something for other than that for which it stands appears to afford conclusive evidence that something has a mind.*¹⁴

It is difficult to see how it would be possible to decide whether the semiotic definition of the possibility of a mistake is exhaustive, on the other hand it is not difficult to see that a semiotic definition of a mistake excludes the possibility that the mistake can at the same time define semiotics.

This circular semiotic conclusion also conceals the problem that semiotics has no criterion at all for deciding whether something is understood as an »expression of something other than that it stands for«. Although the mistake criterion has its roots in a justified opposition to ontological truth criteria, used as a theoretical, distinct concept, it stumbles over the same problem. Deciding what is false contains exactly the same problems as deciding what is true. The decision regarding the one is also the decision regarding the other. It is therefore advisable to take care in introducing references to decisions of this character into the epistemological foundations of science, which can rather be motivated by referring to the undecided.¹⁵

As mentioned, Bøgh Andersen, unlike Fetzer, takes his point of departure in Saussure's sign definition rather than in Peirce's. Neither, however, provides any reason for his respective choice of theoretical starting point, nor does this choice appear to be particularly motivated by the respective subjects. There appears to be nothing wrong with using Saussure's sign theory to arrive at Fetzer's conclusions - as the distinction between the symbol theory and semiotics is drawn primarily between the syntactic structure of the symbol theory paradigm and the semantic structure of the semiotic paradigm. Nor, on the face of it, does there appear to be anything to prevent Bøgh Andersen from using a triadic sign concept, as he attempts to add a third dimension to the Saussure-Hjelmslevian concept, which certainly bears a family resemblance to Peirce's interpreter.

The most important difference between the two theories rather has its roots in the different purposes which motivate them. Where Fetzer aims at a general theory of conscious, human sign production, Bøgh Andersen's goal is to

¹⁴ Fetzer, 1990: 40.

¹⁵ C.f. Finnemann, 1990b.

develop a semiotic conceptual inventory with special reference to the computer as a communicative medium.

Seen in relationship to the symbol-theoretical paradigm, the medium perspective is an inversion of the relationship between the theory's original subject area and the new area of use. In the symbol-theoretical paradigm (AI and the later Cognitive Science),¹⁶ the symbol definition has been used as a theoretical foundation for the description of what have been referred to, with an unfortunate term, as »natural languages«.

The opposite path is taken with regard to the medium perspective, as here the linguistic theory which was developed in the description of spoken and written languages is transferred to the description of a different symbol system. In justifying this inversion, Bøgh Andersen introduces four objections to the formal symbol theory.

The first objection is that symbol-theoretical approaches to language description are based on logical or psychological symbol theories rather than linguistic theories. As language is treated as an expression of something else and not as language, the central linguistic insights are simply overlooked.

The second objection is directed towards a general assumption in the AI/CS tradition, namely that it is possible to describe consciousness and language as a well-delimited - individually borne - system, whereas the linguistic viewpoint emphasizes the fact that language is a basic cultural and social phenomenon which exists in the relationship between individuals.

The third objection concerns the more or less explicit mimetic or naturalistic view of representation which in particular lacks the ability to describe that variability which exists between the signifier and the signified due to the arbitrary character of the relationship.

As a corollary to this, the fourth objection is introduced as a criticism of the general *leitmotif* in AI research, namely the idea of imitating human consciousness, which is seen partly as a false analogy, not least with regard to

¹⁶ As separate terms, AI refers primarily to the rationalistic symbol theories of the 1950's and 1960's (among them those of Newell and Simon) and Cognitive Science to the 1970's and 1980's (including Fodor and Pylyshyn). The journal "Cognitive Science" was founded in 1977. AI is also used as a common, general concept for both directions and sometimes also includes the empirical network theories. The latter is also true of Cognitive Science. This terminological sliding reflects an increasing tendency to define areas of research on the basis of methodological criteria, although a definition based on the subject area cannot completely be abandoned. A permanent discipline, however, must increasingly emancipate itself from purely methodological definitory criteria, as otherwise it will end as a victim of its own dogmatism. On the other hand, a direct binding of the method to the subject area would block the investigation of the subject area, not least when it comes to investigating those areas where disciplines draw their mutual borderlines.

language competence, partly as an expression of an effort to replace people with machines, where it would be both more correct and better to look at computers from the point of view of their meaning to those who use them.

These delimitations contribute to two purposes in particular. One is to motivate a return to especially Hjelmslev's theory. The other is to include the sign production, which stems from the symbol theory tradition, in the description of computer-based signs by viewing the AI/CS tradition as a producer of a special type of computer-based sign - to the extent that the results produced can actually be implemented.

However, a position made up of negative statements like »AI is nothing but...«, »AI is not...« effectively discourages one from working seriously with AI. This is unfortunate since AI techniques are both exciting and potentially useful.

A more fruitful attitude in the present framework would be to describe AI as a special mode of sign production. Instead of describing a question-answering system as a case of machine-intelligence, one could describe the question-answering pairs as a special kind of computer-based signs. This would imply moving AI-questions from the »language as knowledge« box to [the] »language as art(ifacts)« box, reinterpreting AI as a discipline concerned with [the] invention of a new kind of signs.¹⁷

The combination of these two purposes provides a double advantage. By demanding of the semiotic theory that it also include the - new - forms of sign production which are carried out with computers - it becomes clear at the same time that the semiotic theory cannot be expected to be available in an adequate form either.

Computer-based sign are new, very few systematic descriptions exist, and... the glossematic procedure only gives advice for presenting scientific descriptions of well-known domains.

The problem related to working with little known symbol-systems was not recognized in the earlier stages of glossematics where the analytical procedure was mixed up with the discovery procedure.¹⁸

¹⁷ Bøgh Andersen, 1990: 24. C.f. also the use of this viewpoint for developing »narrative systems«, Bøgh Andersen and Berit Holmqvist, 1990.

¹⁸ Bøgh Andersen, 1990: 16.

The theory - like any programme in relation to data - is on the same agenda as its subject.

9.3 The computer-based sign

To isolate the concept of the computer-based sign, Bøgh Andersen takes his point of departure in a sign model which includes four possible perspectives in the consideration and analysis of signs, namely:

- The semiotic perspective - studying signs as systems.
- The psychological, psycho-linguistic and cognitive science perspectives, studying signs as knowledge.
- The sociological and socio-linguistic perspectives, studying signs as behaviour.
- The aesthetic perspective, studying signs as art(ifacts).¹⁹

The primary purpose of the model is to place the semiotic description in relationship to other approaches by pointing out the advantages of the approach. When semiotics, in a graphic illustration, is thus placed in the centre from which the other approaches branch out like the legs on a milking stool, this does not express - at least in advance - a postulate to the effect that semiotics should or can create the foundation for other approaches. The reason, on the contrary, is that semiotics is regarded as the most suitable theory for describing the sign *system* which is the main theme of the book.

Semiotic theory is thus seen as a specific perspective which views »the subject area through a particular pair of glasses«, relative to other perspectives, as the semiotic perspective can only include »a subset of phenomena in the field«. ²⁰

In spite of this delimitation, the semiotic point of view is principally applied to all computer systems and use contexts, as the presence of the sign function is the ultimate criterion for delimiting the subject area of semiotics.

Hereby, the borderlines just established again become fluid, as both the psychological, sociological and aesthetic approaches are based on sign functions. If a border between these perspectives must be maintained, we must

¹⁹ Bøgh Andersen, 1990: 18-20.

²⁰ Bøgh Andersen, 1990: 20.

therefore assume that the semiotic theory is not seen as an exhaustive theory of signs.

Whether this is a principle limitation or the expression of an evaluation of the, as yet incomplete, character of the semiotic description is not made quite clear in Bøgh Andersen's exposition. The missing answer, however, is not necessarily a weakness or a flaw, but rather one of the productive questions which motivate the exposition. The relationship between the linguistic and non-linguistic must therefore also be seen as one of the central, unsolved theoretical problems in semiotic theory, as the theory on the one hand concerns all sign formation and thereby becomes a factor in the self-reflection of other sciences, while on the other hand it indicates the sign function as a specific subject area which can be studied separately from the knowledge content expressed in the sign function.

In addition to the - perhaps provisional - borderlines which are initially drawn in order to place the computer-semiotic theory, there is another borderline, however, which is drawn with rather more distinctiveness, namely the borderline between the semiotic description of the computer as a sign system and the AI/CS descriptions of the computer as a symbol system.

While the four different perspectives regarding the sign concept previously mentioned can be understood as different - complementary or competing - suggestions for the interpretation of the computational system's relationships to non-linguistic contexts, the relationship between the semiotic and symbol-theoretical descriptions is more a dispute regarding the way the system is included in a sign function.

Where the symbol-theoretical views regard the system as a depiction of the external world - and, if it is consciousness which is being depicted, also therefore as an autonomous or self-dependent, sign producing system - Bøgh Andersen sees the system as an expression substance which can be used in human sign production.

As the system itself thus contains no signs, it cannot be part of a communicative process. On the other hand, it can be included as a medium for communication between users.²¹

This critique is partly inspired by Winograd and Flores (1986), who denied that the computer system itself had any form of semantic content.

²¹ Bøgh Andersen, 1990: 120.

*There is nothing in the design of the machine or the operation of the program that depends in any way on the fact that the symbol structures are viewed as representing anything at all.*²²

The description of the machine processes as symbolic processes requires a motivation which qualifies this description as distinct from a description of the computer process as a purely physical process. As this motivation cannot be produced by any known machine, just as there is not even the hint of an idea as to how such a machine could be built, it is not difficult to follow Winograd and Flores' main point of view: »the significance of what is stored in the machine is externally attributed«.

Hereby, however, all that is produced is a new problem, as a description of how this attribution can take place is still lacking. There is a certain vagueness in Winograd and Flores' argumentation on this point. While, on the one hand, they insist that the system as a whole must be seen in relation to a outside interpreter - and thereby as part of a sign function - on the other they are inclined to believe that this sign function can be defined solely from the use perspective and independently of the system.

While Bøgh Andersen joins Winograd and Flores on this aspect of their thinking, which goes against the symbol-theoretical understanding of the system as an independent and semantically closed system which possesses a meaning content independent of the interpreter, he deviates in his view of how the system can be described, as he uses the linguistic distinction between the expression form and content form to describe the system as:

*a calculus of empty expression units, some of which can be part of the sign system that emerges when the system is used and interpreted by humans.*²³

Where Winograd and Flores attempted to subsume the view of the system under the use perspective, Bøgh Andersen emphasized the description of how - part of - the system can be included in a - use-motivated - sign function. As a consequence of this, the critique of the symbol-theoretical description of the system as an autonomous system is not directed towards the idea that meaning can be ascribed to the system, but towards the idea that only one meaning can

²² Winograd and Flores 1986: 86.

²³ Bøgh Andersen, 1990: 120.

be ascribed to it. The system is a - semantically empty - expression system to which several meanings can be ascribed.

The symbol-theoretical descriptions are thus rejected because they lack the semiotic distinction between expression form and content form. This distinction can be avoided, it is claimed, by assuming that the same form - the system perspective - can describe both the expression and content planes.²⁴

According to Bøgh Andersen, such homomorphism is certainly not always unimaginable, but it places unnecessary - and often also incorrect - restrictions on the understanding of the informational potential, as it can be shown that the practical use of computers introduces structures into the system process which are not contained in the system's own structure.

*Since content and interface are not properties that can be assigned to the system in itself, but are a relation between system and use, it follows that the system should not be viewed as a semiotic schema in which content and expression planes are homomorphic, but rather as a mechanism for generating the expression substance for one or more interfaces.*²⁵

The symbol theoretical description thus constitutes a valid description of the system only in those cases where the interpreter allows the system to determine the use completely. It is not the system itself, however, which contains the meaning, but the interpreter who establishes the semantic content by using the system as a means of expression in a sign relationship. Computers are correspondingly described as »sign vehicles that can only exist as real signs in situations where users interpret them«.²⁶

There are good reasons to accept - and emphasize - the possibility of using the same system to create different interfaces where different parts of the system are used in different sign functions. But the description of the system as a semantically empty expression substance is not without its problems. One of these problems appears directly if we put a programmer in the user's place, as it will hereby become evident that the semantically empty expression substance itself is produced through a sign production in which the programmer expresses a meaning content.

Bearing the programmer in mind, Bøgh Andersen himself also takes a step towards modifying the description of the system as a semantically empty

²⁴ Bøgh Andersen, 1990: 128.

²⁵ Bøgh Andersen, 1990: 130.

²⁶ Bøgh Andersen, 1990: 23.

expression substance, as he moves the expression elements in the system closer to an independent sign function by describing them as »sign candidates« which *almost* represent an intentional meaning content.

To say that the computer itself is an empty expression system is only a half truth: by relating it to other semiotic systems, e.g. the existing work language, the designer can strongly invite certain interpretations and a certain content system.

I will say that the computer system generates sign candidates, reflecting the view and intention of the designers.²⁷

The same, however, can be said of the relationship between an author, his book and its reader. But the relationship between the programmer's sign production and the user's differs from the relationship between an author and a reader because it is possible for the user to process each individual notation unit in the notation structure which comprises the communicative link.

The vagueness which appears here is due to the fact that Bøgh Andersen, fully in line with Winograd and Flores, treats the interpreter function as an occasional function which only commences when the system is being used. As the system itself, however, is the result of a sign production, the description of the use must consequently include at least two interpreters whose mutual relationship is distinct from the classical relationship between sender and receiver.

The central question here is not so much the relationship between the two semantic objectives which meet in use, but rather the question as to how they interfere at the expression level.

Although Bøgh Andersen accepts that the programmer has supplied the system with a hint of a semantic relationship, he still maintains the overall understanding of the system as an expression substance, as he connects up with Hjelmslev's description of the asemanic language system as a set of rules for using the figures of language.

Here, Bøgh Andersen utilizes Hjelmslev's view of the system as an asemanic structure which does not represent a content, but unlike Hjelmslev, he does not see the system as a determinant of the sequence. On the contrary, the sequence is bound to an interpreter function which is first manifested in use.

²⁷ Bøgh Andersen, 1990: 131.

This adaptation of Hjelmslev's theory for analysing the informational system raises a problem, however, because the informational system, unlike Hjelmslev's language system, is available as an explicitly expressed notation system which itself can become the object of interpretation and which additionally contains the rules Hjelmslev considered as invariant. As Hjelmslev's concept of an asemantic language system stands or falls with the demand that the rules which comprise the system are not themselves an explicit part of the linguistic expression, because in such a case they would be accessible to semantically motivated variation, it is not possible to transfer it to the description of the informational system.

Bøgh Andersen's attempt also leads to an untenable distinction between one part of the manifested expression substance (or the sign candidates) which are assigned to the »system«, because they presumably do not enter into a sign function, and the other part which does. Of the manifested expression elements there are thus only some which can be utilized in a sign function.

But what, we may ask, about the part that is not used? Could this be dispensed with? Or how many possible uses should be taken into account in order to be able to establish such a borderline between notation sequences which are included in a sign function and sequences which are »only« unused substance? How long, for example, must use be observed in order to delimit what is used?

These questions concern not only that plethora of - often unused, yet usable - possible instructions which nowadays characterize any good programme, but also the relationship between the parts of a programme which are necessary for the system and which are described as underlying instructions (e.g. the operative system and many of the other automatic sequences which can enter into the performance of a programme) and those which are included as expression elements in sign production.

Nor is this a question of the extent to which it is both meaningful and necessary to work with hierarchic structures which prevent a large number of instructions from becoming used operationally in a given use, but on the contrary of the extent to which such an operative borderline between the concept of use and the concept of system is a borderline between sign and non-sign.

As the manifest »unused« notation elements which comprise a necessary condition for the functionality of the system are the result of a sign production and are accessible to potential use in new sign functions - depending solely on

the user's competence and the purpose of the use - it is difficult to see how it is possible to exclude part of the informational notation from the sign-theoretical description. The definition of borderlines between the sign candidates which are at the user's disposal and those which are not, constitutes not only a - significant - part of the programmer's work, it is also included in the factual, implemented system which is accessible to the user's processing.

As the user's possibility of using all parts of the system to regenerate it in other expression forms is not limited by the system, but by his own competence, it is not possible to eliminate any part of the system from the description of the sign function. And as the sign function does not first enter into the picture when a system is used, but already in the construction of the system, the relationship between the system and the user must rather be seen as a meeting place where two sign functions, the one that is included in the system and the one that is included in the use, must interfere. The possibility of such an interference is due to the fact that the synchronically manifested notational structure can be used as a redundancy structure.

That the user can use the programmer's work as a tool for his own purpose - without thinking for a second of the programmer's sign production - does not mean that the programmer does not produce signs, but on the contrary that the user turns these signs into tools by accepting the programmer's symbolic definition.

If the distinction between user and programmer (or the corresponding »internal« distinction between system and interface) constitutes a relevant distinction at all, this is not due to the fact that it coincides with the borderline between sign and non-sign, the distinction first and foremost indicates a difference between purposes of use and between competences in sign handling.

That it is possible to connect these two different ways of sign handling at all in the computer based »communication« is due to the fact that the synchronous manifestation implies that the informational sign system can be subject to two different semantic regimes at one and the same time.

The problem which emerges here is a question - in linguistic terminology - of the description of a communicative process where the same notation and syntactic structure contains several possibilities for semantic organization and interference between several semantic regimes.

This, however, also indicates a limitation on the applicability of linguistic terminology, because in spite of the sharp distinction between the semantic

and syntactic planes, linguistics assumes that a given semantic potential corresponds to a given syntactic structure. Syntax parallels semantics.

As it holds true of other communicative media - such as the book, the film, the television, the telephone - that they build upon a semantic regime which is common to the sender and the receiver, it is also possible to conclude that the simultaneous, multisemantic regime constitutes one of this medium's specific communicative properties.

While the conformity between semantic regimes is a basic and general condition for other communicative media and languages, the possibility of conformity in the computer medium simply constitutes a specific threshold case. The programmer cannot, in Bøgh Andersen's words, control the user's utilization.

*Although a skilled programmer can be said to have full control over the computational processes that manifest the interface, he can only partially control which of its features the user exploits in his interpretation and how he exploits them.*²⁸

In the terminology used in the preceding chapters, we can say that Bøgh Andersen rightfully criticizes the symbol-theoretical views which regard the diachronic process as a function of the synchronic state, as he points out that the diachronic process permits semantic regimes which are not bound to the semantic description of the synchronic representation.

It thereby appears at the same time that the semantic interference between programmer and user has its characteristic form precisely because the programmer's total sign work is in the form of a synchronic re-presentation.

The synchronic form can be described as a meeting place between two different diachronic - and individually semantically determined - sequences; that which is determined by the programmer and that which is determined by the user. It is thus the user who decides the extent to which - and at which semantic level - he will subject himself to the diachronic bond the programmer has prepared. The limit to this independence lies, as previously described, exclusively in the demand that the semantic regime must be expressed in a

²⁸ Bøgh Andersen, 1990: 183. One might object here that it is always possible for the receiver to interpret any message independently of the intentions of the sender - and hence not under his control, but the synchronous manifestation still provides the computer with a multisemantic potential of its own, since it both allows the receiver to take the position of the sender as editor of the message (the programme), to use the message as intended in a variety of ways, and to use the message in a variety of ways which were not foreseen, by reinterpreting various features.

physically defined, synchronically manifested notation system which can be used as a redundancy system.

Although the user does not re-interpret the system as a whole, it is part of his sign activity. That it will often be purposeless, or directly contrafunctional to re-interpret large parts of the system, does not change this structural relationship. If the process is regarded simply as the transition between two steps, it is quite true that it is possible to isolate part of the system as the unused part. The unused part acts here as a chosen, completely passive redundancy. As soon as there is a question of a sequence involving several transitions, however, the possibility of making a sharp distinction between the redundant and the distinctive parts of the system is lost. Those parts which are redundant in one state may become distinctive in the next.

The synchronic redundancy structure which is manifested in the transition between two states does not therefore coincide with the diachronic. The synchronic redundancy structure can be described precisely, but only at the level of notation where it includes the entire system, except the actual instruction and the entity the instruction handles. As the diachronic sequence comprises the transitions between different synchronic states, where alternating parts of the notation system are used distinctively, it is also characterized by a variable, semantically defined redundancy structure which does not include a specially delimited part of the notation system. Redundancy in the diachronic sequence cannot be described at the level of notation, here it is a function of the syntactic and semantic choices.

The synchronic structure is thus the condition for the exchange between the programmer's and the user's two different semantic expressions, which individually have a diachronic structure.

When Bøgh Andersen draws the untenable conclusion that only part of the synchronic notation structure is included in the diachronic sign function, it is not simply a consequence of the fact that language theory has no concepts with which to describe the relationship between the synchronic and diachronic processes. The explanation must also be found in the design theoretical purpose which motivates the semiotic description of the computer system, as the point of departure here is the design strategic distinction between a given system and the abundance of different possible interfaces between system and user.

It is thus the description of the interface as a mediation between system and user which forms the foundation of the definition of the concept of the

computer-based sign, which does not include all the system processes it is based on.

While the system's processes are defined without recourse to the sign concept - which »permits all the computer processes and the system's structure« - all computer based signs are defined as:

a sign whose expression plane is manifested in the processes changing the substance of the input and output media of the computer (screen, loudspeaker, keyboard, mouse, printer etc.).²⁹

This definition again creates a foundation for a linguistic definition of the interface concept as a collection of computer-based signs which include all the parts of the system process which can be seen, heard, used and interpreted by users.

The important thing in this definition of interface is that it denotes a relation between the perceptible parts of a computer system and its users. The system processes are substances that can be turned into expressions of computer based signs in an interpretative process that simultaneously establishes their content. The definition is one more example of a structuralist shift from focus on objects to their interrelation.³⁰

It is also, however, an example of how the description of the interface structure in Bøgh Andersen is limited by yet another premise of linguistic theory, as the interface, which is defined as a collection of computer-based signs, is delimited by the perceptibility criterion which may well be a valid linguistic criterion for the definition of linguistic expressions, but is not valid for the computational expression system which is precisely distinguished by the use of a physically defined notation system which is not bound to the senses.

Bøgh Andersen himself also refers directly to linguistic theory in his justification of the point of view, as he introduces the perceptibility criterion as the first of six important characteristics for the semiotic view:

²⁹ Bøgh Andersen, 1990: 129. By defining the figures without recourse to the sign concept, Bøgh Andersen moreover breaks with Hjelmslev's premise, as the figures here can only be distinguished through a sign analytical dissolution of the expression into the smallest units.

³⁰ Bøgh Andersen, 1990: 129.

*The default requirement for a sign is that a human interpreter must be able to perceive it. Without expression, no content.*³¹

Although it is correct that the sign function, defined by the relationship between a content and expression plane, must necessarily have an expression and even though it is correct that the sign function has to be perceptually accessible, it is not correct that the two requirements justify each other. The demand for perceptibility need not necessarily be valid for the notation. It may, as is the case with the computer, be fulfilled through mechanically executed transformations to an output medium with the help of physical notation which is not accessible to the senses. Nor, conversely, does the demand for notation always serve the need for perceptual recognition. It may, as is also the case with the computer, similarly serve as a non-perceptible, physically-mechanically organized, but semantically controlled manipulation of the notation system.

That the perceptibility criterion is not suitable for delimiting the sign function is also indirectly indicated by Bøgh Andersen's own analysis, as this includes invisible sign manifestations - c.f. next section - just as he also introduces a special class of invisible »ghost signs« which are defined as:

*... signs that lack both permanent and transient features [which are visible]. They are not represented by icons or other identifiable graphical elements, and they cannot be manipulated directly. However, they do have a function to other [visible] signs. Like controller signs they show their existence by influencing the behaviour of other non-ghost signs.*³²

The visual criterion for the definition of the expression form appears here as a filter which conceals the unique properties of the informational sign system, namely that any informational sign element, unlike those from other sign systems, always has an invisible manifestation. The possibilities for transforming these expressions into a visually recognizable expression mechanically are always limited, a complete representation of the notation during the process is not possible - and certainly not desirable.

That the visual criterion for the definition of the sign function's expression plane is misleading is finally also indicated indirectly by Bøgh Andersen's

³¹ Bøgh Andersen, 1990: 188.

³² Bøgh Andersen, 1990: 221.

presentation, as he motivates the analysis of the visual representation as a design-strategic goal. The visual expression, the interface structure, is produced as a result of sign work which uses non-visible notation forms. It is also indirectly evident from this that the criterion of perceptibility has its relevance because the informational sign system is not available in a form accessible to the senses, as visualization is seen as a means to make the user's handling of the notation system easier.

Because of the supremacy of the interface and its functions regarding the work context, a good system structure is one that makes it easy for the designer to experiment with the different effects for achieving a given communicative purpose, and makes visible the role of the different system parts in the creation of meaning.³³

The concept of the computer based sign is thus defined as a - visual - mediation - a symbolic interface - between system and use.

9.4 The properties of computer-based signs

The concept of the computer-based sign is described here on the basis of a productive contradiction between two linguistic theories, related to system and use respectively. Among other things, the productive aspect in this is that it locates the relationship between the two poles as a centre of gravity whereas the linguistic tradition has to a great degree been formed in the struggle between theories, which give prominence to the one aspect at the expense of the other.

The background for this accentuation is correspondingly clear, the system does not play the same explicitly preordained role in spoken and written languages as it plays in the informational processes.

The concept of the computer-based sign, however, is not only interesting because it accentuates the relationship between system and use, but also because it gives rise to a classification of a number of informational sign properties - described at the interface level.

³³ Bøgh Andersen, 1990: 175.

In Bøgh Andersen's classification the - prototypical - computer-based sign is created as a composition of three features, a handling feature, a permanent feature and a transient feature.

The handling feature embraces the possibilities available to the user for influencing the system with given, physical input mechanisms. Permanent features, on the other hand, are features which are generated by the system, they are constant in a given sign expression's »lifetime«, they serve to identify the sign and represent the system's components. Transient features are also generated by the computer system, but unlike the permanent features, are subject to variation during use and therefore represent changes in the system state.³⁴

That computer-based sign expressions can have permanent features is only surprising inasmuch as this feature has not previously been specified in the description of sign systems. The fact that it now acts as a specified feature is not only because it has become relativized and specific relative to the two other features, but also because the permanent features of the computer-based sign possess, in spite of everything, no more permanency than lies in the fact that they are defined, facultative and editable features. The same naturally also goes for the so-called transient features. The permanent features are thus not parts of an invariant language system, »behind« the sign function, but are on the contrary established in a manifested sign function. The »permanence« itself is defined as a specific symbolic value and part of the expression.

That which characterizes the sign features which are »generated by the system« is therefore the structural possibility of operating with the combination of features which are maintained and the features which are varied. This is also an expression structure which is unique to informational systems. That Bøgh Andersen places great emphasis on the unique aspects of handling features which are generated by the user is probably connected with the general attempt to extend the potential use of the medium.

The characteristic feature of computer systems is the availability of handling features. The active hand movements of the »reader« are an essential ingredient of computer-based signs... Because of the handling features, the computer medium differs from the older ones in having properties also known from tools. This shows up in the interpretation of the signs... what we

³⁴ Bøgh Andersen, 1990: 176 ff. with examples and a more detailed analysis.

*see are not objects, tools and actions - we see and use signs signifying these phenomena.*³⁵

If, however, there is to be an advantage in emphasizing the difference between the tool and the sign for the tool, this must be due to the fact that the sign function is not bound to be maintained. It is also a quite banal experience that we can use the same machine both to simulate and/or execute many different tool functions, whereby we once again come to the conclusion that there is no expression element in the system which is external to the informational sign system.

This also means that the features Bøgh Andersen connects with the interface structure must rather be seen as a more specific utilization of the general properties which are connected with the informational sign system as such.

If we similarly maintain that the sign function is connected with human use - there is nobody else who can point out the referent - whether this is a question of the design of the physical circuit, programming the machine, the preparation or adaptation of applications, or the end user's utilization for a given purpose, we can conclude that the handling feature is not just a new, marginal sign property in the informational sign system, but on the contrary the basic property whereby we both define permanent, variable and new handling features. All computational processes begin with a user-defined command which produces a physically organized effect in the machine.

While the handling feature at the interface level appears as determined by the system, a more general viewpoint of the informational sign system shows that is not simply a secondary or derived sign feature, but on the contrary that feature which defines the informational sign system. The sign theoretical definition of the handling feature simply constitutes the semiotic concept of the programming process which constitutes the informational sign as distinct from all other known sign systems.

Unlike the more established programming concepts which are connected with the idea of a semantically closed whole, the sign theoretical definition of the handling feature, however, points both to the semantic and compositional freedom of choice in the construction of handling precepts and leaves no theoretical gulf between the system, the interface structure and the use context. On the other hand, it actualizes, as Bøgh Andersen moreover discusses in detail in his analysis of the work language's relationship to the

³⁵ Bøgh Andersen, 1990: 311.

non-linguistic, the theoretical and practical problems in our understanding of the relationship between symbolic and non-symbolic actions.

The concept of the symbolic handling feature not only reveals that often overlooked semantic freedom of choice in the programmed composition, it also reveals that feature which makes it possible to use Turing's choice machine, as this feature creates a foundation for yet another unique sign function, namely the interactive sign.

Bøgh Andersen defines the interactive sign as a composite sign which, unlike other composite signs as actors, object signs and controllers, is formed in a compositional structure of system and user-generated instructions.

The interactive sign possesses both permanent and variable features, but is distinct from other sign compositions because the variable features can be regulated by the user-defined action. Named as typical examples of this interactive sign function are the hero figure in innumerable games, the scroll function and a number of other tool functions from ordinary application programmes.³⁶

As it stands, the theory of the computer-based sign is motivated in particular by design theoretical considerations which are profiled partly in relationship to other design strategies and partly in relationship to linguistic sign theories.

As the interactive sign is defined as a specific utilization of the action component, it appears - if only indirectly - that it is not simply a sign function at the interface level, it also occupies a central place in the general informational sign concept.

While such a generalization is necessary, on the one hand, because all elements in the informational system both emanate from and can be included in a sign production, on the other it raises the question as to how it is possible to describe the symbolic dimensions of the interface level.

9.5 The interface between the internal and the external

The main emphasis in the theoretical profiling is placed on the difference to symbol theoretical views characterized by the description of the compu-

³⁶ Bøgh Andersen, 1990: 199 ff., where the typology is described in more detail.

tational process as a symbolic imitation, either of mental processes (such as Simon and Newell's neo-Cartesian AI paradigm) or of processes in the surrounding world (represented, among other things, by model and object oriented programming strategies which, with regard to the representation theory, operate with a mimetic relationship between system and external reality).

The basic reservation of Bøgh Andersen towards these theories concerns the idea that the computational system has any representational content at all which can be described independently of a human interpreter. On this point, Bøgh Andersen is completely in accord with Fetzer's critique and other Peirce inspired critiques of the symbol theoretical paradigm. The theoretical objection, however, is utilized in a different way, as Bøgh Andersen attaches himself to tool-oriented design strategies, primarily those of the American Human Computer Interaction tradition and the Scandinavian activity and work-oriented design tradition.³⁷

While these strategies, and with them also those of Bøgh Andersen, have a common focus at the interface level, which is seen as a strategic key point for the integration of the system into a use context, they diverge in the theoretical description of the connection between the system's »text« and the context. It was this difference which motivated Bøgh Andersen to distinguish between a semiotic, psychological and aesthetic approach to the interpretation of what in linguistic terminology can be described as the contextual referent.

The semiotic approach, however, also implies an opposition to one of the principal design ideals in the use and work-oriented strategies, namely the idea of the »transparent« interface which does not attract the user's attention because such attention would disturb the execution of the tasks the tool is to be used for.

This opposition is a direct consequence of the element which constitutes the merit of semiotic theory, namely the focus on the possible interplay between the expression form and the content form. From the semiotic point of view, the demand for transparency with regard to the tool is an expression of a one-sided concentration on the content side of the sign function which leads to the loss of the semantic variation possibilities which are connected with the sign relation between content and expression form.

³⁷ The »Scandinavian tradition« is usually traced back to the Norwegian computer scientist, Kresten Nygård. The label 'activity-oriented' »human activity approach« is taken from Susanne Bødker, 1987, who provides an analysis of the interface concept. The label »work-oriented« is taken from the title of Pelle Ehn's book, 1988, where he discusses a number of the Scandinavian tradition's projects as an approach to an extension and renewal of the design concept.

If the idea of the invisible or transparent screen, the screen as a window on the world, is a central element in the use-oriented strategies, semiotic theory is concerned with the visible screen, the screen as a pictorial or symbolic construction. The difference which is manifested through the different views of the screen, however, emerges because what is to appear on the screen must be obtained from two different places. Whereas the use and work oriented strategies regard the screen as a medium for semantic regimes in the surrounding world, in semiotic theory the screen is regarded to a higher degree as a medium for articulating a selected part of the semantic potential of the internal informational system.

If the two different views of the screen emerge because the screen is approached from two different directions, they need not necessarily conflict with each other. The difference can also be viewed as a result of the double determination of the interface level itself.

In Bøgh Andersen's definition, the interface comprises a collection of perceptually accessible computer-based signs, where the signs are used and interpreted in a given use context. Like other definitions of the interface concept, this definition was formulated with regard to the development of design strategies. The interface concept is thus defined as a working area from the point of view of the designer, as it serves to thematize the question as to how the designer can meet the user's needs. There is no reason to deny that such needs exist, but there are reasons to consider why a professional management of this need is necessary at all.

Perhaps the most obvious answer is that the need to design good interfaces stems from the fact that the lay user does not possess - and should not have to possess - professional programming competence. A good interface can thus be seen as a means of maintaining an appropriate division of labour.

This sounds like a plausible reason. But it cannot explain precisely why the interface concept originates and how it acquires its special significance for the efficient division of labour in connection with computer technology, where in many other cases the division of labour can be established without correspondingly specialized and professional mediation between different areas of competence.

If the consideration regarding efficiency is the correct reason for working with the design of interface structures, this must therefore be conditioned by the fact that a special kind of incongruousness exists in this area.

Most interface theories ascribe the need to the many different areas of use, each of which requires its own specific interface structure, which must thus be

modified relative to the different use contexts. No matter which special use is in question, however, they all have one thing in common, namely the need for an interface. While the answers to the problem differ from case to case, the source is always the same. The need to design the many different interface structures does not stem from one or another of the use contexts, or the special features of working competence, but from the character of the computer and the informational representation.

It would therefore appear most obvious to define the interface concept relative to the informational system.

If we take our point of departure in the lay user's standpoint, it is natural to point to the formal descriptive languages, which have often been used to handle the informational process, as a central competence barrier. This, however, can be compensated for through training without removing the need for an interface. An interface structure is also required in order to utilize formal languages to control the informational process. The need for an interface does not thus stem from the formal language, on the contrary, it stems from the mechanical form of the informational process which is not accessible to the senses.

The demand for perceptual accessibility is therefore rightfully included as a basic criterion in Bøgh Andersen's definition of the interface concept as »the relation between the perceptible parts of a computer system and its users«. ³⁸

In opposition to the older system theoretical definitions, which describe the interface as part of the system, he connects the criterion of perceptibility to the needs of the lay user, as the perceptible part of the system is seen at the same time as a set of restrictions placed on the lay user through the system.

Both the programmer and the lay user, however, must always handle the informational process through some kind of interface which uses perceptible expressions to handle the internal process in the machine which is inaccessible to the senses, just as all operations involve a change in the total state of the system, no matter which parts are accessible to the senses. The interface must therefore be described as a medium which permits the necessary exchange between a perceptible expression form and the non-perceptible informational notation. In its general form the concept therefore embraces any kind of input or output medium, which is also in accordance with the postulate that the interface is not necessary because of the user's - lack of - competence, but due to the character of the technology involved.

³⁸ Bøgh Andersen, 1990: 129.

Although we may theoretically be able to imagine that the conversion from perceptible to non-perceptible expression forms takes place as a complete conversion - for example with the use of the binary notation of input and output - such a complete conversion would in reality imply that the computer could not be used as a computer. Pure binary notation contains no syntactic or semantic structures. Consequently these structures can only come to expression at the interface level which, for exactly the same reason, must be designed as a selective - perceptible - compression of an internal notation structure which is not accessible to the senses.

The informational sign system is thus characterized by a double expression structure, whether the machine is used to control another machine, to simulate a calculating machine, a logical procedure, a drawing apparatus, a typewriter, or as a medium for storing and processing information.

If the machine is used as a dedicated machine which must always execute the same set of repetitive procedures notwithstanding their complexity, designing the interface constitutes a one-off problem. If the syntactic and semantic structure required for executing these procedures has been discovered, the machine can work as an automaton and the demand for perceptibility will only be in evidence before, after and in the case of disturbances. This borderline case at the same time reveals that the demand for perceptibility is closely connected with the utilization of the computer's syntactic and semantic potential and that this potential can only be expressed at the interface level, while it is effectuated at the internal notation level.

This background also makes it possible to understand the use of the screen as a central interface medium. The screen, as will be familiar, is not a necessary part of a computer system and even though the first screen was made use of in the middle of the 1950's, a quarter of a century would elapse before the comprehensive syntactic and semantic control potential made possible by the use of the screen was taken up in earnest.³⁹

Looked at from the lay user's point of view, these possibilities lie especially in the introduction of graphic and linguistic means of control which redress

³⁹ René Moreau, (1981) 1984: 86. The first screen used as a medium for the operator's intervention in the process is believed to have been used for the first time in 1954 in a machine built by IBM (NORC, or Naval Ordnance Research Calculator, which was inaugurated by John von Neumann on 2 December 1954). Cathode ray tubes and radar had formerly been used for more specific purposes where visual access was required to particularly critical parts of the process. Visual representation, however, was only regarded as an auxiliary function in monitoring the system process and the screen image was usually defined in very few parameters, for example a fixed number of lines with a fixed number of signs per line, whereas the graphic screen image is typically defined by dots.

the formal description barrier. From the designer's point of view, the same possibilities offer the opportunity to include information on later use in system development.

The result was a significant breakthrough, a new epoch, both in computer technology and in the history of society. There are nevertheless reasons to see the convergence between the two attempts as a provisional convergence, with the two parties each taking their own direction, which in both cases raises a more general problem of competence.

Where the designer is on his way out into the world, the user is on his way into the system. A good interface does not therefore help to remove the barrier, neither for the designer nor the user, on the contrary, it extends it because it implies that both parties will find it necessary to acquire more knowledge of an unfamiliar area of competence.

To the immediate and in itself far-reaching advantage which lay in the use-oriented definition of the interface can thus be added another, which may also have far-reaching effects, namely the advantage that lies in the fact that the same interface has both a semantic component, which is determined through the system, and one which is determined through use. This implies that the definition of the interface - including the screen - must be abandoned as a limited meeting place between two distinct components. The actual meeting between these areas of competence does not take place at the screen's interface level, but between two different interpreters who regard the screen in different ways.

In order to describe the relationship between these interpreters it is necessary to describe the interface as a synchronic transitional state between two - or more - different diachronic, semantic sequences.

Seen in relationship to the internal notation structure, the interface reproduces only a segment which originates as a semantically motivated selection carried out by the system's designer. There is thus no question of a complete representation of the system's synchronic structure at a given stage, but of a semantically motivated compression which distinguishes a sequence of diachronic transitions at the level of internal notation as a perceptually accessible semantic structure. The synchronic re-presentation on the screen, seen from inside the notation, is a fiction, the image on the screen is only synchronic if it is seen as a semantic structure without taking into account the flicker which reveals that the constant image itself is diachronically constructed.

While the screen image, seen from the system's side, appears as an output, from the user's side it is at the same time the point of departure for an input, where it is not only possible to utilize the perceptible output, but the entire system. Screen representation, therefore, permits a transition between output and input *without loss of the informational notation*.

Even though the synchronic interface is produced as semantically defined restrictions which are meant to help the user to handle the internal process, the synchronic form, however, means that the user also gains semantic freedom with regard to these restrictions. Not only can he choose between what is offered, but - solely dependent on his competence - can also choose to redefine the semantic structure by ignoring what is offered or by using it for other purposes.

On the face of it, while this possibility appears contrafunctional viewed from the use-oriented design viewpoint, it is not necessarily the case that this really is so from the user's. The central question here is the degree to which it is relevant for the user also to acquire areas of competence which make him capable of utilizing this potential of the informational sign system.

As poles in this area, we have on the one hand the fully developed, finalized application system which, for this very reason, approaches a functional use similar to that of a traditional machine and, on the other, a machine which only works as a heater. The interesting area, however, is all the possible intermediate forms between these two mechanical poles, as it is only these which make the machine a computer, determined by its symbolic properties.

If the idea that we must all become programmers is untenable, which there is at present good reason to accept, because it unnecessarily disregards the advantages of the division of labour, the idea that most of us should only be innocent users is equally so. The informational medium has its own properties which can only be used by those who learn to express themselves through them.

Just like the picture of the automatic machine, the picture of the perfect interface is also the picture of a computer which is not a computer. In these cases, the machine wins out over the sign. In all other cases, the thought wins out over the sign and the machine because there is a functional relationship between at least two semantic regimes which require two different forms of sign work, the programmer's and the user's. In order to edit the programme, the user himself must execute the programmer's sign work.

If, however, we wish to use this for a purpose, we must necessarily perform another sign work - namely the user's. The informational sign system's

syntactic structure is always subject to both semantic regimes, which coincide only in certain borderline cases. The informational sign system, relative to other sign systems, thus implies a structural doubling of the sign work.

10. Epilogue

10.1 What is a computer?

With the analysis of the computer's symbolic properties given here it is possible both to distinguish this machine from all other machines, whether these be clocks, steam engines, thermostats, or automatic calculating machines, from all other symbolic media such as the telephone, the telegraph, the radio, the television, the VCR and from all other symbolic languages, whether these be written languages and other visual languages, speech and other auditive languages, or music, as well as all formal symbolic languages, just as it is also possible to distinguish the symbolic properties of this machine from those of the human mind.

The description hereby fulfils a basic demand which must be made on any description of the computer, as the idea itself of describing the computer assumes that it exists as a distinct phenomenon.

As the computer possesses properties which are related both to those of the machine, other symbolic media and other symbolic languages and can be used to execute a great number of mental processes mechanically, the description of these properties raises a number of questions which are also connected with previous views, not only of the computer, but also of these more or less related phenomena.

This holds true in particular of the understanding of the relationship between the mechanical and the symbolic, the relationship between the symbolic expression and the content and the relationship between the rule and its execution.

It is not my purpose to provide any complete answer to these problems, which, however, it has not been possible to ignore either. The conclusions in the book are therefore divided into two parts, as in this section there is a summary of the analysis of the computer, while in the following sections there is a short account of the theoretical and cultural perspectives.

The most obvious place to start a description of the computer's symbolic properties is in relationship to the automatic calculating machine. There are historical reasons to do so, as the computer was a product of attempts to build a calculating machine which could execute any calculable operation mechanically. But this is even more obvious and informative because the comparison

leads directly to the basic principles which provide the computer with its unique characteristics.

By what could resemble a historical accident, Alan Turing presented the first theoretical description of the principles of the modern computer almost at the same time as the German engineer, Konrad Zuse, built the hitherto most perfect automatic calculating machine. While Zuse's machine, however, used a mechanical calculator and thereby assumed that the rules of calculation were incorporated into the machine's physical architecture, Turing's theoretical analysis showed that a universal calculating machine assumed that the rules of calculation were not incorporated into the invariant physical architecture. Where Zuse's machine could and should only be fed with the data for calculation, the Turing machine could and should also be fed with data which could produce the rules of calculation that were to be executed.

There is a world of difference between these two construction principles because the demand that the machine must be fed with data which produce the rules of calculation means that the rules must not only be specified, they must also be expressed in the same notation units as the data for calculation.

As a consequence of this, the Turing machine cannot operate with formal notation systems because formal notation contains no explicit description of the rules which the notation refers to and does not permit rules and data to be expressed in the same notation units.

The epoch-making leap forward from the automatic calculating machine to the universal symbol handler was thus brought about in and through the development of a new notation system. This event occurred, by and large, in a couple of pages of Turing's article *On Computable Numbers*, where he converted the formal expression to the notation form necessary for mechanical execution.

Turing himself saw this conversion as an operation which was necessary from a purely technical point of view, as the new notation could be read as completely defined by the original formal expression.

It was nevertheless a question of a new notation system with a number of new properties. Those features which make the Turing machine a universal calculating machine also make the machine a universal symbol handler, as the new notation can contain not only formal symbolic procedures, but any symbolic expression which can be formulated in a discrete notation system with a finite number of previously defined notation units, as the demand on this definition is primarily a demand that the notation must have a physical form which is capable of producing a simple mechanical effect.

The conditions made on this notation can be summarized in three points, which also express the necessary and sufficient condition allowing both symbolic and non-symbolic processes to be represented or simulated in a computer:

- All rules which must be executed mechanically must be available in the same notation units as data, the individual notation units must have a physically distinct value on the same scale as the other notation units because the notation must be mechanically active.
- There must be a previously established, finite number of notation units. The number is arbitrary, but in practice binary notation is used. There are no other general rules for establishing the value of the notation units and the notation system is independent of the demand for perceptual recognition.
- No independent semantic value can be ascribed to the individual expression unit, which can thus be defined as a semantically empty, semantic variation mechanism.

In addition to this - as a kind of negative condition - a fourth condition, comes a demand that there be a purpose which is not represented in the system.

This condition stems from the demand on the physically defined notation system. As the notation is solely defined on the basis of physical (mechanically active) values, it can also be manifested as a purely physical form which activates the same mechanical effects in the system without being intended. In other words, the machine cannot decide whether a given physical value is simply a physical value which is produced as a noise effect, or whether it is the physical expression of an intended notation unit. Any definition of notation systems thus contains an intentional element, but this element cannot be implemented in a mechanical machine. The problem can be solved in practice by using control codes whereby each signal's validity as a notation is determined by the surrounding signals.

With this description of the notation system it is possible to provide an initial, elementary description of the computer, partly as distinct from other machines and partly as distinct from other symbolic media, as:

- Unlike other machines, the computer is based on a complete dissolution of physical-mechanical determination into its »atomistic« components. The physical determination always only includes a step between two states and

this step can either involve changing one notation unit to another, or allowing it to remain unchanged.

- The same dissolution also goes for the symbolic interpretation of the physical process, as it must be possible to produce any symbolic process through such a step-by-step, physical-mechanical process, where it is possible, in principle, to intervene step by step.

This simultaneous dissolution of and connection between the mechanical and symbolic procedures represents both an innovation in the history of mechanical and symbolic theory, in the history of machine technology and of symbolic media.

Now, the use of informational notation is determined by the algorithmic linking of shorter or longer sequences of notation units and it might therefore be asked whether the notation system's multisemantic openness is limited by the algorithmic condition. A closer look at the algorithmic procedure, however, shows that this is not the case. First, because the algorithmic structure itself has polysemic properties, second, because when the algorithm is implemented in a computer it is represented in a notation system which permits an arbitrary modification or suspension of the algorithmic structure which creates the basis for the machine's multisemantic potential.

The first argument can be expressed in the following points:

- While each notation unit in an algorithmic expression has a well-defined value (a referent which is either a data or rule value), the total algorithmic expression has no definite referent. The same algorithmic procedure can represent a plurality of significations, purposes or meanings and different algorithms can represent the same signification, purpose or meaning. At the same time, the algorithmic procedure is characterized by the fact that it can be executed quite independently of these meanings and the result of the procedure is semantically empty. The algorithmic procedure does not prevent us from comparing or multiplying the height of the Eiffel tower with or by the sound of a thunderclap.
- While any algorithmic expression is completely determined, there are no general rules for joining algorithmic sequences. All expressions can be multiplied, divided, integrated, differentiated and combined as much as desired, as long as the order for each operation is described.
- The algorithm's start and stop conditions cannot be expressed in algorithmic form. The algorithmic expression cannot contain its own interpretation.

It must be interpreted in another language and the same goes for the algorithmic rules of procedure. The algorithmic expression contains references to formal rules, but the rules are not contained in the expression, they are, on the contrary, represented by a distinct and declared notation which refers to a rule outside the expression.

- The number of notation units used can be freely varied, depending on the task and the purpose.

The algorithmic expression can be described on this basis as a deterministic, syntactic structure with polysemic potential. In linguistic terms it could be said that the algorithmic procedure represents an empty expression system, a syntactic structure, which is emancipated from the content form. This emancipation is only relative, however, because the algorithmic expression is produced through a linguistically articulated definition of premises, just as the interpretation of the procedure and its result depend upon the re-establishment of a sign function which links the expression form with a content form.

The features of the algorithmic procedure which are drawn attention to here are perhaps not the most important features when we work with algorithms ourselves, but they are central when it comes to understanding what happens when the algorithmic procedure is converted to a mechanically executable form, because this conversion takes its point of departure solely in the algorithmic expression form. This conversion also implies a dissolution of semantic determination and the result of this can be summarized in the following points:

- When an algorithmic expression is to be implemented in a computer, it must be converted to another notation system which comprises a finite and invariant number of notation units. The individual notation units have no referent, the same notation units act both as expression parts for data and algorithmic rules of procedure.
- When the algorithmic procedure, which itself is sequentially constructed, is stored in the computer it is also available as a synchronic redundancy structure which implies that it is possible to move from any place to any other place and thereby break the sequential order, as the system is always completely determined by the relationship between the actual state and the next, individual step.
- An algorithmic procedure can represent both:

- A semantic content (e.g. in the form of logical rules or knowledge)
- A syntactic content (e.g. as a programme for constructing a digital picture, where the result of the serial process must be available to us in a visual, simultaneous form).
- A notation unit in another notation system (e.g. a letter, a number or a pictorial element).
- We can therefore intervene both from these different planes and intervene in the system at the corresponding planes (the binary plane, the algorithmic-syntactic planes, which may be hierarchically stratified, and the semantic plane).

While the automatically executed procedure can be described as an intervention, where the semantic intervention plane is maintained over a sequence, for each new intervention we can choose to vary the intervention plane »up and down«, or between different semantic regimes, whether these be formal regimes which can be mechanically executed, or informal, where it is the user who effectuates the semantic regime through his choice of input.

If this description of the symbolic properties of the algorithmic procedure is correct, we can draw the conclusion that the algorithmic procedure does not place any limitation on utilizing the multise semantic potential which is contained in the informational notation system.

While there are still sharp restrictions regarding which rules can be executed mechanically, there is only a single restriction regarding which symbolic and non-symbolic expressions can be represented and handled in a computer. With respect to the latter, this restriction is constituted solely by the demand that it must be possible to express the given content in a finite notation system with a finite number of empty notation units. With respect to the former, the question as to which rule systems can be implemented in a computer, it is still the case that the rule system must be characterized by well-defined start and stop conditions, that several rules cannot be used simultaneously, that there must be no unclarified overlapping between the extent of different rules (no over-determination, such as in common languages), that there must be no part of the total expression which is not subject to a given rule (no under-determination) and that the rules (or rules for creating new rules) must be declared in advance.

As Turing showed, these demands can be fulfilled for all formal procedures which can be executed through a finite number of steps. Whereas there has since been an explosive development in the number of procedures which fulfil

these demands, no rule system has hitherto emerged which fulfils both these demands and at the same time completely covers the description of a specific subject area, except that of abstract, formal systems. The explanation for this is to be found in the circumstance that we are not capable of fulfilling the demand for a precise definition of start and stop conditions in the description of non-symbolic relationships and are only able to fulfil this demand for a very limited set of artefacts produced by humans, including theoretically delimited, finite physical or logical »spaces«.

As the computer is a symbolic machine, a semantic dimension is included in all uses and as it can be subjected to a plurality of semantic regimes, it is consequently described as a multise semantic machine.

By a semantic regime we understand that set of codes we use to produce and read a symbolic expression, whether we are capable of formulating these codes in a complete or incomplete form or not. In this terminology, written and spoken languages comprise two semantic regimes which again distinguish themselves from formal regimes because they are based on different codes. In addition, there are a number of other semantic regimes, some of which are pictorial, others auditive. The concept is used both of symbolic expressions which are available as distinct notation units and as symbolic expressions (as pictures) which are not - or need not necessarily be.

It follows from this that the different semantic regimes need not necessarily build upon one and the same sign function and a description is therefore given of the way in which the relationship between the expression form and the content form are formed in different symbolic languages, as the emphasis is placed on the function of the notation forms.

The general results of the comparative analysis can be summarized in the following points:

- As all physical forms which can be used as notation forms can also occur without being notation forms, any use of notation systems is connected with two problems of noise theory, as it must both be possible to 1) delimit the individual notation unit relative to the physical medium and to other legitimate notation units, and 2) relative to the occurrence of an identical physical form which is not a valid member of the message. There is thus always a semantic component in the definition of a valid notation.
- The different notation systems build on different solutions to the two basic problems of noise, but the solution of the one noise problem is always included in an internal relation with the solution of the other, as the

individual notation systems possess - mutually different - possibilities for varying the relationship between the physical and semantic components which are included in the solution. This semantic component is therefore included in different ways in different notation systems.

- A given notation system always uses only a limited selection of the possible variations the expression substance permits, but different notation systems operate with different criteria for this restriction and these criteria also establish the - mutually different - smallest semantic variation mechanisms which characterize the given notation system.
- While the different notation systems can operate with different degrees of precision in connection with the demand for physical definition, the demands on the physical definition in the individual notation system can also be varied relative to the semantic component. The physical and semantic criteria thus form two mutually connected variation axes, so that the one axis permits variation in pattern formation and the other in the content of signification and/or strength of signification, as variation on the one axis can both be independent of and connected with variation on the other.
- As some kind of uncertainty is always inherent in the relationship between the components which are included in the definition of a notation system, notation systems cannot be described as completely rule determined. The comparative analysis is therefore based on a theoretical definition of the concept of redundancy and the individual notation systems are characterized by the different criteria for the use of both physical and semantic redundancy, as these criteria are both included in the solution of the two problems of noise and establish the smallest semantic variation mechanisms which characterize the mutually distinctive features of different symbolic languages.

Although this description is not exhaustive with regard to each symbolic language, it is sufficient to show that they use different expression forms and substances and that these differences provides a basis for the use of different reading codes. The comparative analysis thereby also provides the possibility of amplifying and going into greater detail in the description of the special relationship between the expression form and the reading code which characterize informational notation.

In formal and common languages the definition of the semantic component of the notations is thus closely connected with the given, superior semantic

regime. In these cases there is a fixed bond which connects a given expression form with (a set of) reading codes. While such a bond appears to be a precondition for the use of other notation systems, it is not a precondition for the use of informational notation, as the semantic component, which is included in the definition of the notation unit, is defined through a formal semantic which is independent of the superior semantic regime. The background for this difference lies in the circumstance that informational notation is not directly defined relative to human sense and meaning recognition, but on the contrary, relative to the demand for mechanical effectiveness, which implies that the semantic component must always be manifested in a physical expression.

This is thus a question of a difference which justifies speaking of a symbol system of a new type. The absence of the fixed bond between the expression form and the reading code gives this symbol system a central property, as the absence is a precondition for the fact that we can represent all these other symbolic expressions in the informational notation system. In other words, it is the precondition for the multisemantic properties of the machine.

By multisemantic properties, the three following circumstances should be understood:

- That it is possible to use this machine to *handle* symbolic expressions which belong to different semantic regimes (linguistic, formal - including both mechanical, mathematical and logical - as well as pictorial, auditive and so on) with the sole restriction that the expression which is handled can be represented in a notation system comprising a finite number of expression units.
- That it is also possible to *control* the machine (or the computational process) with different semantic regimes with the same restriction, as this control, however, can only be effectuated mechanically for a limited class of procedures, while for others it requires the semantic regime to be exercised through continuous intervention.
- That any process executed in the machine runs as a relationship between *at least two semantic regimes*, namely those which are laid down in the system and those which are contained in the use. The two regimes may coincide, as can happen when a programmer is editing a programme, or when there is a question of an execution of a closed semantic procedure such as in the form of an automatic execution of a demonstration. Usually,

however, this will rather be a question of a plurality of semantic regimes, but always at least two.

With this description it now becomes possible to add yet another criterion both to the distinction between a computer and other machines and to the distinction between the computer and other symbolic expression media.

While other machines can be described as mono-semantic machines in which a given, invariant rule set, which establishes the machine's functional mode of operation in the machine's physical architecture, has been implemented, the computer is a multisemantic machine based on informational architecture which is established by the materials the machine processes.

While other symbolic expression forms can be described as mono-semantic regimes with rule sets which connect the semantic regime with notation and syntax, the computer is a multisemantic symbolic medium in which it is possible to simulate both formal and informal symbolic languages as well as non-symbolic processes, just as this simulation can be carried out through formal and informal semantic regimes.

Together, these two delimitations contain a third, important criterion for the definition of the computer, as a computer can be defined as a medium in which there is no invariant threshold between the information which is implemented in the machine's architecture and the information which is processed by that architecture.

On the basis of this analysis of the properties of the computer it is possible to draw the conclusion that the computer, seen as a medium for the representation of knowledge, not only has the same general properties as written language, but also properties which create a new historical yardstick both for the concept of a mechanical machine and for the symbolic representation of knowledge.

Although this thesis hereby follows the research traditions which are in accord with the belief that it is possible to provide an unambiguous answer to the question as to whether the computer sets new historical standards, the interpretation given here deviates both in the understanding of the computer's mechanical and symbolic properties. It will therefore be reasonable to round off this section by characterizing and motivating this deviation.

When the computer is considered in continuation of the history of the mechanical technologies, the discussion has particularly centred on the extent

to which and how this machine contributes to the transition from an industrial society to an information society.

Within this descriptive framework, the computer is seen as a technology which makes it possible to reduce the industrial production sector and control the industrial functions through information processes. It seems, however, to lead to the paradox of controlling industry by industrial means of control.¹ It could, therefore, be claimed with equal justification, that this is also a question of a machine which can contribute to an expansion of industrialization, as it permits both a) mechanization of control functions which were formerly handled (or not handled) with other means; this holds true of many administrative functions, for example, b) the use of mechanical methods in new areas, for example in biology and psychology, but also in handling purely physical material and c) the use of mechanical registration and processing of data in connection with phenomena not accessible to the senses (including macrocosmic, micro-physical and molecular-biological phenomena). Whether the historical result can actually best be described as a transition from an industrial to an informational social paradigm, or as a qualitative renewal and extension of the industrial paradigm can hardly be considered as decided.²

We can, however, establish that the mechanical procedure can now be dissolved (or subdivided) into »atomistic« components and manipulated and organized as sequences of individual steps. In this perspective, the question is one of an extension of the mechanical handling potential through an analytical dissolution of the mechanical procedure and thereby the operative intervention plane.

This new handling potential not only permits a much greater differentiation between various kinds of industrial use, but also provides the possibility of choosing other uses which fall outside both old as well as renewed mechanical-industrial paradigms. The computer can be used as an indu-

¹ A paradox because the need to control industrial processes reflects the fact that industrial processes do not provide control by themselves.

² Present-day society is sometimes described as an information society with reference to the fact that more than half the people employed work with information services. If we use this definition of the information society, the computer may well be the instrument for a transition from this to a new industrial society, as many of these information services can be executed mechanically. On the other hand, however, all societies could be described as information societies because knowledge and the organized exchange of information are necessary conditions for any society. Under any circumstances, it is therefore necessary to differentiate between the »information« society we are familiar with today and the possible social forms which can be created with the computer as the basic information technology in society. Such a distinction can be established with the point of departure in a conceptual distinction between information technologies which have no informational architecture and information technologies such as the computer, which have.

rialization machine, but it can also, as such, be used in several ways, although even together these do not constitute the only possibility. It offers a choice (or a combination of several choices) which, in the social scale, have the same multisemantic dimensions as the machine itself.

The concept of the computer, on which the idea of a transition from industrial society to information society is based, is highly debatable, but the description given here also gives occasion to consider whether the industrial society and the mechanical-industrial paradigms are the right parameter for a description of the properties of the new technology and its implications.

There is one circumstance in particular which gives occasion to raise this problem, namely that with the computer we have obtained a symbol-controlled, mechanical machine in which we can represent all the forms of knowledge which were developed in the industrial society in one and the same symbolic system, where in the industrial society we represented different forms of knowledge in different symbolic expression systems. This means that the computer possesses a set of properties which make it a new, general medium for the representation of knowledge.

Although as yet we can only have vague ideas of what this implies, it is certain that this technology will bring about a change in the possibilities we have for producing, processing, storing, reproducing and distributing knowledge. In other words, this is a question of a change at level of knowledge technology, which forms an infrastructural basis of the industrial society.

Although the industrial societies have produced a great number of new, largely electrical and electronic symbolic media - including the telephone, the telegraph, the radio, the magnetic tape, the television and the VCR - writing and the printed book have maintained their position as the most important knowledge media with regard to the functioning of society. The computer, however, shakes this knowledge technological foundation.

It is therefore also reasonable to assert that it is writing and the printed book and not industrial mechanics, the calculating machine or the former use of mechanical energy systems for symbolic purposes which are the most important parameters for comparison and this implies that the horizon within which we relate to the cultural implications of the computer cannot be less broad than the horizon delimited by the role of writing and the printed book as media for knowledge in modern Euro-American history from the Renaissance up until today. The postulate is not that we can take in this field at a glance, it is simply that the computer revolution has a range which will

affect all the themes inherent in the history of modernity since the Renaissance. In other words, an extremely comprehensive, and in many respects probably new history of modernization. For the present, however, only vaguely outlined.

Just as little as other views, the view of the computer presented in the preceding pages can naturally not be used to predict the future. This is particularly so because, according to this view, it is a technology which offers many possible choices and variations with very few invariant features. This so-called prediction machine's own development has also hitherto evolved in the face of all predictions. Regarding factors such as speed and capacity, all predictions have been superseded by reality, the same goes for the differentiation of potential use, whereas the introduction of this technology has often created results which were completely different to those which were expected in the form of greater efficiency, breadth of perspective and control. Whereas 20-30 years ago in Denmark, it was expected that very few mainframe machines would be sufficient to cover Danish society's need for calculating power - and nobody imagined that the machine would be used for very much else - today, there is still a need which has not been catered for in spite of an enormously expanded calculating capacity. Where, only ten years ago, these machines could be marketed in the name of the 'paper-less' society, they have instead created even higher stacks of paper.

The fact that the predictions which describe the meaning of the computer as a means for achieving some definite purpose have often been completely wrong can to a great degree be explained on the basis of the machine's multise-mantic properties, as these imply that the machine is not determined by or bound to the purposes which are implemented in the same way as other machines. In respect of this point too, it is more relevant to compare the computer with other knowledge media, as such a comparison reveals that it is not possible to draw direct conclusions from a description of the medium to the content of that which is expressed in the medium. The individual book does not decrease the need for new books, it increases the need.

Similarly to the book, the computer is a medium of knowledge and both produce a set of - mutually different - conditions for the articulation of knowledge with regard to form. While the medium's form is thus probably part of the message, the content of the individual book, its effect or significance, cannot be predicted on the basis of this form.

The comparison with other knowledge media, however, shows not only the dubious aspect of a certain type of prediction, it also contains a point of

departure for another type, as the description of the computer as a knowledge medium also indicates the cultural plane, that sphere in society which is undergoing change, notwithstanding the way in which the medium is used.

It is also possible, on the basis of the description of the machine presented in the preceding, to suggest some of the structural features which characterize this new knowledge medium.

The first link in this sketch concerns the structural changes in the organization of knowledge as a whole, while the second concerns the changes which come into play at each link in the chain.

Where structural changes are concerned, at least three main points can be indicated, as the computer:

- First, is both a medium for *producing, editing, processing, storing, copying, distributing, searching and retrieving* knowledge. It thereby integrates the production of knowledge, the production of books, bookselling and library into a single symbol system and medium.
- Second, is both a medium for presenting *linguistically (spoken and written) formally, pictorially and auditively* expressed knowledge. It thereby integrates all modern society's staple forms of knowledge into the same medium and in the same symbolic representation system and thereby also provides the possibility of integrating written and pictorial forms of knowledge with auditive forms.
- Third, it is a medium for *communication*. It thereby integrates the most important previous means of communication, such as mail, telegraph, radio, telephone, television etc. whether one-to-one, one-to-many, many-to-many and both close to real-time interactive communication and communication, independently of the presence of the receiver.

In itself, the integration of all these functions, which were formerly distributed between different media and functions, is epoch-making, but in addition to this comes the fact that the computer's properties also change the conditions and possibilities in each of these individual areas. Although these cannot be described under the same heading, they have, however, a common background in the general properties of the machine. It is possible here to point out three important aspects which will be of significance in all areas:

- First, the machine operates with an independent symbol system (with respect to notation, syntax and semantics and the relationship between these

planes) and there is no invariant borderline between the knowledge which is incorporated in the machine's construction and the knowledge it processes. In other words, working with this machine requires an area of competence which is different to those areas of competence which are connected with other symbolic expression systems.

- Second, it integrates a symbolically controlled mechanics with the mechanical execution of symbol manipulation. In other words, working with this machine permits a number of new knowledge processing and knowledge retrieval systems. It therefore requires new forms of knowledge validation.
- Third, a great number of the restrictions which were formerly connected with the physically bound architecture of the symbolic media are here transformed into facultative symbolic restrictions which are implemented in a physically variable (energy-based) form. Symbolic representation is thus available in a permanently editable form.

10.2 A new technology for textual representation.

Although the symbolic properties of the computer go far beyond the capacities of any previously known means of representation, there are two basic limitations.

First, that any representation in computers is conditioned by a series of sequentially processed notational units. No matter what the specific function or semantic format used, and no matter what the specific purpose, any use of computers is conditioned by a representation in a new type of alphabet, implying that the content is manifested in an invisible, textual form, which can be edited at the level of this alphabet.

Second, that the global reach is conditioned and limited by the actual presence of and access to the machinery.

Taken together, these limits delineate a system for knowledge representation which is most properly conceived of as a new global archive of knowledge in which anything represented is manifested and processed sequentially as a permanently editable text.

Hence, the computer is basically a technology for textual representation, but as such it changes the structures and principles of textual representation as known from written and printed texts, whether they belong to common or formal languages.

The character of this structural change, however, goes far beyond the internal structure of textual representations, because - due to the integration of both linguistic, formal, visual and auditive formats of knowledge - it widens the range and logic of textual representation and - due to the integration of globally distributed archives in one system - widens the social and cultural reach of any kind of textual representation.

We can therefore say that, as an agent of change, the computer provides a new textual infrastructure for the social organization of knowledge.

The basic principle in this change is inherent in the structural relation between the hidden text and its visible representation. While the informational notation shares linear sequencing with other kinds of textual representation, it is always randomly accessible as a synchronic manifestation from which a plenitude of »hypertexts« can be derived independently of previous sequential constraints. What is at stake here, however, is not a change from seriality to non-seriality, but a change in which any sequential constraint can be overcome by the help of other sequences, as anything represented in the computer is represented in a serially processed substructure.

One of the significant implications is that sequences defined by a sender can be separated - and rearranged and reinterpreted - with sequences defined by any receiver, while the position of receiver in the same act is changed to a more active role as »writer«, »co-writer« or simply as user. Hence, interactivity becomes a property inherent in the serial substructure and available as an optional choice for the user, limited only by his or her skills and intentions.

Seriality persists, even in the case of non-serial expressions such as photographs and paintings, since non-serial representation is only the result of an iteration of a selected set of serially processed sequences. The same is true of the representation of any stable expression, whether of a certain state or of a dynamically processed repetitive structure and even in those cases where one or another binary sequence is made perceptible for editing as a first order representation.

As an interplay between the textual substructure and any superstructure (whether textual or not) is indispensable in any computer process, this is the core of the structural change in the principles of textual representation.

10.3 Computerization of visual representation as a triumph of modern textual culture.

The inclusion of pictorial representation seems to be one of the most significant indicators of the new range and logic of textual representation, as now, for the first time in history, we have an alphabet in which any picture can be represented as a sequential text.

Textual representation is a feature common to all computer-based pictures, and defines their specificity by contrast with other pictures. Since any picture in a computer has to be processed in the identical - binary - alphabet, it follows that any picture can be edited at this level, implying that any computer-based picture can be transformed into any other picture in this alphabet. Morphing may perhaps in many cases be only a curiosity, but the basic principle that any computerized picture is always the result of an editable textualized process performed in time is far from a curiosity since it changes the very notion of a picture as a synchronously and not serially manifested whole.

Seriality and time are not only introduced into the notion of pictures as an invisible background condition, they are also introduced at the semantic and perceptible levels, since the textualized basis allows the representation of - editable - time to be introduced at both these levels. While the synchronously manifested whole is an axiomatic property of a painting or a photograph - even though they are produced serially in time - the same property in the computer has to be specified and declared as a variable at the same level as any other feature whether it belongs to the motive, to the compositional structure or to the relation between foreground and background. Variability and invariance become free and equal options on the same scale, applicable to any pictorial element which implies that there is no element of the picture whatsoever which is not optionally defined and permanently editable.

There is of course a price to be paid for this new triumph of textualization, as the textual representation presupposes a coding of the picture into an alphabet. The basic principle in this coding is the substitution of physically defined notational units for physical substance, implying a definition of a fixed set of legitimate physical differences (i.e.: differences in colours) which are allowed to be taken into account. Since we cannot go back to the original if we only have a digitized version, the coding is irreversible and the possible secondary codings and transformations will therefore always be constrained by the primary coding.

The relevance and weight of this constraint is itself a variable which has to be taken into account in the use of computer-based representations, but in general there are two main aspects.

First, that some of the substance qualities of the original will always be missing since there is a change of expression substance. There will therefore always be some doubt about the validity of the reference to the original. This is obviously a serious constraint on the scholarly study of art.

Second, that the definition of a fixed set of legitimate physical differences at the time of the original coding may later prove to be misleading, in that physical differences which are not taken into account may be of significance. Since the computer-based picture is conditioned by an invariant distinction between differences in noise and information in the substance, there may be cases - in medical diagnostics, for instance - in which a reinterpretation of this distinction is needed.

The constraint here is directly related to the logical interrelation between noise and information, which implies that information can only be defined by the delimitation and treatment of potential information as noise, since information is always manifested in one or another kind of substance.

While missing information concerning some qualities of substance cannot be completely avoided, computerization at the same time allows a broad repertoire of possible enrichments concerning global accessibility, as well as analytical and interpretational procedures.

Since the constraints on informational representation are basically those of notation and process time, it is not possible to define any other invariant semantic or syntactic limitations to these enrichments. That this is itself a significant property can be seen by comparing previously known pictorial representations for which there does exist one kind or another of textual representation, such as those described in Euclidean geometry for instance, by the analytical geometry of Descartes, or in the various other forms of syntactically defined pictures, whether based on a well-defined perspective or a well-defined iconic or diagrammatic system.

The basic and general change in representational form towards any of these representations can be described as a transition from representation at a syntactic level to representation at the level of letters (those of the new alphabet). The textual representation of geometrical figures defines a naked syntactic structure, whether two-dimensional or three-dimensional, without regard to substance qualities such as colours etc., while any syntactic structure in a computer-based representation of a picture can be dissolved into a series of

notation units, including the representation of some kind of substance. Although this is a change from a higher to a lower level of stable organization, it is for the same reason a change from a more restricted set to a more elaborate set of variation potentialities in which the higher level structures become accessible to manipulation at the lower level. In the first case the picture is defined by a stable syntactic structure - to which can be added certain rules for variation, while in the latter, stability is defined solely at the level of notational representation - to which it is possible to ascribe a plenitude of - editable - syntactic and compositional structures as well as to integrate representations (only partially, however) of substance qualities such as colours and backgrounds at the same textual level. Form, structure and rule become editable on the same scale as substance. The representation of substance is necessary, but need not, however, be a simulation of the substance of the original, the representation of an arbitrarily defined and itself editable background on the screen will suffice.

Moreover, informational notation is a common denominator in which some substance qualities, the syntax as well as the motive, are manifested on a par with each other. As any sequence representing one or another element of a picture can be selected and related to other sequences in various ways and possibly ascribed various functions as well (i.e. add an referential function, which is itself editable, to other sequences) it follows that any fragment of a picture or a picture as a whole can be integrated into a still increasing - or decreasing - syntactic and semantic hierarchy completely independently of the original form and source. The insecurity in the referential relation to the original is thus complementary to the enrichment of possible hierarchies and frames of reference.

Perspective becomes optional and variable and so do other kinds of representational structures such as representation based on the size and positioning of motifs and the choice of colours in accordance with semantic importance, as was often used during the Middle Ages. The resurrection of - or a return to - the Middle Ages, however, is not on the agenda of computerization, since no single, non-optional hierarchy of values can be established.

When seen from the cognitive point of view this is a radical extension of the ways in which cognitive content can be manifested in pictorial representations, whether in iconic, diagrammatic or geometrical form. When seen from the pictorial point of view, it is a radical extension of the ways in which the representation of both physical objects and pictures can be made subject to cognitive treatment.

Much of this is a result of the fact that the computer-based representation of stable structures has to be »played« in time, but since time has already been represented in the film and on the television screen, the proposition must be qualified accordingly.

In the case of film making the basic difference is that the definition or selection of perspective is constrained by the optical artefacts - the lenses of the camera - used, while the definition of perspective in the computer has to be defined as - a still editable - part of the same text as the motif, which implies that the very division between the optical constraints and motif becomes editable. So with regard to freedom of choice the computerized picture more closely resembles the animated cartoon than the film.

In the case of television the difference is primarily the result of the notational definition of the signals, as the stable picture on the TV screen is only the - perceptible - result of serial processes. As will be familiar, a basic constraint on real time digital television is the enormous amount of binary letters needed to represent what was formerly an analogue signal. This is a constraint, however, which at the same time transgresses a series of other constraints which characterize the old-fashioned television of the 20th century. The most far-reaching of these is probably the possible breakdown of the one-way transmission and communication. Since a receiving computer can also be a sender, the receiver can also become the editor of the editors, able to decide what and when he will receive from whom. And since the computer is not only a medium for communication but also for storing in a completely editable form, the new medium transgresses the documentation monopoly of senders too.

If, as has often argued in media studies, other modern electronic media contribute to a revitalization of visual and oral culture - although in a mediated secondary form, as claimed by Walter J. Ong - at the expense of the hegemonic regime of the »typographic culture« as it was claimed by Marshall McLuhan, the computer can more properly be understood as a medium by which the reach of modern discursive culture is extended to embrace visuality and pictorial expressions by the textualization of electronics, which at the same time allows the representation of other media as genres within this medium.

It is not only the picture or any other visual object which can now be embraced by a text. As the author of a discursive text is able to represent himself in the text, so the observer or spectator - given the appropriate paraphernalia of »virtual reality - is now able to represent himself as an interacting

part of any picture. In both cases however, only as a fragmentary representation.

Under any circumstances, computerization implies that some physical and organizational constraints and invariants (whether substantial, structural or conventional) are converted to text and hence becoming optional variables.

10.4 One world, one archive.

That the computer - due to the properties described - has the potential to become a new general and globally distributed network medium for representing knowledge does not necessarily imply that it will actually do so.

There are, however, strong indications that it will.

First of all it seems beyond reasonable doubt that the use of computers will spread almost everywhere, whether this is rational or not, due to a widespread, powerful human fascination. The spread of computers into a still growing number of fields - and throughout the world - indicates that a profound change in the basic infrastructural level of all societies has already begun.

Although we are not able to predict what will happen in the future, there are very few reasons to believe that this process can be stopped and the only argument which should not be marginalized seems to be the risk of a breakdown due to inadequate electricity supplies.

Computerization in general need not to be argued for and arguments given in the past have often turned out to be wrong, or have had no particular impact.

If we are only able to guess at what may happen anyway, we might ask why we should bother about this matter at all. In this connection I should therefore like to mention two arguments which could indicate a high degree of social and cultural necessity resultant on the process of computerization.

The first argument is closely related to changes in the global reach of modernity. While the global perspective - inherent both in the claim of universality for human rights and western rationality in general, as well as in the process of colonization - is as old as modernity itself, most decisions in modern societies have until recently depended mainly on knowledge based on a more limited - locally restricted - scale. Today, however, a rapidly increasing number of local decisions on local issues depend on knowledge based on global considerations. This is true both of economical, political, military and especially ecological information and, in consequence, there is also a need for a global

scale for cultural issues. While some might argue that it would be better to attempt to re-establish a local economy and local political and military government, there no longer appears to be any room left for the idea of a locally restricted ecology.

Given that an increasing number of local decisions concerning ecological issues need to be based on a corpus of knowledge of global dimensions, there is no real alternative to the computer.

While this is an argument of the natural conditions for cultural survival, the second argument comes from within culture and is a consequence of the exponential growth in the production of knowledge anticipated by J. D. Bernal in the 1930's and Vannevar Bush in the 1940's and later described in the steadily growing number of books, papers and articles which have appeared since the pioneering work of Derek de Solla Price, among others,³ in the early 1960's. Whether measured in number of universities, academic journals, published articles, or the number of scientists and scholars in the world, or the number of reports prepared for politicians for making decisions etc., the overall tendency is the same. Limits to the growth of knowledge production are in sight - whether seen from an economical or organizational point of view, or as a general perspective on a chaotic system in which nobody can keep abreast of what is known even within his or her own specialized field.

Basic structural changes are inevitable, whether in the form of a cultural collapse or a cultural reorganization. The computer is obviously not the solution to the handling and reorganization of this exponential growth, but is an inevitable part of any viable solution, since any cultural reorganization must include a repertoire of remedies for storing, editing, compressing, searching, retrieving, communicating etc., which can only be provided by computers.

The computer may widen some cultural gaps, but if it were not used there might be no cultural gaps to bridge, since there might be no culture.

10. 5 Modernity modernized.

It should be evident from this that the computer is in the process of becoming a new platform for the social organization of knowledge and communication based on textual representation. While the very idea of a universal computer was the outcome of a short-circuiting of the modern dualism between mind

³ J. D. Bernal, 1939. Vannevar Bush (1945) 1989. Derek de Solla Price, (1961) 1975.

and mechanical nature and hence represented a rupture in the principles of discursive representation in modernity, it became at the same time a means with which to expand modern discursive representation, but in a new form as a hidden second- order representation beneath perceptible first-order representations.

Although it may seem odd seen from previous modern viewpoints, it is a change which is in complete accordance with one the most stable and persistent principles of modernity, i.e. that of placing former axioms on the agenda as objects for investigation, description and thereby textual representation.⁴

The principle of transgressing a former conceptual framework by placing the axioms on the agenda can be found at work throughout the history of modernity, but although it is a general principle, the outcome naturally depends on the conceptual structure of the specific axioms to which the principle is applied. For this reason the same principle may cause different effects, which implies that modernity can only exist as a history of permanent self-transgression. In consequence, a conceptual rupture related to the transgression of axioms becomes a basic principle of continuity in modern culture. If this is the case, modernity cannot exist without a history in which progressive expansion is based on theoretical regression, i.e. the theoretical undermining of previous theories.

There would be no modern history, however, if continuity were only represented in the form of conceptual ruptures. On the contrary, they can only exist in the distinct modern form as conceptual ruptures at the level of axiomatics because they are always manifested in and bound to discursive textualization.

Since computerization is completely in accordance with both these modern principles of continuity, it can most properly be seen as a genuine modern phenomenon contributing to the ongoing process of modernizing modernity.

⁴ Previous examples which could be mentioned are: the transgression of the Newtonian distinction between physical matter and immaterial forces manifested in the new concept of material energy in 19th century physics; the transgression of the absolute distinction between matter and energy inherent in Einstein's theories of the early 20th century; the transgression of the definition of substance as form inherent in 20th century theories of structuralism, information theory, functionalism and pragmatism, among others; the transgression of formalist axiomatics inherent in Gödel's theory; the inclusion of human emotionalism and sexuality in the concept of man inherent in late 18th century philosophy and Romantic literature. Or in more general terms the transgression of the concept of a static universe inherent in 19th century theories of evolution, development and growth, the transgression of 19th century materialistic dynamics inherent in 20th century functional dynamics, such as that manifested in Chomsky's generative grammar theory, for instance.

The main impact of computerization on this process is beyond doubt the modernization of the modern textual infrastructure, which implies that the process of modernization has now come to embrace the primary medium of truth in modern societies. If discursive textual representation formed the basis for the modern secularization of the human relationship to nature, the very same process has now come include the textual representation itself.

There seems to be a kind of logic in this process of secularization, which takes its point of departure in the notion of inanimate and external nature - initially conceived of as materially well-defined entities moved by immaterial forces, later as well-defined material entities and energy processes - and expanded to include biological processes leading towards the inclusion of mental processes and symbolic representation, which imply that the observer is observed and included in the very same world as any observed phenomenon.

It may seem that this is only a form of logic concerning the movement towards an all-embracing inclusion of subject matter, as the story of theoretical and epistemological developments is in many respects one of increasing divergence, in spite of many vigorous efforts to create a unified, scientifically based corpus of knowledge. Even though this may be true, it is also true that there is a logic in theoretical and epistemological developments as the movement towards the inclusion of all subject matter, whether physical, biological or mental, is related as a main cause to the history of axiomatic transgressions.

While the theories of the 16th and 17th centuries relate to the axioms of a static universe based on fixed entities and substance defined by form, 19th century theories relate to - various - axioms of dynamic and developmental systems based on variable entities, while 20th century theories predominantly differ from both of these, in that the notion of form is now separated from the notion of substance and is hence seen as a self-reliant structure or pattern which can organize arbitrary substances. In these theories substance does not matter. The computer is one of the fruits of this development, caused among other things by inner tensions in mechanical theories and most theories relating to the computer are still based today on the same type of axiomatics.

So, how then, is it possible to predict that computerization will bring about a new transgression of axioms? A new textual infrastructure as such would not, if it were not at the same time based on the very fact that substance does matter, and does so because - contrary to the main axiomatics of the 20th century and contrary to the ideas necessary for the invention - substance can neither be identified with form nor reduced to amorphous matter without affecting form.

This being so, we can predict that computerization will necessarily return substance to the theoretical and epistemological agenda, from which it was removed in late 19th and early 20th century theories. It will not, however, return as it was when removed. The return of substance will not take the shape of a notion defined by - extensional form - nor will it return leaving the notion of self-reliant forms untouched. On the contrary, it will return primarily as a resource which will force a change in the notion of form, as the same substance can be the carrier - itself transformed - of various forms, patterns and repetitive or unique structures.

Just as in modern physics, where energy under certain circumstances is converted into corpuscular matter, which implies a complete substitution of properties (from those of interfering waves to those of colliding particles), material substance seems to need an interpretation as a generic resource or material which allows the formation and change of various forms and structures.

In the case of complete substitution, there seems to be nothing left for further description except the curious fact that two completely different sets of properties are ascribed to the very same »phenomenon«. To say that energy is completely transformed into matter implies that a specific amount of energy is identical with a specific amount of matter, although they have no common properties except the rule of exchange.

Now since there is a physical process taking place in time and space before as well as after the conversion, we may wonder how it could be possible to maintain that the process of exchange is not itself a process which takes place in time and space? And since there is substance before as well as after it would seem that there must also necessarily be substance in between. Whether there is a way to get around this question in physics, it is impossible to say that substance can be identified with only a single invariant form.

Thus the break with early modern concepts of form as something which defines substance must be maintained, while a break with late modern concepts of self-reliant forms is placed on the agenda.

A most intriguing aspect of this is that the very notion of rules and coding procedures must now be included as processes taking place in time, space and substance, in a world identical to that of the coded substances.

The logic of this process is the logic of progressive secularization, as it moves from the idea of the transcendental, cosmological rules of the Middle Ages and Renaissance, passing through the Enlightenment reinterpretation as natural laws immanently given in the world, but still seen as axiomatically

given invariants and functioning as transcendently given on the phenomena ruled (as the rules of language were still described in 20th century structuralism) while we are now confronted with a third step in the transition from transcendently to immanently given rules, that of the breakdown of the idea that rules are functionally transcendental invariants to the ruled.

Even if the notion of a rule or code must imply a dividing borderline between the code and the coded, there is no way to maintain that the borderline is invariant, as it can only be established through the very same process as the coding itself.

Although it may be convenient to assume that some codes have existed since the very origin of the universe, this does not tell us much, as the very idea of such an origin can only refer to the idea of some divinely given invariant codes. There may or may not be such transcendently given codes which are not the result of processes taking place in time, space and substance, but there is certainly a multitude of codes which can only exist as the result of coding procedures which actually do take place in time, space and substance.

A basic conceptual inversion implicitly comes from the need to explain how stability is possible at any level, including the question as to how levels come into existence. The very question implies that the notion of stability, rule, code and invariance must be moved from the field of axiomatics to the field of what is to be explained.

This is exactly the type of question posed by computerization, as the rules governing the processes in the computer must come in the same package as the governed, ready to be processed and edited in exactly the same way. To the notion of rule based systems we must now add the notion of rule-generating systems. Among the properties of such systems, redundancy functions seem to be one of the most important, as these functions can provide stability, although they allow existing rules and levels to be suspended or modified and new rules and levels to be created in ways which are not possible in strictly rule based systems.

Although the computer is not a rule-generating system such as we - in some respects - are ourselves, it transgresses the constraints which define strictly rule based systems, placing the very notion of rules on the agenda and thereby removing this notion from its sacred position of axiomatically given phenomena. A position in which nothing now appears to remain.

What has been said here about notions of substance, rules and codes is parallel to what could be said about the notion of the observer, the brain-mind relationship, the notion of human subjectivity and so forth. The process of

modernization has come to embrace exactly those notions on which the process itself has been based in previous epochs. If this is the case, we are heading towards a secularization of the relationship to the secularizing mind or a transition from modernizing on a first-order scale to modernizing on a second-order scale. A continuation of modernity both through the integrative transgression of former axioms and through the extension of global reach, whether in the form of second-order textualization of such things as visual representation or second-order integration on a global scale. A continuation, however, which is only possible because the principles of modernity are not those of rule based systems, but those of rule-generative systems based on redundancy functions which allow any specific axiom or rule to be modified, suspended or transgressed.

Literature

- Albeck, Ulla, 1960. *Dansk stilistik*. Gyldendal, København.
- Andersen, Peter Bøgh & Holmqvist, Berit, 1990. »Interactive Fiction: Artificial Intelligence as a Mode of Sign Production«. *AI & SOCIETY*, vol 4.4: 291-313, Springer Verlag, London.
- Andersen, Peter Bøgh, 1990. *A Theory of Computer Semiotics*. Cambridge University Press, Cambridge.
- Andersen, P. B, Holmqvist, B. & Jensen, J., 1993. *The Computer as Medium*. Cambridge University Press, New York.
- Augarten, Stan, 1984. *Bit by Bit. An Illustrated History of Computers*. New York.
- Bannon, L. & Pylyshyn, Z., (eds.) 1989. *Perspectives on the Computer Revolution*. (2. ed.) Ablex Norwood, New Jersey.
- Bannon, L. & Schmidt, K. 1989. *CSCW: Four Characters in Search of a Context*. Paper delivered on EC-CSCW, London, 1989.
- Bannon, Liam, 1989. »From Cognitive Science to Cooperative Design«. In Finnemann (ed.) 1989c: 33-58.
- Beeson, Michael J., 1988. »Computerizing Mathematics. Logic and Computation«. In Rolf Herken, (ed.) 1988: 191-225.
- Bell, Daniel, 1973. *The Coming of Postindustrial Society*. Basic Books, New York.
- Beniger, James R., 1986. *The Control Revolution*. Harvard Univ. Press, Cambridge, Mass.
- Berggren, J. L. & Goldstein, B.R., (eds.) 1987. *From Ancient Omens to Statistical Mechanics*. Universitetsbiblioteket, København.
- Bernal, J.D., 1939. *The Social Function of Science*. London.
- Bernal, J.D., (1954) 1978. *Science in History*. Norw. transl. *Videnskabens Historie I-IV*, Pax, Oslo.
- Bolter, J. David, 1984. *Turing's Man. Western Culture in the Computer Age*. The University of North Carolina Press, Chapel Hill.
- Boltzmann, Ludwig, (1872). *Weitere Studien über das Wärmegleichgewicht unter Gasmolekülen*. Boltzmann, 1909. WA I: 22.
- Boltzmann, Ludwig, (1886) 1905: 25-50. »Der zweite Hauptsatz der mechanischen Wärmetheorie«. Lecture, Kaiserlichen Akademie der Wissenschaften, 29.5 1886.

- Boltzmann, Ludwig, (1890) 1905: 76-80. »Über die Bedeutung von Theorien«.
- Boltzmann, Ludwig, (1894) 1974: 201-209. »Certain Questions of the Theory of Gases«. *Nature* 51: 413-415.
- Boltzmann, Ludwig, (1897a) 1974: 221-265. *Vorlesungen über die Principe der Mechanik*, I. Leipzig. Eng. transl.(selected): *Lecturers on the Principles of Mechanics*.
- Boltzmann, Ludwig, (1897b) 1905: 162-187. »Über die Frage nach der objektiven Existenz der Vorgänge in der unbelebten Natur«. *Wien. Ber. 106 IIa*: 83.
- Boltzmann, Ludwig, (1897c) 1905: 158-161. »Nochmals über die Atomistik«. *Annalen der Physik und Chemie* 61, 1897: 790.
- Boltzmann, Ludwig, (1899a) 1905: 198-227. »Über die Entwicklung der Methoden der theoretischen Physik in neuerer Zeit«.
- Boltzmann, Ludwig, (1899b) 1905: 253-307. »Über die Grundprinzipien und Grundgleichungen der Mechanik«.
- Boltzmann, Ludwig, (1902). 1974: 213-220 »Model«. *Encyclopaedia Britannica* (1902-1910).
- Boltzmann, Ludwig, 1905. *Populäre Schriften*, Barth Verlag, Leipzig.
- Boltzmann, Ludwig, (1909) 1968. *Wissenschaftliche Abhandlungen (WA) I-III*, Chelsea Publishing Company, New York.
- Boltzmann, Ludwig, 1974. *Theoretical Physics and Philosophical Problems*. Ed. by Brian McGuinness. D. Reidel, Dordrecht.
- Boyer, Carl B., (1939) 1959. *The Concepts of the Calculus, A Critical and Historical Discussion of the Derivative and the Integral*. Rev. 1949, reprinted as *The History of the Calculus*. Dover Publ. Inc., New York, 1959.
- Brillouin, Leon, 1962. *Science and Information Theory*. New York.
- Bullock, A. et al., (eds). 1988. *The Fontana Dictionary of Modern Thought*, 2. ed., London.
- Burks, A.W., Goldstine, H. H. & Neumann, John von, (1946) 1989. »Preliminary Discussions of the Logical Design of an Electronic Computing Instrument«. Uddr. i Bannon, L. & Pylyshyn, Z., (eds.) 1989: 39-48.
- Burton, N. G. & Licklider, J. C. R., 1955. »Long-Range Constraints in the Statistical Structure of printed English«. *The American Journal of Psychology*, Vol. 68, no 4: 650-653, Dec. 1955.
- Bush, Vannevar, (1945) 1989. »As we may think.« Reprint in Bannon, L. & Pylyshyn, Z., (eds.) 1989.

- Bødker, Susanne, 1987. *Through the Interface - a Human Activity Approach to User Interface Design*. DAIMI PB, 224. University of Aarhus, Aarhus.
- Chomsky, Noam, 1957. *Syntactic Structures*. The Hague: Mouton.
- Christiansen, Peder Voetmann, (ed.) 1988. *Charles S. Peirce: Mursten og mørtel til en metafysik*. Imfufa, no: 169, Roskilde.
- Christiansen, Peder Voetmann, 1985. »Informationens elendighed«. In Th. Söderquist, (ed.) 1985: 61-72.
- Cohen, E.D.G. & Thiring, W., 1973. *The Boltzmann Equation. Acta Physica Austriaca, Supplementum X - Proceedings of the International Symposium "100 years Boltzmann Equation" in Vienna 4th-8th September 1972*. Springer Verlag, Wien.
- Cohen, John, 1966. *Human Robots in Myth and Science*. George Allen & Unwin, London.
- Cordeschi, Roberto, 1991. »The discovery of the artificial. Some protocybernetic developments«. 1930-1940. *AI & SOCIETY*, vol 4. nr. 3 1991.
- Courant, Richard & Robbins, H., (1941) 1948. *What is Mathematics*. Oxford Univ. Press, London.
- Crary, Jonathan, 1988. »Modernizing Vision«. In Hal Foster, (ed.) 1988: 29-44.
- Cronberg, Tarja, et al. (eds.) 1991. *Danish Experiments - Social Constructions of Technology*. New Social Science Monographs. Copenhagen.
- Darwin, Charles (1859) 1964: *On the Origin of Species - A Facsimile Of the First Edition (1859)*. Harvard University Press, Cambr. Mass.
- Davis, Martin, (ed.), 1965. *The Undecidable. Basic Papers On Undecidable Propositions, Unsolvability Problems And Computable Functions*. Raven Press, New York.
- Davis, Martin, 1988a. »Mathematical Logic and the Origin of Modern Computing«. In Rolf Herken, (ed.) 1988: 149-174.
- Davis, Martin, 1988b. »Influences of Mathematical Logic on Computer Scienc«. In Rolf Herken, (ed.) 1988: 315-326.
- Derrida, Jacques, (1967) 1976. *De la grammatologie*. Engl. Ed. *Of Grammatology*. John Hopkins University Press, Baltimore-London (1974) 1976.
- Descartes, René, (1637) 1985. »Discourse on the Method« Engl. transl. of *Discours de la Méthode*: In John Cottingham et al. *The Philosophical Writings of Descartes*. Vol 1. p. 111-151, Cambridge University Press, Cambridge, UK.
- Dev, S. B., 1990. Migration of physical Scientists to Molecular Biology and Its Impact, *Interdisciplinary Science Reviews*. vol. 15, no 1. 1990. Bristol.

- Dreyfus, H. (1972) 1979. *What Computers Can't Do*. New York.
- Dreyfus, H. & Dreyfus, S., (1986) 1989. *Mind over Machine*. Paperback edition including a new preface: Free Press, New York.
- Eco, Umberto, (1968) 1971. *La Struttura assente*. Swedish transl. *Den frånvarande strukturen*. Bo Cavefors, Lund.
- Eco, Umberto, (1976) 1979. *A Theory of Semiotics*. Indiana University Press, Indiana.
- Eddington, Arthur, (1928) 1930. *The Nature of the Physical World*. Cambridge.
- Edelman, Gerald M., 1987. *Neural Darwinism - The Theory of Neuronal Group Selection*. New York.
- Ehn, Pelle, 1988. *Work-Oriented Design of Computer Artifacts*. Arbetslivscentrum, Stockholm.
- Ehrenfest, Paul & Tatiana, (1912) Engl. transl. 1959. *The Conceptual Foundations of the Statistical Approach in Mechanics*. Cornell Univ. Press, Ithaca, New York.
- Eisenstein, Elisabeth L., 1979. *The Printing Press as an Agent of Change*. I-II, Cambridge.
- Elias, Peter, 1983. »Entropy and the Measure of Information«. In Machlup & Mansfield, 1983: 497-502.
- Emmeche, Claus, 1990. *Det biologiske informationsbegreb*. Kimære, Århus.
- Feenberg, Andrew, 1991. *Critical Theory of Technology*. New York.
- Feferman, Solomon, 1988. »Turing in the Land of O(z)«. In Herken, (ed.) 1988: 113-147.
- Feigenbaum, Edward A. & Feldman, Julian, (eds.) 1963. *Computers and Thought*. McGraw-Hill, New York.
- Fetzer, James H., 1990. *Artificial Intelligence: Its Scope and Limits*. Klüwer, Dordrecht.
- Feyerabend, Paul, 1981. *Philosophical Papers*. Vol I-II, Cambridge Univ. Press, Cambridge.
- Fink, Hans & Hastrup, Kirsten (eds.), 1990. *Tanken om enhed i videnskaberne*. Kulturstudier 9, Aarhus Universitetsforlag, Århus.
- Finnemann, Niels Ole, 1972. *Modernismens erkendelsesteoretiske problematik*, GMT, Grenå.
- Finnemann, Niels Ole, (ed.) 1989a. *Tidens Tegn, Natur•Information•Kultur*. Kulturstudier 3, Universitetsforlaget, Aarhus.
- Finnemann, Niels Ole, 1989b. »Teknologiske perspektiver«. Finnemann, (ed.) 1989a: 138-174.

- Finnemann, Niels Ole, (ed.) 1989c. *Theories and Technologies of the Knowledge Society*, Center for Kulturforskning, Aarhus.
- Finnemann, Niels Ole, 1990a. »Computerization as a Means of Cultural Change: On the Relations between Information Theories and the Idea of an Information Society«. *AI & SOCIETY*, vol.4.4: 314-328. Springer International, London.
- Finnemann, Niels Ole, 1990b. »Om viden og det vi ikke ved«. In Fink & Hastrup (eds.), 1990.
- Finnemann, Niels Ole, 1991a. »Den informationelle billedreformation«. In N. O. Finnemann, et al., (eds.) 1991b: 130-174.
- Finnemann, Niels Ole, et al., (eds.) 1991b. *Synets Medier*, Kulturstudier 11, Universitetsforlaget, Aarhus.
- Feigenbaum, E. & Feldmann, J. (eds.), 1963. *Computers and Thought*. McGraw Hill, New York.
- Flamm, D., 1973. »Life and Personality of Ludwig Boltzmann«. In Cohen & Thirring, 1973: 3-16.
- Flamm, D., 1983. »Ludwig Boltzmann and his Influence on Science«. *Studies in History and Philosophy of Science* 14, 4: 255-279. Pergamon Press, Oxford.
- Foster, Hal, (ed.) 1988. *Vision and Visuality*. Seattle.
- Gandy, Robin, 1988. »The Confluence of Ideas in 1936«. In Rolf Herken, (ed.) 1988: 55-111.
- Gibbs, J.W., (1902) 1960. *Elementary Principles in Statistical Mechanics*. New York, 1960.
- Gibson, J. J., 1971. »Information available in Pictures«. *Lenorado*, 1971 vol. 4: 27-35.
- Goldmann, Martin, 1983. *The Demon in the Aether, The Story of James Clerk Maxwell*. Edinburgh.
- Goldstine, H.H. & Neumann, John von, (1947-48). *Planning and Coding of Problems for an Electronic Computing Instrument; Report on the Mathematical and Logical Aspects of an Electronic Computing Instrument*. Vol. 1-3, Princeton, New Jersey. Reprinted in J. von Neumann 1961-63 Bd. V, no. 3-4.
- Goldstine, Herman H., 1972. *The Computer - from Pascal to von Neumann*. Princeton University Press, Princeton.
- Gorlée, Dinda L., 1990. »Degeneracy: A reading of Peirce's writing«. *Semiotica* 81-1/2, 1990: 71-92.

- Gorn, Saul, 1983. »Informatics (Computer and Information Science. Its Ideology, Methodology and Sociology)«. In Machlup & Mansfield, 1983: 121-140.
- Greimas, A. J. & Courtés, J. (1979) 1982. *Semiotics and Language. An Analytical Dictionary*. Indiana University Press, Bloomington. Fransk orig.: *Semiotique. Dictionnaire raisonné de la théorie du langage*.
- Gödel, Kurt, (1931). »Über formal unentscheidbare Sätze der Principia Mathematica und verwandter Systeme I«. *Monatshefte für Mathematik und Physik vol. 38*: 173-198. Reprint in Davis, 1965: 5-41.
- Gödel, Kurt, (1946). »Remarks before the Princeton bicentennial Conference on Problems in Mathematics«. In Martin Davis, 1965: 84-87.
- Göranzon, B. & Josefson, I., (eds.) 1988. *Knowledge, Skill and Artificial Intelligence*. Springer Verlag, London-Berlin.
- Hamming, R. W., 1980. »We Would Know What They Thought When They Did It«. In Metropolis et al. (eds.), 1980: 3-11.
- Haugeland, John, (1985) 1987: *Artificial Intelligence, The Very Idea*. Bradford Books, Massachusetts.
- Havelock, Eric A., 1982. *The Literate Revolution in Greece and its Cultural Consequences*. Princeton Univ. Press, Princeton.
- Hayles, N. Katherine, 1990. *Chaos Bound. Orderly Disorder in Contemporary Literature and Science*. Cornell University Press, Ithaca.
- Heims, Steve J., 1988. »Optimism and Faith in Mechanism among Social Scientists at the Macy Conference on Cybernetics, 1946-1953«. *AI & SOCIETY* vol 2. no 1: 69-75, London.
- Herken, Rolf, (ed.) 1988. *The Universal Turing Machine, A Half-Century Survey*. Oxford Science Publications. Oxford.
- Hjelmslev, Louis, (1934) 1972. *Sprogssystem og sprogforandring*. København.
- Hjelmslev, Louis, (1943) 1966. *Omkring sprogteoriens grundlæggelse*. Akademisk Forlag, København. Eng ed.: (1953) 1961. *Prolegomena to a Theory of Language*. University of Wisconsin Press. (translated by Francis J. Whitfield, 2. ed.).
- Hodges, Andrew, 1983. *Alan Turing: The Enigma*. Burnett Books, London.
- Hofstadter, Douglas 1979: *Gödel, Escher, Bach*. Basic Books, New York.
- Hofstadter, Douglas R., & Dennett, Daniel C., ed. 1981. *The Mind's I - Fantasies and Reflections on the Self and Soul*. Basic Books, New York.
- Hofstadter, Douglas R. 1985. (1986) *Metamagical Themes*. Penquin, London.
- Horstbøll, Henrik, 1991. »Synets geometri og skriftens typografi«. In Finnemann et al. 1991b: 9-44.

- Jensen, Hans Siggaard, 1989. »Informationsbegrebet. Om det postmoderne køleskab og dets indhold«. In Finnemann, (ed.) 1989a: 80-110.
- Kay, Alan & Goldberg, Adele, 1977: »Personal Dynamic Media«. *Computer*, March 1977: 31-41.
- Kleene, Stephen C., 1988. »Turing's Analysis of Computability and Major Applications of It.« In Rolf Herken, (ed.) 1988: 17-53.
- Klein, M. J., 1973. »The development of Boltzmann's statistical Ideas«. In Cohen & Thirring, 1973: 53-106.
- Knudsen, Ole, (1987) 1989. »The influence of Gibbs European Studies on his later Work«. In Berggren & Goldstein 1987: 271-280, Knudsen, 1989: 167-176.
- Knudsen, Ole, 1989. *Studier i elektromagnetismens historie*. Århus.
- Knuth, Donald E. & Pardo, Luis Trabb, (1977) 1980. »The Early Development of Programming languages«. In Metropolis et al, 1980: 197-274.
- Koyré, Alexandre, (1957) 1974. *From the Closed World to the Infinite Universe*. Baltimore.
- Kuhn, Thomas, (1962) 1970. *The Structure of Scientific Revolutions*. Univ. of Chicago, Chicago.
- Langefors, Börje, 1966: *Theoretical Analysis of Information Systems*, Lund 1966.
- Lewis, Gilbert N., (1930). »The Symmetry of Time in Physics«. *Science* vol. 71, 6: 569-577.
- Lyotard, Francois, 1979. *La Condition Postmoderne*. Paris. Da. transl: *Viden og det postmoderne samfund*. Aarhus (1982).
- Lytje, Inger, 1990. »Natural Language Understanding within a Cognitive Semantics Framework«. *AI & SOCIETY*, vol. 4, 4. Springer Verlag, London.
- Machlup, Fritz & Mansfield, Una, (eds.) 1983. *The Study of Information*. John Wiley & Sons, New York.
- Machlup, Fritz, 1962. *The Production and Distribution of Knowledge in the United States*. John Wiley & Sons, New York.
- Mackay, Donald M., 1983. »The Wider Scope of Information Theory«. In Machlup & Mansfield, 1983: 485-493.
- Mandler, George, 1955: »Associative Frequency and associative Prepotency as Measures of Response to Nonsense Syllables«. *The American Journal of Psychology*, Vol. 68, no 4: 662-665, Dec. 1955.
- Markov, A. A. (1954) 1961. *Teoriya Algorifmov*. Eng. overs. *Theory of Algorithms*. Jerusalem.
- Maxwell, James Clerk, (1871) 1970. *Theory of Heat*. 3. ed., Westport, Conn.

- Mazlish, Bruce, (1967) 1989. »The Fourth Discontinuity«. Bannon & Pylyshyn, (eds.) 1989: 71-84.
- Mc Corduck, Pamela, 1979. *Machines who Think*. San Francisco.
- McCulloch, Warren S. & Pitts, Walter (1943) 1966. »A Logical Calculus of the Ideas Immanent in Nervous Activity«. *Bulletin of Mathematical Biophysics*. 1943, vol. 5: 115-133. Reprint, Swets & Zeitlinger N.V., Amsterdam.
- McClelland, J. L. & Rumelhardt, D. E. (eds). 1986. *Parallel Distributed Processing - Explorations in the Microstructure of Cognition*. Cambr. Mass.
- Metropolis, N., Howlett, J., & Rota, Gian-Carlo, 1980. *A History of Computing in the Twentieth Century*. Academic Press, New York.
- Mey, Jacob L., 1989. *A Pragmatic look at Artificial Intelligence or: the proper proper treatment of connectionism*. Odense Universitet.
- Michael R. Williams, 1985. *A History of Computing Technology*. Prentice Hall. London.
- Miller, George A., 1983. »Information Theory in Psychology«. In F. Machlup & U. Mansfield, 1983: 493-497.
- Miller, George A., Galanter, Eugene & Pribram, Karl, 1960. *Plans and the Structure of Behavior*. Holt, Rinehardt & Winston, Inc.
- Moreau, René, (1981) 1984. *The Computer Comes of Age*. MIT Press, Cambridge. Oversat fra den franske originaludg. Ainsi naquit l'informatique.
- Neumann, John von, (1932) 1955. *Mathematische Grundlagen der Quantenmechanik*. Eng. overs. *Mathematical Foundation of Quantum Mechanics*. Princeton Univ. Press, Princeton.
- Neumann, John von, (1945). *First draft on a Report on the EDVAC*.
- Neumann, John von, (1945). *Memorandum on the Program of the High-Speed Computer Project* (8.11 1945).
- Neumann, John von, 1958. *The Computer and the Brain*. Yale Univ. Press, New Haven.
- Neumann, John von, 1961-63. *Collected Works. Vol I-VI*. Ed. A.H. Taub. Pergamon Press, Oxford.
- Newell, A., Shaw, Cliff & Simon, Herbert A. 1961: *GPS, A Program that simulates Human Thought*. München. Reprint in E. Feigenbaum & J. Feldmann (eds.), 1963.
- Newell, Allen & Simon Herbert A., (1976) 1989. »Computer Science as Empirical Study: Symbols and Search«. In Bannon, L. & Pylyshyn, Z., (eds.) 1989: 109-133.

- Newell, Allen & Simon Herbert A., 1972. *Human Problem Solving*. Prentice-Hall, Inc. Englewood Cliffs, New Jersey.
- Norman, D. A. & Draper S. W. (eds) 1986: *User Centered System Design*. Hillsdale, New Jersey.
- OED, *The Compact Edition of the Oxford English Dictionary*. 1971. Vol. 1-2. London.
- Peirce, Charles S., 1887. »Logical Machines«. *The Am. Journal of Psychology*, 1887: 165-170.
- Peirce, Charles S., 1892. »The Doctrine of Necessity Examined«, *The Monist*. vol. II no. 3. Da. overs. i Christiansen, (ed.) 1988: 89-110.
- Peirce, Charles S., 1940. *The Philosophy of Peirce. Selected Writings*. Ed. by Justus Buchler, Kegan Paul, New York. Reprint 1955ff as *Philosophical Writings of Peirce*. Dover Publ. Inc., New York.
- Price, Derek de Solla, (1961) 1975. *Science since Babylon*. New Haven & London.
- Prigogine, Ilja, 1973. »The Statistical Interpretation of Non-Equilibrium Entropy«. In Cohen & Thirring, 1973: 401-450.
- Provenzo, Jr., Eugene F., 1986. *Beyond the Gutenberg Galaxy. Microcomputers and the Emergence of Post-Typographic Culture*. Teachers College Press, New York.
- Pylyshyn, Zenon W., 1983. »Information Science. Its Roots and Relations as viewed from the Perspective of Cognitive Science«. In Machlup og Mansfield, 1983: 63-81.
- Pylyshyn, Zenon W., (1984) 1985. *Computation and Cognition. Toward a Foundation for Cognitive Science*. Bradford Books, Cambridge, Mass.
- Randell, Bryan, (1983): *The Origins of Digital Computers*. New York.
- Richta, Radovan et al. (1968) 1970. *Zivilisation am Scheideweg - Soziale und Menschliche Zusammenhänge der wissenschaftlich-technischen Revolution*. (Prag), Freiburg.
- Ricoeur, Paul, (1969) 1974. *Le Conflit des interpretations. Essais d'hermeneutique*. Paris. Engl. transl. ed. by Don Ihde: *The Conflict of Interpretation. Essays in Hermeneutics*. Northwestern University Press. Evanston.
- Rosen, Robert, 1988. »Effective Processes and Natural Law«. In Herken (ed.) 1988: 523-537.
- Roszak, Theodore, (1986) 1988: *The Cult of Information*. London.

- Saussure, Ferdinand de, (1916) 1983. *Cours de Linguistique Générale*. Engl. transl. by Roy Harris *Course in General Linguistics*, Duckworth, London. References to the french standard edition, 1922ff in brackets.
- Searle, John, 1990. *Is the Brain a Digital Computer?* Presidential Address to the APA. Manuscript, 8.10 1990.
- Sedgewick, Robert, 1983. *Algorithms*. Addison Wesley Publ. Co., New York.
- Shannon, Claude E., (1938) 1976. »A Symbolic Analysis of Relay and Switching Circuits«. *Trans AIEE 57*, 1938: 713ff. Reprint in *Computer Design Development: Principal Papers*, Hayden, New Jersey.
- Shannon, Claude E., (1948). Shannon, Claude & Weaver, Warren, (1949). *The Mathematical Theory of Communication*. University of Illinois Press, Urbana 1969.
- Shannon, Claude E., 1951. »Prediction and Entropy in printed English«. *Bell Syst. Tech. J.*, 30: 50-64.
- Sinding-Larsen, Henrik, 1988. »Notation and Music: The History of a Tool of Description and its Domain to be Described«. Sinding-Larsen (ed.). *Artificial Intelligence and Language: Old Questions in a new Key*. Complex 7/88, Oslo.
- Stjernfeldt, Frederik, 1990. *Runes and the A priori stance. On a Question Crucial to any Cognitive Science or Linguistics Whatever*. Unpubl. paper, Center for Cultural Research, University of Aarhus.
- Szilard, Leo, 1925. »Über die Ausdehnung der phänomenologischen Thermodynamik auf die Schwankungserscheinungen«. *Zeitschrift für Physik*. Vol. 32: 753 ff. Berlin.
- Szilard, Leo, 1929. »Über die Entropieverminderung in einem thermodynamischen System bei Eingriffen intelligenter Wesen«. *Zeitschrift für Physik*. Vol. 53: 840 ff. Berlin.
- Sørensen, Torben Smith, 1987. »Ilja Prigogine og entropien - et kritisk essay«. *Paradigma* 1. årg. nr. 2: 42-50, Århus, 1987.
- Söderquist, Th., (ed.) 1985. *Informationssamfundet*. Århus.
- The Plan for Information Society - a National Goal toward the Year 2000*. Japan Computer Usage Development Institute, Tokyo. Kilde: Göranson & Josefson (eds.) 1988.
- Trakhtenbrot, Boris A., 1988. »Comparing the Church and Turing Approaches: Two Prophetic Messages«. Herken (ed.) 1988: 603-630.
- Trakhtenbrot, Boris A., (1960) 1989. »Algorithms«. In Bannon & Pylyshyn, (eds.) 1989: 203-222.

- Tribus, Myron, 1983. »Thirty Years of Information Theory«. In Machlup & Mansfield (eds.), 1983: 475-484.
- Turing, Alan M., (1939) 1965. »Systems of Logic based on Ordinals«. *Proceedings of the London Mathematical Society*, ser. 2 vol. 45, 1939: 161-228. Davis, (ed.) 1965: 154-220.
- Turing, Alan M., 1950. »Computing Machinery and Intelligence«. *Mind*, vol. 59 No. 236, October: 433-460.
- Turing, Alan, M., (1936) 1965. »On Computable Numbers - with an Application to the Entscheidungsproblem«. *Proceedings of the London Mathematical Society*, ser. 2 vol. 42. 1936-37: 230-265 with corrections in i vol. 43, 1937: 544-546. Reprint in Davis, (ed.) 1965: 115-154.
- Ulam, S.M., 1980. »Von Neumann: The Interaction of Mathematics and Computing«. In Metropolis et al. 1980: 93-100.
- Weaver, Warren, (1949) 1969. »Recent contributions to the Mathematical Theory of Communication«. Introduction to Claude Shannon (1948, 1949) *The Mathematical Theory of Communication*. Illinois.
- Wells, Mark B., 1980. »Reflections on the Evolution of Algorithmic Language«. Metropolis et al. 1980: 275-289.
- Wiener, Norbert, (1948) 1962. *Cybernetics - or control and communication in the animal and the machine*. M.I.T. Press, Cambridge, Mass.
- Wiener, Norbert, (1950) 1963. *The Human Use of Human Beings. Cybernetics and Society*. Da. transl. *Menneske og automat*. Gyldendal, København, 1963.
- Wiener, Norbert, (1954) 1964. *I Am a Mathematician. The Later Life of a Prodigy*. Cambridge, Mass.
- Wilkes, M.V., Wheeler, D. J. & Gill, S., 1951. *The Preparation of Programs for an Electronic Digital Computer*. Cambridge, Mass.
- Williams, Michael R., 1985. *A History of Computing Technology*.
- Winograd, Terry & Flores, Fernando, 1986. *Understanding Computers and Cognition. A New Foundation for Design*. Ablex, Norwood, New Jersey.
- Witt-Hansen, J., 1985. *Filosofi*. Gyldendal, København.
- Zuboff, Shoshana, 1990: *In the Age of the Smart Machine*. New York.
- Zuse, Konrad, (1945) 1972. »Der Plankalkül«. *Ber. Ges. Math. Datenverarbeitung*, 63, 3.