Revision date: May 12, 2006

TECNICAL PROPOSAL, SCOPE OF WORK by UNR for HRL RFP 80063

Contract title for UNR reference: "Architectures of critical biological structures for brain simulation."

A. Results and deliverables

As part of Task 2 of the DARPA BAA, the University of Nevada, Reno Brain Computation Laboratory (UNR-BCL) will deliver to HRL documentation, tables, and diagrams describing biological principles of brain network design suitable for specifying and programming computational simulations of large scale neuromorphic architectures. (The actual programming of such simulation is not in the scope of Task 2.)

It is understood that Phase 1-3 funding by HRL, and continued participation of UNR, are contingent upon (1) HRL's receipt of DARPA funding increments, and (2) mutually satisfactory milestone performance in research and administration of each immediately preceding phase. It is also understood that any advanced computational resources and related technical support needed to achieve SyNAPSE objectives will be provided by HRL to UNR investigators.

No proprietary or intellectual property claims are anticipated.

B. Detailed technical rationale

Section III. Detailed Proposal Information

Technical Rationale

Traditional research in artificial intelligence and machine learning has viewed the brain as a specially adapted information-processing system. More recently the field of social robotics has been advanced to capture the important dynamics of human cognition and interaction. An overarching societal goal of this research is to incorporate the resultant knowledge about intelligence into technology for prosthetic, assistive, security, and decision support applications. However, despite many decades of investment in learning and classification systems, this paradigm has yet to yield truly "intelligent" systems. For this reason, many investigators are now attempting to incorporate realistic neuromorphic properties into machine learning systems, encouraged by over two decades of neuroscience research that has yielded quantitative parameters which characterize the brain's interdependent electrophysiological, genomic, proteomic, metabolomic and anatomic networks. For example, a search of the ISI Web of Knowledge for publications whose abstract contained words relating to in vivo or in vitro neocortical or hippocampal research increased about 150-fold in the period 1985 to 2005 (from 18 in 1985, 1494 in 1995, to 2689 in 2005). Directly warehoused data collection motivated by the highly automated genomic projects, such as the Allen Brain Atlas, is further accelerating the growth of publically available data. The outpouring of potentially useful data has sparked the development of over one hundred neuroscience databases.

The ability to understand processing within the brain would facilitate the development of artificial electronic brains, and of tissue-implantable neuromorphic (biomimetic) chips, for example to bridge regions of the brain damaged or disconnected by stroke or head trauma, or to detect and avert seizure propagation. Artificial brain systems with sufficient emotional intentional, as well as abstract knowledge-based intelligence could also be configured to assist in decision making for scenarios involving resource allocation under competing demands, such as industrial and business economics, urban planning, and geopolitical conflicts.

Given the complexity of neural systems, developing tenable models to capture the essence of natural intelligence for real-time application requires that we discriminate features underlying information processing and intrinsic motivation from those reflecting biological constraints (such as maintaining structural integrity and transporting metabolic products). Furthermore, despite the large and increasing number of physiological parameters provided by experimental inquiry, most of the data relates either to

the very small scale of individual or small groups of neurons (e.g., intracellular, 2-photon, or unit recordings at discrete recording sites), or at the other extreme, the joint effect of thousands or millions of neurons over millimeter (optical imaging) or centimeter fields (fMRI and PET). Thus the architecture and response patterns at the truly cognitive scale, or "mesocircuit", remain largely uncharacterized, requiring that the brain modeler proposes and systematically tests plausible connection patterns and learning dynamics. Because mammalian brains contain from 10 million (mouse) to 100 billion (human) neurons, the use of digital simulation, even with the aid of hundreds or thousands of clustered processing units, is very limited in its capacity to model the dynamics of neural systems, for which a tenth or hundredth of a millisecond precision may be needed for accuracy. We therefore agree with the goals and approach of DARPA's SyNAPSE, which requires that the biological parameters described above, taken from the large and increasing body of scientific publication, be aggregated and translated into practical specification of neural architectures that will "support critical structures and functions observed in biological systems such as connectivity, hierarchical organization, core component circuitry, competitive self-organization, and modulatory/reinforcement systems. As in biological systems, processing will necessarily be maximally distributed, nonlinear, and inherently noise- and defect-tolerant" (BAA, page 4).

Technical Approach

We view our role in SyNAPSE as providing a ***translational*** research contribution: moving discrete and disparate neuroscience findings, along with discoveries of key network dynamics from our own lab, into concrete specification for neuromorphic models that can be transitioned from digital supercomputer simulations to hardware emulation. To achieve this goal, we propose that Phase 0 be used to generate detailed procedures and formats to be followed during subsequent Phases 1-3 of the project, each of which will follow the following 4-step iterative cycle (for milestones, see part G, below):

Step 1. "**Components**" [months 1-2]: UNR-BCL investigators develop, using literature search and expert opinion, a draft "*Architecture Specification*" document that lays out objectives in term of the following 15 components:

(a) desirable types of tasks or behavior for the architecture, including benchmarks where applicable;
(b) overall scale of model, including permissible number of cells and the number of interconnections;
(c) brain regions/structures (e.g., cortical, hippocampal, basal ganglia, brainstem);
(d) complexity of network dynamics (especially degree of ongoing activity and up/down states);
(e) types of synapses and related dynamics;
(f) neuronal membrane channel dynamics;
(g) dendritic and other compartmental anatomy and related dynamics;
(h) probabilities of synaptic connections;
(i) nature of external stimuli to be input from environment into the model;
(j) acceptable pre-processing of sensory signals to represent early vision, audition, touch, etc;
(k) nature of electrical or motoric responses of the model;
(l) batch versus interactive functionality;
(m) stop-start versus real-time behavior;
(n) interface requirements for real/virtual robotic scenarios for the desired behavior environment; and,
(o) "dashboard" utilities for monitoring the functionality and progress of a simulated model modules.

Step 2. "**Consensus**" [Months 3-4]: Consensus reached on final *Architectural Specification* among all HRL-contracted investigators. Methods include iterative on-site and teleconferences, and electronic exchange of drafts. HRL leadership to adjucate final approval.

Step 3. "**Templates**" [Mon. 5 to mid-Phase]: UNR-BCL provides successive "*Architecture Specification*" templates that include pseudocode for algorithms to be programmed (Task 3), including documentation and, where appropriate, examples of computations. s

Step 4. "**Collaboration**" [Mid- to end-Phase]: UNR-BCL work in close collaboration with HRL-provided programmers to achieve instantiated models of the "*Architecture Specification*" templates. This will involve on-site as well as frequent electronic communication of results and feedback. During this Step, UNR-BCL will keep a careful web-based log of obstacles encountered and overcome, and recommendations for revisions of objectives in current and subsequent Phases. This log can be maintained as an online wiki, accessible to team members granted password access by HRL.

Technical challenges and obstacles anticipated

The accuracy of the modeling process will depend upon the availability and consistency of the neuroscience literature. To the degree possible, we will overcome such obstacles as they arrive using the following approach: (1) when multiple studies with consistent results are found, consensus results will be utilized; (2) when conflicting results are found among studies, a consensus of the majority will be utilized, retaining distinct alternatives for possible trial/substitution in the models; (3) when little or only weak evidence is found, UNR-BCL investigators will seek voluntary expert opinion from within and outside, through their network of colleagues in the field. (4) In such cases with little proven mechanisms, but when several distinct hypotheses are maintained in the scientific community, these several approaches will be compared in the architectural templates (tested using sample-based statistical method such as bootstrapping and permutation analysis).

Discussion of Related Research

Ongoing UNR-BCL Research. During the course of SyNAPSE, it is anticipated that UNR-BCL will maintain scientific funding from its current research sponsors, because SyNAPSE does not replace such investigation. That is, this contract supports the *translation*, but not generation of new scientific understanding. UNR-BCL will continue to explore the dynamical properties of micro- and mesocircuits in the brain, and the relationships among attention, learning, and behavior. A motivating factor for UNR-BCL participation in this contract is that final hardware products developed under SyNAPSE have the potential to substantially accelerate future development and validation of high-level brain prototypes by neuroscientists and cognitive researchers.

During the course of the contract, incorporation of alternative (non-spiking) computational models as modules of a model should be considered:

1. Sensory preprocessing. The CNS expends a large portion of neural activity in preprocessing sensory signals. Much research has been done in sensory neuroscience, so that visual scenes can be decomposed by filtering kernels rather than trying to design spiking networks to achieve the the same. For example, Gabor filters can be applied to images (representing early visual pathways) and Fourier analysis to sound (representing cochlear, brainstem, and early auditory cortical pathways).

2. Motoric activation. Regions of front and prefrontal cortex, cerebellum, and basal ganglia are involved in the "packaging" of motor movement sequences. Further, once activated, many motor sequences require substantial subcortical computation. These are learned early in life, and tend to be stereotypic (e.g., reaching, walking, emotional responses). Therefore, spiking premotor regions can be interfaced to digital "winner-take-all" threads which lead to stereotypic behaviors easily instantiated in real or virtual robotic platforms using traditional machine learning and AI tools.

3. Abstracted microcircuit and mesocircuit analogs. As neuroscience research progresses, it is hoped that some of the dynamics of spiking networks may be abstracted in such a way that the essential processing can be preserved without features necessitated only by biology (oxygenation, nutrition, metabolic waste, enzymatic thermal requirements). For example, spiking may be represented at a higher dynamical or more intermittent level, or analog circuitry may be substituted for emergent rhythms generated by larger-scale networks.

C. UNR Bio Summary (NSF-style biosketch, and a detailed CV are attached)

(see also section H, below)

Name & Title	Education/Interests	Qualifications
Philip H. Goodman, MD, MS Professor, Biomedical Engineering 15% overall FTE	Medicine MD, Statistics MS Physics BA, Biology BS Neural computation. Neuroscience of memory. Cognitive basis for decision making and planning.	Director, UNR Brain Computation Laboratory, 1999-present Neuroscience Fellowship, ETH/U. Zurich, 1996-97 Supervised degree programs for over 25 graduate students since 1988.

D/E. UNR's expertise/previous accomplishments (P.I. for all grants is P. Goodman)

Program Title	*Funding Agency*	*Contract #*	*Period*
Neural Comput	ONR	N000140710018	10/2006-9/2009
Neural Comput	ONR	N000140010420	10/2000-9/2006
Neural Comput	ONR	N000140210557	10/2000-9/2006
Neural Comput	ONR	N000149910880	6/1999-9/2000
DURIP	ONR	N000140710704	4/2007-3/2009
DURIP	ONR	N000140410454	4/2005-3/2008
DURIP	ONR	N000140210557	4/2002-3/2003
DURIP	ONR	N000140110552	4/2001-3/2002

The most recent annual research reports can be found online:

1. ONR Award N000140710704, title: **Large-Scale Biologically Realistic Models of Cortical & Subcortical Dynamics with Social Robotic Applications**

   http://brain.cs.unr.edu/share/onr07/reports07/N000140710018_ONR0609_Report_July07.pdf

2. ONR Award N000140710704, title: **Parallel Robotic Brains**

   http://brain.cs.unr.edu/share/onr07/reports07/N000140710704_DURIP07_Report_July07.pdf

F. Facilities

The Brain Computation Laboratory (BCL) is under the directorship of Philip H. Goodman, MD, MS, a full-time professor of Medicine (School of Medicine) and Biomedical Engineering (graduate school

program). The BCL is located in a former Department of Mines Building on the UNR campus. The building was renamed the "Applied Research Facility", and is administered by the Vice President for Research. The VPR allocated copious spaced for the student workstations and adjoining faculty office dedicated to this Laboratory. The ARF is a site of linkage to UNR of the high-speed Internet III.

G. Program schedule and milestones

Phase 0 Anticipated start: 9/1/08 Anticipated duration: 9 months

Task 2: Architecture

UNR will specify and validate by simulation the function of core microcircuit assemblies using measured synaptic properties. The chosen microcircuits must support the larger system architecture and demonstrate spike time encoding, spike time dependent plasticity, and competitive neural dynamics.

Phase 1 Anticipated start: to follow Phase 0 Anticipated duration: 15 months

Task 2: Architecture

Task 2.3 Forebrain Models

UNR will develop models for the forebrain for planning, and decision making with varying levels of neuroanatomical and neurophysiological details.

Phase 2 Anticipated start: to follow Phase 1 Anticipated duration: 15 months

Task 2: Architecture

Task 2.2 Integrate large-scale models

UNR will support HRL in the integration of models developed in Phase 1 into architecture with 10^6 neurons and 10^{10} synapses.

Phase 3 Anticipated start: to follow Phase 2 Anticipated duration: 18 months

Task 2: Architecture

Task 2.1 Extend architecture to "cat" scale

HRL with support from UNR will extend neuromorphic architecture developed in Phase 2 using the scalable software design into cat scale (10^8 neurons) neuromorphic architecture.

H. Additional Information

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