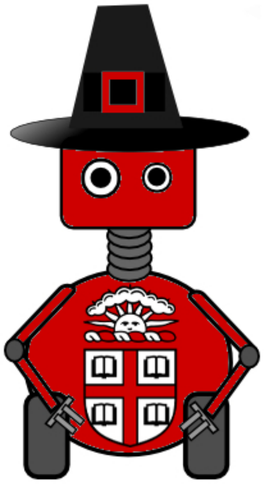

# 3rd Annual Northeast Robotics Colloquium

Alumnae Hall
Brown University
Providence, RI

October 11th, 2014

JAYBRIDGE ROBOTICS

HCR HUMANITY CENTERED ROBOTICS INITIATIVE

## Welcome

NERC is back in 2014, hosted by Brown University! Robotics is poised for rapid and dramatic growth in the coming decade as the combination of technical advances, the growing availability of talented and highly-trained roboticists, and falling hardware costs render many real-world applications, involving ever more complex systems, feasible.

Robotics is also a field whose progress depends directly on sustained technology and skill transfer between academia and industry, and between different industry sectors. The Northeast is dense with world-leading universities, cutting edge robotics research laboratories, and robotics companies — yet there are very few events where roboticists from all of these institutions can mix freely and forge productive local collaborations.

The Northeast Robotics Colloquium brings together all of these many varieties of robotics practitioners in the northeastern United States, in an event that is simultaneously a research meeting, a networking event, a job-fair, and a showcase for established and up-and-coming robot companies. Ultimately, we hope to promote the kind of healthy and well-connected robotics community that will be essential in fueling the field's rapid growth in the coming decade.

This year our program includes invited speakers from both academia and industry, an eclectic collection of posters and demos, and tours of robotics labs at Brown.

NERC is co-located with Waterfire, Providence's well-known festival of fire and water. After the colloquium, enjoy a full-basin lighting of braziers along the rivers in Providence, along with music and other festivities.

We hope you enjoy it as much as we have in bringing it to you!

Stefanie Tellex, Brown University
Suzanne Alden, Brown University
Mehmet Dogar, Massachusetts Institute of Technology

## Schedule

| | |
|---|---|
| *9:00am–9:45am* | Registration |
| *9:45am–10:00am* | Welcoming Remarks |
| *10:00am–11:00am* | Invited Talk: Holly Yanco<br>*Robot Research, Development and Testing at the NERVE Center* |
| *11:00am–12:00am* | Invited Talk: Nicholas Roy<br>*Planning in Information Space for Autonomous Air Vehicles* |
| *12:00pm–12:15pm* | Sponsor Spotlight: Jaybridge Robotics |
| *12:15pm–1:30pm* | Lunch (Provided) |
| *1:30pm–2:30pm* | Invited Talk: Joseph Jones<br>*How to Move 7 Million Plants: A Case Study of Robots, Enterprise, and Technology* |
| *2:30pm–4:30pm* | Poster Session and Laboratory Tours<br>*For lab tours, please sign up and meet at registration desk. There are a limited number of spots available.* |
| *4:30pm–5:30pm* | Invited Talk: Bertram Malle<br>*The next great challenge: Moral competence in robots* |
| *5:30pm–5:45pm* | Concluding Remarks |
| ***** | |
| *6:15pm* | WaterFire Festival<br>*The braziers from Exchange Street to Crawford Street will be lit shortly after sunset.* |
| *7:45pm* | WaterFire Festival<br>*Waterplace Park basin lighting will occur in conjunction with special performances and a large torch lighting ceremony.* |

## Invited Talks

### Robot Research, Development and Testing at the NERVE Center

**Holly Yanco**
**Professor of Computer Science**
**University of Massachusetts Lowell**

**Abstract:** The New England Robotics Validation and Experimentation (NERVE) Center at the University of Massachusetts Lowell is a dedicated research, testing, and training facility. The mission of the NERVE Center is to improve the development of robotic systems by both academic researchers and corporations by facilitating evaluation throughout the design cycle. The NERVE Center houses replicas of the National Institute of Standards and Technology's (NIST) Standard Test Methods for Robots, water test areas designed in collaboration with the Army, an indoor rain area, NERVE-specific apparatuses, and the ability to simulate a variety of operational scenarios. In this talk, I will present the testing methods available at NERVE and discuss new research on the development of new standards and training methods. I will demonstrate the use of these testing methods through discussion of my lab's research and testing of other robot systems.

**Bio:** Holly Yanco is a Professor of Computer Science at the University of Massachusetts Lowell and the Director of the New England Robotics Validation and Experimentation (NERVE) Center. Her research interests include human-robot interaction, multi-touch computing, interface design, robot autonomy, fostering trust of autonomous systems, evaluation methods for human-robot interaction, and the use of robots in K-12 education to broaden participation in computer science. Yanco's research has been funded by the National Science Foundation, including a CAREER Award, the Army Research Office, DARPA, NIST, and Google. Yanco was the General Chair of the 2012 ACM/IEEE International Conference on Human-Robot Interaction and is now the co-chair of the conference's steering committee. She served on the Executive Council of the Association for the Advancement of Artificial Intelligence (AAAI) from 2006-2009 and was the Symposium Chair for AAAI from 2002-2005. She is a senior member of AAAI. Yanco has a PhD and MS in Computer Science from the Massachusetts Institute of Technology (MIT) and a BA in Computer Science and Philosophy from Wellesley College.

## Planning in Information Space for Autonomous Air Vehicles

**Nicholas Roy**
**Associate Professor, Department of Aeronautics & Astronautics**
**Massachusetts Institute of Technology**

**Abstract:** Decision making with imperfect knowledge is an essential capability for unmanned vehicles operating in populated, dynamic domains. For example, a UAV flying autonomously indoors will not be able to rely on GPS for position estimation, but instead use on-board sensors to track its position and map the obstacles in its environment. The planned trajectories for such a vehicle must therefore incorporate sensor limitations to avoid collisions and to ensure accurate state estimation for stable flight – that is, the planner must be be able to predict and avoid uncertainty in the state, in the dynamics and in the model of the world. Incorporating uncertainty requires planning in information space, which leads to substantial computational cost but allows our unmanned vehicles to plan deliberate sensing actions that can not only improve the state estimate, but even improve the vehicle's model of the world.

I will discuss recent results from my group in planning in information space. I will describe the navigation system for a variety of air vehicles flying autonomously without GPS using laser range-finding, and will show how these results extend to autonomous mapping and general tasks with imperfect information.

**Bio:** Nicholas Roy is an Associate Professor in the Department of Aeronautics & Astronautics at the Massachusetts Institute of Technology and a member of the Computer Science and Artificial Intelligence Laboratory (CSAIL) at MIT. He received his Ph. D. in Robotics from Carnegie Mellon University in 2003. His research interests include autonomous systems, mobile robotics, human-computer interaction, decision-making under uncertainty and machine learning. He has returned to MIT after two years at Google [x] as the founder of Project Wing.

## How to Move 7 Million Plants: A Case Study of Robots, Enterprise, and Technology

**Joseph Jones**
**Cofounder and CTO**
**Harvest Automation, Inc**

**Abstract:** Many critical elements must converge for a robot to achieve commercial success in a new market. The application must be something customers want, the technology must be within reach, and the price of the completed product must be competitive with that of existing solutions. Harvest Automations HV-100 robots demonstrated their viability by moving more that seven million plants for paying nursery and greenhouse customers over the last two years. The talk will describe the application and the economic and technology choices that define the HV-100. Potential future applications and robots will be touched on.

**Bio:** Joseph L. Jones is cofounder and CTO of Harvest Automation, Inc. His primary interest is the practical application of robotic technology to real-world problems. Prior to forming Harvest, Mr. Jones was a senior roboticist with iRobot Corporation. There he proposed and helped develop the Roomba floor cleaning robot. Before joining iRobot Mr. Jones served on the research staff at the MIT Artificial Intelligence Laboratory. A graduate of MIT he holds over 25 US and several international patents.

## The next great challenge: Moral competence in robots

**Bertram F. Malle**
**Professor, Department of Cognitive, Linguistic, and Psychological Sciences**
**Brown University**

**Abstract:** Some great challenges of robotics have led to success stories (e.g., bipedal walking, mapping of environments, and human safety); others are still daunting (e.g., natural language communication, closing the perception-action loop). It may seem unfair, but we need to add one more challenge: some robots, namely social robots, must have moral competence. I argue briefly why social robots need to be moral and then offer a framework for what moral competence is and sketch the prospects for it to be developed in artificial agents. Typically, proposals for moral capacities in robots focus on moral agency; but moral competence goes further. I propose that it consists of five distinct but related components: (1) A system of norms; (2) a moral vocabulary; (3) moral cognition and affect; (4) moral decision making and action; and (5) moral communication. I briefly discuss each component and two sets of goals: to properly understand their human implementation and to prepare for their robotic implementation.

**Bio:** Bertram F. Malle earned Master's degrees in philosophy/linguistics (1987) and psychology (1989) at the University of Graz, Austria. After coming to the United States in 1990 he received his Ph.D. at Stanford University in 1995 and joined the University of Oregon Psychology Department. Since 2008 he is Professor at the Department of Cognitive, Linguistic, and Psychological Sciences at Brown University. He received the Society of Experimental Social Psychology Outstanding Dissertation award, a National Science Foundation CAREER award, and he is past president of the Society of Philosophy and Psychology. Malles research, which has been funded by the NSF, Army, Templeton Foundation, and Office of Naval Research, focuses on social cognition, moral judgment, and more recently human-robot interaction. He has published over 80 articles and several books, including: Intentions and intentionality: Foundations of Social Cognition (with L. J. Moses and D. A. Baldwin, eds.), MIT Press, 2001; How the Mind Explains Behavior, MIT Press, 2004; and Other minds (with S. D. Hodges, eds.), Guilford Press, 2005.

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## Exhibits

**Jaybridge Robotics**

**Humanity Centered Robotics Initiative**
*Brown University*

**Kinova Robotics**

**Designing Humanity-Centered Robots**
Michael Littman, *Brown University*

**Humans to Robots Laboratory**
*Brown University*

**Building Emotional Understanding through Interactive Role-Play using Robots**
Iolanda Leite and Brian Scassellati, *Yale University*

**Dragonbot**
Media Lab, *Massachusetts Institute of Technology*

**Tega: Robot for Long-Term, In-Home HRI**
Luke Plummer, Jin Joo Lee, Cynthia Breazeal, *Massachusetts Institute of Technology*

**BRINA**
Brendan McLeod, *Worcester Polytechnic Institute*

## Poster Exhibits

**Affordance-Aware Planning**
D. Abel, G. Barth-Maron, D. Hershkowitz, S. Brawner, K. O'Farrell, J. MacGlashan, and S. Tellex *Brown University*

**A Passive Rotary to Linear Continuously Variable Transmission**
J. Belter, A. Dollar *Yale University*

**Instrument Tracking and Visualization for Ultrasound Catheter Guided Procedures**
L. Brattain, P. Loschak, C. Tschabrunn, E. Anter, and R. Howe *Harvard, MIT*

**"Could you be polite, please?": Mechanisms for Understanding and Generating Polite Language for Human-Robot Interaction**
G. Briggs *Tufts University*

**Autonomous Vehicles for Remote Sample Collection in Difficult Conditions**
S. Chandra, D. Diggins, S. Hughes, L. Lye, V. Preston, M. Rush, M. Tieu, J. Woo, A. Bennett, I. Kerr *Franklin W. Olin College of Engineering*

**Assembly and Magnetic Actuation of Microbot Prototypes from Anisotropic Patchy Microcubes**
N. Diwakar, K. Han, C. Shields IV, B. Bharti, G. Lopez, and O. Velev *NCSU, NSF, Duke, WPI*

**Theoretical Progress in Sampling-Based Motion Planning with Practical Implications**
A. Dobson, Z. Littlefield, K. Bekris *Rutgers University*

**Real-time Pedestrian Crossing Recognition for Assistive Outdoor Navigation**
S. Fontanesi, A. Frigerio, L. Fanucci, W. Li, N. Wang *MIT, University of Pisa*

**Development of autonomous sampling capability for small marine organisms**
A. Govindarajan, J. Pineda, M. Purcell, G. Packard, M. Dennett, A. Girard, K. Tradd, J. Breier *Woods Hole Oceanographic Institution*

**Cellular Decomposition and Classification of a Hybrid System**
A. Johnson and D. Koditschek *University of Pennsylvania*

**Selecting Paths to Minimize Conflicts in Crowded Scenes using Minimal Information**
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**Rearranging Similar Objects with a Manipulator using Pebble Graphs**
A. Krontiris, R. Shome, A. Dobson, A. Kimmel, K. Bekris, *Rutgers University*

**Modeling and Control of Nonlinear Tissue Compression and Heating using a LQG Controller for Automation in Robotic Surgery**
B. Li, U. Sinha, and G. Sankaranarayanan *Rensselaer Polytechnic Institute*

**Informed Motion Planning for Kinodynamic Systems Without a Steering Function**
Z. Littlefield, K. Bekris *Rutgers University*

**Brown-UMBC Reinforcement Learning And Planning Java Library**
J. MacGlashan and M. Littman *Brown University*

**Localizing Grasp Affordances in 3-D Points Clouds Using Machine Learning**
A. ten Pas and R. Platt *Northeastern University*

**A General Platform for Immersive Virtual Reality and Interactive Manipulation with Haptic Feedback via Motion Capture**
A. Shariati *Lehigh University, University of Pennsylvania*

**Cloud Automation: Precomputing Roadmaps for Flexible Manipulation**
R. Shome, A. Krontiris, A. Dobson, K. Bekris *Rutgers University*

**A Dempster-Shafer Theoretic Approach to Understanding Indirect Speech Acts**
T. Williams, R. C. Núñez, G. Briggs, M. Scheutz, K. Premaratne, and M. Murthi *Tufts University, Miami University*

**Analogical Generalization of Activities from Single Demonstration**
J. Wilson and M. Scheutz *Tufts University*

**20 Years of Scientific Exploration of the Deep Sea with ABE and Sentry**
D. Yoerger, A. Bradley, C. Kaiser, M. Jakuba, J. Kinsey *Woods Hole Oceanographic Institution*

**An Experimental Study for Identifying Features of Legible Manipulator Paths**
M. Zhao, R. Shome, I. Yochelson, K. Bekris, J. Rubinstein, E. Kowler *Rutgers University*

## Poster Abstracts

**D. Abel, G. Barth-Maron, D. Hershkowitz, S. Brawner, K. O'Farrell, J. MacGlashan, and S. Tellex**
Brown University

**Title:** Affordance-Aware Planning

**Abstract:** Planning algorithms for non-deterministic domains are often intractable in large state spaces due to the well-known curse of dimensionality. Existing approaches to planning in large stochastic state spaces fail to prevent autonomous agents from considering many actions that are obviously irrelevant to a human solving the same task. To prevent agents from exploring irrelevant action applications, we formalize the notion of affordances as state space independent, goal-oriented knowledge added to an Object Oriented Markov Decision Process (OO-MDP). Affordances prune irrelevant actions based on the agents goal and the current state, reducing the number of state-action pairs the planner must evaluate in order to formulate a near optimal policy. Affordances may be provided by an expert or may be learned without supervision. We demon- strate our approach by planning in the state-rich Minecraft domain, showing significant increases in speed, reductions in state space exploration, and improvements in the quality of the synthesized policy. Additionally, we show that learned affordances often surpass the performance of those provided by experts. Finally, we demonstrate that affordance-aware planning enables a robot to assist a person performing a cooking task.

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**J. Belter, A. Dollar**
Yale University

**Title:** A Passive Rotary to Linear Continuously Variable Transmission

**Abstract:** In this work, we present the synthesis and design of a rotary-to-linear continuously variable transmission with the ability to passively change gear ratio as a function of the output load. The primary mechanism involves variable-pitch rollers whose angle changes as a function of the output load due to the compliance properties of their housing. By changing spring stiffness, the relationship between the linear output load and transmission ratio can be tuned to optimize drive motor operating conditions over the entire range of output loads. After laying out the working concept, we show the performance analysis for such a transmission applied to a 6-W DC motor and present an example design analysis for tuning to maximize power output over the entire range of operating conditions. A prototype system was used to measure key parameters such as rolling resistance and lateral slip coefficients and to evaluate the transmission performance in a target application.

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**L. Brattain, P. Loschak, C. Tschabrunn, E. Anter, and R. Howe**
Harvard, MIT

**Title:** Instrument Tracking and Visualization for Ultrasound Catheter Guided Procedures

**Abstract:** We present an instrument tracking and visualization system for intra-cardiac ultrasound catheter guided procedures, enabled through the robotic control of ultrasound catheters. Our system allows for rapid acquisition of 2D ultrasound images and accurate reconstruction and visualization of a 3D volume. The reconstructed volume addresses the limited field of view, an inherent problem of ultrasound imaging, and serves as a navigation map for procedure guidance. Our robotic system can track a moving instrument by continuously adjusting the imaging plane and visualizing the instrument tip. The overall instrument tracking accuracy is 2.2mm RMS in position and 0.8 in angle.

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**G. Briggs**
Tufts University

**Title:** "Could you be polite, please?": Mechanisms for Understanding and Generating Polite Language for Human-Robot Interaction

**Abstract:** The field of social robotics and human-robot interaction has been increasingly interested in developing robotic agents that can interact with people as human-like social actors. As such, there has been a variety of prospective studies that seek to investigate how humans react to agents with display a variety of human-like social behaviors, such as the use of polite speech. However, while these investigations have shed light on the utility of politeness modulation by robots in natural language interactions, the challenge of actually developing mechanisms for robots to systematically and appropriately deploy politeness strategies still remains. We present our work that describes mechanisms that appropriately deploy both literal and non-literal utterances to be able to generate polite requests and instructions. Our solution is an extension of prior that manipulates the directness of utter-

ances in order to protect what is known in politeness theory as negative face — which pertains to the autonomy of the addressed agent. We also discuss the challenge of protecting positive face, or the self-image and social perceptions, of an agent, which will require novel social reasoning representations and mechanisms.

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**S. Chandra, D. Diggins, S. Hughes, L. Lye, V. Preston, M. Rush, M. Tieu, J. Woo, A. Bennett, I. Kerr**

Franklin W. Olin College of Engineering

**Title:** Autonomous Vehicles for Remote Sample Collection in Difficult Conditions

**Abstract:** The rapidly dropping costs and increasing capabilities of robotic systems are opening up unprecedented opportunities for the world of scientific research. It is now becoming possible to conduct remote sample collection operations under conditions that were previously impossible due to expense, location, timing, risk, or all of the above. Examples include environmental diagnostic sample collection during and after a natural event (storms, flood, tides), monitoring wildlife in remote locations throughout a season, and rapid sample collection in a shortduration rare event (i.e. a whale surfacing to breathe). The advantage of remote sensing is that the stress on the environment or wildlife due to human presence is removed. Olin College in collaboration with Ocean Alliance, a foundation that has been monitoring whales globally for a halfcentury, has been developing "SnotBot," a robot designed to enable marine biologists to collect exhaled breath condensate, or whale spray, samples without disturbing the target whale. Spray samples are almost comparable to blood samples, containing DNA, hormones, indicators of infection, and more. Currently, the collection process entails a human in a boat to approach a whale at the surface, and use a long pole to collect samples. Whales appear to be stressed by the presence of a boat and tend to move away from it, making sample collection more difficult for the human biologist. With SnotBot, the biologist can maintain a standoff distance of hundreds of meters while collecting a sample. Before a license allowing this research to continue can be issued, Olin College and Ocean Alliance must assemble a baseline dataset to determine if the whale might experience distress with this system. Using data from tests conducted on a simulated whale equipped with anemometers and hydrophones in the Gulf of Mexico in the summer of 2014, we use this poster to present our preliminary findings.

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**N. Diwakar, K. Han, C. Shields IV, B. Bharti, G. Lopez, and O. Velev**
NCSU, NSF, Duke, WPI

**Title:** Assembly and Magnetic Actuation of Microbot Prototypes from Anisotropic Patchy Microcubes

**Abstract:** Field-directed assembly of anisotropic patchy particles represents an efficient method for the construction of microstructures. These particles have potential as building units in the assembly of soft robotic devices. Such assembly requires research on the manipulation of the structures and control of the field-driven particle interactions. We have found that microscale, top-coated metallodielectric cubes exhibit various chain-assembly patterns and undergo repeated bending and folding motions along contact edges between adjacent cubes. Through use of dielectrophoresis (DEP) and magnetophoresis (MAP), these particles were assembled into staggered and linear chains. By direct assembly of these patterns, we can form structures with a variety of modes of actuation allowing external field manipulation. The modes of bending and actuation can be interpreted on the basis of the induced and residual dipolar interactions between the metallic patches on the particles. Further use of an electric or magnetic field gradient makes possible the transportation of these structures across the experimental field. This investigation examines the patterns of assembly, actuation, and transportation of these cubes under varying conditions, while varying external field parameters, sample type, and electrode orientation. On the basis of these experiments, we optimized the processes to produce structures with the greatest interaction response. These structures were then manipulated to demonstrate basic operations in soft robotics, including grabbing, moving, and release of microscale particles and live cells.

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**A. Dobson, Z. Littlefield, K. Bekris**
Rutgers University

**Title:** Theoretical Progress in Sampling-Based Motion Planning with Practical Implications

**Abstract:** Sampling-based motion planners are efficient methods to solve the motion planning problem, especially for high-dimensional and geometrically complex problems. As these methods advance, the formal guarantees they provide become stronger. Recent developments showed that asymptotically optimal versions of these methods exist which converge to returning optimal solutions, though they can quickly build up dense planning structures. This work examines how these methods can be made more practical. First, by relaxing optimality constraints, the work shows that sparse structures can attain near optimality properties, as well

as showing near-optimality holds after finite computation. Secondly, these methods can be extended to work with complex dynamical systems, attaining near-optimal solutions without access to a steering function. Lastly, this work also shows these properties can be achieved in a computationally efficient manner, having low running time and memory requirements, creating structures with orders of magnitude fewer nodes.

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**S. Fontanesi, A. Frigerio, L. Fanucci, W. Li, N. Wang**
MIT, University of Pisa

**Title:** Real-time Pedestrian Crossing Recognition for Assistive Outdoor Navigation

**Abstract:** Navigation in urban environments can be difficult for people who are blind or visually impaired. In this project, we focus on recognizing pedestrian crossings in outdoor environments. Our goal is to provide navigation cue for crossing the street and reaching an island or sidewalk safely. Using a state-of-the-art Multisense S7S sensor, we collected 3D point cloud data for real-time detection of pedestrian crossing and generation of directional guidance. We demonstrate improvements to a baseline, monocular-camera-based system by integrating 3D spatial prior information extracted from the point cloud. Our systems parameters can be set to the actual dimensions of real-world settings, which enables robustness of occlusion and perspective transformation. The system works especially well in non-occlusion situations, and is reasonably accurate under different kind of conditions. As well, our large dataset of pedestrian crossings, organized by different types and situations of pedestrian crossings in order to reflect real-word environments, is publicly available in a commonly used format (ROS bagfiles) for further research.

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**A. Govindarajan, J. Pineda, M. Purcell, G. Packard, M. Dennett, A. Girard, K. Tradd, J. Breier**
Woods Hole Oceanographic Institution

**Title:** Development of autonomous sampling capability for small marine organisms

**Abstract:** Sampling small marine organisms such as larval and juvenile animal stages in the water column is crucial for the study of the dispersal of marine life, but traditional methods do not adequately sample all regions of the water column. Moreover, fine-scale measurements of larval concentrations relative to sharp environmental gradients in temperature, salinity and circulation are needed for elucidating larval transport and accumulation mechanisms, but current methods are expensive, labor intensive, and inadequately resolved on different temporal and spatial scales. Autonomous sampling can overcome many existing limitations and at the same time, collect environmental contextual data. The Suspended Particulate Rosette Sampler was recently developed to collect discrete microbial and geochemical samples in the deep sea. We coupled this sampler to a REMUS 600 autonomous underwater vehicle to enable larval sampling in coastal areas. We conducted two deployments in Buzzards Bay, Massachusetts, at a time when larvae are known to be abundant. The missions included cross-shelf transects where larvae were sampled at pre-programmed intervals and co-registered temperature and conductivity measurements were taken. Sampling followed a sawtooth pattern and extended to approximately 1 meter off of the seafloor. The second mission followed a topographically complex channel and larvae were sampled at discrete depth intervals. Following collection, larvae were genetically identified to obtain species-specific vertical distributions. Our results demonstrate the utility of autonomous sampling for coastal marine plankton in the context of key environmental parameters. Such data will be useful for biologists, conservationists, and fisheries management.

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**A. Johnson and D. Koditschek**
University of Pennsylvania

**Title:** Cellular Decomposition and Classification of a Hybrid System

**Abstract:** Robots are often modeled as hybrid systems providing a consistent, formal account of the varied dynamics associated with loss and gain of kinematic freedom as a machine impacts and breaks away from contacts with its environment. This hybrid structure induces an abstract simplicial complex indexed by the active contact constraints, where each vertex in the complex is a single constraint. This complex provides a concise description of the possible edges of the hybrid system through impacts — they must lie in the closure of the star of the current cell (i.e. $(I, J) \in \Gamma \Leftrightarrow J \in Cl\,St\,I$). This structure is in some sense dual to the "ground reaction complex", wherein constraints reduce dimension and the equivalent adjacency property is instead that the star of the closure (i.e. $(I, J) \in \Gamma \Leftrightarrow J \in St\,Cl\,I$). Under either formulation, sequences of contact conditions ("letters") define smooth families of executions ("words"). Points of discontinuity lie within the boundaries between words, but in certain cases the evaluation map can still be continuous over an open set including these boundaries, even though the associated words change abruptly across these boundaries. We present examples of these "convergent" and "divergent" word boundaries.

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**A. Kimmel, K. Bekris**
Rutgers University

**Title:** Selecting Paths to Minimize Conflicts in Crowded Scenes using Minimal Information

**Abstract:** This work aims to avoid conflicts between moving, non-communicating agents, which employ minimum sensing information. Since safety can be guaranteed by reactive obstacle avoidance for holonomic systems, the focus is on deadlock avoidance given proper selection of global paths in cluttered scenes. A method to compute the "interaction cost" of a path is proposed, which considers only the neighboring agents' observed positions. Minimizing the interaction cost in a prototypical challenge involving two agents moving through two corridors from opposing sides guarantees the selection of non-conflicting paths. Complex scenes, however, where agents have many paths to follow are more challenging. This leads to a study of alternatives for decentralized path selection. Simulated experiments indicate that following a "minimum-conflict" path given the other agents' observed positions results in deadlock avoidance. A scheme that selects between the minimum-conflict path and a set of shortest paths given their interaction cost improves path quality while still achieving deadlock avoidance. Finally, learning to select between the minimum-conflict and one of the shortest paths can also be achieved by reasoning using regret minimization. This hindsight learning method allows agents to be adaptive to the behavior of their neighbors.

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**A. Krontiris, R. Shome, A. Dobson, A. Kimmel, K. Bekris,**
Rutgers University

**Title:** Rearranging Similar Objects with a Manipulator using Pebble Graphs

**Abstract:** This work proposes a method for effectively computing manipulation paths to rearrange similar objects in a cluttered space. Rearrangement is a challenging problem as it involves combinatorially large, continuous configuration spaces due to the presence of multiple bodies and kinematically complex manipulators. This work leverages ideas from algorithmic theory, multi-robot motion planning and manipulation planning to propose appropriate graphical representations for this challenge. These representations allow to quickly reason whether manipulation paths allow the transition between entire sets of object arrangements without having to explicitly store these arrangements. The proposed method also allows to take advantage of precomputation given a manipulation roadmap for transferring a single object in the same cluttered space. The resulting approach is probabilistically complete for a wide set of problem instances. It is evaluated in simulation for a realistic model of a Baxter robot and executed on the real system, showing that the approach solves complex instances and is promising in terms of scalability and success ratio.

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**B. Li, U. Sinha, and G. Sankaranarayanan**
Rensselaer Polytechnic Institute

**Title:** Modeling and Control of Nonlinear Tissue Compression and Heating using a LQG Controller for Automation in Robotic Surgery

**Abstract:** Introduction: Robotic surgery has various benefits that includes reduced patient trauma and increased dexterity and ergonomics for the operating surgeon. Currently robotic surgery is performed by a surgeon teleoperating the surgical robot from a master console. Autonomous control of surgical robot is essential for telesurgery with time delay and increased patient safety. In this work, we have developed an autonomous control for surgical robot to perform the electrosurgical task, which is used to dissect tissues and arrest bleeding by coagulation. Methods: The electrosurgical procedure such as coaptic vessel closure involves tissue compression to a desired distance and heating to a set temperature. Both tissue compression and conductance exhibit nonlinear properties, which are modeled as a multiple input multiple output MIMO nonlinear system. After linearizing the models, a LQG controller was designed to control the tissue compression process and tissue heating process separately. A particle swarm optimization (PSO) algorithm was used to choose the optimal weighting matrices for the LQG controllers according to the desired controlling accuracy. A ramp and hold trajectory was chosen as the desired tissue compression and temperature references. The model parameters for tissue were chosen from literature and simulated using Matlab (Mathworks Inc.). Results: The LQG controllers with optimal weights (Q and R) were able to track both the tissue compression and temperature references in finite time horizon and with minimal error (tissue compression - the max absolute error was $9.6057 \times 10^{-5}m$ and temperature - the max absolute error is 0.4561 Celsius). Compared to LQG controller with weighting matrices chosen by trial and error, PSO based optimized controller provided the least error and faster convergence. Conclusion: We have developed a framework for automating surgical tasks in robotic surgery and modeled the automation of electrosurgical task using LQG controller with optimal weighting matrix obtained using a PSO algorithm. Currently we have shown the feasibility of our system through simulation. Our next step is to implement the controller in the RAVEN 2, an open source surgical robot. Acknowledgements: We acknowledge the RPI Office of Research Seed Grant for supporting this work and the China

Scholarship Council grant that supported Baichun Li.

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**Z. Littlefield, K. Bekris**
Rutgers University

**Title:** Informed Motion Planning for Kinodynamic Systems Without a Steering Function

**Abstract:** Motion planning is an active area of research in the robotics concerned with the basic problem of finding the required actions to take a robot from a start to a goal. Starting from this basic definition, different modifications and complications can be considered, such as uncertainty, increased complexity of the robots, and many task-specific challenges. In many of these cases, information can be given to the motion planner to allow it to optimize its performance for the given task. This can be accomplished through means such as cost maps in your workspace, heuristics for building the data structure, and other factors that a human operator may be able to provide. This work showcases a modification of the authors' previous motion planner, SST, to problems where information can be utilized to make planning more efficient. The new algorithm, iSST, aims to provide an alternative motion planner that can provide anytime behavior for real world problems, while taking advantage of analysis that argues about improvements to paths given any computation that is available.

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**J. MacGlashan and M. Littman**
Brown University

**Title:** Brown-UMBC Reinforcement Learning And Planning Java Library

**Abstract:** In this poster we present the Brown-UMBC Reinforcement Learning and Planning (BURLAP) java library. Although there are a number of existing reinforcement learning or planning libraries, what separates BURLAP is its breadth of functionality, modularity, and ability to express a wide range of problems that makes it an excellent tool for designing more complex systems that require various forms of behavioral reasoning and learning. The core of BURLAP is a state representation that is based on and extends the object-oriented Markov decision process formalism (OO-MDP) (Diuk, Cohen, and Littman, 2008), enabling the construction of discrete, continuous, or relational single and multi-agent domains that can consist of any number of objects in the world. A number of common domains and domain generators are included in BURLAP making it easy to test algorithms on common problems. For algorithms, BURLAP currently covers classic goal-directed forward-search planning algorithms (e.g., A*), a wide range of stochastic MDP planning algorithms, model-free and model-based reinforcement learning, value function approximation, temporally extended actions, inverse reinforcement learning, and a number of variants of multi-agent Q-learning and value iteration. Numerous other features are currently in development such as partially observable MDP planning, learning from human-delivered reward, and a standard interface to make interfacing BURLAP with physical robots controlled by ROS easy. To get new users and students learning about AI up to speed, our website (http://burlap.cs.brown.edu) contains complete java documentation; numerous detailed tutorials that also explain some of the theory behind planning and learning algorithms; an FAQ; user email list; and short video tutorials.

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**A. ten Pas and R. Platt**
Northeastern University

**Title:** Localizing Grasp Affordances in 3-D Points Clouds Using Machine Learning

**Abstract:** Perception-for-grasping is a challenging problem in robotics. Inexpensive range sensors such as the Microsoft Kinect provide sensing capabilities that have given new life to the effort of developing robust and accurate perception methods for robot grasping. This paper develops a new approach to localizing grasp configurations in 3-D point clouds efficiently. Given a particular robot hand geometry, our method localizes all hand poses relative to a point cloud where a grasp performed by that hand is expected to succeed. The key idea is to reduce the dimensionality of this search space by constraining all potential grasp poses to be orthogonal to the axis of principle curvature of the surface being grasped. This constraint enables us to represent the local geometry of each potential grasp compactly as a two-dimensional image. We classify these grasp "images" as good or bad grasps by encoding them using HOG features and performing SVM classification, a standard machine vision approach to category recognition. Our initial evaluation shows that this method can detect grasp affordances robustly on a large variety of objects and that the method is effective in the context of practical robot grasping experiments.

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**A. Shariati**
Lehigh University, University of Pennsylvania

**Title:** A General Platform for Immersive Virtual Reality and Interactive Manipulation with Haptic Feedback via Motion Capture

**Abstract:** Most virtual reality systems generally fall into one of two categories: graphics oriented - which focus on developing immersive environments but generally fail to provide users with a strong sense of interactivity - and haptics oriented - which focus on constructing

tools for touch-based manipulation and auditory interaction but tend to be very specialized and exist in tightly bound device ecosystems. I present an approach for creating immersive graphical settings with a high degree of interactive manipulation using any number of haptic devices. The Oculus Rift seen in Fig. 1 is the current state of the art in HMD VR technology. Its greatest asset is its speed. The VR realism is directly tied to this response time, and the Oculus overcomes the problem of graphical latency, which has plagued all of its predecessors. It does so by sampling data from its 3-axis gyro, accelerometers, and magnetometers at a rate of 250Hz. Its ability to gather data so quickly from its propriocetive sensors allows the graphics on the display to be adjusted to correspond to real time head movements. However, the greatest limitation of the technology is that the position of the user cannot be extrapolated from the current sensing suite. By placing the device within a motion capture system we are able to obtain position information within a large 3D volume. Leveraging, a large motion capture system such as a Vicon also allows for the tracking of any number of devices by creating different models. For my experiment, I built a model to track a Nintendo Wiimot . While the Wiimote is far from a state of the art haptic device, it does provide some one-dimensional haptic feedback and is very simple to use. Since the system can determine the relative position between the device, the headset, and an arbitrary world frame, the graphical environment can now be manipulated to correspond to movement in the real world. The demo features a game of virtual squash. The user is placed within a room which approximately corresponds in size to the motion capture volume - 5 meters long, 2.5 meters wide, and 2.5 meters high. Alongside the user is a paddle and ball. The pose of the paddle corresponds directly to the pose of the Wiimote within the volume. See Figure 2 for a snapshot. When the virtual paddle makes contact with the ball, the Wiimote vibrates, and the paddle supplies the ball with an instantaneous velocity in the direction of the normal vector defining the face of the paddle with which it made contact.

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**R. Shome, A. Krontiris, A. Dobson, K. Bekris**
Rutgers University

**Title:** Cloud Automation: Precomputing Roadmaps for Flexible Manipulation

**Abstract:** This work aims to highlight the benefits of Cloud Automation, the opportunities that arise for industrial adopters and some of the research challenges that must be addressed in this process. The focus is on the use of cloud computing for efficiently planning the motion of new robot manipulators designed for flexible manufacturing floors. In particular, different ways that a robot can interact with a computing cloud are considered, where an architecture that splits computation between the remote cloud and the robot appears advantageous. Given this synergistic robot-cloud architecture, this work describes how solutions from the recent motion planning literature can be employed on the cloud during a periodically updated preprocessing phase to efficiently answer manipulation queries on the robot given changes in the workspace. In this setup, interesting tradeoffs arise between path quality and computational efficiency, which are evaluated in simulation. These tradeoffs motivate further research on how motion planning should be executed given access to a computing cloud.

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**T. Williams, R. C. Núñez, G. Briggs, M. Scheutz, K. Premaratne, and M. Murthi**
Tufts University, Miami University

**Title:** A Dempster-Shafer Theoretic Approach to Understanding Indirect Speech Acts

**Abstract:** Understanding Indirect Speech Acts (ISAs) is an integral function of human understanding of natural language, and is thus a necessary capability for effective Human-Robot Interaction. Recent attempts at understanding ISAs have used rule-based approaches to map utterances to deep semantics. While these approaches have been successful in handling a wide range of ISAs, they do not take into account the uncertainty associated with the utterance's context (which can be highly uncertain in real-world HRI scenarios), or with the utterance itself. We present a new approach for understanding ISAs using the Dempster-Shafer theory of evidence and show how this approach increases the robustness of ISA inference by (1) accounting for uncertain implication rules and context, (2) fluidly adapting rules given new information, and (3) enabling better modeling of the beliefs of other agents.

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**J. Wilson and M. Scheutz**
Tufts University

**Title:** Analogical Generalization of Activities from Single Demonstration

**Abstract:** Learning new activities (i.e., sequences of actions possibly involving new objects) from single demonstrations is common for humans and would thus be very desirable for future robots as well. However, "one-shot activity learning" is currently still in its infancy and limited to just recording the observed objects and actions of the human demonstrator. In this paper, we introduce a process called "Mental Elaboration and Generalization by Analogy" to create a generalized representation of an activity that has been demonstrated only once. By abstracting over various dimensions of the learned activity, the obtained activity representation is applica-

ble to a much wider range of objects and actions than would otherwise be possible. Mental Elaboration is a process of envisioning alternative scenarios in which the demonstrated activity could be applied. The Generalization by Analogy compares each of these scenarios to the demonstrated activity and constructs a generalized activity description. Finally, when a new scenario is presented, the generalized activity is compared to the new scenario to determine how similar they are and whether the activity is applicable to the scenario. The comparison process also generates possible inferences to be made about the new situation. Included in these inferences are the action to take and the parameter bindings for the action. We provide an initial set of algorithms to create the generalized activity. The quality of the generalization is evaluated by comparing it to new situations and ranking them by similarity. The generalized activity is most applicable to the situations with the greatest similarity.

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**D. Yoerger, A. Bradley, C. Kaiser, M. Jakuba, J. Kinsey**
Woods Hole Oceanographic Institution

**Title:** 20 Years of Scientific Exploration of the Deep Sea with ABE and Sentry

**Abstract:** The past 20 years has seen a revolution in our methods for studying the deep seafloor. Previously, the primary tools were human-occupied vehicles like the deep-diving Alvin submersible and tow sleds such as Scripps Institute of Oceanography's Deep Tow and the Woods Hole Oceanographic Institution's ANGUS and Argo vehicles. These systems served science well, exploring the mid-Ocean Ridge, discovering hydrothermal vents, and even finding the Titanic. While human- occupied vehicles still play a prominent role in seafloor studies, Remotely Operated Vehicles now provide superior endurance and allow scientific results to be broadcast live worldwide. Tow sleds have largely been supplanted by Autonomous Underwater Vehicles (AUVs), which are free from the influence of a cable to the surface. These have proven to be far superior sensor platforms, in that they are faster, more stable, can follow complex survey tracks more precisely, and are more nimble in rugged terrain. We are also beginning to take advantage of acoustic telemetry and on-board intelligence to run adaptive missions based on real-time sensor data. We also use AUVs for sampling microbes and larvae in the water column. This poster will summarize our progress with the ABE and Sentry AUVs over the past 20 years. In 1994, we made our first deep-water test cruise with our new AUV the Autonomous Benthic Explorer, ABE. Operating in water 4500 meters deep, we nearly lost ABE when our main ballast weight release failed. Rather than descending to 1000 meters and executing a search pattern as planned, ABE went straight to the bottom and refused to surface. Only a rescue by the Alvin submersible saved the vehicle. We demonstrated many engineering details of the vehicle, however. After a redesign of our weight releases and many software improvments, ABE's ability to map grew steadily. In 1995 and 1996, we accomplished our first scientific surveys with ABE. ABE made survey tracks over a recent lava flow at 2400m depth, measuring the local magnetic field while determining its position with long-baseline acoustic navigation. The resulting data set enabled our collaborators to determine the thickness of the lava flow. In 1999, ABE produced the first high- resolution bathymetric maps of a Mid-Ocean Ridge crest by an AUV on the Southern East Pacific Rise north of Easter Island. We repeated similar surveys at the 9N site west of Costa Rica and in the Galapagos Rift. In 2004, ABE played a key role in the discovery of hydrothermal vents in the Lau Basin between Fiji and Tonga. We later used ABE to discover and map the first hydrothermal vents on the Southern Mid-Atlantic Ridge and the Southwest Indian Ridge. ABE was lost off Chile in 2010, disappearing while conducting a hydrothermal survey at 3000m depth on its 222nd deep ocean dive. We had begun designing and building ABE's successor Sentry in 2002. Sentry was designed to maneuver like ABE with a more hydrodynamically efficient form. Sentry also carries superior navigation and mapping sensors, including a state-of-the-art bathymetric sonar. It has now completed nearly 300 dive-ocean dives. In 2010 we mapped terrain in the Galapagos Rift, providing targets for closeup examination and sampling with Alvin. Sentry mapped deep coral environments before and after the BP oil spill in the Gulf of Mexico and also quantified the deep hydrocarbon plume emanating from the broken well. Finally, we will examine some steps forward for Sentry, including new sensors, communications schemes, sampling capabilities, and cooperative operation with Autonomous Surface Vehicles (ASVs).

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**M. Zhao, R. Shome, I. Yochelson, K. Bekris, J. Rubinstein, E. Kowler**
Rutgers University

**Title:** An Experimental Study for Identifying Features of Legible Manipulator Paths

**Abstract:** This work performs an experimental study on the legibility of paths executed by a manipulation arm available on a Baxter robot. In this context, legibility is defined as the ability of people to effectively predict the target of the arm's motion. Paths that are legible can improve the collaboration of robots with humans since they allow people to intuitively understand the robots intentions. Each experimental trial in this study reproduces manipulator motions to one of many targets in front of the robot. An appropriate experimental setup was developed in order to collect the responses

of people in terms of the perceived robot's target during the execution of a trajectory by Baxter. The objective of the experimental setup was to minimize the cognitive load of the human subjects during the collection of data. The extensive experimental data provide insights into the features of motion that make certain paths more legible for humans than other paths. For instance, motions where the end-effector is oriented towards the intended target appear to be better in terms of legibility than alternatives.

## Lab Tours

**Humans to Robots Laboratory**
PI: Stefanie Tellex

**Brown Robotics**
PI: Chad Jenkins

**Computer Graphics Group**
PI: Andries van Dam

*For lab tours, please sign up and meet at the registration desk. There are a limited number of spots available.*

## Information for Families

**Attractions**

Providence is a great city for families, and has a wonderful Children's Museum close to Brown University. *(Children's Museum: 100 South St, Providence, RI 02903, Phone: (401) 273-5437)*

The closest playground is just 7 minutes walk from the NERC venue *(Brown Street Playground: Brown St. and Halsey St., College Hill, Providence, RI 02906).*

There are also many great beaches and parks; one of our favorites is Lincoln Woods *(Lincoln Woods State Park: 2 Manchester Print Works Rd, Lincoln, RI 02865, Phone: (401) 723-7892).*

Finally, NERC is on the same day as the famous Waterfire festival. Please request a Waterfire flyer from NERC registration desk. After NERC finishes, about 10 minutes away in downtown Providence, more than eighty braziers will be lit in the rivers. There will be live music, food, and other activities.

**Kids' Table**

At NERC, there will be a kids' table with coloring and toys!