Springer Series in Cognitive and Neural Systems 12


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*Editors*


# Blended Cognition

## The Robotic Challenge

Springer

# Springer Series in Cognitive and Neural Systems

Volume 12

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ISSN 2363-9105 ISSN 2363-9113 (electronic)
Springer Series in Cognitive and Neural Systems
ISBN 978-3-030-03103-9 ISBN 978-3-030-03104-6 (eBook)
https://doi.org/10.1007/978-3-030-03104-6

Library of Congress Control Number: 2019930998



This Springer imprint is published by the registered company Springer Nature Switzerland AG.
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

# Preface

## Introduction: Blended Cognition

Two views on natural and artificial cognition seem to be locked in a contest today: the naturalistic, bottom-up and embodied/enactive/extended/morphological approach to cognitive systems vs. formal, top-down, and highly symbolic/statistical approaches. Facing these traditional battles, we suggest an ambitious hypothesis: these two views are not only biased, but are also theoretically overrated—there is a coherent middle way.

Embodiment contains, in its own structure, a syntax that expresses specific methods of semantics; while pure symbolic systems are not able to generate meta-discourses. Eventually both views converge at the same problem: how to deal with the multiplicity of strategies in cognition, and the choice between these strategies. The main idea of the present volume is to ask experts from different fields (e.g., engineering, logic, anthropology, computer sciences, and psychology) questions on how to design machines that are able to decide on combining multiple heuristics, or to explain how humans are able to make these decisions. This ability appears to be fundamental for many cognitive skills in humans.

This volume is a serious attempt to face both challenges: to study the pros and contras of morphology and symbolic processing without considering how both are deeply intertwined in decision-making. The structure (physical or formal) in which a reasoning process is performed shapes the individual's own reasoning, and this is never completely perfect (e.g., because of lack of data, inaccurate data, wrong data integration, misleading reasoning formalization, and changing conditions), but can be, at least, designed to satisfy minimal requirements. The natural way of integrating different heuristics and reasoning strategies is a good example of how adaptability provides some benefits, while it produces some 'biases'. For example, at a certain point in decision-making procedures, we need to choose between the accuracy and the speed of the answer. And even this process can vary depending on whether we are considering the performance of individual tasks or, rather, whether we are looking at social-network joint collaborative work, which can be either not directly supervised, as happens with swarm intelligence, or supervised and coordinated, as happens in human hierarchical collaborative actions. Humans do not act as rational agents, and think in different ways according their individual conditions: such as whether they are alone, sad, as members of a crowd, or excited. This vast range of ways of combining even imprecise or unconventional reasoning styles is of the greatest interest for the future of artificial intelligence (AI) and the design of artificial general intelligence (AGI).

This book introduces a new concept to cognitive sciences research: *blended cognition*, a concept that will contribute to the design of more realistic and efficient robots. After the extensive introduction of recent ideas into the field, such as extended, embodied, enactive, grounded, or morphological cognition (among several others), it may seem unnecessary to introduce a new category. But the truth is the opposite: we need a new conceptual space from which we can be able to understand real complex cognitive systems, such as human ones. Looking at the daily decision-making procedures undertaken by human beings, we can observe an unprincipled mixture of methods, as well as many intuition-driven actions. What can be affirmed is that humans blend and combine several kinds of heuristics, consciously or not, at symbolic or sensorimotor levels. This blending can occur in parallel or procedurally (one step at a time, completely sequential, or using turns/changes/dead ends).

Let us introduce the idea with an example: a young researcher who buys a cup of coffee. She has a headache and decides to walk to the coffee machine, she looks into her pockets (in fact, she feels with her fingers), grasping some coins while she is looking at the number code of the milk coffee. Then she inserts the coins into the machine, selects the desired option, and waits in front of the machine, thinking about what she has in the fridge for dinner. A characteristic smell makes her aware of the fact that the coffee is ready. She takes the cup, which is too hot to handle and must be changed from hand to hand every few seconds, and moves toward the office, but her phone rings; it is her best friend, who has a serious problem. She looks for a place to put down the hot coffee cup and meanwhile she downloads some files, checks them, and then decides to forward some to her friend. After that she carefully picks up the coffee and comes to the office. In this example some basic sensorimotor processes have been required to allow her movements; among them are object identification and selection (tactile as well as visual and auditory), action planning, object grasping, context evaluation, parallel actions, and mental calculations; some of the movements have followed automated processes (e.g., walking, looking at the pathway, pain arousal, and object identification and avoidance), while some of the movements have required several decisions (holding the cup alternatively in each hand until the required task was performed could lead to skin damage, and she decides to put the cup on a stable surface), as well as cognitive heuristics (how to solve the friend's problem while pending duties are also waiting for her at her desk and the headache needs resolution). She has undertaken all these processes, and more not described here, without falling to the ground, collapsing, or feeling blocked (some possible situations also experienced by stressed humans). Our analysis is that she has blended several heuristics and strategies in order to satisfy the demands of the actions she must solve.

Humans combine several heuristics and even think in meta-heuristic procedures in order to achieve their necessities. *Induction, common sense, analogy, syllogistic procedures, abduction, Bayesian statistics, classic logical reasoning, frequentist statistics, imitation, likelihoodism, amodal thinking, non-monotonic logics, deduction, algorithmic rules, moral codes, attribute substitution, fuzzy logics, swarm reactions, the availability heuristic, the representativeness heuristic, and the anchoring heuristic*—among a very long list of possible strategies or heuristics—are used indistinctively, being combined into a flowchart of possibilities while an action is required to be solved by the experiencer. The uses of these possible strategies or heuristics will, seemingly, vary according to the external and internal context of the human. From sensorimotor to symbolic, from intuitive to highly formalized, and from conscious to unconscious processes, performed sequentially or in parallel, humans select from among a long list of options in order to solve complex tasks. This process is what we call *blended cognition.*

The design of modern robotics and AI cannot be placed under the umbrella of a single and over-simplistic research field: good old-fashioned AI (GOFAI) is not worse or better at all possible scenarios than embodied or morphological approaches. It is true that the symbolic framework requires a bodily revolution, exemplified by the new ideas provided by embodied, enactive, grounded, or extended cognition. And that, after the alternate dominion of one of both sides (the mental and the corporal), it is time to be pragmatic and try to design new strategies to implement multi-heuristic procedures.

We will need to define a subsumption architecture and layer-managing system that makes possible this jump and combination between possible heuristics. At the same time, a discretization of possible flows of actions will be required. This process forces us to think about a grid of procedures, mechanisms, heuristics, and codes that are combined at different places according to the necessities and skills of the agent.

Blended cognition is, thus, the study of how an intelligent system can use or even partially combine several methods to decide among possible action outputs or data evaluation and storage. Here, there is a combination of possible data and task demands: semantics-body-mind**.** By ‘semantics’ we mean the value of information at a specific moment for the agent; by ‘body’ we mean the bodily requirements and possibilities (DOF (Degrees of Freedom), for example, flexibility and impact absorption) that the agent exhibits; and by ‘mind’ we refer to the heuristics mechanisms designed to give answers to the data flows. The importance of blended cognition is that there is no pre-established and rigid hierarchy of control among these possible main layers, or among their sub-layers. There are optimized functional strategies of agreement and combination, but the key point here is the *flexibility* and *adaptability* of the system.

Thanks to the collaboration of experts from a very broad range of academic fields, we have been able to create this book about blended informational processes. After the introduction by the editors, Professor Jordi Vallverdú explains the conceptual nature of the concept of *blended cognition*, following a naturalistic approach to multi-heuristic reasoning that can be applied to AI. Chapter 10 is a fundamental anthropological view of the naturalistic analysis of activity-based AI. Written by Corentin Chanet and David Eubelen, this chapter connects anthropological knowledge with possible ways of modeling AI. In Chap. 5, Gabriele Ferretti and Eris Chinellato propose an embodied model for neurorobotics. After this embodied approach, Chap. 6 suggests a specific way of implementing a bioinspired model using neurosimulation and emotional mechanisms; from an engineering perspective, Max Talanov, Alexey Leukhin, Fail Gafarov, and Jordi Vallverdú suggest a complex computational model that is very close to physical implementation via memristors. From the psychological research, Kay-Yut Chen and Daniel S. Levine explore the heuristics of numerical choice, adding more evidence in Chap. 9 about multiple reasoning strategies used by humans. Chapter 2 explores, with Professor Lorenzo Magnani, the possible connections between abduction and blended cognition, a field to be explored in more detail in the future. Chapter 7, by Qiang Zhang, Stef van der Struijk, and Toyoaki Nishida, analyzes the challenges of cognitive robotics, taking into account this multi-tasking problem and the presence of several heuristics. Robert Earl Patterson and Robert G. Eggleston, from the United States Air Force, make a sound contribution in Chap. 8, exploring the ways of blending the cognitions of humans and autonomous machines. In Chap. 3, Professor Douglas Walton constructs a deep analysis of the formal mechanisms present in practical reasoning in the deliberations of intelligent autonomous systems. Chapter 11, written by Professor Pei Wang, constitutes a fundamental logical analysis of the logics of everyday reasoning, something that is of the utmost interest for robots, which must operate in complex and diverse ‘trivial’ (for humans) contexts. Finally, Chap. 4 is a theoretical exploration, by Vassilis Galanos, of possible theoretical aspects of increasing intelligence automation to consider in the near future.

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# Philosophy

# Chapter 1
# Blended Cognition: The Robotic Challenge

**Jordi Vallverdú**

**Abstract** This chapter is a transdisciplinary study on the fundaments of cognition, considering this process at human level as the combination of biological and (multi)cultural values. The main idea is to describe the skill of human beings for using several heuristics for task-solving activities as a process of combining and blending techniques, something that is called here as "blended cognition". This rich and complex way of dealing with multi-heuristic frameworks provides not only a more adequate model for the understanding of real human cognition, but also it is of the most interest for the design of creative and adaptive artificial intelligences.

**Keywords** Multimodal · Blended cognition · Multi-heuristics · Emotions · Evolutionary · Bias · Challenge · Biomimetic

## 1.1 Cognition: From Experience to Meaning

### *1.1.1 The Mechanisms of Experiences*

Cognition is the set of processes by which a living entity offer answers to the data it has at a certain moment. In this sense, and following previous researches (Vallverdú and Trovato 2016), we can affirm that as a fundamental mechanism of the cognitive system, we can find emotions. Thus, emotions are the informational mechanism used by living entities to give appropriate sensorimotor answers to external inputs as well as a way to assign meaning to internal data. This mechanism is bodily oriented and maintains a coupled relationship with environment (Barsalou 2008; Barsalou et al. 2003, 2007), generating the notion of "emotional meaning" (a semantic corollary). By "emotions" (see Damasio 1999; Ekman 1999; Levine and

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J. Vallverdú, V. C. Müller (eds.), *Blended Cognition*, Springer Series in Cognitive and Neural Systems 12, https://doi.org/10.1007/978-3-030-03104-6_1

Perlovsky 2010; Scherer 2005 for a detailed analysis), we mean informational states employed by organisms (and/or viruses) to give semantic value to informational values (originated by external inputs captured or internal autonomous processes). By "informational states" we mean any way that uses a living entity to evaluate observational inputs (generated as a result on internal processing in any case, because there is nothing in cognition like raw external data, once we consider the role of structure into the data acquisition, analysis, and evaluation).

Thus, an evolutionary and naturalized approach to cognition provides us several examples about how living systems deal with information and adjust their actions or responses to it (Dukas 2004), and even very simple systems like slime mold are able to perform extraordinary processes like image processing, logic and arithmetic, creativity, identity detection, or cooperation (Adamatzky 2016; Adamatzky et al. 2013). It is very important to keep in mind that a naturalist approach to these minimal cognitive systems is possible and that stochastic thermodynamics offers an integrated framework for these studies (Parrondo et al. 2015; Seifert 2012).

From basic bacterial chemotaxis (Porter et al. 2011; Wadhams and Armitage 2004) to natural numeric and spatial processing (Howard et al. 2018; Vallverdú 2016), together with the social aspects involved into cognition (Axelrod 2004; Casacuberta and Vallverdú 2015; Engeström et al. 1999), we can observe a rich set of natural adaptations to action selection. The last step of complex strategies was observed when humans adopted symbolic thinking, making possible the generation of more elaborated heuristics to guide their actions. Firstly they created them verbally and secondly in a written format (and in our days from a numerical perspective computationally implemented).

Finally, we should not forget the layered cognition that happens in systems which need to take parallel decisions using several sources of data. It explains how complex biological systems like humans are able to perform several cognitive tasks ruled at different informational processing layers. Sleeping discoveries (Baylor 2001), like those of Kekulé or Ramanujan (Eysenck 2003), or readiness potential evidences (Jo et al. 2014) about how brain decides before we are aware of it at a conscious level offer us a scenario in which thinking processes are beyond our control as well as facing multiple heuristics (Siegler and Stern 1998). Studies on convergent vs. divergent thinking and its relation with creativity (Csikszentmihalyi 2014; Perlovsky and Levine 2012) show us that there is not a clear path for the creation of knowledge.

### 1.1.2 The Emergence of Meaning

From an evolutionary point of view, humans were not only coerced by their own morphologically inferred images and models of the world but also by the mechanisms they choose to use to deal with symbolic information, like suggesting the Sapir-Whorf hypothesis on language (Harpham 2002; Imai 2000; Kay and Kempton 1984). We must consider this process as a coupling mechanism between bodily morphology and information management, with deep feedback from evolutionary constraints. These mechanisms shaped human decision-taking strategies (Hammerstein and Stevens 2012), for example, the use of *dilemmas* as some sort of bivalent logics that are shortcut among possibilities (why not dodecalemmas, icosalemmas, etc.?). This is the result of cognitive fitness and its related ethnological situatedness of thinking, as well as its related set of contradictions (Berliner et al. 2016; Campbell and Xue 2001; Hamill 1990; Rusconi et al. 2007).

From the normative and optimal perspectives of classic decision theory, it can be affirmed that humans violate the expected and best options (Gigerenzer 1991; Kahneman and Tversky 1979). This is very important because *intuition*, the fastest and automated way to deal with imperfect information settings, was the result of specific evolutionary forces (Buchtel and Norenzayan 2008; Dorfman et al. 1995; Lieberman 2000; Sinclair 2010). At the same time, we need to remark that intuitive reasoning is not worst or biased than rational thinking in several decision-taking contexts (Lu 2015). Even in complex AI systems, an intuitionist approach can provide good solutions. An example of it could be DeepStack the artificial poker player, which combines recursive reasoning to handle information asymmetry, decomposition to focus computation on the relevant decision, and a form of intuition that is automatically learned from self-play using deep learning. According to the programmers, "DeepStack's depth-limited continual re-solving is sound (...) If DeepStack's intuition is "good" and "enough" computation is used in each re-solving step, then DeepStack plays an arbitrarily close approximation to a Nash equilibrium" (Moravčík et al. 2017).

From a supranaturalist perspective, first cosmogonic relates, myths, magic, or religious practices provided a framework for the understanding of the world, conditioning the way by which humans considered their own nature and looked for the best or optimal reasoning practices. According to the classic Western knowledge's history reconstruction, after this initial magic period began the rational paradigm, shifting from myth to logos (Calame 2002). But the truth is that a deep analysis of reasoning strategies in Ancient Greece provides us a completely different scenario: consider, for example, Plato's constant appeal to myths across his writings show us how the magical and unproved data (you could also call them euphemistically "reason's axioms," but they still are the same tricky explanation). Natural and supernatural explanations coexisted during all Western history, and this process is the object of study for anthropologists, psychologists, or evolution theorists (Whitehouse 2011). Although it could be easy to explain naturalist explanations as objective and physical/mechanical oriented and supranaturalist ones as social and normative, the best analysis offers a different scenario: both ontological positions can be found across the history of science or Western societies. Just remember medical connections with religion, biology and religion (what else caused USA ban on stem cells research during G. W. Bush mandate?), and a large list of crossing fields.

Finally, we need to consider deeper consequences of these mechanisms: languages also shape the ways by which we think the world from a moral perspective; it has been discovered that our morals depend on our language (Costa et al. 2014b).

The mechanism is cognitive: using native language or, instead, a foreign learned tongue modifies our perception of the problem as well as our reasoning process related to emotional values.

### *1.1.3 Defeasibility as a "Anything Goes" Rule?*

In human reasoning scenarios, we can find a very common fact, which still has not been critically explored by academicians: defeasible reasoning. By "defeasible reasoning" we mean a kind of reasoning in which the corresponding argument is rationally compelling but at the same time is not deductively valid (Bochman 2001). In a nutshell: it seems to be consistent with our rational beliefs but cannot be completely deduced and affirmed from our current knowledge. The crucial point here is to define "rationally compelling," especially when we are considering not only small debates but also big paradigm shifts.

The defeasibility of an argument can be biased and/or supported according to how we attach truth/false values to the basic premises of the argumentation, as well as according to the plausibility we give to some reasoning style. Sometimes, our plausibility can be flawed by some unconscious cognitive aspects also related with cultural processes, as, for example, in moral reasoning using a foreign learned language (Čavar and Tytus 2017; Costa et al. 2014a; Geipel et al. 2015). It must be also implemented into a moral framework in which we can even talk about ethics without principles (Dancy 2005).

On the other hand, the defeasibility can be supported by tricky argumentative techniques (or bullshit (Frankfurt 1986)) or, plainly, rhetoric artifacts. It can not only justify all kind of arguments but also create vicious experimenter's regresses also at scientific level (Oreskes and Conway 2010).

Consequently, defeasibility is affected or directly related with cognitive biases, cultural values, and also social agreements about epistemological mechanisms. The experts' disagreement on a long list of fundamental issues can be found in any kind of research field (Chalmers 2011; Lackey 2013; Mills et al. 2012).

## 1.2 From Nature to Philosophy and Decision-Taking Processes

As a response to the increasing complexity of data under analysis, and trying to find some unified perspective, philosophy (哲学, knowledge) emerged as a (cultural) tool to deal with information trying to define meanings beyond ad hoc supranaturalistic explanations. One of the basic aims of ancient philosophies from East and West was by one side, to understand reality, tracing a conceptual arch from Being to Nothingness (Heisig 2001; Russel 1953), and on the other side, to find ways to deal with ethical actions, that is, what to do. Despite some similitudes and other obvious differences (Schroeder and Vallverdú 2015; Zilberman 2006), it is out of discussion the fact that paradigmatic perspectives that shaped the philosophies were spread all throughout the human world (Nisbet 2003). That is, ontological views define the horizon of events and the tools we will use to deal with them, even logical rules for "good reasoning." Consider, for example, how ancient ontological Greek-Western claims against horror vacui defined a dyadic logic based on true/false premises or syllogisms, while in Indian-Eastern logics, free from these limitations, we can find four-valued or even seven-valued logics (Vallverdú 2017a, b, c). The funny thing is that recent Western non-monotonic logics have several contact points with classic ancient-Eastern four-valued *catuṣkoṭi*. So, we can affirm that logics did not represent the world adding layers of coherence, but reinforced axiomatically cultural views about the ontological nature of reality. Consequently, it is painful to see that the philosopher most related to the notion of "rationality" and "rational method," René Descartes, introduced in the crucial point of his reasoning about a method and a starting position toward the achievement of a universal knowledge, which he defined as the "me" (remember, cogito ergo sum), required from the support of a benevolent God which made possible that there was not a misunderstanding or a devil's interference which could make me doubt about it, that I am I. Besides, some supranaturalist version of the Christian God offered him a good mechanistic way to explain the physical universe (Hatfield 1979). Not only this ontological perspective affected philosophy but all scientific domains, such as physics of biology, chemistry, or medicine (Vallverdú and Schroeder 2017).

But classic argumentation and cognitive studies neglected this situated nature of knowledge and considered that language captured nature by itself, as if there was not even a loss of accuracy between *noumenon* (*Ding an sich;* thing-in-itself) and language. Still some "lost" structuralists still maintain these theses. A clear example is first Ludwig Wittgenstein, who, after the completion of his wonderful (but wrong) book *Tractatus Logico-Philosophicus*, abandoned philosophy because he considered that the possible tasks this field could do have been finally logically and linguistically clarified. Under such assumptions about good reasoning, psychologists entered during the twentieth century into the definition of human reasoning. Economists even tried to model this rational activity, defining the *homo economicus* and forced reality to understand why their models did not fit with real human behavior. After some formal attempts (game theory, Nash equilibrium, etc.), more detailed and sincere studies offered a radically different scenario: humans behaved in a set of strange and weird ways, far from the expected ones. This new wave studies defined the new paradigm of behavioral economics and made possible a new concept "bounded rationality" (Gigerenzer and Goldstein 1996; Simon 1972). This new concept tried to explain human behavior taking into consideration three facts: (a) the decisions of individuals are limited by the information they have (uncertainty), (b) their decisions are the result of the cognitive limitations of their minds, and, finally, (c) they are biased or affected by the finite amount of time they have to make a decision. Several experimental studies reinforced this idea (Kahneman and Tversky 1979) and even explained the existence of vague heuristics (Gigerenzer 1996). Humans were not good thinkers with minor biases, but on the contrary, their main cognitive performance was limited and biased, something that explained the real behavior of humans (and collectives of them) under observation. These researches contributed to the real understanding of collective behavior, not only in economic domains but also in several other frameworks of human activity. The recent Nobel Prize Richard H. Thaler has extended these ideas in his studies on economic behavior (Thaler 2000), expressing them even funnily predicting that *homo economicus* will evolve into *Homo sapiens*, thanks to the real understanding of human cognitive processes. Thaler's work also established that people are predictably irrational in ways that defy economic theory.

Among several other advances, magnetic resonances provided a key tool to discover the fundamental role of emotions into cognitive reasoning (Damasio 1985, 1999), a field in which we've devoted most of our academic researchers during the last 15 years (Casacuberta and Vallverdú 2015; Vallverdú et al. 2018; Vallverdu and Trovato 2016; Vallverdu 2015; Vallverdú 2017b; Vallverdú and Casacuberta 2008).

But, once mapped the basic historic evolution of the studies about cognition and rationality (sic), emerges from our humble point of view the only serious question here: *is this complex human a "design failure" provided by blind evolutionary forces and the good luck and, consequently, we should describe his cognition as "irrational"?* My answer is clear: no. For several reasons, this approximate informational processing system that we call "human" is successful in various ways: it combines several heuristics in order to achieve certain goals, it is able to answer fast, to decide even not having enough meaning, or to decide being influenced by too much information. This parallel data processing, in which several bindings are produced, and a diverse range of heuristics are applied according to local values is what we've called *blended cognition*.

### 1.2.1 Blending Concepts or Blended Cognition?

There is a concept created by Fauconnier and Turner (2008), called "conceptual blending," which despite of having an apparent similarity with our research is not strictly related to it. Basically, it is because they suggested the necessity of introducing a concept which could capture the mental process devoted to the conceptual projection of one mental space to another. According to them, when comparing a past action and revising it for a future one, we create a comparison framework that enables to share data, processes, or expectations in order to decide something about them. This framework was the conceptual blending.

In our model of cognition, we are considering a different way of understanding "blending." First of all, we make a universal observation: humans use plenty of different cognitive and/or reasoning heuristics when they are trying to solve problems in order to take actions. Secondly, they are not only using several heuristics, one for each different action category, but they are able to combine them sequentially (as well as in parallel) and even mix them according to local variables. See Table 1.1 as a compilation of heuristics used by humans for action-decision purposes.

**Table 1.1** A taxonomy of human heuristics

| Level | Framework | Heuristics | Variations |
|---|---|---|---|
| Unconscious | Unconscious | Several | Sleeping, natural calculators, … |
| Subconscious | Subconscious | Readiness potential | Sensorimotor coupling, imitation, natural statistics,, … |
| Conscious | Religious | Magical thinking | Faith, revelation, authority, apophactic vs. cataphactic, homeopathic thinking |
| | Main | Learning | Imitation, bounded cognition, opportunism, |
| | “Innate” thinking | Common sense | Imprecise reasoning |
| | | | Convergent-divergent thinking |
| | | | Modal vs. Amodal |
| | Formal/ academic | Deduction | Hypothetic-deductive |
| | | Induction | Retro-induction, |
| | | | Reverse inference |
| | | | Complete or incomplete induction |
| | | | Statistical generalizations, causal reasoning, probability, inference to best explanation, arguments from analogy. |
| | | Abduction | Inference best explanation (IBE) |
| | | | IBAE = inference best available explanation |
| | | Authority | |
| | | Analogical reasoning | Analogies, metaphors, … |
| | | Axiomatic | Myth (Plato) |
| | | Logics | Monotonic |
| | | | Two-valued classic logic (propositional calculus, first-order predicate calculus) |
| | | | Modal logic |
| | | | Non monotonic (defeasible reasoning) |
| | | | Abduction + best explanation. |
| | | | Intuitionistic logic (Brouwer) aprox!!!! |
| | | | Para-consistent logics |
| | | | Many-valued: 3, 4, 8 |
| | | | Non-monotonic |
| | | | Fuzzy/grey … |
| | | | Uncertain logic |
| | | | Imaginary logic (Nikolai Vasiliev) |
| | | | Eastern 4-valued Catuskoti, 7-valued Perhapism |
| | | | Flexible logics |
| | | | Universal logics (?!) |
| | | Dialectics | Models of argumentation |
| | | | Dialecticism (east) |
| | | | Pragma-dialecticism |

(continued)

**Table 1.1** (continued)

| Level | Framework | Heuristics | Variations |
|---|---|---|---|
| | | Rhetoric | New rhetoric |
| | | | Metaphor |
| | | | Models |
| | | | Analogies |
| | | | Bullshit reasoning |
| | | | Post-truth |
| | | Syllogisms | Thinking styles |
| | | Combinatorial | Combinatorial wheels by Raimundus Lulius |
| | | Controversies | Problem-solving |
| | | | Explanations |
| | | | Nets of controversies |
| | | Contradiction | Buddhist middle way logics (vs Western bivalent contradictory) |
| | | Mathematics | Axiomatic reasoning |
| | | Experimental | Mental experiments, simulations, labs, real, ... |
| | | Statistics | Bayesian, Frequentism, likelihoodism, ... |
| | Artificial | Deep learning (causal induction, causal deduction), | |
| | | Neural networks | |
| | | Expert systems | |
| | | Model-based reasoning | |
| | Political | Rhetoric | |
| | | Persuasion | |
| | Legal | Legal argumentation | |
| | Social-group/ interpersonal | Drugs intake | Collective behavior, swarm cognition |
| | | Tradition | |

Consider, for example, analogical thinking: it can be supported using different combinations of support from inductive, deductive, or abductive reasoning processes (Bartha 2013). Even the use of metaphors shows a subtle range distribution of apparently isomorphic or analogical values (Hoffman 1980; Lakoff and Johnson 1997; Taggart and Valenzi 1990). Analogies are extremely present into scientific reasoning; take as examples the following ideas or concepts: neural networks, genetic algorithms, brain as a computer, "*wormholes* in general relativity," "electron *cloud*," atoms as "*miniature solar systems*", body machine, bacteria grow in groups or *colonies*, polypeptide takes the linear form of a *chain*, “*lifetime* of chloride” referred to the length of time chloride is present at a particular site in the membrane of a cell, correlations with the length of time human beings are present on earth, DNA *library,* or *clockwise* rotation of flagella.

From a basic observation of common humans performing daily activities, we can see that most of the decisions use mental shortcuts or even rules of thumb. Cognitive markers allow us, thanks to a collection of stereotypic recorded set of patterns of actions, to decide quickly among different possibilities we are constantly faced to. This can obviously lead us to an inefficient (from a general perspective) performance of actions. But in no case we can define these decisions as “irrational.” It is a multi-heuristic process, an opportunist too, but at the same time is a highly sophisticated way of choosing between patterns of reasoning. At a meta-level analysis, we even could consider this process as an opportunistic one that at social level defines the whole epistemological process as a Ponzi scheme in which rhetorical devices are valued or undervalued according to transitory and/or evolutionary values (Lewis 2012; Mirowski 2012).

Even deception processes must be considered as cognitive variations of rational thinking (Herring et al. 2013). When hundreds of women from the USA in the twenty-first century explain to their doctors that they are pregnant while being virgin, we cannot just reduce this process to a banal cheating process, but instead we must consider them as a psychological adaptation to the cultural (religious) values that are present into the way of reconstruction of causal patterns (Glas 2005). They are not just ignorant, but they are creatively rational. The truth values of their fundamental premises perhaps are wrong, but this is another different topic. Obviously, lying is a fundamental part of human communication, and we cannot hide or neglect the study this behavior, which find the first treatise in Saint Augustine *De mendacio* (395 A.D.) and also in worldwide studies (Aavik et al. 2006). This is a mechanism that must be explained here but it is out of the explicit interests of this study. The apparent existence of such heuristic and values *contradictions* are nothing wrong in human nature, but a general distributed skill (Berliner et al. 2016; Lambek et al. 2016). Under this light we must analyze the real value of blended cognitive processes.

### *1.2.2 The Real Dilemma . . . and Why Do We Work with Dilemmas?*

At the basis of the understanding of human reasoning processes, in a form of reversed engineering approach, we could think that we are facing two opposite domains: *formal efficiency* vs. *cultural fitness*. First, we could evaluate reasoning strategies as the result of cognitive mechanisms that are evaluated through the efficiency of the obtained results. Here, it would be an isomorphic relationship between our models and the reality, obtained thanks to evident symbolic processes.

But nothing is further from the truth: as describes the infra-determination of theories, a model can work correctly or make good predictions despite of the fact that it is false. It has happened all throughout the history of Western sciences. On the other hand, and entering into the second possibility, we are facing reasoning with cultural fitness, that is, the agreement between our models, ideas, and methods with those held by our social peers. At least from an abstract perspective, good reasoning would be controlled by efficiency in the first place but by agreement in the second place.

Being more accurate in our analysis, we should consider the dilemmatic thinking, based on pairs of possibilities as a cultural artifact too. Do really thinking processes based on a dual process, like the classic idea of slow-analytic vs. fast-emotional reasoning mechanisms? The current neurological evidences show us a more complex scenario in which some patterns of reasoning can follow certain regularities like those indicated, but in no case emotional thinking is only related to fast-reaction thinking processes, being also involved into fundamental analytical processes (Djulbegovic et al. 2015; Lu 2015; Moore et al. 2011; Trémolière et al. 2016). Hence, dilemmas are not a reliable way of reasoning, just a form that fits with our current strategies. Besides, during the process of deciding about the scenarios in which we are placed to, it is not possible to find clear reasoning ways which are not related to emotional values (Damasio 1994).

## 1.3 Culture and Reasoning or How the Social Sphere Shapes the Way We Think

During the twentieth century, philosophers of science tried to understand and capture the mechanisms that ruled scientific reasoning, as if it was a single and unified project (O'Hara 2011). Immersed into this idealized framework, some of them devoted their efforts to the analysis of the scientific discourses creating formal structures using the structuralist reconstruction methodology (Reynolds 2011; Slack and Semati 1997). But we know that scientific reasoning is not captured correctly or even susceptible of being partially reconstructed through the study of the written discourses. Tacit knowledge, for example (Larivière et al. 2009), is very important, as well as the difference between real expert practices and their written (only successful) results (Cressey 2015; Van Raan 2004). The publication of only positive results, and the exclusion of negative ones, increases the repetition and waste of wrong strategies (Kuhn 1962, 1963, 1976). Besides, the huge amount of published results make impossible that all accepted results, placed at the public and highest place of the iceberg of already done researches, can be read, confirmed/falsified, and/or quoted, but with failures of the peer review process, like what happened with classic Sokal affair (Vallverdú 2017). The distribution of not cited papers is increasingly worrying: 12% of medicine articles are not cited, 82% for the humanities, 27% for natural sciences, and 32% for social science (Gigerenzer and Goldstein 1996; Simon 1972). Finally, we have those exceptional papers that are ignored for decades and once discovered again provide crucial ideas for the revolution inside a research field; they are called “sleeping beauties” (Glas 2005). On the other hand, we need to consider a very important aspect: scientific facts can be revisable but the conceptual or experimental tools with which we think the world are related to the general paradigm in which they have been created (Thaler 2000). For that reason, when new or unconventional ideas emerge, they are outside the limits of what can be though coherently (that is, rationally) inside a discipline. At certain points, knowledge operates like a game with sound or verified rules, but from time to time, this knowledge can change if and only if a conceptual after this punctual change, new rules, and facts are achieved and the process is stabilized. Otherwise, a conceptual system collapses over itself and does not improve or change, being blocked by cul-de-sacs or dead-end crazy approaches.

Following a biological metaphor (and think again about the role of metaphor in knowledge), after showing little evolutionary change for most of their geological history, or *stasis*, a species experiments intense and important changes (the punctuated equilibrium) that will allow a new step into the evolution, again stabilized. During the whole process, and despite of the deep changes suffered at structural levels, some things may remain under new forms.

This blended process allows creativity, innovation, as well as the generation of several strategies which make possible new knowledge, even at scientific level (Pöyhönen 2017). The cognition of mixing, blending, and combining ideas and cognitive mechanisms is surely the fundamental key for the understanding of the success of human beings at cultural level as well as explain the wide range of possible actions they can perform.

From an eco-cognitive perspective (Arfini and Magnani 2015; Beretti et al. 2009; Magnani 2016), this flexibility explains the success of human performing. A world plenty of only “highly rational” (by over-deductive) Mr. Spocks would have not achieved such diversity and richness as that we find looking at the evolutionary patterns of human beings.

## 1.4 Forgetting the Perfect Human Reasoner (PHR) or “A Day with My Preferred Deductivist”

Perhaps Plato, Leibniz, Descartes, or Kant worked for the improvement of human thinking processes, but all them failed because they misunderstood the real power of human cognition as an approximate, opportunistic, and integrative process. The increasing precision or complexity of formal reasoning did not imply that philosophy achieved universal results beyond any doubt. In fact, magical thinking is still ruling the world: when Donald J. Trump took less than 1 year ago the oath of office as the President of the USA (most powerful country in the world), he did it with his hand on two Bibles: his own and one used by Abraham Lincoln in 1861.

And he is not an exception: European rulers still defend the Christian origins of the continental social values as a proof of the religious nature (and present) of such community. Checking of the yearly selected winners of the Darwin Awards could make an oversimplistic evaluation of human performances, considering some of us as true rationalist, while some others are just defective or "irrational." Galileo was a Christian, Kepler believed into astrology and Newton in alchemy and theology, and Einstein was not able of thinking into a universe ruled by chance, depending again about a fuzzy idea of God. Perhaps the motto of Royal Society, created in 1663, was *nullius in verba*, and Newton's *hypotheses non fingo* was extremely successful, but at the same time, we know that all those scientists were deep believers into irrational things (Barker 2000; Westfall 2000). In an analysis of the personal library of Newton, which included 1752 books with identifiable titles on this list, no less than 477 (27.2%) were on the subject of theology, 169 (9.6%) on alchemy, 126 (7.2%) on mathematics, 52 (3.0%) on physics, and only 33 (1.9%) on astronomy. Surprisingly, Newton's books on the disciplines on which his scientific fame rests amount to no more than 12% of his library, as has been stated by Robert H. van Gent in several publications.

For such reason, as well as recent studies of approximate calculation or thinking show us (Sunnåker et al. 2013; Welling 2010; Xu et al. 2016; Yang et al. 2013), even in the case of selecting some heuristics and values as wrong or misleading, we can neglect the skill (but *not defect*) of being able of combing heuristics, even when they can look contradictory. For those who are combining them, they always look as plausible! Therefore, instead of thinking on de-biasing human cognitive processes or those we are creating for AI devices, perhaps we should invest our forces into how to design best biases (Vallverdú 2018) and support these blended mechanisms with possible minimal control rules (Teng 2013).

## 1.5 Concluding: Blended Cognition and Hyper-heuristics in AI Systems

As bioinspiration has been so successful across different fields of knowledge and even is part of our previous researches (Bridges et al. 2015; Vallverdú et al. 2015), it is necessary to consider as a final part of our chapter to introduce this approach into AI. Beyond classical ways of implementing such views, like neural networks, genetic algorithms, or fuzzy networks, new methodological trends are entering into AI and computer sciences. Someone with deep learning is using deep statistical analysis, while some others are exploring the combination of multiple heuristics. Hyper-heuristics belongs to this second group (Burke et al. 2005; Chakhlevitch and Cowling 2008; Garrido and Riff 2007). As part of our recent contribution to the *Marcus Wallenberg International Symposium Foundations of cyber-physical computation morphological and embodied computing symposium on theory and applications* with my talk "How to Bias Hyper-heuristics Through Bioinspira-

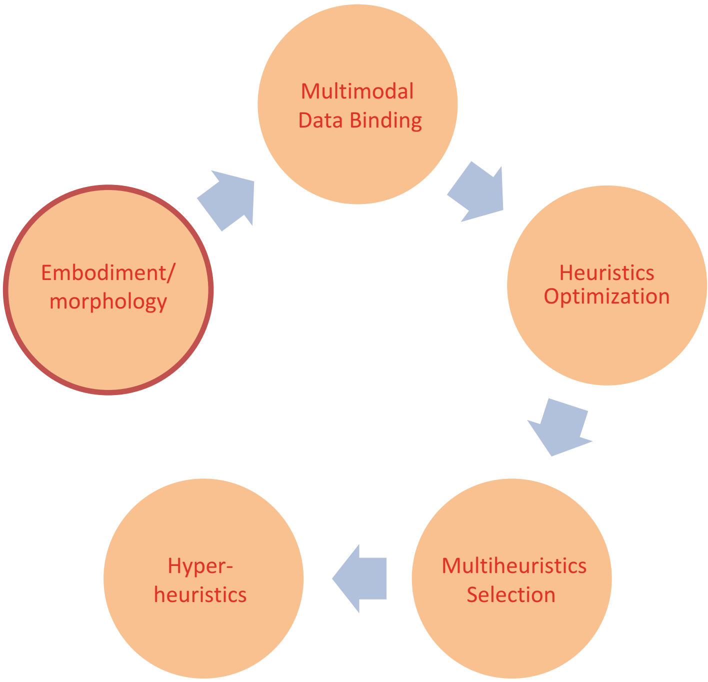


**Fig. 1.1** The broken cognitive circle

tion" (University of Gothenburg-Chalmers), it is fundamental to understand the connections between human blended cognition and artificial hyper-heuristics. A hyper-heuristic is a heuristic search method that seeks to automate, often by the incorporation of machine learning techniques, the process of selecting, combining, generating, or adapting several simpler heuristics (or components of such heuristics) to efficiently solve computational search problems. One of the motivations for studying hyper-heuristics is to build systems which can handle classes of problems rather than solving just one problem (source: Wikipedia). But even for artificial bioinspiration, most of times, once the initial bioinspiration is implemented, then the formalization of the whole system is maintained at a formal level. At higher levels of data analysis, only formal rules are available, making impossible to being truly creative. It is what we have called "the broken cognitive circle." (Fig. 1.1).

For AI systems, there is not a method of methods, like what happened in human contexts in which "anarchy," improvisation, or epistemic opportunism makes possible to combine rules or to create new ones. As a consequence, from a strict formal point of view, we should forget a theory on artificial creativity and autonomous hyper-heuristics.

For that reason, the only way to create deep bioinspired AI hyper-heuristics should be double-related to natural cognition: from the bottom and the top. Thanks to the role of emotional mechanisms into cognitive processing, we should consider to bias or intentionally orientate new data processing models. Approximate computing or neuromorphic chips are ways of reconnecting formalization and bodies under new rules, where precision at high levels is not the most important thing, but to the flexible, easy, affordable, and creative. Emotional reasoning is useful in most of circumstances, as well as necessary for managing several computing complex tasks. Hyper-heuristics and embodied-morphological architectures can contribute to deal with complexity increase. New bioinspired views on hyper-heuristics should provide innovative exploring paths (as synthetic forms of the DRD4-7R "wanderlust gene," dopamine receptor D4), sometimes useful and optimized according to limited informational resources, sometimes stupid. Anyway, they will boost the studies on dynamic and creative cognitive performance.

As a conclusion, we should be aware about the real multi-heuristic human activities, which we've called as "blended cognition," in order to design artificial reasoning systems which thanks to bioinspiration models implemented at various informational and decision levels will be able to create new ways of dealing with information and, thus, also to improve the complexity of their actions.

**Acknowledgments** I thank Pilar Dellunde for her advice about logical analysis and AI, Alger Sans for his suggestions about abductive reasoning, and Sarah Làzare for her support during this long process, blending our personal, work, and leisure times around such project. This work has been partially funded by the project FFI2017-85711-P.

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