

Autopoietic Machines: Beyond Half-Brained AI and Church -Turing Thesis

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Introduction

All living organisms are autopoietic and cognitive. Autopoiesis refers to a system with well-defined identity and is capable of reproducing and maintaining itself. Cognition, on the other hand, is the ability to process information, apply knowledge, and change the circumstance. The autopoietic and cognitive behaviors are executed using information processing structures that exploit physical, chemical and biological processes in the framework of matter and energy. These systems transform their physical and kinetic states to establish a dynamic equilibrium between themselves and their environment using the principle of entropy minimization. Biological systems have discovered a way to encode the processes and execute them in the form of genes, neurons, nervous system, the body and the brain etc., through evolutionary learning. The genome, which is the complete set of genes or the genetic material present in a cell, defines the blueprint that includes instructions on how to organize resources to create the functional components, organize the structure and the rules to evolve the structure while interacting with environment using the encoded cognitive processes. Placed in the right environment, the cell containing the genome executes the processes that manage and maintain the self-organizing and self-managing structure adapting to fluctuations. The mammalian neocortex and the reptilian cortical columns provide the information processing structures to assess risk and execute strategies to mitigate it. The genome and the networks of genes and neuronal structures are organized to function as a system with various components which have local autonomy but share information to maintain global stability with high degree of resiliency and efficiency in managing the resources.

General Theory of Information (GTI) tells us that information is represented, processed and communicated using physical structures. The physical universe, as we know it, is made up of structures that deal with matter and energy. As Mark Burgin points out “Information is related to knowledge as energy is related to matter.” A genome in the language of GTI [2 - 4], encapsulates “knowledge structures” coded in the form of DNA and executed using the “structural machines” in the form of genes and neurons. It is possible to model the autopoietic and cognitive behaviors using the “structural machines” described in the GTI.

In addition, GTI also allows us to design and build digital autopoietic machines with cognitive behaviors building upon current generation information processing structures built using both symbolic computing and neural networks. The autopoietic and cognitive behavior of artificial systems function on three levels of information processing systems and are based on triadic automata [4 - 7]. The efficient autopoietic and cognitive behaviors employ the structural machines.

Following four papers presented in the Theoretical and Foundational Problems (TFP) in Information Studies (IS) provide a framework to design and build the new class of autopoietic and cognitive machines:

1. Mikkilineni, Rao; The Science of Information Processing Structures and the Design of a New Class of Distributed Computing Structures
2. Mikkilineni, Rao; and Burgin, Mark; Designing a New Class of Digital Autopoietic Machines
3. Renard, Didier; Fitness in a change of era: Complex Adaptive Systems, Neocortex and a New Class of Information Processing Machines
4. Morana, Giovanni; Implementing a Risk Predictor using an Autopoietic Machine

The Theory and Practice of Information Processing Structures

The structural machines supersede the Turing machines by their representations of knowledge and the operations that process information [2, 3]. Triadic structural machines with multiple general and mission-oriented processors. enable autopoietic behaviors.

1. From Turing Machines to Structural Machines [2, 3]:

Structural machines process *knowledge structures which incorporate domain knowledge in the form of entities, their relationships and process evolution behaviors as a network of networks* with each node defining functional behaviors and links defining the information exchange (or communication). The operations on the knowledge structure schema define the

creation, deletion, connection and reconfiguration operations based on control knowledge structures. They are agnostic to what the functions of the nodes or what information is exchanged between them. This provides the composability of knowledge structures across domains in processing information. In contrast, the Turing machines process data structures which incorporate domain knowledge in the form of entities and relationships *only and their process evolution behaviors are encapsulated in algorithms (programs) which operate on the data structures*. Therefore, the Turing machine operations are domain knowledge specific and lacks composability across domains and increases complexity in processing information and its evolution.

2. Changing system's behaviors using functional communication [3, 4]:

The behavioral changes are embedded in the knowledge structures and therefore functional communication or information exchange induces the behavioral changes in various entities in the knowledge structures. Changes are propagated through knowledge structures when events produce changes in arbitrary attributes of the system entities. This enables self-regulation of the system. In contrast to self-regulation, the external control causes the behavioral changes by the rules embedded in the algorithms outside the data structures and to execute the behavioral changes, the programs have to understand the domain knowledge of the data structures in order to perform operations on them.

3. Triadic structural automata and autopoietic behavior [3, 4]:

A triadic structural machine with hierarchical control processors provides the theoretical means for the design of auto-poietic automata allowing transformation and regulation of all three dimensions of information processing and system behavior – the physical, mental and structural dimension [5]. The control processors operate on the downstream information processing structures, where a transaction can span across multiple distributed components by reconfiguring their nodes, links and topologies based on well-defined pre-condition and post-condition transaction rules to address fluctuations; for example, in resource availability or demand.

4. Providing global optimization using shared knowledge and predictive reasoning to deal with large fluctuations [5]:

The hierarchical control process overlay in the design of the structural machine, allows implementing 4E (embedded, embodied, enactive and extended) cognitive processes with downstream autonomous components interacting with each other and with their environment using system-wide knowledge-sharing, which allows global regulation to optimize the stability of the system as a whole based on memory and historical experience-based reasoning. Downstream components provide sensory observations and control using both neural network and symbolic computing structures.

We present utilization of this theory for building self-managing federated edge cloud network deploying autopoietic federated AI applications to connect people, things, and businesses which enable global communication, collaboration and commerce with high reliability, performance, security, and regulatory compliance. Just as the mammalian neocortex utilized the reptilian cortical columns by repurposing them as required, the structural machine overlay architecture utilizes the Turing machine-based information processing structures deployed today without requiring fork-lift for change.

References

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