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Rationality for Engineers

Part II- Heuristics and Biases

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ABSTRACT

Two major research programs on the use of heuristics in decision-making exist, and each has its own set of followers. The first program was initiated by Kahneman and Tversky in the 70s. They primarily concentrated on the errors caused by using heuristics. This has now grown into many heuristics named after their associated biases. The second program was initiated by Gigerenzer and colleagues in Germany. Gigerenzer argues that although simple heuristics sometimes leads to "biased" decisions, they can deliver better answers in some situations. This is particularly true for uncertain or complex environments, where there is only a small data sample or there is no time to formally seek an optimized decision. Gigerenzer and colleagues have generated a substantial body of evidence that humans use simple heuristics, often with great results. Like Kahneman and Tversky, Gigerenzer's work has attracted researchers exploring the power of "Fast and Frugal" Heuristics, and how they are used by humans. This part, of the four-part paper, discusses Kahneman and Gigerenzer's findings concerning engineering decision making. Avoiding errors when using simple heuristics is discussed in Part IV.

1. Introduction

There are two ways that thought can enter the brain; one is through structured calculations, which is thinking in stages and applying rules; this is termed "Type 2". The second comes through perception and intuition, which is termed "Type 1". When you see a woman with an angry expression you can tell she is angry as easily as you can tell she is wearing a red dress. Perception predicts using patterns and this is closely linked with intuition. If you are asked the results of the multiplication of two long numbers, you need to follow the rules that you have learned. These are the two types of human thinking. Engineers as experts primarily use Type 1 thinking; it comes about by reinforced learning. If a situation is multi-faceted or complex, Type 1 thinking is not very useful. Perception, intuition, and practiced skills are type 1 thinking. For example, for driving a car or understanding languages, Type 1 will be more appropriate. Type 1 allows functioning within a complex environment and with conflicting information since it ignores much of the information. Engineers particularly populate their brains with rules required for Typ1 thinking and gradually refine them by feedback accumulated by their use. So that they do not need to labour on every decision, just the high-value ones. Mistakes happen when there is a mismatch between perception and reality. Perception is influenced by culture. For example, two distinct perceptions of social events exist, people from the east provide a behavioural explanation, while people from the west favour situational explanation.

Tversky and Kahneman's (1983) work led to the development of the above dual thinking mode termed the 'Dual-process Model". The dual concept encompasses a variety of theories with different approaches to the processes involved in thinking. These two co-existing processes have also been named "System 1" and "System 2" [21,31], intuitive and deliberative [35] associative and rule-based thinking [36], and fast and slow thinking [19]. Researchers who originally coined System 1 and System 2, now use Type 1 and Type 2 processes instead.

Kahneman's concept of thinking fast and slow [19] postulates that humans have two modes of thinking: a heuristic (intuitive) mode that is fast to act, and another mode that is slower, and more deliberative. The latter is the kind of thinking encouraged in critical thinking tests. The dominant "fast-acting" mode usually serves the decision-maker well enough, as it helped our foraging ancestors to survive, so it has become embedded in our thinking processes. Fast thinking is effortless, associative, and experience-based. While slow thinking requires effort and the use of cognitive resources; it also uses symbolic and abstract rule manipulation. Not all fast and intuitive processes are genetically embedded but learned. In learning to drive one acquires a host of heuristics necessary for confident driving, such as assessing speed, keeping distance, etc. Engineers also learn quick intuitive responses that are reliable. However, on some occasions, when probabilistic reasoning is required, this fast and intuitive reasoning can lead to an erroneous (or biased) decision. These biases have been identified in a wide range of experiments by cognitive psychologists [19].

The concept that people have two co-existing, but separate sets, of decision-making processes, is described by Kahneman [19]:

System 1: This is impulsive, fast, emotional, and acts without deliberation – but relies on heuristics and past knowledge/experience.

System 2: This is a more cognitive, deliberate, thinking process that can take in a greater range of data than just our own experience.

This suggests that if our impulsive nature reacts strongest, this may lead individuals to pursue irrational decisions. For example, 'impulse buys', 'jumping to conclusions. *"Jumping to conclusions is efficient if the outcomes are likely to be correct and the costs of an occasional mistake are tolerable. But it could lead to a risky outcome when the situation is unfamiliar, or the stakes are high* [19].

We need System 1 to function, to free up some of our limited cognitive ability to permit more involved decisions. Without it, tasks such as driving would be very trying. Heuristics and cognitive error are especially relevant when responding to emergencies. In such a situation it may be a struggle to balance efficiency and accuracy, especially in large emergencies that require many fast decisions.

People who originated the idea of System 1 and System 2, abandoned this naming convention in favour of Type 1 and Type 2 to avoid giving the impression that the two systems are operating independently in the brain.

Engineers must think to earn a living. What they know matters, it is not just abstract reasoning. They may carry expertise from one field to another (causal knowledge) which is known as lateral thinking. Each engineering community has developed its own rules and best practices which are primarily experienced-based. Even if they are analytic, they are backed up by proof of the concept in practice. This is the wisdom of the crowd of well-practiced engineers. Here, the term crowd does not mean mob, rather a collection of diverse and informed (albeit partially) people where everyone thinks independently. When the problem is complex, rules are vague, and the environment is uncertain such a crowd performs better, however not unconditionally.

2. Biases Program

Herbert Simon [32] posed the question of how humans make decisions under uncertainty, limited information, and time constraints. He formulated a heuristics decision-making model which he called "Satisficing" [44]. Amos Tversky and Daniel Kahneman in the 1970s linked heuristics to cognitive biases. Their research is known as the "Heuristics and Biases Program". Psychologists and philosophers identified heuristics that were used by humans to make decisions in the past. The original ideas by Herbert Simon[32] were also taken up in the 1990s by Gerd Gigerenzer and others, which is further discussed in the next section.

Heuristics can lead to cognitive biases. What others call heuristics, Kahneman calls biases [19], i.e., he named heuristics by the biases they cause. Kahneman in his book lists 97 cognitive biases and explains how they could happen but does not explore why. In the following, some of the most common biases are described, and a longer list (but not exhaustive) is given in the Appendix to this part.

<u>Confirmation Biases</u>. These biases favour information that confirms our already held beliefs. These biases impact the way we gather information, namely, we only gather evidence [42] that supports our previously held opinions. They also influence how we interpret and recall information. For example, people will interpret news stories in a way that upholds their existing views. They will also remember details in a way that reinforces their attitude. During the election season, for example, people tend to seek positive information that favours their candidates. They will also look for information that casts a shadow on the opposing candidate. By not considering facts objectively, interpreting information incorrectly, and only remembering details that uphold our beliefs, will often lead us to miss important information. A divorcing couple only remembers the bad feeling of the last few months of the divorce proceedings, not the many happy years they had together.

"Till death do us part" is a common phrase exchanged between the bride and groom at a Christian wedding, indicating a commitment to their union. The confirmation bias when takes root has a promise of till death do us apart and getting rid of them is as traumatic as getting a divorce.

Galen was a renowned physician of Greek origin during the times of the Roman Empire (c. 130-210 A.D.). A famous quote attributed to him is a good example of confirmation bias. "*All who drink of this remedy recover in a short time, except those whom it does not help, who all die. Therefore, it is obvious that it fails only in incurable cases*." We hear the same blind confidence when engineers talking about failure "My design is explosion-proof, and it undoubtedly works. Except when it does not. And, when that happens, it is not because our thinking is flawed, it is the fault of others who didn't follow the intention."

Confirmation bias serves as an efficient way to process information primarily due to the abundance of information humans are exposed to. A few common types of confirmation biases are:

- Biased Search for Information
- Biased Interpretation
- Biased Memory
- Biased Information Processing

Cognitive dissonance also explains why confirmation bias is adaptive. Cognitive dissonance is a mental conflict that occurs when a person holds two contradictory beliefs which cause psychological distress. To minimise dissonance, we adapt to confirmation bias by avoiding information that is contradictory to our views and seek evidence confirming our beliefs.

Representative Heuristics. The perceived likelihood that an object belongs to a particular group is based on how well that object is thought to represent it. Representative Heuristics occur when we believe the probability of an event occurring is based on a perceived similarity with another event. An example of a Representative Heuristic can be seen in "judging a book by its cover", which is an adage that warns us not to assume that similar packaging of a product or an idea will result in the same good outcome, as people tend to associate quality with the packaging, i.e., how it is presented. For the same reason, generic brands package their products to resemble well-known brands. We look for a similar situation we have seen before or similar decisions we have made in the past. Presentation is taken as the quality based on the similarity in packaging.

Using Representative Heuristic, an engineer's decision can be biased by failing to consider relevant and potentially critical evidence. For example, an engineer when predicting the outcome of an event may forget to consider the prevalence of that event. This bias may work differently when considering rare events with a small sample, compared to more common events where there may be larger numbers of atypical samples. This would lead to underestimating the likelihood of a very rare event, perhaps to the extent that thinking they are improbable. Representative bias directs an engineer's attention towards trusting in sets of information that appear to be more consistent. For example, some may believe that in a coin-flipping exercise a heads-and-tails sequence like THTTHT is more likely than TTTHHH because it appears more random [46]. Paraphrasing Popper looking for data to prove yourself wrong is a good way to come up with the right decision. Probability calculations are not like counting apples in a basket.

Affect Heuristics: This heuristic typically involves fast feelings based on prior beliefs. i.e., positive, and negative feelings are associated with certain stimuli in the brain. It happens when feelings take over the process of thinking [47]. The idea behind it is that an emotional response to a stimulus can affect the decision made. When people have little time to reflect and evaluate a situation thoroughly, they may base their decision on their immediate emotional reactions. The Affect Heuristic focuses on eliciting an automatic, fast, and reactionary response.

Advertisements can influence an emotional response, thus affecting purchase decisions. Fast-food companies design their ads to elicit a positive emotional response, that encourages people to view their products positively. People rarely take the time to evaluate the risk and benefit of everything that they see, and often the automatic, emotional response will dominate. Fast-food chains exploit the Affect Heuristic to create a positive emotional response towards their product [48].

Another name for this heuristic is "going with your gut", which causes emotions to influence decisions and perceptions of risk or reward. If you have good feelings about someone e.g., a politician, you are more likely to accept what they say is true, without fact-checking.

Availability Heuristics: This heuristic is about making judgments of the likelihood of an event using information that comes quickly to mind and acts as emotional tagging. In making decisions people typically rely on prior knowledge of an event; mostly they remember such an event. Thus, they tend to overestimate an event's likelihood simply because it comes quickly to mind. Such heuristics allow us to make decisions fast, but their accuracy may be questionable. However, this heuristic prevents us from considering alternatives.

Causes of bias may be the differences when retrieving from memory for different instances. For example:

- ✓ Salience (the probability of a car crash appears higher right after we have seen one).
- ✓ Familiarity (after being given a list of names of celebrities, we will tend to base our estimate of how many were male based only on the better-known among them, whom we can recall more easily).
- ✓ The relative ease of different search modes.
- ✓ Anything which requires the correct application of rules of probability.
- ✓ Seeing correlation when there is none.

✓ More publicized, disease events and products are easily recalled.

Availability Heuristics can be useful and accurate in many situations, however, if we can think of a similar situation that ended unfavourably, we are more likely to be cautious.

Two burglaries in your vicinity could change your view on the likelihood of being robbed. The experience of seeing an event may make accidents more vivid in your memory, thus making them seem more probable. However, the probability of an accident in one place is not increased by seeing one in another. Probably "seeing *is believing*".

Anchoring and Adjustment: Engineers often make an initial estimate (guess), based only on one part of the available evidence, and then adjusting it for the rest of the evidence. However, more often the initial guess is very stubborn, and the adjustment process seems to be sluggish, i.e., the initial estimate will not be altered by much. Once we reach a value that we deem plausible and believe to be reasonable, we stop adjusting. Thus, decisions with different starting points will yield different outcomes commensurate with the initial estimate. In a situation with limited information anchoring has the most influence.

An adage says, "don't drop anchor in the ''mockery'' of the past errors". Social ranking is another type of anchoring caused by believing that the truth comes from people who rank above us, while truth can come from both above and below.

Anchoring bias is frequently used in negotiations. You are in a car showroom, and you see a car you like. The showroom has priced the car at $32,000 but is prepared to sell at $28000. After discussing the details of the car, the salesman makes an offer to the customer of $30,000. This is the anchor. The customer hears the $30,000 price and thinks 'oh, that's way out of my price range'. However, at the same time, the customer has anchored their valuation of the car to $30,000.

The salesman then says, 'There is a promotion today, I can make a deal especially for you, I will go down as low as $28,000 if you buy it today.' The customer thinks 'That's an excellent deal, it's a bit out of my price range, but I can't miss out on this offer. Since he has anchored your price expectation at $30,000, anything below it sounds like a bargain. Street vendors and merchants in bazaars are highly skilled at anchoring their customers.

Don and Dan were two brothers who owned a gentleman's attire shop. Don's job was to look after the customers in the front, while Dan always busied himself with the accounts and orders out the back. Don helped customers to find a suit that they liked. When a customer inquiry about the price; Don shouts, "Dan what's the price on this suit?", Dan shouts back "which one?", Don says "the double-fronted blazer with gold buttons, matching trousers, and waistcoat in size 36." Dan shouts back "$825", and Don asks again "how much did you say?"; "$825" shouts Dan in a louder voice. Don tells the customer "$625". The customer heard $825 from Dan; however, the shop was willing to sell it for $525. But the customer is anchored and thinks $625 is cheap. Hence, the customer quickly pays up thinking he has got a bargain.

Simulation Heuristic is present when you are imagining how various scenarios will unfold. People often imagine how a conversation will go, or how they will be treated by others they meet, or what their friends or boss will think. These simulations, like movies in our heads, help us prepare and do a better job when the moment arrives. But they can also lead us to mistaken expectations. People may not react as we imagined, things may go in a much different direction, or we may misread the situation. Our preparations may fail because the outcome of our simulation has misled us into thinking that things would have to go as we had imagined.

Mental Accounting. Another name for this behavioural bias is the "two-pocket" theory. Some people mentally put their money into separate categories, namely dividing them into different mental accounts, depending on their source, or the intent of the account. A $10 lottery win may be ladled as "windfall" and earmarked to buy more tickets. In other words, putting different values on the same amount of money, based on subjective criteria. Regardless of the origin of the money or intended use, all monies are the same. To avoid this mental accounting bias, we should think of money as money when allocating it between our different accounts, be it for food, holidays, or savings.

Hindsight: Causes people to convince themselves after an event that they had accurately predicted the outcome before it happened. This can lead people to conclude that they can accurately predict other events. In hindsight, everybody is an expert, and we knew all along what would happen. When there is no expert, then everybody is an expert. When things go wrong (especially in emergencies), expert witnesses, peers, and senior colleagues often blame someone for not seeing the writing on the wall, forgetting that it was written in invisible ink and only became visible after the event.

Though engineers are not gamblers, they do share some of a gambler's optimism. According to Kahneman's theory of lottery [19], gamblers use different heuristics such as Representative, Availability, Anchoring, and Adjustment, and Framing of Decisions to select their lottery numbers. The Alternative Cognitive Theory of gambling emphasizes the gamblers' irrational beliefs according to *"entrapment, belief in hot and cold* *numbers, unrealistic optimism or perceived luckiness, superstitious belief, an illusion of control, near miss and a few more.*" [1]

3. Fast and Frugal Heuristics

Another heuristic program headed by Gigerenzer and colleagues in the 1990s took up Herbert Simon's idea [32]; they called it "Fast and Frugal Heuristics". According to their perspective, the study of heuristics requires formal models that allow predictions of behaviour to be made *ex-ante*.

Their program had three aspects:

1. What are the heuristics humans use? (The descriptive study of the "adaptive toolbox")

2. Under what conditions should humans rely on a given heuristic? (The prescriptive study of ecological rationality)

3. How to design heuristic decision aids that are easy to understand and execute? (the engineering study of intuitive design)

This program has shown that heuristics can lead to fast, frugal, and accurate decisions in many real-life situations, characterized by uncertainty. Fast and Frugal Heuristics, as defined by Gigerenzer [10] and Gigerenzer and Todd [13], are simple, task-specific decision strategies learned by experience. They do not require much information and do not involve appreciable computation. Fast and Frugal Heuristics consist of three building blocks which are:

- The way that information is searched for (the search rule).
- When the information search should be stopped (the stopping rule).
- How the processed information is integrated into a decision (the decision rule), and how to choose between two or more options.

"*Judgment and decision tasks are often too complex to be tractable even if time and cognitive capacity were without a limit*" [13].

Gigerenzer has built on Simon's [32] concept of bounded rationality. Simon [32] noted that "*people generally do not have the time, available information, or cognitive ability to optimize*". Simon [32] proposed the notion of bounded rationality as an alternative to optimizing normative models, suggesting that the quality of people's choices should be evaluated in a less "*black-and-white manner according to how reasonable the choices are given realistic constraints of the situation*" [32]. He proposed simple rules of thumb (i.e., heuristics) as a normative alternative to optimizing models of rationality - in his case, "Satisficing", a heuristic that involves choosing the first option that meets one's minimum criteria.

Simon [33] wrote: ''*Human rational behaviour is shaped by scissors whose two blades are the structure of task environments and the computational capabilities of the actor''*. This is equivalent to stating that rationality not only depends on internal criteria but also on the structure of the environment. This notion of ecological rationality looks at human rationality as the result of the adaptive fit between the human mind and the environment [12]. Ecological rationality is a special version of bounded rationality, which focuses on two questions:

1. What are the environmental regularities, and how frequently do they change?
2. How well can people adapt their use of specific strategies to a particular environment?

According to Gigerenzer [10], ''*The basic tenet of ecological rationality is that the rationality or irrationality of a judgment can only be decided by an analysis of the structure of the environment or the experimental task''*. That means that "*ecological rationality is about the fit between a particular heuristic and the environment within which it is applied*" (14). This view suggests different heuristics should be considered in environments with different informational structures [9]. Whether a heuristic is effective depends on how well it fits within the environmental information structure, that is, the ecological rationality. Ecological rationality does not mean that heuristics are good or not, but if they are useful relative to the environment. Thus, their success depends on how well they match the structure of a given environment [11].

Gigerenzer's vision of heuristics, which he calls Fast and Frugal Heuristics (FFH), "*begins with the assumption that the processes people use to make decisions are matched to the environments within which they make these decisions''* [10,33]. This concept is based on the hypothesis that there is a relationship between heuristics and the environments within which they are used. For example, if an FFH performs well in a particular environment, then people tend to use that heuristic within that environment; or if a heuristic is in wider use, then environments that favour that heuristic will tend to be also ubiquitous. Though these assumptions are not universally correct, adaptive assumption serves as a useful starting point for hypothesizing heuristics that people use in each environment [12]. Thus, it can be assumed that heuristics are adapted to the environments within which people find themselves, letting them make fast and effective decisions, even if there is a limitation on available information and cognitive capacity.

Gigerenzer & Todd [13] named the range of "*available heuristics as the mind's, 'adaptive toolbox', from which one can select the best tool, or strategy, for a given task in an uncertain world*." For example, the Recognition Heuristic is frequently used with reasonable outcomes, as a rule of thumb [27]. Goldstein and Gigerenzer [14] asked students in the United States and Germany: *"Which city has more inhabitants, San Antonio or San Diego? Given the differences in background knowledge about American cities, one might expect that American students would do much better on this task than German students. Most of the German students did not even know that San Antonio is an American city*." Goldstein and Gigerenzer's [14] findings were the opposite of what one would expect: "*Whereas about two-thirds of the American students correctly inferred that San Diego has more inhabitants than San Antonio, all the German students got this question correct. How could this be? The German students' lack of recognition enabled them to use the RH, which, in general, says, "If one of two objects is recognized and the other is not, then infer that the recognized object has the higher value concerning the criterion." The American students could not use the RH because they had heard of both cities; they knew too much. This heuristic cannot be applied if the options are both known or both unknown*."

The RH allows for fast decisions and yields reasonable decisions in many environments because recognition is often systematic rather than random. Domains in which the RH works well include sizes of cities, performances of tennis players in major tournaments, or the productivity of authors. Conversely, the RH does not work well when, for instance, cities are compared concerning their mayor is male or female or comparing the average seasonal temperature.

Complex methods, use tools from logic or statistics that fuse many pieces of information, weighting them according to their perceived importance. It is not difficult to find a specific task for which a simpler method has an advantage over a more complex method. These simple heuristics rely on the concept that **less can be more**, like when a simpler decision strategy outperforms a more complex one or having fewer options leads to appropriate decisions [29]. This **less is more** is akin to the concept that humans do not maximize (i.e., consider all options) but rather 'Satisfice' (i.e., consider one or a few options to reach an acceptable, solution rather than the optimal one [32]. Evidence against pure rational behaviour which supports the less-is-more concepts has been found in many other decision situations such as medical treatment decisions [41]

Take the First (TTF) Heuristic [16]. According to this Heuristic, engineers ''rather than exhaustively generating all possible options and subsequently processing them deliberately [18], simply pick one of the initial options generated. In other words, the heuristic relies on the quality of options that comes to mind spontaneously.

Take the Best Heuristic (TTB). This Heuristic describes searches for cues in the order of their importance. TTB is a Cue Based Heuristic that does not use information integration to make an inference, but bases decisions on single cues. For example, when inferring the size of a city, the decision-maker could consider cues such as whether a city has an airport, a railway station, or is on a major bus route. TTB's search rules look for the cues based on their importance. The best choice should outperform relatively all other choices for the specific cue used. The search stops when one object has a higher positive cue value relative to all other choices. The validity of a cue is taken as the probability of making a correct inference under the condition that the cue discriminates, which means, one object has a positive cue value, while the other object a negative cue value. The search is halted when a cue is found that discriminates so that only one single cue is considered. Otherwise, the next-most valid cue is considered. According to this decision rule, the object that is favoured has a higher criterion value. If no discriminating cue can be found, then TTB takes a random guess. The cues within the heuristic are learned adaptively, as they are the most ecologically valid, and a range of simple heuristics are developed for different situations.

Conan Doyle said through Holmes "I never guess. It is a shocking habit - destructive to the logical faculty". But an "educated" or "inspired" guess is one of the tools in the tool bag, and like any other heuristic, if used in the right environment has a chance of success.

Research on Fast and Frugal Heuristics [4] has produced a significant amount of evidence showing that heuristics can often perform very well, by using just a fraction of the time and data., as they are designed to solve tasks and fit better. The heuristic tool bag of each engineer reflects his/her experience and is domain-specific. By focusing only on relevant pieces of information, heuristics may become portable from one situation to another. Heuristics may be the only tool for undecidable.

The difference between Kahneman and Gigerenwiser often appears to be framing rather than substance. The debate revolves around whether "biased" decisions are an error or "irrationality".

These Fast and Frugal Heuristics often fail the test of logical coherence, as pointed out by Kahneman. Gigerenzer and Todd [13] argue pursuing rationality, as an ideal, misses the point that much of our reasoning is powerful and accurate despite not being logically coherent. Gigerenzer and Todd [13] wrote "*we should replace the coherence criteria with an assessment of the real-world environment and heuristics are the way the mind uses to respond to the structure of the environment, i.e., ecological rationality, which is a* *result of the interaction between the heuristic and the environment*."

4. Heuristics for Dealing with an Emergency

The limits of human rationality in decision making as discussed in Part I [44] become more apparent when time is limited and the pressure to act is high. However, knowledge about decision biases can improve emergency management. Simon's bounded rationality [32] concept is more visible during an emergency as it requires engineers to make critical decisions with limited information, time constraints, and often under high demand, and in an environment that is marked by multiple, often conflicting goals, such as resource allocation and priorities as well as preferences.

Natural disasters such as hurricanes, earthquakes, and floods have occurred frequently in recent years. Emergency supply chains are generally formed in response to the needs for the collection and distribution of relief supplies to the affected areas. This is different from commercial supply chains that are perfected by trial and error. In addition to the high expectation, emergency supply chains face challenges such as high expectations, poor information, inadequate communication, uncertainties in network capacity and coverage, limited resource availability, lack of coordination, and a frequent last-minute change of priorities in the shipment content, quantity, and destinations. A similar situation arises in other disasters, such as oil spills, large-scale offshore fires & explosions, aircraft crashes, and so on which require a different approach due to being localized.

Fast and Frugal Heuristics are useful tools when dealing with emergencies since they exploit evolved or learned human capabilities. Fast and Frugal Heuristics are task-specific decision strategies, and they are part of a decision maker's toolbox of cognitive strategies for decision making within a particular environment, which are adequate relative to the structure of that environment. Fast and Frugal Heuristics are composed of simple building blocks that specify how information is gathered, and when enough is gathered, the collected information is processed to develop robust decisions.

The adverse impacts of a disaster can be substantially mitigated if during the disaster accurate information regarding the available volunteers can be gathered, and victims' locations can be determined on time, enabling a well-coordinated and efficient response. This is more visible when there is a spike in requests and public resources are limited. The mismatch between victims and volunteers represents a challenge. Thus, it is important to improve the emergency services' coordination to enable them to efficiently share data, coordinate efforts, allocate the limited resources equitably and offer guidance on optimal resource allocation. These are outside of this paper's focus. The problem of resource coordination has attracted the attention of optimization researchers, and several algorithms on data mining approaches have been proposed to address this problem.

This complex nature of disaster makes it difficult to execute a recovery plan. It is not always possible to plan and optimize response for *every part* of a disaster area. In these situations, heuristics provide an optimal decision-making tool. In the following, a template is proposed for the management of emergencies, without the need to expend significant resources. The first step is to differentiate between critical and acute needs. It is beneficial to view these heuristics as a checklist for planning optimal disaster recovery.

1. *Evaluate the situation and your resources*. An inventory check should tell you if you can match the demand, or where, when, and how much additional resource is required.

2. *Visibility of response status* - Stakeholders should know which stage of the process they are involved in, what they are required to do, and what outcome their actions will have. The point of contact for most stakeholders should be identified.

3. *Match between response and the disaster*. The system should "communicate" to the stakeholders in a way they understand. The flow of processes should be commensurate with the situation on the ground, and stakeholders should be able to readily understand what is going on.

4. *Ready to change course*. Responders should be ready and able to undo mistakes.

5. *Consistency and standards.* Do not initiate changes unless you have a strong reason to do so, and then make your reasoning obvious to others.

6. *Error prevention.* Vigilance to spot errors *before the field agents do*. If this is not practical, then decisions should be validated in real-time.

7. *Recognition does not recall*. Make actions as intuitive as possible, without requiring the responder to remember instructions from a previous operation or consult their field manual.

8. *Flexibility and efficiency*. Allow responders to tailor the response as they see fit. To improvise

9. *Help the responder to recognize, diagnose, and recover from errors*. Clearly describe possible pitfalls, pinpoint the problem, and offer a solution.

10. *Monitor, review, and amend*. Collect data from the field agents and review it continually. Cross-check information from various sources to detect biases and propose corrective action if necessary.

Good communication is vital in an emergency. You never know what goes on in somebody's mind. When you attribute a belief or an opinion to others, most probably you hold that belief yourselves. Every action may become comprehensible if meanings are attached to it.

Emergencies are “natural laboratories of errors” because of the number of decisions, constant need to switch between tasks, high emotional and cognitive loads, frequently hopping between demands by field agents, and sleep deprivation. Such high demands make emergency responders particularly vulnerable to cognitive missteps. Furthermore, there are limited opportunities for feedback on many emergency decisions, and the lack of feedback makes it challenging to calibrate one’s decision-making process, which is a prerequisite for Adaptive Heuristics.

5. Conclusions

The brain does not faithfully transmit what you see. It provides you with an edited version which is a loose definition of what is going around you. The brain fills in missing information and gaps and serves you on a “need to know basis” without a controller to determine what you need to know. You need to be aware of this. Memories are pieces of information that the brain stitches together and sends to you when it considers they will be useful; they have more functional value than accuracy. Memory works like an archaeologist with scant information, just a piece here and a piece there, filling in the gaps by guesswork.

Two major heuristic research programs have been discussed, and a few common heuristics are explained in this part of the paper. The errors associated, and ways to guard against them, are presented briefly here, with a detailed discussion in Part IV [46]. The disciplined use of heuristics, considering their limitations and applicability, was also emphasized.

Heuristics are useful when used appropriately but can lead to biases in judgments. The important thing is to be aware of the bias. The dual representation of human decision-making assumes two types of thinking processes working together; one is fast and impatient, and the other slow and more deliberative. Type 1 replaces ambiguity with automatic guesses, mostly by pre-conceived stories. It creates stories that sound coherent and vivid, but no data to support them. Type 1 suppresses ambiguity by making stories from scanty data. Type 2 is the sceptic within, it weighs pros and cons, questions conclusions, and suspends judgment until a proper foundation can be established. When Type 1 thinking jumps in and makes mistakes, the Type 2 thinking process will slow us down and provide alternatives. We see the world much more coherently with Type 2.

Engineers are expected to think on their feet and appear on the scene ready and tooled up to deal with the situation; possibly while the situation still unfolding, such as during an offshore fire. A car mechanic checks how an engine is running, opens it up, fixes the engine, and puts it all back together so it works as well as new. The engineer is expected to do all these while the engine is running.

Although much of this part focuses on the way that heuristics can cause errors, most of the time, heuristics can provide substantial advantages, even though they may occasionally lead to error. For example, the Availability Heuristic, which directs us to follow the most immediately workable alternative, undoubtedly reflects the fact that an emergency demands fast decision-making more than perfect judgment. Non-optimal solutions often carry significant benefits, even though they may interfere with an accurate assessment of some situations.

There are no great differences between the two programs. Gigerenzer embraces heuristics with enthusiasm, while Kahneman is more cautious and gives a long list of errors arising from the unchecked use of heuristics. The primary emphasis of this article is the dual processing mode. Biases and heuristics have a substantial literature and research base. Their importance for engineers cannot be overestimated. For a quick reference, MacFarlane and Leigh (2014 25) provide a summary and brief description of the main ones that affect situational awareness and decision-making in crises, with a description of their main effects. A range of tools is described by MacFarlane [26] and MacFarlane and Leigh [25].

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Appendix

Cognitive biases and their impact on the risk management process

Bias	Definition	Problems or Flaws??	How to Avoid
Anchoring and Adjustment Bias [5, 39]	Relies on an initial piece of information but fails to adjust the conclusions sufficiently considering new information.	The framing of questions/interactions with leading information can anchor the decision-maker to that information. By using a starting point, DM may simply scale up or down from that initial position.	Avoid putting too much emphasis on a particular information time. The world dynamic is fluid and a compelling story a year ago might not be compelling anymore.
Affect Biases [6]	The tendency to use the incidental and integral emotional experience as the basis for decision-making.	DM uses emotional cues as salient and relevant information. DM also uses emotional cues when objective and emotional evaluations diverge.	The Affect Heuristic happens when you make a gut decision based on some sort of "feeling". To avoid this, you should apply quality controls in a systematic, consistent, and rigorous way.
Availability Bias [28, 38]	A tendency to use information that comes to mind quickly and easily. Assigning more importance to the information that one can recall easily. This heuristic is the core cognitive function of saving mental effort.	Undue influence of recent event(s) when estimating the likelihood of events because DM remembers this but not all past events. The availability heuristic describes behaviour that results from numerous shortcuts that our brain makes to process all information.	Awareness helps but cannot change one's thought process, it is essential to support and implement policies that recognize this heuristic in formulating a decision.
Attribution Bias, [38]	A tendency to blame others when things go wrong, instead of objectively analyzing the situation. Particularly, you may judge someone based on a stereotype or a perceived personality flaw.	In a car accident, when the other driver is at fault, you are more likely to assume that he/she is a bad driver than you rather than bad weather. A tendency to place blame on external events. If you have a car accident that is your fault, you are more likely to blame the brakes or the wet road rather than your reaction time.	Look at situations and the people involved in a non-judgmental way. Use empathy to understand why people behave in the way they do.
Base Rate Neglect [37].	Assessments of probabilities are based almost exclusively on new evidence, without adequate consideration of base rates.	This is a fundamental flaw in reasoning, resulting from our innate weakness in analyzing complex probability problems. It is an example of where our intuitive judgments or instincts can lead us astray.	This is due to assessing the likelihoods and subsequent probabilities ignoring the conditional probabilities. Make a habit of considering all relevant data. Understanding base rate neglect and the probability theory can help
Bandwagon Effect [15]	Individuals conforming to the majority opinion, believing in the crowd's wisdom.	Face-to-face interactions among group decision-makers could have coercing effects in voicing dissenting opinions or overrule the loudest voice in the room.	Conder the possibility that everybody could be wrong.
Choice-supportive Bias [3]	Recalling positive attributes more than negative ones when reconsidering past choices. Avoiding looking confused or wrong.	Selectively searching memory for information that supports the decision rationally and ignoring evidence to the contrary.	Regularly introduce new perspectives. Involve another expert halfway through.
Confirmation/my side Bias [15].	Evidence and information are interpreted to support current notions and expectations.	Strongly held beliefs and expectations, or when DM is made privy to the predetermined objectives and desired outcomes.	Do not interpret ambiguous information as supporting your position, and do not use it to construct a story. (This can also be called Reinforcement Theory).
Conservatism in Belief Revision [7].	Reluctance to revise one's opinions relative to Bayesian probabilistic predictions contrary to the evidence.	The tendency to favour prior data over new information. DM can be slow or reluctant to revise the initial judgments and may ignore the true value of any new evidence.	Explore the ways to refute the story that you have constructed rather than seeking to prove it.
Distance Bias [17]	The tendency to favour people who are closer to us in space and time. Out of sight out of mind.	People may unconsciously perceive someone that is not within proximity to them is of a lesser value, which can impact decision-making processes	Collect evidence as to the merit of people around you as well as at a distance.
False Consensus Effect [30]	Also known as Consensus Bias, is thinking your own behavioural choices and judgments are quite common and appropriate to existing circumstances. That is assuming that your personal qualities, characteristics, beliefs, and actions are relatively widespread.	False Consensus can occur when incorrectly believing that most peers agree with the decisions. These put people who are working in a remote location at a disadvantage. Believing incorrectly how well one's opinions align with the others.	Consider diversity; people are more different than we think.

Framing Effect [24]	Deciding based on how the information is presented, i.e., positive, or negative cues.	Decisions are made based on how the information or potential outcomes are expressed, not on objective probabilities.	Re-phrase the question. Look at the problem from a different angle. Remove some information and see if you reach the same decision.
Gambler's Fallacy [36, 37]	Believing that an event that has occurred recently is less likely to be random, i.e., assuming there is a correlation between independent trials	DM may misinterpret the likelihood of an event(s) that has recently occurred and ignore the element of chance.	Acquaintance with laws of probability help to avoid this bias. Make sure that you look at trends from probability vantage.
Illusion of Validity [23, 38]	Exhibiting unwarranted high confidence in their subjective judgments, predictions, and decisions.	This illusion can cause ignoring all possible outcomes adequately.	Generate options and evaluate them objectively.
Loss Aversion [38]	People give something of greater value simply because they own it. Loss hurts more than wins generates good feelings.	Losing something hurts people more than winning the same thing makes us happy. It is why we keep things for longer than we need them because losing hurts.	Awareness and asking for another opinion help.
Observer-expectancy Bias [8]	The expectations of an authoritative figure can impact the performance of an individual(s).	Seeking to provide assessments aligned with your perception of what responses are expected by others.	Consider that everyone is fallible or not in possession of all facts.
Optimistic Bias [20]	Ignoring probabilities and unduly believing in positive outcomes.	Giving more weight to personal opinions over probabilities.	Challenge your assumption.
Outcome Bias [2]	The tendency to judge previous decisions based solely on their outcomes, i.e., ignoring the chance element.	Ignoring probabilities, and incorrectly assuming that bad outcomes are the results of bad decision-making only, shifting from probabilistic judgments to subjective evaluations.	Consider the element of chance.
Primacy Bias [15]	The tendency to allow first impressions, and initial information or options to unduly influence subsequent decisions.	The initial information, observations, or other stimuli can skew decisions.	Give yourself time to investigate all aspects of the problem. The first impression may be right, but the burden of proof is on you.
Overconfidence [37, 39,40]	Placing too much faith in one's knowledge and opinions. Believing that one's contribution to a decision is more valuable than it is.	Failing to spot the limits to one's knowledge. Such a failure often yields the wrong decision. Engineers are more likely to display the Overconfidence Bias than the public, which is due to not being challenged often.	Overconfidence in genealogy has its roots in relying on some specific sort of information, which might not be fact-based. Or, information might not have been gathered systematically or suffered from missing data, or lack of trust in people who gathered information
Representative Heuristic [37, 39]	The tendency to allow probability to be influenced by the assessments of resemblance (i.e., the degree to which an event is judged as representative of another event) to save time and energy.	Engineers make snap decisions and assumptions in emergencies without thinking too much about looking for evidence. This bias can enter when the decision is based on one event only because of similarity or representativeness.	Look for evidence from all available sources
Similarity Bias [17]	Making judgments based on the perceived similarity of two situations.	Judging based on the similarity between current situations and other situations. The decision is based on how favourable or unfavourable the present situation is based on perceived similarity to the past situation.	Do not let previous experience shape the current situation. Gather more data and look for differences.
Sunk cost Effect. [22]	The bias to persist in a particular direction to avoid wasting the significant investment that has already been made is termed Sunk-cost Bias.	This bias applies more to risk management decisions made during construction activity.	Practitioners can show a lack of willingness to alter the course of action about managing risks when considerable resources already have been invested.
Survivorship [37, 39]	A tendency to focus too heavily on what remains standing, instead of considering what you cannot see.	It happens when we assume that success tells the whole story, and we do not adequately consider past failures. The road to success is strewn by corpses of those who failed.	Consider the thing you do not see, or you cannot see.
Von Restorff Effect [15]	Also known as the Isolation Effect, predicts that when multiple similar objects are present, the one that differs from the rest is most likely to be remembered!	People value a thing differently depending on whether it is placed in an isolation orbit or placed next to an alternative.	A certain choice can be made to look more attractive if it is placed next to an inferior alternative.