Identification and Significance of the Problem or Opportunity

CroftSoft Inc proposes to develop a conceptual bioinspired navigation system for micro air vehicle situation awareness in complex urban terrain. The navigation system will be developed using a neuromimetic flight simulator based on SIEVE, a patent pending invention described in a following subsection.

The solicitation description states:

> The world is populated with a seemingly countless number of tiny machines that exhibit very complicated adaptive behaviors in challenging environments – living creatures. Even very tiny and simple creatures manage to solve the problem of sensing their environment and control of motion and flight in a turbulent atmosphere. They do this with the aid of neural systems that are nearly microscopic. There is more than one reason that this effectiveness is surprising. They perform their information processing with a neural system in which signal propagation speed (1m/s – 100 m/s) and switching times (~ 1 millisecond) are roughly one million times slower than the comparable numbers for a modern silicon based microprocessor. These processing elements are themselves living systems (neurons and associated cells) [...].

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 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 without the necessity of supervised training.

Reverse-engineering biological neuronal network systems is the pathway to developing aircraft, automobiles, and other vehicles that can autonomously learn to navigate and perform obstacle avoidance in real-time based on sensory inputs from the local environment. There are two primary components to the development of this neuromimetic technology: reinforcement learning algorithms for neuronal networks and virtual reality training environments.

A key reinforcement learning algorithm for neuronal networks which CroftSoft Inc 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.

Virtual reality training environments, the other primary component, 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 Neuromimetic Flight Simulator will provide a virtual reality training environment for micro air vehicle navigation systems that is optimized for training spiking neuronal networks using SIEVE.

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

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. Another example is the opening or closing of a pore in response to nerve stimulation. 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.

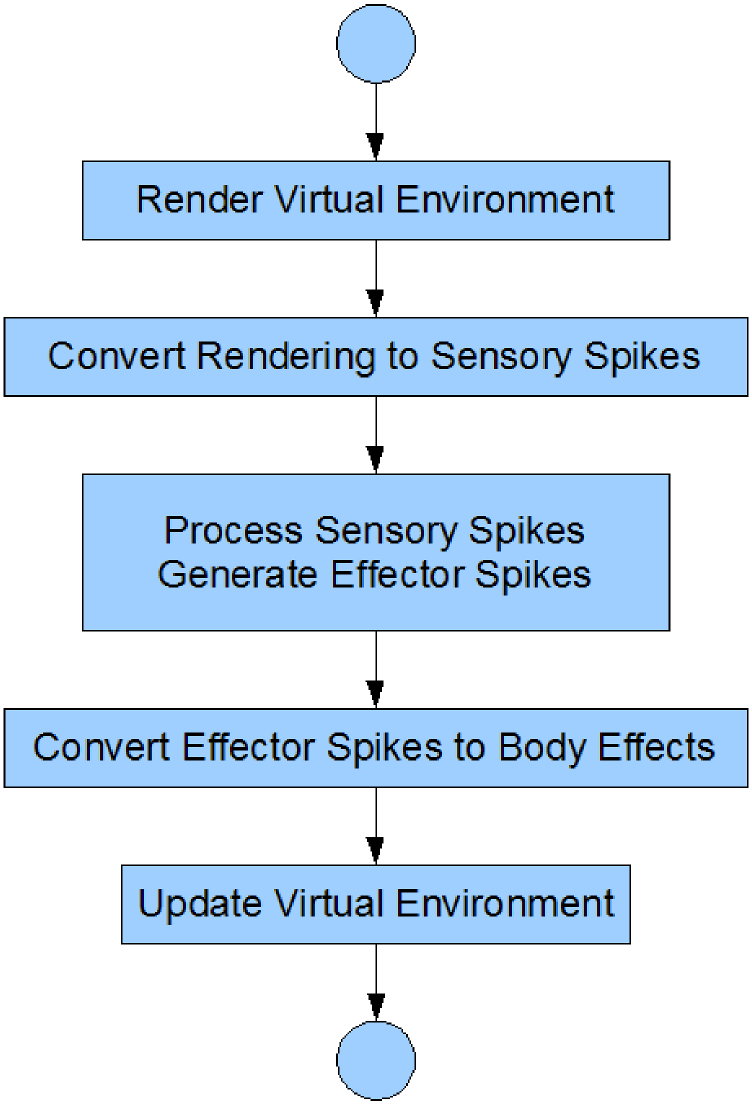

Figure 1: SIEVE loop phases.

Phase I Technical Objectives

The Phase I technical objectives stated in the solicitation are as follows:

- Develop a conceptual bioinspired navigation system for micro air vehicle situation awareness in complex urban terrain.
- Report on the environmental awareness challenges for the system.
- Detail a conceptual design for coping with those challenges.
- Incorporate the design and operation of the sensor and control systems employed by small aerial bio-systems such as hummingbirds and dragonflies.

During the first six months of Phase I, the principal investigator will achieve the following objectives:

- Select one or more micro air vehicle platforms to be used in Phase II. In Phase II, the micro air vehicle platform(s) selected will be modeled in the simulation and then field validated. The criteria for the Phase I selection process will include simulation suitability and commercial availability of the hardware.
- Select sensor and control systems employed by small aerial bio-systems to be used in Phase II. In Phase II, selected sensor and control systems will be modeled in the simulation and integrated into the micro air vehicle platform hardware for field validation. The criteria for the Phase I selection process will include simulation suitability, commercial availability of the hardware, and potential contribution to environmental awareness and maneuvering ability.
- Select training and validation environments to be used in Phase II. In Phase II, virtual environments will be modeled in the training simulation and physical environments will be used for field validation. The criteria for the Phase I selection process will include similarity to urban terrain and coverage of environmental awareness challenges.
- Select bioinspired navigation system architectures and training algorithms. In Phase II, selected architectures and training algorithms will be used to develop a bioinspired navigation system. The criteria for the Phase I selection process will include compatibility with the SIEVE training framework, real-time processing implementation ability, and potential environmental awareness and maneuvering capability.

During the following four months of the transition period option, the principal investigator will verify selections by refining the simulation models. Platforms, systems, environments, and architectures selected for Phase II might be reassessed based on initial implementation attempts and experimentation during the option period.

Phase I Work Plan

The principal investigator will be assigned full-time to the project for an estimated 840 hours during the initial six months and an additional 600 hours during the four month option period. The research will be performed by the principal investigator in the Dallas area.

Month 1

In the first month of Phase I, the principal investigator will select one or more micro air vehicle platforms to be used in Phase II. The principal investigator will develop a model of the selected platform(s) for simulation in the SIEVE framework.

Month 2

In the second month, the principal investigator will select sensor and control systems employed by small aerial bio-systems to be used in Phase II. The principal investigator will develop models of the selected sensor and control systems for simulation in the SIEVE framework.

Month 3

In the third month, the principal investigator will select training and validation environments to be used in Phase II. The principal investigator will develop a model of a virtual training environment for simulation in the SIEVE framework.

Months 4, 5, and 6

In the final half of Phase I, the principal investigator will select bioinspired navigation system architectures and training algorithms. The principal investigator will simulate the selected architecture and training algorithms in the SIEVE framework with the platform, systems, and virtual training environment developed in the first three months. The principal investigator will also finalize and submit the Phase I report including the trade-off study analyses for the platform, systems, environments, and architectures considered and the modeling and simulation results.

Option Period

The models of the platform(s), systems, virtual training environment, and architecture developed in Phase I will be incomplete. During the four month option period, the principal investigator will refine the models to increase their reliability in predicting the actual characteristics experienced during field validation during Phase II. The principal investigator may reassess selected options and consider secondary alternatives.

Related Work

Related work by the principal investigator is described in the Key Personnel section.

Micro Air Vehicle Platforms

A collaboration between BioRobots LLC, Case Western Reserve University, the University of Florida, and the Naval Post Graduate School describes the use morphing micro air-land vehicles (MMALVs) which combines micro air vehicles with wheel-legs ("whegs").[2] The Honeywell Micro Air Vechicle (MAV) is available as a Class I Unmanned Aerial Vehicle (UAV) for military applications.[3] Both the MMALVs and the Honeywell MAVs will be included in the micro air vehicle trade-off study. The Neuromimetic Flight Simulator will be designed to be used with multiple micro air vehicle platforms.

Bioinspired Architectures

Chao, Bakkum, and Potter recently published a paper entitled "Shaping Embodied Neural Networks for Adaptive Goal-directed Behavior".[4] Using a biologically realistic simulation of spiking neurons and the spike timing dependent plasticity (STDP) learning algorithm, they demonstrated the ability to train the neuronal network to move an animat (artificial animal) toward a target. Both the input and the output were in the form of simulated spikes. This is a potential candidate architecture for the trade-off study of Phase I.

Vaidyanathan, et al., describe a biomimetic neural network system for UAV collision avoidance. This is available from BioRobots LLC as the Micro Air Vehicle Intelligent Context-dependent (MAVIC) collision avoidance system which includes "[d]evelopment of MAV simulation model for MAVIC system testing, neural network training".[5] The Phase I bioinspired architectures trade-off study might identify an opportunity to integrate the SIEVE-based Neuromimetic Flight Simulator with the BioRobots MAVIC system for collaborative commercialization.

Michael Dickinson of the California Institute of Technology (Caltech) is a neurobiologist who studies the mechanics of fruit fly flight. Dickinson uses a virtual reality flight simulator to determine the responses of fruit flies to visual stimuli.[6] His laboratory has published 60+ papers that would be relevant to the development of a neuromimetic flight simulator.[7] In addition to a visual flight simulator for flies, his laboratory has developed an olfactory flight simulator. A SIEVE-based flight simulator would use the same interface for integrating input from visual, olfactory, and auditory sensory stimuli.

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[2] Bachmann, et al., "Utility of a Sensor Platform Capable of Aerial and Terrestrial Locomotion", Proceedings of the 2005 IEEE/ASME International Conference on Advanced Intelligent Mechatronics Monterey, California, USA, 24-28 July, 2005. Available from http://biorobots.cwru.edu/projects/mmalvweb/.

[3] Crane D, "Micro Air Vehicle: Backpackable UAV for Tactical Reconnaissance & Surveillance", http://www.defensereview.com/modules.php?name=News&file=article&sid=811.

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

[5] Vaidyanathan, et al., "An insect-inspired targeting/evasion reflex for autonomous air vehicles". See links at http://faculty.nps.edu/ravi/Bio_insp_control/Projects.htm.

[6] Caltech Media Relations, "Fly Flight Simulators Reveal Secrets of Decision Making", 2008 March 25, http://mr.caltech.edu/media/Press_Releases/PR13122.html

[7] http://www.dickinson.caltech.edu/Research/Publications

Relationship with Future Research or Research and Development

As stated in the solicitation:

> The primary Phase II products will be a detailed design, simulation, and prototype for the bioinspired autonomous situation awareness and navigation system. The design and prototype will mitigate or solve the problems of the micro-aerial system operating autonomously in a complex domain. Those problems include avoidance of obstacles, maneuver in a crowded urban air space with complex atmospheric flows, and the ability to cope with other hazards of the urban battlefield environment.

Phase I of the Neuromimetic Flight Simulator project will provide a foundation for Phase II research and development by selecting the micro air vehicle platform(s), sensors and control systems, virtual and field test environments, and the bioinspired navigation system architectures and training algorithms as documented in trade-off study analyses included in the Phase I report. This will provide a basis for the estimated material and manpower required in the Phase II proposal in order to move from concept to implementation.

Commercialization Strategy

As stated in the solicitation:

> The technologies developed in phases I and II are immediately applicable to small autonomous military systems, and should be readily commercializable for such applications. In addition, the same technologies are relevant to many or most of the other autonomous and semi-autonomous systems now under development for applications such as hazard inspection and disaster recovery, patrol of communication and transport routes, and surveillance, policing, and protection.

The principal investigator has filed a provisional patent application on the proprietary technology SIEVE, described in a previous section, to ensure a sustainable competitive advantage. The CroftSoft SIEVE framework will be licensed to DoD, other Federal Agencies, and private sector markets. The Neuromimetic Flight Simulator, including simulation models, will be sold separately as an optional configuration package for the SIEVE framework. Licensees will also be offered a support option.

CroftSoft will resell and support micro air vehicles configured with the sensors, controls, and bioinspired navigation system selected and developed during Phases I and II. CroftSoft will also license the patent for SIEVE for embedding in third-party micro air vehicles and other autonomous robots. Third-party micro air vehicle developers will license the Neuromimetic Flight Simulator in order to train and test their own variants of the bioinspired navigation system.

The following will be commercialized:

- CroftSoft SIEVE framework, the neuromimetic simulation engine
- CroftSoft SIEVE framework support and documentation
- Neuromimetic Flight Simulator configuration package including simulation models
- SIEVE Bioinspired Navigation System
- Micro air vehicles with the SIEVE Bioinspired Navigation System pre-installed
- Micro air vehicle support and documentation
- Patent licenses for embedding SIEVE in third party micro air vehicles
- Patent licenses for embedding SIEVE in other autonomous robots

The first product to be commercialized will be the CroftSoft SIEVE framework and the Neuromimetic Flight Simulator toward the middle of Phase II. Resell of micro air vehicles with SIEVE pre-installed will begin toward the end of Phase II. Commercialization of SIEVE in third party micro air vehicles and other autonomous robots will commence in Phase III.

If the technology can be successfully transferred to other autonomous robots such as passenger vehicles including automobiles, aircraft, and ships, the potentially substantial market size warrants investment. Key risk factors include technological success and the ability to secure relevant patents.

Key Personnel

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 2). 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[8].

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"[9]. 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[10]. 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 environment (Figure 3). Event messages generated by movements controlled by the students in the

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[8] http://www.CroftSoft.com/library/software/newt/

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

[10] http://croftsoft.com:8080/space/

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 4). 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

- Fundamentals of Aerodynamics, United States Air Force Academy (semester course)
- Neuromorphic Engineering Workshop, Third Annual (1996, 3 weeks)
- Flight Test Engineering Short Course, National Test Pilot School

Associations

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

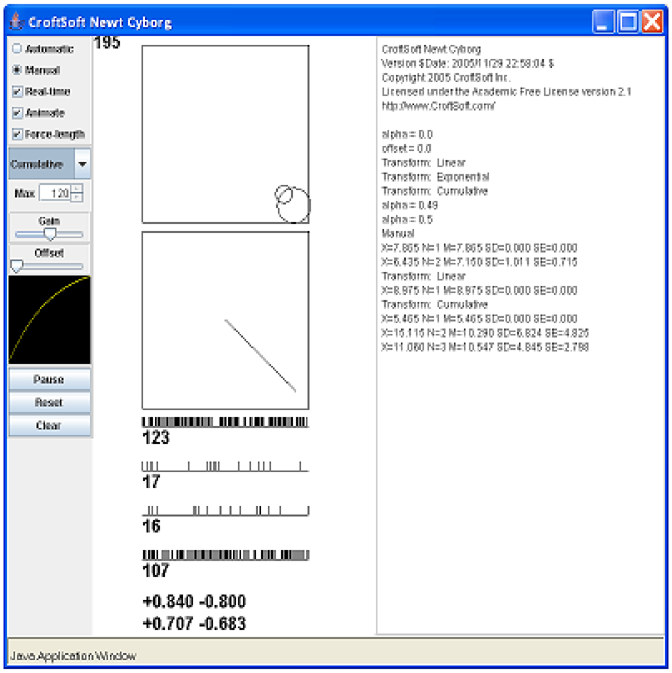
Honors and Awards

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



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☑ Real-time
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☑ Force-length
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Gain
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CroftSoft Newt Cyborg
Version $Date: 2005/11/29 22:58:04 $
Copyright 2005 CroftSoft Inc.
Licensed under the Academic Free License version 2.1
http://www.CroftSoft.com/

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Transform: Exponential
Transform: Cumulative
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Transform: Cumulative
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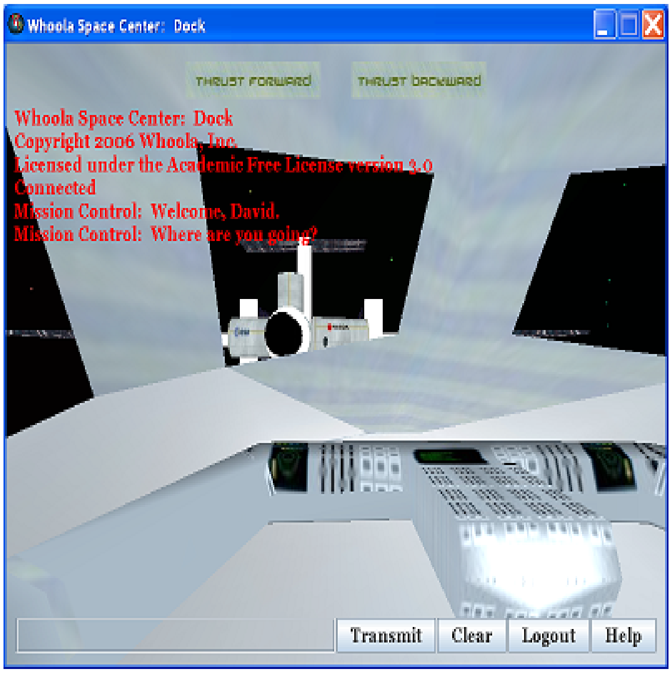
Figure 2: CroftSoft Newt Cyborg.



```
Whoola Space Center: Dock
Copyright 2006 Whoola, Inc.
Licensed under the Academic Free License version 3.0
Connected
Mission Control: Welcome, David.
Mission Control: Where are you going?
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Figure 3: Whoola Dock.

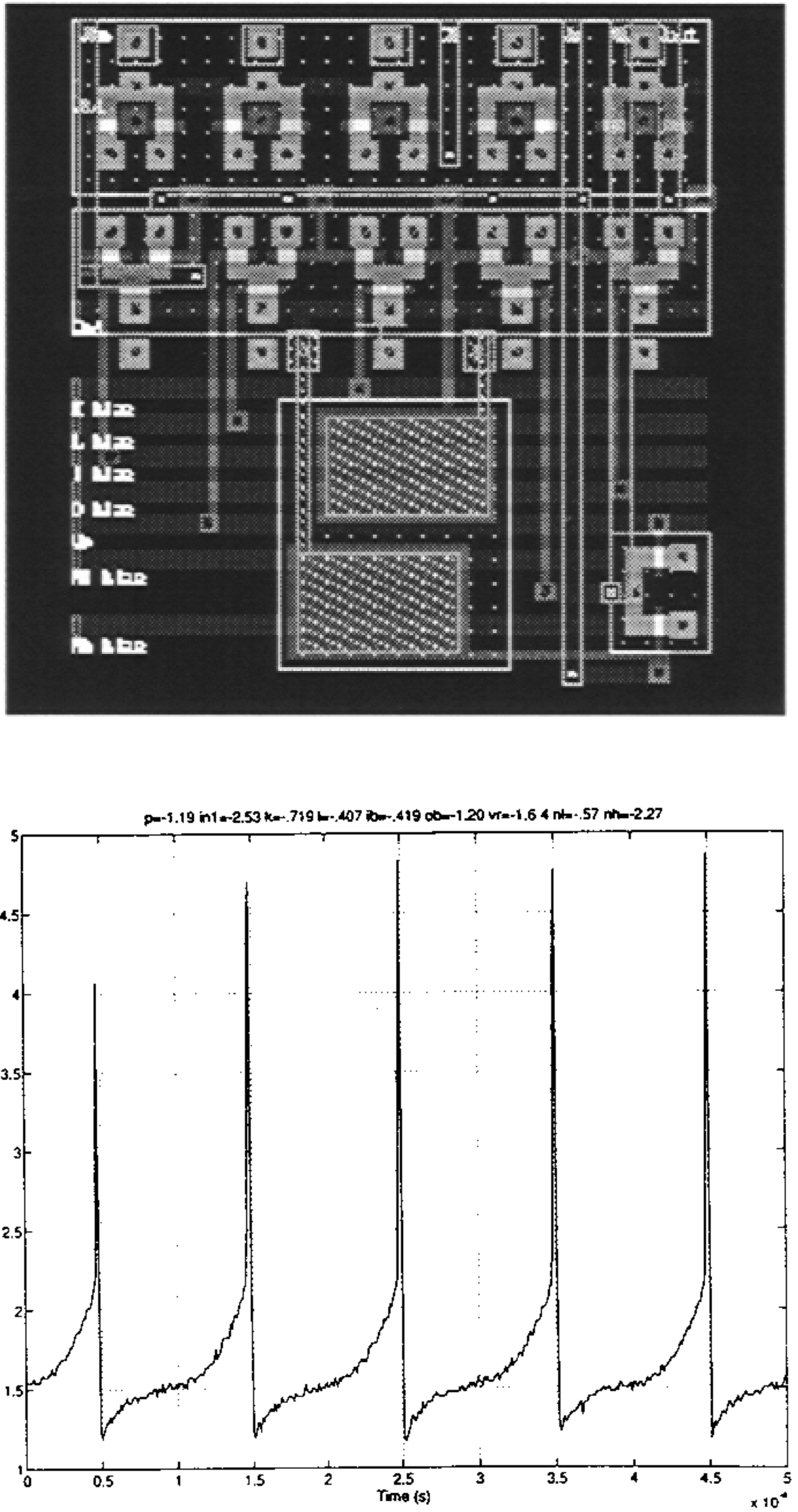

Figure 4: Neuromorphic VLSI for STDP.

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 in Carrollton, a city within 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.