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Units, Events and Dynamics in Memetic Evolution

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Abstract

An evolutionary recursive replicator theory of mental/brain information is presented. With all replicator theories resting at least tacitly upon the fundamental notions of causation and of calling two or more entities "the same" with respect to an abstraction, the concept is rendered explicit in defining the terms "mnemon" and "meme". It is argued that memetics may have no "absolute" system of memory abstractions much as physics has no absolute coordinate system (framework of space-time abstractions). A symbolic calculus of mnemon conjugations and replication events is introduced. The term "meme" is given a technical definition, and reasons are offered for avoiding more expansive definitions. Arguments that meme sets are generally only partially ordered then

provide a formal reason for rejecting mnemon "size" as a crucial element in defining the word "meme". Differential equations are developed for meme host population versus time in a two-meme system, modeling the dynamics whereby events at the individual level give rise to trends at the population level. This lays a foundation for computerized simulations and the falsification or validation of specific memetic hypotheses, and for testing population memetics theory with animal experiments. As memetic hypotheses generally involve observable communication events, they are found to have stronger empirical standing than hypotheses involving unidentified genes. Mechanisms of creativity as a population phenomenon are examined, with memetic analysis yielding a novel explanation for the temporal clustering of independent co-creations. Creation and propagation are integrated into a theory of evolution by variation and natural selection of memes.

KEYWORDS: Meme, mnemon, evolution, replication, abstraction, transmissivity, receptivity, longevity, recursive algorithm, differential equation.

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1 Introduction

In the last chapter of his 1976 book *The Selfish Gene* [3], Richard Dawkins introduced the term "meme" for lay audiences as "a unit of cultural transmission or a unit of imitation". He went on to explain that this covers ideas, tunes, fashions, and other information stored in brains. In *The Extended Phenotype* [4] Dawkins more explicitly clarified that "a meme should be regarded as a unit of information residing in the brain"[1]. I have since taken this meaning of the word "meme" and refined it into a more technical definition suitable for symbolic and mathematical analysis [11]. In arguing that meme theory is not only sound but also broadly unifying, my book *Thought Contagion* [12] went on to use a great variety of non-technically presented examples to show the relevance of meme theory to important human phenomena. Yet the further development of strong theoretical treatments, formal definitions of terms, mathematical analyses, discussions of empirical methodology, and criteria for falsifiability remain subjects of interest among hard core scientists. This paper revisits the theoretical issues and the underlying philosophy of science, and elaborates on topics of empirical methodology and falsifiability.

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2 Non-Metaphoric Memetics

In memetics, organic evolution, biological contagions, plasmids, and computer viruses have served as metaphors for the spread of ideas. In principle, however, someone could have offered a treatise on the replication, proliferation, and evolution of ideas long before Darwin's work on evolution, Pasteur's work on microbiology, Mendel's work on genetics, or Turing's work on automata. Indeed, that treatise might even have afforded metaphors to these other disciplines had it appeared by the early 1800's. On this planet, though, the history of science has its social and information fields drawing metaphors from biology rather than the other way around.

Like all metaphors, the ones linking beliefs to organic and software contagions have their limitations. Metaphors make powerful literary and explanatory devices, and can render a potentially dry and abstruse subject interesting and readable. They also serve to spark important new scientific insights. But relying too heavily on them can lead to bad science. It makes sense, then, to recast the core concepts of memetics theory in language that does not depend on analogies to the biological or computer sciences. The analysis is drier, but it does formally illuminate some ways that memes depart from strict analogy to other replicators. It also provides some philosophy of science behind memetics theory while offering a stronger platform for mathematical and empirical investigations.

3 Units of Memory Replication

Defining the "unit of imitation" is as critical to memetic evolution theory as defining the units of heredity was to genetic evolution theory. The gene's definition developed as empirical investigations led away from the hypothesized inheritance of acquired characteristics to the biochemical sequencing of DNA strands. The universal code of these strands constituted a natural "language" upon which scientists based their own more symbolic and abstract language.

Yet for the evolution of ideas, no equally understood concrete language has been discovered. Science has achieved no direct observation of the neural encoding of ideas, which might have provided us a precise language for discussing ideas. Indeed, even if we knew in principle how to express the ideas of a single person in terms of neurons, synapses, etc., the description would likely be prohibitively complex. Moreover, as Dennett points out in *Darwin's Dangerous Idea* [5], it would be flabbergasting to find that the brain-cell complex that stores an idea in one person is the same as or very similar to the brain-cell complex that stores the idea in all who have that idea[2]. So instead of language based on a concrete mechanism of information storage, we must settle for an abstract representation of the information stored. Thus, memory abstractions form the basis for memetic evolution theory.

Most people use abstract representations of memory content on a daily basis to discuss ideas. When we say that two people have "the same" idea, we do not use "sameness" to mean equality in every concrete detail, or else we could never correctly say that two people have "the same" idea. As Dawkins [3] put it, "If this were not so, then almost any statement about two people agreeing with each other would be meaningless". What we mean by saying that two people have "the same" idea is that one person's idea has at very least one quality in common with the other's idea. Perceiving two people to have "the same" idea involves abstracting out a set of common qualities. So saying that two people's ideas are "the same" only means that they are in some way "of the same kind".

This ability to say that two people have the same idea lies at the foundation of the notion of a "replicating idea". When an idea "replicates", it acts to produce or preserve ideas that we call "the same idea". The resultant ideas can for now be called "self-replicated" ideas. To be a self-replicated idea means not only to have resulted from a given idea, but also to be "the same" as that idea. Specifically, it means meeting some abstract, observer-defined criterion for sameness.

Self-replicated ideas are not all exact replicas of their originals. A wide range of ideas may result from each self-propagating original. An observer just selectively lumps these proliferated ideas along with their original(s) into a set, using an abstract inclusion criterion.

As an example, the belief that "abortion is wrong" has a wide range of different meanings to different people. The range includes people who regard abortion as merely unethical to those who see the "morning after pill" as a high felony. So, although the belief varies greatly from person to person, its occurrences are all "the same" in the limited respect of fitting the above definition. Encountering a range of such beliefs in actual people, one "abstracts out" a common element running through all of them. On writing out a definition of this abstracted common element, or sameness criterion, one can proceed to use it for natural selection reasoning.

The abstraction could just as well be more general or more specific, depending upon our interests. A memeticist might, for instance, choose the more specific belief "abortion is a mortal sin". Then many quantitative variables involved in its natural selection would differ from those associated with the broader definition. First, the more restrictive definition would almost certainly identify a smaller host

population. Second, when the hosts communicate their belief to friends and family, a likely smaller fraction of listeners will become new hosts per exposure. This is because any listeners who go away newly convinced that abortion is merely unethical no longer count as new hosts. Becoming a host of the more restrictively defined belief takes more of what Dawkins [3] calls *copying fidelity*. Third, once a host, one may do less "ideological wavering" before being counted as a drop out. That is, remaining the host of a more restrictively defined belief takes more preservation fidelity. So changing an idea's definition can make a big difference in the evolutionary phenomena identified with it.

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4 Other Propagating Items

Many psychological phenomena other than ideas can be observed to self- replicate. These include certain habits, attitudes, class identities, cognitive associations, education, emotional dispositions, addictions, and even neurotic and psychotic symptoms.

All these traits may be broadly classified as human memory content. This category is more general than the word "idea" or even "memory" usually connote. It includes everything in the fairly broad meaning of "memory", as defined in Merriam Webster's Collegiate Dictionary, 10th edition: "the store of things learned and retained from an organism's activity or experience as evidenced by modification of structure or behavior or by recall and recognition". Thus, the principle abstractions manipulated with memetics theory are memory abstractions, or *mnemons*[3]. Mnemons do not include inanimate propagating items such as chain letters, Bibles, etc. Nor do they include traits considered genetically instinctual.

Using mnemons helps to standardize the measurement of propagation in terms of a host count. Thus, a chain letter or the copying machine duplicating it do not count as hosts, but the person photocopying the letter does. The relationship of artifacts to mnemons is discussed later.

If a mnemon resides very redundantly in someone's brain, that person still counts as only one host and one mnemon instantiation. The number of duplicates of a memory item in one brain is not currently measurable, so it escapes further treatment in this article.

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5 Representing Mnemons Symbolically

Mnemons can be represented conveniently with symbols such as "*A*", "*B*", etc. Thus, we can call the hell belief mnemon A, the imminent doomsday belief mnemon B, and a combination of mnemons such as the hell/imminent doomsday combination "*A*B*". The "*" indicates that *A* and *B* are instantiated in the same host. Extending this concept, one can represent a whole system of mnemons as "*A*B*C*..".

Symbolic expressions can also represent mnemon replication much the way chemists represent chemical reactions. Thus, the hell belief's non-parental conversion propagation may be represented as $A+{\sim}A \rightarrow 2A$. This expression is read as "Host of *A* together with a non-host of *A* yields two hosts of *A*". (The "~" indicates only non-host of *A* status, and does not of itself imply hostship of a contrary belief.) The two hosts on the arrow's right are the same two people as on the left side, one of whom is converted from non-host to host status. (The word "horizontal" may also be used, to describe this kind of non-parental event, as long as it is not taken to refer only to transmissions between people of similar social status.) The mnemons on the left side of the arrow are called the input mnemons, and those on the right, the output mnemons.

A transition such as $A+{\sim}A \rightarrow 2A$, realized in particular people at a particular time, constitutes an evolutionary event in the ideosphere[4]. Other evolutionary events include: $A \rightarrow {\sim}A$ (host of A drops out), ${\sim}A \rightarrow A$ (non- host independently forms A), $A \rightarrow 0A$ (host of A dies), and $2A \rightarrow 2A+{\sim}A$ (two hosts of A have a baby non-host of A).

Even multistage evolutionary events are handily represented by this system. For instance, the childbirth event can be extended to the form $2A \rightarrow 2A+{\sim}A \rightarrow 3A$. (Two hosts of A have a baby and then spread their A-mnemon to the child.) A more complicated possibility is $A+{\sim}A \rightarrow A+2{\sim}A \rightarrow 2A+{\sim}A$. (Host plus non-host of A have a baby who later adopts the A-mnemon from the A-host parent.)

Some multistage events are best represented by two or more diagrams. For example, if two hosts of A have a baby non-host and then have their local Sunday school teacher instill the A-mnemon in the child, one would represent it as two events: $2A \rightarrow 2A+{\sim}A$ (the birth) and $3A+{\sim}A \rightarrow 4A$ (the catechism). In the second event, the three input A-hosts are the teacher and the two parents (who select the teacher). Representing the events separately (instead of as $3A \rightarrow 3A+{\sim}A \rightarrow 4A$) conveys with greater clarity that the teacher's role happened only after the birth. Many two stage events pertain to the parental replication because that mode generally involves both having and training children.

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6 Complementary Mnemons

Treating ~A as a mnemon along with A may seem rather strange. People labeled "~A" may be called ~A-mnemon hosts or A-mnemon non-hosts. (A and ~A are called complements of each other.) But can a person's lack of the A-mnemon justifiably be called a mnemon itself? It sounds like saying that nothing is something.

The meaning of the term "mnemon" provides an answer to this question. Mnemons are merely memory abstractions. As such, a negatively defined mnemon which only states what a person does not have is just as much of a memory abstraction as is a positively defined mnemon. Saying that someone "has" or "hosts" a mnemon like ~A, really means that the person satisfies the definition of the particular memory abstraction (i.e., the person instantiates the abstraction). This is what we mean when we say that a person "hosts" a positively defined mnemon. The only difference is that the term "memory" is expanded in a way that somewhat resembles its usage in computer science: it now includes some (partly) "empty memory" states that are not *specifically* determined by genetically based instinct.

Negatively defined mnemons can also self-propagate, as with the childbirth event $2{\sim}A \rightarrow 3{\sim}A$, where A is a knowledge-of-birth-control mnemon. (One might define this mnemon functionally as knowing how to use at least one of some particular list of methods.) Because ~A-hosts have fewer birth control options than do A-hosts, the ~A-mnemon enjoys a greater quantity-parental replication advantage. Nonetheless, the A-mnemon has done very well in modern times, largely since people can be taught about birth control far more easily than they can be made to forget about it. Since proselytizing it is impossible, the ~A mnemon depends on parental events that occur just a few times per generation. The A-mnemon, on the other hand, proliferates by non-parental conversion for various reasons, including both the sexual and humanitarian motives of its hosts. So both A and ~A self-propagate, leaving us no choice but to consider the propagation of both a positively defined mnemon and a negatively defined mnemon in investigating this example.

Incidentally, ~A's parental propagation does not conform to the tendency, mentioned earlier, for the parental replication mode to involve multistage evolutionary events. People are born with ~A, so that giving birth and "imparting" the mnemon are actually the same event. After birth, the parents can at most

act to preserve ~*A* in their child.

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7 Mnemon Combinations

Multi-mnemon events describe phenomena ▭ like idea alteration or recombination ▭ too complex to represent with one complementary mnemon pair alone. For example, forming the hell/imminent doomsday pair by recombination can be represented as *A**~*B*+~*A***B*▭*A**~*B*+*A***B*, where *A* = the hell mnemon and *B* = "doomsday is imminent". In this event, a person with only the A-mnemon spreads it to someone with only *B*, so that the latter person now has both *A* and *B*. This new combination may very well spark some new ideas in the *A***B*-host. He might experience the event *A***B**~*C*▭*A***B***C*, where *C* is the belief that "I must urgently spread my faith to others because it may soon be too late!" Consequently, he may repeatedly play the leading role in the event *A***B***C*+~*A**~*B**~*C*▭2*A***B***C*. *A*, *B*, and *C* act cooperatively here to bring about their collective propagation.

Mnemons *A*, *B*, and *C* are all rather "unpleasant" ideas, so it does not seem too surprising to find them propagating cooperatively. Yet in the real world, these three propagate cooperatively with a very "pleasant" mnemon *D*: "Love your neighbor as yourself". *A***B***C**~*D* motivates its hosts to spread their faith only to those "unbelievers" that they really care to see saved from hell. In marked contrast, *A***B***C***D* hosts should be motivated to spread their faith to any unbelievers they should happen to meet. So the combination of mnemons probably spreads more vigorously due to the inclusion of the *D*-mnemon.

When mnemons propagate synergistically as do *A*, *B*, *C*, and *D*, they may propagate primarily as a set rather than individually. In such cases, the set may be usefully defined as one mnemon. Thus, one might define *E*=*A***B***C***D* and consider *E* to be a stable, propagating mnemon in its own right. This approach can sometimes be used to study very large ideological systems, such as religious and political doctrines, by treating them as single (but lengthily defined) memory abstractions. The propagation events, however, often contain many intricate stages.

Moreover, in specifying mnemon "*X*" by an equation like *X*=*A***B***C**..., one runs the risk of specifying so many "little" constituent mnemons that no one person ever actually has all of them. Mnemon *X* would then be a useless abstraction. This symbolic method allows its own hosts enormous freedom to specify their preferred abstractions, yet writing down symbols does not guarantee all those abstractions to be useful in studying the real world.

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8 Competing Mnemons

Competition rather than cooperation characterizes many interacting mnemons. A mnemon competes against its complement in the knowledge-of- birth-control case mentioned above. The two complementary mnemons ▭ each "armed" with distinct replication advantages ▭ "struggle" for host population.

Yet more heated than this competition ▭ at least in some nations ▭ is the competition between moral stances on the subject. Personal morality, after all, has a greater bearing on an adult's use or non-use of various methods in a society where birth control information is highly available. Moreover, morality strongly influences the parental decision to actively instruct children on birth control or to actively obstruct their learning on the subject.

So in addition to the knowledge-of-birth-control mnemon (mnemon *A*), we should also consider mnemon *B*, the moral acceptance of practicing birth control, and mnemon *C*, the belief that birth control is immoral. Here people are born with the *~A*~B*~C* combination, but they never end up simultaneously having *B* and *C* later on. This is because *B* and *C* are *contrary*, as distinct from complementary mnemons. Since they are mutually exclusive, they are destined to have a competitive rather than a cooperative relationship in the population. The *B* mnemon is favored by a high occurrence of the non-parental conversion event *B+~B→2B*, while *C* is favored by a high rate of the parental event *2C→2C+~C→3C*. *B* benefits spreads due to the same kind of sexual and humanitarian motives for spreading it as those shown by the *A* mnemon. *C* spreads "parentally" because people who believe that birth control is immoral do tend to have more children. Economic motives for spreading and adopting the two mnemons also exist, and vary among situations. Additionally, the drop out rate of children raised as *C*-hosts varies with population homogeneity, media exposure to *B*, etc.

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9 Homogenic and Heterogenic Events

The birth control example as treated so far fails to acknowledge people's ability to independently invent or re-invent moral decisions on their own. People are portrayed as acquiring mnemons only by copying them from others or by being born with them (as in the case of negatively defined mnemons).

To remedy this omission, consider the cases of two students who learn about birth control methods and then make moral judgments based on what they have learned. The first decides the practice is morally acceptable (*A*~B→A*B*). The second decides it is not (*A*~C→A*C*). Of course, people can make moral judgments without knowing birth control methods, but in this case our two hypothetical students judged only upon gaining the knowledge.

So one mnemon precipitates the formation of another mnemon, instead of just a new copy of itself. Mnemons that do this are called *heterogenic*, or "other-forming". The corresponding events, such as *A*~B→A*B*, are called *heterogenic events*. The other type of event, which produces copies of input mnemons, is appropriately called a *homogenic*, or "same-forming" event. The input mnemon that gets copied is called a *homogenic mnemon*.

Mnemon event diagrams and terminology now acknowledge that people can form opinions without simply copying others' ideas. Yet on many topics, people copy more ideas than they either originate or "re- originate". For many beliefs, such as the birth control taboo, homogenic formation far outweighs heterogenic formation in its overall occurrence rate. The reason is that homogenic events have the tendency toward self iteration while heterogenic events do not. Generally speaking, anything that increases the availability of the input mnemons will increase the expected frequency of the event. Homogenic events, such as *2A→2A+~A→3A*, increase their own input mnemons. So they often tend to increase their own likelihood of recurring. When they do, they exhibit the *recursion principle*, which can lead to vast increases in mnemon prevalence.

In contrast, heterogenic events, such as *A*~B→A*B*, actually decrease their own input mnemons by one with each occurrence. This tends to decrease the heterogenic event's recurrence rate. Yet the independent thinker can pass the new, *heteroderivative* mnemon along, resulting in homogenically formed, or *homoderivative* mnemons. So after the first few heterogenic formations of the birth control taboo, the formation of new taboo hosts tends to become rapidly predominated by recursive, homogenic events.

One mnemon whose host population accumulates many members through both homogenesis and heterogenesis is the belief that "It is best not to go to church on Sunday". Many of its hosts received it

(homogenically) from parents or friends who already had the idea. This makes their mnemons homoderivative.

However, many people got the idea because as children their parents made them go to church every Sunday, even when they did not feel like going. The resulting aversive experiences often lead the children to conclude that it is best not to go to church on Sunday. Ironically, their belief results from their parents' strict adherence to exactly the opposite belief. The pro-churchgoing mnemon influences some parents to generate something radically different in some of their children. So those parents' mnemon is heterogenic while the children's mnemon is heteroderivative. Any parent who raises some children to be church going and some to be church avoiding has a churchgoing mnemon that is both homogenic and heterogenic.

The concepts of replicator evolution and epidemiology directly pertain only to the homoderivative sector of a mnemon's host population. In this sector, we can properly refer to mnemons as the "units of imitation" discussed by Dawkins. This allows a very restricted denotation in which a meme is *defined* as a *homoderivative mnemon*. The definition of a particular meme contains an abstract sameness criterion like the ones defining mnemons, but also includes a criterion of causality, namely, that it is homoderivative. So each meme has a corresponding mnemon: the memory abstraction defined without reference to homoderivative causation.

Although the church-avoiding mnemon does not occur primarily as a meme, one can still understand its proliferation in terms of memes. Simply divide the hosts into two groups: hosts of the church avoiding meme and dropouts of the church going meme (meme and meme-derived mnemon hosts). The first group can be studied directly as meme hosts. The second group's growth rate can be studied as a function of the church-going meme frequency. So the study of meme proliferation can be valuable to understanding the growth or decline of both of these constituent groups, whose combined numbers include nearly all the church-avoiding host population.

Some mnemons are neither memes nor meme-derived in most of their instances. For these mnemons, the study of meme proliferation is of little use. Consider what happens when an earthquake of harmless but noticeable intensity strikes Los Angeles. Millions of people suddenly have the idea that an earthquake has struck on that particular day. So at first the host population does not result primarily from mnemon copying. In fact, the people who directly experience the quake may remain a majority of the idea's hosts, especially if the quake is too mild to get much news coverage. Replicator theory has extremely limited relevance in studying this kind of host population growth. The theory best applies to the limited but still vast realm of memes and meme-derived mnemons, i.e., the realm of memetics.

The ability to unambiguously identify mnemons as homoderivative now becomes crucial to memetic theory. For instance, when someone receives the hell mnemon from one person and the imminent doomsday mnemon from another, is the resulting *A*B* combination homoderivative or heteroderivative? The *A*B* host has copied both mnemons from pre-existing hosts. But the event that actually forms *A*B*, namely *~A*B+A*~B*→*~A*B+A*B*, does not actually contain *A*B* as an input mnemon. The mnemon appears not to be distinctly homoderivative or heteroderivative, a problem in deciding how to proceed.

The problem can be resolved by recalling that mnemons propagate only with respect to an abstraction. Although the *A*B* host is homoderivative with respect to abstraction A, and homoderivative with respect to abstraction *B*, the instance of *A*B* is clearly heteroderivative with respect to abstraction *A*B*. So *A*B* formed by the event *~A*B+A*~B*→*~A*B+A*B* is not a meme, although it is meme-derived.

Yet as mentioned earlier, *A*B* can also propagate as a set by the non-parental conversion event *A*B+~A*~B*→*2A*B*. Formed this way, *A*B* is a meme. Thus, the host population of *A*B* is yet another

mixture of memes and meme-derived mnemons.

Disingenuous propagation raises similar questions. Consider the following mnemons:

> Mnemon *P* is the *belief* that "bee pollen invigorates".
> Mnemon *Q* is *awareness* of the "bee pollen invigorates" proposition.
> Mnemon *R* is the belief that "it is profitable for bee pollen merchants to tell customers that bee pollen invigorates".

If a merchant holds the *~P*Q*R* combination, then a disingenuous propagation event might then be represented as

*~P*Q*R+~P*~Q*~R**~P*Q*R+~P*Q*R**~P*Q*R+P*Q*R*.

This event clearly involves replication with respect to the awareness meme Q, and the profitability meme *R*. Yet this event alone is not homogenic with respect to *P*, because the merchant is a non-host of *P*. Still, there is a mechanism of indirect replication in this case. If the *P*Q*R* host goes on to pay the merchant, it helps preserve the meme *R* in the merchant and also pays helps pay the bills that the merchant needs paid in order to continue instilling *P*Q* in new hosts. This form of recursion is already recognized in such fields as marketing science and consumer education, and hence is not a distinctly memetic insight. Also, the actual profitability of transmitting *P*Q* involves numerous business and marketing science considerations, such as how many people are persuadable, how much they are willing to spend, how much the bee pollen costs to produce and distribute, etc. Understanding the disingenuous spread of *P*Q*R* is largely covered by older disciplines, so the propagation event here serves mainly to illustrate how it is diagrammed and in what sense it can involve replication of *P*. Note that the event *~P*Q*R+~P*~Q*~R*  *2~P*Q*R* may also happen recursively when bee pollen is incorporated into multi-level marketing schemes.

Simple non-commercial lies also qualify as events in which the transmitting party holds an awareness of a proposition but not the belief in that proposition. If the lie is believed by the recipient, it would take the form *~S*T+~S*~T**~S*T+~S*T**~S*T+S*T*, where *S* is the belief in a given statement and *T* is mere awareness of it as a proposition. There may be reasons for the *~S*T* host to repeat the lie many times to many people, and of course the new *S*T* hosts may have reasons for honest retransmission as well (by events such as *S*T+~S*~T*  *S*T*).

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10 *Meme*, Concisely Defined

Defining the word meme concisely but technically without reference to the other neologisms, we have:

> *MEME*
> > *A memory item, or portion of an organism's neurally-stored information, identified using the abstraction system of the observer, whose instantiation depended critically on causation by prior instantiation of the same memory item in one or more other organisms' nervous systems. ("Sameness" of memory items is determined with respect to the above-mentioned abstraction system of the observer.)*

The causation of a new instantiation can happen by a great many routes. The role a meme plays in causing a new instantiation can seem rather passive, as when parents spend days trying to decide which meme they will use for naming a newborn. Or the meme can play a strong role in manipulating host's communication behaviors toward retransmission, as when the idea of astrological compatibility

motivates believers to retransmit to all potential mates. The latter kind of meme qualifies for the more restrictive term *thought contagion*.

Although my meme definition refines Dawkins's original informal definition, it still covers a vast range of phenomena. There are, however, those who want the term "meme" to refer to all sorts of cultural phenomena that might be regarded as replicators. Yet this can lead to great confusion, especially over how to measure the extent of propagation.

Still, one can study either a chain letter (non-meme) or the thought propagated by the chain letter (a meme) as replicators. Artifacts and numerous other cultural phenomena might be investigated as instantiations of informational replicators, yet they are not memes by the above definition[5]. The above definition does not have memes "residing" in anything but an organism's nervous system, though it might be generalized to include artificial minds.

Yet clothing zippers, co-dependencies, chain letters, groups, behaviors, institutions, entire societies, and numerous other social or cultural phenomena have been discussed using various kinds of replicator and vehicle models. The strength of the replicator concept varies across such a wide range of phenomena. Yet Pocklington and Best [1, 14], for instance, have published good evidence of culturally replicating information in the medium of usenet postings. They quantify instantiation in terms of distinct postings rather than copies downloaded, messages read by people, or mnemons retained by people. The distinctions between postings and human hosts matter, especially because people on the usenet often create new copies of material with which they *disagree* by clicking the "post reply" button in their Internet software. Usenet postings would qualify as *meme relics*, or from Dawkins [4] *meme phenotypes*, or even *text contagions*, but not *memes* under the above definition. They are valuable indirect evidence of memetic replicators, much as sea shells washed ashore are valuable evidence of reproducing organisms in the water.

When viewed as replicators, most artifacts involve brains at some point in the causal pathway to forming new "copies". A computer virus, however, can be seen as an artifactual replicator that usually spreads from machine to machine (or disk to disk, etc.) without being hosted by a new brain for every replication. The instantiations of the computer virus are not memes, but the algorithm of the virus can be a meme: the prankster who initially wrote the code may find his code being learned and copied by other pranksters. We thus have artifactual and brain-stored replicators.

Similarly, one can investigate the role an enzyme plays in causing new instantiations of "the same" enzyme in one or many cells. The investigation will, of course, always find that nucleic acids play a crucial ("central") role in causing new "copies" of the enzyme a fact that makes it not scientifically *necessary* to treat ordinary enzymes as replicators. But the enzyme can still be viewed as a very indirect, multistage replicator. Cytochrome C, for instance, helps produce ATP that in turn helps produce new "copies" of cytochrome C. Yet much as one does not say that a protein enzyme is or contains a "gene", so too do I not say that an artifact is or contains a "meme". Still, an artifact can function as a medium of communicating knowledge of how to make new copies of "the same" artifact, and this difference from the role of proteins in biology suggests that there should not be a "central dogma" in memetics. It is a situation that Dawkins [4] notes in his remark that "there may be 'Lamarckian' causal arrows leading from phenotype to replicator"[6].

A more general term than *meme* might nevertheless help clarify these distinctions and provide a way of discussing other kinds of cultural replicators. Noting that biologists took the word *code* and invented *codon*, we can take the word *replicate* and coin the word *replicon*. The adjectival form is then *repliconic*. The associated discipline name would be *repliconics*. Its central theory would be the generalized evolutionary replicator theory or just generalized replicator theory. The subfield dealing with culture

would be *cultural repliconics*. Text contagion theory, computer virology, and memetics would be some of the sub-subfields.

The various preliminary distinctions that go into defining the "meme" may appear to be another example of how memetics departs from analogy to genetics. Yet chemistry also has many distinctions that place nucleic acids in a very small subclass. Molecules can be catalysts or not. They can also be autocatalysts or heterocatalysts. The early oceans may have contained oligonucleotides formed by polymerization of smaller components. Some would have formed by non-autocatalytic polymerization, even in outer space. But if any did behave autocatalytically, they would have proliferated into predominance. They would have been a subclass of molecules generally, much as memes are a special subclass of memory items. The "new replicators" that Dawkins introduced are in an environment with similar non-replicators, much as the earliest biomolecules were.

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11 Stemming the Tide of Expanded Definitions

Because Dawkins never offered an explicitly formal definition of the word *meme*, a great many writers have taken the liberty of expanding its meaning to include nearly any social or informational phenomena they wished to see treated with seemingly the same clarity and precision found in a molecular genetics lab. Taking this to extremes, some have said that since "the meme" is just propagating information without regard to medium, that even genes are just a special case of memes. One writer even posted to the Internet that memetics was the science of information in all sectors of the universe. Another sees "proto-memes" in the infinitesimally early stages of the Big Bang. There are even writers who insist that memes can be instantiated only in artifacts, never in brains. The problem is that if the word *meme* means just about whatever a writer wants it to mean, then it means practically nothing at all. The resulting bedlam has lead some critics to issue blanket indictments against all of memetics, insisting that memeticists have not clearly defined their subject matter. These are generally people who have not yet read a formal and more restrictive definition.

Still, some expansions of Dawkins's original usage need to be addressed carefully. Among these is the expansion offered by Dennett, in which a "meme" can be instantiated by a wide range of "meme vehicles" other than brain-based or artificial minds. Thus, a "meme" for spoked wagon wheels is instantiated not only in the brain of the carpenter building it, but also in the finished wheel itself. The wheel does, after all, contain information that a new carpenter can use to copy the wheel. This departs from Dawkins's usage, in which the meme resides only inside the brain and an artifact such as a wheel would presumably be part of its extended phenotype.

Dennett does, however, correctly recognize the wheel as an artifactual medium of communication. This can seem synonymous with the phrase "vehicle of communication", a connection that tempts us to consider the wheel as a meme vehicle and a locus of meme instantiation. Dennett recognizes moreover that communication by artifact is not always intended, as when the enemies of those traveling by spoked wheel copied the visible and mobile artifact for their own benefit. The actual communication event generally involves more than just a stray wheel resting in a field, but includes a human being demonstrating its usefulness by riding around with two or more wheels, an axle, a horse, and the rest of the wagon.

Expanding the term "meme" in Dennett's manner has a further appeal, in that it seems to offer a continuous chain of material substrates from one instantiation to the next. Yet when a carpenter builds a wheel from memory, there is actually no instantiating medium in between the brain and the finished wheel. So any worry about instantiation gaps applies for both definitions. That worry is unfounded

anyway, because an instantiation gap does not imply any gap in physical causation. An instantiation gap exists between one autocatalyst molecule and the next, too, as various intermediates are formed and the initial molecule always has at least a tiny physical separation from the new copy. Likewise for a spreading computer virus, where the cable connecting one computer to the next is often too short (and transfer rate too slow) to contain an entire copy of the viral software: a long physical gap may exist between one instantiation of the virus and the next. Yet Dennett's examples show that useful insights are gained by treating artifactual information as replicators, and it is for just such cases that I offer the term *cultural repliconics*.

A more serious problem with allowing for all sorts of "meme vehicles" as meme instantiation loci is that it tends to confuse the measurement of propagation. Even when the "vehicles" are discrete, there are questions of whether they should all be enumerated equally. Copies of an old advertising logo may still exist in landfills a century after the product disappeared. The fact that the human host population of a meme is zero certainly temps us to call the meme extinct, even if it can be brought back from extinction by an inter-century communication event to some future excavator. And if supernova radiation from a few light-years away leaves an earth full of unused artifacts until the Sun's demise, we would tend to say that the memes went extinct with the end of humanity rather than with the end of the planet.

The problems of enumerating the instantiations become even murkier with non-discrete "meme vehicles". How many copies of the distress signal from the Titanic now exist at a radius of 86 light-years? What about a still local message crammed into a 300 kilometer thick (1 millisecond) burst of microwaves from a satellite? In such cases we tend not to enumerate the theoretically feasible number of receptions of the message as "memes", but instead only those which actually *are* decoded and stored in minds.

The consideration of replicating cultural phenomena not instantiated by any single mind has led to interesting and worthwhile insights. Yet sayings such as "a scholar is just a library's way of making another library [7] bring on questions of whether even Dennett is trying to pack too many possible meanings into the one word "meme". Scientists reading these statements often get the impression that while "cute", it is not specific enough to be part of a real science. Not surprisingly, Dennett himself, after venturing down this road filled with every variety of "meme vehicle", ends up questioning whether there can be a science of memetics at all and answering in a doubtful voice[8]. The challenges of developing a unified replicator theory for so many kinds of vehicles are perhaps big enough to become terrifying. Better, in my view, to consider the scientific merits of a more restrictively defined "memetics" and take up the question of other classes of cultural replicators separately.

The substrate-specific definition of "meme" stands in some contrast to the apparent substrate neutrality of the term "software". Yet this is actually a result of the many kinds of artifacts that serve as computer "memory". The term "software" does not really refer to information in *any* medium. Suppose a robot using Cartesian coordinates builds a screw. A different model of robot using polar coordinates analyzes the screw and builds copies using completely different measuring units, and digitizing in finer detail. We do not say that the screw contains the "software" for making screws, or any kind of "data" or "software", even though it does contain replicating information. So the word "software" is actually medium-specific, but only with respect to an ever-expanding *class* of information media. The screw can, however, be viewed as a *software relic* much as the spoked wheel can be viewed as a meme relic. Both can also be viewed as instantiations of generalized (non-meme) information replicators. In this latter perspective, a robot is the screw's way of making another screw and a carpenter is the wheel's way of making a new wheel. It is a repliconic perspective that has some of the flavor of memetics even though memes as I define them are not the direct topic of discussion.

In biology, the term "gene" has progressed toward more specific and technical definitions. Scientists have

not attempted to expand its meaning to include the information stored in all sorts of vehicles, even though many types of vehicles contain biological information. Even other replicating entities such as prions are not considered to be or contain instantiations of genes. And we certainly do not see anyone attempting to expand the term "gene" to include information in all sectors of the universe. In order to be taken seriously in science, the term "meme" needs to be refined toward greater, not lesser, specificity than its original usage. The definition I offer is more formal and specific than what Dawkins presented in 1976 [3], yet it still covers the vast territory that he intended.

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12 Meme Sizes

Some efforts have been made to incorporate the idea of "size" into the definition of the word *meme*. This includes those who favor the "smallest" possible units, as well as those who favor the "largest" possible units. Unlike those who expand the definition of *meme*, these scientists are indeed looking for ways to render the meaning more specific. Yet not all attempts at specificity are equally useful in the study of real phenomena.

Size is a fairly easy thing to measure for segments of DNA or their corresponding proteins, as well as for pieces of text. However, the concept of "size" becomes troublesome with beliefs and other information stored in the brain: general methods of "size" measurement are not currently available, and even if they were, they might register different "sizes" for "the same" belief in different brains. The most we can really say is that a set of memes is, in general, a partially ordered set (as defined in set theory). One rather arbitrary system of partial ordering is based on the size of conjunctions of the mnemons identified by a particular abstraction system. Take the mnemons expressed by the following 3 statements, for instance:

> Mnemon A: "There is only one true God".
> Mnemon B: "Christ is Lord".
> Mnemon C: "Unbelievers are damned".
> Mnemon D: "Earthly life is better among believers".

We have no basis for saying if $A>B$, $A<C$, etc.

We can say $A*B>A$, and $A*B>$B.

But you cannot say $A*B>C$ or $A*B<B*C$, etc.

We can, however, say $A*B*C>A*B$, $A*B*C>A*C$, etc.

In other words, if the hypothetical faith only says "There is only one true God", and "Christ is Lord", we cannot, for instance, say that it is "bigger" (has more "size") than the faith that only says "Christ is Lord" and "Unbelievers are damned". Nor can we compare the "sizes" of these component beliefs. Moreover, completely unordered sets such as $S=\{A*B*C, A*B*D, A*C*D, B*C*D\}$ demonstrate clearly that size cannot be a universal criterion in defining which mnemons are memes.

Mnemon size can, however, become an empirical consideration when studying the special case of a fully ordered set of mnemons, such as $S'=\{A, A*B, A*B*C, A*B*C*D\}$. We might find that element A does not induce much replication. Then we might find that $A*B$ induces more replication, but that $A*B*C$ induces still more. Yet we may also find that $A*B*C*D$ achieves less replication, perhaps by requiring too much information transfer to happen reliably. One can still decide based on this to choose $A*B*C$ as the main subject of investigation without requiring size to be a criterion in the definition of all memes. Since A may have propagated long before the first occurrence of $A*B$, and $A*B$ long before A$*B*C$, it is

important to be able to consider all the elements of set *S′* as memes.

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13 Massively Cooperative Propagation

Though religious meme sets such as those above spread by inducing a wide variety of one-to-one transmission events, some can also induce events involving large numbers of participants. In multistage events, there can also be large numbers of participants in some stages and few in others. Thus, (retaining the symbol meanings of the preceding paragraph) an individual might spread *A*B*C* through the event *A*B*C*D+~A*~B*~C*~D*→*A*B*C*D+A*B*C*~D*. But then it may take the 1000 other believers in a community to achieve the next event: *1000A*B*C*D+A*B*C*~D*→*1001A*B*C*D*.

Now consider what happens when adding a few more memes:

Meme E: "Love your neighbor as yourself"

Meme F: "The Spirit lives in the community of believers"

Meme G: "Church X is God's Church".

As I noted in *Thought Contagion* [12], memes which cause greater cooperation among their own hosts can thereby achieve propagation advantages by raising prosperity and suppressing the sort of personal conflicts that may lead to dropouts. The "love your neighbor" meme *E* even motivates more one-on-one evangelism in some settings while promoting collective meme propagation in other settings. The meme expands the range of unbelievers that adherents wish to save from damnation: instead of just wanting to "save" a few friends and relatives, they want to "save" even strangers. Yet the meme also works in many ways to improve *community* life among believers, an effect I discussed in *Thought Contagion* [12] and Stark documents for early Christians in *The Rise of Christianity* [16]. So when an individual Christian attempts to spread memes *A* through *G* to a pagan, the pagan may well remain unconvinced. Yet the pagan realizes that meme *D* is testable merely by spending some time among believers, and without waiting for an afterlife. In ancient times, they would have found a Christian community thriving from cooperation, and taking better care of each other's misfortunes than did the pagans. That would have impressed them that at least the meme *D* part of the Christian message was true. This in turn would have made it cognitively easier to believe the "Spirit" meme *F*, and the "Spirit" meme F would make it easier to believe the "God's Church" meme *G*. Finally, that would make it easier to believe other Christian memes such as memes *A*, *B*, and *C*.

In addition to these cooperative conversion effects, a community can also achieve greater rates of preventing the dropout event *A*B*C*D*E*F*G*→*~(A*B*C*D*E*F*G)* and the mortality event *A*B*C*D*E*F*G*→*0(A*B*C*D*E*F*G)*. The community role in dropout prevention would result in part from conformity pressure, and in part providing social, emotional, material, and health care benefits. It would augment such dropout prevention effects as the threat of hellfire discussed by Dawkins [3], and the efforts of individuals to shore up the faith of anyone expressing renewed doubts. The mortality prevention effect, resulting from such things as the community feeding the poor and nursing the sick, is documented by Rodney Stark in *The Rise of Christianity* [16].

For some memes, the effect on rates of cooperative propagation is particularly striking. With Hutterites (denoted here with meme symbol *H*), for instance, we observe many events of the form *2H*→*2H+~H* (Two Hutterites have a baby non-Hutterite), followed by an event such as *20H+~H*→*21H* (Twenty Hutterite adults impart the faith to the child). Then we see events such as *165H*→*83H+82H* (One

Hutterite colony of 165 splits into two colonies of 83 and 82)[9]. Crucial to setting the rate of this event, however, are the family structure memes that raise childbirth rates to 10 per couple while keeping the (permanent) parent to child inculcation rate above 90 percent. A distinctly Hutterite meme distributing the chores and costs of child raising among the whole colony's adults probably plays a strong role here, as it dilutes the usual pragmatic motives for regulating fertility. The idea of splitting the colony when it grows to a certain size range keeps colonies always in a phase where they need a constant source of new young hands to build and run the collectives. Since they do not recruit outsiders, it effectively augments the pressure to keep having the numerous children.

The phenomenon of large numbers of humans propagating a movement by acting in concert has been cited as evidence for the group selection of human genes. Wilson and Sober [17], for instance, take the colony behavior of Hutterites as evidence of innate hive-like social dispositions arising from group-selected genes. Yet the ideological imperatives discussed above can explain the evolution of a Hutterite meme set in terms of memetic selection alone without requiring any new innate factors beyond a very general capacity to learn and comply with cultural mores[10]. Likewise, the Christian propagation advantages that arise through community behavior do not suggest a special genetic mechanism. As important as they are, massively cooperative meme replication events remain a subclass of memetic events in general. The fact that they happen for a variety of memes in various populations suggests that communities can achieve certain meme transmission effects beyond the capacities of single individuals. Yet it does not of itself show that the memes must be relying on an innate imperative for highly collective action.

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14 Centralized Communication

Centralized meme transmission stands in contrast to massively cooperative propagation. Here, a very few people act to spread a meme to vast numbers by events such as *A+1000000~A10001A+990000~A*. (Host of *A* communicates to 1000000 non-hosts of *A*, yielding 10000 new hosts of *A* plus 990000 continued non-hosts of *A*.)

Mass media often play an important role in such replication events. When they do, most of the recipients cannot go on to play the role of meme retransmitter by the same kind of centralized event. This may at times make centralized communication less suitable for study with *recursive* replicator theory. It can also at times limit the role of distributed replication: much as humans can acquire legionella bacteria centrally from central air conditioning systems, so too can we acquire memes by way of intentionally central meme spreading systems.

Another feature of centralized communication is that not all of the people transmitting the message are actually hosts of the meme. The idea that "Coke is the real thing", for instance, has probably been broadcast by many celebrities who prefer to drink something entirely different in the privacy of their homes. This again limits the usefulness of the recursion principle, as sender and receiver do not always have "the same" meme. The sender, for instance, may only have the idea that it is *profitable to say* "Coke is the real thing" rather than actually *believing* in the message. Yet as with non-centralized profitable communications, people who adopt the meme often spend money that pays merchants and advertisers to send the message again and again. This is a phenomenon recognized and applied long before the advent of memetics, and already studied in marketing science.

Mature recipients of centralized messages often understand that the sender may not believe what she says, thus limiting receptivity to the message. Communications from friends and family generally do not have an apparent profit motive, too, and can thus enjoy a more privileged reception. Desires to maintain

harmonious relationships also cause people to pay closer attention to messages from direct acquaintances. This helps maintain the importance of non-centralized communications from immediate family and acquaintances in the age of mass media. In turn, it prevents all of memetics from being reducible to existing work in media studies or marketing science.

The continued importance of distributed communications even manifests itself in the recursive propagation of memes specifying which centralized sources to consume. The Bible, for instance, may look like a centralized communication, coming from mass production plants ever since moveable type was invented. But the idea of buying and reading it propagates person to person in the population, along with various memes specifying what passages to emphasize and what they mean. Another example that I discussed in *Thought Contagion* [12] was the localized propagation memes for listening to centralized political talk-radio shows. Listeners to shows with pro-business, anti-tax messages play the radio openly in the workplace, allowing co-workers to learn about the show and its message. But listeners to shows that might politically offend the management feel inclined to use headphones, which blocks the local retransmission of their political and show-preference memes. Even that most centralized of modern media, television, exhibits natural selection processes, as when the remote control caused a trend toward greater violence, sex, and melodrama the types of content that happen to stop the passing "channel surfer"[11]. Far from replacing distributed memetic evolution, the centralized media have instead opened up new realms for recursive propagation and natural selection in competing meme bundles.

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15 The Fundamental Role of Abstraction in Science

The great potential for confusion in discussing cultural phenomena forces explicit reference to systems of abstraction. Yet the axiom of abstraction, fundamental to all of science, is generally invoked on a tacit level in most disciplines. Indeed, the axiom of abstraction is also known as the axiom of comprehension. It merely states that for any attribute, one can define a set of all the entities that have that attribute. Saying that two entities are "the same", then, is tacit shorthand for saying that they are elements of the same set, whose inclusion criterion is the attribute. The phrase "the same with respect to an abstraction" serves to remind readers of the underlying mental operations involved in calling any two entities "the same".

In the physical sciences, abstraction manifests itself every time someone refers to an entity as having the attribute of being a "water molecule". "Water molecule", is an abstraction which scientists have found useful for discussing phenomena. What they really mean by "water molecule" is a particular *pattern* of matter and energy. It is a way of calling two or more patterns of matter and energy "the same", ignoring such differences as location, velocity, rotational states, vibrational states, oxygen 18, Hydrogen 2, nuclear spin states, electron spin states, electron excitation states, quark states, etc.

Is it ever legitimate to identify *patterns* amid all this seething matter and energy? A philosophy of science question. Yet the grouping of vast categories of objects into sets defined by attributes seems to be a fundamental feature of human thought. Without formally justifying the practice, one can note that this can be an efficient way of storing vast amounts of knowledge in a finite brain. One can also theorize that evolution has favored brains that do this because it provides sufficiently functional representations of reality to give an animal a survival and reproductive advantage. But these arguments themselves depend on abstractions.

Regardless of why we rely so much on abstractions, science as we know it is largely a project to develop and test ever stronger systems of abstractions with which to describe and comprehend reality. The "stronger" systems of abstractions are defined as those which explain more of reality with reliance on

fewer essential abstractions. Yet deep questions remain on whether nature will some day indulge the physicist's quest for the kinds of "ultimate" abstractions of "grand unification theories". Will our desire for ever more unifying abstractions instead be frustrated by some fundamental complexities of a reality not designed specifically to please the human mind? This we have yet to learn.

Despite advances in fundamental knowledge, we cannot run through the equations of quantum mechanics to explain something as complicated as a cell or a DNA molecule. So we invoke further layers of abstractions for these vastly complicated systems. Instead of representing "adenosine" in terms of a chemical formula, a single letter is used. And "little things" like the dissociation of H+ from phosphate groups and particular serpentine shape traced out by the molecule are ignored. Compared to the level of elementary particles, molecular biologists focus on patterns of patterns of patterns, layers of abstraction removed from what physicists call "fundamental".

A great deal of science went into demonstrating that "genetic material" is a useful abstraction, and that "nucleic acid" can be used as an equivalent abstraction here on Earth. Likewise for the discovery that "nucleotides" are useful abstractions for describing nucleic acids. Yet the pre-molecular concept of "gene" was a useful abstraction, and its very utility provided impetus to the research that lead to more powerful molecular abstractions. More recent arguments over different molecular definitions of "the gene" amount to arguments about which abstractions are stronger. Yet the "the gene" started as an abstraction based on studies of entire organisms, and has progressed into an abstraction based on studies of molecules.

Materials can also be *manipulated* to fit a set of desired abstractions, as has been done with digital electronics. One voltage interval is chosen to represent the abstraction "1", and another the abstraction "0", with all sorts of "low level noise" to be ignored. Analog vacuum tubes, transistors, and other devices are then wired to produce abstractly bimodal outputs corresponding to abstract operations on abstractly bimodal inputs. Hence the "NOR gate", for instance. Still higher levels of abstraction arise when referring to "software", where specific voltages and even patterns of "1's" and "0's" can be ignored in deciding whether two "programs" are "the same". Science again builds layers of abstractions, this time working from the low level up rather than the high level down.

Because "replication" depends on "sameness", and the "sameness" of any two "water molecules", "DNA molecules", etc. exists only with respect to an abstraction, it follows that replication only happens with respect to an abstraction. Abstraction systems and sameness criteria are important in all evolutionary replicator theories. Yet "replication" also involves the notion of causation. Specifically, the word "replicator", can be replaced with the cumbersome phrase "instantiation of an abstraction that causes a new instantiation of the same abstraction". This is the tacit meaning in use for all kinds of evolutionary replicator theories ranging from the "artificial life" to memes to autocatalytic molecules that might evolve in the oceans of Europa.

Memes are abstractions currently based on macroscopic observation. Whether it will stay at this level remains to be seen. There is, however, a school of thought that seems to insist that memes must be "detected" by some kind of molecular or microscopic means in order to be valid abstractions. Yet the same people may routinely treat "Nazism" or "monotheism" as "real" phenomena without providing any molecular or cellular basis. Many even go on to attempt to get others to hold "the same" idea as theirs about memetics. In doing so, they unwittingly affirm the underlying premise of memetics, that one person can cause another person to have "the same" idea by way of "communication". They need only admit further that different ideas can spread recursively at different rates before seeing the evolutionary arguments of memetics follow mathematically. There too, many of them affirm a principle of memetics by avidly trying to make their own beliefs spread at a greater rate than competing beliefs. This is not the same thing as accepting specific memetic hypotheses, but it does show tacit acceptance for the

underlying tenets of memetics.

Nevertheless, some of the discomfort that many voice over memetics arises almost subconsciously from the fact that science has not discovered an absolute, fundamental, or privileged system of abstractions with which to discuss socially transmitted information. To worsen the situation, some popular writers seem convinced that they have actually discovered a set of fundamental "units" of mass culture, that is, a strongly preferred or "privileged" system of abstractions resembling the nucleotides and genes of biology. But the "sameness" of any two people's learned information about a topic depends on the abstraction system of the observer. With genes, nature has rendered a few very similar abstraction systems far more powerful than the alternatives, so that scientists do not notice the role of the observer's abstraction systems. But there are many ways to define "anti-abortionism", for instance which is another way of saying that the abstraction system and survey questions can be constructed in many different ways.

In reality, memeticists will probably have to abandon the "fundamental unit" idea much as physicists have now abandoned the idea of an absolute coordinate system (framework of location and time abstractions) for the universe. Not only are meters and seconds arbitrary units of measure, but measurement results depend on the framework in which measurement is taken. More fundamentally, just as physicists now accept that the "simultaneity of events" exists only with respect to an observer's coordinate system, so too must memeticists accept that the "sameness of ideas" exists only with respect to an observer's abstraction system. While this is not a "special theory of cultural relativity", it does show scientific precedent for admitting that multiple systems of abstraction can apply to a given class of phenomena. It does not mean that all abstraction systems are equally useful, but it does suggest that science can proceed without the assumption that there must be one abstraction system that is universally right for memetics.

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16 Population Memetics

Evolution is fundamentally a quantitative as well as a qualitative theory. The abstractions that allow us to discuss memes and memetic events set the stage for discussing quantitative *event rates*. Differences between memes in the rates of replication and termination events are what give rise to the natural selection of memes. They are hence essential to the evolution by natural selection in memes.. From the fact that event rate parameters differ between memes, it follows *mathematically* that natural selection must happen. Yet this statement can be rendered much more specific. The mathematically *necessary* consequences of differing event rate parameters can be *characterized*, using systems of differential equations for meme host population versus time. Defining the units and quantifying the events thus allows us to analyze the host population *dynamics* of memetic evolution.

The particular terms needed for a system of equations to model the population dynamics of a specific set of memes will depend upon what kinds of events occur at non-negligible rates for the memes being modeled. A vast range of event forms can be conceived, but the rarest of them do not need to be modeled in order to gain acceptable accuracy much as the rarest side reactions in a chemical process can be ignored in quantitative chemistry. Models will in general have to account for at least two population groups, namely, those for hosts and non-hosts of a meme. Accounting for additional population groups is accomplished by expansion to a system of more than two equations. Most models will also have account for some very common types of memetic events, such as simple parent to child transmission, non-offspring conversion, spontaneous dropout, and mortality. Two-equation systems to model these basic kinds of events therefore constitute a starting point for mathematical memetics, allowing further elaborations to be added as required.

The following two differential equations pertain to two memes whose host populations are represented by $N_1(a,t)$ or $N_2(a,t)$ ▭ population age profiles. All members of the total population $N(t)$ are assumed to be counted somewhere in either $N_1(a,t)$ or $N_2(a,t)$, indicating that the two memes are complements of each other. (In actual practice, one would often want to divide the population into more subgroups, such as the host populations of an idea, its opposite, and hosts of neither. Some subgroups might correspond non-replicated mnemons rather than memes. The present discussion is limited to two groups in order to illustrate quantitative methods as simply as possible.)

The other parameters in the equations have the following meanings: t is time in years, a is host age, p is the age of a second person ▭ the idea propagator ▭ used in places where two people's ages are involved.

$R_1(a)$ is the fertility rate for meme-1, in children per host of age a per year ▭ the quantity parental parameter. $K_{11}(p,a)$ is the fraction per year of children of age a who learn meme-1 from an age p parent who hosts meme-1-the efficiency parental rate. $K_{21}(p,a)$ is the fraction per year of children of age a who learn meme-1 from an age p parent who hosts meme-2, a kind of parental "failure rate" for meme-2. Again, for the sake of "simplicity", the different R and K values that may occur when one's parents come from different host populations are not modeled here. (More than just R and K parameters are involved, since the occurrence rates of "mixed" versus "unmixed" couples change with changing host populations.)

$_{12}(p,a)$ is the average annual net number of non-parental converts a meme-1 host of age p makes per unit meme-2 host population-age density at age a in his society. $_{12}(p,a)$ is the average annual net number of non-parental converts a meme-1 host of age p makes per *percentage*-year of meme-2 hosts of age a in his/her society. Non-parental conversion rates represented by $_{12}(p,a)$ are sensitive to how crowded the society is as a whole while $_{12}(p,a)$ rates per meme-1 host are purely sensitive to the *fraction* of meme-2 hosts in the society. The latter reflects the non-parental conversion between, for instance, spouses: people do not generally double the number of spouses as the population doubles. Yet the number of people one encounters on the street might well double as the population doubles. If so, then non-parental conversations on street corners would be modeled using $_{12}(p,a)$.

$_1$ is the fraction per year of meme-1 hosts who convert to meme-2 without any prior meme-2 hosts teaching them, or who at least convert by mechanisms that do not depend on the size of the meme-2 host population[12]. Preventing such "dropouts" is one form of preservational advantage (information longevity advantage) for meme-1. Finally, $M_1(a)$ is the rate of mortality per age a meme-1 host per year.

Swapping "2" subscripts for "1" subscripts in the above sentences gives the parameter definitions corresponding to changes in meme-2 prevalence [13].

$$
\begin{aligned}
\frac{dN_1(a,t)}{dt} &= \int_a^\infty R_1(p-a)K_{11}(p,a)N_1(p,t)dp \\
&+ \int_a^\infty R_2(p-a)K_{21}(p,a)N_2(p,t)dp \\
&+ \int_0^\infty \gamma_{12}(p,a)N_1(p,t)N_2(a,t)dp \\
&+ \int_0^\infty \frac{\beta_{12}(p,a)N_1(p,t)N_2(a,t)}{N(t)}dp \\
&- \alpha_1 N_1(a,t) + \alpha_2 N_2(a,t) \\
&+ \frac{\partial}{\partial a}N_1(a,t) - M_1(a)N_1(a,t)
\end{aligned}
\tag{1}
$$

$$
\begin{aligned}
\frac{dN_2(a,t)}{dt} &= \int_a^\infty R_2(p-a)K_{22}(p,a)N_2(p,t)dp \\
&+ \int_a^\infty R_1(p-a)K_{12}(p,a)N_1(p,t)dp \\
&+ \int_0^\infty \gamma_{21}(p,a)N_2(p,t)N_1(a,t)dp \\
&+ \int_0^\infty \frac{\beta_{21}(p,a)N_2(p,t)N_1(a,t)}{N(t)}dp \\
&- \alpha_2 N_2(a,t) + \alpha_1 N_1(a,t) \\
&+ \frac{\partial}{\partial a}N_2(a,t) - M_2(a)N_2(a,t)
\end{aligned}
\tag{2}
$$

The first two terms in equation 1 are the parental terms. In the first term, the group of $N_1(p,t)$ parents of age p is multiplied by the average number $R_1(p\text{-}a)$ of children per adult that they had a years ago to get the number of children of age a having parents of age p. This then is multiplied by $K_{11}(p,a)$, the fraction per year of children in this latter group having meme-1 passed down to them (while they are of age a and the teaching parent is of age p). This is then integrated over the entire range of parents' ages ($p=a$ to $p=$) to get the total rate at which meme-1 hosts are passing the meme down to children of age a. The second term gives the rate at which the meme-2 host population parentally produces meme-1 hosts of age a.

In practice, there may be many cases where a useful mathematical model can be attained by treating the parent to child meme transmission as if it all happened when the children reached the single age c_1, the *average* age at which they pick up meme-1 from a parent. Also, one might find that the transmission rate per child depends very little on parent age differences within the mainstream host child raising years. If this is true, then one can replace the $K_{11}(p,a)$ function with the very simple function k_{11} $(a\text{-}c_1)$, where denotes the delta function, and k_{11} is simply the overall fraction of children who acquire meme-1 from their parents a much easier thing to measure than transmission versus age. The remaining functions in the parental terms are just fertility versus age and the population age profile the sort of data that demographers and census-takers have already measured for some groups.

The next two terms in the equation concern the non-parental conversion mode of transmission. The first of these is the one that is sensitive to the total number of potential converts, $N_2(a,t)$, rather than merely their proportion to the total population. If both $N_1(a,t)$ and $N_2(a,t)$ doubled, each individual meme-1 host would be winning twice as many converts and the meme-1 host population (at double size) would be winning four times as many converts per year. On the other hand, the second term on line two would only double, and not quadruple, if each group doubled. In reality, the dependence of non-parental conversation rates on host population sizes is more complicated than the two terms suggest, and the nature of the dependency would need to be studied empirically as part of any detailed mathematical modeling effort for memes with significant non-parental transmission. As with the parental terms, the non-parental conversion terms may be simplified in some cases by replacing the age dependencies with "lumped" effective propagations at certain effective ages.

The following two terms (beginning of line 3) express the "spontaneous" dropout rate for meme-1 and meme-2, respectively. "Spontaneous" dropout rates are assumed to be proportional simply to the number of hosts capable of dropping out. Such rates could also be modeled as age-dependent rates by replacing $_1$ with $_1(a)$ and $_2$ with $_2(a)$.

The next term is the partial derivative of $N_1(a,t)$ with respect to a. This term indicates that part of the changing population age profile of meme-1 is due to simple aging of its host population.

The final term expresses the mortality rate as a function of age among meme-1 hosts. Mortality per host per year at age a (a kind of actuarial data) is simply multiplied by the number of hosts at age a to give the overall rate.

Equation 2 above models the same kinds of propagation processes for meme-2 as are modeled for meme-1. Equation 1 and equation 2 form a system of non-linear differential equations modeling the interdependent propagation of meme-1 and meme-2.

What follows are five more equations that go with equation 1 and equation 2, defining relationships between the propagation parameters. Equation 3 states that all offspring of meme-1 parents end up

holding either meme-1 or meme-2. Equation 4 says the same thing for meme-2 parents. Equation 5 and equation 6 state that one group's non-parental conversion gains are the other group's non-parental conversion losses, so that the net non-parental gain to the whole population is 0. The last equation (equation 7) merely defines the function $N(t)$, the total population versus time, as the sum of the as the sum of the two meme host populations, all ages included.

$$(3)\ \int_{\tau=0}^{\tau=a}\left[K_{11}(p,\tau)+K_{12}(p,\tau)\right]d\tau=1,\ a>0$$

$$(4)\ \int_{\tau=0}^{\tau=a}\left[K_{22}(p,\tau)+K_{21}(p,\tau)\right]d\tau=1,\ a>0$$

$$(5)\ \gamma_{12}(p,a)+\gamma_{21}(a,p)=0 \quad \text{for all } a, p$$

$$(6)\ \beta_{12}(p,a)+\beta_{21}(a,p)=0 \quad \text{for all } a, p$$

$$(7)\ N(t)=\int_{0}^{\infty}[N_1(a,t)+N_2(a,t)]da$$

Not all meme propagation events are given their own separate terms in equation 1 and equation 2. For instance, if it frequently happened that meme-1 hosts produced meme-2 offspring who then converted their parents to meme-2, then the rate at which meme-1 hosts were non-parentally converted to meme-2 might depend greatly on how many children they had. A new term might have to be added to the equations to make this phenomenon adequately modeled. The model can, in fact, be made arbitrarily complex, but it is obviously desirable to keep it as simple as the application permits.

Another elaboration of the equations, and one that might interest mathematical sociobiologists, is the explicit inclusion of specific genes and their propagation parameters into the picture. Such a model would analyze "host populations" of memes, genes, and meme-gene combinations all in the same system of equations. Of course, one sets the 's, 's, and 's to zero wherever the propagation of a gene is modeled. The parental terms become more numerous and take on a diversity of forms corresponding to all the combinations of genes and memes that can occur in two mating adults. Keeping track of the homozygous and heterozygous combinations would also cause more population parameters and equations. Each possible outcome of each parent combination must have its own term in one of the equations. Such equations embody no *a priori* assertions about the relative importance of either genetic change or cultural change over a modeled time span, nor any assertions of how strongly or weakly prior genetic and cultural evolution constrains the course of change over that time span. Instead, they allow for considering these matters on a case by case basis once the requisite starting data are fed into the models.

Although emotional and cognitive receptivity factors are not readily conspicuous in equation 1 and equation 2, they are in fact represented. The reason is the *K*'s, 's, and 's are measures of *successful* meme transfer events. As such, they are composites of both the rates at which propagation is attempted and the rates at which it is cognitively and emotionally well-received. Likewise, the "spontaneous" dropout rates ('s) include their own products of cognition and emotion.

Anti-competitor propagation advantage, on the other hand, is not fully represented by the *K*'s, 's, and 's. Part of the reason is that this mode can occur in quite a wide range of ways. It makes a big difference, for instance, whether the meme-1 group merely bans meme-2 proselytizing or launches a meme-2

extermination campaign. Moreover, the effectiveness of such measures does not vary as a simple function of the meme host populations. The Nazis, for instance, became dramatically more harmful to competitors after they became numerous enough to gain political power. Such phenomena may well defy mathematical modeling techniques based solely on predicting host populations versus time, and require the detailed modeling of political processes as well.

The *K*'s, 's, and 's are each modeled as overall *effective* rates of meme transmission. The *K*'s, for instance, do not indicate how many times a parent needs to repeat a message to her children before it is effectively learned. The 's, and 's likewise do not reflect how many a message was voiced from hosts to a non-host before that non-host converted. A more detailed model might therefore break down these parameters into the subfactors of *transmissivity*, a measure of how often each host attempts to transmit a meme, and *receptivity*, a measure of the likelihood each host to non-host transmission attempt has of actually imparting the meme to a new person. Much research has been done on how various components of receptivity affect the diffusion rates of innovations [15]. Receptivity parameters can also be broken down to reflect different probabilities of meme acceptance on first, second, third, etc. exposure. Modeling meme-based *differences* in receptivity to meme-1 or meme-2 that result from the presence or absence of third or fourth (etc.) memes requires expansion to more than two main equations, but may be necessary in cases where the empirical evidence suggests that non-host populations have both "susceptible" and "non-susceptible" subsectors. Such elaborations generate more complicated mathematics.

All meme propagation involves some level of transmissivity, receptivity, and longevity of the memes. Memetic evolution arises from differences in transmissivity, receptivity, and longevity [14]. One of the differences between memetics and "classical" social science is that memetics looks at all three of these general factors, while the classical social sciences often neglect transmissivity and longevity in favor of receptivity. Though pre-memetic social sciences do acknowledge transmissivity differences in mass media, questions of why a whole society came to believe something are often posed as questions of "why did the people want to believe". Investigating such questions does provide useful information, but not a complete picture.

Equation 1 and equation 2 model fairly ideal cases of the two-idea propagation problem, but also serve as the kernel of a multi-equation system for cases involving three or more memes with host populations N_1, N_2, N_3, etc. The equations offer a sample of the kinds of terms that can arise in realistic applications, and they illustrate that a unified quantitative analysis can be given to qualitatively dissimilar modes of propagation. They also illustrate the concept that once the main mechanisms of an idea's propagation have been empirically discovered and measured, the degree to which each mechanism contributes to instantaneous rates of propagation can be mathematically modeled. The resulting systems of differential equations govern host populations as a function of time, and so can be used to generate limited predictions of what will happen if the equation parameters remain reasonably constant in non-chaotic intervals.

The model presented above treats each meme as being either instantiated or not instantiated in a given person. An alternative is to model ideas as a continuum, in which there are an infinite number of mutually exclusive degrees of "hostship" that are instantiated or not. In other words, each individual is considered to occupy a single point on an ideological continuum. Strictly speaking, it would no longer model "replication". Instead, each point on the continuum would exhibit its own birth and mortality rate. Parents at each degree of the trait would have a distribution of rates of imparting all possible degrees of the trait to offspring. People communicating with non-offspring would have distributions of second-party transfer rates denoting how often they move people from one level of the trait to any other level of the trait. Yet in measuring such continuum traits, investigators generally end up assigning subjects to a finite

number of trait levels such as "strongly agree", "agree", "neutral", "disagree", and "strongly disagree", designated here as mnemons *A*, *B*, *C*, *D*, and *E*, respectively. This returns us to dividing the total population into five (or alternately, seven, ten, etc.) mnemon host populations with a corresponding number of equations. Still, horizontal communication can involve heterogenic events in which, for instance, someone in the "strongly agree" category gets someone in the "disagree" category to transfer to the "neutral" category. As noted earlier, not all memory items are memes with respect to the abstraction system in use, and an abstraction system using finitely stratified categories would include both memetic and non-memetic (heterogenic) events. However, certain unidirectional multistage heterogenic events can add up to form homogenic (memetic) events with multiple participants. If, for instance, four distinct *E*-hosts convert an *A*-host into an *E*-host with in stages (a separate *E*-host participating in each stage), then the heterogenic stages still add up to a homogenic event. The first three events taken individually are heterogenic: $A+E \rightarrow B+E$, $B+E \rightarrow C+E$, and $C+E \rightarrow D+E$. Only the fourth event $D+E \rightarrow 2E$ is homogenic by itself. Yet the overall sequence adds up to the net event $A+4E \rightarrow 5E$, which is homogenic with respect to *E*, and hence potentially recursive. Other events, including ones going in the opposite direction (e.g., $E+4A \rightarrow 5A$), are also potentially recursive. The potential for recursively shifting large segments of population to higher levels of agreement or disagreement would be inherent in the system of five equations for the host populations of *A*, *B*, *C*, *D*, and *E*. The question of which, if any, of the potential recursive events predominate would be determined by the measured event rate functions (generalized  's, and  's) used in that system of five equations[15].

Returning to non-stratified memes, a great many phenomena that may look like two-meme problems are in fact applications calling for three or more equations. This includes cases that enumerate not only the hosts of a meme, but also the exposed and unexposed non-hosts. For instance, if we define mnemon *P* as *belief* in proposition *X*, then non-belief is ~*P*. If *awareness* of proposition *X* is designated as *Q*, then unawareness is ~*Q*. An exposed non-host of the proposition is designated as ~*P***Q*. Exposed hosts are *P***Q*. Unexposed non-hosts are ~*P**~*Q*. The *P**~*Q* combination presumably has a host population of zero. The resulting mathematical model therefore has three equations modeling N_1 hosts of ~*P**~*Q*, N_2 hosts of ~*P***Q*, and *N3* hosts of *P***Q*.

Host populations modeled as distributions in age and time in equation 1 and equation 2 can also be measured and modeled using a variety of additional parameters such as those of geography (e.g., longitude and latitude), duration of hostship (as distinct from the age of the host), family income, years of schooling, etc. The *R*'s, *K*'s,  's,  's,  's, and *M*'s could be modeled with the additional parameters as well. The *R*'s, *K*'s,  's,  's,  's, and *M*'s would then quantify a range of events that include individuals changing not only their belief their host status, but also individuals changing their locations, incomes, etc. The corresponding event diagrams would include non-memetic attributes, such as location coordinates *x*, *y*, and *z*, so that the simple migration of a meme *P***Q* host from location 1 to location 2 would become $P*Q*(x_1,y_1,z_1) \rightarrow P*Q*(x_2, y_2, z_2)$. The modified a's could then quantify this migration event in addition to memetic events such as $P*Q*(x_1,y_1,z_1) \rightarrow P*\sim Q*(x_1, y_1, z_1)$.

As an alternative to working with systems of difficult equations, one can also use quantified propagation mechanisms to run predictive computer simulations of memetic evolution without the intermediate step of writing down differential equations. The latter method can run particularly well on systems based on generalized cellular automata, where each "cell" simulates the memetic state and behavior of a person. Such an individual-based computer simulation is now feasible using the *SWARM* program developed by the Santa Fe Institute [8].

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17 Qualitative and Quantitative Evolution

As mentioned earlier, occurrence rates of heterogenic events often depend on the prevalence of precursor memes. When vigorous precursor memes proliferate, they achieve substantial odds of causing the creation of memes that only a rare host can form. Additionally, when the new meme is simply *defined* as a combination of two or more precursor memes, the vigorous propagation of the precursors greatly hastens the arrival of the combination. So the independent spread of meme *X* and meme *Y* hastens the formation of the combination *X*Y*. Indeed, if *X* and *Y* spread vigorously, *X*Y* can pop up explosively among many widely separated individuals. So if *X*Y* tends to inspire hosts to create mnemon *Z*, then *Z*, too can pop up explosively among widely separated individuals. This much acclaimed feature in the innovation of ideas shows that creativity is largely a population phenomenon.

The most vigorous precursor memes tend to recombine with more varieties of new ideas, some of which form an even more vigorously propagating meme package in combination with the precursor set. Mnemon variation thus feeds new operands into the quantitative processes of natural selection while the quantitative processes give many subsequent qualitative variations an appreciable chance to occur. The two kinds of change continuously feed back on each other to form a genuine process of evolution. A recursive process therefore happens at a higher level than that of individual mnemon replications. This is the iterating cycle of variation and selection that Dennett [5] describes as an *algorithm*. It is, more specifically, a *recursive algorithm*, a central feature of all evolutionary replicator theories.

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18 Falsifiability

The sort of predictions generated by mathematical models and computer simulations are falsifiable. This provides a general method for attempting to falsify specific memetic hypotheses. In general, propagation parameters can be measured over the duration of the time interval being modeled, as can the initial host populations of the memes under study. If the propagation parameters remain in some specified interval, then the final host population plus or minus a calculable error margin should be measured at the end of that interval. A host population measurement outside those error margins would then falsify the model being used for the specific memes under study. The procedure can be quite elaborate, as it involves conducting surveys and performing difficult computations.

Yet particular aspects of a specific memetic hypothesis can be falsified by less elaborate means as well. If a proposed model for the spread of anti-abortionism hypothesizes that the belief "abortion as wrong" leads adherents to raise more children than non-adherents, then the whole model could be falsified by, for instance, showing that non-adherents raise equal or greater numbers of children. If such data were gathered, and proven representative of whole societies over long time spans, then there would be no need to begin the more elaborate procedures of measuring additional parameters and performing computations.

In some cases, this method can be performed using existing data sets. For example, the National Health and Social Life Survey [9] contains data about respondents' attitudes toward various sex acts. It also has data on reproductive histories. So, after making suitable functional definitions based on the questionnaire, one can statistically reanalyze the raw data set to see how much of the variance in reproductive history is attributable to variance in a particular attitude response. Applying the method to the older respondents could provide results that tend to either corroborate or falsify a hypothesis that a particular sex taboo, for instance, increases its hosts' average number of offspring[16].

The overall theory would conceivably be falsified by refuting its premises or the logic and mathematics based on those premises. The assertion that memetics is a *useful* theory is also falsifiable, for instance by showing that differences in propagation parameters are *never* great enough to account for large-scale ideological shifts, or that the only parameters that ever account for large-scale ideological shift are the

"classical" receptivity parameters.

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19 Other Empirical Issues

At present, there is no brain scanning device that tells unambiguously whether someone holds a particular belief or not. Nor is there a memory probe that recovers all the communications that lead someone to adopt a particular idea. This means that measuring host populations and propagation parameters must depend on survey methodology. Questionnaires and interview protocols may thus form functional definitions of the abstractions used in memetics.

The rates of occurrence of specific events must also be measured for use in a quantitative model, in order to determine the propagation parameters. Surveys already exist which ask how many children people have. Parent to child meme transfer rates would have to be measured by new survey designs that interview both parents and offspring. Human subjects would in general have to be asked to remember what roles their friends or parents may have played in imparting specific beliefs. Respondents "crediting" their parents or people the parents designate on the basis of memetic similarity would be counted toward a meme's parental transmission. Respondents "crediting" other people would be counted toward the meme's non-offspring conversion rate. Much work and proper funding are needed for such surveys.

In a few cases, raw data may have been incidentally gathered for entirely different purposes. The Mormons, for instance, have kept unusually extensive long-term records not only of member births and deaths, but also of how many children followed their parent's faith and how many dropped out, as well as which members arrived through non-parental conversions [10]. A project to re-tabulate such data by types of events should enable the calculation of parameters for use in the above differential equations or computer simulations. The resulting host population versus time figures can then be compared to the records of total membership also culled from church records.

With non-human animals, behavior and communication can in principle be monitored with tiny, individual electronic recording devices and studied in detail later. The method is ethically encumbered for humans, but some useful propagation data may still emerge in limited consensual monitoring studies. Though it gets past some of the limitations of surveys, it is still an enormous project.

Small recording devices may also be used in animal experiments in memetics. Bonner has documented the imitational spread in British titmice of the learned skill of pecking through foil caps of milk bottles delivered outside of houses [2]. A more deliberate experiment could place a large number of smaller artificial food containers throughout an extended (perhaps closed) environment and monitor them. They would be designed so as not to resemble any previous food source, but would be easily opened by the species under study. A container that looks like a distinctive pebble but can be pecked open in a particular spot might do. (To study multiple modes of transmission, care may have to be taken to insure that a single bird cannot have too many imitators in a single feeding, or else the meme will spread to saturate the population under study in less than one generation. Limiting the food per container and choosing a solitary-foraging bird may be necessary.) A large display screen with computer-simulated images of birds opening the containers and eating from them could then be used to release a synthetic meme into a small initial host population. Subsequent monitoring of the birds for reproductive rates, death rates, parent to offspring imitation rates, non-offspring imitation rates, and "forgetting" rates could yield useful parameters that differ between host and non-host populations. Observed host and non-host population sizes versus time can then be compared to those predicted using the quantitative theory and measured parameters.

Human society also affords some specialized environments in which to investigate memes by investigating meme relics. Modern libraries, for instance, allow us to track the proliferating citations of scholarly papers indexed in a computer database. Pocklington and Best [1, 14] have also provided strong evidence of meme proliferation by demonstrating the corresponding proliferation of meme relics on the Internet.

Some look at the lack of a strictly physical definition of meme instantiation as reason for dismissing memetic evolution entirely in favor of theories that describe the same phenomena in terms of genes. Genes, after all, have reliable molecular definitions and are detected using impartial technologies such as nucleotide sequencing. One problem with this argument is that even genetic psychology theories still require functional definitions of psychological features as abstract as a meme. Thus, if an evolutionary psychologist hypothesizes that the valuation of female premarital chastity is genetically based, the empirical investigation must include a method of deciding which females value premarital chastity and which females do not. Then some specific genetic factor must be linked to the presence or absence of this trait. It should, moreover, not just be responsible for learning in general, as the same gene would then account for the ability to learn either the valuation of chastity or the valuation of promiscuity. Rather, it should be a genetic factor whose phenotype and evolutionary adaptation can somehow be more specifically identified with chastity preferences than with strong sexual cravings or cerebral functioning in general.

In many such cases, memetic hypotheses are on empirically *stronger* footing than alternative genetic psychology hypotheses. We can, for instance, *observe* the hypothesized memetic replication event of parents telling sexually eager daughters to "say no". Yet no one has identified and *observed* a gene that makes daughters want to repress the sexual urges brought on presumably by other genes. The memetic hypothesis involves parents feeling economically motivated to impart the meme to daughters and having more grandchildren when they do so [12]. It is, in essence, as much Darwinian as the genetic hypothesis is. Yet the memetic hypothesis is more parsimonious: a competing genetic explanation must still account for the *observable* communication of sexual repression messages from parents to daughters.

When a communication event is *not* observed, however, it can serve as indirect evidence of genetic influences. For instance, if parents and others are consistently observed *not* teaching their daughters any preferences for male lower body physique, but daughters develop their preferences anyway, then a genetic hypothesis for such preferences is on stronger footing than a memetic hypothesis. Specific genetic factors still need to be identified to completely validate this hypothesis, but it at least does not face a stronger and more parsimonious memetic alternative.

Memetics does face methodological challenges in measuring prevalence and propagation parameters that are more complicated than the functional issues in polling. Yet these should not be seized as arguments for the universal superiority of genetic theories.

Conclusion

Even physical scientists routinely take the existence of human "memory items" and "ideas" as a given. They even accept the concept that there is such a thing as "communication", in which one person can "cause", by complex means, the occurrence of an "idea" or "memory item" in another person. Sometimes the newly caused "memory item" in the other person is even considered to be "the same" as one in the former person, an event called "replication" by Dawkins and others. Replication events include many cases where participants assume the ideas to be playing very passive roles in causing new instantiations of "the same" ideas.

Yet even physical scientists again routinely assume that "ideas" can influence "behavior", including "communication behavior". When an "idea" causes "communication behaviors" that result in a new instantiation of "the same" idea in a different person, we have a generalized kind of autocatalysis, or "replication", in a stronger sense of the term. It is a stronger sense of the term "replication" primarily because these special-case ideas are seen as playing a stronger role in the causation of "the same" idea in new individuals. Ideas which play such strong causal roles in their own replication can thereby gain extreme prevalence and influence in a population. Moreover, their propagation results in the formation of new varieties of strongly replicating ideas. These observations cause dismay in many who have become accustomed to viewing themselves as controlling their ideas rather than the other way around, but major advances in scientific theory have often caused initial discomfort. The new theory offers a strong and parsimonious understanding of diverse phenomena in the areas of religion, sexual ideology, family structure, health beliefs, war, fascism, and numerous others. The theory of evolution by natural selection of memes is thus a solid and broadly unifying theory whose time has come.

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Notes

1. From Dawkins [4], p. 109.

2. See the discussion of the meme for bifocals in Dennett [5], p. 353.

3. "Mnemon" is being introduced as a neologism here, and may differ in meaning from the word as coined elsewhere for use in other fields.

4. The term *ideosphere* was co-invented by myself and Douglas Hofstadter. See *Metamagical Themas* by Douglas Hofstadter [6], p. 66.

5. Dawkins [4], uses the term *phenotypes* in connection with memes to describe the "outward and visible (audible, etc.) manifestations of the memes within the brain".

6. See Dawkins [4] p. 112.

7. See Dennett [5], p. 346. He uses this statement as a pithy summation of the memetic perspective, whereas I regard it as an example of what memetics is *not*. Libraries do indeed help scholars to write new books, and the production of new books plays a crucial role in causing the formation of new libraries. In this sense, libraries can be treated as cultural replicators that use scholars (among other things) in the process of replication-especially as the abstraction "library" does not call for even a single shared volume between "parent" and "daughter" libraries. But the phenomenon captures only the *flavor* of memetics, as

the library itself is not a meme.

8. See Dennett [5], p. 369 for the summary of chapter 12.

9. Colony sizes here come from Hostetler [7], p. 188, Table 1, which presents demographic charts of a colony branching event in 1969.

10. Dennett [5] argues effectively on pp. 473-475 that the Hutterites exhibit a striking *clash* between memes and genetic proclivities.

11. This argument is spelled out more completely in [13].

12. If there is a non-zero rate of completely "spontaneous" dropouts in the model, then it is technically more accurate to use the terms "mnemon-1" and "mnemon-2" in place of "meme-1" and "meme-2".

13. The population age-time profiles [$N_1(a,t)$ & $N_2(a,t)$], fertility rates [R's], child inculcation rates [K's], non-parental conversion rates [ 's, and  's], and mortality rates [M's] are represented as distribution functions, but this does not mean that smooth continuous functions will ever emerge from the data gathered for an actual application. Rather, age and time will be divided into discreet intervals such as a month, a year, or a decade. The population age-time profiles, fertility rates, etc. will then be the kind of functions often represented with 2- or 3-dimensional bar graphs. The specific time and age resolution ("granularity") used in data gathering will in general have some effect on the accuracy of computational solutions to equation 1 and equation 2. This is because differing ways of subdividing time and age into discrete intervals amount to making different approximations of the functions in these parameters. Conversely, the required accuracy plays a key role in determining just how finely time and age must be partitioned into intervals to gain useful data for a specific application. Once such a partitioning is chosen for a given application, the distribution functions in time and/or age take on a finite number of measured [R's, K's,  's,  's and M's]or computed [$N_1(a,t)$ & $N_2(a,t)$] values and the integrals may be reduced to finite summations for computational purposes. The present treatment does not use any specific time/age partitioning scheme, because the optimal scheme varies across applications. Hence, functions are left in their short-hand form rather than as data sets for fertility rates, child inculcation rates, non-parental conversion rates, and mortality or computed result sets for population age-time profiles. (The a's are treated as constants, but they too could be measured as functions of age a.)

14. The term "longevity" might be replaced by "durability" to better signify the resistance to dropout and mortality.

15. Recursive multistage events such as the ones that add up to $A+4E \rightarrow 5E$ or $E+4A \rightarrow 5A$ are especially likely to predominate if people at the extremes ("strongly agree" or "strongly disagree") play a preponderant role in persuading others to take those small steps of unidirectional mnemon change. The circumstance is probably common. Sequences of heterogenic events adding up to smaller recursive homogenic events such as $C+2E \rightarrow 3E$ and $C+2A \rightarrow 3A$ might happen most frequently, because they do not require shifting an individual from one extreme to another-although there are individuals who go from one extreme to the opposite on a topic. To model all possible two-party conversion events for A, B, C, D, and E where only one participant changes mnemons requires 80 event rate functions (160 if both b and g types are used), but measurement could determine that many of them are negligible in a given application.

16. I say "*tend to* either corroborate or falsify" because there remains the possibility that a taboo that increased reproduction for thousands of years no longer does so, or that a taboo that had no effect for thousands of years suddenly made a difference in the 1994 data.

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The author has written a post-publication addendum to this paper containing some addittional material and some corrections. This is accessible from the author's web site at URL:

http://www.mcs.net/~aaron/UEDerrata_addenda.html.

Back to Issue 1 Volume 2