MEMETIC SCIENCE: I - GENERAL INTRODUCTION

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Abstract. Memetic Science is the name of a new field that deals with the quantitative analysis of cultural transfer. The units of cultural transfer are entities called "memes". In a nutshell, memes are to cultural and mental constructs as genes are to biological organisms. Examples of memes are ideas, tunes, fashions, and virtually any cultural and behavioral unit that gets copied with a certain degree of fidelity. It is argued that the understanding of memes is of similar importance and consequence as the understanding of processes involving DNA and RNA in molecular biology. This paper presents a rigorous foundation for discussion of memes and approaches to quantifying relevant aspects of meme genesis, interaction, mutation, growth, death and spreading processes. It is also argued in this paper that recombinant memetics is possible in complete analogy to recombinant DNA / genetic engineering. Special attention is paid to memes in written modern English. KEYWORDS: meme, replicator, language, culture, copy, idea, evolution, computer, virus, knowledge, artificial intelligence, brain, mind.

I. Memes and Replicators - An Informal Introduction.

In 1987 the book "Engines of Creation" (EOC) by K. Eric Drexler[1] appeared. EOC primarily espouses Drexler's vision of nanotechnology, a technology of human-designed molecule-sized machines, a technology based on the concept of *replicators* - entities that generate copies of themselves. All kinds of replicators surround us, the most rigorously (but not necessarily, fully) understood replicators being RNA and DNA molecules. Attention was drawn to a special kind of replicator that Drexler loosely termed mental-replicators. The ideas of replicators and mental-replicators were first articulated in a systematic fashion by Richard Dawkins in his landmark book "The Selfish Gene"[2] (TSG) and later, in more technical detail, in "The Extended Phenotype"[3] (TEP). In TSG Dawkins coined the word "meme" (pronounced 'meem' to rhyme with cream) to describe a unit of cultural transmission or imitation.

While Dawkins and Drexler provided articulation and emphasis to the concepts of replicators and memes, their discussions remain at the qualitative, general descriptive level. However, in the same time frame, Lumsden and Wilson introduced their concept of 'culturgen' in order to allow an integrated discussion of genetic and cultural transfer. Their theory is articulated in full mathematical detail in their 1981 book "Genes, Mind, Culture" [4] (GMC), and in a more easily digested introductory book "Promethean Fire"[5] (PF) which appeared in 1983. Culturgen theory is a very comprehensive theory that incorporates cultural transfer subject to epigenetic rules. Epigenetic rules, according to Lumsden and Wilson, are the "genetically determined procedures that direct the assembly of the mind, including the screening of stimuli by peripheral sensory filters, the internuncial cellular organizing processes, and the deeper processes of directed cognition". Lumsden and Wilson argue that their theory predicts that culture acts to slow the rate of genetic evolution, while joint genetic-cultural evolution leads to major change in epigenetic rules over a time as short as 1000 years.

The books EOC, TSG, GMC, TEP and PF set the stage for rigorous understanding of cultural transfer in terms of tools successfully utilized by biologists. During this general period, the capabilities and compellingly powerful consequences of mass media started coming to the national foreground. When one considers mass media in light of these sociobiological and sociocultural tools, one comes to several realizations. One inescapable realization is that it is entirely possible that many political, economic, and social events can be understood and possibly controlled by an understanding of the process of spread and replication of cultural entities.

Paralleling the sociobiological and sociocultural trends, developments and automated production of electronic storage media and computers have continued at an unrelenting pace. The pace of the computer industry is placing powerful computers and large cumulative databases of information and knowledge at the disposal of most inhabitants of the United States and its economic and military allies. Developments of computer chips such the Intel 80860 and Motorolla 88000 promise to place supercomputer power in the hands of any middle class consumer who wants that power. And, paralleling the understanding that many cultural objects can spread in an infective manner, we are becoming aware of electronic entities such as 'computer viruses' that can spread between computers via 'infected disks' and electronic networks. These computer viruses and similar electronic artifacts share many of the attributes of replicating cultural objects.

Given Dawkins' concept of memes and Lumsden and Wilson's concept of culturgen, it is evident that more theoretical development of the two concepts is required before one can utilize them in a practical

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manner. While the culturgen approach may be an entirely valid representation, a time scale of 1000 years (required by the theory) to test predictions is too long. At the same time, memes have only been defined as general constructs and lack a rigorous quantifiable definition. The challenge is to utilize the best of both approaches in a constructive fashion that can be unambiguously tested, and then applied. To this end, I suggest that, at least initially, one work with the limiting case of the culturgen theory, where one deals with generation, mutation, spread, and death of purely cultural entities. These purely cultural entities will be called memes since they resemble Dawkins' memes (however, the memes in this article are not necessarily identical to Dawkins' memes).

Some of the goals of this paper are to: provide rigorous formulation of the concept of memes, discuss the utility of using the concept of memes, and provide a quantitative foundation for further work and exploitation of the concept of meme. Since this topic is relatively new and the desire here is to make this field accessible to a large community, the structure of presentation will proceed by statements, informal discussion and then rigorous discussion. Readers are encouraged to read the paper first with a view to familiarizing themselves with the terminology, scope, and potentialities associated with this subject matter, and then to read the paper again to extract specific useful components for further consideration. Thus the terminology utilized in the initial sections will tend to be informal; terms such as meme and replicator will be defined and refined in later sections of the paper.

What are some examples of memes? Common examples include ideas, tunes, fashions, and virtually any cultural and behavioral unit that gets copied with a certain degree of fidelity. Photo-copied documents (Xerox copies) are prime examples in [modern culture] of embodiments of meme replication. Chain letters, prayers, slogans and jokes, are other (mass replicated) embodiments of memes. An example of an extremely potent electronic meme is the computer-virus.

One type of meme that gets reported often in the popular press is that of celebrity based or movie-based behavior pattern. Shouler[6] reports that following the MGM movie "The Hustler", which depicts the life of pool hustler Minnesota Fats, "The industry effects were overwhelming, more than 3000 new [pool] rooms shot up across the nation in just three years." Another specific example of a continuingly powerful meme is hair style; notice the spread of [British] Princess Di's hairstyles. In order to avoid getting bogged down in the semantics of what is 'behavior' and what is 'meme', and where there may be similarities and where there may be differences, this paper will focus on discussion of a particular category of memes, namely that of 'idea-memes'. In what follows, the terms 'idea', 'concept', 'meme' and 'idea-meme' will be utilized interchangeably. As we proceed it must be recognized, though, that developing a theory of 'idea-memes' is potentially treacherous. Many opportunities for confusion exist. There may be situations where shifts of frames of reference can occur, there are ample opportunities for unintentional substitutions of general cases for particular cases, which may lead to Russell type paradoxes [Bertrand Russell types of statements about sets of subsets that don't include themselves, and a variety of self referential statements discussed by Hofstader [7,8,9]].

Historically, philosophers have dealt with the questions of theories of knowledge, abstract ideas, existence of 'perfect forms' and universal truths. Philosophers of all eras have concerned themselves with how concepts arise, their relationship to the physical world, and mind/body or mind/matter questions. One of the uniform aspects of philosophical theories of ideas and knowledge is the question of 'truth' of ideas and concepts. Questions of truth naturally lead to questions of ethics and morality. In developing the theory of memes it is important to stress that one is not trying to determine truth of ideas. Truth and similar notions can enter as parameters that can be used to describe memes, their interdependencies, and their survival, spread, and 'death'; however, memes exist regardless of their truth condition. Consequently, theories of memes must steer clear of general statements about truth, ethics and morality.

It will be asserted here that there are useful aspects to the thorough understanding of these so called mental replicators. In fact, it is quite possible that whole processes of development of science, philosophy, and many other human cultural enterprises can be explored and perhaps predicted from a quantitative theory of genesis, interactions, growth and death of memes. It is this conviction that motivates one to set out to explore and quantify what is known about memes and their interactions. This activity of systematizing and quantifying properties of memes and interactions between memes is what I term Memetic Science.

The remainder of the paper is organized as follows:

II. Replicators, Vehicles, and Memes - Reintroduction. Here replicators, memes, and associated terminology that forms the linguistic foundations, get more rigorous definitions.

III. Roots. In this section similar concepts explored by others will be visited briefly. While Dawkins was the first to emphatically articulate the concept of memes and replicators, others before and after Dawkins' TSG have come up with useful approaches that approximate and converge on the meme framework.

IV. Population Dynamics and Replicator Equations. In this section, the basic population equations are introduced. The population equations are the modern version of the Voltera-Lotka predator-prey equations for competing species in an ecological niche. This section rests on contributions from Lotka[10], Volterra[11], E. Montroll[12], R. May[13], L. Cavalli-Sforza[14,15], Lumsden & Wilson,[4,5] Schuster and Sigmund[16], and Diedrich and Opper[17].

V. Language Based Memes - Fundamentals. Here we take up the study of memes that are manifested in language, and in particular in Written Modern English (WME). The particular interest in WME is due to two facts. First, Modern English is becoming the most widely used language, especially in international communications. The second fact is that developing memetic science by investigating WME allows a truly scientific research approach based on unambiguous raw data which is accessible to any individual. An interesting historical aspect here is that Markov started his work in stochastic theory by investigating statistical attributes of language[18]. Similarly, Claude Shannon was led to many insights in information and communication theory by investigating redundancy and coding of English language[19]; finally, Benoit Mandelbrot of fractal fame[20] started his professional work in study of statistical distributions of word frequencies[21]. An interesting observation here is that it is estimated that there are 1,500,000 species of plants and animals that have already been described and named[22], all of these names and their descriptions are memes. Given that the wealth of language based memes exceeds that of the flora and fauna of the natural world one requires memetic constructs that correspond to every hierarchical level we find in the biological world. The beginnings of classification is embarked upon as is the topic of complexity. Finally, this section introduces the notion of knowledge representation in memetic phase space. A preferred ordering is presented using word frequency ordering. One question explored here is whether each individual constructs his own phase space or has an internal phase space which is different from the 'universal' phase space. The universal phase space is essentially that of the collection of all individual phase spaces, with 'universal frequencies' obtained from summarizing all the individual phase spaces.

VI. Memetic Spread Equations. In this section, the initial approaches to memetic spread equations are laid out in the form of probabilities of interactions and thermodynamic weights. The complete construction of spread equations naturally follows, and is left for subsequent papers.

II. Replicators, Vehicles and Memes - Reintroduction.

In TSG Dawkins first introduces the term "replicator" as a biological molecule that has "the extraordinary property of being able to make copies of itself". Dawkins describes replicators in terms of several necessary properties. In order to consider an entity a replicator, the entity must possess attributes of fecundity, fidelity and, longevity. Furthermore, to be considered an *active replicator* the replicator must have some influence over it's probability of being copied. Thus, a replicator is anything of which copies are made. Examples of replicators can be DNA and RNA molecules, monomers and polymers, songs, sheets of paper that get xeroxed, chain letters, 'junk' faxes, books, records, videotapes, behavior, memes, ladies' fashions, patterns on snake skins, etc. All these entities can be characterized by the attribute that they spawn copies or are examples of entities that have been copied. In most cases, copying of these entities is performed with special care to reduce any errors that may be introduced in the copying process, and that the items copied exist for a duration that can allow further copies (or generations) to be made; i.e. they normally do not cease to exist when a copy has been made.

Replicators can be categorized in a variety of ways. Dawkins suggested the categories of dead-end and germ-line replicators. Dead-end replicators give rise to a finite number of copies and have only finite number of descendant generations. A germ-line replicator, is the potential ancestor of an indefinite number of copies. It is the germ-line replicator that is of considerable interest for us as the item for further investigation. Now, in complete analogy with the biological cases, we seek a descriptive process that allows us to treat replicators or a collection of replicators as being 'alive' or 'dead'. To refine this point, one can make use of a formalism developed by Dyson[23] to model the evolution of life. Dyson looks at a deceptively simple model where 'aliveness' is related to order, and 'death' is related to disorder. What is of interest to Dyson is the transition from disorder to order (as the crux of the origin of life). What emerges from Dyson's model is that death of a complex 'alive' entity is statistically possible, whereas the 'resurrection' of a 'dead' entity is not possible. A further consequence of Dyson's model is that the number of distinct basic building blocks that primary replicators (in his case species) must be made of is greater than nine. What one can take from Dyson's work is that a reasonable number (several thousand) of molecular units, that are allowed mutations and mutual catalysis, can support transition from disorder to order (life generation) and active replication which can be regarded as life.

A particular challenge is to recast this disorder --> order transition in general terms, and apply it to memes and memetic constructs. One approach is to consider memes expressed as ideas which utilize language (such as English) and to track the genesis, mutation, replication and spread of ideas which use one or more 'modern' languages on which we can perform quantitative analysis.

For completeness one has to address the question of the context and embedding of replicators. In other words, replicators may be rather small, fragile entities (e.g. genes, DNA segments, words). What then directly assists replicators in their existence and struggle for survival in the arena of natural selection? In TSG and TEP Dawkins suggests that there are 'vehicles' in which replicators 'travel about'. In particular, to quote Dawkins, " A vehicle is an entity in which replicators (genes and memes) travel about, an entity whose attributes are affected by replicators inside it, an entity which may be seen as a compound tool of replicator propagation. " Aside from individual organisms that can act as vehicles, Dawkins allows for " a hierarchy of entities embedded in larger entities ", any one of which may act as a vehicle.

While Dawkins concentrates on biological organisms as vehicles, and memes/replicators housed in biological organisms such as brains and bodies, it is important for us to clearly understand that non-biological entities such as books, computers, optical disks, etc. are just as important (if not more so). The issues of the latter being phenotypical manifestations and biologically produced is a matter left for epistemologists for future discussion.

At this point we return to memes as the principal item of interest.

The concept of units of cultural transfer and inheritance has been hypothesized by many individuals. As early as 1935, one can find a reference to hereditary-like cultural entities in Zipf[24]. In discussing properties of language, Zipf identifies the 'acteme' as the smallest unit of experiential classification, and in particular as a 'gene of meaning'. While Zipf's interest lay mainly in analysis of language and relationship of frequencies of word usage, their rank and their length, more recent investigators use units of cultural transfer to study and explain modification of behavior. In Wiener's seminal monograph on Cybernetics[25] one finds references to ideas and collection of ideas as an interacting system. Bateson[26] amplifies these in talking about ecologies of ideas and explicitly states that "in the ecology of ideas there is an evolutionary process".

There are many issues when one starts the discussion of evolution of ideas and/or cultural evolution. There are always questions of biological evolution independent of cultural evolution, cultural evolution independent of biological evolution, interdependent biological and cultural evolution and the questions of natural selection and fitness in a changing environment. In the past two decades, a number of relevant exploratory books (in addition to TSG and TEP monographs of Dawkins) have been published in the area of cultural evolution which treat these types of questions. The primary monographs by Bonner[27], Cavalli-Sforza and Feldman[15], Lumsden and Wilson[4,5], and Boyd and Richerson[28] serve as a good foundation, and provide useful references for additional research into this topic from the biological evolutionary perspective while Hull provides a modern philosophical perspective[29].

In the introduction, a preliminary definition of memes was given as units of cultural transmission or imitation. This is the original definition given by Dawkins in TSG. In TEP Dawkins revised the definition of meme to be "a unit of information residing in a brain", with a subsidiary clarification that words, music, gestures etc. are to be regarded as phenotypic effects of memes which are perceived by sense organs and lead to 'meme imprinting' in other brains. At this point one must realize that Dawkins has provided two different definitions for memes. In fact Dawkins has tied down memes to dependencies on biological entities, and in particular he reiterates Bonner's statement that "Memes are utterly dependent on genes, but genes can exist and change quite independently of memes". This last statement must be treated with great caution. Later, in this paper, it will be evident that while biological entities originally gave rise to early memes, this is no longer the case. It is important now to appreciate the magnitude of Dawkins' contributions to the articulation and foundation of study of memes but at the same time also realize that his contributions form the starting point and leave significant and interesting work to be done.

III.1 Roots: Philosophical Beginnings.

There are many individuals throughout recorded history that speculated about the nature of thought and knowledge. Highlights of the most prominent Western philosophical thinking in this area are discussed by Bertrand Russell[30]. We can find the roots of memetic science distributed, albeit unevenly, throughout history. The main recognizable periods are those of the early Greeks, the Interregnum between Plato and the Renaissance, the Renaissance, Darwin and post Darwin, the early modern era, and present modern era during which the concepts of Dawkins, Bonner, Cavalli-Sforza, Lumsden and Wilson, Boyd and Richerson, and Hull started taking shape.

The recognizable contributors of the Early Greek Period include Parmenides, Anaxagoras, and Plato. Parmenides, father of logical metaphysics, identified thoughts with the object of thoughts, and held that if words are used in some meaningful way, what the word means must somehow exist (objectively). His approach implicitly assumes constancy of meaning of words and is known to lead to logical difficulties. Another early principal philosopher is Anaxagoras who introduced philosophy to Athens as well as the concept that 'mind' was the principal cause of physical change.

The earliest generally developed and most influential theory of knowledge is that of Plato originally presented in "Theaetetus" and subsequently in "The Republic"[31]. Plato advances the theory of forms or ideas [we'll call them P-ideas]. P-ideas were argued to be those ideas with which individuals are endowed at the time of birth. P-ideas are abstract constructs that exist in the absence of individuals, they were regarded as objective truths. Any object could then be described as possessing properties or qualities of one or more of these P-ideas or forms. For example a blank sheet of white paper would be described as possessing the form of rectangleness, whiteness, and blankness. Geometric propositions were regarded as P-ideas that existed as true abstract entities even in the absence of a thinker. Associated with P-ideas are four states of mind: imagining, belief, thinking, and intelligence. P-ideas operate or exist in the 'intelligence' state of mind.

Representations of physical and abstract entities in terms of P-ideas, and variations of P-ideas, dominated a significant fraction of philosophical thinking [much of which was concerned with issues of truth, supreme creator, morals and ethics]. Russell expressed the critical question associated with P-ideas, and ultimately ontology, as follows, "The real question is: Is there anything we can think of which, by the mere fact that we can think of it, is shown to exist outside our thought?".

During the Interregnum between Plato and the Renaissance one finds a small group at the University of Paris, called the Averroists, who during the mid Thirteenth Century held the belief that immortality is associated with the intellect, and that intellect is an impersonal entity which can exist in identical forms in different intellectual beings. This is probably the earliest conception of unlabeled memes (where the concept of meme can be substituted for the concept of intellect). Another major contribution comes from William of Occam (originator of Occam's Razor principle) who elaborated on words and concepts, defining 'concepts' as natural signs and 'words' as conventional signs. One of Occam's contributions is his insistence that it is always possible to study logic and human knowledge without resorting to metaphysics or theology. By maintaining this insistence, Occam contributed to the emergence of the scientific method. Later, Nicolo Machiavelli's thesis that "power is for those who have the skill to seize it in a free competition" contributed to the the stream of thought leading to the theory of natural selection.

The Renaissance and post Renaissance periods yielded a vital continuation of early Greek thinking. During this period the importance of thought and P-ideas continued to evolve. Descartes' ***cogito ergo sum*** and his Cartesian geometry set the stage for much of contemporary theoretical science. In declaring 'cogito', as the prime irreducible, he elevated the importance of the concepts of 'thought' and 'thinking' to the premier indisputable aspect of perception from which everything else follows, or with which every sensible perception must be explained. Of course, Descartes recognized that all such thoughts are private thoughts, perceived by the individual thinking them without the possibility of determining what another individual is able to know or comprehend about them. Cartesian thoughts of this nature will be denoted by C-ideas.

Descartes paved the way for John Locke and David Hume. Locke originated the strict empiricist approach based on the notion that all knowledge is derived from experience (except perhaps for mathematics and logic). Locke asserted that there are no innate ideas, and that all ideas derive from either sensation or perception of the operation of our mind. A major philosophical insight of Locke is that all things that we perceive are 'particular' instances of those things, but that we have the ability to frame ideas about 'universals' (recall here that Plato and Aristotle had severe problems in their treatments of particulars and universals).

Among some of the other insights of Locke is that we cannot fully know physical things, we can only know word-definitions of them. This is important to memetics in that words and word-constructs are the principal entities we can deal with in a robust way. Additionally, Locke pointed out that many of the distinctions we claim between objects are not facts of nature but facts of language. With respect to 'ideas' the themes that mind has no immediate objects but its own ideas, and that knowledge is the perception of agreement or disagreement of two ideas, are themes that underly Locke's philosophy.

Locke's work form the foundation for Hume's. Hume's approach to the notion of ideas can be summarized as follows: a) impressions are the immediate sensations we are aware of due to external stimuli, b) ideas are faint images of impressions [we'll tag these H-ideas], c) we cannot know anything we have not had a prior impression of, and d) there are complex impressions which lead to complex ideas made up of simple ideas.

With this foundation, Hume asserted three fundamental 'laws of ideas'.

1. Ideas are connected by resemblance of ideas; for example, a picture of Einstein makes us think about Einstein.

2. Ideas are connected by contiguity in space and time. If we think of one room in a house, we are very likely to think about rooms adjoining it.

3. Our mind is impelled to seek/postulate cause & effect relationships between ideas. When we are exposed to two events, A and B, that are contiguous in space and/or time, we tend to postulate a cause & effect relationship between A and B. This is particularly true if we observe the conjunction of A & B repeatedly. Philosophically, Hume argues that while we cannot know [perhaps, ever] that a particular cause must have a particular effect, we will still tend to associate the ideas of A and B and search for a necessary connection.

Hume has also given us the notions of analytic propositions (propositions about logic) and synthetic propositions (about matters of fact), with the assertion that the only knowable propositions are the analytic propositions. These classes of propositions and their relationship to memetic constructs are areas of potential interest to the philosophers.

The next major step before Darwin is that of Kant. Immanuel Kant is considered by many as the foremost thinker of his period and one of the principal philosophers of all times. His most important work, "The Critique of Pure Reason", develops the argument that while none of human knowledge can transcend experience, some of this knowledge is not necessarily obtained inductively from experience. Kant calls this non-inductively obtained knowledge *a-priori* knowledge. Thus there are multiple categorizations of knowledge. There are synthetic and analytic propositions as well as empirical and a-priori propositions (the lines of division being different). Technically, according to Russell, an analytic proposition is one in which the predicate is part of the subject, while a synthetic proposition is a proposition that is not analytic. Finally, empirical propositions are based on sensory perception. Kant's "Critique" works at answering the question of feasibility of a-priori synthetic propositions.

The Kantian synthesis is this:

* outer world (W) causes inner (I) sensation.

* inner mental tools order I-sensation in space and time.

* inner mental tools supply concepts with which we understand experience (collection of I sensations).

* things in themselves (W-things) are unknowable.

* inner mental tools include 12 'categories' or a-priori concepts:

  - unity, plurality, totality
  - reality, negation, limitation
  - substance & accident, cause & effect, reciprocity
  - possibility, existence, necessity.

* space and time are subjective concepts that apply to all I-sensations.

* W-things are not in space and time.

* fallacies in logic arise when one tries to apply space and time discussion to a-priori concepts.

Kant utilized his system to argue that there are 'ideas of pure reason' (such as God, Freedom and Immortality) and that while pure reason leads us to form ideas such as these, pure reason cannot prove their existence. In memetic parlance, this is equivalent to saying that we can originate memes using our mental tools, but we cannot prove their truth or the existence of meme predicates.

The Kantian synthesis, while somewhat aged, is one to keep in mind as we later examine Edelman's theory of consciousness[32]. Additionally, while we got the notions of a-priori, a-posteriori, and synthetic knowledge from Kant, Kant's "Critique of Pure Reason" was a source of great concern to many. To this day, many of the issues raised by Kant remain unanswered in a satisfactory manner leading some of this century's prominent physicists, such as Sir J. Jeans[33], to avoid the issue of existence of a-priori knowledge.

As the Kantian roots of memetics were being completed, the most significant biological roots were emerging with the appearance of Charles Darwin's "Origin of the Species"[34]. Darwin's contributions are now regarded as the center piece of biological sciences namely the theory of evolution based on natural selection operating on results of random mutations. While there is still discussion as to what random mutation means and at what level (gene, organism, group,...) natural selection operates, all biologists and most scientists accept the evolutionary approach as operationally true. This biological evolutionary theory forms the backbone of the various socio-biological theories and is a natural component of memetic science.

III.2 Roots. Cultural Evolution, Sociobiology, . . .

The last section addressed the general foundations that form the basis for the language and concepts that allowed discussions of memes. In this section the more modern and direct foundations of memetic science are addressed. There are two types of modern foundations: those that lay the technical (quantitative basis) and those that explicitly refer to cultural entities as replicating and spreading entities. Without question, the two individuals who have originated the primary socio-cultural and socio-biological framework which contributed most significantly to memetic science, though not under the label memetic science, are E.O. Wilson of Harvard University and R. Dawkins of Oxford University. As has happened in the history of science before, Wilson's and Dawkins' ideas matured at about the same time and both men published significant books in close temporal proximity. Wilson's "Sociobiology"[35] appeared in 1975, while Dawkin's "The Selfish Gene"[2] appeared in 1976. This is reminiscent of the Darwin / Wallace intellectual priority questions. Over the next decade both individuals continued to contribute significantly to the clarification of their concepts. Dawkins followed up with a more technical (but regrettably non-quantitative) book "The Extended Phenotype"[3] which appeared in 1982, while Wilson and his collaborator, Lumsden, came out with a detailed rigorous quantitative theory of gene-culture interaction in the book "Genes, Mind, Culture"[4] in 1981 followed by a qualitative descriptive book "Promethean Fire"[5] in 1983.

The quantitative tools required for memetics draw from two communities. The bio-mathematical roots trace to Volterra[11] and Lotka[10]. Lotka wrote a very readable book, "Elements of Mathematical Biology"[10], in 1924. Although most of the book deals with a unified mathematical description of biology, (starting with a statistical basis, and delving into questions of the kinetics of evolving systems , biochemical basis, inter-species rivalries and equilibrium processes, and discussions of consciousness), Lotka is aware of the significance of cultural interactions. In fact he has a 'pseudo-memetic' outlook as can be gleaned from the following paragraph in his book,

> "In the human species the communication of information from one to another takes place chiefly through speech, tradition and carved, written or printed records. In a recent number of *Nature* there appeared Professor Bohr's address on the structure of the atom, delivered on the occasion of the award to him of the Nobel prize for 1922. In this historical survey of the development of his theory he mentions nearly fifty names of investigators who directly or indirectly contributed to this part of our-world picture. A person intelligently reading this lecture, making the picture part of his own mental stock-in-trade, is thus virtually endowed with fifty pairs of eyes and hands, and has the benefit of fifty brains, for the most part brains of the first rank, ... Faraday, Maxwell, ..., Lorentz, Plank, Einstein, to mention only a few. It is this thought-transmitting propensity of the human species, more than any other, that gives it a superlative lead over all the other creatures of the globe. .... Evolution in this case proceeds not merely by the slow process of selection, but is immensely hastened by the cumulative and continuous growth of a body of knowledge exempt from those laws of mortality which set a term to the life of an individual. .... Our Galileos, our Newtons, our Thomsons, have not been singled out by a process of lethal selection from others less fit to survive. The process by which viable, pragmatically competent systems of thought (or world-description) are evolved is quite other than this. ... The decisive factor was the simplicity .... eased further advance of knowledge."

The bio-statistical tools for memetics are the same as those of population genetics, namely the classical works of Fisher[36], Wright[37], and Haldane[38]. These tools, articulated in the early 1930's, have in fact formed the basis of much of contemporary human population genetics (an excellent, readable reference on this topic is Cavalli-Sforza and Bodmer's book "The Genetics of Human Populations" [14] which contains sufficient yet not stifling quantitative discussions). At about the same time (1935), Zipf published a thorough investigation of certain statistical aspects of language in a book titled "The Psycho-Biology of Language"[24] (hence to be designated PBL). PBL is a rather remarkable product that has been largely ignored, we will use many of the empirical findings recorded there for the initial construction of word-oriented memetic theories.

During the late 1940's we see a number of areas emerging. Hebb developed a theory of adaptive reinforcement[39] which has found much use in modeling artificial neural systems. Wiener articulated the basics of control and communications system theory in his book "Cybernetics"[25], published in 1948, and Shannon and Weaver[40] laid the definitive foundation of Information Theory in 1948. It is interesting to note here that Wiener also recognized the contribution of the British empiricists Locke and Hume. Wiener addresses the theory that mind is made of entities known as 'ideas' and that ideas unite themselves into 'bundles'. Wiener recalls the contiguity principle of Hume which allows one H-idea to trigger its associated idea bundle. Wiener also discusses Pavlov's experiments with dogs and the experimental confirmation of union by contiguity, which in the case of dogs is evident in their pattern of behavior. Wiener recognizes the interest of researchers of psychology and sociology in cybernetics, but explicitly states his view that these communities lack adequate conceptual frameworks, and in particular, they lack tools equivalent to those of dynamics theory in physics. Zipf appears again at this time (1949) with his little understood "Human Behavior and the Principle of Least Effort"[41] in which the physics' principle of least action is discussed. One can derive from the principle of least action much of the needed dynamics. Unfortunately, the field of psychology was not ready in the 1940's for an injection of theoretical physics. Zipf's expertise and background in philology did little to endear him or his theories to either psychologists, sociologists, biologists or physicists with significant loss of opportunities.

Before passing to a detailed discussion of the direct technical foundations of memetics, it is worth mentioning the perspective of Sir James Jeans, a prominent physicist and astronomer. Jeans' views are representative of physicists of the Golden Age of Physics during which a new world view emerged, namely the theory of relativity and quantum mechanics. Jeans discussed the conceptual evolution of physics in his very readable book "Physics and Philosophy"[33]. Many physicists, who one would normally think of as dealing with inanimate objects of nature (such as atoms, electrons, stars and galaxies), found themselves concerned with the interaction of observer and observed entities.

Concerning the importance of the entities we call ideas Jeans says:

> "What were mere associations of ideas in the brains of animals readily became translated into natural laws in the mind of thinking men. .... But now the complication intervenes that our minds do not take kindly to knowledge expressed in abstract mathematical form. Our mental faculties have come to us, through a long line of ancestry, from fishes and apes. At each stage the primary concern of our ancestors was not to understand the ultimate processes of physics, but to survive in the struggle for existence, to kill other animals without themselves being killed. They did not do this by pondering over mathematical formulae, but by adapting themselves to the hard facts of nature and the concrete problems of everyday life. Those who could not do this disappeared, while those who could survived, and have transmitted minds to us which are more suited to deal with concrete facts than with abstract concepts, with particulars rather than universals; minds that are more at home in thinking of material objects, rest and motion, pushes, pulls and impacts, than in trying to digest symbols and formulae."

However, all this is to trick us. The fact that our brains are organized to deal with concrete facts does not force nature to actually be made up of simple entities digestible to our brains. The physicists of the Golden Age discovered, to their chagrin, that forces such as Newtonian forces do not have real objective existence, they are instead "mental constructs which we make for ourselves in an effort to understand the workings of nature". Quantum mechanics led to the realization that one cannot describe physical processes in terms of the usual concepts of time and space. The trend of our understanding of nature is consistent with Einstein's view that, as Jeans states it, "as experimental research advances, the fundamental laws of nature become simplified more and more, and , as in many other departments of physics, we find this simplicity residing neither in the physical facts, nor in their explicit pictorial representation, but solely in the mathematical formulae that describe the pattern of events."

There are other notable discussions in Jeans' book concerning the different interpretations of space and time. The discussion of conceptual space and time is particularly interesting because it shows that the notion of memes is immanent. Jeans provides the following description of conceptual space,

> "*Conceptual space* is primarily the space of abstract geometry. It has no existence of any kind except in the mind of the man who is creating it by thinking of it, and he may make it Euclidean or non-Euclidean, three-dimensional or multidimensional as he pleases. It goes out of existence when the creator stops thinking about it- unless of course he perpetuates it in a text-book."

Jeans is of course incomplete in that he ignores the fact that conceptual space can exist in some respects in memory and can be recalled by the original thinker of the particular conceptual space. However, we see some of the basic features of memes in his description. For Jeans, conceptual space can exist in two ways, one in the mind of a thinker, and the other in a textbook. Already, by the act of transcribing a thought, one is creating a representational replica of the conceptual-space-thought in the textbook. Next, when one reads the textbook, one creates another representational replica of the conceptual space in the readers' neural system (i.e. the reader's brain). Obviously there is no way to ascertain that the original conceptual-space thought is replicated identically in the brain of the reader, however, the fact that we all can conceive of some things, write instructions down for creating them, and then have others produce that which we have described, indicates that certain degree of replication of thought is possible. Again precise discussions require an elaborate mathematical representation; this will be provided later.

We now come to the contemporary foundations of memetics. There have been a number of individuals who have contributed directly or indirectly. While the theories of Dawkins and Wilson and Lumsden deserve special attention, there are a number of other individuals that have contributed. All those individuals who have concerned themselves with cultural transmission have contributed in a broad sense. Cavalli-Sforza and Bodmer[42], have discussed cultural evolution and its effect on natural selection as early as 1971. They recognize the important fact that rate of cultural evolution is much faster than biological evolution. They characterize cultural evolution in terms of invention and infective transmission, and state their perception that "the interactions between cultural and genetic evolution have not been investigated in any depth". It is clear from their discussion that it would be a long time before a science of memetics would be ready to emerge. (My informal observation here is that while the kernel of cultural evolution was articulated, and the bio-mathematical tools readily available, the focus was on relating cultural entities to genetics. While this aim is admirable, it is a severe constraint due to the fact that no useful planned experiments can take place over a human lifetime. The only type of discussion that can take place is analysis of historical data too poorly documented to yield more than broad qualitative statements.)

Clearly, the major text to present a coherent, well formulated theoretical and semi-empirical basis for cultural evolution is Wilson's "Sociobiology"[24]. There have been many discussions of this pivotal text, with all kinds of axes to grind by different camps. Again, what is important to stress here is that memetic science, at this point, should not strive to generate a broad discussion of biological or sociobiological principles and goals. Memetics should aim to explain the mechanism by which cultural entities , and in particular language and word based replicators replicate! Thus as one discusses "Sociobiology", one must note its excellent and logical presentation of the basic mechanisms of population biology, group selection, time-energy budgets, communication, and of course, discussion of particular social species. However, this treatise still does not address cultural replicators as replicators and objects requiring specific study.

The stage is set, however, for Dawkins. In 1976 Dawkins' TSG appears. Dawkins, in TSG mentions Sir Karl Popper's analogy between scientific progress and genetic evolution [43]. Dawkins also refers to L. L. Cavalli-Sforza [42], F. T. Cloak[44], and J. M. Cullen[45], in his discussions of memes, and to E. O. Wilson's tome, "Sociobiology", as a general reference.

As mentioned earlier Lumsden and Wilson introduced their concept of 'culturgen' shortly after Dawkins articulated the concept of memes. The culturgen concept makes its first appearance in the July 1980 issue of the Proceedings of the National Academy of Science (USA) [46]. L&W loosely define culturgen as an array of behaviors and artifacts that are transmitted by a cultural species during the process of socialization. The roots of the word culturgen, from Latin, are cultur (culture) + gen (produce). Cultergens are subsequently used for the integrated discussion of genetic and cultural transfer. The culturgen theory is developed and refined in several articles[46-50] and two books [4,5]. Ultimately, L&W suggest that culturgens can be equated to the "node of semantic memory"[50] (this is in fact an evolution of the original culturgen, and more closely related to the concept of memes as they are utilized here than the original culturgen). Lumsden and Wilson provide references to a number of cultural constructs in their books and papers. The reader is referred to GMC[4] for these references.

Closely related to the theories of Lumsden and Wilson and Dawkins, are the quantitative formulations of Cavalli-Sforza and Feldman, best represented in their book "Cultural Transmission and Evolution"[15] which appeared in 1981. CS&F are aware of Dawkins' memes; however, they argue that it is hard to observe discrete units of imitation or discrete changes in cultural traits. As the title of their book indicates, they focus on the mathematical theory of transmission of cultural traits. To their added credit, they recognize the importance and utility of studying the evolution of language. In their words,

> "Our first topic is the evolution of language, an issue less fraught with emotional overtones than say, social interactions and inequality, or altruism. Language also has the advantage of reliable, accurate measurement not only because of the nature of the cultural object under study but also because of the tradition of rigor that has characterized this discipline".

The availability and desirability of language as a domain of testing of memetic science is thus implicitly recognized.

While Dawkins, Lumsden and Wilson, and Cavalli-Sforza focused on cultural transmission in general with distinct application to humans, John Bonner of Princeton University investigated culture in animals. Interestingly enough, Bonner's book was also published in this exciting period (1980). Bonner's very readable text, "The Evolution of Culture in Animals"[27], generalizes discussion of culture; with culture in animals being the principal subject matter. In this book Bonner takes up discussion of Dawkins' memes, and makes use of the word meme as "any bit or any collection of bits of information passed by behavioral means from one individual to another". Bonner clearly does not favor attempts at lumping genetic and cultural selection (as Lumsden and Wilson have done).

Bonner stresses three major differences between genetic and cultural evolution. To Bonner, modes of information transfer, rates of evolutionary change, and asymmetric dependencies of genes and memes on each other are critical differences. We will amplify some of his observations later in this paper.

A later yet still major contribution to the field of cultural evolution is the monograph by Boyd and Richerson "Culture and the Evolutionary Process"[28]. Boyd and Richerson restrict their attention to structures of cultural transmission in humans. In a manner reminiscent of Lumsden and Wilson, they link models of cultural transmission to models of genetic evolution to yield what they call "duel inheritance theory". While their model makes use of the mathematical machinery of population genetics, their stated goal is "not to make quantitative predictions" but to " clarify the logical relationships between cultural transmission and other Darwinian processes .... that may eventually allow us to make general statements about the evolution of human behavior". Boyd and Richerson make a point of defining culture as follows,

> "Culture is information capable of affecting individuals' phenotypes which they acquire from other conspecifics by teaching or imitation"

Here too we see the importance of the concept of imitation, however B&R shy away from specifics of the nature of the 'information' they refer to. They adopt much of the formalism and nomenclature of Cavalli-Sforza and Feldman[15] as well as general reluctance to discuss culture in terms of particulate units such as memes or culturgens. B&R also express reservations about the cultergenic "thousand year rule" and call for experimental studies of a "laws" of cultural transmission.

Finally, in the realm of mathematical biology, one needs to mention Brooks' and Wiley's casting of evolutionary biology in terms of thermodynamic and entropic consideration. Brooks and Wiley present their efforts toward a unified evolutionary biology theory in "Evolution as Entropy"[51] where they detail calculation of information theoretic entropy for a number of examples of evolutionary process models. B&W's work is representative of a new breed of evolution theorists who are searching for an entropy based unified theory of evolution.

While the sociobiologists and ecologists were busy developing alternative mathematical and logical formulations of evolutionary biology, a philosopher of biological systematics and taxonomy was articulating a model for the development of science. David Hull, of Northwestern University, used his extensive background in philosophy, biology, and history of biology to detail a model for describing what he calls "an evolutionary account of the social and conceptual development of science". Hull's model and extensive theory is presented in a detailed, excellently researched book "Science as a Process" [29]. In this book, Hull reflects on Dawkins' memes, Lumsden and Wilson's culturgens, Boyd and Richerson's and Cavalli-Sforza and Feldman's theories, and a host of other related discussions. Hull provides a wealth of discussion of episodes in science where one can observe cooperation, competition, mutation and selection. Hull accepts Dawkins' memes and replicators as appropriate concepts but rejects Dawkins' vehicles; relative to Boyd and Richerson he states "On my view, conceptual entities are replicators, not traits". What one is left with upon reading this book is that some of the basic concepts for a science of concepts are here, and to quote Hull again, "The fantasies of Oz must be made as familiar as Kansas. There really is no place like home".

With these philosophical and theoretical roots in place we can proceed to the detailed development of a rigorous framework for a science of ideas.

IV. Population Dynamics and Replicator Equations.

The thrust of this section is to introduce some quantitative tools with which to discuss the amount of replication that takes place in populations that contain objects that get replicated. Since the community that is being introduced to the meme concept is made up of individuals with varying mathematical backgrounds, the discussions henceforth will omit rigorous mathematical proofs in favor of outlining critical points.

Some of the original investigations dealing with replicating objects were concerned with describing population growth. In this case, the replicating objects are biological organisms, and the items of interest are describing historical population data and predicting future populations (particularly human). The simplest situation to describe is that of uninhibited growth of a single species population. If we denote by $N = N(t)$ the number of individuals of the single species population at time t, the equation describing the rate of change of N is

$$\frac{dN}{dt} = AN \tag{1}$$

with A being a constant. This equation models a rate process where the rate of increase of a population is directly proportional to the population. The solution of equation (1), as expected, is an exponential one with $N(t) = N_0 \exp(At)$, N_0 being the initial population. A more realistic model is one where there are some inhibiting factors. The simplest rate equation that can be used to describe a population with an upper limit is

$$\frac{dN}{dt} = AN - BN^2 \tag{2a}$$

with A, B constant. An alternate form of this equation is

$$\frac{dN}{dt} = AN\left(1 - \frac{N}{k}\right) \tag{2b}$$

with $Ak = B$. The solution of equation (2b) takes the form

$$N = \frac{k}{1 + C\exp(-At)} \tag{3}$$

with C being a constant of integration. When plotted, this solution yields an S shaped curve known as the *logistic curve*. The single species model with finite resources was used by Pearl and Reed[52] to model the population of the United States from 1790-1910. Pearl and Reed obtained a very good fit to the then observed population data (see Lotka, reference 10). Their model resulted in the expression

$$N_{US} = \frac{197{,}273{,}000}{1 + \exp(-0.0313395t')} \tag{4}$$

with t' being the time in years from the reference date of April 1, 1914. The graph corresponding to this logistic curve is depicted in Figure 1.

PEARL-REED MODEL OF U. S. POPULATION

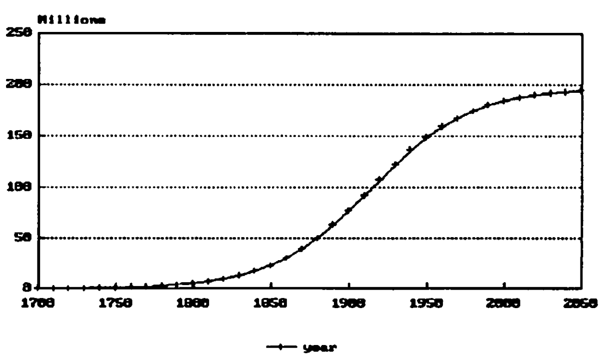

Figure 1: Example of a Logistic Curve.

The single species bounded growth model is formally identical to models that are used to describe the spread of infectious diseases (in an epidemic) and to diffusion of innovations[15].

The next step in developing models of replicators is to consider interacting replicators. The simplest multi-species environment is obviously the two species predator-prey idealized ecology. If one denotes the population of species-1 and species-2 by N_1 and N_2, the simplest model is a linear first order model

$$\frac{dN_1}{dt} = aN_1 - bN_2 \tag{5a}$$

$$\frac{dN_2}{dt} = cN_1 - dN_2 \tag{5b}$$

where a, b, c, and d are positive constants. The pathologies of this system of equations have been discussed by Davis[53]. Davis shows that if one defines $\Delta = bc - a^2$ then the solution of this system is expressed by:

$$N_1 = A\cos(\sqrt{\Delta}t + p) \tag{6a}$$

$$N_2 = B\cos(\sqrt{\Delta}t + q) \tag{6b}$$

where A, B, q, and p are determined by initial conditions (there are consistency relationships that relate parameters and populations; these are not discussed here). A quick observation here is that N_1 and N_2 have a sinusoidal or harmonic functional form and there is an obvious phase lag relative to each other. Additionally, one can explore the relationships of N_1 and N_2 in a phase plane representation, this type of analysis is presently popular especially for nonlinear chaotic systems.

A more realistic generalization is the one studied by Volterra and Lotka. Their approach models the populations of one species that preys on a second species. The population of the prey species is N_1 while the predator population is given by N_2. Qualitatively what happens is when the prey population, N_1, is large, the predator species has 'easy food' and its population N_2 grows. As N_2 increases, N_1 decreases resulting in a tight food supply and starvation for the predators. The reduction in N_2 then leads to increases in N_1 and repetition of the entire cycle. This Volterra-Lotka process is described by the coupled nonlinear equations:

$$\frac{dN_1}{dt} = aN_1 - bN_2N_1 \tag{7a}$$

$$\frac{dN_2}{dt} = cN_1 - dN_2N_1 \tag{7b}$$

A detailed mathematical discussion of this system is given in Davis[53] and will not be repeated here save to say that there exists a phase relationship between predator and prey populations (as in the linear case), while the oscillations in population are not harmonic. The existence of a stable arrangement between the two populations is critically dependent on initial conditions, and can easily result in a catastrophe for a balanced system.

One can easily generalize to a larger number of interacting species with more complicated interactions. Schuster and Sigmund[16] use the form:

$$\frac{dN_i}{dt} = N_i\left(F_i(N_1,\ldots,N_n) - \frac{\phi}{c}\right) \tag{8}$$

to describe generic replicator equations. By definition, in their system, $N_1 + \ldots + N_n = c$ is a positive definite invariant and $\sum N_iF_i = \phi$ is a fitness functional.

While it is possible to explore different orders of replicator equations, it appears that equations of order 3 or 4 are sufficient to capture most of the dynamical aspects of simply-interacting species. An example of a homogeneous replicator equation of order 4 is:

$$\dot{x}_i = x_i\left(\sum a_{ijklm}x_jx_kx_lx_m - \frac{\phi}{c}\right) \tag{9}$$

where summation extends over the indices j, k, l, and m. Note that lower order equations may be recovered by a suitable choice of the coefficient matrix and initial conditions. A critical shortcoming of these type of replicator equations is their inability to deal with mutating and emerging species as newly appearing species. Another shortcoming is the absence of explicit discussion of spatial relationships (for memetics 'distance' is not necessarily limited to geographical distance but can include a generalized distance in an appropriate phase space). It is however possible to conceive of the replicator equations as summarizing the 'population statistics' of competing traits in cultural transfer or of competing memes.

If one carefully examines quantitative works exemplified by CS&F[15], L&W[4] and B&R[28] [summarized in detail by B&R] one would notice the prevalence of replicator type equations (especially in discussions of diffusion of innovations). Another recurrent feature is the analysis in terms of cultural transmission along vertical, horizontal, and oblique channels with associated biasing described in terms of probabilities of occurrence. A generalized Fokker-Plank equation is also implicitly or explicitly presented for calculating evolving probability densities in terms of individual meme frequencies[4,15,28].

A prevalent feature of most quantitative theories of cultural transfer is the reliance on the extensive mathematical machinery developed in theoretical genetics to treat biparental transmission with cultural allele 'inheritance'. The models typically work with a dominant/recessive representation and eventually progress to multiple state representation based on rigorous but *a-priori* probabilistic formulation. While these canonical approaches are suitable for addressing the standard questions of genetic analysis and ethnographic descriptions, they do not lend themselves to direct extensions for answering the core questions that face memetics, and ultimately the micro-theory of cultural evolution. In particular, as expressed by B&R, these theories ignore the detailed nature of the information that is passed, and the way that detailed nature affects the phenotype. This state of affairs has led B&R to remark that "our understanding of the neurophysiology of social learning is at a primitive state". Finally, to summarize the state of affairs regarding quantitative theories of cultural evolution it is useful to quote B&R, who in their concluding observations about the field state [ref. 28, p 299]

"We have taken as our task the construction of simple models for as many of the basic mechanisms of cultural evolution as we could find suitable detailed suggestions for and for which we could make a plausible empirical case. ... Like a sixteenth-century map of the world, the scale is small, distortions undoubtedly exist, some of the processes included are likely to prove apocryphal, and large areas are blank. ... much hard work remains to be done."

V. Language Based Memes.

The development of a generalized quantitative theory of cultural evolution is probably one of the more ambitious pursuits of modern science. In the remainder of the paper we will address only a part of this goal, namely the development of a rigorous science of ideas. This science of ideas has as its ultimate goal the elucidation of the micro-dynamics that govern the initiation, combination, mutation, spread and death of ideas. To this end, direct discussion of the interaction of phenotypic expressions with genotype manifestations is omitted. Rather, a fuller discussion of some particular language based and information/knowledge based mechanisms is pursued.

A useful basis and context for language based memes is that of knowledge representation. Moritz[54] argues that *Homo sapiens'* premier role in nature is due to the extremely highly developed human abilities of information manipulation, knowledge extraction, and knowledge application. Since the invention of language, continuing through the introduction of writing and record keeping, and culminating in the unprecedented pace of development of computer software and hardware of the past five decades, progressively more ***powerful tools have been developed that aid and amplify human cognitive abilities.*** The kernel of cognitive abilities and cognitive function amplifiers is composed of three principal components: 1) knowledge, 2) physical structure, and 3) [inter and intra system] communication channels and protocols.

With respect to communication channels, transmission of culture and spread of scientific research are two activities that could not exist without the tools language provides. In fact, language acts as the principal element in all vectors (e.g. speeches, books, journals, TV, radio) that spread culture and ideas.

A key to development of the theory is the realization that language is a particular manifestation of a communication strategy. Furthermore, the communication strategy is governed by thermodynamical physical principles. where the relevant thermodynamic representations are best expressed in terms of information theoretic and complexity measures.

Processes that involve ideas or memes are dynamic processes of information and knowledge manipulation. Any process of this nature is referred to as a **Knowledge Information Process** or **KIP**. Examples of KIPs in machine based systems include: communications of ASCII files via modems, representation of information in a semantic net, query processes in a relational database, merging of two dissimilar databases, extraction of rules from data for expert system construction, application of knowledge-based system heuristic rules, training of an artificial neural network classifier, extraction of a feature vector from raw data, generation of logical inferences or hypotheses in knowledge based systems, and, in general, execution of any data processing algorithm.

KIPs have been present in biological systems much earlier than in machines. KIPs in [mammalian] biological systems are processes that engage the brain and/or the central nervous system (CNS). Examples of [human] neuro-biological KIPs include: seeing and enjoying a painting, giving a lecture on a technical subject, performing a mathematical calculation, writing a letter to a friend, and numerous other high level cognitive activities. Other neuro-biological KIPs involve non [directly] observable low level processes such as biological memory formation, synaptic transmission, flow of information from the cortex to the amygdala, and inter- and intra- neuronal processes.

With the definition of a KIP Agent as any biological or machine Knowledge/Information Processing entity (e.g., child, adult -human, computer, fax - machine), it is possible to explore knowledge formation, knowledge representation and knowledge spread as activities that occur within and between KIP Agents. Use of the notions of KIPs and KIP Agents will allow application of memetics to knowledge/information processes in both biological and machine systems.

In this context we recall that there are a number of distinctly different categories of memes. In particular one can distinguish: 1) linguistic memes, 2) visual memes, 3) musical memes, and 4) procedural/behavioral memes. These categories are not orthogonal; in fact, there may be elements common to two or more.

Linguistic memes are those we are familiar with through language interactions. Visual memes are those that are integrally connected with two or three dimensional visual representations (these may be patterns on moths and butterflies, designs on American Indian tapestry, international road sign symbols). Visual memes depend on and evoke activity in the 'visual' senses. Similarly, musical memes are dependent on the auditory senses and cannot be described faithfully via either language memes or visual memes (e.g. bird and whale songs, symphonies, popular tunes). While one can utilize linguistic memes to describe the procedure with which to generate visual or musical memes, the linguistic procedure description will be entirely different from say the Mona Lisa or Beethoven's Fifth Symphony.

The information measures useful for our discussion come from rigorous information theory[55], and include measures such as self information $I_k = -\log_2 P(a_k)$ and entropy $H = -\sum_{k=1}^{K} P(a_k)\log_2 P(a_k)$ (where a_k is the k-th letter of the alphabet of K letters, and $P(a_k)$ is the probability of occurrence of the k-th letter) are quantities that describe unexpectedness in information, not meaning. Measures that describe value or meaning of strings of letters are distinct from information-theoretic measures and must be treated extremely carefully. Brillouin[55] distinctly associates value with possible use by a living entity. Ultimately, we will address value in our discussions. [A temporary hypothesis here is that value is related to entities further up on the hierarchy of units (not words or lemmas, but certain collections of them)].

Language is a very broad topic; when reference is made here to language we restrict our attention to the written manifestation of a very specific language, namely written modern English. This is not a severe handicap since what is developed here applies broadly to any other written language (of any age). A valid argument may be made that one needs to also consider spoken language. Detailed consideration of spoken language is left for another time. However, one should notice the clear benefit of using written language, namely the vast amount of real, objective, empirical data available in the form of published material of all kinds.

An interesting by-product of this investigation is the potential applicability of language evolution rules, and replicator dynamics in the area of computer systems. Computer languages are after all, highly stylized languages with very deterministic components. Furthermore, certain collections of computer instructions exist which fall into the replicator category (re-usable code can be seen to be a type of passive replicator, likewise computer viruses are a type of active replicators). The emerging fields of computer simulations using genetic algorithms, self programming, true-artificial intelligence and machine intelligence belong to the class of areas that are derivatives of memetic science.

V.1 The Core Program of Memetics.

Initially *the core program of memetics is to demonstrate that: 1) ideas (memes) develop according to certain predictable rules, 2) culture transmission and spread of ideas of all types (in particular, scientific ideas) embody these rules 3) there is a distinct similarity of evolution of meme building blocks to that of genetic building blocks (which raises the obvious question of whether language structure is controlled by human genetic structure), and 4) new, unanticipated language and meme structures can, and possibly already do, exist.*

The question may arise as to the justification for working with written language. Many approaches are possible for investigation of replicator dynamics in language, and language evolution. One reason described in the introduction was the accessibility of robust experimental data. Another prime reason is that written language embodies a significant degree of precision.

It is crucial to state, and re-state, that the most accessible memes available for knowledge representation are linguistic memes (i.e linguistic informational replicators) or L-memes. L-memes have syntactical, grammatical and semantical attributes. The most successful general implementation of L-memes is through the use of Written Modern English or WME. Studies of language use in scientific publication has conclusively shown that WME is "by far the primary language of international research" (Garfield[57]). Similarly, spoken English is the principal language for verbal communication between individuals of differing origins, (e.g. English is the principal language for communication between international air-traffic controllers and pilots). It is clear that research publications constitute one of the major, if not principal, forms of knowledge documentation. It is thus quite probable that WME is the principal form of knowledge representation. However, WME is not necessarily the most efficient or machine accessible form for knowledge representation and manipulation.

Before proceeding, one needs to view the place of written language in the hierarchy of communication strategies. Communication strategies for humans may embody any one or more of the physical senses. The most practical, in terms of their range (both distance and frequency spectrum) are those based on optical and acoustical strategies. Among the optical and acoustical communication strategies one can observe the following general classes:

i) general sound with which it is very difficult to associate precise meaning (additionally, a limited variety of differentiable sounds can exist here).

ii) stylized sound such as music. Here again, it is difficult to associate precise meaning, but distinct differences are possible. In fact an infinity of variations are possible; many parameters are available to work with [frequency, amplitude, duration, modulation, simultaneous superposition of individual patterns,...]

iii) verbal or spoken language. It is easy to associate meaning in communication using spoken language, but of ambiguity is still present. It is normally subject to ones ability of recall. Spoken language cannot be re-examined (this has improved this century with the availability of tape recorders, which makes re-examination of speech possible for the first time). In verbal language, there exists an infinity of sequential assembly choices of finite extent [limited by number of words in a series that can be perceived as a unit and can be logically analyzed]. Verbal communication is not dependent on sensory apparatus to the extent that it is within certain amplitude and frequency ranges.

iv) written language. Written language is primarily a visual communication strategy, although it is usually initially based on the learning of a verbal communication strategy. Here, there exist an infinity of possibilities. Written language is available for re-examination leading to reduction in ambiguity, and requires less ability for precise recall. This last feature is crucial since more people can make use of complicated information relative to verbal communication. Limitations still exist since complex or long sequences can be understood only by a small set of people.

v) symbolic language. Symbolic language is a specialized subset of written language. Here math, physics, music (to name a very few) concepts can be described precisely and denoted by symbols. Symbolic language is a result of consensus formation (as to the definition of symbols). Symbolic language also offers an infinity of possibilities with the same advantages as with written language but with more rigorous intellectual requirements on users. Symbolic language acts to limit the number of people with access to the full use of this communication strategy. Note here that computer languages form a special subset of symbolic language. Computer languages are quite interesting because of the degree of precision they require. Computer languages are designed to force different machines (e.g. electronic computers) to execute instruction identically and repeatedly. An interesting trend in computer software and architecture design is the development of Reduced Instruction Set Computer [RISC] architectures and improved algorithms that optimize performance over general purpose architectures.

And finally,

vi) visual language, as in using motion of limbs, the whole body, other body parts, or extension of body parts, tools, and flags. Visual language may include sign language or interpretive cues. It shares many similarities with general sound and music. However it is limited by severe limitations with respect to the number of distinct concepts/ideas/signals expressible and receivable. Most beneficial use of visual language is in that often, gradients in visual flows are the cues one uses for fight/flight information.

An axiom of this paper is that language is made up of combinations of discrete elements. There are a number of candidate "atoms" of language. Written Modern English (WME) is obviously made up of discrete strings of letters taken out of a finite alphabet of 26 letters, roman or Arabic numerals, spaces and punctuation symbols. Spoken Modern English (SME) is recognized by linguists to be made up of a finite number of elementary sounds known as *phonemes*. While it is clear that spoken language appeared before written language, clear correspondences exist between letter combinations and phonemes. In fact, Sejnowski and Rosenberg[58] have demonstrated an artificial neural network system, NETtalk, which can produce speech from text after algorithmic training [NETtalk was trained with the 1000 most common SME words, using 29 input nodes and 26 output units]. Another candidate building block is "molecular" in nature when compared with either letters or phonemes. The natural molecular linguistic building block is the morpheme. Linguists define the *morpheme* to be the minimal unit of grammatical structure[59]. The important feature of morphemes is that a given morpheme usually has a clear and constant meaning in all its uses. While morphemes have a constant WME representation, a given morpheme may vary in its SME representation (i.e. it may have different pronunciation).

While morphemes constitute the molecular building blocks (made up of letters which can be regarded as "atomic" units of WME), there exist other categorizations of elements of WME. It is particularly worthwhile to observe the evolution of categorization in the major studies of Kucera and Francis[60,61]. In their 1967 study, Kucera and Francis listed the relative frequency of occurrence of over one million words (of what is now known as the Brown Corpus or Corpus). Each different manifestation of a word or sequence of graphic symbols (our atoms) was counted as a unique entity. By 1982, the Corpus was reanalyzed in terms of units called "lemma" and "lexeme". A sequence of graphic symbols was recognized as a "graphic word", where the constraining elements are spaces on either side of the sequence of symbols. Each graphic word was assigned a tag indicating the grammatical category to which the graphic word was assigned. Kucera and Francis then introduced the "grammatical word" which is the graphical word with its tag. The concept of lexical word or "lexeme" was then introduced. The lexeme is defined as one or more grammatical words forming a lexical unit, with the *critical aspect that all manifestation of the lexeme have a unitary meaning.* Closely related is the lemma which is the set of words having the same stem/or meaning, and having the same tag. Lemmas can differ in inflection and/or spelling. In their 1982 treatise, Francis and Kucera provide two major frequency lists; first an alphabetical frequency list of lemmas and then a rank list of lemmas.

Using these definitions, an L-meme is a combination of graphic words. In some respects, the Francis-Kucera lexeme and the L-meme defined in this paper are similar, although the lexeme concept does not imply replication.

There exist a number of interesting points in regards to WME which are worthwhile to bring out at this time. First, some very useful and definite metrics exist for published WME. Barschall[62] recently examined costs per printed character and *impact* (frequency with which articles in a given journal are cited). Barschall found that the average cost per printed character was the same in three fields he examined (physics, philosophy, mathematics), however costs within a field varied. He also found that R_{ci} the ratio of cost to impact varies between 0.063 to 54, with R_{ci} for scientific society publications being lowest and R_{ci} for commercial publishers being highest. These criteria are being used by libraries to help decide on journal cancellations, an activity clearly critical in determining the rate of spread of scientific ideas (and physical survival of specific journal meta-memes). Other metrics on scientific WME are derived from citation analyses. These are used to evaluate and track the impact of scientific papers, and are at times used for tenure decisions.

A further justification for restricting the discussion to WME as opposed to SME, at this point, is the experience attained with automatic (machine) speech recognition. A significant amount of effort has been invested in the past two decades in developing machine speech recognition (MSR)[63-66]. The key difficulties that MSR has to contend with result from ambiguity, nongrammaticality, and wide variance in human speech (between individuals, and in speech of a single individual in different physical and mental states). MSR specialists have developed multilevel classification schemes of different kinds. Isolated spoken word recognition tasks are considered relatively simple, while connected speech recognition is quite difficult. A principal difficulty with connected speech is the recognition of word boundaries. Unrestricted MSR, where the speaker does not utilize specialized vocabulary and an even speech pattern is quite difficult to deal with.

MSR systems typically utilize a wide variety of knowledge about the speech in use. Reddy[63] discusses *phonetics* (speech sound characteristics), *phonology* (variability in speech sounds), *prosodics* (speech stress, rhythm, tempo, pauses, and intonation patterns), *lexicon* (sound patterns of words), *syntax* (grammatical structure) *semantics* (meaning of words and sentences), and *pragmatics* (context of conversation). The possible variety of these features is at present too large for acceptably accurate MSR of unrestricted speech. This experience in the MSR arena indicates the difficulty of constructing algorithms suitable for analysis and testing of hypothesis in replicator dynamics of SME samples. This is not to say that there is nothing to gain, in fact SME analysis and theory is fascinating and more reflective of memetic content in the "mind" or brain. It is the difficulty and ambiguities involved that encourage postponement of this effort until a solid foundation for WME replicator dynamics is developed.

V.2 Zipf's Laws of Language.

Over half a century ago, George Zipf undertook a comprehensive examination of statistical regularities of language. Due to his encyclopedic treatment of many aspects of language, few people are aware of the key features of his two treatises "The Psycho-Biology of Language"[24] and "Human Behavior and the Principle of Least Effort"[41]. While many of Zipf's concepts ultimately require refinement, a set of his observations calls for restatement here.

According to Zipf (and borne by many statistical tests), word length and frequency of occurrence of words are closely related. In particular increased frequency of word use is correlated with shorter words (i.e. smaller letter counts). Zipf regarded word length as one of the most striking differentiating features. However, he did not ascribe the frequency of occurrence to word length. In his investigations he came across a good fit to the mathematical formula:

$$ab^2 = k \tag{9}$$

where a is the number of words of a given occurrence, b is the number of occurrences of these words and k is a constant. Zipf acknowledged this law to be valid for the less frequently occurring words, with the anticipation that this law would be applicable to 95% of the (different words) of any given sample.

After numerous empirical curve fittings to large amounts of textual material, Zipf enunciated what is now known as Zipf's Law [20,21,56,67]:

$$p(r) = \frac{A}{r} \tag{10}$$

where p(r) is the probability of occurrence of the r-th word in commonness and A is a constant (which for reasonably sized samples = 0.1). Mandelbrot[20,21] has shown that Zipf's law (eq. 10) can be derived from first principles. Mandelbrot shows that if one assumes that language is a finite Markov chain process (where after-effects of events have a short persistence time), the exact rank-frequency relationship emerges:

$$p(r) = P(B-1)V^{B-1}(r+V)^{-B} \tag{11}$$

where P, B and V are constants. One obtains equation 2 upon setting P = 0.1, V = 0 and B = 1. (An interesting aside that Mandelbrot points out is that Markov originated his stochastic approach to model linguistic processes).

V.3 Information Theory, Entropy, and Channel Capacity.

The concept of information and entropy in communication theory as introduced by Shannon[19,55,56,67] is not the same as the one utilized in thermodynamics and physics in general. Entropy in physics represents a measure of disorder. In association with physical processes entropy remains the same or increases (third low of thermodynamics), while in information exchange processes (e.g. communication) entropy decreases. Clearly there is a difference in the two constructs which requires clarification since both physical and information entropy are of use to us in this investigation. Brillouin devotes an entire book[56] to this topic. We adopt Brillouin's terminology here.

Negentropy is a measure which reveals the possibility of a system doing work. Typically a system which has constituents at different temperatures can be used to do work, and is said to contain a certain amount of negentropy. Negentropy (N) is related to physical entropy S by the relation N = -S. Typically, corresponding to an increase of Δq heat, the entropy in a system increases by

$$\Delta S = \Delta q / T \tag{12}$$

where T is the absolute temperature of the system (degrees Kelvin). Physical entropy S can also be interpreted statistically (as originated by Boltzman) in terms of the Boltzman formula:

$$S = k \ln \Omega \tag{13}$$

where k is Boltzman's constant (1.38×10^{-16} ergs per degree centigrade) and Ω is the number states the system can be in (given its constituent elements and its total energy). The form of equation 4 is rather similar to the form utilized in information-theoretic entropy, and it is directly the source of much confusion. The Shannon information entropy is in fact directly related to (and in some cases identical to) negentropy (-S).

Brillouin categorizes information into several kinds. Free information I_f occurs when the possible states of a message are abstract (e.g. in the mind of an observer) whereas bound information I_b occurs when it is related to physical manifestations. In this formalism, bound information is a special case of free information and it is bound information that is related to entropy (or negentropy). A typical example of Brillouin's definitions in our context is given below,

A. A person possesses information (free information).

B. He writes it down (bound information on paper)

C. He transmits it via a telefax machine (bound information, subject to coding/decoding and transmission errors).

D. Fax is received at destination and printed on paper (bound information).

E. Another person reads the fax (free information).

F. The reader forgets some information (loss of free information).

In this example there is an opportunity for loss of information at every step of the process with the best case being no loss of information; the steps where we are dealing with bound information can be connected with physical entropy. Note that there are a variety of physical mechanisms with which WME information can be obtained. Consider optical means (reading with eyes), Braille reading (mechanical), computer scanning and voicing of text (optical/electrical/acoustical), another person reading to us (optical/acoustic generation of speech). All these phenomena involve physical energy and entropy. Note, however, that entropy costs are low due to the minute value of Boltzman's constant. Thus, information exchanged physically can still take place and not impact macro-entropy directly.

A key information theoretic concept is that of channel capacity and limits on information transfer through a communication channel. Shannon and Weaver[40] conceive of an information communication system as composed of an information source (which generates a message), a transmitter (which sends a signal carrying the message), a communication channel (on which a noise source may act), a receiver (which receives a signal and translates it into a received message) and a destination. The message may be words, music, images, et cetera.

A channel is fundamentally characterized by the amount of information it can transmit per unit time. The key question in information and communication theory is what are the limits on information transfer for arbitrary (or specific) communication channels, with given noise sources and message generators. Using the definition of channel capacity as:

$$C = \lim_{T \to \infty} \frac{\log N(T)}{T} \qquad (14)$$

where N(T) is the number of messages of duration T, Shannon established the fundamental theorem for discrete noiseless channels, namely that given a symbol source of entropy H (bits per symbol) and a channel with a capacity C (bits per second), then:

i. It is possible to encode the output of the source in such a way as to transmit at the average rate of $C/H - \varepsilon$ symbols per second over this channel (with ε arbitrarily small).

ii. it is not possible to transmit at an average rate greater than C/H.

In the case of continuous information (messages) and communication channels, and in the presence of noise, the rate of binary digit transmission can be show to be governed by the following channel capacity:

$$C = W \log_2\left(1 + \frac{P}{N}\right) \qquad (15)$$

where W is the frequency bandwidth of the channel, P is average power used in transmitting the signal and N is the average (band limited white thermal) noise power. [Recall here the relevancy of the Nyquist sampling theorem that says that a band limited signal, with frequency range 0 to W, and duration T, can be completely specified by 2TW numbers].

With the aid of Shannon's theorems, one can revisit earlier made claims about efficiency of communication strategies which were concerned with the improved efficiency of optical and acoustical communication strategies. It is clear here that optical communication strategies are optimal for humans (and other biological organisms), if a large amount of information needs to be communicated (note, we are **not** discussing the **value** of information in this context). We take (conservatively) the lower limit to human audition as a frequency of 0 Hertz, and the upper limit as 31.5 kiloHertz (based on the upper limit specified in OSHA regulations), with ambient noise being characterized as 35 dBA for areas requiring extreme quiet, and 100 dBA as the maximum tolerable human acoustic input (which is already above safety limits). These numbers can be used to establish a maximum acoustic information channel input rate as 31500 $\log_2(1 + 100/35)$ per ear.

The corresponding optical limits can be constructed as follows: human visible range is approximately from 400 to 700 nanometers (violet to red). This corresponds to frequencies of 4.2-7.5 $\times 10^{14}$ Hertz, and a bandwidth of approximately 3.3 $\times 10^{14}$ Hertz. Even with marginal signal to noise performance, it is clear that the visual communication channel can support significantly higher information transfer rates over the acoustical. This by itself, is a clear reason why written/visual based systems are better than acoustically based systems, and why cultures based on optical systems will outperform and outdistance acoustically based systems.

V.4 L-memes, WME, Meaning and Knowledge.

In view of the foregoing discussion, it is clear that memes possess two key attributes. Accordingly, a more suitable definition for L-memes in the context of knowledge representation is:

Definition 2: A meme is an informational replicator whose principal attributes are pattern and meaning.

Definition 2 is a rather abstract definition of a meme. What is important to recognize here is that no dependencies are assumed or required on the physical media via which a meme is expressed or on which it is recorded. For example, consider the following string of letters in quotes "to be or not to be, that is the question". This meme [call it WS_1] can be understood when it is heard (acoustic encoding in air) or when read (material encoding in print and light / printed page interactions). The meme can reside in someone's neuronal circuitry, as a pattern of pits on a CD-ROM disk, or in magnetized domains on a floppy disk. Replication of the meme WS_1 occurs when we make a photocopy of a page containing it, or a copy of the diskette or file in which it resides, and when we recite it or read it into RAM. WS_1 is easily seen to be composed of the memes "to", "be", "or", "not", "that", "is", "the", and "question". Obviously these eight 'simple' memes are in some ways less profound than WS_1. However, they can still be regarded as memes (and in fact more successful memes than WS_1 since they get replicated more frequently).

It is now useful to embark on a strategy to investigate collections of simple memes. To do so we need to define the terms lexicon and dictionary. A **lexicon** is a collection of lexical words or lexemes. A **dictionary** is an ordered set of graphic words with **associated definitions**. The associated definitions are serially ordered collections of other graphic word entries in the dictionary. Dictionaries can be static (i.e. have a fixed number of entries for all times), or dynamic (new entries being added in order to improve dictionary and language efficiency). In WME, graphic words are ordered strings made up of the letters of the English alphabet {a,..,z} & {A,..,Z}, the Arabic numerals {0,..,9} and the elements of { - , ', 'space'}. If we designate the i-th dictionary entry (graphic word) as w_i, then an L-meme can be regarded as a particular ordered collection of graphic words which can be denoted by $M_n = \{w_{n1}\, w_{n2}\, w_{n3}\, w_{n4}\, ...w_{nm}\}$. The subscript n indicates the nth meme and the subscripts 1..m denote word order. The w_{nj}'s may be any of the dictionary entries. Other symbols may be defined using the basic WME graphic words.

We look now for directly measurable quantities on L-memes in WME. Some very basic metrics are word counts and letter counts. Denote by $WC(M_i)$ the word count of the meme M_i, and by $LC(w_{ik})$ the letter count of word w_{ik}. Consider now the meme M_i. The letter density [average number of letters per word of M_i] is:

$$\rho_L(M_i) = \frac{1}{WC(M_i)} \sum_{j=1}^{WC(M_i)} LC(w_{ij}). \quad (16)$$

One can calculate metrics on memes constructed from constituent memes. Consider the two memes M_r and M_s; one can construct a meme by concatenation, namely $M_t = M_r \oplus M_s$. The word counts add algebraically, i.e., $WC(M_t) = WC(M_r) + WC(M_s)$. With the aid of equation (16) it is provable that:

$$\rho_L(M_t) < \rho_L(M_r) + \rho_L(M_s). \quad (17)$$

It is useful to construct entropy measures on memes. The Shannon information entropy template, $H = -\Sigma$ {Probability} log {Probability} can be extended to memes by considering the probability of WME word occurrences. With the use of $P(w_{ij})$ as the probability of occurrence of word w_{ij}, the meme entropy is defined as:

$$H(M_i) = -\sum_{j=1}^{WC(M_i)} P(w_{ij}) \log(P(w_{ij})). \quad (18)$$

It can be easily shown then that meme entropies are additive, i.e., $H(M_t) = H(M_r) + H(M_s)$. The calculation of entropies of memes in KIPs forms a fruitful area of research. The probabilities of individual words depend on the frequency distribution of words in the total corpus of written records at the time the calculation takes place. As soon as new text is recorded, the total corpus expands, allowing shifts of frequency distributions, and consequently changing meme entropies. Thus even for a fixed meme the entropy of the meme can change in time. Furthermore, as new words are created, entropies can change as well. This is where the substantive and interesting aspects of memetics begin to manifest themselves.

The notion of ***meaning*** is very important and complicated. Ultimately, meaning must enter if we are to correctly describe memetic spread. Here, we only sketch the beginnings of a constructive working [not final] definition. To define meaning one starts with dictionaries. A *dictionary* $\mathcal{D}$(t) is a time dependent 'macro' L-meme. The particular ordering of the single word L-meme entries in $\mathcal{D}$(t) with associated definitions [composed of L-meme entries in $\mathcal{D}$(t)] is *the semantic network that embeds meaning in the particular connections of the associated definitions*. This is essentially an obvious statement of *consensus embedding of 'meaning'*. The difficulty of generally applying the concept of meaning lies in the fact that one has to search for 'meaning' in arbitrary L-memes, rather than in a codified [printed] single entry dictionary $\mathcal{D}$(t). An operational meaning of an arbitrary L-meme is obtained by decomposing the arbitrary meme into the smallest number of multi-word sub-memes and inducing a virtual dictionary on the sub-memes. The effective [operational] meaning is then the sequence of meaning imparted by the induced virtual dictionary.

It is this virtual dictionary aspect that poses the problem and the inherent diversities and mutations that can occur. The decomposition of a complex L-meme into constituent sub-memes is a contextually dependent constructive procedure that changes value when either a specific context embedding changes or when the dictionaries change. Additionally, the virtual dictionary is usually a purely mental, not a WME, construct which is not recorded anywhere (hence, no consensus procedures could be applied, nor would there be time or resources to document virtual dictionaries of all the KIPs interacting with the arbitrary L-meme chosen). When particularly useful complex L-memes recur, dictionary changes occur. These can be regarded as a meme-mutation to allow efficient [Huffman - like] encoding of long compound memes into single word or low word count memes. It can be seen that the entropies associated with new memes are lower than those of the definitions. Finally, it is clear that meanings are functions of the 'knowledge systems' that exercise their particular KIPs. Therefore, there is the high likelihood that different 'knowledge systems' will impart different meanings to the same [complex] L-memes.

While 'meaning' is difficult to define unambiguously, the notion of concept set is more reachable. The reason one wants to define concepts is that memes reproduce, in general, with a certain amount of mutation, yet they retain their meaning; in general cultural analysis one ultimately wishes to deal with the replication of general systems of belief or knowledge rather than be limited to specific instances. Thus, it is useful to **define the concept set S_i as the set of all memes $\{M_{ij}\}$ having the same meaning.** Furthermore, there is a particularly important L-meme in S_i called the underlying concept. **The underlying concept C_i is defined as the first, lowest complexity element of S_i.** A practical measure of complexity is the one of Traub et Al[67].

It is possible now to define structures called **theories**. Theories are constructed as ordered collections of concepts. A uniquely important theory is the ***ideal theory which is the ordered collection of underlying concepts, i.e.,*** $\Theta_{I,K} = \{UNDERLYING\_CONCEPTS_{I,K}\} = \{C_{I,K}\}$. Typical underlying concepts that would occur in ideal theories include: 1) rules of combining $C_{I,K}$, 2) dictionary definitions, 3) hypotheses and theorems, 4) axioms, and 5) auxiliary terms. Ultimately, theories (which are loose connections of concepts) evolve and combine to become ideal theories expressed in terms of underlying concepts.

V.5 Knowledge Systems, Knowledge Acquisition, Learning and Discovery.

It is clear that when there exist interactions or transactions between knowledge agents, a knowledge system is operative. A general knowledge system (KS) is a system composed of a memory subsystem, a knowledge acquisition subsystem, a knowledge processing subsystem and an input/output subsystem. These subsystems individually and collectively engage in KIPs and require knowledge representation (KR) capabilities. A knowledge system is usually a computer based electronic system or human based system [with one or more human agents]. Two principal mechanisms of knowledge acquisition by independent systems are learning and independent discovery. *Learning can be shown to be a particular case of meme-replicator spreading.* Discovery is characterized as application of KIP rules to knowledge entities already acquired by the knowledge system. A measure that characterizes a knowledge system is total knowledge. When two or more independent, dissimilar knowledge systems interact, total knowledge of the combined system can increase and be larger than the sum of the individual non-interacting systems. The only way for total knowledge to increase through interaction of two or more KSs is to have copying [read - replication] of knowledge between systems and knowledge combination (new meme construction). Reinforcement (i.e. copying of knowledge already present in both systems) is something that can and is usually accounted for. In KSs that allow for value-assessment, an L-meme that is reinforced by an objective KIP will usually have greater value. Advanced KSs may have rather developed mechanisms for discovery, in this case, there typically are built-in reward functions for construction of theories and ideal theories.

Computer viruses satisfy the conditions of being replicators. When regarded as symbolic codes, computer viruses also satisfy the condition of being electronic memes that can mutate in a way similar to general meme replicators. These electronic memes can then also be described by the equations expressing meme mutation and spread. Meme mutations are reflected in change of dimensionality of the meme phase space which is used for knowledge representation.

The L-memes discussed here started with an implicit assumption of 'atomic' or fundamental units. Combination of primitive memes yield complex memes. A sequence of increasing complexity memes is: sentences, paragraphs, chapters, books, libraries etc. With regard to computer oriented replicators, one can look at hierarchical levels of data record entries, records, databases, collection of databases, machine level instructions through high level languages and pseudo-codes. All these can be interpreted via the meme formalism.

In this context one needs to mention that the replication aspects of L-memes are precisely those that are required to formulate a basis of evolving artificial intelligence. The concepts of replicators and memes have been shown to be of high value in describing growth, mutation, and selection processes in biological and ecological systems. As interacting AI (Artificial Intelligence) systems become capable of learning from other systems along with the informational environment (in a non-trivial manner), the calculus of concept acquisition and knowledge acquisition will require the type of knowledge replication and spread calculus described here.

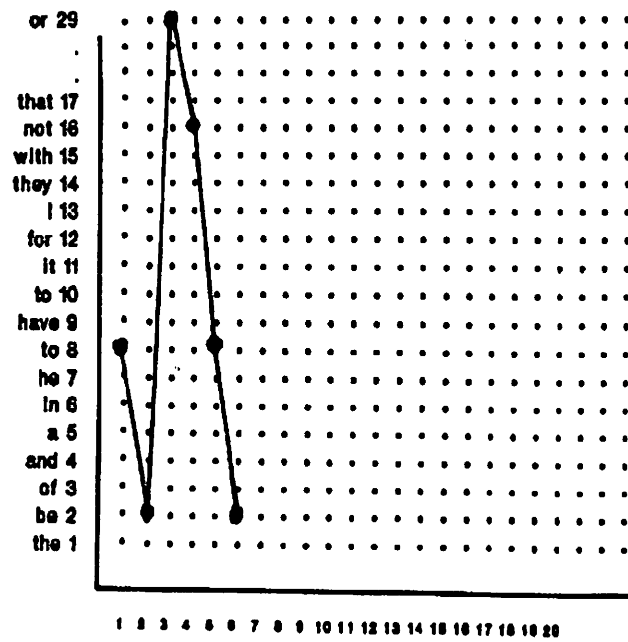

Figure 2 - Trajectory representation of the meme "to be or not to be". The ordinate entries are the rank ordered lemmas of the Brown Corpus, the abscissa entries are the meme [word] entries according to their sequential order of occurrence in the meme.

V.6 Memetic Phase Space.

One of the more powerful techniques for visualizing organization and development is the use of phase-space descriptions. In section V.4 the syntactic form for denoting a meme was introduced. In order to describe memes via the phase-space approach, a particular ordering of basic memes is required. We will initially adopt the word-ranking calculated by Francis and Kucera in their most recent re-analysis of the Brown Corpus [ref. 61]. The basic L-meme building blocks used will be the lemma (where, for example, 'be', 'am', 'are' and 'art' are different inflections of the lemma 'be', while the L-meme 'to' has two tags: the first one being a being an infinitive mark 'to_1'and the second 'to_2' being a preposition).

The ordinate axis of the memetic phase plane is constructed by enumerating the Francis-Kucera lemmas according to their ranked [adjusted] frequency of occurrence [in the Corpus]. Thus the null-lemma or null-meme is represented by the ordinate value 0; the lemma 'the' (which is the most frequent word in the Corpus [and in the English Language]) has rank 1 and ordinate value 1, etc. The abscissa denotes the serial location of occurrence of a particular lemma in an arbitrary L-meme. To illustrate the construction of a meme phase-space portrait, consider the L-meme 'to be or not to be'. The lemma 'to' appears in the first and fifth serial location of the meme, 'be' occurs in the second and sixth locations, etc. One could also use the syntactical description [8,2,29,16,8,2] to describe 'to be or not to be' unambiguously. The pictorial representation of 'to be or not to be' is given in figure 2.

A very interesting feature of describing L-memes via this phase-space approach is the immediacy of entropy/information calculation. By combining equation 18 and Zipf's Law (equation 10), and noticing that the ordinate value of the i-th lemma in an L-meme is the rank required as input into Zipf's Law, a Zipf-information measure can be calculated for arbitrary L-memes, namely:

$$H_z(M) = \sum_{j=1}^{wc(M)} \frac{A}{r} \log \frac{A}{r}. \qquad (19)$$

Thus, one has a directly calculable information measure. From this discussion one notices some interesting topics for future research, namely: i) the comparison of the Zipf-information to the true information value of a meme (which takes into account all WME in existence), and ii) the sampling based estimation of true WME entropies, given that in reality it is impossible to have access and summarize the totality of all written material in WME.

V.7 Memetic Hierarchies.

In closing this section on language based memes, one must mention that there are obviously hierarchies of memes. In the manner that one can regard hierarchies in biological organization and society, one has equivalent scales of hierarchies in memetic structures. Table 1 provides a summary hierarchy tabulation for four categories of entities and rough correspondences. In this context, we use L&W's[4] term euculture ".. advanced form of culture, in which individuals not only teach and learn information, but also conceptualize much of it into concrete entities that can be more readily labeled by symbols and handled by language."

We also introduce here the concepts of *trans-culture* and *Homo trans-sapiens* (or simply *trans-sapiens*). While being topics of a future paper, trans-culture can be described as the next step of culture dominated by deep connections, interactions, and relationships between objects created by large human/machine teams. A manifest property of trans-culture is the extreme and transcendent complexity of interactions and relations between humans and the cultural objects involved, with the additional property of being non-accessible to *Homo sapiens*. Examples of trans-cultural objects already exist; for example, there is no individual who (at any given temporal instance) is an expert in all aspects of medicine, or who is familiar with all biological species and their relationships, or is an expert in all aspects of physics, or who is totally familiar with all aspects of even a single cultural artifact (e.g. Hubble space telescope, Space Shuttle design, or the total design of a nuclear power plant). In fact, we are approaching the point that certain proofs of mathematical theorems are becoming too long and difficult for any one individual to keep in conscious awareness. In a way, these transcendent and extended complexity relationships are examples of more complicated 'meta-memes', which is one of the reasons it is interesting to study the evolution of ideas.

Ecological Sequence	Cultural Sequence	Homo Sequence	Memetic Sequence
atoms	no culture	*no human*	letters
molecules			morphemes
chains	proto culture	*proto human*	words
cells			parts of sentences
organs	culture	*Homo sapiens*	sentences
individuals			paragraphs
species	euculture		chapters
ecologies			books
grand ecologies			libraries
trans ecologies	trans-culture	*Homo trans-sapiens*	hypertexts, hypernets, electronic mega-databases

Table 1. Hierarchies in biological organization, cultural evolution, human evolution, and memetic complexity/organization. The correspondences are rough at this point.

Homo trans-sapiens is the [postulated] next step in evolution of homo sapiens. There is no reason to expect or require that *Homo sapiens* will not undergo further evolution. The bio-historical trend indicates that the major evolutionary development in *Homo* is in the cortico-neural arena (i.e. increasingly more complex organization of the nervous system and the brain). Specifically it is the higher level cognitive-KIP functions that set *H. sapiens* apart. It is asserted here (and to be discussed in a future paper) that *H. trans-sapiens* is a logical consequence of evolution, and that the milieu and adaptive epigenetic landscape for *H. trans-sapiens* is already present in the form of trans-culture. It is indeed possible that the basic mutations are in place and *trans-sapiens* already exists or will appear in the biologically-near time frame.

VI. Memetic Spread Equations.

Earlier, memes were argued to be a particular case of replicators. Basic replicator equations were discussed and a representative case of two species predator-prey was articulated (equation 7). Unfortunately, the previously discussed replicator equations [section IV and references 4, 12, 15-18, 28] are not sufficiently developed to yield practical results that support and extend the memetic core program (section V.1).

We assume that the context of discussion is that we have a large set (or population) of Knowledge Systems. If we denote by KS_i the i-th Knowledge System, and regard it as being composed of {Input/Output channels, Memory Store [that stores memes received through the I/O channels as well as memes generated internally, and also stores other internally or externally generated sense traces], and a Processor that executes knowledge/information processes [KIPs]}, we can pose the following quantitative questions regarding meme evolution and spread:

Q.1: Given that a meme M_i originates in Knowledge System KS_r, when does the meme M_i arrive at an arbitrary KS_t?

Q.2: Given a state configuration of all Knowledge Systems at time t (i.e., a detailed description of the memory store of all KSs), what is the state configuration of the KSs at some future time t'=t+ nδt (i.e. n time intervals later)?

Q.3: How many, and which KSs accept meme M_i as 'true'?

In order to answer these questions an interaction model is required. Reasonable starting points are the following *ansatzs*:

A.1: When two Knowledge Systems KS_i and KS_j are within some 'distance' d_{ij} from each other they will communicate (or interact) spontaneously at some time, with increasing probability as time goes on.

A.2: The relative probability that a particular meme M_k is communicated by KS_i depends on the internal complexity of the meme, its relative acceptance state, and the number of times KS_i received the meme.

A.3: Any meme or set of memes can undergo mutations and combinations. These mutations/combinations are internal KIPs of a Knowledge System.

A.1 is usually evident when the KSs are humans and the mode of interaction is speech (e.g., SME). For example, when two adult humans come within some threshold geometrical distance, the probability that they will interact will grow with time and increase with decreasing distance. A probability of interaction between KS_i and KS_j can thus be written as:

$$P_{I,ij} = C_I e^{-\alpha d_{ij}^{m1} / t^{m2}} . \qquad (20)$$

Here the parameters m1 and m2 need to be determined by dimensional analysis; C_I and α are constants. Note that at this time no particular assumption is made concerning the number of connections between Knowledge Systems, nor is any linear, planar, hyper-linear or hyper cubic assumption made. It will be useful later on to impose particular geometries, such as linear chains or Ising spin type models, to make actual calculations tractable.

One can express the relative probabilities referred to in A.2 using the partition function formalism of statistical mechanics. The relative probability of meme M_k being communicated can then be given as:

$$P_l = \frac{w_l e^{-H_l/kT}}{\sum_i w_i e^{-H_i/kT}} . \qquad (21)$$

where H_i incorporates a complexity metric and other energy costs, and the weighting factor w_i incorporates the relative acceptance state (accepted/believed, rejected as false, no judgement, etc.) and the number of times a particular Knowledge System has been exposed to the meme in question. The constant k is Boltzman's constant while T is a parameter that plays the role of temperature, and represents internal noise or fluctuations internal to and external to the Knowledge Systems.

A.3 is a general statement reflecting the evolutionary aspects underlying all of modern biological thought. Its practical application with respect to strings of symbols is manifested in Holland's development of theories of adaptation in natural and artificial systems and the particular implementations in the Genetic Algorithm techniques for solution of search problems [69].

Equations 20 and 21, and the realizations of suitable mutations are the elements required for proper meme spread equations. The author's paper "Memetic Science: II - Meme Spread Equations"[70], in the next issue of J of I, will present the next step in the development of these equations. There, the formalism of the Einstein A and B coefficients for deriving probabilities of spontaneous and stimulated transitions will also be utilized in the structuring of the memetic formalism. This approach will allow accounting for both learning (stimulated transition) and discovery (spontaneous transition) in terms of the metrics on memes discussed in section V.

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23