

Knowledge Generation as Natural Computation

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ABSTRACT

Knowledge generation can be naturalized by adopting computational model of cognition and evolutionary approach. In this framework knowledge is seen as a result of the structuring of input data (data → information → knowledge) by an interactive computational process going on in the agent during the adaptive interplay with the environment, which clearly presents developmental advantage by increasing agent's ability to cope with the situation dynamics. This paper addresses the mechanism of knowledge generation, a process that may be modeled as natural computation in order to be better understood and improved.

Keywords: Knowledge generation, information, computation, informationalism, nfo-computationalism.

1. INTRODUCTION

The ubiquity of computers and the constantly increasing availability of computer power accelerate the use of computer-based knowledge generation, which includes digitalized representations, simulations and emulations, modeling and model-based reasoning, contributing to the ever more dynamic development of human knowledge. Administration, sciences, technology and businesses all rely on computational models of systems which they use to describe, understand, predict and control. Semantics of information is seen as a part of the data structuring process, in which complex structures are self-organized by the computational processing of data. This presupposes natural computation defined by MacLennan [21] as computation occurring in nature or inspired by that in nature, which is the most general computing paradigm.

Taking information and computation as basic principles in a dual-aspect info-computational model, a common framework is formulated by Dodig-Crnkovic [8], who argues that knowledge generation can be understood as natural computation. Computing methods beyond Turing-Church limit are needed to handle complexity of phenomena such as knowledge, living processes, multifaceted social phenomena, etc. The source of inspiration for this model is found in natural computation, and seen as evolutionary development.

2. INFORMATION, COMMUNICATION AND KNOWLEDGE TECHNOLOGIES

ICT and Knowledge Generation

Technology, science and philosophy of knowledge have always been closely related and intertwined. It is apparent that during

the previous mechanistic epoch, the current technological paradigm of mechanical machinery was also the leading idea of scientific models and even the one dominant of philosophy of knowledge.

Present day's Information and Communication Technology (ICT) is centered on information processing, information appearing as a link in the semantic enrichment succession, which consists of the following: (raw) data → information → knowledge.

Contemporary technology operates on data which are used to synthesize information, and on information from different contexts which are synthesized into knowledge. It is envisaged that technology in the future will be able to structure not only data and information but also knowledge. What is vital for that future knowledge technology that will be able to manage knowledge is understanding and implementation of artificial intelligence.

Intelligent Systems, Knowledge, Information

Future Knowledge Generation technologies are closely related to the current state of the art of the Intelligent Systems technology and its possible developments. The account is based on Meystel, Albus and Goertzel in [1, 2, 11, 12, 24].

Intelligence may be described as the characteristic of an agent that increases the probability of the success of its actions in its relationship with the "world" (including the agent itself). Consequently, the functioning of intelligent agents must be understood in their interaction with the environment and related to their goals. The mechanisms of intelligent behavior are data acquisition (perception), information processing, knowledge management including anticipation and decision making. Intelligent agents often have actuators to execute their decisions, especially in the case of living organisms.

Recent studies in biology, ethology (study of animal behavior) and neuroscience, which have increased our knowledge of biological brain functions, has led to the insight that the most important feature of cognition is its ability to deal efficiently with complexity, in apparently common ways in living organisms, Gell-Mann in [10]. Such insights into natural intelligence, together with the increase in power of electronic computing bring us closer to the modeling of intelligent behavior and even the designing of better, increasingly intelligent knowledge-management systems. Modern computers and even more the future ones will eventually enable us to cope with complex systems in a way completely impossible to knowledge acquisition strategies unaided by powerful computational tools.

It is worth to point out, that the idea of artificial intelligence is based on the belief that intelligent behavior can be understood in such a way so that a machine can be constructed able to simulate it. One of the most appropriate theoretical frameworks for formulating artificial intelligence is informationalism and computationalism. For more details on informationalist and computationalist approaches see Chaitin and Lloyd in [7, 20]. Popper [25] gives an interesting view of objective knowledge with an evolutionary approach.

From the computationalist point of view intelligence may be seen as based on several levels of data processing (Goertzel) [11, 12] in a cognizing agent:

Information (sensory data processed by an agent) can be understood as an interface between the data (world) and an agent's perception of that world. Patterns of information should thus be attributed both to the world and to the functions and structures of the brain.

In an analogous way, knowledge can be understood as an interface between perception and cognition. Structures of knowledge can be attributed both to percepts (information) and to the brain cognitive organization. Meaning and interpretation are the results of the processes of temporal development of information, its refinement (relating to already existing memorized information), and thus conversion to knowledge.

Data, information, perceptual images and knowledge are organized in a multiresolutional (multigranular, multiscale) model of the brain and nervous system. Multiresolutional representation has proven to be a good way of dealing with complexity in biological systems. Search and sort are basic operations for building of the architectures of representation and the processing of data/information/knowledge. They are using two fundamental mechanisms of differentiation (identifying differences) and integration (identifying similarities) in the environment.

From cognitive robotics, it is becoming evident that intelligence is closely related to agency. Anticipation, planning and control are essential features of intelligent agency. A similarity has been found between the generation of behavior in living organisms and the formation of control sequences in artificial systems. Self-organization, self-reproduction and self-description (or self-representation) are accepted intrinsic properties of natural intelligent systems. They are studied within the field of Artificial Life (AL), which is a subfield of the AI field.

Learning is an essential part of each of the above three capabilities and it requires among others the development of a symbolic system which is easy to maintain and use. It is possible to build intelligent control systems that can collect and process information, as well as generate and control behavior in real time, and cope with situations that evolve among the complexities of the real world, inspired by the sophisticated abilities of biological organisms to cope with complexity. Artificial learning systems are developing in a number of new directions, such as neural networks, fuzzy systems and evolutionary programming (including genetic algorithms).

Intelligent biological systems are based upon a multiresolutional hierarchy of the loops of functioning. Each of these loops can be treated as a control system per se. Structures of the sensory processing (data), information, knowledge representation and decision making are built in a multiresolutional way, with many pattern recognition and control methods hardwired.

Goertzel in [11, 12] hypothesizes that (intelligent) mind is basically a superposition of two systems: a structurally associative memory and a multilevel perceptual-motor process hierarchy. By superposing these two systems, the mind emerges combining memory (structure) and process (control).

Intelligence Augmenting Technologies

Apart from cognitive robotics and similar tools for generating intelligent behavior, there are other knowledge management (KM) technologies that might augment humanity with intelligent services. The Semantic Web (Berners-Lee, Hendler and Lassila, [4]) is a project intended to create a universal means for information exchange by publishing documents with computer-manageable semantics (meaning) on the World Wide Web. Other interesting related fields of intelligence-enhancing application include service-oriented information- and knowledge-level computation, interactive agents, inter-agent dialogues, belief change, semantics-assisted problem-solving on the semantic grid, ontology-enabled problem-solving environments, knowledge discovery, e-science, Wisdom Web and Knowledge Grids.

3. NATURALIZING KNOWLEDGE GENERATION

Computation beyond the Turing Limit

Computerized information processing affects more and more of our civilization today – we are surrounded by computer systems connected in global networks of multitasking, often mobile, interacting devices.

The classical mathematical theory of computation is based on the theory of algorithms. Ideal, classical theoretical computers are mathematical objects and they are equivalent to algorithms, or abstract automata (Turing machines), or effective procedures, or recursive functions, or formal languages.

What is typical of all of the above mentioned intelligence augmenting technologies, from the perspective of theoretical computing, is that they are highly interactive and thus do not resemble Turing Machines. If we have an ambition to be able to develop the theory of the Semantic Web, we must also generalize our ideas of what computation is and what it might be. For new computing paradigms, see Wegner, [27], Kurzweil [19] and Dodig-Crnkovic [8].

Present day's syntactic mechanical symbol manipulation is to be replaced by information processing, with both syntactical and semantical aspects being expressed in the computing. Knowledge management is more effectively implemented based on information management than on data management, which is the current practice. (see [12], Dodig-Crnkovic, Paper B)

Compared with new computing paradigms, Turing machines form the proper subset of the set of information processing devices.

According to Burgin [6], information processing is performed on several levels. The following two are the fundamental operations carried out on the basic level: preserving information (protecting information from change – identity operation) and changing information or its representation. Burgin identifies three distinct components of information processing systems: hardware (physical devices), software (programs that regulate its functioning), and infoware which represents information processed by the system. Infoware is a shell built around the software-hardware core which is the traditional domain of automata and algorithm theory. Semantic Web is an example of infoware.

Interactive Naturalism

Interactivism as defined by Birkhard, Kulakov and Stojanov, [5, 18] is an approach especially suited to the analysis of agency. It involves naturalism, which means that the physical world (matter) and mind are integrated by interaction. The interactive model offers a critique of correspondence or “spectator” models of cognition, with focus on the consequences of interaction and the emphasis on the process (interactive) nature of perception (data) as well as information (representation). It is thus related to process metaphysics of Whitehead [28]. The interactivist theory has been applied to a range of mental and social phenomena, including perception, consciousness, learning, language, memory, emotions, development, personality, rationality, biological functionality, and evolution.

Naturalizing Knowledge Generation

“Indeed, cognitive ethologists find the only way to make sense of the cognitive equipment in animals is to treat it as an information processing system, including equipment for perception, as well as the storage and integration of information; that is, after all, the point of calling it cognitive equipment. That equipment which can play such a role confers selective advantage over animals lacking such equipment no longer requires any argument. (...)

But this is just to say that any conception of animal behavior which makes sense of it all will have to see the animal’s cognitive equipment as serving the goal of picking up and processing information. And this commits one to the notion of animal knowledge.” Kornblith, [17]

Naturalized epistemology, Harms [15], and thus even knowledge generation in general, is an idea that knowledge may be studied as a natural phenomenon. The subject matter of knowledge generation is not our concept of knowledge, but the knowledge itself.

Within info-computationalist framework our specific interest is in how the structuring from data to information and knowledge develops on a phenomenological level in a cognitive agent (a biological organism or an artificial agent) in its interaction with the environment.

One can say that living organisms are “about” the environment, they have developed adaptive strategies to survive by internalizing environmental constraints. The interaction between an organism and its environment is realized through the exchange of physical signals that might be seen as data, or when structured, as information. Organizing and mutually relating different pieces of information results in knowledge. In that context, computationalism appears as the most suitable framework for naturalizing knowledge generation.

Maturana and Varela [22, 23] presented a very attractive and powerful idea that even the simplest organisms possess cognition and that their meaning-production apparatus is contained in their metabolism. Of course, there are also non-metabolic interactions with the environment, such as locomotion, that also generate meaning. Maturana and Varela’s theory can be taken as a basis of a computationalist account.

The interesting question is: how does information acquire meaning naturally in the process of interaction of an organism with its environment? A straightforward approach to naturalized knowledge generation goes via study of evolution and its impact on the cognitive, linguistic and social structures of living beings from the simplest ones to those at highest levels of organizational complexity, Bates, [3].

Complexity is a typical phenomenon that is best explored with the use of computers. It is not surprising that the field has experienced an unprecedented growth during the past twenty years. Computer modeling and simulation are becoming invaluable tools in complexity studies. The following are some of the issues of the highest interest: dynamic computer simulations, dynamic systems theory and developmental theory, dynamics of control of processing, emergence, intermodality, brain and cognitive functions, language development, neurobiology. For knowledge management or relevance are learning, sensory-motor and perception-action loops and self-organization of behavior studied as complex phenomena.

Artificial agents may be treated in analogy with animals in terms of different degrees of complexity; they may range from software agents with no sensory inputs at all, to cognitive robots with varying degrees of sophistication of sensors and varying bodily architecture.

An agent receives inputs from the physical environment (data) and interprets these in terms of its own earlier experiences, comparing them with stored data in a feedback loop. Through that interaction between the environmental data and the inner structure of an agent, a dynamical state is obtained in which the agent has established the representation of the state of affairs. The next step in the loop is to compare the present state with one’s own goals and preferences (saved in an associative memory). This process is related with the anticipation of what various actions from the given state might have for consequences. (Goertzel, [12]) Normally this takes time, but there are obvious exceptions. Situations where the agent is in mortal danger are usually hard-coded and connected via a shortcut to activate an immediate, automatic, unconscious reaction. For a living organism, the efficiency of the computational process is decisive for the survival.

Studies of vision show that cognition focuses on that part of the scene which is variable and dynamic, and uses memorized data for the rest which is static (frame problem of AI). Based on the same mechanism, we use ideas already existing to recognize, classify and characterize phenomena (objects). Our cognition is thus an emergent phenomenon, resulting from both memorized (static) and observed (dynamic) streams. Considering chunks of structured data as building blocks, instead of performing time-consuming computations on those data sets in real time is an enormously powerful speed-up mechanism. With each higher level of organization, the computing capacity of an organism's cognitive apparatus is further increased. The efficiency of meta-levels is becoming explicitly evident in computational implementations.

Cognition as the multilevel control network in Goertzel's model is "pyramidal" in the sense that each process is connected to more processes below it in the hierarchy than above it in the hierarchy. In order to achieve rapid reaction, not every input that comes into the lower levels can be passed along to the higher levels. Only the most important inputs are passed.

Goertzel illustrates this multilevel control structure by means of the three-level "pyramidal" vision processing parallel computer developed by Levitan and his colleagues at the University of Massachusetts. The bottom level deals with sensory data and with low-level processing such as segmentation into components. The intermediate level handles grouping, shape detection, and similar; and the top level processes this information "symbolically", constructing an overall interpretation of the scene. This three-level perceptual hierarchy appears to be an extremely effective approach to computer vision.

4. CONCLUSIONS

So, in conclusion, let me sum up the proposed view of naturalized knowledge generation, based on the following insights from knowledge generation strategies developed by biological systems:

- All cognizing beings are in constant interaction with their environment. They are open complex systems in a regime on the edge of chaos, which is characterized by maximal informational capacity, Flake [9].

- The essential feature of cognizing living organisms is their ability to manage complexity, and to handle complicated environmental conditions with a variety of responses which are results of adaptation, variation, selection, learning, and/or reasoning, Gell-Mann [10].

- As a result of evolution, increasingly complex living organisms arise that are able to survive and adapt to their environment. It means they are able to register inputs (data) from the environment, to structure those into information, and in more developed organisms into knowledge. The evolutionary advantage of using structured, component-based approaches is improving response-time and efficiency of cognitive processes of an organism.

- The Dual network model, suggested by Goertzel for modeling cognition in a living organism describes mind in terms of two

superposed networks: a self-organizing associative memory network, and a perceptual-motor process hierarchy, with the multi-level logic of a flexible command structure.

In a nutshell, naturalized knowledge generation acknowledges the body as our basic cognitive instrument. All cognition is embodied cognition, in both microorganisms and humans (Gärdenfors, Stuart [13, 14, 26]). In more complex cognitive agents, knowledge is built upon not only reasoning about input information, but also on intentional choices, dependent on value systems stored and organized in agents memory.

It is not surprising that present day interest in knowledge generation places information and computation (communication) in focus, as information and its processing are essential structural and dynamic elements which characterize structuring of input data (data → information → knowledge) by an interactive computational process going on in the agent during the adaptive interplay with the environment.

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