Laboratory for Information and Decision Systems

The Laboratory for Information and Decision Systems (LIDS) is an interdepartmental laboratory for research and education in systems, control, optimization, communication, networks, and statistical signal processing. These disciplines, which span the domain of the analytical information and decision sciences and share a common approach to problems and a common mathematical base, play a critical and pervasive role in science, engineering, and society more broadly. LIDS provides this melting pot of disciplines with an energized environment that fosters the research needed for the future and instills in our students the disciplinary depth and interdisciplinary understanding required of research and engineering leaders of today and tomorrow.

LIDS draws its faculty principally from the Department of Electrical Engineering and Computer Science (EECS) and the Department of Aeronautics and Astronautics (Aero-Astro). However, because the disciplines in which LIDS is involved are also of great interest across the Institute, it has built and continues to build collaborations and interactions with many other units, including the Operations Research Center (ORC), whose recently named codirector Patrick Jaillet is a LIDS faculty member; the Computer Science and Artificial Intelligence Laboratory (CSAIL); the Research Laboratory of Electronics; the MIT Energy Initiative (MITEI); the Transportation Initiative; the Department of Civil and Environmental Engineering (CEE); the Department of Mechanical Engineering; the Department of Earth, Atmospheric, and Planetary Sciences; the Department of Brain and Cognitive Sciences (BCS); the Department of Economics; the Sloan School of Management; and the Harvard–MIT Division of Health Sciences and Technology. LIDS also plays an important role in a new project within the Singapore–MIT Alliance for Research and Technology (SMART) on the future of urban mobility. In addition, LIDS has a strong and growing set of interactions with industrial organizations, national laboratories, and international institutions that provide funding, collaborators, and challenging problems to drive its research. Among the organizations with which it has or is developing relations are Draper Laboratory, Lincoln Laboratory, Los Alamos National Laboratory, Siemens, Shell Oil Company, Honeywell, Ford Motor Company, Société Nationale des Chemins de fer français, and Aurora Flight Sciences. Also, thanks to a rich history of research excellence and leadership, LIDS remains a magnet for the very best, attracting not only outstanding students and faculty but also a continuing stream of world-class researchers as visitors and collaborators.

Recent activities and events continue to demonstrate LIDS's position as a world leader among research organizations. Of particular note was the Paths Ahead in the Science of Information and Decision Systems symposium, held in November and organized by LIDS. This was a major international event, attended by over 340 researchers from around the world, including many of the most recognized names in the field (Figure 1). The panel included six members and one foreign associate of the National Academy of Engineering. A permanent website, http://paths.lids.mit.edu/, includes a description of the meeting as well as archival material including a brief history of LIDS. In addition, LIDS faculty and students continue to receive numerous national and international awards for their contributions. The recently redesigned LIDS website, http://lids.mit.edu/, contains details on LIDS activities, people, awards, and research accomplishments and directions, including those mentioned in this report. There is also a link to professor Alan Willsky's presentation on LIDS given at a recent EECS faculty lunch.

Figure 1: Members of the panel session honoring Sanjoy K. Mitter (LIDS) at the Paths Ahead symposium. L to R: Thomas Kailath (Stanford), Dimitri Bertsekas (LIDS), Y.C. Ho (Harvard), Pravin Varaiya (UC Berkeley), Jan Willems (Leuven), Roger Brockett (Harvard), Petar Kokotovic (UC Santa Barbara), and Karl Johan Åström (Lund).

Intellectual Vision and Research Areas

The domain of research in LIDS can be described along several different dimensions:

- A common set of mathematical disciplines, including probability and statistics, dynamical systems, and optimization and decision theory
- A set of core engineering disciplines—namely, inference and statistical data processing, transmission of information, networks, and systems and control
- A set of broad challenges, emerging applications and critical national or international needs, and intellectual opportunities.

Research at LIDS involves activities within and across all these dimensions. The convergence of the issues that arise in the challenges of the present and future has led to research that cuts across mathematical and engineering disciplines in new, exciting, and important ways. Research flows in both directions across these dimensions: work in each of the mathematical disciplines leads to new methodologies that enable advances in core disciplines and in interdisciplinary investigations; work in attacking those emerging interdisciplinary challenges provides direction and drivers for fundamental disciplinary activities and has led to the charting out of emerging new disciplines.

In particular, the availability of increasingly capable sensing, communication, and computation systems enables the collection and transfer of large amounts of data pertaining to complex and heterogeneous interconnected systems. The need for an intellectual platform to simultaneously address questions of data fusion, distributed learning, information transfer, and distributed decision making is stronger than ever as existing techniques fall short in addressing issues of scalability, robustness, and performance limits. Examples of areas in which LIDS research has and will continue to contribute include the following:

- Intelligence, surveillance, and reconnaissance systems
- Coordination of unmanned autonomous systems
- Energy information systems
- Biological systems and biomedical data analysis
- Large-scale data assimilation for the geosciences
- Network scheduling and routing
- Sensor networks
- Social network analysis and characterization
- Ultra-wideband and other emerging communications technologies.

Furthermore, traditional paradigms of sensing, communication, and control are not adequate to address many emerging challenges. As a result, LIDS has initiated a set of fundamental research themes that cut across disciplinary boundaries and involve considerable interaction and collaboration with colleagues in other units at MIT and in other disciplines:

- Foundations of network science, including network algorithms, approximation, and information
- Foundations of decision theory for teams involving cooperation and competition, including dynamic mechanism design in game theory, learning in stochastic games, and the study of rational decisions for large interacting networks of agents
- Foundations of cyber-physical systems, including architectural design, cross-layer algorithms, and tools for analysis, verification, and performance guarantees
- Foundational theory for multiscale/granularity modeling, including methods for describing complex phenomena at multiple granularities, learning of such models from complex and heterogeneous data, and reduction/simplification of models to levels appropriate for particular questions of analysis or design.

Faculty Activities

Much of the major research activities of LIDS faculty not only cuts across the disciplines, applications, and emerging areas mentioned previously but also is collaborative with others within LIDS and elsewhere at MIT.

Dimitri Bertsekas

Professor Bertsekas is interested in deterministic optimization problems and the role of convexity in solving them, possibly through the use of duality. He has recently written a textbook on the subject, which involves new research on the fundamental structures that guarantee the existence of optimal solutions, while eliminating duality gaps. He is writing a companion textbook on convex optimization algorithms, which includes some of his recent research on problems whose cost function involves a sum of a large number of component functions: (1) separable large-scale convex optimization problems, known as extended monotropic programming problems, for which special duality results and algorithms are possible; (2) new polyhedral approximation algorithms for extended monotropic programming problems; (3) incremental subgradient and proximal methods; and (4) application of these methods to large-scale machine learning and energy production and distribution systems.

Professor Bertsekas also performs research on problems of sequential decision making under uncertainty, which are pervasive in communication networks, manufacturing systems, and logistics, and in the control of nonlinear dynamical systems. In theory, such problems can be addressed with dynamic programming techniques. In practice, only problems with a moderately sized state space can be handled. This research effort deals with the application of neural networks and other approximation and interpolation methodologies to overcome the curse of dimensionality of real-world stochastic control problems. Recent effort has focused on the use and analysis of popular temporal difference methods and Q-learning algorithms, in the context of fully and partially observable Markov decision problems, on the simulation-based solution of large-scale least-squares problems, and on a number of issues relating to the central method of approximate policy iteration: convergence, rate of convergence, singularity and susceptibility to simulation noise of policy evaluation, exploration-enhanced methods, error bounds, policy oscillation, and issues of decision making in an asynchronous multi-agent environment.

Robert Berwick

Professor Berwick's research has spanned the broad areas of learning, evolution, and complex systems and dynamical systems theory in human cognition and biology, designing algorithms that can mimic human competence in language acquisition, evolution, and dynamical language change over time, as well as exploring the limits of current statistical techniques in light of human abilities. In particular, Professor Berwick has developed a Bayesian approach to the acquisition of human word semantics that can make use of relatively small data samples, similar to the one-shot learning that is observed in children. He has also continued to develop algorithms that apply new developments in linguistic theory to computer applications of natural language processing, specifically, the so-called minimalist framework of linguist Noam Chomsky and colleagues. This framework attempts to reduce as much as possible the human-specific component of language, attributing the rest to general computational abilities that other animals presumably share with people, such as Bayesian inference methods directed towards the discovery of "hidden" latent variables in sequential signals, such as speech to young infants.

Two new directions of Professor Berwick's research lie in the area of the core biological foundations of language. The first, a collaboration with Cold Spring Harbor Laboratory and geneticists at Harvard Medical School, covers biology and language at the genetic level, in particular, the development of phenotypic markers for assessing the genetic variation of language in normal individuals. Prior to this work, there had been little analysis of naturally occurring variation in language abilities, apart from extreme pathology. The second, in collaboration with researchers in BCS, the University of Utrecht, and RIKEN Center/University of Tokyo, connects human language to birdsong in a new way, by probing the commonalities in the rhythmic structure of both as a window into the common neurological basis of speech and birdsong.

During AY2010, Professor Berwick organized two international symposia focusing on human language and biology, both leading to the publication of edited books by Oxford University Press. The first, held at MIT, reviewed the current state of the art about the early biological stages in human language acquisition. The second, held at Banbury Center at Cold Spring Harbor Laboratory, brought together for the first time leading molecular biologists and geneticists studying language pathology in Alzheimer's and Down's syndrome patients as well as the evolution of language at the molecular level, with computer scientists, linguists, neuroscientists, and cognitive scientists who study language at the behavioral level. The outcome has been the development of new screening tests grounded on linguistic theory, along with the initiation of large-scale genome-wide association studies to assess the potential of phenotypic linguistic markers for certain of these conditions.

Munther Dahleh

Professor Dahleh has led a research effort focused on control of networked systems, with emphasis on the problem of distributed decision making and control under limited observations and communications. This work includes problems of coordination of mobile agents, control in the presence of communication constraints, and distributed computation over networked computational units.

Limitations of Networks on Control and Optimization

With students Nuno Martins and Sridevi Sarma, Professor Dahleh analyzed the effect of noisy channels in standard feedback and feed-forward networks on the achievable performance measured in terms of tracking and disturbance attenuation. These results provided a bridge between information theory (capturing the limitations on maximum transmission rate) and control theory (capturing the limitation of noise cancellation). Along with professor Devavrat Shah and student Ola Ayaso, Professor Dahleh collaborated on understanding the effect of finite-capacity multiagent networks on distributed function computation. In this context as well, information theory is linked to distributed computation and optimization of special classes of functions. With student Michael Rinehart, Professor Dahleh addressed the problem of channel selection when an agent can request certain information about the underlying system to maximize its performance.

Combinatorial Optimization with Dynamic Constraints

In collaboration with student Sleiman Itani, Professor Dahleh and professor Emilio Frazzoli addressed optimization problems that arise in trajectory planning of dynamic systems. Examples of such problems include the traveling salesman problem (TSP) for a real vehicle, the problem of matching a number of real vehicles to a number of targets in minimum time, and the problem of designing roads to maximize throughput. Explicit bounds were provided in the case when such problems are randomized, such as when the number of cities that need to be visited is large and randomly selected.

Bayesian Learning in Large Complex Networks

In collaboration with professors Asuman Ozdaglar and Daron Acemoglu, Professor Dahleh and student Ilan Lobel led an effort in understanding sequential learning problems that arise in social networks. Their work focused on analyzing Bayesian learning for sequential decision makers who base their decision on observing a subset of the previous decision makers and external signals sampled from a distribution conditioned on the correct state of the world. Their work provided necessary and sufficient conditions on the observations and external signals that guarantee asymptotic learning of a binary state of the world. They also provided results on the speed of convergence for specific classes of learning problems.

Networked and Sustainable Energy Systems

Professor Dahleh, in collaboration with professor Sanjoy Mitter, Professor Bertsekas, research scientist Mardavij Roozbehani, and postdoctoral fellow Pavithra Harsha, formed a research group in LIDS to conduct basic and applied research on the systems, information, and decision theoretic problems relevant to the emerging energy networks, in particular, smart grids. Of particular emphasis are fundamental problems arising from the increased uncertainties and complexities induced by large-scale integration of the renewable resources and distributed generation/storage. The group's focus is on methodological developments for modeling, analysis, design, and optimization to address various problems of interest, ranging from fundamental limitations and architectural designs to development of practical algorithms for energy management and dynamic pricing. The current list of activities include: (1) market mechanisms for matching supply and demand in smart power grids; (2) probabilistic paradigm for power systems and markets operation; (3) storage management and optimal investment for renewable sources; and (4) smart grid architecture design.

Automotive Application

Along with his students Rinehart and Yola Katsargyri, Professor Dahleh led a collaboration with Ford Motor Company focusing on the utilization of global positioning system (GPS) information to minimize fuel consumption in a hybrid car by optimally switching between the electric motor and the engine. The work relies on using road information such as road slope, traffic lights, and other road attributes to plan trajectories as well as engine-switching strategies that will produce optimal fuel consumption. The methods produced favorable results on the Ford simulator of a hybrid car.

Emilio Frazzoli

Professor Frazzoli's main research interests are in the area of control of planning and control for mobile cyber-physical systems, with an emphasis on autonomous vehicles, mobile robotics, and transportation networks.

Real-time Planning and Control for Autonomous Vehicles

Building on the efforts leading to MIT's successful participation in the 2007 Defense Advanced Research Projects Agency (DARPA) Urban Challenge, Professor Frazzoli and his group have continued to work on developing real-time planning and control algorithms for autonomous vehicles. In particular, in the past year, Professor Frazzoli's group developed planning and control algorithms for autonomous forklifts, in the context of the Agile Robotics for Logistics (ARL) program (led by professor Seth Teller in CSAIL, in collaboration with professor Jonathan How's group in LIDS). This program is aimed at automating logistics for the US Army in forward deployment areas. In addition to several challenges already faced in design of the DARPA Urban Challenge vehicle, the ARL program required new advances due to the ability of the forklift to interact directly with its environment—for example, manipulating pallets. LIDS students Sertac Karaman, Jeong Hwan Jeon, and Brandon Luders (advised by Professor How) have extended the DARPA Urban Challenge planning and control software to the forklift and developed novel algorithms for pallet detection and manipulation. The effectiveness of the autonomous forklift in realistic Army logistics scenarios was successfully demonstrated in June at Fort Belvoir, VA, in the presence of Army leadership.

These technologies are being further developed in the context of a new project on the future of urban mobility with SMART. In particular, Professor Frazzoli and his group—in collaboration with Professors Dahleh and Jaillet in LIDS and research affiliate Susmita Roy, professor Daniela Rus, and Professor Teller in CSAIL—are working on:

- Autonomy in mobility-on-demand systems: The goal is to demonstrate how autonomy, and in general automatic control/optimization (on-board cars and/or in the traffic infrastructure), can drastically enhance the safety and throughput of urban mobility, e.g., through mobility-on-demand services.
- Green driving: The goal is to demonstrate how autonomy and in general automatic control/optimization (on-board cars and/or in the traffic infrastructure) can drastically reduce fuel consumption and noxious emissions, both at the car level and at a city-wide level.
- Scalable situation awareness: The goal is to reduce the cost of the sensor package used on autonomous vehicles from approximately $500K down to approximately $50K. The idea is to leverage wireless communications, e.g., for localization and situational awareness (where the car is relative to the world, and relative to other cars).

Unmanned Aircraft Systems

As part of a multiyear collaborative effort on control science with the Air Force Research Laboratory and the University of Michigan, Professor Frazzoli is investigating mission planning and control systems for heterogeneous, mixed-initiative networks of unmanned aerial vehicles (UAVs), piloted aircraft, and human operators. During the past year, significant contributions were made in the context of incremental sampling-based algorithms for real-time motion planning. It was shown that state-of-the-art algorithms, such as the rapidly-exploring random trees (RRT), almost surely converge to non-optimal solutions; new algorithms were proposed, called rapidly-exploring random graph (RRG) and RRT* (an incremental sampling-based motion planning algorithm with the asymptotic optimality guarantee), which are provably asymptotically optimal, i.e., almost surely converge to an optimal solution. The computational complexity of these new algorithms is shown to be essentially the same as that of the baseline RRT. The analysis of the new algorithms hinges on novel connections between sampling-based motion planning algorithms and the theory of random geometric graphs. In addition, RRG is at the core of a new computational framework, enabling the efficient (i.e., polynomial time) incremental computation of mission plans subject to complex logic and temporal constraints. This can be accomplished by combining state-of-the-art motion-planning algorithms in robotics with a general class of formal language (e.g., mu-calculus), so far ignored in the context of mission specification languages. The above is joint work with student Karaman, and was recognized with the 2010 Robotics: Science and Systems best open-source code award by Willow Garage. Also, Professor Frazzoli and his students are developing strategies for UAV mission planning that embed cognitive models of human operators, explicitly taking into account the effects of human operators, workload, and situational awareness. A theory of queuing systems with humans in the loop is being developed along with queue-control techniques based on the exploitation of human cognitive models. Research scientist Ketan Savla and student Christine Siew at LIDS are involved in this work.

Mobile Robotic Networks

Another main focus of Professor Frazzoli's research is the development of analysis and synthesis tools for control of mobile robotic networks. Within the context of several projects on the topic sponsored by the National Science Foundation (NSF), his research group is analyzing a broad class of multiple-vehicle motion coordination problems, from dynamic vehicle routing to path coverage and traffic deconfliction. Recent advances include the analysis of dynamic vehicle routing problems with priority demands (joint work with student Marco Pavone at LIDS, and professor Francesco Bullo and student Stephen Smith at the University of California, Santa Barbara) and customer impatience, the analysis of decentralized algorithms for equitable partition of a planar region (also with Pavone), and the discovery of an endogenous phase transition in the optimal network "social" organization caused by the vehicles' dynamics (with University of California, Los Angeles, visiting researcher John Enright, and Dr. Savla at LIDS). Such phase transitions have been observed in biological systems but the understanding of such phenomena remains limited.

Spacecraft Formation Flying

A special class of mobile robotic networks studied by Professor Frazzoli, in collaboration with professor David Miller and students Jaime Ramirez and Pavone, is spacecraft clusters. Decentralized control laws were designed to provably ensure convergence of the spacecraft to an evenly spaced configuration on a zero-effort elliptical trajectory, with minimal requirements on the computation and communication capabilities of the spacecraft. The proposed control laws were tested in an experiment conducted on the synchronized position hold engage and reorient experimental satellites testbed aboard the international space station by astronaut (and MIT alumnus) Gregory Chamitoff—who reportedly stated that the orbiting spacecraft were "the most beautiful thing" he saw during his space mission.

Other projects address diverse topics such as high-speed driving (with professor Panagiotis Tsiotras at the Georgia Institute of Technology), vision-based navigation, and sampling-based algorithms for differential games (with Jim Paduano at Aurora Flight Sciences).

Jonathan How

Professor How has led a research effort focused on the control of multiple autonomous agents, with an emphasis on distributed decision making with uncertainty. The work has focused on two application domains—planning for multiple UAVs, and ARL.

Robust Distributed Planning for Multiple UAVs

Under Air Force Office of Scientific Research (AFOSR) and Office of Naval Research (ONR) funding, Professor How and team (postdoctoral associates Han-Lim Choi and Luca Bertuccelli, and students Cameron Fraser and Luders) have developed new algorithms to address the issues of robustness and adaptation to parameter uncertainty in Markov decision problems. This includes the development of a Bayesian consensus framework to explicitly and rigorously account for uncertainties in agents' beliefs when the local uncertainties are not Gaussian, e.g., arrival rate, transition probability, and process noise covariance. The team addresses the problem of information consensus in a team of networked agents by presenting a generic consensus method that permits agreement to a Bayesian fusion of uncertain local parameter estimates. In particular, the method utilizes the concept of conjugacy of probability distributions to achieve a steady-state estimate consistent with a Bayesian combination of each agent's local knowledge, without requiring complex channel filters or being limited to normally distributed uncertainties. It is shown that this algorithm, termed hyperparameter consensus, is adaptable to many local uncertainty distributions within the exponential family, and will converge to a Bayesian fusion of local estimates over generally arbitrary communication networks with some standard assumptions on the network topology.

The team also developed a distributed task planning algorithm that provides provably good conflict-free task allocations that are robust to poor network connectivity and inconsistencies in the situational awareness over the team. Recent work demonstrated key theoretical properties of this consensus-based bundle algorithm (CBBA), and numerous extensions to the initial CBBA approach have been recently developed, including the ability to specify time windows of task validity; the explicit handling of breaks in the network connectivity; coordination constraints between agents to perform tasks; the explicit handling of operator/UAV interaction; and an asynchronous formulation that is better suited for real-world implementation. With these additions, CBBA has become a very general framework that can be used to do predictive planning in real-time with nonlinear cost functions, realistic vehicle dynamics for heterogeneous agents, and time-window constraints on tasks. The results have been presented at many conferences and in an Institute of Electrical and Electronics Engineers (IEEE) *Transactions on Robotics* article.

With Professor How, student Albert Wu has been working on robust planning and decision making. This includes augmenting receding horizon path planners to account for collision avoidance with other vehicles even after the explicit planning horizon. In order to avoid entering situations where other vehicles could make a collision inevitable, conservative velocity obstacles can be used in a computationally efficient way and require the planner to preserve safe escape trajectories. Professor How has also been looking at risk-sensitive and robust formulations for single- and multi-agent Markov decision processes (MDP), such that the resulting policy does not suffer severe performance degradation either from random inputs or from modeling errors, where the latter is often a serious hurdle between planning on paper and actual implementation.

With Professor How, student J. Teo has developed the gradient projection anti-windup (GPAW) scheme for nonlinear systems/controllers. It is a well-recognized fact that control saturation affects virtually all practical control systems. Its effects are called windup and cause performance degradation, with potential catastrophic consequences if it induces instability. While anti-windup compensation is well-studied for linear time-invariant systems, it was recognized in a recent survey paper that anti-windup compensation for nonlinear systems/controllers remains largely an open problem. The GPAW scheme is a generalization of the conditional integration method (one of two methods reported in perhaps the first study on anti-windup in 1967) using J. B. Rosen's 1960 gradient projection method, to nonlinear systems/controllers. Because windup is traditionally interpreted as an inconsistency between the controller state and output, early ad hoc schemes attempt to achieve controller state–output consistency, which continues to be an implicit conceptual objective for numerous (if not most) modern anti-windup schemes. One unique and attractive feature of the GPAW scheme is that it achieves controller state–output consistency that has been elusive for existing anti-windup schemes to date. While this does not imply stability of the closed-loop system, it is significant at least on a conceptual level. Stability results have been obtained for some classes of systems, with promising and revealing insights. Current work is on expanding the class of systems to provide stability guarantees. This research also raises many interesting questions that will provide a rich source of research problems.

Joint with Professor How, student Brett Bethke has developed a new approximate dynamic programming approach called Bellman residual elimination (BRE), funded by Boeing. While prior work on BRE has focused on learning an approximate policy for an underlying MDP when the state transition model of the MDP is known, recent work developed a model-free variant of BRE that does not require knowledge of the state transition model. Instead, state trajectories of the system, generated using simulation and/or observations of the real system in operation, are used to build stochastic approximations of the quantities needed to carry out the BRE algorithm. The resulting algorithm can be shown to converge to the policy produced by the nominal, model-based BRE algorithm in the limit of observing an infinite number of trajectories. To validate the performance of the approach, model-based and model-free BRE are compared against least-squares policy iteration, a well-known approximate dynamic programming algorithm. Measuring performance in terms of both computational complexity and policy quality, results show that BRE performs at least as well as, and sometimes significantly better than, least-squares policy iteration on a standard benchmark problem. This work appeared in the 2010 American Control Conference and was submitted to the IEEE journal *Transactions on Automatic Control*.

In collaboration with Professor How, student Josh Redding introduced the intelligent cooperative control architecture (iCCA). Fast planners presented within the control community assume certain conditions about the domain often not satisfied by real-world applications. On the other hand, learning techniques formulating the problem as an MDP tend to scale poorly to large-scale domains. iCCA provides a framework where fast planners such as CBBA can provide attractive starting points for the agent, while learning methods enable the agent to adaptively boost its behavior through interacting with the domain. Jointly worked with PhD candidates Alborz Geramifard and Aditya Undurti, and Dr. Choi, they successfully demonstrated the advantage of iCCA in several domains, including UAV planning scenarios where the planning space exceeds billions of state-action pairs. Corresponding results appeared in the 2010 American Control Conference and the 2010 Guidance, Navigation, and Control Conference.

In collaboration with Professors How and Roy and student Finale Doshi, Geramifard introduced incremental feature dependency discovery (iFDD) algorithm as an online computationally cheap representational expansion method, which can be combined with online value-based reinforcement learning algorithms using binary features. iFDD facilitates a seamless transition from a coarse to a fine representation by adding promising features incrementally in parts of the state space where feedback error perpetuates. Additionally, the algorithm enjoys the asymptotic convergence property. Empirical results demonstrated much faster learning rates for iFDD on various problems including UAV planning scenarios with hundreds of millions of state-action pairs. The work was presented at the 2010 LIDS student conference and will be submitted to the 2011 International Conference on Autonomous Agents and Multi-agent Systems.

Robust Path Planning to Enable Agile Robotics for Army Logistics

Working with Professors How and Frazzoli, students Luders and Vishnu Desaraju have developed a framework for multi-platform autonomous vehicle operations as part of the ARL program, funded by the US Army Logistics Innovation Agency. This program seeks to demonstrate semi-autonomous robotic capabilities in an unstructured, outdoor warehouse scenario, including cluttered spaces, dynamic obstacles (humans and other vehicles), and uncertain terrain. In a presentation at Fort Lee, VA, in June, the project demonstrated reliable operation of both an unmanned forklift and support rover, despite limited sensing and GPS data.

Collaborating with other team members, Luders has extended the forklift's planning and control framework to incorporate higher-level task reasoning and robust navigation. This work leverages recently proven robustness results for the closed-loop–RRT path planning algorithm, presented by Luders at the 2010 LIDS student conference and the American Control Conference. Student Desaraju has helped design and implement a small rover to support the forklift by performing simpler, long-duration tasks, such as a human-guided tour of the warehouse or autonomous inventory checking. This work has expanded the focus of the ARL program to developing multi-robot capabilities in these complex environments, allowing the robots to complete a broader set of tasks with greater efficiency.

Patrick Jaillet

Professor Jaillet's main research has recently been concentrated on formulating and analyzing online, dynamic, and real-time versions of classical network and combinatorial optimization problems, such as the shortest path problem, the TSP problem, and the assignment/matching problem, as well as some of their generalizations. Specific research interests deal with provable results (algorithmic design and analysis) on what one can do to solve such problems under uncertainty, with or without explicit stochastic modeling of the uncertainty. Methodological tools include those from online optimization (competitive analysis) and stochastic optimization (robust analysis), with an eye toward their eventual integration.

Motivating applications include various routing problems that arise from transportation and logistics networks, data communication and sensor networks, and from autonomous multi-agent systems, as well as dynamic resource allocation problems in various internet applications (such as search engines or online auctions).

Two examples of recent research results involve work with Xin Lu, doctoral candidate from ORC: (1) online TSP with rejection options, and (2) online generalized assignment problem. On the first topic, the best possible online algorithms for online versions of the TSP and Hamiltonian path problem are provided, where the server does not have to accept all requests. A penalty is incurred if a request is rejected. Requests are revealed over time to the server, which must decide which requests to accept in order to minimize the time to serve all accepted requests plus the sum of the penalties associated with the rejected requests. On the second topic, two online algorithms, a greedy algorithm and a primal dual algorithm, are proposed, analyzed, and empirically compared, proving that they are asymptotically best possible among any other deterministic or randomized online algorithms.

Current funded research programs come from the operations research division of ONR (Large-scale Online and Real-time Optimization Problems Under Uncertainty), from the optimization and discrete mathematics division of AFOSR (Data-driven Online and Real-time Combinatorial Optimization), and from SMART (Future Urban Mobility [FUM], a large project with nine other MIT principal investigators).

Within the FUM project, Professor Jaillet is leading a new subproject entitled Real-time Paths Tracking/Prediction and On-demand Route Guidance Under Uncertainty. The project goals are to develop algorithms using real-time data (from many heterogeneous sources) in order to (1) track and predict paths in dynamic transportation networks, and (2) provide on-demand route guidance under uncertainty, based on a combination of optimization, data fusion, machine learning, and novel behavioral techniques. The team includes two other FUM principal investigators (professors Amedeo Odoni, Aero-Astro, and Cynthia Barnhart, CEE), other MIT faculty (professors Hari Balakrishnan, EECS, and Cynthia Rudin, Sloan), MIT doctoral candidates (Maokai Lin, ORC, and Yin-Wen Chang, EECS), and Singaporean collaborators from local academies and agencies.

Alexandre Megretski

Professor Megretski and his students work on identification and model reduction of nonlinear dynamical systems, as well as on optimization of discrete decision making in dynamical analog control systems, and analysis of distributed nonlinear systems.

Professor Megretski's approach to system identification and model reduction is based on combining nonlinear dynamical system analysis tools with convex relaxation techniques in addressing some major unsolved challenges in the field, such as efficient optimization of the output error and automated certification of robustness of the resulting models. The theory and resulting algorithms, implemented in the system polynomial optimization tools Matrix Laboratory toolbox, are used extensively in two application areas: (1) modeling of analog integrated circuit components, where the need for converting large amounts of measurement or simulation data into reliable compact dynamical models is strong; and (2) modeling of live neurons and small live neural networks, where a number of approaches are available for designing nonlinear systems to mimic neural behavior, but generation of models to accurately match the actual input/output relations remains a challenge. The applications in circuit modeling are pursued with professors Luca Daniel, Vladimir Stojanovic, and Joel Dawson. The applications in neural modeling are conducted in collaboration with professor Russell Tedrake.

The research on optimization of discrete decision making in dynamical analog control systems is concentrated on discovery of special analytical properties of the associated optimal control tasks, with the aim of enabling the finding of either analytical or efficient numerical solutions. One application of this effort is optimization of analog-to-digital converters.

Sanjoy Mitter

Professor Mitter's research has spanned the broad areas of systems, communication, and control. Although his primary contributions have been in the theoretical foundations of the field, he has also contributed to significant engineering applications, notably in the control of interconnected power systems and pattern recognition. His current research interests are theory of stochastic and adaptive control; mathematical physics and its relation to system theory; image analysis and computer vision; and structure, function, and organization of complex systems.

Professor Mitter has continued his long-standing collaboration with Dr. Charles Rockland (RIKEN Brain Science Institute, Tokyo) on issues of autonomy and adaptiveness in neural systems. There is renewed interest in studying the nematode from the viewpoint of understanding the structure-to-function map, a program the two proposed in the 1980s.

In joint work with Emery Brown (BCS), professor Peter Doerschuk (Cornell University), and professor Bud Mishra (New York University), Professor Mitter has been investigating topological properties of large data sets using ideas from differential geometry and algebraic topology. New results on manifold learning have been obtained in joint work with postdoctoral associate Hariharan Narayanan.

In addition, Professor Mitter has continued his collaboration with Dr. Nigel Newton (University of Essex) on the relation between statistical mechanics, statistical inference, and information theory. In recent work, they have given a proof of the noisy channel coding theorem (including error exponents) from the variational point of view of Bayesian inference.

Investigations on the subject of the interaction of information and control have continued with Anant Sahai (University of California, Berkeley) and Sekhar Tatikonda (Yale University).

Also with Sahai, Professor Mitter has shown for the first time that unstable processes generate two fundamentally different kinds of information, one requiring Shannon capacity for its reliable transmission, and one requiring anytime capacity for its reliable transmission. Completion of this work required developing new rate distortion theory for a family of channels. This work constitutes part of doctoral candidate Mukul Agarwal’s thesis, in which a new result on source channel separation for networks has been presented. With doctoral candidate Lav Varshney, he is studying the problem of reliably transmitting both energy and information over a noisy channel.

With Professors Bertsekas and Dahleh and research assistant Dr. Mardavij Roozbehani, Professor Mitter has been working on various systems aspects of smart grids.

Asu Ozdaglar

Professor Ozdaglar’s research group focuses on modeling, analysis, and optimization of large-scale dynamic multi-agent networked systems, including technological networks (such as communication and transportation networks), social, and economic networks. The research draws on advances in game theory, optimization theory, dynamical systems, and stochastic network analysis. It focuses on both investigating substantive issues in these areas and developing new mathematical tools and algorithms for the analysis of these systems.

A major current research area in Professor Ozdaglar’s group is social networks, which are becoming ever more extensive and complex with parallel developments in communication technology. The group works on developing game-theoretic models for studying dynamics of social behavior over complex networks. In collaboration with Professor Acemoglu (Economics), Professor Dahleh and student Ilan Lobel, Professor Ozdaglar has provided a new framework to study the problem of Bayesian (equilibrium) learning over general social networks. This work identifies conditions on network topologies, information structures, and heterogeneity of preferences that lead to equilibrium information aggregation in large networks. A recent project, in collaboration with postdoctoral associate Alireza Tahbaz-Salehi, extends this framework to study the effect of adversarial behavior on Bayesian learning.

Another recent project, joint with postdoctoral associate Giacomo Como and professor Fabio Fagnani (Department of Mathematics, Politecnico di Torino), provides models of misinformation and shows how a set of "prominent agents," which may include community leaders as well as media outlets, can spread misinformation and influence average opinion in the society. The work provides conditions on interaction structures under which consensus obtains or persistent disagreements prevail in the society. This research effort is supported by an NSF grant in human and social dynamics, an Army Research Office (ARO) project, and the Draper Directed Research and Development Program.

Professor Ozdaglar's group also works on understanding the role of networks in economics. A recent project, joint with Professor Acemoglu and Dr. Tahbaz-Salehi, investigates the cascade effects that arise in economic and financial markets because of supply or financial linkages among firms. Results show that the traditional economic insight that neglects firm level variations in aggregate economic fluctuations (using law of large numbers type arguments) fails in interconnected systems, and provide a general framework for the analysis of the relationship between the network structure of an economy and its aggregate volatility. This research effort is supported by an AFOSR project.

Another recent project, in collaboration with professor Pablo Parrilo, student Ozan Candogan, and postdoctoral associate Ishai Menache, provides a novel flow representation for strategic form finite games, which (using Helmholtz decomposition theory from algebraic topology) allows decomposing an arbitrary game into three components, referred to as the potential, harmonic, and nonstrategic components. The decomposition framework provides a systematic approach for the analysis of static and dynamic (equilibrium) properties of general games through their distance to the set of potential games (which admit tractable equilibrium analysis). Another project, in collaboration with Professor Parrilo and student Noah Stein, investigates new equilibrium notions for symmetric strategic form finite games, which lie between the set of Nash and correlated equilibria and admit efficient computation. This research effort is supported by an AFOSR multidisciplinary university research initiative, joint with the Georgia Institute of Technology and the University of Maryland, and an NSF project.

Professor Ozdaglar also studies game-theoretic models for resource allocation problems in communication networks, with a focus on pricing and investment incentives of providers and implications of competition on network performance. A recent project, joint with student Paul Njoroge and professors Nicolas Stier-Moses and Gabriel Weintraub of Columbia University, develops a game theoretic model based on a two-sided market framework to investigate net neutrality issues from a pricing perspective. Results highlight important mechanisms related to internet service providers' investments that play a key role in market outcomes, providing useful insights for the net neutrality debate. This research is supported by an NSF career grant.

Professor Ozdaglar's group also works on developing novel decentralized optimization algorithms for resource allocation problems that emerge in communication and sensor networks. In collaboration with students Lobel and Alex Olshevsky, and professors Angelia Nedic (University of Illinois at Urbana–Champaign) and John Tsitsiklis, this work has developed algorithms that can optimize general performance metrics and operate over dynamic networks with time-varying connectivity and imperfect information. A recent project, joint with Lobel, extends this framework to problems with state-dependent communication. These problems arise when the current information of decentralized agents influences their potential communication pattern, which is relevant in the context of location optimization problems and in social settings where disagreement between the agents would put constraints on the amount of communication among them. Another recent project, joint with student Ermin Wei and professor Ali Jadbabaie (University of Pennsylvania), develops novel Newton-type second order methods to solve network utility maximization problems in a distributed manner, which are significantly faster than the standard first-order (or gradient) approaches. This research is supported by the DARPA information theory for mobile ad-hoc networks program (joint with Stanford University, the California Institute of Technology, and the University of Illinois at Urbana–Champaign) and an AFOSR multidisciplinary university research initiative.

Pablo Parrilo

Professor Parrilo's research group is focused on optimization, systems, and control, with emphasis on control and identification of uncertain complex systems, robustness analysis and synthesis, and the development and application of computational tools based on convex optimization and algorithmic algebra.

In joint work with Professor Ozdaglar and their joint student Utku Ozan Candogan, as well as Dr. Menache, Professor Parrilo has developed a structural approach to normal form games that allows for the decomposition of a given game into its "potential" and "harmonic" components. The methods are based on the classical Helmholtz-Hodge theory for differential forms, and constitute a far-reaching generalization of the well-known potential games, which enables the analysis of many static and dynamical properties of games, such as equilibria or the convergence of fictitious play mechanisms.

Amir Ali Ahmadi (LIDS student) and Professor Parrilo are looking at the interplay of sum of squares (SOS) and the question of deciding convexity of polynomials. Similar to the SOS relaxation for polynomial nonnegativity, an algebraic notion known as SOS-convexity can be proposed as a tractable sufficient condition for polynomial convexity. Many natural questions arise: are there polynomials that are convex but not SOS-convex? If so, for what dimensions and degrees? Are there algebraic analogues of classical analytic theorems in convex analysis? At a theoretical level, the overall goal of this project is to better understand the connections between the geometric and algebraic aspects of positivity and convexity. Practical applications of this work include efficient algorithms for minimizing polynomial functions, parameterizing convex polynomials that best fit given data, or searching for polynomial Lyapunov functions with convex sublevel sets.

In joint work with Parikshit Shah (LIDS student), the group has developed a complete state-space solution to H2-optimal decentralized control of poset-causal systems with state-feedback. The solution is based on the exploitation of a key separability property of the problem that enables an efficient computation of the optimal controller by solving a small number of uncoupled standard Riccati equations. The group's approach gives important insight into the structure of optimal controllers, such as degree bounds that depend on the structure of the partially-ordered set (poset). A novel element in the state-space characterization of the controller is a remarkable pair of transfer functions that belong to the incidence algebra of the poset, are inverses of each other, and are intimately related to estimation of the state along the different paths on the poset.

In recent joint work with Noah Stein (LIDS student) and Professor Ozdaglar, the rich structure of the set of correlated equilibria of games is analyzed through the simplest of polynomial games: the mixed extension of matching pennies. While the correlated equilibrium set is convex and compact, the structure of its extreme points can be quite complicated. In finite games there can be a superexponential separation between the number of extreme Nash and extreme correlated equilibria. In polynomial games there can exist extreme correlated equilibria that are not finitely supported. In general, the set of correlated equilibrium distributions of a polynomial game cannot be described by conditions on finitely many joint moments, in marked contrast to the set of Nash equilibria, which is always expressible in terms of finitely many moments.

Professor Parrilo is currently investing further extensions of "compressed sensing" techniques that deal with low-rank assumptions as opposed to sparsity. In earlier work with Venkat Chandrasekaran (LIDS student), Sujay Sanghavi (Purdue University) and Professor Willsky, the methodology has been extended to the problem of decomposing a given matrix into a sparse and a low-rank component. In recent work, the results have been applied to the important problem of identification of Gaussian graphical models with hidden variables. The results show that it is possible to simultaneously identify the structure of the underlying graph, as well as the number and features of a set of latent variables, from a relatively small set of samples (i.e., the high-dimensional statistical setting).

John Tsitsiklis

Professor Tsitsiklis and his research group—Systems, Networks, and Decisions Group—work on system modeling, analysis, optimization, and control in possibly stochastic and dynamic environments, and in the possible presence of multiple agents with conflicting interests. Research activities have focused on developing methodologies, mathematical tools of broad applicability, and computational methods. Motivating applications for recent work have come from domains as diverse as cancer radiation therapy, direct mail marketing, and sensor networks. This work involves collaborations not only with the students in the group but also with Professors Ozdaglar and Shah, Thomas Bortfeld (Massachusetts General Hospital), and Duncan Simester (Sloan).

Distributed Systems and Decision Making

A particular area being investigated involves models of distributed decision making. One direction concerns information fusion and aggregation in sensor networks, which involves the selection of the effective choices of messages, given a particular information processing goal, as well as higher-level architectural choices. A second direction involves an analysis of simple and fast algorithms for prototypical and generic distributed sensing and control problems, with "averaging algorithms" a prominent example. This research also overlaps with the nascent field of "social networks," where under certain assumptions of rational behavior similar models are receiving a fair amount of attention.

Resource Allocation in Communication Networks

This research concerns the analysis and optimization of resource allocation methods (routing and scheduling) in queuing networks, with communication networks being the prime motivation. It involves the development of novel mathematical techniques to address new types of problems (e.g., the effect of heavy-tailed traffic statistics and the effect of a limited amount of scheduling flexibility in server farms), or to better understand well-established models (e.g., the stability of popular scheduling disciplines, and game-theoretic models of bandwidth allocation when multiple users are contesting the same resources).

Systems Optimization

Professor Tsitsiklis and his students carry out research involving the analysis and optimization of various stochastic system models that are of current practical interest. One example concerns adaptive radiation therapy, whereby the dosage during each fraction of the treatment is adjusted based on information collected in the course of the treatment. Another example concerns the design of experiments (temporary price modifications) that a retailer can make to improve its demand model and its revenue.

Alan Willsky

Professor Willsky leads the Stochastic Systems Group (SSG). SSG's general focus is on developing statistically-based algorithms and methodologies for complex problems of information extraction and analysis from signals, images, and other sources of data. The work extends from basic mathematical theory to specific areas of application. Funding for this research comes from sources including AFOSR, ARO, Lincoln Laboratory, and the Royal Dutch/Shell Group. In particular, Professor Willsky's recently initiated program with Shell Oil Company has grown significantly. In addition to providing considerable funding for research within LIDS, the program has provided funding and collaboration opportunities with other units at MIT, including BCS and MITEI. The collaboration was highlighted by MITEI as instrumental in building a significant relationship with Shell Oil Company, and has generated funding across the energy-related research activities at MIT, as well as several graduate fellowships, one of which is resident in LIDS. In addition, Professor Willsky's research contributions and leadership have led, during the past year, to his receiving the Technical Achievement Award from the IEEE Signal Processing Society, and to his recent election to the National Academy of Engineering.

A major thrust of research in SSG continues to be the extension and exploitation of a growing methodology for statistical inference, information fusion, and estimation for problems involving complex graphic models, such as those that arise in military command and control, mapping from remote-sensing data, and monitoring complex systems. SSG's work involves examining complex graphical representations and developing tractable algorithms based on these representations. This research continues to yield significant advances, including new classes of signal and image-processing algorithms that have provable performance properties, that can be applied to very large problems in a scalable manner, and that outperform previous methods. Recent applications of these methods are to computer vision, mapping of subterranean surfaces in support of oil exploration, and tracking of multiple vehicles from networks of small sensors. Among the most recent advances in this area are new classes of models that represent complex phenomena at multiple resolutions or granularities. These models show great promise for modeling geophysical phenomena that exhibit behavior at a multitude of scales; stock indices, such as the Standard and Poor's, in which SSG's models provide enhancements to the well-established organization of stocks into groups and industries; and computer vision, in which the different granularities of representation range from low-level image features to objects (e.g., computer monitors or keyboards) to higher-level characterizations (e.g., workstations). A number of the methods developed are or already have been transitioned to research and engineering organizations including Shell Oil Company, Lincoln Laboratory, and BAE Systems. This part of SSG's research portfolio has received considerable international attention, as evidenced by a string of best paper awards, as well as extensive citations and influence on the work of others in fields ranging from systems and control to chemical engineering to groundwater hydrology.

An increasingly important component of research in SSG is in the area of machine learning, in particular the extraction of statistical models, usually in graphical form, of complex phenomena. One part of this research, which deals with the direct learning of graphic models from data, has led to new methods for learning models for multiple types of behavior, with an eye toward using these models to discriminate among these modes of behavior when presented with new data. A second aspect of this work deals with the learning of "hidden" explanations of the complex behavior of observed data—that is, the learning of coarser descriptions of complex phenomena that explain much of the complexity of the observed data and hence simplify the modeling of the remaining behavior not captured by these hidden causes. Both of these projects have led to significant theoretical advances as well as to new algorithms for applications in fields ranging from computer vision to modeling complex geophysical phenomena. Figure 2 provides an illustration of one of the new methods, in this case, the data on stocks in the Standard and Poor's 100 Index. This new method augments the hierarchical structure provided by Standard and Poor's breakdown into divisions, industries, and companies, by uncovering strong residual correlations (indicated by the dashed blue lines). This approach is also being applied to problems in computer vision, including integrated scene and object recognition.

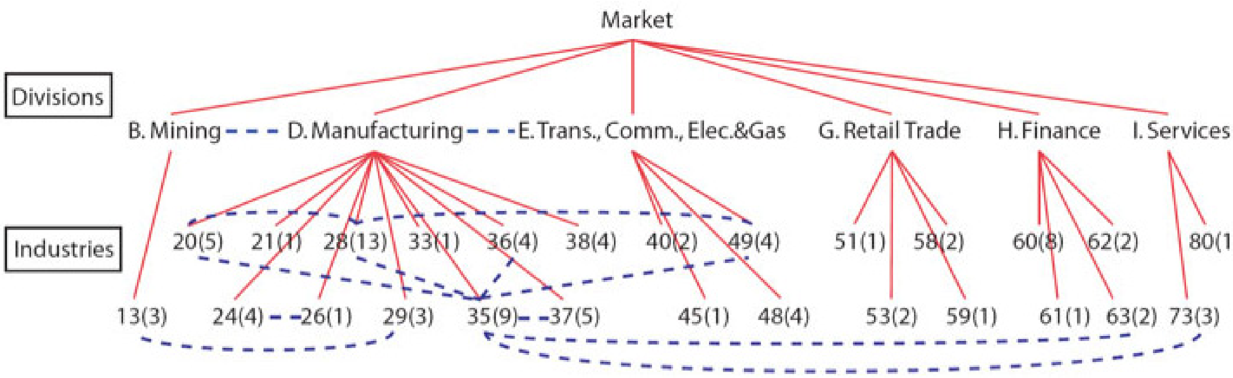

Figure 2: Illustration of a method developed by SSG graduate student Myung Jin Choi, under supervision of Alan Willsky, for the learning of hierarchical statistical models of complex data.

In addition, a major and growing focus of SSG is the development of so-called nonparametric methods for the extraction of behavioral models for dynamically evolving phenomena. This research has led to significant advances, led by Professor Willsky and especially by his student Emily Fox, recently graduated. One method developed in this work was successfully applied to analyzing so-called "dances" of honeybees (in which the motion of bees has been characterized as having several distinct components—see Figure 3), stock market data (in which SSG's methods automatically detect changes in volatility models that match well with detailed analysis by economists), and human exercise routines. Dr. Fox, who is currently a postdoctoral researcher at Duke University, has accepted a faculty position in the Statistics Department at the Wharton School, University of Pennsylvania. (Figure 3) This work has received considerable publicity, in *Tech Talk*, on the MIT home page, and in a long article in the Armed Forces communication and electronics association magazine, *Signal*. In addition, Dr. Fox's doctoral dissertation has received two noteworthy awards: the inaugural Jin-Au Kong doctoral thesis award from EECS, and the Savage Award for applied methodology in Bayesian statistics, presented by the International Society for Bayesian Analysis.

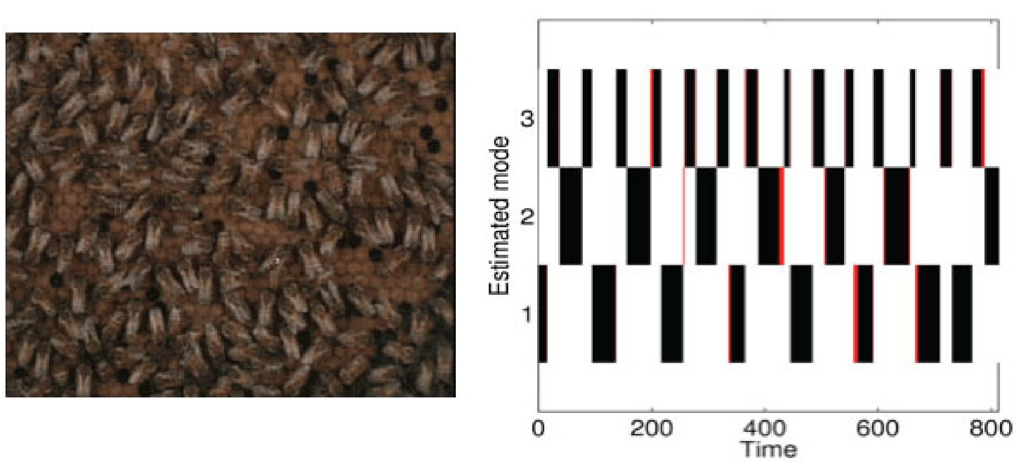

Figure 3: Dr. Emily Fox and her advisor, Alan Willsky, developed new statistical methods for discovering complex modes of behavior of dynamic phenomena, in this case, the motion of honeybees, which circle left, circle right, and waggle. The figure on the right shows how the method correctly identifies the three modes of behavior and when each occurs.

Moe Win

The Wireless Communication and Network Sciences Laboratory (http://wgroup.lids.mit.edu/), led by Professor Win, is involved in multidisciplinary research that encompasses developing fundamental theories, designing algorithms, and conducting experiments for a broad range of real-world problems. Current research topics include location-aware networks, network synchronization, aggregate interference, intrinsically-secure networks, time-varying channels, multiple antenna systems, ultra-wide bandwidth systems, optical transmission systems, and space communications systems. Details of a few specific projects are given below.

The group has been working intensively on location-aware networks in GPS-denied environments that provide highly accurate and robust positioning capabilities for military and commercial aerospace networks. It has developed a foundation for the design and analysis of large-scale location-aware networks from the perspective of theory, algorithms, and experimentation. This includes derivation of performance bounds for cooperative localization, development of a geometric interpretation for these bounds, and the design of practical, near-optimal cooperative localization algorithms. The group is currently validating the algorithms in a realistic network environment through experimentation in Professor Win's laboratory.

Professor Win and one of his students have been engaged in the development of a state-of-the-art apparatus that enables automated channel measurements. The apparatus makes use of a vector network analyzer and two vertically polarized, omni-directional wideband antennas to measure wireless channels over a range of 2–18 GHz. It is unique in that extremely wide bandwidth data, more than twice the bandwidth of conventional ultra-wideband systems, can be captured with high-precision positioning capabilities. Data collected with this apparatus facilitates the efficient and accurate experimental validation of proposed theories and enables the development of realistic wideband channel models. Work is underway to analyze the vast amounts of data collected during an extensive measurement campaign that was completed in early 2009.

Professor Win's students are also investigating physical-layer security in large-scale wireless networks. Such security schemes will play increasingly important roles in new paradigms for guidance, navigation, and control of UAV networks. The framework developed introduces the notion of a secure communications graph, which captures the information-theoretically secure links that can be established in a wireless network. The students have characterized the secure communications graph in terms of local and global connectivity, as well as the secrecy capacity of connections, and have also proposed various strategies for improving secure connectivity, such as eavesdropper neutralization and sectorized transmission. Lastly, they analyzed the capability for secure communication in the presence of colluding eavesdroppers.

Professor Win and a team of undergraduate and graduate students competed in the Institute of Soldier Nanotechnologies soldier design competition. In this contest they demonstrated the first cooperative location-aware network for GPS-denied environments, using ultra-wideband technology, leading to the team winning the L3 Communications Corporation Prize. The group is now advancing the localization algorithms in terms of scalability, robustness to failure, and tracking accuracy.

To advocate outreach and diversity, the group is committed to attracting undergraduates and underrepresented minorities, and to giving them exposure to theoretical and experimental research at all levels. For example, the group has a strong track record for hosting students from both the Undergraduate Research Opportunities Program and the MIT Summer Research Program. Professor Win maintains dynamic collaborations and partnerships with academia and industry, including the University of Bologna and the University of Ferrara in Italy, the University of Lund in Sweden, the University of Oulu in Finland, the National University of Singapore, Nanyang Technological University in Singapore, Draper Laboratory, Jet Propulsion Laboratory, and Mitsubishi Electric Research Laboratories.

Highlights, Awards, and Events

AY2010 was an eventful and important year for LIDS. In addition to a continuing record of research accomplishments and intellectual excitement, the laboratory has grown in every meaningful dimension. Research volume has exceeded LIDS's ambitious strategic plan (with excellent prospects for the future). The laboratory welcomed, and will be welcoming, additional faculty as members of the community; made major strides in engaging other units across MIT; took major steps in several new initiatives; continued the series of events and activities that have added so much to LIDS's environment; and hosted a major international event that has helped LIDS reaffirm and extend its position of leadership in the international research community.

Continuing successful activities within LIDS include the colloquium series and the 15th annual LIDS student conference. A fifth edition of the LIDS's community-oriented magazine, *LIDS-ALL*, was produced, and the sixth edition is being readied for the start of AY2011. LIDS also completed several major components of its long-term plan, including the launch of an enhanced website and expanded outreach to other units across MIT, such as CSAIL and ORC. One new faculty member was welcomed, Patrick Jaillet, who joined LIDS after serving as head of CEE. Professor Jaillet recently took on the position of codirector of ORC, further enhancing the close relationship between LIDS and ORC. In addition, LIDS faculty have played significant roles in several major research thrusts that align well with the intellectual agenda and areas of expertise that define its research. These include a major initiative in energy systems and smart grids, as well as a significant LIDS role in FUM, the long-term research program, funded by Singapore, focusing on the future of urban mobility. The Singapore program tackles problems of exploiting fine-grained information through the increasingly powerful internet and the explosion of personal devices and devices located on individual vehicles. The program includes developing integrated models for planning land, resource, and energy use, as well.

One of the major events during this past year was the Paths Ahead in the Science of Information and Decision Systemssymposium, organized and hosted by LIDS, with sponsorship from NSF, ARO, AFOSR, and a number of industrial and research organizations. The symposium was a great success, with more than 340 attendees from around the world, including world leaders in each of the research areas articulated in LIDS's intellectual vision. Numerous enthusiastic comments and words of thanks were received from those who attended. Without question, the event has served as the exclamation point to the goal articulated in LIDS's strategic plan of enhancing international recognition of the laboratory as one of the leading centers of research in the information and decision sciences.

Finally, LIDS students and faculty members continue to receive awards and significant recognition for their accomplishments:

Dimitri Bertsekas received the 2009 Institute for Operations Research and the Management Sciences (INFORMS) Expository Writing Award.

LIDS administrative officer Debbie Deng was promoted to LIDS's assistant director for administration.

Emily Fox received the inaugural EECS Jin-Au Kong Outstanding Doctoral Thesis Prize. Fox also received the Savage Award for applied methodology in Bayesian statistics; this award is given for a PhD dissertation that makes outstanding contributions in Bayesian econometrics and statistics.

Pavithra Harsha received honorable mention in two dissertation award categories at 2009 INFORMS for her thesis "Mitigating Airport Congestion: Market Mechanisms and Airline Response Models": the Aviation Applications Section dissertation prize, and the Transportation Science and Logistics dissertation prize.

Julien Hendrickx, along with coauthors Changbin Yu, Baris Fidan, and Brian D. O. Anderson, won the award for best paper of the *Asian Journal of Control* for the 2006–2008 period.

Jonathan How was named the next Richard Cockburn Maclaurin Professor.

Daniel Iancu was awarded the 2009 INFORMS Optimization Society student paper prize. Iancu was also awarded the International Business Machines (IBM) Goldstine Fellowship. He is jointly supervised by Dimitris Bertsimas and Pablo Parrilo.

Raphael Jungers received the 2009 IBM Belgium award for a PhD contributing to the theory of computer science.

Sertac Karaman and Emilio Frazzoli received the Willow Garage's Best Open-Source Code Award for RRT*, a software library implementing the algorithms introduced and analyzed in their paper "Incremental Sampling-based Algorithms for Optimal Motion Planning." Professor Frazzoli also advised on the paper, coauthored by former LIDS visiting student Lucia Pallottino, V. G. Scordio, and Antonio Bicchi, which received the 2009 IEEE Robotics and Automation Society Italian chapter young author best paper award.

Stefano Maranò, Wesley Gifford, Henk Wymeersch, and Moe Win received the best paper award at the 2009 IEEE Global Communication Conference (Globecom) for their paper "Nonparametric Obstruction Detection for UWB Localization."

Jinwoo Shin and Shreevatsa Rajagopalan (supervised by Devavrat Shah) received the Kenneth C. Sevcik best student paper award at the 2009 Association for Computing Machinery Sigmetrics/Performance conference for their work on efficient medium access algorithm.

LIDS affiliate Eduardo Sontag of Rutgers University has been selected as the recipient of the 2011 IEEE Control Systems Award for fundamental contributions to nonlinear systems theory and nonlinear feedback control.

John Tsitsiklis delivered the Applied Probability Society Markov Lecture at the 2009 INFORMS annual meeting.

Alan Willsky was elected to the National Academy of Engineering. Professor Willsky was also the recipient of the 2010 IEEE Signal Processing Society Technical Achievement Award.

Moe Win received the 2010 Outstanding Service Award of the IEEE ComSoc Radio Communications Committee "for outstanding service to the radio communications committee and for furthering radio communications in the IEEE Communications Society." Professor Win also received the 2009 Royal Academy of Engineering Distinguished Visiting Fellowship for "sharing firsthand insight into world-class, cutting-edge knowledge, recognising excellence, and inspiring the next generation."

Future Outlook

During the past year, LIDS met and exceeded nearly all of the goals set in the strategic plan developed in spring 2008. LIDS research has always been of the highest quality, and now that research is complemented by an energized community, a greatly strengthened funding base, a reaffirmed and strengthened international presence, significantly enhanced engagements and interactions with other units at MIT, and substantial roles in several major research initiatives at the Institute, including energy and transportation.

All of these accomplishments lay the foundation for a very bright future. The prospects for additional growth are substantial. LIDS expects to welcome at least two additional faculty members (one of whom, Thomas Magnanti, is working to remodel some of LIDS space to support his activities). Initiatives in energy (with support from various funding agencies, industry, and MITEI) are expected to grow, and LIDS's role in the recently initiated transportation initiative funded by Singapore is expected to be substantial. Future symposia and workshops are planned and will continue to position LIDS as both a catalyst and source of cutting-edge research in areas of considerable international importance. The success of the Paths Ahead symposium will enhance outreach to LIDS alumni, and plans are being made for modest remodeling of LIDS space to support its many activities.

As AY2010 closes, it is extremely gratifying that the efforts of all in LIDS have led to so much success in realizing the vision articulated several years ago. LIDS is an energized and welcoming community and is now, once again, recognized as a leading center for research in the information and decision sciences. LIDS is an exciting and fulfilling environment for all who are part of its community, and it intends to build on its successes to ensure continued growth and fulfillment of its promise.

Alan S. Willsky
Director
Edwin Sibley Webster Professor of Electrical Engineering and Computer Science

Munther A. Dahleh
Co-associate Director
Professor of Electrical Engineering and Computer Science

John N. Tsitsiklis
Co-associate Director
Clarence J. Lebel Professor of Electrical Engineering

More information about the Laboratory for Information and Decision Systems can be found at http://lids.mit.edu/.