The Ersatz Brain Project: A Brain-Like Computer Architecture for Cognition

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ABSTRACT

The Ersatz Brain Project develops programming techniques and software applications for a brain-like computing system. Its brain-like hardware architecture design is based on a select set of ideas taken from the anatomy of mammalian neo-cortex. In common with other such attempts it is based on a massively parallel, two-dimensional array of CPUs and their associated memory. The design used in this project: 1) Uses an approximation to cortical computation called the network of networks which holds that the basic computing unit in the cortex is not a single neuron but groups of neurons working together in attractor networks; 2) Assumes connections and data representations in cortex are sparse; 3) Makes extensive use of local lateral connections and topographic data representations, and 4) Scales in a natural way from small groups of neurons to the entire cortical regions. The resulting system computes effectively using techniques such as local data movement, sparse data representation, sparse connectivity, temporal coincidence, and the formation of discrete “module assemblies.” The authors discuss recent neuroscience in relation to their physiological assumptions and a set of experiments displaying what appear to be “concept-like” ensemble based cells in human cortex.

Keywords: Brain-Like Computing, Brain-Like Computing Architecture, Ersatz Brain Project, Networks, Software Applications

INTRODUCTION

Parallelism has been studied by computer scientists for a generation because of its clear potential advantages in speed and hardware. Unfortunately, parallelism really works well only for a restricted set of problems, most notably the graphics seen in movies and video games or for important but specialized scientific and engineering applications. Most real programs have both a serial part where steps must be done one after another (waiting for a result before proceeding),
and a parallel part (moving images in a block around in a video game). This situation is described by “Amdahl’s Law,” named for Gene Amdahl, an influential computer architect and founder of Amdahl Corporation, now part of Fujitsu.

Amdahl pointed out that even if the parallel parts of the program were infinitely fast, the program would still take finite time to run because of the need to wait for the serial parts of the program that must be done in sequence to finish. But this observation suggests that an opportunity may appear if a class of cognitive operations can be performed efficiently on parallel computers.

Human brains evolved a particular structure to perform certain classes of operations that are important to us as humans. The human cerebral cortex is very slow (millisecond devices), but very highly parallel. A traditional computer is very fast (nanosecond devices), but only does one very simple logical operation after another in serial.

At present, surprisingly, brains and computers seem to be of roughly comparable power for a number of important “cognitive” applications such as chess or Jeopardy! Humans excel in perception and sensory integration and are far more flexible. But the way the two systems work are totally different. For example, computer chess works through brute force search of perhaps millions of future board positions. Humans look through a handful of future positions but they are the “right one” chosen through intuition, strategic insight, and memory.

One future way intelligent machine technology might evolve is to join the two approaches. Both have strengths. Humans are strong at putting large amounts of information together, recognizing and working with patterns, forming simplifications from complexity, and are exceedingly flexible. Computers are precise, but inflexible, and work tirelessly with the finest detail in a way that humans find impossible. Merging the virtues of human computation and computer computation would provide a synthesis that would let machines work on difficult human problems.

**ESSENTIALS OF THE ERSATZ APPROACH**

The human brain is composed of on the order of $10^{10}$ neurons, connected together with at least $10^{14}$ connections between neurons. These numbers are likely to be underestimates. Biological neurons and their connections are extremely complex electrochemical structures that require substantial computer power to model even in poor approximations. The more realistic the neuron approximation, the smaller is the network that can be modeled. Worse, there is very strong evidence that a bigger brain is a better brain, thereby increasing greatly computational demands if biology is followed closely. We need good approximations to build a practical brain-like computer. Here we discuss one possible way to do it.

**The Ersatz Cortical Computing Module and the Network of Networks**

Received wisdom has it that neurons are the basic computational units of the brain. However the Ersatz Brain Project is based on a different assumption. We will use the Network of Networks [NofN] approximation to structure the hardware and to reduce the number of connections required.

We assume that the basic neural computing units are not neurons, but small (perhaps $10^3 - 10^4$ neurons) attractor networks, that is, non-linear dynamical networks containing many neurons (modules) whose behavior is dominated by attractor states that are built in or acquired through learning. Basing computation on module attractor states – that is, on intermediate level structures – and not directly on the activities of single neurons, reduces the dimensionality of the system, allows a high degree of intrinsic noise immunity, performs important local information processing, and allows interactions between modules to be approximated as interactions between attractor states. Interactions between modules are similar to the generic neural net unit except scalar con-
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