The Eureka Effect

The Art and Logic of Breakthrough Thinking

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"Perkins' style is engaging–not for eggheads only–and the brainteasers are entertaining and surprisingly fresh."
–CHICAGO TRIBUNE

tions, and criteria for progress and success are not usually as neatly or overtly defined as in chess. But after all, chess and many other games are deliberately constructed in lean, logical ways to remove the fuzziness characteristic of real problem-solving situations. Whether the world at hand is the world of chess, cats, apple pickers, poems, paintings, scientific theories, bridge architecture, or recipes for bouillabaisse, the language of spaces of possible states, operations, and gauges of progress and success provides a conceptual system for examining the process of thought and contrasting the demands of different kinds of problems.

When Smart Is Reasonable

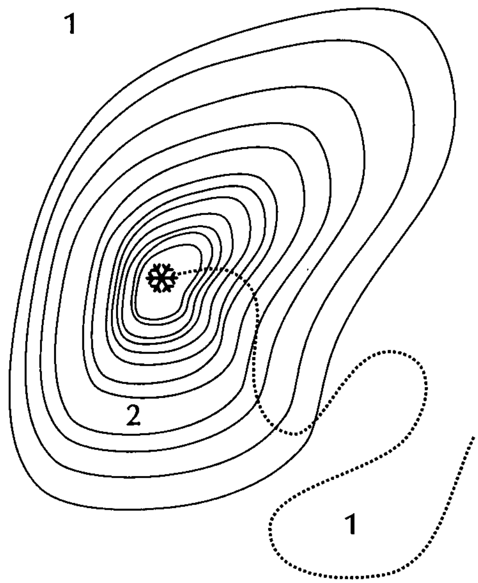
With all this as background, we turn to the contrast between reasonable and unreasonable problems. Both are a matter of search. In the one case, reasoning offers a smart way of searching, but in the other it does not.

The simplest search strategy is to examine all the possibilities. In some situations this is the right thing to do. Most people at some point master the familiar game of tic-tac-toe, either learning the ropes from someone older or figuring it out. I remember getting annoyed when my father kept beating me, so I sat down with paper and pencil and figured it out. When one takes into account the symmetries, there are really only three places to start—corner, side, or middle. For the next play, there are only a few other genuinely different possibilities. From then on, I could hold my own.

Examining all the possibilities is not always a trivial strategy. It requires attentive and systematic action to be sure not to miss possibilities. Nonetheless, for most problems examining all the possibilities is not smart strategy because there are too many to investigate. The DONALD + GERALD = ROBERT cryptarithmetic puzzle has ten different letters, standing for the ten digits 0 through 9. It's stated that D = 5, so there are nine remaining letters to assign to the nine remaining digits. Mathematically, this might be done in 362,880 different ways. A problem solver certainly would not want to consider all those possibilities. In general, in problems that are at all challenging, there are too many states and too few solution states to find solutions by searching thoroughly. What is needed is another style of smart search. Cognitive scientists speak of heuristic search, the term *heuristic* referring to strategies that increase the chances of success without guaranteeing success.

A basic strategy of smart search is to follow the measure of promise, tracking its increases through the fitness landscape to a solution. In the case of a cryptarithmetic problem, this means proceeding incrementally, starting with one letter-digit assignment consistent with the information given, then adding another, then adding another until all are in place. The key to this strategy is to use the logic of the situation. A smart search would try to find a digit-letter assignment forced by the given information—that is, one that could not be any other way—and then another and another, drawing out any immediate implications and exploring alternative branches only when necessary. When there are many possibilities, smart search examines far less than the entire space.

The strategy of following promise applies not only to formal problems but to fuzzy ones too. Consider the woman searching through different possibilities for an apple picker and how one step led to the next. The search was progressive: first a hook, but the apples would bruise on the ground; then a bag, but it would get unbalanced; then a counterweight, but that would be heavy too; then a cloth tunnel. In a loose sense, this progression is like solving a cryptarithmetic problem. The first idea contributed part of the solution, leading on to other adjustments and extensions that provided a more complete solution.



Search in a Homing Space: 1. Clueless regions.
2. Large clued regions leading to the target.

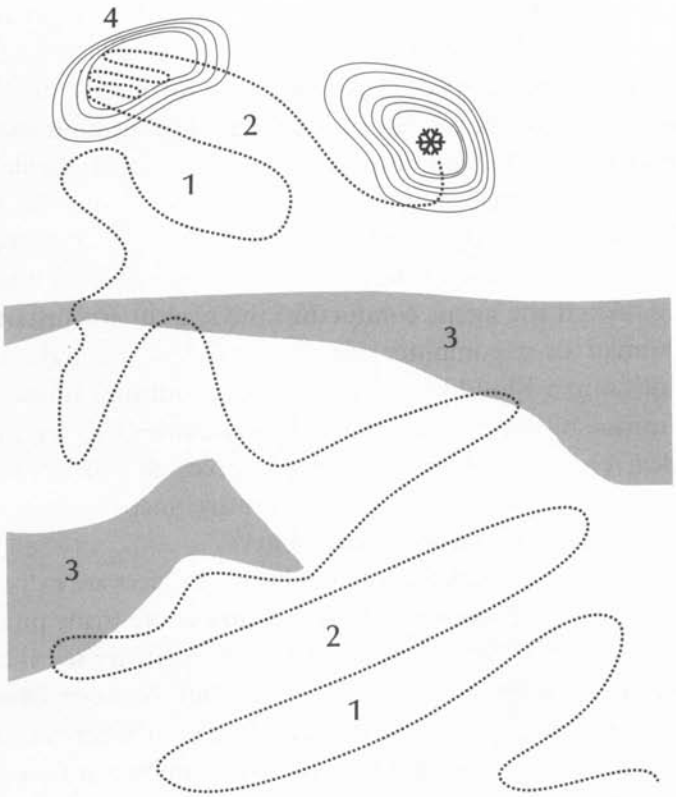
The accompanying figure illustrates in a general way the fitness landscape of a reasonable possibility space—one that lends itself to following promise. As the picture shows, such a possibility space has a relatively simple structure. The contour lines show regions where there is a discernible slope to the measure of promise. In those regions, the problem solver can follow the slope of increasing promise to the solution, homing in on it systematically. Such possibility spaces might be called homing spaces because of this convenient structure.

Is homing easy? Not necessarily. Although following promise is a reasonable approach, it can be a very challenging one. Following promise requires systematic attention and meticulous logic. Following promise means making the most of the given information. Solving a difficult problem of this sort is like climbing a cliff: The climber needs to capitalize on each little niche for a handhold or toehold.

When Smart Is Unreasonable

Challenging though the world of homing spaces can be, it is not the world of Leonardo da Vinci's or the Wright brothers' insights about flight, nor the world of Gutenberg's invention of the printing press, nor Darwin's discovery of natural selection, nor the Sufi tales and their hidden meanings, nor The Nine Dots problem. These problems and puzzles have unreasonable possibility spaces—Klondike spaces. A visualization of a Klondike space appears in the next figure.

Think of the space as huge with, in this case, only one solution in the top right. The size and rarity of solutions reflects a wilderness of possibilities. There are large regions without contours, where the measure of promise points in no particular direction—a clueless plateau. The lower part is boxed off, keeping the search away from the upper regions until it finally breaks through at a thin spot—the lower part is a narrow canyon of exploration. And there is a tempting contoured region that contains no solution—an oasis of false promise where a problem solver might



Search in a Klondike Space: 1. A large space wtih few solutions (a wilderness trap). 2. Regions with no clues pointing direction (plateau traps). 3. A barrier isolates the solution (creating a canyon trap). 4. An area of high promise but no solution (an oasis trap).

linger in hopes of finally finding a solution. Smart search in such a possibility space is a matter of thinking in ways that cope with the wilderness, plateau, canyon, and oasis traps. It's a matter of setting sequential reasoning aside and being unreasonable in a smart way, along the lines of the four operations introduced earlier: roving around flexibly, detecting hidden clues, reframing the situation, and decentering from false promise.

Since Klondike spaces have their own distinctive difficulties, one might hope that the challenges of homing spaces could be left behind. But not so. Notice that Klondike spaces have small homing spaces inside them. In the Klondike figure, the small contoured region in the upper right that contains a solution is a homing space in miniature. When the agent conducting the search (for instance, a human or a computer) finally gets close enough to a solution in a Klondike space to detect promising signs, the solution still has to be extracted. Sometimes this happens reflexively, as the human mind assembles all the information spontaneously in a quick cognitive snap. Sometimes the process of extraction takes longer.

Of course, Klondike spaces and homing spaces are extreme types. Most real problems are mixed, and so are many puzzle problems. Smart search means having a sensitivity to what a problem requires and a readiness to shift between breakthrough thinking and sequential reasoning as the terrain suggests. Klondike spaces and homing spaces are worth thinking about not because they sort the world of problems into two extremes but because they anchor the two ends of a continuum, revealing the continuum more clearly.

The Structure of Breakthrough Thinking

Although wilderness, plateau, canyon, and oasis are metaphors, they have rigorous interpretations as formal features of possibility spaces. They can be described in terms of the state space of possibilities, the available operators, and the indicators of promise and success.

Wilderness of possibilities. In the language of possibility spaces, a wilderness has a large number of possible states, only a few of which are solution states. An effective search process somehow has to cope with the sheer magnitude of the state space and the rarity of solutions.

Clueless plateau. In a possibility space, a plateau is a large region of neighboring possible states where the measure of promise does not vary much, or perhaps varies erratically from state to state around an average for the whole plateau, so there is no trend. On such a plateau, a search process cannot progress from possibility to possibility with a steady improvement in the measure of promise.

Narrow canyon of exploration. In a possibility space, a canyon trap is a solutionless region of many neighboring possible states with a boundary around it that tends to trap the search process. Such a boundary can arise from the available operations. Perhaps only a very few operations from a very few states in the region take the search process outside the region. Metaphorically, there are very few paths out of the canyon. Alternatively, the boundary can arise from the measure of promise. The measure may drop to very low values all the way around the region. Although the search process can penetrate those areas in principle, it tends not to because of the low promise. Also, these two kinds of boundaries can work in combination to create a canyon.

Oasis of false promise. In a possibility space, an oasis is a state where the measure of promise has a relatively high peak that is not quite a solution state. The search process tends to circulate near the deceptive peak in hopes of finding a full solution nearby, rather than venturing off to possibilities of lower promise.

The five-phase pattern of breakthrough thinking introduced in Chapter 1 also finds an explanation in the language of possibility spaces.

1. *Long search.* Why are insights preceded by long searches? Because the space is large with few solutions (wilderness), the measure of promise does not point a clear and systematic direction (plateau), the measure of promise and available operations tend to constrain the search to limited regions (canyon), and the measure of promise yields high points with no real solution that cause the search to linger fruitlessly in their neighborhood (oasis).

2. *Little apparent progress.* Why is the apparent progress minimal for most of the search? The same reasons apply. In particular, only close to a solution does the measure of promise offer a clear guide to homing in on it.

3. *Precipitating event.* What causes precipitating events? A precipitating event can take different forms. It may simply be the arrival of the search process at a small homing subspace within the larger space. The search process then relatively quickly converges on a solution. Alternatively, the precipitating event can be some cue, internal or external, that leads the search process to escape from an oasis or canyon into another region that, relatively quickly searched, leads to a homing region and a solution.

4. *Cognitive snap.* What is the cognitive snap? The rapid homing process that occurs when the search process

finally arrives at a solution-containing homing space within the larger Klondike possibility space. The homing space allows quick convergence to a solution.

5. *Transformation.* Why the sense of transformation? Solutions tend to surprise because they often involve escape from an oasis of false promise or from a narrow canyon of exploration to a solution of a very different kind than expected.

An unusual and important feature of these explanations is that they do not specifically concern the human mind. They have little to do with a creative knack or a peculiarly flexible cerebral cortex. A Klondike possibility space is a breakthrough waiting to happen!

The search process that achieves the breakthrough may unfold in the human mind, as an artist, scientist, inventor, or businessperson explores alternative perspectives. It may occur in a computer, as automated processes of heuristic search examine a large set of possibilities. It may happen in the course of the long blind search of biological evolution, as the random shuffling of genes tries this and that new prototype for survival and reproduction. (This theme is revisited in the last chapters of the book.) Whatever the setting, most fundamentally the phenomena of breakthrough thinking derive from the underlying structure of a Klondike space.

Jack London's Klondike

One of the many outdoor tales of Jack London is a short story called "All Gold Canyon." In a few pages, London relates the struggles of a prospector to find gold. The prospector comes with the basics: a pick, a shovel, a gold pan, and most of all a hungry spirit. He chooses to start his dig in this particular canyon because there is "wood an' water an' grass an' a side-hill! A pocket hunter's delight . . . a secret pasture for prospectors and a resting place for tired burros, by damn!"

London's prospector begins with a shovelful of dirt from the edge of the stream below the side hill. He pours it into his gold pan. He partially immerses the pan in the stream and with a circular motion sluices out most of the dirt until only fine dirt and the smallest bits of gravel remain. Now comes the slow and deliberate work, the prospector washing more and more delicately until the pan seems empty of all but water. But with a quick semicircular motion that sends water flying over the rim into the stream, he reveals a thin layer of black sand on the bottom of the pan. A close look discloses a tiny gold speck. He drains more water over the black grains. A second speck of gold appears.

He pursues the painstaking process, working a small portion of the black sand at a time up the shallow rim of the pan. His efforts yield a count of seven gold specks. Not enough to keep, but enough to charge up his hopes. He continues down the stream repeating the same tedious procedure—a pan of gravel, the careful washing, the meticulous teasing out of tiny specks of gold. As he works his way downstream, his "golden herds" diminish. A pan yields one speck, another none. So he returns to where he began and starts panning upstream. His tally of gold specks mounts to thirty, then pan by pan dwindles to nothing. He has homed in on the richest point in the stream, but still nothing worth keeping. The real treasure lies above, somewhere on the face of the side hill.

A few feet up from his first line of test pans he begins digging a second row of holes, crosscutting the hillside. Fill the pan, carry it to the stream, pan out the gravel, count the flecks—each tedious cycle gathers more information. He works his way up the side hill in rows of holes. The center of each row yields the richest pans, and each row ends where no gold specks appear. The rows grow shorter as he mounts the hill, forming an inverted V. The converging sides of the V mark the boundaries of the gold-bearing dirt.

The apex of the inverted V is the prospector's goal, where "Mr. Pocket" resides. As the prospector mounts the hill, the pans get rich enough for their yield to be worth saving. But the work grows harder. As the sides of the V converge, the gold retreats underground. The gold at the edge of the stream was right at the roots of the grasses. Then it lies 30 inches down, then 35. Then 4 feet, then 5.

Finally the sides of the V come together at one point. He digs his way 6 feet down into the earth. His pick grates on rotten quartz. He digs the pick in deeper, fracturing the rock with every stroke. He holds a fragment of the rotten quartz in hand and rubs away the dirt. Half the rock is virgin gold. More scrabbling about yields nuggets of pure gold. Eventually the prospector draws 400 pounds of gold from the find.

Can London's tale of the real Klondike have meaning in the esoteric conceptual world of possibility spaces and smart search? Indeed it can. London's prospector carries out a smart homing search for gold, progressing systematically up from the creek bed toward the source. Each hole he digs probes a possibility, yielding some gold and helping him to focus his search better. In Klondike terms, London's prospector searches a homing space within the larger Klondike wilderness.

SCIENCE

Breakthrough thinking comes as a sudden, seemingly un countable moment of inspiration: From Archimedes' disc ery in the bathtub of the principle of water displacement Einstein's Theory of Relativity, from Brunelleschi's develo ment of perspective drawing to the Impressionist revoluti from the taming of fire to the creation of the laser, it shaped and advanced civilization.

David Perkins explores the common logic behind breakthroughs in ma fields, historical periods, and evolutionary epochs. Drawing on a rich know edge of both artificial intelligence and cognitive psychology, he sets fort uniquely integrative theory of how insights occur. Along the way he off dozens of often playful puzzles and illustrations that reveal the four k processes behind breakthrough thinking.

"[An] absorbing introduction to cognitive theory."
—PUBLISHERS WEEKLY

David Perkins is a founding member of the think tank "Proje Zero" at the Harvard Graduate School of Education and has published boo on mind, intelligence, creativity, and learning.

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