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Preface

Welcome to RSS 2011!

This is the seventh Robotics: Science and Systems meeting, and we are very pleased to again have an extremely strong technical program. We have four invited speakers representing the broad range of research areas in robotics, and have continued the tradition of two early career presentations. In terms of technical papers, 45 papers were accepted out of 183 submissions. Motion planning, learning and estimation continue to be strongly represented at RSS, and thanks to the work of the area chairs, we have a growing number of papers in new areas, especially human-robot interaction and formal methods.

Part of the RSS tradition is to try new ideas at the conference, and this year has seen some substantial changes to the format of RSS.

Firstly, workshops and tutorials have always been an essential part of the RSS program, and this year is no different. We received a remarkable number of very strong workshop proposals, many more than we could feasibly hold. We initially expected to have 8 workshops, but with the overwhelming demand, we extended the conference by a day. For the first time at RSS, we now have sixteen workshops and tutorials over two very full days.

Secondly, RSS has historically been committed to considering papers presented at the poster session as equals of papers presented at the plenary session. The poster session is now in the middle of the day in order to be inclusive as possible and ensure that no attendees miss the poster session due to family commitments in the evening. To further emphasize the parity among papers, all papers will appear this year at the poster session as well as receiving time for an oral presentation at the plenary session, with the length of presentation as the only variable. Thanks to our sponsors, we are also able to have electronic poster displays, which will give the authors considerable flexibility in they present their research. We hope this new format for the poster session leads to an even more exciting and energetic event and increased visibility for all papers.

Robotics is a fast-moving field. The paper and workshop processes do not always make it easy to anticipate new topics that people would like to talk about. To give ourselves a forum for in-depth discussion on topics that come up during the conference, we have created an “open session” on the last day. Throughout the first two days of the conference, attendees can propose a discussion they would like to lead. All other participants are free to join any of the discussion sessions, to hear what others are thinking and provide their own ideas in an informal setting. Our expectation is that the open sessions will be a form of ad hoc workshops that show more of what we are all thinking about right now.

The banquet of RSS is always a highlight and this year is no exception. The banquet will occur at the landmark Spago in Beverly Hills, and will be preceded by a video session organised by Paul Newman and Dylan Shell. Polished and professional videos are of course the hallmark of robotics, but Paul and Dylan are looking for brutally honest robotics videos — the pre-dinner cocktail hour promises to be highly entertaining!

And lastly, our thanks to all authors and reviewers, and especially the area chairs and the entire organising committee. Your hard work is the bedrock of a successful conference.

We hope you enjoy this year’s RSS.

Hugh Durrant-Whyte            Cyrill Stachniss
Nicholas Roy                  Pieter Abbeel
Gaurav Sukhatme              Danica Kragic
Stefan Schaal
Conference Information

Location

The conference will be held on the campus of the University of Southern California (USC) in Los Angeles, California, USA. USC is located close to Los Angeles downtown, which is home to a high density of cultural and social hotspots, including many restaurants and bars. The main conference will be held in the Andrus Gerontology Auditorium (GER) on the USC campus. This is also the site for all sponsor displays. Workshops will be held in the Grace Ford Salvatori Hall (GFS) on the USC campus. The interactive poster session will be held in the ballroom of the Radisson Hotel (RMH). The map below shows the USC campus with the main conference site and workshop locations as well as the two recommended housing choices.
Registration

The Conference Desk will be staffed for registration and information services according to the following schedule:

- **Monday, June 27**: 8:30 to 16:00 (at the Grace Ford Salvatori Hall (GFS))
- **Tuesday, June 28**: 8:30 to 17:00 (at the Andrus Gerontology Auditorium (GER))
- **Wednesday, June 29**: 8:30 to 13:00 (at the Andrus Gerontology Auditorium (GER))
- **Thursday, June 30**: 8:30 to 13:00 (at the Andrus Gerontology Auditorium (GER))
- **Friday, July 1**: 8:30 to 13:00 (at the Grace Ford Salvatori Hall (GFS))

The conference registration fees are:

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<th>Early (until June 1)</th>
<th>Regular (after June 1)</th>
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<td>Student</td>
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<td>June 27 workshop-only:</td>
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<td>July 1 workshop-only:</td>
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Both student and non-student registration includes attendance to the main conference oral and poster sessions, as well as the workshops on Monday, June 27th and Friday, July 1st. In addition, it includes one hardcopy of the conference proceedings, and one ticket for the conference banquet on Wednesday, June 29th evening at *Spago* in Beverly Hills.

A workshop registration for one day includes access to any of the workshops on that day. It does **not** include access to the conference proper, a hardcopy of the proceedings, and the banquet.

A workshop registration for two days includes access to all workshops. It does **not** include access to the conference proper, a hardcopy of the proceedings, and the banquet.

At registration, attendees may purchase extra banquet tickets (e.g. for companions). Each extra banquet ticket is $175.

The registration desk at the conference accepts only major credit cards. No cash or check transactions are possible.
Sponsors

The conference gratefully acknowledges the following sponsors. In addition to other benefits, sponsor support allows the conference to keep its registration and workshop fees to a minimum, particularly for students.

Financial sponsors:

GOLD SPONSORS

SILVER SPONSORS

BRONZE SPONSORS

Award Sponsors:

Best Paper Award  Travel Awards  Best Student Paper Award

Technical Sponsors:

Organized by:
Workshop Locations

The workshops on Both Monday, June 27th and Friday, July 1st will take place in the Grace Ford Salvatori Hall (GFS) on the USC Campus.

Monday, June 27th workshops

- **WS1. RGB-D: Advanced Reasoning with Depth Cameras**
  *Location: GFS 101*
  *Organizers:* Dieter Fox, University of Washington  
  Kurt Konolige, Willow Garage  
  Jana Kosecka, George Mason University  
  Xiaofeng Ren, Intel Labs Seattle

- **WS2. The State of Imitation Learning: Understanding its Applications and Promoting its Adoption**
  *Location: GFS 201*
  *Organizers:* Brenna Argall, École Polytechnique Fédérale de Lausanne EPFL  
  Nathan Ratliff, Google  
  David Silver, Carnegie Mellon University

- **WS3. Toward High-Performance Computing Support for the Analysis, Simulation, and Planning of Robotic Contact Tasks**
  *Location: GFS 202 & GFS 101 (June 28th morning)*
  *Organizers:* Chris Carothers, Rensselaer Polytechnic Institute  
  Dan Negrut, University of Wisconsin  
  Jeff Trinkle, Rensselaer Polytechnic Institute

- **WS5. ALONE - Autonomous Long-Term Operation in Novel Environments**
  *Location: GFS 104*
  *Organizers:* Jonathan Kelly, University of Southern California  
  Paul Newman, University of Oxford  
  Sebastian Thrun, Stanford University / Google

- **WS6. Aquatic Robotics: Ocean Science and Marine Systems**
  *Location: GFS 105*
  *Organizers:* Ryan N. Smith, Queensland University of Technology  
  Noel Du Toit, California Institute of Technology  
  Burton H. Jones, University of Southern California  
  Kanna Rajan, Monterey Bay Aquarium Research Institute

- **WS7. Guaranteeing Motion Safety for Robots**
  *Location: GFS 109*
  *Organizers:* Thierry Fraichard, INRIA Grenoble Rhone-Alpe  
  Kostas Bekris, University of Nevada  
  Jur van den Berg, University of North Carolina

- **WS8. Mobile Manipulation - Learning to Manipulate**
  *Location: GFS 118*
  *Organizers:* Thierry Fraichard, INRIA Grenoble Rhone-Alpe  
  Kostas Bekris, University of Nevada  
  Jur van den Berg, University of North Carolina
Friday, July 1st workshops

- **WS9. Tutorial on 3D Point Cloud Processing: Point Cloud Library**
  *Location: GFS 116*
  *Organizers:*
  - Radu Bogdan Rusu, Willow Garage
  - Bastian Steder, University of Freiburg
  - Nico Blodow, Technical University of Munich
  - Dirk Holz, University of Bonn

- **WS10. A Comparison of Reinforcement Learning and Optimal Control Methods for Real-World Robotic Tasks**
  *Location: GFS 107*
  *Organizers:*
  - Freek Stulp, University of Southern California
  - Evangelos Theodorou, University of Southern California
  - Stefan Schaal, University of Southern California

- **WS11. Integrated Planning and Control**
  *Location: GFS 118*
  *Organizers:*
  - Surya Singh, ACFR, The University of Sydney
  - Russ Tedrake, Robot Locomotion Group, MIT
  - Peter Corke, CyPhy Lab, Queensland University of Technology

- **WS12. Human-robot interaction: Perspectives and contributions to robotics from the human sciences**
  *Location: GFS 101*
  *Organizers:*
  - Leila Takayama, Willow Garage
  - Maja Mataric, University of Southern California
  - Odest Chadwicke Jenkins, Brown University
  - Holly Yanco, University of Massachusetts Lowell
  - Brian Scassellati, Yale University

- **WS13. Automated SLAM Evaluation**
  *Location: GFS 104*
  *Organizers:*
  - Michael Kaess, Massachusetts Institute of Technology
  - Giorgio Grisetti, Sapienza University of Rome/University of Freiburg
  - Kai Ni, Georgia Institute of Technology/Microsoft

  *Location: GFS 105*
  *Organizers:*
  - Francesco Bullo, University of California, Santa Barbara
  - Emilio Frazzoli, Massachusetts Institute of Technology
  - Marco Pavone, NASA JPL, California Institute of Technology
  - Ketan Savla, Massachusetts Institute of Technology
  - Stephen L. Smith, University of Waterloo

- **WS15. 3D Exploration, Mapping, and Surveillance with Aerial Robots**
  *Location: GFS 108*
  *Organizers:*
  - Nathan Michael, University of Pennsylvania
  - Mac Schwager, University of Pennsylvania
  - Vijay Kumar, University of Pennsylvania

- **WS16. Tutorial on Stochastic Models, Information Theory, and Lie Groups**
  *Location: GFS 109*
  *Organizers:*
  - Gregory S. Chirikjian, Johns Hopkins University
WS17. HRI Workshop on Grounding Human-Robot Dialog for Spatial Tasks

Location: GFS 109
Organizers: Thomas Kollar, Massachusetts Institute of Technology
Stefanie Tellex, Massachusetts Institute of Technology
Robert Ross, Dublin Institute of Technology
Antoine Raux, Honda Research Institute
Matthew Marge, Carnegie Mellon University

Exhibits

The current list of exhibitors includes:

- Willow Garage
- Aldebaran Robotics
- Microsoft
- iRobot
- Barrett Technology

The exhibits will be displayed from Tuesday, June 28th to Thursday, June 30th in the Andrus Gerontology Courtyard (GER) courtyard on the USC Campus.

Poster Session and Buffet Lunch

The poster session will take place on Wednesday, June 29th from 13:15 to 16:30 in the ballroom of the Radisson Hotel (RMH). The poster session will begin with a catered buffet lunch at the same location.

Unlike previous years, posters will be presented electronically on big screen displays. Poster presenters should bring their own laptop to display their poster. The conference will provide a power outlet for the laptop and a VGA cable to connect the laptop to the large LCD display. The display will be mounted in 'landscape' mode. Please make your poster accordingly.

Presenters may arrive at the Radisson ballroom anytime after 12:00 to test their laptop’s connection to the display.

Banquet

The conference banquet will be held on Wednesday, June 29th at Spago located in Beverly Hills. Buses for the banquet will leave from the Radisson hotel at 17:00. After the banquet the buses will return attendees to the Radisson. This excursion is complimentary with full conference registration. Each registrant will receive a banquet ticket with the registration packet. Each registrant should make sure you have the banquet ticket handy when boarding the bus. Additional banquet tickets may be purchased for $175 per person. The banquet will commence with a cocktail reception featuring an unusual appetizer: a robot-related video session designed to provoke, amuse and entertain.

USC Robotics Lab Tours

The robotics labs at USC will hold an open house in the lunch break on Tuesday June 28th (from 13:15 to 14:30). This is not a catered lunch event. Conference attendees are encouraged to pick up a quick lunch from one of the on-campus eateries and come to the 4th floor of Ronald Tutor Hall (RTH) [across the street from the Geontology Center (GER)] to see short displays and presentations by USC students about their research.
Accommodation

The following accommodation options are available. Keeping in mind that hotels in the Los Angeles area are expensive and one typically needs a car to get around, the conference organizers have tried to make affordable housing arrangements within walking distance of the conference site. It is strongly recommended that attendees use one of the two options below.

- Student dorms:
  - Shared bedroom, shared bath: $38
  - Private bedroom, shared bath: $50
  USC Parkside International Residential College (IRC)
  3771 S McClintock Avenue
  Los Angeles, CA 90007

Check-in at Parkside is available at the Parkside complex itself. Parkside residents will receive the access cards for their rooms upon checking in. The USC campus is open 24 hours. The entry gate number 6 (located on Vermont and 36th Place) is open round the clock for campus access. For late check-in or check-out (or if you are locked out of your room) please call (213) 986-6USC.

- USC Radisson Hotel: $139
  3540 South Figueroa Street
  Los Angeles, CA 90007
  phone: (213) 748-4141

Both recommended conference accommodations are at walking distance (maximum 10 minutes) to the conference site.

Internet Access

Wireless internet access will be available at the conference site via USC Wireless. The system is open to guest users. No password is needed.

Lunch Breaks

As part of the conference registration, lunch will be provided on Wednesday June 29 (buffet lunch as part of the poster session) and Thursday June 30 (box lunch for the open sessions). There will be morning and afternoon coffee breaks with snacks every day during the workshops and the main conference.

On the workshop days and on Tuesday June 28, all attendees are encouraged to plan accordingly, taking into consideration the technical schedule of events. On the USC campus as well as the immediate surrounding, there are many food places including fast food (sandwiches, burgers, burritos,...) and restaurants offering more upscale dining options. We have prepared a list of food places close to the conference site, together with a map showing their locations. This is by no means an exhaustive list and there are many other options available.

1. **The Lab** (American, Bar, $$)
2. **Mc Kays’s** (American, Sandwiches, Bar, $$$)
3. **Rosso Oro’s** (Pizza, $)
4. **Pizza Rustica** (Pizza, $)
5. **Chick-Fil-A** (Fast Food, Burgers, $)
6. Chipotle Mexican Grill (Fast Food, Mexican, $)  
7. California Pizza Kitchen (Fast Food, Pizza, $)  
8. Carl’s Jr. (Fast Food, Burgers, $)  
9. Panda Express (Fast Food, Chinese, $)  
10. Burger King (Fast Food, Burgers, $)  
11. Subway (Fast Food, Sandwiches, $)  
12. Bamboo Express ($)  
13. Berrybest Yogurt ($)  
14. Health Hut ($)  
15. Kebab Master ($)  
16. Manna Japanese Grill ($)  
17. Mongo Fresh ($)  
18. Nahm San Korean BBQ ($)  
19. Panchos ($)  
20. Taste of India ($)  
21. Sandwich Island ($)  
22. Thai Trio ($)  
23. Togo’s (Fast Food, Sandwiches, $)  
24. Taco Bell (Fast Food, Mexican, $)
Dinner/Bars

Los Angeles downtown is just a few miles away from the USC campus and can be conveniently reached by bus or taxi. We particularly recommend L.A. Live which is right next to the Staples Center. It is a few minutes from the USC campus by bus or taxi, is spectacular at night and offers a lot of restaurants and bars. Los Angeles downtown is fairly safe, however for your own safety please try to avoid walking alone through the streets after midnight. Bars in Los Angeles downtown close at 2:00.

L.A. Live

1. ESPN Zone (American, $$)
2. Fleming’s Prime Steakhouse & Wine Bar (Steakhouse, $$$)
3. Katsuya (Sushi Bar, Asian Fousion, $$$)
4. Wolfgang Puck Bar & Grill (American, Italian, $$$)
5. Yard House (American, Sports Bar, $, Great place, >70 beers on tap)

Other downtown locations

6. Library Bar (Bar, $, Great bar)
7. The Standard Rooftop Bar (Bar $$$, Mon-Thu no cover, dress-code, Awesome view, definitely worth a visit, best night Thu)
8. The Edison (Bar, $$$, Wed-Sat, dress-code, spectacular ambience)
9. Takami Sushi & Robata Restaurant (Sushi Bar, Japanese, $$, Nice view since you are up on the 21st floor)
10. Dublin’s Irish Pub (Sports Bar, $, Lot of beers on tap)
11. Mac & Cheeza (American, $, Mac and Chees)
Transportation

Airport: Los Angeles International Airport (LAX) is located approximately 15 miles southwest of the USC campus. USC does not provide transportation to and from airports. The following services are available to and from the airport to the university and the recommended conference accommodations.

- Taxi (approximate cost is $45)
- Shuttle Bus Service (approximate cost is $15-$20 per passenger)
  - Prime Time Shuttle: 1-800-733-8267
  - Super Shuttle: 1-800-258-3826
  - Xpress Shuttle: 1-800-427-7482

Parking: For participants who will arrive by car, visitor parking is available on the USC campus for a daily rate of $8. Visitors should enter the USC campus on Vermont Ave (Entrance 6) and park in parking structure A (PSA), adjacent to the Gerontology Center (the site of the main conference).

Getting around:
Many interesting places in Los Angeles are only reachable by car. However some locations can be reached using the Los Angeles public transportation system. The Los Angeles County Metropolitan Transportation Authority is a good starting point to plan a trip (http://www.metro.net).

About Los Angeles

Los Angeles also nicknamed the City of Angels is the most populous city in California with a population of 3.8 million and the second most populous in the United States. With a metropolitan population of over 15 million people it is also one of the largest in the world and the second after New York in the United States.

Los Angeles itself was founded 1781 by a Spanish governor and became part of Mexico in 1821 following the Mexican War of Independence. In 1848, at the end of the Mexican-American War, Los Angeles and the rest of California were purchased as part of the Treaty of Guadalupe Hidalgo, thereby becoming part of the United States. Today Los Angeles is one of the most multicultural counties in the United States, while the entire Los Angeles area itself is recognized and regarded as the most diverse metropolitan area in the United States.

Los Angeles is a city of diverse cultures and many are showcased in or around downtown. The area’s highlights include Grand Central Market, MOCA, Disney Concert Hall, The Music Center, Olvera Street, Chinatown, Little Tokyo, the Natural History Museum, and the Japanese-American Museum. Downtown is also home to some of the most unique and stunning examples of American and international architecture. No trip to Los Angeles is complete without a visit to its most famous district: Hollywood, best known as the self-declared entertainment capital of the world. The core of Hollywood for a tourist is its three fascinating boulevards: Sunset Boulevard, Hollywood Boulevard, and Melrose Avenue. All three are worth seeing. Hollywood Blvd. is known for its entertainment history; Sunset Blvd. for its clubs and nightlife; and Melrose Ave. for its dining, shopping, nightlife, and eclecticism.

Los Angeles enjoys plenty of sunshine throughout the year, with an average of only 35 days with measurable precipitation annually. During the conference period the historical average daytime high temperature is 82 °F (28 °C) and the average nighttime low temperature is 63 °F (17 °C).
Program Highlights

Location: Andrus Gerontology Auditorium (GER)

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<th>Time</th>
<th>Session</th>
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<tr>
<td>9:30-11:00</td>
<td>Session 1. Gerontology Auditorium (GER). Chair: Danica Kragic</td>
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<td>9:30-10:30</td>
<td>Invited Talk</td>
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<td>David Forsyth</td>
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<td>More Words and Bigger Pictures</td>
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<td>10:30-11:00</td>
<td>Oral 1</td>
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<td>From Caging to Grasping</td>
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<td>Alberto Rodriguez, Matt Mason, Steve Ferry</td>
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<td>11:00-11:30</td>
<td>Break. Gerontology Courtyard (GER)</td>
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<td>11:30-12:00</td>
<td>Session 2. Gerontology Auditorium (GER). Chair: Pieter Abbeel</td>
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<td>11:30-12:00</td>
<td>Early Career Spotlight</td>
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<td>Aaron Dollar</td>
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<td>Reengineering the Hand: Towards Robust Open-Loop Grasping and Dexterous Manipulation</td>
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<td>12:00-12:30</td>
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<td>Load Balancing for Mobility-on-Demand Systems</td>
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<td>Marco Pavone, Stephen Smith, Emilio Frazzoli, Daniela Rus</td>
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<td>12:30-1:15</td>
<td>Session 3. Gerontology Auditorium (GER). Chair: Siddhartha Srinivasa</td>
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<td>12:30-1:15</td>
<td>5 Minute Talks</td>
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<td>Fast Trajectory Correction for Nonholonomic Mobile Robots Using Affine Transformations</td>
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<td>Quang-Cuong Pham</td>
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<td>Infinite-Horizon Model Predictive Control for Periodic Tasks with Contacts</td>
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<td>Tom Erez, Yuval Tassa, Emanuel Todorov</td>
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<td>The Motion Grammar: Linguistic Perception, Planning, and Control</td>
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<td>Neil Dantam, Mike Stilman</td>
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<td>Sliding Manipulation of Rigid Bodies on a Controlled 6-DoF Plate</td>
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<td>Tom Vose, Paul Umbanhowar, Kevin Lynch</td>
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<td>Coupled Dynamical System based hand-arm grasp planning under real-time perturbations</td>
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<td>Ashwini Shukla, Aude Billard</td>
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<td>Motion Planning under Uncertain Motion, Sensing, and Environment Map</td>
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<td>Hanna Kurniawati, Tirthankar Bandyopadhyay, Nicholas Patrikalakis</td>
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<td>Finite-Time Regional Verification of Stochastic Nonlinear Systems</td>
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<td>Jacob Steinhardt, Russ Tedrake</td>
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<td>Exploiting Variable Stiffness in Explosive Movement Tasks</td>
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<td>David Braun, Matthew Howard, Sethu Vijayakumar</td>
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1:15-2:30 Lunch

2:30-4:00 Session 4. Gerontology Auditorium (GER). Chair: Matt Mason

2:30-3:00 Early Career Spotlight
J. Andrew Bagnell
From Supervision to Imitation to Reinforcement: Machine Learning for High Performance Robotics

3:00-3:30 Oral 3
TERMES: An Autonomous Robotic System for Three-Dimensional Collective Construction
Kirstin Petersen, Radhika Nagpal, Justin Werfel

3:30-4:00 Oral 4
Comparing Heads-up, Hands-free Operation of Ground Robots to Teleoperation
Matthew Marge, Aaron Powers, Jonathan Brookshire, Trevor Jay, Odest Jenkins, Christopher Geyer

4:00-4:45 Session 5. Gerontology Auditorium (GER). Chair: Wolfram Burgard

4:00-4:45 5 Minute Talks
Automatic Calibration of Multiple Coplanar Sensors
Jonathan Brookshire, Seth Teller

Model-Based Proprioceptive State Estimation for Spring-Mass Running
Uluc Saranli, Ozlem Gur

A Serial Approach to Handling High-Dimensional Measurements in the Sigma-Point Kalman Filter
Colin McManus, Timothy Barfoot

Unmanned Aircraft Collision Avoidance using Continuous-State POMDPs
Haoyu Bai, David Hsu, Wee Sun Lee, Mykel Kochenderfer

Spatial Formation Model for Initiating Conversation
Chao Shi, Michihiro Shimada, Takayuki Kanda, Hiroshi Ishiguro, Norihiro Hagita

Identifying Homotopy Classes of Trajectories for Robot Exploration and Path Planning
Subhranjit Bhattacharya, Maxim Likhachev, Vijay Kumar

Passivity-Based Decentralized Connectivity Maintenance in the Bilateral Teleoperation of Multiple UAVs
Paolo Robuffo Giordano, Antonio Franchi, Cristian Secchi, Heinrich Bülthoff

Real-time prioritized kinematic control under inequality constraints for redundant manipulators
Oussama Kanoun

Tracking-based semi-supervised learning
Alex Teichman, Sebastian Thrun

4:45-5:15 Break. Gerontology Courtyard (GER)
5:15-6:30 Session 6. Gerontology Auditorium (GER). Chair: Oliver Brock

5:15-5:45 Oral 5
Learning to Control a Low-Cost Manipulator Using Data-Efficient Reinforcement Learning
Marc Deisenroth, Carl Rasmussen, Dieter Fox

5:45-6:30 5 Minute Talks
A Linear Estimation Framework for Solving Simultaneous Localization and Mapping
Luca Carlone, Rosario Aragues, Jose Castellanos, Basilio Bona

Visual Segmentation of “Simple” Objects for Robots
Ajay Mishra, Yiannis Aloimonos

Kinematic Cartography for Locomotion
Ross Hatton, Howie Choset

Collision-Free and Curvature-Continuous Path Smoothing In Cluttered Environments
Jia Pan, Liangjun Zhang, Dinesh Manocha

Designing Petri Net Supervisors from LTL Specifications
Bruno Lacerda, Pedro Lima

Controlling Ergodic Bodies Using Linear Temporal Logic
Leonardo Bobadilla, Oscar Sanchez, Justin Czarnowski, Katrina Gossman, Steven LaValle

Operational Space Control of Constrained and Underactuated Systems
Michael Mistry, Ludovic Righetti

Understanding Slip Perception of Soft Fingertips by Modeling and Simulating Stick-Slip Phenomenon
Van Ho, Shinichi Hirai

Probabilistic Analysis of Correctness of High-Level Robot Behavior with Sensor Error
Benjamin Johnson, Hadas Kress-Gazit

Assisted Teleoperation Strategies for Aggressively Controlling a Robot Arm with 2D Input
Erkang You, Kris Hauser

Global Optimization of Robotic Grasps
Carlos Rosales Gallegos, Josep Porta, Lluis Ros

An Interaction Design Framework for Social Robots
Dylan Glas, Satoru Satake, Takayuki Kanda, Norihiro Hagita
Wednesday, June 29, 2011

9:30-11:00  Session 7. Gerontology Auditorium (GER). Chair: Chad Jenkins

9:30-10:30  Invited Talk
            Catherine Mohr
            *Robots in the OR*

10:30-11:00  Oral 6
            *Motion Planning Under Uncertainty in Highly Deformable Environments*
            Sachin Patil, Jur van den Berg, Ron Alterovitz

11:00-11:30  Break. Gerontology Courtyard (GER)

11:30-1:00  Session 8. Gerontology Auditorium (GER). Chair: David Hsu

11:30-12:00  Oral 7
            *Multi-Level Partitioning and Distribution of the Assignment Problem for Large-Scale Multi-Robot Task Allocation*
            Lantao Liu, Dylan Shell

12:00-12:30  Oral 8
            *Cross-Entropy Randomized Motion Planning*
            Marin Kobilarov

12:30-1:00  Oral 9
            *An Art Gallery Approach to Ensuring that Landmarks are Distinguishable*
            Lawrence Erickson, Steven LaValle

1:00-5:00  Session 9. Poster Session. Radisson Ballroom (RMH)

1:00-1:15  Walk to Poster session in RMH

1:15-4:30  Lunchtime Poster session

5:00  Buses Depart from RMH for Banquet at Spago, Beverly Hills

6:00-7:00  Session 11. Spago, Beverly Hills. Chairs: Paul Newman and Dylan Shell

6:00-7:00  Cocktails and Video Session

7:00-  Banquet
Thursday, June 30, 2011

9:30-11:00  Session 12. Gerontology Auditorium (GER). Chair: Russ Tedrake

9:30-10:30  Invited Talk
Andy Ruina
Balance: Brooms, STanding, Walking and Biking

10:30-11:00  Oral 10
Distributed Robot Ensemble Control for Deployment to Multiple Sites
T. William Mather, M. Ani Hsieh

11:00-11:30  Break. Gerontology Courtyard (GER)

11:30-1:00  Session 13. Gerontology Auditorium (GER). Chair: Maja Mataric

11:30-12:00  Oral 11
Friendly Patrolling: A Model of Natural Encounters
Kotaro Hayashi, Masahiro Shiomib, Takayuki Kanda, Norihiro Hagita

12:00-12:30  Oral 12
Lying Pose Recognition for Elderly Fall Detection
Simin Wang, Salim Zabir, Bastian Leibe

12:30-1:00  Oral 13
A Framework for Push-Grasping in Clutter
Mehmet Dogar, Siddhartha Srinivasa

1:00-1:15  Pick up box lunch and walk to open sessions in Grace Ford Salvatori Building (GFS)

1:15-2:45  Open Sessions

2:45-3:00  Return to plenary session in Gerontology Auditorium (GER)

3:00-4:00  Session 14. Gerontology Auditorium (GER). Chair: Jeff Trinkle

3:00-4:00  Invited Talk
Chris Urmson
The Google Self-Driving Car Project

4:00-4:30  Oral 14
Monte Carlo Pose Estimation with Quaternion Kernels and the Bingham Distribution
Jared Glover, Radu Rusu, Gary Bradski

4:30-5:00  Break. Gerontology Courtyard (GER).

5:00-6:00  Session 15. Gerontology Auditorium (GER). Chair: Kevin Lynch

5:00-5:30  Oral 15
An Analytic Motion Planning Solution for the Snakeboard
Elie Shammas, Mauricio de Oliveira

5:30-6:00  Oral 16
Construction of Cubic Structures with Quadrotor Teams
Quentin Lindsey, Daniel Mellinger, Vijay Kumar

6:00-6:15  Awards Ceremony. Gerontology Auditorium (GER)

6:15-7:00  Farewell Reception. Gerontology Courtyard (GER)
Abstracts

Technical Session 1, Tuesday, June 28, 2011

Invited Talk: David Forsyth
More Words and Bigger Pictures

Abstract:
Object recognition is a little like translation: a picture (text in a source language) goes in, and a description (text in a target language) comes out. I will use this analogy, which has proven fertile, to describe recent progress in object recognition. We have very good methods to spot some objects in images, but extending these methods to produce descriptions of images remains very difficult. The description might come in the form of a set of words, indicating objects, and boxes or regions spanned by the object. This representation is difficult to work with, because some objects seem to be much more important than others, and because objects interact. An alternative is a sentence or a paragraph describing the picture, and recent work indicates how one might generate rich structures like this. Furthermore, recent work suggests that it is easier and more effective to generate descriptions of images in terms of chunks of meaning (“person on a horse”) rather than just objects (“person”; “horse”). Finally, if the picture contains objects that are unfamiliar, then we need to generate useful descriptions that will make it possible to interact with them, even though we don’t know what they are.

Schedule: see page[17]

From Caging to Grasping
Alberto Rodriguez, Matt Mason, Steve Ferry

Abstract:
This paper digs into the relationship between grasps and cages of a rigid body, in particular into the use of cages as waypoints to grasp an object. We introduce the concept of pregrasping cages, caging configurations from which the object can be reached while maintaining the cage on it. In the well understood case of two-fingered manipulators, the squeezing/stretching caging characterization implies that all cages are indeed pregrasping cages and, as a consequence, are useful waypoints to grasp an object. We show in this paper that the same does not hold for more than two fingers. There are caging configurations from which a grasp of the object cannot be reached without breaking the cage on it. We explore the natural generalization of the squeezing/stretching characterization to the case of n fingers and exploit it to give sufficient conditions for a cage to be a pregrasping cage.

Schedule: see page[17]
Technical Session 2, Tuesday, June 28, 2011

Early Career Spotlight: Aaron Dollar
Reengineering the Hand: Towards Robust Open-Loop Grasping and Dexterous Manipulation

Abstract:
Despite decades of research, current robotic systems are unable to reliably grasp and manipulate a wide range of unstructured objects in human environments. Part of the reason for this failure is the nature of the approach that has traditionally been taken: attempting to copy the immense mechanical complexity of the human hand in stiff robotic”mechanisms with the subsequently required high levels of sensing and control. Alternatively, with careful attention to the design of the mechanics of hands, including adaptive underactuated transmissions and carefully tuned compliance, we have been able to achieve a level of reliability and dexterity as yet unseen in the robotics community. I will describe ongoing efforts to further develop grasping and dexterous manipulation capabilities in engineered systems as well as utilizing our approach in applications ranging from prosthetics to manipulation from small aerial vehicles.

Schedule: see page 17

Load Balancing for Mobility-on-Demand Systems
Marco Pavone, Stephen Smith, Emilio Frazzoli, Daniela Rus

Abstract:
In this paper we develop methods for maximizing the throughput of a mobility-on-demand urban transportation system. We consider a finite group of shared vehicles, located at a set of stations. Users arrive at the stations, pick-up vehicles, and drive (or are driven) to their destination station where they drop-off the vehicle. When some origins and destinations are more popular than others, the system will inevitably become out of balance: Vehicles will build up at some stations, and become depleted at others. We propose a robotic solution to this rebalancing problem that involves empty robotic vehicles autonomously driving between stations. We develop a rebalancing policy that minimizes the number of vehicles performing rebalancing trips. To do this, we utilize a fluid model for the customers and vehicles in the system. The model takes the form of a set of nonlinear time-delay differential equations. We then show that the optimal rebalancing policy can be found as the solution to a linear program. By analyzing the dynamical system model, we show that every station reaches an equilibrium in which there are excess vehicles and no waiting customers. We use this solution to develop a real-time rebalancing policy which can operate in highly variable environments. We verify policy performance in a simulated mobility-on-demand environment with stochastic features found in real-world urban transportation networks.

Schedule: see page 17
Technical Session 3, Tuesday, June 28, 2011

Fast Trajectory Correction for Nonholonomic Mobile Robots Using Affine Transformations
Quang-Cuong Pham

Abstract:
Planning trajectories for nonholonomic systems is difficult and computationally expensive. When facing unexpected events, it may therefore be preferable to deform in some way the initially planned trajectory rather than to re-plan entirely a new one. We suggest here a method based on affine transformations to make such deformations. This method is exact and fast: the deformations and the resulting trajectories can be computed algebraically, in one step, and without any trajectory re-integration. To demonstrate the possibilities offered by this new method, we use it to derive position correction, orientation correction and obstacle avoidance algorithms for three classical nonholonomic systems: the unicycle, the bicycle, and an underwater vehicle.
Schedule: see page 17

Infinite-Horizon Model Predictive Control for Periodic Tasks with Contacts
Tom Erez, Yuval Tassa, Emanuel Todorov

Abstract:
We present a method that combines offline trajectory optimization and online Model Predictive Control (MPC), generating robust controllers for complex periodic behavior in domains with unilateral constraints (e.g., contact with the environment). MPC offers robust and adaptive control even in high-dimensional domains; however, the online optimization gets stuck in local minima when the domains has discontinuous dynamics. Some methods of trajectory optimization that are immune to such problems, but these are often too slow to be applied online. In this paper, we use offline optimization to find the limit-cycle solution of an infinite-horizon average-cost optimal-control task. We then compute a local quadratic approximation of the Value function around this limit cycle. Finally, we use this quadratic approximation as the terminal cost of an online MPC. This combination of an offline solution of the infinite-horizon problem with an online MPC controller is known as Infinite Horizon Model Predictive Control (IHMPC), and has previously been applied only to simple stabilization objectives. Here we extend IHMPC to tackle periodic tasks, and demonstrate the power of our approach by synthesizing hopping behavior in a simulated robot. IHMPC involves a limited computational load, and can be executed online on a standard laptop computer. The resulting behavior is extremely robust, allowing the hopper to recover from virtually any perturbation. In real robotic domains, modeling errors are inevitable. We show how IHMPC is robust to modeling errors by altering the morphology of the robot; the same controller remains effective, even when the underlying infinite-horizon solution is no longer accurate.
Schedule: see page 17
**The Motion Grammar: Linguistic Perception, Planning, and Control**
Neil Dantam, Mike Stilman

**Abstract:**
We present and analyze the Motion Grammar: a novel unified representation for task decomposition, perception, planning, and control that provides both fast online control of robots in uncertain environments and the ability to guarantee completeness and correctness. The grammar represents a policy for the task which is parsed in real-time based on perceptual input. Branches of the syntax tree form the levels of a hierarchical decomposition, and the individual robot sensor readings are given by tokens. We implement this approach in the interactive game of Yamakuzushi on a physical robot resulting in a system that repeatably competes with a human opponent in sustained gameplay for the roughly six minute duration of each match.

**Schedule:** see page 17

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**Sliding Manipulation of Rigid Bodies on a Controlled 6-DoF Plate**
Tom Vose, Paul Umbanhowar, Kevin Lynch

**Abstract:**
We model the full dynamics of a rigid part in three-point frictional sliding contact with a flat rigid 6-degree-of-freedom plate. Given a periodic plate motion and the geometric, inertial, and frictional properties of the part, we define an asymptotic twist field mapping each part configuration to a unique part twist (linear and angular velocity). Asymptotic twist vectors in the field approximate the part’s cycle-averaged twist at each configuration and are independent of time or the system’s initial state. Simulations and experiments show that the trajectory of the part’s configuration as it slides on the plate is well described by the field. With the ability to program arbitrary plate motions, part manipulation reduces to finding plate motions that generate asymptotic twist fields to accomplish desired tasks. Several simple fields useful for manipulation tasks (e.g., sensorless part alignment) are verified in simulation and experiment. For the special case of a rigid part with infinitesimal thickness, we show that the part’s cycle-averaged twist for any configuration asymptotically converges to a unique asymptotic twist vector.

**Schedule:** see page 17

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**Coupled Dynamical System based hand-arm grasp planning under real-time perturbations**
Ashwini Shukla, Aude Billard

**Abstract:**
Robustness to perturbation has been advocated as a key element to robot control and efforts in that direction are numerous. While in essence these approaches aim at “endowing robots with a flexibility similar to that displayed by humans”, few have actually looked at how humans react in the face of fast perturbations. We recorded the kinematic data from human subjects during grasping motions under very fast perturbations. Results show a strong coupling between the reach and grasp components of the task that enables rapid adaptation of the fingers in coordination with the hand posture when the target object is perturbed. We develop a robot controller based on Coupled Dynamical Systems that exploits coupling between two dynamical systems driving the hand and finger motions. This offers a compact encoding for a variety of reach and grasp motions that adapts on-the-fly to perturbations without the need for any re-planning. To validate the model we control the motion of the iCub robot when reaching for different objects.

**Schedule:** see page 17
**Motion Planning under Uncertain Motion, Sensing, and Environment Map**
Hanna Kurniawati, Tirthankar Bandyopadhyay, Nicholas Patrikalakis

**Abstract:**
Motion planning that takes into account uncertainty in motion, sensing, and environment map, is critical for autonomous robots to operate reliably in our living spaces. Partially Observable Markov Decision Processes (POMDPs) is a principled and general framework for planning under uncertainty. Although recent development of point-based POMDPs have drastically increased the speed of POMDP planning, even the best POMDP planner today, fails to generate reasonable motion strategies when the environment map is not known exactly. This paper presents Guided Cluster Sampling (GCS), a new point-based POMDP planner for motion planning with uncertain motion, sensing, and environment map, when the robot has active sensing capability. It uses our observations that in this problem, the belief space $B$ can be partitioned into a collection of much smaller sub-spaces, and an optimal policy can often be generated by sufficient sampling of a small subset of the collection. GCS samples $B$ using two-stage cluster sampling, a subspace is sampled from the collection and then a belief is sampled from the subspace. It uses information from the set of sampled sub-spaces and sampled beliefs to guide subsequent sampling. Preliminary results suggest that GCS generates reasonable policies for motion planning problems with uncertain motion, sensing, and environment map, that are unsolvable by the best point-based POMDP planner today, within reasonable time. Furthermore, GCS handles POMDPs with continuous state, action, and observation spaces. We show that for a class of POMDPs that often occur in robot motion planning, GCS converges to the optimal policy, given enough time. To the best of our knowledge, this is the first convergence result for point-based POMDPs with continuous action space.

**Schedule:** see page 17

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**Finite-Time Regional Verification of Stochastic Nonlinear Systems**
Jacob Steinhardt, Russ Tedrake

**Abstract:**
Recent trends pushing robots into unstructured environments with limited sensors have motivated considerable work on planning under uncertainty and stochastic optimal control, but these methods typically do not provide guaranteed performance. Here we consider the problem of bounding the probability of failure (defined as leaving a finite region of state space) over a finite time for stochastic nonlinear systems with continuous state. Our approach searches for exponential barrier functions that provide bounds using a variant of the classical supermartingale result. We provide a relaxation of this search to a semidefinite program, yielding an efficient algorithm that provides rigorous upper bounds on the probability of failure for the original nonlinear system. We give a number of numerical examples in both discrete and continuous time that demonstrate the effectiveness of the approach.

**Schedule:** see page 17
Exploiting Variable Stiffness in Explosive Movement Tasks
David Braun, Matthew Howard, Sethu Vijayakumar

Abstract:
It is widely recognised that compliant actuation is advantageous to robot control once high-performance, explosive tasks, such as throwing, hitting or jumping are considered. However, the benefit of intrinsic compliance comes with high control complexity. Specifically, coordinating the motion of the system through a compliant actuator and finding a task-specific impedance profile that leads to better performance is non-trivial. Here, we utilise optimal control to devise time-varying torque and stiffness profiles for highly dynamic movements in compliantly actuated robots. The proposed methodology is applied to a ball-throwing task where we demonstrate that: (i) the method is able to tailor impedance strategies to specific task objectives and system dynamics, (ii) the ability to vary stiffness leads to better performance in this class of movements, (iii) in systems with variable physical compliance, our methodology is able to exploit the energy storage capabilities of the actuators. We illustrate these in several numerical simulations, and in hardware experiments on a device with variable physical stiffness.

Schedule: see page 17.
Technical Session 4, Tuesday, June 28, 2011

Early Career Spotlight: J. Andrew Bagnell
*From Supervision to Imitation to Reinforcement: Machine Learning for High Performance Robotics*

Abstract:
Programming robots is hard. While demonstrating a desired behavior may be easy, designing a system that behaves this way is often difficult, time consuming, and ultimately expensive. Machine learning promises to enable "programming by demonstration" for developing high-performance robotic systems, and in the last decade that promise has truly begun to become a reality. I’ll discuss the spectrum of machine learning techniques of increasing sophistication from the most familiar classification problems, to structured prediction, to imitation learning, and to making reinforcement learning practical in robotics. I’ll consider case studies in learning dexterous manipulation, activity forecasting of drivers and pedestrians, to imitation learning of robotic locomotion and rough-terrain navigation. These case-studies highlight key challenges in applying the algorithms in practical settings.

*Schedule: see page 18*

TERMES: An Autonomous Robotic System for Three-Dimensional Collective Construction
Kirstin Petersen, Radhika Nagpal, Justin Werfel

Abstract:
Collective construction is the research area in which autonomous multi-robot systems build structures according to user specifications. Here we present a hardware system and high-level control scheme for autonomous construction of 3D structures under conditions of gravity. The hardware comprises a mobile robot and specialized passive blocks; the robot is able to manipulate blocks to build desired structures, and can maneuver on these structures as well as in unstructured environments. We describe and evaluate the robot’s key capabilities of climbing, navigation, and manipulation, and demonstrate its ability to perform complex tasks that combine these capabilities by having it autonomously build a ten-block staircase taller than itself. In addition, we outline a simple decentralized control algorithm by which multiple simultaneously active robots could autonomously build user-specified structures, working from a high-level description as input.

*Schedule: see page 18*

Comparing Heads-up, Hands-free Operation of Ground Robots to Teleoperation
Matthew Marge, Aaron Powers, Jonathan Brookshire, Trevor Jay, Odest Jenkins, Christopher Geyer

Abstract:
Today, most commercially available UGVs use teleoperation for control. Under teleoperation, users’ hands are occupied holding a handheld controller to operate the UGV, and their attention is focused on what the robot is doing. In this paper, we propose an alternative called Heads-up, Hands-free Operation, which allows an operator to control a UGV using operator following behaviors and a gesture interface. We explore whether Heads-up, Hands-free Operation is an improvement over teleoperation. In a study of 30 participants, we found that when operators used these modes of interaction, they performed missions faster, they could recall their surroundings better, and they had a lower cognitive load than they did when they teleoperated the robot.

*Schedule: see page 18*
Technical Session 5, Tuesday, June 28, 2011

Automatic Calibration of Multiple Coplanar Sensors
Jonathan Brookshire, Seth Teller

Abstract:
This paper describes an algorithm for recovering the rigid 3-DOF transformation (offset and rotation) between pairs of sensors mounted rigidly in a common plane on a mobile robot. The algorithm requires only a set of sensor observations made as the robot moves along a suitable path. Our method does not require synchronized sensors; nor does it require complete metrical reconstruction of the environment or the sensor path. We show that incremental pose measurements alone are sufficient to recover sensor calibration through nonlinear least squares estimation. We use the Fisher Information Matrix to compute a Cramer-Rao lower bound (CRLB) for the resulting calibration. Applying the algorithm in practice requires a non-degenerate motion path, a principled procedure for estimating per-sensor pose displacements and their covariances, a way to temporally resample asynchronous sensor data, and a way to assess the quality of the recovered calibration. We give constructive methods for each step. We demonstrate and validate the end-to-end calibration procedure for both simulated and real LIDAR and inertial data, achieving CRLBs, and corresponding calibrations, accurate to millimeters and milliradians. Source code is available from http://rvsn.csail.mit.edu/calibration.

Schedule: see page 18.

Model-Based Proprioceptive State Estimation for Spring-Mass Running
Uluc Saranli, Ozlem Gur

Abstract:
Autonomous applications of legged platforms will inevitably require accurate state estimation both for feedback control as well as mapping and planning. Even though kinematic models and low-bandwidth visual localization may be sufficient for fully-actuated, statically stable legged robots, they are inadequate for dynamically dexterous, underactuated platforms where second order dynamics are dominant, noise levels are high and sensory limitations are more severe. In this paper, we introduce a model based state estimation method for dynamic running behaviors with a simple spring-mass runner. By using an approximate analytic solution to the dynamics of the model within an Extended Kalman filter framework, the estimation accuracy of our model remains accurate even at low sampling frequencies. We also propose two new event-based sensory modalities that further improve estimation performance in cases where even the internal kinematics of a robot cannot be fully observed, such as when flexible materials are used for limb designs. We present comparative simulation results to establish that our method outperforms traditional approaches which rely on constant acceleration motion models and that it eliminates the need for an extensive and unrealistic sensor suite.

Schedule: see page 18.
A Serial Approach to Handling High-Dimensional Measurements in the Sigma-Point Kalman Filter
Colin McManus, Timothy Barfoot

Abstract:
Pose estimation is a critical skill in mobile robotics and is often accomplished using onboard sensors and a Kalman filter estimation technique. For systems to run online, computational efficiency of the filter design is crucial, especially when faced with limited computing resources. In this paper, we present a novel approach to serially process high-dimensional measurements in the Sigma-Point Kalman Filter (SPKF), in order to achieve a low computational cost that is linear in the measurement dimension. Although the concept of serially processing measurements has been around for quite some time in the context of the Extended Kalman Filter (EKF), few have considered this approach with the SPKF. At first glance, it may be tempting to apply the SPKF update step serially. However, we prove that without re-drawing sigma points, this ‘naive’ approach cannot guarantee the positive-definiteness of the state covariance matrix (not the case for the EKF). We then introduce a novel method for the Sigma-Point Kalman Filter to process high-dimensional, uncorrelated measurements serially that is algebraically equivalent to processing the measurements in parallel, but still achieves a computational cost linear in the measurement dimension.

Schedule: see page 18.

Unmanned Aircraft Collision Avoidance using Continuous-State POMDPs
Haoyu Bai, David Hsu, Wee Sun Lee, Mykel Kochenderfer

Abstract:
An effective collision avoidance system for unmanned aircraft will enable them to fly in civil airspace and greatly expand their applications. One promising approach is to model aircraft collision avoidance as a partially observable Markov decision process (POMDP) and automatically generate the threat resolution logic for the collision avoidance system by solving the POMDP model. However, existing discrete-state POMDP algorithms cannot cope with the high-dimensional state space in collision avoidance POMDPs. Using a recently developed algorithm called Monte Carlo Value Iteration (MCVI), we constructed several continuous-state POMDP models and solved them directly, without discretizing the state space. Simulation results show that our 3-D continuous-state models reduce the collision risk by up to 70 times, compared with earlier 2-D discrete-state POMDP models. The success demonstrates both the benefits of continuous-state POMDP models for collision avoidance systems and the latest algorithmic progress in solving these complex models.

Schedule: see page 18.
Spatial Formation Model for Initiating Conversation
Chao Shi, Michihiro Shimada, Takayuki Kanda, Hiroshi Ishiguro, Norihiro Hagita

Abstract:
In a situation where a robot initiates conversation with a person, when is the appropriate timing and where is an appropriate position from which to say the first greeting word? In this study, we analyze human interaction and establish a model for a natural way of initiating conversation. The model mainly concerns the participation state [1] and spatial formation [2]. When a person is going to participate in a conversation, at a moment when a particular spatial formation occurs, she would feel that she is participating in the conversation; once she perceived her participation she would try to maintain particular spatial formations. There are theories in human communication for these concepts [1, 2], but they only cover the situation after people have started to talk. We build a model that precisely describes the constraints and expected behaviors for the phase of initiating conversation. The proposed model is implemented in a humanoid robot, and it is confirmed as effective in an evaluation experiment based on a shopkeeper scenario.

Schedule: see page 18

Identifying Homotopy Classes of Trajectories for Robot Exploration and Path Planning
Subhrajit Bhattacharya Maxim Likhachev, Vijay Kumar

Abstract:
There are many applications in motion planning where it is important to consider and distinguish between different homotopy classes of trajectories. Two trajectories are homotopic if one trajectory can be continuously deformed into another without passing through an obstacle, and a homotopy class is a collection of homotopic trajectories. In this paper we consider the problem of robot exploration and planning in three-dimensional configuration spaces to (a) identify and classify different homotopy classes; and (b) plan trajectories constrained to certain homotopy classes or avoiding specified homotopy classes. In previous work [1] we have solved this problem for two-dimensional, static environments using the Cauchy Integral Theorem in concert with graph search techniques. The robot workspace is mapped to the complex plane and obstacles are poles in this plane. The Residue Theorem allows the use of integration along the path to distinguish between trajectories in different homotopy classes. However, this idea is fundamentally limited to two dimensions. In this work we develop new techniques to solve the same problem, but in three dimensions, using theorems from electromagnetism. The Biot-Savart law lets us design an appropriate vector field, the line integral of which, using the integral form of Ampere’s Law, encodes information about homotopy classes in three dimensions. Skeletons of obstacles in the robot world are extracted and are modeled by current-carrying conductors. We describe the development of a practical graph-search based planning tool with theoretical guarantees by combining integration theory with search techniques, and illustrate it with examples in three-dimensional spaces such as two-dimensional, dynamic environments and three-dimensional static environments.

Schedule: see page 18
Passivity-Based Decentralized Connectivity Maintenance in the Bilateral Teleoperation of Multiple UAVs
Paolo Robuffo Giordano, Antonio Franchi, Cristian Secchi, Heinrich Bülthoff

Abstract:
In this paper, we present a decentralized passivity-based control strategy for the bilateral teleoperation of a group of Unmanned Aerial Vehicles (UAVs). The human operator at the master side can command the group motion and receive suitable force cues informative about the remote environment. By properly controlling the energy exchanged within the slave side (the UAV group), we guarantee that the connectivity of the group is preserved and we prevent inter-agent and obstacle collisions. At the same time, we allow the behavior of the UAVs to be as flexible as possible with arbitrary split and join maneuvers. The results of the paper are validated by means of human/hardware-in-the-loop (HHIL) simulations.

Schedule: see page 18.

Real-time prioritized kinematic control under inequality constraints for redundant manipulators
Oussama Kanoun

Abstract:
This paper describes a fast algorithm for the prioritized kinematic control of redundant manipulators. Building on the classical prioritized task framework, the focus is set on efficient computation and handling of inequality constraints throughout priority levels. Classical approaches that tend to account for inequality constraints through potential fields are computationally competitive but have quality issues. Formulating the same control problems with a Quadratic Program (QP) removes these issues but is known to be costly. The following work revisits the formulation of a hierarchy of QPs for the prioritized control of redundant manipulators and proposes an algorithm that can meet real time requirements for current humanoid robots. Because lower control objectives often become infeasible, a particular point of focus is the numerical stability, hereby addressed with Tikhonov regularization. The method was tested in simulation for the control of the humanoid robot HRP-2.

Schedule: see page 18.

Tracking-based semi-supervised learning
Alex Teichman, Sebastian Thrun

Abstract:
In this paper, we consider a semi-supervised approach to the problem of track classification in dense 3D range data. This problem involves the classification of objects that have been segmented and tracked without the use of a class model. We propose a method based on the EM algorithm: iteratively 1) train a classifier, and 2) extract useful training examples from unlabeled data by exploiting tracking information. We evaluate our method on a large multiclass problem in dense LIDAR data collected from natural suburban street scenes. When given only three hand-labeled training tracks of each object class, semi-supervised performance is comparable to that of the fully-supervised equivalent which uses thousands of hand-labeled training tracks. Further, when given additional unlabeled data, the semi-supervised method outperforms the supervised method. Finally, we show that a simple algorithmic speedup based on incrementally updating a boosting classifier can reduce learning time by a factor of three.

Schedule: see page 18.
Technical Session 6, Tuesday, June 28, 2011

Learning to Control a Low-Cost Manipulator Using Data-Efficient Reinforcement Learning
Marc Deisenroth, Carl Rasmussen, Dieter Fox

Abstract:
Over the last years, there has been substantial progress in robust manipulation in unstructured environments. The long-term goal of our work is to get away from precise, but very expensive robotic systems and to develop affordable, potentially imprecise, self-adaptive manipulator systems that can interactively perform tasks such as playing with children. In this paper, we demonstrate how a low-cost off-the-shelf robotic system can learn closed-loop policies for a stacking task in only a handful of trials—from scratch. Our manipulator is inaccurate and provides no pose feedback. For learning a controller in the work space of a Kinect-style depth camera, we use a model-based reinforcement learning technique. Our learning method is data efficient, reduces model bias, and deals with several noise sources in a principled way during long-term planning. We present a way of incorporating state-space constraints into the learning process and analyze the learning gain by exploiting the sequential structure of the stacking task.

Schedule: see page 19

A Linear Estimation Framework for Solving Simultaneous Localization and Mapping
Luca Carlone, Rosario Aragues, Jose Castellanos, Basilio Bona

Abstract:
This article investigates the problem of Simultaneous Localization and Mapping (SLAM) from the perspective of linear estimation theory. The problem is first formulated in terms of graph embedding: a graph describing robot poses at subsequent instants of time needs be embedded in a three-dimensional space, assuring that the estimated configuration maximizes measurement likelihood. Combining tools belonging to linear estimation and graph theory, a closed-form approximation to the full SLAM problem is proposed, under the assumption that the relative position and the relative orientation measurements are independent. The approach needs no initial guess for optimization and is formally proven to admit solution under the SLAM setup. The resulting estimate can be used as an approximation of the actual nonlinear solution or can be further refined by using it as an initial guess for nonlinear optimization techniques. Finally, the experimental analysis demonstrates that such refinement is often unnecessary, since the linear estimate is already accurate.

Schedule: see page 19
Visual Segmentation of “Simple” Objects for Robots
Ajay Mishra, Yiannis Aloimonos

Abstract:
The ability to automatically segment a “simple” object of any size from its background is important for an active agent (e.g. a robot) to interact effectively in the real world. Recently, we proposed an algorithm [12] to segment a “simple” object in a scale invariant manner, given a point anywhere inside that object. However, in [12], a strategy to select the point inside a “simple” object was not provided. In this paper, we propose a new system that automatically selects the points inside different “simple” objects in the scene, carries out the segmentation process for the selected points, and outputs only the regions corresponding to the “simple” objects in the scene. The proposed attention mechanism for the segmentation problem utilizes, for the first time, the concept of border ownership [17].

Schedule: see page [19]

Kinematic Cartography for Locomotion
Ross Hatton, Howie Choset

Abstract:
Kinematic motion planning often requires a notion of “distance” between configurations. Euclidean distances on a parameter space are easy to compute, but can drastically distort the effort required to change configuration. Here, we present a framework for characterizing this distortion, based on principles adopted from the cartographic community, and a method for transforming configuration coordinates to better represent actuation costs. As a demonstration of this approach, we derive a true configuration distance metric for an important class of locomoting systems: low Reynolds number swimmers. Applying our cartographic coordinate transformation to these systems both provides intuition for previous numerical results, and allows direct geometric comparison between systems with heterogeneous morphology.

Schedule: see page [19]

Collision-Free and Curvature-Continuous Path Smoothing In Cluttered Environments
Jia Pan, Liangjun Zhang, Dinesh Manocha

Abstract:
We present a novel trajectory computation algorithm to smooth jerky collision-free paths computed by sample-based motion planners. Our approach uses cubic B-splines to generate G2 or curvature continuous trajectories. The algorithm performs local spline refinement to compute smooth, collision-free paths in narrow passages and satisfy velocity and acceleration constraints. We also present a fast and reliable algorithm for collision checking between robot and the environment along the B-spline trajectories. We highlight the performance of our algorithm on complex benchmarks, including path computation for rigid and articulated models in tight spaces and cluttered environments.

Schedule: see page [19]
Designing Petri Net Supervisors from LTL Specifications
Bruno Lacerda, Pedro Lima

Abstract:
We present a methodology to build a Petri net realization of a supervisor that, given a Petri net model of a (multi-)robot system and a linear temporal logic (LTL) specification, forces the system to fulfil the specification. The methodology includes composing the Petrinet model with the Büchi automaton representing the LTL formula and trimming the result using a known method to reduce the size of the supervisor. Furthermore, we guarantee that the obtained supervisors are admissible by construction by restricting the LTL formulas that can be written to an appropriate subset. To illustrate the method, we provide an example on how to specify coordination rules for a team of simulated soccer robots.

Schedule: see page 19

Controlling Ergodic Bodies Using Linear Temporal Logic
Leonardo Bobadilla, Oscar Sanchez, Justin Czarnowski, Katrina Gossman, Steven LaValle

Abstract:
There is substantial interest controlling a group of bodies from specifications of tasks given in a high-level, humanlike language. This paper proposes a methodology that creates low-level hybrid controllers that guarantee that a group of bodies execute a high-level specified task without dynamical system modeling, precise state estimation or state feedback. We do this by exploiting the wild motions of very simple bodies in an environment connected by gates which serve as the system inputs, as opposed motors on the bodies. We present experiments using inexpensive hardware demonstrating the practical feasibility of our approach to solving tasks such as navigation, patrolling, and coverage.

Schedule: see page 19

Operational Space Control of Constrained and Underactuated Systems
Michael Mistry, Ludovic Righetti

Abstract:
The operational space formulation (Khatib, 1987), applied to rigid-body manipulators, describes how to decouple task-space and null-space dynamics, and write control equations that correspond only to forces at the end-effector or, alternatively, only to motion within the null-space. We would like to apply this useful theory to modern humanoids and other legged systems, for manipulation or similar tasks, however these systems present additional challenges due to their underactuated floating bases and contact states that can dynamically change. In recent work, Sentis et al. derived controllers for such systems by implementing a task Jacobian projected into a space consistent with the supporting constraints and underactuation (the so called support consistent reduced Jacobian). Here, we take a new approach to derive operational space controllers for constrained underactuated systems, by first considering the operational space dynamics within projected inverse-dynamics (Aghili, 2005), and subsequently resolving underactuation through the addition of dynamically consistent control torques. Doing so results in a simplified control solution compared with previous results, and importantly yields several new insights into the underlying problem of operational space control in constrained environments: 1) Underactuated systems, such as humanoid robots, cannot in general completely decouple task and null-space dynamics. However, 2) there may exist an infinite number of control solutions to realize desired task-space dynamics, and 3) these solutions involve the addition of dynamically consistent null-space motion or constraint forces (or combinations of both). In light of these findings, we present several possible control solutions, with varying optimization criteria, and highlight some of their practical consequences.

Schedule: see page 19
Understanding Slip Perception of Soft Fingertips by Modeling and Simulating Stick-Slip Phenomenon
Van Ho, Shinichi Hirai

Abstract:
Slip, especially incipient slip, is a complicated process for soft fingertips; and detection of this slip is important for stable manipulations by both human and robotic fingertips. Experimental research has attempted to explain this phenomenon, but dynamic changes during this process could not be fully delineated. We propose here a dynamic model to investigate the sliding motion of soft fingertips on a plane with friction. The fingertip is comprised of a finite number of elastic, compressible and bendable cantilevers whose free ends act as infinitesimal contact points. The contact surface is afterward meshed using a finite element method based on the coordinates of the contact points. By introducing Coulomb’s law and contact compliance into each contact point, we were able to assess the frictional characteristics of the sliding motions of the fingertips. We also could successfully describe the dynamically localized displacements on the contact surface during stick-slip transition, displacements that represent the sliding motion of a soft fingertip. This model can be applied to different shapes of robotic fingertip, including the cylindrical and hemispherical models tested here. We also performed experiments to validate the proposed simulation, including force/moment and vision setups.

Schedule: see page 19

Probabilistic Analysis of Correctness of High-Level Robot Behavior with Sensor Error
Benjamin Johnson, Hadas Kress-Gazit

Abstract:
This paper presents a method for reasoning about the effects of sensor error on high-level robot behavior. We consider robot controllers that are synthesized from a set of high-level, temporal logic task specifications, such that the resulting robot behavior is guaranteed to satisfy these specifications when assuming perfect sensors and actuators. We relax the assumption of perfect sensing, and calculate the probability with which the controller satisfies a set of temporal logic specifications. We consider parametric representations, where the satisfaction probability is found as a function of the model parameters, and numerical representations, allowing for the analysis of large examples. We illustrate our approach with three examples of varying size that provide insight into unintuitive effects of sensor error that can inform the specification design process.

Schedule: see page 19
Assisted Teleoperation Strategies for Aggressively Controlling a Robot Arm with 2D Input
Erkang You, Kris Hauser

Abstract:
This paper studies assisted teleoperation techniques for controlling a 6DOF robot arm using click-and-drag input from a computer mouse. Experiments were conducted to investigate how task performance and user preferences are affected by low-level motion control strategies, which must deal with collision avoidance, dynamics constraints, and erroneous input. Five strategies were implemented and compared. As baseline strategies we study direct joint control and Cartesian positioning via inverse kinematics. We also implemented three obstacle avoidance strategies, including a predictive safety filter, a reactive potential field, and a real-time sample-based motion planner. Blind experimental trials assigned 22 novice subjects to five subgroups corresponding to each strategy and asked them to control the arm in simulation on a variety of reaching tasks in cluttered environments. Unsurprisingly, the obstacle avoidance strategies achieve major safety improvements, although subjects felt noticeably less in control of the robot than those using the baseline methods. The motion planning strategy shows the most promise; it completed tasks twice as fast as any other method and received high ratings for perceived safety, cooperativeness, and overall satisfaction.

Schedule: see page 19.

Global Optimization of Robotic Grasps
Carlos Rosales Gallegos, Josep Porta, Lluis Ros

Abstract:
This paper presents a procedure to optimize the quality of robotic grasps for objects that need to be held and manipulated in a specific way, characterized by a number of tight contact constraints. The main difficulties of the problem include that the set of feasible grasps is a manifold implicitly defined by a system of non-linear equations, the high dimension of this manifold, and the multi-modal nature of typical grasp quality indices, which make local optimization methods get trapped into local extrema. The proposed procedure finds a way around these difficulties by focussing the exploration on a relevant subset of grasps of lower dimension, which is traced out exhaustively using higher-dimensional continuation techniques. Using these techniques, a detailed atlas of the subset is obtained, on which the highest quality grasp according to any desired criterion can be readily identified. Experiments on a 3-finger planar hand and on the Schunk anthropomorphic hand validate the approach.

Schedule: see page 19.

An Interaction Design Framework for Social Robots
Dylan Glas, Satoru Satake, Takayuki Kanda, Norihiro Hagita

Abstract:
We present a novel design framework enabling the development of social robotics applications by cross-disciplinary teams of programmers and interaction designers. By combining a modular back-end software architecture with an easy-to-use graphical interface for developing interaction sequences, this system enables programmers and designers to work in parallel to develop robot applications and tune the subtle details of social behaviors. In this paper, we describe the structure of our design framework, and we present an experimental evaluation of our system showing that it increases the effectiveness of programmer-designer teams developing social robot applications.

Schedule: see page 19.
Technical Session 7, Wednesday, June 29, 2011

Invited Talk: Catherine Mohr

Robots in the OR

Abstract:
Robotics is often thought of primarily as development of manipulator technology. In the operating room, however, surgical robots provide improvement in clinical outcomes that comes from improved vision and navigation as well as dexterity enhancement. It may be that on future surgical platforms, augmenting the surgeon’s clinical decision making becomes the largest contributor to improved outcomes. The various ways in which robotics may change the way we do surgery will be discussed.

Schedule: see page 20

Motion Planning Under Uncertainty in Highly Deformable Environments
Sachin Patil, Jur van den Berg, Ron Alterovitz

Abstract:
Many tasks in robot-assisted surgery, food handling, manufacturing, and other applications require planning and controlling the motions of manipulators or other devices that must interact with highly deformable objects. We present a unified approach for motion planning under uncertainty in deformable environments that maximizes probability of success by accounting for uncertainty in deformation models, noisy sensing, and unpredictable actuation. Unlike prior planners that assume deterministic deformations or treat deformations as a type of small perturbation, our method explicitly considers the uncertainty in large, time-dependent deformations. Our method requires a simulator of deformable objects but places no significant restrictions on the simulator used. We use a sampling-based motion planner in conjunction with the simulator to generate a set of candidate plans based on expected deformations. Our method then uses the simulator and optimal control to numerically estimate time-dependent state distributions based on uncertain parameters (e.g. deformable material properties or actuation errors). We then select the plan with the highest estimated probability of successfully avoiding obstacles and reaching the goal region. Using FEM-based simulation of deformable tissues, we demonstrate the ability of our method to generate high quality plans in two medical-inspired scenarios: (1) guiding bevel-tip steerable needles through slices of deformable tissue around obstacles for minimally invasive biopsies and drug-delivery, and (2) manipulating planar tissues to align interior points at desired coordinates for precision treatment.

Schedule: see page 20
Technical Session 8, Wednesday, June 29, 2011

Multi-Level Partitioning and Distribution of the Assignment Problem for Large-Scale Multi-Robot Task Allocation
Lantao Liu, Dylan Shell

Abstract:
A team of robots can handle failures and dynamic tasks by repeatedly assigning functioning robots to tasks. This paper introduces an algorithm that scales to large numbers of robots and tasks by exploiting both task locality and sparsity. The algorithm mixes both centralized and decentralized approaches at different scales to produce a fast, robust method that is accurate and scalable, and reduces both the global communication and unnecessary repeated computation. We depart from optimization and bipartite matching formulations of the problem, observing instead that an assignment can be computed through coarsening and partitioning operations on the utility matrix. First, a coarse assignment is calculated by evaluating the global utility information and partitioning it into clusters in a problem-domain independent way. Next, the assignment solutions in each partition are refined (either recursively, or via an existing algorithm). This multilevel framework allows the repeated reassignment to execute among interrelated partitions. The results suggest that only a minor sacrifice in solution quality is required for gains in efficiency. The proposed algorithm is validated using extensive simulation experiments and the results show advantages over the traditional optimal assignment algorithms.

Schedule: see page [20]

Cross-Entropy Randomized Motion Planning
Marin Kobilarov

Abstract:
This paper is concerned with motion planning for nonlinear robotic systems operating in constrained environments. Motivated by recent developments in sampling-based motion planning and Monte Carlo optimization we propose a general randomized path planning method based on sampling in the space of trajectories. The idea is to construct a probability distribution over the set of feasible paths and to perform the search for an optimal trajectory through importance sampling. At the core of the approach lies the cross-entropy method for estimation of rare-event probabilities. The algorithm recursively approximates the optimal sampling distribution which guides the set of sampled trajectories towards regions of progressively lower cost until converging to a delta distribution at the optimum. Our main goal is to provide a framework for consistent adaptive sampling correlating the spatial structure of trajectories and their computed costs. The approach is illustrated with two simple examples—a point mass vehicle and the Dubins car, and is then applied to a simulated helicopter flying optimally in a 3-D terrain.

Schedule: see page [20]
An Art Gallery Approach to Ensuring that Landmarks are Distinguishable
Lawrence Erickson, Steven LaValle

Abstract:
How many different classes of partially distinguishable landmarks are needed to ensure that a robot can always see a landmark without simultaneously seeing two of the same class? To study this, we introduce the chromatic art gallery problem. A guardset \( S \subset P \) is a set of points in a polygon \( P \) such that for all \( p \in P \), there exists an \( s \in S \) such that \( s \) and \( p \) are mutually visible. Suppose that two members of a finite guard set \( S \subset P \) must be given different colors if their visible regions overlap. What is the minimum number of colors required to color any guard set (not necessarily a minimal guard set) of a polygon \( P \)? We call this number, \( \chi_G(P) \), the chromatic guard number of \( P \). We believe this problem has never been examined before, and it has potential applications to robotics, surveillance, sensor networks, and other areas. We show that for any spiral polygon \( P_{spi} \), \( \chi_G(P_{spi}) \leq 2 \), and for any staircase polygon (strictly monotone orthogonal polygon) \( P_{sta} \), \( \chi_G(P_{sta}) \leq 3 \). For lower bounds, we construct a polygon with \( 4k \) vertices that requires \( k \) colors. We also show that for any positive integer \( k \), there exists a monotone polygon \( M_k \) with \( 3k^2 \) vertices such that \( \chi_G(M_k) \geq k \), and for any odd integer \( k \), there exists an orthogonal polygon \( R_k \) with \( 4k^2 + 10k + 10 \) vertices such that \( \chi_G(R_k) \geq k \).

Schedule: see page 20
Technical Session 9, Thursday, June 30, 2011

Invited Talk: Andy Ruina
Balance: Brooms, Standing, Walking and Biking

Abstract:
There are open loop or uncontrolled ways to keep all of these things from falling over. These are interesting in themselves and interesting to compare to the means by which they can be balanced using control. How do things balance themselves and does this matter for controlled stability? Does passive stability depend on dissipation? Are there necessary tradeoffs between passive stability, efficiency and maneuverability?

Schedule: see page 21

Distributed Robot Ensemble Control for Deployment to Multiple Sites
T. William Mather, M. Ani Hsieh

Abstract:
We address the ensemble synthesis of distributed control policies to allocate a team of homogenous robots to a collection of spatially distributed tasks. We assume individual robot controllers are derived via the sequential composition of individual task controllers and develop an appropriate macroscopic description of the team dynamics. A feedback control strategy is synthesized using the macroscopic model to enable the team to maintain a desired distribution of robots across the various tasks while minimizing the variance of the robot population at each task. We present a distributed implementation of the proposed ensemble feedback strategy that can be implemented with minimal communication requirements. We establish stability properties of our ensemble controller and verify the feasibility of the distributed ensemble controller through high-fidelity simulations.

Schedule: see page 21
Technical Session 10, Thursday, June 30, 2011

Friendly Patrolling: A Model of Natural Encounters
Kotaro Hayashi, Masahiro Shiomi, Takayuki Kanda, Norihiro Hagita

Abstract:
This study addresses encounter interactions in public environments where people and robots walk around. In daily life, security guards, police officers, and sales clerks roam around environments and nonverbally present friendly behavior so that people feel comfortable talking to them. We modeled the behavior of human experts during friendly patrolling, which we defined as a roaming behavior that nonverbally presents a friendly attitude, to encourage people to talk to such professionals. The model was implemented in a humanoid robot, Robovie, and tested in a shopping mall. The experimental results with 39 participants demonstrated that the model worked as intended.

Schedule: see page 21

Lying Pose Recognition for Elderly Fall Detection
Simin Wang, Salim Zabir, Bastian Leibe

Abstract:
This paper proposes a pipeline for lying pose recognition from single images, which is designed for healthcare robots to find fallen people. We firstly detect object bounding boxes by a mixture of viewpoint-specific part based model detectors and later estimate a detailed configuration of body parts on the detected regions by a finer tree-structured model. Moreover, we exploit the information provided by detection to infer a reasonable limb prior for the pose estimation stage. Additional robustness is achieved by integrating a viewpoint-specific foreground segmentation into the detection and body pose estimation stages. This step yields a refinement of detection scores and a better color model to initialize pose estimation. We apply our proposed approach to challenging data sets of fallen people in different scenarios. Our quantitative and qualitative results demonstrate that the part-based model significantly outperforms a holistic model based on same feature type for lying pose detection. Moreover, our system offers a reasonable estimation for the body configuration of varying lying poses.

Schedule: see page 21

A Framework for Push-Grasping in Clutter
Mehmet Dogar, Siddhartha Srinivasa

Abstract:
Humans use a remarkable set of strategies to manipulate objects in clutter. We pick up, push, slide, and sweep with our hands and arms to rearrange clutter surrounding our primary task. But our robots treat the world like the Tower of Hanoi — moving with pick-and-place actions and fearful to interact with it with anything but rigid grasps. This produces inefficient plans and is often inapplicable with heavy, large, or otherwise ungraspable objects. We introduce a framework for planning in clutter that uses a library of actions inspired by human strategies. The action library is derived analytically from the mechanics of pushing and is provably conservative. The framework reduces the problem to one of combinatorial search, and demonstrates planning times on the order of seconds. With the extra functionality, our planner succeeds where traditional grasp planners fail, and works under high uncertainty by utilizing the funneling effect of pushing. We demonstrate our results with experiments in simulation and on HERB, a robotic platform developed at the Personal Robotics Lab at Carnegie Mellon University.

Schedule: see page 21
Technical Session 11, Thursday, June 30, 2011

Invited Talk: Chris Urmson
The Google Self-Driving Car Project

Abstract:
Self-driving vehicles hold the promise of transforming the automotive industry and reshaping our relationship with the automobile. The Google Self-Driving car project was created to rapidly advance autonomous driving technology. Building from the foundation of decades of research and the DARPA Challenges, we have developed a small fleet of autonomous self-driving vehicles. In this talk, I will provide an introduction to the work Google has been doing in advancing the state-of-the art in autonomous vehicles. When driving the vehicles use a combination of prior map data and on-line sensing. Prior to driving the vehicles are used to build high-resolution models of the world. On line, the vehicles use these models to estimate their position and to help them track objects that move through the world (pedestrians, cyclists, cars, etc.). A motion planner then combines the a priori model of world with objects that are detected online to determine safe trajectories through the world. In the course of the talk, I will demonstrate the capabilities (and limitations) of our vehicles, and talk briefly about the promise of self-driving vehicles.

Schedule: see page 21

Monte Carlo Pose Estimation with Quaternion Kernels and the Bingham Distribution
Jared Glover, Radu Rusu, Gary Bradski

Abstract:
The success of personal service robotics hinges upon reliable manipulation of everyday household objects, such as dishes, bottles, containers, and furniture. In order to accurately manipulate such objects, robots need to know objects’ full 6-DOF pose, which is made difficult by clutter and occlusions. Many household objects have regular structure that can be used to effectively guess object pose given an observation of just a small patch on the object. In this paper, we present a new method to model the spatial distribution of oriented local features on an object, which we use to infer object pose given small sets of observed local features. The orientation distribution for local features is given by a mixture of Binghamons on the hypersphere of unit quaternions, while the local feature distribution for position given orientation is given by a locally-weighted (Quaternion kernel) likelihood. Experiments on 3D point cloud data of cluttered and uncluttered scenes generated from a structured light stereo image sensor validate our approach.

Schedule: see page 21
Technical Session 12, Thursday, June 30, 2011

An Analytic Motion Planning Solution for the Snakeboard
Elie Shammas, Mauricio de Oliveira

Abstract:
This paper provides a closed-form analytical solution to the motion planning problem for the Snakeboard. Given a desired planar trajectory in the fiber space, an explicit solution is computed for the gaits in the base space that locomote the Snakeboard along the desired trajectory. This is achieved by introducing a new momentum-like variable that simplifies the Snakeboard’s equations of motion to allow for such an explicit gait generation technique.

Schedule: see page 21

Construction of Cubic Structures with Quadrotor Teams
Quentin Lindsey, Daniel Mellinger, Vijay Kumar

Abstract:
We propose and investigate a system in which teams of quadrotor helicopters assemble 2.5-D structures from simple structural nodes and members equipped with magnets. The structures, called Special Cubic Structures (SCS), are a class of 2.5-D truss-like structures free of overhangs and holes. Grippers attached to the bottom of each quadrotor enable them to pick up, transport, and assemble the structural elements. The design of the nodes and members imposes constraints on assembly which are incorporated into the design of the algorithms used for assembly. We show that any SCS can be built using only the feasible assembly modes for individual structural elements and present simulation and experimental results with a team of quadrotors performing automated assembly. The paper includes a theoretical analysis of the SCS construction algorithm, the rationale for the design of the structural nodes, members and quadrotor gripper, a description of the quadrotor control methods for part pickup, transport and assembly, and an empirical analysis of system performance.

Schedule: see page 21
Open Sessions — Thursday, June 30, 1:15-2:45pm in GFS

RSS 2011 contains a new style of technical interaction in the form of open sessions. The open sessions will occur during lunch on Thursday, June 30th from 1:15-2:45pm in the Grace Ford Salvatori Hall (GFS). During this time, there will be eight parallel technical discussions, but the topics for these discussions have not been set.

During the first two days of the conference, RSS attendees can propose discussion topics at the white board next to the registration desk, and these topics will be accepted simply on a first-come-first-serve basis until there are eight. The proposer of each discussion topic will lead the session, and is expected to introduce the topic briefly in the first few minutes of the session. All other attendees can join any of the sessions, participate in the discussion, learn what people are thinking in real-time, and provide their own ideas in an informal setting. Our expectation is that these open sessions will be a form of ad hoc workshops where we can talk about different topics in-depth that have come up during the conference.

There will be no formal presentations, and no projectors in the rooms. We further ask that participants keep their laptop and iPhones closed and stowed away. If you need to check or send email, please step outside the room.

Lunch will be provided.
## Workshops

### Monday, June 27, 2011

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<td>Session 1.</td>
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<td>10:30-10:45</td>
<td>Break</td>
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<td>10:45-12:15</td>
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### Friday, July 1, 2011

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WS1. RGB-D: Advanced Reasoning with Depth Cameras

Schedule and Location:
Full-day workshop, Monday, June 27, 2011
Location: GFS 101

Organizers:
Xiaofeng Ren Intel Labs Seattle
Dieter Fox, University of Washington
Jana Kosecka, George Mason University
Kurt Konolige, Willow Garage

Description:
The arrival of Microsoft Kinect, with $150 a unit and 8 million sales in two months, is causing a revolution across robotics research landscapes. Affordable RGB-D cameras, with real-time synchronized color and dense depth, are to dramatically improve and fundamentally change robots' capabilities to perceive and interact with people and environments. Last year's RGB-D workshop at RSS successfully brought together experts from multiple research fields with converging interests and discussed major RGB-D opportunities and challenges in robotics. This year, the main purpose of this workshop is to understand the scope and impact of the rapidly growing RGB-D-based research activities, to solicit and showcase in-progress RGB-D-based systems and applications, to clarify a research agenda for depth camera perception, and to coordinate efforts across communities to lead the emerging RGB-D revolution.
WS2. The State of Imitation Learning: Understanding its Applications and Promoting its Adoption

Schedule and Location:
Full-day workshop, Monday, June 27, 2011
Location: GFS 201

Organizers:
Brenna Argall, École Polytechnique Fédérale de Lausanne
Nathan Ratliff, Google
David Silver, Carnegie Mellon University

Description:
Imitation learning has grown into a large field with applications across robotics, neural computation, and artificial intelligence. As the field has developed, ideas have sprouted from a wide range of motivations and applications resulting differing terminology and significant overlap; terms such as apprenticeship learning, learning from demonstration, inverse optimal control, and inverse reinforcement learning mean the same thing to some, while to others they have vastly different connotations. Imitation learning is already creating a stir within the robotics community as an effective and practical way to transfer our intuition to real world robotics systems, and has the potential to revolutionize the way we approach system development. In this workshop, we will examine the collection of subfields within imitation learning together and attempt to construct a formal taxonomy of the tools and techniques available to solidify its foundation and promote wider adoption with the robotics community.
WS3. Toward High-Performance Computing Support for the Analysis, Simulation, and Planning of Robotics Contact Tasks

Schedule and Location:
1.5 day workshop, Monday, June 27, 2011 and Tuesday, June 28, 2011 (morning)
Location: GFS 202 (Monday) and GFS 101 (Tuesday morning)

Organizers:
Chris Carothers, Rensselaer Polytechnic Institute
Dan Negrut, University of Wisconsin
Jeff Trinkle, Rensselaer Polytechnic Institute

Description:
A key need in robotics is reliable prediction of actions involving intermittent contact such as legged locomotion over rough terrain, grasp acquisition, multi-robot manipulation, and assembly. As the reliability and speed of prediction increase, more capable planners can be developed that produce robust plans for more complex tasks. Current software that can analyze and simulate contact tasks vary greatly in their speed, physical fidelity, and stability. The main goals of the proposed workshop are two-fold. First, the participants will assess the state of the art in the analysis, simulation, and planning of robotic contact tasks. Second, they will assess the needs of the robotics community for a software platform related to robotic contact tasks. If the recommendation of the workshop participants is to move ahead, then the organizers will seek sources of support to pursue development.
WS4. Tutorial on Designing Social Behavior (CANCELED)
WS5. ALONE - Autonomous Long-Term Operation in Novel Environments

Schedule and Location:
Full-day workshop, Monday, June 27, 2011
Location: GFS 104

Organizers:
Jonathan Kelly, University of Southern California
Paul Newman, University of Oxford
Sebastian Thrun, Stanford University / Google

Description:
The majority of future robots will operate outside of the laboratory or the factory, performing tasks in challenging, dynamic environments. In many situations, removal from service for maintenance or adjustment may be infeasible or impossible. As such, these robots will need to function reliably and autonomously on time scales ranging from days to years. Developing adaptive and flexible systems capable of this level of independence will require significant technical advances. The aim of the ALONE workshop is to bring together researchers from a diverse range of sub-disciplines, to identify and discuss fundamental challenges related to long-term autonomous operation; focus will be given to robots working in particularly demanding locations, e.g., busy homes and offices, on existing road networks, underground, underwater, in space, and on remote planetary surfaces. The workshop will include short talks and panel discussions on topics including, but not limited to: resource-constrained long-horizon planning; long-term learning and adaptation; estimation in dynamic environments; fault tolerance and failure prediction; and online calibration. We hope that the workshop will foster opportunities for collaboration, with the goal of developing robust, integrated autonomous systems.
WS6. Aquatic Robotics: Ocean Science and Marine Systems

Schedule and Location:
Full-day workshop, Monday, June 27, 2011
Location: GFS 105

Organizers:
Ryan N. Smith, Queensland University of Technology
Noel Du Toit, California Institute of Technology
Burton H. Jones, University of Southern California
Kanna Rajan, Monterey Bay Aquarium Research Institute

Description:
This full day workshop will bring together researchers from aquatic robotics, AI, sensor networking, communications, physical and biological oceanography, and marine microbiology with the intention of creating collaborative links between these communities through sharing recent results and discussing future research directions. The workshop features technical talks by experts in marine robotic systems (single and multi-agent), as well as experts in marine science and biology. The organizers will have multiple platforms deployed off the Los Angeles coast during the workshop (and the conference). A novel aspect of this workshop is the concluding panel discussion: workshop attendees will collaborate to design and implement a sampling strategy/mission plan for the deployed vehicles. The objective is long-term data gathering on effluent plume development and vertical mixing off the Los Angeles, CA coast. The mission plan and actual execution will be available to all conference attendees, in real-time, via an online mission planning tool.
WS7. Guaranteeing Motion Safety for Robots

Schedule and Location:
Full-day workshop, Monday, June 27, 2011
Location: GFS 109

Organizers:
Thierry Fraichard, INRIA Grenoble Rhone-Alpes
Kostas Bekris, University of Nevada, Reno
Jur van den Berg, University of North Carolina, Chapel-Hill

Description:
In the near future, it is expected that robotic systems will share the human living and working spaces. While moving (especially at high speed), automated vehicles, mobile manipulators and humanoid robots can be potentially dangerous should a collision occur. It is therefore critical to assert and characterize their motion safety, i.e., their guaranteed ability to avoid collision. While there is a rich literature on collision avoidance schemes, motion safety in the real world for systems with interesting dynamics remains an open problem. The purpose of this workshop is to disseminate recent research advances in guaranteed motion safety for complex robotic systems operating in challenging situations. Topics include, but are not limited to: collision avoidance, multi-robot coordination, safe reactive (re)planning approaches, safe motion for robots with kinodynamic constraints, control theoretic and probabilistic approaches to motion safety, and deadlock and livelock avoidance.
WS8. Mobile Manipulation - Learning to Manipulate

Schedule and Location:
Full-day workshop, Monday, June 27, 2011
Location: GFS 118

Organizers:
Oliver Brock, TU Berlin
Dov Katz, UMass Amherst
Ellen Klingbeil, Stanford University
Sarah Osentoski, Bosch Research
Radu Bogdan Rusu, Willow Garage

Description:
This workshop explores new approaches to mobile manipulation with an emphasis on the relationship between machine learning and successful interaction in human environments. Autonomous manipulation in human environments is challenging because of the associated high dimensional state space and its inherent uncertainties. It requires perceptual and manipulation skills which are robust against sparse, incomplete and noisy information. In such environments, leveraging past experience, oftentimes resulting from the robot's own interactions, promises an increased robustness and reliability. Therefore, these challenges naturally connect autonomous manipulation to machine learning. The proposed workshop will explore these issues and feature research that addresses the challenges of autonomous manipulation in this context. The workshop will feature invited talks on the topics of machine learning, manipulation and perception. This would be the seventh in a series of mobile manipulation-centered workshops at RSS.
WS9. Tutorial on 3D Point Cloud Processing: Point Cloud Library

Schedule and Location:
Full-day workshop, Friday, July 1, 2011
Location: GFS 116

Organizers:
Radu Bogdan Rusu, Willow Garage
Bastian Steder, University of Freiburg
Nico Blodow, Technical University of Munich
Dirk Holz, University of Bonn

Description:
With the advent of new, low-cost hardware such as the Kinect and continued efforts in advanced open source 3D point cloud processing, 3D perception gains more importance in robotics and other fields. We offer a tutorial on point cloud processing using the emerging Point Cloud Library (PCL), which presents an advanced and extensive approach to the subject and provides an overview of existing systems applying these techniques. Our goal is to provide an excellent reference material for students and researchers interested in this subject and take our guests through a complete application demonstration (given live) that combines subjects such as filtering, feature estimation, segmentation, registration, object recognition and surface reconstruction. The tutorial will be held using Microsoft Kinect/PrimeSense sensors, so we encourage the audience to bring theirs so we can follow all the steps together.
WS10. A Comparison of Reinforcement Learning and Optimal Control Methods for Real-World Robotic Tasks

Schedule and Location:
Half-day workshop, Friday July 1, 2011 (afternoon)
Location: GFS 107

Organizers:
Freek Stulp, University of Southern California
Evangelos Theodorou, University of Southern California
Stefan Schaal, University of Southern California

Description:
Planning and control of robotic systems is challenging because robotic domains typically involve high-dimensional state and action spaces, uncertainty in state and action, and a large task space which requires generalization across tasks. In this workshop, we consider state-of-the-art methods and algorithms from the domains of reinforcement learning and optimal control, and discuss how they address the challenges above. Do they scale to high-dimensional tasks? Are they robust in the face of uncertainty? Do their solutions generalize well across tasks? Do they do so both in theory and in practice, when implemented on a physical robot system? We use a set of concrete robot tasks (performing flight maneuvers, humanoid locomotion and object manipulation) as use cases to focus the discussion.
WS11. Integrated Planning and Control

Schedule and Location:
Half-day workshop, Friday, July 1, 2011 (morning)
Location: GFS 118

Organizers:
Surya Singh, ACFR, University of Sydney
Russ Tedrake, Massachusetts Institute of Technology
Peter Corke, CyPhy Lab, Queensland University of Technology

Description:
Dynamic systems have to integrate both (1) the plan and (2) the regulation. Not only are interesting systems dynamically constrained, but they often have several solution pathways available. So it the task in not only how, but also when.

Solutions range from decision-policy searches to optimal controls to robust hardware. The goal of this workshop is to provide a forum for both the science and the systems: from algorithms to tools to make this work.
WS12. Human-Robot Interaction: Perspectives and Contributions to Robotics from the Human Sciences

Schedule and Location:
Full-day workshop, Friday, July 1, 2011
Location: GFS 101

Organizers:
Leila Takayama, Willow Garage
Maja Matarić, USC
Odest Chadwicke Jenkins, Brown
Holly Yanco, UMass Lowell
Brian Scassellati, Yale

Description:
As robotic capabilities improve, these robotic systems are becoming increasingly pervasive in real human-robot interaction settings, including (1) people interacting with autonomous robots, (2) people and robots sharing control, and (3) people tele-operating robots with direct control. The addition of humans into the equation presents a challenge and opportunity for engaging more seriously with the human sciences, including cognitive, behavioral, and social sciences. Without a deeper understanding of human user contexts, real user needs, user skills and limitations, and an ability to evaluate a robotic system’s performance in terms of user needs, robotics runs the risk of inventing technologies for the sake of the technologies themselves. We will address this risk by engaging in a discussion of what the human sciences have to offer robotics in terms of theoretical perspectives, empirical methods, useful concepts and models, and potential collaborations.
WS13. Automated SLAM Evaluation

Schedule and Location:
Full-day workshop, Friday, July 1, 2011
Location: GFS 104

Organizers:
Michael Kaess, Massachusetts Institute of Technology
Giorgio Grisetti, Sapienza University of Rome / University of Freiburg
Kai Ni, Georgia Institute of Technology / Microsoft

Description:
Due to its high relevance, Simultaneous Localization and Mapping (SLAM) is one of the most deeply investigated fields in mobile robotics. Over the last two decades hundreds of publications addressing the topic have been produced, and effective approaches are nowadays available. However, having such a large choice can become an issue both for the SLAM user that does not know what to select and for the SLAM researcher that has to compare their method with hundreds of others. These problems could be solved by an automated and open SLAM evaluation system. However, the construction of such a system poses different conceptual and practical problems, such as: What are the properties of interest? How to measure them? And how to compare heterogeneous systems? In this workshop, we will discuss how to answer these questions and we will present a system to compare a well defined sub-problem in the domain of graph-based SLAM systems, the graph-optimization.

Schedule and Location:

Full-day workshop, Friday, July 1, 2011
Location: GFS 105

Organizers:
Francesco Bullo, University of California, Santa Barbara
Emilio Frazzoli, Massachusetts Institute of Technology
Marco Pavone, NASA Jet Propulsion Laboratory, California Institute of Technology
Ketan Savla, Massachusetts Institute of Technology
Stephen L. Smith, University of Waterloo

Description:

This tutorial presents a joint algorithmic and queueing approach to the design of cooperative control and task allocation strategies for networks of robots, which must fulfill spatially-localized tasks generated over time by an exogenous process. As in queueing theory, task arrivals are modeled as a stochastic process, and queueing-style algorithms are required to enable robots to search, identify, allocate, prioritize, plan paths, and form teams. The design and analysis of these algorithms typically require a combination of receding-horizon resource allocation, distributed optimization, combinatorics and control. The key novelty lies in the integration of geometric and combinatorial aspects (e.g., coverage, traveling salesman problems) with stochastic and differential aspects (e.g., queueing effects and differential constraints on robot dynamics) in the context of distributed coordination of multi-robot networks. Applications of these algorithms are numerous, and include surveillance and monitoring missions, as well as transportation networks and automated material handling.
WS15. 3D Exploration, Mapping, and Surveillance with Aerial Robots

Schedule and Location:
Full-day workshop, Friday, July 1, 2011
Location: GFS 108

Organizers:
Nathan Michael, University of Pennsylvania
Mac Schwager, University of Pennsylvania
Vijay Kumar, University of Pennsylvania

Description:
Aerial robots play an increasingly important role in surveillance and exploration missions in both military and civilian domains, however most currently fielded aerial robots are teleoperated. Fully autonomous aerial robotic systems are within reach, though further research and development is needed. This workshop seeks to bring together theorists and experimentalists in aerial robotics to focus on the topics of exploration, mapping, and surveillance with aerial robots; including 3D SLAM, autonomous exploration, vehicle routing for surveillance, coverage control, and cooperative exploration. The workshop will emphasize the presentation of recent high-quality results in the pertinent areas and will encourage discussions to address the challenges of transitioning from theory to practice in this important and clearly motivated area of research. Participants will provide slides/videos for an on-line proceedings with the expectation of a journal-quality paper following the workshop. The organizers will pursue a special issue with IJRR or Autonomous Robots.
WS16. Tutorial on Stochastic Models, Information Theory, and Lie Groups

Schedule and Location:
Half-day workshop, Friday, July 1, 2011 (afternoon)
Location: GFS 109

Organizers:
Gregory Chirikjian, Johns Hopkins University

Description:
In this tutorial the aim is to illustrate that concepts of information, communication, and motion come together in a natural way as stochastic processes on Lie groups. It will be shown how this formulation is natural to describe many problems in robot planning and localization including those associated with nonholonomic mobile robots and steering problems involving flexible needles for medical applications. It is well known that Robotics combines information processing and action in the physical world. Sensors collect information, multi-agent systems communicate, and individual robots execute actions accordingly. Both the sensing/communication and physical aspects of robotics are subject to noise. Hence stochastic models are appropriate, as is well-understood by those who work on filtering. The presentation of this half-day tutorial will be concrete, focusing on the Lie group of rigid-body motions/poses. And it will address issues such as: (1) How do the concepts of mean, covariance, convolution, and Fourier transform extend from Euclidean space to the case of pose data? (2) How do information-theoretic inequalities generalize to non-Euclidean spaces? (3) How can assembly planning and localization problems be formulated in a way that is not subject to artificial singularities introduced by Euler angles and other parameterizations? (4) How are these applied in concrete applications in robotics and in structural biology?
WS17. HRI Workshop on Grounding Human-Robot Dialog for Spatial Tasks

Schedule and Location:
Half-day workshop, Friday, July 1, 2011 (morning)
Location: GFS 109

Organizers:
Thomas Kollar, Massachusetts Institute of Technology
Stefanie Tellex, Massachusetts Institute of Technology
Robert Ross, Dublin Institute of Technology
Antoine Raux, Honda Research Institute
Matthew Marge, Carnegie Mellon University

Description:
Unconstrained spoken language is an intuitive and flexible way for humans to command robots to perform spatial tasks such as navigation or manipulation. Dialog (i.e., conversational) interfaces offer a rich way to establish common ground between a person and a robot, and hence facilitate natural and flexible interaction. This workshop specifically aims to bring together communities studying robotics, natural language understanding, spatial cognition, and perception to build powerful spatial dialog systems for robots. We aim to bridge the gap between the theoretical understanding and practical application of spatial language understanding, create and discuss shared datasets and problems, and define key research problems and challenges.
## Conference Organizers

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