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PSEUDOCORTEX:

An algorithmic GPU-based framework for testing brain theory

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The Cerebral Cortex

The cerebral cortex is a massively parallel, highly repetitive, elegantly organized computational structure. While once considered to be composed of a mosaic of discrete structurally unique areas [1], new evidence indicates this view is incorrect.

Instead, the mammalian cortex appears to be structurally uniform, with the same types of cells in the same percentages and layering appearing in all cortical regions [2]. But perhaps most striking is the fact that any cortical area appears capable of performing the same functions as any other cortical area, if it is simply provided with the appropriate inputs [3].

These empirical findings lead to a new view of the cortex as a network of **knowledge-seeking agents** connected together by a massive number of specific inputs and outputs.

Each agent's specified connections form its individual **microconnectome**. Together the set of all cortical microconnectomes constitute the global connectome of the cerebral cortex.

Cortical agents are small groups of cells that implement knowledge-seeking functions.

What is Pseudocortex?

Pseudocortex, as its name implies, is not cortex, but it is cortex-like. Pseudocortex is an approach to quantitative simulations of the cerebral cortex that emphasizes **realistic biological constraints**. Its main tool is **principled reverse engineering**, that observes a set of very explicit assumptions and contraints. A pseudocortex model defines both the representation of the information available to the simulated cortex and the algorithms that the simulation must follow in processing that information. But it has nothing to say concerning the biological implementation of either the representations or the algorithms of the model.

In our view, the computational purpose of cortex is to employ knowledge-seeking processes that attempt to extract the regularities in the information available to it without supervision. Such regularities constitute knowledge and are of use to the organism.

In pseudocortex, theories are expressed at an algorithmic level in terms of agents that are arranged in a fixed, physical 2-dimensional grid, the rules that agents obey, and the set of connections that provide agents with inputs and outputs. Thus, pseudocortex, like the actual cortex, is a highly parallel structure and therefore is well suited for GPU implementation.

Self-Organizing Maps

In his provocative and influential analysis of the primate cortical motor system, Graziano [4] makes a strong argument that something like Kohonen's self-organizing map (SOM) algorithm [5] operates in the motor or output system of the cerebral cortex. Its function, according to Graziano, is to map high dimensional motoric information onto the 2-dimensional cortex, keeping like information together with as little separation as possible.

Testing the SOM Algorithm

Here, we provide a test of the SOM algorithm in the pseudocortex context using primary visual cortex, rather than motor cortex, as our simulation target. As input we use 3,000 16x16 gray-scale photographic patches from the van Hateren image archive [6]. But unlike previous attempts to test the SOM algorithm with visual input, we do not use raw images. Rather, we filter the images in the same manner as does the mammalian retina with its contrast-detecting center-surround retinal ganglion cells [7]. This results in a sparse matrix of positive and negative retinal contrast values. It is this representation of visual information that the mammalian retina actually processes.

C^{++}/CUDA programs using Thrust were written to allow the standard SOM algorithm (see reference 6 for details) to execute on a GPU wherever possible. Simulations were run on an Intel i7 based Linux system (Ubuntu 12.04.3) with an Nvidia C2075 graphics processing unit. 8x8 SOMs were trained on 4x4, 8x8, or 16x16 element patches extracted from 1000 different photographs in the van Hateren database [6]. Results for the 8x8 patches are shown in Figure 1.

These learned common patches resemble the receptive field mappings of actual neurons in the primary visual cortex. Since such field patterns are not present at birth, this finding raises the possibility that the cortical receptive fields are actually learned from the visual data that they receive from the optic nerve with experience.

What's wrong with the standard SOM?

It is apparent that the SOM algorithm has proven itself to be extremely useful in the world of artificial intelligence and, even more important to the neuroscientist, it seems to have captured some of the key features of living information processing systems, that is, of brains [8]. Yet problems remain.

First, the SOM algorithm was designed to converge to a "best solution" for any training set of data by gradually reducing the extent and the scope of its plasticity with experience. In contrast, biological systems maintain their plasticity throughout their lifespan. Various solutions to this problem have been proposed [9].

Further, as formulated, the SOM algorithm is not well suited for spatial expansion, from a patch, say, to an entire scene. By definition, SOMs seek a local maxima within a small, clearly defined region, whereas the algorithms of the biological cortex appear nearly infinitely extensible, covering the entire visual field. This difference is resolvable with the use of progressively shifting microconnectomes.

What's next for Pseudocortex?

Pseudocortex is ready for both a minor revision, adjusting its parameter setting by new methods, such as Berglund [8] suggested, and a major revision, extending very small patches to very large scenes. This new pseudocortex model will then be quantitatively tested and examined in great detail, much as Wolfram did with his cellular automata [10]. Hopefully this effort will contribute to "a new science of the brain" and a deeper understanding of the human cerebral cortex.

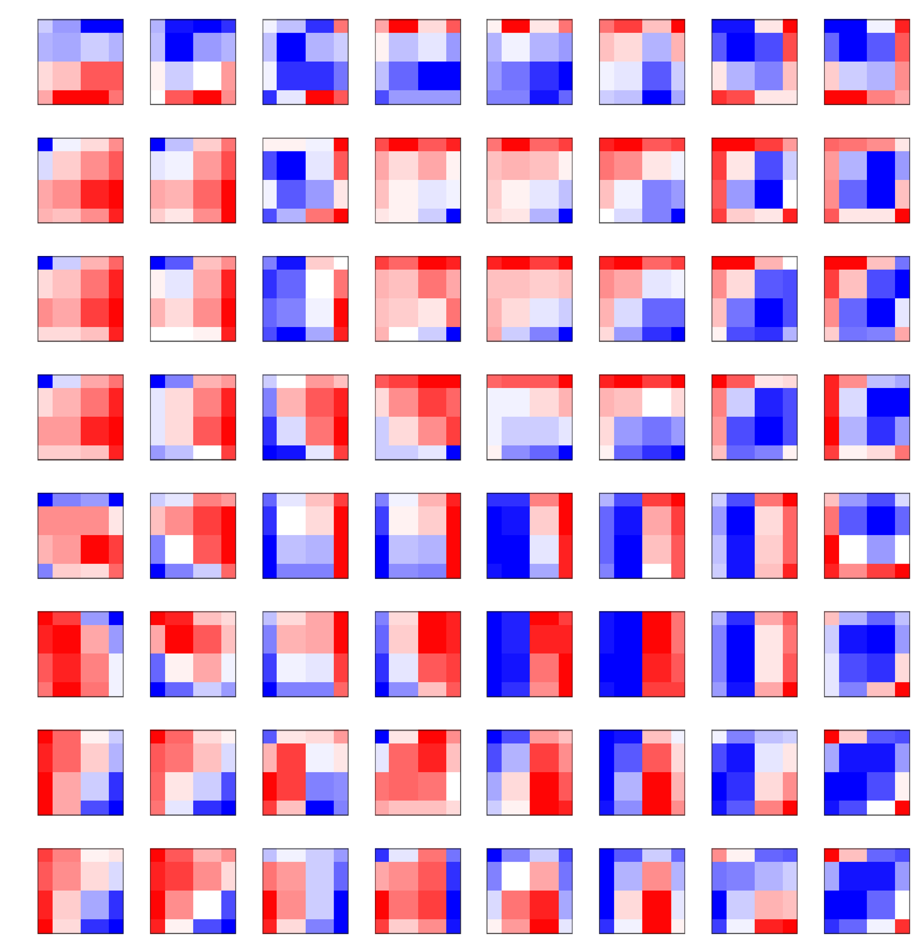

Figure 1. Basis functions extracted by the knowledge-seeking algorithm from 1000 patches of random natural images. Red signals activity of on-center agents and blue the activity of off-center agents, much as in neurophysiological recordings from mammalian cortex. Notice the line-like character of these receptive fields.

The Take Home Message...

Pseudocortex illustrates the potential for systematically studying simple agent-based algorithmic systems exposed to real world stimuli. It provides a framework for testing different hypotheses and in so doing extends our understanding of knowledge-seeking systems, both natural and artificial.

References

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Although by no means suitable for widespread distribution, preliminary versionsof the Thrust-based GPU software employed here is available from the author in the spirit of open source collaboration.