Cultural Transmission, Network Architecture, and the Evolution of Human Self-awareness

by
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Biography of Sam Yeaman

Sam Yeaman is working to complete his doctorate in Zoology at University of British Columbia. He collaborates with Michael Whitlock on theoretical and experimental questions related to evolution under migration-selection balance. He plans to defend his thesis in September, after which he will begin a post-doctoral position at the University of Neuchatel in Switzerland with Laurent Lehmann. For his post-doctoral research, Sam will be exploring questions related to the effect of network architecture on evolutionary dynamics in culture. He also plans to continue his theoretical studies of multi-locus adaptation.

The Importance Of The History Of Science

"The history of the universe is the collective memory of the universe. The science of cosmology probes the limits of what we can know of the collective memory. At the root of science is the simple idea that there can be a methodology by which intelligent people can agree on what they observe and, as a corollary, agree to disagree without murdering each other. Science itself evolved in the West as a necessity for stopping the ongoing murderous tribal wars lodged in separate arguments about divine truth and divine favor. Science is a process that creates conventions of truth. It is the process that itself must be either accepted or denied. Necessarily, to accept science is to accept the process that has led to the scientific concept of evolution. The evolution of life is the collective memory of life on our planet, and it determines what, at any point in history, we are capable of knowing of the collective memory of the universe." [1]
– Jeffrey Rubinoff

Evolution

"Evolution is directional and progresses to ever more complex and adapted orders of organization.

Quite elegantly, the concept is constantly evolving rigorously validated evidence of itself. As rigorously validated evidence expands the idea of evolution, the human mind itself can evolve, thereby contributing to the collective memory of life itself. Arguably, the theory of evolution supports the concept of the potential value of all humanity, as opposed to theistic or other rationalizations for the ascendancy of specific tribes."[2]
– Jeffrey Rubinoff

These are statements from which sculptor Jeffrey Rubinoff calls his insights – nascent ideas that have "evolved with and from his artistic work". These insights form the core argument that Rubinoff makes about an immediate, fundamental change to historical reality that occurred with the invention and subsequent use of the atomic bomb against Japan. He has named this sudden change "The End of the Age of Agriculture". To test this core argument, Rubinoff invited a forum of interdisciplinary scholarly collaborators to present papers that explored the insights. This essay was part of that effort.

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[1] Jeffrey Rubinoff, "The Importance of the History of Science". See http://www.rubinoffsculpturepark.org/coi.php.
[2] Ibid, "Evolution". See http://www.rubinoffsculpturepark.org/coi.php.

Preamble

Rubinoff's insights on evolution and the importance of the history of science contain three main arguments. Firstly, that science provides a convention by which inter-subjective truth claims can be evaluated and continually refined. Secondly, to accept science is to accept the cannon of scientific knowledge and what it tells us about evolution and how we came to be humans. And thirdly, that science evolved as a response to the conflicting ideologies that developed along with human civilization, from tribes to nation – ideologies that proposed mutually exclusive explanations of human origins, often claiming the right of ascendancy over other groups. This paper will situate Rubinoff's insights within an evolutionary approach to understanding culture, exploring how differences between the social structures that transmit science, religion, and art affect their evolution.

Introduction

Life on Earth has progressed from very simple beginnings to a bewilderingly complex and interconnected system in a little over 3.5 billion years. Relatively simple chemical compounds that were able to catalyze reactions and create copies of themselves tended to persist and multiply. As random errors during the copying process introduced variation in the form and catalytic chemistry of these molecular "species", the first episodes of natural selection occurred on the planet. Those variants that were able to multiply more quickly tended to persist, while those that were less efficient were lost. Eventually, early molecular evolution yielded the chemical ancestors of RNA and DNA and the beginning of the genetic code. All genetic novelty is ultimately created through mutation; refinements are tailored by natural selection favouring variants that increase the efficiency of reproduction, while random fluctuations can result in unpredicted changes that may compromise this efficiency. At its essence, the evolutionary process arising through genetic transmission that has generated the vast diversity of life on Earth has remained unchanged from these early beginnings. The emergence of novel forms and innovations, however, has vastly changed the ways in which the organisms themselves interact and shape the ecological landscape upon which evolution unfolds. From the first membranes that enclosed interacting molecular species to the social systems and division of labour of the ants and bees, biological innovations have resulted in an incredible array of novel ecological interactions whose emergent characteristics feedback and affect the course of evolution.[3]

Perhaps the most remarkable innovation in the history of life on Earth is the emergence of consciousness and the capacity for self-awareness. While there seems to be evidence for

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[3] J. Maynard Smith and E. Szathmáry, *Major Transitions in Evolution*. Oxford: Oxford University Press (1995).

some level of consciousness in several animal species[4], none but *Homo sapiens* appears to have progressed to a point where it can apprehend the very nature of the processes that brought about its existence. Human beings have evolved a diverse range of cultural ideologies that seek to answer the question: "How did we come to be?". Answers to this question have been numerous and diverse, and in a somewhat ironic turn, the conflicts generated in part by their disagreements have generated another novelty that is apparently unique to humans: the capacity for self-annihilation. Technologies that evolved along with culture have now reached a point where human beings have amassed an arsenal of weaponry, such as nuclear weapons, powerful enough to bring about our own extinction. It is of course a gross oversimplification of history to ascribe all violent conflict to ideological disagreement, but the contribution of this aspect of human culture is pervasive.

A major theme of evolution on Earth has been its reactive nature. As genetic evolution is based on random mutations sorted by natural selection, solutions closer to some environmentally defined optimum are only achieved through a gradual groping, often with missteps and deleterious side effects. Many evolutionary novelties have radically changed the future trajectory of the resulting lineages (and those of other species that interact with them) in a way that could never have been predicted before the fact. The invasion of an early prokaryote by the ancestor of mitochondria eventually yielded a novel symbiotic body plan that enabled the radiation of subsequent eukaryotic lineages.[5] With the advent of consciousness, however, life on Earth has developed the capacity for foresight (albeit an arguably limited capacity). Imagination, experimentation, and learning allow conscious organisms to adapt to their environments within their own lifespan. Without cultural transmission of the information accrued within the lifespan of an organism, this learning is lost at death and long-term evolution is unaffected. Cultural transmission of beneficial ideas imbues evolution with predictive power by enabling imaginative and directed responses to the problems of existence to be passed down through time. It may of course be argued that imagination is fundamentally limited and random and that experimentation and learning are simply extensions of natural selection operating within the mind of a single organism, sorting the good ideas from the bad. While the semantics of this problem are important and meaningful, it is clear that cultural transmission has radically changed the way in which the human species evolves.

The aim of this essay is to discuss how the emergence of human consciousness and culture has resulted in new evolutionary modalities, yielding a capacity for self-awareness and foresight. Where this capacity has been focused on understanding our origins, it has yielded a vast range of cultural narratives, each of which constitutes an independently evolving cultural lineage. Considerable conflict has emerged as human societies have

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[4] G.R. Griffin and D.B. Speck, "Animal Cognition," in *New Evidence of Animal Consciousness*. (2004), 7: 5-18.

[5] L. Margulis, *Symbiosis in Cell Evolution: Microbial Communities in the Archean and Proterozoic Eons*. W.H. Freeman (1992).

collectively contemplated and disagreed about their understanding of their place in the universe. Where conflicting ideologies about the origins of human existence have typically been settled through violence or other coercive means throughout much of history, the scientific method has provided a means for evaluating the truth of statements through experimentation and inter-subjective agreement. By setting up logical statements about the nature of reality that can be tested and falsified independently by different individuals, science has created a new cultural means of understanding reality that is radically different from all other ideological approaches. It is through the scientific method that humans have come to formulate and test the theory of evolution, which at present provides the most parsimonious explanation for the how life came to be as it now appears.

As described by Rubinoff in his reflections on the novelty that is the scientific method, "quite elegantly, [evolution] is constantly evolving rigorously validated evidence of itself".[6] Nonetheless, science is inherently limited in the scope of answers it can provide to questions about our origins, due to its reliance upon empirical evidence and logical axioms for inference. Where religions provided universal explanations for all questions that could be conceived (regardless of their truth value), science is limited in its answers. While a scientific understanding of our origins has supplanted the earlier religious explanations in many cultures, its inability to address the full range of questions that arise from the collision of subjective and objective realities has left something of a void. As science has gradually replaced religious explanations of the mechanics of origins, art has evolved to reflect both upon the insights yielded by science and the gaps that it cannot address. Science, art, and religion differ considerably both the ways that they approach the problem of human origins and in the ways that they are transmitted and evolve.

Differences in the structure of the communications networks through which science, art, and religion are transmitted fundamentally affect the diversity of opinions that evolve, along with the conflicts generated from any resulting disagreements. While scientific consensus about our origins has never been more complete, conflicts centered around religious disagreements persist to the present day. Only through understanding the dynamics that govern our continuing evolution, including the ways in which we conceive of ourselves through these different cultural approaches, can we hope to prevent our own immolation. If evolution is the "collective memory of life on our planet", as suggested above by Rubinoff, then it is only through accessing this collective memory through science and celebrating and communicating it through art that we will avoid the potentially apocalyptic eventualities that confront humanity at the End of the Age of Agriculture.

[6] Jeffrey Rubinoff, "Evolution". See http://www.rubinoffsculpturepark.org/coi.php.

Culture in Non-human Animals

Most changes in biological form and function have been mediated through the elaboration and refinement of genetic control. In some cases, however, the emergence of some behavioural novelty has resulted in the development of a parallel system of inheritance transmitted through learning or mimicry. The actual traits involved can vary from mating vocalizations to rudimentary tool use, but are broadly categorized as cultural variants or "memes".[7] The process and dynamics of cultural evolution can differ from those of genetic evolution in two important ways: the architecture through which variants are transmitted, and the manner by which variation arises.

Any trait that is currently evolving through cultural transmission is necessarily derived at some point from ancestors that did not engage in behaviours that allowed cultural evolution. For example, the mating calls made by Darwin's finches (*Geospiza fortis*) are usually learned from their parents in the nest, but can sometimes be learned by imprinting on the song of another nearby individual.[8] These calls are derived from some distant ancestor that either did not call or whose calls were under complete genetic control (*ie*. purely instinctive). As the elaboration of any behaviour moves from genetic control to development through learning, cultural evolution can begin to operate as a parallel system of inheritance. At the early stages of this transition, most transmission is likely from parents to offspring, thus closely following genetic transmission (this is termed "vertical transmission"). Depending on the type of trait and its affect on fitness, however, cultural variants may also be passed horizontally, between unrelated individuals, as is the case with tool use behaviours in chimpanzees.[9] This is an important difference, as it potentially allows positively selected variants to spread much more rapidly than genes.

The second major difference between cultural and genetic evolution is the means by which new variants are created. The simplest way that culture can evolve is through simple copying error from one generation to the next, which is effectively quite similar to genetic evolution through random mutation. This passive modality is likely involved in the elaboration of behaviours that are derived from ancestral traits that were under complete genetic control, such as the variation in bird songs in Darwin's finches. Bird song typically does not perform a function that directly affects the survival of the individuals involved, but is critical in securing a mate and in some cases presents a barrier to mating between closely related species, preventing them from hybridizing and thus contributing to the emergence of new species.[10] Novelty in passively evolving variants thus emerges through random copying error, typically during transmission between generations or individuals.

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[7] R. Dawkins, *The Selfish Gene*. Oxford: Oxford University Press (1976).
[8] B.R. Grant and P.R. Grant, "Cultural Inheritance of Song and its Role in the Evolution of Darwin's Finches," in *Evolution 50* (1996), pp. 2471-2487.
[9] A. Whiten, J. Goodall, W.C. McGrew, T. Nishida, V. Reynolds, Y. Sugiyama, C.E.G. Tutin, R.W. Wrangham, and C. Boesch, "Cultures in Chimpanzees," in *Nature 399* (1999), pp. 682-685.
[10] Grant and Grant.

Because some cultural traits are learned and can perform a function, they can also be elaborated within the lifespan of a single individual through experimentation and refinement. This method of novelty generation is profoundly different from random mutation and genetic evolution. In this case, novelty is either generated through random variations in the execution of the behaviour (unconscious) or through imaginative problem-solving and directed alteration of behaviours to solve a given problem (conscious). At the present time, it is unclear how often culture in non-human animals evolves through unconscious versus conscious direction of variation, as proving conscious intention in animals is a difficult endeavour.[11] In any case, it is clear that learning occurs in animals, whether or not the variations that are experimented with are consciously constructed or the product of effectively random behavioural noise. How does learning affect the evolution of memes?

Evolution in Genes Versus Memes

A significant effect of the potential for the refinement of memes within the lifespan of a single individual is to greatly increase the pace of evolution. The occurrence of learning within the ontogeny of an individual effectively constitutes a nesting of evolutionary process, as learning is akin to natural selection in the way that it sorts between potential solutions according to their suitability for a given problem. Ignoring for the moment the ways in which novel memes are generated, whether through imaginative creativity (conscious) or through random variations in the execution of a behaviour (unconscious), they can be selected upon both at the level of the individual through learning and internal cognitive processes, and at the level of the population through their affects on the biological fitness of the individual. Whereas the problems that drive genetic evolution favour solutions that maximize reproductive fitness, learning-based cultural evolution can be driven by a range of problems, either closely related to biological fitness or completely decoupled from it, depending upon the strength of selection at each of these levels. Some memes may have little influence on the biological fitness of the individual, and are thus free to evolve through whatever cognitive processes affect them. To take a simple example from chimpanzees, memes concerned with tool use for extracting termites from their nests are likely much more closely coupled to biological fitness than those concerned with the "rain dance", where male individuals make dancing motions at the onset of thunder showers. Memes may be favoured within an individual because they result in behaviours that yield enjoyable physiological stimuli (*e.g.*, cigarette smoking), because they represent ideas that are in harmony with other memes favoured by the individual (*e.g.*, belief in a toast-based miracle by a devout Christian[12]), because they represent ideas or behaviours that promote identification and inclusion within a social group (*e.g.*, wearing a team sports jersey; cigarette smoking), because they aid in performing some task related to the

[11] Griffin and Speck.

[12] Author is referring to holy images appearing on pieces of toast

problems of biological and social existence (*e.g.*, lighting a fire), or because they provide a more logically consistent explanation of some phenomenon than other competing memes (*e.g.*, Copernican cosmology).

The decision to publicly communicate a meme also affects its net fitness and the rate at which it increases or decreases in frequency. Dawkins proposed that memes such as evangelist religious teachings that induce the individual to actively work to transmit them, often at considerable cost to their biological fitness (*e.g.*, celibate monks) effectively function as viruses of the mind.[13] This is hardly an exhaustive list of possible reasons why a meme may be favoured or disfavoured[14], but in all cases, the memes involved can be selected either through cognitive processes within the individual (often in response to perceived effects on biological or social "fitness") or through direct consequences on biological fitness. In any case, the possibility for learning and selection within the lifespan of an individual causes memes to evolve much more rapidly than genes.

While the effect of the nesting of evolutionary process on the pace of change applies to any memes for which variation can be generated and selected upon within the lifespan of an individual (as opposed to songs learned at birth in birds), memes also evolve much more rapidly when variation is generated consciously. While it is unclear whether animals consciously modify and combine cultural variants in response to failures and challenges, humans clearly do. The capacity to consciously refine and combine memes results in one of the most significant differences between the processes of genetic and cultural evolution. If two parents each carry a unique allele that is beneficial, their offspring may inherit both alleles and gain some additive benefit, or even a synergistic benefit from the interaction between the alleles, but they typically are never combined together to form a single new allele (barring some sort of macro-mutation fusing their protein structure, which would very likely be deleterious). Memes suffer no such constraints and can combine to form new memes with completely novel characteristics and benefits. It is important to note that unlike genes, memes cannot really be measured or delineated precisely as independent units, so the sense in which they are combined to form new memes really refers to the pattern in which they are inherited and the way in which they can be built upon. Because genes cannot combine together, the joint inheritance of the two beneficial alleles described above can never be assured, and their interaction yielding a beneficial phenotype cannot be built upon directly. The phenotype yielded by these two alleles must be affected either by a subsequent mutation at one of the alleles or by a mutation at a third allele for further evolution to occur. By contrast, memes can be passed along together and can be built upon directly with further ideas. Even more importantly, the combination of these ideas can be directed towards solving problems through the conscious understanding of the significance of their components. For example, the first steam engine was conceived because its creator, Thomas Newcomen, understood the physical

[13] R. Dawkins, *A Devil's Chaplain*. Houghton Mifflin Harcourt (2003).
[14] R. Boyd and P. Richerson, *Culture and the Evolutionary Process*. Chicago: University of Chicago Press (1985).

processes and properties of the materials involved and built and refined the entire mechanism in a directed fashion.

By contrast, the evolution and refinement of the mitochondrial respiratory machinery that powers all eukaryotic life occurred through gradual random tinkering of the component proteins through mutations at the underlying genes. While this comparison may seem elementary and self-evident, the emergence of consciousness and the possibility for the combination of information contained within independently evolving lineages through cultural transmission constitutes a revolution in the process of evolution. Never before could problems be dynamically confronted through purpose-built solutions; transcending the dependence upon randomly generated variation increased the pace of evolution more than any previous transition in design.

Transmission Dynamics

Although it is undoubtedly true that novelty can be generated much more rapidly and with directed purpose through learning and cultural change, truly *de novo* ideas that arise without any cultural precursors are likely rare. While Newton developed a system of mathematics and physics that revolutionized the way humans understood their relation to the world, he famously acknowledged that he was "standing on the shoulders of giants". Viewed another way, if the capacity for imagination is limited, then novel solutions will typically be built upon pre-existing structures, whether or not the structures are particularly well adapted to suit a given problem. In either case, whether the generation of novelty is enabled by drawing upon pre-existing variants or whether it is constrained by building upon that which already exists, the dynamics underlying the process are the same; the only difference lies in the ultimate adaptive value of the product (more on this below).

Since much cultural novelty consists of elaborating upon, combining, and refining existing memes, the dynamics through which memes are transmitted have a critical influence on evolutionary outcomes. Before the advent of written communication, inheritance of ideas was constrained by the ecology of the communicators; if two people could not interact in physical space, then they would never exchange ideas. Successive technological developments (themselves the product of cultural evolution) have enabled communication spanning both time and space, transcending the physical limitations of purely verbal modes of cultural inheritance. Memes have been sent between the Earth and the moon and out into deep space and have been recovered from the texts of ancient civilizations. While technology has allowed the transcendence of physical limitations in an absolute sense, the relative ease by which ideas are distributed and the depths they reach and speed they percolate are decidedly constrained by the architecture of the communication networks created by technology.

To return to the comparison with genetic evolution, beneficial genetic mutations will typically spread with a probability relative to their effect on fitness and the size of the population through which they must diffuse. If a mutation has no effect on fitness, it will rise to fixation (*ie.* replace all other mutations) with a probability equal to 1/(2N), where N is the size of the population. By contrast, if a mutation increases the fitness of an organism by s[15], it will fix with probability of approximately 2*s* for large populations.[16] Thus, for every mutation that has increased the fitness of an organism by 1%, an average of 98 similarly beneficial mutations have occurred that were lost purely by chance. By contrast, in a population as large as the current human population, a novel mutation with no effect on fitness would only have a 1 in 12,000,000,000 chance of rising to fixation. These limits derive from the vertical nature of genetic transmission and the constraint that genes can only be passed from parents to offspring. Because memes can spread from one individual through many through mass communication, the probabilities of them spreading are very different. Lieberman and colleagues have shown how certain communication architectures that feature a few highly connected nodes passing memes to many minimally connected nodes can virtually guarantee the spread of a novel beneficial cultural variant, no matter how small its fitness advantage.[17] While a 2% chance of fixing a beneficial genetic mutant is large relative to the chance of fixing a neutral mutant, some cultural transmission architectures virtually guarantee the spread of neutral or even deleterious memes. In population genetic terms, this increase in fixation probability is akin to the dynamics that arise when there is high variance in reproductive success, with a few individuals contributing the majority of gametes to the subsequent generation.

While they used a few stylized network designs, the results of Lieberman and colleagues suggest that networks with a scale-free distribution architecture[18] might similarly favour the spread of beneficial or neutral memes. Scale-free design is thought to be common in many modern technologically mediated networks such as the connections among Facebook users on the internet. By contrast, in more traditional social networks where all individuals have approximately the same connectivity (*e.g.*, every person is connected to a small number of other people), memes will tend to spread much more slowly, in a fashion similar to the spread of genetic mutants.

It is thus clear that the architecture of the transmission network will substantially affect the variation in memes to which an individual is exposed. As described above, because memes can be combined to form new memes with completely novel characteristics, exposure to variation mediated by the architecture of the transmission network can greatly affect the rate at which evolution progresses. While scale-free networks favour the spread

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[15] Where *s* is the relative increase in the proportion of offspring contributed to the next generation by organisms with the new mutation.
[16] M. Kimura, "On the Probability of Fixation of Mutant Genes in a Population," in *Genetics 47* (1962), pp. 713-719.
[17] E. Lieberman, C. Hauert and M.A. Nowak, "Evolutionary Dynamics on Graphs," in *Nature 433* (2005), pp. 312-316.
[18] Scale-free networks are characterized by having very few individuals with many connections and many individuals with few connections. The number of connections between any given node is its 'degree'; in scale-free networks the distribution of nodes with degree *x* is defined by a power law.

of evolutionarily beneficial memes, this does not necessarily mean that the memes themselves have any inherent truth value or benefit to the individual. As described above, memes can spread (*ie.*, be evolutionarily beneficial) for a number of reasons, many of which are completely unrelated to their truth value or effects on the individual's biological fitness. For example, memes concerned with technological innovation will typically be selected because they improve the performance of some task, such that the effect of a meme on individual fitness is correlated to the fitness of the meme itself. By contrast, memes concerned with explaining why the sky is blue or how the universe came to exist may spread with little correlation to individual fitness or truth-value (as evidenced by the prevalence of the world's religions, many of which offer mutually exclusive answers to the latter of these questions). Because scale-free networks favour the spread of any evolutionarily beneficial mutations, they can facilitate the spread of memes with little truth-value or benefit to the individual.

While the theoretical dynamics of evolution in networks are still being derived, it also seems likely that the probability of a novel variant spreading would also depend upon its proximity to a highly connected node. If a few highly connected individuals are able to transmit a given meme to all other minimally connected individuals, its chance of spreading through the population should be very high relative to that of a new meme arising in a minimally connected individual. The results of Lieberman and colleagues depend critically upon the connection of the low-degree nodes back to the highly connected central nodes.[19] If communication is unidirectional, flowing out from the highly connected nodes without cycling back, the evolutionary dynamics may depend even more strongly upon the architecture, effectively limiting the potential for a novel meme arising in a minimally connected node to spread to other minimally connected nodes. Boyd and Richerson have described several types of biases that influence the probability of transmission of a meme, including the tendency for humans to conform to social trends or to preferentially favour memes that issue from individuals in positions of power.[20] Because individuals in positions of power have often exerted control over the means of mass communication, and because mass communication can breed social conformity, both of these biases to transmission probability would tend to further increase the probability of memes spreading through the population when they originate in a highly connected node.

When memes offer competitive and mutually exclusive explanations of real-world events or phenomena, the influences of transmission architecture and biased transmission may sometimes drive dynamics more strongly than selection at the individual level, especially when communication is mediated by networks with one-to-many unidirectional architecture. Furthermore, when individuals are not presented with an alternative explanation from competing memes, even memes with very inaccurate information can easily spread through populations connected by one-to-many networks. By contrast, when

[19] Lieberman et al.
[20] Boyd and Richerson.

memes do not compete (*i.e.* they do not offer mutually exclusive explanations of some phenomenon), one-to-many transmission networks will simply increase the rate at which each meme spreads, without compromising the spread of other memes. While it is well beyond the scope of this paper to explore the possible dynamics that can unfold due to the interactions of these factors (and the myriad complexities of human social ecology), it is clear that transmission architecture can greatly impact cultural evolution.

A Brief History of the Technology Underlying Human Communication Networks

For the majority of human history, all communication was conducted orally and was thus only possible between physically proximate individuals, effectively limiting the variance in the connectivity between individuals. Communication thus presented one of the principle obstacles to early political conquest and attempts at empire building. With the advent of written communication, it became possible to communicate both across time and space, but with physical limits placed on message duplication due to the labour involved in the recording process. Subsequent innovations in communications technology can be coarsely divided into two groups: those that enabled one-to-one communication (*e.g.,* telegraph, telephone) and those which enabled one-to-many transmission (*e.g.,* printing press, radio, television). While the former of these enabled communication across much greater distances and changed the nature of human interaction, the latter exerted much more substantial effects on the dynamics of cultural evolution by giving rise to networks with the concentrated transmission architecture described above. The first generation of any of these technological advances was typically restricted in its use to the more empowered social classes, due to the economic costs involved in their development and operation. While successive generations of a given technology generally increased the access to central distribution nodes to a wider range of the human social spectrum, control of large-scale communications media has remained largely in the hands of a concentrated group of individuals. Television represents the most concentrated of the unidirectional one-to-many means of communication, while printed media are perhaps the most accessible. The internet and all associated social networks represent the most radical novelty in the architecture of communications network, due to their fluid and rapidly evolving structure. The use of search engines that prioritize access to different websites based on a range of measures of importance enable access to highly connected nodes with less cost than ever before. As such, the internet has democratized the control of communications in a way that no other previous technology was able.

How Did We Come to Be?

Perhaps one of the most poetic results of the process of evolution is the emergence of cultural narratives attempting to explain their very origin and genesis. As described by

Rubinoff: "Quite elegantly, [evolution] is constantly evolving rigorously validated evidence of itself".[21] Approaches to answering the question, "How did we come to be?" can be coarsely divided into three categories: art, religion, and science; each of which has evolved through very different patterns. Ironically, the conflicts generated by clashes between cultures organized around religious ideas have threatened the very existence that their ideology seeks to celebrate and explain. By providing a system for categorizing and relating observations, science has yielded explanations about evolutionary origins that have the potential to unify (but not necessarily validate) these disparate and opposing cultures, if it can satisfactorily explain the reasons for their differences.

Understanding the ways in which evolutionary process has yielded the cultural patterns we see today is thus central to any long-term peace. The final section of this essay thus seeks to compare and contrast the modes by which these three types of culture have evolved, with specific focus on differences in the types of memes and the transmission networks through which they are communicated. While clarifying and explaining the diverse reasons for specific disagreements between cultures is well beyond the present scope, understanding the constraints inherent in the processes governing the evolution of these cultures may illuminate the patterns themselves. As Marshall McCluhan famously stated: "the medium is the message"[22]; in the present context, the medium may be seen as the technology or social network that mediates the transmission of the evolving ideas.

Religious explanations of human origins have deep roots in the human experience. Putting aside the question of what originally inspired the stories that make up a religion, all religions survive through some form of transmission from the individual(s) who were designated to maintain the original narratives to those in the present day who take on the responsibility of ensuring their continued transmission. Whether religion is transmitted orally or through written texts, the major religions of the world have in common a respect for tradition and for the truth value of the teachings inherited from the past. Knowledge derived from individual human experience is typically interpreted relative to the perceived absolute truth value of this received religious knowledge, and will rarely modify the information content of the religious memes transmitted from one generation to the next. Even in cases where religious knowledge and explanation are seen as providing metaphorical rather than absolute truth, those designated to transmit religious memes still typically resist alteration or revision in light of subjective experience. Radical challenges to received wisdom have sometimes resulted in the founding of new religions in light of the perceived need for revision (*e.g.,* by prophets such as Christ and Mohammed), but in any case, revision of religious narratives in light of experience is the exception rather than the rule.

Religious communication networks are typically tailored to preserve the integrity of the information they transmit. From the Amazonian Shaman to the Catholic Priest, religions

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[21] Jeffrey Rubinoff, "Evolution." See http://www.rubinoffsculpturepark.org/coi.php.

[22] M. McCluhan, *Understanding Media: The Extensions of Man*. Boston: MIT Press (1994).

have typically converged upon very similar structures for their transmission, usually involving the maintenance of the traditions by passing them between appointed individuals from one generation to the next, coupled with the dissemination of traditions through the general public by some form of one-to-many transmission. From early churches and gathering houses to modern super-churches and continent-wide communication of sermons via satellite television, one-to-many unidirectional transmission from the priest class to the public has effectively minimized the potential for revision and modification of received traditions. Furthermore, the priest class typically follows a range of social conventions and hierarchical organizational structures that give the impression of ensuring the faithful reproduction and transmission of inherited traditions from one generation of priest to the next.

This very architecture may be seen as a natural evolutionary consequence of the worldview espoused by most religions, namely that by prioritizing the truth value of inherited traditions, those religions that find ways to ensure their faithful reproduction tend to be the most successful (*i.e.* natural selection favours religions with transmission networks that minimize the potential for deviations from tradition). It is also important to note that when new religions are founded from old ones, it is typically due to some difference in interpretation of received doctrine. Subsequent competition between these daughter religions may favour those that are most vocal or able to evangelize, as religious doctrine typically contains no formal mechanism to evaluate the relative truth value of competing explanations. A form of natural selection thus operates at the level of competing religions, where the "fitness" of the competing religions is not at all connected to their truth-value.

The emergence of the scientific method represents a radical departure from this type of cultural approach to explaining human origins. Where religion prioritizes the truth derived through inherited traditions, science emphasizes truth derived from experience and inter-subjective agreement about the interpretation of this experience. While scientific knowledge is passed from one generation of researcher to the next and disseminated to the public through the education system (thus closely resembling the priest-congregation organization), revision of the knowledge passed through this network is open to any individual presenting appropriately codified explanations of the reasons for challenging previously existing explanations, whether they are formally recognized as a researcher or a part of the general public.

Indeed, some of the most substantial scientific revolutions, such as Einstein's theory of relativity, have been formulated outside of the academic system formally charged with the transmission of the scientific canon. Highly connected nodes can thus originate anywhere in the network, as opposed to the rigorous vertical transmission of typical religious architectures. While the ideas of both science and religion are dogmatic, science is formulated around a mechanism for the comparison, evaluation, and selection among competing mutually exclusive explanations. Religious networks are characterized by few-to-many architecture with unidirectional meme flow and vertical inheritance between the highly connected nodes from one generation to the next. While scientific networks are also characterized by few-to-many architecture, they tend to allow reticulated meme flow back to the central nodes, and allow highly connected nodes to arise from anywhere in the network. This results in a type of architecture that is much more fluid, but which still provides a mechanism for rapid dissemination and revision of memes.

If we assert that there is some objective truth, regardless of whether it can ever be perceived by a human consciousness, science approaches this truth through a process that is evolutionary in its very nature. The process of generating a range of explanations and then selecting those which are most concordant with human experience and observation, is, at its essence, an evolutionary process. In contrast, by codifying the experience of a single individual or group of individuals and transmitting this information faithfully, the religious approach effectively constitutes an attempt to counteract the processes that give rise to variation and natural selection. Fundamentally, the processes involved in the transmission of religions represent an attempt to resist the changes involved in evolution, as the very architecture of the communication network prioritizes traditionally inherited memes over those derived from experience. The religious devotee thus places faith in the accuracy of the original insight of its founder(s) and in the accurate replication of all subsequent transmission events. While transmission through written communication may be relatively error-free, most religions undergo a period of oral transmission before being codified, which may be considerably more error prone. Furthermore, as was the case with early Christianity, many religions are only codified following the competition of varying interpretations of the original inspiration of the founder (*e.g.*, the Gnostic gospel versus the Roman Catholic interpretations of Christianity).

As described above, selection between competing splinter religions may be driven more strongly by economic power and the capacity for transmission than by any inherent truth-value, since religions do not typically contain any formal mechanism for evaluating their relative truth values. By comparison, the scientific devotee places faith in explanations that have satisfied the criteria for empirical testing and inter-subjective agreement, and even then, faith is based on probability and likelihood rather than a belief in absolute truth. As all scientific knowledge is subject to the evolutionary process and natural selection according to the concordance between a given explanation and empirical observations, the scientific devotee places faith in the process rather than in any specific explanation. A product of the constraints of the scientific method, however, is that its adherents must satisfy themselves with an incomplete understanding of the universe, as uncertainty is inherent in the process and approach to satisfactory answers is necessarily slow. It is here that art can provide a complement to the empirically-based scientific exploration of the question of human origins. If science represents humanity's attempts to become aware of the "collective memory of life itself", as described by Rubinoff, then "art is the map of the human soul; each original piece is proof of the journey. As the artist navigates the unknown, the art adds to the collective memory".[23]

While art is perhaps the oldest form of human cultural expression for which we have concrete evidence, it has changed more rapidly and generated more diversity than either science or religion. Unlike science and religion, art does not typically attempt to provide dogmatic explanations of objective truth. Rather, art provides a medium for the communication of individual perceptions and is intensely rooted in the subjective experience, both in its creation and its interpretation. Furthermore, while art is typically distributed from one artist to many individual observers, the structure of transmission networks that diffuse artistic creations is very fluid and constantly changing as new artists emerge and older artists cease to create. This architecture contrasts strongly with religious transmission networks, as the one-to-many architecture allows the rapid spread of memes, but its fluidity does not prioritize the transmission of any single group or social class over long periods of time. As such, art tends to evolve rapidly; while transmission networks have undoubtedly influenced the spread and codification of certain styles (*e.g.*, Expressionism, Surrealism) and the subsequent responses to these styles, the transmission network does not constrain the evolution of art in the same way that could be said of science or religion because artistic memes are non-dogmatic and non-competitive (*e.g.*, the meaning that may be interpreted from Dali's melting clock does not conflict with that which may be interpreted from Warhol's can of soup).[24]

The emergence of scientific explanations of human origins has effectively challenged the dogmatism of earlier religious explanations, throwing their universalism into question. But as described above, science is fundamentally constrained in its depth of explanation due to its reliance on empirical observation and logical axioms. As many of the questions surrounding the existence of the universe and the nature of human consciousness lie beyond the reach of the scientific method, the replacement of religious explanations with scientific ones has left a void where science can make no comment. It is here that art has evolved and flourished, providing a complement to scientific understanding; art can provide an entry point and means to reflect upon and enrich the understanding of any given subject material. When it reflects upon the discoveries of science, as seen in the art of Rubinoff[25], Juan Geuer[26], and many others[27], it can situate the discoveries of science within the larger range of human experiences that are less accessible to the scientific method. Together, art and science can provide a means to unify the diversity of

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[23] Jeffrey Rubinoff, "Importance of Art History". See http://www.rubinoffsculpturepark.org/coi/php.
[24] The author refers here to Salvadore Dali's *Persistence of Memory* (1931) and Andy Warhol's Campbell's Soup series, which was begun in the 1950s and includes countless versions in a range of media.
[25] http://www.rubinoffsculpturepark.org/
[26] http://www.juangeuer.com/index.html
[27] Multiple works reflecting on a range of scientific discoveries were collected in the *Big Bang* exhibit held at the DeCordova Museum and Sculpture Park in 2007.
See http://www.decordova.org/decordova/exhibit/2006/bigbang.html.

interpretations about human origins that evolved through the various religious traditions around the world, thereby contributing to the “collective memory of the universe”.

Summary

Evolution on Earth has generated a vastly complex system of interconnected organisms and ecosystems with the emergence of novel biophysical features enabling novel types of interaction and evolutionary modalities. Perhaps most remarkably, through the elaboration of culture, evolution has yielded an organism capable of conceiving of its own origins. Equally remarkable, this creature has developed the capacity to threaten its own existence through the clash of civilizations in war. It is perhaps ironic that the same cultural system, science, is responsible for the most advanced developments in each of these fields: evolutionary theory and the atomic bomb. The modernist culture that spawned each of these has phenomena is also the source of the universal declaration of human rights, which envisions a peaceful world through cooperation and restraint. As many of the conflicts that ripple through the modern world are the product of centuries of clash between civilizations with different political or religious cultures, an understanding of the processes that generated these cultures is necessary before there is any hope of a lasting peace.

The dogmatism and disagreements of competing religions can be seen as an inevitable byproduct of the structure by which they evolved, just as the gradual groping of science towards ever more accurate descriptions of natural phenomena is a direct consequence of its own structure. This essay has been limited to a comparison of religion, science, and art, but similar analyses would illuminate our understanding of the evolution of other political and social organizations. Perhaps by understanding how evolutionary processes are themselves affected by the social ecology that shapes the networks through which culture evolves, we can learn to channel our evolution towards more humane solutions to the problems of existence.

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GLOSSARY

Allele	A specific copy of a gene, often characterized by a mutation that varies from one individual to another.
DNA	Deoxyribonucleic acid. The molecule that encodes genetic information in most higher organisms.
Eukaryote	More highly evolved organisms with chromosomes, a nucleus, and membrane-bound organelles; can be either single- or multi-cellular.
Meme	A term coined by Richard Dawkins to describe the cultural analogue of a gene; *i.e.,* a unit of cultural inheritance that can be transmitted from one individual to another.
Mitochondrion	A membrane bound organelle in all eukaryotes that controls cellular respiration, providing energy for the cell.
Ontogeny	The process of an individual organism growing organically through the various stages of its development.
Phenotype	The morphological, behavioural, biochemical, or life-history trait that results from the influence of a specific allele on the development of an individual.
Prokaryote	A single-celled organism lacking a nucleus or membrane-bound organelles.
RNA	Ribonucleic acid. The molecule that encodes genetic information in some viruses; is also used by the machinery that translates the DNA-based code into proteins.