OVERVIEW

The Laboratory for Engineering Man/Machine Systems (LEMS) provides an outlet for collaborative research on the design and analysis of intelligent computer systems. Faculty work closely with appropriate university, governmental, and private organizations to foster high-technology growth in the region. This growth is effected through substantive research, from theory to practical application, and the training of skilled graduate and undergraduate computer engineers and scientists. The Laboratory was founded in 1981 within the Electrical Sciences faculty of the Division of Engineering at Brown University. The faculty members associated with LEMS have expertise and interests in theoretical and practical problems in the following areas:

- Computer Vision and Image Processing
- Pattern Recognition
- Modeling and Control of Complex Dynamical Systems
- Industrial Design and Metrology
- Speech Recognition and Processing
- Microphone Array Systems
- Reconfigurable Parallel Computers
- Digital Signal Processing
- High-Performance Low-Power Computer Architectures
- VLSI Computer-Aided Design

The research activities of the group span the range from developing theoretical-mathematical frameworks, to the construction and use of

LEMS

The Laboratory for Engineering Man/Machine Systems

Division of Engineering
Brown University
Providence, RI 02912-9104

Present and Past Affiliates

AMP

Analog Devices

Augat

AT&T Technologies

Bellcore

GTECH

Honeywell

IBM

Loral Ifrared and Imaging Systems

NYNEX

Polycom

Sanders Associates

U.S. West Advanced Technologies

Vtel Corporation

Wang Laboratories

original, advanced hardware and software systems for new product prototypes. Collaborative efforts not only cross disciplines among various LEMS faculty members, but also include other departments, including Applied Mathematics, Computer Science, Cognitive and Linguistic Sciences, and Neural Sciences.

A fundamental motivation for LEMS is to promote the transfer of ideas, know-how and technology developed by faculty into industrial practice. This occurs through various means including graduate student/postdoctoral fellow projects sponsored by companies, joint research projects, and the licensing of technology developed at LEMS. In addition, many LEMS students find employment with affiliate companies, further strengthening the links between industry and LEMS to their mutual benefit.

INDUSTRIAL AFFILIATES PROGRAM

Strong two-way ties with industry are an important part of the LEMS program. To implement these ties, LEMS has developed a corporate affiliation program, which benefits both the corporations and the laboratory. The major benefit to the corporation is the exchange of technology, occurring primarily through the interaction between corporate and LEMS personnel. Other benefits include:

- Placement of LEMS students in companies
- Graduate student projects based around problems identified by the company
- Company employee resident programs within LEMS
- Participation in LEMS industrial symposia
- Access to LEMS publications.

Basis of Collaboration

Companies typically work with LEMS in one or more of the following ways:

- **By becoming a participant in our Industrial Affiliates Program**

  Industrial partners may take advantage of all the benefits listed above including access to faculty and exchange of technology and ideas.

- **Graduate and Postdoctoral Fellowships**

  These are used to support graduate students pursuing a Ph.D. degree or postdoctoral research fellows. The fellowships can be either unrestricted or for a named candidate.

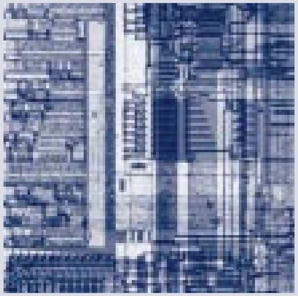
- **Specified Project Support**

  Personnel and/or equipment support are devoted to a specific research or development project agreed by the company and the LEMS participants.

- **Grants**

  Unrestricted additional equipment or monetary grants are used to support basic LEMS research.

Details of the current affiliation fees and levels of graduate student/ postdoctoral fellowship support are available on request.



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R. IRIS BAHAR

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LEMS FACULTY

PROFESSOR BAHAR's research interests include computer-aided design of VLSI circuits, computer architecture, and hardware/software co-design. Her particular emphasis within these areas is on high-performance and low-power design techniques. Her work currently focuses on three areas:

- **Reducing Power Dissipation in High-Performance Microprocessors**
  Today's high-performance microprocessors use various techniques to increase the throughput and decrease the cycle time to execute a wide range of applications. These techniques include out-of-order execution, speculative execution, advanced branch prediction techniques and data and instruction pre-fetching. Together, application of these techniques has shown significant increases in microprocessor performance. This research focuses on analyzing the effects of these techniques on performance and power dissipation of the microprocessor, and developing new techniques to optimize for both constraints.

- **Integration of Non-Conventional CMOS Structures into Fully-Automated Synthesis Tools**
  Design automation tools have proved to be an invaluable resource in logic synthesis, technology-mapping, simulation, verification, and testing of VLSI systems and chips. While ASIC designers have benefited in particular from these tools, designers of semi-custom or fully-custom high performance chips continue to rely on manually designing major portions of their chips. The goal of this research is to automatically synthesize designs that combine both conventional and non-conventional CMOS structures within the same circuit in order to take optimal advantage of each structure in terms of area, delay, power consumption, and robustness of design.

- **Hardware/Software Co-Design for Embedded Systems**
  Traditionally, the hardware and software components found in embedded electronic systems were designed separately and brought

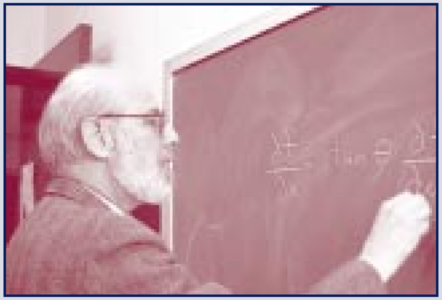
together only during the final ''system integration'' stage. Today it is becoming increasingly important that software and hardware components be simulated and synthesized together so as to better meet design and time-to-market constraints. This research explores new ways of integrating these two design efforts together to more effectively explore different solutions within the constraints of low-power design.

Professor Bahar is talking to a number of companies about possible collaborative projects. She teaches courses on the Design of Computing Systems, Synthesis of VLSI Systems, and Advanced Computer Architecture.

PROFESSOR COOPER's research presently focuses on the development and application of new geometric, algebraic, and probabilistic approaches, models, and algorithms for recognizing and estimating 2-D and 3-D geometric information from images, video and range data.

Specific projects in progress include:

- Geometry-based searching of image databases.
- Development of a new methodology and algorithms for implicit algebraic 2-D curves and 3-D surfaces, that consist of algorithms for fitting these models to data, and geometric invariants and single-computation pose estimation for object recognition and shape alignment.
- Automated aerial image analysis.
- Automated document analysis.
- Estimation of 3-D shape and 3-D geometric information of objects and scenes from images, video, or range data.
- Human/computer geometry communication through user-made sketches.



DAVID B. COOPER

Computer Vision, Image and Video Processing, Pattern Recognition, Applied Stochastic Processes

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◆ Automated video analysis.

Professor Cooper teaches courses on Computer Vision, Image Analysis, Digital Communications, Pattern Recognition, and Applied Stochastic Processes.

BENJAMIN B. KIMIA

Computer Vision, Object Recognition, Perceptual Shape Similarity and Categorization, Medical Imaging, Indexing into Image Databases, Digital Halftoning, 3-D Scene Recovery

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Vision is the complex task of recovery of scene structure from single or multiple images. Biological systems have mastered the task and successfully interact with their environment through visual and other sensory signals. Our goal is to engineer vision systems to automate this task for industrial and other applications, not only from optical images, but also for images from magnetic resonance (MR), computerized tomography (CT), ultrasound (US), infrared, and other modalities.

PROFESSOR KIMIA'S research is focused on several areas of computer vision and image processing. Specifically:

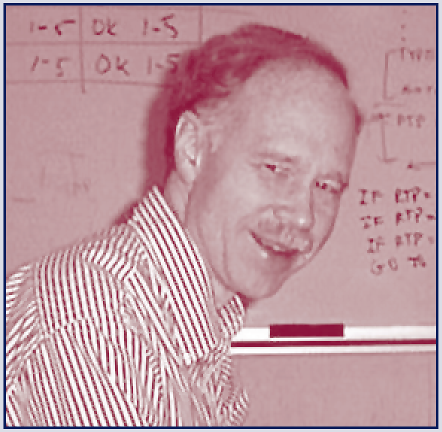
◆ **Recognition and representation of two-dimensional forms** using symmetry-based, medial representations (shocks) which are viewed as singularities of a wave propagation process, detected and classified as shocks of nonlinear PDEs, and organized into a graph, and matched against a database of shapes organized into categories. A key goal is to understand the fundamental role of shape similarity for categorization of shape, both from computational and perceptual aspects, and the roles of parts, protrusions, and bends as the three-pronged perceptual organization of shape.

◆ **Medical imaging analysis** of MR and CT images of medical structures, e.g., the brain, carpal bones, the bronchial airway, vascular structure, etc. The goal is semi-automated segmentation of these structures and their registration over time, patient, and scanning modality, for visualization, morphometric measurements, and multimodal fusion, as used for pre-surgical planning and other clinical needs (in collaboration with Rhode Island Hospital).

◆ **Digital halftoning of color images** for printing on binary output devices (laser, thermal, and inkjet printers). The goal is to "paint" a photograph with a limited set of colored dots to generate the illusion of a continuous-tone image, not unlike the artwork of Seurat. An understanding of how the human visual system abstracts and perceives levels of structure (beyond a lens blurring model), and how colors are perceived from an amalgamation of nearby and overlapping color dots is essential in generating optimal quality halftones.

◆ **The interactive recovery of 3-D scenes from multiple images.** The goal is to develop 3-D free-form models that can be easily generated, modified, and placed in a scene by a user as the initial coarse estimate of shapes in the scene. The detailed structure is then recovered automatically. The resulting 3-D reconstruction is suitable for a variety of applications including virtual reality presentations for industrial, medical, and military training, for entertainment, virtual tourism, and numerous other applications.

PROFESSOR PATTERSON is a Senior Research Engineer and Lecturer who has been active in the Microphone Array Project led by Professor Sliverman. He also teaches a wide range of courses, primarily upper division courses on logic and circuits.



WILLIAM R. PATTERSON

Microphone Array Systems, Analog and Digital Circuits, Instrument Design, Remote Sensing Spectroscopy

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ALLAN E. PEARSON

Control Theory, System Modeling and Parameter Identification

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PROFESSOR PEARSON's current research topics include the following:

- System Modeling and Parameter Identification: Techniques are under development for the least squares parameter identification of systems modeled by nonlinear input-output differential and functional differential equations. Examples can be found in diverse areas such a pharmacokinetics, robotics, lasers and viscoelastic materials, as well as modeling for control systems engineering. The least squares formulations make use of projections on the data in ways that circumvent dealing with unknown initial and boundary conditions for time-limited input-output data. Structure determination procedures are under development for particular classes of systems, like those modeled by polynomial input-output differential equations, using the singular value decomposition as the basic computational tool.
- Control of Differential Delay Systems: Systems with pure time delays, like transport lag in chemical plants, are inherently difficult to control owing to the infinite dimensionality of the systems when modeled by differential equations. Research is currently underway on a reducing transformation technique for linear differential delay systems, which facilitates using finite dimensional methods in a variety of control problems. These include feedback stabilization, observers, approximate lumped parameter models, and optimal feedback control utilizing a separation principle. The basic aim is to devise a functional transformation on the state of the system such that the reduced order model inherits all the unstable and poorly damped modes of the system.

Courses taught by Professor Pearson include Linear and Nonlinear Systems, Classical and Modern Control Systems Theory.

PROFESSOR SILVERMAN's main research areas are speech recognition, microphone-array acoustics, digital signal processing algorithms, and parallel architectures for the above. Current projects include:

- Armstrong reconfigurable architecture project (Armstrong is a parallel multiprocessor): Three versions of this system have been designed, constructed and tested at LEMS. Armstrong III, currently operational, consists of twenty nodes, each with flexible reconfigurability as the concept of Metamorphic Computing has been introduced.
- System and development for microphone arrays for locating talkers, beamforming to them, and collecting speech and other acoustic data: The largest real-time microphone array system (for 512 microphones) ever built has just been completed and is being used in current research.
- Algorithms for microphone arrays for beamforming/dereverberation, locationing and noise reduction: Two new algorithms have just been patented and licensed to two companies.
- High-speed distributed signal processing for speech recognition: The application of Armstrong III for training hidden Markov models is an important topic.
- Time-varying modeling for speech recognition.
- Improvements in acoustic processing for a real-time, talker-independent, connected-alphadigit recognition using hidden Markov modeling: Acoustic processing for representation of semantic features is a key research area.

Professor Silverman teaches courses in Computer Architecture, Digital Signal Processing, Communication Systems, Circuit Theory, and Speech Processing.

HARVEY F. SILVERMAN

Speech Recognition, Microphone Array Systems, Parallel Computing Architectures for Digital Signal Processing

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WILLIAM A. WOLOVICH

Image Understanding, Industrial Design and Metrology, Intelligent Systems

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PROFESSOR WOLOVICH's primary research areas are machine intelligence applied to image understanding and automatic control, with particular emphasis on precision manufacturing applications. Professor Wolovich and his students are developing innovative mathematical and computational methods for identifying, comparing and orienting algebraic curves and surfaces. Their methods involve new decompositions of implicit polynomial equations as sums of conic-line products, as well complex variable representations for algebraic curves.

Professor Wolovich and his students have begun a comprehensive investigative effort in collaboration with Brown and Sharpe Measuring Systems in North Kingston, RI, with the broad overall goal of applying their advanced mathematical and computational algorithms to significantly enhance current methods of acquiring, collecting and analyzing measured data obtained from a variety of two and three dimensional manufactured parts. This effort will require extensive use of a new Brown and Sharpe Chameleon Coordinate Measuring Machine, which was recently provided to LEMS by Brown and Sharpe to support this research effort.

Current projects include:

- 3-D surface construction (CAD) from 2-D cross-sectional models, using conic-factor alterations for local shape changes and affine transformations for global shape changes.
- The use of absolute algebraic invariants for object identification and integrity verification.
- Robust algebraic models for 2-D curves and 3-D surfaces.
- Precise and rapid measurement of manufactured parts.

- Vision-based motion estimation and control.
- Co-stabilization of multivariable systems.

FACILITIES

LEMS is housed in a 3200 square foot laboratory in the Division of Engineering at Brown University. Some twenty graduate students (fifteen Ph.D.), three Visiting Scholars and fifteen undergraduate Honors program students conduct research here and are involved in projects with industrial affiliates.

The computing facilities at LEMS consist of twenty SUN, six Silicon Graphics/O2 systems and a new PC cluster of Pentium II machines running NT. In addition, LEMS hosts a range of devices for image acquisition, some special systems for microphone arrays and parallel processing, and equipment for building advanced hardware.

LEMS has also recently acquired a $200,000 Brown and Sharpe Chameleon Coordinate Measuring Machine. This state-of-the-art instrument uses both tactile and optical probes to locate and precisely measure geometric and free-form object features.

LEMS STAFF

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DESTINATIONS OF LEMS GRADUATES

Both undergraduate and graduate students from LEMS find employment in top research organizations and companies throughout the world. Here is a sample of some of the organizations employing LEMS alumni/ae.

Academic

- Academia Sinica, Taiwan
- Dartmouth College
- McGill University
- University of Denver
- US Air Force Academy
- Cooper Union
- Harvard University
- University of Cape Town
- University of Sheffield
- US Naval Academy

Research Laboratories

- BBN
- MIT Lincoln Laboratories
- Xerox PARC
- IBM Research
- Siemens

Large Companies

- Analog Devices
- Digital
- Intel
- Microsoft
- Picker
- Trilogy
- Data General
- Hewlett Packard
- Sanders Lockheed Martin
- Oracle
- Silicon Graphics
- Xerox

Start-ups and Small Companies

- Advanced Systems
- Nuance
- Omnia

Produced and edited by Jane Williams