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Rationality for Engineers:

Part IV: Misconceptions and Debiasing

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ABSTRACT

Humans are thought of as predictably irrational, primarily due to apparent inconsistencies in their decision-making. When presented with the same information on different occasions, the same people often draw different conclusions. There is a noise in the decision-making of individuals, whether in the same or a different environment. Humans are likened to a faulty scale; every time you weigh the same thing you get a different answer. This variation is more pronounced when we examine decisions by different decision-makers. Noise in decisions implies that humans' internal gauges are imprecise and that their dial rests on a different position when confronted with the same choice at different times. Decision errors can relate to; correlation, causal reasoning, probabilistic reasoning, thinking statistically, hypothetical thought, dubious justification, not seeing everything, and even seeing something which is not there. This part of this series of papers attempts to clarify errors in engineers' decision-making processes and describe how to avoid them.

1. Introduction

Engineers' approach to finding solutions is often to develop a model of the required system. The solution is not separate from the 'purpose' and 'objective' of the system's owner. A skill set, as well as a knowledge base, is required to solve a problem, or design and implement a system. The knowledge base is most likely to be multidisciplinary, and dependant on the type of problem. It may also need regular topping up of the skill. Design and implementation define engineering profession, and this differentiates engineering from pure science.

Engineering aims to work with available knowledge to fulfil society's needs. Good engineering practice is founded on the experience and applying existing knowledge, together with suitable heuristics, to produce 'desirable outcomes' which in turn produce new 'experience' leading to the refinement of an engineer's skill; this is the evidence-based approach to engineering [44]. An engineering knowledgebase also allows the use of routines and rules of thumb for problem-solving, which are usually denied to scientists. The knowledge gained might be in an improved heuristic, more refined approach, or how to deal with constraints. Evidence-based engineering requires; finding the evidence, understanding what it means and where it might lead, and then drawing a conclusion [44]. Engineers often rely on heuristics to simplify their work and enhance their effectiveness. Heuristics on occasions may lack accuracy or even proper justification. However, heuristics used with good engineering judgment [44] rooted in the understanding of when and where a heuristic can be applied, would afford an important tool. Here, the engineer relies on the collective experience of all the engineers who came before as well as his/her own.

To be effective, engineers need to look deeper to discover what you ae not seeing. What you see is not always all there is. Take this story- two friends were walking along a riverbank. Suddenly they saw somebody in the water drowning and calling for help. One of them jumps into the river and rescues the victim. Before he can catch his breath, he sees a second person in the river shouting for help. Without hesitation, he jumps back in the river and saves the second person. A few moments later, they hear another person calling for help. Though he is tired, he jumps again into the river and saves the third person. The friend who was just observing these events, runs upstream and returns a few hours later. His friend asks, "Where have you been? I saved two more people since you have been away, however, for the last hour, the river did not bring any more people. The friend who came from the upstream said "When I saw the river bringing the bodies downstream, I wondered what the cause could be. I went to investigate. When I reached a bridge further up, I saw a man on the bridge pushing people who were to cross the bridge into the river. I subdued him and took him to his family in the village. That is the reason why there have been no more bodies in the river". All you see might not be all there is. Research suggests that experts who regularly work with uncertain information have better numeracy skills and a better ability to interpret events than the public [33,40]. The assumption is that the experts know better because they have seen it before. They are certain that there is more than what they see. Analysis of biases and heuristics among experts adds credence to this belief, and thus the effects of framing and biases may be enhanced due to their domain-specific training and experience which keeps them alert.

This part looks at misconception of statistics and how to avoid them. Debiasing of decision-making process is discussed in some details in this part.

2. Ergodicity

Sometimes it is assumed that the average behaviour over time is the same as the average behaviour at a point in time; this is known as ergodicity assumption [49]. Few things are precisely ergodic, but many things are reasonably close for the practical purposes. The real reason for caring about ergodicity is to decide if we can rely on predictions from past data at all. If we have a hundred-year sample of data that looks ergodic, there is no guarantee that tomorrow will not bring a surprise, nevertheless we have some confidence that it won't deviate too much from historical norms. However, if historical data is full of violent event that seem to occur irregularly, we don't have too much confidence that we can predict tomorrow.

Suppose you are looking at waves coming from the distance up on a shore. If you look from sides, you form an opinion about the distribution of heights at different locations at any given time. That is If you measure at one location, you get an impression of height distribution at that specific location over time. If you assume the process is ergodic, then by walking up and down the beach, you can judge the behaviour of waves over time and decide on a safe spot to spread your blanket as close as possible to the water's edge without risking getting wet. You would look at the maximum height you see in either direction, also, perhaps, you add a couple meters to be sure you are on the safe side. Your inference is incorrect since the wave heights are not ergodic over the relevant time scale. You may not see evidence of the tide during your observation, neither you have observed changes in sea conditions. You may also have forgotten that wave heights are affected by the height and slope of the beach at different locations.

Japanese building codes were based on the highest tsunami observed at different locations. The assumption was that the distribution of tsunami extent is ergodic, so the highest flood ever observed is a good estimate of the maximum likely extent. The Fukushima Daiichi disaster [43] proved this assumption not to be correct- there were also other errors beside assuming tsunami ergodicity.

We assume ergodicity any time we use a sample of data taken at one point in time to estimate likely future outcomes; or take samples of data over time to estimate probability distributions for the next event. An example is using a baseball player's season batting average to estimate his probability of getting a hit at his next at-bat.

One practical example is casino gambling. A roulette wheel is very close to ergodic, the distribution of numbers that have come up in the past is very close to the probability distribution of numbers on the next spin. But Blackjack is dealt from a set of cards that are not reshuffled after each hand. Therefore, the probabilities for the next hand are distinct from the outcomes earlier in the deck. Players need an Ace and a ten card to make a blackjack, and there are fixed numbers of them in the deck, so a high number of historical blackjacks means a lower probability of future blackjacks, and vice versa, all else equal. Players can exploit non-ergodicity to gain an advantage over the house.

Another example:

1. Take a coin and toss it 1 billion times and record the results.

2. Then imagine one billion people flipping a coin once and recording their results.

In Case 1: the random process (coin flipping) is taking place over "time" - sequentially flipping the same coin repeatedly. In Case 2: the random process is taking place in "space" - different coins, different people, different locations but all at the same time. If any given statistical measure that you choose gives the same results for both cases, then you can say the system is "ergodic."

Suppose a coin appears to be completely fair when given to you, but it is made of different materials on each side, and one material wears faster than the other. When you flip this coin one billion times, it is going to become less and less fair. It is not possible that this coin in one billion flips to be identical with coins that flipped by one billion people, as they do not have this problem of wear. The statistics of the two trials, i.e., your coin over time and the one billion other coins over "space", will not be the same.

To "do" statistical inference, we need to know how a system evolves over time. However, it is possible by considering the "ensemble" of all possible configurations. The idea of an "ensemble" can be helpful to understand ergodicity in general [49]. Instead of the simple coin flipping of above example, consider something more complex and perhaps more practical. Suppose you have a machine that you know will randomly make some mistakes. But you do not know exactly what the rate or distribution of mistakes is. If you can justify the idea that these mistakes will be ergodic, then you could create an "ensemble" of 100 machines and observe them each for 100 hours of running and conclude that any statistical observations you make would be the same as observing one machine for 10,000 hours.

2. Data, Information, Knowledge, and Wisdom

Russell Rakoff's [50,51] stepped flow from data to information to knowledge to understanding to wisdom must be at the heart of any profession that relies on knowledge.

According to Russell Ackoff, the content of the human mind can be classified into five categories:

Data simply exists and has no significance beyond its existence. Its existence does not imply being usable or not. They can be on paper or in a computer database and can have any form numbers, words, pictures. For example, census takers collect data. The Bureau of the Census processes that data, converting it into information that is presented in the numerous tables published in the Statistical Abstracts [51].

Information is obtained when data is interrogated, distilled and potential can be gainfully exploited; but not necessarily are meaningful. For example, a data bases turns data to information and store it. Information is contained in descriptions, answers to questions that begin with such words as who, what, when, where, and how many[51]. "Like data, information also represents the properties of objects and events, but it does so more compactly and usefully than data. The difference between data and information is functional, not structural [51]" .

Knowledge is making sense of relevant collection of information. The aim is to make it useful. When people "memorize" information, then they believe they have the knowledge. This knowledge has meaning for them, but don't know its applicability, implementation and limitations. but it does not provide for, in and of itself, an integration such as would infer further knowledge. Even, my not help to further gaining more knowledge. Use of the acquired knowledge requires reasoning and analytical ability which in turn requires understanding of the knowledge. They are just stored 'knowledge'. Knowledge is conveyed by instructions, answers to how-to questions. Understanding is conveyed by explanations, answers to why questions [51]

Understanding is the process apply the knowledge. It is cognitive and analytical. One can use previously held knowledge and synthesis it to gain new knowledge. The difference between understanding and knowledge is the difference between "applying" and "knowing". Those who have understanding can synthesise new knowledge, or in some cases, at least new information, from what is previously known (and understood). That is, understanding can build upon currently held information.

Wisdom [52] is the ability to think and act using knowledge, experience, understanding, common sense, and insight. It is also the ability to guess where your action will take you and consequences of your decision. It calls upon all the previous experiences, and specifically upon all human values (moral, ethical codes, etc.). It is the essence of probing the likely consequence of an action. Asking question to which there is no easy answer, there may be no answer. Wisdom is, therefore, the process by which we also discern, or judge, between right and wrong, good and bad. Wisdom is a very human trait; it is what that makes a person human.

Ackoff asserts the first four categories relate to the past; they deal with what has been or what is known. Only the fifth category, wisdom, deals with the future because it incorporates vision and consciousness. With wisdom, people can create the future rather than just grasp the present and past. But achieving wisdom is not easy; one must travel successively through the other categories.

Engineers should use wisdom to create the society's future and well-being to solve problems and decide how to move forward. This is done in situations when there are no clear answers.

Peter Drucker wrote: "There is a difference between doing things right and doing the right thing." Ackoff has amended the above to this: "Doing the right thing is wisdom, effectiveness. Doing things right is efficiency. The curious thing is that the righter you do the wrong thing, more wrong you become. If you're doing the wrong thing and you make a mistake and correct it, you become even more wrong. So, it's better to do the right thing wrong, than the wrong thing right. Intelligence is the ability to increase efficiency; wisdom is the ability to increase effectiveness."

Wisdom deals with values. It involves the exercise of judgment. Evaluations of efficiency are all based on a logic that, in principle, can be programmed into a computer and automated. These evaluative principles are impersonal. We can speak of the efficiency of an act independently of the actor. Not so for effectiveness. A judgment of the value of an act is never independent of the judge, and seldom is the same for two judges [52].

Accessing information stored in our brain an accessing information stored somewhere else are just knowing; accessed fact is just the bigging of wisdom an intelligence, that is wisdom is not just accessing information but understating them and apply them effectively. It is this which marks somebody as intelligent, not the ability to regurgitate masses of information. Sometimes we are fooled to think otherwise. Knowledge alone of the content of papers and books is not an indicator of wisdom or intelligence. It is what we do with that knowledge counts.

2. Misconceptions of Chance

The French Mathematician Laplace said, "Probability is the common sense reduced to calculus", but common sense does not make better probability assessments. It enables one *to get a feel for the real world, which inevitably involves biases.* Misconceptions of the rules of probability are discussed next section.
Kahneman's idea of biases mostly revolves around the misconception of probability. This section explores the misconception of chance events.

The second of Hammurabi's laws states, "If anyone brings an accusation against a man, and the accused go to the river and leap into the river if he sinks in the river his accuser shall take possession of his house. But if the river proves that the accused is not guilty, and he escapes unhurt, then he who had brought the accusation shall be put to death, while he who leaped into the river shall take possession of the house that had belonged to his accuser." This law seems to presume that the guilty are more likely to be drowned than the innocent. Hammurabi is not alone in misunderstanding the rule of probability. This is faith-based reasoning.

The following example illustrates humans' comprehension of probabilities. Suppose you wish to know what the weather will be like next Monday, as you are planning a job which requires a dry spell or clement weather such as installing offshore facilities. You look for the weather forecast and read, "There is a 10% chance of rain." You decide to go ahead with the job, then low and behold, it rains. You get frustrated, but was the forecast wrong? No, the forecast did not say it would not rain, only that rain was not probable. The forecast would have been wrong only if a probability of zero was predicted and it subsequently rained. However, if you assemble every prediction over an extended time and ascertained that it rained on 50% of the days that the forecasted probability was 0.10, then again you could say the weather forecast is wrong. The question is when is it correct to say that the probability of rain is 0.10? According to frequency interpretation, this means that it will rain 10% of the days for which the probability of raining is forecasted at 10% rain, not 10% of the day nor 10% of places where the forecast applies.

Many people excruciatingly scrutinize a lot of statistics but suddenly leave them aside and make a snap judgment based on what their gut says. Mr. Phillips, the protagonist of John [27], is an accountant, and on the previous Friday he was made redundant, a victim of his own cost-benefit analysis. His wife and family, and his neighbours, do not know he has been sacked. His hobby is calculating the odds of everything; the percentage of Londoners who have never seen a corpse; or been on a boat on the Thames; or at what time before each lottery draw should he buy a ticket to have a probability of winning the jackpot that exceeds the probability of dying before the draw. The novel tracks Mr. Phillips roughly from 9 am to 5 pm on the first Monday of the rest of his life. He leaves home pretending to go to work. On this fatal day, he walks into his bank to check his bank balance, only to find he is stumbled into a robbery. He passes the time calculating the odds of winning the lottery (one in 13,983,816) against the odds of dying in any given minute (one in 49,200,000). He speculates as he lies face down on the floor, about "how rational bank robbers must be; how they need to think of everything. 'There must be a lot of details to think about, being a bank robber.' He muses, 'It would seem like a job for the headstrong and reckless, but there must be a great deal of planning too,". But, out of nowhere, Mr. Phillips suddenly stands up, in the middle of the drama, and says: 'I'm not doing that anymore.' It is a moment of astonishing and consummate bravery, by refusing to comply. It is the being told to lie down that Mr. Phillips is objecting to, not just (or necessarily) the robbery, nor if odds are in his favour. It is what is called a risk taken with reckless disregard for the consequences. Mistakes happen when there is a mismatch between reality and perception.

Kahneman [19] stated "*people expect that a sequence* of events generated by a random process will represent the essential characteristics of that process even when the sequence is short." In the independent trial of tossing a coin. The same probability rule applies for getting the specific sequences of HHTHT or THTHT. Since the probability of getting a tail, or head is 0.5, then the probability of both sequences is obtained by multiplying 0.5 five times, which yields 0.03125. This probability is true for both sequences – but it implies no relationship between the probability of a specific outcome at each toss. Coins, unlike people, have no sense of equality and proportion.

There is a specific variation of the misconception of chance that is known as the "Gambler's Fallacy". This fallacy implies that when you come across a local imbalance, you expect that future events will smooth it out. We will act as if every segment of the random sequence must reflect the true proportion and, we expect the imbalance to be corrected. The basis of the Gambler's Fallacy is a misconception of the laws of chance and the belief in fairness, which is believing that if the nature has done something wrong, it will correct itself and balance things out the gambler feels that the fairness of the coin toss entitles him to expect that any aberrance in one direction will soon be corrected by a corresponding aberrance in the other direction. Kahneman illustrates this with an example of the roulette wheel and our expectations when a reasonably long sequence of repetition occurs. After observing a long run of black on the roulette wheel, most people mistakenly believe that it is now the turn of red. Roulette is random, in which the chance of getting red or black will never depend on the past sequence.

A small random sample is not representative of a larger population. If you are relying on data inference, then beware of the data size; when statisticians say a large sample, they mean a very large sample. If luck has a larger share in success than skill, then you need more data to separate chance from skill. A gambler said, "if it wasn't for my bad luck, I would have won every game". Luck is not a noise that can be cancelled, but it is governed by the rules of probability. In the long run, quality of decision is a winning strategy, not good luck. History remembers those who have succeeded, not perished. The road to success is not signposted by rose petals.

For example, assume that the average IQ of a specific country is known to be 100. To assess the intelligence in a specific district, we draw a random sample of 50 people. The first person in our sample happens to have an IQ of 150. What would you expect the mean IQ to be for the whole sample? The correct answer is (100*49 + 150*1)/50 = 101. Yet without knowing the correct answer, it is tempting to say it is still 100 – the same is true for an entire country.

Some natural phenomena obey such laws, that is a deviation from a stable equilibrium produces a force that restores the equilibrium. This is only true for the problem of physics. Idioms such as "errors will cancel each other out" reflect the image of an active self-correcting phenomenon. Indeed, this may be true in thermodynamics, chemistry, and physics (every action has an equal and opposite reaction). However, these are false analogies. It is important to realize that the laws governed by chance are not guided by principles of equilibrium, and the number of random outcomes in a sequence does not have a common balance.

The skill part of a decision can be controlled and improved, but one cannot control the chance. If a drunkard decides to drive and has no accident, it does not mean that he has made a good decision. The quality of the outcome is not an indication of the quality of the decision. In the short run, the chance element may not be favourable. One needs to be careful not to confuse luck with skill.

3. Thinking in Probability

The following three simple laws are at the heart of Probability Theory; if applied correctly, they can give insight into how nature works [31]:

1. "The probability that two events will both occur can never be greater than the probability that each will occur individually.

2. If two possible events, A and B, are independent, then the probability that both A and B will occur is equal to the product of their probabilities.

3. If an event can have several different and distinct possible outcomes, A, B, C, etc., then the probability of the occurrence of either A or B is equal to the sum of the individual probabilities of occurrence of A and B. Also, the sum of the probabilities of all possible outcomes (A, B, C, and so on) is 100% (or 1)."

Navigating through the laws of probability, andomness, and statistics sometimes leads to a misunderstanding of chance. Kahneman [19] used the term "misconceptions of the chance" to describe the phenomenon when people extrapolate from small size samples to large-scale situations. For this, the random process must be ergodic. As discussed in Section 2 A random process is said to be ergodic if the time averages of the process tend to the appropriate ensemble averages. In other words, "A radon process is ergodic if its statistical properties can be deduced from a single, sufficiently long, a random sample of that process" This means if you observe a process long enough, then you will learn all the statistical properties of that process, since your observation approaches (converges) to the "true" ensemble properties of the process. Some things never repeat themselves, like the weather on Christmas Day 2022. However, if the weather were ergodic (which it is not) you could watch the weather for many days or years and then determine the probabilities of different weather conditions on Christmas Day of 2022. This means, if you live long enough, you will experience everything. Using statistical properties of an ensemble to predict the behaviour of the whole process is not possible. As such, ergodicity establishes some equivalence between multiple trials in the same period and prolonged observation of the same process over time.

Imagine that you face a tough decision between investing in the production of two different products, A and B. You are interested in knowing which product would appeal to most of the market, so you decide to conduct a customer survey. Out of the first five pilot surveys, four customers show a preference for Product A. While the sample size is quite small, given the time pressure involved, many of us would already have some confidence in concluding that the majority of customers would prefer Product A. However, a quick statistical test will show that the probability of a result just as extreme is, in fact, 3/8, assuming that there is no preference among customers at all. In simple terms, this means that if customers had no preference between Products A and B, you would still expect 3 customers out of 8 to prefer Product A). Studies of such a small size have little to no predictive validity; such results could easily be obtained from a population with no preference for one or the other product. The more random cases we examine, the more reliable and accurate are the results, and the closer we will be to obtaining the true proportion. If we want absolute certainty, we need a very large sample.

There will always be cases where a guesstimate, based on a small sample will be enough because we have other critical information guiding our decision-making process or we simply do not need a high degree of confidence. Yet rather than assuming that the samples we come across are always perfectly representative, we must treat random selection with the suspicion it deserves.

The ease of remembering or imagining an event in our mind is taken as evidence of the degree of likelihood (beware of representative bias). Naturally, events that are frequently experienced will be easily remembered and judged to be likely. On the other hand, if it is hard to remember a particular event, then it is of rare probably and hence remote. However, if an unusual event happens, and if we witness it, or it happened to someone that we know, then there is a tendency to overestimate its probability. If we cannot even imagine how an event could happen, then we consider there is no chance for that event to occur. But according to Gumbel [14] "*improbable is bound to happen one day*." Which is the same advice given by Sherlock Holmes to Dr. Watson "*When you have eliminated the impossible, whatever remains, however improbable, must be the truth*."

When a numerical estimate of likelihood is not possible, it may be assessed in linguistic terms as negligible, moderate, high, remote. These are vague terms, but the strategy must be to use different approximate methods in parallel, to build up a better understanding of seeing through probability. Probability is an estimate, not a telephone number.

Kahneman makes a lot of emphasis on conjunctions. A "conjunction", is a sentence in the form: "…and—." For instance, the sentence: "Today is Saturday and it is raining" is a conjunction (together). When a conjunction is used as a noun, it means either term of the conjunction, whereas the verb conjunction means the act of joining or the condition of being joined. A conjunct is a statement that is part of conjunction. For example, conjuncts of the example sentence are "Today is a Sunday" and "it is raining". The probability of conjunction is never greater than the probability of its conjuncts. In other words, the probability of two things being true can never be greater than the probability of one of them being true. For example, 'the probability of seeing an alien is more likely than the probability of seeing an alien and being offered a lift in their spaceship'; For the second to be true, both seeing the spaceship AND being offered a lift must true, i.e., both conjuncts must be true which is less likely. People sometimes think that the conjunction is more probable than one of the conjuncts. This happens when the conjunction suggests a scenario that is more easily imagined than its conjuncts alone. One reason for this error may be people assume that there is an unstated conjunct that is withheld [15].

4. The Potential for Error

You see what we want to see. If there are several events taking place at the same time, then your brain cannot keep track of all of them. You can track one possibly two of concurring events. Seeing other people's intention where none is apparent, is a result of attributing the action to others of what you would do in their place.

We confuse causality for correlation, and we make more out of a coincidence than statistics should warrant.

Subjective approaches, involving probability, expert opinion, and decision theory, are employed in 'Probabilities-as-degree-of-belief' and 'Probabilities-as-revealed-by-actions'. These tools are less precise and may be a virtue provided one remembers this fact; like the economist Milton Keynes who "preferred to be approximately right than precisely wrong."

Relying on memory and imagination when judging the probability of events has served foraging humans well, but in the modern world, we are constantly exposed to vivid vicarious experiences through the media. However, common events are uninteresting, and it is the out-of-the-ordinary events that capture our imagination. There is an old saying: "When a dog *bites a man that is not news, but when a man bites a dog that is news*." Unusually, a relatively uncommon event will make the news. The media choose uncommon events as "news", and hence we mistakenly believe that such events are quite common. In my newspaper, there is a report about the CO_2 hazard to the environment and melting the ice caps, while your paper warns about shutting down power plants leading to the loss of employment; We get two different views on the use of fossil fuels.

This is the "Anecdotal Fallacy" which occurs when the perception is based on a single anecdote, leading to an unwarranted generalization. No matter how emotionally compelling a specific incident is, it is just one data point and nothing more. But, if it is based on more than one anecdote, the set of these stories is unlikely to be representative of the class. This is especially true if the anecdotes are based on news stories since journalists tend to write about unusually extreme events. What we read or hear about from the news media are the best or worst-case scenarios.

5. Cognitive Debiasing

It is difficult to completely avoid cognitive biases as they are built into the way our brain functions [1,21,23] Humans think in patterns, and it is very difficult to ignore them. Whether these patterns help to solve a problem or lead to wrong decisions depends on the context. The key is for the engineer to take advantage of the positive aspects of heuristics while mitigating the biases by being vigilant and implementing processes for mitigating their effects. Identification of the source of erroneous reasoning improves decision-making.

Mitigating biases through targeted "Debiasing" interventions can have a positive impact [9,11,28]
Debiasing techniques can appear in many forms, and they often revolve around the concept of "*Metacognition"*, which involves awareness and understanding of one's thinking process. A common debiasing technique is to simply make people aware of a certain bias and explain to them when and how they're likely to experience it.

Debiasing techniques may be categorized into different practices; namely, techniques that attempt directly to influence decision-makers and those that attempt to modify the decision-making environment, which in turn influence the decision-makers. For instance, when you make decisions by following others, you may be subject to a bias called the "*Bandwagon Effect",* which is blindly believing the wisdom of the crowd. This bias causes people to follow the crowd because they believe that others are acting rationally, or they know better. One approach could be to consider alternative options beyond those being promoted by the crowd. Conversely, one could shut out the opinion of others completely.
The decision-maker should consider the specifics of a debiasing method, i.e., if the method applies to a particular case or it is of general applicability. Then it is possible to categorize debiasing techniques into groups based on whether they are

- Universal: namely they work on most cognitive biases,
- Generic: namely they work on substantial groups of cognitive biases, or
- Specialized: namely they work only on a small number of biases.

Debiasing techniques may be also categorized based on other factors. For example, they can be categorized based on required training and skill level. Similarly, they can be categorized based on time and effort, with some techniques requiring little-to-no effort.

Cognitive biases can also be explained through the "Dual Process" theory. Under this model, biases occur for two main reasons:

- System 1 generates an erroneous intuitive judgment, and System 2 fails to correct it, either because System 2 fails to supervise System 1 properly, or because System 2 goes into action, but fails to stop System 1's hasty intervention.
- System 2 fails to engage in proper analytical reasoning.

Thus, debiasing involves one of the following:

- Train System 1 to generate better intuitions.
- Train System 2 to better supervise and stop System 1, as well as conducting a proper reasoning process.

A few debiasing techniques are described below:

<u>Develop awareness of the bias:</u> In some cases, simply being aware of a cognitive bias can reduce its impact. For example, consider the *illusion of transparency*[39], which is a cognitive bias that causes people to believe that their thoughts and emotions are more apparent to others than they are. This bias means that people tend to think that others can tell if they're feeling nervous or anxious, even in situations where there is no clue. Speakers who were informed of this bias before giving a public speech would appear more composed and calmer than those who were not told about it. One reason may be our own emotional experience is so strong, that it 'leaks out' [39].

<u>Improve the way information is presented</u>: How you present information can affect the way people process it. The same information, presented in two different ways to the same person, can lead to two very distinct outcomes. An example of this is presenting statistical information using an easy-to-understand graph instead of a numerical description.

<u>Use simpler explanations and solutions:</u> When it comes to information presentation in general and debiasing, simple explanations and solutions are often preferable to complex ones. For example, consider the *"Hindsight Bias"* [8], which is a cognitive bias that causes people to overestimate how predictable a past event was. Just asking people to think of ways in which a past event might have turned out differently, could reduce this bias. If you ask people to list only two ways, they will find it easier compared to asking them to list 10 ways which could result in a significant Hindsight Bias. Generally, a useful debiasing technique is using the simplest explanation, provided all things being equal.

<u>Express beliefs without ambiguity</u>**.** Asking people to express their beliefs more clearly can sometimes help reduce their biases.

<u>Make the reasoning process explicit.</u> Clearly outlining things such as what evidence is available and how it supports the conclusions that were reached.

<u>Standardize the reasoning process.</u> Checklists can be used to reduce cognitive load, and hence bias [7,17] (

<u>Slow down the reasoning process</u>**.** Many cognitive biases can be mitigated by slowing down and taking time to carefully thinking through the relevant information.

<u>Elicit external feedback.</u> Encourage others to react and give feedback, in an attempt to reduce certain cognitive biases. This is useful when trying to mitigate biases that influence people's perception of themselves, such as believing they are *worse-than-average*, i.e. people incorrectly believe that they are <u>worse than others</u> at performing certain tasks.

Reduce reliance on memory**.** Our memory of past events is subjective, malleable, and prone to various distortions. For example, there is a cognitive bias that causes people to remember past events as being more positive than they were. Another example is divorcing couples remember acrimonious days of divorce, not the many happy years they had together.

Consider alternatives**.** Considering alternative explanations for a certain phenomenon, or alternative interpretations for an event can help reduce some cognitive biases.

Create psychological self-distance**.** This means to separate yourself from your egocentric perspective when assessing events and emotions. This helps to reduce cognitive biases in some cases. For instance, the *spotlight effect* is another cognitive bias that causes people to overestimate the degree to which they are observed or noticed by others, as well as the degree to which others care about the things that they notice about them. This bias may cause people to overestimate the degree to which others are likely to notice their actions or appearance, that is believing that others are likely thinking that they are wearing something funny or saying something stupid, which may not be the case.

A list of useful debiasing techniques is given in Appendix. The focus is on relatively general debiasing techniques that can be helpful for a large range of cognitive biases. For an extended list of biases see https://thedecisionlab.com/biases/

Reasoning backward. In solving a problem, it is important to be able to reason backward. Johnny, a 3rd-grade pupil was 10 minutes late. The annoyed teacher asked him what his excuse was. Johnny answered, "I was running too fast to think of an excuse". He worked backward to come up with an excuse; not because he woke up late or started up late.

In problem-solving sometimes, it is useful to start from it being solved and work backward to what you must do to generate the solution. Another use for backward thinking is in risk management, where you assume an undesirable event has happened. The question you must ask is 'What must happen just before that to make that undesirable event occur?' Reasoning means being conscious of basic facts. It also requires making logical, sound inferences and deductions that avoid the many fallacies. It requires arguments that link cause and effects together, rather than making breath-taking leaps of faith.

Safety engineers when studying the safety requirement of a plant, create credible stories of undeniable future states (scenarios). By starting from an undesirable future, they see how they can control all triggering events that could lead to undesirable consequences and manage to prevent their happening. Engineers think ahead and generate scenarios to explore all possible outcomes, and then reason backward to investigate how to prevent the undesirable events.

Backward reasoning is a type of cause-and-effect thinking that is useful to weed out errors. When you think forward, you are looking for consequences caused by a triggering event. But there can be several triggering effects and it can be difficult to know which one will cause the future event. While probable future states may have many causes, and one can trace all of such causes. The past to the present and then to the future is often clearer than vice versa.

Although backward reasoning is a useful tool to avoid biases, it also can be used for fallacious arguments as well.

In reasoning backward, one should be aware of ambiguity or loose use of language. A puzzle known as "unexpected hanging paradox" [54]. Baggini has re-told it as a story of a pizza restaurant. The logic is the same, but the details differ [54].

"When the health inspector visited Emilio's pizzeria and immediately closed it down, none of his friends could believe he had let it happen. After all, they said, he knew that an inspection was imminent, so why didn't he clean things up?

Emilio had been told that an inspector would be making a surprise call sometime before the end of the month. Emilio reasoning was simple. It could not be on the 31st: if the inspector hadn't come before then, the inspection could only be on that day, and so it wouldn't be a surprise. If the 31st was ruled out, then so was the 30th, for the same reason. The inspection couldn't be on the 31st, so if it hadn't taken place by the 29th, that would only leave the 30th, and so it again would not be a surprise. But then if the inspection couldn't be on the 30th or the 31st then it couldn't be on the 29th either, for the same reasons. Working backwards, Emilio eventually concluded that there was no day the inspection could take place.

Ironically, having concluded no surprise inspection was possible, Emilio was very unpleasantly surprised when the inspector walked through his door one day. What was wrong with his reasoning?"

One version of this paradox is about a judge passing sentence on a death row prisoner. It is also often set up using a teacher telling his students that they will get a surprise exam the following week. Regardless of the circumstances involved, the gist of the story is the same and its logic has been widely studied.

Chow, a mathematician has published a **paper on the paradox**, which does a very thorough job of explaining the difficulties involved here. Chow first acknowledges the main paradox whereby the logic seems correct for the pizza restaurant's owner (or the prisoner in the original version, or the students Chow uses in his chosen example), and yet the restaurant still gets inspected, and the owner is also surprised by that. Beyond this, there is also an important second paradoxical level to be aware of, which Chow describes as a "meta-paradox." He said:

"The meta-paradox consists of two seemingly incompatible facts. The first is that the surprise exam paradox seems easy to resolve. Those seeing it for the first time typically have the instinctive reaction that the flaw in the students' reasoning is obvious. Furthermore, most readers who have tried to think it through have had little difficulty resolving it to their own satisfaction. The second (astonishing) fact is that to date nearly a hundred papers on the paradox have been published, and still no consensus on its correct resolution has been reached. The paradox has even been called a "significant problem" for philosophy. How can this be? Can such a ridiculous argument really be a major unsolved mystery? If not, why does paper after paper begin by brusquely dismissing all previous work and claiming that it alone presents the long-awaited simple solution that lays the paradox to rest once and for all?"

Okay, okay. I must be delusional if I hope to follow that up by claiming a solution to the paradox, so let's make sure we understand what those "nearly one hundred papers" had to say. As Chow summarises: "In general, there are two steps involved in resolving a paradox. First, one establishes precisely what the paradoxical argument is. Any unclear terms are defined carefully, and all assumptions and logical steps are stated clearly and explicitly, possibly in a formal language of some kind. Second, one finds the fault in the argument."

Seek contradictory opinion. Paraphrasing Carl Popper [36] "*Disagreement is the engine of progress*". Give the argument some chance to take shape. You will learn more when others disagree with you, and you are forced to justify your decision. Dismissing opposing views without a good reason is falling into the abyss of irrationality.

6. Putting it all Together

To be or not be rational: The primary objective was to discuss the use of heuristics for fast decisions in the context of rationality. Heuristics are intuition and experienced-based tools, not guaranteed to produce optimal, perfect, logical, or rational results, but they have been shown to be adequate for fast decision-making, and possibly acceptable given all constraints. Heuristics always have a limited range of applicability and are affected by the environment where they are used. If their underlying assumptions are not valid or not well established or understood, they should be treated with suspicion. Statements such as "It is a fact" and "It stands to reason", are assumptions not proof.

In most branches of engineering, heuristics are commonly used and known as empirical methods, implying that they are not entirely based on the first principles. Engineers also learn them in practice, from their own experience, mentors, or colleagues. Even when rigorous analytical methods are used, heuristics are often employed as a sense-check on the credibility of the results. Heuristics are also the systematization of collective wisdom, experiences, and common sense. For example, the safety margin (or the safety factor) is a heuristic. The safety factor for strength design of aircraft is 1.2, which is adequate because of rigorous analyses, testing, quality control, operational monitoring, and strict operating regime, while the same level of safety factor is not used for bridges and buildings. We can pretend to know safety margins for common engineering constructions, but the use of a safety factor, in general, is precarious for most unexpected or unknowable hazards.

It may be rational to open a restaurant without a kitchen because you are convinced that your customers want burgers and you can source them from a nearby burger outlet, and re-brand them by adding your own secret sauce; what works is rational. Some airlines are also big hoteliers without having a single hotel, which is not considered as irrational. Rationality is also knowing what works and what is possible. A rational person is one who always has a good reason for what he/she thinks and does. Each step can be shown to be the best way towards their well-defined objectives.

Problem-solving: Rationality exists within a system with values and mechanisms to achieve them. Looking from the outside the scope of the system and its rational behaviours may be described as consistent and logical. Those who have lived their entire lives within one system, have difficulty making sense of the possibility that another set of totally different behaviours can also be "rational". Any decision or choice is only valuable in the context of the environment that it was made. For example, imagine that you go to a bank to deposit some money, but you also have a loan at the same bank. While talking to the clerk you notice that hooded men are running towards the bank. You believe that they are bank robbers, and you are certain that you are going to be robbed. Is it rational to pay your money towards your loan? Though paying back the loan is perfectly rational, insisting on paying it back under these circumstances may not be.

In engineering, some heuristics involve the use of visual representations (e.g., diagrams, and sketches), additional assumptions, forward/backward reasoning, and simplification. For example, George Polya's book, How to Solve It [35], gives this guidance:"

- If you are having difficulty understanding a problem, try drawing a sketch.

- If you cannot find a solution; assume that you have a solution and consider what you can deduct from that ("working backward" and reasoning backward (Section 3 of Part 3)

- If the problem is stated in abstract format, try to find a concrete example of it.

- Try solving a more general problem first; the more ambitious plan may have more chances of success)."

Polya [35] had mathematical problems in mind, but engineering shares 50% of its genes with mathematics.

To think rationally means adopting appropriate goals, taking the appropriate action given one's goals and beliefs, and holding beliefs about the world that are commensurate with the available evidence. Engineers need to be critical thinkers. "The ability to reason independently of prior beliefs is only one component of critical thinking. Many theorists view critical thinking as a sub-species of rational thinking, or at least closely related to rational thinking" [25].

Does the thought process during the concept generation phase of a project differ between engineers and architects? Both professions are required to create new or innovative designs, but their education in creative techniques is not the same. In engineering training, greater emphasis is placed on technical/analytical issues, and practical training is included in the form of project work with some emphasis on creativity to generate new ideas. In contrast, architects' training emphasis is not on the analytical ability, but repeated regeneration of the design concept combined with a critique process by a mentor as well as peers. In this training process, both engineers and architects develop heuristics to explore possible solutions, without constantly watching for constructability.

Ethics: Only Noah could sail without a compass; the rest of us need a compass, especially a moral one. Ethical issues are always a consideration in engineering decisions. For example, when an engineer has designed a "state-of-the-art communication system", this means that it is consistent with the best set of heuristics known to the engineering community at the time it was designed. With these definitions in place, we can now define ethical behaviour for the engineer, which is taken to mean complying with best known practices and social norm in good faith.

A car repair shop supervisor catches an employee stealing car parts. When confronted, the employee says. "Boss, I've become a compulsive thief." The thief also admits that he cannot change. Must the supervisor accept that he cannot change? The dilemma is, how to make an ethical decision and be fair. After a couple of minutes of thinking the supervisor says, "wash your hand every 15 minutes, if you are not cured in a couple of weeks could you please steal a Ferrari for me?" This is not an example of ideal behaviour but illustrates a point - whether to accept what you saw, pass on the problem to others, or rectify? but how? Such decisions normally have two main reference points - the difficulty of how to change behaviours, and the ethical implications of the situation. Naturally getting rid of the rotten apple is also an option even when there is only one.

Jean-Paul Sartre [53, 54] described a situation in a story. Here is Baggini's version [54]

"Mary, Mungo, and Midge. You stand accused of a grievous crime. What do you have to say for yourselves?

"Yes, I did it," said Mary. "But it wasn't my fault. I consulted an expert and she told me that was what I ought to do. So don't blame me, blame her."

"I too did it," said Mungo. "But it wasn't my fault. I consulted my therapist and she told me that was what I ought to do. So don't blame me, blame her."

"I won't deny I did it," said Midge. "But it wasn't my fault. I consulted an astrologer and she told me that since Neptune was in Aries, that's what I should have done. So don't blame me, blame him."

The judge sighed and issued his verdict. "Since this case is without precedent, I have had to discuss it with my senior colleagues. And I'm afraid to say that your arguments did not persuade them. I sentence you all to the maximum term. But please remember that I consulted my peers and they told me to deliver this sentence. So don't blame me, blame them."

You could say that Mary, Mungo, and Midge all agreed with someone else's opinion to justify their actions, which begs the question if they committed the confirmation bias fallacy - the tendency to favour information that confirms one's beliefs or hypotheses and to ignore information that disagrees with one's point of view. You could also say that Mary, Mungo, and Midge can claimed to be blameless because they intended to do the right thing by asking people, they trusted to be expert which brings up the question of what is reasonably required to do due diligence. You could also say Mary, Mungo, and Midge all made their own choices nobody forced them to take a course of action. there is nothing to dictate a person's course of action, and only the individual can decide what road to take. Sartre claims that people must take responsibility for their actions [53].

<u>Substitution:</u> Replacing a more difficult problem that you can't solve with an easier one is not uncommon. The Serenity Prayer is by the American theologian Reinhold Niebuhr (1892–1971); Wikipedia [42]. It is commonly quoted as Shapiro [39]:

"God, grant me the serenity to accept the things I cannot change, courage to change the things I can,

and wisdom to know the difference."

The original Niebuhr's prayer is this:

"Father give us the courage to change what must be altered, serenity to accept what cannot be helped, and the insight to know the one from the other."

Niebuhr's asked for courage first, and specifically for changing things that must be changed, not things that simply can be changed. This is replacing a difficult problem with an easier one.

Accuracy: Heuristics are not meant to be accurate. However, after you have spotted all the holes, enough truths are left in the fabric to be gainfully employed. The tools in an engineers' toolboxes are there to boost the engineer's skills. Heuristics must be critically reviewed before use. Heuristics are there to shorten the response time, not to replace the engineer's analytical knowledge. This generalization is the primary problem, as one may stretch heuristics to fit the situation, rather than look for alternative heuristics.

Heuristics should not be taken as universally true. Is it as valid as it was twenty years ago? and will it be as valid twenty years from now? A heuristic may involve ethical assumptions (overt or covert) which the society now finds unacceptable - it pays to stop and think. They are just working hypotheses to use until proven wrong.

Some may believe that rational decision-making means exhaustively identifying all options, ranking them, and then selecting the best. But in time-constrained situations, few aspects of decision-making are as important as when to stop, since the most rational course of action is not always possible. Humans are faced with the complexity and messiness of real life, abandon the rational model, and follow simple heuristics. The difference between theory and practice, abstract and applied, reminds us of Yogi Berra's wisdom - in academia, there is no difference between academia and the real world; in the real world, there is.

7. Conclusion

Two types of thinking govern our decision-making process. Type 1 is fast, impulsive, and automatic and we rely on this to get by in our daily life. Type 2 is slower and deliberative. These two types do not work in collaboration, but Type 1 runs the show and does most of the decision-making. Type 1 system makes decisions using heuristics which may lead to errors if not used carefully. Heuristics draw their power from the various kinds of regularity and continuity in the world; they arise through specialization, generalization, and very often from analogy. As the world changes, a heuristic that was valid and useful may lose its validity. To decide we must search for further clues and guidance. The first part of this paper has discussed how and where we can go wrong. The last section of the paper discusses cognitive biases and how to mitigate their effects.

Exciting stories are more attractive than accurate statistics. In constructing a fabricated future, negative information is more vivid, and the brain stores it in such a way that it is easily accessible. This is a heritage from our foraging ancestors, who needed negative stories to be vigilant. As the newspaper's motto "if it bleeds it leads".

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Appendix

Biases and how to avoid them.

Bias	Description	How to avoid
Cognitive diversity [26,29,30]	This is the difference in the perceptions and expectations among individuals in a group.	Building a group with differing experience levels and beliefs can significantly enhance the creativity, performance, and comprehensiveness of strategic assessments and decisions by adding thought conflicts that require resolutions.
Cognitive mapping [18]	This approach requires individuals to map out their cognitive strategy before making decisions.	The application of this technique requires experts and stakeholders to list key variables and build a network diagram that promotes statistical reasoning during assessments.
Think of unknowns [19,41]	Like considering the opposite, this approach asks individuals to specifically evaluate uncertainty.	The approach reduces overconfidence in assessments and improves the decision-making quality by making individuals balance known and unknown information.
Consider the opposite [3,16, 24, 34]	This approach asks individuals to consider counter-evidence or decisions that go against the consensus of the group.	Each time a panel of experts or stakeholders needs to make assessments or decisions, they should be asked to evaluate counter-evidence and alternative possibilities as a dedicated step in the overall process. Considering any plausible alternative outcome for an event, not just the opposite outcome, leads participants to simulate multiple alternatives, resulting in debiased judgments.
Delayed decision-making [37]	This strategy requires individuals to adopt a more deliberate approach to making decisions by delaying the actual decision-making process to consider the information again.	This strategy is a simple, cost-free, and effective practice that requires experts to reconsider the information and brainstorm avenues for improvement, avoiding inaccurate diagnoses due to hasty decisions.
Incentive program [2,10,26]	This approach rewards optimal behaviour. It is useful in improving individual motivation to increase effort and to apply more cognitive resources.	By itself, this is an ineffective debiasing strategy because it does not educate individuals on biases in their judgment. However, when paired with other debiasing strategies, it can improve their effectiveness by enhancing motivation and effort among practitioners.
Mindspace [6]	This is a process that focuses on improving intuitive decision-making skills by adopting and applying nine interventions (messengers, incentives, norms, defaults, salience, priming, affect, commitments, and ego).	Application of the nine tools/strategies to improve behavioural impulses can be applied at different times during the risk management process. These can range from controlling how the information is presented (i.e., messenger) to managing social pressures (i.e., ego and norms).
Nudges [4,12]	Subtle nudges (e.g., visual cues, audio cues, default selections) alongside text-based and numerical-based information can improve critical reasoning skills by providing practitioners some direction and context to avoid potential cognitive pitfalls.	Nudges are a positive debiasing approach that reduces the abstractness and complexity of the situation to assist practitioners in using all the available information
Scenario planning [29]	This tool is used to hypothesize about future paths and potential outcomes. The aim is not to become fortune predictors, but rather for the decision-maker to consider all possible logical paths and outcomes to develop creative and comprehensive plans.	Scenario planning is a cost-free, simple, and effective strategy that would seamlessly integrate with each step of the risk management process, allowing practitioners to consider all logical eventualities.
Third-party direct intervention [5]	This is used during negotiations when a third party invested in the decisions enters the decision-making process to resolve disputes or improve performance.	A proxy (i.e., third party) with a deeper understanding of biases and faulty heuristics is placed in the group to resolve disputes, reframe information, and proffer counterarguments. Although resource-intensive, this approach results in more-deliberated assessments and decisions.
Training [13,32]	Training programs on heuristics and biases, normative rules, and statistical reasoning is designed to improve calibration, encourage. individuals to consider all the evidence and reduce overconfidence.	Multimedia training platforms can serve as quick and engaging interventions to educate practitioners and calibrate assessments and decisions.