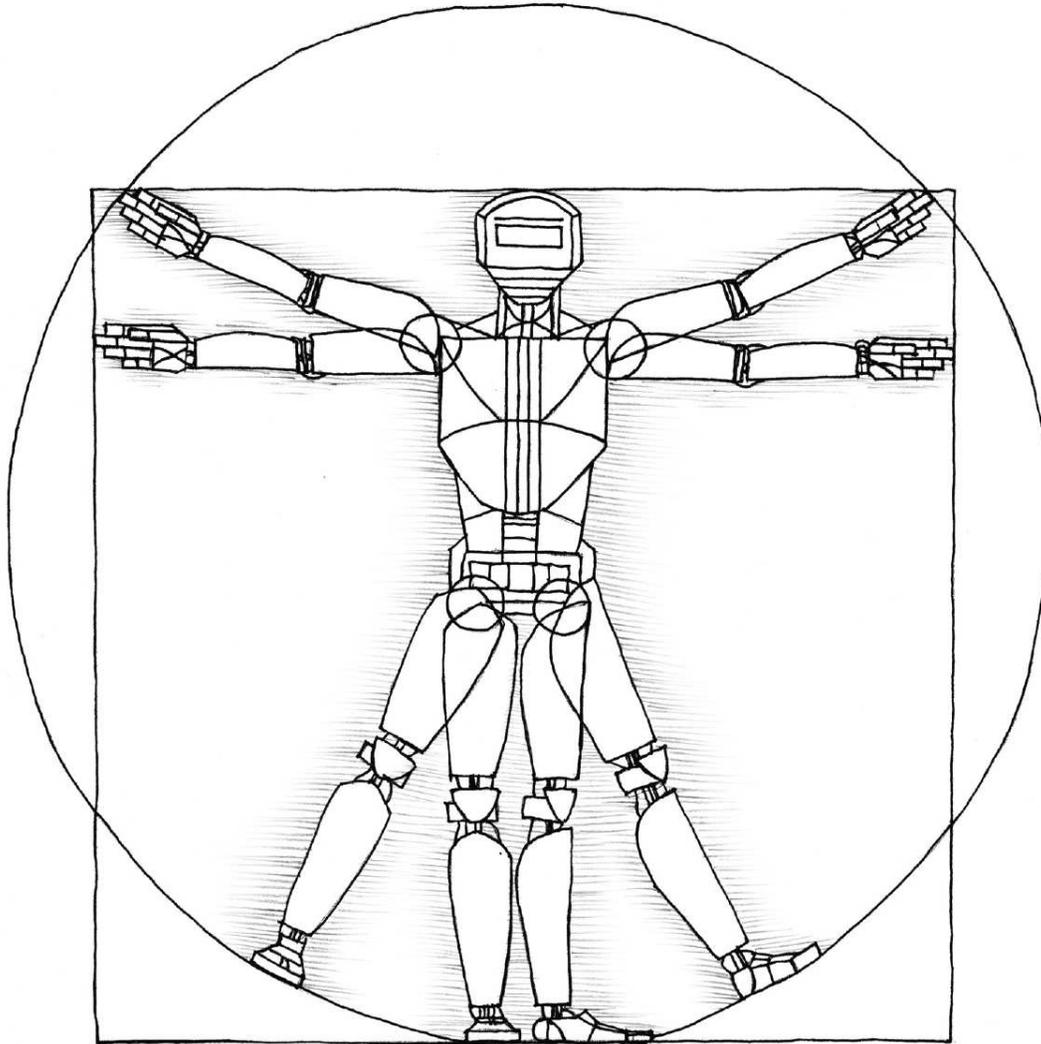


# ROBOTICS

## SCIENCE AND SYSTEMS



Conference Booklet

July 9 - July 13, 2012

University of Sydney

Sydney, Australia

[www.roboticsconference.org](http://www.roboticsconference.org)



# TABLE OF CONTENTS

PREFACE	page 4
CONFERENCE INFORMATION	page 5
TECHNICAL PROGRAM	
Program Overview	page 15
Workshops	page 24
Tutorials	page 29
Invited Speakers	page 30
Early Career Spotlights	page 32
ABSTRACTS	page 34
CONFERENCE ORGANIZERS	page 61
AUTHOR INSTRUCTIONS	page 65

# Preface

Welcome to RSS 2012 – the 8th incarnation of this remarkable conference. This time we find ourselves in Sydney Australia and what a gorgeous spot this is.

This year we have 61 papers being presented by authors from all around the world. Beyond doubt, RSS continues to represent the best work from across the whole spectrum of the robotics science endeavour. The span of papers is quite astounding. This, in conjunction with a single track format will, without you needing to move from your seat, furnish you with a tour of what is judged by peer review to be new, exciting and sometimes challenging. This then is an appropriate place to thank you, the robotics community, for reviewing 177 papers and putting up with a stream badgering emails. Every submitted paper received at least four peer reviews and was discussed in person at the area chair meeting in Oxford. But without your hard work as reviewers, RSS would be greatly impoverished. So thank you.

This year RSS takes on a different format. In the hope that change is good, we have tried to integrate workshops, plenaries, early career spotlights, technical paper talks and e-poster sessions. Everyday begins with a morning of workshops or tutorials. Here you should be able to find discussions and interactions covering the latest and best of robotics science. The afternoon sessions begin with a plenary from one of our four outstanding invited speakers. They are sure to impress with both visions of the future and revelations of the state of the art. The afternoon proceeds with a heady mix of best paper finalist talks, early career spotlight talks and the all important rapid fire, e-poster teasers. Instead of having one monster e-poster session, each day ends with a smaller, refreshment-enhanced e-poster session with around 15 presenters. We hope that these sessions fulfil their mission of allowing authors and attendees to interact in a meaningful and two way discussion without attendees being overwhelmed by 61 poster shows running in parallel!

A huge thanks to the area chairs who once again brought panache, insight and professionalism to the paper reviewing process. There was a lot to do but it was worth it.

We save the last and greatest thanks for Stefan Williams and Fabio Ramos for their unflappable approach to local arrangements, to Dylan Shell for elegant and timely action as Publicity Chair, to Jose? Neira for building an outstanding program of workshops and tutorials to Siddhartha Srinivasa for being the final gatekeeper of quality as Publications Chair and finally Anca Dragan for dealing with the messy business of getting this booklet together. If this conference is a success, it is in no small part because of these folk.

That is enough from us. Now go and enjoy RSS 2012 and tell us what you think. It's great to see you.

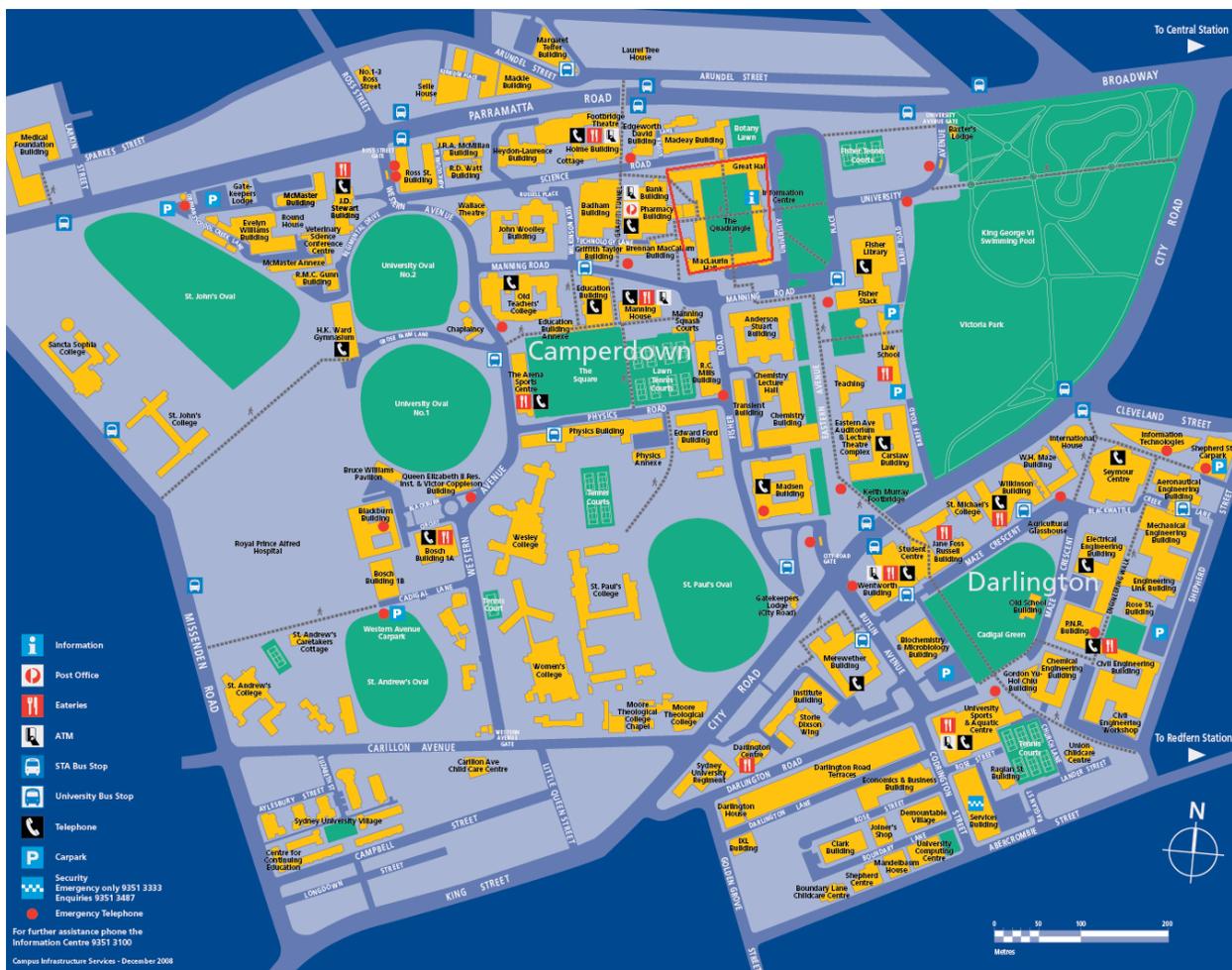
Paul Newman and Nicholas Roy

# Conference and Local Information

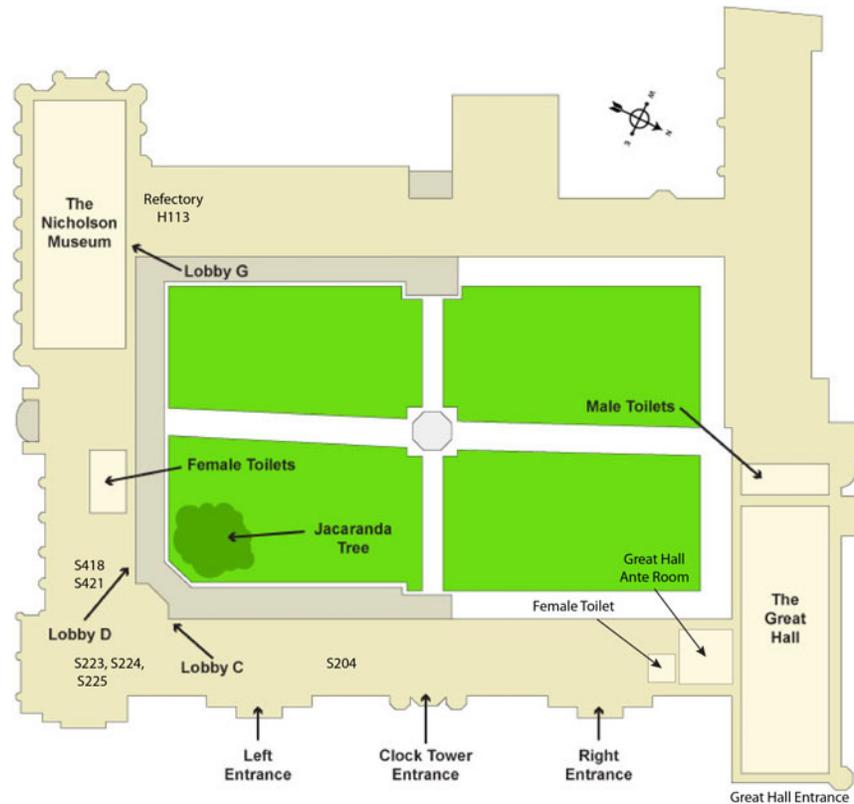
## Location

RSS 2012 will be held on the Camperdown campus of the University of Sydney. This 72-hectare site is located near the junction of Parramatta and City Roads just outside of downtown Sydney. It features landscaped grounds, sports ovals and centres, museums, galleries, two major complexes devoted to student recreation and services, and the famous Quadrangle and many other beautiful modern and historic buildings. RSS 2012 Workshops will take place within the Quadrangle with lectures and the interactive poster sessions to be held in Great Hall.

**Conference Venues:** The following campus map shows the location of the Quadrangle and nearby train stations.



The workshops, oral sessions and interactive poster session will all take place within the University of Sydney's Main Quadrangle. Here is how to find the rooms:



- The Great Hall (Oral presentations, interactive posters, T1, W6): Enter via the Great Hall Entrance.
- Oriental Room S204 (W4, W7): Enter via Left entrance. You will be in a green lobby, with a flight of stairs on your right. Go through the door at the bottom of the stairs. The Oriental Rm is on the left.
- History Room S223 (W3, W10): Enter via any entrance and walk to Lobby C (see map). Go through the double doors. The History Rm is first on your left.
- Latin Room 1 S224 and Latin Room 2 S225: Enter via any entrance and walk to Lobby C (see map). Go through the double doors. Latin Rm 1 is the second on your left; Latin Rm 2 is at the end of the hall.
- McRae Room S418 (W2, W9, W11): Enter via any entrance and walk to Lobby D (see map). Go up four sets of stairs and turn right. Go up the two stairs on your left. The McRae Rm is first on your left.
- Room S421 (W5, W12): Enter via any entrance and walk to Lobby D (see map). Go up four sets of stairs and turn right. Go up the two stairs on your left then turn right. Room S421 is first on your left.
- The Refectory H113 (W1, W8): Enter via any entrance and walk to Lobby G (see map). Go down the stairs and turn left. Go down three steps. The Refectory is on your right.

**About:** The University of Sydney is one of Australia's leading research institutions. The country's first tertiary education institution, it attracts some of the best students, researchers and academic staff from around the world. It is unique among Australian universities in the breadth of disciplines on offer, providing wide opportunities for personal development and cross-disciplinary study that delivers unique insights and breakthroughs. Since its foundation in 1850, the University has produced over 270,000 graduates – many who lead their fields both nationally and on the world stage. The University can proudly claim four Prime Ministers, an early president of the United Nations, two Governors-General, two Nobel Laureates, several Chief Justices and High Court Judges, presidents of the Royal Society and World Bank, business leaders, outstanding literary writers, poets and an Oscar-winning film director.

### **Getting there:**

- **By train:** Catch a train to Redfern train station, and then take a 10-minute walk to the main campus. Timetables, network information and route planners are available from the City Rail website.
- **By bus from the City:** For stops on Parramatta Road (closest to the Quadrangle) catch routes 412, 413, 435, 436, 437, 438, 440, 461, 480 and M10 from George Street or Railway Square. For stops on City Road (closest to Darlington Campus) catch routes 422, 423, 426, 428 from Castlereagh Street or Railway Square.
- **By bus - cross routes:** Route 370 runs between Coogee and Leichhardt. Route 352 runs between Bondi Junction and Marrickville. Route M30 runs between Mosman, George St in the city and Sydenham. Alight on City Rd for Sydney University.
- **By Taxi:** The University is readily accessible by taxi from the airport (approx. 20 minutes) and the city (also a 20 minute fare).

## **Accommodation**

There are a variety of accommodation options available in Sydney. Accommodation close to the RSS 2012 venue is available in the University Colleges and there a number of hotels near the campus or in the city that are readily accessible. There are also many Budget accommodation options around the campus and in the city. A number of online booking services provide discounted rates for hotels in Sydney. Buses and trains provide ready access to the University of Sydney campus from most areas of the city.

## **Colleges**

As the conference will take place during a mid-semester break, a number of the University colleges have rooms available. These are in close proximity to the conference venue and provide accommodation at relatively modest cost.

- **Mandelbaum House** is the newest and most modern residential college at the University of Sydney. They accommodate 34 students and offer a warm and stimulating environment, open to both men and women, regardless of religion or nationality. (\$60-100/night)
- **International House** is a University owned and operated residential college. It is home to an exceptional residential community of over 200 student members from Australia and other countries around the world. (\$75-110/night)

## Hotels

There are a number of hotels on campus, in the city, or at the Darling Harbour. Please visit

<http://roboticsconference.org/pmwiki/index.php?n=Main.Accommodation>

for a list of hotels, with prices and contact information.

## Registration

### On Site Registration

Registration will be available in the Ante Room of the Great Hall from 8am on Monday, July 9th, 2012.

### On Line Registration

Registration for the conference can be completed online at the following url: <http://roboticsconference.eventbrite.com>. The conference registration fees are:

	Early (until June 1st)	Regular (after June 1st)
Student:	\$250	\$300
Non-Student:	\$475	\$575

Both regular and student registrations include attendance to the conference oral presentations, interactive poster sessions and workshops as well as a single ticket for the conference welcome reception and banquet. Additional social event tickets may be purchased during registration.

Extra reception ticket: \$75

Extra banquet ticket: \$150

## Sponsors

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

### Financial sponsors:

#### PLATINUM SPONSOR



#### GOLD SPONSORS



#### SILVER SPONSORS



#### BRONZE SPONSORS



### Award Sponsors:



Best Paper Award



Student Travel Awards



Best Student Paper Award

### Technical Sponsors:



### Organized by:



## Events

### Ice Breaker

An optional Ice Breaker will be held at the Rose Hotel, located at the corner of Cleveland and Shepherd St. This character filled pub is located next to the Sydney University Engineering precinct this pub is popular with ACFR staff and students. We have booked the venue to provide delegates with an opportunity to chat after the first day's proceedings, to grab a drink and a bite to eat and to pit their wits against each other in a round of robotics trivia.

### Banquet

The Banquet for RSS 2012 will take place in the halls of the Australian Museum. Buses will be available to take delegates from the conference venue to the Museum at 6:30pm on Thursday, July 12th. Dinner will include drinks and meals as well as an opportunity to explore some of the museum's collections while catching up with friends and colleagues.

Australian Museum  
6 College St (corner of Williams St)  
Sydney, NSW 2010  
Ph: 02 9320 6000



### Lunch

Lunches will be catered on Monday and Thursday of the conference. On other days, consider the following venues near the conference for a bite to eat.

- Taste Baguette Bar: Located in the new law buildings just across the road from the main Quad, Taste features a variety of gourmet baguettes.
- Subway: There is a Subway located in the Jane Foss Russell building at the end of the pedestrian bridge crossing City Road.
- Wentworth Building: The Wentworth building, next to the Jane Foss Russell building, features a number of small cafes that serve a variety of options, from burritos and crepes to pizza and sandwiches.
- Royal Hotel: The Royal Hotel, at the corner of Codrington and Abercrombie on the far side of the campus, has a variety of pub style meals, including a \$9 rump steak.
- Newtown: As outlined below, King St. in Newtown is well know for its outstanding Thai cuisine. You'll find terrific value with lunch time specials starting from \$6. Newtown Thai II and Thai La Long are both on the northern end of King St near the University and are popular with ACFR staff and students.
- Broadway Shopping Centre: The Broadway Shopping Centre at the corner of City Rd and Parramatta Rd features all of the usual fare you would expect in a large shopping complex with a large food court offering everything from burgers to kebabs and sushi.
- Glebe Point Road: Glebe Point Road features numerous restaurants and pubs and is a short walk across Victoria Park.

## Dinner/Bars

### Restaurants:

Sydney has too many restaurants to name. However, various suburbs are known for their particular styles of cuisine. Some of these are listed below.

- **Newtown:** Located within a few minutes walk of the University of Sydney campus, King St in Newtown has a reputation for quality, low cost eateries. Every other restaurant seems to be serve up tasty Thai meals but there are also a variety of gourmet burger bars, Mexican, Vietnamese, Nepalese and Japanese options available.
- **Glebe:** Glebe Point Road is located across Victoria Park (yes, the Victoria Park for those of you who have worked with the early SLAM datasets). It features numerous restaurants ranging from modern Australian to Spanish, Mexican and others.
- **China Town:** Sydney's China Town is nestled on the outskirts of the downtown precinct. It is easily accessible from Town Hall or Central station. It features a wide variety of Chinese options, from small holes in the wall to Yum Cha and fine dining. Prepare to be accosted by restaurant staff offering great deals to lure you into their premises.
- **Darling Harbour:** Darling Harbour features a variety of eateries to suit all palates. With a number of pubs as well as fine dining this makes for a good night out. Take a train to Central Station or Town Hall and follow the signs to Darling Harbour.
- **Leichardt:** Norton St. in the inner west suburb of Leichardt (a few minutes drive or bus down Parramatta road from the University) is known for its outstanding Italian eateries.
- **Circular Quay:** Circular Quay features a number of eateries. Be wary of the tourist traps in the Circular Quay train station but the Overseas Passenger Terminal features some outstanding restaurants with views over the Opera House and Harbour Bridge.
- **The Rocks:** Once a somewhat rundown area on the outskirts of downtown, the Rocks has been transformed into a vibrant area of the city, featuring narrow cobblestoned streets and a variety of pubs and restaurants. The Sunday markets are a bit of an institution and feature live music as well as stalls selling all manner of arts and crafts.

### Pubs:

- **The Rose:** A character filled pub next to the Sydney University Engineering precinct this pub is popular with ACFR staff and students. A great range of local beer, wine and cocktails as well as an extensive menu make for a great night out.
- **The Nag's Head:** A few minutes walk from the RSS 2012 conference venue, this English style pub and eatery features a good selection of beer and wine with a nice bistro out the back. Definitely worth a visit.
- **The Opera Bar:** The Opera Bar sits just under the Opera House forecourt, looking out over Circular Quay and the Harbour Bridge. A fantastic place to grab a drink or a bite to eat and unwind after a hard day's work (or for a lazy Sunday afternoon).
- **The Lord Nelson:** Sydney's oldest licensed hotel, the Lord Nelson is located in the heart of the Rocks. They serve up a terrific selection of beers brewed on the premises.

- The Hero of Waterloo: Another Rocks stalwart, the Hero of Waterloo is a convict built pub that has withstood the test of time. Featuring live music and a good selection of food and beverage options.
- The Argyle: A modern take on the great Australian pub tradition serving up meals and a variety of local and imported wine and beer in the Rocks.
- The Löwenbräu: Located in the Rocks, the Löwebräu is modelled on a traditional German beer garden and serves up hearty meals and large german style beers.
- The Bavarian Beer Cafe: Located on the East side of the city, this pub features a variety of Bavarian style ales.
- Redoak: The Redoak Boutique Beer Cafe, located near Town Hall Station Station, has been voted Best Specialty Beer Venue and feature a range of boutique beers brewed onsite.
- Local Taphouse: The Local Taphouse in Darlinghurst operates as a neighbourhood bar with a diverse of specialty and boutique beers. Their burgers come highly recommended.
- Manly Wharf Bar: Manly's Wharf Bar sits out on the Ferry Terminal wharf at Manly. Taking a ferry to Manly is a great way to see the Harbour and you're sure to find some refreshing beverages waiting for you on your arrival.

### **Cocktail Bars (From Sydney's Best Bar Awards 2012):**

- Victoria Room: "The Victoria Room is the real deal, combining craft cocktails, incredible bartender knowledge and a beautiful venue."
- Eau de Vie: "This speakeasy-style bar has a wealth of talented bartenders working with exceptional hooch. It's an industry haunt, a den of iniquity, and probably the best fun you can have with a glass in your hand."
- Low 302: "The Crown Street stalwart has been delivering on the cocktail front since '09 and they're showing no signs of slowing down. You might go for a beer (and many do) but you'd be mad not to stay for a Gimlet."
- Rockpool Bar and Grill: "If there's one place in Sydney you're guaranteed to get a great drink and a great snack, it's here. Bartenders make their own sodas and syrups and can rustle up a tasty drink faster than you can say Julep"
- Shady Pines: "They'll pour you a beer as fast as they pour a Sazerac and all with the same level of attention and care. If you haven't had them make you a Negroni topped with Coke (blasphemous!) then you haven't truly lived."

## **What to Do**

Within easy access of the University and the city:

- Sydney Aquarium: Arguably Australia's most popular tourist attraction, the Sydney Aquarium is located at Darling Harbour. See a variety of displays including coral reefs, a crocodile and the always popular shark tunnel walk.
- Wildlife World: Right next door to the Aquarium (and available for combined entry on a double pass), Wildlife World provides close access to a variety of Australian wildlife. A great opportunity to see some kangaroos and wallabies and to get up close and personal with a Koala.

- **Opera House:** Sydney's iconic Opera House sits on a spit of land in the Harbour between Circular Quay and the Botanical Gardens. The Opera House features many varieties of music, theatre and dance performance. Daily tours are also available for those wanting a behind the scenes look at this landmark building.
- **Bridge Climb:** For a different perspective on this cosmopolitan city, book in to climb the Sydney Harbour Bridge. Look down over the Opera House, the Harbour and Sydney's downtown from the lofty heights of this spectacular structure.
- **Botanical Gardens:** Take a tour of the Botanical Gardens to see a variety of trees and plants from around the world. The giant figs have to be seen to be believed and keep an eye out for the thousands of flying foxes (a giant fruit bat) roosting in the trees. The bats come out at night to circle the city searching for a meal.
- **Darling Harbour:** Darling Harbour features one of the highest concentrations of tourist attractions in the city. With the Aquarium, Wildlife world, the Powerhouse Museum, the IMAX theatre, the Japanese Gardens, the Maritime Museum and countless restaurants and bars this is a great spot for a night out or a day of shopping.
- **Bondi Beach:** The crescent of sand that makes up Bondi Beach is a great place to take a dip or catch a few waves. Popular with tourists and locals alike the beach is packed with sun bathers on a hot summer's day. Even in the middle of winter, Bondi attracts many visitors. Consider taking the Bronte walking track along the seaside cliffs on the south end of the beach.
- **Ferry to Manly Beach:** Take a ferry from Circular Quay to see a bit of the Harbour and the stately homes overlooking this spectacular waterway. Manly, one of Sydney's favourite beachside suburbs, features a pedestrian corso, great beaches for surfing, snorkelling or splashing in the waves and the Wharf Bar is a favourite amongst locals. The spit bridge walk is a popular city walk that takes in some of the local feel of the suburb.
- **Whale Watching:** June and July are prime whale watching months off the coast of Sydney. A number of tour operators will take you out to sea to witness the migration of the Humpback whales making their way North to Queensland for the winter. You may also catch sight of dolphins riding the bow wave of the boat.

Further afield:

- **Hunter Valley:** The Hunter Valley is approximately 2 hours north of Sydney. It features a variety of boutique wineries as well as some more familiar names in the wine industry. Some of Australia's most popular wines are made here. Tours to the Hunter Valley range from day tours to multiple days ensconced in a cottage by a vineyard with a glass of local wine always close at hand.
- **The Blue Mountains:** An hour and a half west of Sydney are the Blue Mountains. This range of hills forms part of the Great Dividing range which runs along the east coast of Australia. The spectacular red cliffs are a must see. Trains from Central Station head up to Katoomba and the iconic Three Sisters rock formation. There is some fantastic 'bush walking' (hiking) as well as abseiling, rock climbing and canyoning for the more adventurous.
- **Jervis Bay:** About 3 hours south of Sydney, Jervis Bay is a popular holiday destination for Sydneysiders. The bay features pristine white sandy beaches, national parks and resident dolphin populations.
- **Nelson Bay:** Around 3 hours north of Sydney, Nelson Bay and Port Stephens are also popular holiday destinations and are another great place for a bit of dolphin watching or R and R. A visit to Nelson Bay can be combined with a stop in the Hunter Valley for a great couple of days that is easily accessible from Sydney.

- The Great Barrier Reef: One of Australia's must see holiday destinations is a few hour flight away. The reef is accessible from Cairns, Port Douglas, Townsville and the Whitsunday Islands. Diving and snorkelling tours are popular and private sailing charters can be organised from the Whitsunday Islands to really escape from it all.
- Uluru: Uluru, formerly known as Ayer's Rock, is a large sandstone rock formation in central Australia. It is a popular tourist destination and is accessible from Alice Springs.

# Technical Program

## Overview

Monday	Tuesday	Wednesday	Thursday	Friday
	8:30-10:00 Workshops			
	10:00-10:30 Coffee Break			
	10:30-12:00 Workshops			10:30-12:00 ACFR Lab Tour
	12:00-13:15 Lunch		12:00-13:00 Lunch	
	13:15-14:05 Invited Talk		13:00-13:50 Invited Talk	13:00-15:00 Fellowship
	14:05-15:20 Oral Session 1		13:50-15:05 Oral Session 1	
	15:20-15:45 Coffee Break		15:05-15:30 Coffee Break	
	15:45-17:00 Oral Session 2		15:30-17:00 Oral Session 2	
	17:00-18:30 Interactive Poster Sessions			
			18:30-Late Banquet	

**Monday, July 9, 2012**
**8:30-10:00 Workshops**

W1: *Generating Robot Motion for Contact with the World (H113)*

W2: *Resource-Efficient Integration of Perception and Control for Highly Dynamic Mobile Systems (S418)*

W3: *Robots in Clutter: Manipulation, Perception and Navigation in Human Environments (S223)*

W4: *RGB-D: Advanced Reasoning with Depth Cameras (S204)*

W5: *Algorithmic Frontiers in Medical Robotics: Coping with Uncertain, Deformable, Heterogenous Environments (S421)*

**10:00-10:30 Coffee Break**
**10:30-12:00 Workshops Continued**
**12:00-13:15 Welcome Lunch**
**13:15-14:05 Invited Talk**

*The robot and the philosopher: charting progress at the Turing centenary*

Anders Sandberg

**14:05-14:30 5 Minute Talks**

*Towards Persistent Localization and Mapping with a Continuous Appearance-based Topology*

William Maddern, Michael Milford, Gordon Wyeth

*Turning-rate Selective Control: A New Method for Independent Control of Stress-engineered MEMS Microrobots*

Igor Paprotny, Christopher Levey, Bruce Donald

*Rigidity Maintenance Control for Multi-Robot Systems*

Daniel Zelazo, Antonio Franchi, Frank Allgöwer, Heinrich Bühlhoff, Paolo Robuffo Giordano

*State Estimation for Legged Robots - Consistent Fusion of Leg Kinematics and IMU*

Michael Bloesch, Marco Hutter, Mark Hoepflinger, Stefan Leutenegger, Christian Gehring, C. David Remy, Roland Siegwart

*Toward Information Theoretic Human-Robot Dialog*

Stefanie Tellex, Pratiksha Thaker, Robin Deits, Thomas Kollar, Nicholas Roy

**14:30-14:55 Award Talk**

*Towards A Swarm of Agile Micro Quadrotors*

Aleksandr Kushleyev, Vijay Kumar, Daniel Mellinger

**14:55-15:20 5 Minute Talks**

*Exploiting Passive Dynamics with Variable Stiffness Actuation in Robot Brachiation*

Jun Nakanishi, Sethu Vijayakumar

*Parsing Indoor Scenes Using RGB-D Imagery*

Camillo Taylor, Anthony Cowley

*Probabilistic Modeling of Human Dynamics for Intention Inference*

Zhikun Wang, Marc Deisenroth, Heni Ben Amor, David Vogt, Bernhard Schölkopf, Jan Peters

*Efficiently Finding Optimal Winding-Constrained Loops in the Plane*

Paul Vernaza, Venkatraman Narayanan

*Time-Optimal Trajectory Generation for Path Following with Bounded Acceleration and Velocity*

Tobias Kunz, Mike Stilman

**15:20-15:45 Coffee Break****15:45-16:10 Award Talk**

*Affine Trajectory Deformation for Redundant Manipulators*

Quang-Cuong Pham, Yoshihiko Nakamura

**16:10-16:35 5 Minute Talks**

*Robust Object Grasping using Force Compliant Motion Primitives*

Moslem Kazemi, Jean-Sebastien Valois, J. Andrew Bagnell, Nancy Pollard

*Multi-Stage Micro Rockets for Robotic Insects*

Mirko Kovac, Rohit Krishnan, Maria Bendana, Jessica Burton, Michael Smith, Robert Wood

*Extrinsic Calibration from Per-Sensor Egomotion*

Jonathan Brookshire, Seth Teller

*Probabilistic Temporal Logic for Motion Planning with Resource Threshold Constraints*

Chanyeol Yoo, Robert Fitch, Salah Sukkarieh

**16:35-17:00 Early Career Spotlight**

*Towards Motor Skill Learning for Robotics*

Jan Peters

**17:00-18:30 Interactive Poster Session**

<b>Tuesday, July 10, 2012</b>
-------------------------------

**8:30-10:00 Workshops**

W1: *Generating Robot Motion for Contact with the World (H113)*

W2: *Resource-Efficient Integration of Perception and Control for Highly Dynamic Mobile Systems (S418)*

W3: *Robots in Clutter: Manipulation, Perception and Navigation in Human Environments (S223)*

W4: *RGB-D: Advanced Reasoning with Depth Cameras (S204)*

W5: *Algorithmic Frontiers in Medical Robotics: Coping with Uncertain, Deformable, Heterogenous Environments (S421)*

T1: *Machine Learning for Robotics: Old Dreams, New Tools (Great Hall)*

**10:00-10:30 Coffee Break****10:30-12:00 Workshops Continued****12:00-13:15 Lunch Break****13:15-14:05 Invited Talk**

*Small Brains, Smart Planes*

Mandyam Srinivasan

**14:05-14:30 5 Minute Talks**

*Recognition and Pose Estimation of Rigid Transparent Objects with a Kinect Sensor*

Ilya Lysenkov, Victor Eruhimov, Gary Bradski

*On the Structure of Nonlinearities in Pose Graph SLAM*

Heng Wang, Gibson Hu, Shoudong Huang, Gamini Dissanayake

*Hybrid Operational Space Control for Compliant Legged Systems*

Marco Hutter, C. David Remy, Mark Hoepflinger, Christian Gehring, Michael Bloesch, Roland Siegwart

*Asymptotically-optimal Path Planning on Manifolds*

Leonard Jaillet, Josep Porta

*Physics-Based Grasp Planning Through Clutter*

Mehmet Dogar, Kaijen Hsiao, Matei Ciocarlie, Siddhartha Srinivasa

**14:30-14:55 Award Talk**

*Formalizing Assistive Teleoperation*

Anca Dragan, Siddhartha Srinivasa

**14:55-15:20 5 Minute Talks**

*The Banana Distribution is Gaussian: A Localization Study with Exponential Coordinates*  
Andrew Long, Kevin Wolfe, Michael Mashner, Gregory Chirikjian

*Modeling and Prediction of Pedestrian Behavior based on the Sub-goal Concept*  
Tetsushi Ikeda, Yoshihiro Chigodo, Daniel Rea, Francesco Zanlungo, Masahiro Shiomi, Takayuki Kanda

*Real-Time Inverse Dynamics Learning for Musculoskeletal Robots based on Echo State Gaussian Process Regression*

Christoph Hartmann, Joschka Boedecker, Oliver Obst, Shuhei Ikemoto, Minoru Asada

*M-Width: Stability and Accuracy of Haptic Rendering of Virtual Mass*

Nick Colonnese, Allison Okamura

**15:20-15:45 Coffee Break****15:45-16:10 Award Talk**

*Walking and Running on Yielding and Fluidizing Ground*

Feifei Qian, Tingnan Zhang, Chen Li, Aaron Hoover, Pierangelo Masarati, Paul Birkmeyer, Andrew Pullin, Ronald Fearing, Dan Goldman

**16:10-16:35 5 Minute Talks**

*Nonparametric Bayesian Models for Unsupervised Scene Analysis and Reconstruction*

Dominik Joho, Gian Diego Tipaldi, Nikolas Engelhard, Cyrill Stachniss, Wolfram Burgard

*A Distributable and Computation-flexible Assignment Algorithm: From Local Task Swapping to Global Optimality*

Lantao Liu, Dylan Shell

*What's in the Bag: A Distributed Approach to D Fabrication by Duplication with Modular Robots*

Kyle Gilpin, Daniela Rus

*What Types of Interactions do Bio-Inspired Robot Swarms and Flocks Afford a Human?*

Michael Goodrich, Sean Kerman, Brian Pendleton, P.B. Sujit

**16:35-17:00 Early Career Spotlight**

*Mobile Manipulation for Healthcare*

Charlie Kemp

**17:00-18:30 Interactive Poster Session**

<b>Wednesday, July 11, 2012</b>
---------------------------------

**8:30-10:00 Workshops**

W6: *Long-term operation of autonomous robotic systems in changing environment (Great Hall)*

W7: *Stochastic Motion Planning and Information-Based Control (S204)*

W8: *Beyond laser and vision: alternative sensing techniques for robotic perception (H113)*

W9: *Biologically Inspired Robotics (S418)*

W10: *Robotics for Environmental Monitoring (S223)*

**10:00-10:30 Coffee Break****10:30-12:00 Workshops Continued****12:00-13:15 Lunch Break****13:15-14:05 Invited Talk**

*Single Atom Devices for Quantum Computing*

Michelle Simmons

**14:05-14:30 5 Minute Talks**

*Robust Navigation Execution by Planning in Belief Space*

Bhaskara Marthi

*Failure Anticipation in Pursuit-Evasion*

Cyril Robin, Simon Lacroix

*Inference on Networks of Mixtures for Robust Robot Mapping*

Edwin Olson, Pratik Agarwal

*Recognition, Prediction, and Planning for Assisted Teleoperation of Freeform Tasks*

Kris Hauser

*Hierarchical Motion Planning in Topological Representations*

Dmitry Zarubin, Vladimir Ivan, Marc Toussaint, Taku Komura, Sethu Vijayakumar

**14:30-14:55 Award Talk**

*Visual Route Recognition with a Handful of Bits*

Michael Milford

**14:55-15:20 5 Minute Talks**

*CompAct Arm: a Compliant Manipulator with Intrinsic Variable Physical Damping*  
Matteo Laffranchi, Nikos Tsagarakis, Darwin Caldwell

*Fast Weighted Exponential Product Rules for Robust Distributed Data Fusion in General Multi-Robot Networks*

Nisar Ahmed, Jonathan Schoenberg, Mark Campbell

*Estimating Human Dynamics On-the-fly Using Monocular Video For Pose Estimation*  
Priyanshu Agarwal, Suren Kumar, Julian Ryde, Jason Corso, Venkat Krovi

*Colour-Consistent Structure-from-Motion Models using Underwater Imagery*  
Mitch Bryson, Matthew Johnson-Roberson, Oscar Pizarro, Stefan Williams

**15:20-15:45 Coffee Break****15:45-16:10 Award Talk**

*On Stochastic Optimal Control and Reinforcement Learning by Approximate Inference*  
Konrad Rawlik, Marc Toussaint, Sethu Vijayakumar

**16:10-16:35 5 Minute Talks**

*Optimization-Based Estimator Design for Vision-Aided Inertial Navigation*  
Mingyang Li, Anastasios Mourikis

*Development of a Testbed for Robotic Neuromuscular Controllers*  
Alexander Schepelmann, Hartmut Geyer, Michael Taylor

*Distributed Approximation of Joint Measurement Distributions Using Mixtures of Gaussians*

Brian Julian, Stephen Smith, Daniela Rus

*Robust Loop Closing Over Time*  
Yasir Latif, Cesar Cadena Lerma, José Neira,

**16:35-17:00 Early Career Spotlight**

*Towards Lifelong Navigation for Mobile Robots*  
Cyrill Stachniss

**17:00-18:30 Interactive Poster Session**

<b>Thursday, July 12, 2012</b>
--------------------------------

**8:30-10:00 Workshops**

W6: *Long-term operation of autonomous robotic systems in changing environment (Great Hall)*

W7: *Stochastic Motion Planning and Information-Based Control (S204)*

W8: *Beyond laser and vision: alternative sensing techniques for robotic perception (H113)*

W11: *From theory to practice of performance comparison and result replications in Robotics Research (S418)*

W12: *Workshop on Aerial Robotics and the Quadrotor Platform (S421)*

**10:00-10:30 Coffee Break****10:30-12:00 Workshops Continued**

**12:00-13:00 Lunch Break. Please note that today's invited talk begins 15 minutes earlier than usual, at 13:00.**

**13:00-13:50 Invited Talk**

*Machine Learning as Probabilistic Modeling*

Zoubin Ghahramani

**13:50-14:15 5 Minute Talks**

*Practical Route Planning Under Delay Uncertainty: Stochastic Shortest Path Queries*  
Sejoon Lim, Christian Sommer, Evdokia Nikolova, Daniela Rus

*Optimization of Temporal Dynamics for Adaptive Human-Robot Interaction in Assembly Manufacturing*

Ronald Wilcox, Stefanos Nikolaidis, Julie Shah

*Contextual Sequence Prediction with Application to Control Library Optimization*  
Debadeepta Dey, Tian Yu Liu, Martial Hebert, J. Andrew Bagnell

*Variational Bayesian Optimization for Runtime Risk-Sensitive Control*  
Scott Kuindersma, Roderic Grupen, Andrew Barto

**14:15-14:40 Award Talk**

*Minimal Coordinate Formulation of Contact Dynamics in Operational Space*

Abhinandan Jain, Cory Crean, Calvin Kuo, Hubertus von Bremen, Steven Myint

**14:40-15:05 5 Minute Talks**

*Tendon-Driven Variable Impedance Control Using Reinforcement Learning*

Eric Rombokas, Mark Malhotra, Evangelos Theodorou, Yoky Matsuoka, Emanuel Todorov

*An Object Based Approach to Map Human Hand Synergies onto Robotic Hands with Dissimilar Kinematics*

Guido Gioioso, Gionata Salvietti, Monica Malvezzi, Domenico Prattichizzo

*Feature-Based Prediction of Trajectories for Socially Compliant Navigation*

Markus Kuderer, Henrik Kretzschmar, Christoph Sprunk, Wolfram Burgard

*E-Graphs: Bootstrapping Planning with Experience Graphs*

Michael Phillips, Benjamin Cohen, Sachin Chitta, Maxim Likhachev

**15:05-15:30 Coffee Break****15:30-15:55 Award Talk**

*Experiments with Balancing on Irregular Terrains using a Mobile Humanoid Robot*

Luis Sentis, Josh Petersen, Roland Philippsen

**15:55-16:20 5 Minute Talks**

*FFT-based Terrain Segmentation for Underwater Mapping*

Bertrand Douillard, Navid Nourani-Vatani, Matthew Johnson-Roberson, Stefan Williams, Chris Roman, Oscar Pizarro, Ian Vaughn, Gabrielle Inglis

*Guaranteeing High-Level Behaviors while Exploring Partially Known Maps*

Shahar Sarid, Bingxin Xu, Hadas Kress-Gazit

*Optimal Control with Weighted Average Costs and Temporal Logic Specifications*

Eric Wolff, Ufuk Topcu, Richard Murray

*Reducing Conservativeness in Safety Guarantees by Learning Disturbances Online: Iterated Guaranteed Safe Online Learning*

Jeremy Gillula, Claire Tomlin

**16:20-17:00 Invited Talk**

*Enter the Dragon: The SpaceX COTS Missions*

Andrew Howard

**17:00-18:30 Interactive Poster Session**

## Workshops

### W1. Generating Robot Motion for Contact with the World

**Dates:** July 9 & 10

**Room:** The Refectory H113

**Organizers:**

Mihail Pivtoraiko (University of Pennsylvania)

Dov Katz (Carnegie Mellon University)

Oliver Brock (TU Berlin)

**Description:** The aim of this proposed workshop is to discuss the state of the art in mobile manipulation research. Robust, reliable mobile manipulation is critical for robotics applications in the home, health care and retail industries. The workshop will focus on research at the intersection of motion generation and manipulation contact.

### W2. Resource-Efficient Integration of Perception and Control for Highly Dynamic Mobile Systems

**Dates:** July 9 & 10

**Room:** MacRae Room S418

**Organizers:**

Michael Suppa (DLR – Institute of Robotics and Mechatronics)

Darius Burschka (TU Munich)

Konstantinos Dalamagkidis (TU Munich)

Korbinian Schmid (DLR - Institute of Robotics and Mechatronics)

**Description:** Subjects of interest include, but are not limited to:

- Robust and accurate perception from limited sensing on light-weight, resource-limited systems (e.g. fusion approaches with an emphasis on error-tolerance and extension of the dynamic range observable)
- Planning and control approaches for highly dynamic systems to cope with the disadvantages of limited sensing on small platforms
- Interaction between internal representation and low-/high-level control for scalable action generation under degrading perceptive conditions
- Integration of perception with action/reaction approaches towards improved performance and safety in small unmanned systems
- Collaborative multi-system approaches to perception and perception/action solutions for planning and control of unmanned systems with limited sensing.
- Novel sensor designs and sensing strategies integrated into resource-limited mobile autonomous systems.

### **W3. Robots in Clutter: Manipulation, Perception and Navigation in Human Environments**

**Dates:** July 9 & 10

**Room:** History Room S223

**Organizers:**

Mehmet Dogar (Carnegie Mellon University)

Siddhartha Srinivasa (Carnegie Mellon University)

Greg Hager (Johns Hopkins)

Kaijen Hsiao (Willow Garage)

Matei Ciocarlie (Willow Garage)

**Description:** Robots operating in our homes will inevitably be confronted with scenes that are simultaneously congested, unorganized, diverse and complex - or, simply put, cluttered. Clutter is a universal problem and severely affects all robot operations: manipulation, perception, navigation, and sensing. This makes it extremely difficult for a single approach to effectively handle clutter, perhaps explaining why robots (and robotics researchers) often shy away from it.

This workshop aims to bring researchers from different domains together and promote a discussion about clutter. This will contribute to robotics research in at least two ways. First, it will be a venue for the exchange of strategies, ideas, and algorithms used by individual domains. Second, it will provide an opportunity to discuss system-level approaches where manipulation, perception, and navigation work together. We hope to explore directions that will accelerate the deployment of robots into real human settings performing useful tasks even in the presence of clutter.

### **W4. RGB-D: Advanced Reasoning with Depth Cameras**

**Dates:** July 9 & 10

**Room:** Oriental Room S204

**Organizers:**

Dieter Fox (University of Washington)

Kurt Konolige (Willow Garage Inc.)

Jana Kosecka (George Mason University)

Xiaofeng Ren (University of Washington)

**Description:** RGB-D (Kinect-style) cameras provide real-time color and dense depth data through active sensing, combining the strengths of passive cameras and laser rangefinders. At \$150 a piece, affordable RGB-D cameras are quickly being adopted as the de facto device for robot perception. At two previous years' RSS conferences, the RGB-D workshops successfully brought together experts from multiple disciplines for presenting and discussing cutting-edge work. Two years after the Kinect release, this year's RGB-D workshop seeks to continue hosting latest developments in RGB-D perception, leading and facilitating efforts across research topics, and building an emerging research community. Our workshop welcomes high-quality work on all topics related to robotics and RGB-D. We will particularly promote and encourage contributions on two major directions in RGB-D perception: (1) large-scale 3D mapping, using RGB-D cameras to modeling indoor environments in geometry and color as well as semantic structures; and (2) human-robot interaction, applying RGB-D perception to understand humans and to enable robots to perform tasks together with humans.

**W5. Algorithmic Frontiers in Medical Robotics: Coping with Uncertain, Deformable, Heterogenous Environments****Dates:** July 9 & 10**Room:** S421**Organizers:**

Dmitry Berenson (UC Berkeley)

Ron Alterovitz (UNC Chapel Hill)

Pieter Abbeel (UC Berkeley)

Ken Goldberg (UC Berkeley)

**Description:** Medical robotics is a rapidly-growing field with new devices and methods emerging from industry, academia, and the medical community. One of the great frontiers in this field lies at the algorithmic level. How can we model and simulate 3D deformable tissues? How do we overcome the uncertainty inherent in surgical interventions? How can we integrate motion planning and control with an intuitive user interface? What advances in hardware can be enhanced with algorithmic components? The purpose of this workshop is to bring together researchers, engineers, and physicians studying the above questions and also to discuss applications of methods in robotics to problems in medicine.

**W6. Long-term operation of autonomous robotic systems in changing environment****Dates:** July 11 & 12**Room:** The Great Hall**Organizers:**

Daniel Meyer-Delius (KUKA Laboratories GmbH)

Patrick Pfaff (KUKA Laboratories GmbH)

Gian Diego Tipaldi (University of Freiburg)

**Description:** The reliable operation of autonomous systems over extended periods of time has been gaining increasing attention in recent years. It is a key aspect in many research projects and a fundamental requirement for any mobile robotic application in the industry. The aim of this workshop is to bring together researchers from different fields and provide a place for discussing the theoretical and practical challenges associated to the reliable operation of autonomous systems over extended periods of time in changing environment.

**W7. Stochastic Motion Planning and Information-Based Control****Dates:** July 11 & 12**Room:** Oriental Room S204**Organizers:**

Mac Schwager (Boston University)

Michael Vitus (Stanford)

Sertac Karaman (MIT)

Claire Tomlin (UC Berkeley)

**Description:** Two fundamental problems in robotics are (1) planning a motion for a robot to accomplish a specified task in an uncertain environment, and (2) controlling a robot so that its motion maximally reduces its uncertainty about the environment. These two problems are intimately linked; stochastic motion

planners implicitly drive robots to reduce their uncertainty about the environment to ensure that the goal is reached. Despite this strong link, research in these two topics has largely proceeded independently from one another. This workshop will seek to bring together leading researchers in stochastic motion planning and in information-based control to fuel an exchange of ideas between these two communities. We will design a full day program of invited talks and submitted posters aimed at illuminating synergies between these problems, and spurring advances in both of them. We will solicit presentations in current stochastic motion planning (SMP) research areas, including SMP in unknown or uncertain environments; SMP formulated as a chance constrained optimization program, randomized SMP techniques, SMP in non-Gaussian belief spaces, multi-robot SMP, and SMP applications in robotic navigation, grasping and surgery. We will also solicit presentations in information-based control research topics, for example control with mutual information gradients, information surfing, informative path planning, model predictive control with entropy-based cost, active sensing, and multi-robot information-based control. Sessions will include a dedicated time for discussion among the speakers and the audience, directed by the organizers to address areas of common interest between stochastic motion planning and information-based control.

### **W8. Beyond laser and vision: alternative sensing techniques for robotic perception**

**Dates:** July 11 & 12

**Room:** The Refectory H113

**Organizers:**

Thierry Peynot (ACFR, The University of Sydney)

Sildomar Monteiro (ACFR, The University of Sydney)

Michel Devy (LAAS-CNRS, France)

Alonzo Kelly (Carnegie Mellon University, USA)

**Description:** Perception based on traditional sensing (a visual camera or a laser range finder) has led to significant realisations in relatively controlled and restricted situations. However, it has also shown important limitations in challenging environments: for example, in the context of field robotics, the presence of airborne dust, smoke, heavy rain or thick fog. As a result, despite significant progress over the last decade, perception arguably remains the bottleneck of greater achievements in robotics.

The future of robotic perception lies in two key elements: “alternative” sensing and intelligent combination of multiple sensing modalities. Robots have an advantage over humans that has been under-exploited so far: they can also sense the environment at various electromagnetic frequencies outside of the visible spectrum, i.e. through alternative sensing modalities. These sensor modalities have opened a range of new possibilities. Examples include: automatic geological analysis using hyperspectral cameras, perception through smoke with infrared imaging, obstacle detection in a dust storm using mm-wave radars or even people detection through walls thanks to Ultra-Wideband radars. Furthermore, by combining data from different sensing modalities that include such alternative sensors, richer environment models can be obtained and higher perception integrity may be achieved. The main purpose of this workshop is to explore and discuss how alternative sensing and original combinations of sensor data: induce new challenges and perspectives, yield to rethinking conventional perception and data fusion algorithms, open a new range of robotic applications and put the next great robotic achievements within reach.

### **W9. Biologically Inspired Robotics**

**Dates:** July 11 & 12

**Room:** McRae Room S418

**Organizers:** Noah Cowan (Johns Hopkins University) Soon-Jo Chung (University of Illinois at Urbana-Champaign) Xinyan Deng (Purdue University)

**Description:** Animals exploit a wide variety of mechanisms for movement, navigation, control, and learning. And, while some engineering systems outperform most biological systems in certain respects (raw speed for example), there is no doubt that animals dramatically outperform their robotic counterparts in complex environments. This workshop will explore shared principles of robotic and biological sensing, actuation, control, and learning.

**Workshop Activities:** The goal of this workshop is to bring together engineers and biologists for a half-day meeting to identify and discuss emerging topics and challenges in both communities. The workshop will include invited presentations by researchers from both communities. In addition there will be a poster session comprising submitted abstracts. Invited speakers will participate in an open, interactive panel discussion, with the goal of formulating a new vision for opportunities at the interface between science and engineering.

### **W10. Robotics for Environmental Monitoring**

**Dates:** July 11

**Room:** History Room S223

**Organizers:** Ryan N. Smith (Queensland University of Technology)

Lino Marques (Institute of Systems and Robotics)

Ibrahim Volkan Isler (University of Minnesota)

Matthew Dunbabin (CSIRO ICT Centre)

**Description:** Major advances in robotics have been achieved in recent decades, with robots moving from the common manipulator, fixed on the factory floor, to more flexible and autonomous devices, capable of operating in natural and unstructured environments. Today, robots play a fundamental role as data acquisition tools for studying our planet. Some example applications include ocean floor sampling, tracking of plumes, tracking pollution, and monitoring volcanic activity. Design and implementation of robotic systems for environmental research presents significant challenges to robotics researchers. This workshop will bring together researchers with various backgrounds relevant to this multidisciplinary field of research with the intention of creating collaborative links between these communities through sharing recent results and discussing research directions. Presentations will come from researchers in field robotics, environmental sensing, sensor networks, environmental data processing, low-energy robot design, algorithm design, telemetry, energy harvesting, environmentally constrained path planning, multi-scale sampling, and coordination of heterogeneous systems.

### **W11. From theory to practice of performance comparison and result replications in Robotics Research**

**Dates:** July 12

**Room:** McRae Room S418

**Organizers:**

Fabio Bonsignorio (Univeristy Carlos III de Madrid)

Angel P. Del Pobi (Jaume I University)

John Hallam (University of Southern Denmark)

**Description:** In 2008 we proposed a set of general guidelines to improve experimental methodology and reporting in robotics in order to facilitate experiment replication and performance evaluation and comparison. We are now at a point where it is possible to give concrete directions for experiment planning and execution, potentially affecting the content of obtained results, not only their 'production process'. One of the raised objections is the huge variety of subfields in robotics. The objective of this workshop will be to identify and

outline the common ground between two subareas of research: Visual Servoing and SLAM. It is time to pass from theory to practice, we will discuss the issues and provide examples.

## **W12. Workshop on Aerial Robotics and the Quadrotor Platform**

**Dates:** July 12

**Room:** Room S421

### **Organizers:**

Peter Corke (Queensland University of Technology)

Robert Mahony (Australian National University)

Roland Siegwart (ETHZ)

**Description:** This workshop will focus on “robotics problems” in the deployment of aerial vehicles. In particular, the workshop will consider questions of perception, manoeuvrability, autonomy, and physical interaction for aerial robotic vehicles. The workshop will feature presentations by key researchers in Europe, America and Australasia that provide a perspective on the most challenging problems that are being considered at the moment in their geographical regions. In addition, there will be significant time set aside for interactive discussion with opportunity for significant input from the audience to determine the key technological and scientific problems for aerial vehicles that face the robotics community.

## **Tutorials**

### **T1. Machine Learning for Robotics: Old Dreams, New Tools**

**Dates:** July 10

**Room:** The Great Hall

### **Organizers:**

Prof. Sethu Vijayakumar (University of Edinburgh)

Prof. Marc Toussaint (FU Berlin)

**Description:** This tutorial will introduce novel approaches to solving classical problems in robot planning and adaptive control by exploiting the recent advances in statistical machine learning. We will present inference planning methods capable of incorporating uncertainty in a natural way, working at multiple hierarchies and most importantly, bringing to bear the methods and guarantees of probabilistic inference techniques to the domain of robot planning. A unique interpretation of the stochastic optimal control formulation will aim to bridge the gap between inference planning techniques, path integral methods and reinforcement learning. We will look at how some of these planning methods can be used effectively to exploit additional redundancies in the emerging field of variable impedance actuation. Finally, we will look at the inner workings of one of the most successful online, incremental learning algorithms capable of working with high dimensional data – exploring its use for on the fly adaptation of dynamics in the context of Model Predictive Control.

## Invited Speakers

Monday through Thursday, at the beginning of the first oral session. On Thursday, also at the end of the second session.

### Anders Sandberg

Anders Sandberg has a Ph.D. in computational neuroscience from Stockholm University. He is currently James Martin Research Fellow at the Future of Humanity Institute at Oxford University. His research at FHI centres on societal and ethical issues surrounding human enhancement and new technology, estimating the capabilities and underlying science of future technologies, as well as issues surrounding global catastrophic risks. Topics of particular interest include enhancement of cognition, cognitive biases, artificial intelligence, neuroethics, rationality, robust reasoning, and public policy. He is also an associate of the Programme on the Impacts of Future Technology, the Oxford Uehiro Center for Practical Ethics and the Oxford Centre for Neuroethics, as well as co-founder of the Swedish think-tank Eudoxa.



**Talk title:** The robot and the philosopher: charting progress at the Turing centenary

### Mandyam Srinivasan

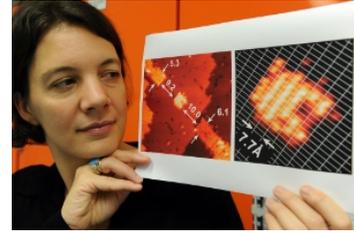
Srinivasan's research focuses on the principles of visual processing, perception and cognition in simple natural systems, and on the application of these principles to machine vision and robotics. He holds an undergraduate degree in Electrical Engineering from Bangalore University, a Master's degree in Electronics from the Indian Institute of Science, a Ph.D. in Engineering and Applied Science from Yale University, a D.Sc. in Neuroethology from the Australian National University, and an Honorary Doctorate from the University of Zurich. Srinivasan is presently Professor of Visual Neuroscience at the Queensland Brain Institute and the School of Information Technology and Electrical Engineering of the University of Queensland. Among his awards are Fellowships of the Australian Academy of Science, of the Royal Society of London, and of the Academy of Sciences for the Developing World, the 2006 Australia Prime Minister's Science Prize, the 2008 U.K. Rank Prize for Optoelectronics, the 2009 Distinguished Alumni Award of the Indian Institute of Science, and the Membership of the Order of Australia (AM).



**Talk title:** Small Brains, Smart Planes

## Michelle Simmons

Professor Simmons is the Director of the Australian Research Council Centre of Excellence for Quantum Computation and Communication Technology, a Federation Fellow and a Scientia Professor of Physics at the University of New South Wales. Following her PhD in solar engineering at the University of Durham in the UK she became a Research Fellow at the Cavendish Laboratory in Cambridge, UK, working with Professor Sir Michael Pepper FRS in quantum electronics. In 1999, she was awarded a QEII Fellowship and came to Australia where she was a founding member, and now the Director of the Centre of Excellence.



Since 2000 she has established a large research group dedicated to the fabrication of atomic-scale devices in silicon using the atomic precision of a scanning tunneling microscopy. Her group has developed the world's thinnest conducting wires in silicon and the smallest transistors made with atomic precision. She has published more than 300 papers in refereed journals and presented over 80 invited and plenary presentations at international conferences. In 2005 she was awarded the Pawsey Medal by the Australian Academy of Science and in 2006 became the one of the youngest elected Fellows of this Academy. In 2008 she was awarded a second Federation Fellowship by the Australian Government and was named the NSW Scientist of the Year in 2011.

**Talk title:** Single Atom Devices for Quantum Computing

## Zoubin Ghahramani

Zoubin Ghahramani is a Professor of Information Engineering at the University of Cambridge. He studied computer science and cognitive science at the University of Pennsylvania, obtained his PhD from MIT in 1995, and was a postdoctoral fellow at the University of Toronto. His academic career includes concurrent appointments as one of the founding members of the Gatsby Computational Neuroscience Unit in London, and as a faculty member of CMU's Machine Learning Department for over 10 years. His current research focuses on nonparametric Bayesian modelling and statistical machine learning. He has also worked on applications to bioinformatics, econometrics, and a variety of large-scale data modelling problems. He has over 200 publications in fields such as computer science, statistics, engineering, and neuroscience.



He has served on the editorial boards of several leading journals in the field, including JMLR, JAIR, Annals of Statistics, Machine Learning, Bayesian Analysis, and was Associate Editor in Chief of IEEE Transactions on Pattern Analysis and Machine Intelligence, the IEEE's highest impact journal. He also served on the Board of the International Machine Learning Society, and as Program Chair (2007) and General Chair (2011) of the International Conference on Machine Learning and will be Program Chair of NIPS (2013). More information can be found at <http://learning.eng.cam.ac.uk/zoubin/>.

**Talk title:** Machine Learning as Probabilistic Modeling

## Andrew Howard

Dr. Howard is Senior Guidance, Navigation and Control Engineer at Space Exploration Technologies and designer of the DragonEye proximity navigation system. Previously, he was a Senior Member of Technical Staff at the Jet Propulsion Laboratory, where he worked on vision-based navigation for a wide variety of projects, including Boston Dynamics' BigDog and the DARPA Crusher UGCV. Prior to joining JPL, he was a Research Assistant Professor at the University of Southern California Robotics Research Laboratory. Dr. Howard is a graduate of the University of Melbourne, with a degree in theoretical physics and PhD in computer science.



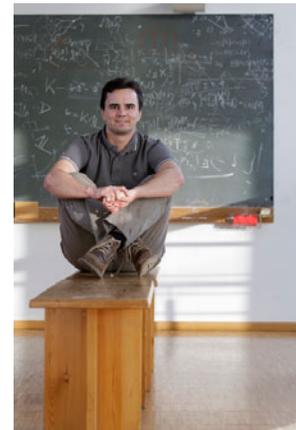
**Talk title:** Enter the Dragon: The SpaceX COTS Missions

## Early Career Spotlights

Monday through Wednesday, at the end of the second oral session.

### Jan Peters

Jan Peters is a full professor at the Technische Universitaet Darmstad and a senior research scientist at the Max Planck Institute for Intelligent Systems (MPI-IS) heading the interdepartmental robot learning group. Until 2011, he was senior research scientist at the Dept. for Empirical Inference and Machine Learning of the Max Planck Institute for Biological Cybernetics (MPI-KYB) in Tuebingen, Germany. He graduated from University of Southern California (USC) with a Ph.D. in Computer Science. He has completed masters degrees in Electrical Engineering (Dipl.-Ing./TU Muenchen), Informatics (Dipl-Inform./FernUni Hagen), Computer Science (M.Sc./USC) and Mechanical Engineering (M.Sc./USC). Jan Peters has been a visiting researcher at the Department of Robotics at the German Aerospace Research Center (DLR) in Oberpfaffenhofen, Germany, at Siemens Advanced Engineering (SAE) in Singapore, at the National University of Singapore (NUS), and at the Department of Humanoid Robotics and Computational Neuroscience at the Advanced Telecommunication Research (ATR) Center in Kyoto, Japan. His research interests include robotics, nonlinear control, machine learning, reinforcement learning, and motor skill learning.



**Talk title:** Towards Motor Skill Learning for Robotics

## Charlie Kemp

Charles C. Kemp (Charlie) is an Assistant Professor at the Georgia Institute of Technology in the Department of Biomedical Engineering. He is also an Adjunct Assistant Professor in the School of Interactive Computing and the School of Electrical and Computer Engineering. He received a doctorate in Electrical Engineering and Computer Science from MIT in 2005, and his BS and MEng from MIT. In 2007, he founded his lab, the Healthcare Robotics Lab at Georgia Tech (<http://healthcare-robotics.com>). His research focuses on mobile manipulation and human-robot interaction with an emphasis on robots for healthcare. He is an active member of the Center for Robotics and Intelligent Machines (RIM@GT) and Georgia Tech's multi-disciplinary Robotics Ph.D. program. He has received the 3M Non-tenured Faculty Award, the Georgia Tech Research Corporation Robotics Award, and the NSF CAREER award. His research has been covered extensively by the popular media, including the New York Times, Technology Review, ABC, and CNN.



**Talk title:** Mobile Manipulation for Healthcare

## Cyrill Stachniss

Cyrill Stachniss is a lecturer at the University of Freiburg in Germany. In 2009, he received his habilitation and *venia legendi* and also served as a guest lecturer at the University of Zaragoza. Before, he was a postdoc at Freiburg University and a senior researcher at the Swiss Federal Institute of Technology in the Autonomous Systems Lab of Roland Siegwart. In 2006, he finished his PhD thesis entitled "Exploration and Mapping with Mobile Robots", supervised by Wolfram Burgard, at the University of Freiburg. Since 2008, he is an associate editor of the IEEE Transactions on Robotics and since 2010 a Microsoft Research Faculty Fellow. In his research, he focuses on probabilistic techniques in the context of mobile robotics, perception, and navigation problems.



**Talk title:** Towards Lifelong Navigation for Mobile Robots

# Abstracts

## Monday, July 9, 2012: Oral Session 1

### *Towards Persistent Localization and Mapping with a Continuous Appearance-based Topology*

William Maddern, Michael Milford, Gordon Wyeth

**Abstract:**

Appearance-based localization can provide loop closure detection at vast scales regardless of accumulated metric error. However, the computation time and memory requirements of current appearance-based methods scale not only with the size of the environment but also with the operation time of the platform. Additionally, repeated visits to locations will develop multiple competing representations, which will reduce recall performance over time. These properties impose severe restrictions on long-term autonomy for mobile robots, as loop closure performance will inevitably degrade with increased operation time. In this paper we present a graphical extension to CAT-SLAM, a particle filter-based algorithm for appearance-based localization and mapping, to provide constant computation and memory requirements over time and minimal degradation of recall performance during repeated visits to locations. We demonstrate loop closure detection in a large urban environment with capped computation time and memory requirements and performance exceeding previous appearance-based methods by a factor of 2. We discuss the limitations of the algorithm with respect to environment size, appearance change over time and applications in topological planning and navigation for long-term robot operation.

**Schedule:** see page [16](#)

### *Turning-rate Selective Control: A New Method for Independent Control of Stress-engineered MEMS Micro-robots*

Igor Paprotny, Christopher Levey, Paul Wright, Bruce Donald

**Abstract:**

We present a novel method for independently controlling multiple stress-engineered MEMS microrobots (MicroStressBots) through a single, global, control signal. Called Turning-rate Selective Control (TSC), this new technique employs designed variations in turning rates between individual microrobots to differentiate their motion. Despite all robots moving simultaneously and being identical except for exhibiting different turning rates, TSC can individually and independently position the robots' centers of rotation within a planar configuration space. This allows the individual robots to be independently maneuverable to within a distance equal to the turning radius (approximately half of a microrobot width) away from an arbitrary location (configuration excluding rotation) in  $R^2$ . We introduce the theory behind TSC and, by using fabricated microrobots, show experimental results that confirm the feasibility of TSC for controlling multiple MicroStressBots through a single, global, control signal. We conclude by discussing how TSC can extend the maximum number of independently controllable MicroStressBots beyond previously published approaches.

**Schedule:** see page [16](#)

*Rigidity Maintenance Control for Multi-Robot Systems*

Daniel Zelazo, Antonio Franchi, Frank Allgower, Heinrich Bulthoff, Paolo Robuffo Giordano

**Abstract:**

Rigidity of formations in multi-robot systems is important for formation control, localization, and sensor fusion. This work proposes a rigidity maintenance gradient controller for a multi-agent robot team. To develop such a controller, we first provide an alternative characterization of the rigidity matrix and use that to introduce the novel concept of the rigidity eigenvalue. We provide a necessary and sufficient condition relating the positivity of the rigidity eigenvalue to the rigidity of the formation. The rigidity maintenance controller is based on the gradient of the rigidity eigenvalue with respect to each robot position. This gradient has a naturally distributed structure, and is thus amenable to a distributed implementation. Additional requirements such as obstacle and inter-agent collision avoidance, as well as typical constraints such as limited sensing/communication ranges and line-of-sight occlusions, are also explicitly considered. Finally, we present a simulation with a group of seven quadrotor UAVs to demonstrate and validate the theoretical results.

**Schedule:** see page [16](#)

*State Estimation for Legged Robots - Consistent Fusion of Leg Kinematics and IMU*

Michael Bloesch, Marco Hutter, Mark Hoepflinger, Stefan Leutenegger, Christian Gehring, C. David Remy, Roland Siegwart

**Abstract:**

This paper introduces a state estimation framework for legged robots that allows estimating the full pose of the robot without making any assumptions about the geometrical structure of its environment. This is achieved by means of an Observability Constrained Extended Kalman Filter that fuses kinematic encoder data with on-board IMU measurements. By including the absolute position of all footholds into the filter state, simple model equations can be formulated which accurately capture the uncertainties associated with the intermittent ground contacts. The resulting filter simultaneously estimates the position of all footholds and the pose of the main body. In the algorithmic formulation, special attention is paid to the consistency of the linearized filter: it maintains the same observability properties as the nonlinear system, which is a prerequisite for accurate state estimation. The presented approach is implemented in simulation and validated experimentally on an actual quadrupedal robot.

**Schedule:** see page [16](#)

*Toward Information Theoretic Human-Robot Dialog*

Stefanie Tellex, Pratiksha Thaker, Robin Deits, Thomas Kollar, Nicholas Roy

**Abstract:**

Our goal is to build robots that can robustly interact with humans using natural language. This problem is challenging because human language is filled with ambiguity, and furthermore, due to limitations in sensing, the robot's perception of its environment might be much more limited than that of its human partner. To enable a robot to recover from a failure to understand a natural language utterance, this paper describes an information-theoretic strategy for asking targeted clarifying questions and using information from the answer to disambiguate the language. To identify good questions, we derive an estimate of the robot's uncertainty about the mapping between specific phrases in the language and aspects of the external world. This metric enables the robot to ask a targeted question about the parts of the language for which it is most uncertain. After receiving an answer, the robot fuses information from the command, the question, and the answer in a joint probabilistic graphical model in the G3 framework. When using answers to questions, we show the robot is able to infer mappings between parts of the language and concrete object groundings in the external world with higher accuracy than by using information from the command alone. Furthermore, we demonstrate that by effectively selecting which questions to ask, the robot is able to achieve significant performance gains while asking many fewer questions than baseline metrics.

**Schedule:** see page [16](#)*Towards A Swarm of Agile Micro Quadrotors (Award Talk)*

Aleksandr Kushleyev, Vijay Kumar, Daniel Mellinger

**Abstract:**

We describe a prototype 73 gram, 21 cm diameter micro quadrotor with onboard attitude estimation and control that operates autonomously with an external localization system. We argue that the reduction in size leads to agility and the ability to operate in tight formations and provide experimental arguments in support of this claim. The robot is shown to be capable of 1850 degrees/sec roll and pitch, performs a 360 degree flip in 0.4 seconds and exhibits a lateral step response of 1 body length in 1 second. We describe the architecture and algorithms to coordinate a team of quadrotors, organize them into groups and fly through known three-dimensional environments. We provide experimental results for a team of 20 micro quadrotors.

**Schedule:** see page [16](#)*Exploiting Passive Dynamics with Variable Stiffness Actuation in Robot Brachiation*

Jun Nakanishi, Sethu Vijayakumar

**Abstract:**

This paper explores a passive control strategy with variable stiffness actuation for swing movements. We consider brachiation as an example of a highly dynamic task which requires exploitation of gravity in an efficient manner for successful task execution. First, we present our passive control strategy considering a pendulum with variable stiffness actuation. Then, we formulate the problem based an optimal control framework with temporal optimization in order to simultaneously find an appropriate stiffness profile and movement duration such that the resultant movement will be able to exploit the passive dynamics of the robot. Finally, numerical evaluations on a two-link brachiating robot with a variable stiffness actuator (VSA) model are provided to demonstrate the effectiveness of our approach under different task requirements, modelling errors and variations in the robot dynamics. In addition, we discuss the issue of task description in terms of the choice of cost function for successful task execution in optimal control.

**Schedule:** see page [17](#)

*Parsing Indoor Scenes Using RGB-D Imagery*

Camillo Taylor, Anthony Cowley

**Abstract:**

This paper presents an approach to parsing the Manhattan structure of an indoor scene from a single RGB-D frame. The problem of recovering the floor plan is recast as an optimal labeling problem which can be solved efficiently using Dynamic Programming.

**Schedule:** see page [17](#)*Probabilistic Modeling of Human Movements for Intention Inference*

Zhikun Wang, Marc Deisenroth, Heni Ben Amor, David Vogt, Bernhard Scholkopf, Jan Peters

**Abstract:**

Inference of human intention may be an essential step towards understanding human actions and is hence important for realizing efficient human-robot interaction. In this paper, we propose the Intention-Driven Dynamics Model (IDDM), a latent variable model for inferring unknown human intentions. We train the model based on observed human movements/actions. We introduce an efficient approximate inference algorithm to infer the human's intention from an ongoing movement. We verify the feasibility of the IDDM in two scenarios, i.e., target inference in robot table tennis and action recognition for interactive humanoid robots. In both tasks, the IDDM achieves substantial improvements over state-of-the-art regression and classification.

**Schedule:** see page [17](#)*Efficiently Finding Optimal Winding-Constrained Loops in the Plane*

Paul Vernaza, Venkatraman Narayanan, Maxim Likhachev

**Abstract:**

We present a method to efficiently find winding-constrained loops in the plane that are optimal with respect to a minimum-cost objective and in the presence of obstacles. Our approach is similar to a typical graph-based search for an optimal path in the plane, but with an additional state variable that encodes information about path homotopy. Upon finding a loop, the value of this state corresponds to a line integral over the loop that indicates how many times it winds around each obstacle, enabling us to reduce the problem of finding paths satisfying winding constraints to that of searching for paths to suitable states in this augmented state space. We give an intuitive interpretation of the method based on fluid mechanics and show how this yields a way to perform the necessary calculations efficiently. Results are given in which we use our method to find optimal routes for autonomous surveillance and intruder containment.

**Schedule:** see page [17](#)*Time-Optimal Trajectory Generation for Path Following with Bounded Acceleration and Velocity*

Tobias Kunz, Mike Stilman

**Abstract:**

This paper presents a novel method to generate the time-optimal trajectory that exactly follows a given differentiable joint-space path within given bounds on joint accelerations and velocities. We also present a path preprocessing method to make nondifferentiable paths differentiable by adding circular blends. We introduce improvements to existing work that make the algorithm more robust in the presence of numerical inaccuracies. Furthermore we validate our methods on hundreds of randomly generated test cases on simulated and real 7-DOF robot arms. Finally, we provide open source software that implements our algorithms.

**Schedule:** see page [17](#)

## Monday, July 9, 2012: Oral Session 2

### *Affine Trajectory Deformation for Redundant manipulators (Award Talk)*

Quang-Cuong Pham, Yoshihiko Nakamura

**Abstract:**

We propose a new method to smoothly deform trajectories of redundant manipulators in order to deal with unforeseen perturbations or to retarget captured motions into new environments. This method is based on the recently-developed affine deformation framework, which offers such advantages as closed-form solutions, one-step computation and no trajectory re-integration. Satisfaction of inequality constraints and dynamics optimization are seamlessly integrated into the framework. Applications of the method to interactive motion editing and motion transfer to humanoid robots are presented. Building on these developments, we offer a brief discussion of the concept of redundancy from the viewpoint of group theory.

**Schedule:** see page [17](#)

### *Robust Object Grasping using Force Compliant Motion Primitives*

Moslem Kazemi, Jean-Sebastien Valois, J. Andrew Bagnell, Nancy Pollard

**Abstract:**

We address the problem of grasping everyday objects that are small relative to an anthropomorphic hand, such as pens, screwdrivers, cellphones, and hammers from their natural poses on a support surface, e.g., a table top. In such conditions, state of the art grasp generation techniques fail to provide robust, achievable solutions due to either ignoring or trying to avoid contact with the support surface. In contrast, we show that contact with support surfaces is critical for grasping small objects. This also conforms with our anecdotal observations of human grasping behaviors. We develop a simple closed-loop hybrid controller that mimics this interactive, contact-rich strategy by a position-force, pre-grasp and landing strategy for finger placement. The approach uses a compliant control of the hand during the grasp and release of objects in order to preserve safety. We conducted extensive grasping experiments on a variety of small objects with similar shape and size. The results demonstrate that our approach is robust to localization uncertainties and applies to many everyday objects.

**Schedule:** see page [17](#)

*Multi-Stage Micro Rockets for Robotic Insects*

Mirko Kovac, Maria Bendana, Rohit Krishnan, Jessica Burton, Michael Smith, Robert Wood

**Abstract:**

One of the main challenges for sustained flight of current aerial micro robots is the low energy density available from common power sources. In this paper we propose solid rocket fuel powered micro thrusters as a high energy density actuation method for aerial micro robots. In a multi stage configuration these thrusters can be used for intermittent flight which can decrease the energetic cost of locomotion. In particular we focus on the fabrication method and characterization of multi-stage micro thrusters with a diameter of 3mm and 6.4mm. We demonstrate a sustained and repeatable thrust force of up to 35mN for a duration of up to 42s and a multi-stage designs with a time delay of up to 4.7s between the propulsion phases. Furthermore, we present a take-off trajectory of a 10cm rocket glider with an integrated micro thruster as propulsion mechanism showing that the technologies developed can be used to successfully power micro robots in flight. Future work will focus on control and flight dynamics of micro thruster powered gliders. Wider applications of similar thrusters can include other robotic applications where low weight and high force is important such as for jumping or running robots.

**Schedule:** see page [17](#)*Extrinsic Calibration from Per-Sensor Egomotion*

Jonathan Brookshire, Seth Teller

**Abstract:**

”We show how to recover the 6-DOF transform between two sensors mounted rigidly on a moving body, a form of extrinsic calibration useful for data fusion. Our algorithm takes noisy, per-sensor incremental egomotion observations (i.e., incremental poses) as input and produces as output an estimate of the maximum-likelihood 6-DOF calibration relating the sensors and accompanying uncertainty. The 6-DOF transformation sought can be represented effectively as a unit dual quaternion with 8 parameters subject to two constraints. Noise is explicitly modeled (via the Lie algebra), yielding a constrained Fisher Information Matrix and Cramer-Rao Lower Bound. The result is an analysis of motion degeneracy and a singularity-free optimization procedure. The method requires only that the sensors travel together along a motion path that is non-degenerate. It does not require that the sensors be synchronized, have overlapping fields of view, or observe common features. It does not require construction of a global reference frame or solving SLAM. In practice, from hand-held motion of RGB-D cameras, the method recovered inter-camera calibrations accurate to within 0.014 m and 0.022 radians (about 1 cm and 1 degree).”

**Schedule:** see page [17](#)

*Probabilistic Temporal Logic for Motion Planning with Resource Threshold Constraints*

Chanyeol Yoo, Robert Fitch, Salah Sukkarieh

**Abstract:**

Temporal logic and model-checking are useful theoretical tools for specifying complex goals at the task level and formally verifying the performance of control policies. We are interested in tasks that involve constraints on real-valued energy resources. In particular, autonomous gliding aircraft gain energy in the form of altitude by exploiting wind currents and must maintain altitude within some range during motion planning. We propose an extension to probabilistic computation tree logic that expresses such real-valued resource threshold constraints, and present model-checking algorithms that evaluate a piecewise control policy with respect to a formal specification and hard or soft performance guarantees. We validate this approach through simulated examples of motion planning among obstacles for an autonomous thermal glider. Our results demonstrate probabilistic performance guarantees on the ability of the glider to complete its task, following a given piecewise control policy, without knowing the exact path of the glider in advance.

**Schedule:** see page [17](#)

## Tuesday, July 10, 2012: Oral Session 1

### *Recognition and Pose Estimation of Rigid Transparent Objects with a Kinect Sensor*

Ilya Lysenkov, Victor Eruhimov, Gary Bradski

**Abstract:**

Recognizing and determining the 6DOF pose of transparent objects is necessary in order for robots to manipulate such objects. However, it is a challenging problem for computer vision. We propose new algorithms for segmentation, pose estimation and recognition of transparent objects from a single RGB-D image from a Kinect sensor. Kinect's weakness in the perception of transparent objects is exploited in their segmentation. Following segmentation, edge fitting is used for recognition and pose estimation. A 3D model of the object is created automatically during training and it is required for pose estimation and recognition. The algorithm is evaluated in different conditions of a domestic environment within the framework of a robotic grasping pipeline where it demonstrates high grasping success rates compared to the state-of-the-art results. The method doesn't deal with occlusions and overlapping transparent objects currently but it is robust against non-transparent clutter.

**Schedule:** see page [18](#)

### *On the Structure of Nonlinearities in Pose Graph SLAM*

Heng Wang, Gibson Hu, Shoudong Huang, Gamini Dissanayake

**Abstract:**

"Pose graphs have become an attractive representation for solving Simultaneous Localization and Mapping (SLAM) problems. In this paper, we analyze the structure of the nonlinearities in the 2D SLAM problem formulated as the optimizing of a pose graph. First, we prove that finding the optimal configuration of a very basic pose graph with 3 nodes (poses) and 3 edges (relative pose constraints) with spherical covariance matrices, which can be formulated as a six dimensional least squares optimization problem, is equivalent to solving a one dimensional optimization problem. Then we show that the same result can be extended to the optimizing of a pose graph with two anchor nodes where every edge is connecting to one of the two anchor nodes. Furthermore, we prove that the global minimum of the resulting one dimensional optimization problem must belong to a certain interval and there are at most 3 minima in that interval. Thus the globally optimal pose configuration of the pose graph can be obtained very easily through the bisection method and closed-form formulas."

**Schedule:** see page [18](#)

*Hybrid Operational Space Control for Compliant Legged Systems*

Marco Hutter, Mark Hoepflinger, Christian Gehring, Michael Bloesch, C. David Remy, Roland Siegwart

**Abstract:**

This paper introduces the concept of hybrid operational space control, a method that unifies kinematic tracking of individual joints with an inverse dynamics task space controller for the remainder of the robot. The proposed control strategy allows for a hierarchical task decomposition while simultaneously regulating the inner forces between the contact points. At the same time it improves fast tracking for compliant systems by means of appropriate low level position controllers. Introducing StarLETH, a compliant quadrupedal robot, the applicability of the controller and the hardware is demonstrated in real-time simulations and hardware experiments. We perform static walking in challenging terrain and show how the controller can combine precise and fast position control with robust and compliant interaction with the environment.

**Schedule:** see page [18](#)*Asymptotically-optimal Path Planning on Manifolds*

Leonard Jaillet, Josep Porta

**Abstract:**

This paper presents an approach for optimal path planning on implicitly-defined configuration spaces such as those arising, for instance, when manipulating an object with two arms or with a multifingered hand. In this kind of situations, the kinematic and contact constraints induce configuration spaces that are manifolds embedded in higher dimensional ambient spaces. Existing sampling-based approaches for path planning on manifolds focus on finding a feasible solution, but they do not optimize the quality of the path in any sense. Thus, the returned paths are usually not suitable for direct execution. Recently, RRT\* and other similar asymptotically-optimal path planners have been proposed to generate high-quality paths in the case of globally parametrizable configuration spaces. In this paper, we propose to use higher dimensional continuation tools to extend RRT\* to the case of implicitly-defined configuration spaces. Experiments in different problems validate the proposed approach.

**Schedule:** see page [18](#)*Physics-Based Grasp Planning Through Clutter*

Mehmet Dogar, Kaijen Hsiao, Matei Ciocarlie, Siddhartha Srinivasa

**Abstract:**

We propose a planning method for grasping in cluttered environments, a method where the robot can make simultaneous contact with multiple objects. With this method, the robot reaches for and grasps the target while simultaneously contacting and moving aside objects to clear a desired path. We use a physics-based analysis of pushing to compute the motion of each object in the scene in response to a set of possible robot motions. Our method enables multiple robot-object interactions, interactions that can be pre-computed and cached. However, our method avoids object-object interactions to make the problem computationally tractable. Through tests on large sets of simulated scenes, we show that our planner produces more successful grasps in more complex scenes than versions that avoid any interaction with surrounding clutter. We validate our method on a real robot, a PR2, and show that it accurately predicts the outcome of a grasp. We also show that our approach, in conjunction with state-of-the-art object recognition tools, is applicable in real-life scenes that are highly cluttered and constrained.

**Schedule:** see page [18](#)

*Formalizing Assistive Teleoperation (Award Talk)*

Anca Dragan, Siddhartha Srinivasa

**Abstract:**

In assistive teleoperation, the robot helps the user accomplish the desired task, making teleoperation easier and more seamless. Rather than simply executing the user's input, which is hindered by the inadequacies of the interface, the robot attempts to predict the user's intent, and assists in accomplishing it. In this work, we are interested in the scientific underpinnings of assistance: we formalize assistance under the general framework of policy blending, show how previous work methods instantiate this formalism, and provide a principled analysis of its main components: prediction of user intent and its arbitration with the user input. We define the prediction problem, with foundations in Inverse Reinforcement Learning, discuss simplifying assumptions that make it tractable, and test these on data from users teleoperating a robotic manipulator under various circumstances. We propose that arbitration should be moderated by the confidence in the prediction. Our user study analyzes the effect of the arbitration type, together with the prediction correctness and the task difficulty, on the performance of assistance and the preferences of users.

**Schedule:** see page [18](#)*The Banana Distribution is Gaussian: A Localization Study with Exponential Coordinates*

Andrew Long, Kevin Wolfe, Michael Mashner, Gregory Chirikjian

**Abstract:**

Distributions in position and orientation are central to many problems in robot localization. To increase efficiency, a majority of algorithms for planar mobile robots use Gaussians defined on positional Cartesian coordinates and heading. However, the distribution of poses for a noisy two-wheeled robot moving in the plane has been observed by many to be a "banana-shaped" distribution, which is clearly not Gaussian/normal in these coordinates. As uncertainty increases, many localization algorithms therefore become "inconsistent" due to the normality assumption breaking down. We observe that this is because the combination of Cartesian coordinates and heading is not the most appropriate set of coordinates to use, and that the banana distribution can be described in closed form as a Gaussian in an alternative set of coordinates via the so-called exponential map. With this formulation, we can derive closed-form expressions for propagating the mean and covariance of the Gaussian in these exponential coordinates for a differential-drive car moving along a trajectory constructed from sections of straight segments and arcs of constant curvature. In addition, we detail how to fuse two or more Gaussians in exponential coordinates together with given relative pose measurements between robots moving in formation. These propagation and fusion formulas utilized here reduce uncertainty in localization better than when using traditional methods. We demonstrate with numerical examples dramatic improvements in the estimated pose of three robots moving in formation when compared to classical Cartesian-coordinate-based Gaussian fusion methods.

**Schedule:** see page [19](#)

*Modeling and Prediction of Pedestrian Behavior based on the Sub-goal Concept*

Tetsushi Ikeda, Yoshihiro Chigodo, Daniel Rea, Francesco Zanlungo, Masahiro Shiomi, Takayuki Kanda

**Abstract:**

This study addresses a method to predict pedestrians' long term behavior in order to enable a robot to provide them services. In order to do that we want to be able to predict their final goal and the trajectory they will follow to reach it. We attain this task borrowing from human science studies the concept of sub-goals, defined as points and landmarks of the environment towards which pedestrians walk or where they take directional choices before reaching the final destination. We retrieve the position of these sub-goals from the analysis of a large set of pedestrian trajectories in a shopping mall, and model their global behavior through transition probabilities between sub-goals. The method allows us to predict the future position of pedestrians on the basis of the observation of their trajectory up to the moment.

**Schedule:** see page [19](#)*Real-Time Inverse Dynamics Learning for Musculoskeletal Robots based on Echo State Gaussian Process Regression*

Christoph Hartmann, Joschka Boedecker, Oliver Obst, Shuhei Ikemoto, Minoru Asada

**Abstract:**

A challenging topic in articulated robots is the control of redundantly many degrees of freedom with artificial muscles. Actuation with these devices is difficult to solve because of nonlinearities, delays and unknown parameters such as friction. Machine learning methods can be used to learn control of these systems, but are faced with the additional problem that the size of the search space prohibits full exploration in reasonable time. We propose a novel method that is able to learn control of redundant robot arms with artificial muscles online from scratch using only the position of the end effector, without using any joint positions, accelerations or an analytical model of the system or the environment. To learn in real time, we use the so called online goal babbling method to effectively reduce the search space, a recurrent neural network to represent the state of the robot arm, and novel online Gaussian processes for regression. With our approach, we achieve good performance on trajectory tracking tasks for the end effector of two very challenging systems: a simulated 6 DOF redundant arm with artificial muscles, and a 7 DOF robot arm with McKibben pneumatic artificial muscles. We also show that the combination of techniques we propose results in significantly improved performance over using the individual techniques alone.

**Schedule:** see page [19](#)*M-Width: Stability and Accuracy of Haptic Rendering of Virtual Mass*

Nick Colonnese, Allison Okamura

**Abstract:**

In many physical human-robot interaction scenarios, such as haptic virtual environments for training and rehabilitation, it is desirable to carefully control the apparent inertia of a robot. Inertia compensation can be used to mitigate forces felt by the user during free-space motion, and rendering of additional inertia is desired for particular rehabilitation and training procedures. Many factors influence the stability and accuracy of rendering for haptic display of a pure mass, including device mechanical properties, sample rate, control structure, and human behavior. Inspired by the Z-Width approach to haptic device stability and performance analysis, we introduce M-width, which we define as the dynamic range of virtual masses renderable in a stable manner. We identify the important parameters for system stability, find stability boundaries, and describe the expected accuracy of the haptic rendering for a canonical haptic system. These results serve as a design tool for designing haptic environments implementing mass, establish limits of performance, and lay the groundwork for new controllers to improve mass rendering."

**Schedule:** see page [19](#)

## Tuesday, July 10, 2012: Oral Session 2

### *Walking and Running on Yielding and Fluidizing Ground (Award Talk)*

Feifei Qian, Tingnan Zhang, Chen Li, Aaron Hoover, Pierangelo Masarati, Paul Birkmeyer, Andrew Pullin, Ronald Fearing, Dan Goldman

#### **Abstract:**

We study the detailed locomotor mechanics of a small, lightweight robot (DynaRoACH, 10 cm, 25 g) which can move on a granular substrate of closely packed 3 mm diameter glass particles at speeds up to 50 cm/s (5 body length/s), approaching the performance of small, high-performing, desert-dwelling lizards. To reveal how the robot achieves this high performance, we used high speed imaging to capture kinematics, and developed a numerical multi-body simulation of the robot coupled to an experimentally validated discrete element method (DEM) simulation of the granular media. Average forward speeds measured in both experiment and simulation agreed well, and increased non-linearly with stride frequency, reflecting a change in the mode of propulsion. At low frequencies, the robot used a quasi-static rotary walking mode, in which the granular material yielded as the legs penetrated and then solidified once vertical force balance was achieved. At high frequencies, duty factor decreased below 0.5 and aerial phases occurred. The propulsion mechanism was qualitatively different: the robot ran rapidly by utilizing the speed-dependent fluid-like inertial response of the material. We also used our simulation tool to vary substrate parameters that were inconvenient to vary in experiment (e.g., granular particle friction) to test performance and reveal limits of stability of the robot. Using small robots as physical models, our study reveals a mechanism by which small animals can achieve high performance on granular substrates, which in return advances the design and control of small robots in deformable terrains.

**Schedule:** see page [19](#)

### *Nonparametric Bayesian Models for Unsupervised Scene Analysis and Reconstruction*

Dominik Joho, Gian Diego Tipaldi, Nikolas Engelhard, Cyrill Stachniss, Wolfram Burgard

#### **Abstract:**

Robots operating in domestic environments need to deal with a variety of different objects. Often, these objects are neither placed randomly, nor independently of each other. For example, objects on a breakfast table such as plates, knives, or bowls typically occur in recurrent configurations. In this paper, we propose a novel hierarchical generative model to reason about latent object constellations in a scene. The proposed model is a combination of Dirichlet processes and beta processes, which allow for a probabilistic treatment of the unknown dimensionality of the parameter space. We show how the model can be employed to address a set of different tasks in scene understanding ranging from unsupervised scene segmentation to completion of a partially specified scene. We describe how sampling in this model can be done using Markov chain Monte Carlo (MCMC) techniques and present an experimental evaluation with simulated as well as real-world data obtained with a Kinect camera.

**Schedule:** see page [19](#)

*A Distributable and Computation-flexible Assignment Algorithm: From Local Task Swapping to Global Optimality*

Lantao Liu, Dylan Shell

**Abstract:**

The assignment problem arises in multi-robot task-allocation scenarios. This paper introduces an algorithm for solving the assignment problem with several appealing features for online, distributed robotics applications. The method can start with any initial matching and incrementally improve the solution to reach the global optimum, producing valid assignments at any intermediate point. It is an any-time algorithm with an attractive performance profile (quality improves linearly) that, additionally, is comparatively straightforward to implement and is efficient both theoretically ( $O(n^3 \lg n)$  complexity is better than widely used solvers) and practically (comparable to the fastest implementation, for up to hundreds of robots/tasks). We present a centralized version and two decentralized variants that trade between computational and communication complexity. Inspired by techniques that employ task exchanges between robots, our algorithm guarantees global optimality while using generalized swap primitives. The centralized version turns out to be a computational improvement and reinterpretation of the little-known method of Balinski-Gomory, proposed over half a century ago. Deeper understanding of the relationship between approximate swap-based techniques developed by roboticists and combinatorial optimization techniques, e.g., the Hungarian and Auction algorithms developed by operations researchers but used extensively by roboticists is uncovered.

**Schedule:** see page [19](#)

*What's in the Bag: A Distributed Approach to 3D Shape Duplication with Modular Robots*

Kyle Gilpin, Daniela Rus

**Abstract:**

Our goal is to develop an automated digital fabrication process that can make any object out of smart materials. In this paper, we present an algorithm for creating shapes by the process of duplication, using modules we have termed smart sand. The object to be duplicated is dipped into a bag of smart sand; the particles exchange messages to sense the object's shape; and then the particles selectively form mechanical bonds with their neighbors to form a duplicate of the original. Our algorithm is capable of duplicating convex and concave 3D objects in a completely distributed manner. It uses  $O(1)$  storage space and  $O(n)$  inter-module messages per module. We perform close to 500 experiments using a realistic simulator with over 1400 modules. These experiments confirm the functionality and messaging demands of our distributed duplication algorithm while demonstrating that the algorithm can be used to form interesting and useful shapes.

**Schedule:** see page [19](#)

*What Types of Interactions do Bio-Inspired Robot Swarms and Flocks Afford a Human?*

Michael Goodrich, Sean Kerman, Brian Pendleton, P.B. Sujit

**Abstract:**

”This paper uses simulations to identify what types of human influence are afforded by the flocking and swarming structures that emerge from Couzin’s bio-inspired model. The goal is to allow a human to influence a decentralized agent collective without resorting to centralized human control. Evidence is provided that, when nominal agents use switching-based control to respond to human-guided predators and leaders, the resulting behavior is responsive to human input but is obtained at the cost of causing the dynamic structure of the collective to follow a single flocking structure. Leaders are more effective in influencing coherent flocks, but predators can be used to divide the flock into sub-flocks, yielding higher performance on some problems. Introducing a so-called stakeholder leadership style makes it possible for a human to guide the agents while maintaining several different types of structures; doing so requires more than one human-controlled agent. We then demonstrate that it is possible to produce potentially useful emergent dynamics without centralized human control, and identify an important type of emergent dynamics: automatic switches between structure types.”

**Schedule:** see page [19](#)

## Wednesday, July 11, 2012: Oral Session 1

### *Robust Navigation Execution by Planning in Belief Space*

Bhaskara Marthi

**Abstract:**

We consider robot navigation in environments consisting of a known static map, but where dynamic obstacles of varying and unknown lifespans appear and disappear over time. We describe a roadmap-based formulation of the problem that takes the sensing and transition uncertainty into account, and an efficient online planner for this problem. The planner displays behaviors such as persistence and obstacle timeouts that would normally be hardcoded into an executive. It is also able to make inferences about obstacle types even with impoverished sensors. We present empirical results on simulated domains and on a PR2 robot.

**Schedule:** see page [20](#)

### *Failure Anticipation in Pursuit-Evasion*

Cyril Robin, Simon Lacroix

**Abstract:**

This paper presents a new approach for the pursuit of targets by a team of aerial and ground robots under realistic conditions. Mobile target pursuit is often a sub-task of more general scenarios, that call for environment exploration or monitoring activities. Since most of the time a single robot is sufficient to ensure the pursuit of a target, our approach aims at minimizing the team resources devoted to the pursuit: while ensuring the pursuit, a single pursuer evaluates its own potential failures on the basis of the situation defined by the target evolution and the environment structure. It thus assesses its need for team support. When support is necessary to keep the target in view, one or more additional robots are involved, according to a task allocation scheme. We provide mathematical bounds of the complexity of the approach, that ensure that the system has real-time performance. Simulations in a variety of realistic situations illustrate the efficiency of the proposed solution.

**Schedule:** see page [20](#)

### *Inference on Networks of Mixtures for Robust Robot Mapping*

Edwin Olson, Pratik Agarwal

**Abstract:**

The central challenge in robotic mapping is obtaining reliable data associations (or “loop closures”): state-of-the-art inference algorithms can fail catastrophically if even one erroneous loop closure is incorporated into the map. Consequently, much work has been done to push error rates closer to zero. However, a long-lived or multi-robot system will still encounter errors, leading to system failure. We propose a fundamentally different approach: allow richer error models that allow the probability of a failure to be explicitly modeled. In other words, we optimize the map while simultaneously determining which loop closures are correct from within a single integrated Bayesian framework. Unlike earlier multiple-hypothesis approaches, our approach avoids exponential memory complexity and is fast enough for real-time performance. We show that the proposed method not only allows loop closing errors to be automatically identified, but also that in extreme cases, the “front-end” loop-validation systems can be unnecessary. We demonstrate our system both on standard benchmarks and on the real-world datasets that motivated this work.

**Schedule:** see page [20](#)

*Recognition, Prediction, and Planning for Assisted Teleoperation of Freeform Tasks*

Kris Hauser

**Abstract:**

This paper presents a system for improving the intuitiveness and responsiveness of assisted robot teleoperation interfaces by combining intent prediction and motion planning. Two technical contributions are described. First, an intent predictor estimates the user's desired task, and accepts freeform tasks that include both discrete types and continuous parameters (e.g., desired target positions). Second, a cooperative motion planner uses the task estimates to generate continuously updated robot trajectories by solving optimal control problems with time-varying objective functions. The planner is designed to respond interactively to changes in the indicated task, avoid collisions in cluttered environments, and achieve high-quality motions using a hybrid of numerical and sample-based techniques. The system is applied to the problem of controlling a 6D robot manipulator using 2D mouse input in the context of two tasks: static target reaching and dynamic trajectory tracking. Simulations suggest that it enables the robot to reach static targets faster and to track trajectories more closely than comparable techniques.

**Schedule:** see page [20](#)*Hierarchical Motion Planning in Topological Representations*

Dmitry Zarubin, Vladimir Ivan, Marc Toussaint, Taku Komura, Sethu Vijayakumar

**Abstract:**

Motion can be described in alternative representations, including joint configuration or endeffector spaces, but also more complex topological representations that imply a change of Voronoi bias, metric or topology of the motion space. In particular certain types of robot interaction problems, e.g. wrapping around an object, can suitably be described by so-called writhe and interaction mesh representations. However, considering motion synthesis in only a topological space is insufficient since it does not account for additional tasks and constraints in other representations. In this paper we propose methods to combine and exploit different representations for motion synthesis and generalization of motion to novel situations. Our motion synthesis approach is formulated in the framework of optimal control as an approximate inference problem. This allows for a direct extension of the graphical model to incorporate multiple representations. Motion generalization is similarly performed by projecting motion from topological to joint configuration space. We demonstrate the benefit of our methods on problems where direct path finding in joint configuration space is extremely hard whereas local optimal control exploiting a representation with different topology can efficiently find optimal trajectories. In real world we demonstrate the use of topological representations for online motion generalization in dynamic environments.

**Schedule:** see page [20](#)

*Visual Route Recognition with a Handful of Bits (Award Talk)*

Michael Milford

**Abstract:**

In this paper we use a sequence-based visual localization algorithm to reveal surprising answers to the question, how much visual information is actually needed to conduct effective navigation? The algorithm actively searches for the best local image matches within a sliding window of short route segments or sub-routes, and matches sub-routes by searching for coherent sequences of local image matches. In contrast to many existing techniques, the technique requires no pre-training or camera parameter calibration. We compare the algorithm's performance to the state-of-the-art FAB-MAP 2.0 algorithm on a 70 km benchmark dataset. Performance matches or exceeds the state of the art feature-based localization technique using images as small as 4 pixels, fields of view reduced by a factor of 250, and pixel bit depths reduced to 2 bits. We present further results demonstrating the system localizing in an office environment with near 100

**Schedule:** see page [20](#)*CompAct Arm: a Compliant Manipulator with Intrinsic Variable Physical Damping*

Matteo Laffranchi, Nikos Tsagarakis, Darwin Caldwell

**Abstract:**

Humans exploit compliance in their biomechanical muscle-tendon-bone actuation structure to enable robust and safe interaction with the environment and utilize the elastic energy stored into muscles and tendons to obtain large energy efficiency or high output mechanical power peaks at their limbs. From the robotic/mechatronic point of view it is clear that emulating such a property in robotic actuation systems enables the achievement of performance which is not possible with classical stiff designs. In contrast to this, transmission compliance introduces some disadvantages as e.g. typically underdamped modes which reduce the achievable control bandwidth, stability margin and accuracy of the controlled system. These limitations are solved in mammals by means of physical damping which clarifies why these biological systems are able of performing fast and smooth yet accurate motions in their limbs. This motivates this work which consists in the analysis and development of the CompAct Arm, a novel compliant manipulator with intrinsic variable damping. This is probably the first robotic system to exhibit these diverse bio inspired characteristics. A motivation analysis is initially presented to show how the drawbacks introduced by compliance can be overcome by means of physical damping. The second part of the paper presents the mechatronic development of the robotic manipulator and preliminary experimental results.

**Schedule:** see page [21](#)

*Fast Weighted Exponential Product Rules for Robust General Multi-Robot Data Fusion*

Nisar Ahmed, Jonathan Schoenberg, Mark Campbell

**Abstract:**

This paper considers the distributed data fusion (DDF) problem for general multi-agent robotic sensor networks in applications such as 3D mapping and target search. In particular, this paper focuses on the use of conservative fusion via the weighted exponential product (WEP) rule to combat inconsistencies that arise from double-counting common information between fusion agents. WEP fusion is ideal for fusing arbitrarily distributed estimates in ad-hoc communication network topologies, but current WEP rule variants have limited applicability to general multi-robot DDF. To address these issues, new information-theoretic WEP metrics are presented along with novel optimization algorithms for efficiently performing DDF within a recursive Bayesian estimation framework. While the proposed WEP fusion methods are generalizable to arbitrary probability distribution functions (pdfs), emphasis is placed here on widely-used Bernoulli and Gaussian mixture pdfs. Experimental results for multi-robot 3D mapping and target search applications show the effectiveness of the proposed methods.

**Schedule:** see page [21](#)*Estimating Human Dynamics On-the-fly Using Monocular Video For Pose Estimation*

Priyanshu Agarwal, Suren Kumar, Julian Ryde, Jason Corso, Venkat Krovi

**Abstract:**

Human pose estimation using uncalibrated monocular visual inputs alone is a challenging problem for both the computer vision and robotics communities. From the robotics perspective, the challenge here is one of pose estimation of a multiply-articulated system of bodies using a single non-specialized environmental sensor (the camera) and thereby, creating low-order surrogate computational models for analysis and control. In this work, we propose a technique for estimating the lower-limb dynamics of a human solely based on captured behavior using an uncalibrated monocular video camera. We leverage our previously developed framework for human pose estimation to (i) deduce the correct sequence of temporally coherent gap-filled pose estimates, (ii) estimate physical parameters, employing a dynamics model incorporating the anthropometric constraints, and (iii) filter out the optimized gap-filled pose estimates, using an Unscented Kalman Filter (UKF) with the estimated dynamically-equivalent human dynamics model. We test the framework on videos from the publicly available DARPA Mind's Eye Year 1 corpus [8]. The combined estimation and filtering framework not only results in more accurate physically plausible pose estimates, but also provides pose estimates for frames, where the original human pose estimation framework failed to provide one.

**Schedule:** see page [21](#)*Colour-Consistent Structure-from-Motion Models using Underwater Imagery*

Mitch Bryson, Matthew Johnson-Roberson, Oscar Pizarro, Stefan Williams

**Abstract:**

This paper presents an automated approach to correcting for colour inconsistency in underwater images collected from multiple perspectives during the construction of 3D structure-from-motion models. When capturing images underwater, the water column imposes several effects on images that are negligible in air such as colour-dependant attenuation and lighting patterns. These effects cause problems for human interpretation of images and also confound computer-based techniques for clustering and classification. Our approach exploits the 3D structure of the scene generated using structure-from-motion and photogrammetry techniques accounting for distance-based attenuation, vignetting and lighting pattern, and improves the consistency of photo-textured 3D models. Results are presented using imagery collected in two different underwater environments using an Autonomous Underwater Vehicle (AUV).

**Schedule:** see page [21](#)

## Wednesday, July 11, 2012: Oral Session 2

### *On Stochastic Optimal Control and Reinforcement Learning by Approximate Inference (Award Talk)*

Konrad Rawlik, Marc Toussaint, Sethu Vijayakumar

**Abstract:**

We present a reformulation of the stochastic optimal control problem in terms of *opKL* divergence minimization, not only providing a unifying perspective of previous approaches in this area, but also demonstrating that the formalism leads to novel practical approaches to the control problem. Specifically, a natural relaxation of the dual formulation gives rise to exact iterative solutions to the finite and infinite horizon stochastic optimal control problem, while direct application of Bayesian inference methods yields instances of risk sensitive control. We furthermore study corresponding formulations in the reinforcement learning setting and present model free algorithms for problems with both discrete and continuous state and action spaces. Evaluation of the proposed methods on the standard Gridworld and Cart-Pole benchmarks verifies the theoretical insights and shows that the proposed methods improve upon current approaches.

**Schedule:** see page [21](#)

### *Optimization-Based Estimator Design for Vision-Aided Inertial Navigation*

Mingyang Li, Anastasios Mourikis

**Abstract:**

This paper focuses on the problem of real-time pose tracking using visual and inertial sensors in systems with limited processing power. Our main contribution is a novel approach to the design of estimators for these systems, which optimally utilizes the available resources. Specifically, we design a hybrid estimator that integrates two algorithms with complementary computational characteristics, namely a sliding-window EKF and EKF-SLAM. To decide which algorithm is best suited to process each of the available features at runtime, we learn the distribution of the feature number and of the lengths of the feature tracks. We show that using this information, we can predict the expected computational cost of each feature-allocation policy, and formulate an objective function whose minimization determines the optimal way to process the feature data. Our results demonstrate that the hybrid algorithm outperforms each individual method (EKF-SLAM and sliding-window EKF) by a wide margin, and allows processing the sensor data at real-time speed on the processor of a mobile phone.

**Schedule:** see page [21](#)

### *Development of a Testbed for Robotic Neuromuscular Controllers*

Alexander Schepelmann, Hartmut Geyer, Michael Taylor

**Abstract:**

Current control approaches to robotic legged locomotion rely on centralized planning and tracking or motion pattern matching. Central control is not available to robotic assistive devices that integrate with humans, and matching predefined patterns severely limits user dexterity. By contrast, biological systems show substantial legged dexterity even when their central nervous system is severed from their spinal cord, indicating that neuromuscular feedback controls can be harnessed to encode stability, adaptability, and maneuverability in legged systems. Here we present the initial steps to develop a robotic gait testbed that can implement and verify neuromuscular controls for robotic assistive devices. The initial stage consists of an antagonistically actuated two segment leg with a floating compliant joint. We detail its electromechanical design and low level, velocity-based torque control. Additionally, we present experiments that test the leg's performance during human-like high fidelity motions. The results show that the robot can track fast motions corresponding to 87

**Schedule:** see page [21](#)

*Distributed Approximation of Joint Measurement Distributions Using Mixtures of Gaussians*

Brian Julian, Stephen Smith, Daniela Rus

**Abstract:**

This paper presents an approach to distributively approximate the continuous probability distribution that describes the fusion of sensor measurements from many networked robots. Each robot forms a weighted mixture of Gaussians to represent the measurement distribution of its local observation. From this mixture set, the robot then draws samples of Gaussian elements to enable the use of a consensus-based algorithm that evolves the corresponding canonical parameters. We show that these evolved parameters describe a distribution that converges weakly to the joint of all the robots' unweighted mixture distributions, which itself converges weakly to the joint measurement distribution as more system resources are allocated. The major innovation of this approach is to combine sample-based sensor fusion with the notion of pre-convergence termination that results in a scalable multi-robot system. We also derive bounds and convergence rates for the approximated joint measurement distribution, specifically the elements of its information vectors and the eigenvalues of its information matrices. Most importantly, these performance guarantees do not come at a cost of complexity, since computational and communication complexity scales quadratically with respect to the Gaussian dimension, linearly with respect to the number of samples, and constant with respect to the number of robots. Results from numerical simulations for object localization are discussed using both Gaussians and mixtures of Gaussians.

**Schedule:** see page [21](#)*Robust Loop Closing Over Time*

Yasir Latif, Cesar Cadena Lerma, José Neira

**Abstract:**

Long term autonomy in robots requires the ability to reconsider previously taken decisions when new evidence becomes available. Loop closing links generated by a place recognition system may become inconsistent as additional evidence arrives. This paper is concerned with the detection and exclusion of such contradictory information from the map being built, in order to recover the correct map estimate. We propose a novel consistency based method to extract the loop closure regions that agree both among themselves and with the robot trajectory over time. We also assume that the contradictory loop closures are inconsistent among themselves and with the robot trajectory. We support our proposal, the RRR algorithm, on well-known odometry systems, e.g. visual or laser, using the very efficient graph optimization framework g2o as back-end. We back our claims with several experiments carried out on real data.

**Schedule:** see page [21](#)

## Thursday, July 12, 2012: Oral Session 1

### *Practical Route Planning Under Delay Uncertainty: Stochastic Shortest Path Queries*

Sejoon Lim, Christian Sommer, Evdokia Nikolova, Daniela Rus

**Abstract:**

We describe an algorithm for stochastic path planning and applications to route planning in the presence of traffic delays. We improve on the prior state of the art by designing, analyzing, implementing, and evaluating data structures that answer approximate stochastic shortest path queries. For example, our data structure can be used to efficiently compute paths that maximize the probability of arriving at a destination before a given time deadline. Our main theoretical result is an algorithm that, given a directed planar network with edge lengths characterized by expected travel time and variance, pre-computes a data structure in quasi-linear time such that stochastic approximate shortest-path queries can be answered in poly-logarithmic time (actual worst-case bounds depend on the probabilistic model). Our main experimental results are two-fold: (i) we provide methods to extract travel-time distributions from a large set of heterogeneous GPS traces and we build a stochastic model of an entire city, and (ii) we adapt our algorithms to work for real-world road networks, we provide an efficient implementation, and we evaluate the performance of our method for the model of the aforementioned city.

**Schedule:** see page [22](#)

### *Optimization of Temporal Dynamics for Adaptive Human-Robot Interaction in Assembly Manufacturing*

Ronald Wilcox, Stefanos Nikolaidis, Julie Shah

**Abstract:**

Human-robot collaboration presents an opportunity to improve the efficiency of manufacturing and assembly processes, particularly for aerospace manufacturing where tight integration and variability in the build process make physical isolation of robotic-only work challenging. In this paper, we develop a robotic scheduling and control capability that adapts to the changing preferences of a human co-worker or supervisor while providing strong guarantees for synchronization and timing of activities. This innovation is realized through dynamic execution of a flexible optimal scheduling policy that accommodates temporal disturbance. We describe the Adaptive Preferences Algorithm that computes the flexible scheduling policy and show empirically that execution is fast, robust, and adaptable to changing preferences for workflow. We achieve satisfactory computation times, on the order of seconds for moderately-sized problems, and demonstrate the capability for human-robot teaming using a small industrial robot.

**Schedule:** see page [22](#)

*Contextual Sequence Prediction with Application to Control Library Optimization*

Debadeepta Dey, Tian Yu Liu, Martial Hebert, J. Andrew Bagnell

**Abstract:**

Sequence optimization, where the items in a list are ordered to maximize some reward has many applications such as web advertisement placement, search, and control libraries in robotics. Previous work in sequence optimization produces a static ordering that does not take any features of the item or context of the problem into account. In this work, we propose a general approach to order the items within the sequence based on the context (e.g., perceptual information, environment description, and goals). We take a simple, efficient, reduction-based approach where the choice and order of the items is established by repeatedly learning simple classifiers or regressors for each slot in the sequence. Our approach leverages recent work on submodular function maximization to provide a formal regret reduction from submodular sequence optimization to simple cost-sensitive prediction. We apply our contextual sequence prediction algorithm to optimize control libraries and demonstrate results on two robotics problems: manipulator trajectory prediction and mobile robot path planning.

**Schedule:** see page [22](#)*Variational Bayesian Optimization for Runtime Risk-Sensitive Control*

Scott Kuindersma, Roderic Grupen, Andrew Barto

**Abstract:**

We present a new Bayesian policy search algorithm suitable for problems with policy-dependent cost variance, a property present in many robot control tasks. We extend recent work on variational heteroscedastic Gaussian processes to the optimization case to achieve efficient minimization of very noisy cost signals. In contrast to most policy search algorithms, our method explicitly models the cost variance in regions of low expected cost and permits runtime adjustment of risk sensitivity without relearning. Our experiments with artificial systems and a real mobile manipulator demonstrate that flexible risk-sensitive policies can be learned in very few trials.

**Schedule:** see page [22](#)*Minimal Coordinate Formulation of Contact Dynamics in Operational Space (Award Talk)*

Abhinandan Jain, Cory Crean, Calvin Kuo, Hubertus von Bremen, Steven Myint

**Abstract:**

In recent years, complementarity techniques have been developed for modeling non-smooth contact and collision dynamics problems for multi-link robotic systems. In this approach, a linear complementarity problem (LCP) is set up using  $6n$  non-minimal coordinates for a system with  $n$  links together with all the unilateral constraints and inter-link bilateral constraints on the system. In this paper, we use operational space dynamics to develop a complementarity formulation for contact and collision dynamics that uses minimal coordinates. The use of such non-redundant coordinates results in much smaller size LCP problems and the automatic enforcement of the inter-link bilateral constraints. Furthermore, we exploit operational space low-order algorithms to overcome some of the computational bottlenecks in using minimal coordinates.

**Schedule:** see page [22](#)

*Tendon-Driven Variable Impedance Control Using Reinforcement Learning*

Eric Rombokas, Mark Malhotra, Evangelos Theodorou, Yoky Matsuoka, Emanuel Todorov

**Abstract:**

Biological motor control is capable of learning complex movements containing contact transitions and unknown force requirements while adapting the impedance of the system. In this work, we seek to achieve robotic mimicry of this compliance, employing stiffness only when it is necessary for task completion. We use path integral reinforcement learning which has been successfully applied on torque-driven systems to learn episodic tasks without using explicit models. Applying this method to tendon-driven systems is challenging because of the increase in dimensionality, the intrinsic nonlinearities of such systems, and the increased effect of external dynamics on the lighter tendon-driven end effectors. We demonstrate the simultaneous learning of feedback gains and desired tendon trajectories in a dynamically complex sliding-switch task with a tendon-driven robotic hand. The learned controls look noisy but nonetheless result in smooth and expert task performance. We show discovery of dynamic strategies not explored in a demonstration, and that the learned strategy is useful for understanding difficult-to-model plant characteristics.

**Schedule:** see page [23](#)*An Object-Based Approach to Map Human Hand Synergies onto Robotic Hands with Dissimilar Kinematics*  
Guido Gioioso, Gionata Salvietti, Monica Malvezzi, Domenico Prattichizzo**Abstract:**

Robotic hands differ in kinematics, dynamics, programming, control and sensing frameworks. Borrowing the terminology from software engineering, there is a need for middleware solutions to control the robotic hands independently from their specific structure, and focusing only on the task. Results in neuroscience concerning the synergistic organization of the human hand, are the theoretical foundation of this work, which focuses on the problem of mapping human hand synergies on robotic hands with dissimilar kinematic structures. The proposed mapping is based on the use of a virtual ellipsoid and it is mediated by a model of an anthropomorphic robotic hand able to capture the idea of synergies in human hands. This approach has been tested in two different robotic hands with an anthropomorphic and non-anthropomorphic kinematic structure.

**Schedule:** see page [23](#)*Feature-Based Prediction of Trajectories for Socially Compliant Navigation*

Markus Kuderer, Henrik Kretzschmar, Christoph Sprunk, Wolfram Burgard

**Abstract:**

Mobile robots that operate in a shared environment with humans need the ability to predict the movements of people to better plan their navigation actions. In this paper, we present a novel approach to predict the movements of pedestrians. Our method reasons about entire trajectories that arise from interactions between people in navigation tasks. It applies a maximum entropy learning method based on features that capture relevant aspects of the trajectories to determine the probability distribution that underlies human navigation behavior. Hence, our approach can be used by mobile robots to predict forthcoming interactions with pedestrians and thus react in a socially compliant way. In extensive experiments, we evaluate the capability and accuracy of our approach and demonstrate that our algorithm outperforms the popular social forces method, a state-of-the-art approach. Furthermore, we show how our algorithm can be used for autonomous robot navigation using a real robot.

**Schedule:** see page [23](#)

*E-Graphs: Bootstrapping Planning with Experience Graphs*

Michael Phillips, Benjamin Cohen, Sachin Chitta, Maxim Likhachev

**Abstract:**

Human environments possess a significant amount of underlying structure that is under-utilized in motion planning and mobile manipulation. In domestic environments for example, walls and shelves are static, large objects such as furniture and kitchen appliances most of the time do not move and do not change, and objects are typically placed on a limited number of support surfaces such as tables, countertops or shelves. Motion planning for robots operating in such environments should be able to exploit this structure to improve its performance with each execution of a task. In this paper, we develop an online motion planning approach which learns from its planning episodes (experiences) a graph, an Experience Graph. This graph represents the underlying connectivity of the space required for the execution of the mundane tasks performed by the robot. The planner uses the Experience graph to accelerate its planning efforts whenever possible and gracefully degenerates to planning from scratch if no previous planning experiences can be reused. On the theoretical side, we show that planning with Experience graphs is complete and provides bounds on suboptimality with respect to the graph that represents the original planning problem. On the experimental side, we show in simulations and on a physical robot that our approach is particularly suitable for higher-dimensional motion planning tasks such as planning for single-arm manipulation and two armed mobile manipulation. The approach provides significant speedups over planning from scratch and generates predictable motion plans: motions planned from start positions that are close to each other, to goal positions that are also close to each other, are similar. In addition, we show how the Experience graphs can incorporate solutions from other approaches such as human demonstrations, providing an easy way of bootstrapping motion planning for complex tasks.

**Schedule:** see page [23](#)

## Thursday, July 12, 2012: Oral Session 2

### *Experiments with Balancing on Irregular Terrains using the Dreamer Mobile Humanoid Robot (Award Talk)*

Luis Sentis, Josh Petersen, Roland Philippsen

**Abstract:**

We investigate controllers for mobile humanoid robots that maneuver in irregular terrains while performing accurate physical interactions with the environment and with human operators and test them on Dreamer, our new robot with a humanoid upper body (torso, arm, head) and a holonomic mobile base (triangularly arranged Omni wheels). All its actuators are torque controlled, and the upper body provides redundant degrees of freedom. We developed new dynamical models and created controllers that stabilize the robot in the presence of slope variations, while it compliantly interacts with humans. This paper considers underactuated free-body dynamics with contact constraints between the wheels and the terrain. Moreover, Dreamer incorporates a biarticular mechanical transmission that we model as a force constraint. Using these tools, we develop new compliant multiobjective skills and include self-motion stabilization for the highly redundant robot.

**Schedule:** see page [23](#)

### *FFT-based Terrain Segmentation for Underwater Mapping*

Bertrand Douillard, Navid Nourani-Vatani, Matthew Johnson-Roberson, Stefan Williams, Chris Roman, Oscar Pizarro, Ian Vaughn, Gabrielle Inglis

**Abstract:**

A method for segmenting three-dimensional scans of underwater unstructured terrains is presented. Individual terrain scans are represented as an elevation map and analysed using fast Fourier transform (FFT). The segmentation of the ground surface is performed in the frequency domain. The lower frequency components represent the slower varying undulations of the underlying ground whose segmentation is similar to denoising / low pass filtering. The cut-off frequency, below which ground frequency components are selected, is automatically determined using peak detection. The user can specify a maximum admissible size of objects (relative to the extent of the scan) to drive the automatic detection of the cut-off frequency. The points above the estimated ground surface are clustered via standard proximity clustering to form object segments. The approach is evaluated using ground truth hand labelled data. It is also evaluated for registration error when the segments are fed as features to an alignment algorithm. In both sets of experiments, the approach is compared to three other segmentation techniques. The results show that the approach is applicable to a range of different terrains and is able to generate features useful for navigation.

**Schedule:** see page [23](#)

*Guaranteeing High-Level Behaviors while Exploring Partially Known Maps*

Shahar Sarid, Bingxin Xu, Hadas Kress-Gazit

**Abstract:**

This paper presents an approach for automatically synthesizing and re-synthesizing a hybrid controller that guarantees a robot will exhibit a user-defined high-level behavior while exploring a partially known workspace (map). The approach includes dynamically adjusting the discrete abstraction of the workspace as new regions are detected by the robot's sensors, automatically rewriting the specification (formally defined using Linear Temporal Logic) and re-synthesizing the control while preserving the robot state and its history of task completion. The approach is implemented within the LTLMoP toolkit and is demonstrated using a Pioneer 3-DX in the lab.

**Schedule:** see page [23](#)*Optimal Control with Weighted Average Costs and Temporal Logic Specifications*

Eric Wolff, Ufuk Topcu, Richard Murray

**Abstract:**

We consider optimal control for a system subject to temporal logic constraints. We minimize a weighted average cost function that generalizes the commonly used average cost function from discrete-time optimal control. Dynamic programming algorithms are used to construct an optimal trajectory for the system that minimizes the cost function while satisfying a temporal logic specification. Constructing an optimal trajectory takes only polynomially more time than constructing a feasible trajectory. We demonstrate our methods on simulations of autonomous driving and robotic surveillance tasks.

**Schedule:** see page [23](#)*Reducing Conservativeness in Safety Guarantees by Learning Disturbances Online: Iterated Guaranteed Safe Online Learning*

Jeremy Gillula, Claire Tomlin

**Abstract:**

Reinforcement learning has proven itself to be a powerful technique in robotics, however it has not often been employed to learn a controller in a hardware-in-the-loop environment due to the fact that spurious training data could cause a robot to take an unsafe (and potentially catastrophic) action. One approach to overcoming this limitation is known as Guaranteed Safe Online Learning via Reachability (GSOLR), in which the controller being learned is wrapped inside another controller based on reachability analysis that seeks to guarantee safety against worst-case disturbances. This paper proposes a novel improvement to GSOLR which we call Iterated Guaranteed Safe Online Learning via Reachability (IGSOLR), in which the worst-case disturbances are modeled in a state-dependent manner (either parametrically or nonparametrically), this model is learned online, and the safe sets are periodically recomputed (in parallel with whatever machine learning is being run online to learn how to control the system). As a result the safety of the system automatically becomes neither too liberal nor too conservative, depending only on the actual system behavior. This allows the machine learning algorithm running in parallel the widest possible latitude in performing its task while still guaranteeing system safety. In addition to explaining IGSOLR, we show how it was used in a real-world example, namely that of safely learning an altitude controller for a quadrotor helicopter. The resulting controller, which was learned via hardware-in-the-loop reinforcement learning, out-performs our original hand-tuned controller while still maintaining safety. To our knowledge, this is the first example in the robotics literature of an algorithm in which worst-case disturbances are learned online in order to guarantee system safety.

**Schedule:** see page [23](#)

# Conference Organizers

General Chair	Nicholas Roy, Massachusetts Institute of Technology
Program Chair	Paul Newman, University of Oxford
Local Arrangement Chairs	Stefan B. Williams, University of Sydney Fabio Ramos, University of Sydney
Publicity Chair	Dylan Shell, Texas A&M
Publications Chair	Siddhartha Srinivasa, Carnegie Mellon University
Workshops Chair	José Neira, University of Zaragoza
Area Chairs	Pieter Abbeel, University of California, Berkeley Tim Barfoot, University of Toronto Han-Lim Choi, KAIST Noah Cowan, Johns Hopkins University Andrew Davison, Imperial College Frank Dellaert, Georgia Institute of Technology Ryan Eustice, University of Michigan Seth Hutchinson, UIUC Takayuki Kanda, ATR George Kantor, Carnegie Mellon University Hadas Kress-Gazit, Cornell University Katherine Kuchenbecker, University of Pennsylvania Ingmar Posner, University of Oxford Cédric Pradalier, ETH Zürich Luis Sentis, University of Texas at Austin Siddhartha Srinivasa, Carnegie Mellon University Cyrill Stachniss, University of Freiburg Salah Sukkarieh, University of Sydney Juan Tardós, University of Zaragoza Sethu Vijayakumar, University of Edinburgh Gordon Wyeth, QUT

## RSS Foundation Board

President	Sebastian Thrun, Stanford University / Google
Directors	Oliver Brock, TU Berlin Dieter Fox, University of Washington Yoky Matsuoka, University of Washington Stefan Schaal, University of Southern California Gaurav Sukhatme, University of Southern California Jeff Trinkle, Rensselaer Polytechnic Institute
Treasurer	Wolfram Burgard, University of Freiburg
Secretary	Nicholas Roy, Massachusetts Institute of Technology

## Advisory Board

Greg Dudek, McGill University  
Hugh Durrant-Whyte, National ICT Australia (NICTA)  
Lydia Kavraki, Rice University  
Oussama Khatib, Stanford University  
Sven Koenig, University of Southern California  
Vijay Kumar, University of Pennsylvania  
John Leonard, Massachusetts Institute of Technology  
Matt Mason, Carnegie Mellon University  
Paul Newman, University of Oxford  
Daniela Rus, Massachusetts Institute of Technology

# Program Committee

Jake Abbott	Greg Chirikjian	Ken Goldberg	Jonathan Kelly
Martin Adams	Margarita Chli	Dan Goldman	Alonzo Kelly
Nisar Ahmed	Youngjin Choi	Clément Gosselin	Jung Kim
Emrah Akin	NakYoung Chong	Stephen Gould	James Kinsey
Henrik Andreasson	Howie Choset	Giorgio Grisetti	Georg Klein
Tamim Asfour	Henrik Christensen	Jessy Grizzle	Ross Knepper
Chris Atkeson	Soon-Jo Chung	Ben Grocholsky	SeongYoung Ko
Nora Ayanian	Timothy Chung	Dan Grollman	Sarath Kodagoda
Abe Bachrach	Javier Civera	Roderich Gross	Daniel Koditschek
Tim Bailey	Jonahthan Clark	Steffen Gutmann	Zico Kolter
Ruzena Bajcsy	Chris Clark	Quang Ha	Jana Kosecka
Ravi Balasubramanian	Francis Colas	Sami Haddadin	Kevin Köser
Devin Balkcom	Andrew Comport	Blake Hannaford	Torsten Kroeger
Chris Beall	Francois Conti	Stephen Hart	Norbert Krüger
Jenay Beer	Peter Corke	Kris Hauser	Rainer Kuemmerle
Michael Beetz	Jacob Crandall	Ali Haydar	Kolja Kuhnlenz
Sven Behnke	Amir Degani	Philippe Henning	Pawan Kumar
Kostas Bekris	Marc Deisenroth	John Hollerbach	Yoshiaki Kuwata
Calin Belta	Xinyan Deng	Geoff Hollinger	Ville Kyrki
Rodrigo Benenson	Ashish Deshpande	Franz Hover	Simon Lacroix
Maren Bennewitz	Mehmet Dogar	Jonathan How	Kevin Lai
Dmitry Berenson	Bertrand Douillard	Matthew Howard	Florent Lamiroux
Sarah Bergbreiter	Anca Dragan	Andrew Howard	David Lane
Marcel Bergerman	Tom Duckett	Kaijen Hsiao	Steve Lavalle
Luca Bertuccelli	Greg Dudek	Ani hsieh	Jerome Le Ny
Antonio Bicchi	Nathaniel Fairfield	David Hsu	Jusuk Lee
Aude Billard	Robert Fitch	Haomiao Huang	Joon-Yong Lee
Mike Bosse	Philippe Fraisse	Albert Huang	Bastian Leibe
Tim Bretl	Friedrich Fraundorfer	Jonathan Hurst	John Leonard
Oliver Brock	Emilio Frazzoli	Baro Hyun	Ales Leonardis
Mitch Bryson	Eric Frew	Auke Ijspeert	Vincent Levesque
Jonas Buchli	Antonio Frisoli	Viorela Ila	Maxim Likhachev
Wolfram Burgard	Mario Fritz	Michita Imai	Achim Lilienthal
Sylvain Calinon	Robert Full	Vadim Indelman	Jim Little
Stefano Carpin	Paul Furgale	Michael Jenkin	Dikai Liu
José Castellanos	Roger Gasserts	Patric Jensfelt	Tomas Lozano-Perez
M. Cenk	Hartmut Geyer	Sungho Jo	Kevin Lynch
Andrea Censi	Christopher Geyer	Michael Kaess	Malcolm Maciver
Odest Chadwicke	Philippe Giguere	Vinutha Kallem	Ian Manchester
Francois Chaumette	Brent Gillespie	Sertac Karaman	Nicolas Mansard
Sonia Chernova	Dylan Glas	Dov Katz	Eric Marchand

Jose Maria	Jason O'Kane	Miguel Salichs	Russ Tedrake
Joshua Marshall	Kai Oliver	Uluc Saranli	Rodney Teo
Bhaskara Marthi	Edwin Olson	Irene Sardellitti	Ashley Tews
Agostino Martinelli	Giuseppe Oriolo	Junaed Sattar	Gian Tipaldi
Oskar Martinez	Christian Ott	Davide Scaramuzza	Emo Todorov
Matt Mason	Lluís Pacheco	Paul Scerri	Marc Toussaint
Larry Matthies	Leslie Pack	Stefan Schaal	Nikolas Trawny
Jerome Maye	Vincent Padois	Mac Schwager	Alex Trevor
Walterio Mayol	Jaeheung Park	Cristian Secchi	Rudolph Triebel
James McLurkin	Lina Paz	Julie Shah	Ales Ude
Christopher Mei	Thierry Peynot	Tomohiro Shibata	Jun Ueda
Nathan Michael	Zachary Pezzementi	Zvi Shiller	James Underwood
Francois Michaud	Patrick Pfaff	Jiwon Shin	Ben Upcroft
Michael Milford	Roland Philippsen	Masahiro Shiomi	Jamie Valls
Takashi Minato	Justus Piater	Gabe Sibley	Jur van
Javier Minguez	Pedro Piniés	Nicola Simeon	Richard Vaughan
Michael Mistry	Oscar Pizarro	Arjun Singh	Andrea Vedaldi
Sayan Mitra	Francois Pomerleau	Christian Smith	Madhusudan Venkadesan
Mark Moll	Josep Porta	Stephen Smith	Matt Walter
Katja Mombaur	Kanna Rajan	Ryan Smith	Steven Waslander
Hyungpil Moon	Subramanian Ramamoorthy	João Sousa	Justin Werfel
Kristi Morgansen	Fabio Ramos	Matthijs Spaan	Louis Whitcomb
Jun Morimoto	Ananth Ranganathan	Luciano Spinello	Stephen Williams
Peter Moutney	Rajesh Rao	Mike Stilman	Nok Wongpiromsarn
Anastasios Mourikis	Nathan Ratliff	Alex Stoytchev	Robert Wood
Mario Munich	Sai Ravela	Hauke Strasdat	Katsu Yamane
Hyun Myung	Wei Ren	Klaus Strobl	Manuel Yguel
Jun Nakanishi	Shai Revzen	Juergen Sturm	Eiichi Yoshida
Nils Napp	Cam Riviere	Gaurav Sukhatme	Yuichiro Yoshikawa
José Neira	Steve Rock	Leila Takayama	Michael Zavlanos
Brad Nelson	John Rogers	James Tangorra	Fumin Zhang
Gerhard Neumann	Chris Roman	Herbert Tanner	Mike Zinn
Stephen Nuske	Radu Rusu	Adriana Tapus	

# Author Instructions

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 August 1, 2012. 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

siddh@cs.cmu.edu

using “RSS info change <number>” in the subject line, where <number> is your paper number as it appears in the conference online proceedings.

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 August 1, 2012:

Siddhartha Srinivasa  
Newell-Simon Hall (NSH)  
The Robotics Institute  
Carnegie Mellon University  
5000 Forbes Avenue  
Pittsburgh, PA 15213  
United States of America

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.html>

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.

**Document Preparation Using Latex:** Please create a PDF file from your Latex source by using the following commands:

```
latex paper.tex
dvips paper.dvi -o paper.ps -t letter -Ppdf -G0
ps2pdf paper.ps
```

The arguments to the dvips command will ensure that all fonts are embedded in the PDF file produced by ps2pdf.

**Checking the PDF file:** Before you submit your file, please open it in Acrobat Reader. In the menu “File” under “Document Properties” you can find information about “Fonts.” Your document should only contain Type-1 fonts. If you followed the instructions above, but your documents contains other types of fonts, they may have been included as part of figures. Please ensure that your submission only contains Type-1 fonts. If you experience difficulties creating PDF files that comply with this requirement, please send email to [siddh@cs.cmu.edu](mailto:siddh@cs.cmu.edu) *prior to the deadline.*

5. **Submission:** Please submit your paper by August 1, 2012 using the link

<https://cmt.research.microsoft.com/RSS2012/>

We are looking forward to receiving your final submission!

## Author Checklist

- Revised paper uploaded via the conference submission software.
- Author agreement form signed and mailed to Siddhartha Srinivasa via physical mail.
- If title or authors have changed, notify [siddh@cs.cmu.edu](mailto:siddh@cs.cmu.edu)

Please note: *We reserve the right not to publish accepted papers should not all information be received by August 1, 2012. We will also exclude papers that violate our formatting guidelines.*

**Deadline is August 1, 2012.**