Cultural Evolution Entails (Creativity Entails (Concept Combination Entails Quantum Structure))

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Abstract

The theory of natural selection cannot describe how early life evolved, in part because acquired characteristics are passed on through horizontal exchange. It has been proposed that culture, like life, began with the emergence of autopoietic form, thus its evolution too cannot be described by natural selection. The evolution of autopoietic form can be described using a framework referred to as Context-driven Actualization of Potential (CAP), which grew out of a generalization of the formalisms of quantum mechanics, and encompasses nondeterministic as well as deterministic change of state. The autopoietic structure that evolves through culture is the mind, or more accurately the conceptual network that yields an individual's internal model of the world. A branch of CAP research referred to as the state-context-property (SCOP) formalism provides a mathematical framework for reconciling the stability of conceptual structure with its susceptibility to context-driven change. The combination of two or more concepts (an extreme case of contextual influence), as occurs in insight, is modeled as a state of entanglement. Theoretical and empirical findings are presented that challenge assumptions underlying virtually all of cognitive science, such as the notion of spreading activation and the assumption that cognitive processes can be described with a Kolmogorovian probability model.

Introduction

In what sense can ideas be said to evolve? That is, in what sense does the concept of evolution apply to human culture? That is the question that I began my research trying to answer. I was led to the conclusion that in order to understand how culture evolves one must understand creativity, the process by which cultural novelty born. From there I reached the conclusion that at the heart of the creative process is a new way of *conceptualizing* something. Thus to understand creativity, one must understand what concepts are, and how they influence one another when they act as contexts for one another. And from there I reached the most surprising conclusion of all: to understand how concepts interact requires formalisms originally developed for quantum mechanics. This paper summarizes this intellectual journey, with its recurring theme that knowledge obtained in one of these interrelated domains constrains what constitutes a promising research direction in other domains.

Evolution Does Not Begin with Natural Selection

It is generally assumed that to prove that culture constitutes a genuine evolutionary process one must prove that it evolves through natural selection (e.g. Fracchia and Lewontin 1999). This follows naturally from the assumption that there is just one process by which entities evolve: natural selection. Indeed theories about how culture evolves generally assume that cultural evolution is Darwinian (*e.g.* Aunger 2000; Cziko 1997, 1998; Cavalli-Sforza and Feldman 1981; Durham 1991; Mesoudi *et al.*, 2004, 2006). But natural selection does not take us far toward an explanation of the emergence of new forms with new dynamics, nor can it account for the origin of life itself.

Examining the earliest stages in the evolution of biological life can constrain the development of a realistic theory of how cultural evolution began. Present day life replicates using a template, a coded set of instructions encoded in DNA or RNA for how to make a copy of itself. The probability of such a structure arising spontaneously is exceedingly small; Hoyle infamously compared it to the probability that a tornado blowing through a junkyard would assemble a Boeing 747 (Hoyle 1981). The implausibility of the spontaneous appearance of a self-assembly code has led to the wide-spread acceptance of *metabolism first* theories, according to which life began with an ensemble of simple, *collectively* replicating molecules, such as an autocatalytically closed[1] set of polymers (Bollobas 2001; Bollobas and Rasmussen 1989; Dyson 1982, 1985; Kauffman 1993; Morowitz 1992; Wäechtershäeuser 1992; Weber 1998, 2000; Williams and Frausto da Silva 1999, 2002, 2003). Self-replication is not all-at-once using a self-assembly code, but piecemeal. Although no one molecule replicates itself, the whole is regenerated through the interactions and transformations of its parts. The ensemble can therefore be said to be *autopoietic* (Maturana and Varela 1980). Genetically mediated template replication emerged subsequently from the dynamics of these molecular systems (Gabora 2006; Kauffman 1993; Vetsigian, Woese, and Goldenfeld 2006;

[1] Closure is used in the mathematical sense, not in the sense that nothing can get in or out.

Depew and Weber 1996). Thus we have (at least) two means by which entities evolve. The one that came later, and with which we are more familiar, is the highly constrained process of natural selection, which makes use of a self-assembly code (*i.e*. the genetic code). The one that preceded it, and which has only recently been recognized as a viable means by which to evolve, is a more haphazard process involving autopoiesis. Given that life itself has exhibited over the course of history two different forms of evolution, what basis is there for assuming that culture evolves through a process more akin to that of present day life than that of early life? Does not Hoyle's 747 argument apply also to culture?

What necessitated the theory of natural selection, a rather intricate theory of *population*-level change, is that acquired traits are not inherited from parent to offspring at the *individual* level in biological lineages. If a cat bites off a rat's tail, it is not the case that the rat's offspring are tail-less. What then does it take for change to stick around generation after generation? That was the paradox that Darwin faced, and the paradox for which natural selection provided a solution. But there is no such paradox for early life, nor for culture. The periodic 'backtracking' to a previous state when one member of a lineages gives birth to another arises because they are von Neumann self-replicating automata. Self-replicating automata use a self-assembly code that is both actively transcribed to produce a new individual, and passively copied to ensure that the new individual can itself reproduce. The new individual may change, but the passively copied code within does not. But cultural traits do not possess such a code, and are not self-replicating automata. Indeed in culture, as in all domains *other* than biology, explanation of change is straightforward. When an entity undergoes a change of state, say from $p(0)$ to $p(1)$, the change is retained. One could say it is 'inherited' by the future states of the entity, $p(2)$, $p(3)$ and so forth. The entity does not spontaneously revert back to $p(0)$. For example, if a billiard ball gets dented, it generally stays dented. Cultural theorists wish to apply natural selection to culture on the grounds that culture exhibits phenomena observed in biology such as adaptation, inheritance, and drift. But it was not adaptation, inheritance, drift, and so forth, that fueled the theory of natural selection. It was that these phenomena occur *despite* the loss of acquired characteristics; *i.e*. despite (one could say) the malfunctioning of the normal mechanism of change. Thus if culture exhibits adaptation, inheritance, and drift, it does not follow that it does so because it is Darwinian. A more parsimonious explanation is that these phenomena arise not just through natural selection occurring at the population level, but also through processes occurring at the level of the individual or artifact where change is straightforwardly retained. Thus the rationale for arguing that culture is Darwinian is faulty. It is hypothesized that *life and culture both began with the emergence of autopoietic form, and this is no coincidence but reflects constraints on what it takes to bootstrap an evolutionary process.*

Evolution through Context-driven Actualization of Potential (CAP)

For natural selection to be applicable to a process there must be no inheritance of acquired characteristics (or at least it must be negligible compared to change due to differential replication of individuals with heritable variation competing for scarce resources). Since autopoietic form does not use a self-assembly code to replicate, acquired characteristics are not obliterated each generation but passed on through horizontal[2] (Lamarckian) exchange. Thus its evolution cannot be described by natural selection as mathematically formulated by population geneticists (Gabora 2004, 2006; Vetsigian, Woese, and Goldenfeld 2006). Furthermore, to the extent that the horizontal exchange involves interaction with an incompletely specified context, thus nondeterminism, it entails a non-Kolmogorovian probability model (Gabora 2006) and cannot be described by, not just natural selection, but any mathematics that assumes a Kolmogorovian probability model (Pitowsky 1989). If natural selection is inapplicable when, as is the case for early life and culture, replication occurs without a self-assembly code, what theory can describe the evolutionary process entailed?

This is the question that prompted the attempt to formulate a cross-disciplinary framework for contextually mediated change of state referred to as *Context-driven Actualization of Potential*, or CAP (Gabora and Aerts 2005). What unites physical, chemical, biological, psychological, and cultural processes in CAP is the actualization of potential form through re-iterated interaction with a context. These processes differ with respect to the degree to which they (i) depend upon a particular internal or external environment or context, (ii) internalize context, (iii) are sensitive to context, and most importantly (iv) exhibit non-determinism. Since we do not always have perfect knowledge of the state of the entity, the context, and the interaction between them, a general description of an evolutionary process must be able to cope with nondeterminism.

Processes differ with respect to the degree of determinism involved in the changes of state that the entity undergoes. Consider an entity—whether it be physical, biological, mental, or some other sort—in a state $p(t_i)$ at an instant of time t_i. If it is under the influence of a context $e(t_i)$, and we know with certainty that $p(t_i)$ changes to state $p(t_{i+1})$ at time t_{i+1}, we refer to the change of state as *deterministic*. Newtonian physics provides the classic example of deterministic change of state. Knowing the

[2] This stands in contrast to the vertical (parent to offspring) transmission in modern day organisms.

speed and position of a ball, one can predict its speed and position at some time in the future. In many situations, however, an entity in a state $p(t_i)$ at time t_i under the influence of a context $e(t_i)$ may change to any state in the set $\{p_1(t_{i+1}), p_2(t_{i+1}), \ldots, p_n(t_{i+1}), \ldots\}$. When more than one change of state is possible, the process is *nondeterministic*.

Nondeterministic change can be divided into two kinds. In the first, the nondeterminism originates from a lack of knowledge concerning the state of the entity $p(t_i)$ itself. This means that deep down the change is deterministic, but since we lack knowledge about what happens at this deeper level, and since we want to make a model of what we know, the model we make is nondeterministic. This kind of nondeterminism is modeled by a stochastic theory that makes use of a probability structure that satisfies Kolmogorov's axioms.

Another possibility is that the nondeterminism arises through lack of knowledge concerning the context $e(t_i)$, or how that context *interacts* with the entity.[3] It has been proven that in this case the stochastic model to describe this situation necessitates a non-Kolmogorovian probability model. A Kolmogorovian probability model (such as is used in population genetics) cannot be used (Aerts 1986; Accardi and Fedullo 1982; Pitowsky, 1989; Randall and Foulis 1976). It is only possible to ignore the problem of incomplete knowledge of context if all contexts are equally likely, or if context has a temporary or limited effect. Because the entity has the potential to change to many different states (given the various possible states the context could be in, since we lack precise knowledge of it), we say that it is in a *potentiality state* with respect to context.

Note that a potentiality state is not *predetermined*, just waiting for its time to come along, at least not insofar as our models can discern, possibly because we cannot precisely specify the context that will come along and actualize it. Note also that a state is only a potentiality state *in relation to* a certain (incompletely specified) context. It is possible for a state to be a potentiality state with respect to one context, and a deterministic state with respect to another. More precisely, a state that is deterministic with respect to a context can be considered a limit case of a potentiality state, with zero potentiality.

In reality the universe is so complex that we can never describe with complete certainty and accuracy the context to which an entity is exposed, and how it interacts with the entity. There is always some possibility of even very unlikely outcomes. However, there are situations in which we can predict the values of relevant variables with sufficient accuracy that we may consider the entity to be in a particular state, and other situations in which there is enough uncertainty to necessitate the concept of potentiality. Thus a formalism for describing the evolution of these entities must take into account the *degree of knowledge* we as observers have about the context.

We have seen that a description of the evolutionary trajectory of an entity may involve nondeterminism with respect to the state of the entity, the context, or how they interact. An important step toward the development of a complete theory of change of state incorporating biological and cultural evolution is to find a mathematical structure that can incorporate all these possibilities.[4] There exists an elaborate mathematical framework for describing the change and actualization of potentiality through contextual interaction that was developed for quantum mechanics. However it has several limitations, including the linearity of the Hilbert space, and the fact that one can only describe the extreme case where change of state is *maximally* contextual. Other mathematical theories lift the quantum formalism out of its specific structural limitations, making it possible to describe nondeterministic effects of context in other domains (Aerts 1993; Aerts and Durt 1994; Foulis and Randall 1981; Foulis, Piron, and Randall 1983; Jauch 1968; Mackey 1963; Piron 1976, 1989, 1990; Pitowsky 1989; Randall and Foulis 1976, 1978). The algebraic structure of the state space may be given by the set of atoms of a complete lattice (they play the role of the rays of a complex Hilbert space in quantum mechanics). Measurements are described by Boolean morphisms on the lattice (they play the role of the self-adjoint operators in quantum mechanics). The original motivation for these generalized formalisms was theoretical (as opposed to the need to describe the reality revealed by experiments). With these formalisms it is possible to describe situations with *any* degree of contextuality. In fact, classical and quantum come out as special cases: quantum at one extreme of complete contextuality, and classical at the other extreme, complete lack of contextuality (Piron 1976; Aerts 1983).

This is why it lends itself to the description of context-driven evolution. For example, let us say an entity undergoes a change of state from to $p_0(t_0)$ to $p_1(t_1)$. The change of state of the entity may evoke a change in its context (or in the sort of context it is subsequently

[3] Another possibility is that the nondeterminism is ontological *i.e.* the universe is at bottom intrinsically nondeterministic. In this case the mathematical structure needed to model the situation is equivalent to that needed to model the situation where the nondeterminism arises through lack of knowledge of the context (Aerts 1994). This means that ontological indeterminism is also described by the CAP framework.

[4] This story has a precedent. The same problem arose in physics in the last century. Classical mechanics could describe situations where the effect of the measurement was negligible, but not situations where the measurement intrinsically influenced the evolution of an entity. This is because it does not provide a way of coping with contextuality (except in the initial conditions or in an *ad hoc* way, by introducing an additional model of perturbation). Modern classical theories, such as chaos and complexity, though they provide a means of transcending reductionism, still have this limitation.

susceptible to), or the context may change of its own accord. Under the influence of this (possibly new) context, which we call $e(t_1)$, there may be many potential states it could change to. We denote this set of states $\{p_1(t_2), p_2(t_2), \ldots, p_n(t_2), \ldots\}$. At time t_2, one of these states, for example $p_3(t_2)$, may actualize. And so forth, recursively. The states $p(t_0), p(t_1), p(t_2), \ldots, p(t_i), \ldots$ constitute the trajectory of the entity through state space, and describe its evolution in time. Thus, the general evolution process is broadly construed as the incremental change that results from recursive, context-driven change. A model of an evolutionary process may consist of both *deterministic segments*, where the entity changes state in a way that follows predictably given its previous state and/or the context to which it is exposed, and/or *nondeterministic segments,* where this is not the case.

Having examined a non-Darwinian means by which an entity can accumulate change we now hypothesize that *culture, like early life, evolves not through natural selection, but through a reiterated process of context-driven actualization of potential (or CAP) in which interaction with a context changes not just the state of an entity but its potentiality for further change*.

The Unit of Replication

In biological evolution the unit of replication is the organism. It replicates to produce another individual and its lineage thereby continues even after it is deceased. Because of mutation and sexual recombination this replication event introduces variation into the lineage; offspring are not identical to parent. Thus self-replication does not merely perpetuate the lineage; it is necessary for the open-ended accumulation of adaptive biological novelty.

If culture evolves then what is the unit of replication? Theories of cultural evolution generally start with isolated units of cultural information such as stories or artifacts as the basic evolving entity (Aunger 2000; Cziko 1997, 1998; Cavalli-Sforza and Feldman 1981; Durham 1991; Mesoudi *et al*., 2004, 2006). But it was shown that such units of cultural information are not self-replicating (Gabora 2004). I propose that the unit of self-replication in cultural evolution is the mind, or more accurately the *conceptual network* that yields an internal model of the world, or worldview (Gabora 1998, 2000). In this approach, stories and artifacts are merely observables; the entity evolving is the conceptual network that *gives rise to* them. A worldview is *conceptually closed* when for any item in memory there exists a way of reinterpreting or redescribing it in terms of others (*e.g*. X is like Y except for Z). Just as polymers catalyze reactions that generate other polymers, retrieval of one item evokes retrieval of another. As the diversity of items in memory increases, the number of associative paths increases even faster, and graph theory tells us that the probability they organize into a connected closure space increases sharply (Cohen 1988; Erdös and Rényi 1960). At this point there exists a potential chain of associations from any one item encoded in memory to any other. The capacity of a conceptual network to capture meaningful regularity in the world is facilitated by the disposition to group related items into concepts, which themselves form hierarchies, bestowing the network with the sparse connectivity, short average path lengths, and strong local clustering characteristic of small world structure (Watts and Strogatz 1998). With sparse connectivity, associations are strong enough that one thought can lead to another, but weak enough that everything does not remind one of everything else. Thus a worldview emerges, the structure of which corresponds somewhat to that of individuals (*e.g.* parents) who kickstarted the process by sharing knowledge and attitudes. As in metabolism-first origin of life theories, the integrity of this communal entity is continually challenged and stimulated by horizontally transmitted inputs. It is self-mending and self-maintaining to the extent that it is inclined to resolve any threat this imposes to its continuation as an integrated whole. It replicates to the extent that it in turn passes its views to others. The child can now go well beyond cued retrieval of fixed responses because he/she has an integrated conceptual structure at his/her disposal to interpret and generate cultural novelty, tailoring responses to the specifics of situations. The more fine-grained the memory, the more features encoded per item, and thus more routes for associative recall. Thus the above hypothesis is elaborated: *cumulative culture arose when human memory became sufficiently fine-grained to be predisposed to achieve conceptual closure.*

The Ephemeral Nature of Conceptual Structure

It would appear that the structure of a conceptual network inheres in its hierarchies of concepts and their relations. However, empirical work on concepts shows that they have neither defining attributes nor definite boundaries, and exhibit gradients of membership (Rosch 1973, 1978). A concept does not represent something in the world in a predefined manner. The applicability of properties of a concept, as well as the typicality of exemplars, shift depending on the frame or context in which it arises (Barsalou 1982). For example under the context 'Christmas', a typical exemplar of TREE is FIR and a typical property is 'needles', but not so under the context 'desert island'. Other studies show that a word's implicitly activated associative structure is clearly linked to and dependent upon context (Nelson, Goodmon, and Ceo, in press).

The ease with which concepts shift under the influence of context implies that the pattern of connectivity of a conceptual network is transient, and therefore that conceptual closure is not a once-and-for-all affair. Thus it is hypothesized that *one does not establish closure just once but re-establishes it with respect to each change-of-context one encounters*. *This is postulated to be the mechanism by which culture accumulates and conceptual networks evolve*. Each interaction with a context actualizes some aspect of what was previously immediately potential for it, and this interaction changes what is now immediately potential for it.

The view that change to a conceptual network modifies its potentiality for further change is incompatible with the pervasive notion that thought functions as a search algorithm. Proponents of the constraint satisfaction theory of concept combination, for example, claim that one "performs a constrained search of the space of possible interpretations" and "selects" predicates (Costello and Keane 2001). Elsewhere it is explicitly stated that thought is Darwinian (Calvin 1996a, b; Calvin and Bickerton 2000; Campbell 1965, Simonton 1998a, b). But in algorithmic search the relevant variables are defined in advance, thus the search space is generally fixed. Creative problem solving, however, proceeds through honing; each thought affects how one will proceed *from there*. It effectively alters the problem space, sometimes imperceptibly, sometimes dramatically (Boden 1993; Gabora 2005). This alteration of the problem space is reflected in that creative ideas often combine concepts such that the combination exhibits *emergent properties* not in either of the constituents (*e.g*. 'spout' for the concept combination TEA POT) or *loss of typical properties* (*e.g*. 'surrounded by water' for ISLAND in the combination KITCHEN ISLAND). Moreover, studies of the creative process suggest that one often knows one has found an idea prior to being able to express it (Feinstein 2005), suggesting that during creative thought ideas need not yet be in a form in which they could compete or get selected amongst or be manipulated as semantic primitives. Thus another hypothesis is that *when conceptual closure is disrupted it can be re-established through contemplation, which does not occur through search but through honing*.

The SCOP Theory of Concepts

A first step toward understanding how a conceptual network evolves and how ideas are honed is to break thought down into transitions from one cognitive state to another, and model how context affects this transition. This is accomplished using an application of CAP to concepts referred to as the State-COntext-Property theory or SCOP (Gabora and Aerts 2002a,b; Aerts and Gabora 2005a,b). A similar approach is being used by others to model contextual effects on word meanings (Bruza and Cole 2005; Widdows 2003; Widdows and Peters 2003). Like geometrical (Gardenfors 2000) and dual theory (Wisniewski 1997) approaches to concepts, the SCOP approach is concerned with conceptual structure, but in SCOP the structure of a concept (or combination of them) is probabilistic and influenced by context. Two concepts can be said to be 'connected' to the extent that they are likely to act as contexts for one another and thereby evoke one another in some form.

A SCOP model of a concept consists of a set of *states*, each of which is elicited by a *context*. Each context-specific state is associated with unique sets of *weighted properties*, *exemplar typicalities*, and *transition probabilities*, the last of which give the likelihood that, under a given context, it will undergo a change of state. If a state of a concept is not affected by a particular context it is said to be an *eigenstate* for this context. Otherwise it is a *potentiality* (superposition-like) *state* for this context, reflecting its susceptibility to change. When one is not thinking of a concept it is in its *ground state.* A concept is always evoked in some context; one never experiences it in its raw or undisturbed ground state. In the ground state typical properties (*e.g*. 'surrounded by water' for the concept ISLAND) have a weight close to 1, while atypical properties (*e.g*. 'square' for ISLAND) have a weight close to 0. From the ground state it is possible to transition to any other state under the influence of some context, and this new state has differently weighted properties. For example, applying the context KITCHEN transforms the ground state of ISLAND to a state where weight or applicability of 'surrounded by water' is (hopefully) low.

The structure of a SCOP is derived by determining the natural relations for sets of states, contexts, and properties. If context e is more constrained than context f (*e.g*. 'in the big box' is more constrained than 'in the box') we say e 'is stronger than or equal to' f, thereby introducing a partial order relation in the set of contexts M. By introducing 'and' and 'or' contexts, M obtains the structure of a lattice. By introducing the 'not' context, an orthocomplemented lattice is derived for M. The same is done for the set of properties L, making it possible to construct a topological representation of a SCOP in a closure space.

To obtain not just qualitative but numerical results, and to model the combination of concepts, the SCOP is embedded in a less abstract, more constrained mathematical structure, complex Hilbert space. A state is described by a unit vector or a density operator, and a context or property by an orthogonal projection. The formalism determines the formulas that describe the transition probabilities between states, and the formulas for calculating the weights of properties, allowing us to predict typicality of exemplars and applicability of properties. The typicalities of exemplars and applicabilities of properties yielded by the calculation matched those obtained in the experiments with human subjects. For example, given a list of questions such as (a) Given context C1, 'The pet is being taught to talk', rate the applicability of the property 'furry', or (b) Given context C2, 'The pet is chewing a bone', rate the typicality of the exemplar 'dog'. Note that we test the prediction that the applicability of *each single property* varies for *each* context, as does the typicality of each exemplar, by an amount that can be calculated from the structure of states and contexts.

Conceptual Entanglement

The SCOP formalism is able to model combinations of concepts as entangled states by taking the tensor product of the Hilbert spaces of the concept and the context (which may itself be another concept or conglomeration of them). This yields a new state space with states that may exhibit a gain or loss of properties compared to its constituents. The tensor product procedure generates two kinds of vectors: (1) *product states*, for which a change of context can affect one component of the combination and not the other, and (2) *non-product states*, for which a change of context cannot affect one component without affecting the other. Non-product states are the states of entanglement.

The definitive test for entanglement (and nonlocality; thus for nonclassical logical structure) is the violation of Bell's inequalities (Bell 1964). To prove that entanglement is present one performs four experiments, each with two possible outcomes, which can be performed together (two experiments at the same time) as coincidence experiments. The outcomes are plugged into Bell's inequalities to see whether they are violated. A procedure for demonstrating the violation of Bell's inequalities in cognition has been published (Aerts *et al*. 2000). The experiments entail asking a subject to think about a particular concept and observing how the subject responds to simultaneous manipulations (coincidence experiments) that cause the subject to think of one of two instances of that concept. Plugging the results into Bell's equations demonstrates in theory at least entanglement amongst instances of a concept. Experimental support for the notion that concepts, their combinations, and the relationships between various instances of a concept or a group of related concept can be accurately described as entanglement comes from findings that an 'action at a distance' hypothesis (synchronous activation of a word's associates) supported the results of cued recall experiments better than the 'spreading activation' hypothesis (Nelson, McEvoy, and Pointer 2003).

Significance and Future Work

There is currently no broadly accepted answer to the question of how culture evolves (or even whether another form of evolution, other than biological evolution, is possible). The theory put forth here is that culture is a genuine form of evolution, with the mind the unit of self-replication, and it evolves, as did early life prior to the emergence of the genetic code, through a non-Darwinian process involving reiterated actualization of potential through interaction with a context.

Psychological experiments as well as mathematical and computer models are being used to generate findings that support, refute, or refine the hypothesis that autopoietic, conceptually closed structure emerges in the mind, evolves through context-driven actualization of potential (CAP), and requires formalisms from quantum mechanics for its description. Further work is to be done on the application of quantum formalisms to creative thought, specifically to how cognitive states described as states of entanglement are disambiguated through honing. The modeling of concept combination using formalisms originally developed to model entangled quantum systems holds promise as a model of insight. Theoretical and empirical work is converging toward support a new framework for understanding what is arguably the most uniquely human characteristic: the capacity to invent, and the propensity to put our own spin on others' inventions such that novelty accumulates. If the research supports the existence of entangled states and structure that necessitates a non-Kolmogorovian probability model in cognition, then this will amount to demonstrating that the vast majority of models in cognitive science (*e.g.* neural / Bayesian networks) use a mathematics that *a priori* cannot capture a class of cognitive states.

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