Chapter 2
Research Objectives and Selected Approaches

I don't demand that a theory correspond to reality because
I don't know what it is.
Reality is not a quality you can test with litmus paper.
All I am concerned with is that
the theory should predict the results of measurements.
Stephen Hawking [196]

2.1 The Main Research Objectives

This book includes a concise summary and analysis of the conclusions, drawn from the completion of many complex projects, both described in literature and experienced by the author himself.

To a great extent, these conclusions concern a scientific exploration of new tools for reducing the discrepancy between the theory and practice of CSE.

An important conclusion drawn from these experiences and their analysis is that it is necessary to consider these new tools as new types of computational models and new techniques for reasoning about these computational models. At the same time, these new computational models and techniques for reasoning about them should ensure a better understanding and a more skillful use of such concepts as "information processing", "learning complex concepts", "intelligence", and "wise interactions among human beings and artificial agents in a dynamic and only partially known environment." In this book we propose to treat **IGrC models for WisTech as such tools.** Essential part of presented approach to models of computation are techniques for monitoring, control of interactive computations, and agents reasoning techniques about interactive computations performed in the physical world.

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The main research objectives of the book encompass, in particular, the following objectives:

1. To develop proposals for counteracting the most significant causes of discrepancies between the theory and practice of CSE projects, based on personal experiences and achievements in the design, construction, and technological development of complex IT projects.
2. To present proposals of CAS computational models, with the aim to achieve goals of MACM (cf. Sect. 1.2.2). The models should support CAS monitoring, controlling, and reasoning about the properties of these computations.
   These models should also, in particular, be designed to simulate key functionalities of a wise teamwork (among human beings and artificial agents) in a partially known, dynamically changing environments, with particular focus on monitoring the performance of such activities as:
   - 2.1. Decision-making and action-taking processes performed by agents, based on the satisfiability (to a certain degree) of concepts that cover the following aspects of these processes:
     - 2.1.1. Identification of complex and time-changing concepts that are important to agents.
     - 2.1.2. Adaptive learning approximations of concepts at the level of details best adapted to the needs of agents.
     - 2.1.3. Discovery of concepts that are currently needed for the efficient fulfillment of the agents' goals.
   - 2.2. Cooperation and/or competition across the societies of agents (humans and artificial) in such actions as:
     - 2.2.1. Creating new technological solutions for the application in AI.
     - 2.2.2. Counteracting substantial risks (e.g., fire and rescue operations, based on the experience from the ICRA project).
3. To propose techniques for reasoning about the properties of computations, carried out within the already proposed computational models, with an emphasis on such applications as CSE project management, creation of practically applied AI techniques, and substantial risk suppression.
4. To apply computational models and models of reasoning about the properties of computations to:
   - 4.1. Improve the identification and understanding of TPGP causes (especially FP3C).
   - 4.2. Reduce the gap in TPGP.

It should be noted that **this book in no way aspires to present a complete solution to the problems presented as part of the main research objectives, as well as in the previous chapter, entitled "Research Motivations"** (cf. Chap. 1).

The author of this book agrees with the view of many specialists (e.g., Sect. 1.1), who consider the aforesaid problems to be among the most important and most difficult problems of the 21st century's scientific research. In some sense, they constitute sub-problems of the problem with "understanding the intelligence."

Intuitively speaking, a **satisfactory solution to these problems would most likely ensure an effective automation of a search for the solutions to many core issues in virtually all areas of the modern life** (e.g., Wisdom Web of Things (W2T), cf. [556, 557]). **The consequences of such an effective automation could be comparable to the consequences of the introduction of information processing breakthroughs, such as the introduction of writing, printing, or a global introduction of computers and computer networks.**

For now, however, we have to remember that we are only approaching this next stage of transformation.

Hence, this book is intended merely as a "small nano-step" on the way to solving the aforesaid problems. It is also worth mentioning that the results of the research described in the book include original achievements in the design, construction, and technological development of many CSE projects. In Part IV of the book, we present examples of projects in which the architecture and implementation of solutions were based on the author's personal experience.

2.2 Selected Approaches to the Objectives

In the chapter entitled "Research Motivations" (cf. Chap. 1), we discussed some relationships between the subject matter of the book and certain approaches to CAS (in particular to CSE). In this section, we describe relationships between particular problems with various approaches to understanding and modeling computations that simulate intelligent decision-making processes.

Of course, concepts such as knowledge, logic, wisdom, etc. have their roots in the earliest civilizations. Certainly, gigantic achievements in this respect were made in ancient Greece, as well as in India and China. Today, our daily life, permeated by the technologies of inter-operating computer networks, opens up new horizons for the creation of innovative products, both in terms of quality and quantity. This has a crucial impact on the development of science. As a result, scientists who investigate modern interactive computational models, including models of information processing, are considered the avant-garde of contemporary science. Rozenberg and Kari [265], expressed this in a slightly different way:

> In these times brimming with excitement, our task is nothing less than to discover a new, broader, notion of computation, and to understand the world around us in terms of information processing.

With the progress in scientific research, there emerged new paradigms for the design, construction, and development of new technologies, aimed at the integration of physical, communicational and information processing processes. A classic example is the research on the so-called cyber-physical systems (CPSs).[1] CPSs refer to the previously discussed ideas, e.g., [75]:

> It is necessary to remark that there is an ongoing synthesis of computation and communication into a unified process of information processing. Practical and theoretical advances are aimed at this synthesis and also use it as a tool for further development. Thus, we use the word computation in the sense of information processing as a whole. Better theoretical understanding of computers, networks, and other information processing systems will allow us to develop such systems to a higher level.

Another very important direction, which combines various results of the research on computational models to support AI techniques is undoubtedly Natural Computing. In [115], it is characterized as follows:

> Natural computation is a study of computational systems including the following:
>
> 1. Computing techniques that take inspiration from nature for the development of novel problem-solving techniques (artificial neural networks, swarm intelligence, artificial immune systems, computing on continuous data, membrane computing, artificial life, evolvable hardware, self-organizing systems, emergent behaviors, machine perception).
> 2. Use of computers to simulate natural phenomena; and
> 3. Computing in nature (by natural materials) (e.g., information processing in evolution by natural selection, in the brain, in the immune system, in the selforganized collective behavior of groups of animals such as ant colonies, and particle swarms, quantum computing, molecular computing, DNA computing, biocomputing, neural computation, evolutionary computation, biological computing/organic computing).

Many studies have been undertaken in this direction and published [420]. Their authors all agree that interactions constitute an important common feature of natural computing.

Among others directions, research concerning various trends in natural computing and software engineering led to the creation of the so-called Interactive Computing. It has been characterized, for example, in [169] as follows:

> - Computational problem is defined as performing a task, rather than (algorithmically) producing an answer to a question.
> - Dynamic input and output modeled by dynamic streams which are interleaved; later values of the input stream may depend on earlier values in the output stream and vice versa.
> - The environment of the computation is a part of the model, playing an active role in the computation by dynamically supplying the computational system with the inputs, and consuming the output values from the system.
> - Concurrency: the computing system (agent) computes in parallel with her/his environment, and with other agents that may be in it.
> - Effective non-computability: the environment cannot be assumed to be static or effectively computable; e.g., it may include humans, or other elements of the real world. We cannot always pre-compute input values or predict the effect of the system's output on the environment.

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[1] http://cyberphysicalsystems.org/, http://ercim-news.ercim.eu/images/stories/EN97/EN97-web.pdf.

The search for computational models that meet the above-mentioned criteria of interactive computation led to the creation of many research directions. These directions include, in particular, very interesting models of quantum computing, which stimulated the birth of the so-called quantum information technology. The following observation regarding this trend, presented in [4], is interesting:

> In particular, the quantum informatic endeavor is not just a matter of feeding physical theory into the general field of natural computation, but also one of using high-level techniques developed in Computer Science to improve on the quantum physical formalism itself, and the understanding thereof. We highlight a seemingly contradictory phenomenon: passing to an abstract, categorical quantum informatics formalism leads directly to a simple and elegant graphical formulation of quantum theory itself, which for example makes the design of some important quantum informatic protocols completely transparent. It turns out that essentially all of the quantum informatic machinery can be recovered from this graphical calculus. But in turn, this graphical formalism provides a bridge between techniques of logic and computer science, and some of the most exciting developments in the mathematics of the past two decades.

From the point of view of this book, Granular Computing (GrC) [21, 394, 546, 549, 554] is no less important than the aforesaid research on interactive computing models. The historical roots of contemporary research in this area can be traced back to the roots of algebraic techniques in logic which can be found, among others, in the works of Gottfried Wilhelm von Leibniz, George Boole, Afred Tarski, Adolf Lindenbaum, Helena Rasiowa, Roman Sikorski, William Lawvere, Myles Tierney, and many other prominent scientists. Certainly, modern research on GrC and AI largely reflects the ideas by Lotfi Zadeh on both fuzzy logic and the CWW paradigm. It also refers to the work of Zdzisław Pawlak, who founded one of the main pillars of this scientific book - the theory of rough sets [384, 386, 389–391]. For more information about the research on GrC one can refer to [21, 393, 394].

It is also worth remembering that the approach presented in the book refers to concepts that are central to AI.[2] The field of AI has developed dynamically since the mid-20th century. One of the first computational models for AI was based on the attempts to model the behavior of neural networks. These models are still being developed and refined: in particular, the research on the so-called reinforcement learning is one of the results of this development. An introduction to this interesting work was presented, for instance, in [490]. In this approach, as well as in many other approaches towards the construction of computational models for AI applications, we encounter a fairly fundamental and common barrier to a technological advancement. To simplify, this barrier means that modern AI solutions are good to some extent, depending on the representation of internal local knowledge, which basically constitutes the domain knowledge of experts about some specific cases and knowledge elicited from available data. Modern systems still have a fairly weak adaptability of action schemes for continuously changing environments. Therefore, these systems are intuitively limited by the closeness of their local world. Many researchers have already paid attention to this. The problem was particularly clearly

[2] http://en.wikipedia.org/wiki/Artificial_intelligence.

manifested a few decades ago when developing one of the first large expert systems, called MYCIN [73].

It turned out that in a particular sense, a "perfect" system (at the stage of design and development) would fail in practical applications due to the difficulty with adapting to the changing environmental conditions, in which it is used. In the following years, some attempts were made to solve this problem, using paradigms that were better adjusted to for implementing the mechanisms of adaptation. A particularly interesting solution was proposed by John Holland in his work entitled "Escaping brittleness: The possibilities of general-purpose learning algorithms applied to parallel rule- based systems" [209]. Three decades after the publication of Holland's work, some progress has been made in this direction, not yet a fully satisfactory one [348, 506, 519].

Many researchers believe that overcoming these barriers requires a better understanding of computational models which simulate the key functionality of a wise teamwork (between human beings and artificial agents) in only partially known, dynamically changing environments. A particular role in such processes is played by the techniques of simulating thinking and communication mechanisms, such as dealing with natural languages. In other words, we encounter here quite fundamental technological barriers to the development of our civilization. The subject of the research in the field of understanding the functionality of natural languages has a very long history and resulted in a number of highly complex approaches. In this book, we refer to the approach to natural language, initiated by Ludwig Wittgenstein, who considers the meaning of language as a form of a game, which he calls language game [539].

It should be noted that the above-mentioned approaches to the subject matter of this book are not exhaustive and it is impossible to discuss them all in such a brief summary. More information on this topic can be found in other chapters of this book. However, it is undoubtedly worth mentioning that there is growing need among researchers to depart from a classical model of computations, which dominates in modern mathematics and is based on various modifications of the Turing machine; instead, they lean towards computational models which are based more on the physical laws than on mathematical laws. There are many important studies and scientific books which emphasize the need for acknowledging physical aspects in computational models [44, 112, 299, 438, 505]. In order to better explain the context and motivation of these research directions, let us cite [112] (cf. p. 266):

> The Turing machine was an abstract construct, but thanks to subsequent developments in computer science and engineering, algorithms can now be performed by real automatic computing machines. The natural question now arises: what, precisely, is the set of logical procedures that can be performed by a physical device? The theory of Turing machines cannot, even in principle, answer this question, nor can any approach based on formalizing traditional notions of effective procedures. What we need instead is to extend Turing's idea of mechanizing procedures, in particular, the procedures involved in the notion of derivability. This would define mathematical proofs as being mechanically reproducible and to that extent effectively verifiable. The universality and reliability of logical procedures would be guaranteed by the mechanical procedures that effectively perform logical operations but by no more than that. But what does it mean to involve real, physical machines in the

> definition of a logical notion? and what might this imply in return about the 'reasonableness' or otherwise of the effectiveness of physics in the mathematical sciences?

After asking these questions, the author of [112] comes to a pretty intriguing conclusion, which is largely coincident with the properties of interactive granular computational models, as presented in this book. This intriguing conclusion, found on page 268, is as follows [112]:

> It seems that we have no choice but to recognize the dependence of our mathematical knowledge (though not, we stress, of mathematical truth itself) on physics, and that being so, it is time to abandon the classical view of computation as a purely logical notion independent of that of computation as a physical process.

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