Chess

Berkeley-Sydney Driving Team

Sydney-Berkeley Driving Team

Making research out of contests.

CHESS and the DARPA Grand Challenge

Jonathan Sprinkle
Executive Director, CHESS
Team Leader, Berkeley-Sydney Driving Team

The University of Sydney

Berkeley

What *was* DARPA Grand Challenge 2?

Autonomous vehicles can operate in difficult terrain over distances (and speeds) required by military missions.

Previous Grand Challenge: Winner

Select images and text courtesy of DARPA

Vehicle	**Stanley**
Team	**Stanford Racing Team**
Hometown	**Palo Alto, California**
Team Leader	**Michael Montemerlo**
Finishing time	**6h 53m (19.2 mph)**

2nd Place:

Select images and text courtesy of DARPA

Vehicle	**Sandstorm**
Team	**Red Team**
Hometown	**Pittsburgh, Pennsylvania**
Team Leader	**Red Whittaker**
Finishing time	**7h 04m (18.7 mph)**

3rd Place:

Select images and text courtesy of DARPA

Vehicle	**H1ghlander**
Team	**Red Team Too**
Hometown	**Pittsburgh, Pennsylvania**
Team Leader	**Kevin Peterson**
Finishing time	**7h 14m (18.3 mph)**

4th Place:

Select images and text courtesy of DARPA

Vehicle	**KAT-5**
Team	**Gray Team**
Hometown	**Metairie, Louisiana**
Team Leader	**Eric Gray**
Finishing time	**7h 30m (17.6 mph)**

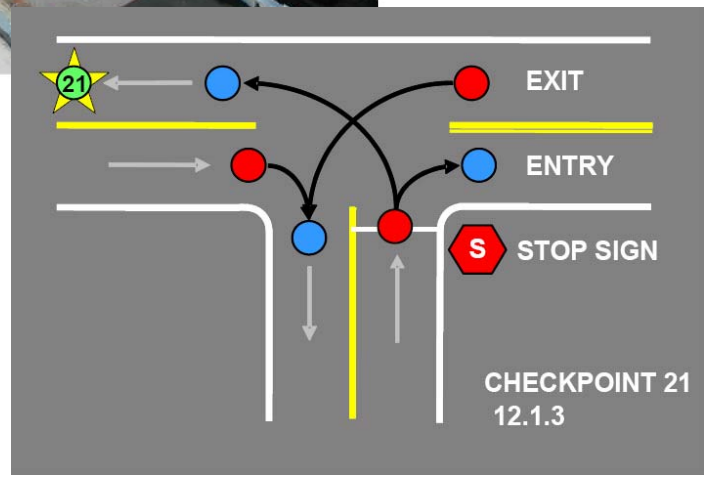
5th Place:

Select images and text courtesy of DARPA

Vehicle	**TerraMax**
Team	**Team TerraMax**
Hometown	**Oshkosh, Wisconsin**
Team Leader	**Jim Fravert**
Finishing time	**12h 51m (10.3 mph)**

What is the DARPA Grand Challenge 3?

- **Safe autonomous driving in traffic**
  - Safe=no collisions
  - Capable=Turns, stops, intersection, passing, merging, parking, following
  - Robust=Blocked roads, erratic drivers, sparse waypoints, GPS outage



- November 3, 2007
  - To use safe autonomous driving to travel at least 60 miles in fewer than 6 hours

Select images and text courtesy of DARPA

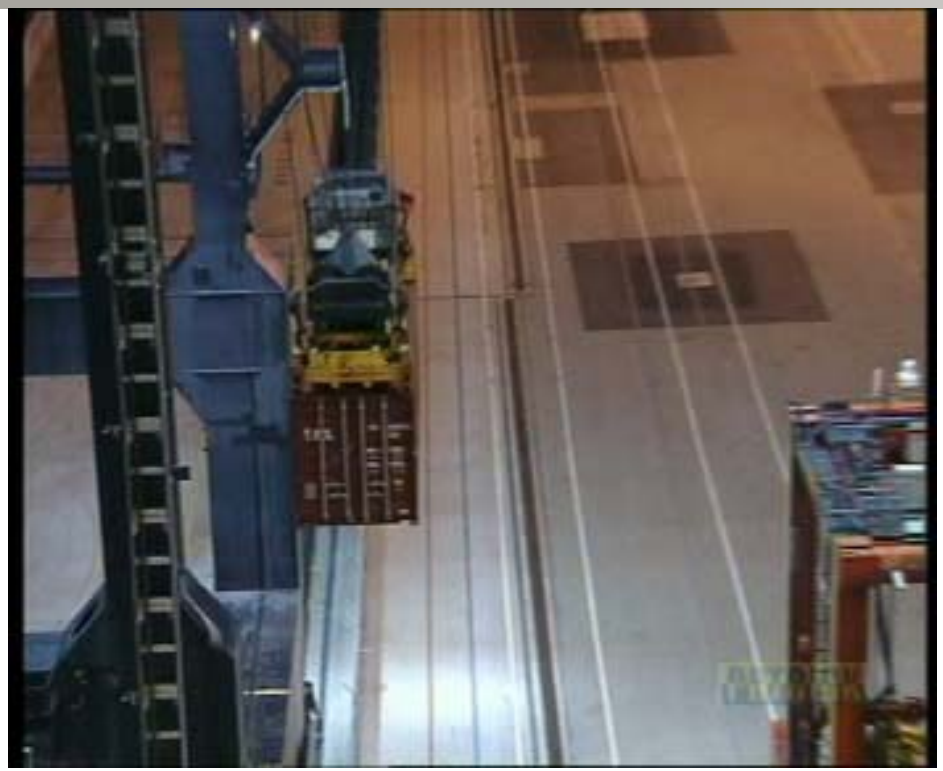
Some Statistics about DGC3:

- **Track-A (DARPA-funded) Research Teams: 11**
  - **Stanford, MIT, Caltech, Carnegie Mellon,**
  - **$1M from DARPA to put toward equipment, personnel, travel**

- **Track-B (DARPA-sundered) Research Teams: 78**
  - **Universities, inventors, somebodies, nobodies**
  - **$0 from DARPA to put toward equipment, personnel**

- **The Prize?**
  - **$2M – First Place**
  - **$1M – Second Place**
  - **$500k – Third Place**
  - **“I went to the DARPA Grand Challenge, and I didn’t even get a lousy T-shirt” – Every other place**

Why Sydney/ACFR?



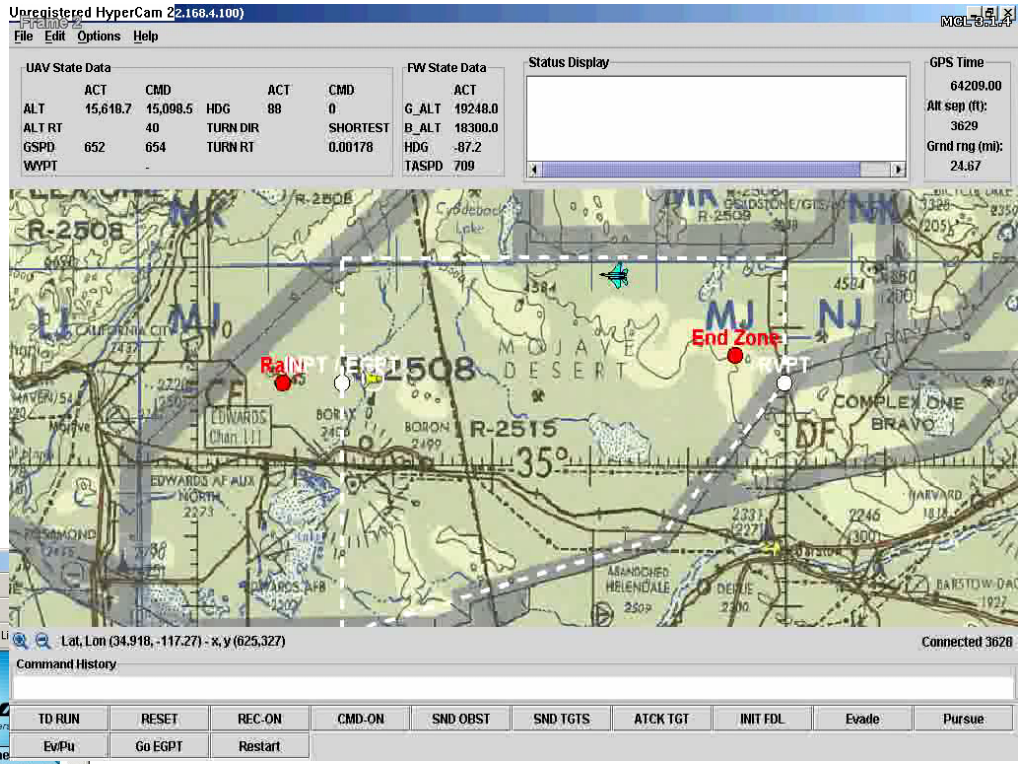
Patrick Project, Port of Brisbane, Australia

- High-precision navigation
- Localization genius
- Path planning
- Optimization
- Ground robotics
- Sensing platforms

- Real-time sensing
- Safety planning

Why UC Berkeley?

Software Enabled Control



- **Control of unstable platforms**
- **Game-style situations**
- **Real-time systems**

Software Enabled Control

Team Vision

A component-based system integration of individually proved components—physical, computational, and abstract—which are rigorously tested.

- **Why is this unique?**
  - ***NOT* a point solution vehicle**
  - **We are developing *individual* solutions which should work in scenarios not envisioned by DGC**

Team Makeup

- **Berkeley EECS**
  - **Dr. Jonathan Sprinkle**
  - **Dr. David H.C. Shim**
  - **Dr. J. Mikael Eklund**
  - **Prof. Vason Srini**
  - **Prof. Shankar Sastry**
  - **Prof. M. Tomizuka**
  - **Prof. J. Karl Hedrick**

http://chess.eecs.berkeley.edu/

- **University of Technology, Sydney**

http://uts.edu.au/

- **Sydney ACFR**
  - **Dr. Ben Upcroft**
  - **Dr. Jose Guivant**
  - **Dr. Alex Makarenko**
  - **Prof. Hugh Durrant-Whyte**
  - **Prof. Eduardo Nebot**
  - **Along with numerous engineering staff/students**

http://www.acfr.usyd.edu.au/

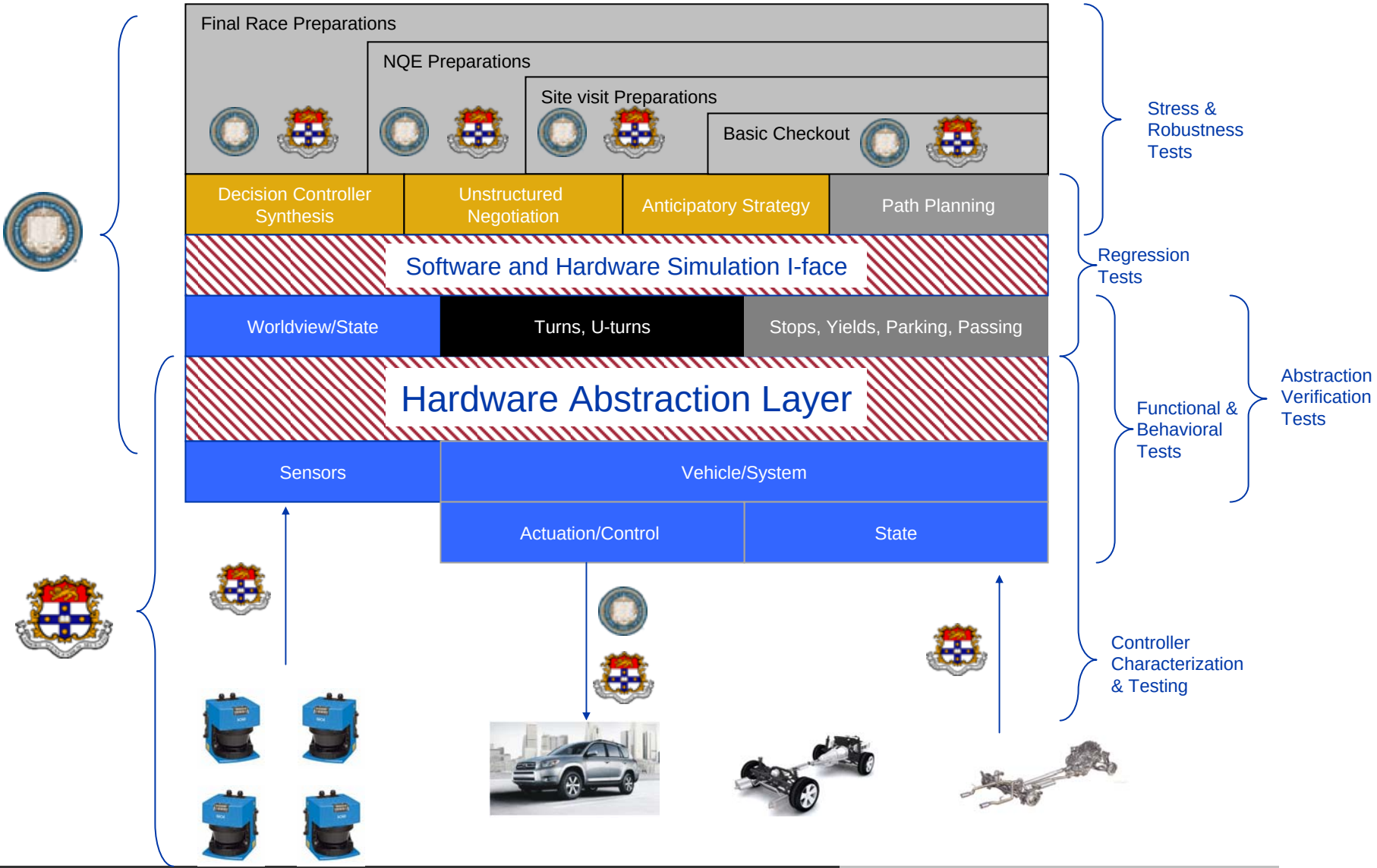
- **National Information and Communication Technology, Australia (NICTA)**

http://nicta.com.au/

Work Breakdown: Teams

1. Vehicle
2. Hardware
3. Sensors
4. Algorithms
5. Software
6. System
7. Testing
8. PR
9. Management

Strategy for component development



Requirements to not get kicked out:

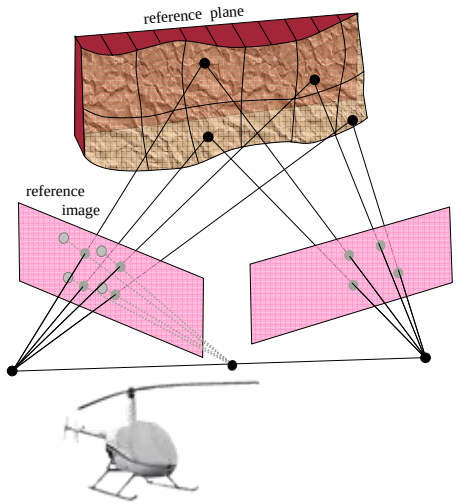
- **Busywork:**
  - Siren goes off when autonomous
  - Use turn signals appropriately
  - Only be safe
- **Hardwork:**
  - Do not pause too long
  - Stay in own lane
  - Keep appropriate distances
  - Don’t be hesitant or jumpy
  - Follow the rules of the road
- **Devilishly difficult work**
  - Anticipate traffic patterns
  - Sense vehicles and intentions
  - Optimize travel paths

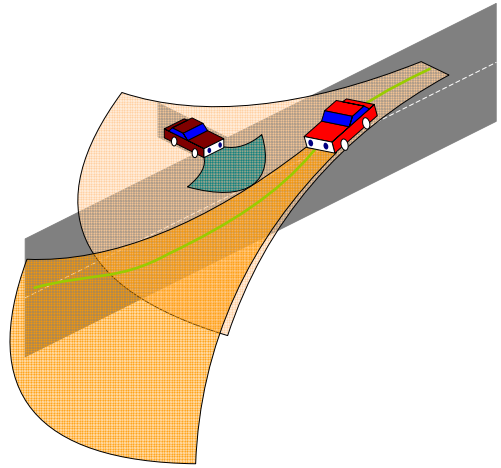
Gates to Pass

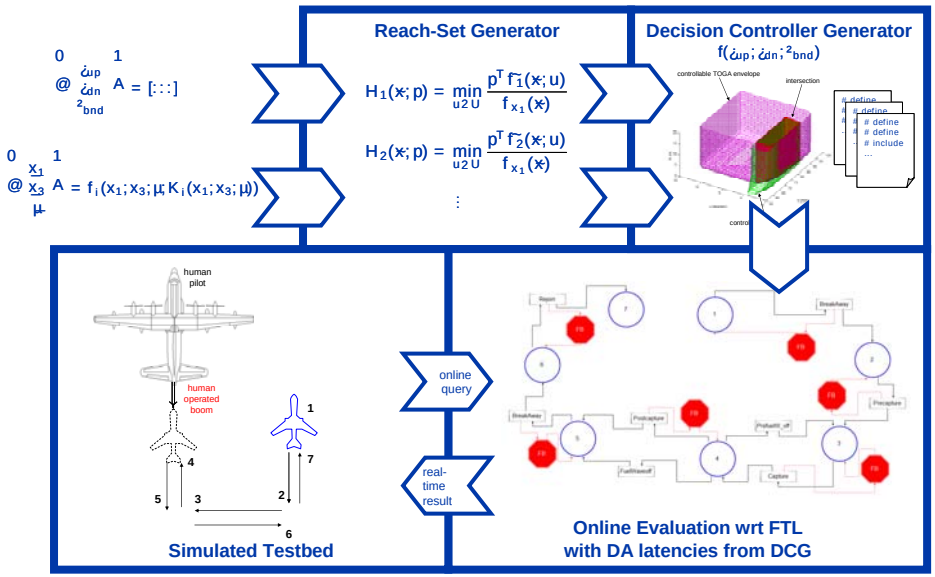
Date	Activity / Event	Location
May 1, 2006	Urban Challenge Program Announcement	
May 20, 2006	Participants Conference	Reston, VA
October 16–November 1, 2006	Track A Kickoff Meetings	Performer Site
October 13, 2006	Track B Application Parts 1 & 2 Due	
March 2, 2007	Site Visit Information Due	
April 13, 2007	Track A Technical Paper Due Track B Video Demonstration Due	
May 11, 2007	Site Visit Announcement	
June 1, 2007	Track B Technical Paper Due	
June 11–July 20, 2007	Site Visits	Performer Site
August 10, 2007	Semifinalist Announcement Location Announcement	DARPATech, Anaheim, CA
October 21-27, 2007	National Qualification Event 1	Western U.S.
October 28-31, 2007	National Qualification Event 2	Western U.S.
November 3, 2007	Urban Challenge Final Event	Western U.S.

What makes CHESS interesting?

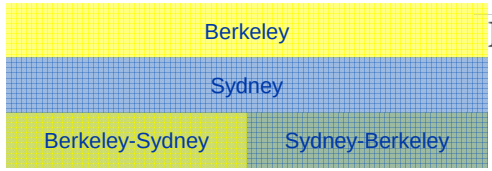
- **Discoveries in focus areas by CHESS can make large impacts on sizeable systems such as DGC**
  - **Reachability analysis**
  - **Code synthesis**
  - **Distributed testing**
  - **Regression analysis**
  - **Models of communication and computation**
  - **Formal models for systems composition**
  - **Real-time computer vision**
- **CHESS's goal in DGC is to show how investment in general research has payoff benefits later**

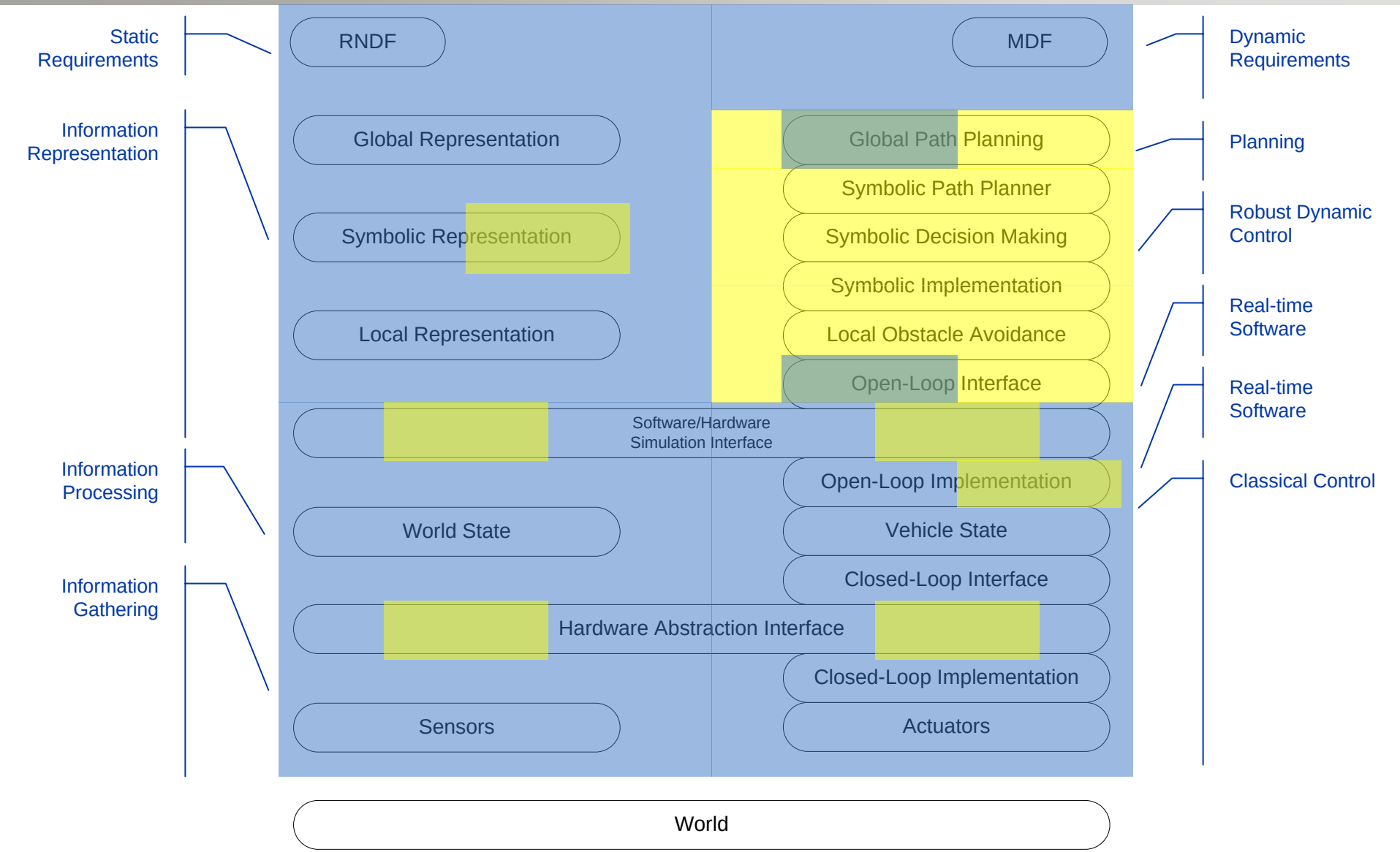






Areas of Contribution





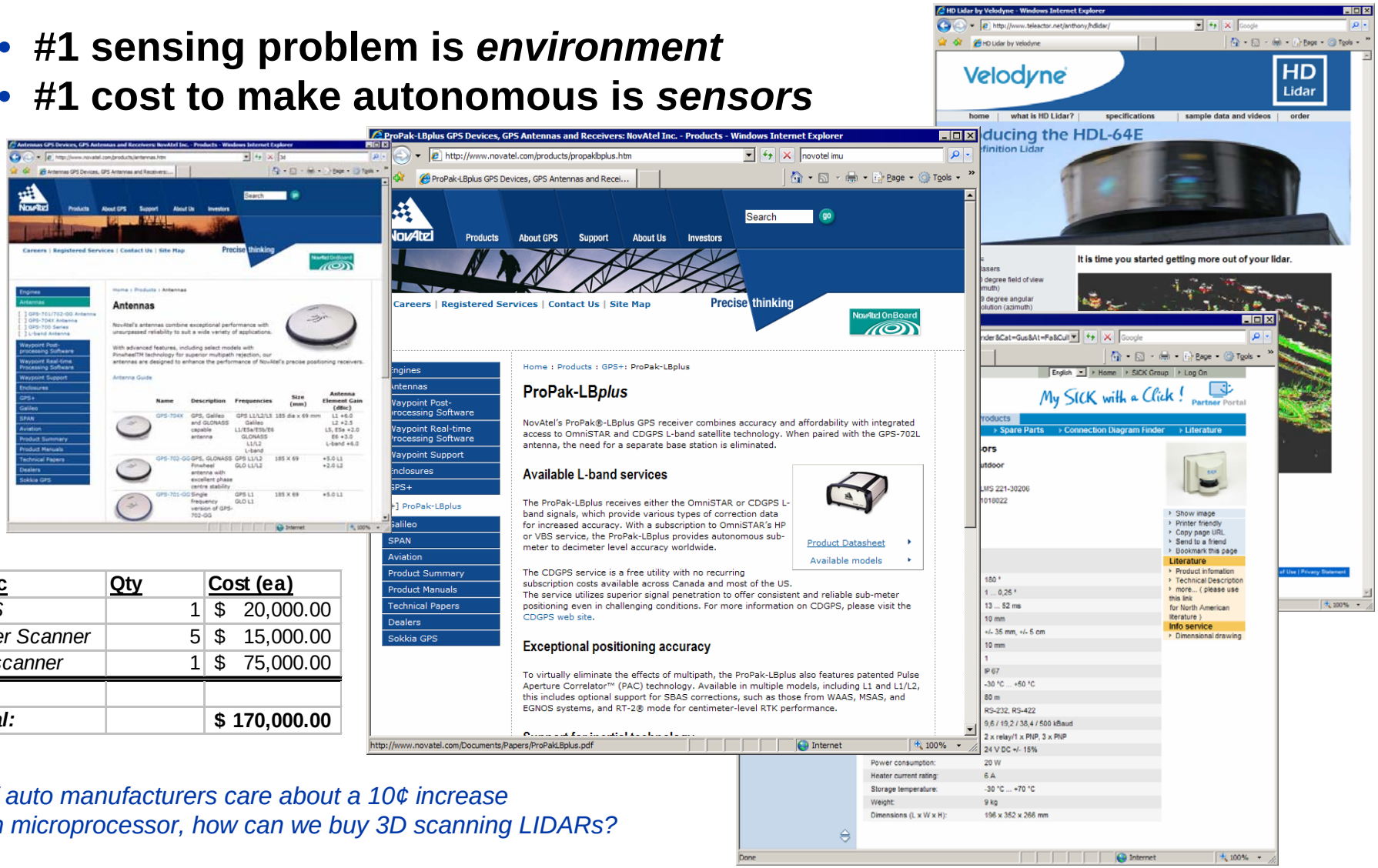
Research Topics Addressed @ Berkeley

- Decision Controller Synthesis
- Collision Free Vehicle Travel
- Real-time computer vision
- Long-range, inexpensive sensors
- Online Nonlin Model-Predictive Control
- Path planning + obstacle avoidance
- Systems Modeling and Code Generation
- High-confidence Setup and deployment

- Composable autonomy
- Affordable Automobile Autopilot

Car Sensors are EXPENSIVE!

- **#1 sensing problem is *environment***
- **#1 cost to make autonomous is *sensors***

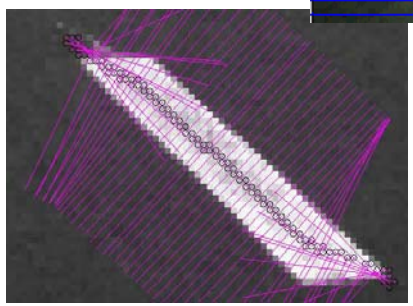


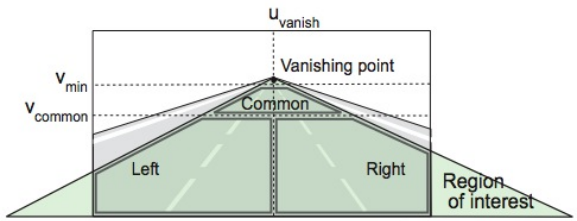
Desc	Qty	Cost (ea)
GPS	1	$ 20,000.00
Laser Scanner	5	$ 15,000.00
3D scanner	1	$ 75,000.00
Total:		**$ 170,000.00**

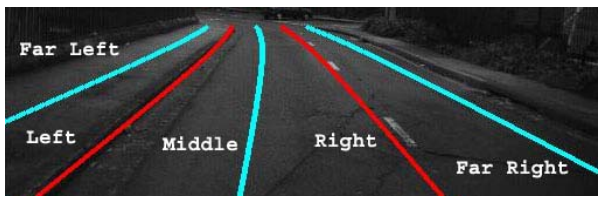
If auto manufacturers care about a 10¢ increase in microprocessor, how can we buy 3D scanning LIDARs?

Research: Computer Vision

- **Recover lane boundary for straight or curved lanes in suburban environment**
- **Recover orientation and position of vehicle in detected lane boundaries**
- **Use temporal coherence for robustness**

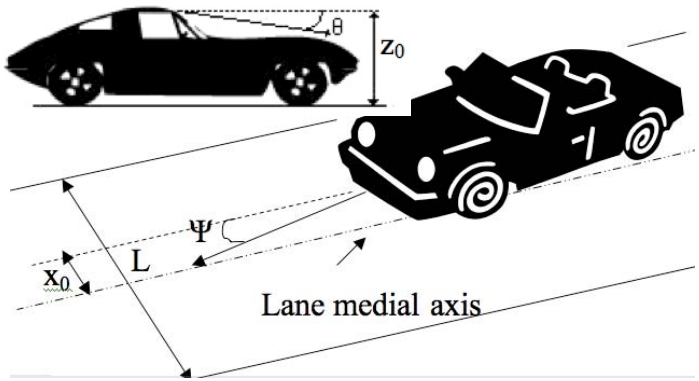






$$\Psi = -\frac{a_1}{E_u}, \quad L = \frac{2E_v a_2 z_0}{E_u}$$

$$x_0 = \frac{E_v a_3 z_0}{E_u}, \quad K = -\frac{2a_4}{E_u E_v z_0}$$

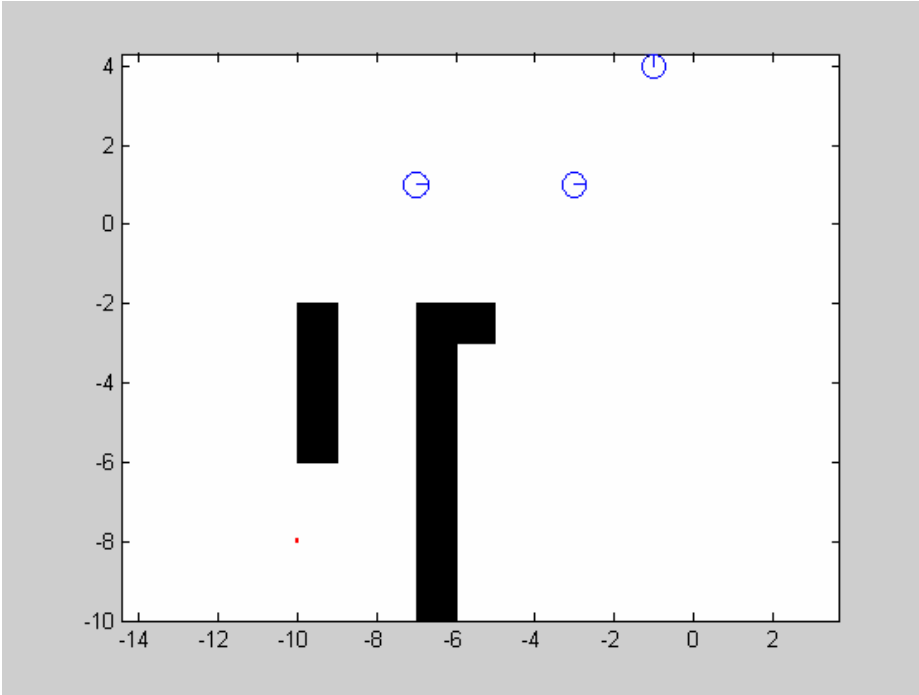


$$u_L = E_u\left(\frac{v - E_v\theta}{E_v z_0}\left(x_0 - \frac{L}{2}\right) - \frac{E_v z_0}{2(v - E_v\theta)}K - \Psi\right)$$

$$u_R = E_u\left(\frac{v - E_v\theta}{E_v z_0}\left(x_0 + \frac{L}{2}\right) - \frac{E_v z_0}{2(v - E_v\theta)}K - \Psi\right)$$

Research: Online Nonlinear Model-Predictive Control

- Waypoint following, obstacle avoidance and variable constraints in the same algorithm.
- Given a time horizon, control is optimal in the sense that the cost function is minimized subject to the car model.



State Cost

Actuation Cost

Obstacles Cost

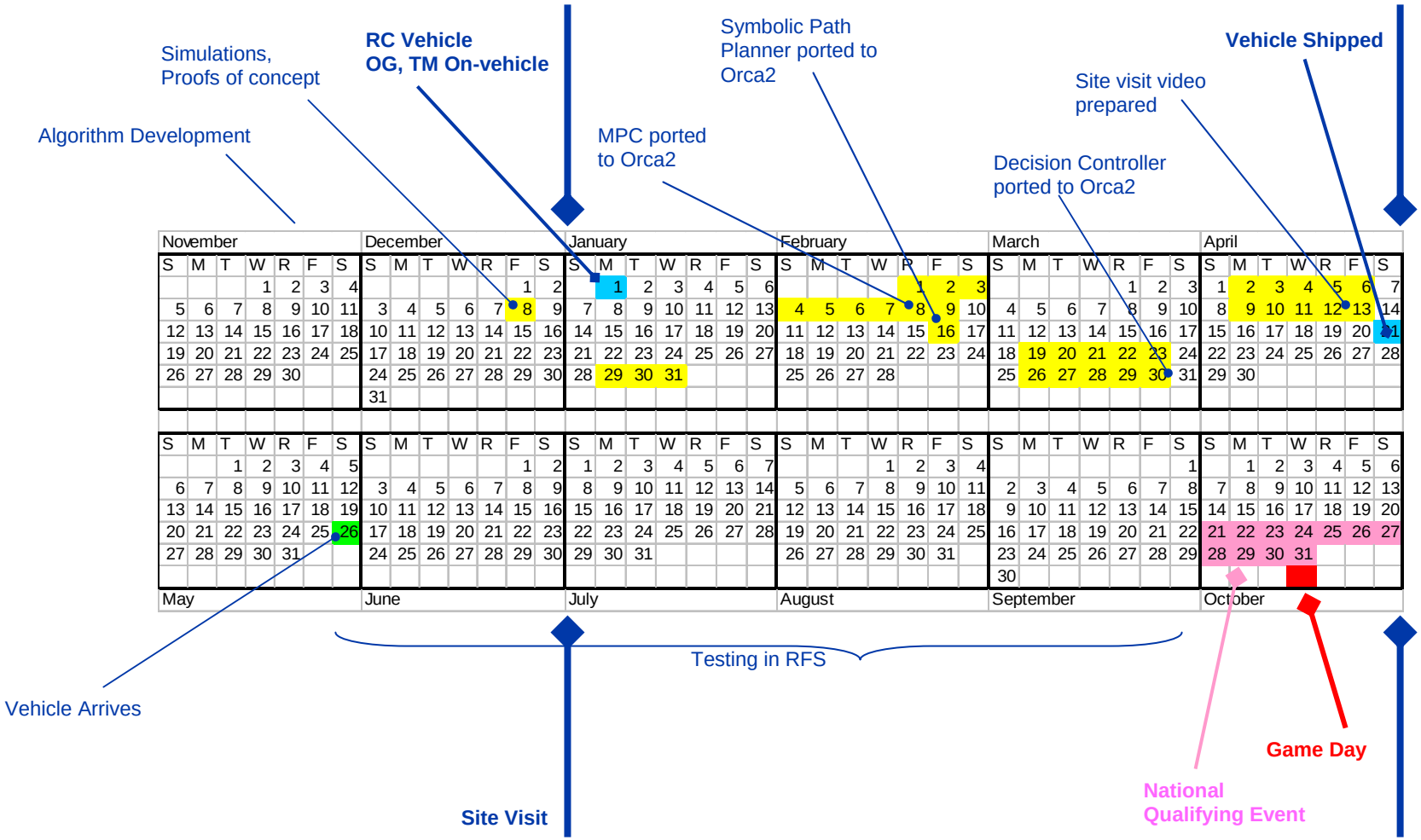
Direction Cost

$$J = \sum_{t=0}^{N-1} K_1 x_t^T Q x_t + K_2 u_t^T R u_t + K_3 J_t^{obs} + K_4 J_t^{dist}$$

$$J_t^{obs} = \max\left\{ \frac{1}{\partial + |X_t - X_{obs}| + |Y_t - Y_{obs}|} - \alpha, 0 \right\}$$

$$J_t^{dist} = \frac{1}{\sqrt{X_t^2 + Y_t^2}} \left\| x_t - \langle x_t, b \rangle b \right\|^2$$

Our life for the rest of the year…



What's a "winning" strategy?

1. **The closest approximation to reality *in simulation***
2. **The capability to decide fastest to go someplace**
3. **The discipline to test algorithms without the vehicle**
4. **The infrastructure to use gathered data to analyze test failures through SWIL/HWIL testing**
5. **The wisdom to build technology that will work if ported to another vehicle—**

i.e., *no gaming the system to hack a win!!!*

Major takeaways…

- **This is about Research, not "winning"**
- **We bring existing expertise in general areas:**
  - **code generation**
  - **optimization and nonlinear control**
  - **embedded software, real-time computer vision**
- **We have new expertise to gain**
  - **fault analysis**
  - **low-cost sensing**
  - **distributed testing**
  - **distributed robustness**
  - **hybrid optimizing controllers**

Targets of opportunity for application of existing CHESS ideas, with rich deadlines and publicity!

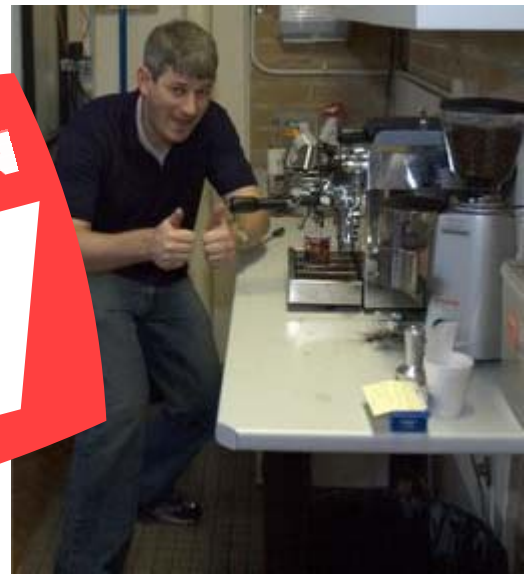
Why's and Wherefore's…

- Why dgc3? Deadlines!
- Why dgc3? Research!
- Why ACFR? Ground robotics, sensing, platform dev
- Why Berkeley? Hybrid systems, decision control, code synthesis, system design, rooted applications
- Why now? People, projects, excitement, and opportunity…and if not now, never.

Jon Sprinkle &
Ben Upcroft

No. 5 is alive!

ECM Giotto!!!!!



Thanks to our sponsors

- **Toyota of Australia**
- **Komatsu**
- **ZeroC**
- **Xilinx**

http://chess.eecs.berkeley.edu/dgc3/

Select images and text courtesy of DARPA