

# CHARLES M. HIGGINS

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## EDUCATION

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- Postdoctoral Research Fellow** (Advisor: Christof Koch) March 1996-July 1999  
*Division of Biology, California Institute of Technology (Caltech) - Pasadena, CA*
- PhD, Electrical/Computer Engineering** June 1993  
*California Institute of Technology - Pasadena, CA*
- MS (Summa Cum Laude), Electrical/Computer Engineering** June 1989  
*Georgia Institute of Technology (Georgia Tech) - Atlanta, GA*
- BS (with honors), Electrical/Computer Engineering** June 1987  
*Louisiana State University - Baton Rouge, LA*
- Queen Mary College, University of London, England** January-July 1986  
*LSU Study Abroad Program*

## ACADEMIC EXPERIENCE

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- Associate Professor**, Department of Neuroscience, *University of Arizona* December 2009-Present
- Associate Professor (with tenure)**, Electrical Engineering / Neurobiology May 2005-December 2009
- Assistant Professor**, ARL Division of Neurobiology May 2001-May 2005
- Assistant Professor**, Electrical and Computer Engineering July 1999-May 2005
- Member, Neuroscience Graduate Program*
- Member, Biomedical Engineering Program*
- Member, Center for Insect Science*

My laboratory focuses on research in the area of biologically-inspired vision and robotic systems: applying a knowledge of neurobiology to the creation of inexpensive, agile, highly capable robotic sensory and motor control systems. This research extends from modeling and simulation of neural systems through the design of analog and mixed-signal VLSI hardware implementations and intelligent autonomous robots, including those which incorporate both electronic components and living insect brains. Insect vision, and in particular visual motion, has provided a source of inspiration for this research for many years. As laboratory experience in electrophysiology has grown in recent years, my lab's research has extended to a study of human sleep and neurofeedback using a custom-built EEG device.

- Visiting Faculty Member**, *University of Adelaide, Australia.* August-September 2006  
*Discipline of Physiology, School of Molecular and Biomedical Sciences (O'Carroll laboratory).*

During this sabbatical trip, I trained in insect visual electrophysiology, which enabled the courses NROS 215 and NROS 415 that I currently teach.

- Visiting Fellow**, Centre for Visual Sciences, *Australian National University* June-July 2001  
*Research School of Biological Sciences, Institute of Advanced Studies (Srinivasan laboratory).*

I spent this 'mini-sabbatical' in a renowned center for insect visual neuroscience learning about behavioral studies on bees and studying computational methods.

- Postdoctoral Research Fellow**, Division of Biology, *Caltech* March 1996-July 1999

The dual goals of this research were developing biologically-inspired solutions to vision problems of engineering interest, and using VLSI as a high-speed biological modeling substrate. Designed analog VLSI chips for visual motion processing based on models of primate visual cortex.

- Research Assistant**, Department of Electrical Engineering, *Caltech* September 1989-September 1993  
*Doctoral Dissertation: **Classification and Approximation with Rule-Based Networks***  
*Advisor: Rodney M. Goodman*

The goal of this research was to integrate a rule-based knowledge representation with the parallelism and layered structure of artificial neural networks to achieve a learning system which operated with the speed and simplicity of a neural network, but the conclusions of which could be explained in terms of conjunctive rules.

**Research Assistant**, Department of Electrical Engineering, *Georgia Tech* September 1987-September 1989  
*Master's Research: A Load-Adaptive Scheduler for Hard Real-Time Multiprocessor Operating Systems*  
*Advisor: Karsten Schwan*

This research extended an existing operating system scheduler for hard real-time multiprocessor systems to obtain improved high-load performance by allowing the scheduler to choose between several code modules (with varying runtimes) for each periodic task.

## INDUSTRIAL EXPERIENCE

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**Consultant**, *Areté Associates*, Tucson, AZ 2009-2011

Provided expertise on insect-inspired visual navigation, including theoretical analyses and detailed simulations of obstacle avoidance and target interception scenarios.

**Consultant**, *Physical Sciences, Inc.*, Andover, MA 2002-2003

Performed simulations of biologically-inspired low-level motion detection.

**Consultant**, *Computational Sensors Corporation*, Santa Barbara, CA 2000-2002

Provided technical advice, theoretical analysis, simulations, and expertise in the area of spatiotemporal frequency based visual motion algorithms for application to missile defense.

**Staff Member**, *MIT Lincoln Laboratory*, Lexington, MA September 1993-March 1996

Analyzed radar data collected with the Airborne Seeker Testbed (ASTB), a highly instrumented airborne radar platform which takes the part of a missile in simulated combat encounters. Specialized in super-resolution algorithms. Designed, coded, developed, and flight-tested a real-time ECCM processor for the testbed. Held a top secret clearance and worked on special programs.

**Programming Consultant**, Pasadena, CA (with partner R.M. Goodman) January 1992-June 1993

Designed, coded, developed and maintained rule-based software to provide a trader with real-time buy/sell suggestions for the S&P 500 index. Trading autonomously via a satellite link, the system made a consistent (but small) profit.

**Technical Staff Member**, *IBM Cambridge Scientific Center*, Cambridge, MA Summers 1987-1990

Developed simulation code for a message-passing parallel computer system including a low-level hardware simulation and a high-level operational simulation. Designed digital hardware for VLSI implementation of a message-passing parallel computer routing algorithm. Participated in the design of a new highly adaptive and fault-tolerant routing system for a message-passing parallel computer. A U.S. patent was awarded for this work. Designed digital hardware for a high-speed interface card to link the new IBM PS/2 with an IBM 370 architecture mainframe.

## HONORS

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**Innovation in Teaching Award**, UA College of Science 2014

**Invited "Nifty Fifty" speaker** 2013, 2014, 2015, 2016  
 USA Science and Engineering Festival, Washington DC

**Invited speaker**, TEDxTucson 2013

**Award for Excellence at the Student Interface** 2000, 2002, 2003, 2009  
 University of Arizona College of Engineering

**Leading Edge Researcher Award**, UA Innovation Day March 2008

**da Vinci Circle Fellow**, UA College of Engineering October 2005

**Senior Member**, Institute of Electrical and Electronic Engineers May 2004

**Outstanding Faculty Member Award** 2001  
 University of Arizona Disability Resource Center

**SELECTED SERVICE ACTIVITIES** 

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- **Creator and Chair**, Faculty Senate *Committee on Information Technology*, 2012-2015
- **Chair**, Faculty Senate *Research Policy Committee*, 2010-2015 (member since 2007)
- **Member**, Faculty Senate Executive Committee, 2010-2015
- **Member**, Center for Insect Science Executive Committee, 2010-Present
- **Chair**, Electrical/Computer Eng. Peer Review Committee, 2008-2010
- **Faculty Senator** (elected), U. Arizona, April 2009-2015
- **Chair**, U. Arizona ECE Graduate Recruiting and Awards Committee, 2005-2008
- **Invited tutorial lecturer**, Telluride Workshop on Neuromorphic Engineering 1997-2010

**SELECTED MEDIA COVERAGE** 

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1. "Engaging With the Sci-Tech of Self/Lesss Sci-Fi" by By Susan Karlin, *IEEE Spectrum*, July 23, 2015.
2. "'Self/less' returns to movie immortality" by Brian Truitt, *USA TODAY*, July 7, 2015.
3. "Will mind transfer ever happen?", by Erik Sofge, *Popular Science*, July 2015.
4. "RoboCop Tech: Science Fact and Fiction," by Nic Halverson, *Discovery Channel News*, Feb. 11, 2014.
5. "We're About 100 Years Away From a Real RoboCop," by Angela Watercutter, *Wired News*, Feb. 12, 2014.
6. "You Have Already Complied: RoboCop And The All-Too-Feasible Horror Of Brain Hacking," by Erik Sofge, *Popular Science News*, February 12, 2014.
7. "When Do I Get My RoboCop? Power before Superpowers," by Patrick Tucker, *The Futurist Magazine*, volume 48, number 2, February 2014.
8. "RoboCop: When Will Cyborgs Walk Among Humans?" by Denise Chow, *LiveScience News*, February 11, 2014.
9. Guest on Michio Kaku's radio show "Science Fantastic," February 2014.
10. "TED Talk analyzes sleep patterns," by Zane Johnson, *The Daily Wildcat*, September 26, 2013.
11. "The science of Sony's 'Elysium': This is your brain on robotics," by John R. Quain, Fox News, August 9, 2013.
12. "How Long until We Have the Superhuman Exoskeletons from Elysium? A roboticist-neuroscientist explains," by David Biello, *Scientific American Magazine*, Aug 7, 2013.
13. "Researchers study bee brains to develop flying robots," by Sharon Gaudin, *Computer World*, October 2, 2012.
14. "The Neuroscience of 'Source Code': Mind Your Brain, Soldier," by Valerie Ross, *Discover Magazine*, April 6, 2011.
15. "'Limitless' and 'Source Code' science not as outlandish as you'd think," by Patrick Kevin Day, *Los Angeles Times*, April 1, 2011.
16. "Living insects become 'eyes' for robots," by Charles M. Higgins, *Arizona Daily Star* (special supplement), November 14, 2010.
17. "The fly who bugged me," by Jessica Marshall, *New Scientist*, March 8, 2008.
18. Radio Interview on '*Fair Game*' from *Public Radio International* with Faith Salie, December 3, 2007.
19. "Scientists put moth on wheels and let the robotic times roll", by Denise Gellene, *Los Angeles Times*, November 7, 2007.
20. "Moth-based robot may lead to 'hybrid' computers," by Sharon Gaudin, *Computer World*, December 10, 2007.
21. "Flight of the Insecti-Blimp," Daily Planet television show, *The Discovery Channel*, December 15, 2004.

**PATENTS** 

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1. C. Higgins (for the University of Arizona), *Systems and Methods for Monitoring Brain Activity, Providing Neurofeedback, and Determining Sleep Quality*, U.S. patent application 61/900213, filed November 5, 2014.
2. A. Frey, J. Gould, and C. Higgins (for IBM Corporation), *Adaptive Routing in a Parallel Computing System*, U.S. patent number 5181017, January 1990.

## PUBLICATIONS

## JOURNAL ARTICLES

1. V. Pant and C. Higgins, "Tracking improves performance of biological collision avoidance models," *Biological Cybernetics* 106(4): 307-322, 2012.
2. Z. Rivera-Alvidrez, I. Lin, and C. Higgins, "A Neuronally-Based Model of Contrast Gain Adaptation in Fly Motion Vision," *Visual Neuroscience* 28(5): 419-431, 2011.
3. J. Dyhr and C. Higgins, "Non-directional motion detectors can be used to mimic optic flow dependent behaviors," *Biological Cybernetics* 103: 433-446, 2010.
4. J. Dyhr and C. Higgins, "The spatial frequency tuning of optic flow dependent behaviors in the bumblebee *Bombus impatiens*," *Journal of Experimental Biology* 213 (10): 1643-50, May 2010.
5. E. Ozalevli, P. Hasler, and C. Higgins, "Winner-Take-All based Visual Motion Sensors," *IEEE Transactions on Circuits and Systems II*, vol. 53, no. 8, pp. 717-721, 2006.
6. T. Melano and C. Higgins, "The neuronal basis of direction selectivity in lobula plate tangential cells," *Neurocomputing* 65-66, pp 153-159, 2005.
7. Z. Rivera-Alvidrez and C. Higgins, "Contrast saturation in a neuronally-based model of elementary motion detection," *Neurocomputing* 65-66, pp. 173-179, 2005.
8. C. Higgins, V. Pant, and R. Deutschmann, "Analog VLSI implementation of spatio-temporal frequency tuned visual motion algorithms," *IEEE Transactions on Circuits and Systems I*, vol 52, no. 3, pp. 489-502, March 2005.
9. E. Ozalevli and C. Higgins, "Reconfigurable Biologically-Inspired Visual Motion Systems using Modular Neuromorphic VLSI chips," *IEEE Transactions on Circuits and Systems I*, vol. 52, no. 1, pp 79-92, January 2005.
10. C. Higgins and V. Pant, "A biomimetic VLSI sensor for visual tracking of small moving targets," *IEEE Transactions on Circuits and Systems I*, Vol. 51, No. 12, pp. 2384-2394, December 2004.
11. C. Higgins and V. Pant, "An elaborated model of fly small target tracking," *Biological Cybernetics*, vol. 91, no. 5, pp. 326-332, November 2004.
12. C. Higgins, "Non-directional motion may underlie insect behavioural use of image speed," *Biological Cybernetics*, vol. 91, no. 5, pp. 326-332, November 2004.
13. C. Higgins, J. Douglass, and N. Strausfeld, "The computational basis of an identified neuronal circuit for elementary motion detection in dipterous insects," *Visual Neuroscience*, vol. 21, no. 4, pp. 567-586, July 2004.
14. C. Higgins, and S. Shams, "A Biologically-Inspired Modular VLSI System for Visual Measurement of Self-Motion," *IEEE Sensors Journal* special issue on Integrated Multi-Sensor Systems and Signal Processing, 2(6), pp. 508-528, December 2002.
15. C. Higgins, "Sensory architectures for biologically-inspired autonomous robotics," *The Biological Bulletin*, pp. 235-242, April 2001.
16. C. Higgins and C. Koch, "A Modular Multi-Chip Neuromorphic Architecture for Real-Time Visual Motion Processing," *Analog Integrated Circuits and Signal Processing*, 24(3), pp. 195-211, September 2000.
17. C. Higgins, R. Deutschmann, and C. Koch, "Pulse-Based 2D Motion Sensors," *IEEE Transactions on Circuits and Systems II*, 46(6), 677-687, June 1999.
18. C. Higgins and R. Goodman, "Fuzzy Rule-Based Networks for Control," *IEEE Transactions on Fuzzy Systems*, vol. 2, no. 1, February 1994.
19. R. Goodman, C. Higgins, J. Miller, and P. Smyth, "Rule-Based Networks for Classification and Probability Estimation," *Neural Computation*, vol. 4, no. 6, November 1992.

## BOOK CHAPTERS

1. N. J. Strausfeld, J. K. Douglass, H. Campbell, and C. Higgins, "Parallel Processing in the Optic Lobes of Flies and the occurrence of motion computing circuits," pages 349-398 in *Invertebrate Vision*, Eric Warrant and Dan-Eric Nilsson, Editors, Cambridge University Press, 2006.

## CONFERENCE PUBLICATIONS

1. T. Pham, and C. Higgins, "A visual motion detecting module for dragonfly-controlled robots," Proceedings of the Annual International Conference of the Engineering in Medicine and Biology Society (EMBC) 2014, pp.1666-1669, Aug. 2014.
2. V. Pant and C. Higgins, "A Biomimetic Focal Plane Speed Computation Architecture," in Proceedings of the Computational Optical Sensing and Imaging (COSI) conference, Vancouver, BC, Canada, June 18-20, 2007.
3. L. Johnson and C. Higgins, "A Navigation Aid for the Blind Using Tactile-Visual Sensory Substitution," in Proceedings the 28th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC '06), pp 6298-6292, New York, NY, USA, 2006.
4. V. Pant and C. Higgins, "A Biomimetic VLSI Architecture for Small Target Tracking," in Proceedings of the International Symposium on Circuits and Systems (ISCAS '04), Vancouver, BC, Canada, 2004.
5. E. Ozalevli and C. Higgins, "Multi-Chip Implementation of a Biomimetic VLSI Vision Sensor Based on the Adelson-Bergen Algorithm," International Conference on Artificial Neural Networks, Istanbul, TURKEY, June 26-29, 2003.
6. C. Higgins, "Information Fusion in the Dipteran Flight Navigation System," Proceedings of the NASA/ONR conference *Combating Uncertainty with Fusion*, the Marine Biological Laboratory, Woods Hole, MA, April 2002.
7. C. Higgins, T. Vaneck, P. Joshi, and N. J. Strausfeld, "A Model for Directional Selectivity in an Insect based on Non-directional Motion Cells and Appropriate to Cross Phyla Comparisons," Society for Neuroscience annual meeting 2001.
8. Charles M. Higgins, "A Computational Model of Dipteran Elementary Motion Detection," (abstract) in Proceedings of the International Conference on Invertebrate Vision, Bäckaskog Castle, Sweden, August 7-12, 2001.
9. C. Higgins and S. A. Shams, "A Neuromorphic Vision Processor for Spatial Integration of Optical Flow," the *Fifth International Conference on Cognitive and Neural Systems*, Boston, MA, June 2001.
10. C. Higgins and S. Korrapati, "An Analog VLSI Motion Energy Sensor Based on the Adelson-Bergen Algorithm," in Proceedings of the *International ICSC Symposium on Biologically-Inspired Systems*, Wollongong, Australia, December 12-15, 2000.
11. C. Higgins, "Sensory Architectures for Biologically-Inspired Autonomous Robotics," Proceedings of the NASA/ONR conference *Invertebrate Sensory Information Processing: Implications for Biologically-Inspired Autonomous Systems*, the Marine Biological Laboratory, Woods Hole, MA, April 2000.
12. C. Higgins and C. Koch, "Multi-Chip Neuromorphic Motion Processing," *the 1999 Conference on Advanced Research in VLSI*, Atlanta, GA.
13. C. Higgins and C. Koch, "An integrated vision sensor for the computation of optical flow singular points," *Advances in Neural Information Processing Systems 11*, MIT Press, Denver, CO, 1999.
14. R. Deutschmann, C. Higgins, and C. Koch, "Real-Time Analog VLSI Sensors for 2-D Direction of Motion," *Proceedings of ICANN'97*, Lausanne, Switzerland, October 1997.
15. R. Deutschmann, C. Higgins, and C. Koch, "Neuromorphic Analog VLSI Sensors for 2-D Direction of Motion," *Proc. of the 4th Joint Symposium on Neural Computation*, University of Southern California, Los Angeles, CA, 1997.
16. C. Higgins and C. Koch, "Analog CMOS Velocity Sensors," *Proceedings of Electronic Imaging '97* (SPIE volume 3019), San Jose, CA, February 1997.
17. R. Goodman and C. Higgins, "Learning Fuzzy Rule-Based Neural Networks for Control," *Advances in Neural Information Processing Systems 5*, Morgan Kaufmann: San Mateo, CA, 1993.
18. C. Higgins and R. Goodman, "Incremental Learning with Rule-Based Neural Networks," *Proceedings of the International Joint Conference on Neural Networks*, Seattle, WA, vol. 1, 875-80, July 1991.
19. R. Goodman and C. Higgins, "Incremental Rule-Based Learning," *Proceedings of 1991 IEEE International Symposium on Information Theory*, Budapest, Hungary, June 23-28, 1991.
20. R. Goodman, C. Higgins, J. Miller and P. Smyth, "A Rule-Based Approach to Neural Network Classifiers," *Proceedings of INNC 90 Paris*, Palais Des Congres, Paris, France, July 9-13, 1990.
21. R. Goodman, C. Higgins and P. Smyth, "A Hybrid Rule-Based/Bayesian Classifier," *Proceedings of the European Conference on Artificial Intelligence*, December 14, 1989.

*DISSERTATIONS / THESES*

1. T. Pham, "A real-time neural signal processing system for dragonflies", MS thesis, Program in Electrical Engineering, The University of Arizona, December 2011.
2. T. Melano, "Insect-Machine Interfacing", PhD dissertation, Program in Biomedical Engineering, The University of Arizona, January 2011.
3. I. Lin, "A Biologically Realistic Model of Fly Elementary Motion Detection," MS thesis, Department of Electrical and Computer Engineering, The University of Arizona, June 2010.
4. J. Dyrh, "Behavioral and theoretical evidence that non-directional motion detectors underlie the visual estimation of speed in insects," PhD dissertation, Program in Neuroscience, The University of Arizona, December 2009.
5. V. Pant, "Biomimetic Visual Navigation Architectures for Autonomous Intelligent Systems," PhD Dissertation, Department of Electrical and Computer Engineering, *The University of Arizona*, November 2007.
6. L. Ortiz, "A Mobile Electrophysiology Board for Autonomous Biorobotics," MS thesis, Department of Electrical and Computer Engineering, *The University of Arizona*, December 2006.
7. A. Muthu-Natarajan, "Adaptive Spatio-Temporal Filters for Infrared Target Detection," MS thesis, Department of Electrical and Computer Engineering, *The University of Arizona*, November 2005.
8. Z. Rivera-Alvidrez, "Computational modeling of neurons involved in fly motion detection," MS thesis, Department of Electrical and Computer Engineering, *The University of Arizona*, August 2005.
9. C. V. Anderson, "Estimation of muscle activity using probability density functions and Bayes' theorem," MS thesis, Department of Electrical and Computer Engineering, *The University of Arizona*, April 2004.
10. V. Pant, "Modular Neuromorphic VLSI Architectures for Visual Motion and Target Tracking," MS thesis, Department of Electrical and Computer Engineering, *The University of Arizona*, June 2003.
11. E. Ozalevli, "Analog VLSI Implementations of Visual Motion Sensors and a Neuromorphic Obstacle Avoidance System," MS thesis, Department of Electrical and Computer Engineering, *The University of Arizona*, May 2003.
12. S. Korrapati, "An Analog VLSI Motion Energy Sensor and its Applications in System Level Robotic Design," MS thesis, Department of Electrical and Computer Engineering, *The University of Arizona*, August 2001.

**SELECTED INVITED TALKS**

1. "Insect-inspired visual navigation and object-level processing," at the *Bio-inspired Unmanned Aerial Systems/State of the Art (BioUAS SOAR5) meeting*, May 2014.
2. "Chronic Monitoring of Human Sleep," *TEDxTucson talk*, September 2013.
3. "A computational architecture for cognition," *U. Arizona Center for Insect Science Hexapodium*, November 2011.
4. "Visual speed estimation in bees", Air Force Research Laboratory *Topical Meeting on Biologically-Inspired Guidance, Navigation and Control*, Eglin AFB, May 2011.
5. "Interfacing insect brains to mobile robots," *International Conference on Invertebrate Vision*, Backaskög Castle, Sweden, August 2008.
6. "Reverse-Engineering the Fly," *Neuromorphic Cognition Engineering Workshop*, Telluride, CO, July 2008.
7. "Interfacing Living Sensory Systems to Mobile Robots," *Caltech Department of Electrical Engineering Seminar Series*, May 2008.
8. "From bio-inspired to bio-electronic neuromorphic systems," US intelligence community *Workshop on Neuromorphic Computing*, Washington, DC, April 2008.
9. "Interfacing Living Neuronal Systems to Robotic Devices," *Joint Workshop on Computational Neuroscience*, Adelaide, SA, Australia, December 2007.
10. "Reverse-Engineering the Fly: An Engineer's Approach to the Fly Visual System," *Telluride Neuromorphic Engineering Workshop*, July 2007.
11. "A Neuronal Model of Insect Visual Motion Processing," HHMI Janelia Farms Research Campus *Visual Processing Workshop*, Washington, DC, May 2007.
12. "Simpler Nervous Systems," National Geophysical Intelligence Agency (NGA) *Neuroscience-Enabled Computer Vision Workshop*, Washington, DC, February 2007.

13. "Insect Visual Navigation: From Computational Models to Biorobotics," *Australian National University, Center for Visual Sciences*, Canberra, ACT, Australia, September 2006.
14. "Insect-Inspired Visual Navigation Algorithms and Robotic Implementations," *Gordon Research Conference on Neuroethology*, Magdalen College, Oxford University, Oxford, England, August 2005.
15. "Visual tracking of small targets by the fly: modeling and applications", *Insect Sensors and Robotics Workshop* (invitation only), Brisbane, Australia, 23-26 August 2004.
16. "Visual target tracking based on fly FD cells," invited tutorial at the *Telluride Workshop on Neuromorphic Engineering*, Telluride, CO, July 2004.
17. "Biomimetic Visual Navigation," *Robotics Institute, Carnegie Mellon University*, May 2003.
18. "Information Fusion in the Dipteran Flight Navigation System," NASA/ONR conference entitled *Combating Uncertainty with Fusion*, the Marine Biological Laboratory, Woods Hole, MA, April 2002.
19. "Analysis of Insect Visual Motion Processing and its Application to a Biomimetic Navigation and Tracking System," *Naval Air Warfare Center – Weapons Division*, China Lake, CA, December 2001.
20. "Biomimetic VLSI Architectures for Real-time Visual Motion Processing," *Research School of Biological Sciences, Australian National University*, Canberra, Australia, December 2000.
21. "Vision Architectures for Biomimetic Autonomous Robotics," *Telluride Workshop on Neuromorphic Engineering*, Telluride, CO, July 2000.
22. "Sensory Architectures for Biologically-Inspired Autonomous Robotics," NASA/ONR conference entitled *Invertebrate Sensory Information Processing: Implications for Biologically-Inspired Autonomous Systems*, the Marine Biological Laboratory, Woods Hole, MA, April 2000.
23. "Neuromorphic Vision Systems: Inspiration for VLSI from Neurobiology," *Physical Sciences Incorporated*, Andover, MA, March 2000.
24. "Neuromorphic Vision Systems," *IEEE Northern California LEOS Society* meeting, Santa Clara, CA, January 1999.

**PERSONAL INTERESTS** 

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Tang Soo Do (second degree black belt), guitar, swing dancing, trail running.