The Neural Basis for the Perceptual Symbol System and the Potential of Building a Cognitive Architecture Based on It

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Abstract

The cortex is modeled as a net of minicolumns. A cell assembly in layer IV of a minicolumn is defined as a "cognit". Higher level cognits integrate lower level cognits. The minicolumn is able to form cognits and extract determinant cognit time series as perceptual symbols. A frame is a set of determinant cognit time series, and simulation is the partially retrieval of these determinant cognit time series. This model can fulfill the requirements for the perceptual symbol system proposed by Barsalou in 1999. I am trying to build neural network simulating this net. It is potentially a Cognitive architecture bearing connectionism.

Keywords: perceptual symbol system, minicolumn, cortex, connectionism, neural network

Introduction

On the standard view, perception and cognition are two distinct processes and the concepts in cognition are represented by amodal symbols. This viewpoint is challenged by the theory of perceptual symbol systems (Barsalou, 1999). They argued that there is no evidence for the existence of an amodal symbol system and symbols are intrinsically perceptual.

According to the work of Barsalou (1999), the kernel ideas of perceptual symbol system are:

1. A *perceptual symbol* is defined as a record of the neural activation during perception, while it is componential, multimodal, dynamic, and schematic.
2. A concept is equal to a simulator, which is composed of "an underlying *frame* that integrates perceptual symbols across category instances, and the potentially infinite set of *simulations* that can be constructed from the frame". A frame is object-centered and composed of multiple subregions, with four basic properties: predicates, attribute-value bindings, constraints, and recursion. The simulations must ensure categorization and categorical inferences, cognitive penetration, and stable conceptualization.

This article proposes a hypothesis of how cortex may fulfill these requirements and actualize the perceptual symbol system, and discuss the potential of building a cognitive architecture based on it.

Foundation from Neuroanatomy

Horizontally the cortex is composed of six layers. Layer IV contains different types of stellate and pyramidal cells, and is the main target of thalamocortical and intrahemispheric corticocortical afferents (input). Layer III contains predominantly pyramidal cells and is the principal source of corticocortical efferents (output) (Creutzfeldt, 1995). Vertically neocortex is columnar organized with elementary module minicolumn (Mountcastle, 1997).

Minicolumn Model

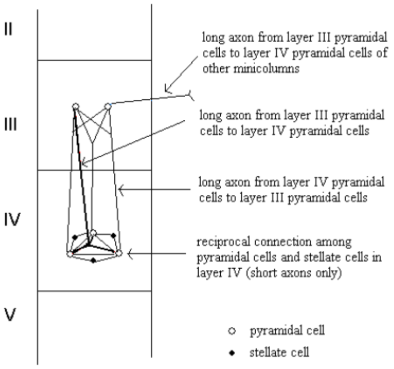

Figure 1: A Modeled Minicolumn

The simplified model for a minicolumn is shown in Fig 1. It is viewed as a recursive neural network. Layer IV composes of both excitatory and inhibitory neurons and is the principle area for external input. Layer III composes of excitatory neurons only and is the principle area for external output. The transmission delay among neurons between layer III and IV is considered. A cell assembly formed in layer IV through Hebbian learning (Hebb, 1949) represents a most basic piece of knowledge, called a "cognit" here.

Cortex Model

The whole cortex is viewed as a net with each node a minicolumn. The nodal connection is from excitatory neurons in layer III of one minicolumn to excitatory neurons in layer IV of another minicolumn.

The cortex is organized with "vague hierarchy". The minicolumns receiving thalamus inputs which transmit information directly encoded by sensory organs are regarded as level 1. The minicolumns receiving inputs from level 1 minicolumns are regarded as level 2. So on and so forth, minicolumns receiving inputs from level n minicolumns are regarded as level n+1. Notice this hierarchy is not perfect as many minicolums can receive inputs from multiple minicolumns of different levels.

Information Processing and Learning

Any perception and cognition starts with sequential inputs from sensory organs. These inputs are viewed as discrete time series of states. Information processing has two aspects: information extraction is to represent each state by cognits (cognit formation) in level 1 minicolumns and associate cognit A to cognit B if pattern (A, B) repeatedly occurs (sequence prediction); information integration is to link higher level cognits to combination of lower level cognits spacially and temporally. Thus a higher level cognit may refer to a spaciotemporal combination of information and have very abstract meaning.

Learning occurring within a minicolumn (intra-minicolumnar) actualizes information extraction (Wang, 2008). Learning occurring among minicolumns (inter-minicolumnar) may actualize information integration.

Fulfillment of Perceptual Symbol System

A perceptual symbol is a time series of cognits in which any cognit predicts its follower (a determinant segment of the entire time series of cognits).

Componential: Any cognit (other than level 1) is a spaciotemporal combination of cognits.

Multimodal: One cognit can integrates information from cognits of minicolumns belonging to different modalities.

Dynamic: The learning modifies the system’s behaviors.

Schematic: An individual is parsed into cognit series each of which represents a specific aspect of it. When perceiving a new individual, same cognit series can be retrieved (controlled by selective attention) if it shares a common specific aspect of the old one, enabling partial information retrieving.

A frame is simply a set of determinant cognit time series. This set stands for an (concrete or abstract) object, and the minicolumns containing these time series are subregions.

Predicates: this set itself is a predicate, as it defines the properties of the object.

Attribute-value Bindings: A specific specialization evokes specific determinant cognit time series in corresponding minicolumns.

Constraints: The many cognit time series identifying a specific specialization are integrated gradually through the hierarchy of the minicolumns, until a single cognit time series in one minicolumn represents this specialization. Feedback interminicolumnar connections enable the ability to retrieve all the attribute values of this specialization and prevent mismatches.

Recursion: multiple cognit time series of a frame can be integrated into a single cognit time series in a higher level minicolumn, which can in turn form an element (attribute) of a new frame.

A simulation is the partially retrieval of these determinant cognit time series. It ensures:

Categorization and Categorical Inferences: The specializations are put into a category if they share common attribute values. Thus one specialization can be put into multiple categories viewing from different aspects. Categorical inference is achieved by finding the frame from one attribute and retrieving this frame’s other attributes.

Cognitive Penetration: When selective attention is paid to retrieving the attribute values of a specialization in higher level frames, the original representation in corresponding lower level frames can be suppressed and modified.

Stable Conceptualization: Concepts formed in this way have stable commonality among different individuals as the representation in level 1 minicolumns are same (similar) defined by genes. The formation of higher level representation is essentially a data mining process, concepts not derivable from level 1 representation cannot form, but only a small portion of information is mined out by an individual. Thus knowledge of individuals may differ, but there is no difficulty for them to communicate and understand others.

Potential for Building a Cognitive Architecture

The idea is to build a neural network with minicolumns as basic functional units. Each subnetwork for a minicolumn actualizes information extraction. The connection among subnetworks actualizes information integration.

The neural network for a minicolumn is already built. Its learning strategy needs to consider the transmission delay, threshold dynamic, and the overlapping problem (Wang, 2008). The strategy for inter-minicolumnar learning should be inspired from the molecular guidance for axon growth, synaptic elimination, etc. during neural development (Dickson, 2002; Lo, Poo, 1991; Purves, Lichtman, 1980).

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