Ronald T. Azuma, Ph.D.

C.V.

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Home: San Jose, CA

Education

University of North Carolina, Chapel Hill, NC
Ph.D. in Computer Science, May 1995
M.S. in Computer Science, May 1990 (Pogue fellowship)

University of California, Berkeley, CA
B.S. in Electrical Engineering / Computer Science, May 1988
With highest honors. Chancellor's and National Merit scholarships.

Experience

Principal Engineer and Research Manager, Intel Labs (Santa Clara, CA)
4/16 – present
Augmented Reality Leader, Intel Labs (Santa Clara, CA)
6/12 – 3/16

Line Management, Technical Leadership and Prototyping: I lead a team designing and building novel experiences and key enabling technologies to enable new media forms. These technologies include computational imaging and computational photography, head-worn displays, and computational displays. I also advise Intel on Augmented Reality and other related technologies and experiences.

Leviathan: I personally implemented part of the Leviathan Augmented Reality demonstrations that Intel showed at CES 2014 to inspire new forms of Augmented Reality storytelling. I also directed my team to build the AR framework that enabled the demonstration in the Intel CEO keynote presentation. I served as the main Intel technical expert on this project.

Research Leader, Nokia Research Center Hollywood (Santa Monica, CA)
10/08 – 1/12

Line Management: Helped build a new research laboratory focused on novel media and entertainment applications, by establishing a new environment and culture, and by recruiting and leading a team to develop new forms of mobile pervasive media.

Project Management: Supervised two research focus areas: 1) Developing a new approach to implement a mobile AR experience that provides a more compelling experience than today's AR browsers, and 2) Exploring the use of pervasive computing technologies combined with mobile devices to enable novel forms of mobile media and experiences.

The Westwood Experience: My team built this novel location-based experience that was an experiment in connecting a narrative to evocative locations via Mixed Reality.

Sr. Research Staff Computer Scientist, HRL Laboratories (Malibu, CA)
11/99 – 10/08
Research Staff Member, HRL / Hughes Research Laboratories (Malibu, CA)
3/95 – 11/99

Project Leadership: Principal Investigator of two DARPA projects and numerous Raytheon, Boeing and GM internal projects in visualization, tracking, and Augmented Reality.

Augmented Reality: Demonstrated the first motion-stabilized outdoor Augmented Reality display. Built a new algorithm for automatically positioning AR labels over real-world objects to avoid occlusions. Demonstrated a basic perception problem in "x-ray vision" in AR visualizations. Active participant in running the IEEE ISMAR conference (serving as program and area chair multiple times).

Visualization: Developed interactive visualization techniques for future "Free Flight" Air Traffic Control applications. Demonstrated them at the ATCA '95, '96 and '98 conventions. Worked on visualization displays for battlefield awareness and time-critical decision making. Examined the application of autostereoscopic displays. Developed non-geographic visualization techniques to generate insight from National Airspace System simulation data. Collaborated with computer vision experts by building visualization tools and designing the software infrastructure to support research in the semantic recognition of objects (buildings, cars, trees, etc.) from dense urban LIDAR data.

Virtual Environments: Built part of a car simulator to investigate the effectiveness of multimodal warnings from Crash Avoidance sensors. Built large head-tracked stereo displays.

Research Assistant, UNC Chapel Hill
5/89 – 2/95

Augmented Reality: Demonstrated the first compelling example of virtual-real registration in an optical see-through display. Developed inertial-based predictive trackers and calibration techniques. Built a see-through Head-Mounted Display system to demonstrate and evaluate these techniques. Reduced registration errors by a factor of 5-10. Published work in two SIGGRAPH papers.

Human Tracking: Built a novel outward-looking optoelectronic tracking system that was the first demonstrated scalable tracker for Head-Mounted Displays (shown at SIGGRAPH '91). This was a team effort; my contributions included designing and simulating the overall

software architecture, developing and coding the mathematics that compute head locations given sensor inputs, and calibrating the optical sensors. The HiBall tracker sold by 3rdTech is a descendent of this system.

Instructor, UNC Chapel Hill
Summer 1992

Completely redesigned and taught undergraduate “Computers and Society” course.

Software Engineer, Apple Computer (summer internships)
Summers of 1986 - 1988

Investigated image compression, wrote AppleTalk file transfer and test programs.

Skills

- Augmented Reality. Extensive knowledge and background in Augmented Reality systems.
- Head-worn displays: 25 years of experience with a wide variety of head-worn display systems, particularly in optical see-through head-worn displays.
- Line and project management, team leadership
- Public speaking and communication
- Development platforms: Windows and Linux. In the past I have also used Macintosh, UNIX and other platforms.
- Languages: C/C++, Processing, and Python are the languages I have used most recently. In the past I have also programmed in a variety of other languages.
- OpenSceneGraph
- Government contract fundraising

Publications

Azuma, Ronald. Location-Based Mixed and Augmented Reality Storytelling. Book chapter in *Fundamentals of Wearable Computers and Augmented Reality, 2nd Edition,* Woodrow Barfield, editor. CRC Press, August 2015, pp. 259-279.

Xu, Yan, Joshua Ratcliff, James Scovell, Gheric Speiginer, Ronald Azuma. Real-time Guidance Camera Interface to Enhance Photo Aesthetic Quality. *Proc. ACM CHI 2015* (Seoul, Korea, 18-23 April 2015), pp. 1183-1186.

Azuma, Ronald. Augmented Reality Systems. Book chapter to be published in *Second edition of Handbook of Visual Display Technology,* Janglin Chen, Wayne Cranton and Mark Fihn, editors. Springer Science and Business Media, 2015.

Laibowitz, Mat, Vids Samanta, Syed Reza Ali, Ronald Azuma. Chamber of Mirrors: A Socially Activated Game Exploits Pervasive Technology. *IEEE Pervasive Computing,* vol. 11, #2 (April – June 2012), pp. 38–45.

Wither, Jason, Sean White, Ronald Azuma. Comparing Spatial Understanding Between Touch-Based and AR-Style Interaction. *Proc. IEEE Int'l Symp. on Mixed and Augmented Reality (ISMAR 2011)* (Basel, Switzerland, 26-29 Oct. 2011), pp. 273-274.

Azuma, Ronald, Mark Billinghurst, Gudrun Klinker. Special Section on Mobile Augmented Reality. *Computers & Graphics, vol. 35, #4* (August 2011), pp. vii-viii. Special issue on Mobile Augmented Reality.

Wither, Jason, Yun-Ta Tsai, Ronald Azuma. Indirect Augmented Reality. *Computers & Graphics, vol. 35, #4* (August 2011). Special issue on Mobile Augmented Reality. pp. 810-822.

Korah, Thommen, Jason Wither, Yun-Ta Tsai, Ronald Azuma. Mobile Augmented Reality at the Hollywood Walk of Fame. *Proc. of IEEE Virtual Reality 2011* (Singapore, 19-23 March 2011), pp. 183-186.

Wither, Jason, Rebecca Allen, Vids Samanta, Juha Hemanus, Yun-Ta Tsai, Ronald Azuma, Will Carter, Rachel Hinman, Thommen Korah. The Westwood Experience: Connecting Story to Locations Via Mixed Reality. *IEEE International Symposium on Mixed and Augmented Reality 2010, Arts, Media and Humanities Proceedings (ISMAR AMH 2010)* (Seoul, Korea, 13-16 Oct. 2010), pp. 39-46.

Livingston, Mark, Ronald Azuma, Oliver Bimber, Hideo Saito. Guest Editors' Introduction: Special Section on The International Symposium on Mixed and Augmented Reality (ISMAR). *IEEE Trans. on Visualization and Computer Graphics*, vol. 16, #3 (2010), pp. 353-354.

Ronald Azuma, Howard Neely III, Mike Daily, Jon Leonard. Performance Analysis of an Outdoor Augmented Reality Tracking System that Relies Upon a Few Mobile Beacons. *Proc. IEEE and ACM Int'l Symp. on Mixed and Augmented Reality (ISMAR 2006)* (Santa Barbara, CA, 22-25 Oct. 2006), pp. 101-104.

Mike Daily, Ron Azuma, Youngkwan Cho, Troy Rockwood, and Susan Gottschlich. Tactial Alert Management. *Proc. 2006 Int'l Conf. on Artificial Intelligence (ICAI '06)* (Las Vegas, NV, 26-29 June 2006), pp. 337-343.

Ron Azuma, Mike Daily, Chris Furmanski. A Review of Time Critical Decision Making Models and Human Cognitive Processes. *Proc. 2006 IEEE Aerospace Conference* (Big Sky, MT, 4-11 March 2006).

Ronald Azuma, Jason Fox, and Chris Furmanski. Evaluating Visualization Modes for Closely-Spaced Parallel Approaches. *Proc. HFES 49th Annual Meeting* (Orlando, FL, 26-30 Sept. 2005), pp. 35-39.

Ronald Azuma, Tim Clausner, Mike Daily, Jason Fox, and Mary E. Miller. Visualization Concepts for Generating Insight from NAS Simulation Data. *Proc. AIAA 2005 Modeling and Simulation Conference* (San Francisco, 15-18 Aug. 2005)

Ronald Azuma, Chris Furmanski. Evaluating Label Placement for Augmented Reality View Management. *Proc. IEEE and ACM Int'l Symp. on Mixed and Augmented Reality (ISMAR 2003)* (Tokyo, 7-10 Oct. 2003), pp. 66-75.

Chris Furmanski, Ronald Azuma, Mike Daily. Augmented-reality visualizations guided by cognition: Perceptual heuristics for combining visible and obscured information. *Proc. IEEE and ACM Int'l Symp. on Mixed and Augmented Reality (ISMAR 2002)* (Darmstadt, Germany, 30 Sept. - 1 Oct. 2002), pp. 215-224.

Ronald Azuma, Yohan Baillot, Reinhold Behringer, Steven Feiner, Simon Julier, Blair MacIntyre. Recent Advances in Augmented Reality. *IEEE Computer Graphics and Applications 21*, 6 (Nov/Dec 2001), 34-47.

Azuma, Ronald T. Augmented Reality: Approaches and Technical Challenges. Book chapter in *Fundamentals of Wearable Computers and Augmented Reality,* Woodrow Barfield and Thomas Caudell, editors. Lawrence Erlbaum Associates, 2001, ISBN 0-8058-2901-6. Chapter 2, pp. 27-63.

Bruce Hoff, Ronald Azuma. Autocalibration of an Electronic Compass in an Outdoor Augmented Reality System. *Proc. of Int'l Symp. on Augmented Reality 2000* (Munich, Germany, 5-6 Oct. 2000), pp. 159-164.

Ronald Azuma, Howard Neely III, Michael Daily, Ryan Geiss. Visualization Tools for Free Flight Air-Traffic Management. *IEEE Computer Graphics and Applications 20*, 5 (Sept/Oct 2000), 32-36.

Azuma, Ronald, Jong Weon Lee, Bolan Jiang, Jun Park, Suya You, and Ulrich Neumann. Tracking in unprepared environments for augmented reality systems. *Computers & Graphics 23,* 6 (December 1999), 787-793.

You, Suya, Ulrich Neumann, and Ronald Azuma. Orientation Tracking for Outdoor Augmented Reality Registration. *IEEE Computer Graphics and Applications 19*, 6 (Nov/Dec 1999), 36-42.

Azuma, Ronald, Howard Neely III, Mike Daily, Mario Correa. Visualization of Conflicts and Resolutions in a "Free Flight" Scenario. *Proc. of IEEE Visualization '99* (San Francisco, 24-29 Oct. 1999), pp. 433-436, 557.

Azuma, Ronald, Bruce Hoff, Howard Neely III, Ron Sarfaty. A Motion-Stabilized Outdoor Augmented Reality System. *Proc. of IEEE Virtual Reality '99* (Houston, TX, 13-17 March 1999), pp. 252-259.

You, Suya, Ulrich Neumann, and Ronald Azuma. Hybrid Inertial and Vision Tracking for Augmented Reality Registration. *Proc. of IEEE Virtual Reality '99* (Houston, TX, 13-17 March 1999), pp. 260-267.

Azuma, Ronald T. The Challenge of Making Augmented Reality Work Outdoors. Book chapter in *Mixed Reality: Merging Real and Virtual Worlds,* Yuichi Ohta and Hideyuki Tamura, editors. Springer-Verlag, 1999, ISBN 3-540-65623-5. Chapter 21, pp. 379-390. Associated with invited presentation at *First Int'l Symp. on Mixed Reality (ISMR 1999)* (Yokohama, Japan, 9-11 March 1999).

Azuma, Ronald T., Bruce R. Hoff, Howard E. Neely III, Ronald Sarfaty, Michael J. Daily, Gary Bishop, Vern Chi, Greg Welch, Ulrich Neumann, Suya You, Rich Nichols, and Jim Cannon. Making Augmented Reality Work Outdoors Requires Hybrid Tracking. *Proc. of First Int'l Workshop on Augmented Reality* (San Francisco, 1 Nov. 1998), pp. 219-224.

Azuma, Ronald T. A Survey of Augmented Reality. *Presence: Teleoperators and Virtual Environments 6,* 4 (August 1997), pp. 355 - 385. Earlier version appeared in Course Notes #9: Developing Advanced Virtual Reality Applications, *ACM SIGGRAPH '95* (Los Angeles, 6-11 August 1995), 20-1 to 20-38. **The most referenced publication in the field of AR. One of 50 influential journal articles selected by MIT Press, from over 80 MIT Press journals from 1969 to 2011, covering all academic fields.**

Azuma, Ronald T. Course notes on "Registration" and "Correcting for Dynamic Error" from Course Notes #30: Making Direct Manipulation Work in Virtual Reality. *ACM SIGGRAPH '97* (Los Angeles, 3-8 Aug. 1997).

Azuma, Ronald, Mike Daily, and Jimmy Krozel. Advanced Human-Computer Interfaces for Air Traffic Management and Simulation. *Proc. of 1996 AIAA Flight Simulation Technologies Conference* (San Diego, CA, 29-31 July 1996), pp. 656-666. **Awarded Best Paper of conference.**

Daily, Mike, Ronald Azuma, Pete Tinker, Kevin Martin, and Cheryl Hein. Soldier System Effectiveness Measurement System Virtual Environments Study. Hughes Studies and Analysis Technical Report (July 1996).

Tinker, Pete, Ronald Azuma, Cheryl Hein, and Mike Daily. Driving Simulation for Crash Avoidance Warning Evaluation. *Proc. of 29th ISATA Dedicated Conference on Simulation, Diagnosis and Virtual Reality.* (Florence, Italy, 3-6 June 1996), pp. 367-374.

Azuma, Ronald and Gary Bishop. A Frequency-Domain Analysis of Head-Motion Prediction. *Proc. of ACM SIGGRAPH '95* (Los Angeles, 6-11 August 1995). *Computer Graphics,* Annual Conference Series, 1995, 401-408.

Dissertation: Predictive Tracking for Augmented Reality. UNC Chapel Hill Dept. of Computer Science technical report TR95-008 (February 1995), 262 pages.

Azuma, Ronald and Gary Bishop. Improving Static and Dynamic Registration in an Optical See-Through HMD. *Proc. of ACM SIGGRAPH '94* (Orlando, FL, 24-29 July 1994), *Computer Graphics,* Annual Conference Series, 1994, 197-204 + CD-ROM appendix

Azuma, Ronald. Tracking Requirements for Augmented Reality. *Communications of the ACM 36,* 7 (July 1993), 50-51.

Ward, Mark, Ronald Azuma, Robert Bennett, Stefan Gottschalk, and Henry Fuchs. A Demonstrated Optical Tracker With Scalable Work Area for Head-Mounted Display Systems. *Proc. of 1992 Symp. on Interactive 3D Graphics* (Cambridge, MA, 29 March - 1 April 1992), pp. 43-52.

Azuma, Ronald and Mark Ward. Space-Resection by Collinearity: Mathematics Behind the Optical Ceiling Head-Tracker. UNC Chapel Hill Department of Computer Science technical report TR 91-048 (November 1991), 23 pages.

Wang, Jih-Fang, Ronald Azuma, Gary Bishop, Vern Chi, John Eyles, and Henry Fuchs. Tracking a Head-Mounted Display in a Room-Sized Environment with Head-Mounted Cameras. SPIE Proceedings Vol. 1290 Helmet-Mounted Displays II (Orlando, FL, 19-20 April 1990), pp. 47-57.

Patents

US 6,408,251. **Calibrating a Magnetic Compass With an Angular Rate Gyroscope and a Global Positioning Receiver.** Ronald Azuma. Issued June 18, 2002.

US 6,577,976. **Real-Time Sensor Autocalibration for a Multi-Sensor Inertial Tracking System.** Bruce Hoff, Ronald Azuma. Issued June 10, 2003.

US 7,002,551. **An Optical See-Through Augmented Reality Modified-Scale Display.** Ronald Azuma, Ron Sarfaty. Issued Feb. 21, 2006.

US 7,120,875. **Augmented Reality Hybrid Tracking System with Fiducial-Based Heading Correction.** Michael Daily, Ronald Azuma, Howard Neely III, Gerald Isdale. Issued Oct. 10, 2006.

US 7,131,060. **System and Method for Automatic Placement of Labels for Interactive Graphics Applications.** Ronald Azuma. Issued Oct. 31, 2006.

US 7,315,241. **Enhanced Perception Lighting.** Mike Daily, Ron Azuma, Chris Furmanski. Issued Jan. 1, 2008.

US 7,599,789. **Beacon-augmented pose estimation.** Jon Leonard, Howard Neely III, Ron Azuma, Mike Daily. Issued Oct. 6, 2009.

US 7,796,155. **Method and apparatus for real-time group interactive augmented-reality area monitoring, suitable for enhancing the enjoyment of entertainment events**. Howard Neely III, Ronald T. Azuma, Jerry Isdale, Mike Daily. Issued Sept. 14, 2010.

US 8,081,088. **Method and apparatus for apportioning attention to status indicators**. Timothy C. Clausner, Ronald T. Azuma. Issued Dec. 20, 2011.

US 8,335,751. **System for intelligent goal-directed search in large volume imagery and video using a cognitive-neural subsystem.** Michael Daily, Deepak Khosla, Ronald Azuma. Issued Dec. 18, 2012.

US 8,488,877. **System for object recognition in colorized point clouds.** Yuri Owechko, Swarup Medasani, Ronald Azuma, Jim Nelson. Issued July 16, 2013.

US 8,515,126. **Multi-stage method for object detection using cognitive swarms and system for automated response to detected objects.** Swarup Medasani, Yuri Owechko, Michael Daily, Ronald Azuma. Issued August 20, 2013.

US 8,838,381. **Automatic video generation for navigation and object finding.** Michael Daily, Ronald Azuma. Issued September 16, 2014.

US 9,122,707. **Method and apparatus for providing a localized virtual reality environment.** Jason Wither, Ronald Azuma. Issued September 1, 2015.

US 9,262,696. **Image capture feedback.** Joshua Ratcliff, Ronald Azuma, Yan Xu, Gheric Speiginer. Issued February 16, 2016.

US 9,317,133. **Method and apparatus for generating augmented reality content.** Thommen Korah, Ronald Azuma. Issued April 16, 2016.

Invited Presentations

Keynote at VARE 2015 (Virtual and Augmented Reality in Education) (19-21 Nov. 2015, Monterrey, Mexico)

Metaio's InsideAR event (Oct. 2014, Munich, Germany)

National Academy of Engineering Gilbreth Lecture (Feb. 2013, Irvine, CA)

HRL colloquium (Mar. 2012, Malibu, CA)

DTS tech talk (Feb. 2012, Calabasas, CA)

Google TechTalk (Sept. 2011, Mtn. View, CA)

eComm 2011 (June 2011, SFO Marriott)

Total Immersion's *"AR Immersion 2010"* event (June 2010, Los Angeles)

International Game/Film Lounge 2010 (Los Angeles)

Virtual Reality and Software Technologies 2000 (Seoul, South Korea)

First International Symposium on Mixed Reality (ISMR '99), Yokohama, Japan

5th Eurographics Workshop on Virtual Environments (with a special focus on AR), Vienna, Austria (June 1999).

Workshop on Wearable Computer Systems (Aug. 1996, Seattle, WA)

Other Presentations

Guest lecturer at Stanford CS377M: HCI Issues in Mixed and Augmented Reality (May 2, 2016)

Leviathan: Inspiring new forms of storytelling via Augmented Reality (Augmented World Expo, May 2014, Santa Clara, CA)

Panels

AR-VR: There Yet? (Intel Capital Global Summit 2015, 2-4 Nov. 2015, San Diego, CA)

The Renaissance of VR: Are We Going to Do it Right This Time? (SIGGRAPH 2015, 9-13 August 2015, Los Angeles)

The Next Ten Years of AR. (IEEE ISMAR 2008, 15-18 Sept. 2008, Cambridge, UK)

Professional Activities

Served as judge for Auggie awards for Augmented World Expo 2016

International Advisory Board member of the *International Journal of Virtual and Augmented Reality (IJVAR)*

IEEE Fellow (January 2016)

Paper Awards Chair for *IEEE International Symposium on Mixed and Augmented Reality* 2015.

I am a member of the team that won an Intel Labs Academy Award for the “Best Promising New Idea” (April 2014).

I started serving on the Advisory Board for NITLE (National Institute for Technology in Liberal Education) in Fall 2013.

I have been a member of the Steering Committee for the *IEEE/ACM International Symposium on Mixed and Augmented Reality* since 2002, and served as Chair from 2008-2012.

My original AR survey paper was selected as one of 50 influential journal articles by MIT Press. These papers were selected from over 80 MIT Press journals from 1969 to 2011, covering all academic fields.

Co-guest editor of *Computers & Graphics* special issue on "Mobile Augmented Reality" (August 2011)

Program Chair for *IEEE/ACM International Symposium on Mixed and Augmented Reality* 2002 and 2005

Program Chair for *International Symposium on Augmented Reality* 2001

Area Chair for *IEEE/ACM International Symposium on Mixed and Augmented Reality* 2004 [There were ten area chairs who decided which papers to accept] and ISMAR 2006 and 2007 [One of 12 area chairs].

Invited attendee of the 9th Annual *National Academy of Engineering Symposium on Frontiers of Engineering* (Sept. 2003). Attendance was limited to 100 young engineers (50% from industry, 50% from academia) chosen through a competitive selection process. Also invited attendee of the 2005 *Japan-America Frontiers of Engineering Symposium* (Nov. 2005)

Co-Organizer for session on Augmented Reality at the *National Academy of Engineering's 2010 EU-US Symposium on Frontiers of Engineering* (Sept. 2010). Held in Cambridge, UK. Responsible for choosing session topic, recruiting speakers and attendees, and organizing session.

Awards Chair for *IEEE/ACM International Symposium on Mixed and Augmented Reality* 2008

Instructor in *SIGGRAPH* 1995, 1997, 2001 and 2004 courses

IEEE VRAIS (95-98) program committee

IEEE Virtual Reality conference (1999-2002) program committee

VRST conference (2004-2005) program committee

First International Workshop on Mobile Geospatial Augmented Reality scientific committee (2006)

International Workshop on Augmented Reality (1998-2000) program committee

Reviewer for *IEEE ISMAR, ACM SIGGRAPH, IEEE TVCG, IEEE VR, Presence, EGVE,* and others

ACM Senior Member

Member ACM SIGGRAPH and IEEE Computer Society

Former Science Advisory Board member of the USC Integrated Media Systems Center

Former advisory board member for UC Irvine's Center for Virtual Reality

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Contract Fundraising

Pre-launch weapon detection. One DARPA STO seedling. (2008)

CT2WS [Cognitive Technology Threat Warning System]. DARPA STO. (2007)

COVER ME seedling. DARPA IXO. (2007)

UltraVis seedling and Immersive Operations panel. DARPA IXO. (2006)

Pre-launch detection of RPG's. One DARPA STO seedling. Two DARPA TTO seedlings. (2005-6)

Visualization for Insight into the Overall NAS (VisION). AFRL Rome (2004-5)

AR Vision System for Ground Controller. SBIR (NASA/Seagull), in two phases (1999-2001)

Direct Visualization of the Electronic Battlefield. DARPA ATO (1999-2000)

Geospatial Registration of Information for Dismounted Soldiers. DARPA ETO (1997-1999)

Human-Computer Symbiotes. DARPA ITO (1997-1999)

Citizenship

I am a US citizen.