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## Principles of Cognitive System Presumed within the Psychology of Rational Thinking

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### Abstract

*Numerous psychological models of the rationality of human thinking have been developed since the middle of the last century within the line of research known as the heuristics and biases approach, descriptive theory of rationality or decision-making, complex cognition, or the psychology of rational thinking. The focal processes or phenomena are reasoning, decision-making, judging, and inferencing. Families of models revolve around formal (cumulative) prospect theory, the cognitivist fuzzy trace theory, ecological rationality, and dual-process theories. Regarding complex cognitive processing, there is a limited set of principles that researchers in the psychology of rationality implicitly, and sometimes uncritically, attribute to the human cognitive system. These principles may be referred to as the “boundary conditions” of the validity of psychological rationality theories, meaning that all psychological models of rational thinking, including the currently dominant dual-process theories, belong to a set constrained by the postulated qualities of the cognitive system's architecture. The following principles, which have not yet been explicitly stated in the literature, are as follows: cognitive miserliness, cognitive processing dependence on the environment, knowledge structures, probabilism, and the challenge of individual differences. The central aim of this paper is to demonstrate the theoretical and empirical value of making explicit the foundational principles of cognition that guide the psychology of rationality, thereby encouraging a critical re-examination of the field's core epistemological and ontological assumptions.*

Keywords: psychology of rational thinking, principles of cognitive systems, reasoning, dual processes, cognitive biases

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## Introduction

Suppose we are cooking a nice soup; the pot is on the stove. When the soup starts to boil over, we instantly reach for the handles to remove the pot from the heat source, and we instantly know we are making a mistake because we are fully aware that the handles are hot. That is the moment when we get burned. A couple of seconds before the burn, two forces clashed in our minds, and if we disregarded the awareness that we had been burned, two types of responses conflicted in this situation. The automatic response prevailed over the rational one.

Clark, one of the founders of the extended cognition hypothesis (ExCog), which “boldly claims that sometimes parts of the environment partially constitute cognitive processes” (Milojević, 2013, p. 4), explains the described situation as an example of the possibility of the existence of coexistent, and quite different, cognitive processes. Some are based on representations, and others are dynamically described without the representations and are described by the processes and mechanisms on which they are based (computationally). The former, Clark assumes, is controlled to a greater degree based on available information, and the latter is, to a greater extent, automatic or, rather, automatised (Clark, 2003; 272; Milojević, 2013). In the present text, the story of boiling soup serves as an example of the cognitive system's potential for two types of responses, i.e., two types of outcomes resulting from Clark's cognitive processes. The automatic, faster response, i.e. grabbing the pot, can also be labelled as heuristic, autonomous, intuitive, even reflexive, or System 1 response. By “rational” (or “reasonable”) behaviour, we consider a normatively rational response, which we reached through a process that is reflective, calculated, strategic, or a System 2 response (for example, taking a heat-insulating kitchen glove). Their supposed conflict in our minds is a conflict of two types of processing (Type 1 and Type 2). The distinctive features that differentiate the two types of processing are working memory and propensity for hypothetical thinking (Evans & Stanovich, 2013). A cramped kitchen and the time pressure of the decision represent a hostile environment, the existence of a glove would represent a sign or signal from the environment that could “trigger” adequate processing (“rational”) that would save us from a burn and the awareness that the handles are hot and that we made a mistake would fall under conflict monitoring, i.e. metacognitive processes<sup>1</sup>. These are the main concepts within the psychological approaches to rationality, more precisely, the contemporary iteration of the psychological examination of the duality of thinking. The most notable psychological approaches to human rationality include bounded rationality, the heuristics and biases approach, dual-process theory, and ecological rationality, with cognitive biases being the central phenomenon. While not mutually exclusive, these approaches offer complementary perspectives on human rational thinking by highlighting different aspects of the phenomenon, even when the overlap is not acknowledged.

Whether we are rational beings is an intriguing dilemma in the social sciences, and almost every scientific discipline has joined the so-called "Great Rationality Debate." This includes economics, philosophy, political science, sociology, anthropology, as well as mathematics and physics, and now the field of artificial intelligence. Although the fact that we have given our endeavor the epithet "great" does not guarantee the quality of the answer to this dilemma, whichever position you intuitively take, "you will find yourself in the excellent company" (French, 1986). The dilemma may not make sense for people who do not follow the great rationality debate by profession: sometimes we are, and sometimes we are not. Moreover, emphasising the opposition

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<sup>1</sup> Many mothers are familiar with this as the dilemma of “whether to save the child or photograph them” in situations when, for example, the child is bathing a doll in the toilet bowl.

of different scientific approaches to rationality and calling the classic scientific discussion "great" (or even "rationality wars") is detrimental to scientific work and unfounded because the viewpoints are not essentially opposed (Sturm, 2019). Some of the approaches within this field of research are also known as behavioural economics, the heuristics and biases approach, judgment and decision-making, or descriptive (as opposed to normative) theories of decision-making. Psychological approaches to rationality try to answer the questions of when and how our thinking as a cognitive process is rational. Psychology has not initiated this debate, nor is it the first time in its history that it has addressed the concept of rationality. Irrationality is one of the fundamental concepts of Freud's psychoanalysis and every other psychoanalysis. In Albert Ellis's rational emotive behaviour therapy, the psychotherapeutic process aims to build rational beliefs about the world that will help our emotions be functional (as opposed to dysfunctional; (Ellis, 1976). However, it was only by including the phenomenon of (ir)rationality of thinking, i.e., the rationality of higher cognitive processes, at the beginning of the 1970s, that psychology offered decision theory, one of the areas of the great debate, research tools, and in return received the conceptual apparatus of traditional (philosophically, economically and mathematically defined) rationality. The most significant contribution of this alliance is the emergence of numerous psychological models that explain how the human mind works. Along the way, psychologists and psychological insights have been awarded several Nobel Prizes for – economics<sup>2</sup>.

By joining the broad field of rationality, psychology has prepared itself for Clark's call: "A suitable project for the new Millenium is to radically reconfigure our image of human rationality" (Clark, 2001; page 1). This love message extended by the philosopher to psychology conveys the notion that the issue of human rationality must be answered not conceptually but empirically, using all the means of modern cognitive science. Stein believes that such a contribution would also have a broader scope, as empirical considerations are relevant to the theory of knowledge; therefore, epistemology should be naturalised (Stein, 1996). The central aim of this paper is to demonstrate the theoretical and empirical value of making explicit the foundational principles of cognition that guide the psychology of rationality, thereby encouraging a critical re-examination of the field's core epistemological and ontological assumptions.

While human cognition can be and is conceptualised in various ways, cognitive psychology considers and studies human cognition as a natural higher-order cognitive system<sup>3</sup>. A cognitive system, broadly defined, is a system that learns and develops knowledge. The cognitive system of humans is a complex system that learns and develops knowledge and connections between knowledge, with a single primary goal: maintaining its functionality in each environment. It achieves this by collecting and operating on sensory (sense-gathered) information, and it is successful in these processes because it has a physical basis (the brain). The human cognitive system cannot function properly if the brain is not operational. Being a higher-order cognitive system, human cognition, in addition to learning and adapting to the environment, is characterised by varying degrees of intelligence (Heyes, 2012; Silberstein & Chemero, 2012). The cognitive-psychological study of rationality focuses on the rationality of thinking in problem-solving.

<sup>2</sup> Herbert Simon, professor of psychology, political scientist by primary education, in 1978; Daniel Kahneman in 2002 (for work with Amos Tversky, but the award is not awarded posthumously); Richard Thaler, economist and close associate of Kahneman, behavioral economist, in 2017.

<sup>3</sup> A cognitive system can be: biological (human, group, organization, knowledge agent) or synthetic (computer) or a combination of the above. All cognitive systems are characterized by a set of equations that determine the time evolution of internal dynamic variables.

## **Cognitive-psychological approaches to the rationality of thinking**

Psychology does not define rationality. Instead, it takes, according to its needs, theoretical frameworks from other disciplines native to rationality, primarily philosophy. However, psychology quite clearly considers that thinking is an inseparable part of the psychophysical equipment with which every person is born, and possessing the ability to think is not a matter of choice. Thinking is not a human right, at least not to a greater extent than having hands or the sense of sight, which are human rights. Thinking is one of the primary mental functions that exists in all people, and it is one, but not the only, way of solving problems and engaging in cognitive processes (both mental and cognitive) by which knowledge about relationships is acquired, phenomena are related and compared, or decisions are made.

This is achieved through operating with (from anything in our perceptive field and those we imagine) mental representations, such as concepts, words, mental images, etc. The thinking processes studied within the psychology of rationality are judgment, inference, and decision-making. These processes belong to directed thinking, which differs from undirected thinking, such as daydreaming or free association (Gilhooly, 1983). The umbrella term for these interconnected processes of directed thinking is reasoning or, strictly psychologically, complex cognition. Complex cognition encompasses all the mental processes a person uses to arrive at new information, whether they "extract" it or "construct" it from given information, and whose purpose is to solve problems and plan actions. We recognise these processes in everyday life whenever we analyse, connect, or judge and evaluate something (analysis, synthesis, evaluation). They rely on the combination and interaction of more elementary processes such as perception, learning, memory, emotions, and motivation (Knauff & Wolf, 2010; Sternberg & Ben-Zeev, 2001). The essential characteristic of complex cognition is that it occurs in complex conditions, where multiple cognitive processes interact with each other and with other non-cognitive processes. The "complexity" in the name is, therefore, twofold and refers to both the processes and the conditions in which they occur (Damjanović, 2024).

## **Assumed Cognitive Architecture**

Researchers in the psychology of rationality attribute a limited set of principles related to the complex cognitive processing to the human cognitive system. We can consider these to be "boundary conditions" for the validity of psychological models of rationality. This means that all cognitive-psychological models of rationality belong to a cluster defined by the assumed characteristics of the cognitive system. Models from that cluster would not be able to survive as convincing scientific models if we were to imagine and accept different characteristics of the cognitive system. The principles on which the psychology of rationality is based are implicitly or explicitly present in psychology before it deals with rationality in this fashion. These principles are reflected in the same or similar form in contemporary cognitive models of rationality, such as dual-process models of cognitive processing. The four basic principles are cognitive economy, environment-dependent processing, knowledge structures, and probabilism.

### **1 Cognitive Miserliness – How Does the Cognitive System Work?**

The idea of cognitive miserliness as an inherent principle of our mental functioning is not exclusively related to complex cognition or integrative functions. The principle of cognitive miserliness implies that in every situation, we try to expend as little mental effort as possible, that

is, to solve the problem using (ideally) the minimum necessary resources. It is important to note, however, that this principle primarily describes directed thinking—cognitive processes aimed at solving problems and achieving specific goals, which are the focus of the psychology of rationality, whose roots are traceable in the idea of utility as the norm of rationality. The principle of cognitive miserliness is less applicable, nor does it aim to describe forms of undirected thinking, such as daydreaming or creative ideation, the primary goals of which are not to find the most efficient, resource-sparing solution. Within the context of rational decision-making, the assumption of cognitive miserliness remains a foundational concept for nearly all major theories. All theorists of the duality of reasoning, when dealing primarily with the function of two assumed modes of thinking (“rational” and “non-rational”), have the same starting point: the basic idea of *cognitive miserliness*, regardless of what kind of cognitive architecture they proposed or adopted (e.g. Arkes et al., 2016; De Neys, 2017; Newman et al., 2017; Oaksford & Chater, 2020; Reyna & Brainerd, 1995; Stanovich, 2018). Cognitive miserliness implies two ideas: that the human cognitive system (a) cannot process everything from the environment or all stimulation, and that (b) it should not process everything.

(a) The first idea that the cognitive system cannot process everything is the ontological aspect of cognitive miserliness. It has been a topic of interest in psychology since the inception of empirical research. The first psychophysical and experimental studies of sensory perception from the 19th century brought findings that imply limitations of mental processing. The psychophysical concepts of just-noticeable difference, absolute and differential threshold, and soon after the textbook example of Wundt's "thought meter" (German: *der Gedankenmesser*), used to measure the mental processing of two simultaneous stimuli, presumed that the mental apparatus somehow arranges processed material and that it cannot process everything (Farr, 1983; Fechner, 1948, according to Farr, 1983). Piaget's developmental stages imply that developmental limitations exist in the ability to form representations, schemas, and cognition and are transformed during development (Piaget, 1983). In one of the most cited psychological papers on the "magical number seven plus or minus two", the central problem is measuring the limit of the mind's capacity to process information (Miller, 1956). The idea that we cannot process or retain everything is present in the signal detection theory (Swets, 1964; Tanner Jr. & Swets, 1954); Broadbent's investigations of attention (Broadbent, 1958); in Sperling's discovery and investigation of iconic memory (Sperling, 1963); the memory models of Atkinson and Shiffrin (Atkinson & Shiffrin, 1968), and in both iterations of Baddeley's model of working memory (Baddeley, 2000; Baddeley & Hitch, 1974). The idea of the limitations of cognitive processing is, therefore, inherent in the entire cognitive functioning of the mental apparatus, which finally gets the name "(humans) cognitive system" in the seventies (Neisser, 1967).

(b) The second constitutive idea of cognitive miserliness, that the cognitive system should not process everything, represents the epistemic aspect. While the impossibility of total processing is not theoretically explained in the listed works, the idea that the cognitive system *should not* process everything is directly debated. The explanation of why we should not and why we cannot process absolutely everything that reaches our cognitive system is partly based on the view of our mind as a (natural cognitive) system that *evolved*. The first attempts to define general principles of functioning that are strategic, not specific, are related to establishing the general theory of systems (von Bertalanffy<sup>4</sup>, 1934). The idea of cognitive miserliness is evident in perceptual economy as

<sup>4</sup> Von Bertalanffy, who was an affiliated Nazi—an affiliation presumed to be driven by career ambition and sometimes embedded in his work—received his doctorate by solving the problem of higher-order

early as Gestalt psychology, first through the tendency towards the best possible structure (Prägnanz principle, (Wertheimer, 1923)), and then through more specific internal perceptual tendencies towards a minimum, to save mental energy, and tendencies towards a maximum, to increase the quality of perception (Koffka, 1935, 2013). The relationship between these two internal tendencies, Gestalt psychologists believed, should be optimal, and the quality of the percept is sustained by – better (adequate) organisation of stimulation, which is also perceptually more economical. Wertheimer points out that observing an object *as a whole* is more accurate and takes less energy. On top of that, the whole contains the essence of what is observed, not individual elements and details. Simon, in his highly influential works on systems theory and bounded rationality (Simon, 1955, 1957, 1972), states that we cannot and should not process everything and that human rationality, being limited, is effective<sup>5</sup> *because* it compensates for its limitations. Human rationality overcomes its limitations by relying on observed regularities from the environment, ultimately leading to a "satisficing solution" (Simon's neologism, combining "satisfy" and "suffice"; Simon, 1947, 1972). In works on categorisation and the problem of higher-order organisation of mental representations, Eleanor Rosch emphasises that the first of the two fundamental principles of categorisation systems refers to their function to provide maximum information with the least cognitive effort (Rosch, 2002).

Finally, social psychologists Susan Fiske and Shelley Taylor coined the phrase "cognitive miser" (Fiske, 2018; Fiske & Taylor, 1984). Cognitive economy (Simon, 1955; Kahneman, 2011) or shallow psychology (Dawes, 1976) is a trade-off, i.e., an optimal relationship between power and cost. In sum, cognitive miserliness as a feature of the system is assumed and supported by numerous evidence, in all models of the duality of cognitive processing (De Neys, 2014, 2017; Evans & Over, 2013; Evans & Stanovich, 2013a; Gilovich & Griffin, 2002; Liberali et al., 2012; Stanovich et al., 2011; Stanovich, 2018b; Stanovich & Toplak, 2023; V. A. Thompson, 2009; Tversky & Kahneman, 1981), as well as in the predecessors, the prospect theory (Kahneman & Tversky, 1979) and cumulative prospect theory (Tversky & Kahneman, 1992), fuzzy trace theory (Reyna & Brainerd, 1995) and the ecological rationality model (Gigerenzer, 2009; Mata et al., 2013). The human mind works like the animal mind, and ...all animals are under stringent selection pressure to be as stupid as they can get away with (Richerson & Boyd, 2005, p. 135). Such "stupidity" is sufficient and even useful when our environment is benign, i.e., one that suits the way of thinking that is activated.

## **2 Dependence on the Environment – Where Does the Cognitive Miser Work?**

The second principle of the cognitive system on which the psychological study of rationality is based is the dependence of cognitive processing on the environment. Behaviour is not only a consequence of our personalities, values, experiences, constructs or preferences, but is also influenced by the situation and the environment (which is more than physical surroundings). We interpret cues from the environment, devise responses, and behave accordingly. This view is not exclusive to psychological models of rational thinking. As in other areas of cognitive psychology, such as psycholinguistics, processing dependence on the environment is explained under the broad

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integration in Fechner's model, a solution in which he described growth using a generalized logarithmic function (Drack et al., 2007; Pouvreau, 2009).

<sup>5</sup> Efficacy – action, effect under ideal conditions; effectiveness – action, effect in real-life conditions.

umbrella term of situated cognition.<sup>6</sup> All four perspectives of situated cognition (embodied, embedded, extended, and enactive; 4E) recognise the vital role of the environment and the body in shaping cognitive processes. Cognition does not occur only in our heads but is also embodied, embedded, enacted, or extended by way of extra-cranial processes and structures (Carney, 2020).

The roughest sketch of psychology could be that psychology explains "how the physical is mapped into the mental." "Mapped into the mental" would mean how something outside of us, in the environment, is transferred and represented in our mind, mental slate, and inner world. The "physical" transferred to the mind can be a moving car, an abstract idea from a book, a change in lighting, or our thoughts or feelings. The fundamental psychological question of the relationship between the mental and physical is answered by the first schools of psychology, psychophysics, and structuralism (which, like most empirical disciplines, do not address the issue of whether innate ideas exist or not). The role of the environment in empirical psychological programs was first posited as a necessary element in functionalism when, under the influence of evolutionism, the adaptive function of consciousness —i.e., emphasising adaptation to the environment —was considered<sup>7</sup>. A broader framework for studying the influence of the environment on our psyche, the environmental complexity, is provided by several psychological concepts. In Lev Vygotsky's socio-constructivist developmental approach, the environment triggers development, referred to as allomorphic development (Vygotsky, 1929). The formative role of the other (object) on the dynamics and structure of personality is highlighted within the psychodynamic framework, from classical psychoanalysis to relational psychoanalysis, as exemplified by Fonagy's connection of cognitive development and attachment theory through the concept of mentalization (Fonagy et al., 2018). At a more molecular level, within the study of cognitive processing and before the emergence of dual processing models, signal detection theory (SDT) describes perceptual regularities in an uncertain environment (an environment that changes in a way that is not entirely known to us). SDT explains how, in that environment, we detect (and do not miss) what is relevant to our decision (a signal that is information) and how we distinguish it from noise (numerous regularities that are irrelevant to us), that is, the avoidance of type 1 error and type 2 errors (Peterson et al., 1954; Tanner Jr. & Swets, 1954).

Perhaps the most remarkable similarity to the concept of automatic and autonomous information processing, which is today called heuristic processing, is Gibson's affordance, which is a term he coined and presented as a concept in most detail in the book *The Ecological Approach to Visual Perception* (Gibson, 1966, 2014). Affordance is a concept that indicates the complementarity between the environment and the organism, measuring what the environment offers the organism so that it can fulfil its needs. The relationship between the ecological niche and the organism shapes perceptual processes to the same extent and in the same way that any ecological niche shapes how an animal lives in that niche. Affordance is a relational concept that demonstrates the suitability of

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<sup>6</sup> In a broader sense, "situated cognition" represents the view that the primary mode of our cognitive activity is precisely "active" cognition, which is then supported by metaphysical and evolutionary claims. Our "offline" or "autonomous" cognitive activity, such as representing past events, daydreaming, using language, planning, etc., is mainly secondary compared to cognition oriented towards action in the environment. Therefore, situated cognition does not claim that we are initially capable of "offline" cognition, which we then transfer to the environment, but on the contrary, that the struggle for survival in the environment has enabled us to perform cognitive operations that are separated from the environment (Milojević, 2013, p. 27).

<sup>7</sup> This is today examined in more detail within the framework of ecological rationality program.

the environment for the observer. For example, stairs with a step height of 30cm will be a receptive and helpful environment for someone who is 3m tall (high affordance, i.e. high complementarity of the organism and the environment) and can afford that person easy and fast climbing but will not be a suitable environment for a person of usual height (low affordance, i.e. low fit). A single environment offers different affordances for various needs and organisms, and the organism's needs dictate the perception of affordance (through selective attention), which triggers actions and modifies the environment. Affordance also implies the selection of elements and information from the environment. Not everything in the environment is "affordant", but only what we perceive from the offer defines our action. Similarly, when we decide (a complex cognitive process) about something, for example, about buying shoes in a store (environment), the mind is surrounded by numerous information, such as the lighting of the store, the dryness of the air, the temperature of the room, the tone of the seller's voice, the price of the shoes, the material from which they are made, the size of the shoes, many models, the method of payment. However, for this decision, our attention focuses only on the information that is important to us, including the shoe model, size, price, and payment method. We do not focus our attention on the room's temperature and the number of windows.

### ***Conditions in the Environment Where Reasoning Takes Place***

We are not always in a completely uncertain environment when we make decisions. In addition to conditions of uncertainty (e.g., who will be the president of the US in 2035), there are conditions of measurable uncertainty or risk (e.g., gambling) and conditions of certainty (e.g., buying shoes) (Knight, 1921; Rakow, 2010), and there is no fourth type of environment. Every decision is made in one of these three conditions. As an explicit definition of the environment in which complex cognitive processes occur, in addition to Knight's exhaustive categorisation of decision-making conditions, Savage's note on decision-making in the "small" and "big" worlds is also cited (Savage, 1972, 2012). A small world is an environment in which all available choices, states of the world, consequences, and probabilities are known, while big worlds are those in which some of the above are unavailable. Savage argues that to apply Bayesian methods to analyse large worlds, we must make simplified, idealised assumptions – to analyse them as if they were a small world. The environment in game theory is conceptualised as "Nature as a player" and refers to all those circumstances and aspects not controlled by the decision-maker (Dixit & Skeath, 2015).

Today, in the dual process paradigm, the terms benign and hostile environment are used (Chater et al., 2018; Evans & Stanovich, 2013b; Kahneman & Klein, 2009; Stanovich, 2018b). A benign environment does not interfere with the cognitive process, i.e., that is an environment in which the probability that a cognitive miserly response (based on intuition<sup>8</sup>) will lead to an error is low or relatively low. As in the example of boiling soup from the beginning, a second is enough to turn off the heat source because the stove is on gas, or you have a pot with heat-insulating handles so that you can react quickly. A hostile environment is an environment that hinders or disrupts the cognitive process and in which the probability that a non-analytical cognitive process, i.e. recklessness, will lead to an error (for example, burns) is high or relatively high (for example, the stove takes time to cool off, the pot does not have heat-insulating handles, gloves are not in sight). In both benign and hostile environments, we can operate recklessly (type 1 processes) and thoughtfully (type 2 processes), and the predictions of theoretical models about the outcomes of judgment, decision-making, and reasoning depend on the combination of environment and

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<sup>8</sup> Intuitive thinking is labeled as Type 1 thinking

processing. Experimental tasks in this paradigm simulate uncertainty or risk and a hostile environment, prompting participants to reason intuitively in such a setting. One way to simulate the hostility of the environment is by experimentally manipulating the deep structure of reasoning tasks by obscuring, concealing, or hiding key information. For example, in the task from the famous Frederick's Cognitive Reflection Test (Frederick, 2005), which reads, "A man bought a pig for 60 euros, sold it for 70 euros, rebought it for 80 euros, and finally sold it for 90 euros. How much did he earn?" in one of the studies, 36.47% answers were correct (20 euros). When the same respondents (N = 94) were presented with the task with the introduction of a reference point, i.e. when the text was preceded by the information "The man has 80 euros in his pocket", 52.94% of correct answers were recorded. Moreover, 31.76% of so-called heuristic (typically incorrect) answers were recorded in the first variant of the question. With the added reference point, the number of such incorrect answers decreased to 21.18% (Damjanović et al., 2019). If the environment is benign, i.e. if the information is not obscured, our thinking more easily reaches the criteria of normative rationality. Finally, in ecological and social rationality approaches, the basic starting point for studying higher cognition is the notion of the interactive, adaptive nature of these processes to the information structure of the environment. The essential assumption is that there is no uniform, universal strategy for rational cognition, but somewhat different principles adapted to different situations – the set of these principles is called the "adaptive toolbox" (Todd & Gigerenzer, 2012).

### **3 Knowledge Structures, or as Dualists Call Them, Mindware – What Does the Cognitive Miser Work With?**

The third principle of psychological models of rationality is the dependence of cognitive processing on knowledge structures. For us to reason, acquiring and possessing a knowledge structure is necessary – a base of organised information with a rich set of relationships that can be generalised and applied in new situations (Hough & Gluck, 2019). Put, function and structure, to a certain extent, are one and single entity – one cannot think without the matter (content) to think about, nor would the matter exist if it did not have the function. Knowledge structures are always involved in solving reasoning tasks (Stanovich, 2018b). Successful, or at least satisfying, reasoning in a hostile environment requires procedural skills and declarative knowledge to avoid attractive miserly processing. Kahneman and Frederick propose the mechanism of attribute substitution as an explanation for the systematic errors observed in tasks that require registering heuristics and biases (HB tasks). A paradigmatic example is the "bat and ball" problem (Frederick, 2005):

A bat and a ball together cost 1.10 \$. A bat costs 1 \$ more than a ball. How much does the ball cost?

The participants, by and large, provide an intuitive (and incorrect) answer (10 cents), for example, 80% of students (e.g., Damjanović et al., 2019). The correct answer is 5 cents. Respondents change the critical relational information "more than" to a more straightforward absolute value "more", and by simply parsing the sum, they arrive at the correct answer – but to the wrong question. The relation between the attributes that are changed comes from knowledge structures. Similar explanations come from fuzzy trace theory's authors Reyna and Brainerd (1995), and ecological rationality, Gigerenzer (2009). Being cognitive misers, we humans developed mechanisms that provide us with functional adaptation to the environment for "little money". By describing intuitive thinking (type 1 processes), Kahneman and Frederick (Kahneman & Frederick, 2005) explain that the mechanism of attribute substitution implies replacing the attribute that is

more demanding to process with an attribute that is simpler, more receptive, and closer to the demanding attribute. According to the Kahneman and Frederick model, the connection between the changed attributes comes from knowledge structures; it is not random. We process the seductive attribute using type 1 processes (intuition), which are probably stored in the implicit procedural memory domain through non-associative and associative learning. We approach the true but more difficult-to-process attribute through a type 2 process stored in the explicit declarative memory domain. Although not stored in the exact memory locations, the connection between the two changed attributes results from learning, which is both associative and discriminative—that is, experience in and with the environment.

Therefore, solving HB tasks relies on stored knowledge from various domains, and the operational term "mindware" relates to this stored knowledge, including rules, procedures, and strategies. The term "mindware" was coined by Perkins (Perkins, 1995, as cited in Stanovich, 2009), and Clark (Clark, 2001) introduced it into cognitive science, somewhat altering its original meaning. The mindware necessary for successfully solving HB tasks varies by task and includes knowledge of probabilistic reasoning, explanations of causality, scientific reasoning, and numeracy. Stanovich (2018) believes that the "irrational System 1" (sic), in addition to declarative knowledge, contains normatively rational rules and strategies that have been repeated, practised, and have become automated. They automatically compete and sometimes win over any alternative non-normative answer. This idea is not new either. The category of autonomous processing in cognitive science has long included the automatic triggering of "overlearned" rules (LaBerge & Samuels, 1974; Moors & De Houwer, 2006; Posner & Snyder, 2004; Schneider & Shiffrin, 1977). In other words, automated subprocesses include not only Fodor's modularity (1983), but also many rules, stimulus discrimination, and decision-making principles that have been practised to automaticity through repetition (Gigerenzer, 2009; Kahneman & Klein, 2009; Schneider & Shiffrin, 1977). In addition to rules that are consciously and intentionally practised and thus automated, a large part of the automatic associative learning accumulated, compiled, and autonomously launched from System 1. Not all "located" knowledge in System 1 is automated through intentional and conscious practice because implicit knowledge can also be automated, such as implicit associative knowledge (Evans, 2010). For example, some statistics lecturers cannot empathise with their students, for whom the fundamental axioms of probability are not transparent. The teacher can no longer recall a time when those axioms were not the primary intuition; in Vygotskian terms, he does not remember the transition from scientific to spontaneous concepts (Vygotsky, 1929). This sociocultural shaping of cognitive strategies contributes significantly to the inter-subjective variance observed in reasoning tasks and complicates the search for a single, decontextualised "rationality quotient". Additional support for the view that intuitive processing grows with experience comes from research findings on expert thinking. A feature of expert thinking is that primacy is given to certain more relevant, abstract, and complex sets of information. Experts do not process every single piece of presented information in the same way that a computer does. The selection of relevant information is based on knowledge and experience within the domain of expertise. Expert decision-making and problem-solving are qualitatively different from a non-expert's solving of the same problem, precisely because they are based on superior gist information and the processing of meaning, rather than on faster and more efficient mental calculation (Helm et al., 2018). Findings from neural research on object and pattern recognition show that expert thinking, although more efficient, accurate, and even faster, activates a larger number of brain regions (Bilalić, 2018). Underlying the seemingly less cognitively demanding process in experts is a complex system based on knowledge and experience (neural networks of amodal

representations). Unlike novices or beginner-experts, who must process presented information one by one, sequentially, experts recognise an object, identify its function, and simultaneously connect it with another object (relational operations on gist information). In the brains of experts, when solving a task, not only is a task-specific zone in one hemisphere activated, but also the same (homologous) zone in the opposite hemisphere (the double take of expertise), a phenomenon observed across multiple expert domains (Bilalić, 2018).

Findings show that, during type 1 processing, the degree to which mindware is instated can affect not only the correctness of answers but also the judgment of the correctness of one's answer (metacognitive assessment, the feeling of rightness, FOR; Thompson, 2007; Thompson, 2009, 2014). In studies that use HB tasks, but also in models developed based on them, the emphasis is on the procedural aspect and task processing, while the knowledge component is not in focus, although the necessity of knowledge is implied (DeNeys, 2006, 2014, 2018, 2022; DeNeys & Glumicic, 2008; Evans, 2007, 2008, 2010, 2014; Ferreira et al., 2016; Pennycook et al., 2015; Stanovich, 2011; Stanovich & West, 2008; Thompson, 2014; Thompson & Johnson, 2014; Thompson & Morsanyi, 2012). All HB tasks include mindware to some, but rarely to a small degree (Stanovich, 2018), which means that success on the task will depend on the degree of "mindware instantiation" in memory. Thus, the answer to the task can be both an indicator of miserly processing and the depth of learned (automated) mindware, which has theoretical and empirical implications.

#### 4 The Probabilistic Mind – How Does the Cognitive Miser Work?

The fourth principle of the cognitive system implied by all cognitive-psychological models of rationality is the ability of our mind to develop and cope with uncertainty. The world and the system in which the cognitive system of *Homo sapiens sapiens* is located abounds with uncertainty. The sensory stimuli based on which we derive mental representations of the environment are surprisingly diverse, the consequences of actions are usually very unpredictable, and even our scientific "laws of nature", at best, represent guesses and valid assumptions, not certainties (Chater & Oaksford, 1999; Damjanović, 2018). We do not know what will happen in five minutes, five hours, or five years. Our expectations and predictions may be more successful for a closer point in time than for the distant future. However, it may also be easier to imagine what will happen to our building in five years than to know when the sudden downpour that caught us on the street will stop. We will be surprised with a game in which a team from a lower league "miraculously" scores not one but two goals against the national champion. However, we will hardly notice when, while studying for an exam, our grandmother, as usual, brings us an apple and cookies. Something will surprise us more, something less, but we generally do not have firm, conscious, and clear expectations about a specific event that should happen. The cognitive system successfully copes with a complex and constantly changing environment and can only function in uncertainty. We could imagine that the cognitive system is pre-equipped with narrowly specialised structures and functions for processing each singular and specific surprising event, but such an assumption would be empirically and theoretically refuted by numerous disciplines, from information theory through systems theory to cognitive psychology (Chater & Oaksford, 1999; Kaplan & Simon, 1989; Damjanović, 2024).

Instead, the cognitive system is characterised by general strategies for overcoming uncertainty, earning the name "probabilistic mind" (Chater & Oaksford, 2008). The idea that the laws of probability are also the laws of the mind has survived since the Enlightenment. The available

mathematical tools, such as Bayes' theorem and Laplace's interpretation, Bernoulli's distribution, were considered descriptions of real reasoning (Daston, 1981, according to Chater & Oaksford, 1999). Probabilism is the view that the probability of an event is related to the conditions with which that event (be that a mental event, such as a decision or anything from the environment) is, to some extent, connected. Within probabilism, when we scientifically observe and predict how, for example, a parent decides whether to allow a child to bungee jump, we assume, even if we do not measure directly, that a) the probability of an unfavourable outcome of bungee jumping was (whether explicit or not) a factor based on which the parent made the decision, that is, that there is a mental representation of probability in the parent's mind; and b) that the cognitive process of decision-making itself takes place following the laws of probability theory. Again, here it is important to note that factors here are subjective probability and imagined outcome(s) of the decision-maker, and that such a decision is also powerfully driven by the imagination of what could happen—the creation of alternative scenarios to reality that makes the risk feel tangible, regardless of its low statistical probability (Byrne, 2005). Psychological models of rationality and mathematical probability theory share a twofold connection: phenomenological and conceptual. In prospect theory, cumulative prospect theory, and fuzzy trace theory, the central question is how we experience, perceive, and operate with environmental probabilities. Connectionist models of reasoning, the application of information theory in cognitive psychology, signal detection theory, or models based on discriminative learning, describe cognitive processing or cognitive architecture directly in terms of the principles of probability theory. All cognitive-psychological theories of reasoning encompass both aspects of the probabilistic mind: we necessarily process probability (for example, information about the riskiness of bungee jumping), and this processing occurs as a function of probability. Uncertainty and the ability to cognitively function in uncertainty are key aspects of thinking, decision-making, and judgment (Chater & Oaksford, 2008, 2012). Retaining the idea that all human cognition, like all natural systems, functions according to the principles of probability theory, psychological approaches to rationality introduce one of the fundamental questions in the field: how we assess and judge probability.

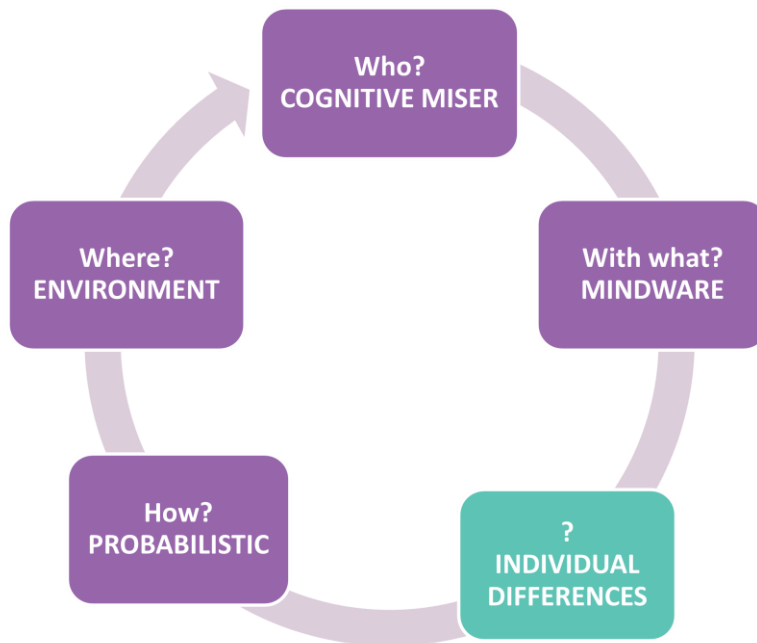


Figure 1: Boundary principles of cognitive-psychological approaches to rationality

### 5 The Missing Fifth Element: The Challenge of Individual Differences, Because Not All Misers are Equally Thrifty

While the idea of a single "g factor" of human non-rationality (or cognitive biases) is intriguing, the evidence points towards a more complex picture. Multiple general and specific factors (cognitive limitations, motivational factors, personality traits, and situational influences) are more likely to contribute to the diverse cognitive biases. Some biases might be more closely related because they operate in similar domains (contextualised in addition to generic) measures need to be improved or developed, involve similar cognitive processes, or rely on the same or similar heuristics. All these different influences also interact. Further, researchers sometimes treat achievement on the e.g. cognitive reflection test (Frederick, 2005) as a dispositional correlate (instead of a phenomenon) of rational thinking. Studies indicate that there is no homogeneous, one-dimensional psychological construct of rationality. Although different cognitive biases share a certain degree of variance (e.g. Reyna et al, 2003; Stanovich et al, 2011; Teovanović et al., 2015), the reliability of the composite score of heuristic answers is relatively low – around 0.20 (e.g. Aczel et al., 2015; Teovanović et al., 2015), to moderate (around 0.5) (Toplak et al., 2011, Stanovich & West, 2008). Stanovich and colleagues elaborated on the construct of the rationality quotient as an intellectual or cognitive ability different from intelligence (Stanovich et al., 2016). In summary, research continues to explore the relationships between different biases and the underlying cognitive processes involved; however, “the measurement of individual differences in cognitive biases is still in its infancy” (Berthet, 2021). We suggest that the elusiveness of a single indicator of rational thinking and its mechanisms (if we aim to describe it) is due, at this point, to methodological limitations within the field.

Psychology has many methods and techniques for observing, registering, “measuring”, and predicting the phenomena it studies. When it comes to the rationality and non-rationality of reasoning, experiments are traditionally used, and biases are quintessential constructs within these experiments. Numerous studies confirm the existence of cognitive biases as reliable experimental effects and demonstrations of (non-)rationality, including the stability of the recorded magnitudes of those effects. Although we can rely on such findings, this approach does not allow us to determine how much people differ from one another in their propensity for cognitive biases. Knowing and understanding the differences in (non-)rational thinking between individuals and within individuals is necessary to confirm the scientific, mainly theoretical, reality of these constructs.

Suppose we operationalise rational reasoning as a set of evolved complex cognitive processes. In that case, we must also consider the differences between individuals in terms of this ability, rather than just the similarities. As mentioned, human reasoning is determined by the situation and the environment and our "internal" characteristics, dispositions, or a set of dispositions with which we can explain the differences between people. For a psychological description, it is not enough for the rationality of reasoning to be understood as unchanging and identical in all circumstances or phases of phylogenetic and ontogenetic development. Just as all people have ears and the sense of hearing, but not all ears are uniform, and hearing is not the same in all people; everyone has a (structure of) personality that differs from each other, so rational and irrational reasoning must exist in all people, but its manifestations are different (intersubjective variance). Rational thinking, as a monomorphic evolutionary organ that serves to solve some of the problems of adaptation, must also have a variance that stems from differences between people; that is, it must be flexible enough. If complex cognition is one of the many functions we have to adapt and survive in a complex environment, it must be adaptable, not just adaptive. The conclusion is derived by analogy with Daniel Nettle's consideration of personality variations in the context of evolution (Nettle, 2006).

A comprehensive account of individual differences would extend beyond dispositional traits to encompass the sociocultural environment in which cognition is situated and learned. Thinking is honed in specific contexts, such as formal education or cultural traditions. Research in cultural psychology and on 'street mathematics' confirms that different human groups develop unique, context-dependent strategies for similar tasks (e.g., Cole, 2024; Saxe, 2015). These environments also supply symbolic resources for imagination, shaping the alternative scenarios crucial for decision-making (Byrne, 2005; Zittoun & Gillespie, 2016). The sociocultural shaping of cognitive strategies and imagination creates inter-subjective variance, complicating the search for a single "rationality quotient" and highlighting how the "adaptive toolbox", like any evolutionary function, is stocked and organised by culture. However, where to aim to map that variance since examining individual differences in cognitive biases did not yield a satisfactory description of the phenomena?

Here, we propose that examination should focus on the variance of underlying cognitive mechanisms of cognitive biases, such as heuristics, and that this could be achieved by integrating the psychology of rational thinking into traditional constructs of cognitive psychology. On a conceptual level, this became possible only with the establishment of the dual process approach as the dominant paradigm in the field. Lee Cronbach, calling for integrating two, at his time, mainstream traditional methods in psychology, experimental research and differential research, pointed out, "...Individual differences were a nuisance rather than a challenge to the experimenter.

His goal is to control behaviour, and within-treatment variations are proof that he has failed... For statistical and philosophical reasons, error variance is to be reduced by all possible means" (Cronbach, 1957, p. 674). Integrating methods for a single phenomenon or a group of related psychological phenomena is far from a trivial task and has not yet been achieved in many areas of psychology. One of the reasons such integration has not occurred is that some tasks traditionally used in the psychology of rationality are unsuitable for addressing individual differences. In the differential approach, reliability refers to a distinct property, which is why researchers encounter difficulties when attempting to translate an excellent experimental design into examining individual differences (Hedge et al., 2018; Ross et al., 2015; Barch et al., 2008).

For example, in a study examining what people think about their own decisions and what they base such self-assessments on, respondents in two experimental situations were asked whether they acted "smartly" when buying shoes online. In one situation, the shoes that arrived fit; in the second, they were not. If the shoes are fit and comfortable, then the decision, the respondents believed, is smart. Regardless of whether they are small or large, the purchase decision is assessed as less informed (Orlić & Damjanović, 2016). The statistically significant difference between the assessments of the identical decision (online purchase of shoes) in two situations with opposite outcomes is the experimental effect, i.e., the difference between the assessments is attributed to the difference between the experimental situations. A reliable experimental effect is a behaviour most participants display in studies examining a phenomenon, and if it is replicated in most studies on the dependence of the judgment on the outcome (called outcome bias; Baron, 1988). In our experiment, as in any other, participants perform the same task (judging) in different ways and to varying degrees (in our example, they evaluated the decision in both conditions). Though the effect overall exists, there are differences in the same behaviour: someone is angry because of the wrong shoes and considers it an irresponsible act, someone else is just dissatisfied and even less judgmental; with the opposite outcome, the first person can be very excited, even proud, that the shoes are good, and the second can say that she was simply lucky with the outcome. Moreover, the same person can exhibit the same effect, albeit with varying magnitudes, on different occasions.

In conclusion, the epistemic contribution of the differential approach, which is a necessary next step in explaining the rationality of reasoning, should be found at another level of molarity, i.e., at the level of the cognitive process and not only at the level of its manifestation.

## Conclusion

Epistemic contributions of the psychological study of (ir)rationality of thinking are phenomenological (for example, cognitive biases), conceptual (e.g., heuristic algorithm) and empirical (posing research questions). The current theoretical state of the psychology of rational thinking presumes that the rationality of our thinking is characterised by cognitive miserliness and probabilism and depends on the environment and knowledge structures. The next endeavor in the field should be to merge experimental and differential approaches. To achieve this, psychology needed to delimit its research problem from normative description and establish its model with psychological constructs, not mathematical or economical<sup>9</sup>. At the beginning of the development

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<sup>9</sup> The understanding of the developmental aspects (also a fundamental test for scientific reality) or rationality of thinking was meticulously developed within the approach proposed by Reyna and colleagues in their fuzzy trace theory.

of psychology of rational thinking, there were normative theories of rationality, and psychology joined the field to observe and understand deviations from defined norms.

As in the case of other areas of psychology, the study of judgment, decision-making, and reasoning initially focused on phenomena and systems described by other sciences or observed in people's lives, rather than being set as a psychological subject of research. For example, in the case of psycholinguistics, we use the linguistic description of the language (say, adjectives and nouns) and view it as a natural system – to describe the linguistic and cognitive function (how we (our mind) make a psychological distinction between “kind” as an adjective and “kind” as a noun). In the case of the psychology of perception, we examine how our sensory cognitive system learns and evaluates physical reality, described by parameters derived from physics. The measuring device used to vary the experiment and measure the outcome is the same. When examining how we estimate distance, we can express both the real objective distance of the bus approaching and the subjectively estimated perceived distance in meters, and we can easily record the deviations between these two data from interval scales. To examine personality structure, we rely on norms from both etic and emic studies, as well as the lexical hypothesis – the basic assumption that important aspects of socio-psychological functioning are encoded as words in natural languages. On the other hand, to describe someone's coping mechanisms, defence mechanisms, motivation for learning, and numerous other states and behaviours, it is sufficient to rely on constructs that originate solely from psychology.

To take the following steps within the psychology of rationality, it was necessary to describe rationality as an ability entirely in psychological concepts. Establishing the dual-processes account for thinking is a milestone that enabled the methodological merger and reconceptualisation of the initial notions. It enabled the debate about whether two types of thinking even exist or are helpful to be used as useful fiction (Melnikoff & Bargh, 2018; Oaksford, 2022), which may be partially answered empirically. All further psychological models of rationality, next to the accepted 4+1 features, should be "immersed" in cognitive psychology and juxtaposed with the basic and researched concepts of cognitive psychology, requiring systematic integration with basic cognitive psychology, moving beyond correlational findings to examine how classic constructs (for example working memory, long-term memory, associative processes...) fundamentally constrain and enable reasoning. Furthermore, this integration must be theoretical, not just empirical, aiming to build comprehensive models that formally account for the established roles of perception, motivation, affect, and sociocultural factors in shaping human thought. This will emphasise the integrity of the currently valid idea of cognitive architecture, in which complex cognitive processes are only one of the necessary parts of manifestation. More importantly, findings from other areas of cognitive psychology can be considered in the context of psychological models of reasoning, and vice versa – the concepts of traditional cognitive psychology (e.g. working memory, associative processes, intelligence, cognitive styles...) can explain findings from the psychology of rationality. The psychology of rational thinking benefits the most from this expansion of the quantity and complexity of empirical findings that we can use – in which the number of constructs that are entirely new and isolated from the body of knowledge about human cognition is small but significant (e.g. heuristics, conflict detection, dual processes, cognitive biases). The scientific question of whether and how human thinking is rational can also be seen as a change in the reference point from which the study of thinking is approached, from observing products of human thinking as deviations from some ideal to humanising human errors and fallacies, and accepting those as our feature, not a bug.

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