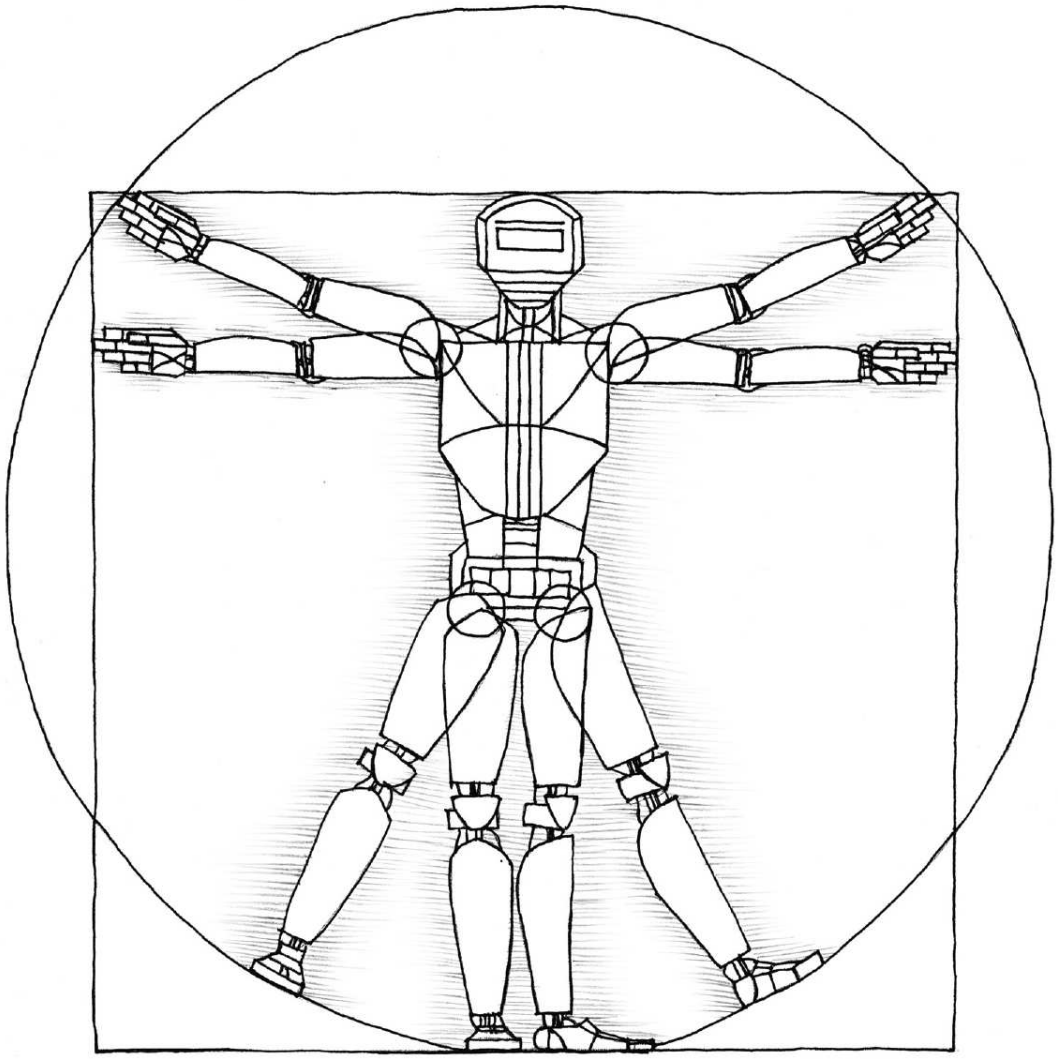
ROBOTICS
SCIENCE AND SYSTEMS



Conference Booklet

June 27-30, 2007
The Fabulous Fox Theatre
Georgia Tech
Atlanta, Georgia, USA
www.roboticsconference.org

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Preface

Welcome to RSS 2007!

After the first two exciting meetings in Boston and Philadelphia, this is the third Robotics: Science and Systems conference.

RSS 2007 takes place in the Fox Theatre which is a beautiful theater that hosts many plays, shows, and movies, including Broadway In Atlanta and the Atlanta Ballet.

The RSS 2007 technical program consists of seven invited talks including two early-career presentations, 18 poster and 23 oral presentations. They all cover a wide spectrum of ongoing research in robotics and related fields. Additionally, RSS 2007 features five workshops and one tutorial which will take place on the fourth day of the conference.

The social program of RSS 2007 includes a reception during the poster session on Wednesday night. Furthermore, we will have a banquet at the Georgia Aquarium, which is the largest aquarium in the world. Exhibits to be seen there are the 100ft (30m) long Ocean Voyager tunnel, the 23x61ft (7x19m) viewing window, the beluga whales, and the live coral reef. The banquet is free for all registered participants and will be accompanied by a banquet talk.

This booklet contains information about Atlanta, the technical and social program. It includes a schedule with all titles and abstracts. We hope you will find it useful throughout the conference.

All papers are available from the conference Web page

http://www.roboticsconference.org/

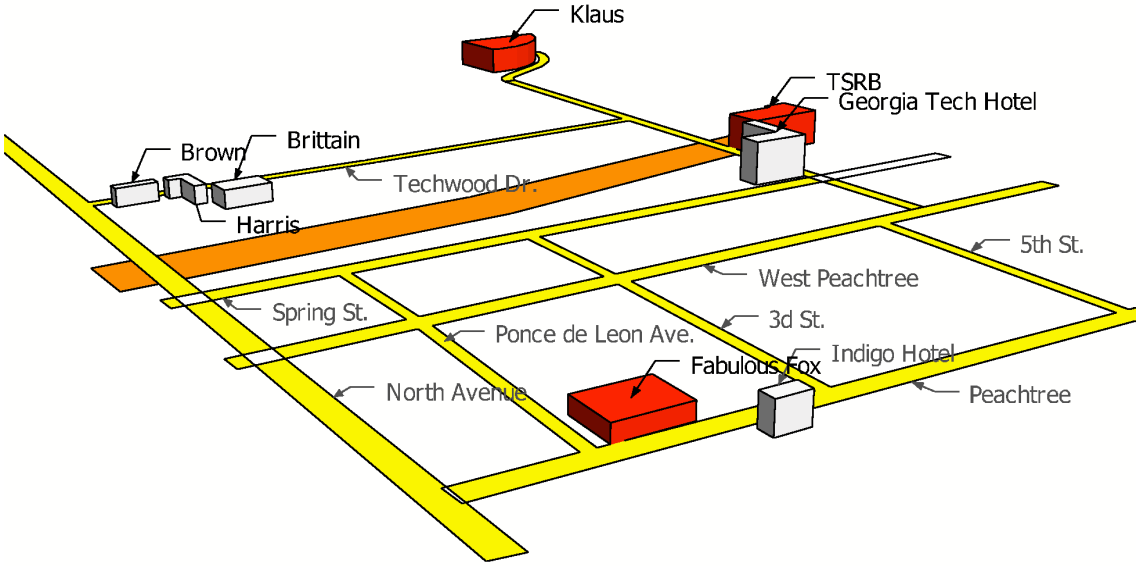
Again, we would like to welcome you and wish you a pleasant stay and inspiring discussions in Atlanta.

Oliver Brock, Wolfram Burgard, Cyrill Stachniss, Frank Dellaert, and Magnus Egerstedt

Conference Information

Location

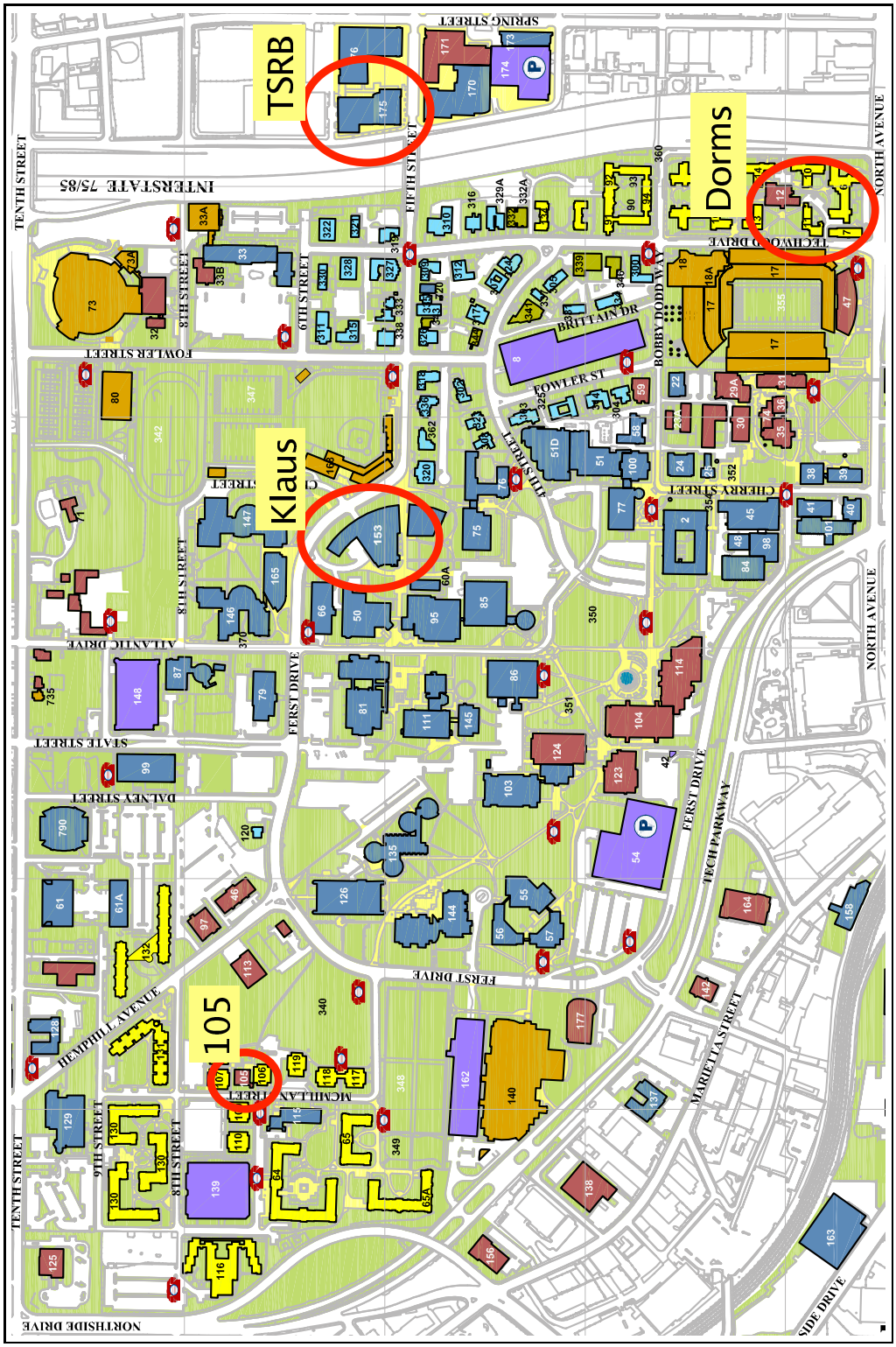
The conference, including oral presentations and exhibits, will be held at the Fabulous Fox Theatre, located in the heart of Midtown, at 660 Peachtree Street N.E., Atlanta GA 30308. The Fox is a 1920 landmark theatre and meeting facility an easy 10 minutes walk from the Georgia Tech campus. The technical sessions will be held in the **Egyptian Ballroom**. A map is shown below.



(c) by Michael Portman

(c) by Michael Portman

Georgia Tech Campus Map

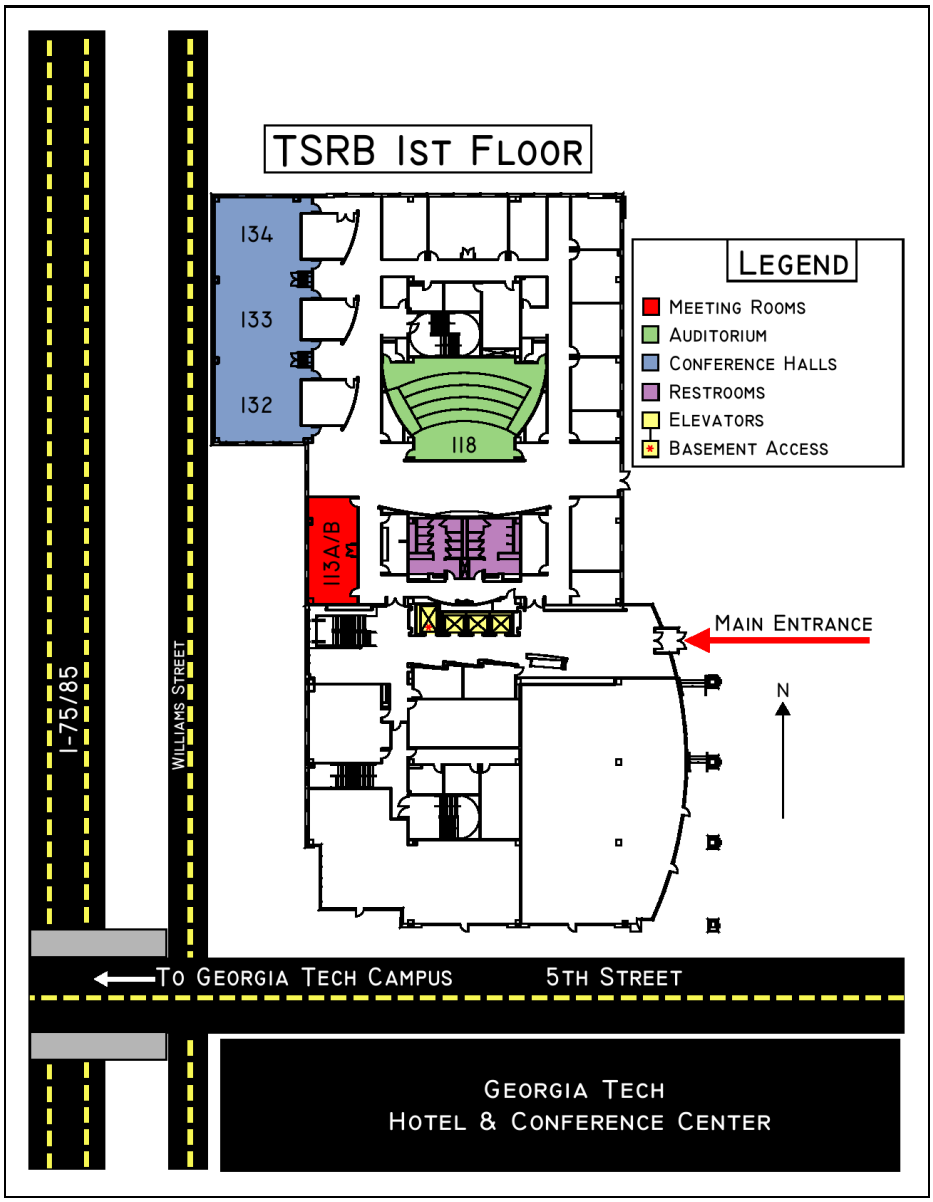


Poster Session and Lab Demonstrations

The poster presentations will be held on Wednesday, June 27 from 7:00 PM to 10:00 PM in the Technology Square Research Building (TSRB), at 85 5th Street, N.W., Atlanta GA 30308, an easy 10 minutes walk from the Fox Theatre. A map of the poster presentation facilities is shown below.

We encourage all conference attendees to complete their dinner by 7:00 pm and join us for cheeses and dessert during the poster session. We will also be serving wine, beer, and soft drinks. If you are presenting a poster, please make sure that the poster is ready by the time the poster session starts. The poster easels will be available after 6:00 pm on Wednesday. Please take down your poster at the end of the evening. If you are presenting a spotlight, your two PowerPoint slides will be pre-loaded on our conference laptop. We will be unable to switch laptops in this session - no exceptions.

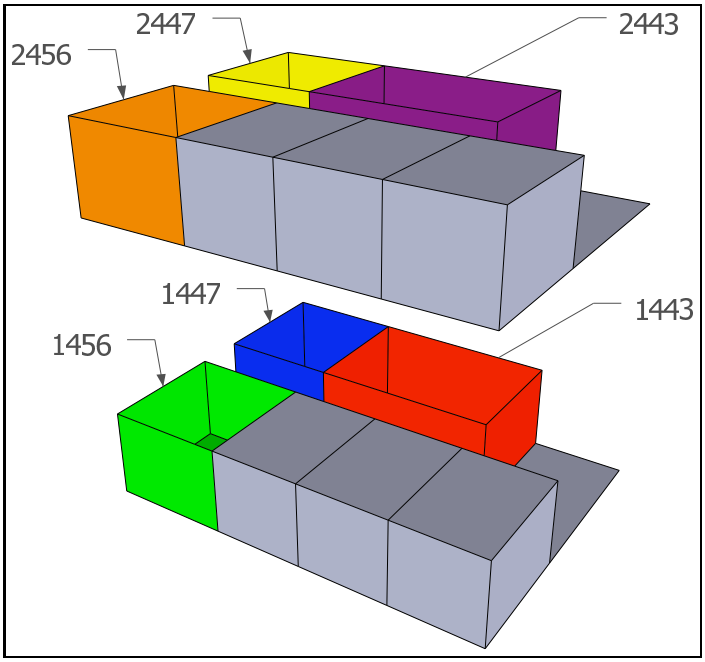
On Friday, June 29, the Robotics and Intelligent Machines (RIM) Center at Georgia Tech will organize a lab tour illustrating an array of projects that are currently under development at Georgia Tech. The demonstrations will take place at TSRB from 4:30 pm until 6:30 pm and transportation from the Fox Theatre will be provided. More information about the demos can be found in your registration packet.



Workshop Location

The workshops will be held on Saturday, June 29, at the Klaus Advanced Computing Building on the Georgia Tech campus, 266 Ferst Drive (Building 153 on the campus map). A map and a frontal view of the Klaus Advanced Computing building, the location for the workshops on Saturday June 30, this shown below.

The workshops auditoriums are at the top of the grand staircase, to your immediate right. The layout of the rooms on two different floors, along with the room numbers, is shown in the accompanying sketch.



Registration

The organizers would like to invite everyone to an informal reception in the Indigo Hotel, 683 Peachtree Street N.E., Atlanta GA 30308, on Tuesday, June 26, from 4:00 pm until 8:00 pm. During that time, a conference desk will be staffed for registration and information services at the Indigo Hotel. Payment for conference registration at that time will be accepted per credit card only.

The conference registration and information services will be available on the following schedule:

- Tuesday, June 26 4:00 pm to 8:00 pm (Indigo Hotel)
- Wednesday, June 27 7:30 am to 5:00 pm (Fox Theatre)
- Thursday, June 28 7:30 am to 5:00 pm (Fox Theatre)
- Friday, June 29 8:00AM to 5:00 pm (Fox Theatre)
- Saturday, June 30 8:00AM to 5:00 pm (Klaus Building)

The conference registration fees are

	On-site Registration
Student	$199
Regular	$449

Both regular and student registration includes attendance to the main conference oral and poster sessions, as well as one full day workshop on Saturday June 30, 2007. In addition, it includes one hardcopy of the conference proceedings (available after the conference), and one ticket for the conference banquet in the Georgia Aquarium.

Sponsors

The organizers of Robotics Science and Systems gratefully acknowledge the following conference sponsors

- AAAI
- Evolution Robotics
- Google
- Kuka
- Microsoft Research
- MIT Press
- Springer

We would like to thank all conference sponsors as their support has allowed us to keep registration and workshop fees to a minimum, particularly for graduate students.

Exhibits

Throughout Wednesday, June 26, and Thursday, June 27, the Fabulous Fox Theatre will host an array of exhibitors. The current list of exhibitors includes:

- AAAI
- Google
- Kuka
- Microsoft Research
- MIT Press
- Springer

Banquet

On Thursday, June 28, the organizers would like to invite you to a conference banquet at the Georgia Aquarium, located at 225 Baker Street, Atlanta, GA 30313. The buffet style banquet provided by Wolfgang Puck is included in the registration fee for all registrants, including students. Your badge will serve as your banquet ticket, so please ensure that you have your badge when boarding the bus. If you would like to bring additional guests to the banquet, please contact the conference desk. There is a charge of $75 per person, payable by credit card. The banquet talk will be given by Ken Goldberg, see page 41 for further details.

There will be transportation from the Indigo Hotel, the Georgia Tech Hotel and the Dorms to and from the Aquarium. Buses will depart from the respective locations starting at 6:15 pm until 7:00 pm. At the end of the evening, around 10:00 pm, buses will depart from the Aquarium and drop you off at your destination.

Dormitory Housing

In addition to the two conference hotels, we are pleased to offer dormitory accommodation in the Brown and the Harris Building on the campus of the Georgia Institute of Technology. The cost is between $35 (1 bed in a 2 bed dorm) and $45 per night (1 bedroom in a dorm suite).

Brown hall is located at 625 Techwood Dr NW (Building 7 on the campus map), whereas Harris hall is at 633 Techwood Dr NW (Building 11 on the campus map). For transportation to and from the airport, the Google map on the RSS venue page
`http://www.roboticsconference.org/venue.shtml`
gives you the exact location of both residence halls.

Check-in tables for the dormitories will be open on Tuesday, June 26 from noon until 8:00 pm, in front of Brittain Dining hall (Building 12 on the campus map). The campus map is shown below or available at:
`http://gtalumni.org/campusmap/bldngmodel.php?id=12`.
Guest arriving during other times can check in in the dormitory offices between 8:00 am and 12 pm on Tuesday, and between 8:00 am and 5:00 pm on other days. The Office of Conference Services is located at 871 McMillan St. (Building 105 on the campus map) which is located in the Commander Commons building on West campus. See map below or at:
`http://gtalumni.org/campusmap/bldngmodel.php?id=105`

Internet Access

Complementary high speed Internet access is available in the rooms in the Indigo Hotel and the Georgia Tech Hotel. During the conference, there will be Internet access in the Fox Theatre. The same holds for the poster session.
Internet access will also be available in the dorm rooms, but you will have to provide your own CAT 5 cable to connect your laptop.

Lunch and Dinner Breaks

The conference will provide coffee and tea services at the beginning of every day as well as one morning and one afternoon coffee break. In addition, the afternoon coffee break will include an afternoon snack. We therefore encourage all attendees to plan accordingly taking into account the technical schedule of events. Atlanta has a stellar variety in restaurants, affordable, expensive and everywhere in between. We listed a few of our favorites for lunch and dinner. Please also consult the restaurant pages of http://www.accessatlanta.com/restaurants for more tips and reviews.

Lunch & Dinner

- Babs (breakfast/lunch). 814 Juniper Street $
- Baraonda (designer pizza). 710 Peachtree Street. 404-879-9962 $$
- Eno Restaurant and Wine Bar (Mediterranean). 800 Peachtree Street. 404-685-3191 $$$
- F2O (salads) 674 Myrtle Street $
- 5th Street Ribs & Blues (BBQ). 86 5th Street, N.W. 404-249-8808 $
- Fune Sushi Bar. 860 Peachtree Street at 7th. 404-541-9322 $$
- Gladys Knight (Southern/soul food). 529 Peachtree Street. 404-874-9393 $$
- Little Azio's (pizza). 903 Peachtree Street. 404 -876-7711 $
- Papi's East Cuban Cuisine. 216 Ponce de Leon Avenue N.E. 404-607-1525 $
- Pleasant Peasant. (French Bistro) 555 Peachtree Street, N.E. 404-874-3223 $$$
- St. Charles Deli. 22 5th Street. 404-249-7733 $
- The Globe (eclectic bistro). 75 5th Street N.E. 404-541-1487 $$
- The Spotted Dog (burgers/salads) 30 North Aevenue. N.W. 404-347-7337 $
- The Varsity (hotdogs/fries). 61 North Avenue. 404-881-1706 $
- Tin Drum (Thai/noodles). 88 5th Street. 404-881-1368 $
- Toast (bistro). 817 West Peachtree Street. 404-815-9243 $$
- The Vortex (brewpub). 878 Peachtree. 404-875-1667 $

Dinner

- Nan Thai. 1350 Spring Street. 404870-9933 $$$
- Fuego Cafe and Tapas Bar. 1136 Cresent Avenue. 404-389-0660 $$
- Nikiemoto's (sushi/fusion). 990 Piedmont Avenue. 404-892-4111 $$
- The Flying Bisquit (Indigo Girls). 1001 Piedmont Avenue. 404-874-8887 $$
- Las Palmeras (Cuban). 368 5th Street N.E. 404-872-0846 $$

- MF Sushi Bar. 265 Ponce de Leon. 404-541-9997 $$
- Rare (tapas). 554 Piedmont Avenue. 404-870-8707 $$
- Trois (French). 1180 Peachtree Street. 404815-3337 $$

ATLANTA'S FINEST

- Bacchanalia (THE Best). 1198 Howell Mill Road. 404-365-0410 $$$$
- Table 1280. 1280 Peachtree Street (High Museum). 404-987-1280$$$
- Tierra. 1425 Piedmont Avenue. 404-874-5951 $$$
- Ecco. 40 7th Street. 404-347-5951 $$$
- Joel. 3290 Northside Parkway. 404-233-3500 $$$
- Lobby at 12. 361 17th Street. 404-961-7370 $$$

Vegetarian

- Cafe Sunflower. 2140 Peachtree Rd. N.W. 404-352-8859 $$
- Dressed. 950 W. Peachtree St. 404-347-3434 $
- Green Sprout. 1520 Piedmont Avenue. 404-874-7373 $
- Olive Bistro. 650 Ponce de Leon (Greek/Mediterranean). 404-874-5336 $
- R. Thomas Deluxe Grill. 1812 Peachtree Road. 404-881-0246 $

Transportation

Arriving form the Airport: Taxies to Midtown cost a flat fee of $32. The easiest way to get from the airport to the hotels is to take MARTA, Atlanta's public transit system. The fare is $1.75, with a one-time surcharge of $.50 for a rechargeable ticket.

- **To Indigo Hotel:**
  - Board the Northbound MARTA train at Hartsfield-Jackson Airport.
  - Get off at the North Avenue station (no changeover necessary).
  - Exit the station on the North Avenue / Peachtree St. side.
  - Walk north one block on Peachtree St.
- **To Georgia Tech Hotel and /Dormitories:**
  - Board the Northbound MARTA train at Hartsfield-Jackson Airport.
  - Get off at the Midtown station (no changeover necessary).
  - Exit the station on the Peachtree Place side. Either turn right on Peachtree Place, then left on West Peachtree St., and walk South three blocks to 5th St., or wait for the Tech Trolley just outside the Peachtree Place station exit. It will stop in the GT Hotel courtyard and the dormitories.

About Atlanta

Overview: Atlanta is the capital of the state of Georgia, and the central city of the ninth most populous metropolitan area in the United States, with a population of 5,478,667. In the last decade, the Atlanta area added over 1,150,000 residents and is recognized as one of the driving forces of the ”New South”. During the Civil Rights Movement, Atlanta stood apart from Southern cities that supported segregation, touting itself as the ”City Too Busy to Hate.” The city’s progressive civil rights record made it increasingly popular as a relocation destination for African Americans, who became the dominant political force in the city; since 1974, all of the mayors of Atlanta have been African-American. The city is divided in three parts: Downtown, the traditional commercial center of Atlanta; Midtown, up and coming commercial and residential area; and Buckhead, the financial district.

Museums: Atlanta hosts a variety of museums. Prominent among them are sites honoring Atlanta’s participation in the civil rights movement. Reverend Dr. Martin Luther King, Jr. was born in the city, and his boyhood home on Auburn Avenue in the Sweet Auburn district is preserved as the Martin Luther King, Jr. National Historic Site. Other history museums and attractions include the Atlanta History Center; the Atlanta Cyclorama and Civil War Museum; the Carter Center and Presidential Library; and the Margaret Mitchell House and Museum.The arts are represented by several theaters and museums, including the Fox Theatre. The High Museum of Art is the city’s major fine/visual arts venue, with a significant permanent collection and an assortment of traveling exhibitions. Atlanta features the world’s largest aquarium, the Georgia Aquarium, which features over 100,000 specimens in tanks holding approximately eight million gallons of water. A unique museum is the World of Coca-Cola featuring the history of the world famous soft drink brand and its well-known advertising. Next door is the CNN building, where tours are organized to show the inner workings of a cable news station. While not a museum per se, The Varsity is the main branch of the long-lived fast food chain, featured as the world’s largest drive-in restaurant.

Parks: The heart of the city is Piedmont Park, with Ultimate Frisbee meet-ups on Saturdays around 10:30 am, and the Atlanta Botanical Gardens. Just east of the city, Stone Mountain is the largest piece of exposed granite in the world. On its face are giant carvings of Jefferson Davis, Robert E. Lee, and Stonewall Jackson. It is also the site of impressive laser shows in the summer.

Technical Program

Technical Program At-A-Glance

Location: Fox Theater, Egyptian Ballroom

Wednesday, June 27	
8:45-9:00	Opening Remarks
9:00-10:20	Session I
9:00-9:55	**Invited Talk** Shree Nayar, Columbia University
11:00-12:15	Session II
12:15-1:40	Lunch
1:40-3:45	Session III
1:40-2:25	**Invited Talk** Arthur Horwich, Yale University
3:25-3:45	**Poster Spotlights 1**
4:25-5:15	Session IV
5:15-5:35	**Poster Spotlights 2**
7:00-10:00	**Poster Session – located in the Technology Square Research Building (TSRB)**

Location: Fox Theater, Egyptian Ballroom

Thursday, June 28	
9:00-10:20	Session V
9:00-9:55	**Invited Talk** Atsushi Iriki, Riken Brain Science Institute
10:55-12:10	Session VI
12:10-1:30	Lunch
1:30-3:15	Session VII
1:30-2:25	**Invited Talk** Daniel Wolpert, University of Cambridge
3:50-5:30	Session VIII
7:00-10:00	**Conference Banquet**

Location: Fox Theater, Egyptian Ballroom

Friday, June 29

9:00-10:20	Session IX
9:00-9:55	**Invited Talk** Mathieu Desbrun, California Institute of Technology
11:00-12:10	Session X
11:00-11:35	**Early Career Spotlight** Noah J. Cowan, Johns Hopkins University
11:35-12:10	**Early Career Spotlight** Hod Lipson, Cornell University
12:10-1:35	Lunch
1:35-3:15	Session XI
3:15-3:25	Closing and Award Ceremony
4:30-6:30	**Lab Tours – located the Technology Square Research Building (TSRB)**

Location: Klaus Advanced Computing Building

Saturday, June 30

9:00-6:00	Workshops

Technical Sessions: Wednesday, June 27, AM

Fox Theatre, Egyptian Ballroom

8:45 Opening Remarks

Session I (Session Chair: Henrik I. Christensen)

9:00 **Invited Talk**
Computational Cameras: Redefining the Image
Shree Nayar, Columbia University
Abstract: see page 25

9:55 P01: Semantic Modeling of Places using Objects
Ananth Ranganathan, Frank Dellaert
Abstract: see page 25

10:20 **Coffee Break**

Session II (Session Chair: Roland Siegwart)

11:00 P02: Design of a Bio-inspired Dynamical Vertical Climbing Robot
Jonathan Clark, Daniel Goldman, Pei-Chun Lin, Goran Lynch, Tao Chen, Haldun Komsuoglu, Robert Full, Daniel Koditschek
Abstract: see page 26

11:25 P03: Online Learning for Offroad Robots: Using Spatial Label Propagation to Learn Long-Range Traversability
Raia Hadsell, Pierre Sermanet, Jan Ben, Ayse Erkan, Jeff Han, Beat Flepp, Urs Muller, Yann LeCun
Abstract: see page 26

11:50 P04: Composition of Vector Fields for Multi-Robot Manipulation via Caging
Jonathan Fink, Nathan Michael, Vijay Kumar
Abstract: see page 27

12:15 **Lunch**

Technical Sessions: Wednesday, June 27, PM

Fox Theatre, Egyptian Ballroom

Session III (Session Chair: Oliver Brock)

1:40 **Invited Talk**
GroEL - A Protein Folding Machine
Arthur Horwich, Yale University
Abstract: see page 27

2:35 P05: Closed Loop Control of a Gravity-assisted Underactuated Snake Robot with Application to Aircraft Wing-Box Assembly
Binayak Roy, Harry Asada
Abstract: see page 28

3:00 P06: Predicting Partial Paths from Planning Problem Parameters
Sarah Finney, Leslie Kaelbling, Tomas Lozano-Perez
Abstract: see page 28

3:25 **Poster Spotlights 1 (P07-P15)**
See page 18

3:45 **Coffee Break**

Session IV (Session Chair: Dieter Fox)

4:25 P16: Map-Based Precision Vehicle Localization in Urban Environments
Jesse Levinson, Michael Montemerlo, Sebastian Thrun
Abstract: see page 32

4:50 P17: Dense Mapping for telemetric sensors: efficient algorithms and sparse representation
Manuel Yguel, Christopher Tay Meng Keat, Christophe Braillon, Christian Laugier, Olivier Aycard
Abstract: see page 32

5:15 **Poster Spotlights 2 (P18-P26)**
See page 19

5:35 Dinner (no planned activity)

Poster Session: Wednesday, June 27, 7:00-10:00

Technology Square Research Building (TSRB)

Poster Session

7:00-10:00

P07: Emergent Task Allocation for Mobile Robots
Nuzhet Atay, Burchan Bayazit
Abstract: see page 29

P08: Passivity-Based Switching Control for Stabilization of Wheeled Mobile Robots
Dongjun Lee
Abstract: see page 29

P09: A Tree Parameterization for Efficiently Computing Maximum Likelihood Maps using Gradient Descent
Giorgio Grisetti, Cyrill Stachniss, Slawomir Grzonka, Wolfram Burgard
Abstract: see page 29

P10: Spatially-Adaptive Learning Rates for Online Incremental SLAM
Edwin Olson, John Leonard, Seth Teller
Abstract: see page 30

P11: Adaptive Non-Stationary Kernel Regression for Terrain Modeling
Tobias Lang, Christian Plagemann, Wolfram Burgard
Abstract: see page 30

P12: Fishbone Model for Belt Object Deformation
Hidefumi Wakamatsu, Eiji Arai, Shinichi Hirai
Abstract: see page 30

P13: Context and Feature Sensitive Re-sampling from Discrete Surface Measurements
Dave Cole, Paul Newman
Abstract: see page 31

P14: Simultaneous Localisation and Mapping in Dynamic Environments (SLAMIDE) with Reversible Data Association
Charles Bibby, Ian Reid
Abstract: see page 31

P15: Sliding mode formation tracking control of a tractor and trailer-car system
Fabio Morbidi, Domenico Prattichizzo
Abstract: see page 31

Poster Session (cont.)

Technology Square Research Building (TSRB)

Poster Session (cont.)

7:00-10:00

P18: Gaussian Beam Processes: A Nonparametric Bayesian Measurement Model for Range Finders
Christian Plagemann, Kristian Kersting, Patrick Pfaff, Wolfram Burgard
Abstract: see page 33

P19: Vision-Aided Inertial Navigation for Precise Planetary Landing: Analysis and Experiments
Anastasios Mourikis, Nikolas Trawny, Stergios Roumeliotis, Andrew Johnson, Larry Matthies
Abstract: see page 33

P20: Optimal Kinodynamic Motion Planning for 2D Reconfiguration of Self-Reconfigurable Robots
John Reif, Sam Slee
Abstract: see page 33

P21: A Discrete Geometric Optimal Control Framework for Systems with Symmetries
Marin Kobilarov, Mathieu Desbrun, Jerrold Marsden, Gaurav Sukhatme
Abstract: see page 34

P22: BS-SLAM: Shaping the World
Luis Pedraza, Gamini Dissanayake, Jaime Valls Miro, Diego Rodriguez-Losada, Fernando Matia
Abstract: see page 34

P23: An Implicit Time-Stepping Method for Multibody Systems with Intermittent Contact
Nilanjan Chakraborty, Stephen Berard, Srinivas Akella, Jeff Trinkle
Abstract: see page 34

P24: Synthesis of Constrained nR Planar Robots to Reach Five Task Positions
Gim Song Soh, J. Michael McCarthy
Abstract: see page 35

P25: Automatic Scheduling for Parallel Forward Dynamics Computation of Open Kinematic Chains
Katsu Yamane, Yoshihiko Nakamura
Abstract: see page 35

P26: CRF-Matching: Conditional Random Fields for Feature-Based Scan Matching
Fabio Ramos, Dieter Fox, Hugh Durrant-Whyte
Abstract: see page 35

Technical Sessions: Thursday, June 28, AM

Fox Theatre, Egyptian Ballroom

Session V (Session Chair: Maren Bennewitz)

9:00 **Invited Talk**
Latent Precursors of Human Intelligence in Monkey Tool Use Actions
Atsushi Iriki, Riken Brain Science Institute
Abstract: see page 36

9:55 P27: Control of Many Agents Using Few Instructions
Timothy Bretl
Abstract: see page 36

10:20 **Coffee Break**

Session VI (Session Chair: Nancy Amato)

10:55 P28: Safety Evaluation of Physical Human-Robot Interaction via Crash-Testing
Sami Haddadin, Alin Albu-Schffer, Gerd Hirzinger
Abstract: see page 37

11:20 P29: Dimensionality reduction using automatic supervision for vision-based terrain learning
Anelia Angelova, Larry Matthies, Daniel Helmick, Pietro Perona
Abstract: see page 37

11:45 P30: The Stochastic Motion Roadmap: A Sampling Framework for Planning with Markov Motion Uncertainty
Ron Alterovitz, Thierry Simeon, Ken Goldberg
Abstract: see page 38

12:10 **Lunch**

Technical Sessions: Thursday, June 28, PM

Fox Theatre, Egyptian Ballroom

Session VII (Session Chair: Vijay Kumar)

1:30 **Invited Talk**
Probabilistic Models of Human Sensorimotor Control
Daniel Wolpert, University of Cambridge
Abstract: see page 38

2:25 P31: A Fundamental Tradeoff between Performance and Sensitivity within Haptic Rendering
Paul Griffiths, Brent Gillespie, Jim Freudenberg
Abstract: see page 39

2:50 P32: Motion Strategies for Surveillance
Sourabh Bhattacharya, Salvatore Candido, Seth Hutchinson
Abstract: see page 39

3:15 **Coffee Break**

Session VIII (Session Chair: Cyrill Stachniss)

3:50 P33: Learning omnidirectional path following using dimensionality reduction
J. Zico Kolter, Andrew Ng
Abstract: see page 39

4:15 P34: A Fast and Practical Algorithm for Generalized Penetration Depth Computation
Liangjun Zhang, Young J. Kim, Dinesh Manocha
Abstract: see page 40

4:40 P35: Planning and Control of Meso-scale Manipulation Tasks with Uncertainties
Peng Cheng, Bogdan Gavrea, David Cappelleri, Vijay Kumar
Abstract: see page 40

5:05 P36: Data Association in O(n) for Divide and Conquer SLAM
Lina Maria Paz, Jose Guivant, Juan Tardos, Jose Neira
Abstract: see page 40

5:30 End of the technial program

7:00 **Banquet**
The banquet talk will be given by Ken Goldberg
Abstract: see page 41

Technical Sessions: Friday, June 29, AM

Fox Theatre, Egyptian Ballroom

Session IX (Session Chair: Gaurav Sukhatme)

9:00 **Invited Talk**
Calculus Ex Geometrica: Structure-Preserving Computational Foundations for Graphics and Simulation
Mathieu Desbrun, California Institute of Technology
Abstract: see page 41

9:55 P37: An experimental study of exploiting multipath fading for robot communications
Magnus Lindhé, Karl Henrik Johansson, Antonio Bicchi
Abstract: see page 42

10:20 **Coffee Break**

Session X (Session Chair: Sebastian Thrun)

11:00 **Early Career Spotlight**
Earky CareSensorimotor Integration in Robots and Animals: Signals, Geometry and Mechanics
Noah J. Cowan, Johns Hopkins University
Abstract: see page 42

11:35 **Early Career Spotlight**
Morphological and Behavioral Adaptation in Robotics
Hod Lipson, Cornell University
Abstract: see page 43

12:15 **Lunch**

Technical Program: Friday, June 29, PM

Fox Theatre, Egyptian Ballroom

Session XI (Session Chair: Lydia E. Kavraki)

1:35 P38: Mapping Large Loops with a Single Hand-Held Camera
Laura A. Clemente, Andrew Davison, Ian Reid, José Neira, Juan Tardos
Abstract: see page 43

2:00 P39: Dynamic Coverage Verification in Mobile Sensor Networks Via Switched Higher Order Laplacians
Abubakr Muhammad, Ali Jadbabaie
Abstract: see page 44

2:25 P40: Discrete Search Leading Continuous Exploration for Kinodynamic Motion Planning
Erion Plaku, Lydia E. Kavraki, Moshe Y. Vardi
Abstract: see page 44

2:50 P41: Active Policy Learning for Robot Planning and Exploration under Uncertainty
Ruben Martinez-Cantin, Nando de Freitas, Arnaud Doucet, Jose Castellanos
Abstract: see page 45

3:15 **Closing and Award Ceremony**

3:25 End of the technical program

4:30 **Lab Tours**
The demonstrations will take place at the Technology Square Research Building (TSRB) and transportation from the Fox Theatre will be provided. More information about the demos can be found in your registration packet.

6:30 End

Workshop Program: Saturday, June 30

W1 Robot Manipulation: Sensing and Adapting to the Real World

9:00 am - 6:00 pm, Klaus Advanced Computing Building, room 2443
Charles C. Kemp (Georgia Tech), Aaron Edsinger (MIT), Robert Platt (NASA JSC), Neo Ee Sian (AIST)
See page 46

W2 Robotic Sensor Networks: Principles and Practice

8:30 am - 4:00 pm, Klaus Advanced Computing Building, room 2456
Gaurav Sukhatme (USC), Wolfram Burgard (University of Freiburg)
See page 47

W3 Algorithmic Equivalences Between Biological and Robotic Swarms

9:00 am - 6:00 pm, Klaus Advanced Computing Building, room 1456
James McLurkin (MIT), Paulina Varshavskaya (MIT)
See page 48

W4 Embodied Agents for Disaster Mitigation

CANCELLED

W5 Research in Robots for Education

9:00 am - 6:00 pm, Klaus Advanced Computing Building, room 1447
Doug Blank (Bryn Mawr College), Maria Hybinette (University of Georgia), Keith O'Hara (Georgia Tech), Daniela Rus (MIT)
See page 49

W6 Interfaces, devices and methods for robots adapted to Small and Medium Enterprises

CANCELLED

T1 Tutorial: Microsoft Robotics Studio (MSRS)- A Technical Introduction

9:00 am - 10:30 am, Klaus Advanced Computing Building, room 1443
Stewart Tansley (Microsoft), Steve Sklepowich (Microsoft)
See page 50

Abstracts

Technial Session I, Wednesday, June 27, AM

Invited Talk: ***Computational Cameras: Redefining the Image***

Shree K. Nayar, Columbia University

Abstract: In this talk, we will first present the concept of a computational camera. It is a device that embodies the convergence of the camera and the computer. It uses new optics to select rays from the scene in unusual ways, and an appropriate algorithm to process the selected rays. This ability to manipulate images before they are recorded and process the recorded images before they are presented is a powerful one. It enables us to experience our visual world in rich and compelling ways. We will show computational cameras that can capture wide angle, high dynamic range, multispectral, and depth images. Finally, we will explore the use of a programmable light source as a more sophisticated camera flash. We will show how the use of such a flash enables a camera to produce images that reveal the complex interactions of light within objects as well as between them.

Biography: Shree K. Nayar received his PhD degree in Electrical and Computer Engineering from the Robotics Institute at Carnegie Mellon University in 1990. He is currently the T. C. Chang Professor of Computer Science at Columbia University. He co-directs the Columbia Vision and Graphics Center. He also heads the Columbia Computer Vision Laboratory (CAVE), which is dedicated to the development of advanced computer vision systems. His research is focused on three areas; the creation of novel cameras, the design of physics based models for vision, and the development of algorithms for scene understanding. His work is motivated by applications in the fields of digital imaging, computer graphics, and robotics.

Schedule: see page 16.

P01: *Semantic Modeling of Places using Objects*

Ananth Ranganathan, Frank Dellaert

Abstract: While robot mapping has seen massive strides recently, higher level abstractions in map representation are still not widespread. Maps containing semantic concepts such as objects and labels are essential for many tasks in manmade environments as well as for human-robot interaction and map communication. In keeping with this aim, we present a model for places using objects as the basic unit of representation. Our model is a 3D extension of the constellation object model, popular in computer vision, in which the objects are modeled by their appearance and shape. The 3D location of each object is maintained in a coordinate frame local to the place. The individual object models are learned in a supervised manner using roughly segmented and labeled training images. Stereo range data is used to compute 3D locations of the objects. We use the Swendsen-Wang algorithm, a cluster MCMC method, to solve the correspondence problem between image features and objects during inference. We provide a technique for building panoramic place models from multiple views of a location. An algorithm for place recognition by comparing models is also provided. Results are presented in the form of place models inferred in an indoor environment.We envision the use of our place model as a building block towards a complete object-based semantic mapping system.

Schedule: see page 16.

Technial Session II, Wednesday, June 27, AM

P02: *Design of a Bio-inspired Dynamical Vertical Climbing Robot*

Jonathan Clark, Daniel Goldman, Pei-Chun Lin, Goran Lynch, Tao Chen, Haldun Komsuoglu, Robert Full, Daniel Koditschek

Abstract: This paper reviews a template for dynamic climbing originating in biology, explores its hypothetical utility, and offers a preliminary look at empirical data bearing on the feasibility of adapting it to build a robot that runs vertically upward. The recently proposed pendulous climbing model abstracts remarkable similarities in dynamic wall scaling behavior exhibited by radically different animal species. The present paper's first contribution summarizes a continuing numerical study of this model to hypothesize that these animals' apparently wasteful commitments to lateral oscillations may be justified by a significant gain in the dynamic stability and, hence, the robustness of their resulting climbing capability. We explore numerically a scaled version of this template devised to inform the design of a physically realizable robotic mechanism with the same climbing behavior. The paper's second contribution documents the design and offers very preliminary empirical data arising from a physical instantiation of this model. Notwithstanding the significant differences between the proposed bio-inspired template and its physical robot model, these initial data suggest the mechanical climber may be capable of roughly reproducing both the motions and ground reaction forces characteristic of dynamic climbing animals. Even without proper tuning the robot's steady state trajectories manifest a substantial exchange of kinetic and potential energy, resulting in vertical speeds of 0.14 m/s (0.35 bl/s) and claiming its place as the first bio-inspired dynamical legged climbing platform.

Schedule: see page 16.

P03: *Online Learning for Offroad Robots: Spatial Label Propagation to Learn Long-Range Traversability*

Raia Hadsell, Pierre Sermanet, Jan Ben, Ayse Erkan, Jeff Han, Beat Flepp, Urs Muller, Yann LeCun

Abstract: We present a solution to the problem of long-range obstacle/path recognition in autonomous robots. The system uses sparse traversability information from a stereo module to train a classifier online. The trained classifier can then predict the traversability of the entire scene. A distance-normalized image pyramid makes it possible to efficiently train on each frame seen by the robot, using large windows that contain contextual information as well as shape, color, and texture. Traversability labels are initially obtained for each target using a stereo module, then propagated to other views of the same target using temporal and spatial concurrences, thus training the classifier to be view-invariant. A ring buffer simulates short-term memory and ensures that the discriminative learning is balanced and consistent. This long-range obstacle detection system sees obstacles and paths at 30-40 meters, far beyond the maximum stereo range of 12 meters, and adapts very quickly to new environments. Experiments were run on the LAGR robot platform.

Schedule: see page 16.

P04: *Composition of Vector Fields for Multi-Robot Manipulation via Caging*

Jonathan Fink, Nathan Michael, Vijay Kumar

Abstract: This paper describes a novel approach for multi-robot caging and manipulation, which relies on the team of robots forming patterns that trap the object to be manipulated and dragging or pushing the object to the goal configuration. The controllers are obtained by sequential composition of vector fields or behaviors and enable decentralized computation based only on local information. Further, the control

software for each robot is identical and relies on very simple behaviors. We present our experimental multi-robot system and simulation and experimental results that demonstrate the robustness of this approach.

Schedule: see page 16.

Technial Session III, Wednesday, June 27, PM

Invited Talk: ***GroEL - A Protein Folding Machine***

Art Horwich, Yale University

Abstract: A host of cellular systems employ molecular machines to carry out specific work, comprising nano-scaled robotics systems. We have been studying one such machine, called a chaperonin, that has the remarkable ability to mediate protein folding in the cell, the final step of information transfer from DNA to effector protein. We have been studying the bacterial chaperonin, GroEL, a double ring machine, whose minimal functional unit, a ring, is comprised of 7 identically-behaving subunits. A ring operates in successive states whose forward progress is directed, as in many other molecular machines, by the binding and hydrolysis of ATP: an open ring, with a hydrophobic lining, captures a non-folded protein via its exposure of hydrophobic surfaces, and then, after binding 7 ATP and a lid-like cochaperonin called GroES, functions as an encapsulated closed now-hydrophilic folding chamber that mediates productive protein folding. The timing of this folding step, the longest step of the reaction cycle, is governed by ATP hydrolysis, whose occurrence discharges the folding-active ring. The ”working parts” of the chaperonin rings are its subunits, each composed of two major domains, a so-called apical domain able to bind polypeptide via exposed hydrophobic surface, and an equatorial domain, able to bind and hydrolyze ATP. These two domains are attached to each other through a smaller intermediate domain, hinged at both its top and bottom aspect to allow rigid body movements of the apical domains on what is a stable collective of 7 equatorial domains that form the ”base” of the machine. Nature has thus employed this simple subunit architecture, fundamentally enabling ATP-driven rigid body movement, 60 elevation and 90 twist of the apical domains relative to the equatorial domains, to assure that proteins can properly fold.

Biography: Arthur Horwich trained in pediatric medicine but became interested in the power of genetics and biochemistry to inform about biological systems. He studied a lethal inherited human disease affecting a mitochondrial enzyme and this led him to study its biogenesis, involving transport of the newly-synthesized enzyme subunit across the mitochondrial membranes. During such studies in a yeast system, his group stumbled across a specialized protein, a large double ring ”machine” called a chaperonin, found to be required for proper folding of proteins. Chaperonins turn out to be present ubiquitously, mediating the folding of a large number of newly-synthesized proteins in all three kingdoms of life. Using a series of studies including biochemical reconstitution, electron microscopy, and X-ray crystallography, it has been possible to deduce a reaction cycle of the bacterial chaperonin machine, GroEL, in which steps of ATP binding and hydrolysis provide the energy to drive large movements in the machine between states that effect distinct steps of capturing non-native polypeptide in an open ring, productively folding it to its native state inside the machine, and then releasing it.

Schedule: see page 17.

P05: *Closed Loop Control of a Gravity-assisted Underactuated Snake Robot with Application to Aircraft Wing-Box Assembly*

Binayak Roy, Harry Asada

Abstract: Stable, nonlinear closed-loop control of a gravity-assisted underactuated robot arm with 2nd order non-holonomic constraints is presented in this paper. The joints of the hyper articulated arm have no dedicated actuators, but are activated with gravity. By tilting the base link appropriately, the gravitational torque drives the unactuated links to a desired angular position. With simple locking mechanisms, the hyper articulated arm can change its configuration using only one actuator at the base. This underactuated arm design was motivated by the need for a compact snake-like robot that can go into aircraft wings and perform assembly operations using heavy end-effecters. The dynamics of the unactuated links are essentially 2nd order nonholonomic constraints, for which there are no general methods for designing closed loop control. We propose an algorithm for positioning the links of an n-link robot arm inside an aircraft wing-box. This is accomplished by sequentially applying a closed loop point-to-point control scheme to the unactuated links. We synthesize a Lyapunov function to prove the convergence of this control scheme. The Lyapunov function also provides us with lower bounds on the domain of convergence of the control law. The control algorithm is implemented on a prototype 3- link system. Finally, we provide some experimental results to demonstrate the efficacy of the control scheme.

Schedule: see page 17.

Poster Session (P07-P15), Wednesday, June 27, PM

P06: *Predicting Partial Paths from Planning Problem Parameters*

Sarah Finney, Leslie Kaelbling, Tomas Lozano-Perez

Abstract: Many robot motion planning problems can be described as a combination of motion through relatively sparsely filled regions of configuration space and motion through tighter passages. Sample-based planners perform very effectively everywhere but in the tight passages. In this paper, we provide a method for parametrically describing workspace arrangements that are difficult for planners, and then learning a function that proposes partial paths through them as a function of the parameters. These suggested partial paths are then used to significantly speed up planning for new problems.

Schedule: see page 17.

P07: *Emergent Task Allocation for Mobile Robots*

Nuzhet Atay, Burchan Bayazit

Abstract: Multi-robot systems require efficient and accurate planning in order to perform mission-critical tasks. However, algorithms that find the optimal solution are usually computationally expensive and may require a large number of messages between the robots as the robots need to be aware of the global spatiotemporal information. In this paper, we introduce an emergent task allocation approach for mobile robots. Each robot uses only the information obtained from its immediate neighbors in its decision. Our technique is general enough to be applicable to any task allocation scheme as long as a utilization criteria is given. We demonstrate that our approach performs similar to the integer linear programming technique which finds the global optimal solution at the fraction of its cost. The tasks we are interested in are detecting and con-

trolling multiple regions of interest in an unknown environment in the presence of obstacles and intrinsic constraints. The objective function contains four basic requirements of a multi-robot system serving this purpose: control regions of interest, provide communication between robots, control maximum area and detect regions of interest. Our solution determines optimal locations of the robots to maximize the objective function for small problem instances while efficiently satisfying some constraints such as avoiding obstacles and staying within the speed capabilities of the robots, and finds an approximation to global optimal solution by correlating solutions of small problems.

Schedule: see page 18.

P08: *Passivity-Based Switching Control for Stabilization of Wheeled Mobile Robots*

Dongjun Lee

Abstract: We propose a novel switching control law for the posture stabilization of a wheeled mobile robot, that utilizes the (energetic) passivity of the system's open-loop dynamics with non-negligible inertial effects. The proposed passivity-based switching control law ensures that the robot's (x, y)-position enters into an arbitrarily small (as specified by user-designed error-bound) level set of a certain navigation potential function defined on the (x, y)-plane, and that its orientation converges to a target angle. Under this passivity-based switching control, the robot moves back and forth between two submanifolds in such a way that the navigation potential function is strictly decreasing during this inter-switching move. Once the system's (x, y)-trajectory enters such a desired level set, at most, only one more switching occurs to correct orientation. Simulation is performed to validate/highlight properties of the presented switching control law.

Schedule: see page 18.

P09: *A Tree Parameterization for Efficiently Computing Maximum Likelihood Maps using Gradient Descent*

Giorgio Grisetti, Cyrill Stachniss, Slawomir Grzonka, Wolfram Burgard

Abstract: In 2006, Olson et al. presented a novel approach to address the graph-based simultaneous localization and mapping problem by applying stochastic gradient descent to minimize the error introduced by constraints. Together with multi-level relaxation, this is one of the most robust and efficient maximum likelihood techniques published so far. In this paper, we present an extension of Olson's algorithm. It applies a novel parameterization of the nodes in the graph that significantly improves the performance and enables us to cope with arbitrary network topologies. The latter allows us to bound the complexity of the algorithm to the size of the mapped area and not to the length of the trajectory as it is the case with both previous approaches. We implemented our technique and compared it to multi-level relaxation and Olson's algorithm. As we demonstrate in simulated and in real world experiments, our approach converges faster than the other approaches and yields accurate maps of the environment.

Schedule: see page 18.

P10: *Spatially-Adaptive Learning Rates for Online Incremental SLAM*

Edwin Olson, John Leonard, Seth Teller

Abstract: Several recent algorithms have formulated the SLAM problem in terms of non-linear pose graph optimization. These algorithms are attractive because they offer lower computational and memory costs than the traditional Extended Kalman Filter (EKF), while simultaneously avoiding the linearization error problems that affect EKFs. In this paper, we present a new non-linear SLAM algorithm that allows incremental optimization of pose graphs, i.e., allows new poses and constraints to be added without requiring the solution to be recomputed from scratch. Our approach builds upon an existing batch algorithm that combines stochastic gradient descent and an incremental state representation. We develop an incremental algorithm by adding a spatially-adaptive learning rate, and a technique for reducing computational requirements by restricting optimization to only the most volatile portions of the graph. We demonstrate our algorithms on real datasets, and compare against other online algorithms.

Schedule: see page 18.

P11: *Adaptive Non-Stationary Kernel Regression for Terrain Modeling*

Tobias Lang, Christian Plagemann, Wolfram Burgard

Abstract: Three-dimensional digital terrain models are of fundamental importance in many areas such as the geo-sciences and outdoor robotics. Accurate modeling requires the ability to deal with a varying data density and to balance smoothing against the preservation of discontinuities. The latter is particularly important for robotics applications, as discontinuities that arise, for example, at steps, stairs, or building walls are important features for path planning or terrain segmentation tasks. In this paper, we present an extension of the well-established Gaussian process regression technique, that utilizes non-stationary covariance functions to locally adapt to the structure of the terrain data. In this way, we achieve strong smoothing in flat areas and along edges and at the same time preserve edges and corners. The derived model yields predictive height distributions for arbitrary locations of the terrain and therefore allows us to fill gaps in data and to perform conservative predictions in occluded areas.

Schedule: see page 18.

P12: *Fishbone Model for Belt Object Deformation*

Hidefumi Wakamatsu, Eiji Arai, Shinichi Hirai

Abstract: A modeling method for representing belt object deformation is proposed. Deformation of a belt object such as film circuit boards or flexible circuit boards must be estimated for automatic manipulation and assembly. In this paper, we assume that deformation of an inextensible belt object can be described by the shape of its central axis in a longitudinal direction called “the spine line” and lines with zero curvature called “rib lines”. This model is referred to as a “fishbone model” in this paper. First, we describe deformation of a rectangular belt object using differential geometry. Next, we propose the fishbone model considering characteristics of developable surface, i.e., surface without expansion or contraction. Then, we formulate potential energy of the object and constraints imposed on it. Finally, we explain a procedure to compute the deformed shape of the object and show some computational results to demonstrate the feasibility of our fishbone model.

Schedule: see page 18.

P13: *Context and Feature Sensitive Re-sampling from Discrete Surface Measurements*

Dave Cole, Paul Newman

Abstract: This paper concerns context and feature-sensitive sampling of workspace surfaces by processing 3D point clouds. We pay particular attention to working with data from 3D laser range finders. We interpret the point cloud as the outcome of repetitive and non-uniform sampling of the surfaces in the workspace. The nature of this sampling may not be ideal for all applications, representations and downstream processing. For example it might be preferable to have a high point density around sharp edges or near marked changes in texture. Additionally such preferences might be dependent on the semantic classification of the surface in question. This paper addresses this issue and provides a framework which given a raw point cloud as input, produces a new point cloud by sampling from the underlying workspace surfaces. Moreover it does this in a manner which can be biased by local low-level geometric or appearance properties and higher level (semantic) classification of the surface. We are in no way prescriptive about what justifies a biasing in the sampling scheme — this is left up to the user who may encapsulate what constitutes "interesting" into one or more "policies" which are used to modulate the default sampling behavior.

Schedule: see page 18.

P14: *Simultaneous Localisation and Mapping in Dynamic Environments (SLAMIDE) with Reversible Data Association*

Charles Bibby, Ian Reid

Abstract: The conventional technique for dealing with dynamic objects in SLAM is to detect them and then either treat them as outliers or track them separately using traditional multi-target tracking. We propose a technique that combines the least-squares formulation of SLAM and sliding window optimisation together with generalised expectation maximisation, to incorporate both dynamic and stationary objects directly into SLAM estimation. The sliding window allows us to postpone the commitment of model selection and data association decisions by delaying when they are marginalised permanently into the estimate. The two main contributions of this paper are thus: (i) using reversible model selection to include dynamic objects into SLAM and (ii) incorporating reversible data association.We show empirically that (i) if dynamic objects are present our method can include them in a single framework and hence maintain a consistent estimate and (ii) our estimator remains consistent when data association is difficult, for instance in the presence of clutter. We summarise the results of detailed and extensive tests of our method against various benchmark algorithms, showing its effectiveness.

Schedule: see page 18.

P15: *Sliding mode formation tracking control of a tractor and trailer-car system*

Fabio Morbidi, Domenico Prattichizzo

Abstract: In this paper a new leader-follower formation of nonholonomic mobile robots is studied. The follower is a car-like vehicle and the leader is a tractor pulling a trailer. The leader moves along assigned trajectories and the follower is to maintain a desired distance and orientation to the trailer. A sliding mode control scheme is proposed for asymptotically stabilizing the vehicles to a time-varying desired formation. The attitude angles of the follower and the tractor are estimated via global exponential observers based on the invariant manifold technique. Simulation experiments illustrate the theory and show the effectiveness of the proposed formation controller and nonlinear observers.

Schedule: see page 18.

Technical Session, Wednesday, June 27, PM

P16: *Map-Based Precision Vehicle Localization in Urban Environments*

Jesse Levinson, Michael Montemerlo, Sebastian Thrun

Abstract: Many urban navigation applications (e.g., autonomous navigation, driver assistance systems) can benefit greatly from localization with centimeter accuracy. Yet such accuracy cannot be achieved reliably with GPS-based inertial guidance systems, specifically in urban settings. We propose a technique for high-accuracy localization of moving vehicles that utilizes maps of urban environments. Our approach integrates GPS, IMU, wheel odometry, and LIDAR data acquired by an instrumented vehicle, to generate high-resolution environment maps. Offline relaxation techniques similar to recent SLAM methods [2, 10, 13, 14, 21, 30] are employed to bring the map into alignment at intersections and other regions of self-overlap. By reducing the final map to the flat road surface, imprints of other vehicles are removed. The result is a 2-D surface image of ground reflectivity in the infrared spectrum with 5cm pixel resolution. To localize a moving vehicle relative to these maps, we present a particle filter method for correlating LIDAR measurements with this map. As we show by experimentation, the resulting relative accuracies exceed that of conventional GPS-IMU-odometry-based methods by more than an order of magnitude. Specifically, we show that our algorithm is effective in urban environments, achieving reliable real-time localization with accuracy in the 10-centimeter range. Experimental results are provided for localization in GPS-denied environments, during bad weather, and in dense traffic.

Schedule: see page 17.

P17: *Dense Mapping for telemetric sensors: efficient algorithms and sparse representation*

Manuel Yguel, Christopher Tay Meng Keat, Christophe Braillon, Christian Laugier, Olivier Aycard

Abstract: This paper focuses on efficient occupancy grid building based on a sparse new grid representation: wavelet occupancy grids and a new update algorithm for telemetric sensors. The update algorithm takes advantage of the natural multiscale properties of the wavelet expansion to update only parts of the environement that are modified by the sensor measurements and at the proper scale. The sparse wavelet representation coupled with an efficient algorithm presented in this paper provides efficient and fast updating of occupancy grids. It leads to real-time results especially in 2D grids and for the first time in 3D grids. Experiments and results are discussed for both real and simulated data.

Schedule: see page 17.

Poster Session (P18-P26), Wednesday, June 27, PM

P18: *Gaussian Beam Processes: A Nonparametric Bayesian Measurement Model for Range Finders*

Christian Plagemann, Kristian Kersting, Patrick Pfaff, Wolfram Burgard

Abstract: In probabilistic mobile robotics, the development of measurement models plays a crucial role as it directly influences the efficiency and the robustness of the robots performance in a great variety of tasks including localization, tracking, and map building. In this paper, we present a novel probabilistic measurement model for range finders, called Gaussian beam processes, which treats the measurement modeling task

as a nonparametric Bayesian regression problem and solves it using Gaussian processes. The major benefit of our approach is its ability to generalize over entire range scans directly. This way, we can learn the distributions of range measurements for whole regions of the robots configuration space from only few recorded or simulated range scans. Especially in approximative approaches to state estimation like particle filtering or histogram filtering, this leads to a better approximation of the true likelihood function. Experiments on real world and synthetic data show that Gaussian beam processes combine the advantages of two popular measurement models.

Schedule: see page 19.

P19: *Vision-Aided Inertial Navigation for Precise Planetary Landing: Analysis and Experiments*

Anastasios Mourikis, Nikolas Trawny, Stergios Roumeliotis, Andrew Johnson, Larry Matthies

Abstract: In this paper, we present the analysis and experimental validation of a vision-aided inertial pose estimation algorithm for planetary landing applications. The algorithm tightly couples IMU and camera measurements of features with a priori known global coordinates (mapped landmarks), and of features tracked between images (opportunistic features), in a resource-adaptive and hence real-time capable fashion. Results from a sounding rocket test, covering the dynamic profile of typical planetary landing scenarios, show estimation errors of magnitude 0.16 m/s in velocity and 7.6 m in position at touchdown. These results vastly improve current state of the art and meet the requirements of future planetary exploration missions.

Schedule: see page 19.

P20: *Optimal Kinodynamic Motion Planning for 2D Reconfiguration of Self-Reconfigurable Robots*

John Reif, Sam Slee

Abstract: A self-reconfigurable (SR) robot is one composed of many small modules that autonomously act to change the shape and structure of the robot. In this paper we consider a general class of SR robot modules that have rectilinear shape that can be adjusted between fixed dimensions, can transmit forces to their neighbors, and can apply additional forces of unit maximum magnitude to their neighbors. We present a kinodynamically optimal algorithm for general reconfiguration between any two distinct 2D connected configurations of n SR robot modules. The algorithm uses a third dimension as workspace during reconfiguration. This entire movement is achieved within O($\sqrt{n}$) movement time in the worst case, which is the asymptotically optimal time bound. The only prior reconfiguration algorithm achieving this time bound was restricted to linearly arrayed start and finish configurations (known as the "x-axis to y-axis problem). All other prior work on SR robots assumed a constant velocity bound on module movement and so required at least time linear in n to do the reconfiguration.

Schedule: see page 19.

P21: *A Discrete Geometric Optimal Control Framework for Systems with Symmetries*

Marin Kobilarov, Mathieu Desbrun, Jerrold Marsden, Gaurav Sukhatme

Abstract: This paper studies the optimal motion control of mechanical systems through a discrete geometric approach. At the core of our formulation is a discrete Lagrange-dAlembert-Pontryagin variational principle, from which are derived discrete equations of motion that serve as constraints in our optimization framework. We apply this discrete mechanical approach to holonomic systems with symmetries and, as a result, geometric structure and motion invariants are preserved. We illustrate our method by computing

optimal trajectories for a simple model of an air vehicle flying through a digital terrain elevation map, and point out some of the numerical benefits that ensue.

Schedule: see page 19.

P22: *BS-SLAM: Shaping the World*

Luis Pedraza, Gamini Dissanayake, Jaime Valls Miro, Diego Rodriguez-Losada, Fernando Matia

Abstract: This paper presents BS-SLAM, a simultaneous localization and mapping algorithm for use in unstructured environments that is effective regardless of whether features correspond to simple geometric primitives such as points and lines or not. The coordinates of the control points defining a set of B-splines are used to form a complete and compact description of the environment, thus making it feasible to use an extended Kalman filter based SLAM algorithm. The proposed method is the first known EKF-SLAM implementation capable of describing both straight and curve features in a parametric way. Appropriate observation equation that allows the exploitation of virtually all observations from a range sensor such as the ubiquitous laser range finder is developed. Efficient strategies for computing the relevant Jacobians, perform data association, initialization and expanding the map are presented. The effectiveness of the algorithms is demonstrated using experimental data.

Schedule: see page 19.

P23: *An Implicit Time-Stepping Method for Multibody Systems with Intermittent Contact*

Nilanjan Chakraborty, Stephen Berard, Srinivas Akella, Jeff Trinkle

Abstract: In this paper we present a fully implicit time-stepping scheme for multibody systems with intermittent contact by incorporating the contact constraints as a set of complementarity and algebraic equations within the dynamics model. Two primary sources of stability and accuracy problems in time stepping schemes for differential complementarity models of multibody systems are the use of polyhedral representations of smooth bodies and the approximation of the distance function (arising from the decoupling of collision detection from the solution of the dynamic time-stepping subproblem). We illustrate this with the simple example of a disc rolling on a table without slip. We model the objects as an intersection of convex inequalities and write the contact constraints as a complementarity constraint between the contact force and a distance function dependent on the closest points on the objects. The closest points satisfy a set of algebraic constraints obtained from the KKT conditions of the minimum distance problem. These algebraic equations and the complementarity constraints taken together ensure satisfaction of the contact constraints. This enables us to formulate a fully implicit time-stepping scheme ($i.e.$, we do not need to approximate the distance function) as a nonlinear complementarity problem (NCP). The resulting time-stepper is therefore more accurate and is the first fully implicit time-stepper (leaving aside the handful of cases when a closed form expression for the distance function is available). We further show examples validating our approach.

Schedule: see page 19.

P24: *Synthesis of Constrained nR Planar Robots to Reach Five Task Positions*

Gim Song Soh, J. Michael McCarthy

Abstract: In this paper, we design planar nR serial chains that provide one degree-of-freedom movement for an end-effector through five arbitrarily specified task positions. These chains are useful for deployment linkages or the fingers of a mechanical hand. The trajectory of the end-effector pivot is controlled by n-1 sets of cables that are joined through a planetary gear system to two input variables. These two input variables are coupled by a four-bar linkage, and the movement of the end-effector around its end joint is driven by a second four-bar linkage. The result is one degree-of-freedom system. The design of the cabling system allows control of the shape of the chain as it moves through the task positions. This combines techniques of deployable linkage design with mechanism synthesis to obtain specialized robotic-style movement with a minimum number of actuators. Two example designs for a 6R planar chain are presented, one with a square initial configuration and a second with a hexagonal initial configuration.

Schedule: see page 19.

P25: *Automatic Scheduling for Parallel Forward Dynamics Computation of Open Kinematic Chains*

Katsu Yamane, Yoshihiko Nakamura

Abstract: Recent progress in the algorithm as well as the processor power have made the dynamics simulation of complex kinematic chains more realistic in various fields such as human motion simulation and molecular dynamics. The computation can be further accelerated by employing parallel processing on multiple processors. In fact, parallel processing enviroment is becoming more affordable thanks to recent release of multiple-core processors. Although several parallel algorithms for the forward dynamics computation have been proposed in literature, there still remains the problem of automatic scheduling, or load distribution, for handling arbitrary kinematic chains on a given parallel processing environment. In this paper, we propose a method for finding the schedule that minimizes the computation time. We test the method using three human character models with different complexities and show that parallel processing on two processors reduces the computation time by 35–36%.

Schedule: see page 19.

P26: *CRF-Matching: Conditional Random Fields for Feature-Based Scan Matching*

Fabio Ramos, Dieter Fox, Hugh Durrant-Whyte

Abstract: Matching laser range scans observed at different points in time is a crucial component of many robotics tasks, including mobile robot localization and mapping. While existing techniques such as the Iterative Closest Point algorithm perform well under many circumstances, they often fail when the initial estimate of the offset between scans is uncertain. This paper presents a novel approach to 2D laser scan matching. CRF-Matching generates a Condition Random Field (CRF) to reason about the joint association between the measurements of the two scans. The approach is able to consider arbitrary shape and appearance features in order to match laser scans. The model parameters are learned from labeled training data. Inference is performed efficiently using loopy belief propagation. Our experiments using data collected by a car navigating through urban environments shows that CRF-Matching is able to reliably and efficiently match laser scans even when no a priori knowledge about their offset is given. Preliminary experiments also show that camera information can be seamlessly integrated into our approach, thereby further improving performance.

Schedule: see page 19.

Technical Session V, Thursday, June 28, AM

Invited Talk: ***Latent Precursors of Human Intelligence in Brain Mechanisms Subserving Monkey Tool Use***

Atsushi Iriki, Riken Brain Science Institute

Abstract: Bimodal neurons in the monkey intraparietal cortex, integrating visual and somatosensory informations, code the image of the self-body, which is subject to intentional modification. When trained to use a tool, it becomes an extension of the hand both physically and perceptually, resulting in alteration of the body image in accordance with the characteristics of the tool at hand. In above bimodal neurons, use-dependent expansion of the receptive field occurred only when the monkeys held a tool and intended to use it as an extension of their hand. This would constitute the neural correlate for modification of the body schema as a basis of assimilation of the tool into our own body. PET imaging studies confirmed that this cortical area is active when monkeys using the rake. Also, we found that these neurons can code the body-image projected onto the video monitor, perhaps corresponding to its iconic representation. During the course of above training, behavioral analyses suggested that a novel mode of somatosensory-visual integration seemed to develop in order to organize adequate bodily movement to manipulate the tool, possibly subserved by reformation of the neural circuitry in which molecular genetic processes in the cortical area described above are involved. Indeed, augmented expression of messenger RNA of neurotrophic factors associated with learning was induced in the corresponding cortical region only during the training to use the tool, but not after monkeys acquired the skill. Corresponding to this period, emergence of novel cortico-cortical projections between temporo-parietal junction and the intra-parietal cortex were detected in monkeys that were trained to use tools, therefore, enabling to integrate the tool in their own body image by presence of a self-objectification mechanism. When above described representations were further advanced, it would become totally free from physical constraints of the actual world to become a symbolic one to represent evolutionary precursors of higher cognitive functions, and might eventually lead to evolution of human language or to the metaphysical thoughts.

Biography: We are trying to uncover evolutionary precursors of human higher cognitive functions grounded onto physical morphologies and patterns of structured bodily actions, based on behavioral and neurophysiological analyses on chronic macaque monkeys, which were trained to use tools and other high-tech apparatus. By sharing above machineries among individuals, we extrapolate these mechanisms to constitute bases of communicatory functions, and eventually understand neural mechanism of social behaviours. Further, we are aiming at extending these mechanisms onto evolutionary as well as developmental clues of symbolic cognitive functions to subserve inference, metaphysical thoughts, etc. that characterise human intelligence.

Schedule: see page 20.

P27: *Control of Many Agents Using Few Instructions*

Timothy Bretl

Abstract: This paper considers the problem of controlling a group of agents under the constraint that every agent must be given the same control input. This problem is relevant for the control of mobile micro-robots which all receive the same power and control signals through an underlying substrate. Despite this restriction, several examples in simulation demonstrate that it is possible to get a group of micro-robots to perform useful tasks. All of these tasks are derived by thinking about the relationships between robots, rather than about their individual states.

Schedule: see page 20.

Technical Session VI, Thursday, June 28, AM

P28: *Safety Evaluation of Physical Human-Robot Interaction via Crash-Testing*

Sami Haddadin, Alin Albu-Schffer, Gerd Hirzinger

Abstract: The light-weight robots developed at the German Aerospace Center (DLR) are characterized by their low inertial properties, torque sensing in each joint and a load to weight ratio similar to humans. These properties qualify them for applications requiring high mobility and direct interaction with human users or uncertain environments. An essential requirement for such a robot is that it must under no circumstances pose a threat to the human operator. To actually quantify the potential injury risk emanating from the manipulator, impact test were carried out using standard automobile crash-test facilities at the German Automobile Club ADAC. In our evaluation we focused on unexpected rigid frontal impacts, i.e. injuries caused by sharp edges are excluded. Several injury mechanisms and so called Severity Indices are evaluated and discussed with respect to their adaptability to physical human-robotic interaction.

Schedule: see page 20.

P29: *Dimensionality Reduction Using Automatic Supervision for Vision-Based Terrain Learning*

Anelia Angelova, Larry Matthies, Daniel Helmick, Pietro Perona

Abstract: This paper considers the problem of learning to recognize different terrains from color imagery in a fully automatic fashion, using the robot's mechanical sensors as supervision. We present a probabilistic framework in which the visual information and the mechanical supervision interact to learn the available terrain types. Within this framework, a novel supervised dimensionality reduction method is proposed, in which the automatic supervision provided by the robot helps select better lower dimensional representations, more suitable for the discrimination task at hand. Incorporating supervision into the dimensionality reduction process is important, as some terrains might be visually similar but induce very different robot mobility. Therefore, choosing a lower dimensional visual representation adequately is expected to improve the vision-based terrain learning and the final classification performance. This is the first work that proposes automatically supervised dimensionality reduction in a probabilistic framework using the supervision coming from the robot's sensors. The proposed method stands in between methods for reasoning under uncertainty using probabilistic models and methods for learning the underlying structure of the data. The proposed approach has been tested on field test data collected by an autonomous robot while driving on soil, gravel and asphalt. Although the supervision might be ambiguous or noisy, our experiments show that it helps build a more appropriate lower dimensional visual representation and achieves improved terrain recognition performance compared to unsupervised learning methods.

Schedule: see page 20.

P30: *The Stochastic Motion Roadmap: A Sampling Framework for Planning with Markov Motion Uncertainty*

Ron Alterovitz, Thierry Simeon, Ken Goldberg

Abstract: We present a new motion planning framework that explicitly considers uncertainty in robot motion to maximize the probability of avoiding collisions and successfully reaching a goal. In many motion planning applications ranging from maneuvering vehicles over unfamiliar terrain to steering flexible medical needles through human tissue, the response of a robot to commanded actions cannot be precisely predicted.

We propose to build a roadmap by sampling collision-free states in the configuration space and then locally sampling motions at each state to estimate state transition probabilities for each possible action. Given a query specifying initial and goal configurations, we use the roadmap to formulate a Markov Decision Process (MDP), which we solve using Infinite Horizon Dynamic Programming in polynomial time to compute stochastically optimal plans. The Stochastic Motion Roadmap (SMR) thus combines a sampling-based roadmap representation of the configuration space, as in PRMs, with the well-established theory of MDPs. Generating both states and transition probabilities by sampling is far more flexible than previous Markov motion planning approaches based on problem-specific or grid-based discretizations. We demonstrate the SMR framework by applying it to nonholonomic steerable needles, a new class of medical needles that follow curved paths through soft tissue, and confirm that SMRs generate motion plans with significantly higher probabilities of success compared to traditional shortest-path plans.

Schedule: see page 20.

Technical Session VII, Thursday, June 28, PM

Invited Talk: ***Probabilistic Models of Human Sensorimotor Control***

Daniel M. Wolpert, University of Cambridge

Abstract: The effortless ease with which humans move masks the true complexity of the control processes involved. This is evident when we try to build machines to perform human control tasks. While computers can now beat grandmasters at chess, no computer can yet control a robot to manipulate a chess piece with the dexterity of a six-year-old child. A major factor that makes control hard is the uncertainty inherent in the world and in our own sensory and motor systems. Sensory and motor uncertainty form fundamental constraints on human sensorimotor control. In my talk I will describe three areas of our research which address how the motor system deals with uncertainty. Together these studies provide a probabilistic framework for sensorimotor control.

Biography: Daniel Wolpert read medical sciences at Cambridge and clinical medicine at Oxford. After working as a medical doctor for a year he completed a PhD in the Physiology Department at Oxford. He then worked as a postdoctoral fellow at MIT, before moving to the Institute of Neurology, UCL. In 2005 he took up the post of Professor of Engineering for the Life Sciences at the University of Cambridge and is a fellow of Trinity College. His research interests are computational and experimental approaches to human sensorimotor control.

Schedule: see page 21.

P31: *A Fundamental Tradeoff between Performance and Sensitivity within Haptic Rendering*

Paul Griffiths, Brent Gillespie, Jim Freudenberg

Abstract: In this paper we show that, for haptic rendering using position feedback, the structure of the feedback loop imposes a fundamental tradeoff between accurate rendering of virtual environments and sensitivity of closed-loop responses to hardware variations and uncertainty. Due to this tradeoff, any feedback design that achieves high-fidelity rendering incurs a quantifiable cost in terms of sensitivity. Analysis of the tradeoff reveals certain combinations of virtual environment and haptic device dynamics for which performance is achieved only by accepting very poor sensitivity. This analysis may be used to show that certain design specifications are infeasible and may guide the choice of hardware to mitigate the tradeoff severity.

We illustrate the predicted consequences of the tradeoff with an experimental study.

Schedule: see page 21.

P32: *Motion Strategies for Surveillance*

Sourabh Bhattacharya, Salvatore Candido, Seth Hutchinson

Abstract: We address the problem of surveillance in an environment with obstacles. We show that the problem of tracking an evader with one pursuer around one corner is completely decidable. The pursuer and evader are assumed to have complete information about each other's instantaneous position and velocity. We present a partition of the visibility region of the pursuer where based on the region in which the evader lies, we provide strategies for the evader to escape the visibility region of the pursuer or for the pursuer to track the target for all future time. We also present the solution to the inverse problem: given the position of the evader, the positions of the pursuer for which the evader can escape the visibility region of the target. These results have been provided for varying speeds of the pursuer and the evader. Based on the results of the inverse problem we provide an $O(n^3 \log n)$ algorithm that can decide if the evader can escape from the visibility region of a pursuer for some initial pursuer and evader positions. Finally, we extend the result of the target tracking problem around a corner in two dimensions to an edge in three dimensions.

Schedule: see page 21.

Technical Session VIII, Thursday, June 28, PM

P33: *Learning omnidirectional path following using dimensionality reduction*

J. Zico Kolter, Andrew Ng

Abstract: We consider the task of omnidirectional path following for a quadruped robot: moving a four-legged robot along any arbitrary path while turning in any arbitrary manner. Learning a controller capable of such motion requires learning the parameters of a very high-dimensional policy, a difficult task on a real robot. Although learning such a policy can be much easier in a model (or "simulator") of the system, it can be extremely difficult to build a sufficiently accurate simulator. In this paper we propose a method that uses a (possibly inaccurate) simulator to identify a low-dimensional subspace of policies that spans the variations in model dynamics. This subspace will be robust to variations in the model, and can be learned on the real system using much less data than would be required to learn a policy in the original class. In our approach, we sample several models from a distribution over the kinematic and dynamics parameters of the simulator, then formulate an optimization problem that can be solved using the Reduced Rank Regression (RRR) algorithm to construct a low-dimensional class of policies that spans the major axes of variation in the space of controllers. We present a successful application of this technique to the task of omnidirectional path following, and demonstrate improvement over a number of alternative methods, including a hand-tuned controller. We present, to the best of our knowledge, the first controller capable of omnidirectional path following with parameters optimized simultaneously for *all* directions of motion and turning rates.

Schedule: see page 21.

P34: *A Fast and Practical Algorithm for Generalized Penetration Depth Computation*

Liangjun Zhang, Young J. Kim, Dinesh Manocha

Abstract: We present an efficient algorithm to compute the generalized penetration depth (PD) between rigid and articulated models. Given two overlapping object, our algorithm attempts to compute the minimal translational and rotational motion that separates the two objects. We formulate the PD computation based on model-dependent distance metrics that minimize the displacement. As a result, our formulation is independent of the choice of inertial and body-fixed reference frames as well as of specific representation of the configuration space. Furthermore, We show that the optimum answer lies on the boundary of the contact space and pose the computation as a constrained optimization problem. We use global approaches to compute an initial guess and present efficient techniques to compute a local approximation of the contact space for iterative refinement. We highlight the performance on many complex models and demonstrate its application to motion planning. Unlike prior PD computation algorithm, our approach is relatively simple to implement and works well in practice.

Schedule: see page 21.

P35: *Planning and Control of Meso-scale Manipulation Tasks with Uncertainties*

Peng Cheng, Bogdan Gavrea, David Cappelleri, Vijay Kumar

Abstract: We consider the canonical problem of assembling a peg into a hole using probes at the end of a micro manipulator using open-loop pushing operations with feedback between the pushing operations from an optical microscope. We develop a quasi-static model for the assembly task incorporating models of frictional contacts and consider three sources of uncertainty. Because of errors in sensing position and orientation of the parts to be assembled, we must consider uncertainty in initial configuration of the system. Second, there is uncertainty because of errors in actuation. Third, there are geometric and physical parameters characterizing the environment that is unknown. We discuss the synthesis of robust planning primitives for meso-scale manipulation using two different probes and the automated generation of plans for manipulation. We show simulation and experimental results in support of our work.

Schedule: see page 21.

P36: *Data Association in O(n) for Divide and Conquer SLAM*

Lina Maria Paz, Jose Guivant, Juan Tardos, Jose Neira

Abstract: In this paper we show that *all* processes associated to the move-sense-update cycle of EKF SLAM can be carried out in time *linear* in the number of map features. We describe Divide and Conquer SLAM, an EKF SLAM algorithm where the computational complexity per step is reduced from $O(n^2)$ to $O(n)$ (the total cost of SLAM is reduced from $O(n^3)$ to $O(n^2)$). In addition, the resulting vehicle and map estimates have better consistency properties than standard EKF SLAM in the sense that the computed state covariance more adequately represents the real error in the estimation. Both simulated experiments and the Victoria Park Dataset are used to provide evidence of the advantages of this algorithm.

Schedule: see page 21.

Banquet Talk: ***Earth Art with Robots and Networks***

Ken Goldberg, UC Berkeley

Abstract: I'm interested in the interactions between nature and technology. I'll present selected artworks developed with students and other collaborators involving robots and networks over the past 20 years. These include the Telegarden, a robot installation that allowed online participants to remotely tend a living garden; Demonstrate, where an ultra high-resolution video camera raised awareness at the 40th anniversary of the Free Speech Movement; Ballet Mori, a classical dance performed at the San Francisco Opera House to music conducted by live seismic data, and a new robot camera that is assisting in the search for the "Holy Grail of Birdwatching."

Biography: Ken Goldberg is an artist and professor of engineering at UC Berkeley. He is an IEEE Fellow and VP of Technical Activities for the Robotics and Automation Society. His artwork has been exhibited at the Venice Biennale, Ars Electronica (Austria), ZKM (Germany), Pompidou Center (Paris), ICC Biennale (Tokyo), Kwangju Biennale (Seoul), Artists Space, and the 2000 Whitney Biennial.

Schedule: see page 21.

Technical Session IX, Friday, June 29, AM

Invited Talk: ***Calculus Ex Geometrica: Structure-Preserving Foundations for Computations***

Mathieu Desbrun, California Institute of Technology

Abstract: Since their inception, computer graphics and animation have thrived by borrowing from mathematical and physical models and by making inroads into computational science—be it in radiosity, surface processing, or fluid simulation. However, it is routinely observed that the passage from differential modeling to discrete implementation often lacks the necessary safeguards to guarantee the preservation of important continuous properties in the resulting discrete algorithms, leading to classical flaws such as numerical viscosity and energy blowups. In this talk, we will argue for a geometric approach to computations. We will show that a discrete geometry-driven calculus can indeed leverage the mature geometric understanding of differential calculus on manifolds (going back to Cartan) on which most physical theories are based. The resulting variational techniques not only result in numerical tools that intrinsically respect key defining properties like symmetries and invariants, but also clarify abstract concepts of algebraic topology. We will demonstrate these properties on a number of graphics and simulation applications. Of particular interests to the robotics community, we will discuss the notion of variational integrators, where optimality of the space-time trajectory (i.e., Hamilton's principle) yields a set of conditions on the path at each time step, from which a time integrator falls out naturally.

Biography: Mathieu Desbrun is an Associate Professor at the California Institute of Technology (Caltech). After receiving his Ph.D. from the National Polytechnic Institute of Grenoble (INPG), he spent a year as a post-doctoral researcher at Caltech before joining the faculty of the CS department at the University of Southern California from 2000 to 2004. He now directs the Applied Geometry lab at Caltech, focusing on discrete differential modeling, i.e., the development of differential, yet readily-discretizable foundations of computations with a wide spectrum of applications, from discrete geometry processing to solid and fluid mechanics.

Schedule: see page 22.

P37: *An experimental study of exploiting multipath fading for robot communications*

Magnus Lindhe, Karl Henrik Johansson, Antonio Bicchi

Abstract: A simple approach for mobile robots to exploit multipath fading in order to improve received radio signal strength (RSS), is presented. The strategy is to sample the RSS at discrete points, without deviating too far from the desired position. We first solve the problem of how many samples are needed for given communications performance and how they should be spaced. Second, we propose a circular and a grid trajectory for sampling and give lower bounds on how many samples they will yield. Third, we estimate the parameters of our strategy from measurements. Finally we demonstrate the validity of our analysis through experiments.

Schedule: see page 22.

Technical Session X, Friday, June 29, AM

Early Career Spotlight: ***Sensorimotor Integration in Robots and Animals: Signals, Geometry and Mechanics***

Noah J. Cowan, Johns Hopkins University

Abstract: Animals execute split-second maneuvers to avoid obstacles, catch prey, and evade predators amidst myriad information from thousands of sensors. Decoding animal sensory systems that achieve this extraordinary closed-loop performance, and designing sensor systems for robots to match it, requires integration along three conceptual axes: spatiotemporal signal processing, geometry, and mechanics. Toward this long-term goal, I will describe several robotic and biological systems that highlight different combinations of these axes.
Signal processing and mechanics. Wall following in cockroaches and refuge tracking in weakly electric fish both reveal that the mechanics of a locomotor task is encoded at the earliest stages of neural processing.
Mechanics and geometry. Mapping rigid motions into a camera image plane provides image-based generalized coordinates for the mechanical system.
Geometry and signal processing. Spatial sampling kernels generate featureless hooks for sensor-based control using natural images.

Biography: Noah J. Cowan received the B.S. degree from the Ohio State University, Columbus, in 1995, and the M.S. and Ph.D. degrees from the University of Michigan, Ann Arbor, in 1997 and 2001, all in electrical engineering. He was a postdoctoral fellow in the PolyPEDAL laboratory at the University of California, Berkeley, before joining the Johns Hopkins University faculty in 2003, where he is now an Assistant Professor in the Department of Mechanical Engineering. Prof. Cowan is the director of the Locomotion In Mechanical and Biological Systems (LIMBS) Laboratory, and his research interests include sensor-based control in robotics and biology and medical robotics.

Schedule: see page 22.

Early Career Spotlight: ***Morphological and Behavioral Adaptation in Robotics***

Hod Lipson, Cornell University

Abstract: Robotic systems are of growing interest both because of their many practical applications as well as their ability to help understand human and animal behavior, cognition, and physical performance.

Though industrial robots have long been used for repetitive tasks in structured environments, one of the long-standing challenges is achieving robust and adaptive performance under uncertainty. This talk will examine two approaches for achieving adaptation in robotic systems: One involves adaptation of behavior, based on the notion of self-modeling; the second approach involves adaptation of morphology: From reconfiguring to self-repairing systems. Several implementations on virtual and physical robots will be shown, as well as the underlying computational challenges.
For adaptive behavior, we use a combination of reinforcement learning and active learning, so that a robot can reconstruct its own body plan by from observed actuation-sensing relationships. Robot actions that cause disagreement among predictions of different candidate models are used for inference because they elucidate uncertainties; actions that cause agreement among predictions of different models are used for robust control as they avoid uncertainties. This process will be demonstrated for virtual and physical robots as they go through damage. Other applications of this process, such as for system biology networks, will also be shown. For adaptive morphology, several new concepts will be overviewed, ranging from printable machines, to stochastically reconfiguring systems, as well as concepts based on statistical mechanics.

Biography: Hod Lipson is an Assistant Professor of Mechanical & Aerospace Engineering and Computing & Information Science at Cornell University in Ithaca, NY. He directs the Computational Synthesis group, which focuses on novel ways for automatic design, fabrication and adaptation of virtual and physical machines. He has led work in areas such as evolutionary robotics, multi-material functional rapid prototyping, machine self-replication and programmable self-assembly. Lipson received his Ph.D. from the Technion - Israel Institute of Technology in 1998, and continued to a postdoc at Brandeis University and MIT. His research focuses primarily on biologically-inspired approaches, as they bring new ideas to engineering and new engineering insights into biology.

Schedule: see page 22.

Technical Session XI, Friday, June 29, PM

P38: *Mapping Large Loops with a Single Hand-Held Camera*

Laura A. Clemente, Andrew Davison, Ian Reid, Jose Neira, Juan Tardos

Abstract: This paper presents a method for Simultaneous Localization and Mapping (SLAM) relying on a monocular camera as the only sensor which is able to build outdoor, closed-loop maps much larger than previously achieved with such input. Our system, based on the Hierarchical Map approach [Estrada-TRO05], builds independent local maps in real-time using the EKF-SLAM technique and the inverse depth representation proposed in [Montiel-RSS06]. The main novelty in the local mapping process is the use of a data association technique that greatly improves its robustness in dynamic and complex environments. A new visual map matching algorithm stitches these maps together and is able to detect large loops automatically, taking into account the inobservability of scale intrinsic to pure monocular SLAM. The loop closing constraint is applied at the upper level of the Hierarchical Map in near real-time. We present experimental results demonstrating monocular SLAM as a human carries a camera over long walked trajectories in outdoor areas with people and other clutter, even in the more difficult case of forward-looking camera, and show the closing of loops of several hundred meters.

Schedule: see page 23.

P39: *Dynamic Coverage Verification in Mobile Sensor Networks Via Switched Higher Order Laplacians*

Abubakr Muhammad, Ali Jadbabaie

Abstract: In this paper, we study the problem of verifying dynamic coverage in mobile sensor networks using certain switched linear systems. These switched systems describe the flow of discrete differential forms on time-evolving simplicial complexes. The simplicial complexes model the connectivity of agents in the network, whereas the homology groups of the simplicial complexes lets one infer about the coverage properties of the network. Our main result states that the asymptotic stability of the switched linear system implies that every point of the domain covered by the mobile sensor nodes is visited infinitely often. The enabling mathematical technique for this result is the theory of higher order Laplacian operators, which is a generalization of the graph Laplacian used in consensus problems.

Schedule: see page 23.

P40: *Discrete Search Leading Continuous Exploration for Kinodynamic Motion Planning*

Erion Plaku, Lydia E. Kavraki, Moshe Y. Vardi

Abstract: This paper presents Discrete Search Leading continous eXploration Plan (DSLX-Plan), a multi-layered approach to motion planning that is suitable for challenging problems involving robots with kinodynamic constraints. Initially the method decomposes the workspace to build a graph that encodes the physical adjacency of the decomposed regions. This graph is searched to obtain leads, that is, sequences of regions that can be explored with sampling-based tree methods to generate solution trajectories. Instead of treating the discrete search of the adjacency graph and the exploration of the continuous state space as separate components, DSLX-Plan passes information from one to the other in innovative ways. Each lead suggests what regions to explore and the exploration feeds back information to the discrete search to improve the quality of future leads. Information is encoded as edge weights, which indicate the importance of including adjacent regions associated with the edge in the next exploration step. Computation of weights, leads, and the actual exploration make the core loop of the algorithm, which is performed multiple times until a solution is found or a maximum amount of time has elapsed. Extensive experimentation shows that DSLX-Plan is very versatile. The discrete search can drastically change the lead to reflect new information allowing DSLX-Plan to find solutions even when sampling-based tree planners get stuck. Experimental results on a variety of challenging kinodynamic motion planning problems show computational speedups of two orders of magnitude over other widely used motion planning methods.

Schedule: see page 23.

P41: *Active Policy Learning for Robot Planning and Exploration under Uncertainty*

Ruben Martinez-Cantin, Nando de Freitas, Arnaud Doucet, Jose Castellanos

Abstract: This paper proposes a simulation-based active policy learning algorithm for finite-horizon, partially-observed sequential decision processes. The algorithm is tested in the domain of robot navigation and exploration under uncertainty. In such a setting, the expected cost, that must be minimized, is a function of the belief state (filtering distribution). This filtering distribution is in turn nonlinear and depends on an observation model with discontinuities. These discontinuities arise because the robot has a finite field of view and the environment may contain occluding obstacles. As a result, the expected cost is non-differentiable and very expensive to simulate. The new algorithm overcomes the first difficulty and reduces the number of required simulations as follows. First, it assumes that we have carried out previous simulations which returned values of the expected cost for different corresponding policy parameters. Second, it fits a Gaussian process (GP) regression model to these values, so as to approximate the expected cost as a function of the

policy parameters. Third, it uses the GP predicted mean and variance to construct a statistical measure that determines which policy parameters should be used in the next simulation. The process is then repeated using the new parameters and the newly gathered expected cost observation. Since the objective is to find the policy parameters that minimize the expected cost, this iterative active learning approach effectively trades-off between exploration (in regions where the GP variance is large) and exploitation (where the GP mean is low). In our experiments, a robot uses the proposed algorithm to plan an optimal path for accomplishing a series of tasks, while maximizing the information about its pose and map estimates. These estimates are obtained with a standard filter for simultaneous localization and mapping. Upon gathering new observations, the robot updates the state estimates and is able to replan a new path in the spirit of open-loop feedback control.

Schedule: see page 23.

Workshops

W1: Robot Manipulation: Sensing and Adapting to the Real World

Schedule and Location:

9:00 am - 6:00 pm
Klaus Advanced Computing Building, room 2443

Organizers:

Charles C. Kemp (Georgia Tech) (lead)

Aaron Edsinger (MIT)

Robert Platt (NASA JSC)

Neo Ee Sian (AIST)

Description:

This workshop will explore new approaches to autonomous robot manipulation that are specifically designed to handle the uncertainties of real world applications. There is a resurgence of interest in robot manipulation as researchers seek to push autonomous manipulation out of controlled laboratory settings and into applications such as domestic assistance, health care, and space exploration. This workshop will investigate promising approaches that address the challenges of autonomous manipulation within domains that require the robot to sense the world and adapt to the unexpected.

This full-day workshop will consist of talks, discussions, a poster session, and demos. It will conclude with a moderated discussion of potential future applications for autonomous robot manipulation focused on identifying tomorrow's driving applications and the research required to enable these applications.

This workshop is a successor to the RSS 2005 Workshop on Humanoid Manipulation and the RSS 2006 Workshop on Manipulation for Human Environments.

W2: Robotic Sensor Networks: Principles and Practice

Schedule and Location:

8:30 am - 4:00 pm
Klaus Advanced Computing Building, room 2456

Organizers:

Gaurav S. Sukhatme (USC)

Wolfram Burgard (University of Freiburg)

Description:

Sensor network research has risen to prominence in recent years. The breadth of research in the area is large. RSS 2007 will feature a one day focused workshop on *robotic* sensor networks, namely sensor networks which incorporate robotic mobility or articulation. Such systems include, e.g., a networked multi-robot group, a network of immobile computing and sensing nodes and mobile robot(s), a network of immobile nodes each with computing and actuated sensing (allowing e.g., each node to change the direction in which a sensor is pointed). The design of such systems raises algorithmic and theoretical challenges as well as challenges associated with the practicalities of of conducting real deployments. This workshop will bring together people interested in the algorithmic aspects, mathematical and statistical foundations, and experimentalists who have fielded robotic sensor networks in the context of specific applications. This synergy between theory and practice is in line with the 'realistic visions' RSS 2007 workshop theme. Structure:

The workshop will be structured as a mix of short technical (though informal) presentations, Q&A sessions, posters, demos, discussion panels, and a concluding summary session. The exact schedule will be formulated shortly. Participation and Outcomes:

We encourage and actively seek participation by all interested members of the robotic sensor network research community. As a participant you may present a poster, give a short talk, or serve on a panel. As a presenter we simply ask that you make material relevant to your presentation (e.g., slides or poster or paper) available to the organizers two weeks before the conference for distribution to the workshop attendees. Please email the organizers with a short statement of interest if would like to participate in the workshop or if you have any questions. We are actively pursuing the possiblity of a journal special issue on this topic based on the workshop.

W3: Algorithmic Equivalences Between Biological and Robotic Swarms

Schedule and Location:

9:00 am - 6:00 pm
Klaus Advanced Computing Building, room 1456

Organizers:

James McLurkin (MIT)

Paulina Varshavskaya (MIT)

Description:

This workshop will bring together researchers in biology, robotics and computer science who study distributed physical systems: swarms, hives, colonies, and multi-robot teams. The main goal is to enable rigorous discussion of the common system constraints and algorithmic solutions employed by natural and artificial swarms.

The first requirement is to identify similarities in our respective high-level models of sensing, communication, processing, and mobility, and discuss how these models constrain the distributed algorithms employed by natural and artificial systems.

- What fundamental mathematical theories underly both biological models of swarm behavior and the design of robotic teams?
- What analytical tools are commonly used in one field, which may be of benefit to the other?
- What specific common constraints apply to the solutions found by nature and robot engineers?
- When do roboticists wish they knew more biology?
- When do biologists wish they knew more computer science or control theory?
- Are there valid equivalences between natural and robotic distributed systems at the algorithmic level?
- What tasks and applications for swarm technology are most like those of their natural counterparts?
- What is the most productive way to use ”natural algorithms” in distributed robotics?

We welcome participants from the robotic fields of swarm robotics, team robotics, modular robotics and other distributed robotic systems. We welcome participation from biologists specializing in the study of group behavior and organisms comprising such groups. Prospective speakers will be asked to submit an extended abstract of their presentation, with less emphasis on their current research and a strong focus on algorithmic equivalences between biological and robotic distributed systems. Previously published research is acceptable if it fits the goals of the workshop. Accepted abstracts will be made available in a digital archive.

W5: Research in Robots for Education

Schedule and Location:

9:00 am - 6:00 pm
Klaus Advanced Computing Building, room 1447

Organizers:

Doug Blank (Bryn Mawr College)

Maria Hybinette (University of Georgia)

Keith O'Hara (Georgia Tech)

Daniela Rus (MIT)

Description:

The landscape of robots in education has continued to change since the 2005 RSS Robotics Education Workshop. Over the last two years, there has been a noticeable spike in interest in the use of robots in education. For example: robots are discussed as platforms for education at leading conferences and workshops such as SIGCSE and AAAI; Universities are integrating robots into their classrooms; Robot- centered competitions like FIRST, BotBall and RoboCup continue to flourish. Industry is interested as well: iRobot recently announced the Roomba Create; LEGO has updated their popular Mindstorm robot; And Microsoft has funded two centers to explore the utility of robots for computer science education.

What is the basis for this excitement? What is the evidence that robots in the classroom advance education? The focus of this workshop is to provide a venue for presentation of the research supporting (or contradicting) the effectiveness of robots in education, and to help shape future research in this area.

In particular, the workshop will explore how robots are used differently as educational tools, in terms of hardware, software, pedagogy, and assessment, in different disciplines (e.g. ME, EE, CE and CS) and why certain types of robots may be more effective for different purposes. As an example, many teachers take a constructionist approach in which students build their own robots, while others provide students with a working platform that they should not change.

The workshop will also explore new curricula and robot platforms and the research behind them. The objective of this workshop is to re-evaluate the state of the art of robotics education and discuss how to continue the broad adoption of tools and materials in the classroom. As part of this discussion, we will explore what areas remain unsolved, and which are immediately available for realistic use. Moreover, we hope to create a community beyond the workshop for future exchange of ideas.

Format

The full-day workshop will include: about 10 formal talks, discussion panels, lightning talks (5 minute talks to promote posters), and a poster/demo session in which participants will be invited to provide hands-on demonstrations their robots and/or curricular materials. The talks will focus on both demonstration and research results.

T1: Microsoft Robotics Studio – A Technical Introduction

Schedule and Location:

9:00 am - 10:30 am
Klaus Advanced Computing Building, room 1443

Organizers:

Stewart Tansley (Microsoft)

Joseph Fernando (Microsoft Robotics Group)

Description:

To further accelerate the growth of the emerging field of robotics, Microsoft has created a new software development kit for the robotics community - the Microsoft Robotics Studio (MSRS). MSRS provides a software platform that enables development of a wide variety of applications which can be used across a variety of hardware, applicable to a wide audience of users.

The robotics session will provide both a high level overview of the MSRS tools and runtime. The content is suited to both novices as well as advanced robotics professionals.

Microsoft Robotics Studio delivers in three areas of software and all will be described in this technical introduction:

- A scalable, extensible concurrency and distributed runtime architecture that can span a wide variety of hardware and devices. The programming interface can be used to create applications to drive robots using 8-bit or 16-bit processors (from a connected PC) as well as 32-bit systems with multi-core processors; and devices from simple touch sensors to laser distance finding devices.
- A set of tools that make programming and debugging robot applications scenarios easier. These include a high resolution visual simulation environment that integrates 3D software physics supplied by the Ageia Technologies PhysX engine. While Microsoft Robotics Studio can be used with programming languages such as those included in Microsoft Visual Studio and Microsoft Visual Studio Express, also included is a new visual programming language that enables the creation of applications using a simple drag-and-drop interface.
- A set of useful technology libraries (services) to help developers get started with writing robot applications, and tutorials which illustrate the basics of how to get started in a variety of programming languages.

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The conference proceedings for Robotics: Science and Systems will be published as a book by MIT Press. The final version of your paper and all other information necessary for its publication will be due on July 30, 2007. Please incorporate feedback you received at the conference into your final submission. Please read these instructions carefully to avoid delaying the publication of the proceedings.

1. **Title and Authors:** If the title or authors for your paper have changed since you submitted your information in January, please email the updated information as soon as possible to

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   using "RSS info change <number>" in the subject line, where <number> is your paper number as it appears in this conference booklet.

2. **Author Agreement Form:** One author must complete and sign the author agreement form (which will be available for download from the Robotics: Science and Systems homepage). Please mail the original, signed author agreement form to the following address by July 30, 2007:

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   Institut f. Informatik, AIS
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3. **Formatting:** Please prepare your final submission according to the IEEE Transactions formatting requirements. A corresponding Latex class file can be obtained from the Robotics: Science and Systems Web site:

   `http://www.roboticsconference.org/authors.shtml`

   Please do not modify the formatting provided in these files. Any change to font sizes, page dimensions, line spacing, etc. will delay the publication of your paper. Please do not include any additional markings such as "Draft" or "To appear in..." on the pages. Make sure your paper does not have page numbers. Papers will be limited to 8 pages. Robotics: Science and Systems offers no provision for accommodating papers that do not meet these requirements.

4. **Creating PDF files:** Delays in the production of proceedings are usually caused by the submission of PDF files that did not embed all fonts. Please follow these simple instructions to ensure that the PDF file you submit does not have this problem.

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- Revised paper uploaded via the conference submission software
- Author agreement form signed and mailed to Cyrill Stachniss via physical mail.
- If title or authors have changed, notify `stachnis@informatik.uni-freiburg.de`

Please note: *We reserve the right not to publish accepted papers should not all information be received by July 30, 2007. We will also exclude papers that violate our formatting guidelines.*

Deadline is July 30, 2007.

Robotics: Science and Systems 2008

The 2008 Conference *Robotics: Science and Systems* will take place in Zurich, Switzerland and is tentatively scheduled to occur June 25-28, 2008. The conference will be chaired by *Oliver Brock* from the University of Massachusetts Amherst. The program chair will be *Jeff Trinkle* from the Rensselaer Polytechnic Institute. The local organization chairs will be Roland Siegwart and Brad Nelson from ETH Zurich.

Oliver Brock
General Chair

Jeff Trinkle
Program Chair

Roland Siegwart Brad Nelson
Local Organization Chairs

View on the main building of ETH Zurich

RSS 2008 will be at ETH Zurich, one of the most renown universities in Europe. The technical sessions will held in ETH's premier auditorium, which is situated in the heart of Zurich. Poster sessions and evening events are planned in the faculty club on the roof of ETH's main building, with a splendid view over Zurich. RSS 2008 will coincide with EURO 2008 (the European Soccer Championship), being held in Switzerland and Austria. The semi-finals are on June 25 in Basel and Switzerland and June 26 in Vienna, Austria. The final will be on Sunday June 29 in Vienna.

Further announcements will be made at the conference's permanent Web site.

`www.roboticsconference.org`

A Word On Philosophy

Robotics: Science and Systems is a single track, highly selective annual conference that seeks to showcase the very best research in robotics today. The conference is new, and the organizers are eager to receive suggestions and to recruit volunteers who might be involved in years to come. In many ways, this is a "grass roots" movement inside robotics. If this endeavor is to succeed, then it will succeed through the enthusiasm and efforts of many many people in the field of robotics.

Here are design criteria for *Robotics: Science and Systems* 2008.

- Reviewing is double-blind. Efforts are taken to ensure that reviewers will provide detailed comments to the authors. Our review process includes a "rebuttal phase" in which authors can comment on reviews before the area chairs make their final acceptance decisions.
- People in the organizational structure revolve relatively quickly! Area chairs are expected to serve for no more than two years, to ensure a proper infusion of new talent into the main decision making body. Other executive positions have a one year term limit.
- The Program Chair has authority over composing the program committee and the selection of papers and invited speakers. The program chair will become the general chair in the next year, to ensure continuity.
- The threshold for accepting posters and oral presentations is identical. In the final proceedings, there will not be any distinction between oral and poster presentations. In particular, none of the chairs (general chairs, program chairs, area chairs) will be eligible for an oral presentation.
- In composing the conference program, we apply no bias with regards to the geographic origin of a paper; we apply no bias with regards to gender, ethnicity, sexual orientation, and various other criteria. Instead, all selection decisions are purely based on the quality and potential of a contribution. The decisions are based on the scientific contributions of a submission. Unfortunately, the number of submissions between the three primary regions (Europe, Asia, Americas) was highly unbalanced in 2005 and 2006, and as a result so is the final program. We would love to change that and draw in people from all around the globe.
- The conference is held at a university to reduce the overall cost. The organizational board makes zero profit; in fact, in all likelihood some of the organizers will subsidize the meeting out of their own discretionary funds. Low costs encourage student participation, which is essential for the health of the field of robotics.