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The Origin and Evolution of Culture and Creativity

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Abstract

Like the information patterns that evolve through biological processes, mental representations, or memes, evolve through adaptive exploration and transformation of an information space through variation, selection, and transmission. Since unlike genes, memes do not come packaged with instructions for their replication, our brains do it for them, strategically, guided by a fitness landscape that reflects both internal drives and a worldview that is continually updated through meme assimilation. This paper presents a model for how an individual becomes a meme-evolving agent via the emergence of an autocatalytic network of sparse, distributed memories, and discusses implications for complex, creative thought processes and why they are unique to humans. Memetics can do more than account for the spread of catchy tunes; it can pave the way for the kind of overarching framework for the humanities that the first form of evolution has provided for the biological sciences.

Keywords: autocatalysis, creativity, culture, evolution, imitation, induction, information, meme, memory, mental representation, natural selection, social learning.

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1 Culture as a Second Form of Evolution

While some ideas instantly fade into obscurity, others spread horizontally through society, and vertically from one generation to another, getting progressively refined and embellished along the way. Thus ideas, like the strands of DNA that encode instructions for building and maintaining living organisms, seem to undergo a process analogous to biological evolution.

Accordingly there has been a slow but steady effort to map the concept of evolution onto the dynamics of culture. Popper [72] and Campbell [11] alerted us to the evolutionary flavor of epistemology. Dawkins [17] introduced the notion of a meme - a replicator of cultural information analogous to the gene. In his words: "Just as genes propagate themselves in the gene pool by leaping from body to body via sperm or eggs, so do memes propagate themselves in the meme pool by leaping from brain to brain." Others have drawn from mathematical models of population genetics and epidemiology to model the spread of ideas (Cavalli-Sforza & Feldman [12], Lumsden & Wilson [56], Schuster & Sigmund [84], Boyd & Richerson [9], Hofbauer & Sigmund [33]).

These works point toward the possibility that memetics constitutes a second form of evolution, distinct from yet intertwined with biological evolution, with the potential to provide the kind of overarching framework for the social and cognitive sciences that the first form provides for the biological sciences. However thus far memetics has not lived up to this potential, a situation that seems unfortunate given the success of the biological precedent. Although much was known about living things before Darwin, his theory of how life evolves through natural selection united previously disparate phenomena and paved the way for further biological inquiry.

Some believe that looking to biological evolution to gain insight into cultural evolution is a waste of time. As Gould [28] put it: "Biological evolution is a bad analog for cultural change... biological evolution is powered by natural selection, cultural evolution by a different set of principles that I understand but dimly." However at an abstract level of analysis they amount to the same thing: exploration and transformation of an information space through variation, selection, and replication. Both present the question of what underlying mechanisms could *launch* a self-perpetuating adaptive process. Thus the possibility that the two have enough in common that the former can pave the way for the latter seems at least worth pursuing. Skeptics may wonder how we can develop a theory of cultural evolution before we understand how memes are instantiated in the brain. This situation has a precedent: Darwin came up with the theory of biological evolution through natural selection before the discovery of genes. It turned out that genes are laid out in a fairly straightforward way in physical space, which does not appear to be the case with memes. This does not mean they can't evolve, so long as there is a way of retrieving the components of a meme so they can work together as a unit. We may not yet know all the physiological details of how the information manifested in, say, a handshake between two individuals - with its unique arrangement of contact points, applied forces, and trajectory - can be traced back to these individuals' mental representations of handshakes, each other, and the situation they are in. But let us proceed with the confidence that a solution exists and can be found.

This paper outlines a theory of how memes evolve, and illustrates how the memetic perspective provides not only not only a foundation for research into the dynamics of concepts and artifacts at the societal level, but a synthetic framework for understanding how mental representations are generated, organized, stored, retrieved, and expressed at the level of the individual. It also sketches a tentative theory of how an infant develops a sustained train of potentially-creative thought and thus becomes a cog in the meme-evolving machinery. Implications of this theory pertaining to the mechanisms underlying creativity, and why it is virtually nonexistent in other species, are explored. It concludes with discussion of how a cultural-evolution perspective can shape and inspire research in the cognitive and social sciences.

1.1 Components of an Evolutionary System

In order for evolution to happen there must be:

1. A *pattern of information* (a state within a space of possible states).
2. A way to generate *variations* of the pattern (explore or transform the space).
3. A rationale for *selecting* variations that are adaptive - tend to give better performance than their predecessors in the context of some problem or set of constraints (a fitness landscape applied to the space).
4. A way of *replicating and transmitting* (or amplifying, as molecular biologists refer to it) the

selected variations.

In biological evolution, the evolving patterns of information are genes encoded as sequences of nucleotides. Variations arise through mutation and recombination, and natural selection weeds out those that are maladaptive. Replication takes place at the level of the genotype. In cultural evolution, the evolving patterns of information are memes - mental representations of ideas, behaviors, or other theoretical or imagined constructs, perhaps encoded as patterns of neuron activation. Variations are created by combining, transforming, and reorganizing representations, consciously or unconsciously, or through errors in transmission. Replication is phenotypically mediated; it occurs when representations are transformed into action or language, transmitted through processes such as imitation, and reproduced, more or less, in another brain. Incorporation of these new information patterns into the society alters the selective pressures and constraints exerted by the social environment, which in turn leads to the generation of yet more patterns. Thus memes, like DNA, comprise a self-sustained system for the relentless exploration and transformation of a space of possible patterns.

1.2 Culture is Not Just a Predictable Extension of Biological Evolution

The line of reasoning presented here can be succinctly conveyed in terms of *information*, which is related to the number of differences required to specify the state of a system (Shannon & Weaver [85], Bateson [4]). States have not only a structure of difference relations between them, but also a combinatorial structure - each state can itself comprise an information space, so that complex information can be built up from simple information. We can rate each state in a space of possible states against some performance measure or fitness criterion and the result is referred to as a *fitness landscape*, and we can move from one state to another by way of a *computation*. The world can be viewed as a vast network of computations wherein information is created, transformed, and destroyed. This information often exhibits *pattern*, or statistical regularity that can be expressed mathematically.

After seeing many shadows cast by the same object we can develop an internal model of what that object looks like without having seen it, and if more than one object is casting shadows we can learn to tell which object is casting any particular shadow. Similarly, by viewing every pattern we encounter as a shadow or footprint of one or more broad causal principles [note 1], we can gain insight into the causal principles that manifest that pattern.

If you were to go back to some time during the first billion years of Earth's history, the only causal principle you would need to invoke to explain pattern in the information present (with the exception of yourself) would be the *physical constraints and self-organizing properties of matter*.

If you were to go back to some time *after* the origin of life, approximately three billion years ago, this would no longer be the case. Not that life doesn't exhibit the properties of matter. But it would be virtually impossible for, say, a giraffe to appear in an information space not acted upon by natural selection. Another causal principle - *biological evolution* - would have to be invoked from this point on.

Today the Earth is embedded with artifacts like computer networks and circuses that cannot be accounted for by appeal to either the properties of matter or biological evolution. That is, biological evolution does not provide us with adequate explanatory power to account for the existence of computers any more than the properties of matter can explain the existence of giraffes. Computers are manifestations of yet another causal principle: *the evolution of culture*.

Thus pattern in the structure and dynamics of information we encounter in the everyday world can be traced to three broad causal principles - the physical constraints and self-organizing properties of matter, biological evolution, and cultural evolution. This classification scheme, like all classification schemes, is somewhat arbitrary. There may be subclasses of these principles that deserve to be considered principles unto themselves [note 2], or one could argue that evolution is a self-organizing property of matter, albeit a spectacular one [note 3]. The point is: culture is the only process that has arisen since the origin of life that relentlessly exploits the combinatorial potential of information. Despite the fact that culture is grounded in biology (like biology is grounded in the physical constraints and self-organizing properties of matter), the probability of computers arising spontaneously in an information space not acted upon by cultural evolution (like the probability of giraffes arising spontaneously in an information space not acted upon by biological evolution) is vanishingly small. Thus it is inappropriate to dismiss culture as a predictable extension of biological evolution. It is qualitatively different from anything else biology has produced.

Since the machinery that renders cultural evolution - the human brain - is a product of biological evolution, much of what is `out there' can not be cleanly traced to a biological or cultural origin. We will discuss how biology constrains culture through the preferential spread of memes that satisfy biologically-derived needs. It goes the other way too; culture not only affects biological fitness through its effect on behavior (a phenomenon known as the Baldwin Effect) but it dramatically modifies the biological world. Some of the ways in which biological information gets tainted with cultural information seem relatively inconsequential, such as the trimming of hedges, whereas others, such as dog-breeding, have a long-lasting effect. (In fact, one could view dogs as the consequence of a memetic trajectory that was launched by the need to protect property.) Nevertheless, much as it is not imperative to address the role of physical constraints like gravity in studies of, say, embryonic development or squirrel foraging behavior, much can be said about culture without addressing the role of biological constraints.

1.3 Taking the Meme-Evolving Apparatus Seriously

The most salient shortcoming of existing models of cultural evolution, and quite possibly the reason they have had relatively little impact, is that although they tell us much about the transmission or characteristics of `catchy' memes, they fail to adequately address the issue of how novelty is generated. To be of significant theoretical or predictive value memetics must give serious consideration to the processes by which experience in the world turns into new memes in our brains, and address how memetic novelty is expanded further through creative processes. Studies of creativity, on the other hand, have focused on the *individual*, obscuring the fact that creativity is a collective affair e.g. (Lenat [54], Schank & Leake [82], Mitchell [67], Boden [6]). The ideas and inventions an individual produces build on the ideas and inventions of others (the ratchet effect). Which memes spread and which ones die off reflects the dynamics of the entire society of individuals hosting them.

Thus although at a sufficiently abstract level the notion that culture evolves is obvious, we lack a theoretical framework that bridges transmission studies with studies of creativity, and spells out explicitly how the concept of evolution maps on to the case of culture. To accomplish this we need more than a quick and dirty list of what makes a meme `catchy'; we have to consider the extent to which it resonates with and enriches the complex web of assumptions, beliefs, motives, and attitudes of its host - no simple matter. In short, we have to take the meme-evolving apparatus very seriously.

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2 Meme: the Unit of Information that Evolves Through Culture

Because the concept of the individual is so germane to the human experience we have an anthropocentric tendency to assume that the individual is the appropriate basic unit of analysis. This tendency is probably exacerbated by the fact that in biology the individual *is* the object of the relevant evolutionary process (or more specifically the phenotypic expression of the information undergoing evolution). The memetic approach involves relinquishing our focus on the individual, and concentrating instead on the meme as the object of a second evolutionary process that makes cognition possible. This perspective can feel unnatural and disorienting but it discloses population-level phenomena that would otherwise go unnoticed because they are not readily detected through introspection.

2.1 The Distinction Between a Meme and its Phenotypic Implementation

Durham [22] defines a meme as "any kind, amount, and configuration of information in culture that shows both variation and coherent transmission." Problems with this definition arise because it does not distinguish between cultural information as mental representation and cultural information as implemented behavior or artifact.

The genotype-phenotype distinction is useful here. The cultural analog of a genotype is the mental representation of a meme, and the analog of a phenotype is its *implementation*, or the form it takes if it gets expressed or communicated, typically as action or vocalization. Implementation transforms a meme, incorporating syntactic features characteristic of the channel through which it is conveyed (Brooks [10]). Thus, for example, a dance step looks different with each individual who performs it.

2.2 The Interconnectedness of Memes

Biologists use the term `allele' to capture the notion of alternative heritable versions of a gene, and Durham [22] accordingly adopted the term `allomeme' to refer to alternative versions of a meme. This basic concept was tailored to meet the constraints of biology; we all have the same number of genes, and two alleles of each gene (one from each parent). The cultural analog may be too clumsy to capture the subtle relationships between memes. Memes often appear to be stored in a distributed, network-like fashion, connected through webs of association (Hebb [32], Quillian [74], Pribram [73]) there is not necessarily a definitive rationale for saying where one stops and another begins, in semantic space let alone physical space. For example would we consider `My mother looks good in blue' and `My mother looks good under a blue umbrella' to be allomemes of the same meme, or different memes?

This kind of difficulty is circumvented by avoiding the notion of alternate versions altogether and using the term `feature' to refer to a component of a meme. Thus related memes share features. In this paper, `feature' can refer to a component with any degree of granularity below that of the meme in question; thus the scope of what might be considered a feature could range from an entire array of visual information depicting every perceived quality of a particular umbrella (such as might occur early on in perception) to one bit of information indicating the presence or absence of an umbrella (such as might occur at an advanced stage of cognitive processing). There can be nonlinear (epistatic) relations amongst the features of a meme, as well as between a meme and its implementation.

2.3 Meme as Pattern of Information Encoded in the Focus

In his book *Thought Contagion* [57], Aaron Lynch claims "Much as computer viruses make up a small fraction of computer software, so too do pernicious thought contagions form a small part of our mental software." But is this conservative approach necessary, or even sensible? Where do you draw the line between potentially culturally-transmittable memes and the rest our "mental software"? The haiku-writer, for example, seems able to draw upon any sort of thought, memory, or imaginary construct. Therefore here we explore the opposite approach to that taken by Lynch; we bite the bullet and consider anything that can be the subject of an instant of experience, to be a meme. The category `meme' now includes not only obviously transmittable ideas like `Be good or you will go to Hell', but everything from a particular experience of vibrant `redness', to a realization of a shorter route to work, to a feeling of dread associated with a teacher's posture or facial expression. This may strike some readers as outrageous, but it doesn't really make things as unwieldy as it might seem to at first glance. For the price of this added complication we gain a bridge that connects memetics with phenomena like perception, body language, planning, deductive reasoning, emotion, categorization, analogy... the stuff of the social and cognitive sciences. It may be our only viable direction. A theory of mind that can account for myth and freestyle dance, not to mention rapid personality assessment, is not easily achieved.

Our concept of meme can be clarified by invoking Kanerva's [42] notion of the *focus* - that part of the mind in which sensation (either external or internal e.g. hunger) and stored memory interact to produce a stream of experience. The states of the neurons that comprise the focus determine the content and experiential quality of an individual's awareness. One can think of a meme as a pattern of information that is or has been encoded in an individual's focus. It can be subjectively experienced as a sensation, idea, attitude, emotion, or combination of these, and it can direct implementation by the motor apparatus.

2.4 Chunking and Categorization of Memes

Frequently many memes get integrated into one through a process referred to in the psychological literature as `chunking' (Miller [65]). Chunking involves forming associations amongst previously-learned memes and establishing this constellation of associations as a new meme in long term memory; it is analogous to the formation of coadapted genes, or *schemata* (Holland [36]). Whereas chunking generally refers to the binding of semantically unrelated memes (as in the memorization of an arbitrary string of numbers), categorization involves the recognition of semantic relationships. Categorization and the resultant hierarchical structure of knowledge will not addressed here in any depth, though it is of relevance to point out that it seems reasonable to expect that the more extensively memes have been chunked or categorized, the greater the complexity of what can be held in the focus at once. Thus what constitutes a meme (and thus a feature) will differ amongst individuals, and within an individual over time.

2.5 Core, Enabler, and Hitchhiker Features

A first step toward a `science of memetics' is to decompose memes into features or feature schemata according to how they relate to fitness. Here we will distinguish the following categories: (1) *core features*, that contribute directly to the fitness of a meme, (2) *enabler features*, that enable or facilitate the implementation of core features, and (3) *hitchhiker features*, which exist in the meme due to arbitrary or accidental historical associations to features of the first two kinds. Core features tend to convey semantic information, and enabler features syntactic information, though one can think of situations in which some semantic information serves simply to facilitate expression of other semantic information i.e. functions as an enabler. The first two categories are vaguely analogous to the categorization of genes as structural or regulatory, and the last category is inspired by the phenomenon of genetic hitchhiking (Kojima & Schaeffer [51], Maynard Smith & Haigh [62], Kaplan, Hudson & Langley [43]). The closer together genes are on a chromosome the less likely they will be separated by crossover, so the more tightly linked they are said to be. Hitchhiker alleles confer no fitness advantage, but endure because they are linked to alleles that are important for survival. In both genetic hitchhiking and its cultural analog there is indirect selection for useless (or even detrimental) patterns through their association with beneficial ones. The concept of hitchhiking is closely related to that of exaptation - the evolution of organs or traits not evolved through natural selection for their current use (Gould [29]).

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3 Selection and the Memetic Fitness Landscape

The next few sections examine in some detail how each of the three phases of evolution - selection, variation, and transmission - map onto the case of culture. Though these phases are discussed one at a time, it is worthwhile to keep in mind that in culture they are less spatiotemporally distinct than in biology. Selection can be coupled to either the generation of variation, or replication, or all three can occur simultaneously (for example when paraphrasing).

3.1 Memes `Rely On' Brains to Select, Vary and Replicate Them

Von Neumann [91] postulated that any self-replicating system consists of two parts: (1) *uninterpreted information* - a self-description that is passively copied to offspring, and (2) *interpreted information* - instructions for how to construct offspring. This turned out to be true of the genetic code; there are genes that provide instructions to the body for how to sustain itself, and genes that provide instructions for how, with the help of someone of the opposite sex, to create a child. But unlike genes, memes do not come prepackaged with instructions for their reproduction. They rely on the pattern-evolving machinery of their hosts' brains to create, select, and replicate them. Since we preferentially spread ideas that satisfy needs, our needs define viable niches for memes to evolve toward. As infants we might cry and kick no matter what need is most pressing, but as children we acquire and continually refine a repertoire of memes that, when implemented, satisfy various needs. We learn that reaching into the cookie jar satisfies one need, shouting `help' satisfies another, et cetera. Our memes, and the behavior they elicit, slide into need-defined attractors (regions of stability) in the memetic fitness landscape.

The fact that memes are not independently self-replicating does not prevent them from achieving reproductive success. In fact it may ironically work in their favor, because the cognitive machinery they depend upon not only actively manipulates them to produce `offspring-memes', but organizes them into a model of the world, or worldview, which it can use to figure out what to do whenever a situation is too complicated for its hardwired instincts. The worldview orchestrates behavior such that a meme gets implemented right when it is likely to be useful, and that increases the probability that other hosts will consider it worthy of replication. This also means that there is a continuous coevolutionary interplay between pattern and landscape, which contributes to the oft-noted rapidity with which culture evolves.

3.2 Brains Select Memes that Satisfy Biological and Cultural Needs

Since many of our needs have a biological basis - e.g. the need for food, shelter, et cetera - meme generation is largely constrained by our heritage as products of biological evolution. Thus the topology of the memetic fitness landscape largely echoes that of the biological fitness landscape. In the short term, the biological fitness landscape, and thus the memetic fitness landscape, fluctuates continuously as one need is satisfied and others take precedence (Hull [41], McFarland & Sibly [64], Gabora & Colgan [24], Maes [59]). For example, after eating, ideas that pertain to finding food are less likely. However over the lifetime of an individual the set of biologically-based needs remains relatively constant. The trajectory of survival-motivated thought can be described as a limit cycle (periodic attractor) that moves through the set of stable memes whose implementations satisfy the various biological needs.

Variation-inducing operations restructure conceptual space and thus affect the memetic fitness landscape. Much as the evolution of rabbits created ecological niches for species that eat them and parasitize them, the invention of cars created cultural niches for gas stations, seat belts, and garage door openers. As one progresses from infanthood to maturity, and simple needs give way to increasingly complex needs, the stream of thought acquires the properties of a chaotic or strange attractor, which can be viewed as the formation of crevices in the original limit cycle. The landscape is fractal (i.e. there is statistical similarity under change of scale) in that the satisfaction of one need creates other needs - every crevice when examined closely reveals more crevices. This is analogous to the fractal distributions of species and vegetation patterns described by ecologists (Mandelbrot [60], Palmer [69], Scheuring & Riedi [83]). An endpoint of a cultural evolution trajectory turns out to be not just a point in multidimensional space, but a set of points with their own fitness metric - a `micro-landscape' in its own right. So although the memetic fitness landscape *loosely* follows the biological fitness landscape, there are places where it deviates, and this effect undoubtedly becomes more pronounced throughout an individual's lifetime. This means that the potential for meme diversity, though constrained by host need, is open-ended.

3.3 Personal Versus Societal Worldviews

Our worldviews overlap to the extent that similar experiences and genetic make-ups cause our brains to store the same memes and styles of computation. But they don't overlap perfectly. Each host's train of thought traces out a unique trajectory through conceptual space. It can be useful to think in terms of not only the worldview of an individual, but also the worldview of a group or even human society at large, wherein all frontiers of human endeavor are incorporated.

3.4 The Landscape is Sculpted by the Need for Worldview Cohesion

A need that seems to surface to the forefront (have a large impact on the focus) when other needs are not pressing is the need to connect fragmented representations of the world into a logically-consistent worldview. Since our ability to make predictions and evaluate possible plans of action hangs on the accuracy of this worldview, the survival value of such a tendency is clear. McCulloch and Pitts [63] showed that networks made of neuron-like components that perform the logical operations AND, OR, and NOT are theoretically capable of computing any Turing machine-computable function. In connectionist-type systems, logical relations are represented implicitly as constraints on the possible states of a system, and computation proceeds through settling into a solution that satisfies many constraints, rather than then explicitly calculating a solution. This is accomplished through modification of the associative strengths amongst the components of the system, and the process is referred to as relaxation or simulated annealing.

3.5 Hard-wired Selection

To the extent that the memetic fitness landscape echoes the shape of the biological fitness landscape, to which we have been adapting since life began, cultural selection is built right into our architecture. Our perceptual and cognitive systems are wired up such that they are primed to focus on and highlight those aspects of external reality that are relevant to our survival (or were in the past). The mental representations we form reflect that bias e.g. (Hubel & Wiesel [39], Marr [61]). Second, the associative organization of memory constrains variation-generating operations. So selection is built right into our hardware.

3.6 Malleable Forms of Selection

In order to create, or even just understand, a new meme, there has to be a conceptual framework from within which it will make sense, and a need, or niche, for it. Therefore, any relevant precursor or "*proto-memes*' must first be assimilated (Wallas [93]). This constraint amounts to a malleable, or plastic, form of selection on new memes.

When one host exhibits a meme that another observing host values, the observing host often displays reinforcing body language and emits words of encouragement. Likewise, if the meme is threatening or inconsistent with valued memes, the observing host's words and behavior tend to be discouraging. Our need for social acceptance makes us more likely to exhibit memes that have been reinforced and less likely to exhibit those that have been discouraged. From a meme's-eye perspective this looks like a subtle strategy by which a meme in one host selectively shapes the probability of its implementation in other hosts.

Selection can also occur after a representation has been internalized but prior to being phenotypically expressed. For example, *mentally simulating* what would happen if an idea were implemented can weed out unworthy ideas (Nersessian [68]). The success of mental simulation varies with the accuracy of ones' internalized model of the world, but it provides at least a rudimentary form of selection.

Finally, selection can operate through *biased transmission*; that is we choose to imitate certain individuals and not others (Boyd & Richerson [9]).

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4 Creativity: the Source of Cultural Variation

4.1 Strategy Guides Trajectories through the Memetic Fitness Landscape

The existence of an open niche does not guarantee that the niche will ever be found. In biology the process by which this happens is largely random. Though most mutations and recombinations are detrimental, so many variants are generated that it is not necessary to be clever about *how* they are generated. We could say that biological evolution is a more breadth-first search algorithm than cultural evolution because it relies primarily on massive parallelism rather than strategy.

In culture, on the other hand, variants are generated strategically. We could say that cultural evolution is a more depth-first approach to searching a space of possibilities. The trajectory of a stream of thought is constrained by connections between representations that are similar or spatiotemporally related (Schank [81]), which increases the probability that an advantageous variant is found. For example, when considering the problem of having to get out of your car every day to open the garage door, you would not think about doilies or existentialism, but concepts related to the problem - electricity, human laziness, and various openers you have encountered before. If you were to spend several months on this problem, ideas that pertain to openers of various kinds would for you become a highly active region of conceptual space, analogous to the uncharacteristically high level of activity (and polymorphism) in a small portion of the human genome known as the major histocompatibility complex (MHC) which deals with immune response (Hughes & Nei [40]). During creative thought, memes potentially relevant to a solution would evoke or activate one another, altering or strategically (though not necessarily consciously) manipulating them, a process that is said to involve pattern completion, constraint satisfaction (Rumelhart & McClelland [80]), and the tweaking, blending, redescription, abstraction, and recoding of representations (Hofstadter [34], Holland &c. [37], Karmiloff-Smith [44], [46], Ram [75], Clark & Thornton [14]). Neurophysiological evidence suggests that creating new contexts for representations, that is manipulating them, involves hippocampal binding or linking (Squire [88]), and synchronization (Klimesch [49]), of features encoded by distributed cortical cell assemblies.

To sum up: fueled by need and constrained by association we carve out trajectories through meme space, and because the fitness landscape that guides this process is fractal, every time that landscape steers the production of a new meme (or even just a slight variant of a preceding meme), the new meme in turn redefines the landscape, and so on, recursively.

4.2 Sparse Distributed Memory as a Platform for Generating Variation

SPARSE, DISTRIBUTED MEMORY (Kanerva [42]), or SDM, is a mathematical model of the mechanics underlying the storage and retrieval of memories. It was motivated by the desire to understand how memory provides conscious experience with a thread of continuity via the spontaneous sequential activation of concepts or experiences that are related to one another, sometimes superficially, and other times through resemblances that are highly abstract or metaphorical.

Kanerva draws an analogy between the focus and a combined address-datum register in a computer; they both contain data and serve as a pointer to memory, and can both read from and write to memory. An instant of experience is encoded in the focus by a high-dimensional vector of difference relations, or bits, that represent the presence or absence of some feature, and the mathematics generalizes such that a pattern of bits can represent a value along some dimension. The Hamming distance between two memes is the number of bits that differ. (So the Hamming distance between 11111 and 11100 is two.) Since each meme has an antipode (for example, the antipode of 11111 is 00000), the space of all possible memes can be visualized as a sphere. The address of a meme is the information pattern that specifies where the meme is stored.

If *L* is the number of possible features in a meme, the number of possible memes is 2^L. Assuming *L* is large the size this space is enormous, so the memory is sparse in that it stores only a small fraction of the set of all possible memes. For example, to construct a SDM with *L*=1,000, then out of the possible addresses, a workable number of them, say 1,000,000, are chosen at random to be actual storage locations. The number of memes at Hamming distance k away from any given meme is equal to the binomial coefficient of *L* and *k*, which is well approximated by a Gaussian or normal curve. If meme *X* is 111...1 and its antipode 000...0, and we consider meme *X* and its antipode to be the `poles' of the hypersphere, then approximately 68% of the other memes lie within one standard deviation ( ) of the `equator' region between these two extremes (figure 1). As we move through Hamming space away from the equator toward either Meme *X* or its antipode, the probability of encountering a meme falls off sharply by the proportion . In our example, the median distance from one location to another is 424 bits, and 99.8% of stored memes lie between 451 and 549 bits of any given location.

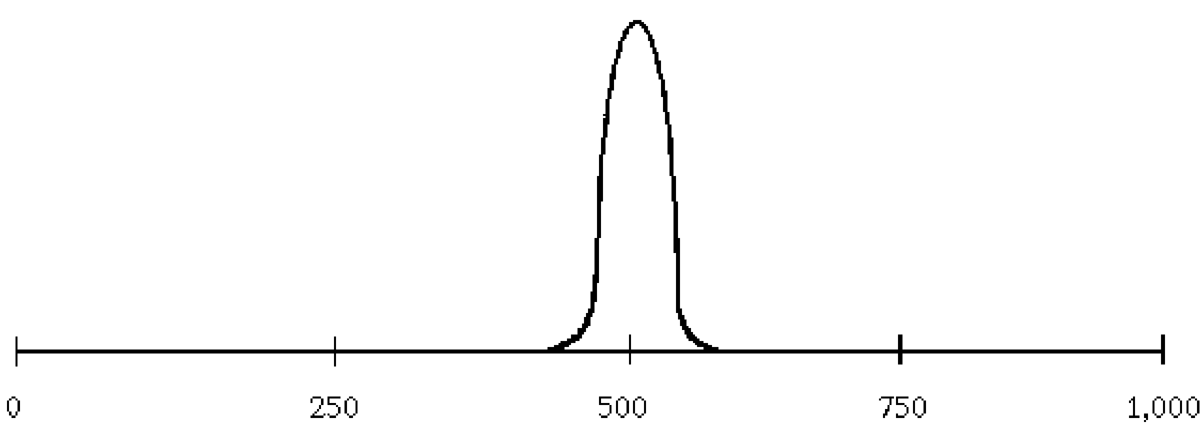

Figure 1: Schematic distribution of Hamming distances between addresses of meme *X* and addresses of storage locations

A computer reads from memory by simply looking at the address in the address register and retrieving the item at the location specified by that address. The sparseness of the SDM prohibits this kind of one-to-one correspondence, but it has two tricks up its sleeve for getting around this problem.

First, it feigns content addressability, as follows. The particular pattern of 1s and 0s that constitutes a meme causes some of the synapses leading out from the focus to be excited and others to be inhibited. The locations where memes get stored are memory neurons, and the address of a neuron amounts to the pattern of excitatory and inhibitory synapses from focus to memory that make that neuron fire. Activation of a memory neuron causes the meme to get written into it. Thus there is a systematic relationship between the memes' information content and the locations they activate.

Second, since the probability that the ideal address for storing a meme corresponds to an actual location in memory is vanishingly small, storage of the meme is *distributed* across those locations whose addresses lie within a sphere (or more accurately, hypersphere) of possible addresses surrounding the ideal address (figure 2). The radius (in Hamming metric) of this sphere is determined by the neuron activation threshold. Each location participates in the storage of many memes. In this example we assume that 10,000 memes have been stored in memory. Each meme is stored in 1,000 (of the 1,000,000 possible) locations, so there are approximately 10 memes per location. The storage process works by updating each of the *L* counters in each location; to store a 1 the counter is incremented by 1, and to store a 0 it is decremented by 1. These nearly one million operations occur in parallel.

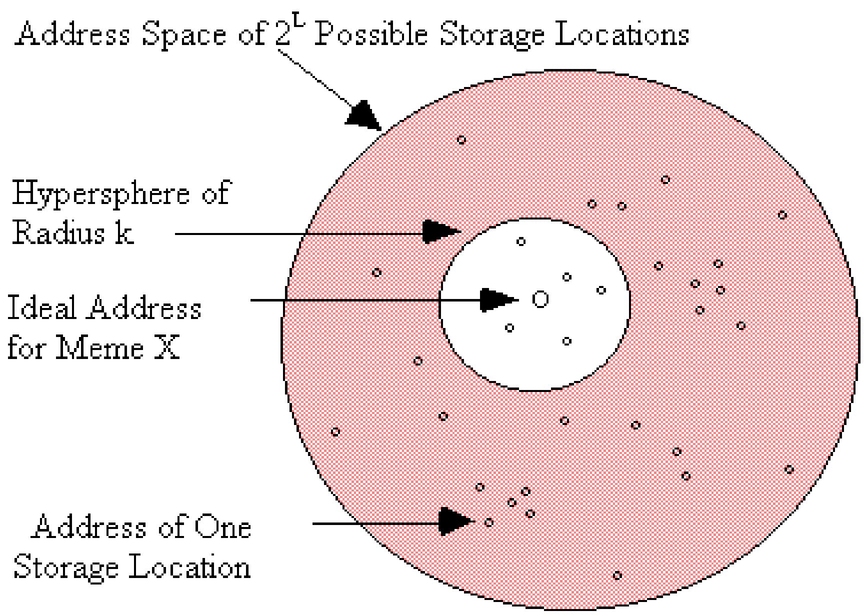

Figure 2: Meme *X* is stored in all locations within hypersphere of radius *k* surrounding its ideal address

If after a meme, say meme *X*, is stored, the individual's attention is directed toward external stimuli, then nothing is retrieved from memory. But to the extent that memory contributes to the next instant of awareness, the storage of *X* activates retrieval of not only *X* itself but all the other memes that have been stored in the same locations. The next meme to be encoded in the focus, , is found by determining the best match; that is, by averaging the contributions of all retrieved memes feature-by-feature. Whereas the 1,000 retrieved copies of *X* (and memes similar to *X*) reinforce one another, the roughly 10,000 other retrieved memes are statistically likely to cancel one another out, so that ends up being similar to *X*. Though is a reconstructed blend of many memes it can still be said to have been retrieved from memory. can now be used to address the memory, and this process can be reiterated until it converges on meme *Y* that satisfies a current need. This is how the SDM accomplishes depth-first search. The closer *Y* is to *X*, the faster the convergence. In our example, assuming r=425, if *X* and *Y* are more than 200 bits apart *Y* is unlikely to be retrieved, but if they are 170 bits apart *Y* will be retrieved in about four iterations.

Keeler [48] has shown that SDM is a superset of Hopfield-type and connectionist models of autoassociative or heteroassociative memory. The SDM formulation is used here because it lends itself to an understanding of the mechanics of phenomena we are interested in. Since the dynamics emerges from the statistics, rather than from a central executive, it can cope with creative and seemingly unmechanical cognitive phenomena such as wordplay or slips of the tongue. Moreover it is ideally suited to handle the problem of sequential access, which will become relevant when we look at how an infant establishes a train of thought. To model the recollection of a sequence, meme *X* is simply used as the address to write *Y*, *Y* as the address to write *Z*, and so on. Working memory can be viewed as the memes that lie within a given Hamming distance of the meme in the focus such that they are retrievable within a certain number of iterations. Categorization could involve the identification of a feature pattern, and readdressing memes that contain this pattern so that their new addresses put them within working memory reach of one another. Kanerva shows that the architecture of common neural components and circuits in the brain are ideally suited to implement a SDM.

In SDM, associations between memes are not explicitly represented as connection strengths but as proximity in multidimensional space. However in the end they amount to the same thing. The smaller the Hamming distance between two memes, the higher the probability that they will be retrieved simultaneously and blended together in the focus (or one after the other in a chain of related thoughts). What allows the memes to be retrieved simultaneously, however, is that they are either stored in the same neurons or in neurons with nearby addresses, which in turn reflects the neurons' connectivity. Thus factors that affect the storage of a meme will also affect retrieval of that meme; the two processes are intimately connected.

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5 The Replication and Transmission of Memes

The memetic approach to cognition is not incompatible with approaches that stress the role of innate mechanisms e.g. (Pinker [70]). Rather, as Lumsden & Wilson [56] point out, it builds on this framework, adding that the study of cognition will flounder until we admit that the role of transmission is equally undeniable. Transmission links the memetic processing within an individual to not only memetic processing in other directly-encountered individuals, but processing in individuals *they* encounter, and so on. The ideas and inventions any one individual produces build on the ideas and inventions of others. This phenomenon is known as the *ratchet effect*, and its impact is demonstrated in the following example. If you were suddenly dropped into the Australian desert, you probably would not survive for long. However if you were to run into an aborigine who grew up learning desert survival skills from her family and community that had been passed on and improved upon for generations (such as how to find water in obscure places) you might survive for some time [note 4].

5.1 Intra-Individual Meme Replication via Implicit Pointers to Memory

We saw how, unlike genetic material, memes do not contain instructions for how to make copies of themselves; they replicate when their hosts teach or imitate one another. The memes in a SDM-like memory, however, have a self-replication capacity in the following sense. The pattern of information that constitutes a meme determines which of the synapses leading out from the focus are excited, and which are inhibited - it determines how activation flows through the memory network - which in turn determines the neurons where the meme is stored and from which the next meme is retrieved. Thus embedded in the neural environment that supports their replication, memes act as implicit pointers to memory. These pointers prompt the dynamic reconstruction of the next meme to be subjectively experienced, which is a variation of (statistically similar to) the one that prompted it. It is in that sense that they self-replicate.

5.2 Transmission is Lamarkian and Phenotypically Mediated

Internal replication (with variation) makes cultural transmission Lamarkian - modifications acquired since the acquisition of a meme can be passed on to others (Dawkins [17]). The related point that transmission is phenotypically mediated, as Dennett [19] points out, makes a "science of memetics' less daunting. It means that, unlike biologists, we don't have to fully understand the nature of mental representation to study transmission.

5.3 Any Experience can Affect Transmission

While biological needs affect the focus from the inside, environmental stimuli impact it from the outside. The information-based orientation supports a broader conceptualization of the transmission process than is generally taken. For the purpose of understanding the evolutionary mechanics underlying culture, any interaction between an organism and its environment that impacts the focus is part of this process. It often occurs through imitation of conspecifics (Smith [86], Bonner [7], Robert [77]), or guided instruction (Vygotsky [92], Tomasello &c. [90]). but not necessarily. For example, does it matter whether a child learns to peel a banana by watching her mother, or a monkey, or a cartoon character on TV? What matters is that the child has a mental representation of how to peel a banana. All kinds of interaction with the environment provide us with new representations or alter existing ones, and therefore have the potential to affect the interplay of ideas and emotions that are culturally transmitted.

5.4 Transmission Studies in the Social Sciences

Steps toward an evolutionary perspective on cultural transmission have been taken in the social sciences. This research falls under various names: social diffusion e.g. (Rogers [79]), social epidemics e.g. (Mackintosh & Stewart [58]), coevolution (Durham [22]), social learning e.g. (Tomasello &c. [90]), and social contagion (Rodgers & Rowe [78]). There has also been work done on group creativity e.g. (Czikszentmihalyi [15]).

The evolutionary context could be made much more explicit in this work, capitalizing on what we have learned about evolution in the biological realm by looking for phenomena such as epistasis and drift (random statistical bias due to sampling error) (Wright [96], Cavalli-Sforza & Feldman [12]) or by viewing reciprocal interactions between like-minded individuals as a cultural analog of biological altruism. It may be through ongoing reciprocal interactions of this kind that a memetically-derived social structure emerges, wherein individuals who regularly generate pleasurable or powerful memes come to be observed carefully and imitated frequently, while other individuals are ignored. These outcasts may be excluded from memetic exchange and come to exhibit a cultural version of the Founder Effect (Holgate [35]) - reduced variation due to drift.

Our knowledge of biological speciation could be applied to study individuation and division of labor in a family or society. In both cases small differences are amplified through positive feedback leading to transformation of the space of viable niches for the evolution of information patterns. This approach could help us address questions such as why siblings are often so different from one another.

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6 A Scenario for the Origin of Cultural Evolution

We have discussed how memes evolve through selection, variation, replication and transmission. We now address the issue of how cultural evolution got started in the first place.

6.1 The Origin of Life and its Cultural Analog

The origin of life poses the following paradox: how could something as complex as a self-replicating molecule arise spontaneously? Traditional attempts to explain this entail the synchronization of a large number of vastly-improbable events. Proponents argue that the improbability of the mechanism they propose does not invalidate it because it only had to happen once; as soon as there was *one* self-replicating molecule, the rest could be copied from this template. However Kauffman [47] proposes an alternative scenario that does not entail the synchronization of numerous improbable events. He suggests that life arose through the self-organization of a set of autocatalytic polymers. When catalytic polymers interact with one another their average length increases. As their length increases, the number of reactions by which polymers can interconvert increases faster than the number of polymers. Therefore a set of interacting molecules under conditions such as are likely to have existed at the time life began would inevitably reach a critical point where there is a catalytic pathway to every polymer present. Jointly they form a self-reproducing metabolism.

We now ask: What is the cultural analog to the origin of life? One could say it is the point in history when organisms acquired the capacity for social transmission, but as many authors e.g. (Darwin [16], Plotkin [71]) have pointed out, although transmission is wide-spread throughout the animal kingdom, no other species has anything remotely approaching the complexity of human culture. Donald [20] argues convincingly that the bottleneck in cultural evolution is the capacity for innovation. Innovation requires more than a kind of awareness that integrates survival needs with environmental affordances, and draws upon memory only to interpret stimuli, or consult a mental map, or recall how some drive was satisfied in the past. It requires an ongoing train of creative representational redescription and counterfactual `what if...' type thinking. This suggests that the cultural analog to the origin of life was the origin of the first self-perpetuated, potentially-creative stream of thought in an individual's brain.

When an infant has its first experience, there is nothing in memory to draw upon to contribute to that experience; the first meme to occupy its focus does not remind it of anything. Therefore experience is initially driven only by external or internal stimuli, not by memory. Thus the evolution of culture poses a paradox analogous to that of the origin of the self-replicating molecule - how does an infant develop the capacity for a self-sustained train of thought that creatively integrates new experiences with previous ones? Consistent with Kauffman's assertion that the bootstrapping of an evolutionary process is not an inherently improbable event, the "it only had to happen once' argument does not hold water here because the cultural analog to the origin of life takes place in the brain of every infant.

6.2 Establishing an Autocatalytic Set of Sparse, Distributed Memories

This section outlines how a SDM-like stream of thought might get established. Let us say that the first meme to occupy an infant's focus and then get stored in memory is a visual experience of its mother in a blue coat. The next is the sound of a dog barking. The Hamming distance between these memes exceeds the maximum for one meme to evoke the memory of another, so the barking does not remind the infant of its mother. Later the infant sees its mother in a red coat. This meme evokes or `catalyzes' the memory of its mother in a blue coat. To avoid getting stuck in an endless loop wherein `mother in blue coat' then evokes `mother in red coat' et cetera, it may form the category `mother'. However *that* meme does not remind it of anything, so this stream of thought dies off quickly.

As the infant accumulates memes, the statistical probability that a meme in the focus will activate a meme from storage increases, so the streams of remindings get longer. Eventually the memory becomes so densely packed that any meme that comes to occupy the focus is bound to be close enough in Hamming distance to *some* previously-stored meme(s) to activate a variant of itself. This marks a phase transition to a state in which, just as with the origin of life, the sequential activation of self-similar patterns is self-propelled; the memes now form an autocatalytic set. The focus is no longer just a spot for coordinating stimuli with action, but a forum for the variation-producing operations that emerge naturally through the dynamics of iterative retrieval. The resultant memes evolve along different trajectories toward different basins of attraction, `specializing' in the fulfillment of one need or another. Those that satisfy the same need compete until one becomes habitual, while those that fulfill different needs are able to coexist within the same host. As with biological speciation, small differences are amplified through positive feedback leading to transformation of the space of viable niches for the evolution of information patterns.

Note that in this example the `mother' meme is the infant's first category. A simple way of describing this situation is: if the `mother in blue coat' meme is represented as 111, and the `mother in red coat' meme is represented as 110, the `mother' meme can be represented as 11*, where * means either 1 or 0. It is also the infant's first *derived* meme. That is, it is the first information pattern to enter the focus not purely by way of external stimuli but through the necessity of a logical operation on previously-stored memes - in this case an OR gate - which could be realized in the brain via adjustment of connection strengths. The act of categorization projects the original information space, which had n relevant dimensions, onto a new space that has n-1 dimensions (for example, here coat color is no longer relevant). It effectively makes the space denser, and increases susceptibility to the autocatalytic state. On the other hand, creating new memes by combining previously-stored memes could interfere with the establishment of a sustained stream of thought by increasing the dimensionality of the space, thereby decreasing density. If indeed cross-category blending disrupts conceptual autocatalysis, one might expect it to be less evident in young children than in older children, and this expectation is born out experimentally (Karmiloff-Smith [45]).

Note also that the density of memes necessary to reach and maintain this autocatalytic state will depend on the neuron activation threshold. If the threshold is too high (the hypersphere of potentially activated memes is too small) even very similar memes can not evoke one another, so a stream of remindings, if it happens at all, dies off readily. If the threshold is too low (the hypersphere too large), then any meme will evoke a multitude of others not necessarily meaningfully related to it. Successive patterns in the focus will have little or no resemblance to one another; the system may be catalytic but it is not autocatalytic. The free-association of the schizophrenic (see Weisberg [95]) seems to correspond to what one might expect of a system like this. For memory to produce a steady stream of meaningfully-related yet potentially creative remindings, the threshold must fall within a narrow intermediate range. This is consistent with Langton's [53] finding that the information-carrying capacity of a system is maximized when its interconnectedness falls within a narrow regime between order and chaos. The situation may turn out to be slightly more complicated; sustaining a creative train of thought may involve not only keeping the activation threshold within a narrowly-prescribed range but dynamically tuning it in response to the situation at hand. This is particularly likely if the memory is not uniformly dense (i.e. clusters of highly-correlated memes) or if different kinds or stages of thought require different degrees of conceptual blending. For example finding unusual associations, such as puns that employ epistatic relationships between semantic and syntactic components of a meme, may depend on the preconscious ability to voluntarily increase hypersphere radius. Refinement of the pun may then require a decrease in radius.

Thus we have a plausible scenario for how cultural evolution, like biological evolution, could have originated in a phase transition to a self-organized web of catalytic relations between patterns.

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7 Why is Culture Unique to Humans? - A Speculative Answer

Recall that in order for a network of memes to reach an autocatalytic state, the activation threshold must be calibrated to fall within a narrow range to achieve a delicate balance between the capacity for semantic continuity on the one hand and creative association on the other. The penalty for having too low a threshold would be very high; successive thoughts would not necessarily be meaningfully related to one another, and thinking would be so muddy that survival tasks are not accomplished. Too high a threshold, on the other hand, would not be life-threatening. The focus would virtually always be impacted with external stimuli or internal drives such as hunger; memory would be pretty much reserved for recalling how some goal was accomplished in the past. A stream of experience that involved the iterative reorganization of stored memes would likely die out before it produced something creative. This may be the situation present in most brains on this planet, and the reason that apes are limited to episodic memory e.g. (Donald [20]).

The advantages of a sustained train of thought would be largely lost on animals because they have neither the vocal apparatus nor the manual dexterity and freedom of upper limbs to *implement* complex ideas. No matter how brilliant their thoughts were it would be difficult to do something useful with them. Moreover, in an evolutionary line there is individual variation, so the lower the average activation threshold, the higher the fraction of individuals for which it is so low that they do not survive. It seems reasonable to suggest that apes are not *a priori* prohibited from evolving complex cognition, but that there is insufficient evolutionary pressure to tinker with the activation threshold until it achieves the requisite delicate balance to sustain a stream of thought, or to establish and refine the necessary feedback mechanisms to dynamically tune it to match to the degree of conceptual fluidity needed at any given instant. It may be that humans are the only species for which the benefits of this tinkering process have outweighed the risks.

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8 Computational Approaches to Cultural Evolution

Meme and Variations, or MAV (Gabora [25]) is a computer model of a society composed of interacting neural network-based agents. Unlike other such models that combine biological and cultural evolution e.g. (Ackley [2], Spector & Luke [87]) these agents don't have genomes, and neither die nor have offspring, but they can invent, implement, and imitate memes. MAV successfully evolves patterns of information through cultural implementations of variation, selection, and replication, and exhibits phenomena observed in biological evolution such as: (1) drift (2) epistasis increases time to reach equilibrium, (3) increasing frequency of variation-generating operations increases diversity, and (4) although in the absence of variation-generating operations meme evolution does not occur, increasing variation-generation much beyond the minimum necessary for evolution causes average fitness to *decrease*. MAV also addresses issues specific to cultural evolution, such as the effects of mental simulation, imitation, and strategy. Perhaps the most interesting finding it yielded was that although for the society as a whole the optimal creation-to-imitation ratio was approximately 2:1, for the agent with the fittest memes, the less it imitated (i.e. the more computational effort reserved for creation) the better.

MAV will hopefully serve as a stepping stone to more advanced models of memetic evolution. Of particular interest will be models that: (1) like Tierra, a model of biological evolution (Ray [76]), harness the power of evolution to explore and transform an *open-ended* space of possible patterns, but (2) explore the space strategically on the basis of accumulated knowledge rather than at random [note 5], (3) have fitness landscapes that emerge through the needs of the agents within the constraints of their environment as in (Maes [59]), and (4) have agents that must learn for themselves which memes, when implemented, best satisfy each of their various needs.

Mathematical models of culture are too minimal to cope with the open-ended diversity of culturally-derived information (variation is generally restricted to trial and error learning or transmission error) l&c.one address the numerous intra-individual factors that undoubtedly have emergent inter-individual consequences, such as how representations are grounded in experience and how they are stored, retrieved, and implemented. Models of individual intelligence and creativity, on the other hand, lack transmission and replication. Although this research may not explicitly attempt to address group processes it typically focuses not on the sorts of simple inferences and creative acts that a person raised alone in the wild would be capable of, but on complex acts such as story comprehension, that might be unlikely to develop in isolation. With the advent of massively parallel computers it is becoming increasingly feasible to place computational models of individual creativity and problem-solving in a cultural context. This approach could provide insight into not only problems pertaining to representation and culture, but evolution in general, through comparison with biology. For example, the question of why there is so much redundancy in the genetic code has generated much discussion which may also apply to the question of why there are redundant mental maps in the brain; both may reflect constraints on the nature of an information-evolving code.

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9 A Memetic Perspective on Induction, Censors, and the Unconscious

We turn now to how the cultural evolution perspective can shed light on some aspects of how people think and interact.

9.1 Mental Censorship and Induction

Initially an infant is unselective about meme acquisition, since (1) it doesn't know much about the world yet, so it has no basis for choosing, and (2) its parents have lived long enough to reproduce, so they must be doing something right. However just as importing foreign plants can bring ecological disaster, acquisition of a foreign meme can disrupt the established network of relationships amongst existing memes. Therefore the infant develops mental censors that ward off internalization of potentially disruptive memes. Censors might also be erected when a meme is found to be embarrassing or disturbing or threatening to the self-image (Minsky [66]). In a SDM-type architecture this could be accomplished by increasing the activation threshold so as to prematurely terminate the relaxation process and prevent the content of the focus from assimilating with stored memes. Much as erecting a fence increases the probability that people will stay on either one side or the other, this would warp the statistical probabilities involved in this meme's partaking in the ongoing process of associative recall, such that the individual either avoids the censored meme or dwells on it excessively. This seems to be consistent with our bipolar attitude toward highly censored subjects such as aggression and sexuality.

On the other hand, when the cost of the disruption is outweighed by the potential benefit accrued by a world model that can accommodate the new meme, the threshold would be lowered. Most thoughts seem to have little effect on our understanding of the world at large, but once in a while we experience a meme that significantly modifies our world view. The situation is reminiscent of superconductivity; lowered resistance increases correlation distance, and thus a perturbation to any one pattern can percolate through the system and affect even distantly-related patterns. It would be interesting to determine experimentally whether the "inductiveness' of our memes, like other self-organizing systems, exhibits the ubiquitous inverse power law (Bak, Tang & Weisenfeld [3]). Just as in a sand pile perched at the proverbial Tedge of chaos' once in a while a collision between two grains will lead to another in just the right chain reaction to generate a large avalanche, occasionally one thought will trigger a chain reaction of others in a way that reconfigures the conceptual network.

9.2 The Unconscious

The concept of the unconscious has been influential and useful despite the obvious incongruity: how is it that we can consciously discuss something that is unconscious? What we may be referring to is the fleeting experience of memes that are dynamically reconstructed as in a SDM but which do not readily assimilate with other memes and so get discarded from the focus. In other words, the need for worldview consistency prohibits further computational resources from being spent on trying to integrate what appears to be a nonsensical construction into the memory. Of course there is no reason why a meme that is not immediately integrated into the memory might nevertheless affect the memory; the very process of determining whether it can be assimilated or not might itself have effects that infiltrate the system. This possibility is supported by the finding that subjects' behavior can be affected by priming material of which they have no recall e.g. (Dunbar & Schunn [21], Fehrer & Raab [23]). Subconscious processing of this sort could, in fact, resculpt the memetic fitness landscape in such a way that a previously-discarded meme is more readily assimilated the next time it is encountered.

9.3 Cultural Momentum

Despite being derived, directly or indirectly, from human need, memes do not always promote our survival (Greene [30], Alexander [1]). As Dawkins [18] points out, "It is true that the relative survival success of a meme will depend critically on the social and biological climate in which it finds itself, and this climate will certainly be influenced by the genetic make-up of the population. But it will also depend on the memes that are already numerous in the meme-pool." Much like runaway selection in biology, once a meme can replicate with variation on the basis of some selection criterion, it can evolve out of the orbit of the need that originated it. We can't *help* but engage in a stream of thought, spontaneously generating new memes like "if only such and such had been different...S, any more than biological evolution can help but generate new species. This *cultural momentum* could explain why, despite the intuition that individuals control their streams of thought, creators often express surprise at the sudden appearance of an idea, and deny active effort in its immediate creation (Bowers &c. [8], Guilford [31], Kubose &c. [52], Wallas [93]). We seem to control the birth of `our' ideas only to the extent that we provide a fertile ground for them to be fruitful and multiply - by internalizing relevant background knowledge, identifying new needs, and exposing ourselves to stimuli that help trigger ideas that fulfill those needs. (So if you don't like this idea, don't blame me.)

Spurious basins of attraction sometimes arise in recurrent neural networks through the compositional interaction of explicitly-trained attractors (Hopfield [38]). Cultural momentum may boil down to a phenomenon of this sort. Just because the memetic fitness landscape largely echoes the biological fitness landscape, that doesn't mean that behavior elicited by memes in spurious basins of attraction arising through representational redescription need always be conducive to survival. Nevertheless a stream of thought could be censored before it elicits harmful behavior. Streams of thought probably get blocked or sidetracked on a regular basis, not just by censors, but by minute-to-minute undulations in the hyperdimensional fitness landscape, that is, change in the relative urgency of the multitude of survival-related or derived needs impacting the focus.

The concept of cultural momentum sheds light on the issue of free will. Those who argue for the existence of a central executive in memory may come to be viewed as the creationists of philosophy and cognitive science. Human will can instead be viewed as the emergent orchestration of needs, stimuli, and retrieved memories impacting the focus, which is subject to cultural momentum and therefore, in a sense, beyond our control.

9.4 The Birth of Creative Ideas

The biologically-inspired model developed here supports a variant of the combination theory of creativity - that new ideas arise through combinations and transformations of old ones (Boden [6], Koestler [50]). The aspect of this theory that does not ring true is that it neglects the role of emotions. Here we consider emotions, as well as ideas, to be encoded as information in memes; some components of a meme are simply interpreted by parts of the mind that experience them as emotion, whereas others are interpreted by parts of the mind that experience them as ideas. Much research on analogy deals with how the structure or `conceptual skeleton' underlying one idea gets abstracted and applied to another

(Gentner [26], Gick & Holyoak [27]). We can expand on this general idea by suggesting that many forms of creative expression begin with the (unvoiced) question: What would the pattern of information that encoded the emotion I experienced during *this* particular event look like if expressed through the constraints of *that* medium? The existence of inherent limitations on how a pattern could be translated from one domain to another is consistent with the frequent observation that creativity involves both freedom and aesthetic constraint. Thus all creativity is directly or indirectly derived from experience in the world, and since the mathematics underlying this world, the set of all natural functions, is a small subset of all *possible* functions, the constraints that guide creation are not arbitrary but objective and familiar; for example the drum beat of a song might echo a heartbeat, when the rhythm and chord progression are reminiscent of the sound of someone sobbing we feel sad, and we hear the wrong note even if we have never heard the song before.

It makes sense to expect that a meme or meme complex that has been censored (for example because it evoked unbearable sadness or anger) would be vulnerable to being targeted as an area where worldview cohesion could be increased. Since at the time the censored material was experienced it was prohibited from forming associations to obviously-related memes, it in turn can not be *retrieved* through these expected or straightforward associations. It can only be retrieved via `backdoor entrances', that is associations that reflect structural congruity at an abstract level. Thus a musician may come to habitually funnel patterns encountered in a variety of domains - and particularly censored material - through modules that filter out hitchhiker and enabler features, and adapt the core features (or feature schemata) to the constraints of music. It is in this repackaged format that memes originally deemed dangerous can be integrated into the memory at large without harm, and it is through this process that the creator establishes a sense of control over memes that were previously `off-limits'.

9.5 Conceptual Linkage Disequilibrium and Hitchhiking

Arguments against a theory of cultural evolution generally consist of a series of statements as to how the cultural situation differs from that of biology e.g. (Gould [28], Thagard [89]). These arguments, however, do not constitute a viable reason to discard the idea that culture is an evolutionary process. Imagine that 100 years before Darwin proposed the theory of biological evolution through natural selection, another scientist had discovered another system whereby patterns of information evolved, say in a test tube. Given this scenario would it have made sense for Darwin to dismiss the importance of biological evolution simply because it proceeds through different mechanisms from the originally-discovered test tube form of evolution? This would obviously have been foolish. It would have robbed humanity of not only the unifying power of a theory of biological evolution, but the opportunity to use knowledge of how evolution works under one set of constraints and affordances as a scaffold to direct the study of how it works under a different set of constraints and affordances. But time and again it is argued that a theory of cultural evolution is doomed simply because it would have to work through different mechanisms from those of biological evolution.

Ironically this situation in itself provides us with a nice example of how knowledge of evolution acquired in the realm of biology can help unravel analogous situations in the realm of culture. The biasing effect of historical association is an important theme in population genetics. Alleles of linked genes, such as the those that code for red hair and freckles, continue to co-occur more often than chance even after individuals in the lineage from which these alleles originated begin mating randomly with individuals from other lineages that did not have these alleles. One can theoretically measure the number of generations necessary for these genes to achieve a state of random association or *linkage equilibrium*, and this process can be modeled computationally. Similarly, people often have difficulty applying an idea or problem-solving technique to situations other than the one in which it was originally encountered, and conversely, exposure to one problem-solving technique interferes with the ability to solve a problem using another technique e.g. (Luchins [55]). Psychologists refer to this as *mental set* (though it is more commonly known as `throwing the baby out with the bathwater'). We could view mental set as a state of conceptual linkage *dis*equilibrium. In the present example, conceptual linkage disequilibrium hinders our ability to abstract the basic concept of evolution from its biological manifestation so that it can be applied with ease to the case of culture. One could argue that it would make sense for cultural evolution to be the default form of evolution in disciplines outside of biology, much as in tropical climates the default form of skiing is water-skiing rather than snow-skiing.

Conceptual linkage equilibrium is achieved when all instances of hitchhiking have been obliterated. In an influential paper on the relationship between DNA polymorphism and recombination rates, Begun and Aquadro [5] suggested that genetic hitchhiking may have significant evolutionary impact:

"This correlation suggests that levels of neutral variation in many of the gene regions for which variation has been measured have been reduced by one or more hitchhiking events. Provided that a new selectively favored mutation goes to fixation before another advantageous mutation arises close to it, each fixation will be surrounded by a `window' of reduced polymorphism, the relative size of which is proportional to the rate of recombination for that region of the genome." The general idea here translates nicely to cognition: if a meme goes to fixation in a society due to selective advantage conferred by one or more core features, its enabler and hitchhiker features will also exhibit reduced polymorphism, and the size of the `window' will vary with the extent to which hitchhiker features are conceptually bound to that meme. (For example, the basic concept of a typewriter/computer keyboard was historically enabled by the QWERTY keyboard design, which has now gone to fixation despite poor performance relative to other possible keyboard designs.) One could argue that recreation is the re-creation of information patterns in different domains from the ones in which they were originally encountered, thereby filtering out conceptual prejudices that reflect nothing more than mechanical constraints or historical legacies of the original domain. Play, intellectual pursuits, and other creative endeavors are then algorithms for achieving a state of conceptual linkage equilibrium through mental operations that, like genetic recombination, increase polymorphism by reducing fixation through hitchhiking.

The account of creativity proposed here may seem too simple to explain the seemingly limitless human potential for creativity, but it may seem less far-fetched when we consider the variety of species produced by biological evolution, which operates without the benefit of strategy. Furthermore, raw materials for the creative process may be acquired in exceedingly subtle ways. It is conceivable that you might watch a stream flow and without your consciously thinking, "It flows... things can flow... *I* could even, in some sense, adopt a more flowing approach to life", the experience might be reconfiguring your memetic infrastructure in a way that makes you more easygoing. I am not making any claims about the extent to which experiences of this sort affect us or even whether they occur at all, but rather suggesting that we not prematurely place a lid on the kinds of processes that could affect a network of representations and thereby affect creation and transmission.

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10 Memetics as the Missing Link Between Science, Spiritual Notions, and Feminism

Recall that to implement a meme is to express it, so that it crystallizes from the world of ideas into words or body language or objects in the physical world. Memes fool potential hosts into believing they want or need or identify with them by attaching themselves to supporting memes that we already identify with, or that represent things we need or want (as advertisers are well aware). Thus the greater the extent to which we identify with or value ourselves in terms of the memes (including those that pertain to the self) and implemented artifacts we possess or lack, the more vulnerable we are to ever-more-seductive forms of persuasion and advertising which tie up time, energy, and resources that could be applied toward other goals.

One way to defend oneself against painful or manipulative memes is to construct what Dennett [19] refers to as a `meme-immunological system'; that is, formulate new memes specifically to deflect `memetic antigens'. However constructing `memetic antibodies' of this sort is time-consuming, and like any immunological response it has to be repeated every time the outside agent evolves a counter-response. Perhaps this explains the purported benefits of `transcending the ego' e.g. (Walsh & Vaughan [94]), which can be taken to mean getting in touch with who we were before our minds were colonized by memes, through practices such as meditation. These practices may also give the brain time to anneal material that was never fully assimilated because of distraction or censorship - mend flaws in the fabric of the individual's worldview - so that the censor-ridden personal worldview comes to more closely approximate unbiased conceptual space. Release from the restrictive power of censors may produce a feeling of unity or one-ness.

One of the things I hope the study of memetics will one day shed light on is the cumulative effect on women's' self esteem of encountering the default "he" or "his", or phrases like "man and his world". Each time it happens, it reinforces, however subtly, the thought `I'm not one of the important ones', or `that doesn't pertain to me so I don't really count'. The effect of this may be insignificant the first few, or even hundred times it happens. But by the time a young girl reaches adulthood, experiences of this kind probably number in the millions, and that may be when the effects start to kick in.

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11 Can Cultural Evolution Provide a Synthetic Framework for the Cognitive and Social Sciences?

This paper presents a theoretical framework for cultural evolution, adopting an approach analogous to that of the population geneticist in that it emphasizes meme evolution through social interaction and de-emphasize individual `hosts'. Although the cultural evolution of memes operates through very different mechanisms from those of biology, culture is the only system comparable to biology, because it is the only other system to exhibit the imperative features of evolution - adaptive exploration and transformation of an information space through variation, selection, and transmission. All pattern in the information we encounter can be traced to either (1) the physical constraints and self-organizing properties of matter, (2) biological evolution, (3) cultural evolution, or (4) interactions between these causal principles.

One important difference between the two forms of evolution is that culture is less random - new patterns have a greater-than-chance probability of being more fit than their predecessors. The reason for this is interesting. Since memes (unlike genomes) do not come packaged with instructions for their replication, they must rely on the pattern-evolving machinery of our brains to do it for them. Ironically, this state of dependence enhances their proliferative potential, because the machinery they depend upon constructs and continually updates mental models of its world - that is, weaves the memes into a worldview - and uses this worldview to enhance the assimilation and implementation of the memes and their offspring.

Cultural evolution presents a puzzle analogous to the origin of life: the origin of a self-sustained stream of potentially-creative thought in an infant's brain. The idea that life originated with the self-organization of a set of autocatalytic polymers suggests a possible mechanism for how this comes about. Once a threshold density of assimilated memes is surpassed, any meme that occupies the focus is close enough in Hamming distance to evoke or `catalyze' the spontaneous retrieval or creative reconstruction of a statistically similar meme, thus the memes form an autocatalytic set. Note that this macroscopic account suggests an explanation for only that aspect of human consciousness that differentiates us from other `experiencers'; it does not address the mystery of `raw awareness' that some say characterizes not only our experience but that of a cow or a mosquito or even a thermostat e.g. (Chalmers [13]). Whether or not this specific theory turns out to be correct, it illustrates how the analogy to biology can focus our study of culture by providing a scaffold around which explanatory theories can be built.

The cultural framework for cognition developed here suggests tentative explanations for psychological phenomena such as censorship and creativity, and why they are virtually unique to humans. It also suggests explanations for various social phenomena. For example the telling of a story, rumor, or joke can be viewed as an act of memetic altruism between like-minded individuals analogous to the biological altruism that occurs between genetically-similar individuals. Ongoing reciprocal interactions of this kind may result in the emergence of a memetically-derived social structure.

If we are to take seriously the idea that culture is an evolutionary process, we can look to evolution to provide the kind of overarching framework for the humanities that it provides for the biological sciences. This approach may put us on the road to understanding the pervasiveness, diversity, and adaptive complexity of the cultural debris that surrounds and infests us.

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Notes

1. Note that by `causal principle' I mean something that generates useful descriptions, rather than a `law'.

2. Though viruses are unique in the biological world in that they rely on hosts to replicate, we will consider viral evolution an anomalous offshoot of biological evolution, because: (1) the evolving patterns of information are encoded as sequences of nucleotides, (2) variation is through mutation and recombination, and (3) transmission and selection are mediated through genotype.

3. Or one could argue that the `selection' of matter over antimatter, and its subsequent amplification and variation, constitutes yet another form of evolution.

4. This example is a variation of one transmitted by R. Boyd pers. com.

5. MAV has this property to some extent; a more sophisticated example is Copycat, a model of analogy-building, (Mitchell [67]).

References

[1] Alexander, R.D. (1980) Darwinism and human affairs, Pitman.

[2] Ackley, D. (1994) A Case for Distributed Lamarkian Evolution. In Artificial Life III, Addison-Wesley.

[3] Bak, P., Tang, C., & Weisenfeld, K. (1988) Self-organized criticality. Phys. Rev. A 38: 364.

[4] Bateson, G. (1972) Steps to an ecology of mind, Ballantine Books.

[5] Begun, D.J. & Aquadro, C.F. (1992) Levels of naturally occurring DNA polymorphism correlate with recombination rates in D. melanogaster. Nature, 356, p. 519-520.

[6] Boden, M. A. (1991) The creative mind: Myths and mechanisms, Cambridge University Press.

[7] Bonner, J. T. (1980) The evolution of culture in animals, Princeton University Press.

[8] Bowers, K.S., Regehr, G., Balthazard, C. & Parker, K. (1990) Intuition in the context of discovery. Cognitive Psychology, 22:72-110.

[9] Boyd, R. & Richerson, P. J. (1985) Culture and the evolutionary process, The University of Chicago Press.

[10] Brooks, V. (1986) The neural basis of motor control, Oxford University Press.

[11] Campbell, D. T. (1987) Evolutionary epistomology. In Evolutionary epistomology, rationality, and the sociology of knowledge, eds. G. Radnitzky and W. W. Bartley, 47-89, Open Court.

[12] Cavalli-Sforza, L. L. & Feldman, M. W. (1981) Cultural transmission and evolution: A quantitative approach, Princeton University Press.

[13] Chalmers, D.J. (1996) The conscious mind: In search of a fundamental theory, Oxford University Press.

[14] Clark, A. & Thornton, C. Trading spaces: Computation, representation, and the limits of uninformed learning. Forthcoming in Brain and Behavioral Sciences.

[15] Czikszentmihalyi, M. (1990) Flow: The Psychology of Optimal Experience. Harper & Row.

[16] Darwin, C. (1871) The descent of man, John Murray Publications.

[17] Dawkins, R. (1976) The selfish gene, Oxford University Press.

[18] Dawkins, R. (1982) The extended phenotype, W. H. Freeman and Company.

[19] Dennett, D. C. (1995) Darwin's dangerous idea, Little, Brown and Company.

[20] Donald, M. (1991) Origins of the modern mind, Harvard University Press.

[21] Dunbar, K. & Schunn, C.D. (1990) The temporal nature of scientific discovery: The roles of priming and analogy. In: Proceedings of the Twelfth Annual Meeting of the Cognitive Science Society, 93-100.

[22] Durham, W.H. (1991) Coevolution: genes, culture, and human diversity. Stanford University Press.

[23] Fehrer, E. & Raab D. (1962) Reaction time to stimuli masked by metacontrast. Journal of Experimental Psychology, 63, 143-147.

[24] Gabora, L. M. & Colgan, P. W. (1990) A model of the mechanisms underlying exploratory behaviour. In The simulation of adaptive behavior, eds. S. Wilson and J. A. Mayer, MIT Press.

[25] Gabora, L.M. (1995) Meme and variations: A computational model of cultural evolution. In 1993 Lectures in Complex Systems, Addison-Wessley.

[26] Gentner, D. (1983) Structure-mapping: A theoretical framework for analogy. Cognitive Science, 7(2).

[27] Gick, M.L. & Holyoak, K.J. (1983) Schema induction and analogical transfer. Cognitive Psychology, 15, 1-38.

[28] Gould, S. J. (1991) Bully for brontosaurus: reflections in natural history. W. W. Norton & Company. p. 63-66.

[29] Gould, S.J. & Vrba, E.S. (1982) Exaptation - a missing term in the science of form. Paleobiology, 8(1), 4-15.

[30] Greene, P.J. (1978) From genes to memes? Contemporary Sociology 7, 6-709.

[31] Guilford, J.P. (1979) Some incubated thoughts on incubation. Journal of Creative Behavior, 13, 1-8.

[32] Hebb, D. (1949) The organization of behavior, Wiley and Sons.

[33] Hofbauer, J. & Sigmund, K. (1988) The theory of evolution and dynamical systems, Cambridge University Press.

[34] Hofstadter, D. R. (1985) Variations on a theme as the crux of creativity. In Metamagical Themas, 232-259, Basic Books.

[35] Holgate, P. (1966) A mathematical study of the founder principle of evolutionary genetic. J. Appl. Probl., 3, 115-128.

[36] Holland, J. K. (1975) Adaptation in natural and artificial systems, University of Michigan Press.

[37] Holland, J. H., Holyoak, K. J., Nisbett, R. E. & Thagard, P. R. (1986) Induction, MIT Press.

[38] Hopfield, J.J. (1982) Neural networks and physical systems with emergent collective computational abilities. Proceedings of the National Academy of Sciences (Biophysics). 79(8), 2554-2558.

[39] Hubel, D.H. & Wiesel, T.N. (1979) Brain mechanisms and vision. Scientific American, 241(3), 150-62.

[40] Hughes, D.M. & Nei, M. (1988) Patterns of nucleotide substitution at major histocompatibility complex class I loci reveals overdominant selection, Nature, 335, 167-170.

[41] Hull, C. L. (1943) Principles of behavior, Appleton-Century-Crofts.

[42] Kanerva, P. (1988) Sparse distributed memory, MIT Press.

[43] Kaplan, N.L., Hudson, R.R., & Langley, C.H. (1989) The Rhitchhiking effect revisited. Genetics, 123, 887-899.

[44] Karmiloff-Smith, A. (1986) From meta-processes to conscious access: Evidence from children's metalinguistic and repair data. Cognition 23, 95-147.

[45] Karmiloff-Smith, A. (1990) Constraints on representational change: Evidence from children's drawing. Cognition 34, 57-83.

[46] Karmiloff-Smith, A. (1992) Beyond modularity: A developmental perspective on cognitive science, MIT Press.

[47] Kauffman, S. (1993) Origins of order, Oxford University Press.

[48] Keeler, J.D. (1988) Comparison between Kanerva's SDM and Hopfield-type neural networks. Cognitive Science 12, 299-329.

[49] Klimesch, W. (1995) Memory processes described as brain oscillations. Psycoloquy, 6.06.

[50] Koestler, A. (1964) The act of creation, Picador.

[51] Kojima, K. & Schaeffer, H.E. (1967) Survival processes of linked mutant genes. Evolution, 21, 518-531.

[52] Kubose, S.K. & Umenoto, T. (1980) Creativity and the Zen koan. Psychologia, 23(1), 1-9.

[53] Langton, C.G. (1992) Life at the edge of chaos. In Artificial life II. eds. C.G. Langton, C. Taylor, J.D. Farmer & S. Rasmussen, Addison-Wesley.

[54] Lenat, D.B. (1974) The ubiquity of discovery. Artificial Intelligence Journal, 9, 257-86.

[55] Luchins, A.S. (1942) Mechanization in problem solving. Psychological Monographs, 54, No. 248.

[56] Lumsden, C. & Wilson, E. O. (1981) Genes, mind, and culture, Harvard University Press.

[57] Lynch, A. (1996) Thought Contagion: How Belief Spreads Through Society, Basic Books.

[58] Mackintosh, D.R. & Stewart, G.T. (1979) A mathematical model of a heroin epidemic: Implications for control policies. Journal of Epidemiology and Community Health, 33, 299-301.

[59] Maes, P., ed. (1991) Designing autonomous agents: Theory and practise from biology to engineering and back, MIT Press.

[60] Mandelbrot, B.B. (1982) The fractal nature of geometry. W.H. Freedman and Company.

[61] Marr, D. (1982) Vision, Freeman.

[62] Maynard Smith, J. & Haigh, J. (1974) The hitchhiking effect of a favourable gene. Genetic Research, 23, 23-35.

[63] McCulloch, W.S. & Pitts, W. (1943) A logical calculus of the ideas immanent in nervous activity. Bulletin of Mathematical Biophysics, 5, 115-133.

[64] McFarland, D.J. & Sibly, R.M. (1975) The behavioural final common path. Philosophical transactions of the London Royal Society 270B, 265-93.

[65] Miller, G.A. (1956) The magic number seven, plus or minus two: Some limits on our capacity for processing information. Psychological Review, 63, 81-97.

[66] Minsky, M. (1985) The Society of Mind. Simon and Schuster.

[67] Mitchell, M. (1993) Analogy-making as perception, MIT Press.

[68] Nersessian, N. (1993) In the theoretician's laboratory: Thought experimenting as mental modeling. In PSA 1992, vol. 2, eds. D. Hull, M. Forbes, & K Okrulik. PSA.

[69] Palmer, M.W. (1992) The coexistence of species in fractal landscapes. American Naturalist, 139, 375-397.

[70] Pinker, S. (1995) The language instinct. HarperPerrenial.

[71] Plotkin, H.C. (1988) The role of behavior in evolution. MIT Press.

[72] Popper, K. R. (1963) Conjectures and refutations, Routledge & Kagen.

[73] Pribram, K.H. (1974) How is it that sensing so much we can do so little? In The neurosciences third sudy program, eds. F.O. Schmidt & F.G. Worden, MIT Press.

[74] Quillian, M.R. (1968) Semantic memory. In Semantic information processing, ed. M. Minsky, MIT Press.

[75] Ram, A. (1993) Creative conceptual change. Proceedings of the Fifteenth Annual Conference of the Cognitive Science Society, 17-26.

[76] Ray, T. (1991) An approach to the synthesis of life. In Artificial life II. eds. C.G. Langton, C. Taylor, J.D. Farmer & S. Rasmussen, Addison-Wesley.

[77] Robert, M. (1990) Observational learning in fish, birds, and mammals: A classified bibliography spanning over 100 years of research. Psych Record 40, 289-311.

[78] Rodgers, J.L. & Rowe, D.C. (1993) Social contagion and adolescent sexual behavior: A developmental EMOSA model. Psychological Review, 10093), 479-510.

[79] Rogers, E.M. (1962) Diffusion of innovations, Macmillan Publishing Company.

[80] Rumelhart, D.E. & McClelland, J.L. eds. (1986) Parallel distributed processing, Bradford/MIT Press.

[81] Schank, R.C. (1983) Dynamic memory, Cambridge University Press.

[82] Schank, R.C. & Leake, D.B. (1989) Creativity and learning in a case-based explainer. Artificial Intelligence, 40(1-3): 353-385.

[83] Scheuring, I. & Riedi, R.H. (1994< Application of multifractals to the analysis of vegetation pattern. Journal of Vegetation Science, 5, 489-496.

[84] Schuster, P. & Sigmund, K. (1983) Replicator dynamics. Journal of Theoretical Biology 100, 533-38.

[85] Shannon, C.E. & Weaver, W. (1963) The mathematical theory of communication. University of Illinois Press.

[86] Smith, W. J. (1977) The behavior of communicating, Harvard University Press.

[87] Spector, L. & Luke, S. (1996) Culture enhances the evolvability of cognition. In Proceedings of the 1996 Cognitive Science Society Meeting.

[88] Squire, L.R. (1992) Memory and the hippocampus: A synthesis from findings with rats, monkeys, and humans. Psychological Review, 99, 195-231.

[89] Thagard, P. (1980) Against evolutionary epistomology. PSA 1980, ed. P.D. Asquith & R.N. Giere 187-96.

[90] Tomasello, M. Kruger, A.C., & Ratner, H.H. (1993) Cultural learning. Behavioral and Brain Sciences, 16, 495-552.

[91] Von Neumann, J. (1966) Theory of self-reproducing automata, University of Illinois Press.

[92] Vygotsky, L.S. (1978) Mind in society: The development of higher psychological processes, eds. M. Cole, V. John-Steiner, S. Scribner & E. Souberman, Harvard University Press.

[93] Wallas, G. (1926) The art of thought, Harcourt, Brace & World.

[94] Walsh, R. & Vaughan, F. (1993) Paths beyond ego, Jeremoy P. Tarcher/Perigee.

[95] Weisberg, R.W. (1986) Creativity: Genius and other myths, Freeman.

[96] Wright, S. (1969) Evolution and the genetics of populations, University of Chicago Press.

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