Demonstration of Safe Human / Robot Coordination on the Athlete Lunar Rover

Professor Brian C. Williams,
CSAIL MIT

NASA AISRWorkshop,

October, 16th, 2009

In joint collaboration with

Patrick Conrad, Shannon Dong, Andreas Hoffman, and Julie Shah at MIT

Mitch Ingham, David Mittman, Vandi Verma at JPL

Supported under NSDEG and JPL SURP

Operating JPL's Athlete Lunar Rover

Commanded through time-stamped sequences, similar to Spirit and Opportunity.

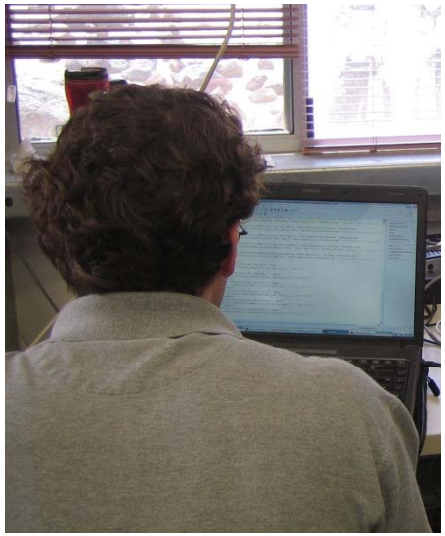
NASA Trends

- Increased complexity in robot morphology.
- Increased task complexity;
- Humans work in the field,
  in close proximity to robots.

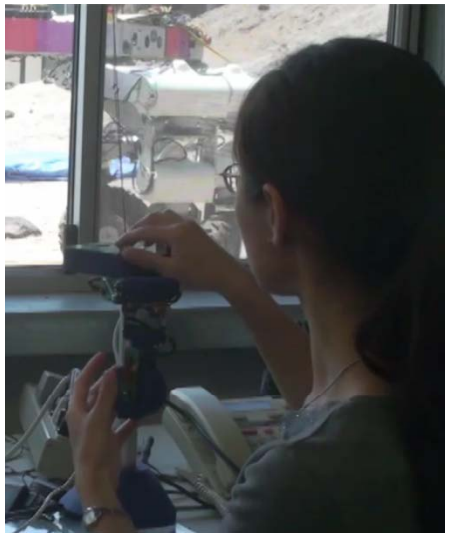
Project Objectives

1. Elevate level of commanding.
2. Increase safety and compliance around humans.
3. Improve fluidity of human / robot coordination.

Approach: Model-based Programming



Write Common sense instructions

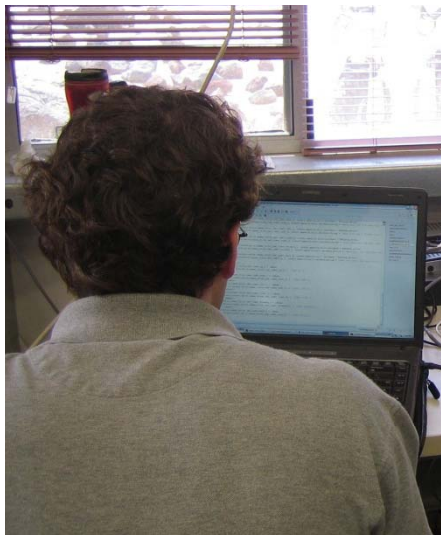


Demonstrate actions by example

Collaborate with Verbal commands

Operational on Athlete – June and July, 2009

Reactive Model-based Programming Language (RMPL)



Write Common sense instructions

```
method run ()
{
    [1s,200s] sequence {
        prepare  limb(6) to attach gripper
        human voice commands the limb
        attach gripper to limb
        prepare limp to pick up rock with gripper

        parallel {
            sequence {
                human voice command the limb
                close gripper on rock
            };
            sequence {
                limb5 prepare limb (5) to receive bin
                human voice commands the limb
            };
        };

        position rock over bin with gripper
        ready bin for rock
        load rock in bin
        store bin for transport
    }
}
```

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        position rock over bin with gripper
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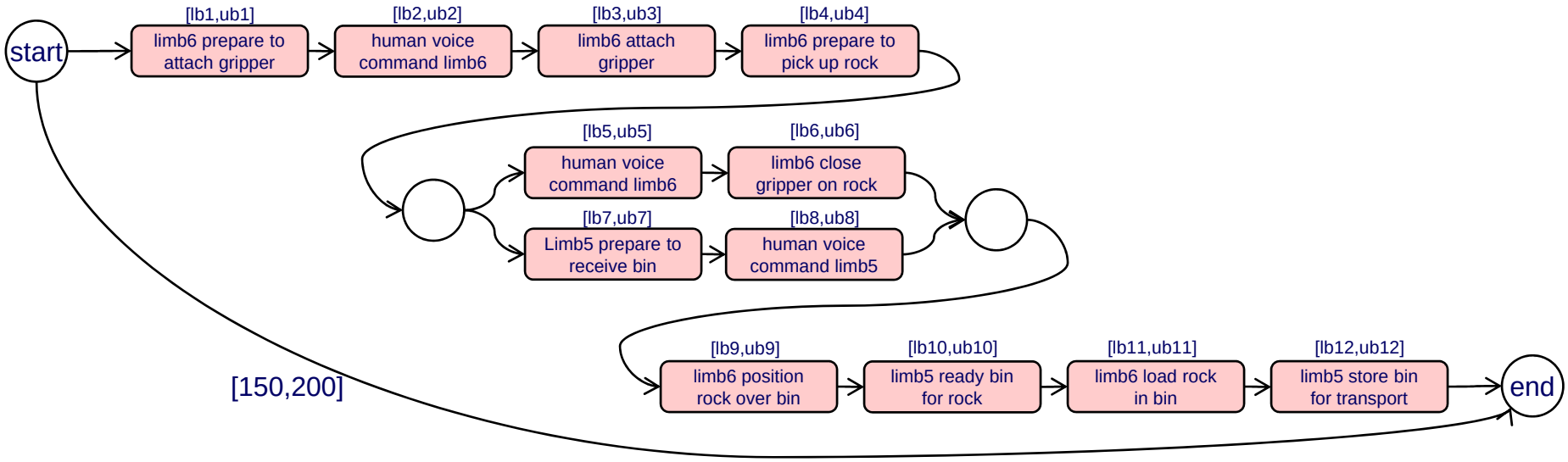
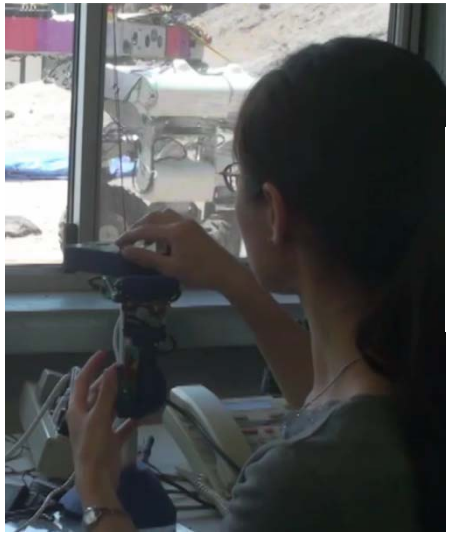
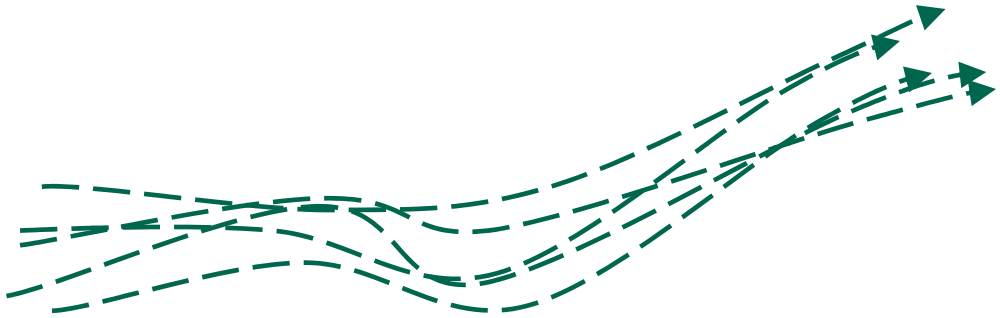
```

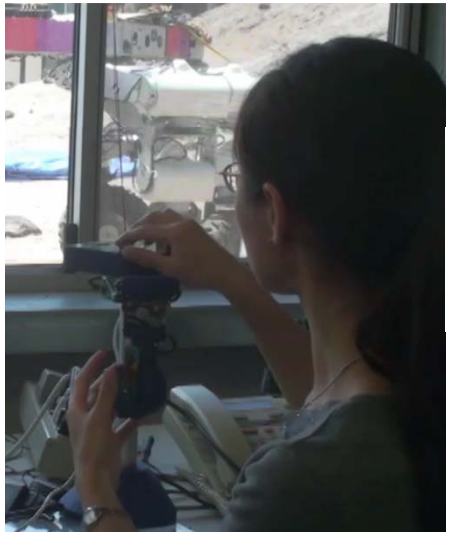
Compile to Executable Form



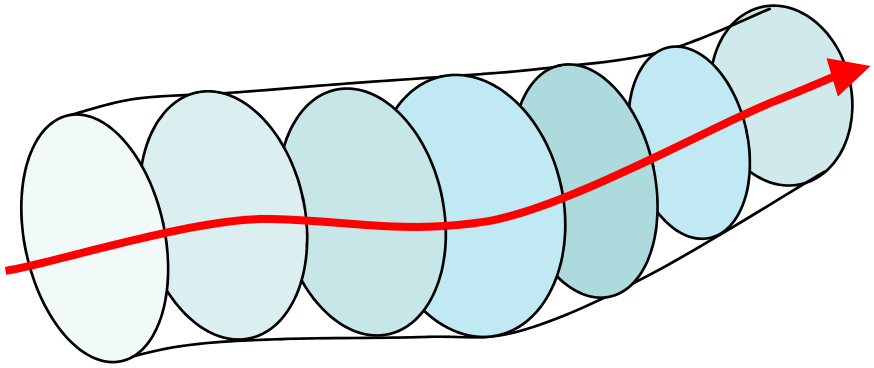




Demonstrate
actions by example



Demonstrate actions by example



Learns tubes of valid trajectories

Collaborate with
Verbal commands

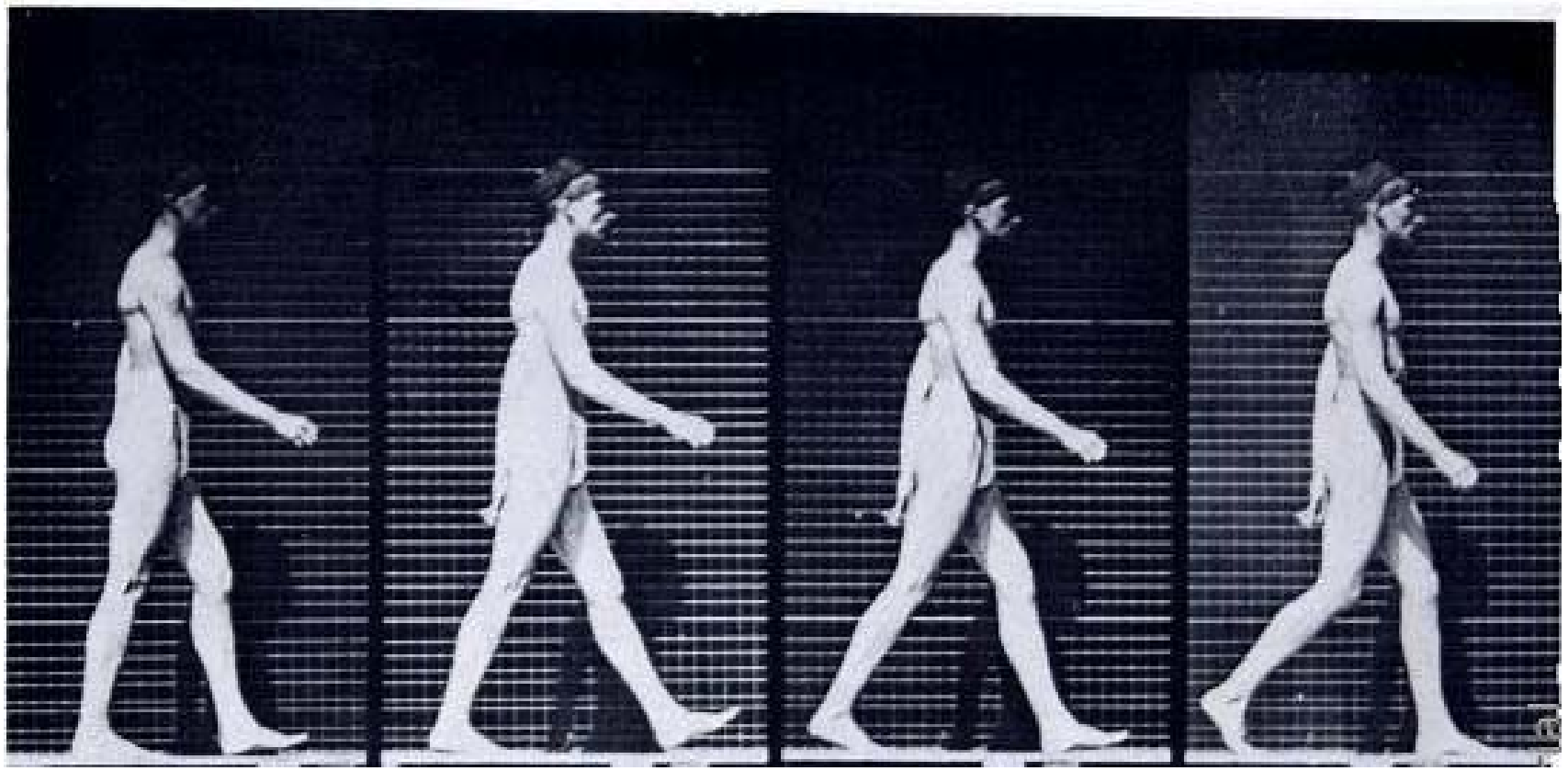
Athlete Demonstration – July, 2009

Model-based Programming of Human Robot Teams

A robot team mate should:

1. Successfully perform shared tasks under time pressure.
   - The robot must quickly adapt…
2. Operate safely among humans and their environment.
   - … to the physical environment.
3. Embody the fluidity of a good human teammate.
   - … to its partner.

Example: Describe Walking Tasks with Qualitative Poses

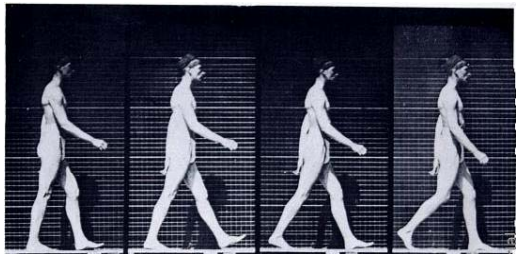


[Muybridge, 1955] Depicted gaits as sequences of distinct qualitative poses

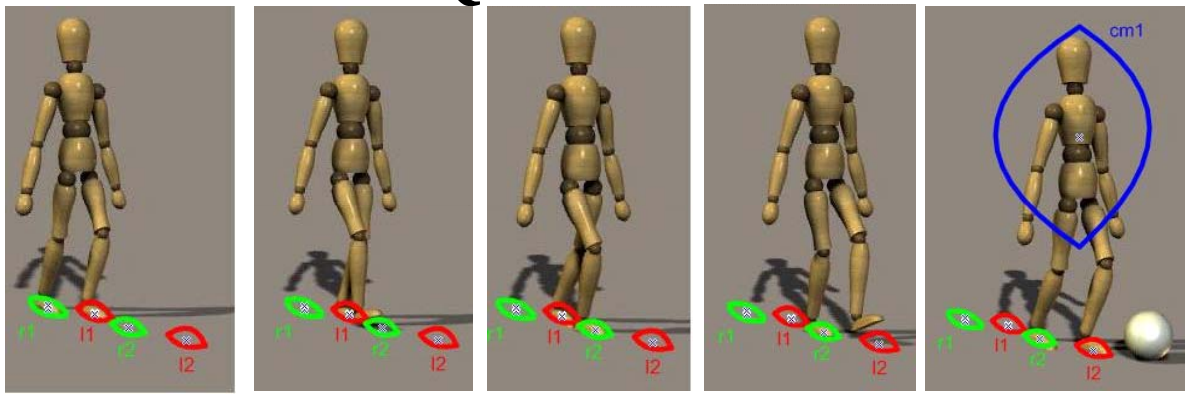
Specify as temporal plan over qualitative states

Supported by NASA

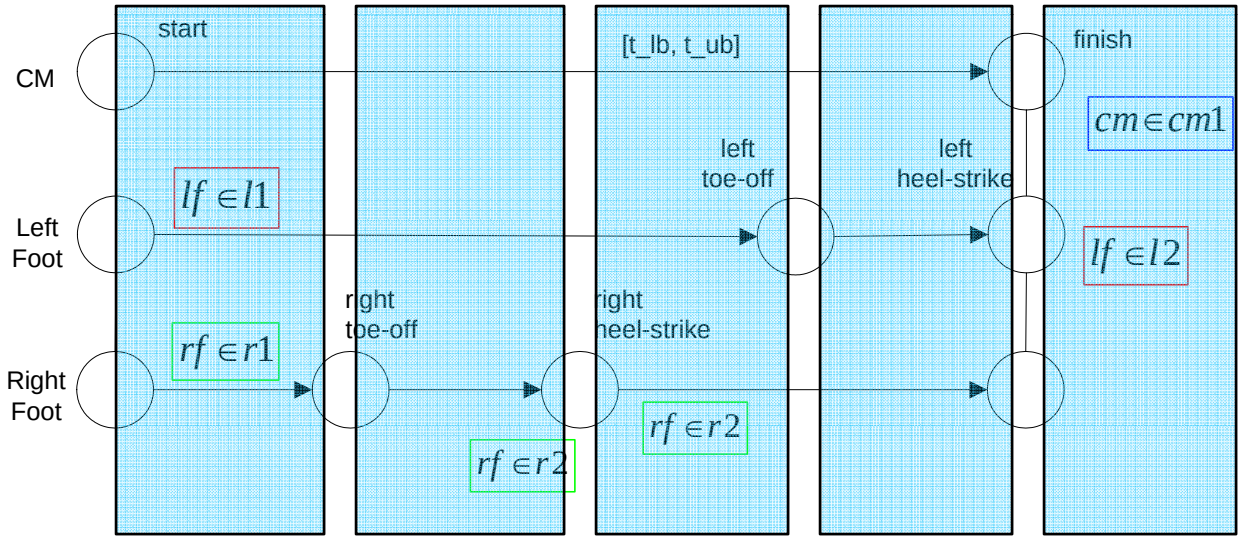
Describe Tasks as Temporal Plans over Qualitative Poses



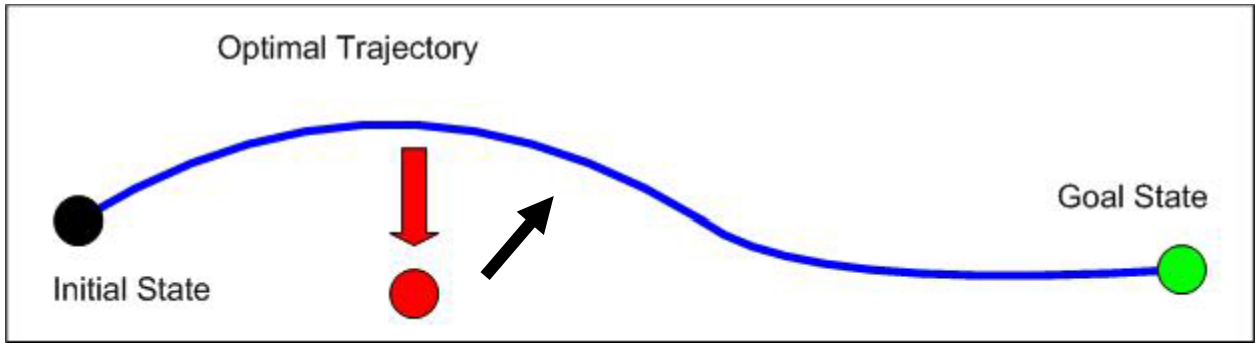
Muybridge



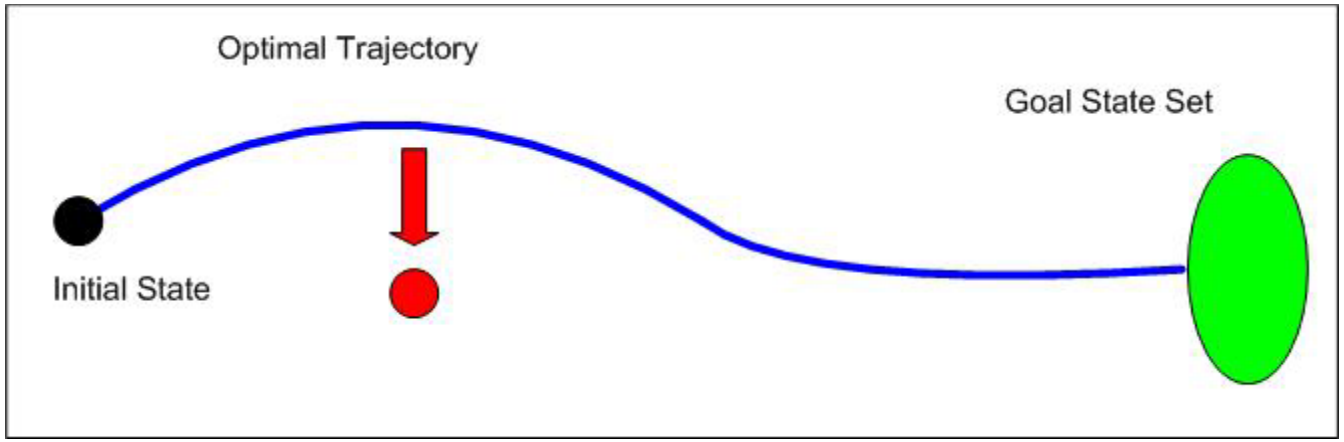
Input:
Qualitative
State Plan



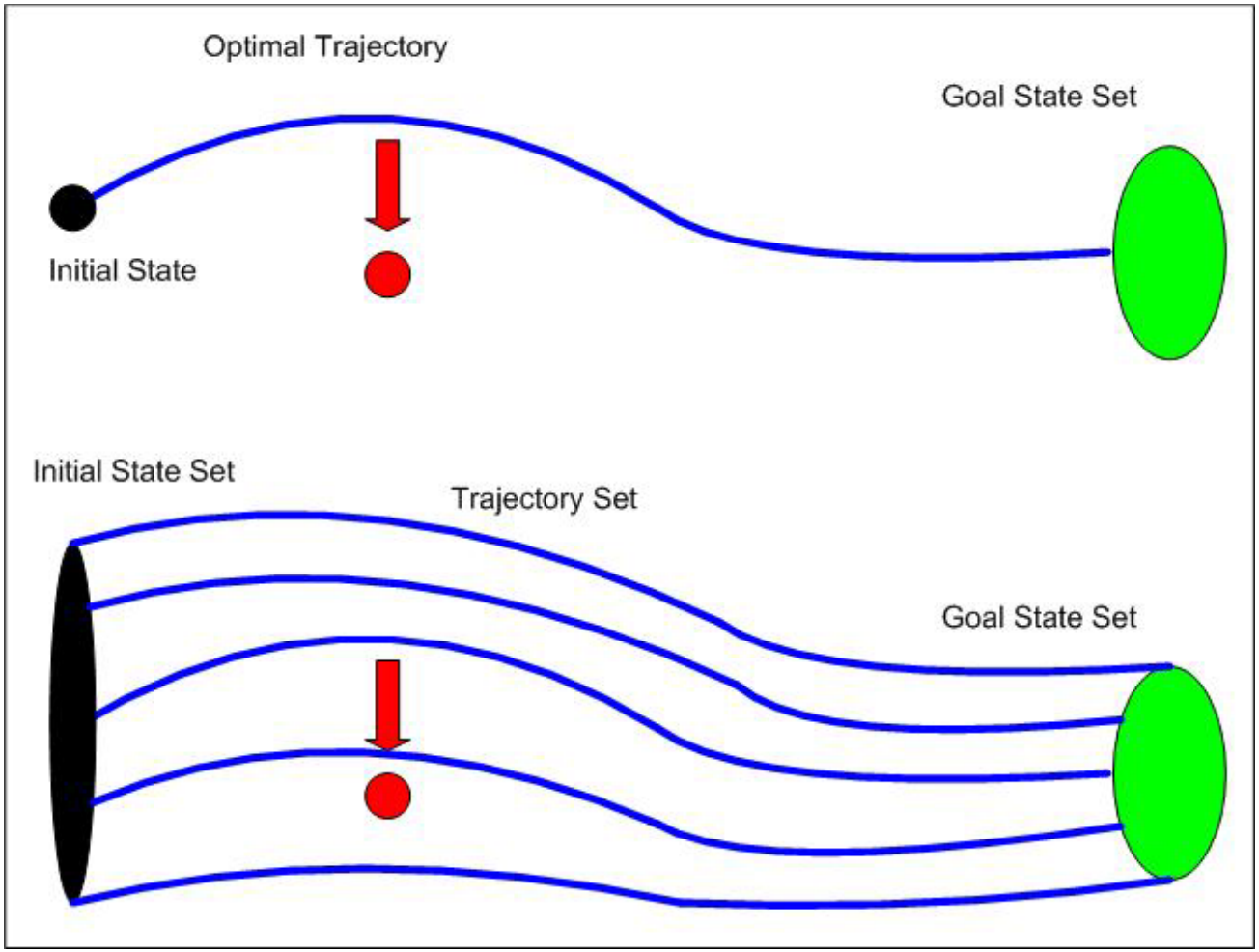
Traditional biped control tracks a reference trajectory



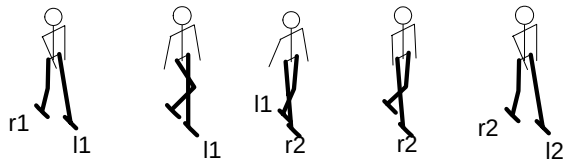
Executive utilizes the flexibility of the Qualitative State Plan

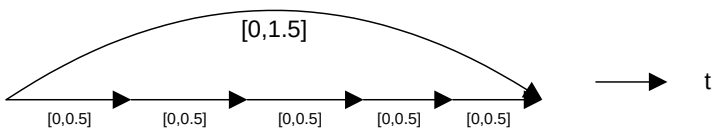


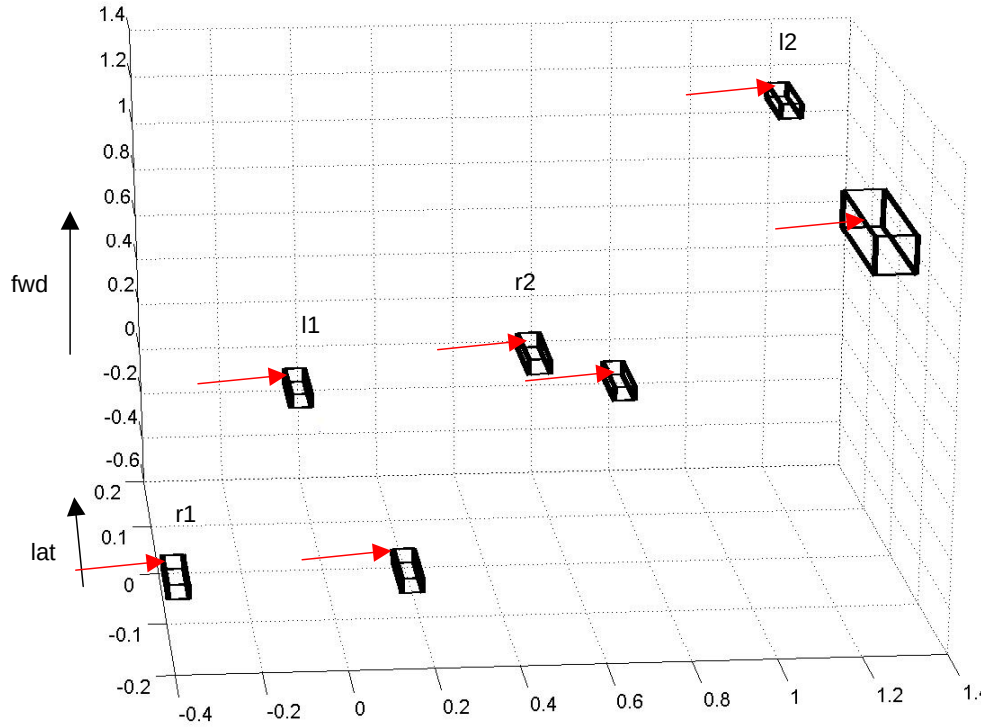
Executive achieves compliance and robustness by precomputing all feasible trajectories, not just one!

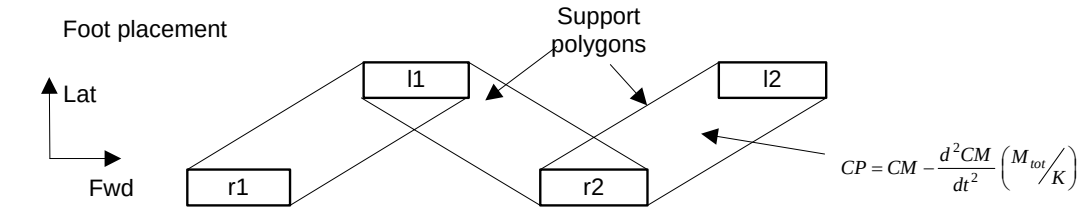


Feasible trajectories must go through goal regions









[Hofmann & Williams, AAAI 06; ICAPS 06]

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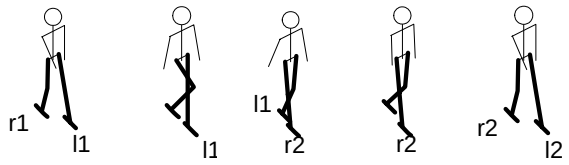
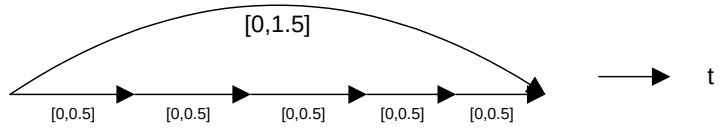
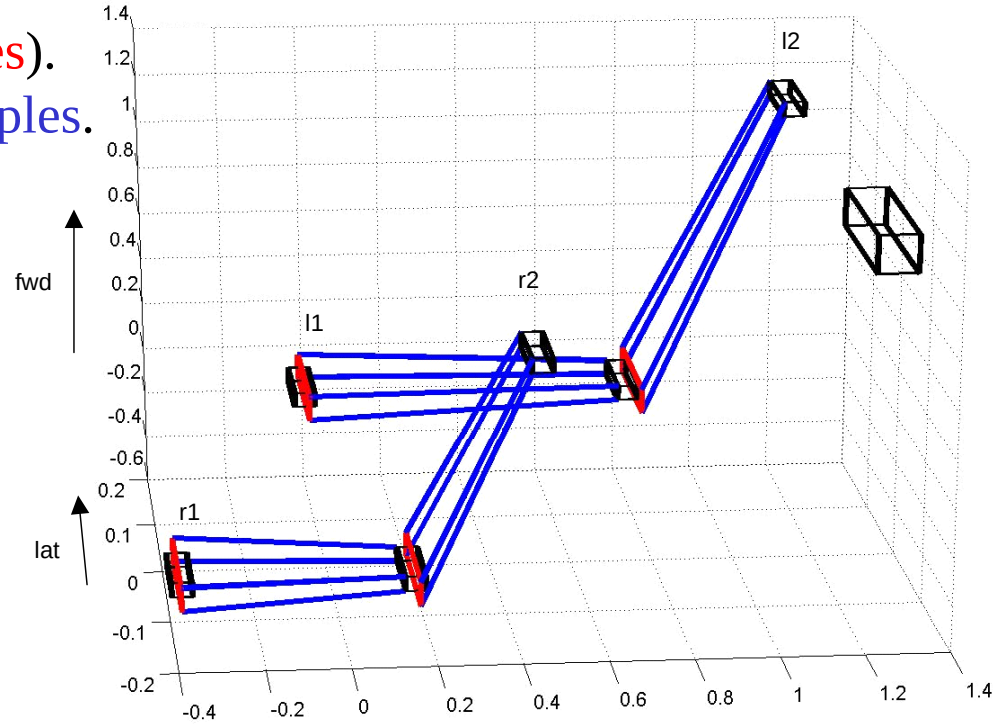
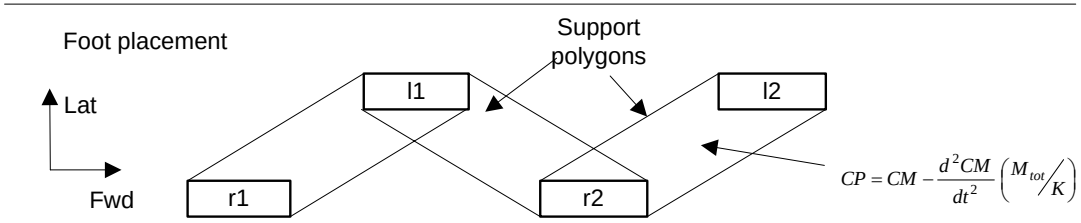


Compile Time:

- Construct all feasible trajectories (Flow Tubes).
- Learn tubes from examples.

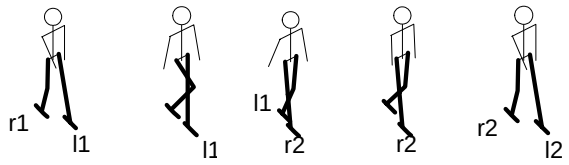






[Hofmann & Williams, AAAI 06; ICAPS 06]

Feasible trajectories must go through goal regions.



Compile Time:

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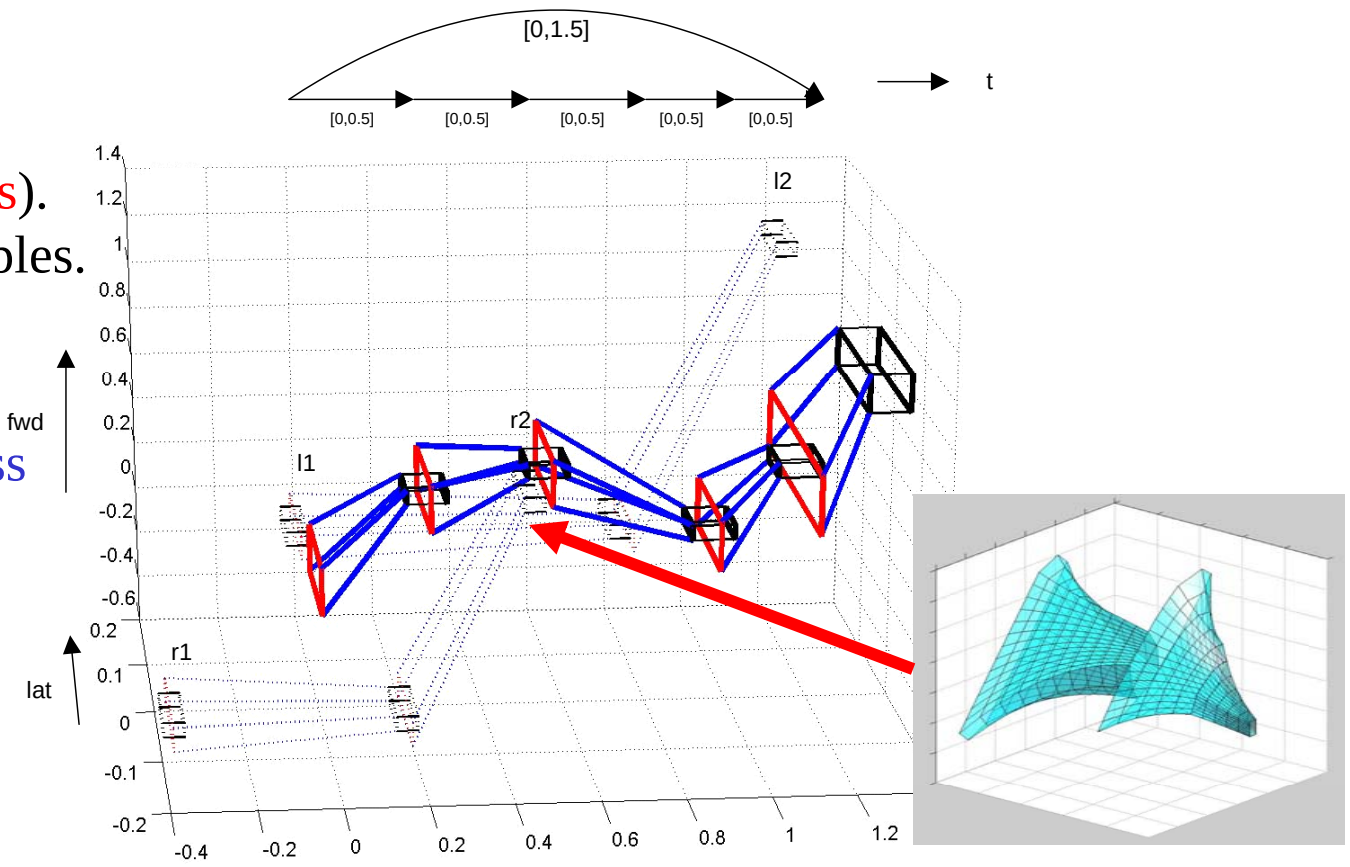
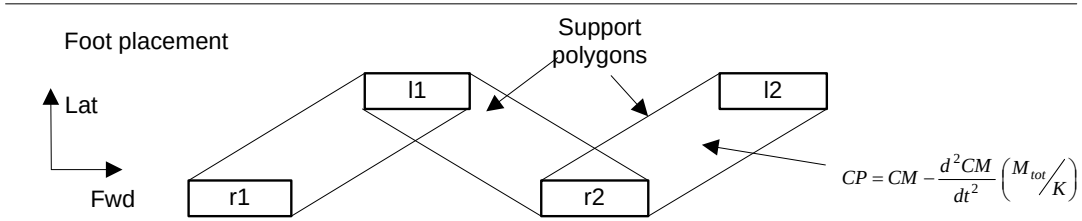
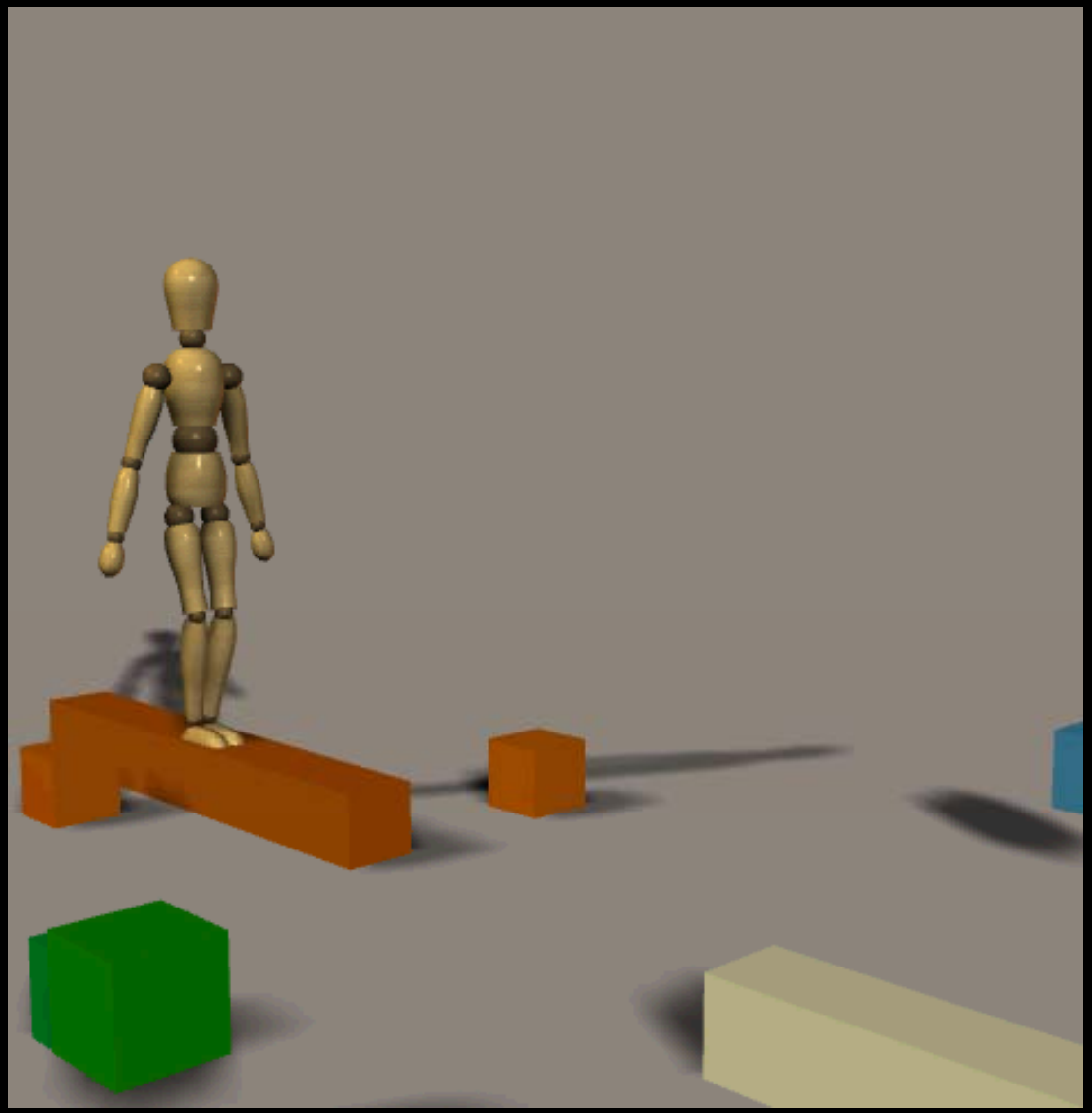
Dynamics couples through center of mass

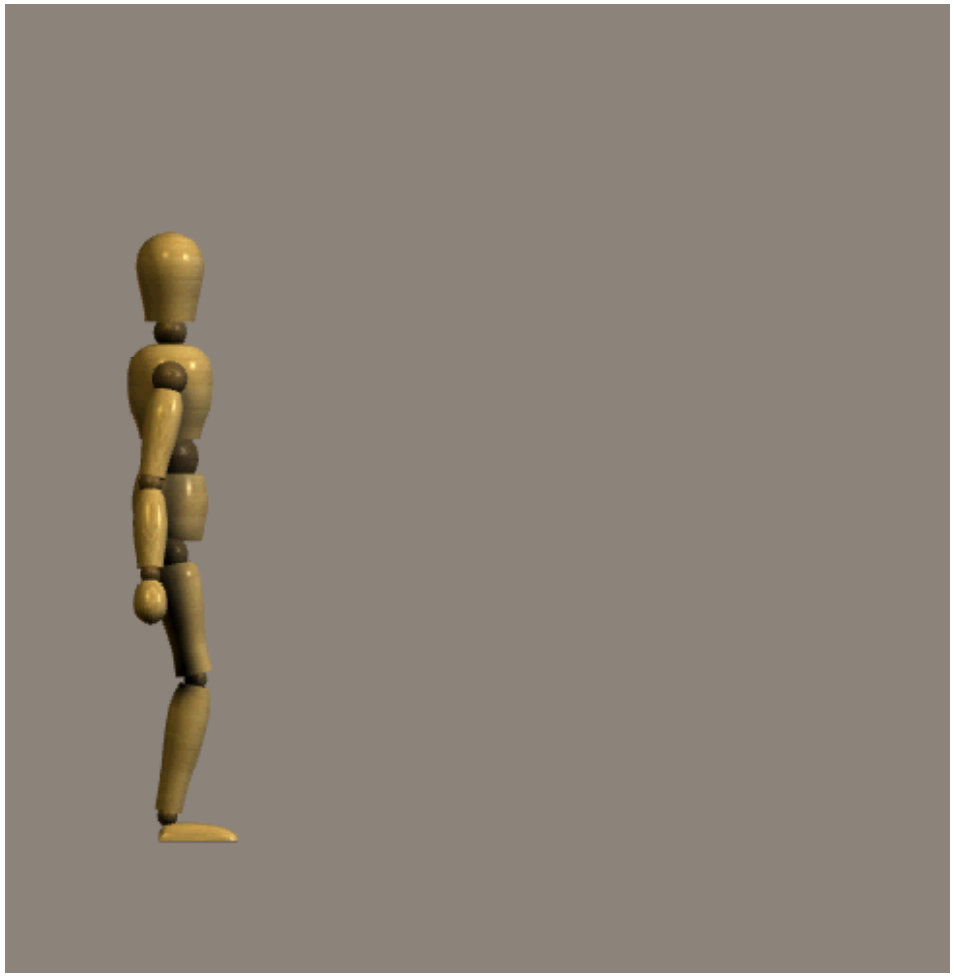




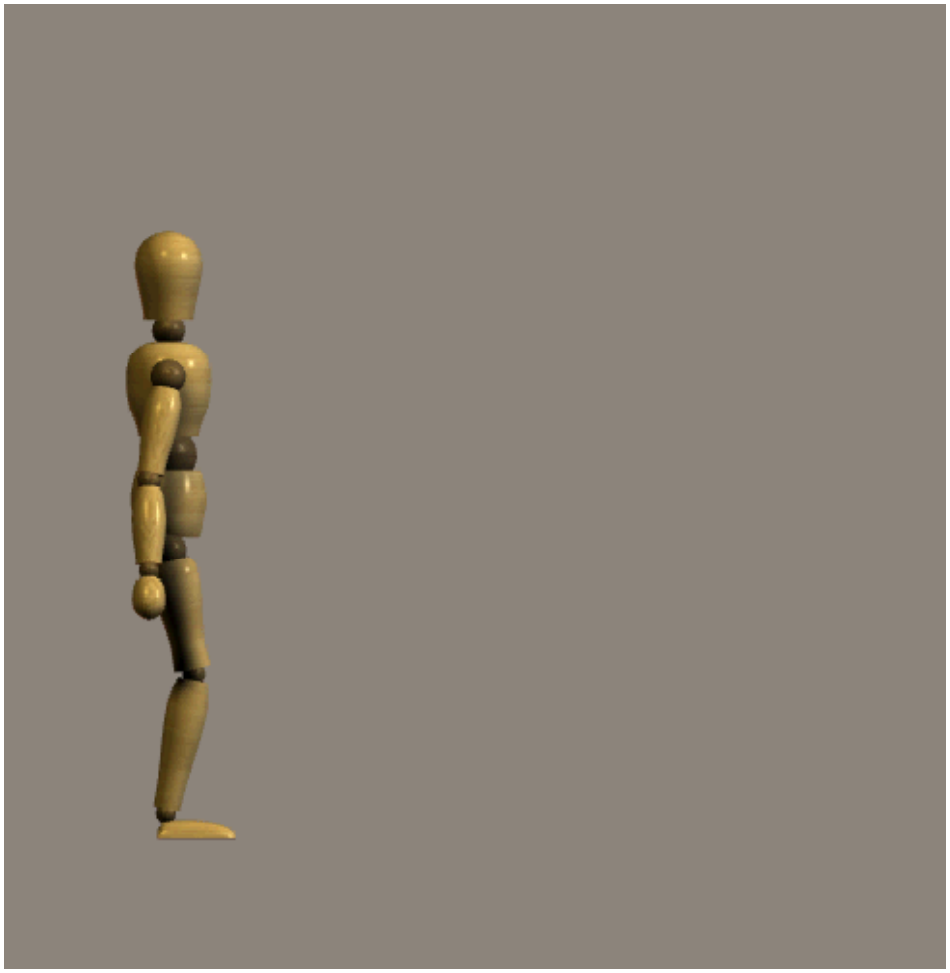
[Hofmann & Williams, AAAI 06; ICAPS 06]



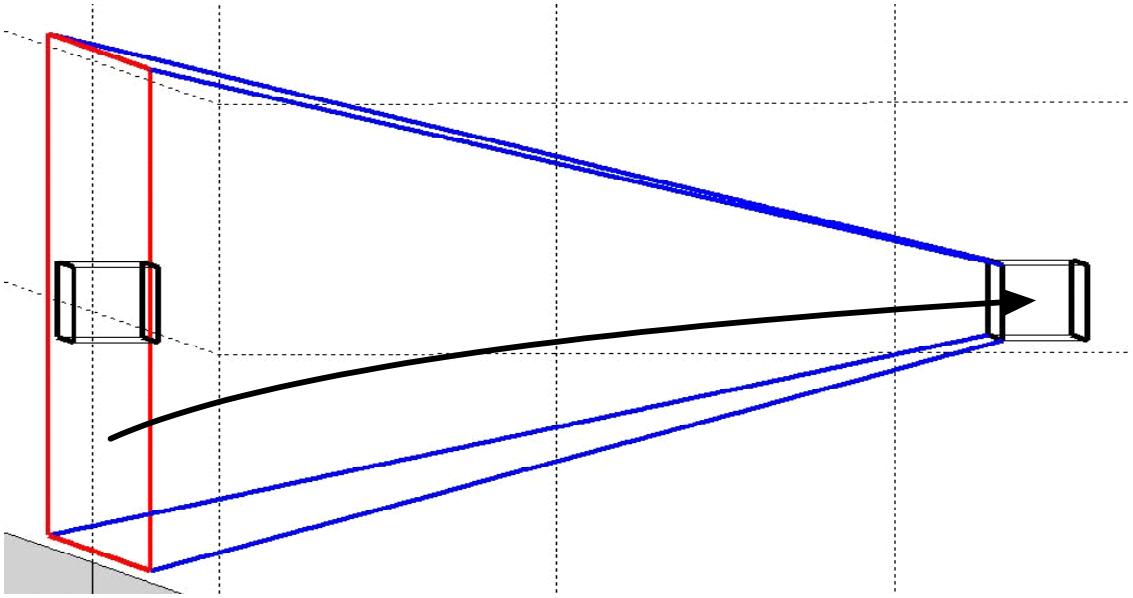
Robustness Requires Temporal Synchronization



Disturbance without temporal coordination



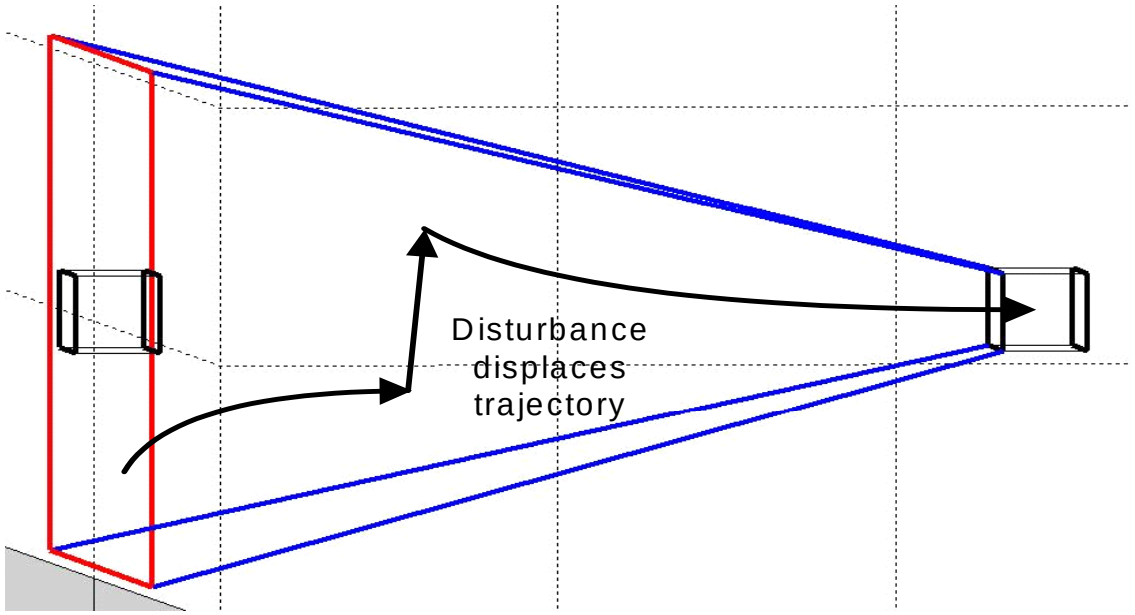
Disturbance with temporal coordination



Execution:

1. Select enabled tube.
2. Schedule goal arrival.
3. Execute control policy until goal achieved.

[Hofmann & Williams, AAAI 06; ICAPS 06]



Execution:

1. Select enabled tube.
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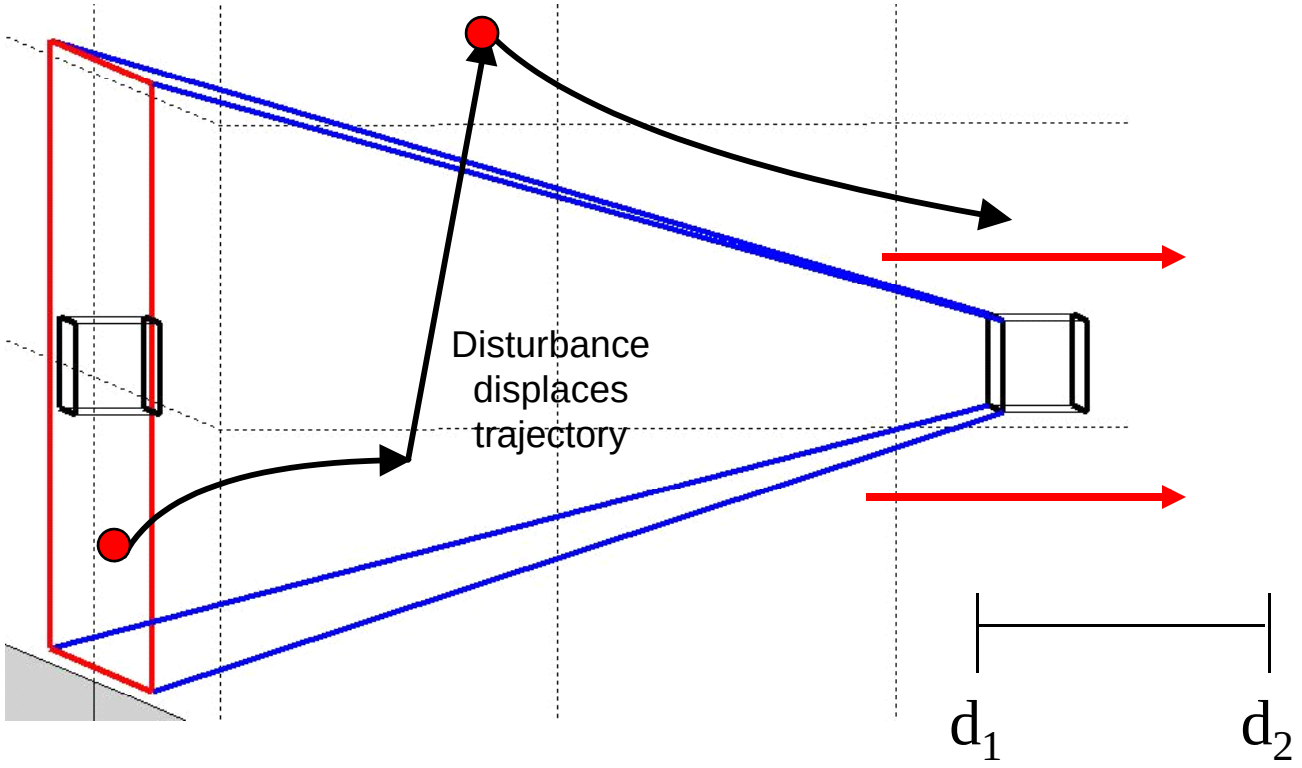
4. If displaced from tube, adjust control parameters or schedule.

[Hofmann & Williams, AAAI 06; ICAPS 06]

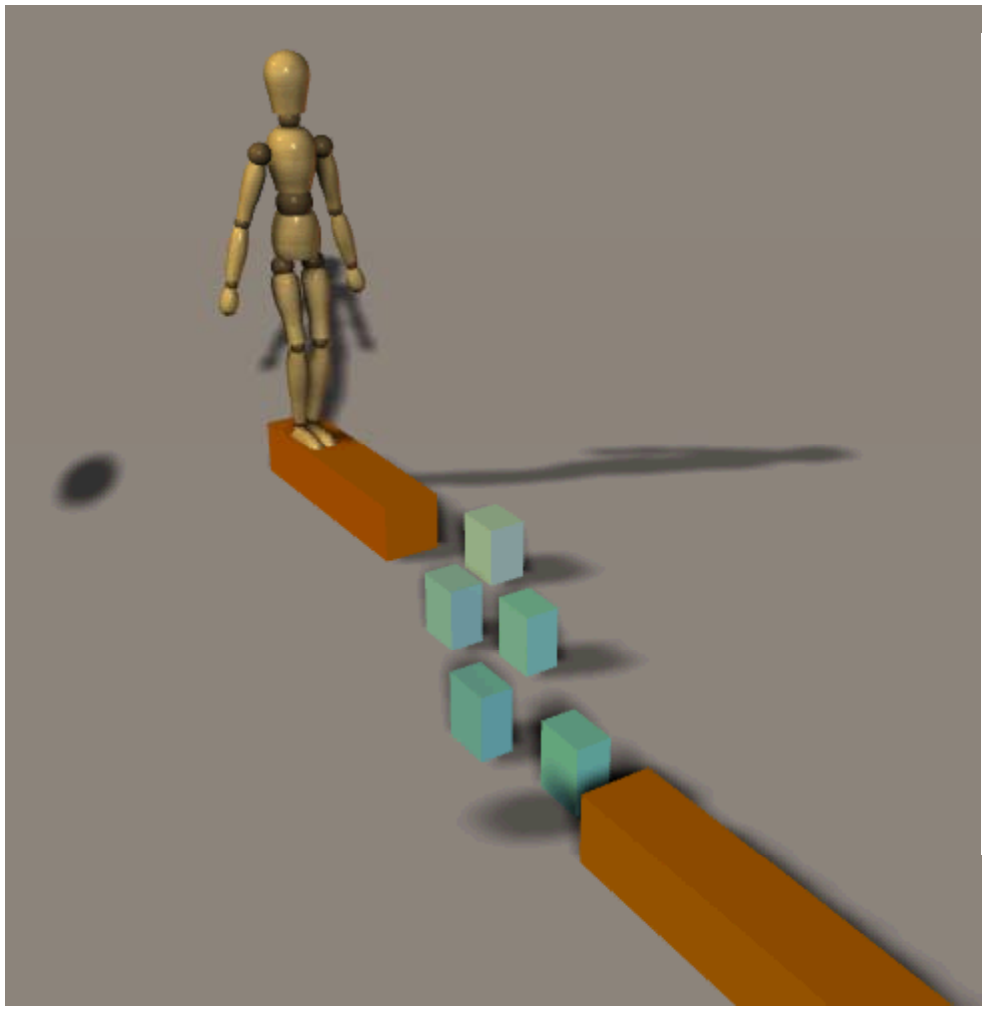


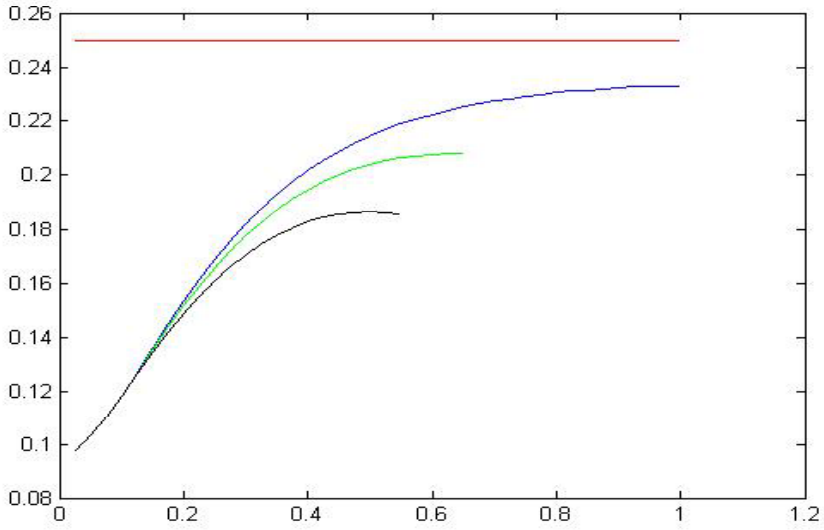
Execution:

1. Select enabled tube.
2. Schedule goal arrival.
3. Execute control policy until goal achieved.
4. If displaced from tube, adjust control parameters or schedule.
   - May require synchronization with other activities.
   - If unschedulable, switch plan.

[Hofmann & Williams, AAAI 06; ICAPS 06]

Compliance Results





Lateral CM with push disturbance

- Blue – 40 N
- Green – 35 N
- Black – 25 N
- Red – Max allowed displacement

Human / Robot Task Coordination

A robot team mate should:

1. Successfully perform shared tasks under time pressure.
   - The robot must quickly adapt…
2. Operate safely among humans and their environment.
   - … to the physical environment.
3. Embody the fluidity of a good human teammate.
   - … to its partner.

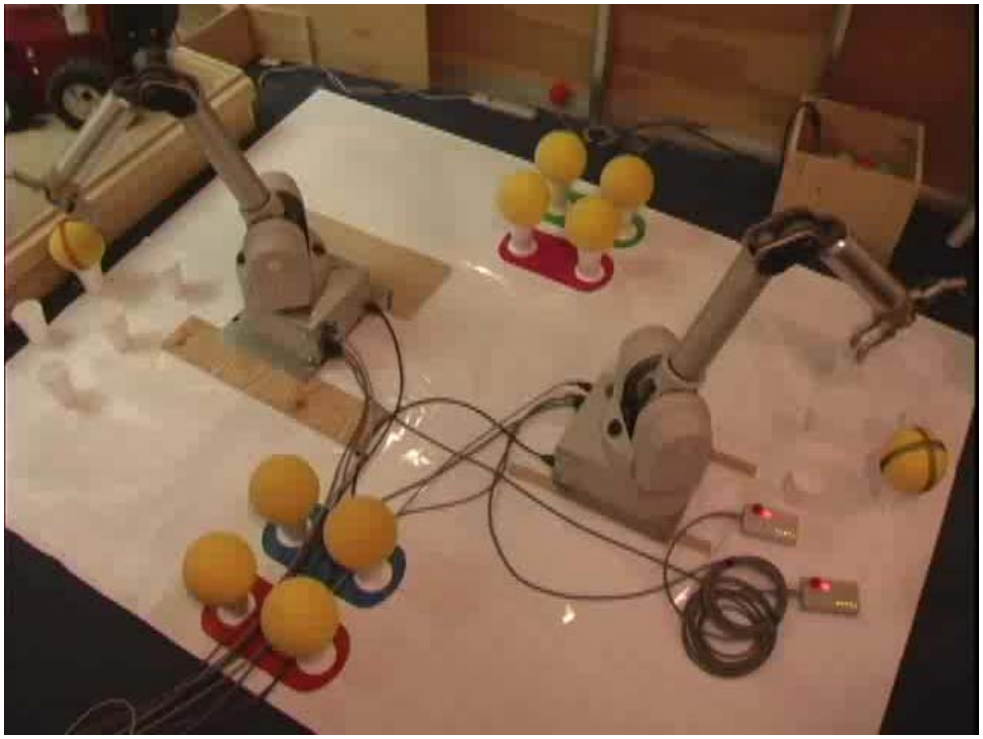
A Good Human Teammate

An effective Scrub Nurse:

- works hand-to-hand, face-to-face with surgeon,
- assesses and anticipates needs of surgeon,
  - provides tools and assistance in order needed,
- responds quickly to changing circumstances,
- responds quickly to surgeon's cues and requests.

[Shah Ph D, In Progress]

Multi-Robot Teamwork

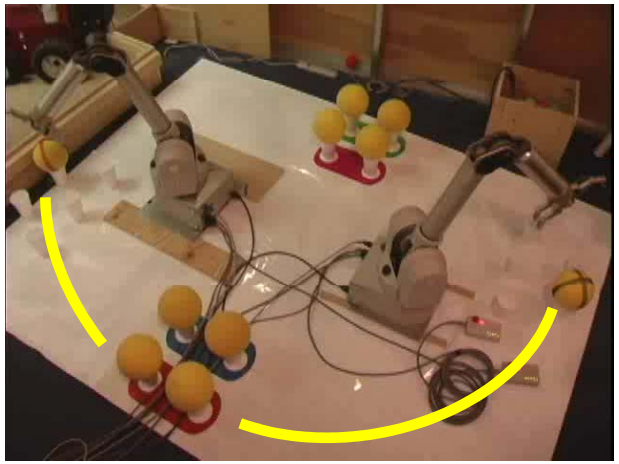


Task Plan

- Move striped balls to opposite end of workspace using hand-to-hand exchanges.

- Remove one ball from red bin.
- Remove one ball from blue bin.
- Remove one ball from pink bin.
- Remove one ball from green bin.

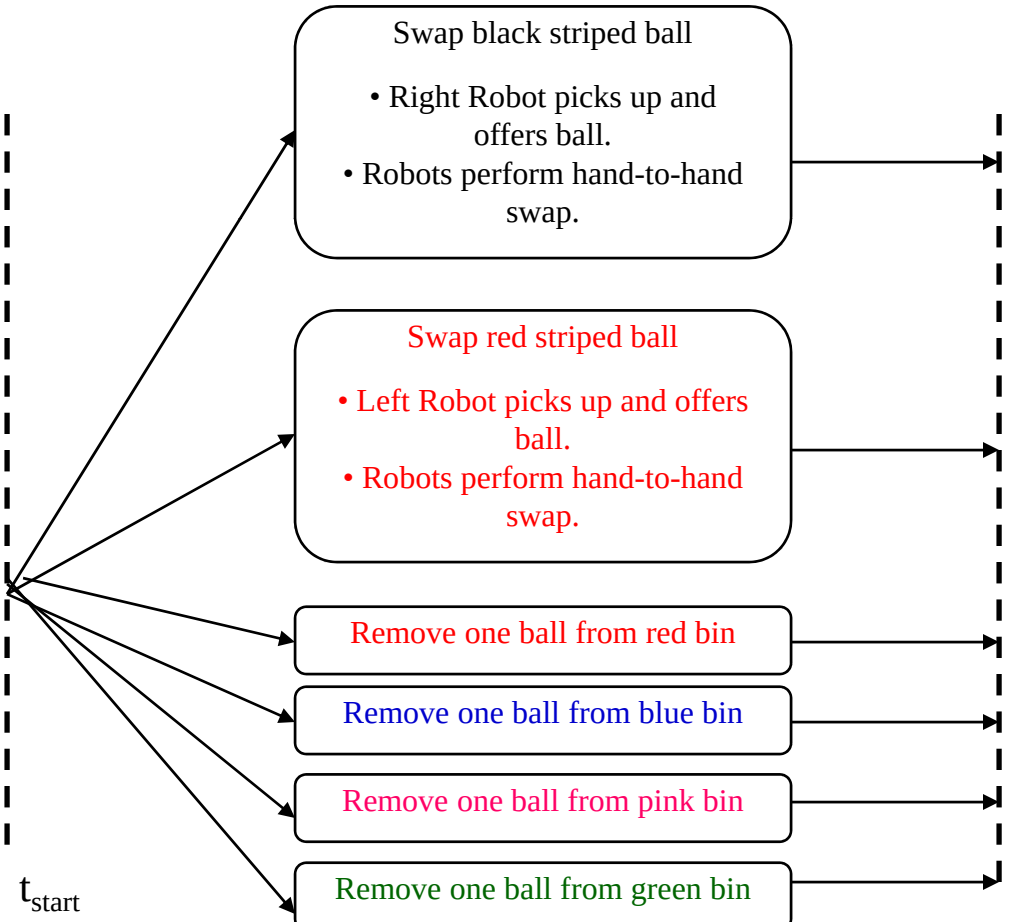
Multi-Robot Teamwork



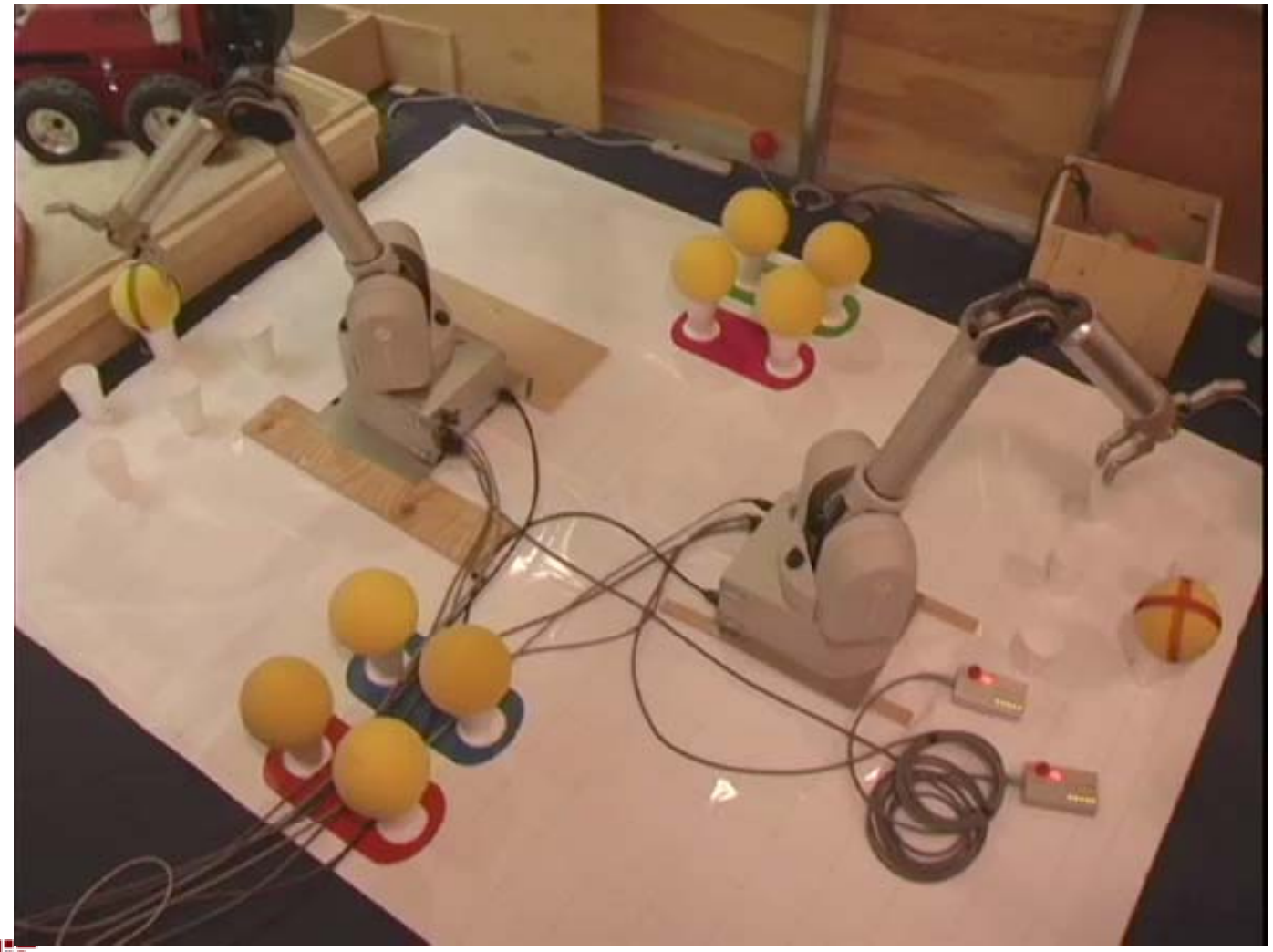
Agents choose and schedule activities

(Someone) Remove one ball from red bin

Remove one ball from red bin

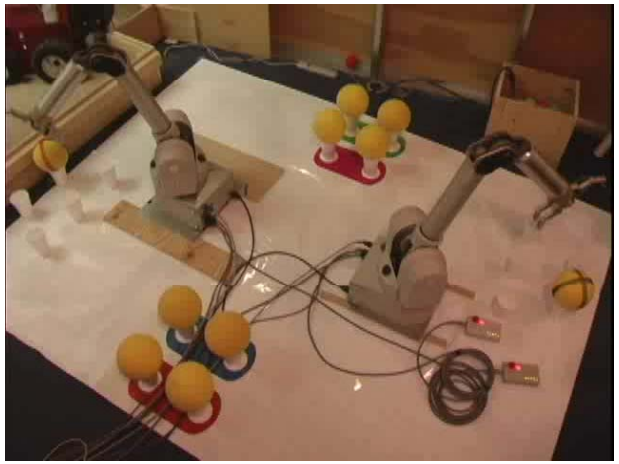


Multi-Robot Teamwork



- Nominal
- Tight Time Constraints

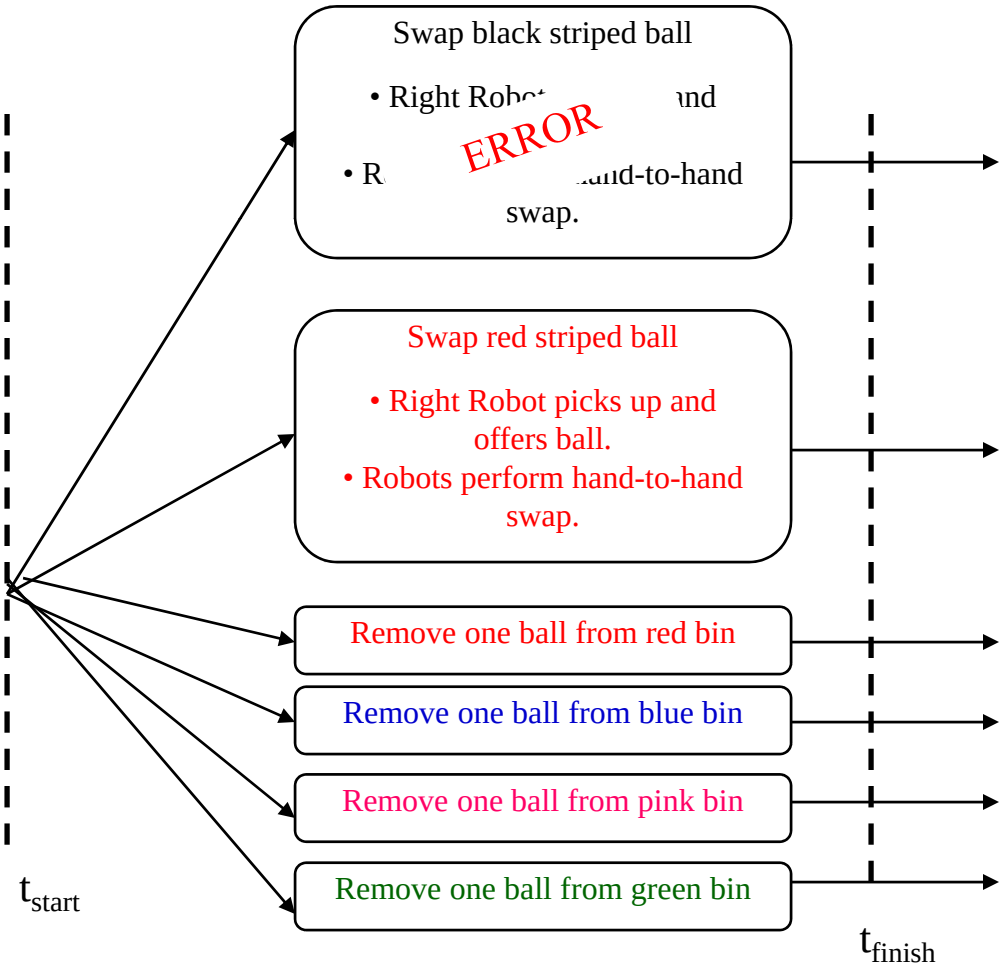
Multi-Robot Teamwork



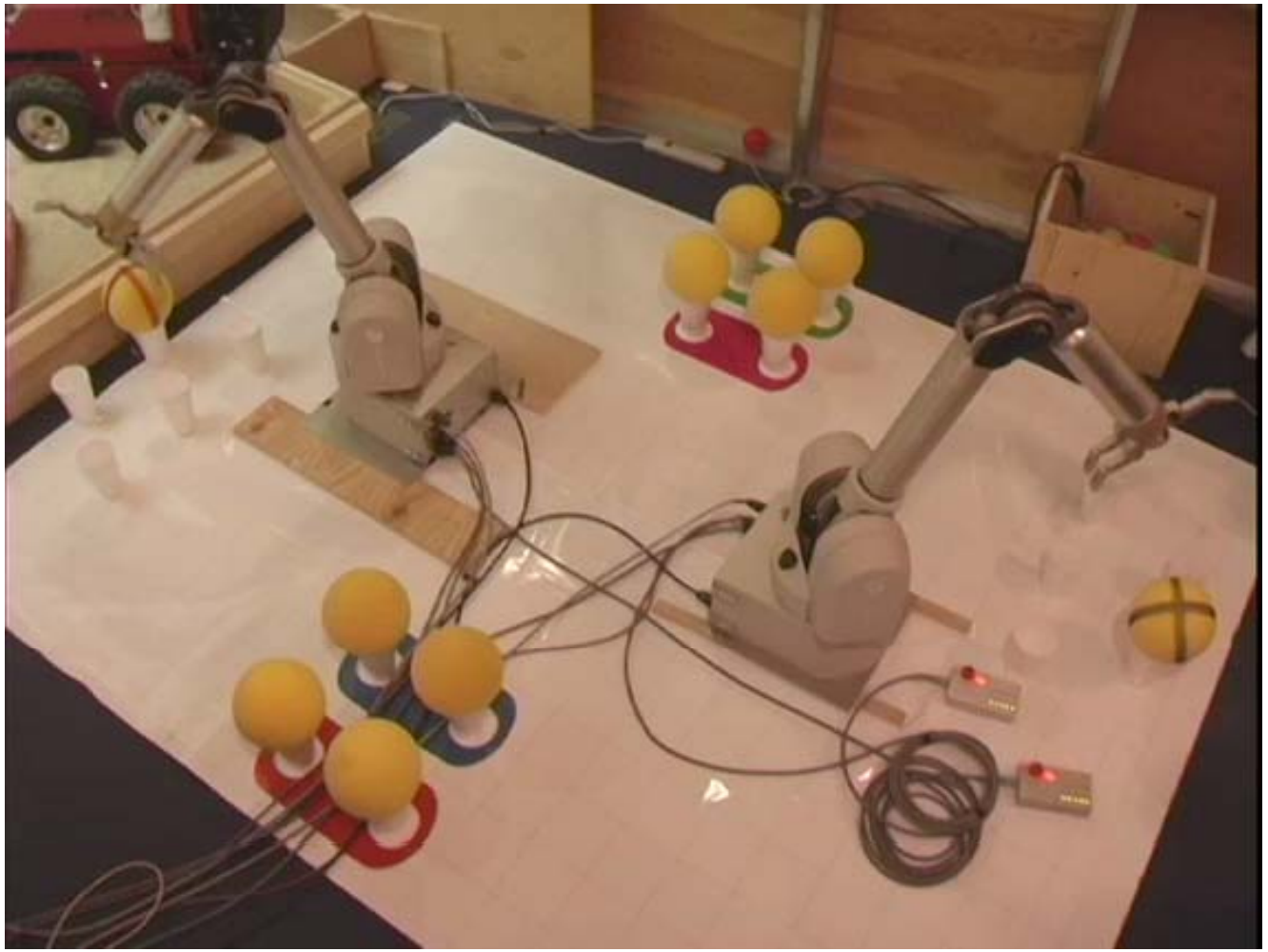
ERROR:

Right Robot takes a very long time to finish "Swap red striped ball."

Watch the Left Robot adapt to ensure task is completed under the tight time constraints.



Multi-Robot Teamwork

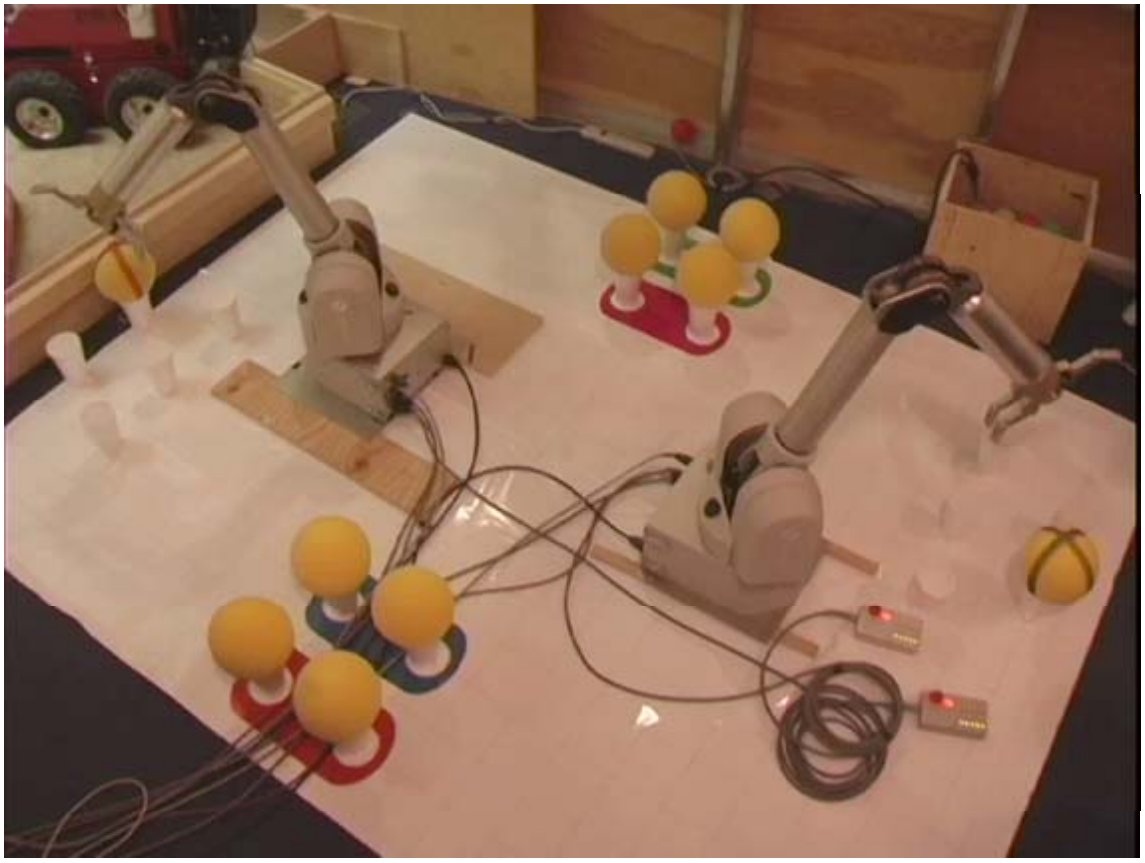


- Off-nominal
- Partner adapts in response to teammate's failure.

Leader & Assistant

Assistant waits to see what Leader will do before acting.

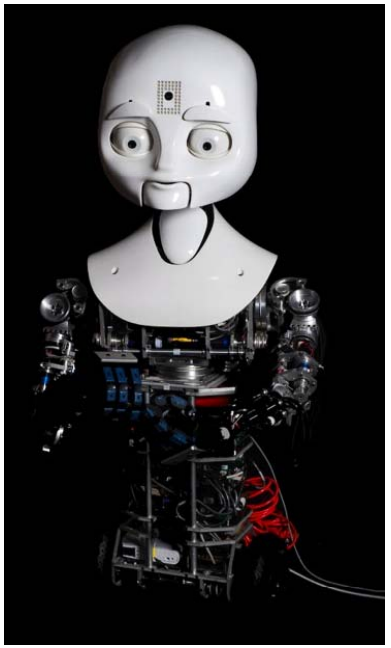
Leader

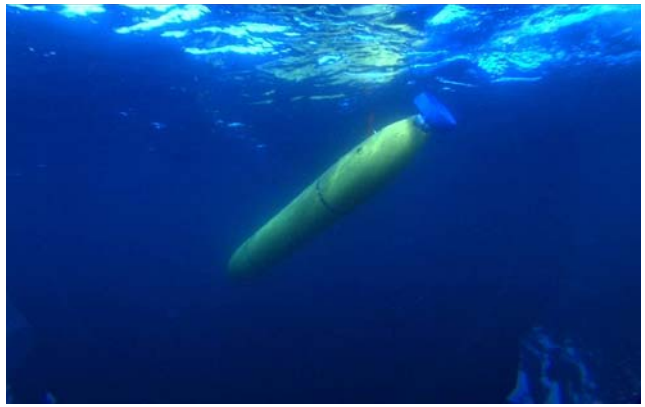


Assistant

Idea: model leader durations and assignments as uncontrollable (TPNU).

Model-based Programming has been applied to a diverse set of robotic systems.





Model-based Programming

mers.csail.mit.edu

- Elevates programming to the goal-level through an idealization in which state is directly observable.
- Simplifies control by learning policies from examples.
- Exploits flexibility to expand robustness.
- Works safely around humans by supporting compliance.
- Supports human / robot teams, by enabling a robot to adapt fluidly and safely to its human counterpart.