COGNITIVE NEUROSCIENCE

Without a Thought

Intuition is rooted in the brain's uncanny ability to rapidly know the answer without knowing why

In the instant before he drove Kuang's sting through the base of the first tower, he attained a level of proficiency exceeding anything he'd known or imagined. Beyond ego, beyond personality, beyond awareness, he moved, Kuang moving with him, evading his attackers with an ancient dance, Hideo's dance, grace of the mind-body interface granted him, in that second, by the clarity and singleness of his wish to die.

—William Gibson, *Neuromancer*, 1984

Sometimes a solution just appears out of nowhere. You bring your multipage spreadsheet to the finance department, and within seconds the accountant tells you something isn't quite right without being able to say what. You're perched on a narrow ledge halfway up Half Dome in Yosemite Valley, 1,000 feet above deck, searching for the continuation of the climb on the granite wall that appears featureless, when your senior climbing partner quickly points to a tiny series of flakes: "Trust me, this is it."

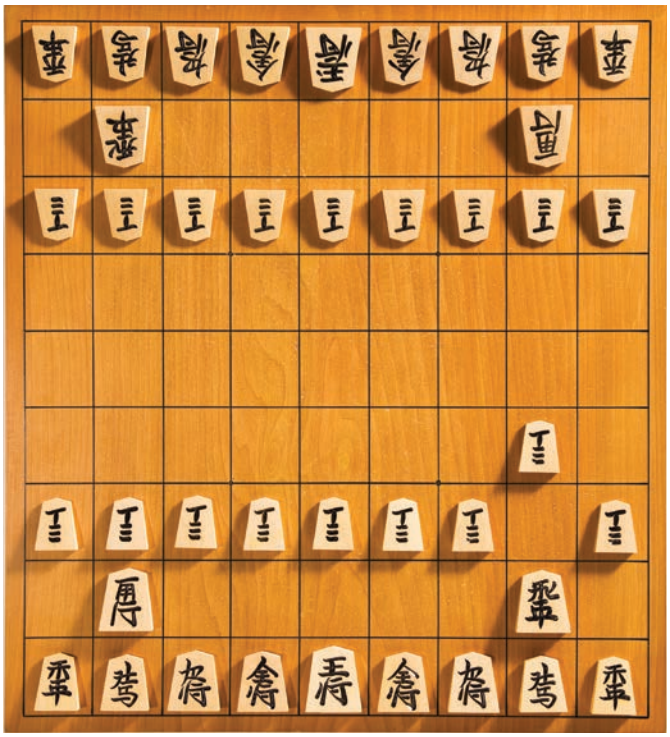
Understanding computer code, deciphering a differential equation, diagnosing a tumor from the shadowy patterns on an x-ray image, telling a fake from an authentic painting, knowing when to hold and when to fold in poker. Experts decide in a flash, without thought. Intuition is the name we give to the uncanny ability to quickly and effortlessly know the answer, unconsciously, either without or well before knowing why. The conscious explanation comes later, if at all, and involves a much more deliberate conscious process.

Intuition arises within a circumscribed cognitive domain. It may take years of training to develop, and it does not easily transfer from one domain of expertise to another. Chess mastery is useless when playing bridge. Professionals, who may spend a lifetime honing their skills, are much in demand for their proficiency.

Let us consider a series of elegant experiments in functional brain imaging that finger one brain structure as being centrally involved in intuition. Shogi is a Japanese strategy game played on a nine-by-nine board, with two sets of 20 distinct pieces facing each other. It is much more complex than chess, given that captured pieces can be dropped into an empty position anywhere on the board at the discretion of the capturer. This rule multiplies the number of possible moves available at any point in the game and prevents the steady attrition of the two opposing armies that face off in a chess match.

Keiji Tanaka of the RIKEN Brain Science Institute outside Tokyo led a group of cognitive neuroscientists who studied the brains of shogi players, using functional MRI to search for the neural signatures of proficiency. First, subjects inside the scanner looked at drawings of shogi boards taken either from tournament games or from randomly shuffled board positions. They also looked at sketches that had nothing to do with shogi: games of chess and Chinese chess, as well as pictures of faces and houses.

In professional players, pictures of board positions taken from real shogi games activated a piece of cortex, the precuneus in the parietal lobe (located at the top of the brain toward the back), much more strongly than any of the other cate-



A traditional Japanese shogi board with its pieces. It is a strategy game related to chess but is considerably more intricate.

CORBIS

BY CHRISTOF KOCH

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gories of pictures. That is, a region of their parietal cortex read out certain perceptual features associated with shogi games and distinguished them from random board positions. Experts see configurations of pieces, lines of control, a weakened defense or an imminent attack—patterns that amateurs do not notice.

In a second experiment, Tanaka and his group presented players with checkmatelike shogi puzzles while they lay in the scanner. Subjects had to find the next move that would lead, inexorably, to the capture of the king. They had to do this within one second, pushing them to rely on their intuition because there was no time to analyze the various moves, countermoves, countercountermoves, and so on. When they controlled for confounding cognitive factors, the scientists found nothing activated in the cortex. They did, however, isolate a small region in the front of the caudate nucleus, under the cortex, that reliably and very distinctly turned on in professional shogi players. The caudate was less reliably and less prominently activated when amateur players tried to find the correct move. And when subjects had up to eight seconds to more deliberately search for the best solution, this subcortical region remained silent.

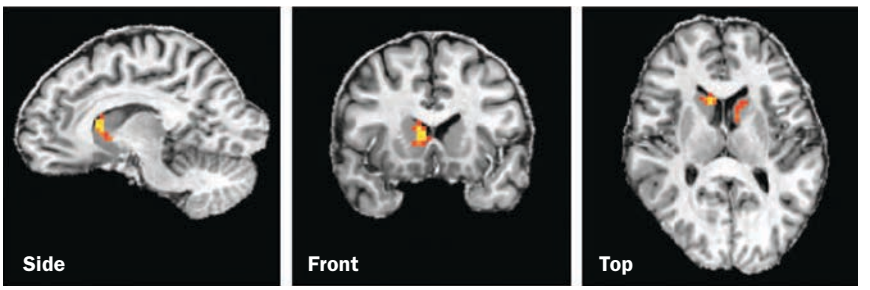
Special-Purpose Hardware

This elegant finding links intuition with the caudate nucleus, which is part of the basal ganglia—a set of interlinked brain areas responsible for learning, executing habits and automatic behaviors. The basal ganglia receive massive input from the cortex, the outer, rindlike surface of the brain. Ultimately these structures project back to the cortex, creating a series of cortical–basal ganglia loops. In one interpretation, the cortex is associated with conscious perception and the deliberate and conscious analysis of any given situation, novel or familiar, whereas the caudate nucleus is the site where highly specialized expertise resides that allows you to come up with an appropriate answer without conscious thought. In computer engineering parlance, a constantly used class of computations (namely those associated with playing a strategy game) is downloaded into special-purpose hardware, the caudate, to lighten the burden of the main processor, the cortex.

So far these experiments relate the task of generating shogi moves to brain activity. Of course, we are not allowed to infer causation from correlation. Just because two things are associated does not imply that one causes the other. As research progresses, the causal structure of intuition and brain activity could be probed by inhibiting or blocking the caudate nucleus to see whether doing so prevents the rapid generation of correct shogi moves. Regrettably there are no reliable technologies to turn bits of brain deep inside the skull on and off in a way conducive to the long-term health of the subject.

Instead Tanaka and his collaborators wondered whether novices who learn to play shogi wire up their caudate nucleus in a similar manner to that of experts. They recruited naive volunteers and subjected them to an intensive 15-week regime of daily play on a simplified computer version of the game. Motivated by prize money, the subjects improved over the approximately 100 days of training, during which they accumulated total practice time ranging from 37 to 107 hours.

Asking subjects in these experiments to quickly come up with the best next move led to increased cortical activity, but that activity did not change over the training period, nor did it correlate with the fraction of correct responses. In contrast, changes in blood flow in the front of the caudate nucleus evolved over the course of training in parallel with better performance. Furthermore, the strength of the caudate signal at the end of the training correlated with how much subjects improved over time. The more the subject learned, the larger the caudate signal.



Brain activity in 17 professional shogi players who had to decide on the next best move without lengthy deliberation was averaged into a single brain image. The most active area, the caudate nucleus, is shown in color from different angles.

It appears that the site of fast, automatic, unconscious cognitive operations—from where a solution materializes all of a sudden—lies in the basal ganglia, linked to but apart from the cortex. These studies provide a telling hint of what happens when the brain brings the output of unconscious processing into awareness. What remains unclear is why furious activity in the caudate should remain unconscious while exertions in some part of the cortex give rise to conscious sensation. Finding an answer may illuminate the central challenge—why excitable matter produces feelings at all. **M**

FURTHER READING

- **The Neural Basis of Intuitive Best Next-Move Generation in Board Game Experts.** Xiaohong Wan et al. in *Science,* Vol. 331, pages 341–346; January 21, 2011.
- **Developing Intuition: Neural Correlates of Cognitive-Skill Learning in Caudate Nucleus.** Xiaohong Wan et al. in *Journal of Neuroscience,* Vol. 32, pages 17,492–17,501; November 28, 2012.

FROM: "THE NEURAL BASIS OF INTUITIVE BEST NEXT-MOVE GENERATION IN BOARD GAME EXPERTS," BY XIAOHONG WAN ET AL., IN *SCIENCE*, VOL. 331; JANUARY 21, 2011