Identification and Significance of the Problem or Opportunity

In response to the solicitation topic "Incremental Learning for Robot Sensing and Control", CroftSoft Inc in collaboration with the University of Texas at Dallas proposes to develop a robotic control system that incrementally learns driving commands based on current sensor inputs and past experience. Spiking neuronal networks will be trained using spike-timing-dependent plasticity in virtual reality environments and then embodied in a robot platform for field testing.

Spiking Neuronal Networks

Biologically-plausible neuronal networks process information using spikes, the brief impulse action potentials propagated along nerves. Spikes are the *lingua franca* of both information processing in the brain and communication with the external environment. Unlike artificial neural networks or rule-based artificial intelligence systems, spiking neuronal networks (SNNs) process information to and from the environment via the sensory and effector nerves in the same format used by their cognitive information processing centers. This might be an important key to the ability of biological systems to autonomously learn to interact with their environment.

Reverse-engineering biological neuronal network systems is the pathway to developing automobiles, aircraft, and other vehicles that can autonomously learn to navigate and perform obstacle avoidance in real-time based on sensory inputs from the local environment.

Spike-Timing Dependent Plasticity

A key reinforcement learning algorithm for neuronal networks which we will integrate is spike-timing-dependent plasticity (STDP). STDP was recently discovered to be a mechanism by which biological neuronal networks adapt by changing the strengths of synaptic connections between communicating neurons based on the timing of spike events.[1] STDP provides a viable mechanism for adapting neuronal network systems using unsupervised and reinforcement training techniques. STDP has been used successfully to train neuronal networks to navigate in simulations.[2,3]

STDP meets all of the following requirements of the solicitation:

> The real world is too complex, ill conditioned, and variable to directly program an autonomous robot's control system. Autonomous robots therefore need to learn how to adaptively respond to sensor input. Due to the vast amounts of information that can be involved, the learning system needs to be trained incrementally, discarding prior data. The system needs to be capable of generating and updating its internal models in real-time. There should be little difference between the learning algorithms used in training and those used in execution.

1 Markram H., Lubke J., Frotscher M., Sakmann B (1997) Regulation of synaptic efficacy by coincidence of postsynaptic APs and EPSPs. Science 275, 213-5.

2 Chao ZC, Bakkum DJ, Potter SM (2008) Shaping Embodied Neural Networks for Adaptive Goal-directed Behavior. PLoS Comput Biol 4(3): e1000042.

3 DiPaolo EA (2003) Evolving spike-timing-dependent plasticity for single-trial learning in robots. Phil Trans R Soc Lond 361, 2299-2319.

Virtual Reality

Virtual reality training environments provide a means of training neuronal network systems prior to field test without damaging or destroying hardware. Training time can be reduced by parallel distributed processing and running simulations faster than real-time. The proposed training simulator will provide a virtual reality training environment for autonomous vehicles and robots that is optimized for training spiking neuronal networks using SIEVE.

Supervised Training

The solicitation proposes a supervised training mechanism:

> One method for training has the robot driving around by itself discovering associations between sensor inputs and control decisions. However, there are catastrophic situations, such as driving off a cliff or over a person, which one wants the system to learn, but not experience. An alternative methodology is to learn from example by having a user teleoperate the vehicle, with the system learning the association between sensor inputs and driving commands. In this case, research would also involve determining the most effective teleoperation strategy in order to generate a reliable autonomous driving system. A combination of these two approaches may provide a better overall solution.

In a neuronal network, the output neurons spike to control effectors such as muscle contractions or wheel rotations. Supervised training can be used with spiking neuronal networks by directly setting or increasing the excitability of the states of effector neurons that should spike at a given moment and inhibiting those that should not. The desired states of the effector neurons can be determined by the inputs from a human or rule-based teleoperator after transduction into spikes. The STDP learning rule will strengthen synaptic connections with interneurons that predict spiking of the effector neurons.

Spike Interface Embodied Virtual Environment

The patent pending Spike Interface Embodied Virtual Environment (SIEVE) is a method for experimenting with cognitive models embodied in a virtual reality environment. Examples of an experimental cognitive model include a biologically realistic neuronal network or a set of rules for interaction behaviors. SIEVE is novel in that the only inputs from the virtual reality environment to the cognitive model and the only outputs from the cognitive model to the virtual reality environment are in the form of simulated spikes, the action potentials that propagate information along a nerve axon.

In biology, the amplitude and duration of one spike tends to be indistinguishable from another. The information that is carried by the spike is communicated solely by the timing of its arrival at the interface of the transmitting axon and the receiver. SIEVE indicates the existence of a spike by the value of a bit, either a one or a zero, sampled periodically during a phase of the simulation loop.

The phases of the simulation loop of SIEVE are illustrated in Figure 1. In the first phase, "Render Virtual Environment", the current state of the modeled virtual reality environment is rendered. An example of this includes rendering a 3D scene graph into a pixel buffer.

The second phase of the loop is "Convert Rendering to Sensory Spikes". An example of this would be to convert the red, green, and blue components of the rendered pixels into simulated optic nerve spikes. The simulation serves as an artificial retina by mapping the color intensity values into ones or zeros in an array of bits representing the current state of a nerve bundle. Note that the sensory spikes represented in SIEVE can include visual, auditory, olfactory, and other senses as all are transduced into nerve impulses on their way toward the central nervous system.

The third phase is "Process Sensory Spikes / Generate Effector Spikes". While sensory spikes travel along afferent nerves toward the central nervous system for cognitive processing, effector spikes travel along efferent nerves from the central nervous system toward effectors such as simulated muscles that manipulate the virtual reality environment. This phase is performed by the simulated cognitive model which acts as a plug-in within the SIEVE framework. This permits the experimenter to test different cognitive models with the same "spikes in / spikes out" interface to the virtual reality environment.

The fourth phase is to "Convert Effector Spikes to Body Effects". An example of this would be a spike stimulating a muscle motor unit to effect a contraction of the muscle and a force on a limb. This can be simulated by reading the bit array representing the effector spikes and converting the values into corresponding forces on the virtual body.

The fifth phase of the simulation loop is to "Update Virtual Environment". In this final stage of the loop, the state of the virtual environment is updated incrementally. This includes converting the forces on the body into accelerations which update the velocities of objects within the virtual environment.

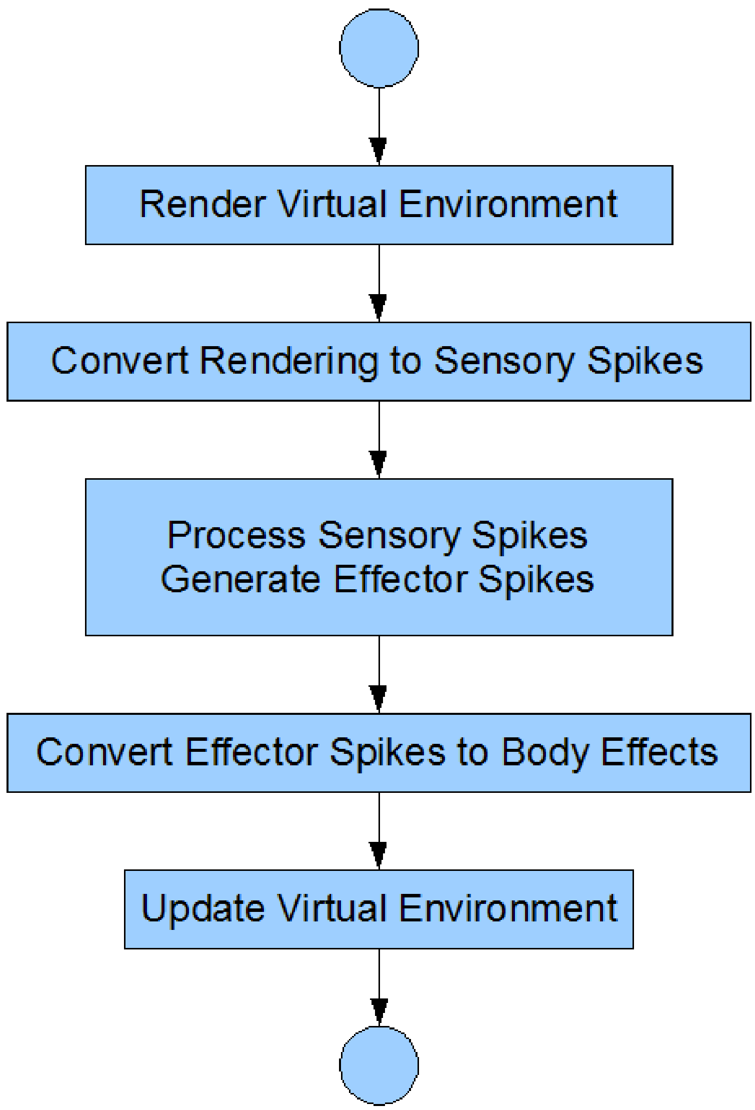

Figure 1: SIEVE loop phases.

Phase I Technical Objectives

As stated in the solicitation:

> The first phase consists of algorithm formulation, perception task selection, and training methodology definition. The feasibility of achieving real-time operation and a comparison against other algorithms shall be required in the final report.

Algorithm Formulation

The investigators shall formulate STDP-based algorithms for training. Algorithm formulation will include a literature review of STDP-based algorithms used in behavioral tasks. At least one of the algorithms considered shall be tailored for teleoperator supervised training. Algorithm formulation will include an exploration of biologically-realistic network topologies for sensory, interneuron, and effector neuron layers.

Perception Tasks

The investigators shall select the perception tasks to be used in training. These perception tasks will be chosen based on suitability for use with STDP-based algorithms, applicability to field testing a robot outdoors in Phase II, and success during prototyping in Phase I. Potential perception tasks include tracking, following, and avoidance.

Training Methodology

The investigators shall define the training methodology. The training methodology will include virtual reality simulation followed by robot embodiment validation. The results from Phase I prototyping of the training methodology will be included in the final report.

Real-time Operation Feasibility

The investigators shall include in the final report an assessment of the feasibility of achieving real-time operation. The assessment will include sensor and effector spike transduction, neuronal network simulation performance, and an analysis of varying parameters such as neuronal network size, simulation detail, and sensory load.

Algorithm Comparison

The investigators shall include in the final report a comparison of training algorithms. The comparison will include the STDP-based algorithms explored in Phase I. The comparison will also briefly contrast the features of non-STDP-based algorithms used in this area of research with a focus on real-time incremental versus off-line batch learning.

Phase I Work Plan

Higher priority tasks are scheduled for the beginning of the six month Phase I period so that less time can be spent on lower priority tasks toward the end of the schedule if necessary. The investigators shall document the results of each sub-phase of the Phase I work plan in the final report as each sub-phase is completed. Each sub-phase corresponds roughly to one month of effort.

Month 1

In the first month, the investigators shall perform a literature review, to be included in the final report, of STDP-based algorithms used in behavioral tasks. Based on the literature review, a set of candidate STDP-based algorithms and perception tasks shall be chosen for prototyping.

Month 2

In the second month, the investigators shall begin prototyping by developing the simulation software to implement the STDP-based algorithms and the virtual reality software to provide the perception tasks. The neuronal network simulation and the virtual reality software will be integrated using SIEVE. The results of the virtual reality training will be documented in the final report.

Month 3

Once one or more algorithms have been successfully prototyped in virtual reality training, the investigators shall select a robot platform to be used in validation. The selection criteria for the robot platform during Phase I shall be limited to operation in an indoor laboratory environment. The investigators shall then develop a software library for the selected robot platform so that the robot sensors and effectors can be mapped to the SIEVE interface developed in the previous sub-phase as part of the virtual reality training.

Month 4

The investigators shall exercise robot embodiment validation in an indoor laboratory environment. The investigators shall analyze any differences in behavioral task performance between the robot operating in the laboratory environment and the virtual reality environment. If necessary, the investigators shall iteratively revise the algorithms, perception tasks, and software selected and developed in previous sub-phases to ensure the integrity of the training methodology.

Month 5

As described in the previous section, the investigators shall assess the real-time operation feasibility.

Month 6

As described in the previous section, the investigators shall compare the training algorithms.

Related Work

Related work by the principal investigator includes initial development of the neuronal network simulation and the SIEVE virtual reality training simulator.

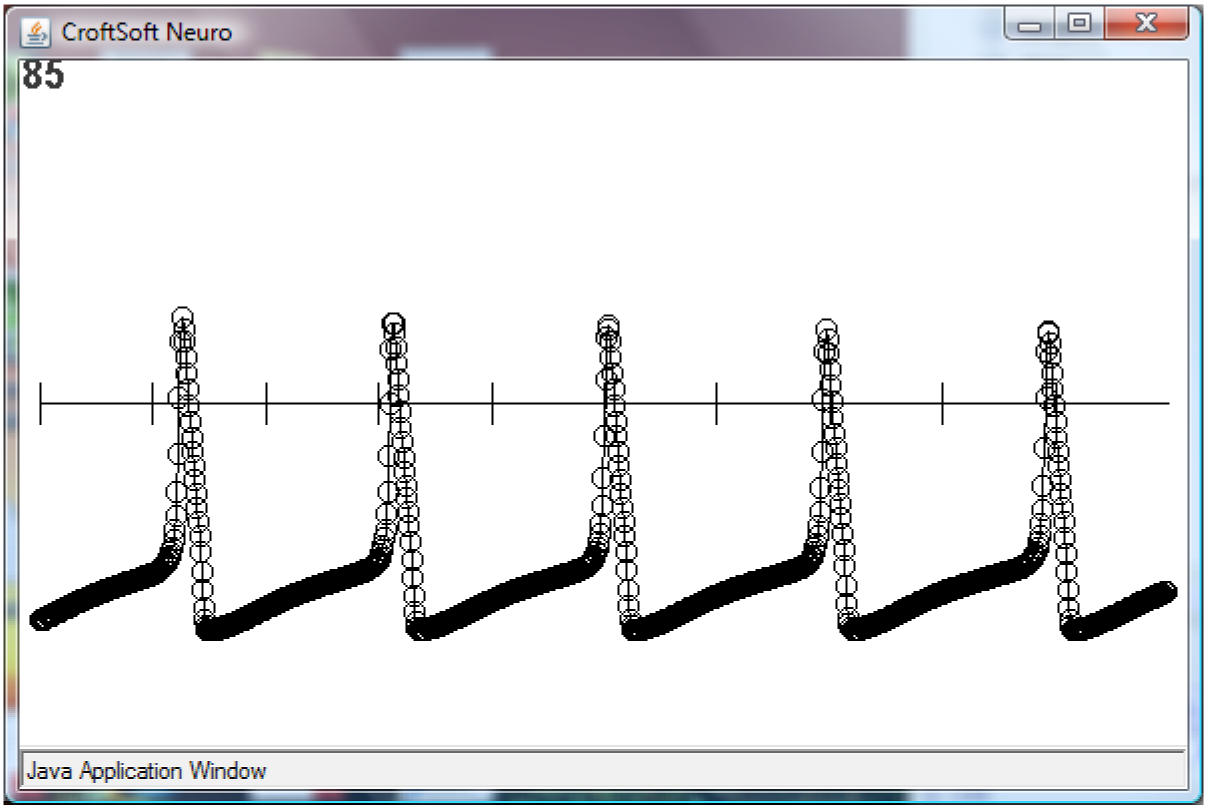

Figure 2: Hodgkin-Huxley neuron simulation

Neuronal Network Simulation

Figure 2 shows a screenshot of CroftSoft Neuro, an interactive animation of a biologically realistic neuron simulation based on Hodgkin-Huxley equations.[4] This software library will be expanded in Phase I to include neuronal networks trained with STDP.

4 http://www.CroftSoft.com/library/software/neuro/

PROPRIETARY

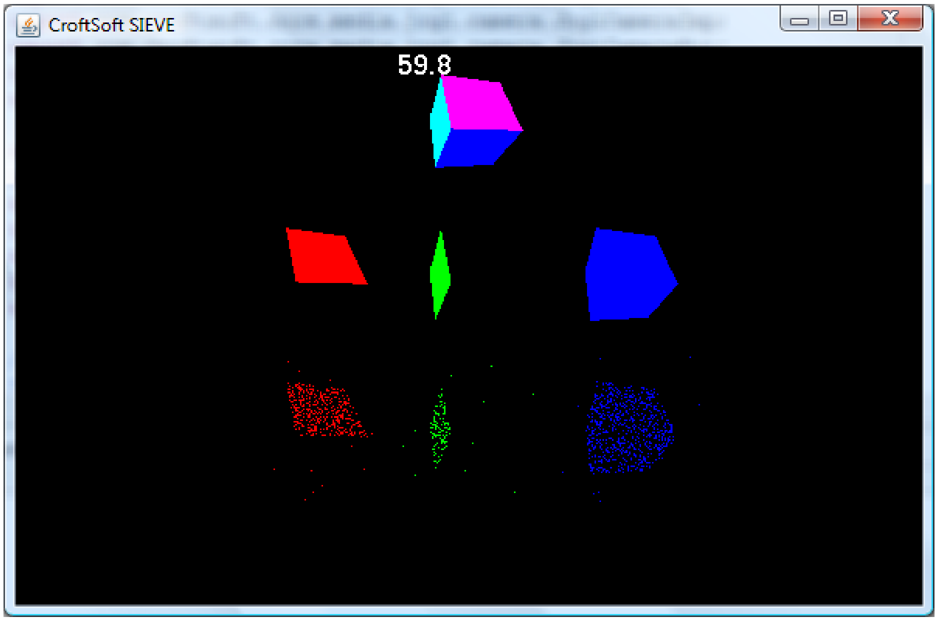

Figure 3: Screenshot of CroftSoft SIEVE

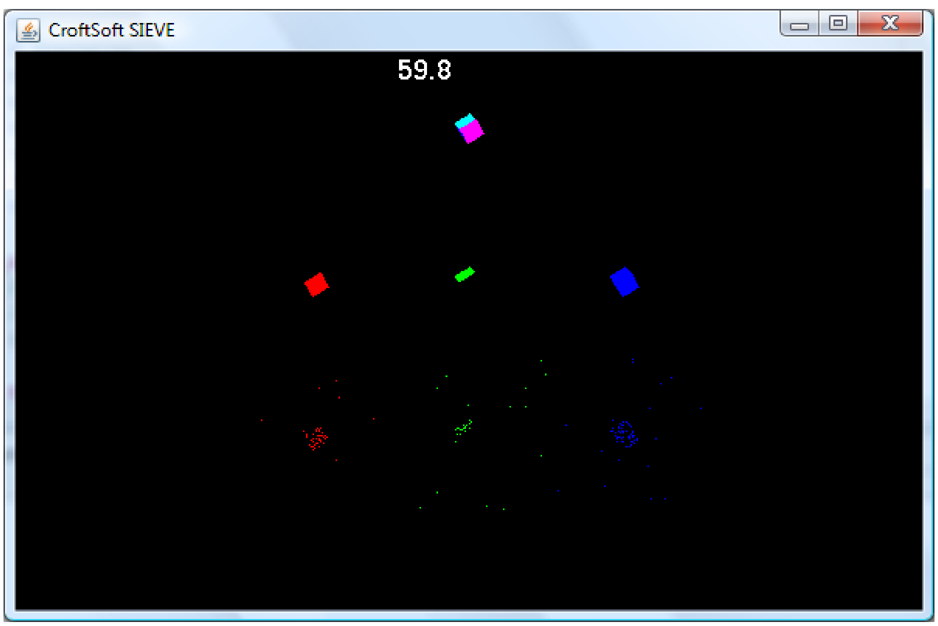

Figure 4: Spinning cube from a distance

PROPRIETARY

SIEVE Virtual Reality Training Simulator

The initial implementation of SIEVE, CroftSoft SIEVE, was a 3D graphics simulation. Figure 3 shows a screenshot of CroftSoft SIEVE with a rendering of a multi-colored spinning cube which exists in the virtual reality environment. The rendering is from the position and the orientation of the viewpoint of the virtual body of the embodied cognitive model. Three of the faces of the spinning cube are within view: the cyan, the magenta, and the blue colored faces. This depicts the initial "Render Virtual Environment" phase of the simulation loop.

Below the spinning cube is the same cube rendered three more times. Each of the three renderings provides a depiction of the virtual reality environment as decomposed into just the red, green, or blue color components separately. As can be seen, the cyan color of the cube face decomposes into green and blue but no red components and the magenta decomposes into red and blue but no green components. This depicts an intermediate step in the "Convert Rendering to Sensory Spikes" phase of the simulation loop.

The bottom row of the screenshot shows a subsequent conversion of the red, green, and blue pixels into sensory spikes. Each dot represents an action potential on the axon of a simulated optic nerve. This depicts the final step in the "Convert Rendering to Sensory Spikes" phase of the simulation loop in which a color pixel buffer is converted into a sensory spike bit array.

Figure 4 shows a screenshot of CroftSoft SIEVE when the viewpoint of the virtual body of the embodied cognitive model is at a greater distance from the spinning cube. In the "Process Sensory Spikes / Generate Effector Spikes" phase of the simulation loop, the cognitive model provided counted the number of red spikes in the sensory spike bit array and compared them to the number of blue spikes. If the number of red spikes was greater than the number of blue spikes, the cognitive model would set a bit on the effector spike bit array to a one to indicate that the virtual body should move forward. If the number of blue spikes exceeded the number of red spikes, a different effector bit is set to move the virtual body backward away from the cube. In Phase I, this cognitive model will be replaced with a biologically realistic neuronal network simulation.

In the "Convert Effector Spikes to Body Effects" phase of the simulation loop, the effector spikes are converted into forces on the virtual body. The conversion here is from one and zeros in the effector spike bit array into simulated magnitudes and directions of forces. In this implementation, the directions of the forces are limited to just one degree of freedom, either toward or away from the spinning cube.

In the final "Update Virtual Environment" phase of the simulation loop, the net force on the virtual body is converted into acceleration which then affects the velocity and position of the virtual body. The animation provides the appearance of a cognitive model exhibiting a behavior in which it moves in the virtual reality environment toward or away from the spinning cube depending on which colors are currently showing.

Relationship with Future Research or Research and Development

As stated in the solicitation:

> The second phase consists of a full implementation of the system, including sensors. At the end of the contract, the incremental learning capabilities of the prototype system shall be demonstrated in a suitable outdoor environment. Deliverables shall include the prototype system and a final report, which shall contain documentation of all activities in this project and a user's guide and technical specifications for the prototype system.

If the Phase I project is successful, the anticipated results of the proposed approach include the following:

- A prototype demonstration of using STDP-based algorithms for incremental learning for robot sensing and control in indoor laboratory environments;
- A prototype demonstration of the training methodology which includes initially training the neuronal network in a virtual reality environment using SIEVE followed by validation in a robot using the same SIEVE interface;
- An assessment of the real-time operation feasibility; and
- A literature review and a comparison of the STDP- and non-STDP-based training algorithms.

The Phase I effort provides a foundation for Phase II by the following:

- Success with STDP-based algorithms in an indoor laboratory environment using a limited feature robot platform during Phase I is a pre-requisite for the more difficult task of training a full-featured robot platform to perform in an outdoor environment in Phase II. The Phase I prototype provides a base from which Phase II can extend in the direction of a greater number of sensor inputs and effector outputs, a more varied operating environment, and more complex perceptual tasks.
- The prototype training methodology established in Phase I establishes a proof of concept which justifies further development of the software components including the neuronal network simulation, the virtual reality training environment, the perception tasks, and the robot platform SIEVE interface libraries. The software will be commercialized for dual use applications in Phase III.
- The real-time operation feasibility assessment established in Phase I will permit the investigators to determine the criteria for the selection of a robot platform for Phase II including, if necessary, any specialized software and hardware such as real-time programming languages and custom sensor and effector transduction processors.
- The literature review and the comparison of the STDP- and non-STDP-based algorithms documented in Phase I indicates where further research on the algorithms is warranted in Phase II. Algorithm research can be performed separate and apart from the software development and hardware integration. Assuming sufficient resources allocated in Phase II, identified variations of the training algorithms can be developed in parallel.

Commercialization Strategy

As stated in the solicitation:

> Commercial applications include many UGV applications, such as security and inspection, hazardous waste monitoring, and planetary exploration. Military applications include robotic mule, scout vehicles, security and inspection.

Intellectual Property

The key personnel and principal investigators are Dr. Larry Cauller, a professor at the University of Texas at Dallas (UTD), and Mr. David Croft, a part-time doctoral student in the laboratory of Dr. Cauller. The patent pending SIEVE technology, described in a previous section, was invented by Mr. Croft at UTD as part of his doctoral studies. UTD has assigned the intellectual property rights in SIEVE to Mr. Croft in exchange for a percentage of royalties from commercialization. Mr. Croft is working with attorney Mr. Dean Cook to convert a provisional patent application on SIEVE to regular patent applications in order to use the patent protection to establish a sustainable competitive advantage in the United States and European markets.

The small business CroftSoft Inc that will manage the grant is owned by Mr. Croft. Mr. Croft will license the SIEVE technology to CroftSoft Inc for the duration of the Phase I and Phase II grants for a nominal fee. Any intellectual property developed as part of the Phase I and Phase II grants and owned jointly by both CroftSoft Inc and UTD will be transferred to the startup business NeuroDynamo. NeuroDynamo will be founded and owned by Mr. Croft, Dr. Cauller, and Mr. Cook. Mr. Croft will license SIEVE to NeuroDynamo for commercialization along with the intellectual property developed as part of the Phase I and Phase II grants such as the software described in the following section.

Revenue Sources

The NeuroDynamo software and hardware framework will be licensed to DoD, other Federal Agencies, and private sector markets. The NeuroDynamo Virtual Reality Training Simulator, including simulation models, will be licensed separately as an optional configuration package for the SIEVE framework. Licensees will also be offered a support option.

NeuroDynamo will resell and support vehicles and robots configured with the sensors, controls, and neuronal network control system selected and developed during Phases I and II. NeuroDynamo will also sub-license the patent for SIEVE for embedding in third-party ground, water, and air vehicles and other autonomous robots. Third-party vehicle developers will license the NeuroDynamo Virtual Reality Training Simulator in order to train and test their own variants of the neuronal network control system.

The following is a listing of revenue sources:

- NeuroDynamo SIEVE framework, the neuronal network simulation engine
- NeuroDynamo Virtual Reality Trainer including task-specific training models
- Vehicles and robots with trained neuronal networks pre-installed

- Patent licenses for embedding SIEVE in third party vehicles and robots
- Software and hardware support and documentation

The first product to be commercialized will be the NeuroDynamo SIEVE framework and the NeuroDynamo Virtual Reality Training Simulator toward the middle of Phase II. Resale of vehicles and robots with SIEVE pre-installed will begin toward the end of Phase II. Commercialization of SIEVE in third party vehicles and robots will commence in Phase III.

Key Personnel

David Wallace Croft, M.Sc.

Mr. David Wallace Croft is the principal investigator and the President of CroftSoft Inc. Mr. Croft has an interdisciplinary background in computer science, electrical engineering, and neuroscience. He has recent industry experience in developing 3D software for unmanned aerial vehicles (UAVs) and learning environments. He has also designed neuromorphic chips and neuronal network learning rules.

Education

Mr. Croft is pursuing a doctorate part-time in the Cognition and Neuroscience program within the School of Behavioral and Brain Sciences (BBS) at the University of Texas at Dallas (UTD). He is a student in the NeuroEngineering Laboratory led by Dr. Lawrence J. Cauller.

Degrees

- M.Sc. Applied Cognition and Neuroscience (2005), University of Texas at Dallas (UTD)
- M.Sc. Electrical Engineering (1995), California Institute of Technology (Caltech)
- B.Sc. Electrical Engineering (1990), United States Air Force Academy (USAFA)

Relevant Employment Experience

In addition to the following government and military research projects, Mr. Croft has years of experience in industry as a Software Developer.

- 1990 Jun - 1993 Oct, Computer Systems Engineer, USAF
  B-2 Combined Test Force, Operational Test and Evaluation
  31st Test and Evaluation Squadron, Edwards A.F.B.
- 1995 Jun - 1996 Jul, Systems Engineer, Tanner Research Inc.
  "Silicon Neural Network Compiler" and "Silicon Cochlea"
  Granting agency: United States Air Force (USAF)
- 1997 May - 1999 Jun, Senior Intelligent Systems Engineer, Analytic Services Inc.
  "Technologies for Identifying Missing Children"
  Granting agency: National Institute of Justice (NIJ)
- 2004 May – 2006 Oct, Software Developer, Whoola Inc.
  "Peer-to-Peer Virtual Reality Learning Environments"
  Granting agency: National Institute of Standards and Technology (NIST)
- 2007 Jan – 2007 Aug, Research Engineer, SET Corporation
  "Swift KillerBee Advanced Ground Control Station"
  3D route planning and control software for unmanned aerial vehicles (UAVs)

Research Summary

Mr. Croft's previous related research by topic includes biologically-plausible learning rules for neuronal networks, computational neuroscience modeling, neuromorphic and artificial neural network (ANN) VLSI chip design, intelligent software agents (ISA), P2P networks, and graphics programming.

3D UAV

In 2007, as an employee of SET Corporation, Mr. Croft was a software developer on the Swift KillerBee Advanced Ground Control Station project. Mr. Croft developed 3D software for unmanned aerial vehicle (UAV) waypoint route planning and flight control including 3D graphics, peer-to-peer (P2P) networking, and integration of video transmitted from the UAV.

Newt Cyborg

In 2006, as a doctoral student in the University of Texas at Dallas NeuroEngineering Lab headed by Dr. Lawrence J. Cauller, Mr. Croft developed a real-time software simulation of peripheral nerve spiking activity, Newt Cyborg (Figure 5). The task to be learned by the user was to use a joystick to generate simulated spiking activity in order to move a cursor to a target and hold it on the target for three seconds. The software and documentation is available for download[5].

Spike signals from individual axons may lack the information content or be too noisy for adequate limb control. The Newt Cyborg project addressed the problem with simulation software that transformed artificial spike signals generated under the control of a joystick into movement commands that controlled the position of a virtual limb. User control of the joystick in this simulation corresponds to the intended movements of the amputee, and the artificial spike signals correspond to those which would be transmitted through peripheral nerves in the amputated stump where they are detected and transformed into limb movements. By providing immediate feedback, the accuracy and responsiveness of the control system was evaluated with respect to a range of spike signal properties. In addition, the project provided a testing platform for alternative transform algorithms. This software served as an initial prototype of a training simulator to prepare amputees for artificial limb control.

Cyberspace

From 2004 to 2006, Mr. Croft was also the lead Software Developer on the National Institute of Standards and Technology (NIST) Advanced Technologies Program (ATP) grant "Peer-to-Peer Virtual Reality Learning Environments"[6]. As part of this effort to provide teachers and students with zero-cost, royalty-free software for creating immersive training simulations, Mr. Croft authored Whoola Cyberspace, a virtual reality web browser with fly-through hyperlinks[7]. The 3D scene graph can be updated using network messages to initiate and terminate animation. This Open Source application is based on non-proprietary and open standards such as COLLADA, HTTP, Java, OpenGL, and XML.

An earlier prototype, Whoola Dock, demonstrates the use of automated assessment in a virtual training

5 http://www.CroftSoft.com/library/software/newt/

6 http://web.archive.org/web/20060217063902/http://jazz.nist.gov/atpcf/prjbriefs/prjbrief.cfm?ProjectNumber=00-00-5541

7 http://croftsoft.com:8080/space/

environment (Figure 6). Event messages generated by movements controlled by the students in the virtual space are monitored by a software agent. The agent assesses the performance of the student in a given task or progress toward a goal. It provides text and verbal feedback using an Open Source text-to-speech (TTS) engine.

Intelligent Software Agents

From 1997 to 1999, as an employee for Analytic Services (ANSER), Mr. Croft was a software developer on research grants from the National Institute of Justice (NIJ) to deploy intelligent software agents (ISAs) for law enforcement applications. As part of this effort, Mr. Croft developed Internet agents such as Web spiders integrated with commercial face recognition libraries.

Digital ANN VLSI

In 1996, as an employee of Tanner Research, Mr. Croft was the lead software developer on the U.S.A.F. SBIR “Neural Network Silicon Compiler” project in which he designed and implemented a software CAD tool to automatically generate the VSLI layout for artificial neural network (ANN) chips. Mr. Croft also performed bench testing of experimental circuits on the Silicon Cochlea project.

Neuromorphic STDP

Mr. Croft was perhaps the first researcher to explore what is now known as spike-timing dependent plasticity (STDP) as he invented a similar or equivalent algorithm as a biologically plausible neuronal network learning rule in the Spring of 1993, prior to the subsequent discovery of STDP in biology as published by neuroscientists in 1997. The goal driving the invention was the pursuit of unsupervised learning by a neuronal network operating in a real-time environment.

As a graduate student at the California Institute of Technology (Caltech), Mr. Croft attended courses taught by Dr. Carver Mead on the subject of neuromorphic VLSI. As a student project, Mr. Croft designed, fabricated, and tested a neuromorphic VLSI chip to implement STDP (Figure 7). This was perhaps the first neuromorphic VLSI chip designed with the characteristic depolarization and hyperpolarization phases of a Hodgkin-Huxley neuron model. Mr. Croft presented his design and test results at the kickoff meeting for the new NSF Center for Neuromorphic Systems Engineering at Caltech in 1995.

Publications

- Mel, B.W., Niebur, E., & Croft, D.W., "When neurons crave regularity and shun cooperativity in their synaptic input stream". In Proc. of the 3rd Joint Symposium on Neural Computation, Caltech and UCSD, 1996.
- Mel, B.W., Niebur, E., & Croft, D.W., "How neurons may respond to temporal structure in their inputs." Proceedings of CNS*96, Computational Neuroscience Meeting, Boston, MA, 1996. In: *Computational Neuroscience: Trends in Research*, 1997, edited by J.M. Bower. New York: Plenum Press, 1997, p. 135-140.
- Croft, David Wallace, *Advanced Java Game Programming*, 558 pages, Apress, 2004.

Professional Talks

- 1995, "An Analog VLSI Depolarizing-Hyperpolarizing Neuron", presented at the kickoff of the NSF Center for Neuromorphic Systems Engineering at the California Institute of Technology.
- 2006, "Real-time Simulation and Processing of Peripheral Nerve Spike Activity", Dallas Area Neuroscience Group.

Teaching

- 2003 Spring and Fall, Lecturer I, "Computer Game Development", UT Dallas
- 2004 Spring, Teaching Assistant, "Research Design and Analysis", UT Dallas
- 2005 Summer, Lecturer I, "Statistics for Psychology", UT Dallas

Related Training

- Neuromorphic Engineering Workshop, Third Annual (1996, 3 weeks)

Associations

- Association for the Advancement of Artificial Intelligence (AAAI), Member
- Society for Neuroscience (SfN), Member
- Dallas Area Neuroscience Group (SfN local chapter), Historian and Co-founder

Honors and Awards

Academic

- 1986 Congressional appointment to United States Air Force Academy (USAFA)
- 1989 Scored perfect 800 on quantitative section of GRE
- 1990 Dean's Honor List, all 8 semesters, USAFA
- 1990 Graduated with Academic Distinction, Top 5%, USAFA
- 1993 Virginia Steele Scott Fellowship, California Institute of Technology (Caltech)

Military

- 1991 National Defense Service Medal
- 1993 Air Force Commendation Medal

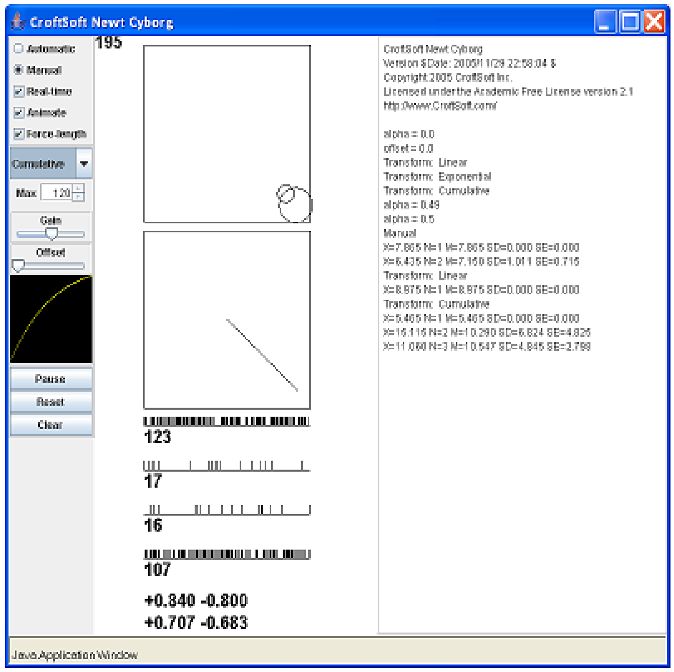

Figure 5: CroftSoft Newt Cyborg.

Figure 6: Whoola Dock.

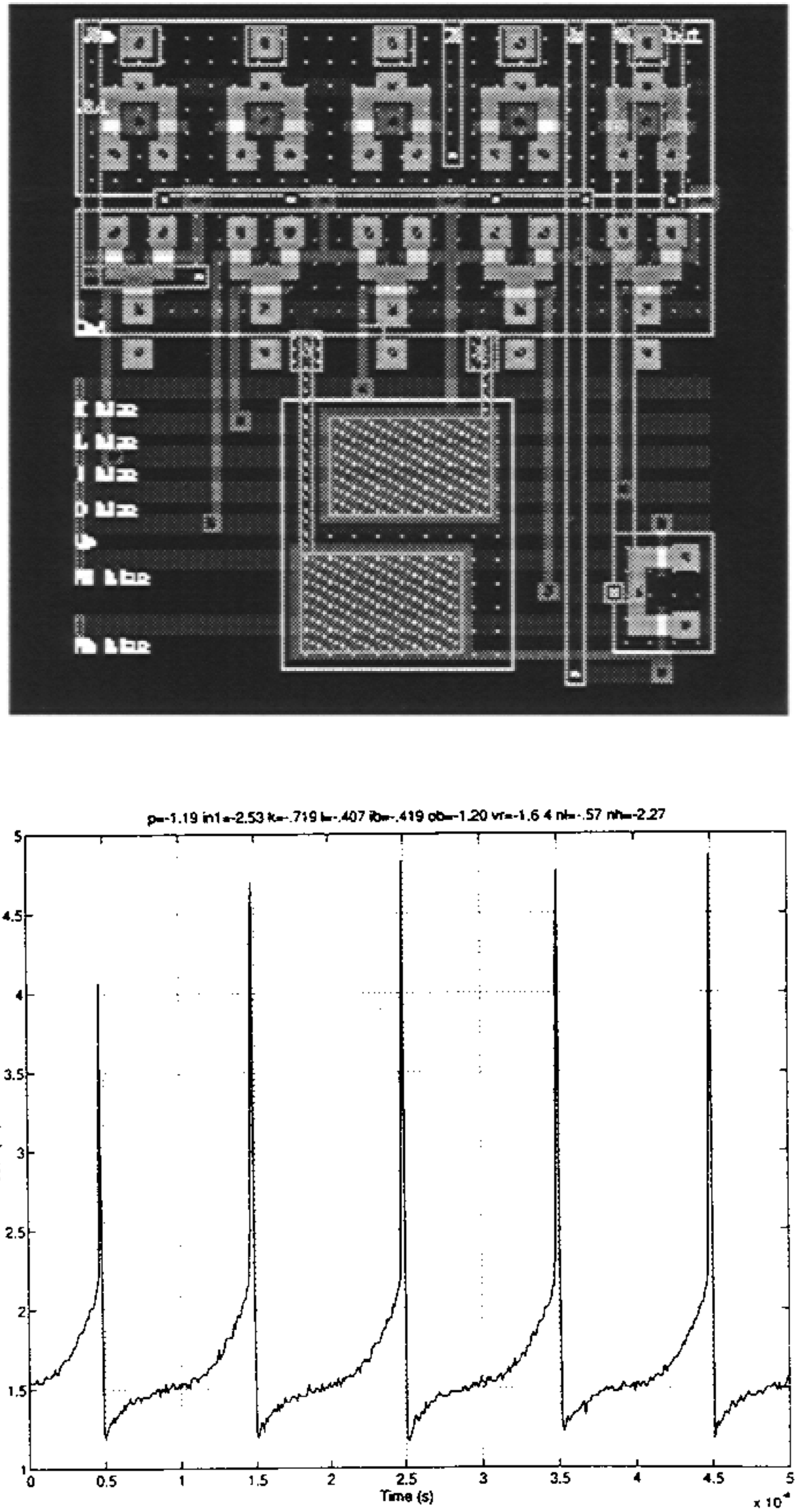

Figure 7: Neuromorphic VLSI for STDP.

Lawrence J. Cauller, Ph.D.

Dr. Lawrence J. Cauller is an Associate Professor with the University of Texas at Dallas (UTD), the research institution. Additional information regarding his background and research is available on the Web.[8]

Education

Ph.D. degree in Biomedical Sciences, September 1988

Northeastern Ohio Universities' College of Medicine, Rootstown, Ohio

M.A. degree in Psychology and Neuroscience, July 1981

Dalhousie University, Halifax, Nova Scotia, Canada

B.S. degree in Psychology, June 1980

University of Utah, Salt Lake City, Utah

Related Work Experience

January 1992 - present

Associate Professor of Neuroscience (tenured Spring 1998)

School of Behavioral and Brain Sciences, University of Texas at Dallas

August 1988 - December 1991

Postdoctoral Research Fellow, NRSA, supported by NIH F32

Sponsor: Barry W. Connors, Professor of Neuroscience

Neurobiology, Div. Biology and Medicine, Brown University

April 1972 - October 1975

Neuropsychiatric Specialist

Class C Physician's Assistant

Walson Army Hospital, Fort Dix, New Jersey

Publications

Lu H.M., C. Goldsmith, L.J. Cauller and J.B. Lee (in press) MEMS-based inductively coupled RFID transponder for implantable wireless sensor applications. IEEE Trans. Magnetics.

Mitchell* B.D. and Cauller L.J. (2001) Corticocortical and thalamocortical projections to layer I of the frontal neocortex in rats. Brain Res. 921(1-2):68-77.

Kern* J., Miller V.S, Cauller L.J., Kendal R., Mehta J. and Dodd M. (2001) The effectiveness of N,N-dimethylglycine in autism/PDD. J. Child Neurol. 16:169-73.

8 http://www.utd.edu/~lcauller/

Kern* JK, Cauller LJ, Dodd M. (2000) Application of the Test of Nonverbal Intelligence (TONI-2) in children diagnosed with autism/PDD. Journal of Developmental and Learning Disorders 4(1):119-131.

Clancy*, B. and Cauller L.J. (1999) Widespread projections from subgriseal neurons (Layer VII) to layer I in adult rat cortex. J. Comp. Neurol. 407: 275-286.

Cauller L.J., Clancy*, B. and Connors B.W. (1998) Backward cortical projections to primary somatosensory cortex in rats extend long horizontal axons in layer I. J. Comp. Neurol. 390: 297-310.

Jackson* M.E. and Cauller L.J. (1998) Neural activity in SII modifies sensory evoked potentials in SI of awake rats. Neuroreport 9:3379-3382.

Jackson* M.E. and Cauller L.J. (1997) Evaluation of simplified computational models of reconstructed neocortical neurons for use in large-scale simulations of biological neural networks. Brain Research Bulletin 44:7-17.

Cauller L.J. (1995) Layer I of primary sensory neocortex: Where top-down converges upon bottom-up, Behavioural Brain Research 71:163-170.

Cauller L.J. and Connors B.W. (1994) Synaptic physiology of horizontal afferents to layer I in slices of rat SI neocortex. J. Neuroscience, 14:751-762.

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Cauller L.J. (2003) The NeuroInteractive Paradigm: Dynamical mechanics and the emergence of higher cortical function. In: Computational Models for Neuroscience: Human Cortical Information Processing, Robert Hecht-Nielsen and Tom McKenna (eds.), Springer-Verlag.

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Jackson* M. E. and L. J. Cauller (1999) The function of reciprocal corticocortical connections: Computational modeling and electrophysiological studies. In: Oscillations in Neural Systems. D. S. Levine, V. R. Brown and T. Shirey (eds.). New York, Lawrence Erlbaum.

Jackson* M.E., Patterson* J. and Cauller L.J. (1996) Dynamical analysis of spike trains in a simulation of reciprocally connected "chaoscillators": Dependence of spike pattern fractal dimension on strength of feedback connections. In Computational Neuroscience, Beeman and Bower (eds.), Academic Press.

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Major Funded Research Projects

"Ultra-Scale Artificial Nervous Systems for Adaptive Computing"

Lawrence J. Cauller, UTD subcontract, Principal Investigator

Research Grant, Defense Advanced Research Projects Agency (DARPA)

subcontracted through Texas Instruments.

September 1997 - 1998, $155,000.

"Advanced Neuroprosthetic Multiple Electrode Arrays Using MEMS Technology"

Lawrence J. Cauller, Principal Investigator

Technology Development and Transfer Grant, Medical Biotechnology

Texas Higher Education Coordinating Board

January 2002 to December 2003, $109,800.

"Neuro-μTransponders: Neural Control for Artificial Arms and Hands"

Lawrence J. Cauller, UTD Principal Investigator

Human Assistive Neural Devices (HAND) Program, Col. Geoff Ling, MD.

Defense Sciences Office (DSO)

Defense Advanced Research Projects Agency (DARPA), Arlington, VA

April 2005 to July 2006, $625,000.

Patents Pending

"System and Method for Interfacing Cellular Matter with a Machine"

Lawrence J. Cauller and Erik Nilsen, co-inventors

US Patent Application 20050137652, published 23 June 2005.

“Groove Electrodes for Interfacing with Peripheral Nerve Fibers”

Lawrence J. Cauller, inventor

Provisional Patent Application, submitted March 2007.

Research Statement

Dr. Cauller has concentrated his research efforts upon the development of novel technology invented to provide a superior alternative neuroprosthesis for the natural sensory-motor integration of artificial prosthetic limbs with the peripheral nerves that originally mediated these functions before amputation. The major advantages of his novel peripheral nerve interface technology include no risk of brain damage, the direct relationship between neuro-muscular signals and limb motor control, and the peripheral stimulation of natural somatic sensations and proprioceptive feedback. His neuro-engineering laboratory has successfully demonstrated the long-term viability of this peripheral nerve interface by stimulating and recording stable sensory-motor fiber activity from implanted animals in some cases for more than 10 months, longer than any previous study. He has recently submitted proposals to the NIH Neuroprosthetics Program to further develop his peripheral nerve technology by training animals to it as a neuroprosthesis for sensory-guided motor control and other commercial applications.

Facilities/Equipment

The facilities where the proposed work will be performed meet environmental laws and regulations of federal, state (Texas), and local Governments for, but not limited to, the following groupings: airborne emissions, waterborne effluents, external radiation levels, outdoor noise, solid and bulk waste disposal practices, and handling and storage of toxic and hazardous materials.

The work will be performed at CroftSoft Inc and the University of Texas at Dallas, both located in the Dallas-Fort Worth metroplex of Texas. The North Texas metroplex provides ready access to universities, a high technology labor pool, and venture capital startup organizations.

Equipment includes high speed personal computers with graphics cards, a programmable iRobot Roomba autonomous vacuum cleaner, and a programmable LEGO Mindstorms NXT robot.

Subcontractors/Consultants

None.

Prior, Current, or Pending Support of Similar Proposals or Awards

None.

THE UNIVERSITY OF TEXAS AT DALLAS

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OFFICE OF SPONSORED PROJECTS

March 20, 2009

David Wallace Croft
President
CroftSoft Inc.
3119 Mayfair Drive
Carrollton, TX 75007-3935

Subject: STTR Letter of Support

Mr. Croft,

The University of Texas at Dallas (UT Dallas) is pleased to submit the following proposal entitled "Incremental Learning for Robot Sensing and Control" under the direction of Dr. Lawrence Cauller. Total budget for UT Dallas' portion of the project is $30,026.

This letter represents UT Dallas' commitment to participate in and accept a subcontract from CroftSoft should the prime STTR proposal be funded. The appropriate programmatic and administrative personnel at UT Dallas are prepared to establish the required agreements consistent with DoD and UT System policy should the prime proposal be funded.

This letter also verifies that UT Dallas has an enforced institutional Policy and Procedure on Conflict of Interest, and that a Financial Disclosure is on file for the investigators involved in this research application.

If you require additional information or assistance in finalizing this proposal, please do not hesitate to contact Amanda Miller, Contracts & Grants Specialist, at area code (972) 883-4575 or via email at amanda.miller@utdallas.edu.

Sincerely,

Rafael Martín
Associate Vice President for Research