The Creative Explosion

Rating novel combinations for quality as the key to evolving higher intellectual functions such as syntax

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1. The Problem. Animal communication is usually about single concepts and their intensification. Human language is about enabling mind-reading, providing clues that allow another person to guess your structured mental concept of, for example, who did what to whom. For commonplace happenings, stock phrases suffice. But the power of language lies in its ability to convey novel, never before encountered, concepts that have been compounded of more familiar components.

It is the novelty that makes long sentences and complicated thoughts so difficult. Yet we may utter hundreds of such novel combinations daily. Gossip provides much everyday exercise in constructing novel sentences (Dunbar 1996), even in people who would not consider themselves "creative."

Creativity is a key aspect of our mental lives, and that is not likely to be the case for other animals and for most of our ancestors. For a half century, archaeologists have emphasized that there is a gap – now estimated to have lasted about 150,000 years – between the first appearance of anatomically modern *Homo sapiens* and the "creative explosion" (John Pfeiffer's term, far better than "the mind's big bang") that marks the transition to behaviorally modern *Homo sapiens sapiens*. People that looked like us, big brain and all, go back nearly 200,000 years in Africa. But initially they did not think as we do. The first 6,000 generations of *Homo sapiens* either rarely innovated or rarely succeeded in passing innovations on. Why the hiatus?

This was, however, not unusual. The first million years of toolmaking lacked major advances. Once bilaterally symmetric tools were invented about 1.6 million years ago, an additional million years followed without much advance. Even in the last 700,000 years when the pace picked up, 100,000 years – 4,000

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generations – would often pass without a noteworthy development. Fifty years ago, one might have ascribed this to the poverty of the archaeological record but stasis is now more clearly established (Klein 2000).

Innovation did not become commonplace until about 75,000 to 35,000 years ago (conventionally, "50,000 years ago") in Africa[2]. We look at the ingenuous tools and art of this time and declare that such people 2,000 generations back must have thought much as we do, a statement that cannot be made of the earlier *Homo sapiens*, even if they did have our external appearance and our big brain.

The behaviorally-modern transition was the most recent (Table 1) of the major transitions in evolution.

Table 1

The Major Transitions in Evolution

Rephrased and *expanded* from those of Maynard Smith and Szathmáry, 1999

1. Bagging those replicating molecules inside a cell membrane.
2. Centralizing replicating molecules onto chromosomes.
3. The division of labor between DNA's information storage and RNA's construction activities.
4. A beyond-the-bacterium cell, the live-together-or-die-together eukaryote confederation of organelles.
5. Sex. (Don't leave variation to chance mutations: shuffle those genes with every generation.)
6. Making various specialized cells from the same DNA.
7. From solitary cells to coexisting in groups (multicellularity, about a billion years ago).
8. *From primate socialization to protolanguage abilities (perhaps a million years ago).*
9. *From unstructured short sentences to the creative higher intellectual functions with quality control (the behaviorally-modern transition to the modern mind was perhaps 50,000 years ago).*

2. Bigger brains and our intellects. Such substantial periods of stasis contradict the conventional wisdom about brains, that bigger-is-smarter-is-better. However true this may be when comparing herbivores to carnivores or mice to men, it appears not to be a good guide to the beyond-the-apes developments. Since brain size could nearly double in a million-year period while

[2] About the same time as behavioral modernity, there was also a migration out of northeast Africa 60,000 to 40,000 years ago. They likely preyed on naïve herds all across the grasslands into central Asia. By 45,000 years, they were in coastal areas of the eastern Mediterranean and then into Greece and the Balkans. It was the behaviorally modern people who displaced the Neanderthals in Europe and most of the remaining *Homo erectus* in Asia, who peopled Australia and later the Americas. That the earliest European cave paintings at 35,000 years ago were sophisticated enough to include perspective suggests that representational art's beginnings lay elsewhere, likely Africa or Asia.

toolmaking remained static, it is unlikely that the demands of stone toolmaking drove the brain size increase.

Presumably brain size repeatedly increased for some other reason. More vocabulary, more sharing, and increased accuracy of throwing and hammering are the ones capable of being repeated for extra credit. If one of them had the incidental benefit of making one more clever, the cleverness did not extend to toolmaking. (It is still possible that, without enhancing technological innovation, brain size increase incidentally enhanced social intelligence.)

In addition, the 150,000 year lag of behavioral modernity suggests that, while the modern-sized brain might be essential for our kind of mind, it certainly was not sufficient. These two findings of stasis makes one wonder about the conventional wisdom, that a bigger brain makes one more clever in a general way.

3. The Final Step to Higher Intellectual Functions. The traditional candidate for this step up in mental abilities is that syntax finally evolved via the usual interaction between culture and gene combinations. The long complicated thoughts enabled by syntax could then produce the innovations that we see in the archaeological record. (This is a bit of a leap as it leaves out the "quality control" issue that I will presently explore.)

Structuring is a characteristic of the whole suite of higher intellectual functions, and so perhaps many of them appeared back then. To keep a half-dozen concepts from blending together like a summer drink, you need some mental structuring. In saying "I think I saw him leave to go home," you are nesting three sentences inside a fourth. We also structure plans, play games with rules, create structured music[3] and chains of logic. We have a fascination with discovering how things hang together, as seen when we seek hidden patterns within seeming chaos – say, doing crossword and jigsaw puzzles, doing history, doing science, and trying to appreciate a joke.

Our long train of connected thoughts is why our consciousness is so different from what came before. Structuring with quality control would have made it possible for us to think about the past, and to speculate about the future, in far more depth.

So before this creative explosion, what were mental abilities like? Something that didn't happen can be as important as those that did, when it comes to reasoning about ancestral abilities. The dog that didn't bark in the middle of the night was a classic Sherlock Holmes clue, suggesting that the intruder wasn't a stranger.

In general, when an animal needs to do something that it has never done before, no plan of action is needed because it can be

[3] We can clearly invent more, and polyphonic music may be such a latecomer. Most need no additional natural selection. In this sense, the free lunch is alive and well.

done slowly. A goal, plus feedback to guide the next step, usually suffices. The ballistic movements, which occur so rapidly that there is no time for sensory feedback to correct a movement command (the movement is complete before feedback begins to act) are the major exception. Correcting an arm perturbation begins after about 1/8 sec, and a dart throw is complete in 1/8 sec. During "get set," a movement program for hundreds of muscles must be readied and then released like a preprogrammed fireworks display. Still, most ballistic movements, such as basketball free-throws and dart throws, are not novel; the objective is to "stay in the groove," to use a previously standardized set of movement commands.

It is only *novel* ballistic movements where a creative plan is really necessary. What novel throws and novel sentences have in common is judging the plan and improving on it.

4. Overestimating our ancestors.

We routinely assume that our pets can speculate and think in terms of stories that connect events, that they can worry as we do about looming contingencies. This is unlikely, however.

Consider all of the things which, having more advanced abilities, they would do to out-compete others – say, practice "dry runs" or make novel plans for tomorrow (seasonal migrations don't count: Calvin 2004). Since we do not observe them doing such things, we come to doubt that they possess such "silent" abilities as the cartoonists imagine. If they had intellect but couldn't speak, they'd use it in some ways we could likely observe.

Similar reasoning must be applied to our ancestors as well: if they had the abilities conferred by higher intellectual functions, they would surely have used them to out-compete others. In some areas, such as sexual selection, we might not see signs in the archaeological record. But signs of trade routes and more complex social organization are as slow to appear as technological innovation.

We find it difficult to imagine a less rich mental life than our own. Development does offer us some insight into simpler mental states. If we know what the two-year-old child's mind is like, and if we set aside the child's advanced imaginative abilities[4] (Turner 1996) and intense acquisitiveness for patterns (nine new words per day), we can get some notion of what mental life would be like if our adult understanding of the world were lacking the richness conferred by higher intellectual functions.

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[4] From Turner (1996): A two-year-old child who is leading a balloon around on a string may say, pointing to the balloon, "This is my imagination dog." When asked how tall it is, she says, "This high," holding her hand slightly higher than the top of the balloon. "These," she says, pointing at two spots just above the balloon, "are its ears." This is a complicated blend of attributes shared by a dog on a leash and a balloon on a string.

But try to imagine growing up without the rich experience which language provides. Consider Oliver Sacks' (1989) description of an 11-year-old boy who was thought to be retarded for his first ten years – but proved to be deaf instead[5]. He was then tutored in sign language. Sacks then interviewed him and put him through some of the usual tests:

> Joseph saw, distinguished, categorized, used; he had no problems with *perceptual* categorization or generalization, but he could not, it seemed, go much beyond this, hold abstract ideas in mind, reflect, play, plan. He seemed completely literal — unable to juggle images or hypotheses or possibilities, unable to enter an imaginative or figurative realm.... He seemed, like an animal, or an infant, to be stuck in the present, to be confined to literal and immediate perception….

Now imagine a whole species much like Joseph, far more capable than apes in many ways but lacking intellect. At some point, our ancestors were unable to juggle images or hypotheses or possibilities, unable to enter an imaginative or figurative realm, and stuck in the present.

So to imagine the mental life of *Homo sapiens* about 2,000 generations ago, perhaps we should omit notions of past and future, omit speculation and even worry. Include all of the commonalities with the apes such as the arm around the shoulders, the reassuring touch, and include considerably more sharing behaviors than seen in the apes. But how much language should be included in our picture of human mental life, back before intellect blossomed? For language per se, it is widely supposed

- That mimicry was an essential setup for acquiring a vocabulary of hundreds and thousands of words.
- That words and speaking short sentences without syntax evolved long before language was capable of expressing long, complicated thoughts.
- That understanding was easier than production and so, during a transition period, a long sentence could be understood by many who could not themselves create one.
- That a key problem with creating long sentences is the structuring which permits phrases and clauses to be independently assembled and, on the receiving side, permits the many combinatorial possibilities evoked by the words per se to be quickly disambiguated and the sender's structured thought inferred.
- That a working memory is needed whose workspace permits more than a half-dozen pieces of the puzzle to be manipulated at the same time.

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[5] Similar cases also illustrate that any intrinsic aptitude for language must be developed by exposure during early childhood. Joseph didn't have the opportunity to observe syntax in operation during his critical years of early childhood.

So add protolanguage to the list as well. Since Joseph probably had little protolanguage experience, his mental state at age 11 may have been more limited than a juvenile *Homo sapiens* living 100,000 years ago.

5. Protolanguage and Mimicry. The everyday example of protolanguage (Bickerton 1990) is the language of the two-year-old child, where production is limited to single words and short sentences (it is also seen in the novel productions of some stroke patients and language-reared animals). Protolanguage is not limited to stock phrases but can handle novel combinations of words. Calvin & Bickerton (2000) suppose that protolanguage could have developed gradually over a million years, that vocabulary and mimicry ability grew over this period but that sentence length did not.

This level of language should have been remarkably useful for many purposes and likely rewarded via natural selection whatever tendencies appeared for better vocabulary building via mimicry. To judge from the apes (Tomasello 2000), mimicry abilities were not well developed in our ancestors. This is surely not a problem with brain size as a bird-sized brain suffices for vocal mimicry.

Yet today we have mimicry abilities so extensive that we unconsciously mimic many of the stock gestures of nearby persons. Cross your legs or scratch your face, then watch for others doing the same thing in the next minute. To some extent, this is just "releasing" innate and overlearned gestures but it has clearly advanced to include mimicking novel combinations, as when we unconsciously tap a foot to a new melody. Variously called mirroring, echoing, or matching, this mimicry helps us learn how to dance and tie knots.

6. Bridges to Longer Sentences. Case marking[6] (for example, *he* if the person is the actor but *him* for the same person acting as a recipient) shows an elementary way of disambiguating a longer sentence, given the customary roles associated with the verb[7]. Hints as to the role played by a noun may suffice to create sentences with more than one verb.

Chunking, the creation of a single word stand-in for a longer expression, shows another route to longer constructions. Acronyms

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[6] English has lost much of its case marking in the last few hundred years, replying heavily on word order to identify roles. Latin is a language which relies heavily on case marking.

[7] When we learn a new verb, we are also learning the roles associated with it. (Sentences are like little plays and we must guess which nouns fill each of the roles associated with the verb.) *Give* requires a noun to serve as the giver, another to serve as the recipient, and a third to serve as the object given. *Sleep* merely requires a sleeper. In addition to a verb's obligatory roles, it may have optional ones such as time and place.

are a familiar form of chunking, as in “USA.” Temporary chunks are words such as “that” and “the” which serve as a stand-in, referring back to a prior concept, often an entire sentence. In American Sign Language, they may be defined on the fly by pointing to a corner of the imaginary tray after a sentence is complete, with subsequent pointing to that corner referencing that prior sentence’s concept.

All of these seem to fit with needing more working memory, and thus with a gradual buildup of long-sentence abilities. But recursion has seemed an aspect that is all-or-nothing. Either you have the idea of nested embedding or you don’t. If you do, you can carry it to considerable depths. It does not stage, with a mastery of the two-deep form needed before the first three-deep nesting, and so on to four and five.

There are some significant limitations to our present language abilities. The quiz-show “He gave *what* to Jane?” is standard English word order but a single element can be moved out of place, as in “*What* did he give to Jane?” You can seldom move more than one element of a sentence out of its standard position without getting hopelessly tangled. We similarly find it difficult to comprehend a web of causation, despite our ability to handle knock-on chains of causation. Think of such limitations as a present-day bottleneck preventing an advance to a “higher syntax” or more complex reasoning abilities.

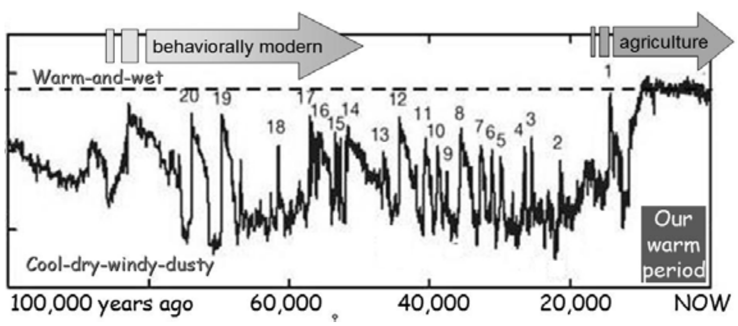

FIGURE 1. Estimated air temperatures in the last ice age, from the Greenland GISP2 ice core. The peak of the last ice age was about 22,000 years ago. After 7,000 years of slow rewarming, climate abruptly popped out of the low mode about 14,800 years ago (at 1) to achieve modern temperatures in less than a century. It then collapsed back down into the Younger Dryas period that lasted 1,300 years. In Africa, the coolings were only about 3°C but the associated droughts were profound. Between peaks 17 and 14, there are a dozen flips, chattering between warm-and-wet and the low mode characterized by cooler, drier, windy and dusty.

7. Candidates for the Keystone. The period just before the creative explosion may, of course, not represent a bottleneck at work. It could be a time when evolution sped up enough so that gradual developments look explosive. This was, indeed, a period of many abrupt climate changes affecting the entire earth, when a warm-and-wet climate like today’s flipped into an alternative mode of operation that was cooler and drier, windy and dusty. Major changes could occur in only five years, the time that it takes a drought to become profound. In only a century, climate could chatter back and forth several times. Such instability was especially prominent 60,000 to 50,000 years ago.

Each flip likely caused a bust and boom cycle for hominids (actually bust-boom-boom: see Calvin 2002) that would have been particularly effective for speeding up many aspects of hominid evolution. But we still have the problem of what changed when. And why.

Clearly, a number of beyond-the-apes abilities must be in place before any major transition into syntax and the other higher intellectual functions. Some were further improved, once long-sentence language started earning its keep, but each might have had a threshold level of ability below which the transition could not occur. Bottleneck candidates include:

– **Insufficient mimicry.** If your vocabulary is limited to several hundred words as in tutored apes[8], your thoughts cannot range widely. Without mimicry, cultural spread is slow. With mimicry, innovations in gesture and vocalization spread horizontally like an infectious disease, making them much more likely to be carried on, instead of dying with the inventor.
– **Working memory limitations.** For production, the best of the language-reared apes still seem limited to two or three word combinations, though they can do much better on tests of understanding novel combinations of words (Savage-Rumbaugh et al, 1996). Even assuming a working memory capacity of more than a half-dozen items at a time, there could be duration limits (Lieberman 1991), being unable to keep candidate combinations stable for long enough to improve them. Evolution likely had to adjust the rate at which workspace items faded, essential to erase the workspace for the next task.
– **Chunking.** What we routinely do is to chunk longer assemblies into a single item as a stand-in. Without this ability, we would be limited in creating more complex thoughts with (once unpacked) a dozen elements. Familiar examples include the overlearned combinations, such as an area code where three digits (“212”) can be treated as a single item. Remembering a ten digit phone number is much easier when three of the digits count as a single chunk rather than as three chunks[9]. A word is a stand-in

[8] Because apes often do not mimic, each word must be laboriously taught.
[9] Grouping long strings into pairs, as in the Parisian telephone number 42-60-13-08, has the additional advantage that some possible pairs are known as single words such as sixty and thirteen, reducing the load from eight chunks to six. When grouping in triples and foursomes, the percentage of memorable chunks is low, making American phone numbers more difficult to hold in mind while dialing.

for a sentence of explanation. Our item limits in working memory (as in "seven, plus or minus two") often prompt us to collapse a series of words into a stand-in (which in turn may become a new item of vocabulary) in order to lengthen a construction while remaining within the item limit.

– **Structuring per se.** To have phrases and clauses, the workspace needs to be partitioned[10] so that, for example, a phrase can be judged separately from the clause. In evolution, such features are routinely achieved by making part-time use of neural circuitry improved by natural selection involving a different kind of payoff. Once structuring mental life has its own payoffs, such circuits will no doubt be improved but something else usually invents them. The creative explosion might have had to wait for such ancillary developments. Without the neural machinery for nesting, recursion would be rare. My favorite candidate for nested embedding is the neural circuitry needed for planning a novel throw (Calvin and Bickerton 2000). Your plan for uncocking the wrist is nested inside the plan for uncocking the elbow. To hit the target, the release velocity must be just so. This means a mutual tweaking of these contributions (and those of fingers, shoulders, forward movement of the trunk, etc.) to avoid the many incoherent combinations that will cause dinner to run away, to find a quality solution that will hit the target.

– **Theory of (another's) mind.** Our ancestors presumably had basic mind-reading abilities before they became capable of structured ones. Without good abilities conferred by the neural circuitry used for an analogous task (say, keeping track of who owes what to whom, paid for by preventing dilution of sharing's benefits by freeloaders), such developments could be slow.

– **Quality controls on creativity**. This is the item that does not appear in the conventional wisdom. It is also the one most relevant to the primary data, the million-year-long periods lacking evidence for innovation and the 150,000 years before the creative explosion at 50,000 years ago when people who looked like us were not innovating very much.

8. Creations of Quality. If bigger brains were smarter, and smarter was rewarded by natural selection, then it seems obvious that the brain ought to get gradually bigger and smarter. We have already seen that this is unlikely. We similarly reason that anything so useful as creative ability ought to have evolved automatically via evolution's algorithmic processes. But evolution

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[10] For a discussion of how cortical workspaces could be partitioned dynamically, see Calvin (1996).

is seldom this simple and indeed imagination for novel combinations and contingencies has a downside.

We often fail to detect the novel combinations that are dangerous or inefficient, compared to the default behaviors better tested by evolution. In assigning the verb's roles to the available nouns, getting the actor and the acted-upon confused can be dangerous as well as nonsensical.

Assembling a new word combination may be relatively easy. (It's just "word association.") The problem is whether the parts hang together, whether they cohere. We get a nightly reminder of an incoherent version from our dreams, which are full of people, places, and occasions that do not hang together very well. An incoherent collection is what we often start with, shaping it up into the coherent version that we occasionally speak aloud. There may be a threshold to clear before the benefits of creativity become manifest. This suggests that quality judgment for language built atop some other quality-control task with less of a downside, such as judging novel throwing commands in "nothing to lose" situations.

There are two hard parts to acting on novel candidates for action. One is judgment: is this candidate combination good enough to act on? Judgment is not easy when the situation and the candidate course of action has no track record in our brain. We are reduced to using "4 on a scale of 10" styles of rating, not perfect fits to a memory. We judge "Dog bites man" to be possible but "Man bites dog" to be highly improbable in our experience. We had to become good at guessing.

The other hard part is how to improve the fit, over and over, until sufficient quality is achieved – and to do it within the time constraints of a window of opportunity. This suggests that innovation was first useful in situations where one could think about something overnight – say, the barter items for a long-distance trading journey. Innovating within the window of opportunity afforded by a conversation might be more recent.

Quality is a matter of coherence, both within a sentence and within an enlarged context, and quality control is surely an important piece of our puzzle. Quality control without a supervising intelligence occurs in nature. On a millennial time scale, we see a new species evolving to better fit an ecological niche. It's a copying competition biased by the environment, making some variants reproduce better than others.

On the time scale of the days to weeks after our autumn flu shot, we see the immune response shaping up a better and better antibody to fit the invading molecule. Again, this is a Darwinian copying competition improving quality.

Can the Darwinian process operate in our brains on the scale of seconds, to shape up a more coherent sentence to speak aloud? Can it bootstrap quality?

9. The Darwinian process for quality. My 1996 book, *The Cerebral Code,* has the worked-out proposal for how neocortical circuits could accomplish the recursive bootstrapping of quality, on the time scale of thought and action, shaping up perceptions, ideas, and action plans into higher and higher quality. The following is adapted from the brief version in *Lingua ex machina*.

Darwin's discovery about how evolution could occur in a simple, almost automatic way revolutionized our notions about how complex plants and animals came into being. Though often summarized by Darwin's phrase, "natural selection," it is really a process with six essential ingredients; when any are missing, interesting things may still happen but the recursive aspect is missing, what allows the course to be repeated for additional credit.

So far as I can tell, you need

- a characteristic *pattern* (the stand-in for the long form, likely a spatiotemporal firing pattern as in Hebb's cell assembly) that can
- be *copied*, with
- occasional *variations* (*A′*) or compounding, where
- populations of *A* and *A′ compete* for a limited territory, their relative success biased by
- a multifaceted environment (Darwin's *natural selection*) under which some variants do better than others, and where
- the next round of variants is primarily based on the more successful of the current generation (Darwin's *inheritance principle*).

There are some other things, such as sex and environmental fluctuations, which will make the Darwinian process operate faster, but they're optional – you can get the recursive bootstrapping of quality without them.

A lot of things loosely called "Darwinian" may involve only some of the essentials – say, neural development where a pattern is created by selective removal of connections biased by a multifaceted environment. It is very useful, but such emergent patterns exhibit no copying with variation, have no populations to compete, and lack a next generation biased by antecedent success. Such a carving process is not able to repeat the course to further improve the quality of the environmental fit, what you can do with a full-fledged Darwinian process.

Such recursion is how you bootstrap quality, why we can start with subconscious thoughts as jumbled as our night time dreams and still end up with a sentence of quality or a logical expression. You need a quality bootstrapping mechanism in order to figure out what to do with leftovers in the refrigerator; with successive attempts running through your head as you stand there with the door open, you can often find a "quality" scheme, that is, one that doesn't require another trip to the grocery store.

Just as bluegrass may do better than crabgrass because of your attempts to cut it regularly, water it, fertilize it, and so forth, so cortex has a number of factors that together allow one pattern to clone territory better than its competitors. They include current sensory inputs to the cortex, the background of neuromodulators (the mix of serotonin, dopamine, norepinephrine, acetylcholine, and a flock of peptides), and the synaptic strengths that allow some patterns to resonate well – in other words, to evoke a memory. Memories of antecedent combinations that worked well probably serve as standards, between which you interpolate when faced with intermediate situations.

10. Quality control. Something must insure that the copying competition is repeated for enough generations so that better-rated combinations can arise. This is much like the fitness landscape of evolution, with many of the same hazards. For example, you can hill-climb – but up a hill that peaks lower than some neighboring hill, trapping you in a mediocre place.

Thus multiple copying competitions need to be done in parallel, the different noise in each allowing higher hills to be discovered. This requires partitioning of the workspace, so that the "simulations" can be independent. An example is the way that the thalamic activating system can enhance activity in some patches of cortex but not neighbors. Partitioning of the cortical workspace is also needed for maintaining independent clauses and phrases.

Fortunately, the need is for good-enough combinations of stand-ins, not the optimal combination. But what is good enough? If in a hurry, the threshold requirement can presumably be lowered. If the threshold is set too high, the delays will cause you to miss windows of opportunity. This shows why speed of neural computation is so important for safe and effective creativity. Speed and partitioning are together what allow for good-enough combinations to be discovered in time to be useful.

11. Quality control as the bottleneck or keystone. Higher intellectual function will not work well without everything else being in place, mostly for other reasons. Thus any one could provide the bottleneck.

Perhaps a more useful way of looking at such a situation involves how an arch is constructed. Scaffolding holds most of the stones in place until the wedge-shaped keystone is placed. It allows the two sides of the arch to lean against one another. Thanks to the stones not being compressible, the arch stands with the props removed.

On such an analogy, most of our "stones" need independent support, at least at the time when things were actively evolving. The arch's self-supporting nature is an emergent property of having all the stones in place. For higher intellectual function, our stones with their own supports are such things as structuring, mimicry, protolanguage, proto planning, proto reasoning, and more general aspects of quality control.

Since it looks like our keystone allowed a full implementation of higher intellectual function after 150,000 years of *Homo sapiens* running around Africa, we must assume that proto versions were already around before the transition. Protolanguage suggests mimicry had to be around as well. I have argued elsewhere (Calvin 1996, 2002) that structured planning is essential for throwing to novel target locations, and it is useful for versatile hammering for toolmaking. It too has a quality control problem, of judging when a novel assembly of movement commands is good enough to go with. Like protolanguage, novel ballistic movement planning may have been improving and elaborating for a million years or more.

So one way to imagine a keystone placement, with higher intellectual function as an emergent property, is to hypothesize that quality control for planning novel ballistic movements finally carried over to planning on longer time scales and for oral-facial sequences as well as hand-arm.

Such are arguments for multimodal quality control being the keystone. But why at 50,000 years ago and not sooner? There are no good arguments for this except the fact that climate change speeds up evolution and speciation opportunities (Calvin 2002). And that 60,000 to 50,000 years ago was a period of flipping back and forth between the warm-and-wet climate mode and the cool-dry-windy-dusty mode. Such climate flips are capable of attracting grazing animals (and their predators) into new territory and then stranding them there, promoting inbreeding's reduction of genetic variety. Natural selection for the new environment makes some of the useful gene combinations more common. But when the climate finally recovers enough for immigrants to arrive, their reintroduction of the missing gene variants usually dilutes out the local adaptations. Speciation sometimes occurs in the isolated population before the immigrants arrive, however, and prevents the dilution of useful novelties by reducing the success rate of between-group matings.

We do not know whether prior ice ages chattered as much as this last one, for the reason that we do not have records of high time resolution beyond 115,000 years ago, despite much effort at extending the reach of the Greenland ice cores (Alley 2000). So while this last ice age was filled with opportunities for bust-and-boom cycles and opportunities for speciation in isolated inbreeding populations, we cannot yet conclude that the period of the creative explosion was unusual in that respect.

In some sense, quality control is just another of the things for which we rely on new uses for old things – in this case, quality judgments for hand-arm movement plans carrying over to judging oral-facial movement plans. For case marking approaches to longer sentences, it is the social calculus of 'Who owes what to whom' that provides a setup for beginning to construct longer utterances about 'Who did what to whom.' For the case of structuring with nesting, it is again hand-arm planning that has the everyday payoffs.

But what makes quality control special is that it is possible to imagine all of the others in place and still not improve creativity's yield and safety. Handling novelty routinely is what the higher intellectual functions are all about and, while they will not work without the structural underpinning, structuring without novelty only provides stock phrases that are longer. Quality control for novelty, but without structuring for long sentences, only improves protolanguage utterances. Having both structuring and quality control is what characterizes the higher intellectual functions.

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