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Heuristics in Decision Making

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Abstract--Heuristics are simple rules of thumbs for problem solving that follow a logic that is quite different from consequential logic. They have long been regarded, as an inferior technique for decision making that is the source of irrational decision behavior. Recently, decision making researchers have demonstrated that some heuristics are highly efficient and can compete with complex decision models in some application domains. This paper explores the different streams of research, summarizes the state of the art decision making model, and discusses its implications for complex decisions in engineering and technology management.

I. INTRODUCTION

The essence of management is decision making. Success in competitive environments often depends on quality decisions despite huge amounts of information and large numbers of alternatives. Making a wrong decision can cause a company to lose its market or to run out of business. Companies do not only need systems and models to improve decision making, but they also need to counsel humans to improve the ways they think, analyze information and make decisions.

Decision making is centrally concerned with the process by which alternatives are evaluated and options selected for implementation [1]. Decision making can be regarded as an outcome of mental processes leading to the selection of a course of actions among several alternatives. To make successful decisions, decision makers have to clearly define the goals to be achieved, build a mental representation of the situation or the system to be managed, predict or forecast the future and make plans for actions under different situations, while monitoring their own (and the organization's) strategies for gathering and processing information [2].

Decision making is not a one-step process, but a compound process where three components interact with each other: *the decision parameters, the decision making process and the decision implementation* [3]. The process by which decision makers choose the decision parameters they will use to evaluate decision alternatives usually involves cognitive biases constrained by past events and individual cognitive styles [3]. *The decision making process* is the stage where all alternatives are evaluated to produce a final choice. This process can be based on reasoning or it can be an emotional process. It can be rational or irrational and can be based on explicit or tacit assumptions [3]. In the final step, actions need to be planned and *decisions implemented* [3].

For a long time, good decision making was considered equivalent to a rational choice between decision alternatives that is free of biases and emotions. Heuristics, simple rules of thumbs, which are based on common sense and used to solve problems quickly, were considered inferior decision making techniques that result in irrational behavior. Recently, this view has changed and psychological research [4], as well as popular management publications [5, 6], stress the usefulness of simple heuristics.

Drawing from psychological and managerial research, this paper reviews different decision theories that can contribute to our understanding of how to improve decision making processes. It starts with presenting the ideal of rational decision theory (section 2) and by contrasting it with behavioral decision theories (section 3) that are based on the observation of real-world decisions. Section 4 describes decision theoretical approaches, such as the theory of bounded rationality and research on fast and frugal heuristics, that integrate the normative ideal of rational decision making and the observed irrational behavior. This section furthermore discusses recent research on simple decision heuristics in real-world settings. Section 5 discusses the findings and section 6 gives an outlook on future research.

II. RATIONAL DECISION THEORY

Rational decision theory was derived from laws that psychologists believed to be the laws of human reasoning [2]: Decision makers identify the best decision to take by computing, with perfect accuracy, how different decision alternatives will play out. They choose the alternative that maximizes the value of outcomes to them [7]. This choice is based on two assumptions about the future: a guess about the future state of the world which is contingent upon the choice and a guess about how the decision maker feels about the future when he experiences it [9]. In many real-world problems, the exact consequences of the choice are unknown. Uncertainty may exist because some processes are vague at the fundamental level, or decision makers are ignorant of the driving mechanism which makes the outcomes look uncertain to them, or because of dependency on unexpected future events [9]. Uncertainty can be modeled through probabilities.

Rational decision theory relies on an extensive use of logic and mathematical models to represent decision situations. The strength of these rational approaches to decision making is in their rigor. Working within the decision theoretic framework allows one to identify answers and weigh the alternatives within the framework. These approaches encompass a substantial amount of educational content that is straightforward to teach and to test. [8]

Although there are many mathematical decision making approaches, few of them are actually used. Rather than using formal methods or following systematic procedures, managers usually make decisions by reflecting on action or

having an understanding only of the immediate situation and 'surface' appropriate courses of action. Some blame this on the mathematical complexity or time limitation [10] [11], others blame the limited applicability of models [8]. Gerald &Smith [8] found that there are just a few decision situations that managers routinely face, which can effectively be addressed by decision analytic techniques. They attribute that to a lack of sufficient information about problems, alternatives, contingencies and outcomes. Uncertainty is not usually localized in a few easily identified contingencies, but is rather highly diffused [12]. Rational models cannot offer enough assistance in identifying the problem, predicting, measuring, quantifying, or generating alternatives and other elements decision makers need to analyze before making decisions [8]

III. BEHAVIORAL "IRRATIONAL" DECISION THEORY

Behavioral decision research is concerned about how people process information and how they make judgments. Studies in the individual psychology of making choice have identified different cognitive and emotional limitations that bind human rationality and produce systematic errors [9]. At the same time, other research shows that every day decision behavior is "smart" and people can use intuitive techniques to make good decisions. When they are asked about the rational reasons behind their decisions, they use external cues as reasons for their decisions [9, 12, 13], even if they are not sure why they made that choice [9, 14].

In order to make a decision, our brains develop cognitive maps and use them in different ways. The following sections describe how we develop and use these maps and how they relate to simple heuristics in decision making.

A. Insight and Cognitive Maps

Our brains develop expectancy or cognitive representation of "what leads to what" based on knowledge and experience that we have learnt. These representations are called cognitive maps [14]. The knowledge we learn may not be applied and tested until later, when there is an incentive to perform. Psychologists refer to this phenomenon as the concept of latent (hidden) learning [14].

By developing cognitive maps, individuals have their own cognitive styles. Cognitive style is "the way people process and organize information and arrive at judgments or conclusions based on their observations" [14]. Kohler [15] concluded that we, as humans, are able to learn and solve problems by insight which is defined as "the sudden perception to a useful relationship that helps to solve a problem". Other behaviorists define the insights as a combination of previous learned responses [4].

We make decisions subconsciously before starting to perform the analysis [16]. When we face a situation, we summarize it, recognize patterns of similarity between the new situation and what we had experienced or learnt, we fill in missing details based on previous experience and make assumptions. We thus develop a "sense of what counts as relevant" to identify the important cues, the goals that need to be accomplished and our expectations [16]. Recognized patterns include routines for responding and action scripts. Even if the situation is not exactly the same as previous situations we have experienced, we discover significant direction depending on our developed sense to know what will work and what will not, by evaluating the actions in our imagination or "mental simulation" [16]. This process of pattern matching and mental simulation is known as Recognition Primed Decision model (RPD) [5]. Figure1 shows this model.

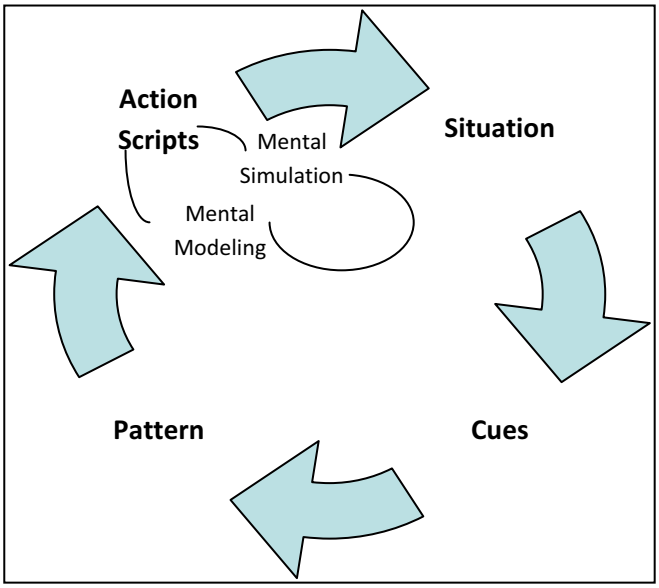

Figure1. Recognition Primed Decision Model [5]

Intuition or "gut feelings" are not based on strategically analytical thinking; instead, intuition resembles a mental map or schema generated out of a cognitive conclusion based on practice, experiences and emotional inputs gained over years and gave the voice of wisdom [17].

Intuition plays a significant role in managers' daily work life especially, when decisions need to be made quickly or unexpectedly, because potential costs are associated with delays, or because of a high level of uncertainty, or because insufficient information pervades the situation. The importance of studying the cognitive style and the role of intuition in decision making increased especially with the increase of rapid and unprecedented change in the business environment where managers needed contemporary decision strategies [18]. Khatri and Alvin [19] found that intuitive synthesis is an important strategy process factor that managers rely on in their decision making process and it helps them improve the organization's performance, especially in an unstable environment. Jon Anderson [20] , who studied problem solving and decision making approaches of 200 managers from eight different companies,

found that 32% of the managers primarily use intuition when making decisions and that the creative and innovative decision making styles were found more often in mangers that combined their intuitions with analytical thinking as an auxiliary. In addition, Burke [17] , found that 40% of managers, in his test, made decisions such as interviewing, hiring, training, scheduling, performance appraisal, harassment complaints, patient care and safety issues based on their intuitions. Intuition helps managers to make predictions in situations where formal decision models cannot be helpful, especially when many changes happen in business environment, under uncertainty, or in situations that need flexibility [17].

We need experts because they have developed many schemas from experience to guide problem solving in their fields; they are much better than novices at recognizing when each schema should be applied [14]. Applying the correct mental blueprint provides a proven route to solve a problem quickly and effectively. Since general heuristics make contact with a person's knowledge base [16], experts depend on their long-term memory, and they can analyze problems deductively, selecting the retrieval cues needed by pulling the appropriate schema from memory and applying them to make a decision or solve a problem. Since novices do not have specialized schemas, they use general problem solving methods that force them to solve a problem in their working memory which is the weakest in the human mind [14]. World chess champion Gray Kasparov has developed chess schemas that enable him to defeat chess playing computers that use logical rules, some capable of logically analyze up to 100,000 moves per second. Only Deep Blue with a weight of 1.4 tons could defeat the schemas in the 3-pound brain of Kasparov [4], [14].

Since we build a cognitive map out of each experience, we face and use it later when we face similar or close problems, psychologists tried to identify the common heuristics we use to solve problems by observing human behavior.

B. Heuristics in Decision Making

Because we seldom know the exact probability that would lead to the best outcome, we tend to apply certain heuristics from judgment of likelihood. Heuristics are "the general problem solving strategies that we apply for certain classes of situations" [14]; they are the rule of thumb for calculating certain kinds of numbers or solving certain problems. They can also be interpreted as rules following behavior that pursue a logic quite different than the consequential logic [9].

In the early 1800s up until about 1970, the term heuristics was used to refer to useful and indispensable cognitive processes for solving problems that cannot be handled by logic and probability theory [21]. In the past 25 years, the definition of heuristics has changed to something that connotes almost its opposite meaning; instead of being useful and indispensable cognitive processes for solving problems, heuristics have come to connote an unreliable method to make decisions. In research on reasoning, judgment and decision making, heuristics have come to denote strategies that prevent one from finding out or discovering correct answers to problems that are assumed to be in the domain of probability theory [21]. "Heuristics and Biases" demonstrated that human judgment has shortcomings and biased conclusions under certain conditions. The naturalistic view sees the decision making process as a "situated activity that cannot be described or prescribed for in general terms" [8]. The Heuristics and Biases theory concluded that human inference is systematically biased and error-prone and suggests that the laws of inference are quick-and-dirty while the laws of probability are not. They accept the laws of probability and statistics as normative, but they disagree about whether or not humans can stand up to these norms [2, 21]. Heuristics and Bias blame this inability of making good decisions to cognitive limitations. One of these limitations is a limit of working memory; where our cognitive system can process, remember, compare and recognize up to seven variables -plus or minus two- at the same time; if we have more variance we become ignorant about what is going to happen [22]. Gay Gould implies that "our minds are not built to work by rules of probabilities" (quoted by Gigerenzer [4] page 94). This Heuristics and Bias point of view, represents the use of heuristics as making decisions that "fly in the face of logic" [14], and they use the term heuristics to account for discrepancies between these rational strategies and actual human thought processes" [23].

The discrepancies between rational decision theory and observed decision behavior, such as the existence of cognitive maps and the use of heuristics, are subjects of an ongoing debate. Increasingly, there is reconciliation and integration of both streams of research, as the following section will demonstrate.

IV. COMBINING RATIONAL AND IRRATIONAL THEORIES

While some models of human behavior (like the rational choice theory) in the social sciences assumes that humans can be reasonably approximated or described as "rational" entities, others, like the Heuristics and Bias theory assume that humans have cognitive limitations that prohibit them from being rational and they are emotional and subjective all the time [6]. Decision makers appear to be good analyzers, learn from their previous experiences and use their schemas efficiently. However, decision makers do not consider all the alternatives, but instead, consider only a few and look at them consequentially instead of simultaneously [9]. Accordingly, studies of decision models in real world show that not all alternatives are known, not all consequences are considered and not all preferences are evoked at the same time [8]. All of these factors helped derive the concept of bounded rationality.

A. Bounded (Limited) Rationality

Herbert Simon pointed out that most people are only partly rational, and are mostly emotional or irrational when they make decisions [24]. His theory is known as the theory of "Bounded Rationality". Bounded rationality is experienced in formulating and solving complex problems and in processing information including receiving, storing, retrieving, and transmitting information [8, 25, 26]. Daniel Kahneman proposes bounded rationality as a model to overcome some of the limitations of the rational-agent models in economic literature [26].

The concept of bounded rationality implies that we cannot feasibly consider the perfect rational decisions in practice to the finite computational resources available for making them. Even if decision makers try to make rational decisions, they will be constrained by limited cognitive capabilities. Therefore, actions may not be completely rational even with the best of intentions and efforts [9]. At the same time, heuristics do not come completely from emotions and against rationality [19], they come from long retained rational experiences that have been saved and previously implemented in our cognitive system [24]. Heuristics are sophisticated reasoning tools based on schemas (or mental databases) that experts hone over years of experience and that help them solve every day problems and make fast and urgent decisions [24].

More research suggests to not ignore the usefulness of heuristics [4,5,6,21,27,28,30] and states that heuristics can help experts solve problems that they face in their domain. Gorgy Polya, a mathematician who researches mathematical problem solving, argues that formality of mathematical proof has little to do with real life problem solving. She describes how decision makers find problem solutions by using heuristics or what she calls "general strategies for attacking a problem that does not guarantee the solutions" [16]. Simon [24] states that intuition is not a magical sixth sense, but a sophisticated form of reasoning, which allows us to think and analyze the situation even if we don't have previous experience and we are not "slaves" to our feelings or intuitions. Klein [5] added that we should treat intuition as a skill that can be acquired and taught.

Gerd Gigerenzer argues that most decision theorists that came after Simon and who have discussed bounded rationality have not really followed Simon's ideas about bounded rationality. Instead, they have researched either how decisions are sub-optimal because of limitations of human rationality, or they have constructed elaborate optimizing models of how people might cope with their inability to optimize [2, 4, 21].

As an alternative, Gigerenzer proposed to examine simple alternatives to a full rationality analysis as a mechanism for decision-making. He, with his colleagues, has shown that, in some cases, such simple heuristics frequently lead to better decisions than the theoretically optimal procedure. These models are known as "Fast and frugal decision models".

B. Fast and Frugal decision models

Gigerenzer and colleagues have identified a new class of cognitive heuristics that can be logically applied. Rather than starting with a normative process model, they started with fundamental psychological mechanisms. The "fast and frugal" techniques that they identified, adaptively match the informational structure and demands of decision makers' environments [25]

Fast and frugal heuristics are simple task specific decision strategies that are ecologically rational because they exploit structures of information in the environment. They are founded in evolved psychological capacities such as memory and the perceptual system. They are fast, frugal and simple enough to operate effectively when time, information and computation might be limited, precise enough to be modeled computationally and powerful enough to model good reasoning [27].

In the classical decision making process, all attributes should be analyzed, scored and weighted for all options. This process can be complex and exhausting for decision makers when the number of options and attributes increase. Because most traditional rational models of inference, from linear multiple regression models to neural networks, try to find some optimal integration of all information available, they take into account "every bit of information." Since decision makers do not usually have sufficient information and time to do such processes, the satisfying algorithms, those who follow the rational theory of probabilistic mental models (PMM), don't search for the optimal solutions, but instead they look for the best solution that would fit with the needs and satisfy the decision maker [2, 28]. In this technique the decision maker, or the computer, need to search their memories for relevant information. They don't have to integrate them, but rather a substitution of pieces of information will be sufficient [2]. One example of such simple heuristics is the Take the Best Algorithm (TTB).

TTB is based on a rule of thumb that we, as human beings, apply in our life: "Try to take the best and ignore the rest." The simple idea of this algorithm is to treat what we know as important, ignore what we do not know and start by testing the most important cues. Once a differentiation is found between the alternatives, stop looking for other cues and choose the alternative that satisfies the tested criteria. A number of psychological experiments suggest that people follow this rule and often base their intuitive judgment on a single good reason [28].

Gigerenzer and his research group have analyzed the quality of results of TTB [4] by asking people to decide which of two cities has a larger population. Employing the TTB algorithms, people would first check if they know one of the two cities. If they do, they pick the one they know. If they do not know either city or both, they search for additional cues, such as "city has a major league soccer team" or "city has a university" until they find one that helps them discriminate between the two choices. In this case, they decide and ignore all other potentially relevant cues. TTB is

thus based on satisfying, rather than optimization: decision-makers choose the first object that satisfies their objectives without surveying all possible alternatives. Gigerenzer et al. tested the algorithm through simulation and compared the results to other algorithms that integrate all information and are considered to be rational. For the simulation, they combined pairs of different cities from a set of 84 German cities to come up with 3,403 city pairs. In addition to the recognition cue, they identified nine cues that had different levels of ecological validity and different discrimination rates. To model limited knowledge of cue values, they simulated classes of people with different percentage of knowledge about cues, which is associated with different values of recognizing objects. They compared the TTB algorithm with other decision algorithms, such as weighted tallying, which weighs and combines all alternatives, and a regression model. They found that TTB algorithm drew as many correct inferences as any of the integration models, including the regression model, and performed substantially better than linear models. Figure 2 shows the results of the six tested models.

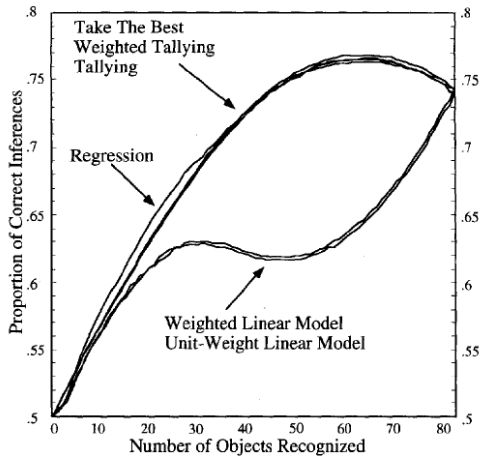

Figure2. The results of TTB algorithm compared with other decision models, TTB performed as good as some cumulated models and outperformed others [2].

Gigerenzer tested TTB again, but instead of predicting the population of a city, he used it to predict the smallest dropout rate in a comparison of 57 high schools in Chicago, Illinois, based on 18 cues [4].

From these two experiments, the simple heuristic of "one good reason", or Take the Best algorithm, proved better and generated faster results than evaluating all reasons in predicting what we do not know. On average, TTB algorithm tested three clues before it stopped searching and picked a choice, which they found to be an acceptable choice. The complex strategies that use all weights and all clues perform better than the TTB when there is enough information about the alternatives and tested criteria but they take a longer time [2, 4].

Gigerenzer explains the reason behind these results as follows: "in uncertain, a complex strategy can fail because it explains too much in hindsight. Only part of information is valuable for future, and the art of intuition is to focus on that part and ignore the rest. A simple rule that relies only on the best clue has a good chance of hitting on that useful piece of information"[4].

C. Researches on other heuristics:

Building on Gigerenzer et al., many studies have tested the efficiency of simple heuristics in decision making. These studies mathematically tested model results and compared them with compensatory mathematical decision models.

Two different approaches are used to assess the quality of heuristics; the first group compares the results of using simple heuristics against commonly used decision models and against logistic regression. Katsikopoulos and Fasolo [29], and Smith and Gilhooly [23] use fast and frugal heuristics to develop multi-attribute models and decision trees to help caregivers diagnose medical conditions and prescribe the right medications. The fast and frugal models have been tested on simulated data, as well as on real cases: Katsikopoulos and Fasolo's model registers a performance accuracy of 72% of the cases, while the logistic regression system achieved 75% accuracy, but took a longer time [29]. Smith and Gilhooly [23] found that their fast and frugal decision model based on matching heuristics achieved almost as good results as the logistic regression model, but was faster and more flexible in making decisions about the medication that should be prescribed for depression.

The second group of studies researched the quality of forecasts that are based on fast and frugal methods. Anderson and Edman [30] tested the fast and frugal method by comparing the performance and information process strategies of experts and non-experts when predicting results in the 2002 World Cup soccer tournament. From this experiment that included 250 participants with different levels of knowledge, they concluded that participants who had obtained a lot of information about the teams did not outperform those who had no such information, because just a slice of information was enough to make good prediction.

In a study on intelligence analysis and early warning systems, Bradley [31] used only three indicators to forecast conflict escalation, instead of drawing on dozens of indicators like the majority of early warning systems. Traditional approaches necessitate access to substantial amounts of data, most of which is highly aggregated and/or of poor quality. Bradley used the results from his "good enough" model to argue that "both the conflict early warning and intelligence communities should consider the value of fast and frugal analysis."

In business forecasting, Astebro and Elhedhli [32] have tested the success of simple heuristics in forecasting commercial success of new products. They tracked the success of 561 projects which have been evaluated between 1989 and 1994 by experts from Canadian Invention

Assessment Program (IAP). They found that a simple decision heuristics (conjunctive decision model) to forecast if early-stage R&D projects are commercialized succeeds in predicting 86.0% of the projects correctly; experts predict 82.6% correct, while a log-linear additive statistical model correctly predicts 78.6%. They tried to link these results to the number of cues used for the forecast and found that the experts' forecasting rules uses 33 out of 37 possible cues, while the model with the best forecast of project success only uses 21 cues. In addition, models that use all cues do not perform as well as those that use a selected set of cues. These results support other researches which call for using less attributes [6], because the use of more information than what they call "optimal" can incorrectly affect the forecasts.

V. DISCUSSION

Even though heuristics can lead to deviations from optimal decisions, recent psychological and social decision research is increasingly interested in decision makers' use of heuristics. Heuristics are rules of thumbs for problem solving [9] that do not guarantee optimal solutions [16]. They do, however, have accuracies close to more complex decision rules and seem particularly useful in difficult decision making contexts [32] especially when there is uncertainty over the future or when we need to make quick decisions [21]. A class of very simple decision heuristics, the so-called "fast and frugal" heuristics, is currently at the center of the academic debate and has found their way into practitioners' literature. They seem to prove that in an unpredictable environment¸ complex problems do not always need complex solutions[4].

Many managerial decisions are highly uncertain and involve a large number of attributes, but many practitioners base their decisions on only a few, mainly financial criteria, such as return on investment [33]. They furthermore do not always use systematic approaches to information gathering and decision making, but often rely on readily available internal information and "gut feeling". At some decision points, the gathering of information for a full-blown multi-criteria decision model could result in long time delays and high costs, and, if decision errors are "cheap" because they will soon be caught at a subsequent checkpoint, it is acceptable to sacrifice decision quality and choose a simpler, fast, and less expensive evaluation method. Simple decision heuristics are therefore potentially useful for some managerial decisions.

VI. FUTURE STUDIES

A complete theory of Fast and Frugal decision making is not available, but formal properties of simple heuristics have been studied to some extent. Future research needs to adopt the simplicity and problem solving qualities of fast and frugal heuristics and develop fast and cheap decision models that fill the need of managers in many areas.

One application area of great practical relevance is the fuzzy front-end of new product development, which consists of a series of decisions. Many decisions are highly uncertain and involve a large number of attributes, but many practitioners base their decisions on only a few of them [33]. Many practitioners express dissatisfaction with the front-end process [34, 35], which is presently not fast and not successful enough. An in-depth study of the potentials of simple heuristics in the fuzzy front end is required. I will allow us to answer the following research questions: How do expert managers in the fuzzy front-end make decisions and what are the heuristics they use? Are there simple non-compensatory selection heuristics that can be effectively used in front-end decisions? Can we develop decision aids for the front-end that are based on simple heuristics and achieve good decision results?

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