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Culture-as-bit: Culture and Cultural Evolution

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Culture-as-bit: Culture and Cultural Evolution

A thesis submitted in partial fulfillment of the requirement
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by

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The philosophical presupposition of this thesis is a simple one: humans are inextricably part of the universe. This may seem obvious; in its application, however, it requires a radical shift in outlook. Anthropology has long recognized and embraced the idea that humans are biocultural beings, but if humans are inextricably part of the universe, then they are acted on and shaped by universal forces. Understanding human nature requires not just understanding ourselves vis-à-vis other primates, or even vis-à-vis other animals, but understanding ourselves vis-à-vis entropy and atoms, biochemistry and black holes. At first, it may seem absurd to think that black holes or quantum mechanics might tell us anything about human nature, but it is important to remember that the basic components that make a black hole, a galaxy or a pocket-watch are the same things from which we are made – quarks and atoms, elements and waves. As Carl Sagan (1990) elegantly put it, we are all made of star-stuff.

Our current understanding of the nature of the universe is approximately as follows: the universe is entirely made up of energy that, in turn, is doled out and divided into various forms following set rules. At the most basic level of this energy distribution system are particles and fields. Particles, which are the components of matter, have energy in the form of mass and momentum and may have other types of energies including charge and color. Fields are the background energy surface on which particles move and interact. Importantly, everything in the universe that is real has in its constituent components a specific organization of particles. The universe, through various mechanisms, is taking a continuous distribution of energy and dividing it into discrete and quantifiable parts.

In turn, these elementary particles can organize into larger structures. Quarks become protons and neutrons that combine with electrons to form atoms. Each elemental atom is made up of a unique configuration of elementary particles - a given number of protons, neutrons and

electrons, which confer upon the atom special properties that none of its constituent parts possess on their own. An atom can interact with other particles and universal fields in a way that a proton, a quark, or an electron cannot. Atoms too can organize, binding together through a sharing of electrons or through field-interactions, to form molecules.

Surprisingly, molecules of our universe too can join and interact dynamically to produce self-sustaining reactions and, ultimately, life. On a world-wide scale, the metabolism of life, which produces the necessary energy for all biological actions, is a carefully controlled series of molecular interactions that converts elementary particles – photons – into usable and productive energy. All life is the result of a complex and dense interaction of molecular interactions, and, in turn, has properties that no molecule on its own exhibits. Life evolves. Through natural selection and other evolutionary forces, life has diversified into a myriad of forms and functionalities. By concentrating and directing molecular interactions, life can interact with the universe in new ways not available to singular molecules.

At this point the reader may be wondering what, if anything, this has to do with anthropology. The answer, at least the answer I am advocating, is that culture and consciousness are the next steps in this organizational story. Culture arises from a specific interaction generated by biological life and, in turn, allows new interactions with the biosphere and the universe. While anthropology has long explored how culture shapes individuals and mediates their interactions with the world, there has been no scholarship, at least of which I am aware, that has seriously attempted to place culture as a physical entity and to locate its boundaries in the universe. To locate culture in such a way, it will be necessary to briefly return to the larger organizational story.

The overarching organization pattern of the universe is the joining of discrete entities which produces outsized, and often *a prioi* unpredictable, effects. In a sense, the universe is a dynamic system writ large, with multiple organizational levels and emergent properties. Elementary particles become atoms which become molecules which become life. Importantly, too, a small number of discrete components can give rise to a huge number of possible combinations. There are only twenty four elementary particles, and fewer than 120 elemental atoms which make up the known universe. On the biological level, life is ultimately produced from a varying sequence of only four distinct nucleotides and some twenty two amino acids. Each level produces a new interaction entity, which in turn gives rise to the organizational structures on that level. These new interaction entities, in turn, might be described as the most fundamental unit of that organizational level, since reducing any of them further would destroy their unique interactional properties. Information theory (Shannon, 1949) provides us with a term for the most fundamental unit of organization – the bit. In a rough sense, then, we might think of particles as the bit of physics, atoms as the bit of chemistry, and DNA and genes, as the bit of biology.

In this thesis I propose that there is also a bit for culture, a biocultural juncture where the metabolic processes of life organize in such a way as to create a new interaction sphere — culture. While the exact mechanisms for how the universe creates this cultural organization are heretofore unknown, recent advances in neuroscience provide a starting point for this investigation. Specifically, research regarding the neural code (Nestor, Plaut, and Behrmann, 2011; Lisman and Jensen, 2013; Stanley, 2013; Shamir, 2014) provides a preliminary understanding of neuronal processing and synaptic firing in the brain that is roughly analogous to the genetic code. In this neural code interpretation of the brain, neurons respond in an organized

and predictable fashion to their environment leading to behaviors and bodily actions generated by repeatable and predictable neuronal interactions. Leading from this, ideas and patterns of thought could be encoded by specific neuronal firing patterns, and as a result, culture could ultimately be described in terms of underlying neuronal activity.

Specifically, what my culture-as-bit hypothesis proposes, based on current understandings of neuroscience and the neural code, is that every individual thought, behavior or belief is the result of a unique firing and neurotransmitter release pattern of the neurons. Ontogenic learning of ideas and thoughts, in turn, are the result of the brain training itself to reliably produce and enact specific neuronal firing patterns, similar to how a baby must learn to move its appendages (Thelen, 1985; Thelen, 1987; Hadders-Algra, 2002; Thalen and Corbetta, 2009) or how an injured person must retrain their muscles to walk (Sheppard, 2001; Fouad and Pearson, 2004; Pearse, *et al.*, 2004). For the individual this is a more or less an open process, with neural plasticity, dendritic reshaping, and non-linear firing action allowing for continual change over the course of a lifetime. Furthermore, while there are a relatively limited number of organization entities at other universal levels (twenty four elementary particles, four nucleotides, and so on), the adult human brain contains some eighty six billion neurons, each interlinked by up to 7000 synaptic connections allowing for an essentially infinite range of permutations (Pakkenberg, *et al.*, 2003; Herculano-Houzel, 2009), easily allowing for the entire range of possible thoughts. Every culture-bit is a specific sequenced firing of neurons across the variable neural network that composes the brain.

The culture-as-bit hypothesis is, primarily, a physical interpretation of what culture actually exists as in the world and universe. Thinking about culture in terms of discrete bits can grant new and important implications for how anthropologists view social organization, cultural

evolution, and human evolution, which I will explore later in this thesis. In the rest of the introduction I place this idea of culture as bit-like in the context of previous anthropological scholarship to illustrate that while the approach and viewpoints are unique, they do not deviate in spirit from previous anthropological works. Importantly, as far as anthropologists are concerned, this hypothesis of culture-as-bit does not alter anthropological findings of how culture builds and organizes itself, except where anthropological literature conflicts with whatever is found to be true regarding the universe or neuroscience, since this proposal necessitates consistency with larger structures of scientific thought. In content, the idea of culture as bit-like is most closely related to the ideas of Claude Lévi-Strauss (1908-2009) and Structuralist traditions while in its approach it resembles Leslie White's (1900-1975) attempts to find universal laws of culture. I will also attempt to demonstrate that viewing culture as bit-like need not overturn previous anthropological findings by arguing that bit-like culture is at least not inconsistent with, and perhaps supports, two major anthropological frameworks – Clifford Geertz's (1926-2006) symbolically-mediated thick description and Sherry Ortner's (1941-) practice theory.

Few anthropologists have had as large a theoretical impact as Lévi-Strauss, who began his fieldwork in 1935 and continued working up until his death in 2009, just short of his 101st birthday. Along with Roman Jakobson (1896-1982) and Edmund Leach (1910-1989), Lévi-Strauss developed the theoretical school of structuralism. In a series of highly cited works, including *The Raw and the Cooked* (1964), *The Savage Mind* (1966) and *Structural Anthropology* (1973), Lévi-Strauss articulated a cohesive view of human culture and thinking. In Lévi-Strauss's model the human mind is universally the same in its construction across all human populations and is driven by a deep grammar or set of rules that predispose it to binary interpretations of the world. Culture, in turn, serves as a mediating agent that seeks to resolve

these binaries and produce unity. Finally, human social organization is driven by the underlying grammatical rules of the brain working subconsciously.

While structuralism covers a huge range of anthropological thought, there are several elements in Lévi-Strauss's thinking that align with or resemble the proposal of culture-as-bit. First and most obviously, the culture-as-bit hypothesis also views culture, and human interpretations' of the world, as fundamental results of human cognitive action and arrangement. Of course, there are important differences. For instance, I see no reason to presume that human brains are predisposed to binary division, as opposed to capably managing multiple, distinct interpretations, but this difference can largely be explained by the cognitive models with which Lévi-Strauss had to work. There is another, more nuanced, similarity between structuralism and culture-as-bit. In his analyses of myth, Lévi-Strauss defined the basic unit of analysis of myth as the "mytheme." For Lévi-Strauss, mythemes are constituent units of myths and are bundled together in a set of relations to produce the meaning of the myth (Lévi-Strauss, 1955). While there appears to be an immediate analogous relationship between mythemes and the proposal of culture-as-bit, it is important to understand that Lévi-Strauss derived his mytheme approach from Saussurean grammar, while culture-as-bit comes from a consideration of the organizational structure of the universe. What is actually shared between the two is not necessarily that the human mind is inherently grammatical, but rather an understanding that apparently continuous and organizationally complex entities, respectively myth and culture, can be fully described by discrete parts and their relationships.

In a more general sense, what is shared between the proposal of culture-as-bit and structuralism is the notion that human culture and organization are a direct product of human cognitive function. Furthermore, that human culture itself is ultimately describable in terms of its

constituent parts and their interrelationships. The concepts differ dramatically, however, in their

specific interpretations of human cognitive function and its impact on the development of

culture. Lévi-Strauss's insistence that all cognitive functions follow the same rules as grammar

seems shallow compared to what we now know to be true regarding human neuroscience, while

culture-as-bit is fully interpretable with innate variation in human thought, neural plasticity, and

environmental effectors. Unlike structuralism, culture-as-bit recognizes, to paraphrase Whitman,

that humans can contain multitudes.

If the culture-as-bit model most closely resembles Lévi-Strauss's ideas in regards to

content, in its general approach it is comparable to Leslie White's attempt to find universal laws

of culture. In his two most prominent treatments of culture, *The Science of Culture: A Study of*

Man and Civilization (1949) and *The Evolution of Culture: The Development of Civilization to*

the Fall of Rome (1959), White outlines his view that culture is a unique phenomenon,

describable only in its own terms and that over the course of time, culture can evolve in its

capacities and abilities. He developed what has become known as White's Law, an argument that

the total sum of cultural development is equal to total energy used for work on a per capita basis.

The differences between White's conception of culture and culture-as-bit are numerous. Perhaps

the most significant is that the culture-as-bit hypothesis need not see culture as purely

determining human behavior, nor does culture-as-bit see culture as autonomously evolving

without respect to human action. Nevertheless, White's general approach to the problem of

culture and cultural evolution closely resemble the ones followed here.

In White's conception of culture's nature and evolution (White, 1943; Barrett, 1989),

culture acts as an organization of energy utilized by humans to fulfill their needs. Similarly to the

culture-as-bit hypothesis, White places culture on a universal scale, in his case by relating the

level of cultural advancement to the energy expenditure and capture of a given society. In doing so, White relies on carefully reasoned relational models, reducing observed phenomena to a few general variables, placing them in relation to one another and justifying this placement through inductive reasoning from the empirical evidence. He is also quite honest about the shortcuts or eliminations he must make. For example, in developing White's Law he states "since the overwhelming portion of a cultural development is due to technological progress, we may legitimately ignore that small portion which is not so dependent by regarding it as a constant" (White, 1943, pg 336.). White privileges technological progress based on his assessment of available ethnographic evidence to make the resulting equation easier to work with by having fewer terms contained within it.

This approach of modeling is the one followed in the thesis, but in an expanded context. White's failures, in my view, have less to do with the power of his ideas than the limitations of math and knowledge at his time. White was particularly leery of looking to other fields for the development of his ideas, explicitly stating that "the culturologist knows more about cultural evolution than the biologist, even today, knows about biological evolution," (White, 1943, pg 339). While I might differ with the truth-value of White's statement, it is true that at the time biology was only beginning to undergo what would be known as the "modern evolutionary synthesis" (Huxely, 1942; Mayr, 1942; Simpson, 1944; Stebbins, 1950) and it is certainly true that biological evolutionary theory has grown manifold since White's time.[1] As such, this thesis, and the culture-as-bit hypothesis, sees no aversion to drawing on biology and biological models. In fact this is probably necessary. In an inversion of White's beliefs, today's modern biology probably knows more about biological evolution than anthropologists know about cultural evolution.

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[1] There is, of course, some meta-irony in this that I would just like to highlight.

Finally, since I recognize too that anthropological theory has grown since the time of Lévi-Strauss and White, I would like to outline how culture-as-bit is at least not inconsistent with more modern theories before beginning the thesis proper. The two major theories to be addressed will be Geertz's symbolically mediated thick description and Ortner's practice theory.

Clifford Geertz (1926-2006) wrote extensively across anthropological subject areas, from field work (Geertz, 1960; Geertz, 1963, Geertz, 1968) to cultural theory (Geertz, 1973; Geertz, 1983) to methodology and the role of the anthropologist (Geertz, 1988; Geertz, 2001). Through these works, Geertz developed his central ideas – that culture is an interconnected set of symbols and it is through these symbols that humans come to understand and mediate their world. In Geertz's view, it is the job of the anthropologist to uncover the meaning of these symbols as understood by those who experience them and accurately describe these meanings to an outsider.

The culture-as-bit hypothesis is not inconsistent with Geertz's interpretation of culture or his views on anthropological goals. Under the culture-as-bit hypothesis, a symbol is simply a consistently and commonly held thought-pattern or understanding of the world. While the foundation of the culture-as-bit hypothesis is neuroscience and the physical universe, it does not by any means insist that all generated ideas need be useful, utilitarian or directly interpretive of the world for those who generate them. Empirical evidence, as gathered by Geertz, as well as many other anthropologists, amply shows that there is a broad diversity in how differing populations can come to understand their world (e.g. Turner, 1970; Bateson, 1972; Crocker, 1990; Shostak, 2000). Under the culture-as-bit hypothesis, each of these differing populations is a large set of individuals that have simply developed and sustained unique thought patterns that, in theory, could be physically interpretable and describable if given sufficient data. Given, however, the current limitations of neuroscience, and the ethical problems such a physical

analysis might entail, Geertz's semiotic thick description is a way of deducing these differences from behavioral observation.

In Sherry Ortner's (1941 – present) analyses, the traditional framework of culture is eschewed in favor of seeing humans interacting in a dynamic tension of roles, understandings and embodiments. Based on field work with the Sherpa in Nepal (Ortner, 1978; Ortner, 1989; Ortner, 1999) and, more recently, in the United States (Ortner, 2003), Ortner seeks to understand individuals' roles and their understanding of their world through the lens of what she terms "serious games," an extension of Bourdieu's practice theory (1977). Serious games "are not just bundles of intentions or fields of language discourse [but] involve players, differentially positioned, differentially situated, with respect to those intentions and those discourses," (Ortner, 1999, pg. 150). For Ortner, what matters is that every person is in a state of constant evaluation, action and flux in their position socially and in relation to the larger world structures. The job of the anthropologist becomes to uncover the dynamics and nature of these interactions at the level of the individual and the level of the society.

Where culture-as-bit might come in is in providing a physical interpretation of this process. The fields of discourse and intentions proposed by practice theory are merely the by-product of consistent or commonly held belief and thought-structures across multiple individuals while evaluation and agency actions are the product of more relatively transient thought processes at the level of the individual. Again, it is probably not of great utility for practice theorists, as of yet, to think of culture in terms of discrete ideas and culture-bits because the questions they ask and the level of interaction and organization they are dealing with are much larger.

What might be clear at this point is that this thesis is not a work of traditional anthropology. There is no single tradition – structural functionalism, practice theory, etc. – into which the views and arguments I express can be readily placed, unless one might consider the small group of mathematical anthropologists a tradition. Nevertheless, my interests – culture, cultural evolution, and human evolution – are distinctly anthropological. While I will draw on many other disciplines in the course of the thesis, my hope in doing so is that the field of anthropology can be moved forward, even if only slightly.

 In terms of the structure of this thesis, the arguments presented here are exclusively methodological and theoretical, relying on analysis and synthesis of other scholarship. Together they advocate for re-grounding the discussion of culture in a firm understanding of the biological, physical, and mathematical and that this re-grounding will yield new insights into and understandings of human nature and culture. The first chapter will advance the use of mathematical graph theory for better understanding human social structure and its role as a storage-unit of culture. The second chapter derives a potential mathematical approach for studying cultural evolution and the spread of culture through populations that allows for a union of two previous lines of anthropological analysis. The final chapter combines the findings of the two previous into a cohesive argument regarding human evolution.

Chapter 1

Human beings on large population scales exhibit a particular social organization that is strongly associated with the ability to maintain and preserve connectivity and information in the face of attack (Liljeros, *et al*., 2001; Song, Havlin and Makse, 2005). In this chapter I will argue that this observed social organization is not a coincidence and likely evolved in order to act as a storehouse for the preservation and maintenance of culture in the face of strong environmental

pressures. In order to make this argument it will first be necessary to briefly discuss mathematical graph theory.

Graph theory is a subfield of mathematics interested in understanding discrete points in space and their interrelationships. The mathematical study of graphs has been progressing for almost 300 years (Euler, 1741), and a large set of mathematical proofs, theorems and understandings has been constructed to understand various graphs and their features. In mathematics, the points of graphs are termed vertices and the connections between these points are termed edges, with the set of vertices and edges together forming the graph. When the vertices and edges have real-world interpretations, however, a different terminology set is used consisting of nodes and links, respectively, which form a network. This notation of nodes, links, and networks will be used in this chapter.

The first to introduce mathematical graph theory to anthropology was the pair of Per Hage and Frank Harary (Hage and Harary, 1984; Jenkins, 2008). In their applications, individual humans formed the node of the networks and the social connections between the individuals formed the links. Hage and Harary utilized graph theory across a wide variety of anthropological areas, including the wealth structure of the *kula* ring (Hage, Harary and James, 1986), New Guinean sexual-duality beliefs (Hage and Harary, 1981; Hage and Harary, 1983) and mathematical structures of kin systems (Hage and Harary, 1995; Hage and Harary, 1996).

More recently, graph theory and networks have been used to study a variety of real-world phenomena including human social organization (Liljeros, *et al*., 2001; Barabási, *et al*., 2002; Ebel, Mielsch and Bornholdt, 2002; Guimera, *et al*., 2003; Song, Havlin and Makse, 2005; Barabási, 2009). These studies collectively found that at large population numbers, *i.e.* a few thousand or more, human interactions collectively form what has been termed a scale-free

network. In such scale-free networks, social connections between humans follow a specific

mathematical pattern[2], which creates a unique network structure. This scale-free network

structure is shown in Figure 1, opposite a random network. The connections between nodes in

the random network are determined purely by change, while in the scale-free network clusters of

connections emerge around hub nodes.

Figure 1. Scale-free versus Random Network
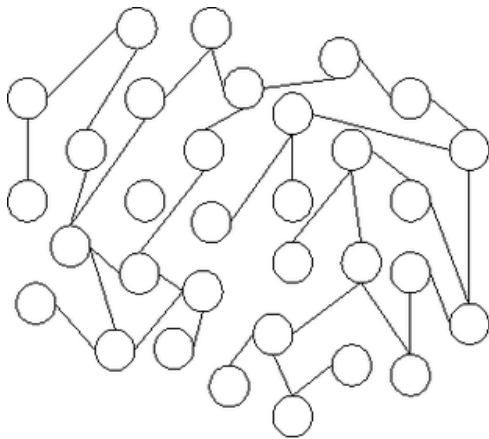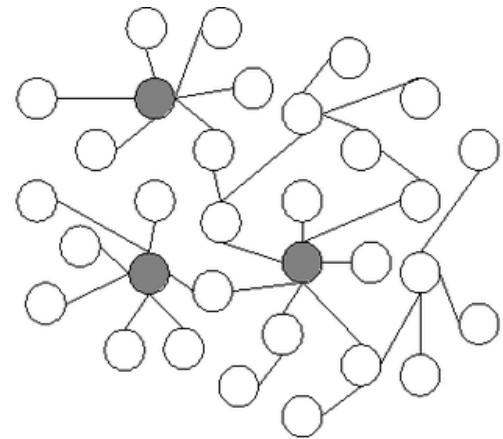
(a) Random network   (b) Scale-free network

The scale-free network on the right contains many more clusters and hubs than the random network on the left.

 Given these recent findings of human scale-free network structures, and similar structures

in other biological contexts, the properties of scale-free networks are currently being studied in

mathematics. One of the most important findings is that scale-free networks are highly resistant

to attack (Albert, *et al*., 2000; Cohen, *et al*., 2000; Callaway, *et al*., 2000; Cohen, *et al*., 2001),

meaning that even when nodes are removed from the network a continuous scale-free structure is

maintained for long periods. The network does not easily fragment into smaller, separate

networks. Additionally, scale-free networks often exhibit another feature termed small-world

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[2] Mathematically, this relation is $P(k) \sim k^{-\gamma}$.

phenomenon (Amaral, *et al*., 2000; Cohen and Havlin, 2003; Wang and Chen, 2003; van Noort, *et al*, 2004). Within networks exhibiting the small-world phenomenon, the path between any two nodes in the network is relatively short, even for networks with large node sizes. It is relatively easy to connect two nodes via a small number of links no matter the number of nodes. To understand this better, it might help to consider the parlor games that have developed around this small-world phenomenon exhibited in human networks - trying to connect an actor/actress to Kevin Bacon in fewer than six relationships is one such example. A similar game has developed in academia, in determining how many sets of shared publishing credits is needed to link a scholar with the prolific mathematician Paul Erdös.[3] The combination of robustness to attack and small-world phenomenon provides scale-free networks with unique features not seen in other network structures.

With both of these features in mind, it is possible construct an argument for why humans may have preferentially evolved scale-free network structures. Under the culture-as-bit proposal ideas and cultural creations are contained in the minds of individuals and generated through specific neuronal interactions. Furthermore, each node of the network represents a single individual. It would be possible, then, to map the entire culture of the population as a network with each nodal person having the ideas and cultural creations specific to itself. The distribution of these culture-bits would roughly follow the knowledge and experience distributions of the network, so that one would expect, for instance, those who hunted to have more culture-bits related to hunting while those who practiced medicine would have more culture-bits related to medicine and healing. The connections of this network would again represent the social connections between individuals. These social connections would act as the major avenues via

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[3] There is a small group of people who possess both Bacon and Erdös numbers, including most prominently Carl Sagan, Richard Feynman, Natalie Portman, and Noam Chomsky.

which any given culture-bits are transmitted (this will be discussed in more detail in the next chapter).

Under this system the network and its nodes are acting as a storage mechanism for the individual culture-bits with each nodal-person containing some number, but not all, of the total culture-bits in the network. We can hypothesize that the total number of persons in the network would correspond to the overall number of culture-bits observed. In fact, this is what has been found in empirical settings. In Oceania, anthropologists Michelle Kline and Robert Boyd (2010) illustrated that local population network size correlated well with the complexity of fishing technology at the time of European contact. Similarly, Joseph Heinrich (2004) has proposed that differences in technological complexity between native Tasmanians and Australians can be explained by the reduction in effective population size in Tasmania when the island split from the continent. Together, these examples provide evidence for social organization structures acting as a storehouse of culture-bits.

If human social networks are serving as a storehouse for culture-bits it would make sense for the storehouse to be designed in a way to minimize loss over time. As has already been discussed, scale-free networks are highly resistant to external pressures and the exhibited small-world phenomenon would make it relatively easy to transmit culture-bits across even large networks. The scale-free network structure, then, likely arose via natural selection as a way of combating external environmental pressures that might sever connections and reduce connectivity in the network. The importance would be greatest when environmental pressures are extremely intense, for instance in epidemic disease or population bottlenecks, where maintaining connectivity is critical to surviving the event.

Obviously, this argument of social organization acting as a storehouse for culture-bits is only a preliminary hypothesis and much research will be needed to test it. Several areas seem like opportune testing grounds. First, it might be expected that populations which have more intense environmental pressures might exhibit more scale-free structures, while those populations that face less severe environmental pressures might exhibit other network structure types. Correlated to this, it is likely that alternate network structures arise to serve different needs related to the propagation, production or maintenance of culture-bits. Universities, for instance, tend to concentrate nodal persons with large numbers of culture-bits all in a tight network structure, which has been variously tied to greater knowledge production (Godin and Gingras, 2000; Griffiths, 2004; Lambooy, 2004). Another important area needing study, and for which anthropologists are particularly suited, is that humans can move through social networks over time as they add new social connections and old ones are removed through falling out or death, a fact which is recently being examined in the mathematical literature (Gozalez, *et al*., 2008; Wang, *et al*., 2011). What motivates these movements, however, and whether these movements follow any predictable rules, is unclear. Additionally, how these movements might impact the culture-bit distribution of the network is also unclear.

In summary, the argument of this chapter is that human social organization acts as a storehouse for the culture-bits of individuals. Scale-free structure may have arisen to minimize connectivity loss in the face of environmental pressures. Alternate environmental conditions, however, might result in differing network structures. More study will be needed to rigorously test the expected outcomes of the proposal across a variety of settings.

Chapter 2

While the previous chapter examined broad-level social organization and how the structure of such organization affects the storage of culture-bits, this chapter addresses the topic of cultural evolution. I will illustrate how thinking in terms of culture-bits can allow for a union of both specific cultural ontogenies and large-scale models of cultural evolution.

Anthropologists have long been interested in how culture propagates, transmits and evolves through time. The study of these questions has taken form in two broad areas of analysis: the process of transmission and modeling large-scale transmission and cultural evolution. Process-oriented culture studies focus on individual ontogenies and how individuals come to learn the beliefs, knowledge, and skills they possess. Margaret Mead's (1901-1978) *Coming of Age in Samoa* (1928) was the first published work extensive treat the topic based on rigorous field-work, and since then the subject has been examined in a number of populations and geographic areas (e.g. Turner, 1970; Bateson, 1972; Crocker, 1990; Shostak, 2000). More detailed studies have used particular subject areas of cultural knowledge, such as hunting skills (Borre, 1991; Hill and Kintigh, 2009; MacDonald, 2010) to determine what factors influence and mold individuals' knowledge acquisition in specific knowledge domains. Other studies focused on the ontogenetic learning differences between humans and non-human primates (Call, Carpenter and Tomasello, 2005; Matsuzawa, Tomonaga, and Tanaka, 2006; Tomasello and Carpenter, 2006; Buttelmann, *et al.*, 2013). The purpose of such works is to determine, at the level of the individual, how a person acquires cultural knowledge and abilities. The culture-as-bit proposal does not yet have much to directly offer this interest in individual learning processes, other than to comment that these processes, at some level, must be contained in the neurochemistry of the individual.

The culture-as-bit hypothesis contributes mainly in the second area: large-scale models of transmission and cultural evolution. Typically, in large-scale models of transmission and cultural evolution, differences in individual ontogenies are collapsed and it is assumed that culture can be more or less freely transmitted among individuals. From there, a general model of how cultures as a whole differentiate and evolve is constructed based on various constraints and assumptions. The earliest debates regarding these large-scale models focused on whether cultures evolved unilineally (Tylor, 1881), multilinearly (Steward, 1972; Lewis, 2001) or through some diffusionary process (Kroeber, 1952). More recently, the debate has focused on whether culture is transmitted primarily horizontally or vertically and how much cultural evolution resembles biological evolution (Mulder, *et al*., 2006; Collard, Shennan, and Tehrani, 2006; Lycett, 2009; Ellen, Lycett and Johns, 2013).

The culture-as-bit hypothesis can offer a way of reconciling the two levels of analysis to incorporate individual ontogenies into models of cultural evolution. This can be done by examining the transmission of culture-bits at the level of the population network. The hypothesis can also provide a reasonable explanation for the differences in cultural and biological evolution. This necessitates, however, applying the arguments of the last chapter to the topic of cultural transmission. Here, it will be assumed that individual humans form a network of connections, that the social bonds between them form the links of this network, and that each nodal-person contains some number of individual culture-bits. Additionally, it will be assumed that cultural evolution occurs when the distribution of culture-bits across the network changes, which can occur from selection, drift, mutation or some other force. This definition of evolution is the classic one provided by early mathematical analyses of genetics at the turn of the 20th century, which illustrated that in absence of any evolutionary force, the distribution of alleles in a

population would remain constant (Castle, 1903; Pearson, 1903; Weinberg, 1908; Hardy, 1908). The population in the context of culture is the network, and alleles are the culture-bits held by nodal-persons.

Additionally, this chapter will assume two types of evolutionary forces: internal and external. Internal forces are specific to a species or population and are defined as those forces which would, even when external forces are held constant, continue to produce evolution up until the point of Hardy-Weinberg equilibrium. These internal forces include but are not limited to: genetic drift, sexual selection, social organization and dynamics, and mutation. The forces of social organization would include many classic areas of anthropologic study including kin structure, political organization, colonial structures and ideology. External forces are global variables defined as those that produce evolution only so long as they are changing and include, non-exhaustively, predation, temperature, geography, and environmental resources.[4]

To explore the differences between cultural and biological evolution and how individual ontogenies of cultural learning can relate to cultural evolution models, let us conduct a thought-experiment. First, we might combine all the forces of evolution, both internal and external, into a single value, transmission cost, which measures how difficult it is to pass on genes or transmit culture-bits. More explicitly, the transmission cost would be the solution to a partial differential equation that contained all the possible causes of evolution. Transmission cost, in turn, could be related to the frequency of a given allele or culture-bit in the population such that when transmission cost is low, the frequency should approach fixation, and when transmission cost is high the frequency should approach extinction. The first derivative of this function solves for the

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[4] For those so inclined, it may be useful to loosely think in terms of a statistical mechanics problem in which the external forces are thermodynamic parameters of the system and the internal forces are the mechanisms by which the system cycles through microstates to find the free-energy minimum (Hardy-Weinberg equilibrium) relative to these parameters.

evolution, or rate of change in frequency, of the allele or culture-bit in the population. A generic

equation depicting this change in allele or culture-bit frequency as a function of transmission

cost, and its resulting corrected first derivative (the evolution function), is shown in Figure 2.

Figure 2. Trait frequency and evolution as a function of transmission cost.
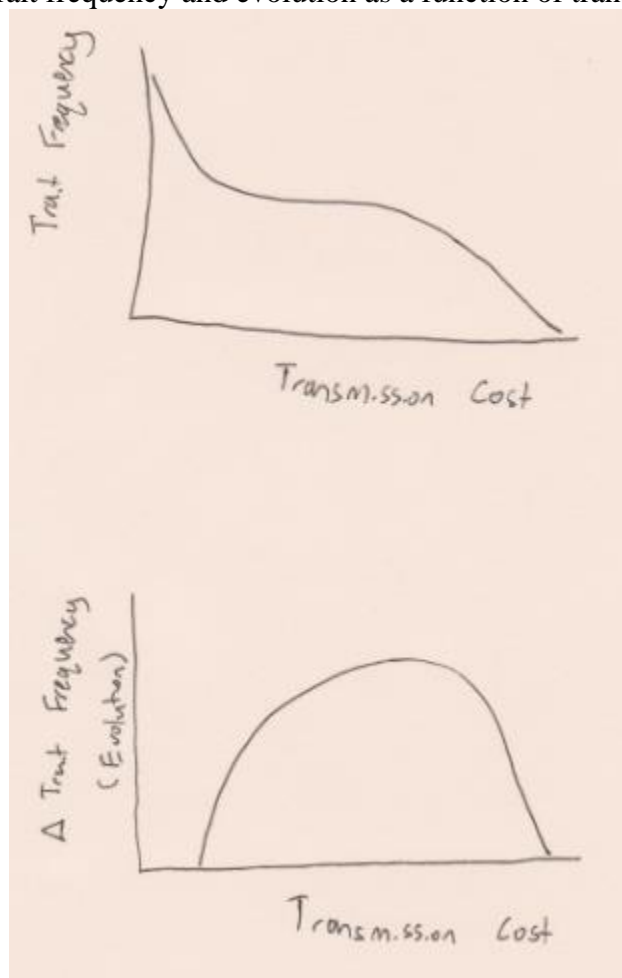
The integrated area of allele or culture-bit frequency as a function of transmission cost

represents all possible states of the system: every possible combination of evolutionary pressures

and the resulting frequencies. It is at this level that we can begin to discern the differences

between cultural evolution and biological evolution, as well as incorporate ethnographically

observed ontogenies. Specifically, the ethnographic ontogenies form part of the differential

equation determining transmission cost, which in turn collapses or expands the range of possible transmission cost values. For example, the fact that agricultural knowledge is mainly learned during the growing season could be incorporated into the transmission cost equation for the culture-bits related to agriculture. As another example, the rule that only men are able to learn the shamanic language would be incorporated into the transmission cost equation related to culture-bits for shamanic rituals and language. The end result is that cultural evolution for the population comes from the enacted sum of all the culture-bit equations. Each equation gives the distribution of a single culture-bit while all the equations together produce the cultural evolution of the system.

In biological systems, the external forces of natural selection act through predation and other environmental pressures. Similar external forces also act on cultural networks at the level of node-persons in that nodes can be removed by way of death or impairment by some environmental force. Internal forces in biological systems are, in turn, demonstrated by the inability to find a random viable mate in biological systems. In cultural systems, the internal forces are the direct result of ethnographic ontogenies in that ontogenies determine the difficulty in transmitting or spreading a given culture-bit. Cultural and biological evolutionary systems diverge, then, from the differing inputs of external and internal forces into the transmission cost differential equation.

For instance, in biological systems, changes in allele frequency due to reproduction come, tautologically, from the ability to find a willing and viable mate. In most biological systems, this ability is limited by a conditional probability in mating. That is, the ability to reproduce is capped by the number of viable females in the population. The fact that a female can only successfully mate a set number of times per generation cycle limits the potential change

in allele frequency in the population.[5] This in turn is factored into the transmission cost equation for that system. This limits the range of allele frequencies by capping the potential set resulting from genetic drift or other internal forces. For example, a single male with a rare mutation cannot pass this on to the majority of the offspring population because he is competing against other males for mates. Females are similarly limited by the upper limit on offspring they can successfully carry to term. Cultural systems however, are not necessarily capped by this limitation and, as such, can have a significantly larger range of culture-bit frequencies that come from drift. In this case, the lack of conditional probabilities in mating allows for a greater range of evolution in cultural systems. This example difference between cultural evolution systems and biological systems is depicted in Figure 3.

Figure 3. Evolution in generic biological system versus cultural system as a function of transmission cost.

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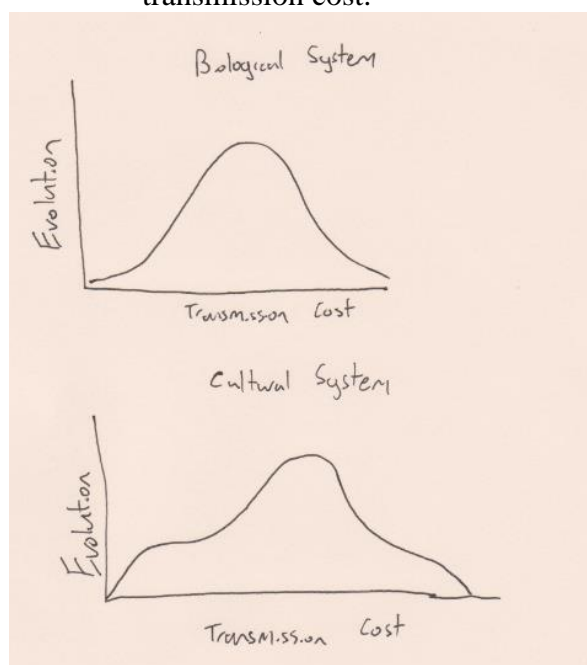
[5] More accurately, the presence of superfetation and heteropaternal superfecundation in many species means that it is not truly the number of females that matter but something closer to the "uterine space," or the maximal offspring possible.

To put this more intuitively, cultural systems and biological systems differ in their evolution in that each has different evolutionary variables and forces acting on them. This is not to say that biological evolution cannot reasonably approximate cultural evolution. Where cultural ontogenic rules resemble the rules governing biological evolution, the resulting frequency change equations will appear similar. For instance, knowledge that is primarily passed matrilineally might be expected to closely resemble models of biological evolution (Tehrani and Collard, 2002; Tehrani and Collard, 2009), since the culture-bits are only passed on to kin relations similar to genes. Similarly, when a culture-bit is already saturated across the population, it may become hard to find a person who does not already possess the bit. In this case, a term similar to the conditional probability of biological systems would come into play and limit the transmission cost range resulting in an evolutionary path similar to that of a biological system.

To summarize briefly, the culture-as-bit hypothesis and the arguments from the previous chapter offer a theoretical basis for synthesizing individual ethnographically-observed learning ontogenies into larger-scale models for cultural transmission and evolution at the population level. They also predict that where learning ontogenies resemble biological conditions, cultural evolution should proceed similarly to biological evolution. Conversely, where learning ontogenies differ from biological conditions then cultural evolution will proceed down its own, unique, evolutionary pathway.

Chapter 3

Approximately six to seven million years ago, the ancestors of what would become modern humans diverged from the ancestors of chimpanzees and bonobos (Stauffer, *et al*., 2001; Kumar, *et al*., 2005;Soares, *et al*., 2009; Langergraber, *et al*., 2012). While the exact cause of this divergence from the last common ancestor is not yet known, the six million or so years following

saw the rapid rise and extinction of a number of hominins until only a single species, *Homo sapiens*, remained (Lieberman, 2011; Wood, 2011; Stringer, 2012; Tattersall, 2012). Over the course of this divergence a number of traits appeared that separated modern humans from chimpanzees and bonobos including but not limited to, bipedalism (Spoor, Wood and Zonneveld, 1992; Lieberman, 2012; Haile-Selassie, *et al*., 2012), tool-enabled large carcass scavenging (McPherron, *et al*., 2010; Ferraro, *et al*., 2013), fire and cooking (Wrangham and Conklin-Brittain, 2003; Wrangham and Carmody, 2010), tool-enabled hunting (Stiner, *et al*., 1999; Clark, 2011; Fa, *et al*., 2013), language (Aiello and Dunbar, 1993; Corballis, 2009; Tattersall and Schwartz, 2009) and later, agriculture (Gignoux, Henn and Mountain, 2011; Walter and Ley, 2011; Henn, Cavalli-Sforza and Feldman, 2012) and animal domestication (Diamond, 2002; Smith, 2007; Vigne, 2011)

Each of these topics is, of course, its own subject area within paleoanthropology, but there have been attempts to find an overall pattern which explains the evolutionary divergence and difference between humans and chimpanzees/bonobos. The most current understanding is that humans and the overall hominin lineage were general cognitive niche exploiters, investing in ever larger brains that in turn allowed for more efficient methods of resource gathering and environmental control (Barrett, 2007; Pinker, 2010; Stotz, 2010; Iriki and Taoka, 2011). Andrew Whiten and David Erdal, (Whiten and Erdal, 2012) have extended this model, arguing that humans are not just cognitive niche exploiters, but rather socio-cognitive exploiters. In addition to our investment in more cognitive power, humans evolved a "deep social mind" marked by several traits including: cooperation, egalitarianism, theory of mind, language and cumulative culture. In this socio-cognitive model, these traits act together in a positive feedback loop to reinforce the social nature of humans, thereby providing a fertile ground for the development of

cognitive abilities. Using Whiten and Erdal's arguments, along with the previous findings of this thesis, in this chapter I will construct a general outline of human evolution.

First it is necessary to review social evolution at a more general level. While many animals live in social groups, only a few species exhibit social traits reaching the level of "eusociality," where social groups possess distinct social and labor roles, overlapping generations and alloparental care of off-spring (Crespi and Yanga, 1995). The majority of known eusocial species are found in the bee, ant, termite, mole rat, and human lineages (Wilson, 2012). Unfortunately for the purposes here, most of the recent scholarship on eusociality has focused on the public debate regarding the exact evolutionary mechanisms that led to eusociality in these taxa, *i.e.* kin selection or group selection (Nowak, Tarnita and Wilson, 2010; Abott, *et al.*, 2010; Strassmann, *et al.*, 2011; Gardner, West and Wild, 2011; Dawkins, 2012; Pinker, *et al.*, 2012; Wilson, 2012) so there has been relatively less cross-species comparison performed to investigate the general environmental conditions that favor eusocial evolution. That being said, there are some general similarities in the niches of the eusocial animals that will serve as a good starting point for determining the biological conditions that likely gave rise to eusociality.

First, and most importantly, the vast majority of the euoscial species are mutualists of some sort. Bees are mutualists with angiosperms, trading pollination for nectar. Ants are mutualists with trees, aphids or fungi (Beattie, 1985; Mueller, *et al.*, 1998; Schultz and Brady, 2008; Detrain, *et al.*, 2010), while termites are, in a larger sense, mutualists with the biosphere – re-releasing carbon sequestered in cellulose for useful biochemical processes (Higashi, Abe and Burns, 1992). This mutualist dynamic can create an autocatalytic feedback cycle that significantly raises the ecological carrying capacity for a species. When bees pollinate flowers, it leads to more flowers that in turn allows for more bees. By growing more fungi, ant queens can

give birth to more ants, which can grow more fungi. The mutualistic framework of these eusocial species avoids the boom and bust population dynamics of a predator-prey interaction (Gilpin, 1973). Additionally, the eusocial species largely monopolize or have first-mover advantage for the available resource: ants are the only known fungi-agriculturists, termites were the first animal to efficiently break down cellulose[6], and only bees can produce honey from nectar rather than immediately consuming it. Finally, eusocial species are all obligate socialists and cannot survive on their own as individuals. As a group, they have only limited recourse should their main energy store deplete. It should also be noted that the euosocial species that do not follow these outlined similarities to the letter often do so in spirit. For instance, the eusocial shrimp (Duffy, 2002) are technically parasites of host sponges in that they consume the products of the sponge without providing any benefit, but there have been no observed negative effects to the sponge and thousands of shrimp can occupy a single sponge, giving the same relative effect of mutualism.

These similarities in eusocial species become, in turn, tunable parameters in the transmission cost equation discussed in the previous chapter. They serve as a suggested minimum set of internal and external evolutionary forces that produce eusociality. If these conditions do lead to eusociality, then we would expect that fixing the required external values in the transmission cost equation and allowing infinite selection from the internal forces would eventually produce a eusocial social organization. In other words, for eusociality in humans to have evolved along similar conditions as other eusocial species, then in the historical transmission cost equation of humans there must be terms that resemble the above conditions. What I will argue from here is that the hallmarks of human evolution previously discussed and

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[6] Why termites, but not ruminants, have developed eusocaility is an interesting question, and an unresolved research question. As a guess, I would suggest it has to do with the diminished energy returns in cellulose breakdown as a function of body-size.

the model provided by Whiten and Erdal give an equivalent set of conditions to those described for other eusocial taxa. Specifically, each hallmark of human evolution outlined previously, and the investment in increasing cognitive abilities, gradually reduced the environmental pressures on humanity that arise from the need for resource extraction and exploitation and made proceeding evolutionary innovations more likely. This, in turn, allowed selective pressures to act towards social optimization, leading to the positive feedback mechanisms recognized by Whiten and Erdal. Finally, this pathway led to a mutualist point of no return from which humans, as a species, cannot likely escape: agriculture and domestication.

To begin, bipedalism, tool-enabled carcass scavenging and hunting, fire and cooking all reduced environmental pressures on humans. Bipedalism gave humans longer range of sight and freed two appendages for environmental interaction and tool-use. Tool-enabled carcass scavenging and hunting, in turn, allowed efficient access to energy-dense meat, with fire and cooking increasing these nutritional benefits and reducing risk of food-borne disease (Lynt, *et al*., 1977;Bhaduri, *et al*., 1991; Sales, Marais, and Kruger, 1996; Chrstensen, Purslow and Larsen, 2000; Lombardi-Boccia, Lanzi and Aguzzi, 2005). Undoubtedly, each of these innovations arose out of specific and contingent environmental conditions of evolution, but noticeably, each serves as a prerequisite for the next. Tool-enabled scavenging is not efficient without free hands, and cooking is unlikely to evolve without a steady supply of roastable material. What is more important is that, even though each innovation likely evolved from its own circumstances, once all three were in place they together acted as a singular unit to greatly increase the available metabolic energy.[7] This available metabolic energy consequently allowed for a general investment in cognitive abilities via rapidly increasing brain-size (Lee and Wolpoff,

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[7] I would also like to note that tool-enabled food acquisition of plant material likely played a critical role as well, in terms of both dietary energy and cognitive development, but the archaeological evidence for this is comparatively thin.

2003; Leonard, *et al*., 2003; Isler and van Schaik, 2009), and additionally, as a sort of tautological corollary, the efficiency of humans in acquiring energy resources in turn diminished the impact of evolutionary selection in these areas, freeing evolution to operate more strongly on social characteristics.

This can be seen by comparing human abilities with those of chimpanzees or bonobos. Using Whiten's and Erdal's proposed relationship between language and theory of mind as an example, it is certainly true that chimpanzees and bonobos both exhibit theory of mind and language abilities. Both are capable of recognizing conspecific intentions and knowledge and reacting accordingly (Boesch, 2002; Call and Tomasello, 2008; Palagi, 2008; Clay and de Waal, 2013), and both show the ability for referential language (Gardner and Gardner, 1969; Savage-Rumbaugh, 1986). These abilities, however, are exhibited at a weaker level than in humans. Neither chimpanzees nor bonobos have shown the ability to distinguish false-beliefs (Call and Tomesello, 2008; Hare, 2011) and both chimpanzees and bonobos have exhibited referential language only in captivity, precisely where most environmental pressures have been alleviated. These intra-species deficiencies, then, are likely the result of some upper limit to chimpanzee and bonobo cognitive function in the wild, and in turn *in vivo* these species cannot develop the more intense social interactions seen in humans. They simply have not yet met the minimum energy intake necessary to support the development and evolution of these capacities.

Humans, having met this metabolic requirement, via bipedal hunting and cooking, were able to expand and engage in deep social interactions, which in turn allowed for the development of cumulative culture (*i.e*. the ratchet effect) which further catalyzed the process as argued by Whiten and Erdal. Relatively freed from the necessities of energy acquisition, human evolution

could turn towards social optimization.[8] Language, theory of mind, developing egalitarianism, and cooperation all contributed to a growing cumulative culture that further reduced the cost of energy acquisition. What can be seen from this is a gradual build-up of evolutionary variables and forces that begin to approximate the conditions of eusocial evolution in other species. The minimum metabolic requirement for large brains met by hunting and cooking paired with the positive social feedback loops explained by the Whiten and Erdal model closely resemble the autocatalytic cycles of the eusocial mutualists. Humans fell into an untapped energy niche, and developed more intense social organization and social-oriented cognitive function to better exploit that niche. At the species level, the peak of this development and the point of no return for humans came with the implementation of agriculture and animal domestication. The domestication of animals and grain granted us strong positive feedback loops in which the breeding and planting of agricultural products allowed for excess food, larger population, and in turn, more breeding and planting of agricultural products. These twin acts made humans true mutualists, and we are now dependent on mass agriculture and domesticated animals to provide the bulk of our food sources. This can be dramatically seen in Figure 3.

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[8] This general model also fits in very well with Marshall Sahlin's arguments regarding hunter-gatherers in *Stone Age Economics* (1974); specifically, that hunter-gatherers spend relatively little time accruing the environmental resources necessary to sustain life. From this, we can deduce there is relatively little environmental pressure on their survival.

Figure 3. Earth's Land Mammals by Weight (Munroe, 2014).
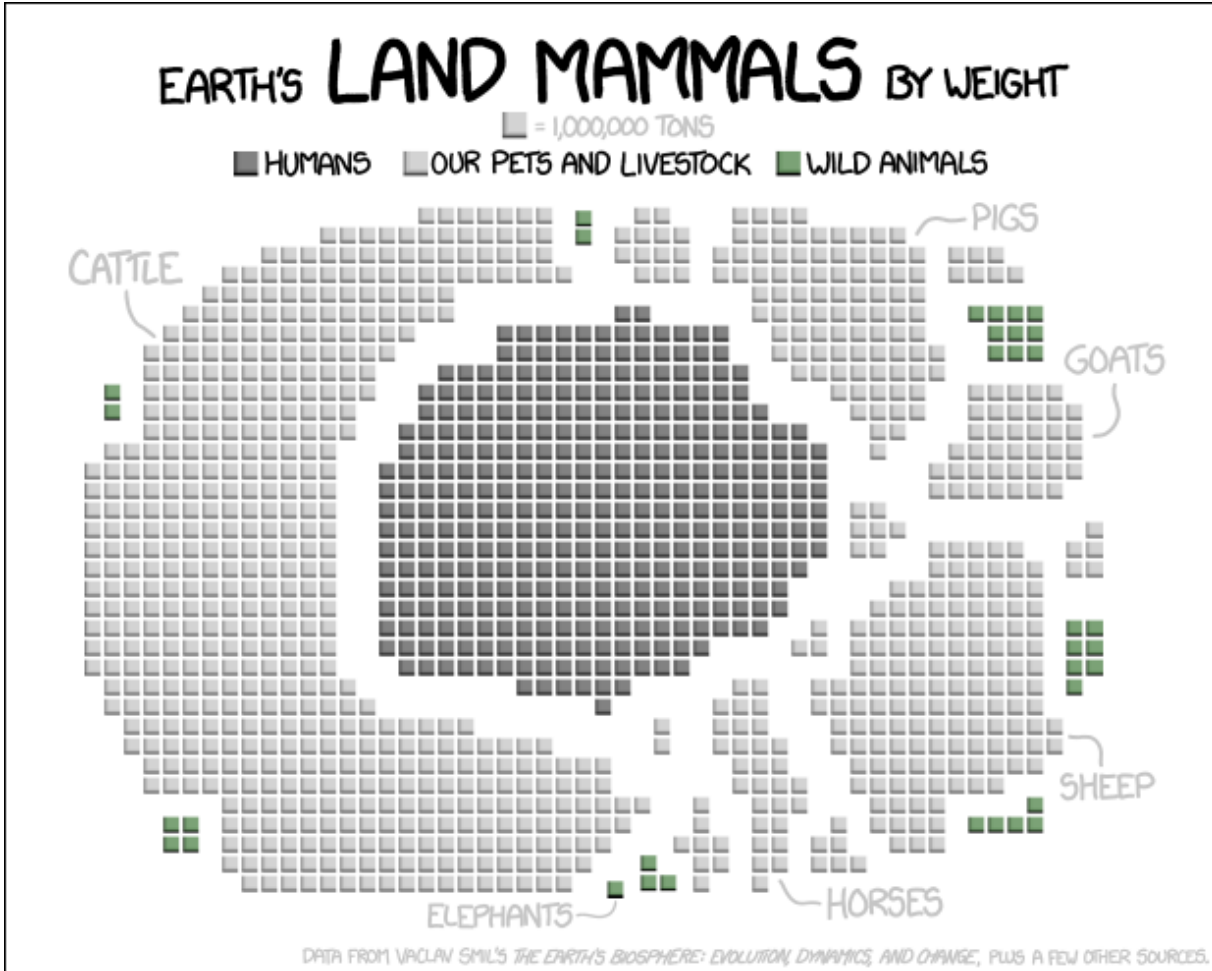
The sorts of pressures causing evolution in humans before and after this eusocial turn can also help explain the rise of scale-free network topologies in human populations. Prior to the increased energy efficiency brought on by the suite of biological adaptions, the evolutionary pressures are mainly selective based an individuals' abilities to acquire energy and avoid predation. After the energetic breakthrough, however, the evolutionary forces remaining are primarily stochastic environmental ones, operating more randomly on populations. This change in types of evolutionary forces likely explains the subsequent network developments in human populations.

To briefly summarize, humans independently evolved bipedalism, tool-enabled scavenging and hunting, and cooking. The combination of these skills allowed for an increased metabolic intake that allowed for a rapid increase in brain size. These increased cognitive abilities, in turn, allowed for a strengthening of humans' social-cognitive functions and the positive feedback loop of the socio-cognitive niche. The end result was the development of obligate mutualism in the form of agriculture and animal domestication. As such, humans have become classically evolved along eusocial lines.

Conclusion

In this thesis I have laid out four main arguments: first, that culture is an actual entity existing as a bit-like structure at some minimum biophysical juncture, likely within neural code. Second, that these culture-bits are distributed across a social network of humans, which exists as a storehouse for the culture-bits. Third, that evolution in this culture-bit network can be explained by a set of partial differential equations that relate the evolutionary forces to the culture-bit frequencies. Finally, that the pathway of human of evolution can be better understood by using general similarities in eusocial animals to derive the likely terms in humans' past transmission cost equations. My construction of these cumulatively building arguments is quite deliberate so that it is entirely possible for one to accept the arguments up to a point but no further. I will be sufficiently happy if one can only agree with the first two points, for instance, but find the second two unconvincing at this time. As I said in the introduction, the work of the thesis is almost entirely theoretical and much more research will be needed to completely validate each argument.

There are several areas, in particular, that would benefit from further study. At some point, the exact biocultural juncture that leads to culture-bits will need to be located. While I

have proposed a one-to-one correlation between neuronal firing pattern and resulting culture-bits, I fully recognize that a similar proposal regarding the genetic code (Crick, 1970) has been found wanting, as mounting evidence shows the flow of information in biology is not a simple unidirectional one (Ahlquist, 2002; Ball, 2013). Additionally, understanding how these culture-bits are actually distributed and flow through networks will be critical. While culture-bits exist as individual entities, it is likely they are transmitted and understood in packets. It seems apparent that when we learn we do not learn just a single solitary item, but a collection of related facts or skills. Learning the shapes of these packets and if they are similar in content density is critical to developing good models of cultural transmission and evolution.

If there is a major deficiency in this thesis, at least for practitioners and field empiricists, it is that the task I have set forth in the transmission cost equations is likely impossible. As a practical matter, one simply cannot capture or determine the strength of every force of evolution. Even if one could, partial differential equations are notoriously difficult to solve, and an exact solution to a set of equations that numbers in millions with an equal number of variables is simply not possible unless there are major breakthroughs in computational power. This, however, does not imply that the proposed equations are not accurately describing the events happening. We cannot yet solve similar equations describing water turbulence (Fefferman, 2000), yet Victoria Falls continues to flow into the Zambezi. Unfortunately, at least for our understanding, the universe seems quite capable of solving these equations in real time without recourse to a calculator. Nevertheless, posing the problem exactly, regardless of our ability to answer it, can lead to new insights and a portion of the equation might be solved to yield critical insights (Zakharov and Shabat, 1972).

To briefly conclude, what I have attempted over the course of the thesis is to construct a framework for understanding anthropological topics that is consistent with the larger modes of thought and analyses being conducted in other scientific fields. Ultimately, it is my belief that anthropology, particularly cultural anthropology, will have to wrestle deeply with the findings and understandings generated in the sciences and this thesis is a first attempt at that. Unlike Leslie White in the 1940's, as anthropologists we can no longer lay claim to epistemological or methodological superiority and rely on field-insular findings to advance our understanding of human nature. Instead our ideas must rise, or fall, in accordance with our larger understandings of the universe.

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