Chapter 4: Domain-General Creativity—On Generating Original, Useful, and Surprising Combinations

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Productive Aberrations

Art you make with the system that you did not expect or understand

Abstract

The author argues that all creative ideas, whether in the arts or the sciences, use the same set of generic processes and procedures – just as persons speaking different languages operate under the same fundamental linguistic principles. The argument begins with the basic observation that all forms of creativity are combinatorial, the generation of new combinations from given ideas. However, because not all combinations are creative, it is necessary to provide a formal definition of what can be considered such. In words, creativity is defined as the joint product of its originality, utility, and surprise. This definition then implies that combinations must be generated by a procedure or process that is blind to the utility values. However, blindness does not imply the lack of constraints on the chosen combinatorial mechanism. The chapter then closes with a discussion of the theory's explanatory scope, research applications, and theoretical syntheses.

Born just a couple of years apart, Albert Einstein and Pablo Picasso became two of the most universally acclaimed creators of the twentieth century. The former, a theoretical physicist, published his creative ideas in highly technical journal articles riddled with mathematical equations. The latter, an avant-garde artist, expressed his creative ideas in paintings and sculptures. Did they think alike when they engaged in the creative process? At first the answer might seem an emphatic "No!" Einstein could no more "paint a Picasso" than Picasso could get a manuscript accepted in *Annalen der Physik*. On further examination, however, the answer is not so straightforward. Certainly both creators were outstanding visual thinkers who could use their imaginations to create spatial-visual ideas that were initially beyond the grasp of many contemporaries. These mindboggling ideas are evident in Einstein's relativity theories and in Picasso's cubist paintings (Miller, 2001). According to Einstein's special theory of relativity, if one observer is moving relative to another observer, then two events might be absolutely simultaneous to one but quite temporally distinct to the other even when they both stand in the same spot. In Picasso's cubism, the parts of a body or face might occupy radically different spatial orientations simultaneously so that, say, the eyes might be on one side of the head but the mouth or nose on another (e.g., his 1941 *Dora Maar au Chat*). Hence, it is not impossible that they might have relied on the same basic cognitive process to visualize the world in ways that most people couldn't – to imagine a reality totally unlike what surrounds us every day.

Einstein's first language was German, Picasso's Spanish. No doubt the two contemporaries would have struggled to carry on a basic conversation about the weather, even less about their chosen domains of creativity. As someone who studied both languages in high school and college, I can appreciate how different they are in phonetics, lexicon, syntax, and pragmatics. But imagine that some afternoon in the early 1920s, the two found themselves in the same Parisian sidewalk café, at adjacent tables talking in their native languages with compatriots. Suppose, too, that both geniuses initiated their respective conversations with a brief reference to the beautiful weather – the blue sky in particular. Would what Einstein said be incommensurate with what Picasso said? Could how Picasso described the weather prove untranslatable into German? Obviously not! Both languages operate with nouns, verbs, adjectives, and other parts of speech that make direct references to the external world. Certainly both statements could be translated into, say, Mandarin, with minimal loss in meaning to a Chinese sipping espresso the next table over. An unusually bright sunny day would remain so in any language. It wouldn't be too farfetched to argue that the underlying cognitive processes behind Einstein's and Picasso's meteorological remarks might be for all practical purposes identical. Whether one says "Blau" or "azul" in response to a blue sky, the basic associative process of retrieving the appropriate adjective must be the same.

I will argue in this chapter that creativity has a generic psychological make-up that transcends the idiosyncrasies of any particular creative domain. Einstein's scientific creativity and Picasso's artistic creativity differed at a superficial level only, just like their divergent use of German and Spanish to describe the weather. The concrete content might vary, but the abstract mental structure would remain equivalent. Creativity is just creativity!

Creativity as Combinatorial

Many eminent creators have themselves claimed that creativity must entail some combinatorial process or procedure (Simonton, 2010). Einstein himself affirmed that "combinatory play seems to be the essential feature in productive thought" (Hadamard, 1945, p. 147). The mathematician Henri Poincaré (1921) provided a more elaborate affirmation when he reported how "ideas rose in crowds; I felt them collide until pairs interlocked, so to speak, making a stable combination" (p. 387). He compared these colliding images to "hooked atoms of Epicurus" that bump against each other "like the molecules of gas in the kinematic theory of gases" so "their mutual impacts may produce new combinations" (p. 393).

Hence, it should come as no surprise that many creativity researchers have made the same claim as the creators themselves (e.g., Finke, Ward, & Smith, 1992; Martindale, 1995). For instance, Mednick's (1962) well-known theory of remote association was explicitly designed to provide a cognitive basis for combinatorial creativity. Empirical support for this position has also been published. Thus, Thagard (2012) demonstrated that 100 top discoveries and 100 top inventions can each be analyzed into combinatorial products of some kind or another (e.g., some verbal, others visual, and yet others mathematical). The same assertion can easily be made for artistic creativity. To use Picasso's *Guernica* as an illustration, detailed analyses of his sketches reveal how much the painting largely represents the arduous end product of the combination and recombination of various visual elements that can be identified in earlier work, including his famous etching *Minotauromachy* that he created a few years before (Damian & Simonton, 2011; Weisberg, 2004). If an idea were completely *de novo*, it would probably not be understood.

When we speak of creativity as combinatorial, we have by no means committed our statement to *what* is undergoing combination (i.e., the content rather than the mechanism). For Picasso and Einstein the combinations definitely involved visual elements. For instance, Einstein noted that "words of the language, as they are written or spoken, do not seem to play any role in my mechanism of thought. The psychical entities which seem to serve as elements in thought are certain signs and more or less clear images which can be 'voluntarily' reproduced and combined" (Hadamard, 1945, p. 147). Nonetheless, other creators may depend on combining more abstract ideas (Thagard, 2012). Thus, Roe's (1953) study of sixty-four eminent scientists found that some used verbal imagery rather than visual imagery.

Sarim: maybe you can do PCA to figure out the components
Of what is being combined LOL

Indeed, the mental elements entering the combinatorial hopper can get even more diverse than what has been identified so far. Choreographers will play around kinesthetically with varied body movements, jazz pianists will manually tinker on the keyboard with chromatic notes and complex harmonies, and chefs will mix exotic flavors, aromas, and textures. As Thomas Edison observed regarding technological creativity, "To invent, you need a good imagination and a pile of junk."[1] Any entities that can undergo combination and recombination can enter into this generic process or procedure.

In fact, this openness can be quite striking in those creators whose creativity is influenced by synesthesia (cf. Dailey, Martindale, & Borkum, 1997). For example, synesthetic composers often associate tones, keys, or chords with colors and thus can combine the two modalities in a single composition. Alexander Scriabin's *Prometheus, Poem of Fire* offers a prototypical illustration. The work is scored not just for piano, orchestra, and (optional) choir, but also includes scoring for the "color organ" (aka the "Chromola" or clavier à lumières) – albeit the piece is seldom heard/seen this way in concerts because most people aren't synesthetes and even synesthetes do not always agree in their cross-modal associations!

At this point a reader may object: "Surely not all combinations are creative! Each morning I prepare breakfast using the exact same combination of elements – a bowl, a spoon, my favorite cereal, and fat-free milk. Nobody will call that creative!" Excellent observation! It now forces us to define that diminutive subset of combinatorial products that can count as creative.

[1]www.thomasedison.org/index.php/education/edison-quotes/.

Defining Combinatorial Creativity

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Creativity researchers have been appropriately creative in creating numerous definitions of creativity (Plucker, Beghetto, & Dow, 2004). Although most may favor the two-criterion "standard definition," which imposes some version of the criteria of originality and effectiveness (Runco & Jaeger, 2012), others have argued for a three-criterion definition, such as that preferred by the United States Patent Office[2] (Simonton, 2012c; cf. Boden, 2004). To earn patent protection, an invention must be novel, useful, and nonobvious – the latter even to someone with the relevant domain-specific expertise. Recently, I have provided a quantitative and multiplicative three-criterion definition that must introduce new rigor into the discussion (Simonton, 2012a, 2013b). Although more rigorous than the norm for most creativity research, this formulation has the distinct asset that it provides the formal basis for domain-general combinatorial creativity. Here some simplifications will be imposed to present that foundation in the most elegant manner possible for our current purposes (e.g., the omission of temporal subscripts, such as required in sequential processing; cf. Simonton, 2013a).

Parameters Defined

Let us start with a set of k combinations, where $k \geq 1$ (for if $k = 0$, we have no combinations to evaluate for creativity). These k combinations can be identified as x_1, x_2, x_3, … x_i … x_k. For example, in Maier's (1931, 1940) classic experiments using the "two-strings problem," research participants were required to tie two cords together that hung from the ceiling with the lower ends resting on the floor (the last critical feature invariably depicted incorrectly in textbook graphs). One potential solution, of course, would be to grab one cord, walk over to the other cord, grasp it as well, and then complete the task. Because this combination of objects and operations would not solve the problem, given that the cords were hung too far apart given their length, the experimenter advised the participants that they could use several items in the laboratory, such as a chair, a pole, an extension cord, and a pair of pliers, using them any way that allowed them to complete the task. Although the details varied according to the specific experiment, the participants could often generate more than a half-dozen combinations of objects and operations to potentially solve the problem, so we might set $k = 7$. For instance, we could set combination x_3 = "While holding one cord the other was pulled in with a pole" (Maier, 1931, p. 183). Whatever the details, these k combinations can vary according to three parameters:

1. The *initial probability* p_i of the combination x_i, where $0 \leq p_i \leq 1$. For example, the combination with the highest initial likelihood in the two-strings problem was to try to tie the two cords directly using the hands only, the first combination that was doomed to fail. The next most common combination was to place a large object, such as the chair, somewhere between the two cords, anchor one cord to that object, and then draw the remaining cord toward the anchored cord (Maier, 1931). The combination with the lowest probability was the least obvious: Shortening one cord so that it no longer hung all the way to the floor, tying the pliers at the end, setting it in motion as a pendulum, and then pulling over the other cord to get in position to catch the swinging cord. In fact, many participants were unable to spontaneously generate this combination of actions. When specifically instructed to use the pliers, some thought to use them as tongs instead – which didn't solve the problem because that combination was too short!
2. The *final utility* u_i of the combination x_i, where again $0 \leq u_i \leq 1$. In many situations, this parameter becomes a dichotomous 0–1 measure, where 0 = useless and 1 = useful. The various combinatorial responses to the two-strings problem were this way: Either a combination worked or it didn't. Nevertheless, in many other situations, the utility can be a continuous or at least ordinal variable. For example, the solution to a particular problem may be only "partial" or "incomplete." When Edison searched for a commercially viable incandescent lamp filament, he often encountered several less-than-ideal solutions, such as platinum wire. A filament might burn out too quickly, use too much electricity, be made of expensive materials, or prove too fragile to hold up to transportation and installation. I must emphasize that the term "final utility" should be taken in the broadest possible sense to include ultimate value, appropriateness, effectiveness, and so forth (cf. Runco & Jaeger, 2012). For instance, many of the ideas that Picasso came up with for his *Guernica* had to be left out because they just didn't fit (e.g., the bull with a human face, the mother climbing a ladder, the Pegasus, or the prominent up-thrust fist in the center). Such images could then be said to have a zero final utility. They ended up on the cutting room floor.
3. The *prior knowledge* v_i of the utility, where once more $0 \leq v_i \leq 1$. If $v_i = 0$, the value of u_i is not known in advance, whereas if $v_i = 1$, the utility value is already known perfectly. If the prior knowledge value falls somewhere between the two extreme values, then the person may only experience a "hunch" or a vague "feeling of knowing state" (cf. Bowers, Regehr, Balthazard, & Parker, 1990). It is critical to recognize that these two parameters are completely orthogonal: The prior knowledge of the utility is independent of the value of the utility. One may know for sure that the combination is useful or useless; or one may be completely ignorant of whether the combination is useful or useless. Even so, the specific parameter values assigned u_i and v_i taken together quite strongly constrain the most plausible parameter values for p_i, as will be demonstrated later.

It should also be emphasized that all three parameters range from zero to one, like probabilities, proportions, or response strengths. Hence, multiplying them together or subtracting any one from unity will also yield a number ranging from zero to one, with a similar potential interpretation.

Creativity Defined

Given the above three parameters, we can then define the *creativity* of combination x_i by the following three-factor product:

$$c_i = (1 - p_i)u_i(1 - v_i), \text{ where } 0 \leq c_i \leq 1$$

The first and third factors need a little more explaining, though. The first, $(1 - p_i)$, represents the *originality* of combination x_i, that is, the inverse of its probability. Highly original combinations have the lowest initial probability. The third factor, $(1 - v_i)$, represents the combination's *surprise*. Surprising combinations are those that provide us with knowledge we didn't have before. This factor can then be considered roughly the same as the "nonobvious" criterion used as the third criterion of the US Patent Office (Sawyer, 2008; Simonton, 2012c). Putting this all together, we get the assertion that creativity is the joint product of originality, utility, and surprise. Note well that according to this multiplicative definition, $c_i = 0$ whenever any of the three components equal zero. Unoriginal, useless, and/or obvious combinations cannot be creative no matter how highly the combinations might score on the remaining factors. Each holds veto power over the others.

To return to the two-strings problem, using the pliers to create a pendulum scores high in creativity by the above definition. According to Maier (1940), only this solution introduced "an element of surprise and a change in meaning since the tool changes to a weight and the string, which was too short, suddenly becomes too long and must be shortened" (p. 52). It was not ordinary thinking by any means. Even participants given prior experience using standard pendulums did not exhibit a higher probability of creating this combination of actions. Indeed, the participants usually had to receive hints from the experimenter before arriving at this combinatorial achievement (Maier, 1931). In stark contrast, using a chair to hold one string while pulling over the other string was much closer to "routine" or "reproductive" thinking. The combination was highly probable and didn't require the participant to use the chair in a radically new way: not that different from using a chair to hold a purse or coat – or blankets when the kids make a "fort" in the living room! The same definition also informs us that eating a bowl of cereal every morning cannot be considered an act of creativity.

[2] www.uspto.gov/inventors/patents.jsp.

Finding Creative Combinations

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Now that creative combinations have been defined, how do we find them? This task must prove rather difficult by the very definition of creativity given earlier. In the first place, holding the utility constant at some non-zero value (i.e., $u_i > 0$), creativity c_i maximizes as $p_i \uparrow 0$ and as $v_i \uparrow 0$. In words, maximally creative combinations have a zero initial probability of generation and no prior basis for even having any usefulness whatsoever! Accordingly, the most highly creative ideas require an incubation period (cf. Wallas, 1926). This period often ends via a "flash of insight" or "Eureka experience" in which an initially ignored combination suddenly pops into awareness (Mandler, 1995). Many such "ah-ha!" events depend on serendipity for this "popping" to happen (Kantorovich & Ne'eman, 1989). Absolutely nothing in Alexander Fleming's exceptional expertise would have made him consider that antibiotics might be extracted from *Penicillium notatum*: That breakthrough combination required the accidental discovery that a staphylococci culture had been successfully invaded by that fungus. Speaking more generally, such highly creative combinations will often emerge through the "opportunistic assimilation" of otherwise irrelevant stimuli in the environment (Seifert, Meyer, Davidson, Patalano, & Yaniv, 1995). The most famous Eureka moment in history, that of Archimedes, was precisely of this nature.

Yet it cannot be overemphasized that such inspired moments by no means guarantee that a creative combination has been identified. Such events might only signify that the generation probability now exceeds zero while it remains true that $v_i = 0$, signifying that the actual final utility remains unknown. It was for this reason that in the classic four-stage formulation of Wallas (1926) the "illumination" stage of the creative process was followed by the "verification" stage. Generation must be followed by test, variation by selection, for trial might result in failure rather than success. After all, creators can experience "false inspirations" as well. What looked good at the time may prove far less so when subjected to extra scrutiny, yielding a "Darn, that won't work either!" moment. Hence, such failed insights often merely increase the size of *k*, the number of blind combinations considered by the creator.

Tellingly, whereas there is only one way a combination can be creative, there are multiple ways it can be noncreative. After all, creativity will be low when the originality is low or the utility is low or the surprise is low or any permutation of low values, including when all criteria are low. In fact, even if the values of p_i, u_i, and v_i are normally distributed in a set of *k*combinations, the expected distribution of c_i will be best described by an inverse power function (Simonton, 2012a). What this means is that the modal creativity for the set of combinations will be zero, with the expected frequency decreasing with the magnitude of creativity, making highly creative combinations most rare. This rarity is a necessary outcome of the multiplicative definition. Even if the three parameter values had a uniform distribution, the same result would obtain (Simonton, 2012a). Combinations that simultaneously possess originality, utility, and surprise are hard to come by. Creativity is an extremely scarce commodity.

Sightedness Defined Skip

Formally speaking, the crucial reason why it is so challenging to find a creative combination is that such combinations cannot rate highly in a quality called *sightedness* (Simonton, 2012b, 2013b; cf. Sternberg, 1998). A combination is sighted to the extent that it is highly probable, highly useful, and highly obvious. Stated in terms of the parameters, we get

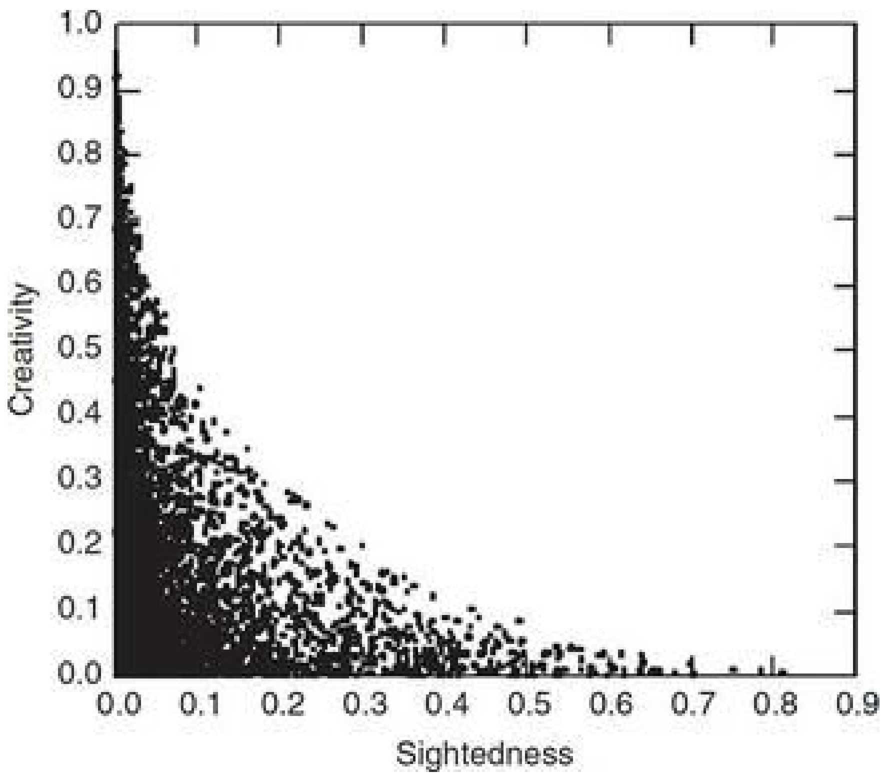
$$s_i = p_i u_i v_i, \text{ where } 0 \leq s_i \leq 1$$

Logically, it must follow from this definition that $c_i \uparrow 0$ as $s_i \uparrow 1$. Stated a little differently, if a combination is highly useful, and we already know that it is highly useful so that it has a high initial probability based on that prior knowledge, then it cannot be highly creative as well (i.e., as $u_i v_i \uparrow 1$, $p_i \uparrow 1$ and thus $c_i \uparrow 0$). Again, such combinations result from routine or reproductive thinking rather than creative or productive thinking. Highly sighted combinations represent direct applications of what we already know rather than enlarge our knowledge – confirm, not extend. It is like that bowl of cereal for breakfast to remove those morning hunger pangs.

Monte Carlo Simulation Skip

Given the above consequence, we might at first infer that the goal would be simply to look for combinations that are low in sightedness. Such combinations can be called *blind* instead, where clearly blindness $b_i = 1 - s_i$. In other words, blindness and sightedness define a bipolar continuum (Simonton, 2011a). Because blind combinations must be both original (low probability) and surprising (low prior knowledge of the utility), some creative combinations might hide among them. Although that conclusion is valid, there is also a catch: Blind combinations will also have a much higher likelihood of low utility. After all, many of the low-sighted ($s_i \uparrow 0$) combinations will have the parameters $u_i \uparrow 0$ and $v_i \uparrow 0$ (whatever the value of p_i may be). This ambivalent consequence of looking for creative combinations among blind combinations has been demonstrated in a simple Monte Carlo simulation (Simonton, 2012a). The results are shown in Figure 4.1.

Larger View



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The graph is adapted from Figure 4 in "Combinatorial creativity and sightedness: Monte Carlo simulations using three-criterion definitions," by D.K. Simonton, 2012, *The International Journal of Creativity & Problem Solving, 22*, pp. 5–17.

Figure 4.1: Scatter plot showing the relation between sightedness and creativity for Monte Carlo–generated combinations, where sightedness is just the inverse of blindness (viz. $b_i = 1 - s_i$). The most creative combinations are found on the left side of the graph, where the most uncreative ideas are also located, thus requiring the implementation of BVSR, generation and test, or trial and error

Here combinatorial creativity is plotted as a function of combinatorial sightedness. Observe right from the start that the most creative combinations are indeed exceptionally rare, occupying as they do the extreme blind (left) end of the graph. Because the upper limit of the generated scatterplot is concave downwards, the maximum possible creativity declines rapidly as we move along the blind-sighted continuum toward the sighted (right) end. Even so, as blindness increases toward the left side of the dimension, the number of combinations with low creativity also increases. Put differently, the variation in creativity increases with blindness, with the distribution becoming increasingly skewed. Hence, the resulting distribution of creativity at the extreme blind end is highly skewed, with most combinations scoring low. So to find the most creative combinations requires that the individual sift through the set of *k* combinations to separate the wheat from the chaff. This sifting process has been variably called "trial and error," "generate and test," "selection by consequences," "bold conjecture and refutation," and "blind variation and selective retention" or "BVSR" (Bain, 1855/1977; Campbell, 1960; Nickles, 2003; Popper, 1963; Skinner, 1981). But whatever the name for the process or procedure involved, it requires that the creator be willing and able to generate combinations without prior knowledge of whether they will actually prove useful – which brings us to the next section.

Generating Blind Combinations

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So how does one generate blind or "unsighted" combinations? Here the answer is simply, "Do anything that works!" (cf. Feyerabend, 1975). Creativity researchers have wasted too much time trying to find the single secret to creative thinking: Too often the quest concentrates on what can be considered *the* creative process as if it required only a restricted type of mental act, such as that needed for recalling a seven-digit number from working memory! Examples include remote association, divergent thinking, cognitive disinhibition (or defocused attention), primary (or primordial) process (or "regression in the service of the ego"), intuition, overinclusive (allusive) thinking, dreams and/or daydreams, analogy, conceptual reframing (frame shifting), finding the right question, broadening perspective, reversal, tinkering, play, juggling induction and deduction, dissecting the problem, etc. (e.g., Carson, 2014; Ness, 2013; Simonton & Damian, 2013). Sometimes the very names for these processes or procedures can even appear quite esoteric, such as Geneplore (Finke, Ward, & Smith, 1992) and Janusian, Homospatial, and Sep-Con Articulation thinking (Rothenberg, 2015). Alternatively, some have tried to establish that creativity involves just ordinary thought (Weisberg, 2014) or at least ordinary problem solving using an assortment of regular heuristic search techniques, such as hill-climbing, means-end analysis, working backwards, and even good old trial and error (Newell & Simon, 1972).

Guess what? All of the above processes or procedures work some of the time, but absolutely none of them work all of the time. That is precisely why so many have had to be identified. Sometimes a tried-and-true creative process will generate nothing but bad ideas (i.e., where $u_i \uparrow 0$). For example, Edison was often inclined to use trial and error (a.k.a. BVSR; Simonton, 2015b). By generating one combination after another, and subjecting each to a set of utility criteria, he eventually ended up with the practical incandescent light bulb that not only made him rich and famous, but also provided the iconic symbol for having a "bright idea." Yet at approximately the same time, Edison applied exactly the same approach to developing a fuel cell that could power these light bulbs directly from the energy source, and dramatically failed. In short, there is no such thing as a single process or procedure that guarantees a creative combination. Instead, what we have is a toolkit of ways to generate combinations that must then be tested for utility. When one tool fails, we pull out another and hope for the best. The person with the biggest set of available tools will probably prove the most creative (cf. Ness, 2013).

The various combinatorial techniques in this toolkit can be called "weak methods" (cf. Klahr, 2000). These techniques are *weak* because they far too often fail, thus proving conclusively that they produce combinations without secure prior knowledge of the utility values. Although weak, such methods have the advantage that they can be applied to almost any domain under the sun. They are truly domain general. For instance, it is hard to imagine a creative domain where a good analogy might not prove useful from time to time. Analogical combinations permeate both the sciences and the arts, from precise mathematical models to allusive literary metaphors – even if not all models or metaphors ultimately prove effective with respect to either truth or beauty.

So-called "strong" methods or techniques (cf. Klahr, 2000), in contrast, can guarantee the production of useful combinations, but they are also far more likely to be domain specific, or at least confined to a small subset of domains. For example, when I was a chemistry student, I learned which catalysts would accelerate certain types of chemical reactions (e.g., the $2CO + O_2 \uparrow 2CO_2$ needed for an automobile's catalytic converter). I have never found the procedures useful in anything I have done in psychology. Even platinum does not catalyze my thoughts! However, I also took calculus so that I know how to differentiate the equations that I am most likely to encounter as a psychologist (e.g., polynomials, as in Simonton, 2014). Better yet, differential calculus is absolutely essential to almost all of the mathematical sciences, such as physics and chemistry. Yet I cannot imagine that most artists would ever find differential (or integral) calculus useful. Einstein used higher mathematics all of the time, but Picasso never did.

Besides, strong methods have another problem: It is virtually impossible for them to generate creative combinations! To the extent that the method is truly strong, then the utility value of its output is already known prior to the method's application. Moreover, to the degree that the foregoing statement holds, then the probability of anything produced by that method must be very high. To give a concrete example, if at a Paris sidewalk café I find myself presented with a difficult (i.e., not easily factorable) quadratic equation and am asked to find its roots using a hand calculator, I will just plug the equation's three parameters into the quadratic formula and be done with it! I might double-check my calculations, but I have absolutely no doubt that the correct computations will yield the answer I seek (even if I end up with the square root of a negative number). In brief, the whole algorithmic procedure is 100 percent sighted and the resulting combination of the derived two roots with the given three parameters will have no creative value no matter how "original" to me. Anyone who knows the quadratic formula could do the same.

So we get back to the toolkit. Highly creative people must possess the cognitive flexibility to resort to whatever works. The larger and more diverse the set of accessible tools, and the more patient and persistent the creator's quest, the higher the odds for finding the right tool for the job. That is why "trial and error" or BVSR can be elevated to the ultimate creative technique – if by this we mean that the creator can readily generate and test multiple weak methods for producing potentially creative ideas.

Continue from here

Constraining Combinatorial Creativity

The theory of creativity as combination is often criticized because it would supposedly lead to a "combinatorial explosion" (e.g., Eysenck, 1995). The number of potential combinations of a given set of mental elements grows exponentially with the number of elements in that set. In theory, it would take several lifetimes to generate and test all possible combinations. This consequence is indeed true. In fact, it has been used to explain the cross-sectional distribution of creative productivity where a small number of creators account for a disproportionate number of creative products (Simonton, 2010). If the number of mental elements are normally distributed among a group of creators, then the distribution of potential combinations should be approximately lognormal, with a long upper tail (see Figure 4.1 in Simonton, 1988, p. 66).

That said, creators seldom if ever generate all possible combinations of the ideas in their heads. Many potential combinations are simply overlooked. For example, when Thomas Henry Huxley first learned about Charles Darwin's new theory of evolution by natural selection, he reportedly cried out "Why didn't I think of that?" (Wolpert, 1994, p. 68). After all, Huxley already possessed the same puzzle pieces that Darwin used in constructing the revolutionary explanation. Indeed, that prior knowledge soon rendered Huxley a highly effective "bulldog" in defending Darwin against Creationist attacks. Perhaps Huxley might have come up with the theory himself if he hadn't been preempted by his older colleague, just as Huxley's contemporary Alfred Russel Wallace managed to do in blissful isolation from Darwin's efforts. Many careers likely hide potential creative combinations that were never generated and tested. Indeed, according to one comprehensive combinatorial model, the entire scientific community regularly overlooks potential discoveries and inventions for generations if not centuries (Simonton, 2010). And with respect to the arts, many great "Tenth" symphonies have never seen the light of day because of the composer having already passed away (Simonton, 2015a).

More importantly, rather than throw every possible thought into the combinatorial mixer, most creators work with an extremely restricted subset. Poincaré (1921) expressed this reality using his chemical metaphor: "mobilized atoms are … not any atoms whatsoever; they are those from which we might reasonably expect the desired solution. Then the mobilized atoms undergo impacts which make them enter into combinations among themselves or with other atoms at rest which they struck against in their course" (p. 389; viz. "spreading activation"). Accordingly, "only combinations that have a chance of forming are those where at least one of the elements is one of those atoms freely chosen by our will" (p. 389). It is for this reason why current BVSR theory talks of "pre-selection" (Simonton, 2011b; i.e., if $u_i = 0$ and $v_i = 1$, then it necessarily follows that $p_i = 0$). For instance, when Picasso began working on his *Guernica*, which depicts a horrific war atrocity, certain visual themes in the artist's repertoire, such as his highly erotic nudes, could be omitted from the get-go. Similarly, when Einstein started developing his special theory of relativity, he automatically left out of the combinatorial mill any assumption that would violate a fundamental law of physics. Blindness does not equal stupidity.

A nice example of a contrarian view

Sarim: Know the tools you're dealing with and see how you can push them

You can choose to ignore some elements to prevent combinatorial explosion

Frequently, creativity is said to require "thinking outside the box." This statement is plain wrong. Creativity always takes place within a box – a set of constraints that increase the odds that the creator will obtain useful combinations. To offer admittedly extreme cases, Picasso could no more insert differential equations in *Guernica* than Einstein could include a figure of a mortally wounded horse in his journal article "On the Electrodynamics of Moving Bodies." Notwithstanding the originality and surprise that would be displayed by such combinations, those combinations would also have zero final utility. Hence, it is more accurate to say that the creator often needs to expand the size of the box, that is, to reduce constraints that might interfere with obtaining a creative combination.

A well-known example concerns the discovery of ring compounds in organic chemistry. Certain chemical features of benzene were not consistent with the carbon chains that had hitherto provided the usual structural interpretation for hydrocarbons. But Friedrich August Kekulé realized – supposedly in a daydream where a snake seized its own tail – that if the six-carbon chain was allowed to close upon itself to produce a ring, the observed chemical properties fell right into place. Such aromatic compounds now form a special branch of organic chemistry. Common aspirin contains one such ring.

From Weak to Strong Methods

Another constraint on combinatorial creativity is the most ironic: Weak methods that require BVSR, trial and error, or generate and tests – including the application of alternative weak methods – can sometimes yield strong methods that enable future creators to bypass the weak methods altogether. In the early history of algebra, for example, mathematicians would solve problems on a case-by-case basis using weak ad hoc procedures. But little by little, mathematicians would discover repeated patterns that permitted the strong, algorithmic solution of specific classes of problems, where those classes became increasingly inclusive over time. Thus, the solution of a complex system of linear equations today requires nothing more than the algorithmic operation of matrix inversion that even a laptop computer can do in an instant (as demonstrated every time someone performs a multiple regression analysis using standard statistical software). If the matrix cannot be inverted (because the determinant is zero), the equations cannot possibly be solved, period. An old proverb says "Give a man a fish and you feed him for a day; teach a man to fish and you feed him for a lifetime." Going from weak methods to strong methods operates in much the same way. You get more bang for your buck.

But herein arises the irony: This weak-to-strong conversion then yields routine (reproductive) combinations rather than creative (productive) combinations! If I now use matrix algebra to solve a system of linear equations, I cannot publish the solution in a mathematics journal. Mathematicians have already "been there, done that" long ago. The solution might be the means to some other end, such as new statistical method, Weak methods have more creative potential than strong methods, which are already well established, and can only serve as a means to an end

but the latter would end up in a statistics journal, not a mathematical one. Just as importantly, the toolkit containing just strong methods has no usefulness beyond a narrow set of creative domains. In contrast, the weak methods that generated the strong methods remain universal in application forever. Both Einstein and Picasso can – and did – use trial and error, but Einstein had no use for well-established techniques for mixing paints and Picasso had no use for Maxwell's equations for explaining electromagnetism. So gains in domain-specific efficiency come at a cost in domain-general applicability and creativity (see the "No Free Lunch Theorem" discussed in Nickles, 2003).

From Strong to Weak Methods

Paradoxically, in fact, the principal way that domain-specific strong methods contribute to creativity is when they unexpectedly turn out not to be strong at all (Simonton, 2011a). In formal terms, a combination generated by a seemingly "strong" method actually has the following parameters: $p_i = 1$, $u_i = 0$, and $v_i = 0$, yielding $s_i = 0$ (rather than $p_i = u_i = v_i = s_i = 1$). In short, the combinatorial procedure that always proved useful in the past, and thus enjoys a high initial probability, is discovered to be surprisingly useless when applied in what at first seems a routine or reproductive application – like tying two strings together hanging from the ceiling. Creativity can arise when strong methods fail

Historic examples include the various "anomalies" that emerge in paradigmatic sciences when predictions from a well-established theory unexpectedly fail to work (Kuhn, 1970). For example, Newtonian celestial mechanics was spectacularly successful in calculating planetary orbits – even predicting the orbit of the unknown planet Neptune – until it failed to account for the observed precession of Mercury's perihelion. That surprising anomaly inspired physicists to engage in a new combinatorial enterprise that eventually led to original, useful, and surprising combinations. In particular, that predictive failure set the stage for a revolutionary theory of gravitation known as Einstein's general theory of relativity. The latter now provides a new set of strong methods that are even stronger than those provided by Newtonian theory – providing the essential basis for modern astrophysics from black holes to the Big Bang. This example helps us understand why some theoretical physicists were disappointed when the hypothesized Higgs boson or "God particle" was finally confirmed. Many had hoped that by disproving the Standard Model, the disconfirmation would lead to some "new physics" that would leave them much more creative work to do. Sometimes creators *want* to be sent back to the drawing board.

The surprising violation of expectations given by the parameters $p_i = 1$ and $u_i = v_i = 0$ can thus be taken as one formal definition of *problem finding*, a central feature of creativity (Getzels & Csikszentmihalyi, 1976; Rostan, 1994). As Einstein noted, "formulation of a problem is often more essential than its solution, which may be merely a matter of mathematical or experimental skill. To raise new questions, new problems, to regard old problems from a new angle, requires creative imagination and marks real advances in science" (Einstein & Infeld, 1938, p. 95). Not surprisingly, Einstein was especially skilled at finding new problems.

Concluding Ideational Combinations

I have argued in this chapter that creativity does indeed have a universal psychological structure that transcends the domain in which that creativity takes place. At bottom, creativity must be combinatorial. The creator must produce at least partially "unsighted" combinations that must then be evaluated for creativity by some trial-and-error, generate-and-test, or BVSR process or procedure. Going from universals to particulars, combinatorial processes and procedures then operate on the specific content defined by a given domain.

Viewing creativity as combinatorial has several critical assets for the field of creativity. These advantages may be grouped into three categories: explanatory scope, research applications, and theoretical syntheses.

Explanatory Scope

The combinatorial nature of creativity applies across the spectrum from commonplace "little-c" creativity to "Big-C" creative genius (cf. Kaufman & Beghetto, 2009; Simonton, 2013c). That smiling cook in your home kitchen using new ingredients to concoct a dish for tonight's dinner must engage in combinatorial processes or procedures just like the illustrious chef of a restaurant earning three Michelin stars. To be sure, the latter will have more domain-specific expertise acquired in culinary school and beyond, and will also be subjected to far higher standards at the instant of first taste. My spouse's newfangled chili con carne is not going to be mistaken for haute cuisine by any gourmet. Yet to the extent that the dish is creative – original, tasty, and surprising – it will be combinatorial in both cases.

Just as significantly, combinatorial theory encompasses various specialized forms of creativity, such as problem solving, problem finding, discovery, and invention (Simonton, 2010). I believe it is literally impossible to conceive a manifestation of creativity that extirpates its essential combinatorial nature. All of the solutions to Maier's (1931, 1940) two-strings problem involved combining the cords with some object and some operation performed with that object (chair with holding, pole or extension cord with pulling, etc.), with solely one combination deemed creative (viz. pliers with swinging). And I have already pointed out Thagard's (2012) decisive demonstration with respect to 200 world-famous discoveries and inventions. Although the days when I could finger jazz improvisations on my electric guitar are long gone (and even admitting that nobody's missing out), from personal experience I am confident that improvisation is combinatorial to the degree that it is creative. That holds for improv comedy, too.

Hence, combinatorial creativity spans all levels and all domains in which creativity is manifested. Might I opine that the theory is really the only game in town?

Research Applications

Combinatorial processes and procedures have already inspired complex mathematical models that explicate a wide range of creative phenomena in the arts and sciences (Simonton, 1997, 2010). Combinatorial processes have also provided the basis for computational models of creativity and insight (e.g., Hélie & Sun, 2010; Thagard & Stewart, 2011). Genetic algorithms and genetic programming, which have provided creative solutions to real-life problems, are also inherently combinatorial (Goldberg, 1989; Koza, 1992). These diverse developments strongly suggest that combinatorial theory provides the most comprehensive and precise basis for understanding creativity.

In fact, computer programs that implement combinatorial procedures have actually generated impressive creative products in the visual arts and music (cf. Boden, 2004). For instance, Cope's (2014) EMI programs can create new musical compositions in the style of any given composer, from Antonio Vivaldi and Johann Sebastian Bach to Ludwig van Beethoven and Scott Joplin (cf. Fugues 1 and 2 in the Appendix, pp. 621–628). Even skilled listeners have difficulty distinguishing the human and computer generated works (Hofstadter, 2002).

Finally, and on the more empirical side, domain-generic theory helps explain why cognitive neuroscientists should be very wary of identifying *the* brain regions associated with creativity (cf. Dietrich & Kanso, 2010; Sawyer, 2011). Besides the crucial fact that very different modalities can contribute to the combinatorial processes or procedures, the processes and procedures themselves represent an extremely varied group of mechanisms both voluntary and involuntary, conscious and unconscious, logical and illogical. Even two creators generating the exact same combination may do so using different parts of their brain if one is a verbalizer and the other a visualizer or if one relies on defocused attention while another depends on a systematic search.

Theoretical Syntheses

As suggested at the close of the previous section, combinatorial creativity is not committed to any particular cognitive or behavioral mechanism. Anything creators can do to get new options from which to choose the optimal will suffice. Given this "anything goes" position, combinatorial creativity is necessarily inclusive rather than exclusive. It does not put forward any single mental process or behavioral procedure as the only or best means to creativity. Indeed, combinatorial creativity accepts that sometimes one approach will work, other times another, and yet other times none at all. All guises of creativity just become special cases of the generic principle. With but one exception, nobody's favorite theory is ruled out. That lone exception involves all domain-specific strong methods, which are rendered uncreative no matter what. To the degree that these methods are truly strong, they are also highly sighted. They're more like using a hammer to hammer nails than using a pair of pliers to make a pendulum bob.

The integrative power of combinatorial theory has two additional manifestations.

First, the generic conception of creativity as combinatorial permits the integration of the process and person perspectives on creativity (cf. Simonton, 2003). The creative person is obviously someone both willing and able to use a variety of weak methods to generate combinations where $p_i \uparrow 0$ and $v_i \uparrow 0$ in the hope of finding one where $c_i \uparrow 1$. Certainly a tendency toward cognitive disinhibition (or defocused attention) would prove highly advantageous, especially given that such a propensity also correlates positively with divergent thinking and openness to experience (Carson, 2014). The proclivity to notice things that other persons automatically filter out would definitely support increased receptiveness to serendipitous events. Yet highly creative people must be distinguishable not just cognitively but also motivationally. After all, creative combinations are extremely rare, requiring the creator to sift through lots of useless combinations by some BVSR process or procedure. This requirement implies that highly creative persons must exhibit considerable persistence and determination even when confronted with failure after failure, and with no guarantee of success (cf. Cox, 1926; Duckworth, Peterson, Matthews, & Kelly, 2007). We must not forget that Einstein devoted the last three decades of his celebrated career to developing a unified field theory that integrated all the forces of nature – an ambitious theory that *never* worked. That great creative genius was even forced to admit that "Most of my intellectual offspring end up very young in the graveyard of disappointed hopes."[3] Yet Einstein persisted in his fruitless BVSR combinatorial endeavors right up to his final days, still trying on his death bed to finally find an integrative solution that would survive him.

Second, combinatorial theory puts creativity in the same broad class of phenomena that share one property: They all attain what may be collectively referred to as *undirected adaptive originality* (cf. Sober, 1992). These phenomena all rely on various kinds of blind (most often "random") combinatorial methods to acquire original adaptations. Examples include neurological growth in the brain, the development of antibodies by the immune system, biological evolution (both Darwinian and non-Darwinian), and Skinnerian operant conditioning (Simonton, 1999). Although the operational details must obviously depend on the specific manifestation of the phenomenon, all share the process of generating combinations from given entities and then selecting those rare combinations that prove most useful (Cziko, 2001; see also Dennett, 1995). As the poet Paul Valéry described the two-stage operation, "It takes two to invent anything. The one makes up combinations; the other one chooses, recognizes what is important to him in the mass of things which the former has imparted to him" (Hadamard, 1945, p. 30). Because so many generated combinations are selected out, the combinatorial process is always to some significant degree blind – operating somewhere on the left side of Figure 4.1. If otherwise, then no selection would be necessary in the first place and the resulting combination would not qualify as an *original*adaptation. It would be too sighted, like any domain-specific strong method. The hammering, not the pliers swinging.

Einstein and Picasso might have observed "What a blue sky!" uttering totally different sounds, but most likely the underlying psychological processes would have been nearly identical in both minds.
[3]www.aps.org/publications/apsnews/200512/history.cfm.

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