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Abstract

The following discussion will consider adaptive and learning systems with high degrees of autono-my from both a mono-contextural and a poly-contextural point of view. Statistical learning algo-rithms, as well as the new class of adaptive computational models such as neural networks, genetic algorithms, or fuzzy logic, which have recently been termed "soft" logical computation, are catego-rized within the present discussion as mono-contextural conceptions. Mono-contextural descriptions are always hierarchically structured, i.e. the triangle inequality as a defining relationship of metrici-ty strictly holds: All input/output-systems with (or without) implemented feedback algorithms belong to this category.

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Eberhard von Goldammer & Rudolf Kaehr

POLYCONTEXTURALITY

Theory of Living Systems – Intelligent Control

01. Overview

The following discussion will consider adaptive and learning systems with high degrees of autonomy from both a mono-contextural and a poly-contextural point of view. Statistical learning algorithms, as well as the new class of adaptive computational models such as neural networks, genetic algorithms, or fuzzy logic, which have recently been termed "soft" logical computation, are categorized within the present discussion as mono-contextural conceptions. Mono-contextural descriptions are always hierarchically structured, i.e. the triangle inequality as a defining relationship of metricity strictly holds: All input/output-systems with (or without) implemented feedback algorithms belong to this category.

However, if self-referential processes are included, for example, "cognition" and "volition" introduced later in this discussion, any mono-contextural description necessarily leads to logical antinomies and ambiguities. Models of cognitive processes belong to the class of heterarchically structured descriptions. In a poly-contextural framework, "heterarchy" is established inter-contexturally (by transitions between different contextures), whereas hierarchical structures are defined intra-contextural (within a contexture).

A contexture is a logical domain where all classical logical rules hold rigorously. Polycontexturality results from the mediation between different contextures by "order" and "exchange" relations defined later, i.e. logical domains or contextures do not exist in isolation, but are mediated with each other by non-classical logical operators such as, for example, the "transjunction" which allows the modelling of parallel and simultaneously existing processes.

Thus Polycontextural Logic (PCL) constitutes an intrinsic parallel calculus with different logical domains (contextures) closely interwoven with one another by means of new logical operators. In contrast to Fuzzy Logic, which is a monocontextural calculus for processing vague and uncertain information, PCL becomes important and necessary as a calculus for an unambiguous modelling of cognitive or higher-order learning processes. Furthermore, it has significance for the design of qualitatively different and new computer architectures. This is particularly important in situations where massively parallel computing should contribute to emergent properties which are qualitatively different from those properties of a system whose processes are organized hierarchically or sequentially – as in the case of conventional computing. This contrasts sharply with the kind of massive parallelism which is introduced to give better quantitative performance (usually faster processing time). In other words, PCL allows the formal mathematical representation of the kind of parallel simultaneity found in heterarchically structured processes, which cannot be described by sequential algorithms without significant qualitative changes of the whole system.

PCL extends the notion of "context-dependence" by introducing the concept of the "contexture", which is basically a generalization of "context" and will be more precisely defined later in this discussion. It also represents a theory which provides the basis for modelling and simulating changes of contextures (contexts) on logical machines in a formal mathematical sense, which opens new possibilities for any theory of cognition and communication, of classification, control, and decision.

02. Introduction

The term "Intelligent Control" was coined by K.S. Fu in 1971, when he was asked to define the next stage beyond "Adaptive and Learning Control" [1]. Since then, "Intelligent Control" was postulated by Saridis [2], "as the process of autonomous decision making in structured or unstructured environments, based on the interaction of disciplines of Artificial Intelligence, Operations Research, and Automatic Control". From this point of view, technical systems which are characterized by autonomous control functions are considered as artifacts with the capability "to perform well under significant uncertainties in the plant and ifs environment for an extended period of time"[3]; able "to compensate for system failures without external interventions"[3], and perhaps able "to even perform hardware repairs, if one of its components fails."[3]

In his text on "Learning Control-Methods, Needs, and Architecture" Kokar[4] states:

> "The main paradigm of 'Intelligent Control' is captured by the 'Perception-Reasoning-Action' loop. Each stage in the loop is a generalization of the three learning control functions: identification, decision, and modification. Perception is a generalization of the identification function, reasoning is a generalization of the decision function, and action is a generalization of the modification function."[4, 5]

Although "Intelligent Control" appears today as a well established field within the discipline of control systems which is reflected by regular reports from many international conferences as well as the technical literature of monographs on the subject, no technical system has yet been constructed with the capability of cognition and volition.[*] Instead, today's situation is characterized by two irreconcilable positions on the concepts of "autonomy" and "control": namely "Artificial Intelligence" (the viewpoint of "control") and modem cybernetics (the viewpoint of "autonomy").

If, for example, "autonomy" is taken literally, its meaning is "self-law" or "self-regulation", viz.

> an autonomous system regulates its own regulation.

In order to see what this entails within the present context, autonomy may be contrasted into its mirror image "allonomy" or "external law", and this is what is generally meant by control. In contrast to "control" which is a well-established field of engineering and has been widely charted out and formalized, "autonomy" remains a somewhat vague concept.

The fundamental paradigm of "control" is associated with an understanding of information as instruction and representation. Discussing autonomy, however, a re-examination of the concept of information itself becomes necessary. From the point of "autonomy":

- information no longer acts as "instruction"; instead, information is "constructed" from incoming signals, where the signals themselves carry no externally defined "meaning";
- information no longer plays the role of "representation"; instead, originates within an autonomous system through the circularly interwoven processes of "cognition" and "volition".

In this way, any description (or construction) of autonomous systems must include at least their cognitive and volitive capabilities.

Traditional "Artificial Intelligence", which is strongly influenced by Platonian ontology, has historically defined "intelligence" as a quality of abstract symbol manipulation rather than as a result of cognition and sensorimotor coordination. Until very recently it has not been conventional usage to call a bird's landing on a twig in the wind an "intelligent" process. Instead it was regarded as a problem of physiology. Conceptionally opposed to the rule-based formalists are the Gibsonian, law-based realists, who assert that sensorimotor behavior should be regarded as "intelligent", they state that perception and cognition should also be included in this category, although they can be described as dynamic events or processes that are entirely "lawful", and not dependent on "information processing" in the "computationalist" sense [6,7].

However, the realists' view suffers from explicit theoretical weakness. In particular it does not answer the following questions:

1. What is the interrelation between the domain of biomolecular descriptions and the domain of cognitive (or sensorimotor) descriptions?

Cognition and volition (as well as sensorimotor behavior) contribute in a significant way to the autonomy of living systems and are characterized by a variety of parallel, mutual interacting processes, by a "contexture of processes".

2. What is the organizational structure of these processes, heterarchical, hierarchical, or both?

Parallel processes, which can also be run sequentially without qualitative changes to their overall effectiveness (for example, the parallel algorithms of a transputer network or connectionist neural networks) are exclusively hierarchically structured [8].

In contrast, heterarchy is constituted by the parallel simultaneity of mutual interacting processes which cannot be represented sequentially without describing a qualitative completely different system.

3. How can these heterarchical structures be modelled in a formal mathematical way, enabling the design of technical artifacts with the capability of cognition and volition, and of sensorimotor coordination?

4. How could present theories of machine learning, connectionism, fuzzy sets, control theory, or polycontextural logic contribute to the handling of structural problems of this kind?

In the following discussion, where the above questions will be answered in more detail, the problem of autonomy, cognition and volition will be considered from two different – but complementary – points of view:

1. in the context of a description of living systems as autonomous and cognitive entities (Chapter 1: "Problems of Autonomy and Discontexturality in the Theory of Live"), and

2. in the context of "cognitive modelling for advanced robotics" (Chapter 2).

Thus the complementary of biological and computer sciences has to be considered as a mutual stimulating potential for the development of a "Theory of Life" and the "Design of Learning and Intelligent Technical Systems".

* * *

The main-chapters of this article are more or less identical to the following papers:

Chapter 1: *Problems of Autonomy*

Cf.: E. von Goldammer & R. Kaehr: "Problems of Autonomy and Discontexturality in the Theory of Life"

and

Chapter 2: *Cognitive Modelling for Advanced Robotics*

Cf.: R. Kaehr & E. von Goldammer: "Poly-contextural modelling of heterarchies in brain function"

3. Summarizing Remarks

In order to appreciate the scientific and technical importance of such an intrinsic parallel (logical) calculus reference will be made to Fig. 3 in chapter 1.8 (which also corresponds to Fig. 3 in "Problems…".

– **Formalization:**

The segment of the diagram labeled "formalization" is selfexplanatory. Most scientific research in the prit has concerned the developing and formalization of the theory of polycontextural logic. Many aspects must be developed further; in particular, software tools are required, which would be of practical use for handling the complex formalism.

The situation may be compared to mathematics, or fuzzy set theory, etc. where many theoretical aspects have been developed independently of their scientific and technical applications.

– **Interpretation:**

In contrast to the linguistic framework of' classical logic -which does not allow any consistent description of self-referential, non-transitive processes, or distributed irreducible domains - the theory of poly-contexturality with its concept of distribution and mediation of domains offers an adequate logical tool for a "Theory of the Living". Since "parallel simultaneity" of processes as well as "closure" are not subject of experimental measurements, but belong instead to the category of description resulting from interpretation of experimental data, the problem for any formal or semi-formal description of living systems meets with a principal difficulty of' combining a semiotic theory with semantics. Since aspects of living systems may be demonstrated by social, economic, ecologic, medical, or biological systems, the problem of' a formal interpretation is an extremely interdisciplinary task, which must be accomplished, if technical artifacts (soft- and/or hardware) with the ability of cognition and volition are to be designed and constructed successfully.

In order to demonstrate the importance of a symbiosis between biological and computer sciences, the immune system as a cognitive system may taken as an example:

The immune system always was considered as a cognitive system, albeit, in a somewhat intuitive way: it recognizes molecular shapes, remembers the history of encounters of an individual organism, defines the boundaries of a molecular "self', and makes inferences about molecular species likely to be encountered. Immunology has left these cognitive terms more or less undefined on a metaphorical level and has concentrated, instead, on the molecular details of immune system components, discovering a great number of various cell types that play a fundamental role in the immune system. So far no model of a cognitive biological network has been developed which allows a simultaneous representation of open networks (as determined experimentally in the molecular domain of description) and closed networks (as required by the biology of cognition). Such a model requires at least three different, but mediated positions of description from which the system can be regarded in a consistent way

- as an open network (system),
- as a closed network (system), and
- as a relation between open and closed networks.

This example again demonstrates the importance of the complementarity of biological and computer sciences not only from a scientific, social, or medical point of view, but also with regard to its potential for stimulation of technical research and development concerning intelligent and autonomous systems.

– **Simulation:**

It is obvious that any simulation of living systems, whether social, economic, ecological, or biological, within the context of formal models is of special scientific, social, and industrial importance.

Within the context discussed in chapter 2, the development of knowledge-based and knowledge-acquiring systems is necessary for the design of automatic scene, image, or object interpreting systems (in the sense of 2nd order learning) as they are required, for example, for the construction of domestic robots. In other words, simulation of learning I and learning I1 is fundamental for the design of adaptive and intelligent (poly-contextural) control.

– **Construction:**

Hardware constructions of living systems is the declared aim of "Artificial Life (AL)". AL was created as a scientific program in competition with the platonically oriented scientific program of Artificial Intelligence (cf. ref.6 – chapter 0.3).

In the light of poly-contexturality any technical construction of formal models reflecting certain aspects of living systems may be realized either by a software development (simulation) or by softand hardware products as, for example, in the field of robotics.

The development of computer components such as a new generation of parallel micro-processors or the design of qualitatively new parallel computer architectures in the sense of "poly-logical machines" may also be envisaged: a machine that allows several simultaneous successions of deductive steps in different logical domains mediated with each other.

03. Footnotes and References

[*] "Cognition" is characterized by a deterministic rationality with respect to an environment and "volition" involves self-initiated and original action, which may be non-deterministic to an outside observer. The two processes will be defined more precisely in a later chapter.

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