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System 0: the overlooked explanation of expert intuition

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What expert intuition is and isn't

This chapter concerns expert intuition, the coping skill that develops in a domain after an individual with innate talent has considerable learning experience accompanied by an awareness of the quality of each performance. Commonly, but not exclusively, such skill involves a sequence of behaviors. Examples of the sort of skillful coping that I have in mind include driving a car on an empty road, reading and understanding the nuances of social situations, a chess master making moves during a game of fast chess, and the actions of an experienced firefighting-team commander. These particular examples are designated as *expert intuition* and are listed among examples of fast thinking in the recent best-selling book *Thinking*, *Fast and Slow* by Nobel Laureate Daniel Kahneman (2011, p. 11, 21,22). Three of these examples are of conventionally recognized skills, but the one involving social behavior is also typical of what I have in mind.

Acting or reacting in familiar sorts of situations such as in the examples above, I shall argue, should not be regarded as *decision-making*, *thinking*, or *mental activity* in the conventional usage of these terms. In fact, most of our adult life is spent exhibiting learned intuitive forms of expertise that are so effortless that they are taken for granted. They are cases of individuals knowing automatically, quickly, and effortlessly, how to proceed in situations without being able to explain their performance. For an example of a firefighter taking for granted what Kahneman and most cognitive psychologists would call decision-making see Klein (2011, p 88, 89).

Intuitive experts generally will be able to recall various helpful rules and principles that they learned as beginners that might help a novice but not an expert, and some also may, if interrogated, invent various rules and principles that they believe that they now use, but I shall argue that these will not be the correct explanation of their behavior.

I am *not* concerned here with individuals behaving in situations of a type that have *not* often been encountered previously or that have been encountered but without feedback on quality of performance. These situations involve some conscious *thinking*, and while *deciding* may be fast compared to employing effortful reasoning and deliberation, the subjects' responses are generally not as rapid and effortless as are the behaviors exhibited by experienced intuitive experts in situations such as those cited in paragraph one above.

TWO INTUITIVE SYSTEMS

System 1 explanation of expert intuition

The traditional literature on expert intuition explained the phenomena exemplified by the above four examples as the product of *associative memory*. Behavior is guided, it asserts, by the memory of some previously experienced similar situation, or perhaps a template or prototypical previously experienced situation, or the synthesis of a group of similar experiences, associated with what action was successful. Expertise involves *pattern recognition*. Chase and Simon (1973) first proposed this idea and were followed by, among others, Klein et al. (1986) with recognition-primed decision-making, Ericsson & Staszewski (1989) with skilled memory theory, Epstein (1989) who has offered a similar, but more nuanced, explanation involving schemata that are organized generalizations derived from emotionally significant past experiences and Sloman (1996) whose representations are presumably stored in factual memory. Most recently, Kahneman reverentially acknowledged his approval of Simon's often reiterated pattern recognition view on page 11 and its endnotes of his 2011 book. There are no doubt other causal explanations in the intuition literature but as far as I know they all involve what is termed an associative process involving trains of thoughts that are all memories of, or abstractions from, past experience. These are stored in what is called *declarative* memory; the memory, perhaps processed and organized, of factual information and of life events, and associated with the brain's hippocampal and diencephalic systems.[1] Stanovich & West (2000) famously designated the brain's relatively fast, effortless and inexplicable intuitive associative way of using declarative memories simply System 1 to distinguish this process from what they called System 2, the slow and effortful reasoning out of appropriate behavior.

I shall present evidence below that the associative System 1 is not the correct explanation of expert intuition by offering an alternative that is well-supported by neuroscientific evidence. I then identify some implications of this substitution.

System 0: The procedural brain

Neuroscientists over 30 years ago identified an entirely different brain system than the associative System 1 and showed as convincingly as is possible given current brain research technology that it explains experientially-learned *knowing how* to successfully respond to familiar situations, i.e. intuitive expertise. What neuroscientists have identified is called *procedural* memory, a type of nondeclarative memory. The name is chosen because this brain system is responsible for *knowing how to proceed* in a situation, and should not be confused with the information-processing use of "procedure" to denote strict rules and "if-then" stipulations. Rather than remember *separately* processed experiences in order to produce skillful coping behavior, procedural memory depends upon *synaptic changes* in areas of the brain different from those producing declarative memory; changes cumulatively brought about by the *totality* of previous relevant experiences. (This is not to deny that an occasional experience can both be stored in declarative memory and impact the synapses of procedural memory.)

It is surprising that as late as 1996, when the procedural memory alternative to the declarative-memory-based associative System 1 had been identified by neuroscientists over 15 years previously, Gobet & Simon (1996) could begin a paper about chess as follows: "For the past 20 years, there has been a general consensus, based on extensive laboratory research, that two psychological mechanisms play a principal role in skilled chess playing performance. The first mechanism is recognition of cues in chess positions that evoke information from the expert's memory about possible moves and other implications of recognized patterns of pieces." It should be noted that the "extensive laboratory research" is unreferenced but presumably refers to the research reported in Chase & Simon (1973) and similar work that it evoked. However that work did not concern chess *play* but rather the *reconstruction* of chess positions viewed by master players for only a few seconds. Chase and Simon merely *speculate* on pages 268 and 269 of the 65-page paper in a section called "Finding Good Moves" that their reconstruction work *might* also explain chess play. The chunk-based explanation in their paper is likely correct for position reconstruction, but that is *not* an experientially-learned skill developed after years of study and practice as is master-level chess play.

In the spirit of the Stanovich and West terminology, I shall designate by the name *System 0* what I shall argue is the most fundamental of all behavioral brain systems—the procedural memory system. I am, therefore, advocating a tripartite theory of coping rather than the dual-system position held by most cognitive psychologists.

Neural Networks

Understanding the procedural memory system elaborated below requires a minimal grasp of the nature of the neural networks that comprise a brain. Viewed as an input-output device, a neural network, given a neuronally-represented input that might be facts or features of a skill domain or might be just raw stimuli provided by various sense organs, combines the firing rate of electrical pulses constituting the input in a way determined by synaptic connections to form the input to other neurons so as to affect their electrical-output firing rate. After this process is repeated between many neurons many times, certain neurons called output neurons exhibit a firing rate that constitute the net's output that might be interpreted as an idea or as a physical motion. Hence, a neural network, or an assembly of such networks, can produce a holistic *mapping* of any domain-relevant input into a domain-relevant output. While it might be said that this system *associates* outputs with inputs, it is not the kind of *association* between processed declarative memories, with one perhaps leading to another and finally to a decision, envisaged by System 1. To avoid confusion, I shall therefore use the term *mapping* of input into output for what a neural network provides.

System 0's discovery

I turn now to a brief history of the identification of the brain's procedural memory system, System 0. A more complete history can be found in Squire (2004) and a response to doubters of the existence of procedural memory in Poldrake & Foerde (2008). I shall then discuss how this system apparently functions.

Early evidence of the dissociation of procedural *(knowing how*) and declarative (*knowing that*) memory was the observation that amnesics with no working declarative memory still possessed skillful coping abilities and, in fact, could learn new coping skills, even though they could not remember the training exercises that produced them. One such skill studied was rapid reading of text whose letters faced backward such as those reflected in a mirror. See Cohen & Squire (1980). In Mishkin et al. (1984) it was noted that patients with Parkinson's disease in which the procedural system plays a key role lost their coping abilities even though their declarative memory remained intact.

Neuroscience then established that procedural coping ability is produced by a system of brain areas centered on the subcortical basal ganglia, including cortico-striatal loops that are subject to influences from neuromodulators such as dopamine, with, in addition, connections with limbic areas such as the amygdala. The limbic system provides *reward* signals needed, as I shall explain later, for the experiential reinforcement learning of skill. The prefrontal cortical part of this system seems to be involved in providing appropriate saliencing, sometimes called top-down modulation, of the incoming sensory stimuli or factual knowledge before passing it on to the striatal areas. See Miller & Cohen (2001), Rougier et al. (2005), Valentin et al. (2007), Watanabe (2009). This saliencing creates a foreground-background distinction that is necessary for an organism to act in accordance with what is variously called, depending upon the context and researcher, a goal, a task, a set, a sense of the situation, a disposition to action, a *perspective* (my preferred all-inclusive term that is therefore generally used in this chapter, see Dreyfus & Dreyfus (1988, pp 27-30)), and without doubt by other names. All goal-directed skilled action is taken under a perspective, so appropriate perspective and how it changes as environmental input change, must be learned prior to, or simultaneously with, learning skilled action. Because of this, skillful coping should be seen as a hierarchical process transcending traditional behaviorism.

Let me illustrate the above text by baseball examples. An intuitively expert baseball outfielder, in order to run to catch a routine fly ball, will find the angle at which he observes the ball to be salient information as well as the direction and velocity of his motion. Given these inputs as he runs, he will have previously learned to then adjust as necessary his velocity and direction so as to end up easily catching the ball. As he does this, his brain need not calculate where or when the ball will land. When the current salient stimuli are experientially directly mapped into a learned running action, his behavior is termed *model-free*. Normally, the sounds of the crowd, the color of the sky, the time, and many other aspects of the situation are nonsalient. Occasionally, if the ball has been hit fairly well, the situation may evolve into one where the fielder will not be able to catch the ball. If the fielder is experientially skilled with this kind of situation, when this happens his perspective will *automatically* change into a previously learned one where many stimuli that were previously irrelevant such as the location of the outfield wall, whether there are runners on base, the score and inning of the game etc. become salient and the fielder's learned actions will radically change to ones that are now appropriate. His behavior in this whole episode would still be termed model-free.

Neuroscientists designate behavior lacking a perspective as *habit*. While aware of the importance of perspective, most of their research has been devoted to laboratory animals acquiring habitual behavior, see Graybiel (2008). When perspective is the focus of attention, the literature often falls into the category of computer simulation of human behavior when subjects perform well-documented psychological tasks (e.g. Rougier et al. (2005)). Some papers go beyond this and study the spiking of neurons in non-human primate brains when dealing with perspective; for a review see Salzman & Fusi (2010). A few have looked at what happens in the brain to *represent* perspective (e.g. Cavanagh et al. (2010), Freeman & Quiroga (2012), Chapter 6). No one, as far as I know, has explained in detail how perspective interacts with other neural systems such as the one described below in order to produce sequential actions in service of a goal.

SKILL LEARNING

I now delve into how the procedural brain system presumably learns to accomplish the skillful actions described above. Note that it is *not* by using stored and indexed knowledge.

Machine learning of skill

The story begins with the announcement by Sutton (1988) of a new method of getting a machine, meaning a computer, to learn from trial-and-error exploration of its environment, how to choose a *sequence of decisions* that maximizes total reward as long as there is feedback of any reward associated with each step and at the end of the sequence. The method was called *temporal difference reinforcement learning* (TDRL). This method, it should be noted, concerns only decisions taken under a fixed perspective. An early application of the method by Tesauro (1994) produced a computer system that learned, using only self-play experiences, to play the game of backgammon as well as the world's best players.

Prior to 1988, *learning* algorithms for sequential decision problems were stymied by what was called the blame assignment problem. If, while learning, the computer program chose a sequence of actions that did badly compared to how it had done previously, how could it identify which decision or decisions out of many during the sequence were responsible for the poor performance? While there clearly was a need for learning an *actor* procedure by which the computer would choose its actions in various encountered situations, what was not obvious was that if the computer could also experientially learn to *predict* the total reward of the remaining sequence, given an initial situation and assuming good decisions thereafter, that the blame assignment problem could be solved. The predictor of overall quality of remaining decisions was called a *critic*. Both the decision-making actor and the sequence-evaluating critic could be learned gradually during trial-and-error exploration. Such a procedure could learn to maximize total reward as long as the computer provided for each action in this sequence the reward from that step and determined what the new situation was after the action taken in a particular situation. (To learn to catch a simulated fly ball, the reward from each step might be zero and the overall reward might be taken to be 1 if the simulated fielder was within a certain small distance of the ball when it came down, and 0 if not.)

Since the procedure does not attempt to learn in any way an explanation of how the computer provides the next situation and reward, but merely observes it to improve its decision-making, this is called *model-free actor-critic learning*. The computer uses a formula-based *model* to determine the next situation but the procedure doesn't need to try to learn this. For large problems, possibly with a continuum of possible states and decisions such as that of a baseball outfielder's positions and velocities and angle of viewing the ball, the actor and critic mappings are stored in a computer in the form of artificial neural networks. During experiential learning, the outputs of the actor and critic networks are adjusted by modifying the artificial synapses of the artificial neural networks. The adjustment is made on the basis of what is called the temporal difference *(TD) error.* This equals the critic network's expected total reward starting at the current situation minus the sum of the reward during a step and the expected total reward of the situation observed after a step of the process. When learning for that step is complete, this difference should be zero. If the TD-error isn't zero the synapses of the action network and critic network should be adjusted accordingly. The TD-error acts as a surrogate reward signal in the sense of Thorndyke's law of effect (Thorndyke, 1911, p 114).

Human learning of skill

Barto (1995), who was involved in the development of the machine-learning algorithm, speculated that, given a fixed perspective, an animal's or human being's procedural brain may, in the basal ganglia, actually execute something similar to the TDRL algorithm. The real world obviously does not, on its own, attach a reward value to actions in situations. But it was not long before neuroscientists discovered that the production by the limbic (emotional) system of the neuromodulator dopamine is interpreted by the brain as the needed reward signal (Schultz et al. 1997). Thus a cottage industry of TDRL neuroscientists who study experiential learning under circumstances where the body provides an emotional evaluation of quality of performance was born. Much of that research uses electrodes embedded in the brain of laboratory animals under training in order to observe neural activity in various areas of the brain. Other research concerns computer simulation of hypothetical TDRL explanations of human skilled-coping behavior and the comparison of the simulation with well-known psychological experimental data. Further research involves imaging the human brain to investigate what brain areas are involved as subjects perform skillful mental behavior.

Of special relevance, given Simon's and Kahneman's interest in fast chess play, is the imaging of subjects while they learn over a 15-week period to play a simplified version of Japanese chess (shogi). When asked to rapidly make move choices when shown unfamiliar but sensible positions (Wan et al. 2012) the imaging revealed increasing activity in areas associated with the procedural system.

Some details are still in dispute, but virtually all of these studies establish that the procedural brain areas identified starting around 1980 are indeed the source of learned skillful coping. Only rarely, and usually concerning the learning of a skill where there is no immediate feedback concerning reward, are the brain areas of declarative memory activated (Smith and McDowall, 2006). The reward provided by feedback is clearly essential for reinforcement learning.

THE NATURE OF SYSTEM 0

Why does it matter how the brain acquires and performs skillful coping? Regarding academic intuition research, it changes a dual process view of the subject into a tripartite one.

Furthermore, It means that one should be very careful before generalizing System 1's heuristics and disturbing biases observed in *novel situations* or occasionally situations lacking feedback concerning quality. These results are irrelevant to understanding experiential real-world behavior that ensues when System 0 produces feedback-based knowing how to cope.

Our current educational system almost exclusively values System 1's declarative knowledge and System 2's rational decision-making. This can inhibit the natural progression, with experience, to the use of the System 0 brain. Returning to the four Kahneman examples at the beginning of this chapter, no one ever tries to teach the skill of reading nuances of social situations. Hence almost all individuals with undamaged brains use observed successful and unsuccessful social behavior to naturally and effortlessly achieve that skill. I know from personal disappointing experience that seeing chess play as the application of rule- or theory-based declarative knowledge can block achievement of the highest levels. We probably all have known drivers who, while learning, have found System 1 and 2 *thinking* so stressful and exhausting that they give up before letting System 0 render driving as natural as walking.

System 0 doesn't think, in the conventional use of the word, it simply *knows how*. It breaks the thought barrier by *directly mapping* input stimuli or factual knowledge into actions or ideas. Remarkably, it can do many things simultaneously. More than just producing Kahneman's driving on an empty road, the System 0 driver of a manual-shift car can attentively carry on a conversation while, without conscious attention, navigating to work through normal traffic along a normal path, while accelerating or decelerating as required, while shifting gears when appropriate, and while making the complicated manual motions to do so.

The temporal difference reinforcement learning algorithm that partially explains System 0 also leads to experientially-learned skillful coping in *stochastic* situations such as gambling games. It can do so based on experiential feedback of the quality of performance in a model-free manner not requiring manipulations, or even the learning, of the probabilities involved. This may explain why, in *novel* situations, the heuristics-and-biases research unsurprisingly disclosed that people are poor statisticians, but incorrectly generalized this result to all experientially -learned stochastic decision behavior (Jessup et al. (2008)).

The procedural System 0 is not evolutionarily designed for immediately coping with changes in the everyday world that would imply that acting in accordance with experiential learning is inappropriate. That requires System 1 or 2. System 0 *can*, however, observe when the trained critic's evaluation of performance is not correct and realize that new experiential learning of perspective and/or critic and action is needed.

System 0 is far from infallible. In bringing salience to its situation, it can overlook a glass that it then knocks over at a dinner party. More importantly, having learned by pleasing its dopaminergic reward system, System 0 can produce addictive or sociopathic behavior if its reward system has been hijacked.

Experiential-Intuition research implications and speculations

This chapter has emphasized the cognitive neuroscience behind what I have termed System 0. There is, however, also an important philosophical tradition that regards *experiential* skillful coping (i.e. knowing how) as the determining factor in *who we are*. Although the associative

System 1, with its heuristics and biases in *novel* situations, seems currently to be the dominant interest of intuition researchers, the serious researcher should also become familiar with the System 0-relevant philosophical literature and its methods. See especially Appendix A of Benner et al. (2009) for a discussion of the narrative-based interpretive-research methodology, with many references, that has proved appropriate for studying the intuitive behavior of experienced skilled-coping nurses.

Aristotle (1953) exhibited an interest in skillful coping in his treatment of practical wisdom (*phronesis*). John Dewey (1997) emphasized the importance of learning through experience with emotional feedback. The crucial distinction between skillful coping and decision-making is made explicit in Heidegger (1962) with his extensive phenomenological treatment of the difference between the *involved* spontaneous use of equipment during skillful coping, called *ready-to-hand*, and the *detached* thoughtful use, called *present-at-hand*, see Polt (1999). My claim, and this is certainly open to research, is that System 0, i.e. what neuroscientists call the procedural brain, is the causal basis of Heidegger's ready-to-hand, while System 1, the brain of decision making in novel situations, is the basis of Heidegger's present-at-hand. The latter not only includes the use of physical equipment when thoughtfully manipulated, but, I contend, also includes the thoughtful manipulation of such equipment as the declarative memory of facts and experiences.

Anyone interested in the role of System 0 coping behavior should see Pierre Bourdieu's "non-intellectualist, non-mechanistic analysis of the relations between agent and world" (1990: p. 10) to study what human beings *are* and how their social practices cohere. Bourdieu (1977). For a developmental account of the acquisition of real-world skills see Dreyfus & Dreyfus (2005), for the specifics of a Heideggerian-like treatment of business and management organizational issues see Chia & MacKay (2007) and Cook & Brown (1999), for the world of nursing see Benner et al. (2009), and for a military application see Sookermany (2011).

Based on my understanding of current neuroscience and on phenomenology, following are some possibly researchable speculations. How much experience in a domain or subdomain before System 0 intuition should be trusted depends on the complexity of the domain: intuitive automobile driving requires much less experience than intuitive chess play. Once one has enough experience, both appropriate action, and the ability to predict both how the situation will turn out and how the current situation will evolve, can be acquired in a model-free way. Model-free skills cannot, in principle, be explained since they are in no way "mental" and depend on synapses that have resulted from the totality of relevant experiences. Unless the situation seems novel in that no action presents itself immediately and effortlessly, explanations of experiential System 0 behavior in terms of mental models, belief systems, heuristic rules and the like are fictions. While one cannot explain the synapse-based learned perspective taken in a situation, one can experience and report what stands out as salient in a situation. Emotion is essential for providing the reward signal needed for acquiring, and refining with every experience, a coping skill. It plays no role, however, in the real-time performance of a skill.

Conclusion

Given situational sensual stimuli or factual knowledge as input, the intuitive System 0 directly and spontaneously will perform an action or present an idea that *experience* has shown to be rewarding. System 1 depends upon associations between ideas, events and the like to intuitively generate decisions in *novel* situations or in familiar situations lacking feedback concerning quality of performance. Lumping these two systems together creates an obstacle to productive intuition research. The two systems activate physically distinct brain areas, their operating principles are quite different, as are the circumstances that recruit them, and their implications for the study of who we are. Both systems are fast and inexplicable, but only System 0 explains real-world coping skill acquired through action accompanied by emotionally-experienced evaluation of its quality.

NOTE

1. A warning: In 1986, lacking knowledge of the embryonic research on the procedural brain, my brother Hubert and I offered, in our hardcover book *Mind Over Machine*, an explanation of expertise similar to the pattern-recognition explanation of Simon. We did, however, insist that the most-similar remembered situation had to be detected holistically. By Dreyfus & Dreyfus (1988), the paperback revised version of the book, we had learned that a neural net could learn to holistically map a situation into a behavior and, as explained in a preface added to the 1986 book, we changed the term "pattern recognition" to "discrimination and association". Unfortunately, when the paperback was reprinted in 2000, without our knowledge the 1986 book was reprinted rather than the 1988 paperback. In 2010 we convinced the publisher to rectify this error and the correct version is now on sale. Someone purchasing the book should be sure that their paperback contains on pages ix-xiv a preface to the paperback edition, as did the original 1988 paperback.

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