MOBILE APPLICATIONS

Kris Pister: “actuation in the Swarm”
Claire Tomlin: “Actionable Swarms”
Nikhil Naikal: “Camera Networks”
Michel Maharbiz: “bioSwarms”
Ankur Mehta: “Mobile Swarms”
ACTIONABLE SWARMS

ANIL ASWANI, HAOMIAO HUANG, JERRY DING, MICHAEL VITUS, JEREMY GILLULA, PATRICK BOUFFARD, AND CLAIRE TOMLIN
Examples

**Air traffic control**
- Controllers, pilots, passengers
- Grouping and conflict classification
- Uncertainty

**Energy Efficient Buildings**
- Controller, occupants
- Interlinked spaces with time-varying objectives
- Uncertainty

[with David Culler]
Backwards Reachable Set

All states for which, for all possible control actions, there is a disturbance action which can drive the system state into a region $G(0)$ in time $t$.

Reachability as **game**: disturbance attempts to force system into unsafe region, control attempts to stay safe.
Example 1: Collision Avoidance

Pilots instructed to attempt to collide vehicles
Capture property can also be encoded as a condition on the system’s reachable set of states.
Maneuver sequencing is accomplished by stringing together capture sets, starting from the target set and working backwards.

Avoid sets can be combined with capture sets to guarantee safety.
Reachability in Air Traffic Control
Automation to aid controllers

- Infeasible to get data from real controllers
- Most experiments use retired controllers or student volunteers
- Retired controllers are rare, students get bored, where to get more data?

Contrails: Air traffic control game for Android

Replay Engine on Server

Trajectories, aircraft states, player inputs
A Typical ATC experiment

28 participants
168 trials (6 each)

Local US college students

Max individual sample (est): 100 planes

Contrails to date

1391 installs
10,391 games played

10+ countries

Contrails install base as of 2/14/2012

Leaderboard

Top controllers from around the world

Sort by? High Score | Top: 10 | Select

Name | Planes Landed
--- | ---
wizbang_fll | 9489
Tobbesuger | 8853
7203644221 | 7761
Rhiannon | 6215
Iolblock | 6210
tony | 5963
spa | 5851
AK | 5073
anek | 4808

Users by country, as of 2/14/2012

1. United States 25.8% (356)
2. Saudi Arabia 6.1% (85)
3. Germany 5.5% (76)
4. United Kingdom 5.3% (74)
5. Russia 2.7% (37)
6. Brazil 2.7% (37)
7. France 2.5% (35)
8. India 2.4% (33)
9. Netherlands 2.4% (33)
10. Australia 2.2% (31)

Example 2: Teaming up humans and robots

- Quadrotor UAVs
- Multiple players
- Adversarial game
- Limited Information
- Multiple objectives

Computing

GPS-enabled Smartphones

3G Wireless

“Capture the Flag”
Action Support For Human Agents

The computed solution can be used to guide and assist human agents.
Supporting Complex Actions

Reachable sets also **assist and enable** more complex actions and strategic decision making.

In this case reachability information helps the attacker mislead the defender to win from a **losing initial configuration**.
Reachability-Guided UAV Search
Learn models from data...

... but stay safe while learning

- **Safety:**
  - A nominal model with error bounds
  - Reachable sets computed to ensure safety in worst case
  - Reachable sets computed using Model Predictive Control (MPC)

- **Performance:**
  - Use online learning to update model
  - Cost function used to generate control action within the safe set

- **Learning-based** Model Predictive Control
Example 3: Learning to fly

- Linear model
  \[ x_{n+1} = Ax_n + Bu_n + d \]

- Statistics augments physics
  \[ O_m = Fx_n + Hu_n + z \]
Example 3: Learning to fly
Example 4: Energy-efficient buildings

- 640 sq. ft. computer space
- Networked thermostat
- Newton’s law of cooling with heating load

- 141,000 sq. ft. building
- Seven floors of mixed-use space
- Convective cooling with heating load

Berkeley Retrofitted and Inexpensive HVAC Testbed for Energy Efficiency (BRITE) [with Aswani, Culler, Taneja, Krioukov]
Temperature Modeling

• Semi-parametric regression modeling
  – Parametric: Newton’s law of cooling
  – Nonparametric: Heating load

\[ T_{n+1} = AT_n + B_1 u_n + B_2 w_n + q_n \]

– Estimate heating load using only temperature measurements of thermostat
Experiments on BRITE

- LBMPC provides significant energy savings
- Simulations and experiments used to compare controllers

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Method</th>
<th>Energy</th>
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</thead>
<tbody>
<tr>
<td>Thermostat Controller</td>
<td>LBMPC</td>
<td>23.6 kWh</td>
</tr>
<tr>
<td>thermostat Controller</td>
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<td>LBMPC</td>
<td>11.8 kWh</td>
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<tr>
<td>thermostat Controller</td>
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</table>
Experiments on BRITE-S

- Comparisons using many experiments and nonparametric hypothesis testing
- 1.5MWh energy saved on average per day
  - Statistically significant (p=0.002)
  - 95% Confidence Interval of 1MWh to 2MWh savings
Conclusions and current work

- **Reachability-inspired control of hybrid systems**
  - Control law directly from the reachable set calculation
  - Discrete control law
  - Automated controller synthesis for switched systems
    - Under sampling and quantization
    - Learning-based control inside reachable sets

- **Current directions**
  - Reachable set over-approximation methods
    - Control and “open loop” games allows for use of Fast Marching Methods
    - Stochastic hybrid systems: Models, Reachability methods, and Trajectory optimization
  - Incorporation of communication constraints into ATC control
  - Models to inspire control schemes in cancer
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NSF CPS “ACTIONWEBS”