Lewis David Girod

CONTACT INFORMATION

MIT Computer Science and AI Lab
32-G918
32 Vassar St.
Cambridge, MA 02139 USA

Voice: (310) 502-8711
Fax: (617) 253-8460
E-mail: girod@nms.csail.mit.edu
WWW: nms.csail.mit.edu/~girod

OBJECTIVE

A tenure-track faculty position in the Computer Science department of a leading research university.

RESEARCH INTERESTS

My general area of interest is *embedded sensor and actuator networks*. Through the development and study of new applications, I will characterize and abstract new principles and primitives that enable robust embedded sensor systems to scale and flourish.

EDUCATION

University of California at Los Angeles, Los Angeles, California USA

Ph.D. Candidate, Computer Science, May 2001—December 2005

- Dissertation Topic: "A Self-Calibrating System of Distributed Acoustic Arrays"
- Advisor: Deborah L. Estrin
- Degree awarded: December, 2005

University of Southern California, Los Angeles, California USA

Ph.D. Student, Computer Science, September 1998—August 2000

- Completed 27 units of coursework
- Advisor: Deborah L. Estrin

Massachusetts Institute of Technology, Cambridge, Massachusetts USA

M.Eng., Electrical Engineering and Computer Science, October 1995

- Research group: Advanced Network Architecture, Laboratory for Computer Science
- Advisor: Karen Sollins

B.S., Computer Science, October 1995
B.S., Mathematics, June 1995

RESEARCH EXPERIENCE

Massachusetts Institute of Technology, Cambridge, Massachusetts USA
Postdoctoral Researcher **February, 2006—present**

- Affiliated with the WaveScope Project (NSF) led by Hari Balakrishnan and Samuel Madden.
- Collaborating on several projects at UCLA, including an industry-sponsored acoustic application and the development of Acoustic ENSBox V2, including bio-acoustic deployments in Colorado and Mexico.

University of California at Los Angeles, Los Angeles, California USA
Graduate Student Researcher **September, 2000—December 2005**

- Project Affiliations:
  - CENS (NSF STC)
  - GALORE (DARPA NEST Program)
  - NIMS (NSF ITR)
  - Acoustic ENSBox (CENS)
  - EmStar (NSF CRI)
- Designed and implemented the localization portion of the GALORE tiered ad-hoc localization system.

- Made major design and software contributions to the EmStar run time environment, including the low level event system interface, the visualization system, routing protocols, libraries, and acoustic localization.
- Led the design and construction of the Acoustic ENSBox, including the development of the system software and the mechanical design of the microphone array.

Sensoria Corporation, Culver City, California USA
Senior Development Engineer **May, 2000—May 2004**

- WINS NG v2 (DARPA/SensIT): developed radio drivers used in the DARPA SensIT Program.
- MGate Automotive Telematics: Instrumental in the development of several automotive telematics demos on the MGate platform.
- DARPA SHM Program: Application framework design, and software development for Sensoria's portion of the DARPA/ATO SHM Project.
  - Phase II: software co-lead (with Jeremy Elson), delivering a successful 20-node demo
  - Phase III: software lead, delivering a successful 100-node demo.
- Contributed to a DARPA-sponsored pilot Trustworthy Embedded Computing project focused on a security analysis of SHM.

University of Southern California, ISI, Los Angeles, California USA
Graduate Student Researcher **September, 1998—August 2000**

- "Tags": Early work on a low-power wireless research platform
- Fine grained localization through acoustic ranging.
- Multiplexing of HTTP requests to improve throughput over high-delay links. Implemented as a modification of the Squid proxy cache.

AT&T Cambridge Research Laboratory, Cambridge, UK
Summer Intern, PEN project (formerly PicoNet) **Summer, 1999**

Worked as a summer intern on the PEN project (then known as PicoNet). After familiarizing myself with their development environment, I designed and implemented two demo applications for an internal project review. One application integrated their Active Badge database with a simple graphical display to create an active "doorsign". When stuck on the wall next to an office door, it would list the current location of employees assigned to that office. Another application was a pocket agenda that could interact with an active doorsign to direct the user to his next appointment.

MIT Laboratory for Computer Science, Cambridge, MA
Sponsored Research Staff, Advanced Network Architecture Group **November 1995–July 1998**

During this period I worked on a name resolution system intended to support document identifiers. The system implements a distributed database of name resolution information with a multicast cache-sharing protocol. Work on this project included participation in the IETF URN (Uniform Resource Names) working group. From November 1996 to July 1998 I participated in an IRTF working group focused on an Internet Information Architecture. Other duties included systems administration tasks, management of undergraduate research students, and participation in numerous short-term projects.

Teaching Experience

University of California at Los Angeles, Los Angeles, California USA

Teaching Assistant **Winter 2004**
Developed and graded homework assignments, advised student projects, and guest-lectured for CS 213, a graduate-level course in Embedded Networked Systems.

Guest Lecturer **2000–2005**
Presented guest lectures to numerous classes on the topic of EmStar, the SHM Project, and Localization in Sensor Networks. Courses included Berkeley CS 294, Fall 2003, UCLA CS 213, Winter 2003 and Winter 2004, USC CS 694, Spring 2004, and UCLA CS 113, Winter 2005.

Mentoring Experience

- As a staff member at MIT LCS (1995–1998) I supervised a group of 4 undergraduate researchers who were working on our project.
- As a Ph.D. student I have mentored many junior graduate students and undergraduates in an unofficial capacity; throughout my tenure as a Ph.D. student, I was consistently involved with mentoring at least one or two students at any given time. In this capacity I have contributed at many levels, from discussion and clarification of ideas and research goals to detailed consultation on specific implementations, to more direct supervision. The students I have been most actively involved with are Thanos Stathopoulos, Martin Lukac, and Nithya Ramanathan. My work with these students has led to several publications.

Primary Author Publications

Girod, L., Jamieson, K., Mei, Y., Newton, R., Rost, S., Thiagarajan, A., Balakrishnan, H., and Madden, S., "The Case for WaveScope: A Signal-Oriented Data Stream Management System". In *Proceedings of the Third Biennial Conference on Innovative Data Systems Research*. 2007.

—, Lukac, M., Trifa, V., and Estrin, D., "The Design and Implementation of a Self-calibrating Acoustic Sensing Platform". In *Proceedings of the ACM Conference on Embedded Networked Sensor Systems (SenSys 2006)*, Boulder, CO. November, 2006.

—, Stathopoulos, T., Ramanathan, N., Elson, J., Estrin, D., Osterweil, E., and Schoellhammer, T., "A System for Simulation, Emulation, and Deployment of Heterogeneous Sensor Networks". In *Proceedings of the International Conference on Sensor Network Systems (SenSys 2004)*, November 2004.

—, Elson, J., Cerpa, A., Stathopoulos, T., Ramanathan, N., and Estrin, D., "EmStar: a Software Environment for Developing and Deploying Wireless Sensor Networks". In *Proceedings of the 2004 USENIX Technical Conference*, Boston MA June 2004.

—, and Estrin, D., "Robust Range Estimation Using Acoustic and Multimodal Sensing". In *Proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2001)*, Maui, Hawaii, October 2001.

Non-Peer Reviewed

—, Roch, M., "An overview of the use of remote embedded sensors for audio acquisition and processing". In *Proceedings of the IEEE International Symposium on Multimedia (ISM) 2006*, San Diego, CA. December 11-13 2006. *Invited Paper.*

—, Lukac, M., Parker, A., Stathopoulos, T., Tseng, J., Wang, H., Estrin, D., Guy, R., and Kohler, E., "A Reliable Multicast Mechanism for Sensor Network Applications". Center for Embedded Networked Sensing Technical Report #48, April 25, 2005.

—, Bychkovskiy, V., Elson, J., and Estrin, D., "Locating tiny sensors in time and space: A case study". In *Proceedings of the International Conference on Computer Design (ICCD 2002)*, Freiburg, Germany. September 16-18 2002. *Invited paper.*

In Submission

—, Elson, J., T. Stathopoulos, N. Ramanathan, M. Lukac, A. Parker, and Estrin, D., "EmStar: a Software Environment for Developing and Deploying Heterogeneous Sensor-Actuator Networks". In submission to *ACM Transactions on Sensor Networks*.

Ali, A, Collier, T., Girod, L., Yao, K., Taylor, C.E., Blumstein, D.T., "An Empirical Study of Collaborative Acoustic Source Localization". In submission to *Information Processing in Sensor Networks (IPSN07)*.

Stathopoulos, T., Girod, L., Heidemann, J., and Estrin, D., "Centralized Routing for Resource-Constrained Wireless Sensor Networks". In submission to *ACM Transactions on Sensor Networks*.

Selected Publications

Lukac, M., Girod, L., and Estrin, D., "Delay Tolerant Shell". In *ACM SIGCOMM workshop on Challenged Networks (CHANTS 2006)*, Pisa, Italy, September 2006.

Feng, J., Girod, L., and Potkonjak, M., "Consistency-Based On-line Localization in Sensor Networks". In *Distributed Computing in Sensor Systems: Second IEEE International Conference (DCOSS 2006)*, San Francisco, CA, June 2006.

Elson, J., Girod, L., and Estrin, D., "EmStar: Development with High System Visibility". In *IEEE Wireless Communications Magazine*, Dec 2004.

Elson, J., Girod, L. and Estrin, D., "Fine-Grained Network Time Synchronization using Reference Broadcasts". In *Proceedings of the Fifth Symposium on Operating Systems Design and Implementation (OSDI 2002)*, Boston, MA. December 2002.

Merrill, W., Girod, L., Schiffer, B., McIntire, D., Rava, G., Sohrabi, K., Newberg, F., Elson, J., and Kaiser, W., "Dynamic Networking and Smart Sensing Enable Next-Generation Landmines". In *IEEE Pervasive Computing Magazine*, Oct-Dec 2004, pp. 82-89.

Elson, J., Girod, L., and Estrin, D., "A Wireless Time-Synchronized COTS Sensor Platform, Part I: System Architecture" (short paper). In *Proceedings of the IEEE CAS Workshop on Wireless Communications and Networking*, Pasadena, CA. September 5–6 2002.

Merrill, W., Girod, L., Elson, J., Sohrabi, K., Newberg, F., and Kaiser, W., "Autonomous Position Location in Distributed, Embedded, Wireless Systems". In *Proceedings of the IEEE CAS Workshop on Wireless Communications and Networking*, Pasadena, CA, September 5–6 2002.

Book Chapters

Merrill, W., Girod, L., Schiffer, B., McIntire, D., Rava, G., Sohrabi, K., Newberg, F., Elson, J., and Kaiser, W., "Defense Systems: Self Healing Land Mines". In *Wireless Sensor Networks: A Systems Perspective*, Nirupama Bulusu and Sanjay Jha (editors) Artech House, Norwood, MA, August 2005.

Savvides, A., Girod, L., Srivastava, M., and Estrin, D., "Localization in Sensor Networks". In C.S. Radhavendra, K.M. Sivalingam and T. Znati, editors, *Wireless Sensor Networks*. Kluwer Academic Publishers, 2004.

Publications

Trifa, V., Girod, L., Collier, T., Blumstein, D.T., Taylor, C.E., "Automated wildlife monitoring using self-configuring sensor networks deployed in natural habitats". In *International Symposium on Artificial Life and Robotics (AROB07)*, Beppu, Japan, January 2007.

Feng, J., Girod, L., and Potkonjak, M., "Localization in Sensor Networks using Consistency-based Statistical Error Models". In *Third Annual IEEE Communications Society Conference on Sensor, Mesh, and Ad-Hoc Communications and Networks (SECON 2006)*, Reston, VA, September 2006.

Feng, J., Girod, L., and Potkonjak, M., “Location Discovery using Data-Driven Statistical Error Modeling”. In *IEEE INFOCOM 2006*, Barcelona, Spain, April 2006.

Stathopoulos, T., Girod, L., Heidemann, J., and Estrin, D., “Mote Herding for Tiered Wireless Sensor Networks”. Center for Embedded Networked Sensing Technical Report #58, December 7, 2005.

Ramanathan, N. Chang, K., Kapur, R., Girod, L., Kohler, E., Estrin, D., “Sympathy for the Sensor Network Debugger”. In *Proceedings of Sensys*, 2005.

Sohrabi, K., Merrill, W., Elson, J., Girod, L., Newberg, F., and Kaiser, W., “Methods for Scalable Self-Assembly of Ad-Hoc Wireless Sensor Networks”. In *IEEE Transactions on Mobile Computing*, Oct-Dec 2004, 4:317-331.

Wang, H., Estrin, D., Girod, L., “Preprocessing in a Tiered Sensor Network for Habitat Monitoring”. In *EURASIP JASP special issue of sensor networks*, 4:392-401, March 15, 2003.

Wang, H., Elson, J., Girod, L., Estrin, D., and Yao, K., “Target Classification and Localization in Habitat Monitoring”. In *Proceedings of IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP 2003)*, Hong Kong, China. April 2003.

Merrill, W., Sohrabi, K., Girod, L., Elson, J., Newberg, F., Kaiser, W., “Open Standard Development Platforms for Distributed Sensor Networks”. In *Proceedings of the SPIE Aero Sense Conference*, 2002.

Estrin, D., Girod, L., Pottie, G., Srivastava, M., “Instrumenting the World with Wireless Sensor Networks”. In Proceedings of the International Conference on Acoustics, Speech, and Signal Processing (ICASSP 2001), Salt Lake City, Utah, May 2001.

Cerpa, A., Elson, J., Estrin, D., Girod, L., Hamilton, M. and Zhao, J., “Habitat monitoring: Application driver for wireless communications technology”, In *Proceedings of the 2001 ACM SIGCOMM Workshop on Data Communications in Latin America and the Caribbean*, Costa Rica, April 2001.

Conference Presentations

Girod, L., “An overview of the use of remote embedded sensors for audio acquisition and processing”. IEEE International Symposium on Multimedia (ISM) 2006, San Diego, CA. December 12 2006.

Girod, L., “The Design and Implementation of a Self-calibrating Acoustic Sensing Platform”, SenSys 2006, Boulder, CO. November 2, 2006.

Girod, L., “High Rate Sensing Wants Smart, Interactive Sensing”. Panel discussion “Applications: Beyond Dumb Data Collection”, The Third Workshop on Embedded Networked Sensors (EmNets 2006), Cambridge, MA. May 31, 2006.

Girod, L., Stathopoulos, T., Ramanathan, N., Elson, J., Estrin, D., Osterweil, E., and Schoellhammer, T., “A System for Simulation, Emulation, and Deployment of Heterogeneous Sensor Networks”. Presentation to the International Conference on Sensor Network Systems (SenSys 2004), November 2004.

Girod, L., Elson, J., Cerpa, A., Stathopoulos, T., Ramanathan, N., and Estrin, D., “EmStar: a Software Environment for Developing and Deploying Wireless Sensor Networks”. Presentation to the 2004 USENIX Technical Conference, Boston MA June 2004.

Girod, L. and Bychkovskiy, V., “Locating Tiny Sensors in Space and Time”. Poster and demo presented at Mobicom 2002, Atlanta, GA.

Estrin, D., Girod, L., Pottie, G., Srivastava, M., “Instrumenting the World with Wireless Sensor Networks”. Presentation to the International Conference on Acoustics, Speech, and Signal Processing (ICASSP 2001), Salt Lake City, Utah, May 2001.

Girod, L., and Estrin, D., “Robust Range Estimation Using Acoustic and Multimodal Sensing”. Presentation to the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2001), Maui, Hawaii, October 2001.

Invited Talks

Girod, L. “Developing the Acoustic ENSBox: Experiences with Emstar”. Talk given to the Harvard Systems Research Group, December 15, 2006.

Girod, L., “The Design and Implementation of a Self-calibrating Acoustic Sensing Platform (SenSys)”. Talk given at Tecnológico de Monterrey, Mexico City, MX, November 29, 2006.

Girod, L., “The Design and Implementation of a Self-Calibrating Distributed Acoustic Sensing Platform (revised)”. Talk given at University of Colorado, Boulder, July 2006.

Girod, L., “The Design and Implementation of a Self-Calibrating Distributed Acoustic Sensing Platform”. Talk given at UMass Amherst, April 2006.

Girod, L., “Acoustic ENSBox: A Deployable Platform for System Calibration and Collaborative Acoustic Sensing”. Presentation to the 2005 CENS Research Review.

Girod, L., “EmStar: A Community Resource for Heterogeneous Embedded Sensor Network Development”. Presentation at the NSF CISE Kickoff PI Meeting, Urbana IL, July 26 2005.

Girod, L., “A Deployable Platform for Collaborative Acoustic Sensing”. Presentation to the MIT Computer Science and AI Lab, Cambridge, MA, June 1, 2005.

Girod, L., “EmStar: A Software Environment for Developing and Deploying Wireless Sensor Networks”. Presentation to the 2004 CENS Research Review.

Girod, L., “Software Systems Infrastructure for Ecosystem Monitoring and NIMS”. Presentation at the 2004 CENS NSF Site Visit.

Girod, L., “EmStar: A Software Environment for Developing and Deploying Wireless Sensor Networks”. Lecture given in USC 694 (Prof. Ramesh Govindan), 13 April 2004.

Girod, L., “Design Lessons from an Unattended Ground Sensor System”. Lecture given in Berkeley CS294-1 (Deeply Embedded Network Systems/Prof. David Culler), September 23, 2003.

Girod, L., “Position Estimation Algorithms”. Lecture given in UCLA IPAM Issues in Sensor Networks Seminar Series, UCLA, May 2002.

Elson, J. and Girod, L., “GALORE Localization Project Demo”. Demo and presentation, given with Jeremy Elson at the DARPA/NEST PI Meeting, July 2002, Bar Harbor, ME.

Grants and Proposals

I have contributed to the technical content of the following successful grant proposals:

- Toyota Research feasibility study for acoustic-based road hazard detection and avoidance, awarded 2006.
- NSF CISE CRI: “EmStar: A Community Resource for Heterogeneous Embedded Sensor Network Development”, awarded 2005–2008.
- UC MICRO: “Robust Fine-Grained Position Estimation for Sensor Networks”, awarded 2002–

2003.
- NSF STC: "Center for Embedded Networked Sensing", awarded 2002–2012.
- DARPA NEST Program: "GALORE: Globally Ad-hoc, Locally Regular Systems", awarded 2001–2004.
- NSF: "SCOWR: Scalable Coordination of Wireless Robots", awarded 2000–2003.
- DARPA SensIT Program: "SCADDS: Scalable Coordination Architectures for Deeply Distributed Systems", awarded 1999–2002.

Service

- TPC Member, Information Processing in Sensor Networks (IPSN) 2007.
- Reviewer for Journal articles in IEEE/ACM Transactions on Sensor Networks, Transactions on Networking, as well as many conferences and workshops.

Honors and Awards

- 2006 Outstanding Ph.D. Award, UCLA CS Department
- Best Poster, 2001 UCLA CS Department Research Review
- USC Engineering Powell Fellowship, 1998–2000.

Patents

Patents resulting from work at Sensoria Corporation.
- 6,832,251: Method and apparatus for distributed signal processing among internetworked wireless integrated network sensors (WINS)
- 6,826,607: Apparatus for internetworked hybrid wireless integrated network sensors (WINS)
- 6,735,630: Method for collecting data using compact internetworked wireless integrated network sensors (WINS)
- 6,859,831: Method and apparatus for internetworked wireless integrated network sensor (WINS) nodes
- 7,020,701: Method for collecting and processing data using internetworked wireless integrated network sensors (WINS)

References

- Prof. Deborah Estrin
  Department of Computer Science
  University of California, Los Angeles
  destrin@cs.ucla.edu
  (310) 206-3923

- Prof. William Kaiser
  Department of Electrical Engineering
  University of California, Los Angeles
  kaiser@ee.ucla.edu
  (310) 206-3236

- Prof. Miodrag Potkonjak
  Department of Computer Science
  University of California, Los Angeles
  miodrag@cs.ucla.edu
  (310) 825-0790

- Prof. Eddie Kohler
  Department of Computer Science
  University of California, Los Angeles
  kohler@cs.ucla.edu
  (310) 267-5450

Detailed Description of Current Projects

Acoustic ENSBox

The Acoustic ENSBox is a platform I developed to support distributed acoustic sensing applications. The platform is a self-contained unit containing an ARM-based CPU module, a wireless network interface, a 4-channel acoustic sampling interface, and a battery. The system connects to a "head unit" that hosts an array of 4 microphones and 4 piezo tweeters in a Lucite and aluminum chassis. The microphones are condenser microphones with a custom pre-amplifier board.

In addition to the hardware, the Acoustic ENSBox includes a complete stack of system software designed to support distributed acoustic sensing. The system autonomously forms an ad-hoc wireless network that supports inter-node coordination, hosts routing services and reports diagnostics to a user with a laptop. It supports accurate time synchronized sampling, enabling application programmers to trivially compare time series data taken at the same time at two or more nodes. An acoustic localization system (described below) autonomously and accurately estimates relative position and orientation for all nodes in the system.

With this stack of system software, this platform is ideal for many types of collaborative sensing, especially target localization algorithms based on "beam-crossing", where multiple states estimate bearing to a target and combine their estimates to compute a location. We hope to see the Acoustic ENSBox platform taken up by several groups at UCLA who are involved in acoustic localization projects. I am currently working with Prof. Kung Yao's group to compare their bearing estimate algorithms to my own that I developed for the position estimation application. I am also working with a student from Prof. Charles Taylor's group who is developing software on the Acoustic ENSBox platform to detect acorn woodpecker calls.

Wideband Acoustic Localization System

I performed early work in acoustic ranging using wideband audible acoustics (2000) and further developed this work in my work on the SHM system at Sensoria (2001-2003). In 2005 I developed a new acoustic ranging system as part of my Ph.D. thesis. This new version is based on the Acoustic ENSBox platform, and leverages networking and coordination primitives I am developing in parallel.

This work has been highly successful, resulting in a highly accurate, self-configuring localization system. This system estimates the 3-D position and orientation of a collection of nodes, with no prior knowledge or anchor points. The resulting relative coordinate system is then fit to anchor points if absolute coordinates are required. The system works outdoors and, unlike many competing systems, is highly resilient to environmental noise and obstructing foliage. In tests localizing 10 nodes in a forested, hilly region 70mx50m, the system achieved an average of 20 cm position error.

Our system also leverages the 8cm baseline microphone array supported by the Acoustic ENSBox to estimate 3-D direction of arrival (DOA). In controlled tests, we achieved an error distribution with a standard deviation of 0.96 degrees, and a maximum range of ± 2 degrees. These results represent an improvement upon similar published work. These results are documented in detail in my thesis[1]. We also plan to submit several papers next year to document these outstanding results.

EmStar

EmStar is a software system and framework designed to support the development of distributed sensor network applications. Similar to the MFC or Gnome toolkit, EmStar provides a specific set of primitives, libraries, and services that support the unique requirements of wireless, distributed sensor systems. EmStar's multi-process design and multi-client message-passing IPC emphasizes modularity, robustness, and transparency. EmStar provides numerous types of real-code simulation and emulation to enable quick-turn development and debugging. EmStar was jointly conceived and developed with Jeremy Elson, and is now seeing wider use in several groups at UCLA, MIT, Ohio

[1] Note that the results of the test in the forest have been improved since the thesis was published. We found that the largest source of error in our results were inaccuracies in our initial survey of ground truth. After re-surveying, we achieved the results quoted above.

State, and elsewhere. EmStar is also the basis of a new undergraduate project class in sensor networks at UCLA. In addition to maintaining much of the core functionality of EmStar, I also use it to develop wireless network protocols and systems as part of my research. EmStar currently comprises about 250K lines of C. Continuing work on EmStar is supported by a NSF CISE Computing Research Infrastructure (CRI) grant awarded in 2005.

Reliable Multihop State Broadcast (StateSync)
One of the underlying components of my thesis work is a middleware layer providing a communications primitive designed to support collaborative sensor applications. The StateSync primitive is a multi-hop reliable broadcast transport that enables a node to reliably and efficiently publish a view of its current state to N-hop neighbors. StateSync provides a convenient API in which key-value pairs can be inserted, removed, and modified. Each of these state changes will be seen at all designated receivers within a probabilistic latency bound. StateSync uses an efficient packet format and Application Layer Framing to achieve low protocol overhead, and uses periodic soft-state refresh of sequence numbers to preserve liveness with very low quiescent overhead.

This system is similar to other distributed primitives such as tuplespaces, but relaxes some of the properties in order to be appropriate to the constraints of distributed wireless systems. For example, where tuplespaces enable locking of tuples and attempts to resolve contention, with StateSync each sender's data is in a different space (i.e. the ID of the sender is an implied part of the key.) Thus where a tuplespace can implement distributed semaphores and other coordination methods, ClusterSync can only be used for looser forms of coordination. In addition, while StateSync guarantees eventual consistency and guarantees that all observed states are previous states of the sender, StateSync does not guarantee that every intermediate state is observed. This was a deliberate design decision because the network overhead and latency of a full tuplespace implementation would be prohibitive, especially considering the higher rates of node and communication failures that occur in distributed wireless systems.

The StateSync primitives are being applied in several projects, including an acoustic localization and habitat monitoring system, a "Mote Herding" system in which multiple microservers collaborate to track and tend a denser network of motes, and for configuration and construction of sink trees in the CENS seismic array. In addition to the multihop version, the same system can be used in a single-hop capacity, where it is useful for increasing the efficiency of many protocols based on soft-state refresh, such as Directed Diffusion.

StateSync is one of several middleware components I envision for sensor networks; I consider this an important research area to continue.

Past Projects

Projects from Work at Sensoria Corporation (2000-2004)
For several years during my Ph.D. I worked part time at Sensoria, a startup in Culver City. The hours I put in varied, usually increasing to full time in the summers and sometimes dropping as low as about 1 day/wk. While working there I worked on a number of projects:

Sensoria: MGate Vehicle Network Gateway (2000-2001).
The MGate is a Linux platform intended to be integrated into a car or truck and provide certain services including Internet access and application hosting. This project presented a very open-ended design problem, in which we were to design a framework to address an unknown set of networked-vehicle applications. We approached the problem by implementing a few initial applications, and then factoring out common services and providing interfaces that enabled multiple applications to share resources and work concurrently. The result was a suite of system services that enabled multiple independent applications to gain secure, accountable, cost-conscious access to network and vehicle services.

I collaborated with Jeremy Elson on the initial system design and implementation, including the services that enable multiple applications to coordinate the use of costly and diverse network access (e.g. via cell phone and 802.11 hotspot). I also implemented a generic "registry" service that integrated with a backend database service implemented by Jeremy Elson. Using these tools we demonstrated the ability to concurrently run a mobile, backend-configurable media player application, and a vehicle diagnostics application. In the later phases of development, I contributed to the design of several additional services, including an automated software upgrade and management system and an automatic speech recognition interface toolkit.

Sensoria: WINS-NG Network Stack (2001).
As part of the delivery to the SensIT Program, the Sensoria WINS-NG platform included a novel interface to its dual low-power TDMA radio systems. This interface was composed of a stack of device drivers implemented in user-space using FUSD. I implemented the low-level radio link drivers for the WINS-NG stack, as well as many utility and interface libraries supporting status interfaces and an event driven programming model.

Sensoria: SHM Demonstration Project (2001-2003).
SHM (Self Healing Minefield) was a 3-year DARPA program that culminated in a 100 node demonstration of a fully autonomous "distributed robot". On startup, the system would form a multi-hop RF network, use acoustic ranging to discover the relative positions of the nodes, and then monitor the health of the network. If a node disappeared from the network (e.g. due to a failure or tampering) and opened a breach through the field, a distributed algorithm would select one or more nodes to fire rocket thrusters to "hop" into the breach. The SHM program had several intermediate demonstrations with increasing numbers of nodes, and the final demonstration was 100% successful.

The SHM project was especially interesting to me because it was very closely related to my actual thesis work. In addition, it represented a deployment on a scale that we had not previously experienced (previous deployments in my USC and UCLA work numbered at most 30 units). We learned a great deal about building developing and deploying large sensor networks in the process, and we are leveraging this knowledge in many of the new CENS applications, such as the CENS seismic array project, and more generally in the EmStar work. Initial Em* development occurred concurrently with the final phase of SHM, and in fact SHM leveraged some of the early EmStar modules (Audio Server and TimeSync) as they were released to the public domain.

The SHM localization system is essentially a first implementation of exactly what my thesis work set out to accomplish. It is a completely distributed, completely autonomous system that constructed a relative coordinate system with no external or a priori information, using the acoustic ranging techniques I had previously developed and published. The final version leveraged the audio server and integrated timesync system published as a result of the GALORE work, but extended that work with a more sophisticated and more scalable positioning algorithm, fully integrated across a low-rate multihop wireless network. The main contribution beyond the GALORE work lay in the acoustic positioning system and a novel publish-subscribe transport layer.

In the final phase of the SHM project (2003), I took the role of software and design lead in an 8 month effort to scale the system up from 25 to 100 nodes. In this process, I was responsible for defining sub-tasks and managing the development efforts of two colleagues. I was then responsible for integrating their efforts, along with components provided by other contractors, into a final, working system.

Sensoria: SHM Acoustic Communications Subcomponent (2002).
As part of the SHM project, Sensoria was contracted to develop a proof-of-concept acoustic communications transceiver. Should the RF channel be completely jammed, the SHM mines would switch over to a mode where they used very low bit-rate acoustic communications to detect nodes that had been destroyed. For this project, I developed a 30 bit/second packet communications link

using the same SHM hardware. This work focused on the simplified problem of a single sender and receiver; there was no implementation of medium access. The system employed a streaming FFT and a 4-symbol coding scheme that was able to achieve 30 bits/second at a range of 10 meters in outdoor conditions.

Sensoria: NetPak Ad-hoc Networking Project (2003).
This project is intended to produce a "plug and play" adhoc network that can provide access to locally networked clients. I have contributed in a design and limited implementation capacity.

Sensoria: Trustworthy Computing Project (2003).
SHM motivated concern about the trustworthiness of networked embedded systems. The trustworthy computing project was a brief pilot program to better characterize where the difficult problems lie in the area of trustworthy embedded systems. This pilot involved considering SHM as a case study and analyzing it to discover methods of detecting an attack in progress, or more generally a system failure, and ways of toughening the system against cascading failures, whether malicious or inadvertent. To address this, we implemented a monitoring system to measure the system's vital signs and some simple responses to take when an unusual condition is detected. We tested this framework with a few simple attacks on the system and used it to construct defenses.

Sensoria: SHM Transition Project (2004).
In this project, we are supporting General Dynamics and Alliant TechSystems in developing the SMM/C4ISR Intelligent Minefield System, based on our previous work on SHM. I am providing support in a design and limited implementation capacity to help apply the SHM work to their system under development.

AT&T Laboratories Cambridge PicoNet project (Summer 1999)
During summer 1999 I worked as an intern at the AT&T Cambridge UK Laboratory, working on the PicoNet project (later renamed PEN). This project had developed a small, low-power hardware platform based on a 16 bit microcontroller running uCOS. I was tasked with developing some demonstrable applications to support continuing the project at their next project review. My contribution was to develop two applications. The first was a "smart doorsign". This was a small device with a screen that would be placed next to an office door and programmed with knowledge of which office it was near and what people sat there. It would then display this information, along with the current locations of the people in the office. This location information was gathered by issuing queries to the active bat system, which had been previously developed at AT&T (ORL). The sign assumed that it was always one hop away from a gateway that could proxy the requests; my part of this effort was to develop the gateway code, both PC and PicoNet side, and the software on the doorsign itself, including a simple GUI toolkit to support menu selections. My second application was an "smart agenda" application integrated with the doorsign. A visitor to the lab would have their agenda programmed into a PicoNet device which they carried in their pocket. Then, if they were lost and needed to find their way to their next appointment, they could walk to the nearest doorsign and query it to discover which way to walk to get to their next appointment. These applications were not very complex, but they resulted in debugging a number of layers of the PicoNet system itself.

USC/ISI Tag Project (1999-2001)
This project was intended to develop a low-power platform for sensor networks. A series of simple, microcontroller-based boards featuring sensors and radios were developed with the help of a contractor who developed the detailed schematics, layout, and assembly. Our "tag" design was based on the idea of having multiple interconnected modules, each with its own processor. Thus, we developed a radio board, a sensor board, and a base board to control power and high-level system management. These components were interconnected by serial busses and interrupt lines. Unfortunately, a combination of factors led us to abandon this effort. Berkeley had just introduced a less-expensive, more fully worked out platform of similar size, and we were unable to justify the resources required to complete the project.

Despite the fact that we suspended work on the Tags project, I came away with a much stronger understanding of the fundamental issues and learned a great deal about the mechanics of hardware design, which was substantially outside of my previous experience. In addition, I have never given up on the idea of a multi-processor tag design, and as it turns out, the Berkeley mote has since run into a number of limitations resulting from its monolithic hardware design. These limitations are leading to new, more modular designs along the lines of our old tags work. Nonetheless, the Berkeley mote has pushed the community forward, in part because of its simplicity. This has been a learning experience for me that it's often best to start simple and gain experience, rather than trying to anticipate the final design.

MIT/LCS URN resolution system project (1995-1998)

This work was an outgrowth of my master's thesis work at LCS in the Advanced Network Architecture group. URNs (Uniform Resource Names) are intended to be persistent document identifiers; a URN resolution service would resolve these identifiers to less-persistent "locators", such as URLs or pathnames. Our system was designed to implement a distributed database, with a caching scheme to improve performance. Similar to DNS, our system enabled decentralized delegation of namespaces, rooted at a centralized root naming service. From 1995-1998 I worked on this project, hiring and managing a team of undergraduates, and participating in the IETF URN working group to discover the requirements for such a system and discuss the various issues surrounding the problem. While standards development on URNs achieved some of its objectives, the community lacked cohesion and clarity of purpose. The effort to develop and deploy a long-lasting URN infrastructure was soon eclipsed by short-term needs developed during the Internet boom.