Preface

This book project is based on several years of collaboration between two editors, starting with the organization of the symposium *Computing Nature* at the AISB/IACAP World Congress in 2012 in Birmingham. It continued with the AISB50 Convention at Goldsmiths, London in 2014 and the symposium *Representation: Humans, Animals and Machines* organized in cooperation with Veronica Arriola-Rios, University of Birmingham. During preparation, the book project was presented at the symposium *Representation and Reality* at UNILOG 2015, World Congress on Universal Logic in Istanbul. All those events, as well as our networks with research communities of cognitive scientists, computer scientists, philosophers, logicians, AI researchers, roboticists and natural scientists, connect us with the authors of the present volume, offering views on the topic of representation and its connections to reality in humans, other living organisms and machines. The choice of the title was made so as to refer to historical attempts at making connections, with Wiener's "*Cybernetics: Or Control and Communication in the Animal and the Machine*" (Wiener 1948), and Putnam's human-centric "*Representation and Reality*" (Putnam 1988).

How to address this vast topic and connect representation and reality in humans, other living beings and machines, based on the best contemporary knowledge? We invited prominent researchers with different perspectives and deep insights into the various facets of the relationship between reality and representation in those three classes of agents. How can we find a common link between reality-constructing agents like us humans with language ability and social structures that define our agency, other living organisms, from bacteria to plants and animals communicating and processing information in a variety of ways, with machines, physical and virtual? We have taken a cognitive, computational, natural sciences, philosophical, logical and machine perspective. Of course, no perspective is simple and pure, but rather a fractal structure in which recurrent mirroring of other perspectives at different scales and in different senses occurs. So in a contribution characterized predominantly as "cognitive perspective" there are elements of natural sciences, logic, philosophy and so on. Our aim is to provide a multifaceted view of the topic of representation and reality in the range of approaches from disciplinary (where a "discipline" is represented with its forefront outlooks) to multidisciplinary, interdisciplinary and cross disciplinary approaches. As a whole, the book presents a complex picture of a network of connections between different research fields addressing the state of the art of the topic reality versus representation.

We can see this book both as a collection of contributions of our authors to their fields of specialization and as an invitation to the reader to reflect on the kaleidoscope of domain-specific insights and their mutual connections in the context of the whole book. It is our common contribution to the continuous learning and shared knowledge about the nature of representation as found in the process of cognition (with "mind" as its philosophical reflection), cognition as it exists in different degrees in all living beings, including humans, and as it is recently being developed and constructed in machines in the field of cognitive computing.

Aspects of the relationship between representation and reality today connect networks of communities of philosophers, computer scientists, logicians, anthropologists, psychologists, sociologists, neuroscientists, linguists, information and communication scientists, system theoreticians and engineers, theoreticians and practitioners in computability and computing, information theory researchers, cybernetic systems researchers, synthetic biologists, biolinguists, bioinformaticians and biosemioticians, and many more. Current knowledge is distributed and no one's insight is total and exhaustive, even though some can see more and broader while others see sharper and in more detail within specific perspectives. Here is a short presentation of different perspectives as represented in the book's chapters, with an attempt to connect them into a common network.

Cognitive Perspectives

Connecting representation with reality, Terrence Deacon investigates the relation between information and reference, i.e. the relation of "aboutness". He starts by making the distinction between the Shannon model of information and semantic information. The Shannon model describes communication of information and its goal is to engineer the best ways of communicating information through a noisy channel, based on the quantitative measure of the amount of information. However, in everyday use, the most important characteristic of information is its *meaning*, that is information about something relates to something in the world. Deacon's analysis focuses on the capacity of a medium to provide reference and argues that this capacity can be seen in the difference between informational and thermodynamic entropy. This qualitative analysis shows that reference is a causally relevant physical phenomenon.

If representation is causally connected to reality, then how about hallucinations? In his contribution, Marcin Miłkowski studies models of visual hallucination in people with Charles Bonnet Syndrome and proposes to see them as illustrative cases where representations are not about anything in the real world. Miłkowski presents the computational model implementing neural network architecture with deep learning that can illuminate representational mechanisms for hallucination. It is interesting to observe that neural networks are often taken to be nonrepresentational models, in spite of the human brain being based on (biological) neural networks.

The old debate is still alive between representationalism and antirepresentationalism with the question of whether cognition relies on *representations mirroring* reality, or it is an *adaptive form of dynamics* based on the *interaction of an agent with the environment*. Typically, it is taken to be important for the critique of computational models of cognition as it is assumed that computations essentially depend on internal representations and that there is no computation without abstract symbol manipulation. This debate continues to this day because we still have no method to directly detect representations in a cognitive system.

In the opposition between *old ("orthodox") computationalism* (based on the idea of the abstract logical universal Turing Machine) and *enactivism* (that emphasizes the central importance of the body and the environment for cognition), Tom Froese connects *meaning* for a living being with its embodiment with the (ever present) possibility of death. The claim this article makes is that *orthodox* computational models cannot account for meaning. Meaning as based in the necessity for active autopoiesis and the struggle for survival is outside the scope of the abstract Turing Machine model of computation.

Computationalism as a theory of mind is often criticized in its classical/orthodox approach, such as the computational representational theory of mind presented by Fodor. Jesus Ezquerro and Mauricio Iza propose an effective alternative *computational model of embodied cognition*, understanding language as predicting sensorimotor and affective effects of the action described by a verb.

Computational Perspectives

Dynamical systems are abstract mathematical objects that are used to describe physical processes. They are defined as "A means of describing how one state develops into another state over the course of time. Technically, a dynamical system is a smooth action of the reals or the integers on another object (usually a manifold)" by Wolfram MathWorld. Dynamical systems are frequently believed to be opposite to and irreconcilable with computational models. However, in their chapter Jan van Leeuwen and Jiří Wiedermann use exactly the dynamic systems formalism to develop a new *dynamic knowledge-based theory of computation* capable of explaining computational phenomena in both living and artificial systems.

Even though many people, even among scientists and philosophers, would say that the process of life and computation have nothing to do with each other, Dominic Horsman, Viv Kendon, Susan Stepney and Peter Young have dedicated their study to computation in living systems. Within the framework of Abstraction/Representation theory (AR theory), computing is assumed to be *representational* activity. In this chapter, the AR approach is used to elicit conditions under which a biological system computes. The framework is developed in the context of a nonstandard human-designed computing and has already been applied.

Nicolas Gauvrit, Hector Zenil and Jesper Tegner take a computational stance and cover in their chapter the whole range of the information-theoretic and algorithmic approaches to human, animal and artificial cognition. They review existing models of computation and propose algorithmic information-theoretic measures of cognition.

Unlike the above computational approaches to cognition, the article by Dean Petters, John Hummel, Martin Jüttner, Ellie Wakui, and Jules Davidoff is of more empirical character. Computational models of object recognition are used to investigate representational change in the course of development in humans. By means of developmental studies in children, and computational modeling of their results by artificial neural networks, in comparison with the existing research on adults, it was possible to follow how visual representations mediate object recognition.

Natural Sciences Perspectives

Reductionism is one of the most severe sins one can commit, according to many philosophers and cognitive scientists. One should not even try to investigate a physical substrate on which cognition definitely relies. Gianfranco Basti is obviously untroubled by the danger of being accused of reductionism, and he examines the deepest roots of information processing in the physical world—the quantum field theory as a dual paradigm in fundamental physics—connecting it with semantic information in cognitive sciences. Basti makes us aware of the paradigm shift with respect to the Standard Model of physics, as well as quantum mechanics conceived as the many-body-dynamics generalization from classical mechanics. The basic assumption of the old paradigm about the closed physical system does not hold, as quantum field theory systems are inherently open to the background fluctuations of the quantum vacuum, and are capable of system phase transitions. It is interesting to observe that Prigogine had that insight in thermodynamics, making the step from closed thermodynamical systems or systems in thermodynamical equilibrium to the study of open thermodynamical systems with the inflow of energy that exhibited stable self-organized patterns. Maturana and Varela's work further developed our understanding of autopoiesis in living cells as processes essentially dependent on the openness of the system to the exchanges and interactions with the environment.

Irrespective of the representationalism versus antirepresentationalism discussion, today we have a broader concept of computation (computing nature) which posits that *every natural system computes*, with computation as its physical dynamics as presented in the chapter by Gordana Dodig-Crnkovic and Rickard von Haugwitz. That would mean that one does not need to search for representations in the brain just for the sake of settling the debate on whether the brain computes. Being a natural system, the human brain computes as well as the rest of nature in the framework of computing nature.

Dodig-Crnkovic and von Haugwitz search for answers to the questions: What is reality for an agent? What is minimal cognition? How does the morphology of a cognitive agent affect cognition? How do infocomputational structures evolve from the simplest living beings to the most complex ones? As a framework for answering these questions an infocomputational nature is assumed, constructed as a synthesis of (pan)informational ansatz (structures in nature are informational structures for us as cognitive agents) and (pan)computational view (dynamics of nature is computation), where information is defined as a structure (for an agent), and computation as the dynamics of information (information processing). Both information and computation in this context have broader meaning than in everyday use, and both are necessarily grounded in physical implementation, and the aim of this approach is to integrate computational approaches with embodiment and enactivism.

Philosophical Perspectives

Raffaela Giovagnoli presents the theme of language, classically central for the problem of representation. She focuses on inferential linguistic practices, which characterize human cognition. A pragmatic account helps us to understand what representational capacities are peculiar to humans, animals and machines. A study of the history of concept formation and use enables a clear distinction between humans and other animals. Starting from Frege, Giovagnoli presents the notion of representation theorized by Searle, and introduces the ideas proposed by the Brandom pragmatist order of explanation. The author points to the clear distinction between human and animal linguistic practices that can also be applied to the study of linguistic practices in machines.

Angela Ales Bello deals with the problem of consciousness in humans, animals and machines in a phenomenological account based on the hyletic dimension. The concept of hylé (a transliteration of Aristotle's concept of *matter*) was proposed by Husserl to denote the *nonintentional*, *direct sensory* aspects of living experience (*qualia*), shared by humans and animals. Ales Bello wishes to launch a challenge to those positions that ground themselves in the presumed objectivity of modern science. Starting from Husserl, Ales Bello examines the essential elements of phenomenology in order to understand how they developed and how they stand in relation to various scientific views. In this context the question "Can we conclude that the human being is like a machine?", looking at machines of today, is answered in the negative.

One of the arguments against computational models of mind is the so-called "hard problem of consciousness", which argues for irreducibility of the qualitative phenomenal features of mental experience to its functional cognitive features. Roberta Lanfredini presents the argument that "not only the classical cognitive pattern but also the classical phenomenological pattern give rise to a problem concerning the qualitative dimension." There is not only "the hard problem of consciousness" but "the hard problem of matter" as well. Lanfredini connects *representation* with *matter* and emphasizes the *central importance of time*, and *dynamics* in the phenomenology of the mind.

Logical Perspectives

The question of capturing homogeneity and heterogeneity is central for representation. Bateson's definition of information as a difference that makes a difference (for an agent) can be applied not only to perception but also to reasoning. How do we define differences and their role in reasoning? Henri Prade and Gilles Richard address comparative thinking as a basis of our comprehension of reality and present a description of logical proportions in comparing two objects or situations in terms of Boolean features within a cube of opposition. Homogeneous and heterogeneous logical proportions are important for classification, completion of missing information and anomaly detection, and they provide insights into human reasoning.

As already mentioned, among the strongest and recurrent objections against computational models of cognition is their alleged incapability to account for meaning (semantics). Ferdinando Cavaliere offers a remedy for this problem in the case of online search engines by means of adding the semantics with the help of a hypothetical program "Semantic Prompter Engine", based on the "Distinctive Predicate Calculus" logic, designed by the author. The aim of this approach is to bridge the gap between natural and artificial representations of concepts and reality by providing the semantics for the latter.

In his chapter Jean-Yves Béziau continues this tradition of critical analysis of human rationality, offering an original comparison between human and animal intelligence. Rationality in language is the logical way we have to represent knowledge but the richness of our emotional life is worth further exploration.

Machine Perspectives

Even Matej Hoffmann and Vincent Müller, like Jan van Leeuwen and Jiří Wiedermann in their chapter, find the dynamical systems framework as the most suitable, in their case for connecting computation controllers and robotic bodies. They introduce the concept of *morphological computation* in the sense it is used in robotics, which refers to "offloading" computational processing from a central controller to the body of a robot, exploiting the use of self-organization of the physical system in its interaction with the environment.

David Zarebski distinguishes between three types of ontology: the mind-independent structure of reality studied in philosophy and formal ontology, the structure of the human representation of the world studied in the cognitive sciences, or the structure of knowledge representation investigated in data engineering. Zarebski describes interactions between those three research fields – philosophy with formal ontology, cognitive science and data and knowledge engineering – as consisting in cognitive science explaining how human cognitive capacities can affect metaphysics, or in what way information systems ontologies can learn from formal ontologies. While cognitive science typically makes no distinction between ontological and epistemological realism, Zarebski defends the position that it is possible, in the Kantian tradition, to be realistic about the epistemology without the need for naturalization of the ontology.

A basic question regarding intelligent machinery concerns the nature of machine intelligence. Philip Larrey's chapter compares human intelligence and machine intelligence, as it looks today and as anticipated in the future. Based on Bostrom's classification of future-envisaged machine superintelligence into speed-, collective- and quality-superintelligence, Larrey presents critical views of all three types, proposing a fourth type that would combine human and machine intelligence, under the assumption that humans will do the really intelligent part while machines will continue as before to provide different services without being conscious of what they are doing. It is hard not to agree with the author's conclusion: "Ours is truly an 'unknown future'".

It remains to see what future developments of machine intelligence, robotics and cognitive computing will bring, and if perhaps in the future machines get one more capacity, "machine consciousness", which will not be like human consciousness, in the same way that "machine learning" is not like human learning, and machine walking is not like human walking but fulfills that function for a machine. Larrey's chapter considers the possibility of building (super)intelligent conscious machines. The next question, whether it is a good idea, or under what constraints is it justified to build possibly (super)intelligent conscious artifacts, is a different one, addressed both by Bostrom as well as Hawkins, Tegmark, Boden and many other prominent scientists. It might be considered a topic for ethicists or for political decision-makers, but the existing knowledge of those communities must be constantly updated through insights from researchers dealing in depth with the phenomena of natural and artifactual cognitive systems.

To sum up, the aim of this book is to enrich our views on representation and deepen our understanding of its different aspects. It is seldom the case that one discipline can exhaust all the complexity of a real-world phenomenon. The historical divisions formed deep trails that even the coming generations of researchers tend to follow, and existing divisions built into academic institutions, publications and research funding often present obstacles that prevent us from researching the big complex picture and our possible role in the overall network of knowledge. We are trying to provide a glimpse behind the mirror of our own specialist views on the phenomenon of representation and its connections to reality, written by researchers with different commitments and preferences regarding divisions into the computationalist versus enactivist approach, cognitive science versus phenomenology, logic versus. emotions, the "hard problem of mind" versus the "hard problem of matter", and so on. It should be emphasized that in spite of seemingly impermeable barriers between well-known opposing choices there is a natural building of networks that produces hybrids—enactivist studies based on computational simulations and physical computation models that take embodiment as fundamental, computational models of dynamical systems as well as dynamic systems formulations of computational frameworks, reductionism with the character of deconstruction, opening new views on emergence, the list goes on. We hope with this to contribute to the dialogue and further mutual connections between the research communities involved.

In conclusion we want to thank our authors for their excellent contributions, as well as for their involvement in the open and completely transparent review process done in a collegial and constructive spirit, where each chapter got at minimum three and at most eight well-informed and helpful reviews. We are thankful to Robert Lowe for his contribution to the review process.

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