Naturalistic Decision Making

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Naturalistic Decision Making (NDM) has been variously described as a ‘movement’ (Klein, 2015), a ‘research community’ (Gore, Flin, Stanton, & Wong, 2015), a ‘framework’ (Klein, 2015, Lipshitz, Klein, Orasanu, & Salas, 2001), and a ‘perspective’ or ‘paradigm’ (Cannon-Bowers, Salas, & Pruitt, 1996). All of these labels are appropriate. As a movement, it originated in 1989 at a small, invitation-only conference in Dayton, Ohio, just one year after the shootdown of an Iranian commercial airliner by a US Navy cruiser, the USS Vincennes. The researchers invited at the 1989 meeting were concerned about applying what was known from the then-existing research on decision making to applied, real-world, contexts, such as the Vincennes tragedy. Their perception of the state of the art of decision making research at that time was that it mainly consisted of laboratory research in which novel tasks were used with inexperienced decision makers (mostly students) who were asked to make a choice among concurrently available alternatives. The findings of this body of research did not generalize to experienced decision makers who often had to make sense of a complex situation before committing themselves to a particular course of action. Thus, a movement was started that evolved into a research community that convened during biennial conferences alternating between the US and Europe. As a movement, then, NDM consists of applied researchers who are interested in how professionals make decisions in real-world situations, with the goal of supporting these professionals through decision aiding and training. The word ‘naturalistic’ in NDM therefore refers to real-world situations, as contrasted with laboratory situations, rather than ‘natural situations’ in the sense of ‘taking place in nature’.

As a framework or perspective, NDM is frequently contrasted with Classical Decision Making (CDM). CDM presents a view of human decision making as fundamentally flawed compared to a normative model. The normative model describes decision making as an exhaustive comparison of options, based on all available information about the options, their weights and consequences. NDM as a perspective on decision making emphasizes the study of how people use their experience to actually make decisions in field settings, rather than how they are supposed to make decisions. In the NDM framework, professional decision making behavior is an adaptation to uncertain, dynamic, environments, shifting, ill-defined or competing goals, time stress, high stakes, multiple event-feedback loops, ill-structured problems, multiple players, and organizational goals and norms that must be aligned with the decision maker’s personal goals and norms (Orasanu & Connolly, 1993). Given these task constraints, decision making does not usually allow for an exhaustive comparison of options, as CDM would claim. The adaptations to these task constraints are usually viewed as successful (Kahneman & Klein, 2009), as long as experts can bring to bear their knowledge and experience in order to make decisions and solve problems. One particularly effective strategy that NDM has described is ‘recognition-primed decision making’. By employing this strategy, experts adapt to the task constraints imposed upon them by recognizing familiar elements in a decision context and then retrieve from memory actions associated with these elements.

The attack on CDM as a correct description of what people actually do when they make decisions, was primarily initiated by Herbert Simon in the late 1940s and early 1950s (Simon, 1947; Simon, 1955). According to Simon, humans do not exhaustively select information in order to compare options. Instead, they apply their limited attentional resources to selecting a satisfactory option that suffices. Hence, their decision-making behavior may be characterized as 'satisficing' (a concatenation of 'satisfactory' and 'sufficing') rather than 'optimizing', as CDM would claim. In order to be able to assess more fully NDM's contribution to the history of decision-making research, I will start by elaborating Simon's views. I will next discuss some prototypical examples of NDM research and findings, as well as the theories and methods developed. Finally, I will broaden the scope of NDM to include other 'macrocognitive' functions than decision making, and position NDM relative to other theoretical frameworks that deal with cognitive adaptation to complexity, as NDM has primarily evolved into.

Bounded rationality

In his autobiography *Models of my life*, Simon (1991a, p. 88) stated that he would not object to having his whole scientific output described as an elaborate gloss on two interrelated ideas that had been at the core of his whole intellectual activity: "(1) human beings are able to achieve only a very bounded rationality, and (2) as one consequence of their cognitive limitations, they are prone to identify with subgoals." Both ideas were already developed when Simon finished his dissertation and revised it to publish it as *Administrative Behavior* in 1947. The book's aim was to understand how organizations could be understood in terms of their decision processes. The first idea, of bounded rationality, is probably his most well-known. It not only applies to organizations, but to individuals as well. Basically, the concept of bounded rationality states that human rationality is bounded by larger areas of irrationality, in the sense of 'ignorance' or 'lack of knowledge', rather than in the sense of 'emotionality' (although Simon did not exclude the latter). Our knowledge is necessarily always limited, because of fundamental limitations to our information-processing systems (what Simon referred to as the 'inner environment') and because of fundamental limitations to the attention we can pay to the external world (what Simon referred to as the 'outer environment'). The concept of bounded rationality is frequently limited to a discussion of limitations of human information processing capacities, such as working memory limitations or the limited speed with which information can be stored in long-term memory. However, Simon intended the concept to be much broader, and also included in his definition incompleteness of knowledge, difficulties in anticipating future consequences, and the limited scope of possible behavior alternatives that come to mind (Simon, 2000). These issues have more to do with the complexity of the environment humans find themselves in than with their limited information processing capacities. In fact, one could say that the typical factors that characterize decision making in naturalistic environments, as put forward by Orasanu and Connolly (1993) and listed above, are the same factors that Simon had in mind when he referred to the 'outer environment' in which humans act and that acts upon them. It is therefore necessary to always take the 'two blades of the scissors' into account: the task environment on the one hand and the limits on the adaptive powers of the system on the other hand (Simon, 1991b). Bounded rationality is not the study of optimization in relation to task environments. According to Simon (1991b, p. 35), "[bounded rationality] is the study of how people acquire strategies for coping with those environments, how these strategies emerge out of problem space definitions, and how built-in physiological limits shape and constrain the acquisition of problem spaces and strategies." If, as NDM might claim, the behavior of experts is completely optimized in relation to their task environments, then NDM as a theory would be barren. It would consist of the single precept: always choose the action that leads to the most complete achievement of your goal. However, even the behavior of experts is never completely optimized. Almost always, structure and limits to adaptation will 'show through' and will have to be taken into account. For instance, limits on the speed and nature of feedback during learning, as well as limits on the validity of the cues experts derive from their environments, prohibit optimization in relation to task environments and may lead to what Kahneman and Klein (2009) referred to as 'fractionated expertise.' According to Simon, fractionated expertise would be the 'normal' state of affairs, whereas 'true expertise' (in the sense of complete adaptation to the environment) would be impossible, or possible only in the simplest of cases (Kahneman and Klein [2009, p. 522] agree that "fractionation of expertise is the rule, not an exception").

This brings us to the second of Simon's fundamental ideas, namely that humans are prone to identify with subgoals. What Simon means here is that humans justifiably treat situations as only loosely connected with each other, simply because most situations are quasi-independent of each other. This is because of the ubiquitous hierarchical nature of natural systems that have evolved out of the assembly of relatively stable, simple structures. Hierarchy will therefore be a dominant architectural form among natural systems and will have the special property of 'near decomposability' (Simon, 1962). The theory of nearly decomposable systems states that the interactions among the subsystems that constitute the complex system are weak, but not negligible. At least some kinds of hierarchic systems can be approximated successfully as nearly decomposable systems. Two propositions sum up this approach:

> "(a) in a nearly decomposable system, the short-run behavior of each of the component subsystems is approximately independent of the short-run behavior of the other components; (b) in the long run, the behavior of any one of the components depends in only an aggregate way on the behavior of the other components." (Simon, 1962, p. 474).

The fact that nearly decomposable systems exist is fortunate for human beings with limited attention, because to deal with complex systems would be unmanageable if human beings had to deal with the full complexity at once. Although perhaps part of the story, it is, however, not the case that hierarchy is merely in the eye of the beholder, as evolution favors hierarchical systems over non-hierarchical systems.

This also ties in with Simon's (1973) observations regarding the structure of ill-structured problems. According to Simon, there are no well-structured problems, only ill-structured problems that have been formalized for problem solvers or are formalized by the problem solvers themselves. Typical ill-designed problems such as designing a house or composing a piece of music are ill-structured in the large, but become well-structured in the small, step-by-step problem solving process in which information and subgoals are retrieved from long-term memory, leading to a decomposition of the problem into more structured component problems. The retrieval system is a recognition system that attends to features in the problem space and the external environment and, recognizing features as familiar, evokes relevant information from memory which it adds to the problem space, making it incrementally more structured (Simon, 1973, p. 192).

Put more generally, recognition-based expertise is one of the mechanisms used by human bounded rationality to cope with real-world complexity (Simon, 1990). In this sense, the 'intuition' that we ascribe to experts, can simply be explained by acts of recognition (Simon, 1981; 1992). For instance, Gobet and Simon (1996) showed that grand master chess players could maintain their success level even during speed chess games against 50 opponents simultaneously, primarily relying on fast recognition processes. The complexity and richness of the outer environment is made manageable by drawing upon a very large repertory of cue-action pairs stored in long-term memory after considerable experience with the outer environment. The property of near decomposability is an essential prerequisite for building up this large repertory; without it, important systems in the world would be beyond our powers of observation and understanding. Without hierarchic, decomposable systems, it would also be impossible to derive valid cues from the environment, preventing us from becoming experts in any domain.

In summary, Simon's two basic insights into bounded rationality and near decomposability have led to a number of core findings and related explanations in the area of decision making that foreshadows many of the findings of NDM, not just the finding that experts rely on pattern recognition and make good decisions without comparing options (Kahneman & Klein, 2009). In particular, the importance of problem structuring, of incremental goal refinement, of recognition processes, of problem spaces (representations) and heuristics to deal with complexity, of scientific discovery by detecting contradictions and being surprised, and of making sense of information rather than gathering more information, are all core findings of Simon and his associates. On the other hand, this theoretical base, although quite general, was sorely in need of application to real-world situations. The filling in of the details of the nature of the adaptive processes of experts to their dynamic environments has been the ongoing work of NDM for the past 30 years. I will discuss this work in the following sections using Simon's distinction between the outer and the inner environment, so as to address both blades of the scissors adequately. I will end with extensions of the NDM work to the team and organizational levels.

The 'outer environment': Expertise as adaptation to goal-relevant constraints

Both Simon and NDM researchers underline the importance of the structure of the environment in acquiring expertise and in task performance in general. Not that they are the first or the only ones to claim that adaptive behavior is to be explained by the shape of the environment (see, for instance, Brunswik, 1955 and J.J. Gibson, 1979 for an ecological approach to cognition). Expertise in general is often viewed as maximal adaptation to domain-specific constraints (e.g., Ericsson & Lehmann, 1996; Vicente, 2000). The issue of how to model these constraints, or what theory of the environment one should adopt, has generally not been dealt with in any detail by either NDM or Simon, in contrast to ecological approaches. Kahneman and Klein (2009) were the first in the NDM tradition to describe the importance of what they referred to as the "validity of the environment" in developing skilled intuitions, that is, expertise. Validity, in Kahneman and Klein's (2009, p. 520) words, "describes the causal and statistical structure of the relevant environment." As, for instance, the economic and political environment generally shows very little structure, it is nearly impossible for humans to develop valid intuitions about developments in such environments, hence the difficulty of developing expertise in such areas. Skilled nurses and fireground commanders, on the other hand, operate in much more structured and predictable environments that allow them to develop skilled intuitions about the cues these environments present them with. Later on in their paper, Kahneman and Klein (2009, p. 524) use a somewhat different definition of validity, in which they include events or actions taken by experts in response to particular cues, thus extending the definition from a mere description of the environment to something that resembles a classic 'if-then rule': "[w]e describe task environments as "high-validity" if there are stable relationships between objectively identifiable cues and subsequent events or between cues and the outcomes of possible actions." A high-validity environment is a necessary, but not a sufficient, condition for the development of expertise. Kahneman and Klein (2009) hence added a second condition for expertise, namely the opportunity to learn the relevant structure of the environment and to practice a skill. Therefore, although both conditions are necessary for expertise to develop, neither one by itself is sufficient: one needs both a valid environment (or a stable relationship between the environment and one's actions upon it) and an opportunity to learn and practice that validity. Only then will skill and expert intuition eventually develop in individuals of sufficient talent.

Kahneman and Klein's (2009) notion of validity of the environment is useful when one needs to determine whether someone's intuitive judgments can be trusted. Hence, it is a useful first approximation when trying to establish whether someone can become an expert or not, at least in principle in the particular environment under consideration. However, their own admission that fractionated expertise is the rule, not an exception, and NDM's general fascination with ill-structured, uncertain, dynamic, ill-defined environments with multiple event-feedback loops, multiple players and organizational norms and goals that must be balanced against the decision makers' personal choice (Orasanu & Connolly, 1993) makes one wonder how true expertise can ever be acquired in such environments. If environments are truly characterized by the factors listed above, they are surely more representative of low-validity environments such as the stock market or the political arena than of high-validity environments. Consequently, such naturalistic environments are unconducive, to say the least, of becoming an expert. What makes matters worse is that many naturalistic environments do not allow for extensive periods of learning (at least not the well-known 10,000 hour or 10-year period frequently stated, first by Simon and Chase [1973], as a requirement for attaining world-class expertise in areas such as musical performance, games, or sports; see Ericsson, 1996, for a review in these areas). This is particularly the case in jobs with high rotation speeds, such as in the military, where personnel change jobs every two or three years. Therefore, in these jobs, the second condition for expertise, being able to learn the validity of the environment, is not met either.

On the other hand, it would be too hasty to conclude that genuine expertise does not exist in naturalistic environments. All we may conclude is that we will mostly encounter, as analysts, isolated islands of knowledge in seas of ignorance—in other words, humans with bounded rationality. And we may predict that when experts in a particular area of expertise are confronted with problems that are entirely new to them, they may be able to use some of their knowledge, for instance a general approach to solving problems in their domain, but they will display more novice-like behavior the more novel the problems become (see Schraagen, 1993a, for an example in the domain of experimental design, or Voss et al., 1983, in the domain of political science). Secondly, fewer opportunities to learn and practice have led to new developments in the area of 'accelerated expertise' (Hoffman et al., 2014). This field endeavors to find new ways of learning that speed up the learning curve—accomplishing within a few years what otherwise would have taken 10 years to learn. What this implies is that the '10-year rule' may not be as hard as some have taken it to be (for empirical evidence disconfirming this rule, see, for instance, Hambrick et al., 2014 and Meinz & Hambrick, 2010; for a theory emphasizing interactions between genes and the environment, see

Ullén, Hambrick, & Mosing, 2015). Thirdly, if fractionated expertise is indeed the rule and genuine expertise is indeed rare in naturalistic environments, then a pragmatic response of the NDM community would be to settle for the best there is—in other words, to satisfice. Expertise in naturalistic environments is mostly defined in relative and social terms, hence, if a community designates a colleague as 'the' expert, even if she has only two years' experience in the domain, then apparently two years suffice. Peer judgments rather than quantitative performance measures are what define expertise in the NDM community.

An example from the domain of pilotage of vessels may illustrate the concepts of validity of the environment, opportunities for learning and definition of expertise (Schraagen, 1993b). This study was carried out on board of large container ships entering or leaving the port of Rotterdam. These vessels, if their master is not exempt from pilotage duty, need a pilot to safely navigate the ship in the confined waterways and open sea areas close ashore. A ship's master may be considered a 'ship expert' insofar as the master has developed an anticipatory control model of the ship's movements based on extensive experience with the ship in all types of conditions (wind, current). A pilot, on the other hand, is far less familiar with the particular ship he or she is navigating. Rather, the pilot may be considered a 'local environment expert', insofar as he or she routinely sails a particular stretch of water, but with a diversity of ships. In this study, I investigated on the basis of which cues pilots made navigational decisions, such as when to change heading or when to change speed. Does the environment provide stable relationships between objectively identifiable cues and subsequent events or between cues and the outcomes of possible actions? If so, the environment would be of high validity and would be conducive to the development of genuine expertise, following Kahneman and Klein's (2009) definition. This raises the question of defining 'objectively identifiable cues'. I used cognitive task analysis methods to answer this question, in particular think aloud and 'constrained information tasks' (see Schraagen, 2006, for more details on the methods used).

The results showed that pilots used a limited number of identifiable cues from the environment to initiate heading or speed changes. For instance, whenever they would sail alongside pile mooring 14, they would order a change in heading by issuing the command 'five degrees to port'. This may seem an overly simplistic way of controlling a complex system such as a 300 meter container vessel, particularly as this system may be subject to various external influences such as wind and current. Given that the pilot, unlike the master, has not developed an anticipatory control model for this particular ship, how does he or she know what the effects will be of ordering a particular command? The answer is surprisingly simple: they do not know exactly nor do they need to know exactly. Pilots have a general 'feeling' or intuition for how a ship should respond to a particular command and what they are good at, is evaluating the ship's response to their command by comparing the actual response to a desired response, stored in long-term memory. The desired response is a generalized schema or prototypical situation, derived from many instances with similar ships (it is likely, although this fell outside the scope of the study, that they have several classes of schemata, depending on various classes of ships they are dealing with). The comparison process is a pattern matching or feature matching process of the actual rate of turn of the ship with the desired rate of turn, and this is based on looking at the ship's bow and seeing how fast it moves relative to a fixed point in the environment (this fixed point, for instance a church, is another 'identifiable cue'). The rate of turn is a complex yet all-encompassing measure, as it includes all external effects at once. Thus, the pilot does not need to make extensive mathematical calculations in his or her head, as this would be impossible and too cumbersome for each navigational change. No calculations are needed at all, as the pilot merely compares actual with desired movements. Note that the only advantage of the pilot, compared to the master, lies in the specific knowledge of the environmental cues to use to either initiate a change or to compare the effects of an initiated change with an intended change.

A second interesting finding in this study was that there were individual differences in the cues pilots used: some used pile moorings, others used buoys, still others used objects such as apartment buildings or churches. Hence, this raises a question about the 'objectivity' of the identifiable cues in the environment. The answer is that the cues are all objectively identifiable, yet idiosyncratic as far as their identity is concerned, probably as a result of highly individualized training (pilots are trained by a personal mentor who teaches them what he or she has been taught long before, at least at the time of this study). It also shows that people are highly creative in exploiting the richness of cues in their environment. The environment does not provide ready-made cues, quite the contrary: experts invest the environment with goal-relevant meaning.

The approach taken in this study is typical of NDM studies in general. It consists of identifying the cues and strategies experts use when carrying out their tasks. NDM has employed a variety of methods in this respect, mostly querying the professionals during or after their work. One of the most well-known methods is the Critical Decision Method (Hoffman, Crandall, & Shadbolt, 1998). Generally, NDM has developed 'process theories' rather than 'product theories' (Vicente, 2000), the difference being that process theories specify psychological mechanisms and representations 'in the head', whereas product theories specify constraints that the environment imposes on humans. Vicente and Wang (1998) claimed that process theories and product theories are complementary, with product theories providing the constraints that process theories need to fulfill. They further claim (p. 50) that "[…] it is the only such theory that systematically accounts for the contribution of the structure of the environment to behavior." If this is the case, one may wonder why NDM has only rarely developed a theory of the environment, for instance in the form of the abstraction hierarchy proposed by Rasmussen (1985). First, it should be clear that NDM does not deny the importance of the environment and the presence of objectively identifiable cues in it. As Kahneman and Klein (2009) claimed, the structure of the environment provides important conditions for expertise. However, NDM has traditionally been more interested in an expert's mental representation of the environment than in a model of the environment as such. Other applied research areas, such as Ecological Interface Design (EID), with its theoretical basis in Gibsonian ecological psychology, has made extensive and productive use of the abstraction hierarchy (see McIlroy & Stanton, 2015, for a recent review). Second, from a practical point of view, it is difficult to see how one could develop an (ontological) model of the environment without being an expert oneself. In cases where the constraints imposed by the environment largely obey the laws of physics, such as in the study of nuclear power plant control, one could develop an abstraction hierarchy as a model of the environment by drawing upon that knowledge. In many other cases, however, specifying the constraints in the environment runs the risk of being a largely ad hoc exercise (Simon & Gobet, 2000), without many additional benefits. Of course, a river pilot needs to deal with particular constraints in the environment, such as the rules of the road and the constraint of sailing the vessel in a safe and timely manner to its port. However, these constraints do not provide any insight in the way river pilots perform this task, what information they use, and how they should be trained or supported. A river pilot's behavior, as any adaptive system, is constrained by the environment, but not completely determined by it, and we need auxiliary assumptions to deal with the limits of adaptation, in other words, a process theory (Simon, 1991b). Third, process theories such as NDM has developed, do not ignore the adaptive and goal-oriented nature of behavior. In particular, in more recent formulations of NDM as macrocognition (Klein et al., 2003), functions such as planning, adaptation, and sensemaking are viewed as being supported by processes such as mental simulation and storybuilding, managing uncertainty and risk, and managing attention. These processes are adaptive and goal-oriented, and contribute to the study of how cognition adapts to complexity (Gore et al., 2015).

In conclusion, both NDM and ecological approaches to cognition stress the importance of the environment. According to NDM, one needs both a ‘valid’ environment and an opportunity to learn the cues offered by the environment in order to develop expertise. A valid environment is an environment that offers stable relationships between objectively identifiable cues and subsequent events or between cues and the outcomes of possible actions (Kahneman & Klein, 2009). Ecological approaches, on the other hand, have traditionally focused on a description of the environment itself, without considering the human role in it. Although NDM is somewhat ambiguous in whether or not to take the human into account when defining the validity of the environment, most NDM studies have not followed the ecological approaches by starting, for instance, with an abstraction hierarchy of the domain of interest. Instead, NDM studies usually start by asking experts how they carry out their tasks, and from there implicitly derive the constraints that the experts have to adapt to.

The ‘inner environment’: Strategies and representations

As discussed above, one of the most prominent strategies humans use when coping with their task environments is the use of recognition-based expertise, particularly when they are experienced and under time pressure. Klein (personal communication, 24 May 2015) first coined the term ‘recognition-primed decision making’. He and his colleagues Roberta Calderwood and Anne Clinton-Cirocco used it in an unpublished report for the Army Research Institute in 1985 (for a final published version with Postscript, see Klein, Calderwood, & Clinton-Cirocco, 2010), and in their paper in the Proceedings of the HFES in 1986, which would be the first published reference (Klein, Calderwood, & Clinton-Cirocco, 1986). Klein wanted an acronym that conveyed rapidity. He toyed with schema-primed decisions (SPD, hinting at "speed"), but he and his colleagues decided they liked RPD (hinting at "rapid") better. Klein’s Recognition-Primed Decision (RPD) model of rapid decision making has been one of the most prominent and influential ideas within the NDM community, even though it should not be equated with NDM. The model was developed on the basis of retrospective process tracing using a semistructured interview technique of incidents remembered by Fireground Commanders (FGCs) (Klein, Calderwood, Clinton-Cirocco, 2010). In order not to disturb the FGCs during their work, using talk aloud protocols was obviously not feasible. Extracting 156 decision points from these interviews, Klein et al. (2010) found that in 80% of the cases, the FGCs considered only one option. In only 16 of the most difficult cases did the FGCs evaluate multiple options. In Klein et al.’s words (2010, p. 198):

> Their ability to handle decision points depended on their skill at recognizing situations as typical instances of general prototypes that they had developed through experience. The prototypes provided them with an understanding of the causal dynamics at work, suggested promising courses of action, and provided them with expectations.

Klein et al. (1986) explained the use of this ‘satisficing’ strategy by the time pressure FGCs are under: if they had generated a large set of options, and evaluated these systematically in terms of expected utility, the fires would undoubtedly have gotten out of control. As one officer said: “Look, we don’t have time for that kind of mental gymnastics out there. If you have to think about it, it’s too late.” (Klein, Calderwood, Clinton-Cirocco, 1986, p 578).

The RPD model was never intended to be solely about recognition or ‘intuition’. It is a blend of intuition and analysis (Klein, Postscript to 2010), as became apparent in later, updated, versions of the model (e.g., Kaempf, Klein, Thordsen, Wolf, 1996). The analysis part of the model deals with contrasting alternative accounts of a situation, and with mentally simulating the outcomes of proposed courses of action. Hence, in later versions of the model, feedback loops were added, such that when situations were not typical, additional information would be gathered and the situation would be clarified through story building or feature matching, until a prototypical or analogue situation would have been constructed. Similarly, when proposed courses of action would not work, they would be modified or a new action would be generated.

The main difference with classical models of decision making is that the RPD model focuses on serial evaluation of options and chooses the first option that works (following Simon’s satisficing theory). Rather than contrasting the strengths and weaknesses of multiple options simultaneously, and having to wait until the analysis is completed before being able to take an action, a recognitional strategy enables a decision maker to commit to the option being evaluated, thus being able to initiate an action continuously (Klein, 1993). Although the RPD model works well in situations of time pressure, results of multiple studies have shown that recognitional strategies are also used when not under time pressure, even with complex problems (Klein, 1989). Analytical strategies are used more often by less experienced decision makers or when making organizational decisions that require the comparison of multiple options. Also, data presented in alphanumeric rather than a graphical format evoke an analytical strategy, as well as the strong requirement to justify actions, or when there is a dispute between different constituencies (Klein, 1993).

The RPD model has been applied to a variety of domains and has received much empirical support, in that experts are found to use recognitional strategies in 80-90% of the cases (see Klein, 1993; Ross, Shafer, & Klein, 2006). One of the intriguing predictions of the RPD model is that the first option considered is usually the best, at least if the professionals making the decision can draw upon extensive domain knowledge and experience. A corollary of this prediction, taking into account the predominance of fractionated expertise, is that when confronted with atypical or unfamiliar problems, the first option considered may not be the best, and it may pay off to engage in further deliberation or mental simulation. The first prediction has received widespread support, and not just from NDM research. For instance, experienced chess players’ first moves considered are typically of higher quality than subsequent moves (Klein, Wolf, Militello, & Zsambok, 1995). Also, under high time pressure, so-called conditions of ‘speed chess’, where experienced players compete with a large number of less experienced players simultaneously, highly skilled players are able to generate moves of high quality (Calderwood, Klein, & Crandall, 1988; Gobet & Simon, 1996). The ‘fast and frugal heuristics’ research tradition (Gigerenzer & Goldstein, 1996; Hoffrage, this Handbook) has also generated support for a “Take The First” heuristic with handball players (Johnson & Raab, 2003; Raab & Johnson, 2007). Johnson and Raab (2003) presented moderately experienced handball players with video sequences from a game and asked what they would have done—for instance, pass the ball to the player to the left or take a shot at the goal. They found that the first option that came to mind was better than later options. This result has been replicated for basketball (Hepler & Feltz, 2012).

Regarding the second prediction, it should be recalled that the RPD model allows for a mental simulation strategy in case the first option is not considered workable. It would therefore be incorrect to state that the RPD model would always predict that experts will, or should, choose the first option that comes to mind. It is important to specify the boundary conditions under which this takes place. Several studies have made progress in this area. For instance, Mamede et al. (2010) studied medical diagnostic reasoning with both complex and routine problems under three reasoning mode conditions: an immediate-decision condition (favoring a "Take The First" heuristic) and two delayed conditions: conscious thought and deliberation-without-attention (Dijksterhuis, Bos, Nordgren, & Van Baaren, 2006). Their participants were 34 internal medicine residents ('experts') and 50 fourth-year medical students ('novices'). They found that the experts benefited from consciously thinking about complex problems, whereas reasoning mode did not differ in simple problems. In contrast, novices benefited from being prevented from thinking about their decision, but only in simple problems. Moxley et al. (2012), in the domain of chess, found that both experts and novices (tournament players) benefited from extra deliberation, regardless of whether the problem was simple or complex. In other words, and in contrast to previous findings, the move chosen after deliberation was stronger than the move first mentioned. Experts chose their first move mentioned as their final move 49% of the time, and were significantly more likely than novices to do so on easy problems, but not on hard problems. In conclusion, these studies provide confirmatory evidence for the RPD model, in that problem complexity seems to provide a boundary condition on the use of a pattern recognition process: when problems become complex or atypical, solution quality may benefit from engaging in mental simulation, or conscious, analytical reasoning. This is in line with dual-process theories of reasoning and judgment (Evans, 2008; this Handbook) and the distinction between System 1 (intuition) and System 2 (deliberative thinking) (Kahneman, 2003).

Extending NDM to the team and organizational level

If we consider human beings to be goal-directed, adaptive systems whose behavior may be described as consisting of applying knowledge in the service of goals, then teams and organizations could in principle also be regarded as goal-directed systems. In fact, the definition of a team that is frequently used, stresses the importance of a mutually agreed-upon, valued, common goal that all team members should strive towards, each using their functionally complementary set of knowledge and skills[1]. In this sense, a team is merely an extension of an individual in the sense that if an individual cannot accomplish a goal on his or her own, teamwork may be required to do so. By the same argument, an organization is a solution to a goal that can neither be accomplished by a team, let alone by a single individual. The question arises: how does a team achieve its goals? What is necessary for adaptive, efficient, team behavior? What strategies and representations do teams need to have to achieve their goals?

[1] Teams can be defined as two or more people who interact interdependently with respect to a common goal and who have each been assigned specific roles to perform for a limited lifespan of membership (Salas, Dickenson, Converse, & Tannenbaum, 1992).

There are basically two perspectives on teamwork: a structural perspective emphasizing representations, and a process perspective emphasizing strategies. From the mid-1990s, the concept of 'shared mental models' became popular to explain excellent teamwork (e.g., Cannon-Bowers, Salas, & Converse, 1993). This is a structural perspective as it focuses on the underlying representations that team members bring to bear. 'Shared mental models' turned out to be somewhat ambiguous, because it was not clear on the exact meaning of the word 'shared', which could either mean 'in common' or 'distributed' (Mohammed & Dumville, 2001). Be that as it may, the concept emphasized the importance of knowing what one's teammate needs in terms of knowledge and information at a particular point in time (referred to as 'transactive memory', Moreland, 1999). As such, it emphasized real-time interdependence and proper preparation for it by means of various types of cross-training (it turned out to be superfluous to cross train team members completely in each other's tasks; rather, the important thing was to know at critical points in the task performance, what one's team members needed). After some years, the concept ran into methodological problems of measurement (Mohammed, Klimoski, & Rentsch, 2000), as well as problems of justification of its importance (Cooke et al., 2013). Another issue is that much of the shared mental models research focused on routine, proceduralized tasks, for which the knowledge requirements could be listed in advance and hence trained for. This reliance on memorization is not always the solution (see, e.g., Fiore et al., 2010). Crew resource management, for instance, relies more heavily upon team processes than shared mental models (Helmreich & Foushee, 1993). Finally, the concept of 'mental models' was ambiguous, as it could refer to static knowledge or to situation-dependent knowledge (Rasker, Post, & Schraagen, 2000). In the latter case, a concept such as 'shared situation awareness' (Stanton et al., 2010) or 'shared problem models' (Orasanu, 1993) would be more appropriate.

Recently, the process perspective has gained more influence (e.g., Cooke et al., 2013). The process perspective states that while sharing particular knowledge in a static sense may be important, what is crucial is actually communicating this knowledge to one's team members. Although the shared mental models perspective frequently stated that "a good team is a silent team", and that 'implicit coordination' would do most of the job (Kleinman & Serfaty, 1989), the process perspective states that "there is nothing as deadly in a crisis as the sound of silence" (Vaughan, 1997). In fact, this perspective goes so far as to state that teamwork only arises during communicative acts (Stanton, Salmon, & Walker, 2015). Knowledge need not be shared completely amongst team members; distributed knowledge is the common practice, and only communicative acts can bring the distributed knowledge together and make it accessible for the team as a whole.

Within the NDM tradition, it has become commonplace to study teamwork in real-life settings and describe what strategies and representations teams use to cope with unexpected situations. I have carried out such a study in the area of pediatric cardiac surgery, using various methods, ranging from teamwork observation and behavioral rating scales to social network analysis (Schraagen, 2011; Barth, Schraagen, & Schmettow, 2015). These analyses show that teams first use standard procedures to respond to increasing difficulty and, on top of those, also use more generic strategies such as 'heedful interrelating' or mutual performance monitoring. Just as individual experts when being confronted with unfamiliar problems in their area of expertise may still use generic problem solving methods or schemata, teams have also learned from experience what to do in case they are confronted with unusually difficult situations: anticipate each other's information needs (shared mental models); provide backup when the going gets tough; explicitly communicate what you are doing so others build up shared situation awareness.

Similar analyses may be carried out at the organizational level, although these studies are mostly not affiliated with NDM. The most extensive analysis of a single organization has been carried out by the sociologist Diane Vaughan in her book *The Challenger Launch Decision* (1996), describing the background to the decision on the eve of the launch to go ahead with the launch of the space shuttle Challenger in 1986. Contrary to common wisdom that NASA managers were the only ones to blame for overruling the engineers who expressed their doubts on the eve of the launch, Vaughan convincingly showed that it was in fact conformity to NASA culture as a whole that was to blame: a culture of production, a culture of bureaucracy, a technical culture, as well as the overriding phenomenon of 'normalization of deviance'. These cultural pressures came together and were played out on the telecon on the eve of the launch, making this a predictable accident the day after. If we abstract from the specifics of this analysis and couch them in more general terms, we see a tension between the pressures of what is common practice in NASA (routine culture) versus the unknown (non-routine situation). The unknown is the uncharted territory of launching under very low temperatures with the hypothesis that the O-rings may burn through at these low temperatures. Although in hindsight this hypothesis has proven to be correct, during the eve of the launch the engineers could not bring to bear sufficient evidence to make the hypothesis credible. Therefore, the pressures of routine culture won over the pressure of non-routine culture. Instead of proving that something was safe, you had to prove it unsafe, because the shuttle generated so many safety issues. This meant that rational analysis with sufficient quantitative evidence had to be presented to persuade management to abort the launch. As the engineers were unable to do so, management, given the pressure to maintain a launch schedule that had already been changed a number of times, decided to go ahead with the launch. The same normalized organizational deviance occurred in response to the tile hitting the wing on the Columbia (CAIB, 2003).

Looking at the individual, team, and organizational level from a more distant perspective, we may thus conclude that any system that is confronted with unfamiliar situations, that is, situations that fall outside the scope for which knowledge is readily available, needs to resort to more effortful, more deliberative, strategies with the aim of searching for new knowledge, and bringing to bear new perspectives. This is a familiar juxtaposition: Newell (1990) called this the 'preparation versus deliberation trade-off', Kahneman (2003) referred to this as the 'System I' versus 'System II' mode of thinking, Klein (1993) referred to this as Recognition-Primed Decision Making versus Analytical Decision Making, and March (1991) referred to this as 'exploitation' versus 'exploration'. The realization that NDM is about macrocognition, after all (Schraagen, Klein, & Hoffman, 2008), has spurred new research on the use of these effortful, deliberative strategies that individuals and teams employ to cope with atypical situations.

Conclusion

In this chapter, I have discussed the NDM movement as a framework or perspective that is compatible with the general notions of decision making as put forward by Herbert Simon. In particular, Simon's core idea of bounded rationality and the derived ideas on satisficing and subgoal identification have been elaborated upon in applied areas by NDM researchers. More importantly, NDM researchers have applied these notions to improve and support decision making and training for professionals. By starting with a cognitive task analysis and describing how professionals actually make decisions, NDM researchers have been able to develop decision support systems and training regimes that are compatible with the way professionals use their knowledge and experience. This approach may be contrasted with approaches that attempt to support professionals by starting from a normative perspective and develop support systems and training regimes that in the end frequently turn out not to be compatible with how professionals actually work.

Adaptive systems are being ground between the nether millstone of their physiology or hardware and the upper millstone of a complex environment in which they exist (Simon, 1980). Macrocognition, as what NDM has evolved into, is about adaptation to complexity. It is neither about the physiological constraints on cognition, as this would be characteristic of a microcognitive approach, nor about the environmental constraints on cognition, as this would be characteristic of an ecological approach. We have seen that macrocognition hovers between the two millstones. The future of macrocognition lies in describing the relative invariants that must be sought in the inner and outer environments that bound the adaptive processes. One of these invariants is the way adaptive systems deal with familiar and unfamiliar situations: recognition-primed when dealing with familiar situations, deliberative and analytical when dealing with unfamiliar situations.

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