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COUNTERFACTUAL DEFORMATION AND IDEALIZATION IN A STRUCTURALIST FRAMEWORK

Introduction

Idealization is a central aspect of scientific knowledge formation, its explication is an important task of philosophy of science. Even if recently a lot of work has been done in this field there is no unanimously accepted account of idealization [cf. Niiniluoto 1986: 257]. However, as a rather uncontroversial common point of departure one might take the assertion that the idealizing character of science has something to do with its applicability. Typically, scientific theories cannot be applied directly, rather their relation to the actual world is mediated and indirect. For instance, the laws of nature can hardly be interpreted as universal statements that involve a material implication – rather they have to be conceived of as counterfactual conditionals that apply to certain unrealized or even unrealizable situations.

One way to explain the idealized character and the indirect and mediated applicability of scientific theories is provided by possible worlds semantics [cf. Lewis 1986]: to explain in this framework that empirical theories such as mechanics or thermodynamics are idealizing theories is to say that they apply to some appropriate possible worlds where such entities as frictionless planes, point masses, ideal gases, etc. exist. Thereby, the framework of possible world semantics enables us to understand the counterfactual character of scientific laws. However, it remains incomplete as long as the relation between the actual and the "ideal" worlds is not elucidated.

Another approach that has contributed to a deeper understanding of the problem of applicability of empirical theories is structuralism [cf. Balzer, Moulines and Sneed 1987]. This has been done by developing a highly sophisticated description of the structure of empirical theories. However, until today, structuralism has hardly taken any notice of possible world semantics: except for a side remark of Stegmüller [1979: 12] on the modal character of constraints and a paper of Miroiu that intended to relate the structuralist concept of theoretical function to the modal concept of Kripke frames [cf. Miroiu 1984] we know of no attempt to bring possible world semantics and structuralism in closer contact to each other.

Finally, as the approach of philosophy of science that has most explicitly dealt with the problem of idealization, the "Poznań School" [cf. Nowak 1980, 1989, 1991 and Krajewski 1977] has to be mentioned. Although Nowak repeatly emphasizes the counterfactual character of economic laws [cf. Nowak 1980, 1991], he never refers to any kind of possible world semantics or to any other account of modal logic. Moreover, his approach is rather syntactically minded and he makes no mention of the structuralist approach.

Only very recently, did structuralism and the idealization approach of the Poznań School come into closer relation. As far as we know, Kuokkanen [1988] and Hamminga [1989] are the first who have explicitly attempt to discuss the relationship between the structuralist approach and the Poznań school. Without doubt the work of these authors provides important steps for establishing a mutually fruitful relation between both strands of thought. We think, however, that more can be done.

The outline of this paper is as follows: In part I we introduce counterfactual (or idealizing) deformation procedures following some recent ideas presented in Nowak [1989, 1991]. As a concrete example we consider the various idealizing deformation procedures performed in the elementary theory of the simple pendulum as they have been studied by Laymon in a series of articles [cf. Laymon 1982, 1985, 1987]. In part II we study counterfactual deformation operators in the structuralist approach. Part III deals with the complementary concepts of idealization and concretization of theories. In part IV we apply the framework of structuralism *cum* idealization structure to the elucidation of the counterfactual character of empirical laws.

I

Counterfactual Deformations

Nowak [1989, 1991] discusses the topic of idealization in the framework of *counterfactual deformations*. The fundamentals of his approach can be succintly described as follows. We start with a set O of possible objects and a set U called the universe of properties. The state of affairs that an object o has a property $u \in U$ is denoted by $<o,u,U>$.

(1.1) Definition. Let U, U' be universes of properties and o a possible object. A *potentialization* or *counterfactual deformation* of $<o,u,U>$ is a triple $<o,u',U'>$. It is called a *soft* counterfactual deformation iff $U=U'$, and a *hard* counterfactual deformation iff $U \neq U'$.

Counterfactual deformations are not arbitrary, a few make sense, and the huge majority does not. An all-important task of a theory of counterfactual deformations that is worth its salt is to distinguish between "good" and "bad" ones. For this purpose we have to take into account the structure of the universes of properties that are involved. A universe of properties U usually is not simply a set, i.e., a heap of unrelated properties, but a set endowed with further structure. Moreover, in the case of hard counterfactual deformations the universes U and U' typically are structurally related. We mention some important cases:

U has the structure of a Cartesian product $U=U_1 \times U_2$: In this case we write $<o,u_1,u_2,U_1,U_2>$ instead of $<o,<u_1,u_2>,U_1 \times U_2>$. The product structure of the universe of properties enables us to define two important cases of hard counterfactual deformation: *reduction* and *transcendentalization*. *Reduction* consists in that a given object is counterfactually postulated not to have some properties it actually has. *Transcendentalization*, as the counterpart of reduction, is the counterfactual deformation that an object has properties that it actually does not possess at all. The precise definition of these counterfactual deformation procedures is the following:

(1.2) Definition. Let $U=U_1 \times U_2$ be a universe of properties with projection maps p_i: $U_1 \times U_2 \to U_i$ defined by $p_i\ (u_1,u_2)=u_i$, $i=1,2$. A *reduction* of $<o,u_1,u_2,U_1,U_2>$ defined by p_i is the counterfactual deformation defined by:

$$<o,u_1,u_2,U_1,U_2> \Rightarrow <o,u_i,U_i>,\ i=1,2.$$

A *transcendentalization* defined by p_i is an "inverse" deformation defined by $<o,u_i,U_i> \Rightarrow <o,u_1,u_2,U_1,U_2>$, $i=1,2$.

Another important example of a structured universe of properties U is the case if there is a distinguished *extremal* element $u_0 \in U$. For instance, if U has the structure of a vectorspace, the base point 0 is often chosen as an extremal element:

(1.3) Definition. Let U be a universe of properties with distinguished extremal element $u_0 \in U$. An *ideation* of $<o,u,U>$ is a counterfactual deformation $<o,u,U> \Rightarrow <o,u_0,U>$.

The various kinds of counterfactual deformations described so far may be combined with each other in various ways yielding a bunch of counterfactual deformations. In the following we shall concentrate on one special case of counterfactual deformation, to wit, *idealization* defined by:

(1.4) Definition. The counterfactual deformation of *idealization* is defined as the combination of *reduction* and *ideation*.

To give a concrete example of idealization let us consider the idealizations involved in an elementary treatment of the simple pendulum [cf. Laymon 1987: 204]. We can treat realistically the bob as being physically extended, or we can perform a counterfactual idealization treating it as a point mass. We can treat the sine of the angle w of displacement as exactly $sin(w)$, or we can perform a soft counterfactual deformation treating it as w. Moreover, we can realistically treat the medium as having hydrostatic effects on the pendulum, or we can perform the idealizing deformation as if it were vacuum. We may conceive these counterfactual deformations of the physical system "symple pendulum" P as caused by counterfactual deformation *operators* b,w, and m applied to P in the following way:

b: P (extended bob) $\Rightarrow$ P (point mass bob)	(ideation)
w: P ($sin(w)$) $\Rightarrow$ $P(w)$	(soft deformation)
m: P (hydrostatic) $\Rightarrow$ P (vacuum)	(reduction)

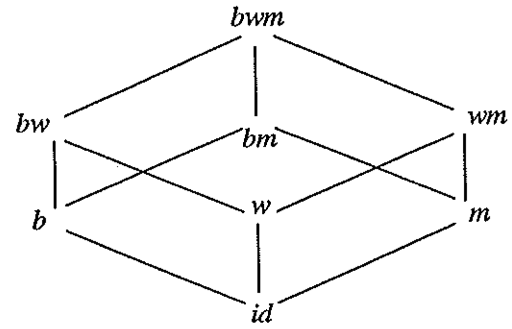
The operators b,w, and m may be combined with each other. For instance, $bw(P)$ is to be read as: first the system P is subjected to the counterfactual deformation that the sine of the angle w of displacement is taken to be w, and then the system $w(P)$ is subjected to the counterfactual deformation of treating the pendulum's bob as a point mass.

We observe that the combinations of the operators satisfy the following properties:

(1)	$bb = b$, $ww = w$, $mm = m$	(idempotence)
(2)	$bw = wb$, $bm = mb$, $mw = wm$	(commutativity)
(3)	$(bw)m = b(wm)$	(associativity)

Thus, if we add the trivial deformation operator *id* that does not change anything at all, the set (b,w,m,id) can be endowed with the structure of a ~~complete~~ *(semi)lattice* [cf. Laymon 1987: 204] that can be displayed in the following diagram:

(1.5) Lattice of deformation operators of the pendulum.



In the following we want to argue that this lattice structure of the set of counterfactual deformation operators is typical for the role idealization plays in the application of empirical theories to phenomena of the real world.

II

Counterfactual Deformations in the Structuralist Approach

We now want to reformulate the sketch of counterfactual deformations given above in the framework of the structuralist philosophy of science. This leads to a better understanding of how idealization works, or so we want to argue. In reformulating the theory of counterfactual deformation in the structuralist framework, we take the above operator approach seriously. This means, we conceive counterfactual deformations as operators defined on the class M_p of possible models of a structuralist theory element.

Recall that the general format of a structuralist (partial, potential) model is the following [cf. Balzer, Moulines and Sneed 1987]:

(2.1) $x = <A_1,\ldots,A_n,f_1,\ldots,f_p>$

where the A_j's are the base sets, i.e., sets of empirical entities like particles, molecules, fields, genes, commodities, persons, the theory is about, and possibly auxiliary mathematical entities e.g. the real numbers R etc. In the following we'll be somewhat more explicit about the relations f_i, mentioning explicitly their carriers U_i, i.e., instead of (2.1) we write

(2.2) $x = \langle A_1,\ldots,A_n,f_1,\ldots,f_p,U_1,\ldots,U_p\rangle$

where each f_i is a subset of U_i. When appropriate we abbreviate (2.2) by $x = \langle A,f,U\rangle$. Then we may generalize Nowak's counterfactual deformations for (partial) (potential) models of structuralist models as follows:

(2.3) Definition. Let $x = \langle A,f,U\rangle$ be a structuralist (partial) (potential) model.

(a) x' is a soft counterfactual deformation of x if and only if x' is of the form $x' = \langle A,f',U\rangle$.

(b) x' is a hard counterfactual deformation of x if and only if x' is of the form $x' = \langle A,f',U'\rangle$ and $U \neq U'$.

According to structuralism the application of an empirical theory is not a monolithic all-or-nothing affair, a theory has not one single universal application to the world as a whole, rather it possesses a variagated and extended family I of intended applications. However, different applications usually are not independent of each other but interrelated. This interrelation can be explicated by the concept of structuralist constraints [cf. Balzer, Moulines and Sneed 1987]. With respect to the problem of idealization this means that we should define counterfactual deformations not for a single isolated model $x \in M_p$ but for all elements of M_p simultaneously. This is made precise in the following definition:

(2.4) Definition. Let $T = \langle K,I\rangle$ be a structuralist theory element, $K = \langle M,M_p,M_{pp},r,C\rangle$. A *counterfactual deformation operator* d of T is a map $d\colon M_p \to M_p$ of the following form:

(1) $d(\langle A,f,U\rangle) = \langle A,f',U'\rangle$

(2) $dd = d$

(3) $d(M) \subseteq M$.

In other words, *d is a projection of M_p onto itself that preserves the subset M of M_p*. The first condition doesn't need any further comment, it is just Nowak's definition applied to structuralist models. The second condition may be explained by the mass point idealization for the pendulum already mentioned above. If we counterfactually assume that the bob of a pendulum is a mass point, a second application of the same counterfactual deformation procedure to that system does not yield anything new, i.e., we have $d(d(x)) = d(x)$. The third condition describes, so to speak, the *direction* of the counterfactual deformation operators: Their *raison d'être* is to eliminate certain factualities that hinder potential models from being actual ones. The purpose of counterfactual deformation is to transform a "good" potential model into an actual one. Of course, this cannot be done for any potential model but we should require that the procedure of counterfactual idealizing does not lead us astray, i.e., if x is already a model of T any idealizing deformation $d(x)$ of x should also be a model of T. As a reasonable generalization of the lattice of counterfactual deformation operators of the pendulum theory we now propose the following assumption concerning the structure of the deformation operators of a structuralist theory element:

(2.5) Assumption. Let $T = \langle K,I\rangle$ be a structuralist theory element, and D its set of counterfactual deformation operators. Then the set D is a (complete) *semilattice*, i.e., the concatenation symbolized by $\circledast$ of counterfactual deformations enjoys the following properties:

(1)	$d \circledast d = d$	(idempotence)
(2)	$d \circledast d' = d' \circledast d$	(commutativity)
(3)	$(d \circledast d') \circledast d'' = d \circledast (d' \circledast d'')$	(associativity).

These conditions are read off directly from Laymon's example (1.5). One could ask more specific questions about the specific structure of D, e.g. is D a special kind of semilattice, e.g. a distributive or even Boolean lattice? However, there is not the space here to pursue these kinds of questions any further. We are content with the general observation that the semilattice of counterfactual deformation adds a further element of concretization to the structuralist notion of a theory element:

(2.6) Definition. A *theory element T with an idealization structure D* is a structuralist theory element $\langle K,I\rangle$ endowed with a semilattice D of counterfactual deformation operators defined on M_p. It is denoted by $\langle K,I,D\rangle$.

The completion of a theory element by a semilattice of counterfactual deformation operators leads to a refining of the empirical claim of a theory:

(2.7) Definition. Let $T = \langle K,I,D\rangle$ be a theory element with idealization structure. Denote the fibre of potential models over x by $r^{-1}(x)$, i.e.,

$r^{-1}(x) := \{y \,/\, y \in M_p$ and $r(y) = x\}$. Then *the empirical claim of T* (*without constraints*) is the assertion that for all $x \in I$ there is an appropriate $d_x \in D$ such that the following holds:

$$d_x(r^{-1}(x)) \cap M \neq \emptyset.$$

Stated informally, this definition requires that all intended applications of T can be extended to potential models of the theory in such a way that appropriate counterfactual deformations of these potential models yield actual models of T. Obviously, if D is trivial, i.e., $D = \{id\}$, (2.7) boils down to the familiar definition of the empirical claim of a theory element. It might be useful to explain the steps of this counterfactual path from data to theory [cf. Laymon 1982] in some detail. For a single intended application x this runs as follows:

First Step: Embedding of the data into the theoretical framework.

In the structuralist framework this means to expand a partial model x to the set $r^{-1}(x) := \{y / r(y) = x\}$ of potential models that are projected by r onto x. Usually, this set has more than one element, i.e. theoretical expansion in the framework of T is not unique.

Second Step: Applying appropriate counterfactual deformation operators to the set $r^{-1}(x)$: $r^{-1}(x) \Rightarrow d_x(r^{-1}(x))$.

The application of d might result in a reduction of the number of elements, i.e., there might be y_1, y_2 with $d_x(y_1) = d_x(y_2)$, but usually the set $d_x(r^{-1}(x))$ is not a singleton, i.e., theoretical expansion *plus* counterfactual deformation of x does not yield a uniquely determined result. The most important point, however, is whether the intersection $d_x(r^{-1}(x)) \cap M$ is non-empty. If this set is non-empty the empirical claim of T is true for x.

An analogous 2-step-procedure has to be carried out if we take structuralist constraints into account thereby treating the whole set I of intended applications instead of a single element x of I. Further modifications of (2.7) are necessary when considerations of approximations come into play.

III

Idealization and Concretization

Counterfactual idealizing procedures might be useful to create exact laws and theories that deal with idealized objects and relations like mass points and economic men, however, these laws and theories do not describe the actual world but tell how physical systems would behave under some counterfactual conditions [cf. Niiniluoto 1986: 255]. Thus, idealization is not an end in itself. Rather, with some qualification, it might even be characterized as a necessary evil or a makeshift solution for the problem of applying theories to the actual world which is definitively not solved by idealization alone. Thus, since we hardly can get rid of idealization *ceteris paribus* we may conclude: the less idealization the better. In order that such a maxim makes sense we have to presuppose that idealization is not a yes-or-no affair but comes in degrees. Hence, in this section we engage in the task to define degrees of idealization.

Having described the set idealizing deformation operators as a semilattice there is a canonical partial order on D defined as follows:

(3.1) Definition. Let D be a semilattice. A *partial order between the elements of D* is defined as follows:

$$d \leq d' \text{ iff there is a } d'' \text{ such that } d'' \circledast d = d'.$$

The partial order $(D, \leq)$ defines in a natural way a partial order on M_p in the canonical way:

(3.2) Definition. Let $T = <K,I,D>$ be a theory element with idealization structure. Then the order relation $\leq$ defined on D by (3.1) induces an *order relation on* M_p in the following way:

$$x \leq y \text{ iff there is a } d \in D \text{ with } d(x) = y.$$

Hence, if $d \leq d'$, we get $d(x) \leq d'(x)$ because there is a d'' such that $d''(d(x)) = d'(x)$. This corresponds to the intuitive idea that $d'(x)$ is a stronger counterfactual deformation of x than $d(x)$ since it amounts to the deformation d *plus* another deformation d''.

Having at our disposal the notion of degrees of idealization we now introduce the concept of *concretization* as the inverse of idealization, i.e., concretization = de-idealization, we can describe the order relation defined in (3.2) informally in the following two complementary ways:

$$x \leq y \text{ iff } \begin{cases} x \text{ is a concretization of } y. \\ y \text{ is an idealization of } x. \end{cases}$$

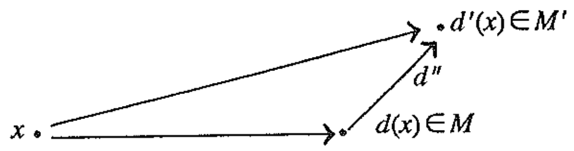
According to the general "holistic philosophy" of the structuralist approach we should not be content with the definition of idealization and of concretization for single potential models, rather we should strive to apply these concepts to theory elements as wholes. This leads to genuinely structuralist versions of idealization and concretization:

(3.3) Definition. Let $T=<K,I,D>$ and $T'=<K',I',D'>$ be structuralist theory elements with idealization structures. T is called a *concretization* of T' iff the following conditions hold:

(1) $K=<M,M_p',M_{pp}',r'>$, $K'=<M',M_p',M_{pp}',r'>$
(2) $D \subseteq D'$
(3) for all potential models x of M_p' for which there is a counterfactual deformation operator $d' \in D'$ such that $d'(x) \in M'$ there is a counterfactual deformation operator $d \in D$ with $d \leq d'$ such that $d(x) \in M$
(4) $I=I'$.

If T is a *concretization* of T' then T' is called an *idealization* of T. This is denoted by $T' \leq T$.

Conditions (1)–(4) are natural requirements for concretizations. They ensure that the counterfactual deformations of a concretization T are not stronger than the counterfactual deformations of the more idealized theory T'. More vividly, this can be expressed by the statement that for a concretization T of a theory T' the counterfactual paths from data (i.e. theoretically expanded intended applications) to theory (i.e. actual models of the theory) [cf. Laymon 1982] are shorter than for the idealization T' of T, or, *vice versa*, that for an idealization T' of T those paths are longer. This is illustrated in the following diagram:



Obviously, the relation $\leq$ between theory elements with idealization structure is reflexive and transitive but not symmetric in general. Hence, the "logic of idealization" is a *S4*-logic.

(3.4) Definition. Let $N_L(T_0)=\{T_l \,/\, T_l=<K_l,I,D_l>; l \in L\}$ be a set of theory elements with idealization structures. $N_L(T_0)$ is an *idealization net with base* T_0 if and only if the following conditions hold:

(1) there is a $l_0 \in L$ such that for all $l \in L$: $T_l \leq T_{l_0}$
(2) If $T_l \leq T_{l'}$ and $T_{l'} \leq T_l$ then $T_l = T_{l'}$

In the next section we'll show that the idealization procedures that take place in empirical science can be described with the help of idealization nets. The example we'll discuss is the paradigmatic example of the Poznań school, to wit, the Marxian law of value.

IV

The Counterfactual Character of Empirical Laws

As has often been observed, most laws of most scientific theories are counterfactual laws, i.e. they do not directly apply to any actual objects in any actual situation, rather they tell us how physical or social systems would behave under idealized counterfactual conditions [cf. Niiniluoto 1986: 255]. A famous case in question is Marx's law of value that asserts that under certain counterfactual conditions C_i the price ratio of any two commodities equals the ratio of their values. These conditions have been carefully explicated in Nowak [1980: 3–22]. Following Hamminga [1989] we can state a highly idealized version of the law of value as follows:

(4.1) $C_1 \& C_2 \& \ldots \& C_8 \Rightarrow (p(x)=w(x))$,

where $\Rightarrow$ is to be interpreted as a counterfactual conditional. To recast (4.1) in the framework of possible world semantics let us first recall a piece of jargon of possible world semantics. If x is a possible world where a proposition p holds this x is called a p-world. Let us assume that there is a certain "neighborhood" system [cf. Lewis 1986] for the actual world a_0 such that it makes sense to speak about nearness. Then (4.1) is rendered as follows:

(4.2) (The $C_1 \& C_2 \& \ldots \& C_8$)-world nearest to the actual world a_0 is a $(p(x)=w(x))$-world.

However, as Nowak rightly emphasizes, (4.2) certainly is not the whole story to be told about the counterfactual character of the law of value or any other scientific law. Thus, even if one accepts Lewis' explication of counterfactuals in the framework of possible world semantics (or some similar account) such an explication is seriously incomplete. What is missing might be called the interplay of concretization and idealization. Science is not content to state some counterfactual idealized laws about ideal objects but rather strives to get rid of these idealizations, at least partially. This may sound somewhat paradoxical from the view point of common sense, as

Nowak has pointed out, but there are good reasons to consider this procedure as the – or at least an important – method of science. Nowak describes this approach labelled as *the* Marxian or even as *the* scientific method [cf. Cartwright 1989: 204] of building theories more precisely as follows [1980: 21f]:

(1) Marx introduces some assumptions which he knows a priori to be false in empirical reality.

(2) With the above assumptions in mind he proposes the formula revealing what the phenomena in question depend on. The formula is based, then, on assumptions that do not hold in empirical conditions.

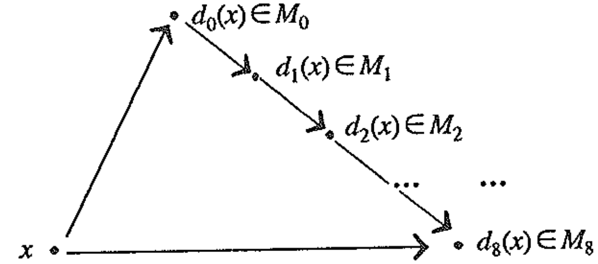
(3) These counterfactual assumptions are then removed, and the consequent of the law in question is corrected correspondingly. Thus, we obtain the "transformed forms" of the initial law which deal with conditions that are less and less abstract (i.e., satisfy less and less counterfactual assumptions). At the same time, those conditions come closer and closer to the empirical ones.

We now want to show that this Marxian procedure can be reconstructed in the structuralist framework with the aid of idealization nets introduced in the preceding section. More precisely, we reconstruct Marx's approach as building up a rather special idealization net $N(T_0)$ such that the assertion of the law of value can be identified with the empirical claim of that net.

The base element $T_0 = <K_0, I, D_0>$ of the Marxian net can be described as a theory element whose semilattice D_0 of counterfactual deformation operators is generated by operators $d_1, d_2, \ldots, d_8$ that correspond to the conditions $C_1, C_2, \ldots, C_8$ respectively. The class M_0 of models of T_0 satisfies the highly idealized law of value $(p(x) = w(x))$. The net itself is a chain

$$T_8 \leq T_7 \leq \ldots \leq T_1 \leq T_0.$$

The semilattices of counterfactual deformation operators D_i of the $T_i = <K_i, I, D_i>$ are generated by the operators $d_1, \ldots, d_i$ respectively, and the classes of models M_i are characterized by the condition that their elements satisfy concretized versions $f_i(p(x), w(x))$, the f_i being certain functions of $p(x)$ and $w(x)$. Then the "paradoxical" way of idealization and concretization of Marxian science in the case of the law of value can be diagrammatically described as follows:



Thus, as the upshot of our sketch of *structuralism cum idealization* we can characterize a scientific law as a cascade of counterfactual propositions defined in the framework of an idealization net of theory elements.

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ASSESSING THE STRUCTURALIST THEORY OF VERISIMILITUDE

In a number of papers, including Kuipers [1982], [1987b] and [1992], Theo A.F. Kuipers has developed a structuralist theory of truthlikeness. In his most recent paper, he is concerned with the problem of *theoretical* truthlikeness rather than with the one of *descriptive* truthlikeness; *i.e.* with the truthlikeness of hypotheses characterizing the subset of *empirical possibilities*, when the set of *conceptual possibilities* is given, rather than with that of hypotheses about the actual possibility, or the possibility that has been realized. However, the problem of theoretical truthlikeness reduces to the descriptive one when there is just one empirically possible alternative, the one that has been realized, and thus his formalism can be used for both purposes. In what follows, I shall first prove a theorem which shows the limited applicability of the Kuipers's definition when dealing with the latter problem, and then construct an example of the former problem in which the definition leads to counterintuitive results.

I shall concentrate on a particularly important special case consisting of cognitive problems which typically arise when predictions about physical experiments and systems are made; namely, I shall discuss the case in which the outcome of an experiment, or the state of a physical system about which the two theories make predictions, can be characterized by n quantitative variables or real numbers $r_1, r_2, \ldots, r_n$. In this case, the conceptually possible states of the system can be thought of as elements of $\mathbb{R}^n$.

Examples of systems falling under both of these restrictive assumptions would be, *e.g.*, a gas characterized by its pressure, temperature and volume, and a set of n identifiable classical particles whose state can be characterized by the their $3n$ position coordinates and $3n$ velocity components provided that n is known. An example of a situation not satisfying the restrictive assumptions is the case in which two theories about a system of this kind give differing answers, not only to the question what the