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Creative Thought as a non-Darwinian Evolutionary Process

LIANE GABORA

(This research was conducted at the University of California, Berkeley.)

Current Address:
University of British Columbia
Okanagan Campus, Kelowna BC, V1V 1V7, Canada
liane.gabora[at]ubc.edu

Abstract: Selection theory requires multiple, distinct, simultaneously-actualized states. In cognition, each thought or cognitive state changes the 'selection pressure' against which the next is evaluated; they are not simultaneously selected amongst. Creative thought is more a matter of honing in a vague idea through re-describing successive iterations of it from different real or imagined perspectives; in other words, actualizing potential through exposure to different contexts. It has been proven that the mathematical description of contextual change of state introduces a non-Kolmogorovian probability distribution, and a classical formalism such a s selection theory cannot be used. This paper argues that creative thought evolves not through a Darwinian process, but a process of context-driven actualization of potential.

INTRODUCTION

Since Darwin introduced the thesis that species evolve through natural selection, there has been a continual stream of effort to frame cultural innovation and the creative processes underlying it in Darwinian terms. The basic idea is that we generate new ideas through variation and selection: 'mutate' the current thought in a multitude of different ways, select the variant that looks best, mutate *it* in various ways and select the best, and so forth, until a satisfactory idea results. Thus supporters hold not only that selection theory is of explanatory value where, for example, various brands of peanut butter compete in the marketplace for the 'peanut butter' niche, and the tastiest 'survive', but that it can describe the process by which someone came up with the idea of turning peanuts into a spreadable substance in the first place.

The goal of this paper is to show that the Darwinian view of creative thought does not go through because the assumptions that make selection theory appropriate for biology do not hold. However, we will see that even if creative thought is not Darwinian, it may still be a process of evolution, and a general framework for unifying creative thought with other processes of change may be possible.

Let us begin by briefly summarizing the steps taken to put creative thought and cultural innovation into an evolutionary framework. The intellectual milieu in which the extension of Darwinism to cognition arose was particularly concerned with the development of scientific thought. Popper (1963), Lorenz (1971), Campbell (1960, 1965, 1987) and others alerted us to the evolutionary flavor of epistemology, describing the growth of knowledge and rationality as a Darwinian process wherein conjectures must be refutable, *i.e.* able to be selected against.

Evolutionary epistemology also stresses that since the original function of knowledge is enhanced survival of self and offspring, its evolution is affected by the survival value it has for its carriers. It is perhaps Campbell who took the approach furthest (and indeed coined the term 'evolutionary epistemology'). He expanded the concept of selection to include *internal selection* processes that operate within the entity of interest, and *vicarious selection* where constraints, pressures, or preferences operating on one level vicariously select for fitter outcomes at another level. For example, the preference for sugar is said to vicariously select for the propensity to adequately nourish oneself. Since vicarious selection is indirect, it cannot invoke an appropriate response in an environment where, for example, sugar is plentiful and robbed of nutrients. As another example, the bearer of a detrimental idea need not die for the idea to be selected against; it can suffice to witness or hear from someone else the consequences of believing in or implementing the idea. Thus instincts and acquired knowledge vicariously anticipate selection by the environment.

Campbell viewed thought as a series of tiny selections. Thus one arrives at an idea by, given ones' current thought, selecting amongst the possible ways of varying it to generate a next thought, and repeating this process until the idea appears. He describes the generation of ideas not as random but 'blind'; produced without foreknowledge of what it will eventually lead to or result in. Campbell stresses that explicit replication is not necessary for Darwinian evolution so long as there is *retention* or preservation of information, and describes categories of thought and perception as a 'nested hierarchy of selective-retention processes'.

A necessary step in the extension of Darwinian theory to thought is the notion of *universal Darwinism*, the idea that Darwinian evolution is not restricted to the physical structure of organic life, but could work with other substrates (Dawkins, 1982). In other words it is 'algorithmic' or *substrate neutral* (Dennett, 1991). It is argued that the evolution of species on earth is not the only Darwinian process. Others may include not only creative thought and/or culture, but also antibody production by the immune system (Burnet, 1959; Jerne, 1967), and perhaps life elsewhere in the universe. Another example given is *neural Darwinism* (Edelman, 1987), the selective pruning through which the circuitry of the brain comes about, wherein neurons that get activated by one another thrive, while others die off. The attempt to apply variation and selection to these phenomena is referred to as *secondary Darwinism* (Simonton, 1999a, 1999b), to distinguish them from *primary Darwinism*, which applies specifically to biological evolution through natural selection as biologists typically conceive of it.

Both supporters and skeptics tend to hold extreme positions. Dennett (1991) has described natural selection as a 'universal acid' that will penetrate all fields of scientific inquiry: "Darwin's dangerous idea is reductionism incarnate, promising to unite and explain just about everything in one magnificent vision." He is not alone; others such as Richerson and Boyd (2000) are equally optimistic: "Darwinians aim for a *comprehensive* theory of organic and cultural change. Our boast is that we can model and investigate empirically *any cogent* proposed mechanism of change." Perhaps the one to go furthest applying Darwinism specifically to creative thought is Simonton(1999a) who refers to the creative mind as the "single most potent Darwinian force on this planet" (see also Cziko, 1997, 1998; Findlay & Lumsden, 1988;Lumsden, 1999; Ziman, 2000). Skeptics, on the other hand, dismiss the proposal just as vigorously with arguments that tend to get stuck on the issues of whether a meme (unit of cultural information such as a saying or song) constitutes a replicator, and whether variation in cognition is generated randomly (*e.g*. Gould, 1991; Hallpike, 1986; Jeffreys, 2000; Perkins, 1998; Pinker, 1997; Sternberg, 1998; Thagard, 1980). It is natural to envision that we will one day possess a broad scientific framework that unites biology, cognition, and social processes under one umbrella. A definitive case either for or against Darwinism provides as good a place as any to start.

WHY THOUGHT IS NOT A DARWINIAN PROCESS

We have sketched the basics of the attempt to place creative thought into a Darwinian framework. Not only has the notion of random variation been loosened to include variation that is 'blindly' generated, but the notion of natural selection has been loosened to include retention processes, which are selective only with respect to which features they 'discard'. Now we will see why, even with these modifications, the project cannot be salvaged.

'Random or Not' is Not the Issue

It is worth saying a few words about the issue of whether or not creative ideas are generated randomly, since this has been a focus of attack in an issue of *Journal of Creative Behavior* devoted to Campbell's view of creativity, a paper on the topic that appeared with peer commentary (Simonton, 1999), and elsewhere. A typical dismissal of the project is the following statement by Pinker (1997): "a complex meme does not arise from the retention of copying errors... The value added with each iteration comes from focusing brainpower on improving the product, not from retelling or recopying it hundreds of thousands of times in the hope that some of the malaprops or typos will be useful." Supporters respond to such critiques by employing terms like 'quasi-random' (Simonton, 1999a, b) to refer to the manner in which creative variation is generated. As a result, some despair that the thesis is neither provable nor falsifiable (Sternberg, 1999).

The situation may not be so grim. Progress can begin by clearing out an ongoing confusion between the nature of the creative process itself, and what kind of model can describe it. A model is merely an approximate description since we lack complete and perfect knowledge of the entity, the context in which it is functioning, and the way they interact. A stochastic model such as selection theory may be appropriate not only when the underlying process is intrinsically random, but also when it is not random but can be approximated by a probability distribution. Thus, even if biological evolution turned out to be *completely* deterministic, nothing random at all, a stochastic model could still give a reasonable description of it. As we will see, it is not because creative thought is not random that a stochastic model is inappropriate. It is because of other assumptions underlying stochastic models, which are violated in creative thought.

Selection Theory Works on Multiple, Distinct, Simultaneously-Actualized States

In another paper that appeared with peer commentary titled 'A General Account of Selection: Biology, Immunology, and Behavior', Hull *et. al*.(2001) attempt to unite biology, immunology and operant learning under the umbrella of selection theory[1].The basic idea is that in all three domains, selection acts as the mechanism of change because imperfect replication alternates with environmental interaction over successive iterations giving rise to differential survival and inheritance. They also stress that for this process to result in complex, novel forms, a high degree of wastefulness and inefficiency are necessary.

Even if Hull *et al*.'s General Account of Selection or GAS does not replicate, it has clearly provided 'fuel for thought'. A serious problem it brought to light is that, as Pepper and Knudsen (2001) put it, selection theory as mathematical formulated by population geneticists Fisher (1930), Haldane (1932), and Wright (1931) requires that at any given iteration there be "multiple concurrent replicators that differ in their replication rate" (p. 550). They point out that the theory of natural selection theory is not merely vague and descriptive; it has been rendered in precise mathematical terms, and it predicts no change unless there is more than one individual in the population. In fact, it predicts no change in a population composed of multiple individuals unless these individuals exhibit genetic variation with respect to the trait of interest *i.e*. unless they are distinct and different. The reason is that adaptive change requires differential rates of replication. If there is only one entity (or a population composed of identical entities), there is nothing for its replication rate to be faster or slower than.

Okasha (2001) makes essentially the same point as Pepper & Knudsen (p. 549):

> The authors note a significant dis-analogy between operant learning and standard examples of Darwinian selection. In the latter, the variants on which selection operates are present at the same time, while in the former the variants form a temporal sequence, each one existing for a moment, before being replaced by another. The authors do not think this disqualifies operant learning from qualifying as a Darwinian process, but I am less sure.

Okasha then reasons that in attempting to apply selection theory to a temporal sequence, whether something gets selected or not depends arbitrarily on how you break up the sequence. Hull *et al*. respond that things are not so tidy in biology either, asking (p. 566) "what might 'the same time' mean in the case of organic evolution?" However there is a fairly straightforward answer to this question, which is intimately tied to their concept of *iteration*. What matters is that there exist multiple individuals that constitute part of the same generation, or iteration [2]. So by "the same time", we mean there are multiple entities undergoing the selective pressures of a given iteration. This is not the situation where creative thought is concerned. Since each thought contributes to the context in which the next is evaluated, never do two thoughts undergo the same 'selective pressure', and they are not 'selected amongst' in the same iteration [3].

Let us make this more concrete with an example. Say the mind is in a certain state, and it selects from amongst the possible successor states—variants of the current state—to generate an *actual* successor state, and repeats this over and over. We call $p(t_0)$the cognitive state at t_0. The set of possible successor states at t_1 we call $P(t_1)$,and the *actual* state at $t_1$we call $p(t_1)$. Thus $p(t_1)$ is an element of $P(t_1)$. Suppose one tries out a few elements of $P(t_1)$, and then selects one of them as $p(t_1)$.In order to select amongst the $P(t_1)$ possible states, it must be possible to distinguish them from one another, since as mentioned previously, selection theory requires multiple distinct entities with different traits. (This is true no matter how miniscule the transition from $p(t_0)$to $p(t_1)$.) To distinguish them, it is necessary to carry out the transformation from $p(t_0)$to the first element of $P(t_1)$, followed by the inverse transformation back to $p(t_0)$so that the process can be repeated for the second element of $P(t_1)$,and so forth. Thus one simulates or vicariously experiences various possibilities before committing to one of them. Note that it isn't possible to carry out *all* these transformations because $P(t_1)$is infinitely large, not just in the sense of the relevant properties being continuous variables, but in the sense of there being an infinite number of them. More concretely, let us say that $p(t_0)$is the thought 'It is raining'. $P(t_1)$ then includes everything from 'I should take my umbrella to work' to 'I wonder why earthworms come out in the rain' to the opening line of a song about rain. There are infinitely many ways of creatively transforming any given thought.

But let us say that a mind is in state $p(t_0)$which corresponds to the thought 'It is raining', and then tries out just the three possibilities for $p(t_1)$ enumerated above starting with 'I should take my umbrella to work'. The cognitive state after considering this first possibility cannot return to $p(t_0)$.The closest it can come is the state of thinking 'It is raining' *in the context of having considered as a possible subsequent thought* 'I should take my umbrella to work'. Nor can the selective pressure return to what it was. The closest it can come is 'what is the best though to have next *having considered as a possibility* I should take my umbrella to work'? So now we face a problem: only the first possibility is truly an element of $P(t_1)$,and more importantly, only it underwent the original selection criterion. In other words, the selective pressure itself is changed by cognitive states it has an impact on. Thus, at any time in a stream of thought there is never more than one possibility to select from, so selection theory cannot apply.

Another way it could work is one generates a variant of the current thought and then selects from only two possibilities: keep it or discard it. This is an idiosyncratic use of the term 'selection', but let's see what happens. Starting from $p(t_0)$, you generate a variant of $p(t_0)$ which we call $p(t_1)$.You decide $p(t_1)$ is no good, so you return to $p(t_0)$, and start again. But once again, you cannot truly return to $p(t_0)$, nor can you truly return to the same selection criterion. (And even if you could, given state $p(t_0)$, the next thing one does is go to $p(t_1)$, which takes you back to $p(t_0)$... Thus *y*ou are trapped in an endless loop.)

Indeed something selection-*like* may take place during the refinement of an idea, in the sense that some aspects and implications are culled out and developed, while others not. But selection theory predicts change only when there exists a variety of actualized states from which to choose amongst. It does not provide a means of selecting amongst potential future states of a single entity. Thus selection may be relevant to processes such as when an artist chooses from amongst his paintings which to show at a gallery, but not the process of articulating an initially vague idea for a painting in the first place.

No Pre-existing 'Neural Configurations' to Select Amongst

Another attempt to salvage the application of selection theory to cognition is to postulate that a thought or idea consists of an ensemble of competing neural patterns. For example, Pepper &Knudsen (2001) suggest that perhaps Hull *et al*.'s General Account of Selection mentioned earlier can be salvaged as follows (p.551):

> If replicators consist of specific neural configurations that produce tendencies or proclivities for certain behaviors, it is not hard to imagine a population of such replicators that compete for the opportunity to be expressed as behaviors (interactors) and to be therefore strengthened or weakened according to their relative "success" (e.g. in eliciting positive affect). It is also not hard to envision that stronger neural configurations would be more likely to persist and to spawn variants.

The idea is reminiscent of Calvin's proposal that mental representations clone imperfect copies of themselves which compete for cortical territory, and those with the most territory clone the most (imperfect) copies of themselves and get thought of most often, thus a 'survival of the fittest' ensues (Calvin, 1996a, b; Calvin & Bickerton, 2000). Since Calvin bases his reasoning on the fact that representations are distributed, let us look carefully at what this means. There are two senses in which representations are distributed. First, they coexist, or are distributed across, the minds of many individuals; we all have a concept 'cup' for example. The more usual sense in which the term is used is that a given item in memory is *distributed* across a cell assembly that contains many locations, and likewise, each location participates in the storage of many items (Hinton *et al*., 1986; Palm, 1980).However it is quite unorthodox to say that representations are distributed in the sense of there being multiple complete copies of them. In fact, the closer one looks at the nature of distributed memory storage, the more unlikely Calvin's scenario becomes. According to the doctrine of *neural re-entrance*, the same memory locations get used and reused again and again (Edelman, 1987). Each location is sensitive to a broad range of *subsymbolic microfeatures* (Smolensky, 1988), or values of them (*e.g*., Churchland & Sejnowski, 1992). Thus location *A* may respond preferentially to lines oriented at say 45 degrees from the horizontal, neighboring location *B* to lines at a slightly different angle, say 46 degrees, and so forth. However, although *A* responds *maximally* to lines of 45 degrees, it responds to a lesser degree to lines of 46 degrees. This kind of organization is referred to as *coarse coding*. Thus when we speak of a distributed memory we speak of one where, for example, location *A* would participate in the storage of all those memories involving lines at close to 45degrees, and each of these memories affect not just location *A* but a constellation of other locations. In order for Calvin's hypothesis to work, not only would we need a different copy of location *A* for each memory involving an angle of 45 degrees, but a different copy of location *A* would be required for each competing clone of each of these memories!

Multiple States at a 'Preconscious' Level?

Campbell would argue that we are unaware of generating and selecting amongst multiple possibilities because it happens subconsciously. Only the selected one gets consciously experienced; the others are vicariously selected out by stored knowledge or intuitions operating at a subconscious level. One argument against this is simply that there *are* times when one is *aware* of selecting amongst alternate possibilities, which suggests that *if* it happens, one *is* aware of it. But there are other times when it does *not* feel like one is selecting amongst alternate possibilities. It just feels like one is honing in on or refining an idea, getting closer to the essence of the thing. Moreover, if we were subconsciously selecting amongst simultaneously activated alternatives, then the cognitive state at any time would consist of a set of similar or even almost identical competing state. Note that this is very different from saying that the mind is modular and one can consider different modules to be indifferent states at a given instant. It is saying that there is a separate portion of the brain devoted to, not just each thought, but each potential subsequent thought.

There is in fact no reason to believe that a memory, concept, or idea is 'stored' in a dormant state as a predefined, discrete neural configuration (or ensemble of them), waiting to be selected out from amongst a set of other such dormant, discrete neural configurations to get actively thought about. One does not retrieve an item from memory so much as *reconstruct* it (Edelman, 2000). Its role in thought is *participatory*(Gabora & Aerts, 2002; Rosch, 1999). Thus an item in memory is never re-experienced in exactly the form it was first experienced. It is colored, however subtly, by what we have experienced in the meantime, re-assembled spontaneously in a way that relates to the task at hand, and if its relevance is unclear it is creatively *re-described* (Karmiloff-Smith,1992) from different real or imagined perspectives or contexts until it comes into focus**.** A detailed description of how the web-like associative structure of memory lends itself to creativity is given elsewhere (Gabora, 2000, 2002a, 2002b, 2003, in prep.). Here it suffices to point out that items assimilated into such a structure can undergo spontaneous adaptive change. Even a rather simple connectionist memory is able to abstract a prototype, fill in missing features of a noisy or incomplete pattern, or create a new pattern on the fly that is more appropriate to the situation than anything it has ever been fed as input (Rummelhart & McClelland, 1986). The new output reflects the input, the context of that moment. There is extensive evidence that context, both physical (McCoy & Evans, 2002) and social (Amabiles, 1996; Csikszentmihalyi, 1996; Felman, 1999; Felman, Csikszentmihalyi, & Gardner, 1994; Howard-Jones & Murray, 2003; Perkins,2000; Sternberg, Kaufman & Pretz, 2001) plays an important role in creative thought. When a memory or concept is not being reconstructed through interaction with a context, it exists only in an implicit sense, *i.e.* there is *some* context that could come along and impact the vast associative structure of the mind in such a way as to manifest it. The various possible forms of a concept are potential, not yet actualized, not even differentiated from one another, so not yet in a state in which they could compete. Rather than viewing the mind as a hotbed of competing memes or ideas that get selected amongst, it is more parsimonious to view it as existing in a state of potentiality that can unfold different ways depending on how it interacts with the contexts it encounters.

Potentiality and Contextuality Necessitate a Different Mathematics

Earlier we saw that a model is usually an approximate description since in general we lack knowledge about the state of the entity, the state of the context to which it is exposed, and the way they interact. The mathematical structure used to build a descriptive model when we lack knowledge about the state of the entity is very different from that when we lack knowledge about the context or how they interact. When lack of knowledge concerns the state of the entity, a classical stochastic probability theory such as selection theory can be used, because the description of this lack of knowledge is mathematically equivalent to the description of a process of selection amongst different possible states. However, it has been proven that when there is a lack of knowledge about the context and how it interacts with the entity, this necessitates a non-Kolmogorovian probability model; a Kolmogorovian probability model—such as the one used in selection theory—is not appropriate(Aerts, 1986; Accardi, 1982; Aerts & Aerts, 1994; Pitowsky, 1989; Randall & Foulis, 1976). It is possible to ignore the problem of incomplete knowledge of context if all contexts are equally likely, or if context has a limited effect on heritability. In biology, since acquired traits are not heritable, the only contextual interactions that exert much of an effect are those that affect survival or the procurement of a mate. Thus it is possible to get away with ignoring the 'lack of knowledge of context' problem and worry solely about the problem of 'lack of knowledge concerning the entity' (where in selection theory the entity is a population of organisms). Thus it is because classical stochastic models work fine when lack of knowledge concerns the state of the entity and not the context that selection theory is useful for the description of biological evolution. In a stream of thought, however, neither are all contexts equally likely, nor does context have a limited effect on future iterations. To use the biological terminology, acquired characteristics *are* heritable. So the assumptions that make classical stochastic models useful approximations do not hold for creative thought. In applying selection theory to thought, one treats a set of *potential*, contextually elicited states of *one* entity as if they were *actual* states of a *collection* of entities, or possible states with no effect of context, even though the mathematical structure of the two situations is completely different.

Moreover, defining an unfocused state of mind as *one or another* of its potential future states does not give us an ontologically accurate description of it, because this unfocused state is a single actual state, not a collection of potential future states. To some this perhaps would not matter so long as the Darwinian approach could nevertheless predict future states as accurately as any alternative approach. However, this is not the case, as the following simple example illustrates. Let us say that your mind is in a certain state which we label $p(t_0)$. If someone were now to ask in a hostile tone of voice 'Are you angry?' you might answer (and believe) 'yes'. Let us refer to this new state of mind as $p_1(t_1)$. Now consider the situation where you are asked the same question in a sympathetic voice. In this case you might well answer (and believe) 'no'. Let us refer to this state of mind as $p_2(t_1)$. One cannot say that the state of mind $p(t_0)$ prior to the question had as a true proposition 'I am angry'. However, we also cannot say that it had as a true proposition 'I am *not* angry'. Because of the contextual nature of the situation, before the question was asked, neither of the propositions was true, but the state $p(t_0)$ had the *potential* for either to *become* true depending on the tone of voice. It isn't a 'one or the other is true' situation, nor a situation of a competition amongst two pre-defined possibilities. It is because the truth of the proposition becomes actual *in the process* of being influenced by the context that the propositions formulated to describe this type of situation entail a non-classical logic. Similarly, in the example discussed previously, at the instant of the thought 'it is raining', it is not true that the idea for the song about rain existed, nor did it not exist. It was merely potential.

Indeed, for a proposition described by classical logic, such as say proposition *A*, it is always the case that either *A* is true or *NOT A* is true. One or the other must be true. However, for a proposition *A* described by quantum logic, situations appear where neither *A* nor *NOTA* is true. It can be shown that this difference is rooted in the presence of the type of contextuality exhibited in the 'Are you angry?' example (for further analysis, see Aerts, D'Hondt, & Gabora, 2000). Thus this type of contextuality is not restricted to the microworld, but is present in the macroworld, and part of ordinary human experience (Aerts, 1982; Aerts, Aerts, Broekaert, & Gabora, 2000; Aerts, Broekaert & Gabora, in press; Aerts, Durt, Grib, Van Bogert & Zapatrin,1993; Aerts & Van Bogert, 1992). It is not something that selection theory is equipped to handle. The existence of contextual states of mind indicates that in order to accurately describe cognition and the cultural phenomena it gives rise to we must look further afield than the classical descriptions that have until now been attempted.

HOW CREATIVE THOUGHT COULD EVOLVE THROUGH A NON-DARWINIAN PROCESS

We have seen that selection theory does not provide us with a formal description of how creative thought evolves, not only because of the oft-cited assumption of randomness, but because of the requirement that we enumerate up front all possible alternatives, and the impossibility of describing situations wherein the outcome emerges spontaneously through interaction between problem constraints and context. But this does not necessarily mean that creative thought is not an evolutionary process. In this section we investigate how creative thought could evolve without natural selection. First we look at why evolution need not be Darwinian. Then we look at how creative thought may fit into a more general, encompassing description of evolution as context-driven actualization of potential.

Evolution Need Not be Darwinian

The term evolution is usually construed as shorthand for Darwinian evolution—descent with modification through repeated iterations of replication with random variation followed by natural selection. However, it is becoming increasingly evident that the Darwinian (or neo-Darwinian) paradigm, powerful though it is, does not even provide a comprehensive account of biological processes of change (*e.g*. Kauffman, 1993; Newman & Muller, 1999; Schwartz, 1999)[4] let alone non-biological processes. There is no reason evolution must be Darwinian, or even involve selection except as a special case. It is not incorrect to use the term evolution in a more inclusive sense as adaptive change in response to environmental constraint; physicists use it to refer to change in the absence of a measurement, without implying that selection is involved. It may be that it is only because Darwinian evolution is such an *unusual* form of evolution that it got so much attention it eventually cornered the word 'evolution'.

It is not difficult to see how an evolutionary process can proceed through non-Darwinian means. Since this topic is covered in considerable detail elsewhere (Gabora, in press; Gabora & Aerts, 2005), it is not elaborated here, but some key points should be made so that we may glimpse how it applies to a stream of thought. A model of an evolutionary process consists of *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 *probabilistic segments* (whether the apparent non-determinism is genuine or merely reflects a lack of knowledge) where a deterministic model cannot be used. Probabilistic segments are further divided into two kinds. In the first, the non-determinism (or lack of knowledge) concerns the state of the entity itself. In the second it concerns the context to which the entity is exposed; thus the state of the entity is a *potentiality state* with respect to its context. Change of state of an entity may in turn evoke a change in its context, or in the sort of context it is subsequently susceptible to, or the context may change of its own accord. Under the influence of a (possibly new) context, it undergoes another change. And so forth, recursively.

Thus, evolution is broadly construed as the incremental change that results from recursive, context-driven actualization of potential, or CAP. Different forms of evolution vary with respect to the frequency of deterministic versus probabilistic change, and the degree of context dependence (how much they are affected by context). Note that whereas Darwinian variation-selection is quite an elaborate affair, CAP is simply change of state in response to a context. CAP subsumes variation-selection, which is one process through which change of state can occur. The CAP framework provides a perspective from which it can be seen how truly unusual Darwinian evolution is, and has been ever since the appearance of a genetic code, when acquired traits stopped being inherited (context-driven change no longer retained). Natural selection is such an unusual means of change, it is perhaps no wonder it does not transfer readily to other domains.

Thought Evolves not through Selection but CAP

Now let us see how creative thought could be viewed as non-Darwinian evolution through CAP. During deterministic segments of thought, the state of the mind may change in a way that reflects the environment to which it is exposed, but deterministically. A typical example is the state of mind one is in driving along a familiar route, not thinking about anything in particular, just following the car in front, obeying the road signs, and so forth.

Other segments of thought cannot be described with a deterministic model. Prototypical examples are decision points and flashes of creative insight. In some situations, a stochastic model may be used because our lack of knowledge concerns the state of the mind. For example, a person driving along a familiar road might at some point decide to stop, and the decision might have nothing to do with their location or the state of the car. For yet other segments of thought, the lack of knowledge concerns the context or how it interacts with the entity, and a non-classical formalism is necessary. Someone driving in their car might drive by a friend's house, and decide to visit the friend. The situation presented earlier where the question 'are you angry?' elicits one response when asked in a hostile voice and another when asked in a compassionate voice, is another example. The situation where rain elicited the composition of a song about rain also falls in this category.

The CAP approach provides a means to describe what Perkins (2000) refers to as *unreasonable problems,* situations in which a creator discovers serendipitously that a solution to one problem is provided by what was considered a completely different problem. Whereas for reasonable problems, the relevant features or dimensions of the problem are already known, and solving it is simply a matter of churning through a step by step procedure to arrive at the result, for unreasonable problems, the features or dimensions are *not* completely specified up front, and the solution requires insight from an external source. Our model describes this process as interaction of *problem* and *context*, recursively reiterated until the relevant features have surfaced and the irrelevant ones have been eliminated. In Gabora (2001), a stream of creative thought is mathematically described with CAP using a hypothetical example in which an ember rolls out of a bonfire leading to invention of the torch. Since it cannot be known with certainty that the inventor will notice the ember, and realize that it could be picked up and used to light the way, the change of cognitive state at the instant the ember rolls out of the fire is described as an contextual probabilistic event. However, the changes of cognitive state before and after this event follow quite deterministically given the previous state and the ongoing context of sitting before a bonfire and needing light to find the way home. The important thing is that nowhere does selection occur. The mind is adapting to its circumstances merely by undergoing a sequence of context-driven changes, actualizing states that were previously potential for it.

Implications

This section will touch on a few implications of the above theoretical arguments for creativity research. Consider for example, cross-sectional distribution of lifetime output. If creativity operates through CAP as described above, the creator must first internalize all relevant background knowledge in order to achieve a conceptual framework that has the potential to solve (or contribute to an understanding of) the problem; thus creative output is initially low, and the greater the body of background knowledge, the longer it remains at this low level. The creator incorporates this knowledge into a framework, which differs (perhaps subtly) from that of others who have worked on the problem. If this framework constitutes a context in which the problem can be solved, elaborated, or understood more deeply, creativity increases. These elaborations may in turn enhance the conceptual framework, such that reconsidering the problem again brings still more insight, and so on, recursively. This continues until the potentiality of the creator's unique worldview to penetrate more deeply into the problem than others do has been exhausted; thus creative output eventually drops. So productivity is expected to follow a hump-shaped curve, as is indeed the case (Simonton, 1984). However, if novelty is randomly generated, there is no reason to expect this hump-shaped curve unless individuals become increasingly less selective and then more selective over their lifespan, which seems unlikely.

The two models also diverge with respect to the relation between quality and quantity of output both within and across careers. A selection-variation model leads to the prediction that the different creative outputs of an individual will not be particularly similar to one another or thematically related, since they are randomly generated. In contrast, CAP is in agreement with Gruber (1989) predicts interrelatedness amongst the various outputs of a creator because they are all part of a 'network of enterprise', merely different ways of actualizing the potential of that individual's mind as it comes into contact with different contexts. The different outputs are likely to be conceptually related, and together form one big puzzle that the creator is trying to disentangle.

CONCLUSIONS

The notion of creative thought as a Darwinian process probably derives from the fact that the means through which a creative mind manifests itself in the world—language, art, and so forth—exist as discrete entities such as stories and paintings. This can lead to the assumption that discrete artifacts in the world spring forth from corresponding discrete entities in the brain. We saw that items assimilated into a distributed memory structure can emerge in modified form. It is difficult to see how items stored in the discrete fashion necessary for them to compete and get selected amongst would undergo spontaneous adaptive change. Thus the image of ideas as discrete and pre-formed leads to the assumption that they must be replicators that get generated through that most celebrated of change-generating mechanisms, Darwinian selection. This is not to say that there *is* no replicator in culture. Since ideas are woven together in minds, if anything is evolving it is not 'memes' but minds. Expressed ideas and artifacts are merely how a mind reveals itself under a particular context. Different situations or contexts expose different parts of this structure, much like cutting a fruit at different angles exposes different parts of the interior of the fruit. Thus it can be argued that the mind constitutes a 'primitive replicator', similar to the self-organized autocatalytic sets postulated to be the earliest forms of life in that it is un-coded and therefore subject to inheritance of acquired characteristics (Gabora 2004). But even if the creative mind acts as a replicator in the evolution of culture that does not mean it is generating novelty through a Darwinian process.

Campbell's notion of selective retention does capture the fact that one doesn't immediately discard all aspects of a thought, nor does one *keep* all aspects. This is also true in biology—never do *all* traits die out, and never are all traits retained, yet selection theory does fine there. But the difference is that there selection is occurring in parallel on actualized entities rather than serially on potential ones. Selection theory requires that in any given iteration there be multiple distinct, actualized states. In cognition however, each successive mental state changes the 'selection pressure' against which the next is evaluated; they are not simultaneously selected amongst. Creative thought is more a matter of honing in a vague idea through redescribing successive iterations of it from different real or imagined perspectives; in other words, actualizing potential through exposure to different contexts. Moreover, selection theory cannot describe situations where the outcome emerges through interaction between an entity and its context. The mathematical description of this kind of change of state requires a model that uses a non-Kolmogorovian probability distribution. A classical formalism such as selection theory cannot be used. Thus it is not applicable to the description of a stream of creative thought, where the mind can exist in a state of potentiality, and change through interaction with the context to a state that is genuinely new, not just an element of a pre-existing set of states. To the extent that creative thought powers cultural change, selection theory is of limited applicability there as well. However, even though selection theory does not provide us with a formal description of how creative thought evolves, this does not necessarily mean that it is not an evolutionary process. It may evolve not through Darwinian variation and selection but through a process of context-driven actualization of potential.

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[1] Of the three components of GAS, it is the section on learning that 'fueled' the most discussion, and is most likely to impact future 'lineages of thought'. (One doesn't go too far out on a limb proposing that selection is important in biology.) Given Hull's previous writings, it is surprising that they didn't just take Darwinism as more or less right as far as biology is concerned, and have Hull focus on culture. At any rate, GAS did a good job of laying the issues onto the table (even if we get more 'mileage' out of puns on its name than ideas it contains).

[2] The fact that many species, in contrast, have complex, overlapping life cycles where the variants are in different states of development and occupy divergent niches, does not in fact make the mathematical modeling intractable, because one can treat individuals at approximately the same stage of development, or even alive at the same time, as part of the same generation. (When you crank out the numbers you see adaptive change over a period of generations.)

[3] This is the case even where there are multiple attempts to fulfill the same creative vision. Just because two (or more) sketches were done on two (or more) different pieces of paper doesn't mean they were two distinct, randomly generated shots at accomplishing something creative. The fact that later ones are refinements of, and incorporate elements of, previous ones, is indicative not of randomly generated variation, but of repeated attempts to hone in on a vision or idea.

[4] For example, non-Darwinian processes such as self-organization, assortative mating, and epigenetic mechanisms play an important role in biology.