Perception, Insight, and Creativity in *Paradigm*, a Game of Pattern Exploration

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ABSTRACT

This paper discusses Paradigm, a game of intuition and pattern exploration. We offer a sample case study aimed at illustrating the game's relevance as a microdomain for studying creativity and related phenomena such as aesthetic sensibility, analogy-making, and high-level perception. We also discuss a few of Paradigm's more influential predecessors, along with some computer programs that have sought to model creativity in similar domains. Rather than focusing on creativity in the sense of generating output (e.g., writing stories or making up jokes), we emphasize its more exploratory and evaluative aspects, which we believe to be prerequisites for genuine "output creativity."

Keywords

Creativity, high-level perception, pattern recognition, analogy, induction, aesthetic judgment

INTRODUCTION

In this paper, we discuss Paradigm, a game of pattern exploration and discovery, which represents a promising domain for the study of creativity and related phenomena such as aesthetic sensibility, intuition, and analogy-making. Paradigm serves as a challenging, yet tractable "microdomain" for the computational modeling of such processes. Meanwhile, it also lends itself well to (empirical) psychological enquiry due to the gradually unfolding, interactive nature of the game.

The goals of this paper are (a) to explain what makes the Paradigm domain interesting; (b) to illustrate why this domain is well-suited for the study of creativity and related aspects of cognition; and (c) and to offer some preliminary results of our own investigations into the domain. In addition, we offer some background on Paradigm, discussing a few of the game's predecessors as well as several computer programs that have attempted to model creativity and related phenomena. Finally, we outline some future directions for research involving the Paradigm domain.

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BACKGROUND

We begin this section by discussing a pair of important distinctions involving types of creativity. Next, we discuss a few of Paradigm's predecessors. Finally, we summarize some relevant computer models of creativity that operate in microdomains similar in spirit to Paradigm.

Creativity: Two Distinctions (and Continuities)

Rather than attempt to define creativity (which is probably a futile task in any case), we instead begin by making a couple of distinctions that will help clarify what we mean by this term. The first of these distinctions contrasts *input* and *output* creativity, while the second has to do with *mundane* (or everyday) and *extraordinary* creativity.

Input Creativity and Output Creativity

According to [20], "Input creativity involves the analysis of incoming data, whereas output creativity involves the production of something new" (p. 212). Examples of input creativity would include solving a puzzle or chess problem, listening to and interpreting a piece of music, or deciphering a joke. Meanwhile, examples of output creativity would include devising a puzzle or chess problem, writing a piece of music, or making up a joke.

Looking back on some of the better-known AI projects dealing with creativity—especially those developed during the 1980s and '90s [e.g., 2, 15, 21]—one finds that most of the emphasis was placed on *output* creativity. Some of this "output" was quite interesting or even entertaining, and certainly, these projects have triggered plenty of discussion and debate—not only about creativity, but also about how humans react to artifacts that *appear* to be creative, regardless of their inner workings [8, 28].Yet it would be hard to imagine a genuine model of creativity that did not account for the role of evaluation, sensibility, and aesthetic judgment—all of which are encompassed by the notion of input creativity. "To be a good writer, you have to be a good reader" [22], which is to say that input creativity is more basic than—and essential to—genuine output creativity. The iterative, back-and-forth relationship between input and output creativity is captured in the notion of the "central feedback loop of creativity" [22].

Mundane Creativity and Extraordinary Creativity

Discussions of creativity often center on those rare acts of genius one associates with the Picassos, Mozarts, and

Einsteins of the world. Boden [3] draws a distinction between *psychological creativity*, which "involves coming up with a surprising, valuable idea that's new *to the person who comes up with it*" (p. 2; italics in original), and *historical creativity*, which encompasses ideas or works that are novel in the scope human history (à la Picasso's *Guernica* or Einstein's theory of relativity). This distinction provides a useful starting point, even if it is often difficult (if not impossible) to determine what qualifies as "historically creative."

Yet even within the realm of so-called psychological creativity, one finds a tendency to focus on certain specific domains—art, music, literature, science—as if creativity were somehow limited to these domains. However, with just a little reflection, examples of creativity can be found in practically every aspect of life—for example, when someone improvises by using a rubber exercise band to remove the lid from a stubborn pickle jar (as one of the authors recently found himself doing), or when someone coins a novel (if not particularly clever) term like "joke-a-thon" on the basis of an old one (say, "telethon," itself a variation on "marathon"). These examples, and countless others like them, are encompassed in the self-explanatory term *mundane creativity* [1]. The advantage of recognizing such mundane acts as creative is that it helps "domesticate" creativity—that is, to portray it as something basic to cognition and pervasive in our daily lives, rather than as something that's only accessible to a relatively select few.

Mundane and extraordinary creativity are best thought of as two endpoints along a continuum, rather than as sharply distinct phenomena. Indeed, it is our belief in this continuity between mundane and extraordinary creativity—and between input and output creativity—that provides the rationale for our focus on the various puzzles and games discussed in the following section.

Games and Puzzles

Here we discuss three domains that can be seen as predecessors to Paradigm—the card game Eleusis, the domain of Bongard problems, and the pen-and-paper game Patterns II—all of which were designed to highlight aspects of creativity, induction, and related cognitive processes.

Eleusis

Created by then-undergraduate student Robert Abbott in 1956, Eleusis is an induction-based card game designed to simulate the processes of exploration and discovery that lead to the so-called "aha" moment [14]. Eleusis garnered broader interest after it was featured in Martin Gardner's *Scientific American* column, Mathematical Games, in 1959, and again, in the simplified form described here, in 1977 [10, 11].

The modern version of Eleusis (sometimes called "Eleusis Express") uses several decks of normal playing cards and supports anywhere from four to eight players. One of these players, the dealer, first makes up a "secret rule" that defines which cards may be played on any given player's turn (e.g., "The card played must either be red or its value must be less than that of the last legal card"). Valid rules must only reference previously played cards; rules concerning external circumstances such as the number of players, the weather, or the time of day are forbidden. The dealer may choose to give a hint before play begins (e.g., "Color is relevant to the rule"). Each of the remaining players is then dealt a hand of 14 cards. Play proceeds in clockwise fashion, with each player laying a card on the table when his or her turn comes around. If the card is a valid play according to the dealer's rule, the card is placed to the right of the last correct play (see Fig. 1). Otherwise, the card is placed below the previously played card, whether it was correct or not, and the player is dealt two additional cards as a penalty. Correct plays form a horizontal row (called the "main line"), while sequences of incorrect plays each form vertical lines (called "sidelines").

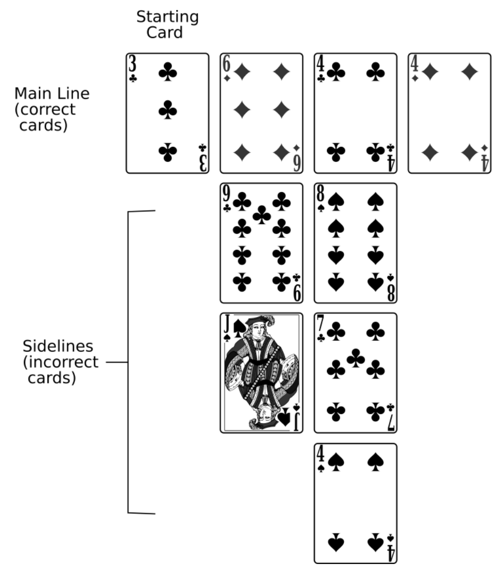


Figure 1. Example Eleusis layout after the initial card followed by three correct plays and five incorrect plays.

There are several interesting variations on the simplified sketch presented above. Players may play multiple cards simultaneously, risking a greater penalty if any of them do not adhere to the dealer's rule. A player may also usurp the role of the dealer by declaring him- or herself a "prophet," a coveted position held as long as (s)he makes correct judgments about subsequent cards played. An elegant scoring mechanism rewards dealers whose rules are neither too easy nor too difficult to guess.

Although useful as an instrument for teaching inductive reasoning and the scientific method [24], there are some limitations to Eleusis as a domain for studying the mechanisms of general exploration that are important to creative insight. A player's decision at any given point is based on the set of previously played cards, not the full set of cards. This limitation encourages explicit hypothesis-testing rather than more general exploration. For example, the rule "The card must be an odd spade" is unlikely to be discovered without the player having seen previous examples of odd spades. Yet the player has limited control over which cards are played (i.e., players can only play they hands they are dealt). Moreover, the dealer cannot rely on a specific progression of cards being played to stimulate a particular line of exploration. The sequence of played cards is determined by the random configuration of the shuffled deck and the collective decisions of the players.

Bongard Problems

The domain of Bongard problems (BP's) was created by a computer scientist, Mikhail Bongard, as a medium for studying visual pattern recognition and "gist extraction" [4]. Each BP consists of 12 black-and-white panels, which are divided into two sets, with one set of six on the left and another set of six on the right (Fig. 2). Each panel contains an image, which is typically made up of geometric figures (e.g., points, lines, circles, polygons, etc.). Figures can vary along any number of dimensions: size, location, orientation, texture, shading, relationship to other figures within the panel, et cetera. For each BP, the challenge is to figure out what the six panels on the left-hand side have in common with one another that collectively distinguishes them from the six panels on the right-hand side.

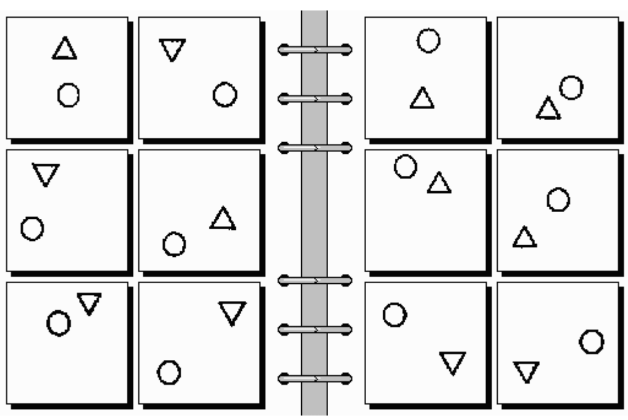


Figure 2. Sample Bongard problem: What do the six panels on the left have in common with one another that distinguishes them from the six panels on the right?

BP's were introduced to a wider audience via their inclusion in Hofstadter's *Gödel, Escher, Bach* [11] and have since been studied extensively by several researchers (see below), although the BP domain is still considered to be largely unsolved in AI. As is the case with Eleusis, the solution to a BP generally involves an "intuitive leap," wherein a subtle shift in perception allows the player to see heretofore unconnected elements as being "the same" at some relevant level of abstraction. Often, this shift in perception occurs without conscious deliberation, after the player has examined both positive examples of drawings that conform to the rule and negative examples that do not.

On the other hand, the exploration of a Bongard problem is a completely unconstrained process, which is not the case with Eleusis. For example, the player might alternate back and forth between the left and right sides, or else concentrate exclusively on the positive examples (i.e., the ones on the left), forming a hypothesis for the "hidden rule" before scrutinizing the panels on the right in search of a counterexample.

One advantage of BP's is that they are based on abstract visual forms that are more or less universal. However, the staggering variety of pixel-level features, along with the need to model the complex processes involved in low-level vision, make the Bongard domain an exceedingly difficult one.

Patterns II

Patterns II, designed by Sid Sackson [26], is Paradigm's most direct predecessor. It is designed for two participants, a *pattern-designer* and a *player*. Each participant begins the game by drawing a six-by-six grid on a piece of paper. Using four types of symbols, the pattern-designer fills in the squares on her grid to form a pattern, which the player is not allowed to see. The player's goal is to divine the designer's pattern through a process of exploration.

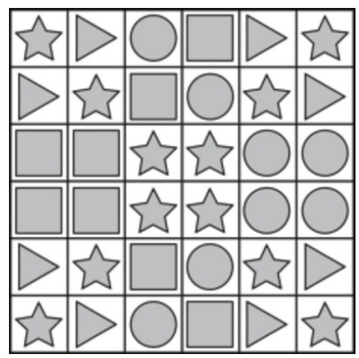


Figure 3. An example from Patterns II: "Diagonal Squares."

In each round of the game, the player indicates a square on his card that he wants revealed, after which the pattern-designer draws in the appropriate symbol, copying it from her grid. The game ends when (a) the player has discovered the "rule" behind the pattern and can fill in the rest of the squares on his own, or (b) the player's six-by-six grid has been completely filled.

There are no limits to the allowed patterns: any arrangement of 36 symbols, chosen from the four available types, is valid. Of course, this doesn't mean that all patterns are equally *interesting*. Many patterns are too simple, too rigid, boring. Others are too chaotic, unbalanced, complicated, or perplexing. Patterns that are the most enjoyable to play seem to achieve a careful balance between order and chaos, simplicity and complexity.

Models

In terms of computational modeling, it is useful to distinguish between domains, on the one hand, and programs or models that operate in such domains, on the other. A clear example is that of the *game* of chess versus a program that *plays* chess (e.g., Deep Blue). Second, it is important to distinguish between results-driven programs and more psychologically motivated ones. For example, Deep Blue was designed first and foremost to succeed in the domain of playing chess, and not necessarily to serve as a plausible model of human cognition. In contrast, the models discussed in this section—Copycat, Metacat, Phaeaco, and GENESIS—are ultimately concerned with domain-independent aspects of cognition. In other words, they operate *within* certain domains (or microdomains), but they are ultimately not *about* those domains.

Copycat and Metacat

Copycat [19] is a program that "solves" open-ended analogy puzzles involving short letter strings—for example, "If **aabbcc** is changed to **aabbdd**, then how should **iijjkk** be changed?" (or simply, **aabbcc → aabbdd; iijjkk → ???**). The word "solves" is slightly misleading, as there are no right or wrong answers in Copycat, though there do to tend to be better and worse ones. Often, there is a general consensus in this regard, but there is also room for disagreement among individuals based on (largely aesthetic) preferences.

Briefly, Copycat's architecture consists of three main components: the *Workspace* (roughly its working memory); the *Slipnet*, a conceptual network with adjustable links between concepts (roughly a long-term memory); and the *Coderack*, which houses a variety of agent-like codelets, which perform specific tasks in simulated parallel, without the guidance of an executive controller. These tasks range from identifying groups (e.g., the **bb** in **aabbcc**) to proposing bridges between items in different letter-strings (e.g., the **bb** in **aabbcc** and the **jj** in **iijjkk**). During the course of a run, Copycat's actions are influenced by a measure known as the *temperature*, which reflects the program's moment-to-moment perception of the "analogy situation." A high temperature reflects a lack of perceived coherence and therefore encourages the program to try out "wilder" ideas, while a lower temperature leads it to focus in on a particular pathway.

The sequel to Copycat, Metacat [17] adds several additional features. These include an the *Episodic Memory*, which allows the program to remember its responses to previous problems (an ability that is completely lacking in Copycat), as well as an ability to monitor the "mental events" that take place during each run, such as detecting a "snag" or noticing a key idea. Metacat also has implicit (albeit primitive) notions of concepts such as *succinctness*, *coherence*, and *abstractness*, which figure into its answer evaluations—specifically in terms of the rules it formulates to explain or justify each answer. For example, it considers **iijjll** a better answer than **iijjdd** on the aforementioned problem (**aabbcc → aabbdd; iijjkk → ???**) because the former "involves seeing the change from **abc** to **abd** in a more abstract way" than the latter; in other words, it involves seeing **c** as changing to its *successor* rather than merely to *the letter **d***. Metacat's ability to employ criteria such as abstractness and coherence in its answer evaluations could be seen as an early step toward understanding how qualitative judgments of this sort—which are crucial to so-called input creativity—can emerge from simpler processes.

Phaeaco

The domain of Bongard problems has been explored using several computational models. For example, the authors in [25] employed a model that took hand-coded first-order logic representations as inputs, emphasizing general heuristic search as a means for finding solutions. More ambitiously, Maksimov [16] employed machine-learning techniques to solve a very similar class of problems, where representations were images processed at the pixel level.

Arguably, the deepest exploration of BP's yet is Phaeaco [9]. As with the program described in [16], Phaeaco takes black-and-white pixels as input. A major difference, however, is Phaeaco's restriction to psychologically plausible mechanisms. For example, when assessing the area of a shape, Phaeaco does not calculate a precise measurement, just as humans are unable look at a circle and "see" its area as, say, 16.7 mm^2. Instead, it estimates areas (and other numeric measurements) using methods that have been empirically shown to match human judgment [6].

Starting with stochastic, low-level visual processing, Phaeaco builds up representations of the figures in the various panels (recall Fig. 2). Instead of searching a tree-like space, it uses a technique known as the *parallel terraced scan* [23], in which multiple pathways are simultaneously explored, with more promising ones receiving more attention.[1] The scan is guided by the perceived relevance of concepts in the program's conceptual network, which fluctuate over time (i.e., during the course of a run). As with Copycat and Metacat, processing in Phaeaco is carried out by codelets, which create, modify, and discard short-term memory structures; adjust the strengths of the connections between concepts in long-term memory; and compete with one another for processing time. The resulting "perceptual structures" emerge from of a coupled system of low-level "retinal" processes and high-level "cognitive" processes.

On the problems it is able to solve, Phaeaco has been shown to perform nearly as well as human subjects [9]. However, it is only able to find solutions to 15 out of the initial 100 Bongard problems, leaving much ground still to be explored in this difficult domain.

GENESIS

GENESIS [20] is a model of creativity that operates in a simplified version of the Eleusis domain, called Micro-Eleusis. There are only four types of cards in Micro-Eleusis: red-even, red-odd, black-even, and black-odd. GENESIS was developed in an effort to (a) test two competing theories of creativity, the *cortical-arousal theory* and the *creativity as normal problem solving* theory; and (b) to compare the effect of two different search mechanisms, *parallel terraced scan* and *best-first search*,

[1] The parallel terraced scan is also an important mechanism in Copycat and Metacat.

on creativity. For the dealer, creativity amounts to formulating a successful rule; for the player (non-dealer), it is equated with discovering the rule (GENESIS is capable of playing either role).

GENESIS uses an agent-based architecture. *Builder agents* construct rule representations, which are represented as tree-structured finite state automata (FSAs). *K-lines* [18], the other type of agent, are themselves collections, or chains, of previously successful builders. For example, if a particular chain of builders is successful in accomplishing some sub-goal (e.g., building an FSA that is consistent with the set of already-played cards), then a k-line is formed from those builders. Thereafter, the k-line may be activated if at least half (or some other threshold) of its constituent agents—either builders or other k-lines—are activated. When activated, the k-line in turn activates the remainder of its sub-agents. In this sense, a k-line can be seen as an "emergent memory," as the authors put it. As with Copycat, Metacat, and Phaeaco, a critical point of emphasis in GENESIS is the potential for fluid representation and the analogies that naturally emerge within such a system.

PARADIGM

In this section, we describe the rules of Paradigm and then discuss the thought processes involved in exploring a particular Paradigm pattern. The goal is to motivate interest in Paradigm as a domain for studying creative exploration, by highlighting the intuitions, false-starts, and bursts of insight that arise in the course of a game.

How the Game Works

Paradigm[2] is an extension of Patterns II—a pen-and-pencil game—into a digital format, although there are some basic differences between them. For example, a blank square in Paradigm plays the role of an empty cell in Patterns II, while a colored square in Paradigm is akin to a Patterns II cell with a particular symbol drawn in.[3] Furthermore, while Patterns II always employs the same sized grid (six-by-six) and the same number of symbols (four), there is no limit to the number and/or configuration of squares that can appear in a Paradigm pattern, nor is there any limit to the number of colors (so long as they are easily distinguishable).

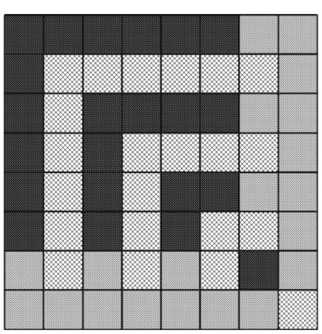


Figure 4. Example of a fully revealed Paradigm pattern.

At the start of each game, all of the squares are blank. The player begins by choosing a square—any square—on the board and guessing its color from a set of possible choices—typically no more than a handful. If the guess is incorrect, the correct color is revealed, the turn ends, and any points earned thus far on the turn are lost. (Typically, a correct guess is worth one point.) If the guess is correct, the player can either continue the turn—risking any points gained from previous correct guesses during the turn—or pass. A turn lasts for as many guesses the player is willing to make, as long as (s)he keeps guessing correctly. The final score for the entire game is the sum of all turn scores.[4]

Correct or incorrect, each guess yields one new piece of information—namely, the color of the newly revealed square. In turn, this information may trigger a shift in the player's perception of the overall pattern, or else simply reinforce an existing set of ideas about the portions of the pattern which remain hidden. Various competing pressures may be in play at any given point in the game, including the pressure to see horizontal, vertical, or diagonal lines of a certain color; to perceive larger groups such as L-shapes, diamonds, or pentonimoes; to notice relationships between individual squares (or groups) of different colors; to make distinctions between background and foreground colors or groups; to spot the potential formation of new groups at the pattern's edges; and so on.

This gradually unfolding perceptual (and conceptual) process leads to hypotheses about the colors of unrevealed squares. Making a guess essentially amounts to testing a hypothesis, one involving a potential mapping between the currently visible pattern and the full pattern (or at least a section of the total pattern). At the beginning of play, guesses are tentative, random, and often wrong. As more squares are revealed, players have more of a basis for their guesses. After each correct guess, a decision must be made to either play it safe and stop—cashing in whatever points have been earned thus far on the current turn—or to keep going and risk losing those points.

Exploring a Paradigm Pattern

In this section, we summarize the first encounter by one of the present authors with a particular Paradigm pattern, "Springtime." This summary is meant to serve as an example of a typical one-player game, not as a rigorous account of the psychological processes involved. However, some general comments and reflections are offered along following the description of the game.

The playing surface for Springtime is a six-by-six grid (Fig. 5). In the standard version of Springtime, there are five colors to choose from, but for the purposes of the following discussion, the pattern has been re-rendered in black-and-white (Fig. 6).

[2] Paradigm was designed by Kory Heath in 2006 (http://www.koryheath.com/games/paradigm).

[3] The full version of Paradigm supports an arbitrary assortment of other shapes in addition to squares.

[4] The full version also includes a multiplayer "hot-seat" variant, which uses a slightly different scoring system.

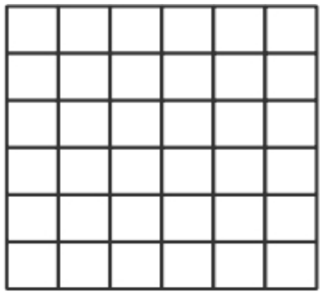


Figure 5. Blank six-by-six board at the start of the game.

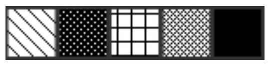


Figure 6. Names for the shading patterns used in the following Paradigm example, from left to right: *diagonal*, *dark gray*, *grid* (or *gridded*), *light gray*, and *black*.

As is typical with Paradigm, the initial guesses in this game were essentially random. Figure 7-a shows the outcome of these two guesses, the first of which (the black square on the left) was correct and the second of which (a black square to right of the first one) was incorrect. [Note: Correct guesses are indicated with shaded arrows, incorrect guesses with white arrows.] The third guess—a dark-gray square in the lower left corner—was also incorrect. However, once the correct answer (black) was revealed, the next move immediately came to mind, based on a visual analogy between the left and right halves of the board. This guess, a gridded square in the lower right-hand corner, turned out to be correct (Fig. 7-b).

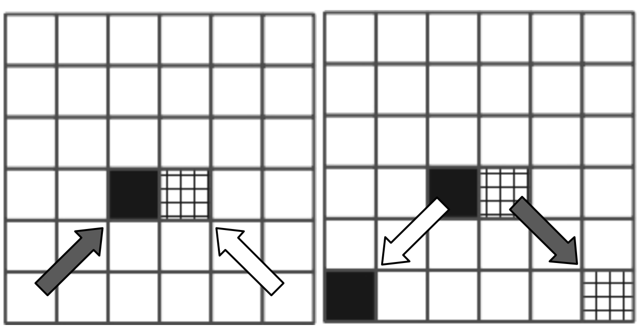


Figure 7. The board after **(a)** two and **(b)** four moves. [A shaded arrow signals a correct guess; a white arrow signals a wrong one.)

Figure 7-b reveals a clear relationship between (1) the two black squares on the left half of the board and (2) the two gridded ones on the right. However, it was still unclear what to do next at this stage in the game, given just this little bit of information. Consequently, the next set of moves involved some guesswork about the remaining squares in the center of the board. The hunch was that the top half of the board would mirror the bottom half—not necessarily in terms of the exact shades or textures, but in the relationship between the center and corner squares. Figure 8-a reveals the outcome of the aforementioned guesswork (one guess was right, and the other was wrong), which was followed by a pair of more confident (and correct) guesses involving the squares in the top two corners (upper left and upper right; see Fig. 8-b).

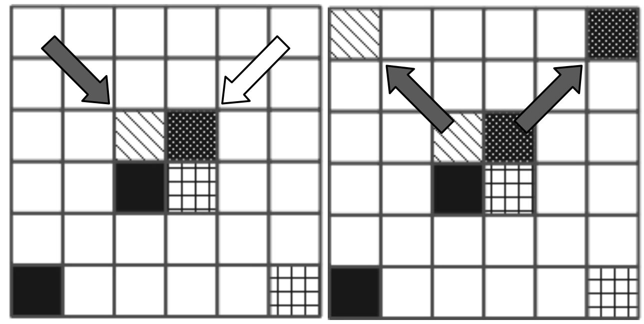


Figure 8. The guesswork shown in **(a)** led to the pair of more confident answers shown in **(b)**.

The next few moves involved more guesswork, this time in search of a pattern (or set of patterns) to flesh out the space in between the block of four squares in the center and the four lone squares in the corners. After three more guesses were made (Fig. 9-a), the concept of *diagonal symmetry* had begun to appear relevant, and there was a sense that the question-marked square in Figure 9-a should match up with the light-gray square that had just been revealed.

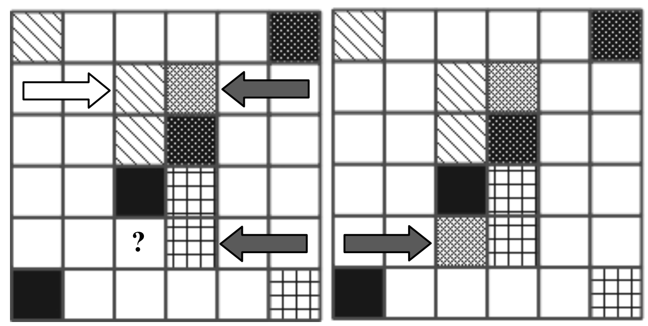


Figure 9. Three guesses (two of them correct) in **(a)** suggested the move in **(b)**, guided by diagonal symmetry.

The hunch was correct (Fig. 9-b), but while the exposed squares were nicely balanced at this point, another plateau of sorts had been reached. Thus, another tentative guess was made, this time in the bottom-right quadrant, directly above the lone gridded square in the corner (Fig. 10-a). This guess (light gray) turned out to be wrong, but once the correct answer (grid) was revealed, it quickly suggested not one, but three analogous moves—one in each of the corresponding spaces in the remaining three quadrants (Fig 10-b).

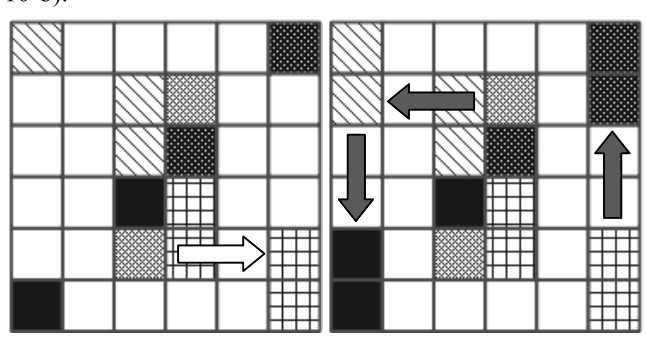


Figure 10. The incorrect guess in **(a)** paved the way for the three correct ones shown in **(b)**.

Stepping back, we can see a combination of radial and diagonal symmetry at work in the pattern-in-progress shown in Figure 10-b. The next move was based on the hunch that the nascent "columns" in each of the four corners would turn out to extend upward (or downward, as appropriate) by an additional unit. Alas, this hunch turned out to be wrong—at least in terms of the lower right-hand corner, where the initial guess was made (Fig. 11-a). Yet once again, the correct answer quickly suggested an analogous follow-up move: a corresponding light-gray square on the other side of the board. As Figure 11-b shows, this guess was correct.

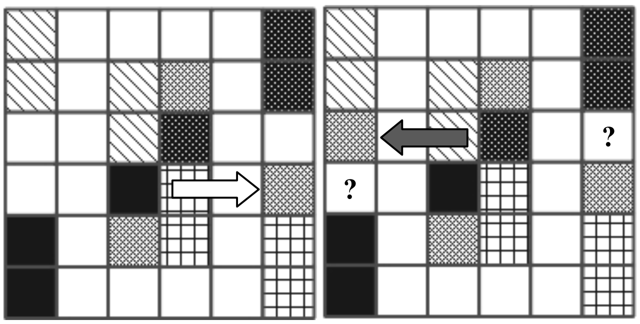


Figure 11. The incorrect guess in **(a)** led to the correct guess shown in **(b)**. But what about the question-marked squares?

The question at this point was what to do with the remaining blank squares in the outer two columns (indicated by the "?"s in Fig. 11-b). The next guess was to try light gray in the question-marked space in the leftmost column, which was wrong—the correct answer was black (Fig. 12-a). Once this answer was revealed, though, the notion of diagonal symmetry became more salient, leading to a more confident guess on the next move: dark-gray for the other question-marked square (Fig. 12-b).

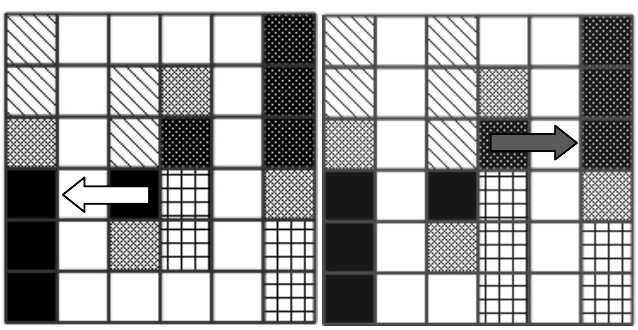
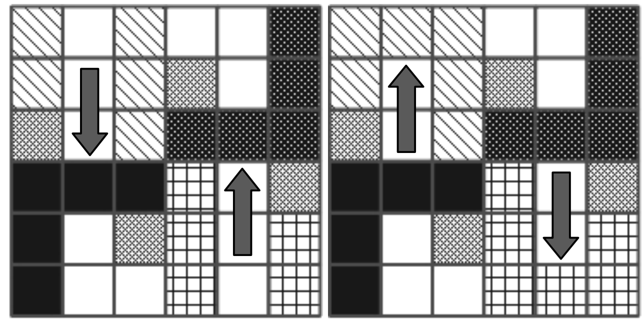


Figure 12. Once again, an incorrect guess in **(a)** suggests a correct follow-up move in **(b)**.

At this point, it had become clear that not only was there a pattern on the game board there was also a *meta-pattern* in terms of the guesses being made. A tentative guess, whether right or wrong, would be followed by a confident guess (or, on those occasions when radial rather than diagonal symmetry was the guiding concept, by *three* confident guesses). Then more guesswork would ensue, and so on. This on-again, off-again pattern manifested itself again over the next two pairs of moves (Fig. 13).



Figures 13-a (left) and 13-b (right). Two pairs of complementary moves, both guided by diagonal symmetry.

In contrast, the next space that was revealed—the light-gray square indicated in Figure 14-a—pointed the way to three additional moves: the trio of light-gray squares indicated in Figure 14-b.

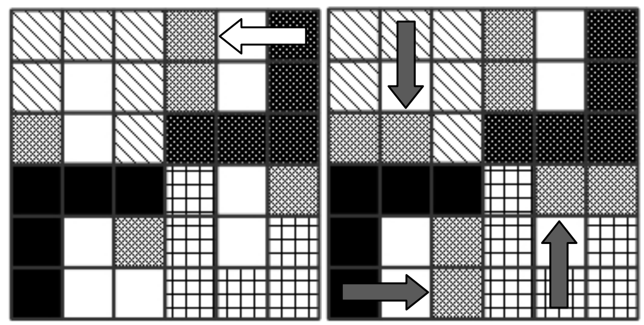


Figure 14. This time, an incorrect guess **(a)** leads to not one, but three correct moves **(b)**.

Looking back at Figure 13-a, we notice what appears to be an important shift in the pattern's appearance with the emergence of a pair of (backward) L-shaped groups: a black one in the lower left corner, and a dark gray one in the upper right corner. In Figure 13-b, things are taken one step further with the establishment of a pair of similarly backward J-shaped groups. Finally, in Figure 14-b, we note the presence of four analogous light-gray pairs, one in each of the four quadrants. The global pattern, which initially appeared to be built around a set of four corresponding quadrants, now looks to be based on a subtle blend of diagonal and radial symmetry.

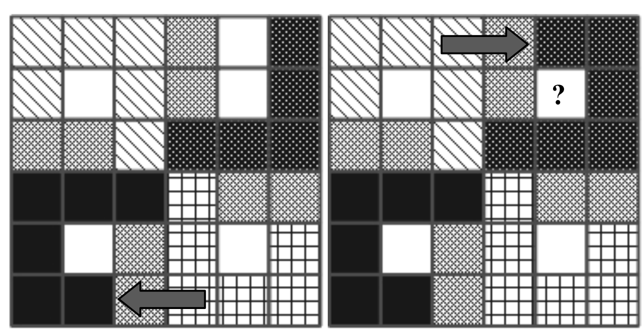


Figure 15. The guess in **(a)** strengthened the hunch that a backward J-shaped group would be found in each quadrant, while the subsequent move in **(b)** confirmed it.

The pathway to the completed pattern involved two more combinations of the kind of "tentative guess, confident follow-up" sequence we have seen many times already. The first guess (Fig. 15-a) confirmed a hunch that the J shapes already evident in the top left and bottom right quadrants would carry over to the other two quadrants (Fig. 15-b). In hindsight, the pattern as it stood in Figure 15-b should have led to a better guess than the one that was actually made (dark gray for the question-marked square in Fig. 15-b). The correct answer (grid) yielded all the information needed for the last three moves to be made. The completed pattern is shown in Figure 16-b.

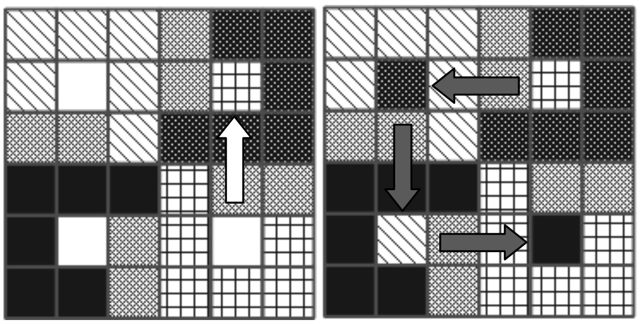
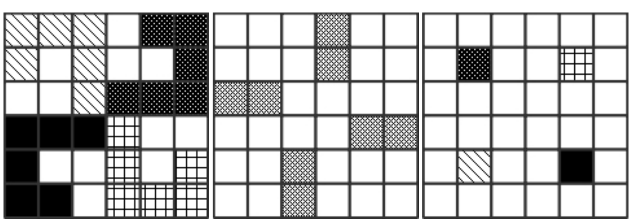


Figure 16. One last incorrect guess **(a)** was all that was needed to suggest the final three moves and complete the pattern **(b)**.

As Figure 16-b illustrates, it turned out not to be *symmetry* that was the central concept behind the pattern, but *rotation*. The full pattern can be seen as consisting of three sub-patterns (Fig. 17), all of which exhibit a sort of rotation: (a) the four (backward) J-shaped groups; (b) the four light-gray pairs; and (c) the four "singletons," whose shades/textures are related to those of the four J-shaped groups. Yet it was not until the uncovering of the gridded square indicated in Figure 16-a that this "aha moment" could occur. This "revelation" (in both senses of the word) made for a nice surprise at the end of the game and a pleasing flourish to the puzzle.



Figures 17-a (left), 17-b (center), and 17-c (right). The three "rotating" sub-patterns that make up the completed puzzle.

Reflections on Springtime (and Paradigm)

Roughly 100 Paradigm patterns have been created to this point, and each game involving a given pattern is capable of unfolding in countless different ways. (For example, there are roughly 10^{41} "paths" through a six-by-six grid such as the one used in Springtime, simply in terms of the order in which the squares can be chosen.) Even so, it is still possible to make some general observations about the domain—and its relevance to the study of creativity—on the basis of the one game detailed in the previous section.

To start with, it is worthwhile to consider some of the concepts involved in working one's way through a puzzle such as Springtime. First, there are concepts that are relevant in terms of the pattern itself. Some of the concepts are spatial—*center*, *corner*, *diagonal*, *symmetry*, *L-shaped*, *J-shaped*, *rotation*, *counterclockwise*, et cetera—while others are more relational: *counterpart*, *pair*, *group*, and even *singleton* (since a singleton can be thought of as a "group of one"). Over the course of the game, the "activation," or perceived relevance, of a given concept is likely to ebb and flow. For example, the relationship between the center and corner squares was perceived to be highly relevant in the early stages of the game, after which symmetry (radial and diagonal) began to appear more salient. It wasn't until the middle stages of the game that various sorts of groups—pairs, L-shapes, and J-shapes—emerged as relevant. And it wasn't until the final stages that rotation (particularly counterclockwise rotation) could be seen as a key idea in making sense of the overall pattern.

In addition to these "pattern-level" concepts, there are also a number of more general "strategy-level" concepts that are relevant—not only to this particular puzzle, but to more or less any puzzle in the domain. These include concepts such as *guess*, *hypothesis*, *rule*, *random-seeming*, *tentative*, and *confident*. The scoring aspect of Paradigm was basically ignored during the walkthrough of Springtime; however, the gist of it is that it rewards justified risk-taking (but not *foolish* risk-taking). Therefore, it's important for players to have a sense of how well they understand the pattern and the rule(s) behind it at each stage of the game—to know whether an upcoming move is a more-or-less random guess or a confident, well-founded one. This sense of "knowing what one knows," or *meta-cognition*, is important not only in playing Paradigm and similar risk-reward games, but in many other realms as well. The creative process, in which self-evaluation, reflection, and scrutiny are crucial, is certainly one such realm.

Finally, there are a variety of more general *aesthetic concepts* [28] that come into play in the Paradigm domain, such as *interesting*, *boring*, *tedious*, *surprising*, *elegant*, *humorous*, *frustrating*, et cetera. These concepts tend to be most relevant when reflecting on a completed pattern. Is the pattern visually appealing? Was the pathway from the early stages of the game to the conclusion interesting or boring, riveting or tedious? Players develop a feel for such aesthetic evaluations with experience, just as one does with any domain, from architecture to avant-garde jazz. Such a feel for the domain—perhaps the most sophisticated degree of so-called input creativity—is likely a prerequisite to high-quality output creativity.

FROM EXPLORATION TO CREATION

Good Paradigm patterns—patterns that are fun to play—are tricky to design, and coming up with a particularly elegant or humorous one is a rewarding exercise. Having gained experience both designing patterns and playing patterns designed by others, we note a few basic characteristics of "good" patterns. These "meta-patterns" reflect aesthetic judgments of the sort described in the previous paragraph, and they would need to be addressed by any model seeking to attain human-level performance in the domain—a difficult task, to be sure.

Balancing Local and Global Constraints

Global constraints work best when they are only expected to exert pressure toward the end of the game, when much of the pattern is already revealed. For example, in a pattern consisting of various shapes, with each one a different color (e.g., all diamonds are red, all L-shapes are blue, etc.), a helpful global constraint might be that there is an identical number of each shape in the completed pattern (i.e., five red diamonds, five blue L's, etc.). In contrast, local constraints, which involve only adjacent or nearby squares, can (and should) play a role throughout the game. Both types of constraints are needed in order for players to make sense of the gradually unfolding pattern during the course of a game. Because Paradigm is played by uncovering one square at a time, patterns that need to be mostly (or even completely) revealed in order for players to guess the rule(s) tend to be frustrating to play. If the gist of the pattern isn't obvious when it has been completely revealed, it will be that much harder for players to figure it out as they try to uncover it in the course of a game.

Balancing Complexity and Order

One-trick patterns such as simple tilings or trivial divisions (e.g., red on the top half of the board and blue on the bottom) are only interesting until the rule is discovered. After that point, the mechanical process of unveiling the rest of the pattern becomes tedious. On the other hand, if a pattern is too complex, players tend to become frustrated. That is, players lose interest in trying to make good guesses when every choice seems equally likely. Even if a pattern has some mathematical or logical structure that can (at least in principle) be discerned, most players will not discover it. This observation is in accordance with psychological theories of what makes games fun [13] (and what's the point of a game if it's no fun to play?).

Balancing the Visual and the Conceptual

People perceive lines, simple shapes, and groups effortlessly. Good Paradigm patterns foster a gradual progression from no understanding to complete understanding. In most cases, visual forms (e.g., squares, diagonals, spirals, etc.) are easier to progressively explore than logical or arithmetical rules are. It might be clever to devise rules that involve, say, mapping colors to numbers, or rules in which each square's color depends on the number of neighbors of a given color. However, such rules seldom yield patterns that are fun to play. These types of rules are also difficult to layer on top of one another.

Balancing Ambiguity and Clarity

As alluded to above, the best Paradigm patterns are those that encourage oscillation between periods of uncertainty and periods of discovery—ones in which previously ambiguous shapes, groups, or other aspects of the pattern suddenly "click." In exploring such patterns (of which Springtime is a good example), the player is never quite certain what the final picture will be, but never feels hopelessly lost either. In addition, good patterns often require players to revisit areas of the board that were previously "understood" and reinterpret them as new information comes to light.

FUTURE DIRECTIONS

The discussion of Paradigm in this paper is motivated by the belief that it represents an interesting and potentially productive domain for studying cognition, creativity, and related phenomena. Like Copycat and Micro-Eleusis, it offers a restricted, yet non-trivial "microworld" in which to explore and model domain-general cognitive *mechanisms*, while filtering out the overwhelming complexities involved in accounting for domain-general *knowledge*. Like the Bongard domain, Paradigm also lends itself to study of the relationship between high-level perception—the "level of processing where *concepts* begin to play an important role" [5, p. 2]—and lower-level (in this case, visuospatial) perception.

Currently, research on Paradigm is proceeding along three different (but interrelated) tracks. First, we have been investigating the domain itself, identifying and systematizing the various "knobs," or dimensions, along which patterns can vary. Among these dimensions are the emphasis (or lack thereof) on (a) lines, paths, or geometric shapes as basic units; (b) symmetry (bilateral, radial, diagonal, etc.) as an organizing principle; (c) foreground–background distinctions; (d) progressively shrinking or expanding shapes or sub-patterns; (e) iconic shapes or patterns (e.g., the sides of a die); (f) arithmetical rules as global constraints; and so on. As previously noted, not all of these "knobs" are equally useful in terms of designing interesting patterns. For example, patterns involving iconic shapes tend to be superficial, while ones involving arithmetical rules can be overly abstract and difficult. This investigative stage largely informal and qualitative: It involves a combination of designing new patterns; observing others while they play the game; and documenting our own thought processes while playing patterns for the first time (as with the Springtime example described in this paper).

The second track involves more systematic empirical studies. A drawback of some the models discussed earlier in this paper (e.g., Copycat/Metacat and Phaeaco) is that it can be difficult to evaluate their performance, since comparison with human subjects is not always straightforward. Given a Bongard problem, for example, a subject's only observable "behavior" is his or her guess at the actual solution to the problem (i.e., the hidden rule). In contrast, Paradigm (like Eleusis) provides a built-in means by which to track players' decision-making, since it takes place incrementally—one move at a time—rather than all at once. In this sense, it allows for a finer grain of comparison between human-subject data and computer models.[5]

The third—and most challenging—track is the development of a model (or models) of pattern exploration in Paradigm. This is a long-term process, one that will necessarily build on the results of the first two tracks mentioned in the previous paragraphs, along with the ideas developed and tested in earlier models (e.g., Copycat, GENESIS, Phaeaco). Current work is focused on evaluating the strengths of these and other predecessors.

CONCLUSION

It's been said that "cognitive science cannot succeed if it cannot model creativity, and it is here that it is most likely to fail" [6, p. 14]. It could also be said that, historically speaking, the study of creativity—in philosophy, psychology, cognitive science, artificial intelligence (AI), and elsewhere—has itself been a succession of failures, although in the best cases, these have been *instructive* failures, either pointing the way to new approaches or disconfirming old ones. Faced with an enormous topic such as creativity, we accept that the gains made via any particular research project are likely to be modest in the big scheme of things. With this in mind, microdomains such as Paradigm can be useful arenas in which to develop models of creativity.

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This is just a placeholder for the acknowledgements, which would be added later.

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[5] An informal study has been carried out using a simplified version of Paradigm, wherein subjects were asked to guess the colors of a predetermined sequence of squares (whereas players in the standard version of the game are free to move through the pattern in any sequence).