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Mechanisms for constrained stochasticity

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Abstract

Creativity is generally thought to be the production of things that are *novel* and *valuable* (whether physical artefacts, actions, or ideas). Humans are unique in the extent of their creativity, which plays a central role in innovation and problem solving, as well as in the arts. But what are the cognitive sources of novelty? More particularly, what are the cognitive sources of stochasticity in creative production? I will argue that they belong to two broad categories. One is associative, enabling the selection of goal-relevant ideas that have become activated by happenstance in an unrelated context. The other relies on selection processes that leverage stochastic fluctuations in neural activity. At the same time, I will address a central puzzle, which is to understand how the outputs of stochastic processes can nevertheless generally fall within task constraints. While the components appealed to in the accounts that I offer are well established, the ways in which I combine them together are new.

Keywords Accumulator model · Creativity · Mind-wandering · Neural fluctuation · Offline · Online

1 Introduction

The topic of creativity has been heavily researched by psychologists (Finke et al. 1992; Smith et al. 1995; Sternberg 1999; Sawyer 2006; Weisberg 2006), and is increasingly attracting the attention of philosophers (Boden 2004; Paul and Kaufman 2014). Psychologists have studied the characteristics that are distinctive of creative people, for example, the factors that modulate people's creativity on a day-to-day or moment-to-moment basis, as well as the brain networks involved. Philosophers have drawn distinctions, such as the distinction between *historical* creativity (which is indexed to an entire culture or all of human history) and *psychological* creativity (which is

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indexed to an individual creator) (Boden 2004). They have also explored creativity as a virtue of character, the relationships between creativity and insight, and more. (See the essays in Paul and Kaufman 2014.) In addition, some have argued that creativity can't be given a psychological explanation at all, largely on grounds of its stochasticity or unpredictability (Hausman 1984; Hospers 1985; Feyerabend 1987), whereas others have argued that creativity *can* be accounted for naturalistically (Stokes 2007; Kronfeldner 2009, 2018).

Although philosophers as a group have not had a lot to say about creativity, they *have* had a good deal to say about imagination, and one might think that imagination and creativity are closely related. But in fact they have rarely been considered together. The encyclopedia essay on imagination by Gendler (2016), for instance, is devoted entirely to imagination's relationships with other mental states, the topic of so-called "imaginative resistance", and so on. And the terms "creative" and "creativity" don't even figure in the index of a well-known volume of philosophical essays on imagination (Nichols 2006). Moreover, Currie and Ravenscroft (2002) in their book on imagination simply note the existence of creative imagination in order to set the idea to one side. One exception to this trend is Stokes (2014), who argues that it is the kinds of cognitive manipulation of ideas made possible by the faculty of imagination that underlies creative thought in general. Another exception is Gaut (2003), who argues for a constitutive connection between imagination and cases of active search for, and exploration of, novelty. But in both of these instances, the authors' focus is entirely on *conscious* manipulation of ideas, whereas my aim is to understand the unconscious processes that enable the production of novelty in the first place.[1]

Indeed, whatever the sources of novelty in the mind are, they would appear to be unconscious ones. As is familiar, new ideas generally just emerge into consciousness unheralded, often at times when one is no longer focused on the topic on which they bear. And likewise, musical improvisers are often surprised by the passages they play. Indeed, the Greeks famously thought that the sources of novelty lay outside the human mind entirely, in the minds of the gods known as the Muses. (This was not an unreasonable position to adopt if one fails to recognize the existence of unconscious mental processes altogether, as most human cultures appear to have done; see Carruthers 2011a.) One can, of course, *try* to be creative. But trying, here, means defocusing one's attention and rejecting obvious ideas when they arise, as we will see. The process that generates novelty among one's ideas remains outside of one's awareness.[2]

This paper will take for granted a cognitive conception of creativity, and will aim to investigate one aspect of its cognitive basis. It will assume the correctness of the GENEPLORE account, according to which creativity generally comprises two distinct (or partially distinct) phases (Finke et al. 1992; Finke 1995; Ward et al. 1999). One

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[1] An important precursor for the present paper is Stokes (2007), which focuses on the unconscious incubation phase that sometimes precedes creative productions. It offers an account in terms of forms of Hebbian learning and neural reorganization that can continue unconsciously while one's attention is directed elsewhere, which is consistent with some of the ideas presented here.

[2] An anonymous referee points out that Poincaré (1921), too, emphasizes the unconscious sources of novelty in ideas. The same referee likewise notes a number of connections between Poincaré's work and the claims outlined in the present paper. These historical parallels will not be pursued further here.

is generative, in which something novel is created; the other is explorative, in which creative products are developed, evaluated, and implemented. (In reality, of course, the two phases can overlap, and many forms of creativity involve iterated cycles of novelty-generation and exploration.) Note that the exploratory phase provides one set of constraints on creativity, since it is at this stage that products that initially seemed promising will often be rejected as inadequate, or modified in ways that enable them to fit one's goals better. Moreover, some have argued that the imposition of additional constraints on one's intended productions can serve as a spur for creativity itself, perhaps by enhancing motivation, or by narrowing one's search-space (Stokes 2005). My focus here is just on the generative component of creativity, however. My goal is to understand the kinds of cognitive mechanism that might enable the production of genuine novelty, while explaining how those mechanisms can nevertheless operate in ways that are antecedently constrained.

This paper will also assume that creative novelty results (or at least *can* result) from a kind of constrained stochasticity, as has been argued over many years by Simonton (1988, 1999, 2003, 2013, 2014, 2016). The constraints are set by the task demands, or by the goals of the agent. They can be quite specific, as in the sorts of insight tasks employed by psychologists. ("Find a way to fix a candle to the wall using only a box of matches and a thumb-tack.") They can be more open-ended, as in tests of so-called "divergent thinking". ("Think of some unusual things you could do with a brick.") Or sometimes the only constraints derive from the medium of production itself. ("Devise a new style of painting.") But given the constraints, there is extensive evidence that the process of creation within those constraints is often stochastic, involving chance combinations of elements. At any rate, that is what I propose to assume here.

In what *sense* is creativity often stochastic, however? Does this commit one to indeterminism (the view that events are not determined by the prior state of the universe together with the laws of nature)? Does it require one to believe that creative production depends somehow on sub-atomic quantum fluctuations, for instance? The answer to each of these questions is surely negative. But it isn't entirely obvious what positive account should be given. One might try saying that creative productions are *epistemically* random, in that, given knowledge of the initial conditions together with the laws of nature (including the "laws" of psychology), one would have no basis for assigning a probability to the outcome. But this is easily seen to be inadequate. For one might know, for instance, that most people will solve the candle-on-the-wall problem if given sufficient time (hence assigning a probability greater than .5 to the claim that a given individual will solve it). It seems better to say that a production is stochastic, in this context, if it has no *rational basis*—that is to say, if there is no sequence of thought (whether conscious or unconscious) that explains the outcome in ways that are either inductively or deductively valid, nor involve sound inferences to the best explanation. This is consistent with most existing characterizations in the literature (Boden 2004; Simonton 2003; Kronfeldner 2018), and will do for our purposes.[3]

There are a number of different sources of stochasticity in creative production. The most basic divide is between those that are exogenous/contextual, and those that are

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[3] Moreover, and despite appearances to the contrary, it is consistent with Gaut's (2012) claim that creativity is fundamentally rational. For this has to do, not with the psychological process of initial creation itself, but rather with the later evaluation and modification of the products that result.

endogenous in nature. For example, a new theory might result from a chance meeting on a train between two scientists with different backgrounds and differing expertise, or a new artistic movement might result from reciprocal influences among painters who happen to find themselves sharing the same studio. Or (famously) a new medical discovery might result from a chance observation of some growth in a neglected petri dish. These external sources of stochasticity in creative discovery and innovation are familiar, and not at all puzzling. My focus here, however, is just on the endogenous sources of stochasticity in creative production. My goal is to understand how the mind itself can be a source of constrained stochasticity.

Many have suggested that creativity considered as a whole is similar to the process of natural selection, in so far as it proceeds via blind variation and selective retention. (This is the BVSR model of creativity—see Campbell 1960; Staw 1990; Simonton 1999, 2003.[4]) However, while stochastic processes are blind, not all blind processes are stochastic. For example, heuristic search may be blind (conducted in ignorance of what one might find), but it isn't stochastic in nature (Simonton 2011). My target is more limited. I aim to account for the *constrained* component of endogenously-caused stochastic forms of creativity, which can be independent of the selective-retention component.

While stochastic production is indeed blind in a sense (since it isn't planned, and isn't the product of any rational process), it is not *just* blind. The ideas that occur to one when searching for a creative solution to some problem aren't *random*, but tend to be closely related, in various ways, to the nature of the problem. Likewise, the sequences of notes played by jazz improvisers aren't random, either, but are related to the theme of the piece. Indeed, there is a puzzle here that has not been explicitly addressed in the existing literature, to my knowledge—how can one-and-the same process be *both* stochastic in nature *and* constrained to be relevant to the topic or problem in hand. That the process is stochastic implies (we are assuming) that there is no rational sequence of thought involved. But if the process is such that the results are somehow constrained to be relevant to the topic or problem, then that suggests the presence of rational connections after all.

It is this puzzle that I aim to sketch solutions to in this paper (different for the different types of creative production; see below). Although the psychological mechanisms and processes that I appeal to are for the most part well-established, the ways in which they are herein combined have not been directly tested. So any conclusions drawn must be tentative. Indeed, my goal is to provide "how-possibly" explanations of constrained stochasticity, rather than "how-actually" ones (Craver 2006). I will outline some *possible* mechanisms that could account for the puzzling combination of stochasticity with rational constraints. The accounts that I provide are more than

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[4] Simonton's more recent work (2013, 2016) generalizes the BVSR model, providing a framework that can describe the full range of behavior, creative and non-creative. The degree of creativity, c, of an idea or behavior is defined as: $(1-p)u(1-v)$, where p is the initial probability, u is the utility, and v the prior knowledge of the utility before generating the idea or behavior (where all three parameters range from 0 to 1). Then $(1-p)$ represents the degree of originality and $(1-v)$ represents the degree of surprise, or the amount of novelty added after an idea or response is evaluated. In this framework habitual (low-creative) but still valuable behavior can be defined as cases where the values of all three of p, u, and v approach 1. My own focus in this paper is much narrower, as explained in the text: it is to elucidate the mechanisms enabling stochastic productions that are nevertheless relevant to task constraints.

just possible, however. They are consistent with existing findings, and are built out of resources that are independently established. So my hope is that the resulting explanations will not only qualify as "how-possibly", but also as "how-*plausibly*" ones (Craver 2006).

Among endogenous sources of creative production, there appear to be two basic *kinds*, neither of which can be fully reduced to the other. This is the distinction between online and offline forms of creativity. The processes that generate novelty can take place as part of an intentional activity of some sort, or they can happen "in the background" while one does something else. Creative improvisation in jazz is online, whereas having a new idea occur to one "out of the blue" while in the shower is offline. While all forms of creative action-selection happen online, it seems that creative idea-generation can be either online or offline. As just mentioned, some new ideas emerge while one is engaged with something else. But new ideas can also be pursued intentionally, as when one is challenged to come up with some new and creative things one could do with a brick. Section 2 will discuss offline forms of creativity, whereas Sects. 3 and 4 will tackle the online cases (discussing ideas and actions respectively). Section 5 will then discuss creative speech and inner speech, which seem to combine elements of both creative ideation and creative action. Finally, Sect. 6 will conclude.

It may be worth noting at the outset that there are points of both agreement and disagreement in what follows with my previous work (Carruthers 2007, 2011b), in which I suggested that action-based forms of creativity might be basic, with creative idea-production depending on creative action. While this may well be true phylogenetically (since there is evidence of stochastic action-selection in many species of animal, including insects; Driver and Humphries, 1988), I now argue that it is not true constitutively—that is, I argue that creative idea-generation is independent of (or at least sometimes independent of) any form of creative action-selection. While the importance of creative activity was well worth pushing, since it had been comparatively neglected in the literature, I now think that I pushed it too hard. Moreover, I made no attempt to explain the mechanisms that enable creative action-selection. Our focus, here, will be on constrained stochastic idea-generation in the first instance.

2 Offline creativity

The account of offline stochastic idea-generation that I will put forward needs to be placed in a specific cognitive-architectural framework; and it turns out that this is the same framework that underlies mind-wandering, now generally referred to as the "default-mode network" (Fox et al. 2015).[5] This is probably no accident, however, since many of one's creative ideas occur to one *while* mind-wandering. It seems that the same kind of defocused attention facilitates each (Bristol and Viskontas 2006; Christoff et al. 2007). But first, I shall describe the architecture, following the account developed at greater length by Carruthers (2015). Although this is just a sketch, it will be sufficient for our purposes here.

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[5] The initial pioneering work on mind-wandering and its potential creative benefits was done by Singer (1966, 1975). See McMillan et al. (2013) for a recent overview. Moreover, Jung et al. (2013), in their review of studies of the brain-correlates of creativity, emphasize extensive overlap with the default-mode network.

We know that conscious thinking depends on the resources of working memory. Indeed, working memory is often defined as the workspace within which ideas can be consciously sustained, manipulated, and sequenced (Miyake and Shah 1999; Baddeley 2003; Alloway and Alloway 2013). But working memory, in turn, seems to depend on the same top-down attentional network that is responsible for conscious perception (Gazzaley 2011; Tamber-Rosenau et al. 2011; Dehaene 2014; Unsworth et al. 2015). This network is also responsible for maintaining previously presented items in working memory, and for activating searched-for long-term-memory representations *into* working memory. It is thought that the executive component of working memory is located in the prefrontal cortex, and that the goals that guide searches of memory, and that motivate one to sustain and manipulate working-memory representations, are realized in dorsolateral prefrontal cortex more specifically. The role of attentional signals is to boost the targeted representations over the threshold needed for them to be "globally broadcast" to a wide range of systems in the brain (thereby becoming conscious; Dehaene 2014), while suppressing the competing representations (Carrasco 2011).[6]

In addition to the top-down attentional network, there is what is now generally described as a *saliency* network (Corbetta and Shulman 2002; Corbetta et al. 2008; Menon and Uddin 2010), which has also often been called the *bottom-up* attentional network. Neither term is wholly appropriate, however (Awh et al. 2012). It is not an attentional network since it is not, itself, responsible for selecting some representations over others for global broadcasting and maintenance in working memory. (Rather, it competes with current goals to redirect the resources of the top-down network.) And it is not merely a saliency network, since it doesn't just evaluate representations for low-level properties like stimulus intensity or sudden change. Rather, it also evaluates the significance of those representations against current goals and standing values. In fact, therefore, the network in question is best described as a *relevance* network.[7]

Even when our attention is engaged on a task, the relevance network continues to monitor (in parallel) a range of unattended percepts, as well as concepts and memory representations that may have become associatively or inferentially activated by features of the context. These are evaluated for importance, and when they are significant enough this can lead the relevance network to win the competition for control of the top-down attentional system, resulting in a shift off-task. This is what happens in the cocktail-party effect, for example. One might be fully engaged in a conver-

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[6] More specifically, the attentional network links dorsolateral prefrontal cortex with the frontal eye-fields and the intraparietal sulcus bilaterally. The frontal eye-fields, guided by goals, initiate shifts in the attentional signals that emanate from the intraparietal sulcus, boosting and sharpening some representations while suppressing others. Note that I assume throughout what Mole (2010) calls a "process-type" model of attention, rather than a "process-manner" one. This is the standard notion of attention employed within cognitive science. Talk of an attentional "network" in the brain would make no sense, for example, if attention were really just a manner in which various cognitive activities could be conducted.

[7] The relevance network links together regions of ventral parietal cortex with ventral prefrontal cortex and the anterior insula (especially in the right hemisphere), interacting with evaluative systems in the basal ganglia, and influencing the top-down network via anterior cingulate (whose function is often said to be conflict monitoring; note that the interactions between the relevance network and the attentional network are competitive ones). Jung et al. (2013) note that increased activity in anterior cingulate, in particular, seems to be associated with creativity, suggesting that unconscious monitoring of potential ideas or solutions might play a critical role in the creative process.

sation with a friend. But plainly, the relevance system must continue to monitor the surrounding conversations, processing some of the most accessible among them up to at least the semantic level for single words (and perhaps even sentences, since we know that multiple-word combinations can be processed unconsciously; see van Gaal et al. 2014). For if someone in one of those conversations happens to use one's name, the sound of the name will often "pop out", and one suddenly finds oneself attending to that person's conversation instead.

Something similar happens during mind-wandering. Suppose one is focused on a task with a specific goal in mind. One might be studying French verbs for a class, or reading an article for work. If the task doesn't command one's full attention—or if it does, but is experienced as effortful and aversive (Kurzban et al. 2013)—then one's mind will be apt to wander. Memories and other representations may become partially activated by what one is reading or hearing, initially remaining unconscious. These are monitored by the relevance network and evaluated against one's values and standing goals, thereby competing for attention. If any are appraised as more relevant than one's current task, then one may suddenly find oneself imagining a tropical beach, or halfway through planning a recipe for dinner.

Sometimes, on these occasions, one's standing goals include problems or puzzles that require a creative solution. And then among the representations that become activated when one is engaged in an unrelated task may be ones that are appraised as relevant enough to that background goal to initiate a switch in the direction of top-down attention. The result is that a novel idea pops suddenly into mind as a potential solution. Sometimes, when consciously explored and evaluated against a wider range of criteria the idea turns out not to work; but sometimes it does. Here novelty has emerged from the way in which concepts, memories, and fragments of memory have become stochastically activated by seemingly-irrelevant features of a totally different context.

Notice that the stochastic processes appealed to here are quite general, and underlie many forms of *non*-creative mentation as well. For instance, seeing a face on the metro that vaguely resembles that of a colleague might result in one remembering that one had promised to send that colleague an email about a prospective student. Here, too, an associatively-activated representation of the colleague activates, in turn, a stored memory of the promise. The latter, prior to emerging in consciousness, will have been evaluated by the saliency system as sufficiently relevant to attract attention, thereby becoming conscious. The associative processes involved here are stochastic in the intended sense: the sequence of thought from facial appearance to a reactivated intention is not in any sense a rational one. But neither is the result in any way new or surprising. What is distinctive of *creative* idea-generation is that associatively-evoked representations emerge into consciousness as providing a novel solution to some existing problem, goal, or need.

Notice that on this account there are two distinct evaluative stages in offline creative idea-production. The first occurs unconsciously, when the idea is appraised for relevance to the standing problem or goal. And then the second proceeds consciously, once the idea is attended to and has been globally broadcast. It is the first that provides the "constraint" component in the idea of constrained stochasticity. For although many different ideas may become activated stochastically by features of the context, the only ones to emerge into consciousness are those that pass through an initial filter—they need to be appraised as relevant enough to one's standing goals to attract attention. So the constraint on the offline production of conscious new ideas is that those ideas are (unconsciously) deemed relevant enough.

Presumably the sort of relevance-evaluation that takes place at the first stage is local and heuristic in nature, without requiring anything resembling discursive or "intelligent" evaluation. (That takes place at the second stage, once the idea becomes conscious.) For example, it might be that any activated idea that is a semantic component of the standing goal (for which a creative solution is required) might be deemed relevant enough to warrant attention. Or it might be that activated ideas that are strongly associatively connected to conceptual components of the standing goal are sufficient.

Consistent with the suggestion that offline creativity results from intrusions of problem-relevant ideas that aren't related to one's current activity or task, it has been found that high levels of real-world creative achievement among adults is linked to low levels of what psychologists call "latent inhibition" (Peterson et al. 2002; Carson et al. 2003). Such people are better at attending to features that they have previously learned to treat as irrelevant, but which have now *become* relevant in a novel task. Similarly, Zabelina et al. (2015, 2016) find that real-world creativity correlates with what they call "leaky attention". Creative people find it harder, for example, to ignore elements in a stimulus-array that are irrelevant to the task. This makes sense, given the account of offline creativity offered above. For it is a matter of chance whether the off-task ideas that are activated associatively by one's current circumstances or aspects of the present task do genuinely provide (the germ of) a solution to the backgrounded goal for which a novel solution is required. So, other things being equal, the more often such ideas break through and intrude into consciousness, the more likely it is that one will end up developing a creative solution.

Here, then, is one source of constrained stochasticity in creative idea production. The *constraint* is provided by one's standing goal of achieving a solution to the problem for which novelty is required. Ideas that are appraised as relevant to that problem are more likely to emerge into consciousness. The *stochasticity* is provided by the way in which ideas are unconsciously evoked by features of an unrelated context. When the two are combined, one can find oneself with a creative solution to the problem (or the germ of such a solution) suddenly in mind, with no idea of its provenance. Notice, moreover, that there will be no rational connection between the features of the context that first evoked the idea and the resulting solution to the problem; for the two are unrelated. So it is not just that one is ignorant of the source of the idea; it has no *rational* provenance at all.

Let me emphasize again that the account proposed here is a "how-possibly" one (or at best a "how-probably" one). I am not aware of any direct evidence of its correctness. But it makes good sense of the finding that real-world creativity correlates with "leaky attention". And the distinction between top-down and relevance networks is widely accepted, as are the claims that these networks compete with one another, that ideas can become activated associatively, and that top-down attention is often necessary and sufficient for an idea to become conscious.[8]

3 Online idea-generation

The above account characterizes one sort of creative idea-emergence quite well. These are cases where novel ideas occur to one while in the shower, or walking the dog, or engaged in some other unrelated task. But creative ideas can also be intentionally pursued, online and in-the-moment. For example, when tasked with coming up with some novel things one could do with a brick one *tries* to generate novel ideas. One cannot just turn to some other activity and let novel ideas emerge, since such tasks are generally time-sensitive. These cases require a rather different treatment, which I shall try to provide here. The account will also turn out to be important in Sect. 4, when we come to consider cases of online creative action (such as jazz improvisation) that are similarly time-constrained (indeed, in some instances, extremely swift; see Berliner 1994).

What does one do when trying to think creatively? It seems one must conduct targeted searches of episodic and semantic memory systems, using some of the task constraints as cues.[9] For example, one searches memory for potential actions and tries to pair them with a representation of a brick. One cannot just rely on memories being evoked stochastically by features of the context, since thinking creatively about what one could do with a brick *is* the context. But how does one set about rejecting ideas that are too obvious, and evoke only thoughts that are to some degree novel? Sometimes, of course, one does consciously think of something too obvious ("I could build part of a wall with it"), immediately appraising the idea as such and moving on to something else. But even here, there must be a way to prevent oneself from re-entertaining the same idea. And in any case, one can often leap straight to ideas that are novel and unusual, without having to work through all the obvious cases first. How can this happen?

The solution to this puzzle involves combining a number of theories in psychology that are already independently well-established. One is that top-down attention has both suppressive and boosting functions: it can suppress some sets of neural representations while boosting others beyond the threshold for consciousness (Carrasco

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[8] There are, of course, many hotly-debated issues concerning consciousness. But most of these aren't relevant to our topic. There are debates about whether there is any real distinction between phenomenal consciousness, for example, and so-called *access*-consciousness (Block 2011; Cohen et al. 2016). There are debates about whether access-conscious concepts and ideas make a constitutive contribution to the phenomenal properties of our lives, or merely causal ones (Siewert 2011; Tye and Wright 2011; Chudnoff 2015). And then there are, of course, debates about whether phenomenal consciousness itself does, or does not, admit of reductive explanation in functional and representational terms (Tye 1995; Chalmers 1996). None of these disputes is relevant to our topic, which is how stochastically-generated new ideas can emerge in a way that makes them available to be considered, evaluated, and acted upon. This requires only access-consciousness, and there is widespread agreement that this is enabled by some sort of global broadcasting mechanism that makes the contents in question available to frontally-located planning and decision-making systems (Dehaene 2014).

[9] On the role of memory—and medial temporal cortex more specifically—in creative cognition, see Ellamil et al. (2012).

2011). This aspect of attention has been stressed in a number of recent investigations of online creativity. For example, Beaty et al. (2017) show how the executive-attentional network is employed in divergent-thinking tasks to suppress "prepotent" ideas that have become activated, and which are too obvious given the requirement to think creatively.[10]

The suppressive function of attention will already be familiar to most readers. But another part of the story will be less familiar, and requires some elaboration. It is that leaky competing accumulator models (LCAs) characterize many neurocognitive processes quite well (Usher and McClelland 2001). One important use for such models, for example, is in accounting for perceptually-based decision making, such as swiftly judging whether a presented stimulus is a word or a non-word (Dufau et al. 2012). Neural activity representing WORD builds up over the course of milliseconds, depending on how closely the stimulus matches the features of a familiar word. If this activity reaches criterion quickly enough one responds with "word". But at the same time the "non-word" response is linked to a fixed value of activity in another population of neurons, from which the activity among the "word" population subtracts. If this value *doesn't* drop below criterion quickly enough one answers "non-word".

According to such LCA models, the criterion-level for a given decision is fixed by task demands and/or features of background motivation. For instance, if the experimenter in a word/non-word task emphasizes accuracy, then the criterion-level for a "word" response will be set high (with the criterion for "non-word" set correspondingly low), with consequent effects on one's reaction times. If the experimenter stresses speed of responding, in contrast, then those criteria can be shifted accordingly.

We can now apply the accumulator-model idea to the results of searches of memory. Neural activity representing the various properties and propositions evoked by the search will build up over time, more or less strongly and swiftly depending on how directly associated the representation in question is with the search cue (Ratcliff 1978). Other things being equal, then, the most obvious ideas will emerge first. But this is where we can appeal to the suppressive properties of the top-down attentional system. When one is attempting to be creative, attentional signals can be used to suppress representations that build up swiftly, allowing others time to bubble through to the surface and attract the boosting signals that are necessary to render them conscious.

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[10] Notice that this seems to be the inverse of the phenomenon of "leaky attention", discussed in Sect. 2. Indeed, whereas offline creativity seems to be a function of "leaky attention", online kinds of creativity depend on efficient attentional suppression (Beaty et al. 2016; Zabelina et al. 2016). Moreover, only the leaky-attention kind seems to be correlated with real-world creative achievement (Zabelina et al. 2015, 2016). What, then, is online creativity for? One possibility is that it has a social function, specifically for social display. There is no denying that this is how online forms of creativity are now employed: jazz musicians and other online performers are revered, as are those who can speak creatively and/or amusingly. (Think here of freestyle rap and improv comedy, as well as more mundane kinds of witty conversation.) They will thereby accrue many of the benefits that come with prestige (Henrich and Gil-White 2001). Or it may be that the benefits of such displays are more specific, having to do with their efficacy in attracting mates (Miller 2000). If either of these suggestions is correct, then one might predict that people who do especially well on tests of divergent thinking (which require online creativity) might be more socially-successful, whereas (as we have seen) those who score highly on tests of "leaky attention" will do better on standard measures of overall creative career-achievement (where it seems likely that offline forms of creativity are more important).

This account can explain how it is that one can often jump straight to a non-obvious idea, never consciously entertaining the more obvious ones. Yet it doesn't yet appear to find a place for stochasticity. However, here we can appeal to another well-known property of neural activity, namely that it undergoes random fluctuations, varying in intensity independently of any variations in the intensity of the stimulus (Stern et al. 1997; Kim et al. 2006; Boly et al. 2007; Hesselmann et al. 2008). If one has set a low bar for ideas to be attended to and become conscious, repressing any that reach that bar within a given time-frame, then the next idea to reach the threshold thereafter is likely to depend, in part, on just such random fluctuations. Among the ideas that have been evoked into activity by the probe, some will be quite remote (and hence unusual), and hence slow to accumulate neural activity toward the threshold. But with early-arriving representations suppressed, random fluctuations in neural activity among the remainder will mean that these remote associations aren't much less likely to end up being selected than are more obvious (but still not very obvious) ones.

Here, then, is how one might go about searching for creative things one could do with a brick. One probes memory for actions that might involve bricks, setting a low criterion-level for attention to the results, while suppressing anything that reaches that level too swiftly. The result is that the ideas that emerge into consciousness will have been significantly influenced by random fluctuations in the intensity of neural activity among the evoked representations.

Let me conclude this section with a now-familiar refrain: the account proposed here is a "how-possibly/how-probably" one. I have offered no direct evidence that it is true. But each of the components appealed to in the account is widely accepted. And by postulating that the components interact in the way proposed, we can explain what would otherwise remain puzzling: how on-line idea generation can have the properties of constrained stochasticity.

4 Online creative action

The account outlined in Sect. 3 can readily be adapted to cover instances of spontaneous creative action, such as occurs in jazz improvisation, for example. Here, too, there is novelty within constraints. And here, too, creativity is intentionally sought, not emerging as a byproduct of some other activity.

The constraints imposed on creative action can be a function of the cues/abstract commands one sends to the motor system. In effect, the latter receives an instruction with a content like, "Play sequences of notes that loosely resemble such-and-such a theme, and that are drawn from any of the following musical keys …". (Note that this is a bit like searching memory for actions one could perform with a brick. Only representations that meet the constraints will become activated.) This intention will activate more or less strongly a number of different motor plans for well-rehearsed multi-note fragments (Berliner 1994), which then compete for selection. With the goal of creativity in the background, the selection strategy can be to repress any motor commands that reach a given (low) threshold of activity within a certain brief time-frame, selecting the ones that reach that threshold next. Here, too, stochastic fluctuations in neural activity will mean that sometimes the continuation selected will be genuinely surprising and novel, while still matching the task constraints.

Each of the components of this account is independently established. We know that action-selection is hierarchical, with activity cascading downwards from the most abstract levels of description ("write a check for $100") to the most concrete ("contract and release such-and-such muscle groups") (Gallistel 1980; Jeannerod 2006). So it makes sense that improvisation might begin from a set of abstract constraints of the sort described above. Moreover, we know that action-selection is often competitive, with numerous actions that fit a certain specification (e.g. "name an action one could perform with a ball") competing with one another for control of the motor system (Cisek 2007; Cisek and Kalaska 2010; Novick et al. 2010).[11]

In addition, there is reason to think that action-selection, like attention, works by boosting some neural representations while suppressing others (Ridderinkhof et al. 2004). Indeed, some maintain that action selection just *is* a form of attention (Wu 2014). In my view this goes too far, since the functional roles are quite different in each case. The function of attention, properly so-called, is to boost representations beyond a threshold for global broadcasting, thereby rendering them conscious. The function of motor-schema selection, in contrast, is to initiate a cascade of increasingly-concrete activation that will eventuate in a physical movement. Nevertheless, there is no denying that the computational roles of attention and action-selection are quite similar. Indeed, this may be no accident, since on some views top-down attending *is* a form of (mental) action (Carruthers 2015). It may well be that the neural circuitry first developed for the one was copied over and/or repurposed for the other.[12]

We also have good reason to think that spontaneous fluctuations in neural activity can play an important role in action, just as they can in other cognitive domains. For example, Schurger et al. (2012) show how such fluctuations can be used to explain the so-called "readiness potential" that precedes spontaneous forms of action (Libet et al. 1983). While Libet and colleagues had interpreted the readiness potential as reflecting an unconscious decision to move that occurs some significant time prior to people's conscious awareness of the decision, Schurger and colleagues show that it is better explained as an artefact of averaging over fluctuations in neural activity in premotor cortex in a manner that is time-locked to the actual time of movement. They suggest that when people are given an instruction to move at a time of their choosing, while being instructed not to base their choice on any features of the stimulus or situation, they set a low bar for threshold-crossing, so that mere stochastic fluctuations in the neural population that initiates such a movement are what determine the time of action. When the electrical potentials produced by such fluctuations are time-locked to the

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[11] Unsurprisingly, Bashwiner et al. (2016) find that musical creativity is correlated with activity in premotor and supplementary-motor cortex. Somewhat more surprisingly—given that online forms of creativity correlate with capacities for focused attention rather than the sort of "leaky attention" that underlies mind-wandering (Beaty et al. 2016; Zabelina et al. 2016)—they find that musical creativity correlates with activity in the default-mode network. However, their measure of creativity involved both online (e.g. improvisation) and offline (e.g. musical composition) components, so it is hard to know how to interpret this result.

[12] On the importance of mechanism-copying in evolution, see Kaas (1989), Marcus (2004), Barrett (2012) and Chakraborty and Jarvis (2015). Note, too, that the frontal eye-fields play a central role in both covert attention and overt eye-movement.

time of action and averaged across multiple trials, it produces a profile with all the features of the readiness potential.

In sum, then, the factors that produce stochasticity in online action-selection may be quite similar to one of the two sources of stochasticity in creative idea-generation (namely, those involved in online creative thought). Both processes may rely on random fluctuations in neural representations. In connection with creative action, the fluctuations are those underlying the motor schemata that meet the task constraints. In creative idea production, they are fluctuations underlying the memory representations that have been activated by a probe. And in both cases, a low selection-criterion combined with a strategy for suppressing representations that meet that criterion early can be what enables stochastic fluctuations to play a role in the outcome.

5 Creativity in speech and inner speech

Speech, of course, is a form of action, and is often speeded, with no time for prior reflection. Yet it is also frequently the medium in which new ideas occur to one. Indeed, speech, one might think, is both *action* and *idea*, and will thus implicate each of the sources of creativity discussed in Sects. 3 and 4. Or so I will now suggest.

How are speech actions selected? The traditional view has been that speech begins with a *message to be communicated* (Levelt 1989). This would be a propositional content of some sort (a thought) that gets motorically encoded, first by selecting lexical items for an appropriate syntactic frame, and then using that to generate phonological plans and lower-level motor instructions. If so, then speech begins with a thought that is already fully-formulated. And in that case specifically action-based forms of creativity will play no role (except at the margins, contributing to the details of how the thought is expressed). But this view is arguably too simple (even if it was once a useful idealization). In fact, speech production in general (like speech comprehension; Hickok and Poeppel 2007) seems to proceed in parallel (or at least interactively; Nozari et al. 2011), with decisions about *what* to say being taken while one is in the process of saying it (Dennett 1991; Lind et al. 2014; Carruthers 2018). If so, then one generally doesn't *first* formulate a determinate message *before* expressing it in speech; rather one often formulates messages *by* expressing them into speech (that is to say, in the course of doing so), perhaps involving competition among multiple possibilities.

One consideration supporting this suggestion is as follows. We know from decades of work in social psychology that there are generally multiple motivational factors at work in any given context, influencing what people choose to say in response to a question (Eagly and Chaiken 1993; Baumeister and Finkel 2010). There are dissonance effects and self-presentation effects, for example, and people may modify what they say when they anticipate disagreement from their audience. Note that most of this literature concerns how people choose to answer a single determinate question, such as, "How opposed would you be to a rise in tuition-costs next semester?" We can assume that in free conversation there will be many more factors influencing what people decide to say in the moment (including a variety of communicative goals, memories or feelings evoked by the circumstances, as well as factors in the immediately preceding conversation).

These suggestions are consistent with the data reported by Novick et al. (2010), that patients with damage to Broca's area (leading to a form of production aphasia) also show much wider deficits, especially in their capacity to inhibit prepotent actions.[13] For the expressive difficulties experienced by some of these people emerge most clearly in cases where there are many competing things they could say. For example, when asked to generate verbs associated with a given noun, patients with damage to Broca's area may become paralyzed when prompted with "ball", since there are many related verbs to choose from ("throw", "kick", "bounce", "pass", "catch", and so on). But they may perform much better when prompted with "scissors", which is associated with just a single action ("cut"). Similarly, healthy people given the same test show increased activity in Broca's area when selecting a verb out of many alternatives, as well as during conflicting-action trials of the Stroop test. At the very least these findings establish that speech production involves competition among expressive *actions*, if not competition among intended messages.

The latter claim is supported, however, by findings from patients with Wernicke's aphasia (who often have severe speech-comprehension difficulties), as Langland-Hassan (2016) points out. For although the speech of such patients can be fluent, it is often garbled or completely unintelligible, containing misused words, non-words, and meaningless concatenations of the "Green ideas sleep furiously" variety (LaPointe 2005). Since Wernicke's aphasia is primarily a speech-comprehension deficit, we can infer that speech production normally proceeds in parallel with comprehension, evaluating the contents attaching to a range of potential speech actions while they are being constructed and implemented. (See also Matsumoto et al. 2004; Aristei et al. 2011; Pickering and Garrod 2013.) If this is right, then we can expect that speech will be capable of benefiting from each of the sources of online stochasticity identified in Sects. 3 and 4, either singly or in combination.

Moreover, although people differ in the extent to which they make use of *inner* speech (Heavey and Hurlburt 2008), such speech will often occupy a significant portion of one's time during episodes of mind-wandering. This has two implications. The first is that, since inner speech arguably results from mental rehearsal of speech actions, influenced by many of the same speech-selection processes that govern overt speaking (Carruthers 2018), such speech will sometimes be creative in the same ways, and for the same reasons, as its overt counterpart. Then second, since inner speech typically occurs during mind-wandering, in conditions of low executive control, it should also be subject to some of the sources of creativity discussed in Sect. 2. That is to say, concepts and conceptual combinations that have become activated associatively or inferentially by unrelated aspects of the context (whether internal or external) will be among those competing for encoding and expression during the process of inner-speech production. Sometimes while mind-wandering, then, one will find oneself saying something in inner speech that either is, or contains the germ of, a creative contribution of some

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[13] For example, they perform quite poorly in the Stroop test. This test requires participants to name the colors of a set of color-words as swiftly as possible. In one condition the words and their colors are consistent. (e.g. the word "red" will be printed in red.) In the other condition the words and their colors are inconsistent, requiring one to suppress the well-rehearsed tendency to *read* the word, and state the name of the color instead. (e.g. the word "red" might be printed in green, requiring one to say "green".)

kind. It appears, then, that inner speech might benefit from all three of the sources of constrained stochasticity identified in Sects. 2, 3, and 4 respectively.

6 Conclusion

The goal of this paper has been to understand the cognitive—endogenous—sources of constrained stochasticity in human thought and behavior. I have suggested that these belong to basic two types: offline and online. In offline forms of creativity, the ideas needed for a creative solution to a task or problem may become associatively activated by features of an unrelated context (whether external, when engaged in an unrelated task, or internal, when mind-wandering). While still unconscious, these ideas are monitored within the relevance network. If the latter appraises them to be sufficiently relevant to the earlier task or problem, then they may attract top-down attention and emerge suddenly and unexpectedly into consciousness.

The second, online, form of constrained stochasticity is under intentional control. It involves initiating a probe to activate a set of representations while setting a low criterion for the activation-level needed for selection among the results, and while suppressing items that reach that criterion too swiftly. This enables stochastic fluctuations in underlying neural representations to influence which ones get chosen. I have suggested that this second form of constrained stochasticity is realized in two separate mechanisms in the human brain, however, which share similar computational properties: one is for activating and selecting among ideas evoked from semantic and episodic memory systems, whereas the other is for activating and selecting among motor representations. So while there are two basic types of constrained stochasticity (offline and online), there would appear to be three distinct mechanisms involved. For while the mechanisms underlying online idea-generation and online action-selection are computationally very similar to one another, they are nonetheless distinct.[14]

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