

## **DANA H. BALLARD**

Born: October 15, 1946

Nationality: United States of America

### **GOOGLE SCHOLAR CITATIONS:**

<http://scholar.google.com/citations?user=67aYFTQAAAAJ>

### **NEUROTREE**

<https://neurotree.org/neurotree/tree.php?pid=792>

A list of neuroscience-oriented students and postdocs that I have supervised

### **EDUCATION:**

B.S., Aeronautics & Astronautics, Massachusetts Inst. of Technology (1967)

M.S., Information & Control Engineering, Michigan (1970)

Ph.D., Information Engineering, U. California at Irvine (1974)

### **PERSONAL STATEMENT**

My PhD research focused on biomedical image processing but as an assistant professor I became more interested on the general problem of modeling vision and collaborated with my University of Rochester colleague Chris Brown to write the first text in computer vision in 1982, which is still accessible on the web. In the middle 80s the field discovered biologically motivated active vision could be much more efficient than static picture analysis. Chris and I built the first real-time binocular robot that could make saccades and pursue moving targets. The robot was enormously influential in showing that motion actually made many of the vision computations simpler by providing efference copy information. As a result, my interests progressed human vision to how the brain realized vision. I had a leave through Rochester's Bridging program to learn tract tracing in visual cortex in cats and rats in the department of Anatomy and Physiology. That experience has led to a lifelong interest in neural models. I was hooked on the brain, but realized my talents were in mathematical modeling. Working with a brilliant student, Raj Rao we were able to define a predictive coding model that showed that neural systems spanning cortical maps could be seen as pivotal in learning memory representations<sup>1</sup>. That model has been enormously successful, but a frustration for me has been that it was cast at a level above spikes. Working with a postdoc, Janneke Jehee, we put together a spiking model, which exhibited several desirable properties, but had unsolved problems. Most recently I have resolved these problems with another star student Ruohan Zhang. We realized that we are at the stage that the elements of the spiking model could be tested. In that process, I have been extraordinarily fortunate in starting a collaboration with Luc Genet who is a leader in cell patch clamp technology, particularly in the two-cell patches we will need for next step. We have been collaborating for the two years and our joint efforts are extremely promising. This effort dovetails with a second interest in How the brain represents movement. Our newest papers show that humans use common postures in whole body tasks and that these are local energy minima, suggesting new constraints for motor cortex.

1. Friston, K., Nature Neuroscience 2018 1019-1026

## PROFESSIONAL EXPERIENCE:

1965-66 Technical Staff, Lockheed Missiles and Space Co., Sunnyvale, CA  
1967-68 Teaching Assistant, University of Michigan, Ann Arbor, MI  
1968-70 Technical Staff, Autonetics, Anaheim, CA  
1970-74 Research Asst., Pattern Recognition Project, U. California, Irvine, CA  
1974-75 Visiting Consultant, Laboratorio Technol. Biomediche, Rome, Italy  
1975-82 Assistant Professor of Computer Science and Radiology, U. Rochester  
1982 Bridging Leave with Department of Anatomy, U. Rochester  
1982-87 Associate Professor of Computer Science, U. Rochester  
1986 Semester at Institute for Theoretical Physics, U. Cal., Santa Barbara  
1987-2006 Professor of Computer Science, U. Rochester  
1987- 2006 Professor, Center for Visual Science, U. Rochester  
1990 Visiting Consultant, ATR, Kyoto, Japan (summer 1990)  
1995-2006 Professor of Brain and Cognitive Sciences, U. Rochester  
2004 Visiting Professor, IIT Kanpur, Kanpur, India, (January-February)  
2006 Visiting Scholar, University of Sydney, Sydney, Australia  
2006- Professor of Computer Science, University of Texas at Austin, Austin, TX  
2006- Professor in the Center for Perceptual Systems, UT Austin, Austin TX  
2011 Visiting Scholar, Queensland Brain Institute, Brisbane, Australia  
2012 Visiting Scientist, ZiF, Bielefeld, Germany  
2018 Simons Institute, Berkeley (Spring semester)  
2022 OIST, Okinawa, Japan (Sumer)

## PROFESSIONAL ACTIVITIES:

1974 Consultant, Actron Industries, Monrovia, CA  
1976- NIH Consultant  
1984 Consultant, Draper Laboratories, Cambridge, MA  
1985 Co-organizer, *Workshop on Cognitive Neuroscience*, Woods Hole, MA  
1987 Program Committee, *IEEE Neural Network Conf.*, Boulder, CO  
1987 Advisory Committee, *Workshop on Eye Movements in Vision*, U. Mich.  
1988- Advisory Bd., Addison-Wesley series *Computation and Neural Systems*  
1988- 98 Action Editor, *Neural Computation* (MIT Press Journal)  
1988- Editorial Bd., *Concepts in Neural Science* (World Scientific Journal)  
1989-91 Editorial Bd., *Network*  
1991 Program Committee, *CVPR; Int'l. Joint Conf. on Neural Networks*  
1991 Instructor, 1-week Active Vision course, Vision Res. Lab., U. Genoa, June 2-9  
1992 Participant, NSF Workshop on Computer Vision, Washington, DC, June  
1992 Participant, NSF Workshop on Face Recognition, Washington, DC, July  
1993 Program Committee, *Int'l. Conf. on Computer Vision*  
1994 Co-organizer and Instructor, Workshop on Neurocomputing, Telluride, CO, July  
1994 Program Committee, Visual Behaviors Workshop, *CVPR*, Seattle, July 1994  
1995 Co-organizer, Telluride Workshop on Neuromorphic Engg., Telluride, CO, July  
1996 Organizer, Center for Visual Science Workshop on Neural Models of Behavior  
1996- 98 Editorial Bd., *Videre* (on-line computer vision journal; MIT Press)  
1999 Associate Editor, *Neural Computation* (MIT Press Journal)  
2002-04 Associate Editor, *Perception*  
2010 Co-organizer, NETI Workshop, UT Austin, April  
2012 Co-organizer, NETI Workshop, UT Austin, April

## **HONORS:**

Best Paper Prize, *Int'l. Joint Conf. on Artificial Intelligence*, Detroit, MI, August 1989 (“Reference frames for animate vision”).

2013 *ICCV* Test of Time award for “Color Indexing”(1991)

2013 Cognitive Science Fellow

2014 UC Merced Distinguished Cognitive Scientist Award

## **DOCTORAL DISSERTATIONS SUPERVISED:**

Lijia Liu, “ Whole-body models for motor control” Tencent Corporation

Ruohan Zhang, “ Modular Reinforcement using Deep Learning,” Stanford PostDoc

Johnson, L. M.”Redundancy reduction in motor control,” Google Corp. CA

Cooper, J. C. “Analysis and synthesis of bipedal human movement,” Google Corp. CA

Iyer , R., “Muscle models of human walking,” (EMC2)

Kit, D., “Image Change Detection,”PostDoc, Northeastern)

Rothkopf, C. A., “Modular models of task based visually guided behavior” (FIAS, Frankfurt)

Shaw, J. “ Unifying Perception and Curiosity” (Shaw Technologies)

Gu, X., “A An Equilibrium Point Based Humanoids Control Model” (Towers Perrin)

Yi, W., “Modeling Sequential Behavior based onVisual Routines” (Microsoft)

Sprague, N.R., “Learning to coordinate visual behaviors”(James Madison University)

Yu, C., “Embodied learning from multisensory input”(University of Indiana)

Zhang, Z., “A predictive coding model of the cortex using distributed synchronous spikes”(Fair Isaac Corp.)

Zhu, S., “Learning to cooperate and coordinate”(NEC Labs)

Bayliss, J.D., “Real-time EEG signal analysis in a dynamic environment”(Rochester Institute of Technology)

Salgian, G., “Driving with Visual Routines” (Sarnoff Corporation)

Rao, R.P.N., “Dynamic Appearance-Based Vision” (University of Washington)

Rosca, J.P., “Hierarchical Learning with Procedural Abstraction Mechanisms” (Siemens Corp.Research)

Karlsson, J., “Learning multiple behaviors” (Xerox Webster Research Ctr.)

Sarukkai, R., “Phone sets for speech understanding” (Kurzweil Applied Intelligence, Inc.)

McCallum, A., “Reinforcement learning algorithms” (University of Massachusetts)

Pook, P.K., “Teleassistance: Using deictic gestures to control robot action” (Asian Univ. for Women, Bangladesh)

deSa, V.R., “Unsupervised classification learning from cross-modal environmental structure” (U. California, San Diego)

Wixson, L.E., “Gaze selection for visual search” (David Sarnoff Research Center)

Whitehead, S.D., “Reinforcement learning for the adaptive control of perception and action” (Verizon)

Simard, P.Y., “Learning state space dynamics in recurrent networks” (Microsoft Research)

Hartman, L.B., “Decision theory and the cost of planning” (Canadian Space Agency)

Swain, M.J., “Color indexing” (AthenaHealth, Watertown MA)

Tenenberg, J.D., "Abstraction in planning" (Washington State University)  
Bandopadhyay, A., "A computational study of rigid motion perception" (independent software consultant)  
Shani, U., "A three-dimensional parametric model for the automatic recognition of abdominal anatomy from CAT-scans" (IBM Haifa Research Lab)  
Schudy, R.B., "A computer model for extracting moving heart surfaces from four-dimensional cardiac ultrasound data" (Metropolitan College, Boston Univ.)

### **INVITED TALKS: 2010-21**

Oxyopia Colloquium Series in the Vision Science Program at Berkeley, October 2010  
Reinforcement Learning Tutorial at the Neural Information Processing Systems Conference, Vancouver Canada, December 2010  
Vision Research Centers Annual Meeting, Murrumbidgee, NSW, Australia March 2011  
Queensland Brain Institute presentation, Mar 2011  
CITEC Summer School Lecture, University of Bielefeld, October 2011  
Max Planck Tubingen, Bernstein Center for Computational Neuroscience Symposium on Perception and Action September 2011  
COSYNE, Salt Lake City, February 2012  
The Gatsby Computational Neuroscience Unit, UCL, London, UK, June 2012  
Craik Series Lecture, University of Cambridge, Cambridge, UK, June 2012  
Donders Institute, Nijmegen, The Netherlands, June 2012  
Hitachi Distinguished Lecture Series, University of Oklahoma, September, 2012  
University of Birmingham, Birmingham, UK, September 2012  
Universitat Pompeu Fabra, Barcelona, Spain, September 2012  
AVA, University of Sussex, Sussex, UK, September, 2012  
University of Rochester, Rochester, NY, September 2012  
University of Osnabruck, Osnabruck, Germany, October 2012  
ETH, Zurich, November 2012  
York University, Toronto, Canada, March 2013  
University of Maryland March 2013  
Telluride July 2013  
University of Rochester CVS 50<sup>th</sup>, October 2013  
Brain Corp. L Jolla San Diego, November 2013  
UC Merced May 2014  
Northwestern Chicago 2014  
U Penn, January 2015  
Rutgers University April 2015  
Giessen Germany July 2015  
FIAS, Frankfurt, Germany December 2015  
IIT, Genoa, Italy December 2015  
KTH Summer Course, Alesse, Sardinia, April 2016  
Ein Gedi, Israel, February 2017  
Weizmann, Israel 2017  
U Indiana, Cognitive Science Dept. June 2017  
York Symposium June 2017  
Finland Symposium July 2017  
Vanderbilt ECE, November 2017

Vanderbilt Neuroscience, November 2017  
Simons Institute at Berkeley (3 talks) Jan-May 2018  
UC Davis, April 2018  
Cognitive Science, Tanenhaus award ceremony, July 2018  
Society for Neuroscience at San Diego, Nanosymposium, November 2018  
ZiF 50<sup>th</sup> Anniversary, Keynote Bielefeld November 2018  
University of Freiburg, November 2018  
University of Geissen, November 2018  
Darmstadt University, November 2018  
Reinforcement Learning Workshop, Barbados February 2019  
Vision Course IK2019 Bad-Nuemahr-Ahrweiler, Germany 2019  
Simons Institute, Berkeley, June 2019  
Center for Perceptual Systems, University of Texas at Austin(virtual),, Sept 2020  
Telluride Workshop on motor control, Zurich(virtual),, July2021  
Vision Conference, Prague(virtual), July 2021

#### **COURSES:**

CS 378 **The Computational Brain** A Computer Science undergraduate writing certificate

CS 391 **Machine Learning** A comprehensive graduate course.

#### **GRANT SUPPORT:**

2019-2024 NIH NEI. R01EY05729-33 “Visual Processing in Natural Tasks”, Principal Investigator.

2017-2022 NIH NEI T32EY021462 Center for Perceptual Systems Training Grant, Principal Investigator (MPI W Geisler).

Center for Perceptual Systems Training Grant  
Co-PI

Agency: NIH-NEI, \$895,260 2012-2017

Neural Models of Behavior

PI: Dana Ballard

Agency: NIH (R01 EY019174-14) 5/1/09-5/1/13.

The goal of this research is to develop computational theories of cognitive behavior in complex environments such as driving in order to understand the organization of complex sensori-motor behavior.

Vision in Natural Tasks

PI: Mary Hayhoe,

Agency: NIH (R01 EY005729-25) 6/1/03-6/30/13.

The goal of the grant is to understand the way that vision functions in the context of ordinary behavior. The experiments focus on what information is extracted and retained

across fixations, whether it is used to guide subsequent eye movements, and how different kinds of information are composed to make up larger behavioral units.

NSF (IIS-0932277) A Real-Time Cognitive Operating System, PI

NIH 1 P41 RR09283 05, A Resource for the Study of Neural Models of Behavior, PI 9/94–8/08.

NIH MH 60624 “Spike Models of Neural Behavior,” PI, \$650,00, 6/01-6/04

NIH, “Training in Sensory-Motor and Integrative Neurosciences,” Trainer (William O’Neill, PI), \$1,457,660, 5/00-4/05.

NIH, 1 P41 RR09283 , “A Resource for the Study of Neural Models of Behavior,” PI, \$3,990,587, 9/94-8/02.

NIH/NEI T32 EY07125, “Training in Visual Science,” Trainer (T. Pasternak, PI), \$937,300, 9/95-9/00.

NSF, “A Laboratory for Intelligent Multi-Sense Interfaces” (equipment only), co-PI (Randal C.

Nelson, PI), \$110,000, 7/99-6/00. NIH Institutional NRSA, “Training in Neuroscience,” Trainer (William O’Neill, PI), \$843,534, 7/89-6/00.

NIH, RO1 EY05729-12, “Visual Processing in Natural Tasks,” Co-PI (Mary M. Hayhoe, PI),

\$311,479, 12/94-11/99. NSF, CDA-9401142, “Rapid Prototyping of Parallel Robot Vision Systems using Virtual Reality and Systems Simulation,” Co-Inv. (Thomas J. LeBlanc, PI), \$1,500,000, 9/94–8/99.

NSF, IRI-9406481, “Learning Fixation Routines,” PI, \$246,276, 9/94–8/97.

NIH, Training Grant for Graduate Students, Trainer (T. Bever, PI), \$107,120, 12/91-11/96.

NSF, IRI-8903582, “Animate Robotics Vision,” PI, \$524,047, 8/92–1/95.

NSF Institutional Infrastructure Program, CDA-8822724, “Parallel Laboratory for Real-Time Vision and Robotics,” co-PI (Christopher M. Brown, PI), \$1,782,106, 7/89–6/94.

Human Scientific Frontiers Program, “Visuo-Motor Coordination in 3-D Space,” co-PI, \$248,026, 6/91–5/94.

## **PUBLICATIONS**

## Books

Ballard, D.H. *Brain Computation as Hierarchical abstraction*. Cambridge, MA: MIT Press 2015.

The only book of its kind

Ballard, D.H. *An Introduction to Natural Computation*. Cambridge, MA: MIT Press (A Bradford Book), 1997.

Ballard, D.H. and C.M. Brown. *Computer Vision*. Prentice-Hall, 1982. (Translated into Japanese, 1987.) Also see: <https://homepages.inf.ed.ac.uk/rbf/BOOKS/BANDB/bandb.htm>

The first book of in the field.

Ballard, D.H. *Hierarchic Recognition of Tumors in Chest Radiographs*. Birkhauser-Verlag, 1976.

## Refereed Articles

Lijia Liu and Dana Ballard, "humans use minimum cost movements in a whole-body task," *scientific reports*, (2021) (2021) 11:20081 | <https://doi.org/10.1038/s41598-021-99423-5>

Lijia Liu, Joseph L Cooper and Dana H. Ballard, "Computational Modeling: Human Dynamic Model," *frontiers in Neurobotics*" (2021), <https://doi.org/10.3389/fnbot.2021.723428>

DH Ballard, R Zhang (2021) The hierarchical evolution in vision modeling  
*Topics in Cognitive Science* 13 (2), 309-328

R Zhang, A Saran, B Liu, Y Zhu, S Guo, S Niekum, D Ballard, M Hayhoe  
Human gaze assisted artificial intelligence: a review *ICAI: Proceedings of the Conference 2020*,  
4951

Zhang, DH Ballard, (2020) Parallel neural multiprocessing with gamma frequency latencies  
*Neural Computation* 32 (9), 1635-1663

R Zhang, C Walshe, Z Liu, L Guan, K Muller, J Whritner, L Zhang, ...

"Atari-Head Atari human eye-tracking and demonstration dataset," *Proceedings of the AAAI conference on artificial intelligence* (2020) 34 (04), 6811-6820

L Liu, L Johnson, O Zohar, DH Ballard, Humans use similar posture sequences in a whole body  
Tracing Task, *Iscience* (2019) 19, 860-871

R Zhang, F Torabi, L Guan, DH Ballard, P Stone, "Leveraging human guidance for deep  
reinforcement learning tasks" *IJCAI: Proceedings of the Conference* (2019)

R Zhang, Z Liu, MM Hayhoe, DH Ballard, "Attention guided deep imitation learning  
(2017) *Cognitive Computational Neuroscience*

R Zhang, Y Yu, M El Chamie, B Açikmese, DH Ballard, "Decision-Making Policies for  
Heterogeneous Autonomous Multi-Agent Systems with Safety Constraints,"  
*IJCAI*, (2016) 546-553

R Zhang, S Zhang, MH Tong, Y Cui, CA Rothkopf, DH Ballard, .(2018)

Modeling sensory-motor decisions in natural behavior, *PLoS computational biology* 14 (10), e1006518

Leif Johnson, Brian Sullivan, Mary Hayhoe and Dana Ballard, (2014) Predicting human visuomotor behaviour in a driving task, *Phil. Trans. R. Soc.*, 369, 20130044.

Rothkopf, C. A. and Ballard D. H. Modular inverse reinforcement learning for visuomotor behavior, *Biological Cybernetics*, 107(4) 477-490 (2013)

Ballard, D. H., and Kit, D., and Rothkopf, C. A., and Sullivan, B., (2013) A Hierarchical Modular Architecture for Embodied Cognition, *Multisensory Research*, 26, 177-204

Sullivan, Brian T., Johnson, L., Rothkopf, Constantin A., Ballard, Dana H., and Hayhoe, Mary, (2012) The role of uncertainty and reward on eye movements in a virtual driving task, *Journal of Vision* 12 (13) 1-16

Ballard, D. H., and Jehee, J. M. F. (2012) Dynamic coding of signed quantities in cortical feedback circuits, *Frontiers in Perception Science*

Ballard, D. H., and Jehee, J. M. F. (2011) Dual roles for spike signaling in cortical neural populations, *Frontiers in Computational Neuroscience*

Tatler, B. W., Hayhoe, M.M., Land, M. F., and Ballard, D. H. (2011) Eye Guidance in natural vision: Reinterpreting salience, *Journal of Vision*

Rothkopf, C. A., and Ballard, D. H. (2010) Credit assignment in multiple goal embodied visuomotor behavior, *Frontiers in Psychology*

Yi, W. and Ballard, D. H. (2009) Recognizing behavior in hand-eye coordination patterns, *Int. Journal of Humanoid Robotics*

Ballard, D. H. and Hayhoe, M. M. (2009) Modeling the role of task in the control of gaze, *Visual Cognition*, 17, 1185-1204

Rothkopf, C. A., and Ballard, D. H. (2009) Image statistics at the point of gaze during human navigation, *Visual Neuroscience*, 26, 81-92

Jehee, J. F. M. and Ballard, D. H. (2009) Predictive Feedback Can Account for Biphasic Responses in the Lateral Geniculate Nucleus, *PLoS Computational Biology*

Rothkopf, C. A., Ballard D. H. and Hayhoe, M. M. (2007) Task and context determine where you look, *Journal of Vision*, 7(14) 1-20

Gu, X., and Ballard, D. H. (2006) An Equilibrium Point based Model Unifying Movement Control in Humanoids, *Robotics: Science and Systems*

Hayhoe, M. M., and Ballard, D. H. (2005) Eye Movements in Natural Behavior, *Trends in Cognitive Science*

Sprague, N. and Ballard, D. H. (2005) Modeling Embodied Visual Behaviors *ACM Transactions on Applied Perception*

W. Yi and D. H. Ballard. Vergence Control in Fixation with Minimal Disparity Information, Proc. 6th International Conference on Cognitive Modeling, pp. 326-330, Pittsburg, July 2004.

Chen Yu and Dana H. Ballard, "A Multimodal Learning Interface for Grounding Spoken Language in Sensorimotor Experience", *ACM Transactions on Applied Perception*. Vol 1, No 1, 2004.

Chen Yu and Dana H. Ballard, "On the Integration of Grounding Language and Learning Objects", Nineteenth National Conference on Artificial Intelligence (AAAI-04), San Jose, California, July 25-29, 2004.

Chen Yu, Dana H. Ballard and Richard N. Aslin, "The Role of Embodied Intention in Early Lexical Acquisition", 25th Annual Meeting of Cognitive Science Society (CogSci 2003), Boston, MA, July



31 - Aug 2, 2003. [The [Marr Prize winner for best student paper](#) ]

Chen Yu and Dana H. Ballard, "A Multimodal Learning Interface for Grounding Spoken Language in Sensory Perceptions", Fifth International Conference on Multimodal Interface (ICMI 2003), Vancouver, Canada, November 5-7, 2003.

Chen Yu and Dana H. Ballard, "A Formal Model of Visual Attention in Embodied language Acquisition", Third Annual Meeting of Vision Science Society (VSS'03), Sarasota, Florida, May 9 - 14th, 2003.

Chen Yu and Dana H. Ballard, "Exploring the Role of Attention in Modeling Embodied Language Acquisition", Fifth International Conference on Cognitive Modeling (ICCM 2003), Bamberg, Germany, April 10 - 12, 2003.

Dana H. Ballard and Chen Yu, "A Multimodal Learning Interface for Word Acquisition", IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP'03), Hong Kong, 2003.

Chen Yu, Dana H. Ballard and Shenhua Zhu, "Attentional Object Spotting by Integrating Multimodal Input", IEEE International Conference on Multimodal Interface (ICMI'02), Pittsburgh, PA, October 14-16, 2002.

Chen Yu and Dana H. Ballard, "Understanding Human Behaviors Based on Eye-head-hand coordination", 2nd Workshop on Biologically Motivated Computer Vision (BMCV2002), Tübingen, Germany, November 22nd - 24th, 2002.

Chen Yu and Dana H. Ballard, "Learning to Recognize Human Action Sequences", IEEE International Conference on Development and Learning (ICDL'02), Cambridge, MA, June 12 - 15, 2002.

Chen Yu and Dana H. Ballard, " Learning Spoken Words from Multisensory Input", International Conference on Signal Processing (ICSP'02), Beijing, CHINA, August 26-30, 2002.

Nathan Sprague and Dana Ballard, "Eye Movements for Reward Maximization", *Advances in Neural Information Processing Systems*, 15 , 2003 (draft) .

Nathan Sprague and Dana Ballard, "Multiple-Goal Reinforcement Learning with Modular Sarsa(0)", *IJCAI 2003* , Acapulco, August 2003.

Nathan Sprague and Dana Ballard, "A Visual Control Architecture for a Virtual Humanoid", *IEEE-RAS International Conference on Humanoid Robots* , Tokyo, November 2001.

Sanders, B.J., D.J. Logan, C.J. Duffy, and D.H. Ballard, "A predictive coding model of MST cells," <<in preparation>>.

Zhang, Z. and D.H. Ballard, "Distributed synchrony," submitted for publication. Zhang, Z. and D.H. Ballard, "A single spike model of predictive coding," *Computational Neuroscience Meeting (CNS\*2003)*, Alicante, Spain, July 2003.

Rao, R., Zelinsky, G., Hayhoe, M., & Ballard, D. (2002). Eye movements in iconic visual search. *Vision Research*, 42(11), 1447-1463.

Shimozaki, S., W.H. Merigan, G.J. Zelinsky, M.M. Hayhoe, and D.H. Ballard, "Spatial memory and saccade targeting deficits from parietal injury," submitted for journal publication (*Visual Cognition*).

Zhu, S. and D.H. Ballard, submitted for conf. publication (*Conf. on Machine Learning*, 2001). Triesch, J., D.H. Ballard, and R.A. Jacobs, "Fast temporal dynamics of visual cue integration," to appear, *Perception*. Yu, C. and D.H. Ballard, "Exploring the role of attention in modeling embodied language

acquisition," *5th Int'l. Conf. on Cognitive Modeling*, Bamberg, Germany, April 2003. Ballard, D.H. and C. Yu, "A multimodal learning interface for word acquisition," *IEEE Int'l. Conf.*

*on Acoustics, Speech and Signal Processing(ICASSP'03)*, Hong Kong, 2003.

Chen Yu and Dana H. Ballard, "Understanding human behaviors based on eye-head-hand coordination," *2nd Workshop on Biologically Motivated Computer Vision (BMCV2002)*, Tubingen,

Germany, November 2002.

Yu, C., D.H. Ballard, and S. Zhu, "Attentional object spotting by integrating multimodal input," *IEEE Int'l. Conf. on Multimodal Interface (ICMI'02)*, Pittsburgh, PA, October 2002.

Yu, C. and D.H. Ballard, "Learning spoken words from multisensory input," *Int'l. Conf. on Signal Processing (ICSP'02)*, Beijing, August 2002.

Yu, C. and D.H. Ballard, "Learning to recognize human action sequences," *IEEE Int'l. Conf. on Development and Learning (ICDL'02)*, Cambridge, MA, June 2002.

Rao, R.P.N., G.J. Zelinsky, M.M. Hayhoe, and D.H. Ballard, "Eye movements in iconic visual search," *Vision Research* 42, 11, 1447-1463, 2002.

Zhang, Z. and D.H. Ballard, "Distributed synchrony—Understanding the brain at the single cell level," *Proc., 8th Int'l. Conf. on Neural Information Processing (ICONIP2001)*, Shanghai, November 2001.

Zhang, Z. and D.H. Ballard, "Distributed synchrony," *Proc., 10th Annual Computational Neuroscience Meeting (CNS\*2001)*, San Francisco and Pacific Grove, June-July 2001.

Zuohua Zhang, Dana H. Ballard, *A single spike model of predictive coding*, Computational Neuroscience meeting, 2003

Zuohua Zhang, Dana H. Ballard, *Distributed Synchrony*, poster at Sensory Coding and the Natural Environment conference, 2002.

Zuohua Zhang, Dana H. Ballard, *Distributed Synchrony - Understanding the Brain at the Single Cell Level*, ICONIP2001.

Zuohua Zhang, Dana H. Ballard, *Distributed Synchrony*, Computational Neuroscience 2001, Journal of Neurocomputing, Vol 44-46C, pp 715-720.

Zuohua Zhang, Dana H. Ballard, *Distributed Synchrony*, poster at Neural Information and Coding Workshop (NIC), 2001.

Dana H. Ballard, Zuohua Zhang, *Distributed Synchrony: a Unifying Principle for Neural Signaling*, oral presentation at Society for Neuroscience, Annual Meeting, 2000.

Ballard, Dana H., Zhang, Zuohua, *A synchronous firing model of L G N*, Computational Neuroscience 2000.

Ballard, Dana H., Rao, Rajesh P.N., Zhang, Zuohua, *A Single-spike Model of Predictive Coding*, Journal of neurocomputing, 32-33 (1-4) (2000) pp. 17-23 .

Dana H. Ballard, Zuohua Zhang, and Rajesh P.N. Rao, *Distributed Synchrony: A Probabilistic Model of Neural Signaling*, chapter in *Probabilistic Models of the Brain: Perception and Neural Function*, Eds. Rajesh P.N. Rao, Bruno A. Olshausen and Michael S. Lewicki, MIT press, 2001.

Ballard D. H. , M.M. Hayhoe, G. Salgian and H. Shinoda, "Spatio-temporal organization of behavior," *Spatial Vision* 13, 2, 321-333, 2000.

Ballard, D.H., R.P.N. Rao, and Z. Zhang, "A single-spike model of predictive coding," *J. Neurocomputing*, 2000.

Bayliss, J.D. and D.H. Ballard, "Single trial P300 epoch recognition in a virtual environment," *Neurocomputing*, 2000.

Bayliss, J.D. and D.H. Ballard, "A virtual reality testbed for brain-computer interface research," *IEEE Trans. on Rehabilitation Engineering*, 2000.

Ballard, D.H. and Z. Zhang, "A synchronous firing model of LGN," *Proc., Computational Neuroscience Meeting (CNS\*2000)*, Brugge, Belgium, July 2000.

Bayliss, J.D. and D.H. Ballard, "Recognizing evoked potentials in a virtual environment," *Advances in Neural Information Processing Systems* 12, 2000.

Bayliss, J.D. and D.H. Ballard, "Single trial P3 epoch recognition in a virtual environment," *Proc., Computational Neuroscience Meeting (CNS\*99)*, Pittsburgh, PA, July 1999.

Bayliss, J.D. and D.H. Ballard, "Single trial P300 recognition in a virtual environment," *CIMA '99*

(*Soft Computing in Biomedicine*), Rochester, NY, June 1999.

Pelz, J.B., M.M. Hayhoe, D.H. Ballard, A. Shrivastava, J.D. Bayliss, and M. von der Heyde, "Development of a virtual laboratory for the study of complex human behavior," *Proc., SPIE (International Society for Optical Engineering), Vol. 3639B, The Engineering Reality of Virtual Reality*, San Jose, CA, January 1999.

Rao, R.P.N. and D.H. Ballard, "Predictive coding in the visual cortex: A functional interpretation of some extra-classical receptive-field effects," *Nature Neuroscience* 2, 1, 79–87, January 1999.

Magnuson, J., D. Bensinger, M.M. Hayhoe, and D.H. Ballard, "Learning to form visual chunks: On the structure of visuo-spatial working memory," *Proc., 20th Annual Conf., Cognitive Science Society*, M.A. Gernsbacher and S.J. Derry (Eds.), Lawrence Erlbaum, Inc., U. Wisconsin—Madison, August 1998.

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