CDS 270-2: Lecture 1-1
Course Overview

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Goals:

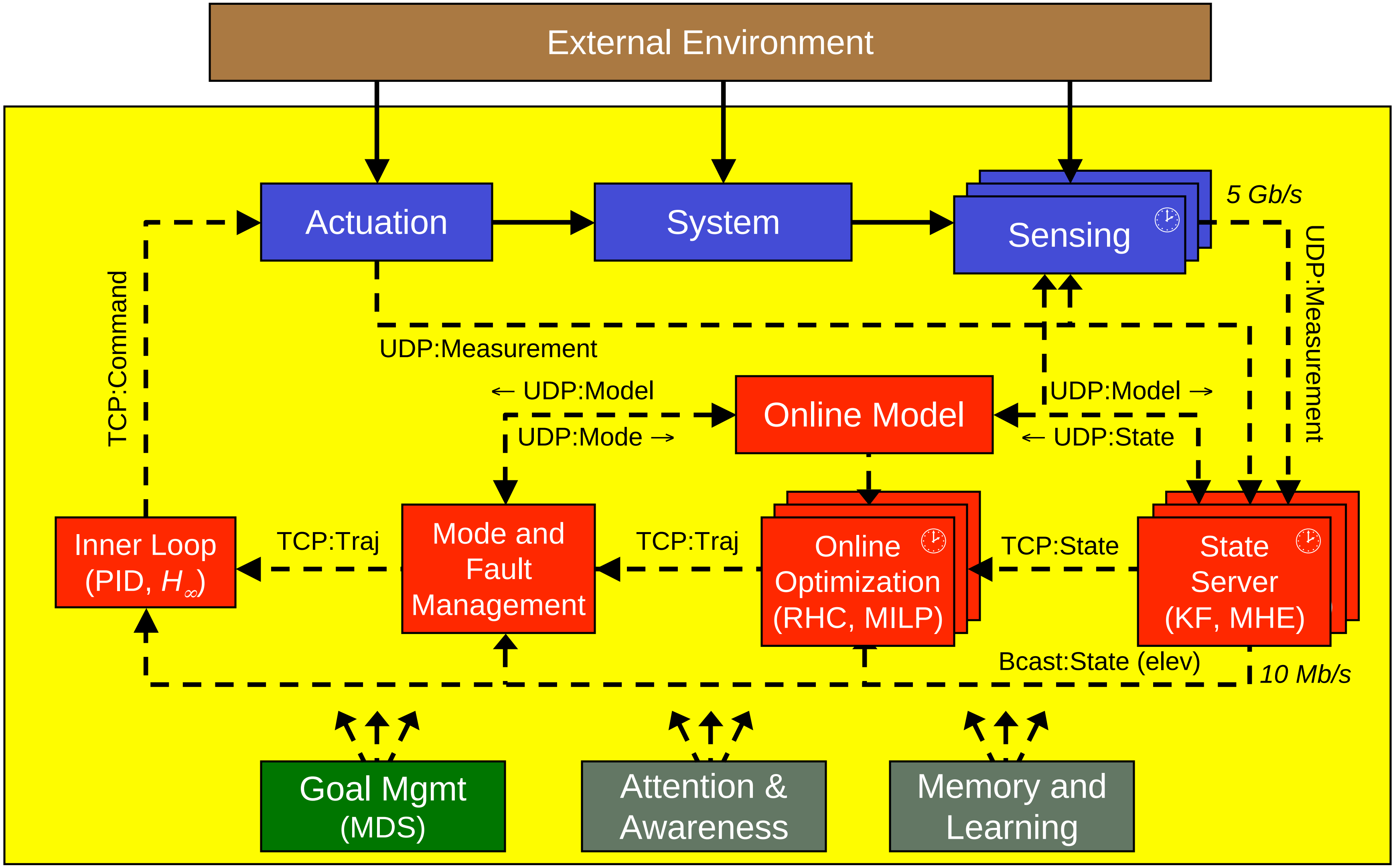
- Provide an overview of the course contents
- Review course administration (project, grading, collab, schedule)

Reading:

- Course syllabus (handout)
- *Control in an Information Rich World*, Section 1, 3.2 and 3.3
- "Design Patterns for Robust and Evolvable Networked Control", Robinson et al, CSER, 2004
- "Issues in the convergence of control with communication and computing: Proliferation, architecture, design, services, and middleware", Graham et al, CDC 2004

Available on course home page

Networked Control Systems



Applications

Alice Overview

Team Caltech

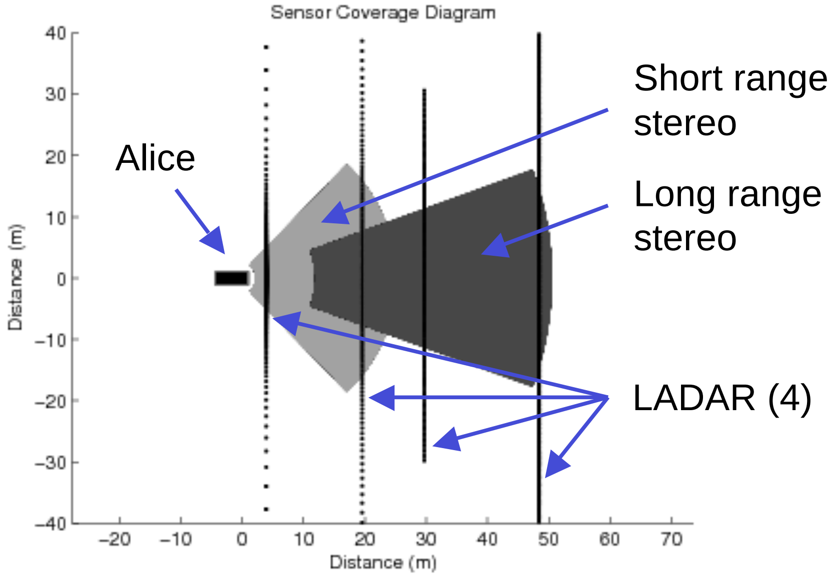
- 50 students worked on Alice over 1 year
- Course credit through CS/EE/ME 75
- Summer team: 20 SURF students + 6 graduated seniors + 4 work study + 4 grads + 2 faculty + 6 volunteers (= ~40)

Computing

- 6 Dell 750 PowerEdge Servers (P4, 3GHz)
- 1 IBM Quad Core AMD64 (fast!)
- 1 Gb/s switched ethernet

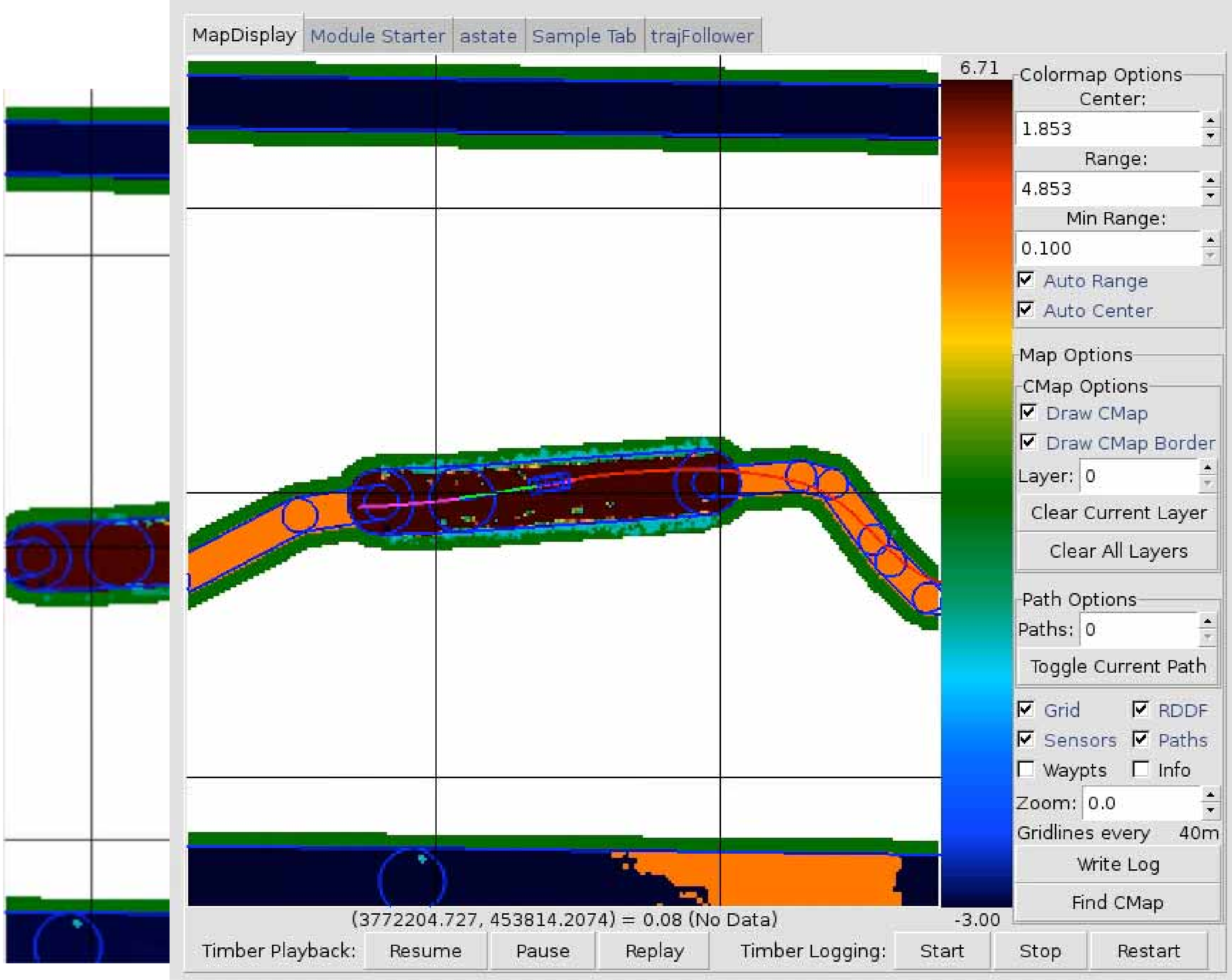
Software

- 15 individual programs with ~50 threads of execution
- Sensor fusion: separate digital elevation maps for each sensor; fuse @ 10 Hz
- Path planning: optimization-based planning over a 10-20 second horizon



Alice

Cremean et al
JFR 05 (s)



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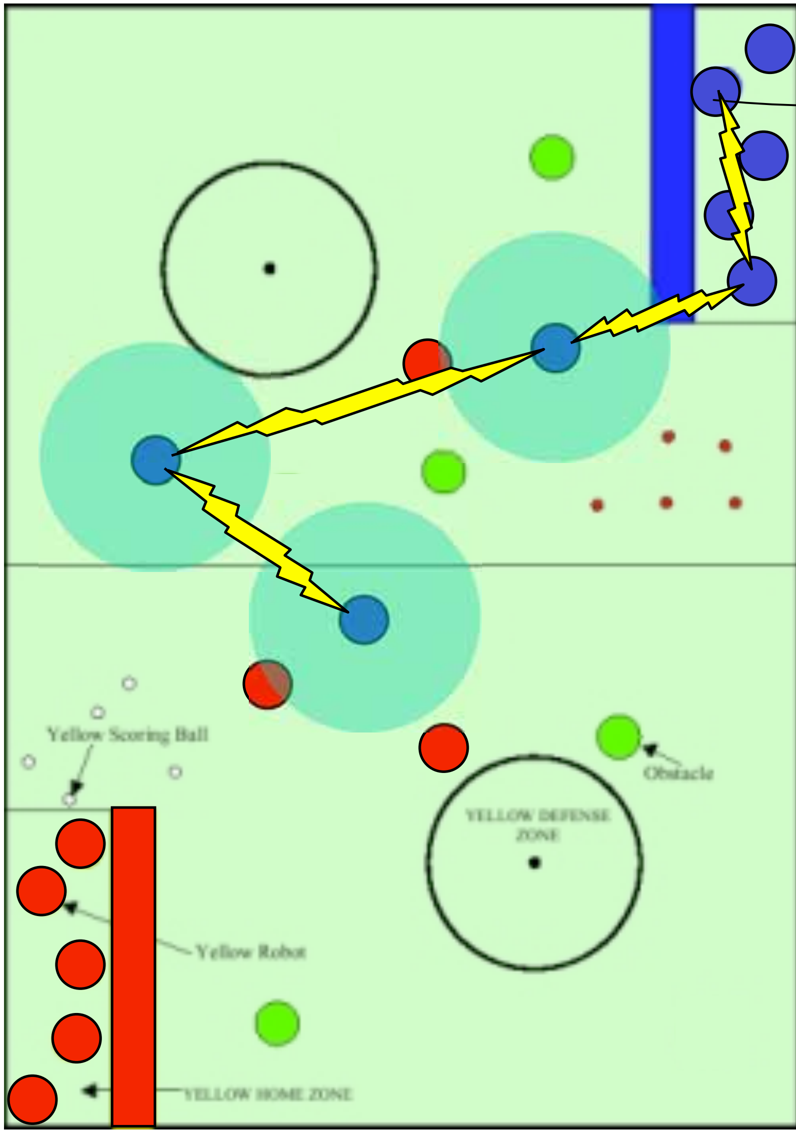
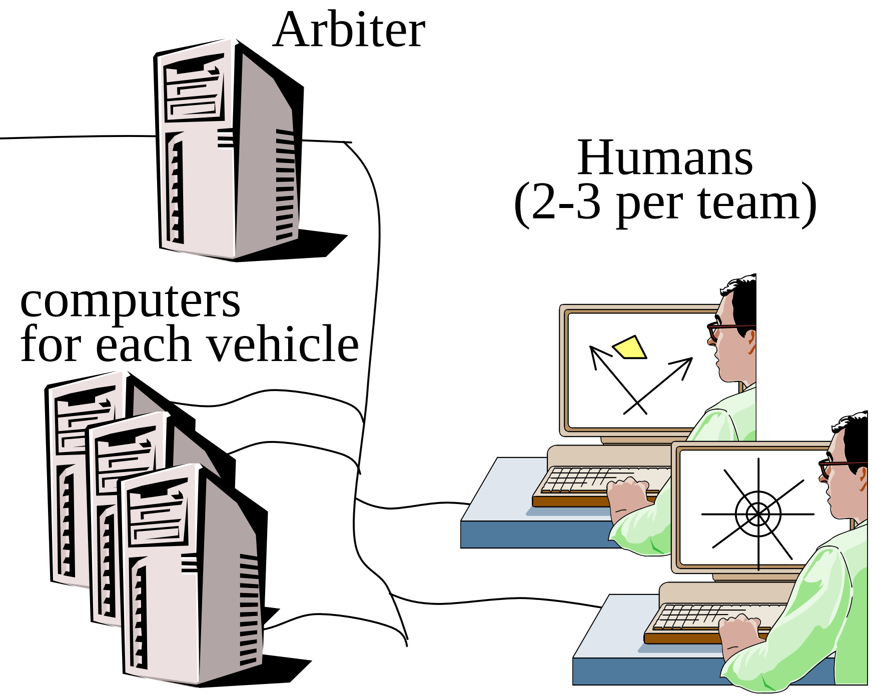
D’Andrea & M
ACC 2003

Example: RoboFlag (D’Andrea, Cornell)



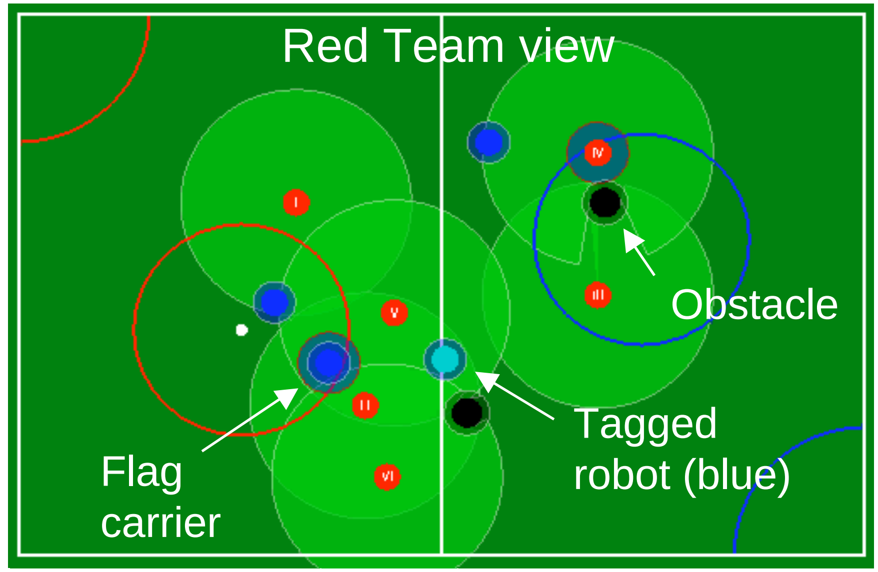


Robot version of “Capture the Flag”

- Teams try to capture flag of opposing team without getting tagged
- Mixed initiative system: two humans controlling up to 6-10 robots
- Limited BW comms + limited sensing

RoboFlag Demonstration

Hayes et al
ACC 2003



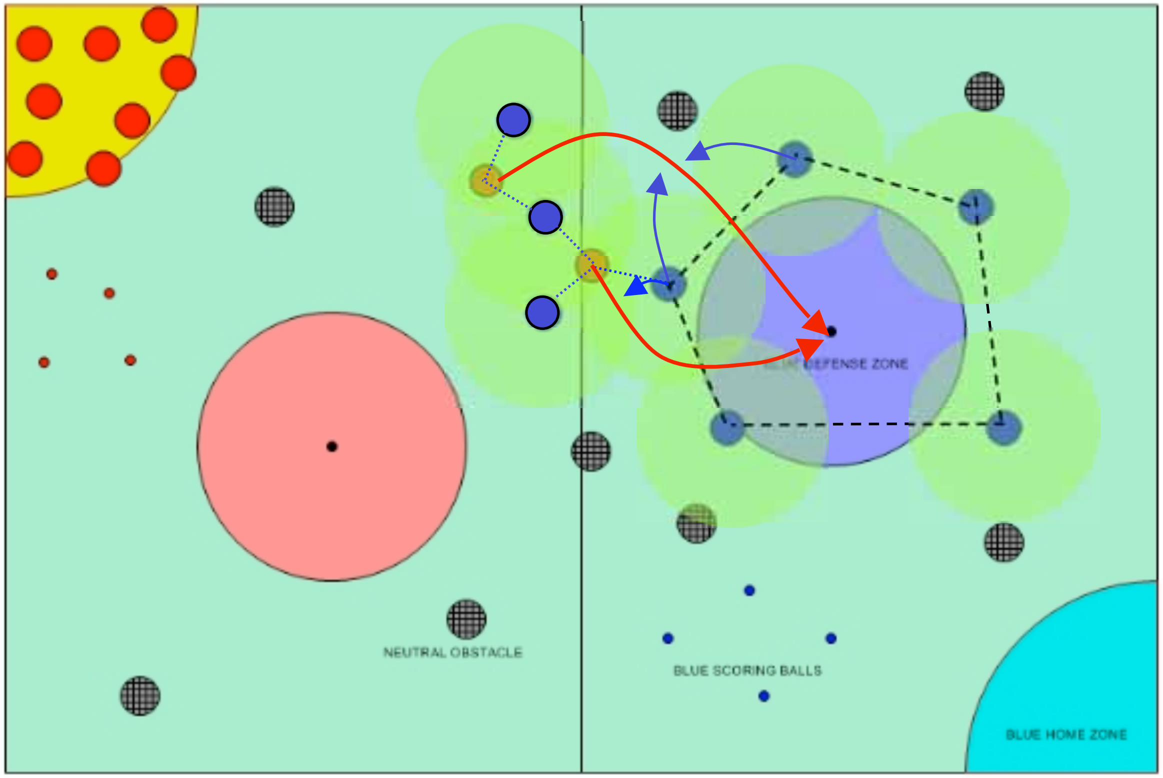
Integration of computer science, communications, and control

- Time scales don't allow standard abstractions to isolate disciplines
- Example: how do we maintain a consistent, shared view of the field?

Higher levels of decision making and mixed initiative systems

- Where do we put the humans in the loop? what do we present to them?
- Example: predict "plays" by the other team, predict next step, and react

RoboFlag Subproblems



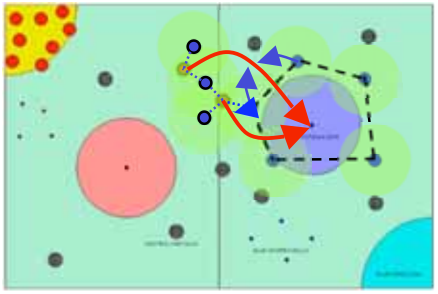
1. **Formation control**
   - Maintain positions to guard defense zone
2. **Distributed estimation**
   - Fuse sensor data to determine opponent location
3. **Distributed consensus**
   - Assign individuals to tag incoming vehicles

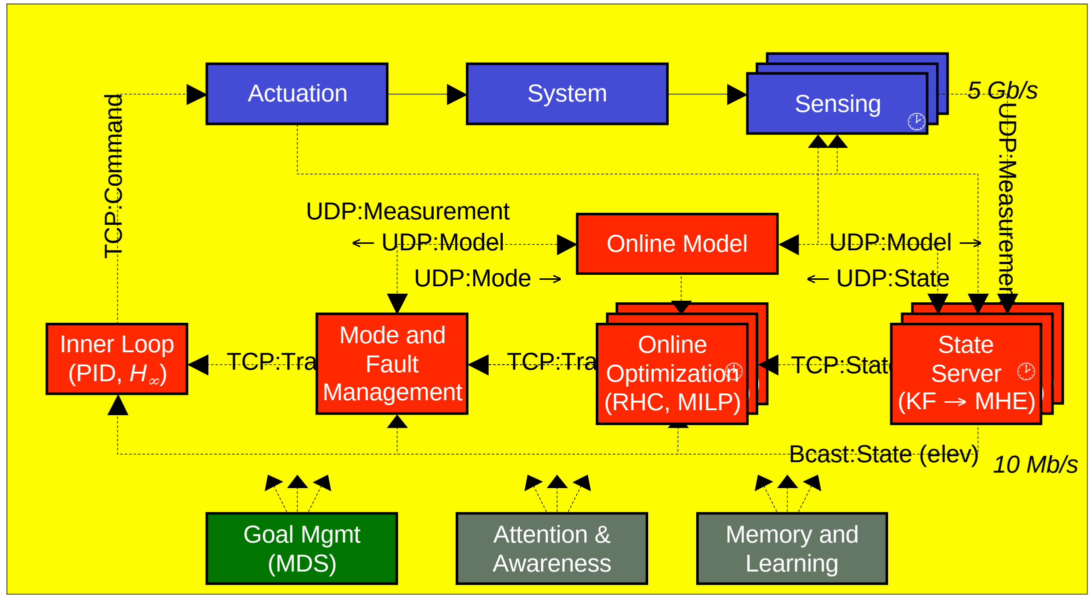
Goal: develop systematic techniques for solving subproblems

- Cooperative control and graph Laplacians
- Distributed receding horizon control
- Verifiable protocols for consensus and control

→ Implement and test as part of annual RoboFlag competition

Control Problems and Design Patterns





Control Challenges (see reading)

- How should we distribute computing load burden between computers?
- How should we handle communication limits and dropped packets?
- How do multiple computers cooperate in a shared task (with common view)?
- What types of protocols should we use for transmitting data between nodes

Candidate Techniques (see reading)

- Local temporal autonomy - allow modules to operate with data losses
- State estimation - estimate future states if current data are not available
- Control buffers - buffer commands to tolerate latency and lost data
- Time servers - time stamp data and track clock skew

Course Outline

I. Introduction (5)

- A. What is a *networked* control system
- B. Applications of networked control systems
- C. The NCS architecture
- D. Examples: Alice, RoboFlag, TriNet
- E. Detailed example: Alice NCS architecture

II. Receding Horizon Control (3)

- A. Real-time trajectory generation
- B. CLFs and RHC
- C. Design approaches (C(s) → Q, R)D
- D. Hybrid systems (MILP)
- E. Computational effects (warm start, safety)

III. State estimation and sensor fusion (3)

- A. Kalman filter
- B. Extended Kalman filter
- C. Moving horizon estimation (non-Gaussian)
- D. Particle filters
- E. Hybrid systems

IV. Packet-Based Estimation and Control (6)

- A. lost packets, coding, routing (rate results)
- B. coding for packet loss (convolution, MD)
- C. latency effects (time tags, predictors)
- D. messaging systems (skynet, MTA, NCS)
- E. synchronization and queueing

V. Distributed estimation and control (3)

- A. distributed optimization (including DP)
- B. distributed RHC
- C. distributed estimation
- D. distributed MHE, particle filters
- E. communication effects and cross layer design

VI. Cooperative Control (3)

- A. protocols, hybrid systems, etc
- B. mode management and MDS
- C. managing connectivity
- D. spatio-temporal planning
- E. asynchronous computation (CCL)
- F. consensus protocols

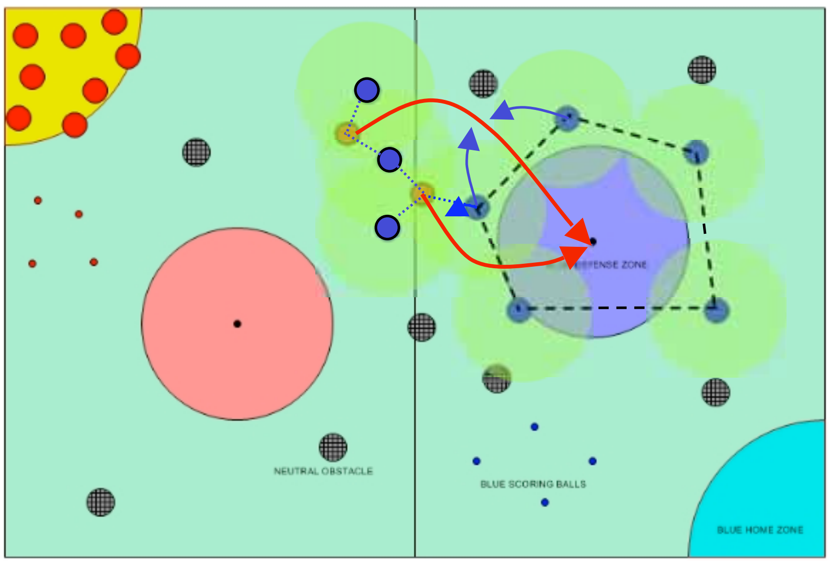
Course Project

Goal: Implement NCS algorithms

- Use ideas from class to implement algorithms on existing testbed
- Group or individual project
- Grade based on project report

Project Timeline

- Midterm: project proposal
- Week 9: project presentation
- Finals: project report
- No (required) HW, midterm or final



RoboFlag

- Simulation testbed available (XP)
- Requires some C++ programming

Alice

- Experimental testbed available
- Requires some C programming

Summary: Networked Control Systems

Large scale computation and communication allows new approach to control

- Build on rich “inner loop” consisting of optimization-based estimation and planning
- Modular design with supervisory control to guide operation via models, cost functions, modes
- Multiple implementations (ducted fan, MVWT, Alice) demonstrate feasibility of approach

Many open problems

- How do we handle/exploit packet-based communications
- How to we partition sensing & optimization across computers
- How do we specify, design, verify and validate supervisory control functionality
- How do we include attention, awareness, memory & learning