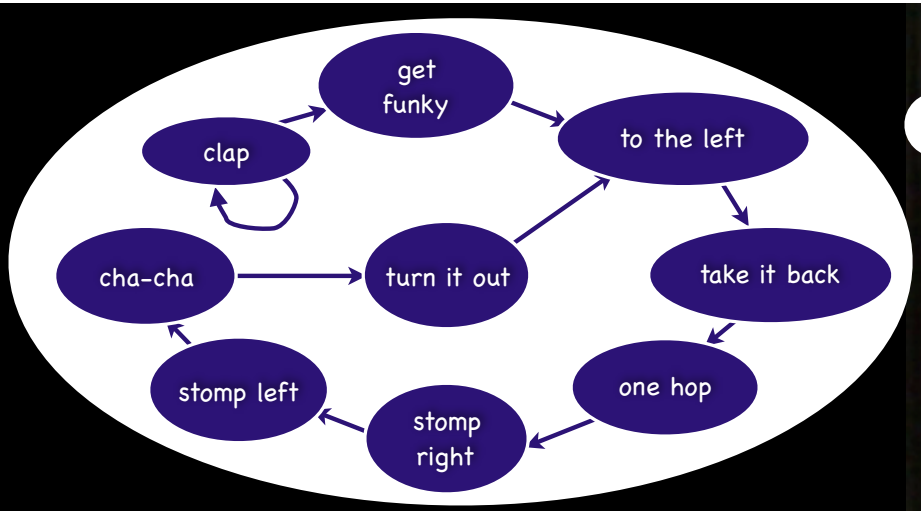


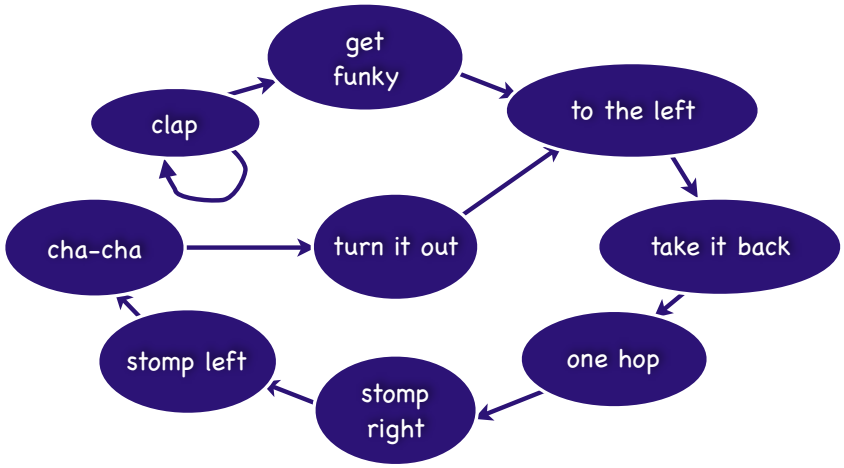
Decision Making and FSMs

EECS 398
Intro. to Autonomous Robotics

ME/EECS 567 ROB 510
Robot Modeling and Control

Fall 2018

Cha-Cha Slide

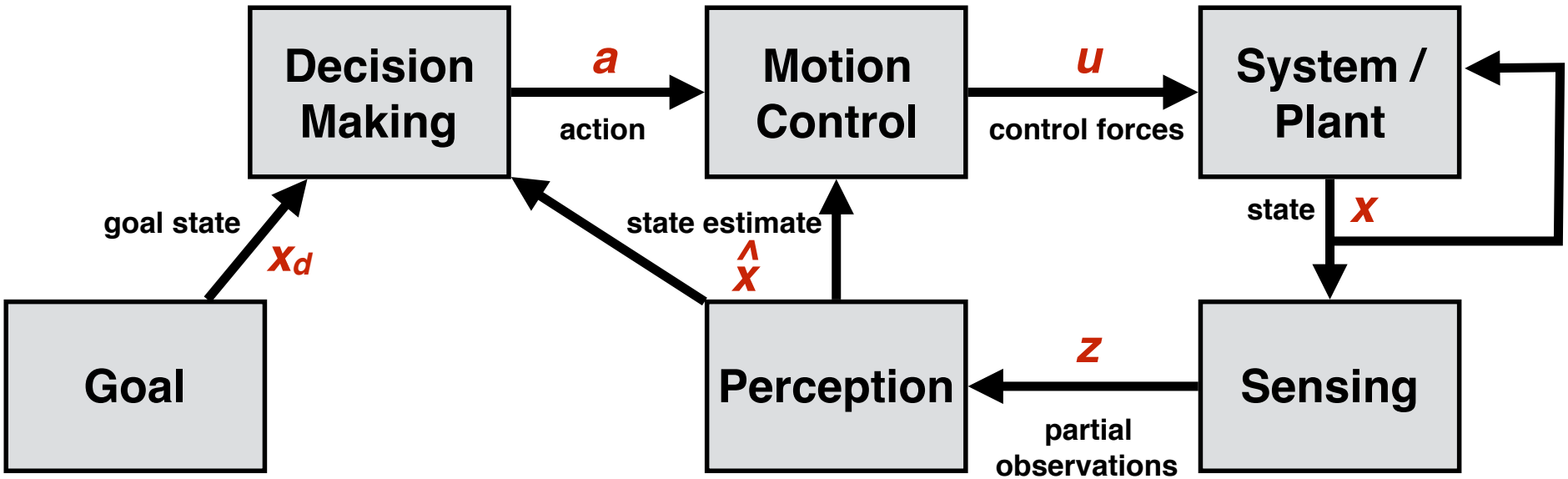


Video: https://www.youtube.com/watch?v=LI64R1bjN7U
Lyrics: https://youtu.be/cb6pJ4AEOoI

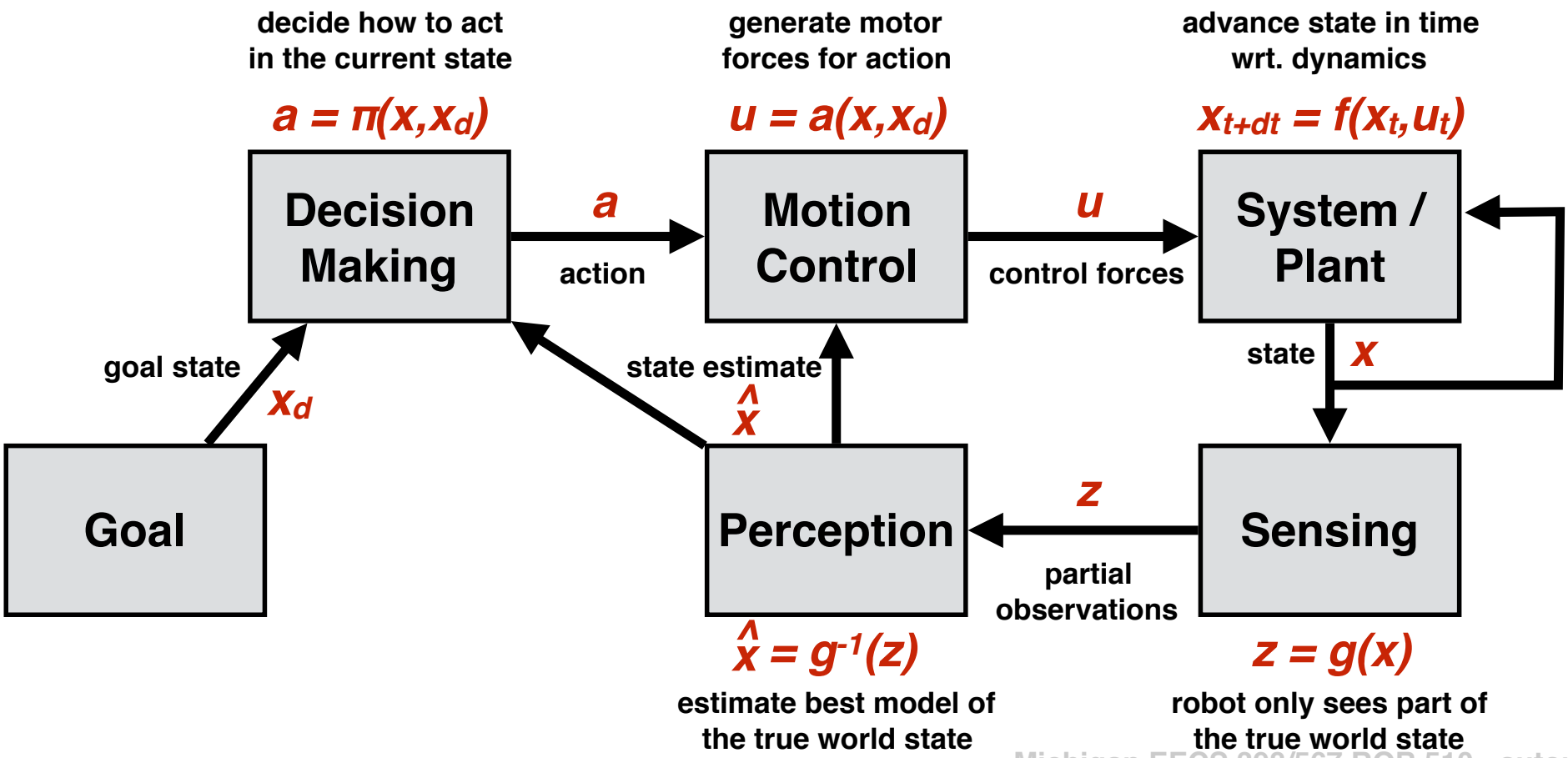
Robot Control Loop

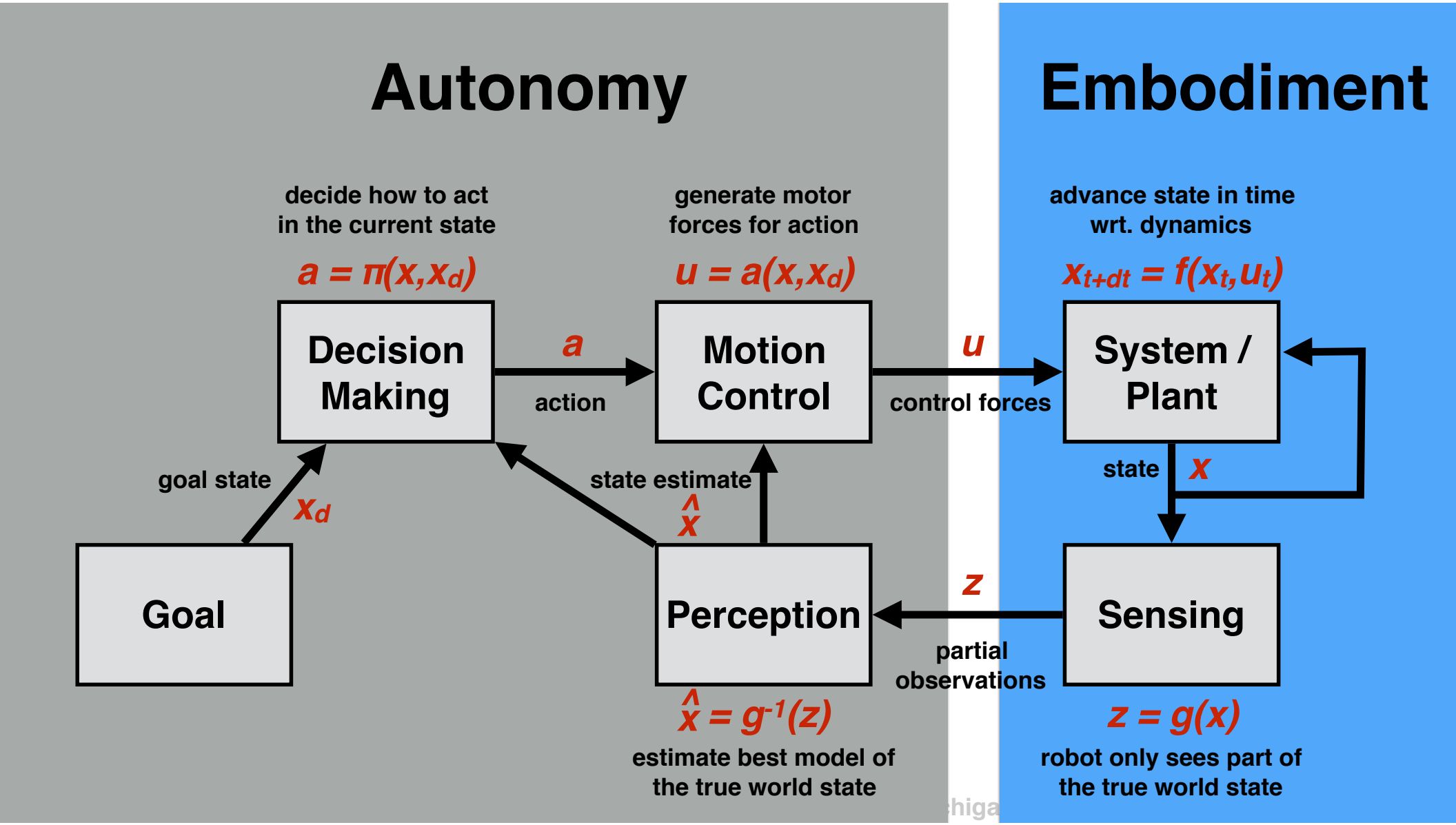
(draw on board)

Robot Control Loop

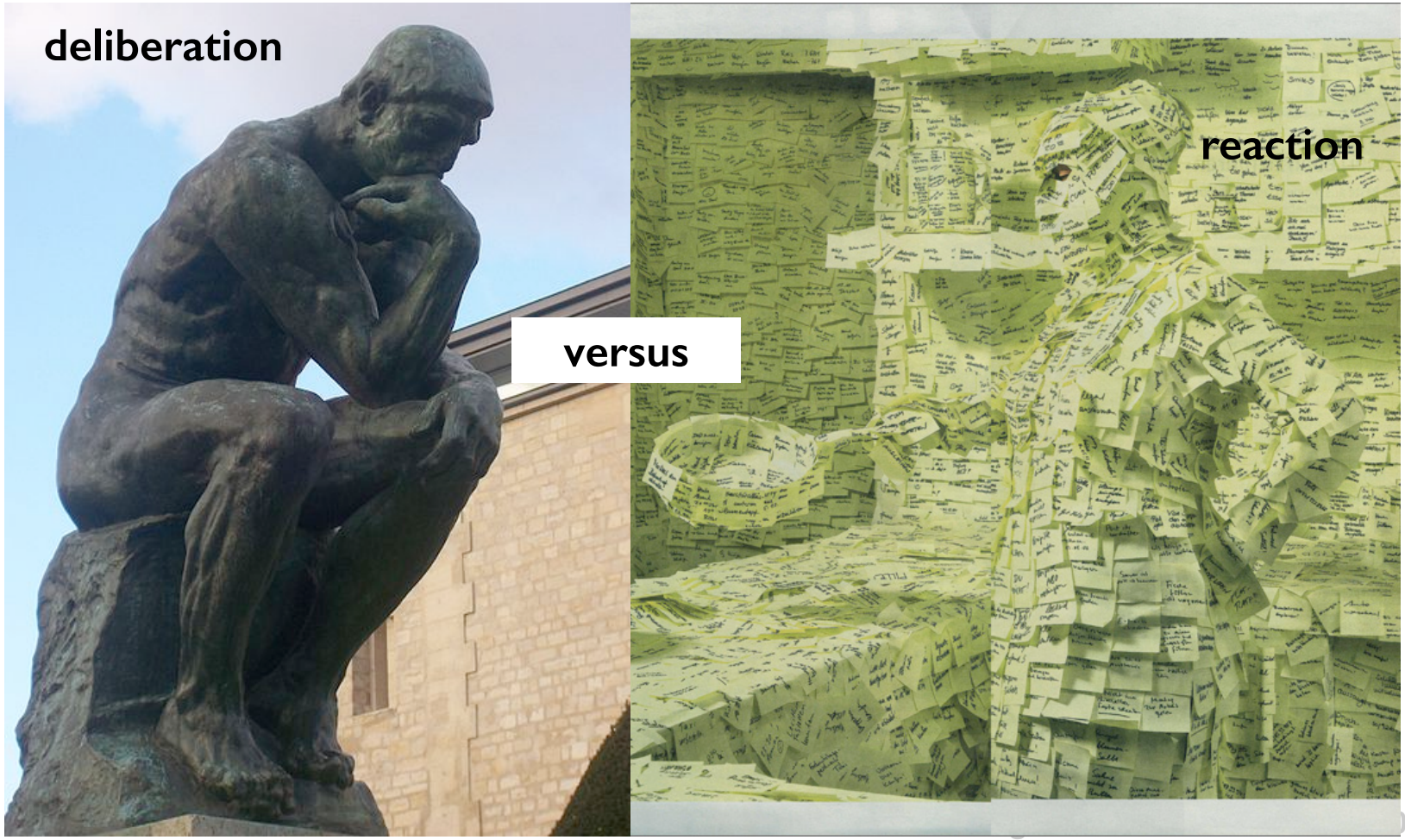


Robot Control Loop



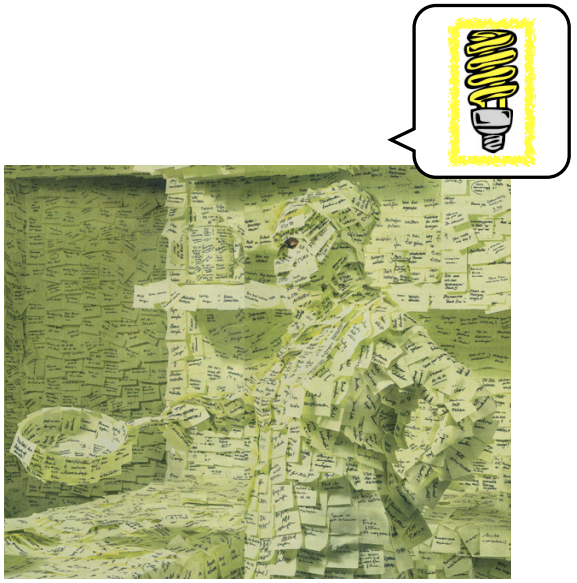

Autonomy
Embodiment
decide how to act
in the current state
$a = \pi(x, x_d)$
generate motor
forces for action
$u = a(x, x_d)$
advance state in time
wrt. dynamics
$x_{t+dt} = f(x_t, u_t)$
Decision Making
a
action
Motion Control
u
control forces
System / Plant
goal state
x_d
state estimate
$\hat{x}$
state
x
Goal
Perception
z
partial observations
Sensing
$\hat{x} = g^{-1}(z)$
estimate best model of
the true world state
$z = g(x)$
robot only sees part of
the true world state

Robot Decision Making



Should your robot's decision making

OR

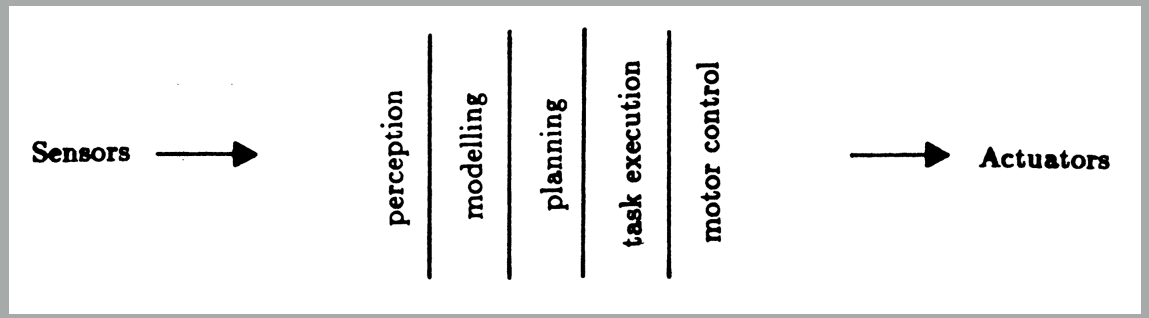


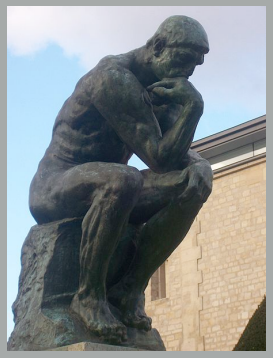
fully think through solving a problem?

react quickly to changes in its world?

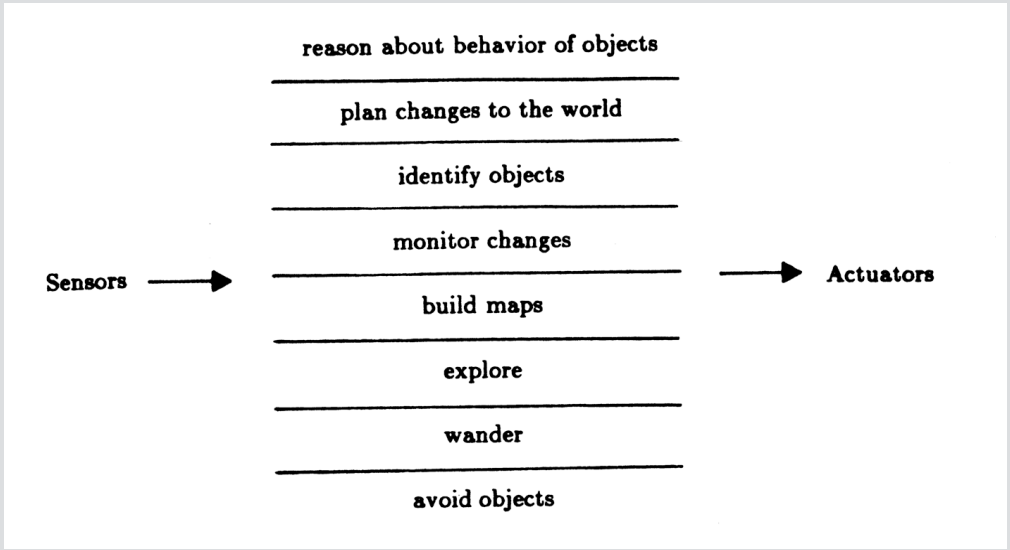
Deliberation v. Reaction

deliberative:
sense-plan-act,
path planning
motion planning



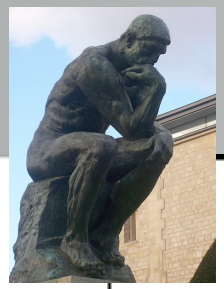


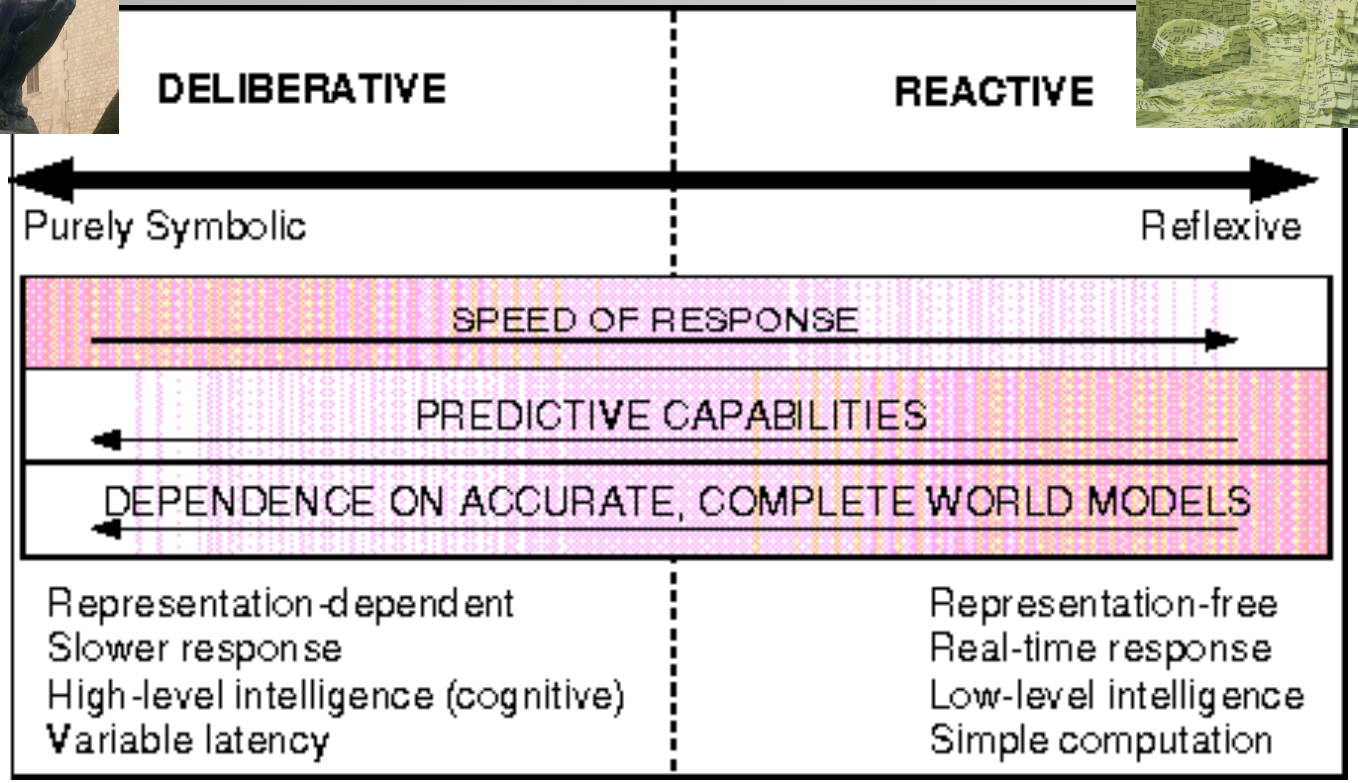
reaction:
controllers acting in parallel
subsumption,
Finite State Machine



Deliberation-Reaction spectrum

[Arkin 1998]





Complete
Adaptive
Optimal
Slower

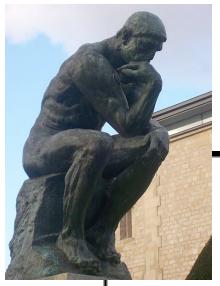
Requires complete model of the world

Faster
Cheaper
More robust
Forgetful

Requires a complete design of the problem

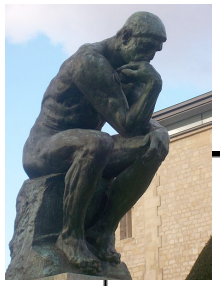
Considerations: time-scale/tractability, generality, representation/state

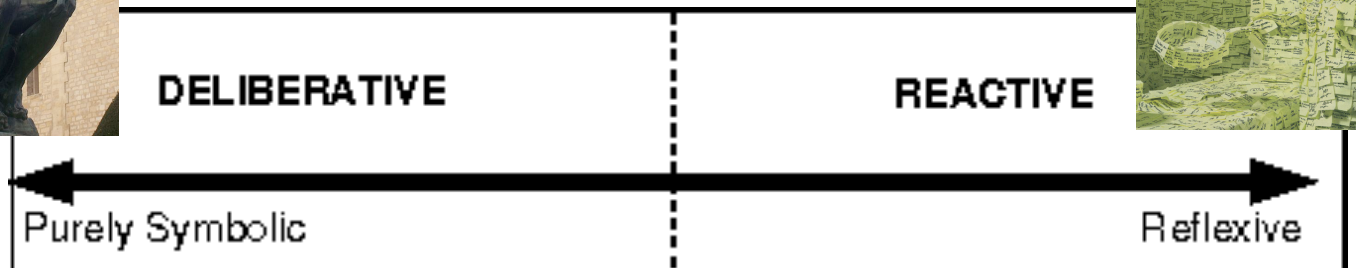
Examples?



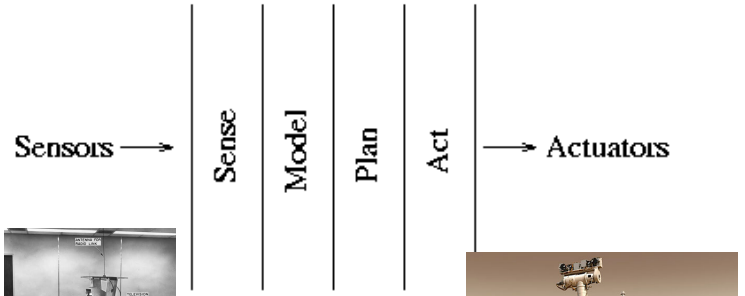
example???

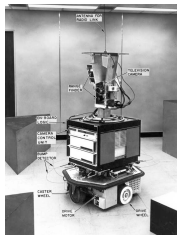
Examples?

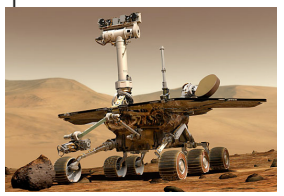




Deliberation

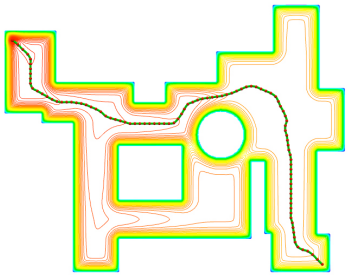


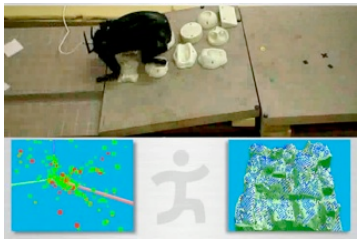




"Sense-Plan-Act" paradigm

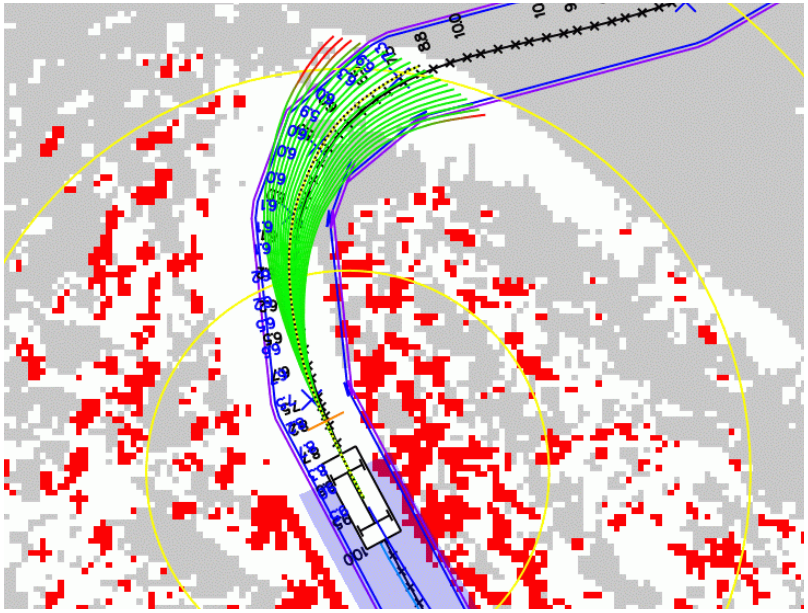
- sense: build most complete model of world
  - GPS, SLAM, 3D reconstruction, affordances
- plan: search over all possible outcomes
  - BFS, DFS, Dijkstra, A*, RRT
- act: execute plan through motor forces





Stanley (Grand Challenge)

Road detection



Navigation costmap

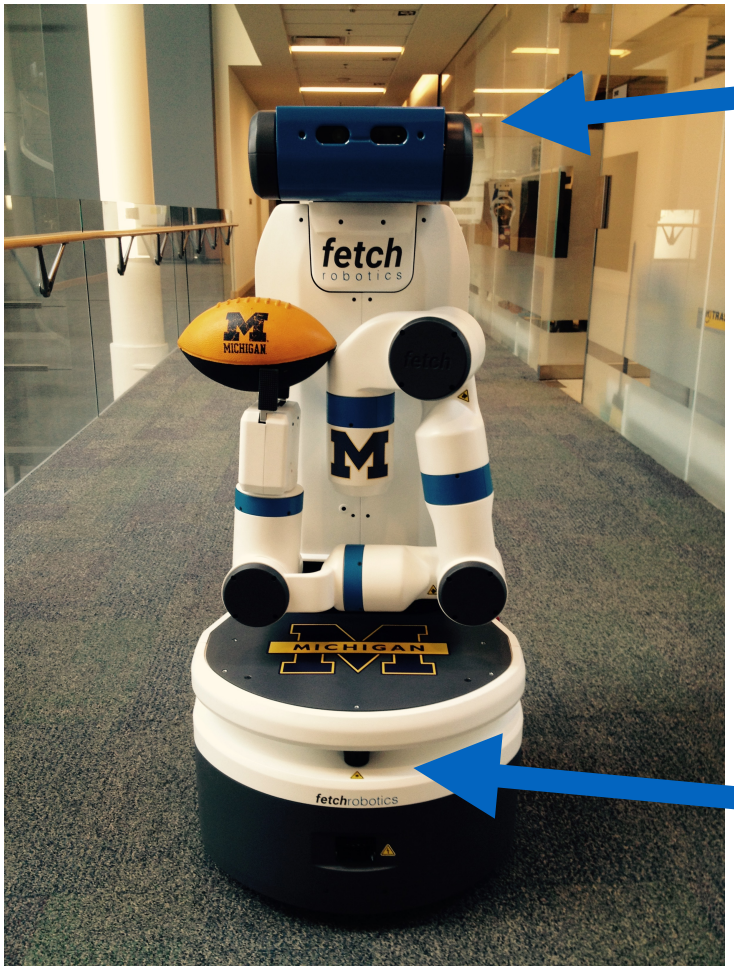
2005

MIT Talos (Urban Challenge)

2007

2013

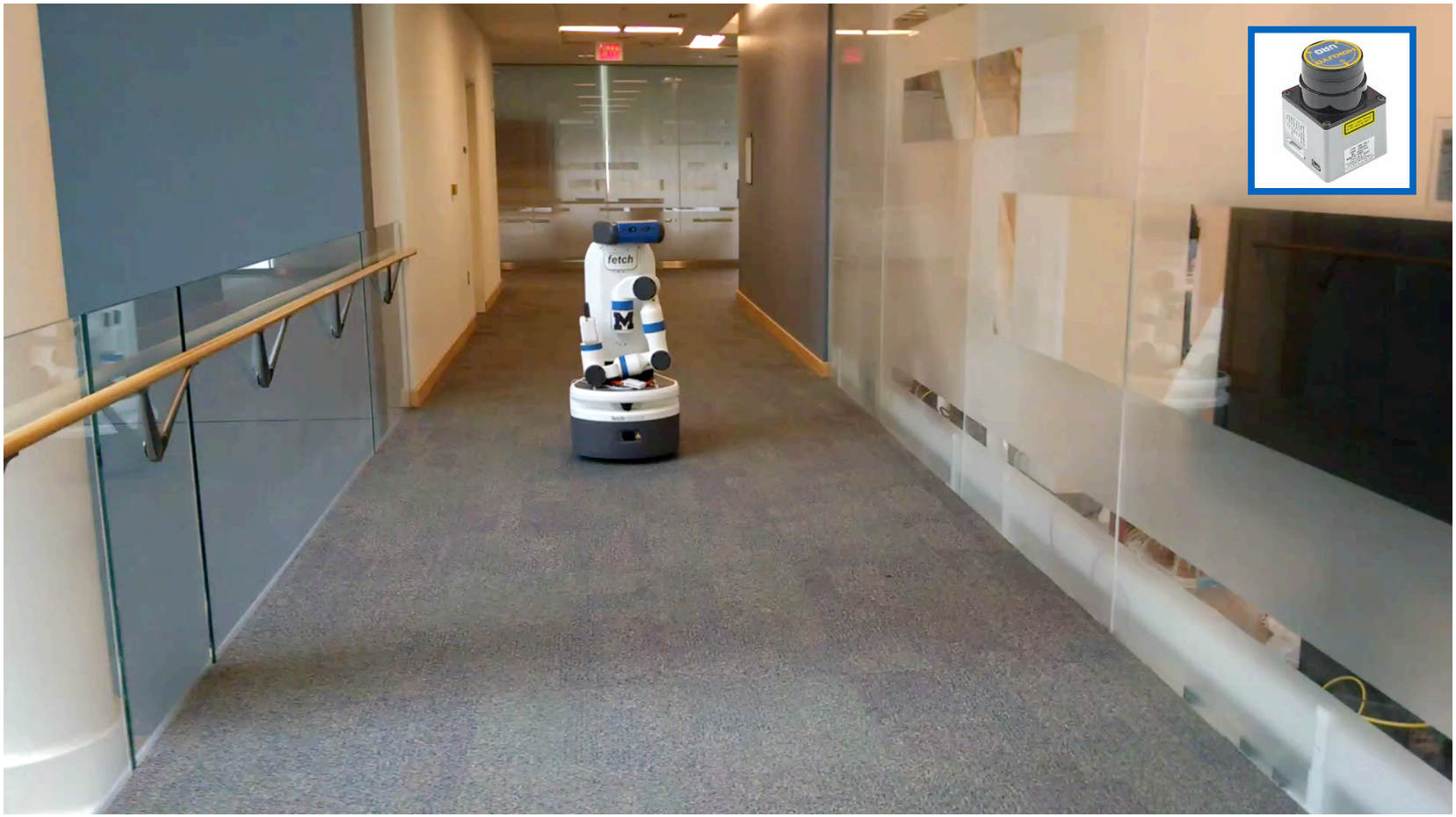
Deliberation
requires a model of the world



Color+Depth Camera

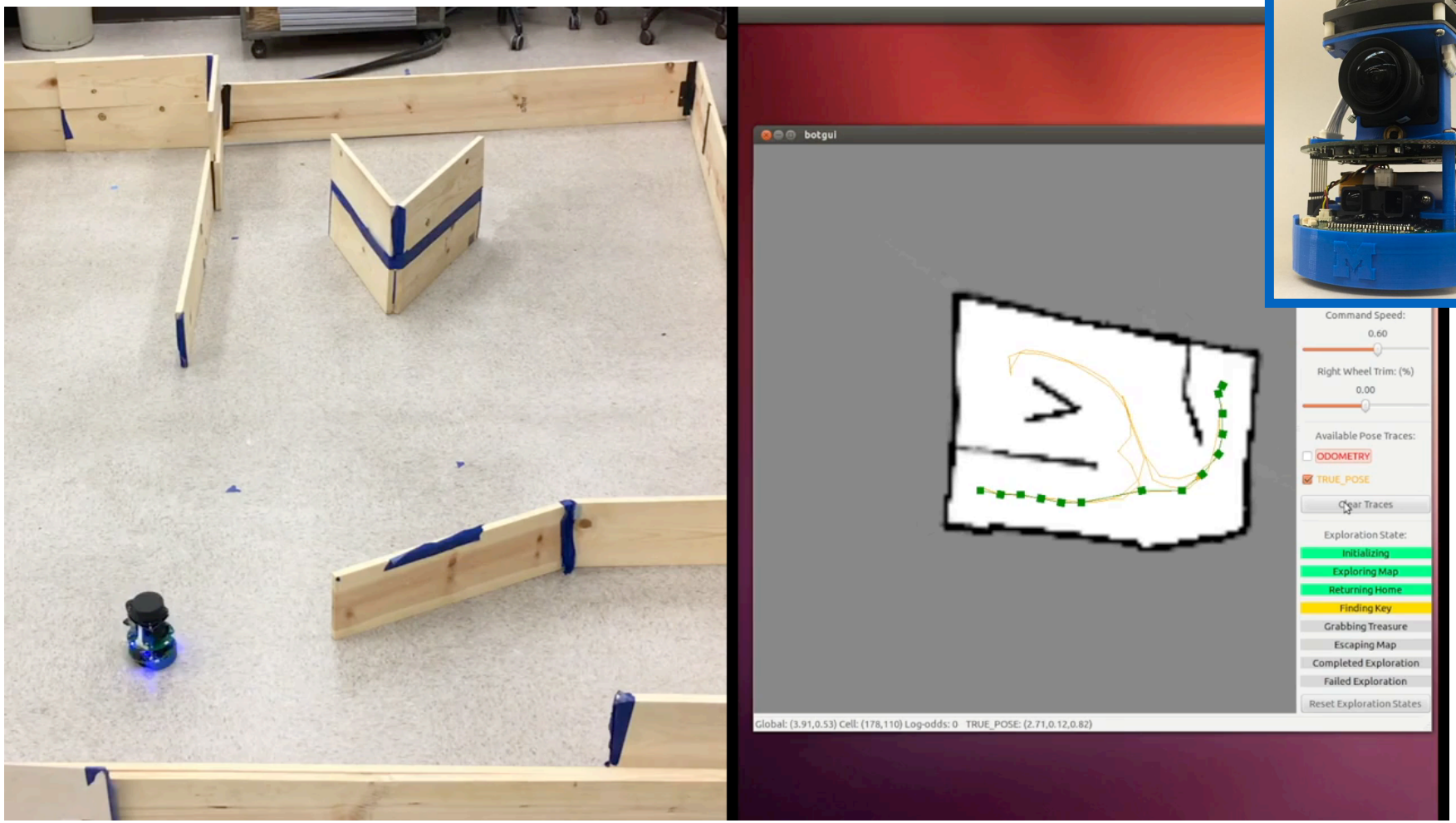
Laser Rangefinder

Simultaneous Localization and Mapping



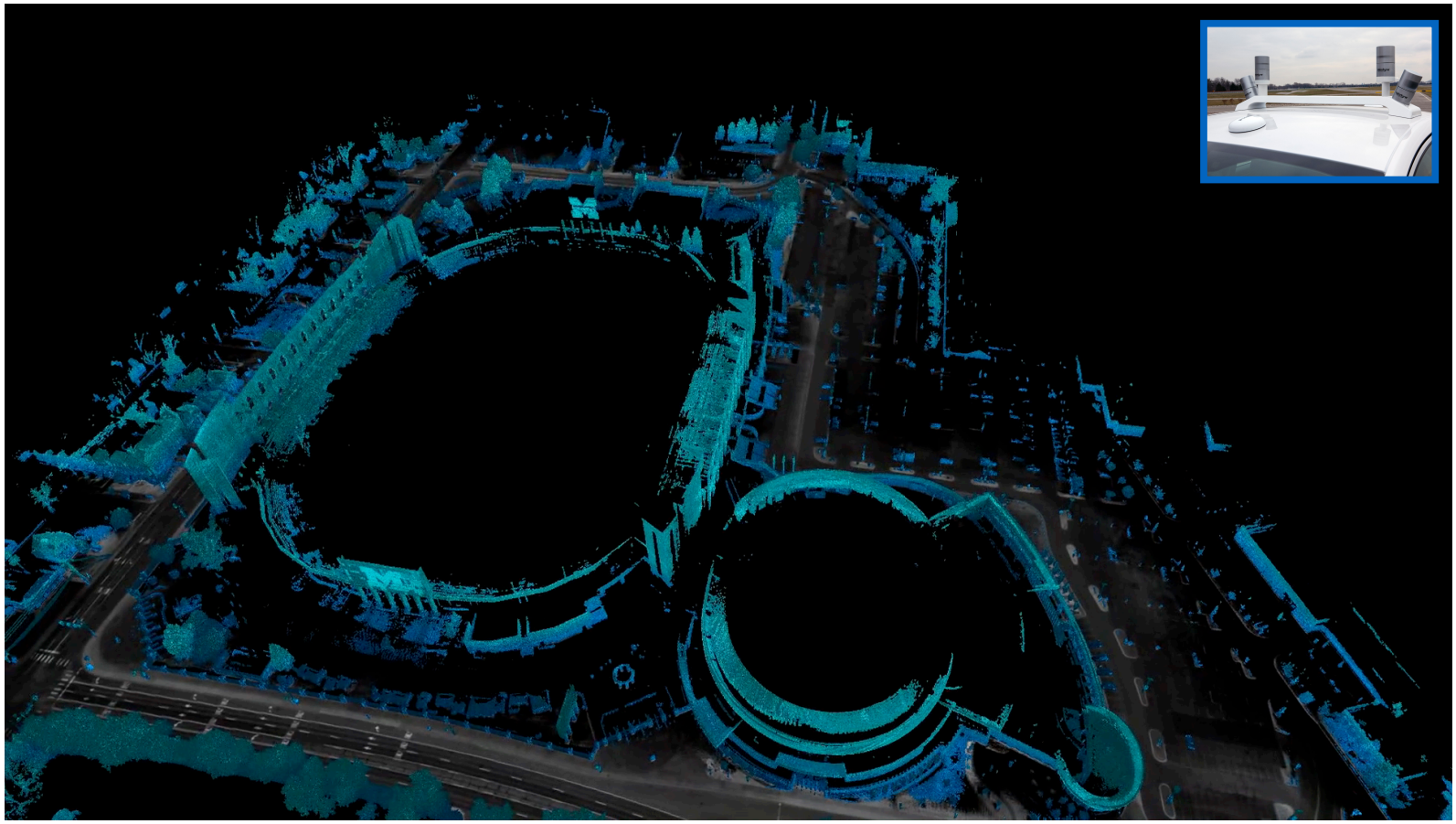
Autonomous robot navigation from previously built map

ROB 550 BotLab / EECS 467 Escape Challenge



Jasmine Liu et al.

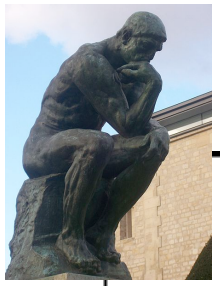
Michigan Next Generation Vehicle (Eustice, Olson et al.)



Autonomous Transportation

Michigan Next Generation Vehicle (Eustice, Olson et al.)

Examples?



DELIBERATIVE

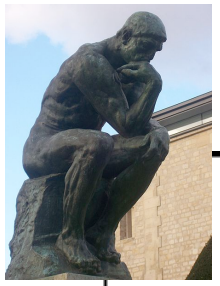
REACTIVE

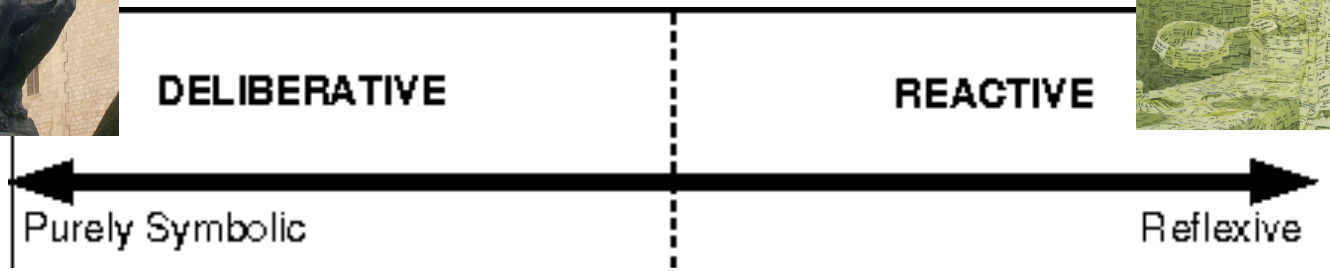
Purely Symbolic

Reflexive

example???

Examples?





https://www.youtube.com/watch?v=jCB3pd-wBw0 Autonomous cars again?

Secure | https://medium.com/may-mobility/the-problem-with-so-so-driving-4a46f60bac37

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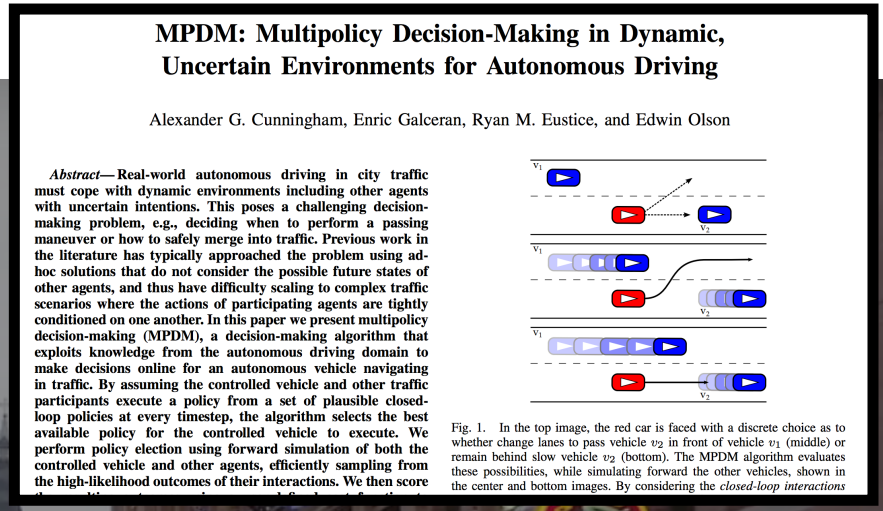
Sign in | Get started

Edwin Olson Follow

CEO of May Mobility, Associate Professor of Computer Science at University of Michigan

Sep 4 · 5 min read



MPDM: Multipolicy Decision-Making in Dynamic, Uncertain Environments for Autonomous Driving

Alexander G. Cunningham, Enric Galceran, Ryan M. Eustice, and Edwin Olson

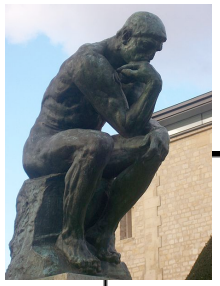
***Abstract*— Real-world autonomous driving in city traffic must cope with dynamic environments including other agents with uncertain intentions. This poses a challenging decision-making problem, e.g., deciding when to perform a passing maneuver or how to safely merge into traffic. Previous work in the literature has typically approached the problem using ad-hoc solutions that do not consider the possible future states of other agents, and thus have difficulty scaling to complex traffic scenarios where the actions of participating agents are tightly conditioned on one another. In this paper we present multipolicy decision-making (MPDM), a decision-making algorithm that exploits knowledge from the autonomous driving domain to make decisions online for an autonomous vehicle navigating in traffic. By assuming the controlled vehicle and other traffic participants execute a policy from a set of plausible closed-loop policies at every timestep, the algorithm selects the best available policy for the controlled vehicle to execute. We perform policy election using forward simulation of both the controlled vehicle and other agents, efficiently sampling from the high-likelihood outcomes of their interactions. We then score**

Fig. 1. In the top image, the red car is faced with a discrete choice as to whether change lanes to pass vehicle v_2 in front of vehicle v_1 (middle) or remain behind slow vehicle v_2 (bottom). The MPDM algorithm evaluates these possibilities, while simulating forward the other vehicles, shown in the center and bottom images. By considering the *closed-loop interactions*

SELF-DRIVING CARS SHOULD BE ***GOOD*** DRIVERS,
NOT ***SO-SO*** DRIVERS. BUT ARE THEY?

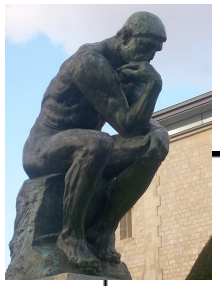
https://medium.com/may-mobility/the-problem-with-so-so-driving-4a46f60bac37

Examples?



more common example???

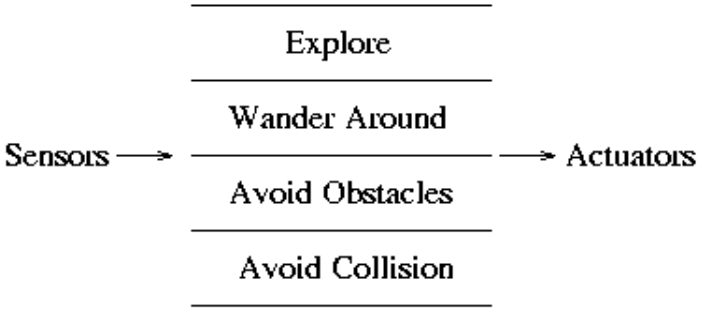
Examples?




DELIBERATIVE
REACTIVE
Purely Symbolic
Reflexive

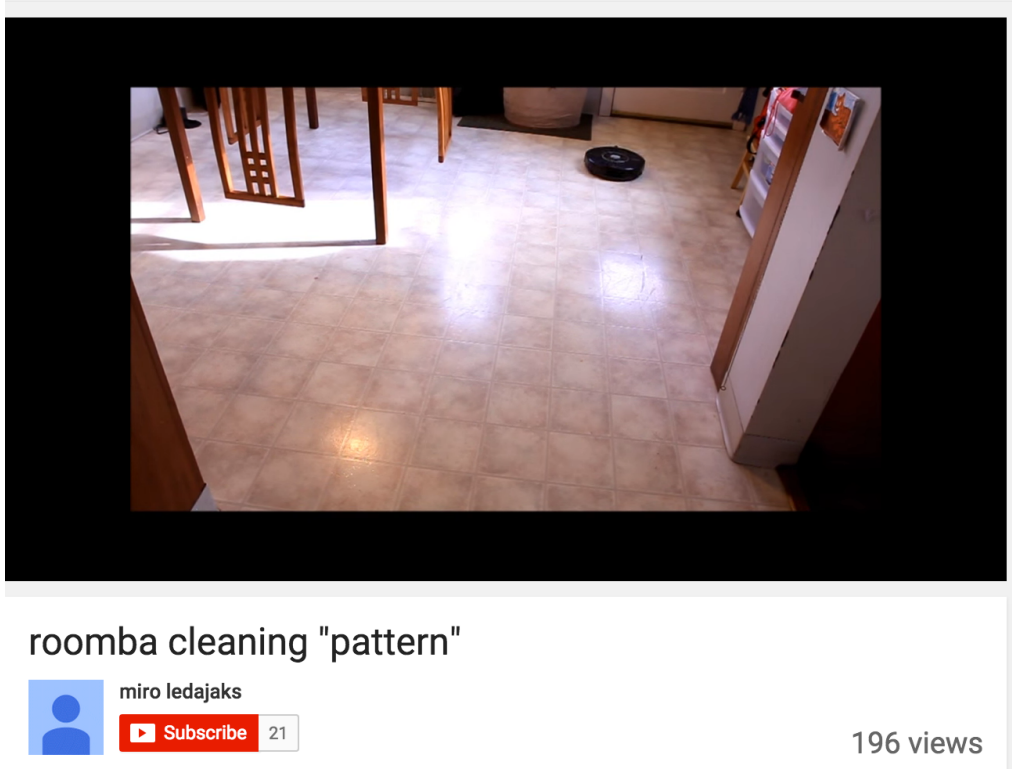

Roomba SE
spot
clean
max
power
iRobot

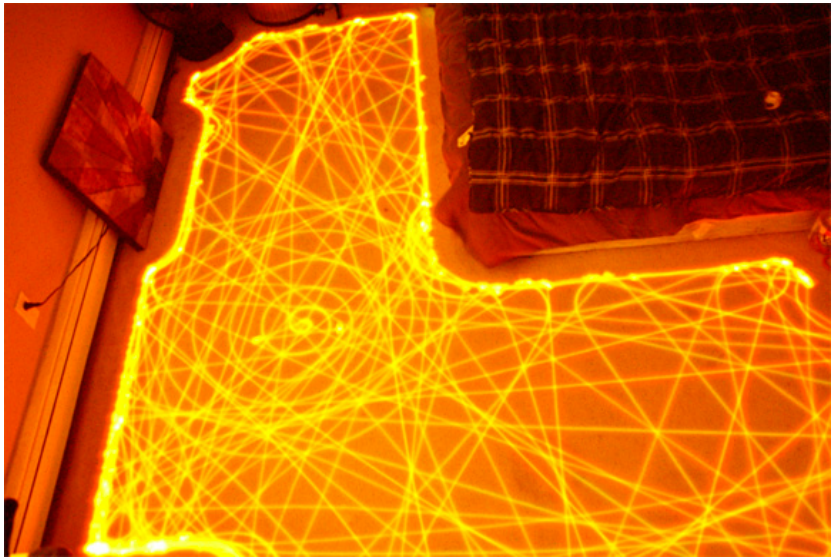
Reaction



- No representation of state
  - Typically, fast hardcoded rules
- Embodied intelligence
  - behavior ← control + embodiment
  - Stigmergy: ant analogy
- Finite State Machines
  - most common
- Subsumption architecture
  - prioritized reactive policies

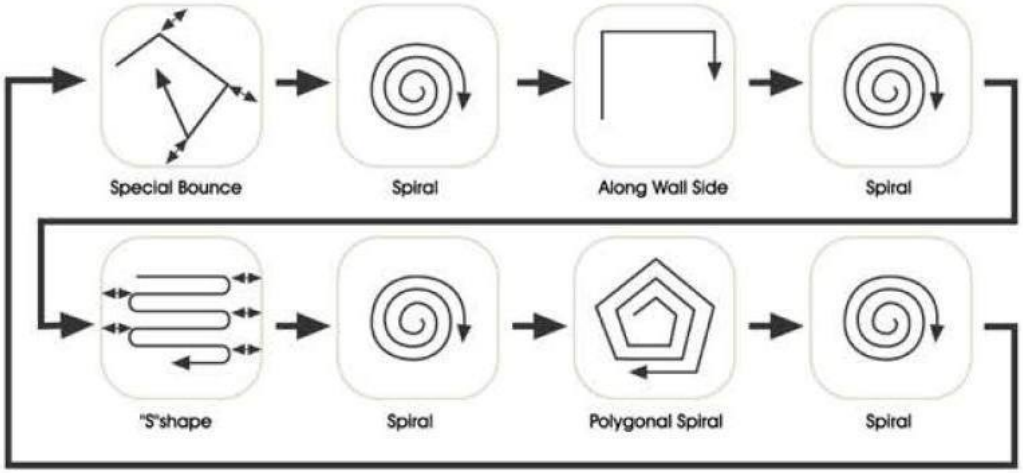
Roomba cleaning pattern

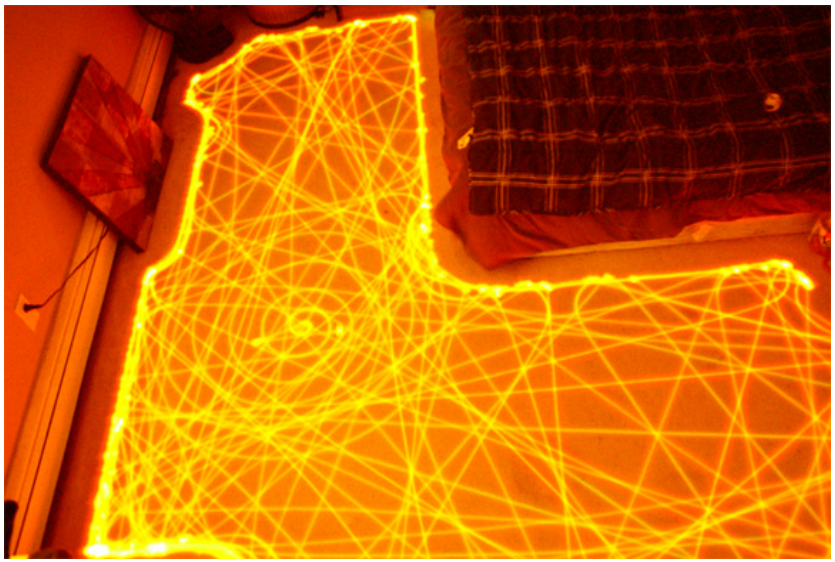




https://www.youtube.com/watch?v=G4ocrevf4ng

Vacuuming Finite State Machine





Secure | https://www.technologyreview.com/s/400145/honey-theyve-shrunk-the-rover/

MIT Technology Review

Ghengis hexapod robot

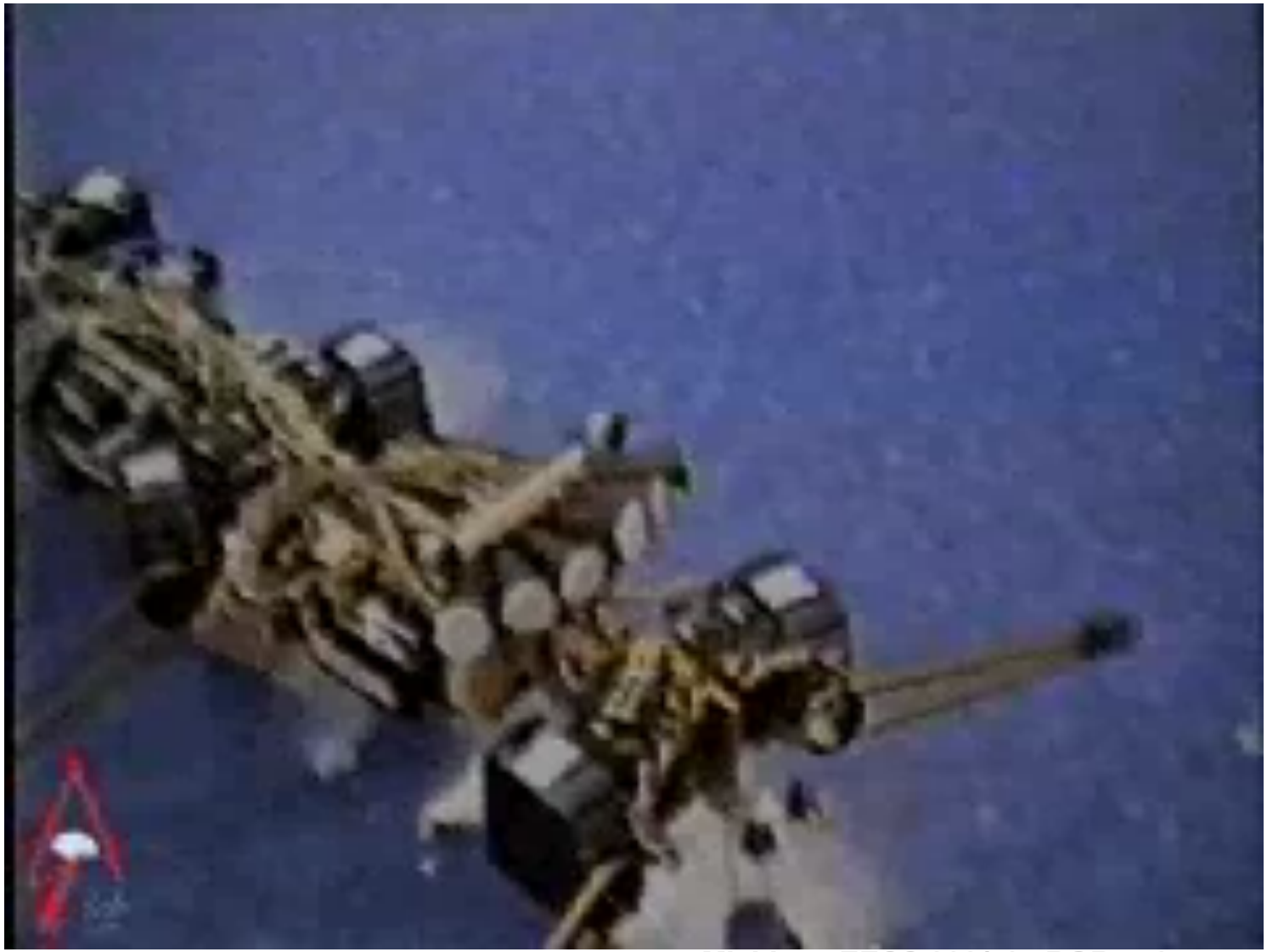
Intelligent Machines

Honey, They've Shrunk the Rover

The Sojourner vehicle that trekked across the Martian surface captured the world's fancy last summer, but we haven't seen anything yet. Next will come rovers that can roam miles across Mars and "aerobots" able to survey other planets.

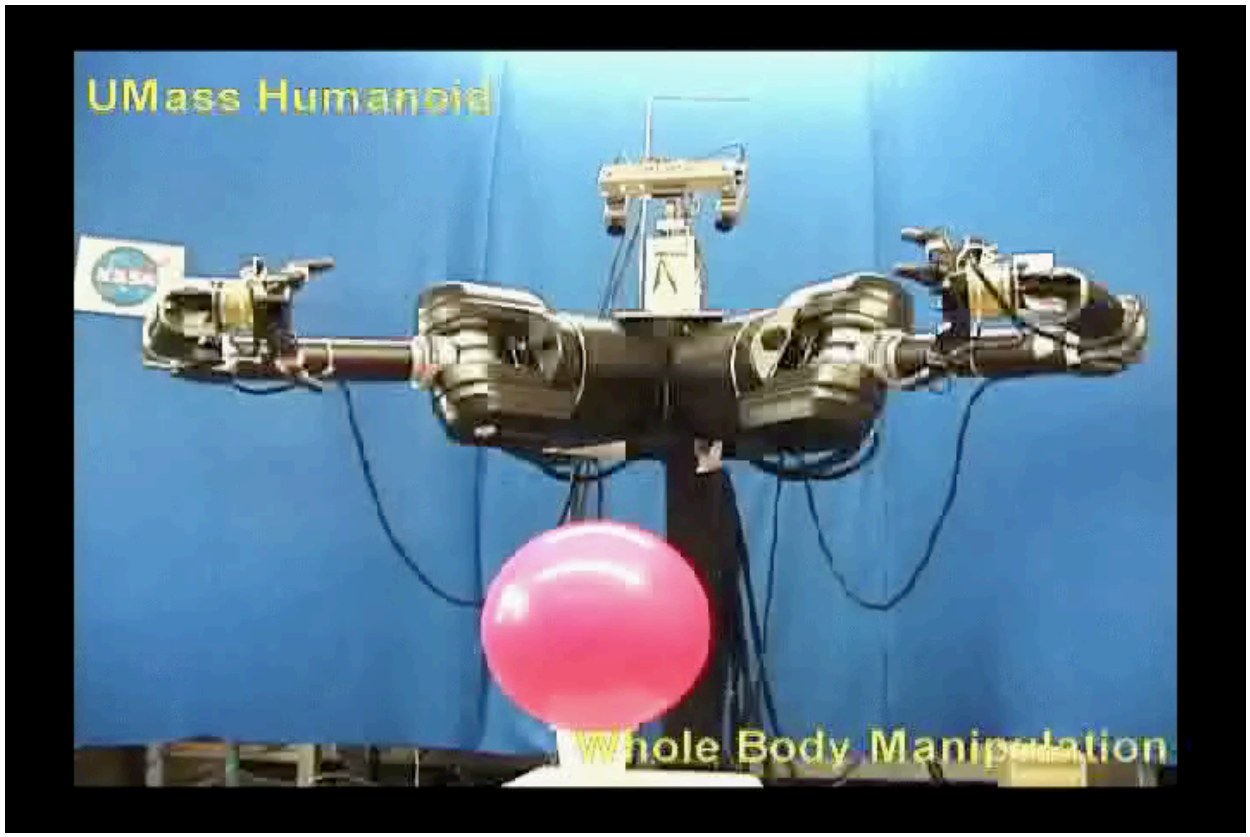
by Eric Scigliano January 1, 1998

MIT Genghis



MIT Genghis

Manipulation Gaits



Collections of robust manipulation controllers

Grey Walter's Tortoise (1949) - https://youtu.be/lLULRImXkKo

Embodied Intelligence

- Do we need to model the world or build sophisticated controllers?
- Embodied intelligence: robot behavior results from embodiment acting in environment
- Braitenberg vehicle
  - "Vehicles: Experiments in synthetic psychology" (1984)

Tiny Braitenberg Vehicle
http://vimeo.com/5664333

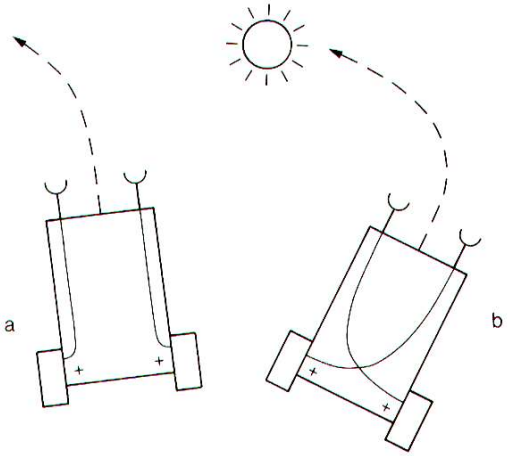


Figure 3
Vehicles 2a and 2b in the vicinity of a source (circle with rays emanating from it). Vehicle 2b orients toward the source, 2a away from it.

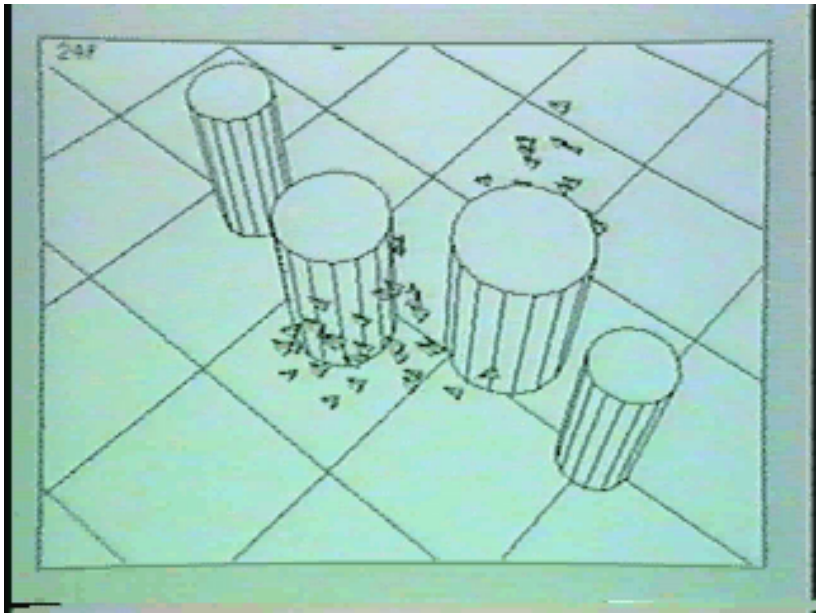
Random Walk: Goal Seeking

- Move in a random direction until you hit something
- Then go in a new direction
- Stop when you get to the goal, assuming it can be recognized

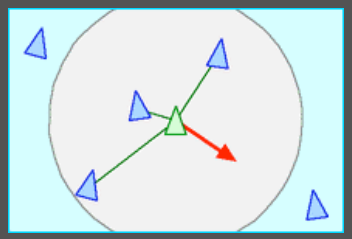
Lisa Miller, http://www.youtube.com/watch?v=VBzXDrz8rMI

Swarm Intelligence: Formations

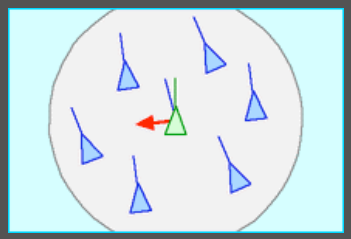
- collective behavior of decentralized, self-organized systems, natural or artificial
- complex group behavior emerges from combination of simple local controllers
- Reynolds' Boids (1987) for flocking



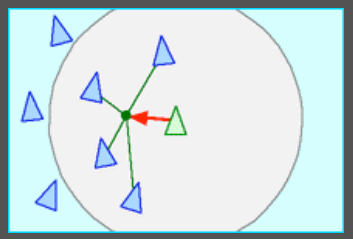
Separation: steer to avoid crowding local flockmates



Alignment: steer towards the average heading of local flockmates



Cohesion: steer to move toward the average position of local flockmates



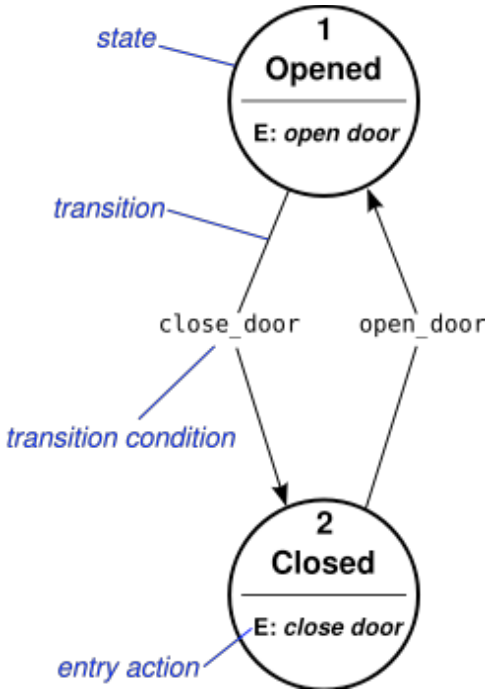
Swarm Intelligence: Box clustering

https://www.youtube.com/watch?v=b_kZmatqAaQ

How do we computationally represent reactive control?

Finite State Machines

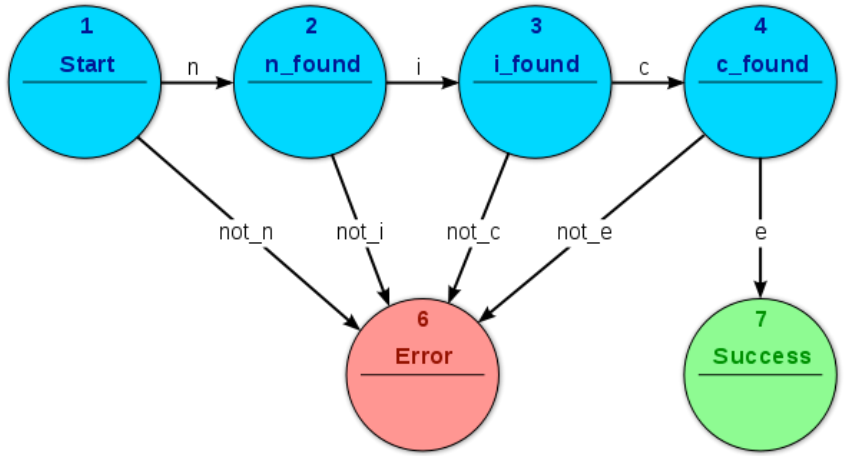
- Components
  - alphabet (or inputs)
    - “observations” in robotics
  - states (some robot action)
  - transitions (between states)
  - stopping condition
- Commonly, implemented as switch-case or if-else within a while loop



http://en.wikipedia.org/wiki/Switch_statement

“nice” recognizer

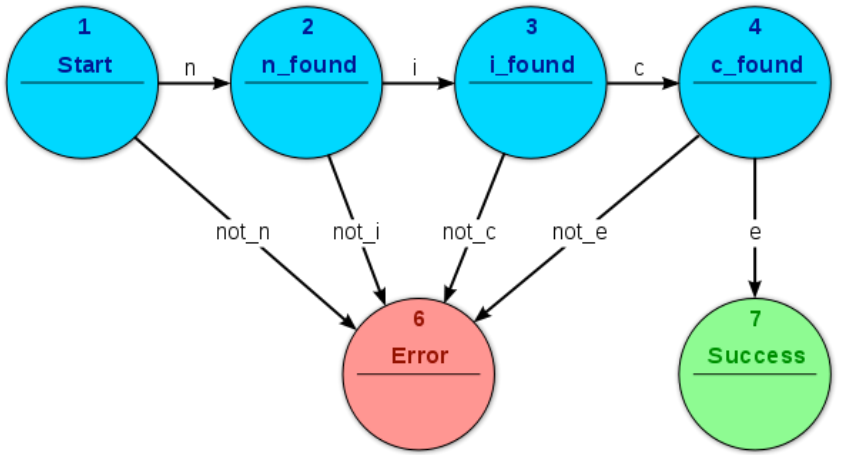
- recognize the string “nice” from input
  - if input is “nice”
    - output **success**
  - if input not “nice”
    - output **error**



- robotics uses
  - preconditions (enter state)
  - postconditions (exit state)

```
state ← start
while state != success and state != error
 token ← <next string character from input>
 switch (state):
   case start:
     if token = “n” then state ← n_found
     else state ← error
     break
   case n_found:
     if token = “i” then state ← i_found
     else state ← error
     break
   case i_found:
     if token = “c” then state ← c_found
     else state ← error
     break
   case c_found:
     if token = “e” then state ← success
     else state ← error
     break
end while loop
output ← state
```

“nice” recognizer



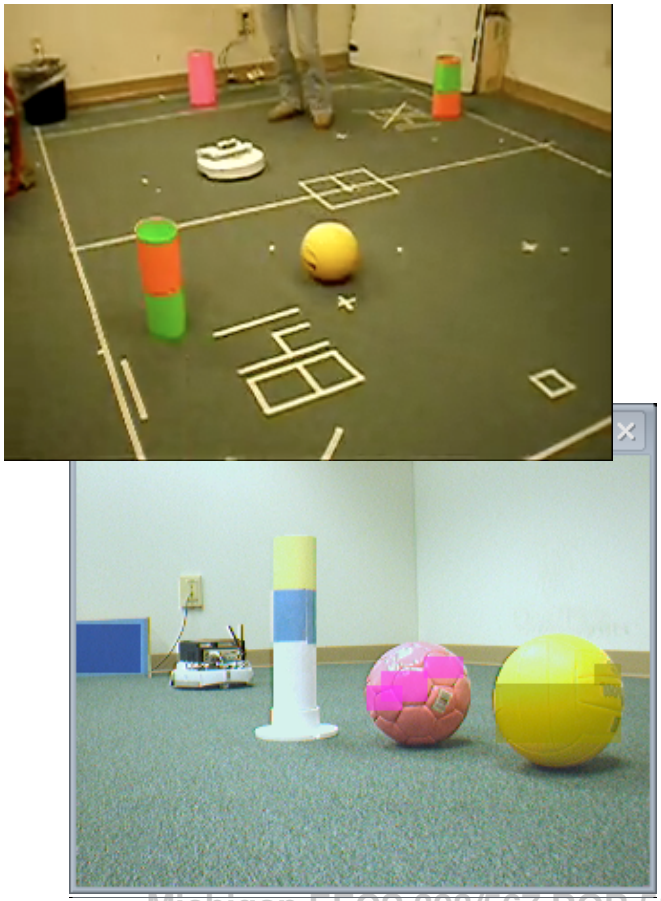
Consider input: “nice”

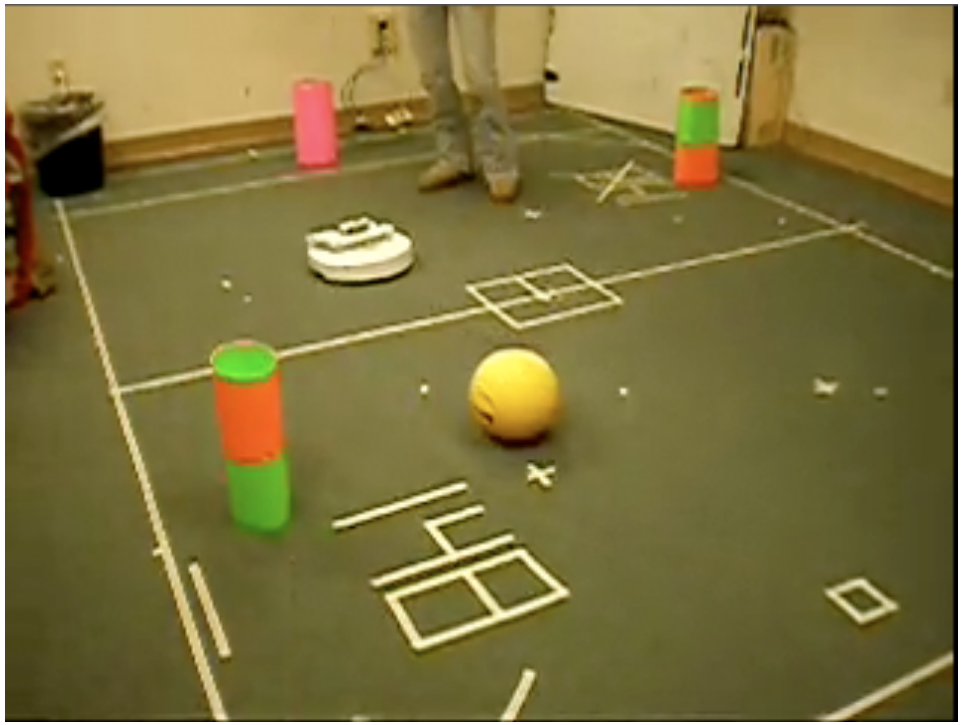
Consider input: “robotics”

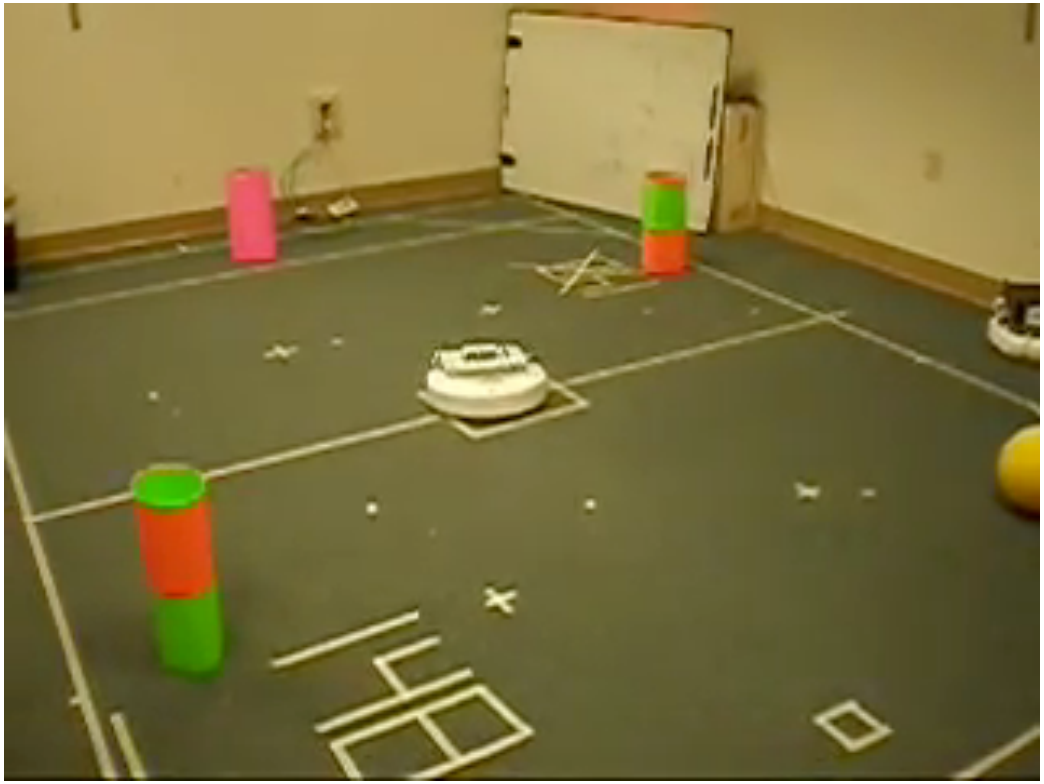
Consider input: “niece”

Move to objects in sequence?

- How to move a mobile robot to a given sequence of objects?
  - yellow ball
  - green/orange landmark
  - pink landmark
  - orange/green landmark







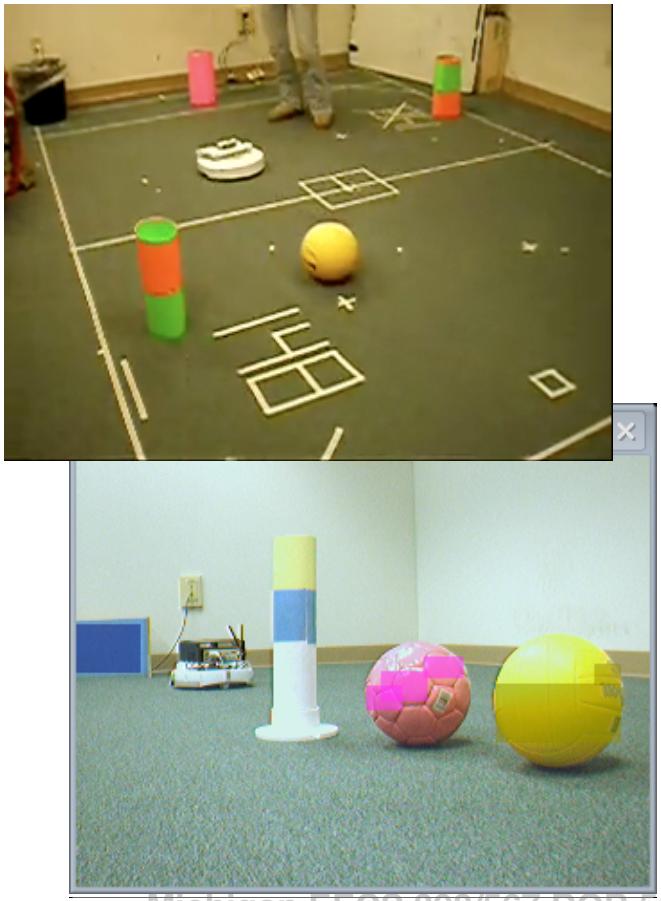
Object Seeking

http://www.youtube.com/watch?v=-hOA0jMUggg

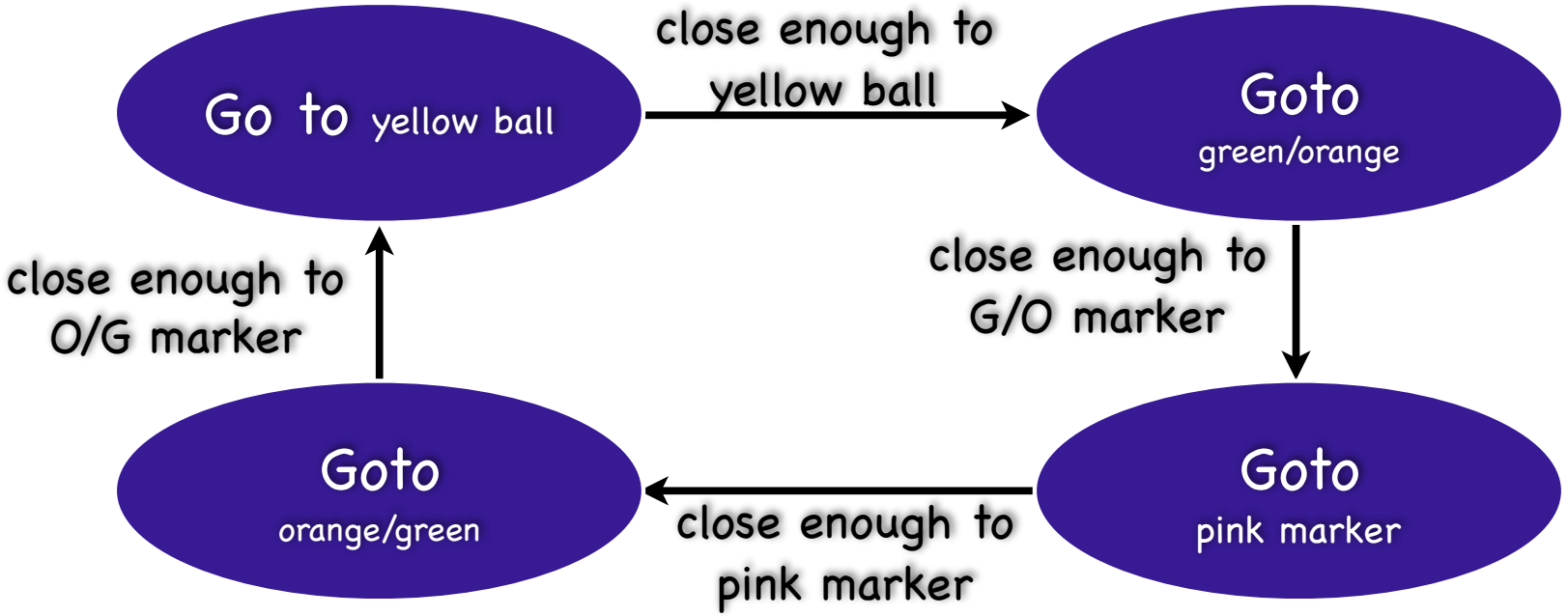
Move to objects in sequence?

- What are the states?
- What are the transitions?
- Preconditions for states?
- Postconditions for states?

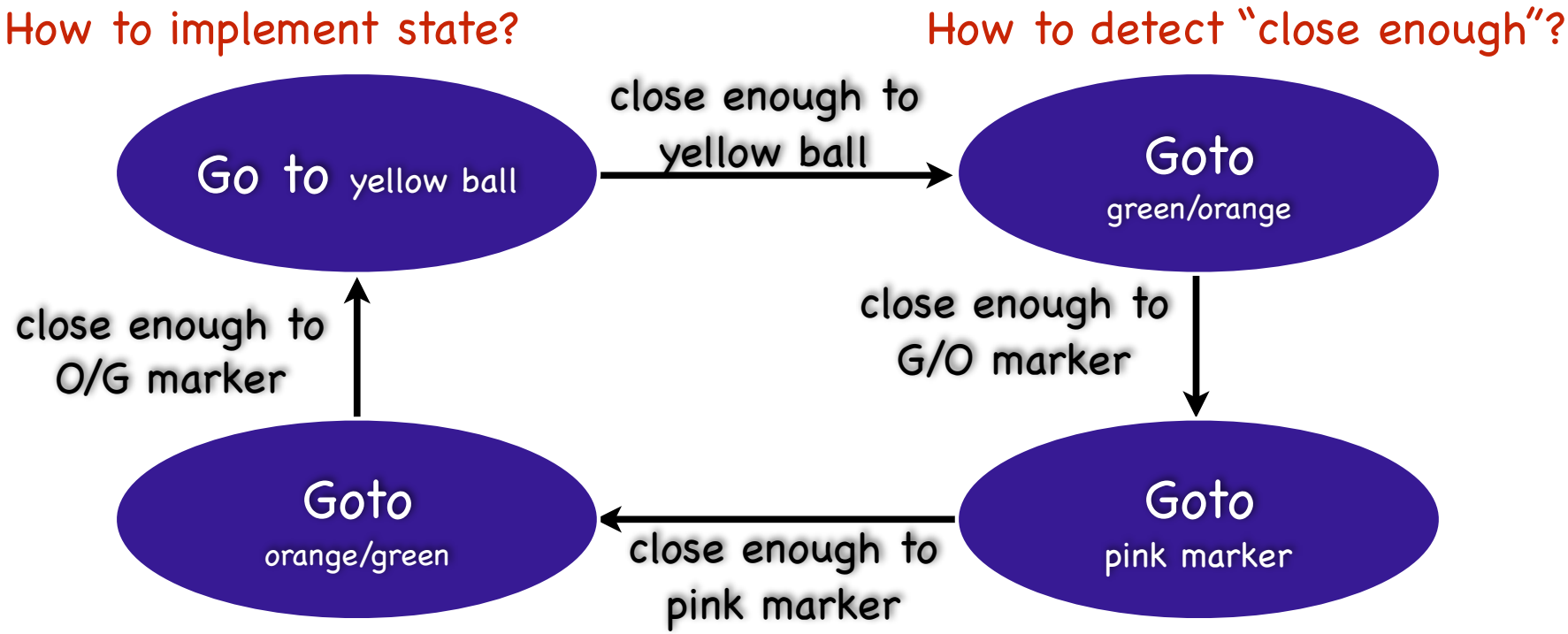
- Can someone sketch on board?



Object seeking FSM

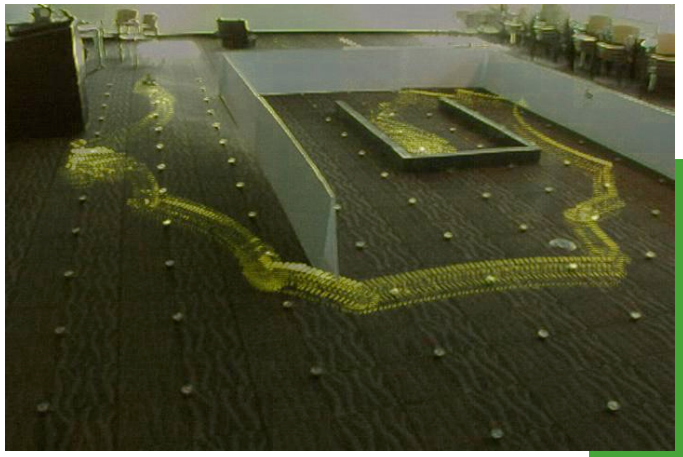


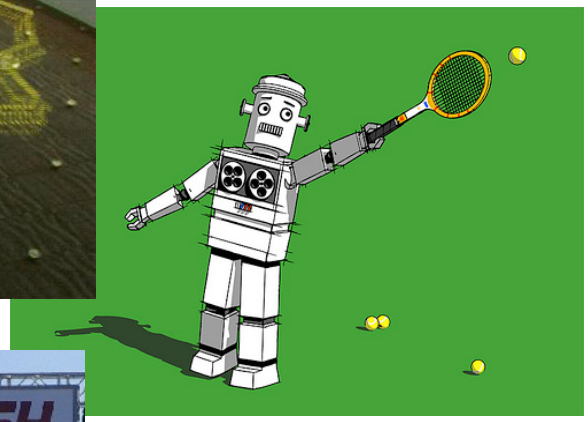
Object seeking FSM

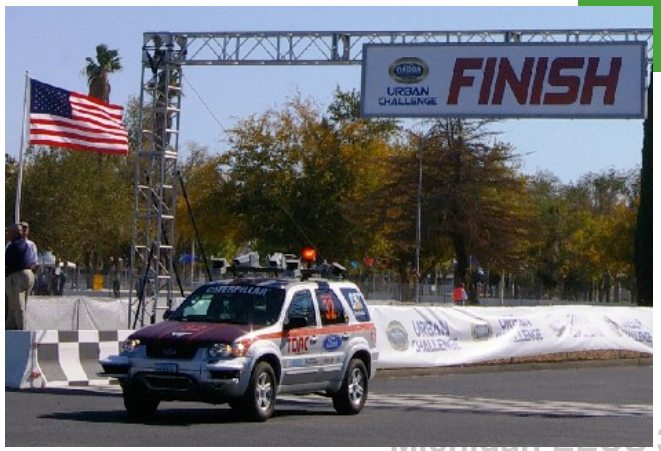


FSMs for Other Tasks

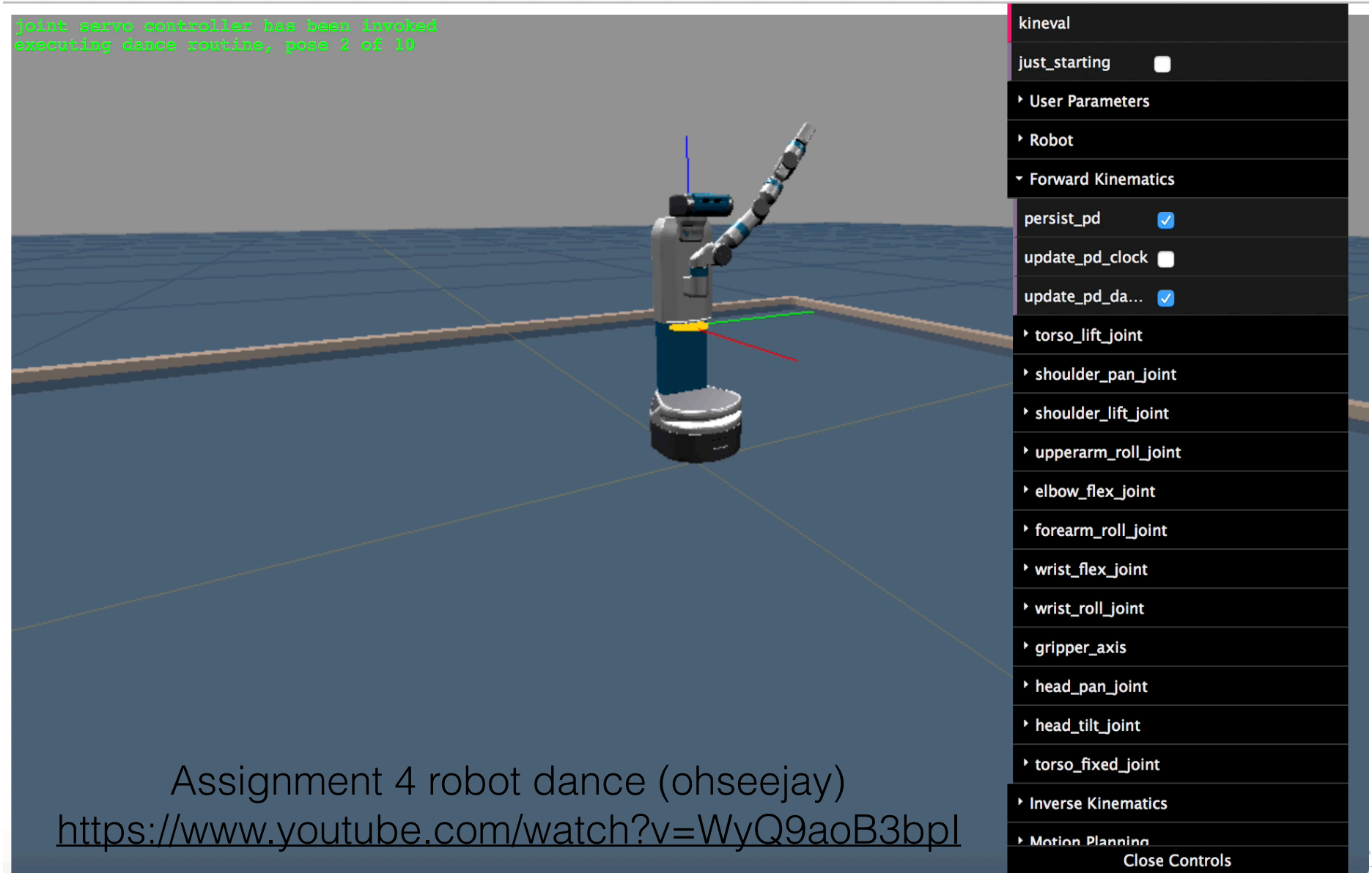
- Robot foraging?
- Robot tennis/pong?
- Pushing a ball into a goal?
- Vacuuming a room
- Driving a car?
- Robot dancing!







Assignment 4:
FSMs for robot dancing



Assignment 4 robot dance (ohseejay)

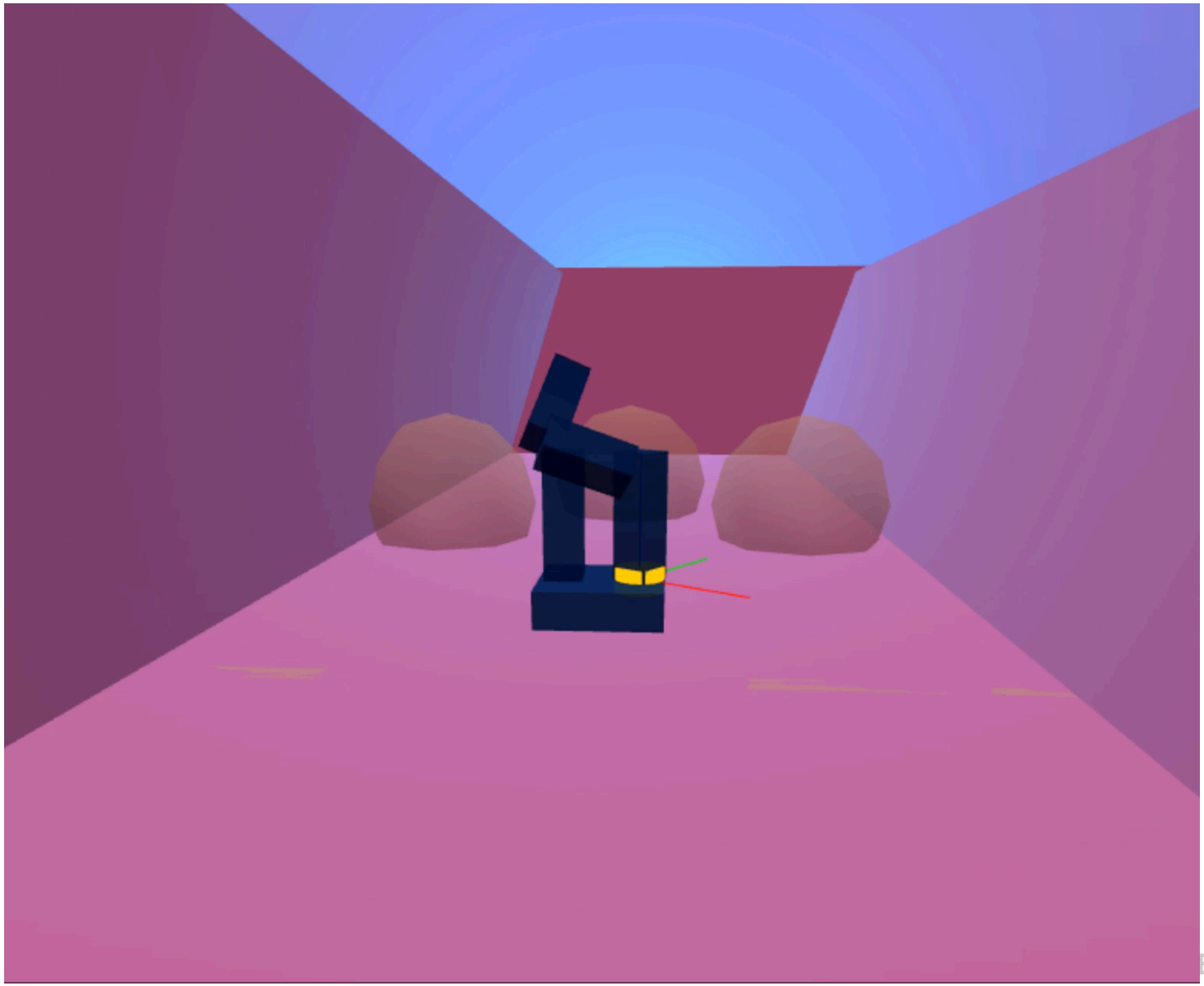
https://www.youtube.com/watch?v=WyQ9aoB3bpI

ocj 3:55 PM

@cszechy: My best attempt to recreate. Just add the following below to kineval.js in initScene() just before the endeffector geometry is created:

```
light_drake3 = new THREE.AmbientLight(0x602845);
  scene.add( light_drake3 );

  var geometry = new THREE.PlaneGeometry( 8, 20, 32 );
  var material = new THREE.MeshLambertMaterial( {color: 0xb05890, side:
THREE.DoubleSide} );
  var plane = new THREE.Mesh( geometry, material );
  plane.rotateOnAxis({x:0,y:0,z:1},-Math.PI*1.2/2);//+Math.PI),
  plane.rotateOnAxis({x:1,y:0,z:0},-Math.PI/2),
  plane.position.set(-3,0,0);
  plane.material.transparent = false;
  plane.material.opacity = 1;
  scene.add( plane );

  plane = new THREE.Mesh( geometry, material );
  plane.rotateOnAxis({x:0,y:0,z:1},-Math.PI*1.2/2),
```

```
light_drake3 = new THREE.AmbientLight(0x602845);
  scene.add( light_drake3 );

  var geometry = new THREE.PlaneGeometry( 8, 20, 32 );
  var material = new THREE.MeshLambertMaterial( {color: 0xb05890, side: THREE.DoubleSide} );
  var plane = new THREE.Mesh( geometry, material );
  plane.rotateOnAxis({x:0,y:0,z:1},-Math.PI*1.2/2);//+Math.PI),
  plane.rotateOnAxis({x:1,y:0,z:0},-Math.PI/2),
  plane.position.set(-3,0,0);
  plane.material.transparent = false;
  plane.material.opacity = 1;
  scene.add( plane );

  plane = new THREE.Mesh( geometry, material );
  plane.rotateOnAxis({x:0,y:0,z:1},-Math.PI*1.2/2),
  plane.rotateOnAxis({x:1,y:0,z:0},-Math.PI/2),
  plane.position.set(3,0,0);
  plane.material.transparent = false;
  plane.material.opacity = 1;
  scene.add( plane );

[3:56]
plane = new THREE.Mesh( geometry, material );
  plane.rotateOnAxis({x:1,y:0,z:0},-Math.PI/2),
  plane.position.set(0,0.1,0);
  plane.material.transparent = false;
  plane.material.opacity = 1;
  scene.add( plane );

  plane = new THREE.Mesh( geometry, material );
  material = new THREE.MeshPhongMaterial( {color: 0xff8db0, side: THREE.DoubleSide} );
  plane.rotateOnAxis({x:0,y:0,z:1},Math.PI/2),
  plane.position.set(0,0,-11);
  plane.material.transparent = false;
  plane.material.opacity = 1;
  scene.add( plane );

  var geometry = new THREE.PlaneGeometry( 800, 800, 800 );
  material = new THREE.MeshPhongMaterial( {color: 0x8070cf, side: THREE.DoubleSide} );
  plane = new THREE.Mesh( geometry, material );
  plane.position.set(0,0,-19);
  plane.material.transparent = false;
  plane.material.opacity = 1;
  scene.add( plane );

  var light_drake4 = new THREE.PointLight( 0xffffff, 1, 30, 0.1 );
  light_drake4.position.set( 0, 2, -13 );
  scene.add( light_drake4 );
```



cszechy
ohseejay

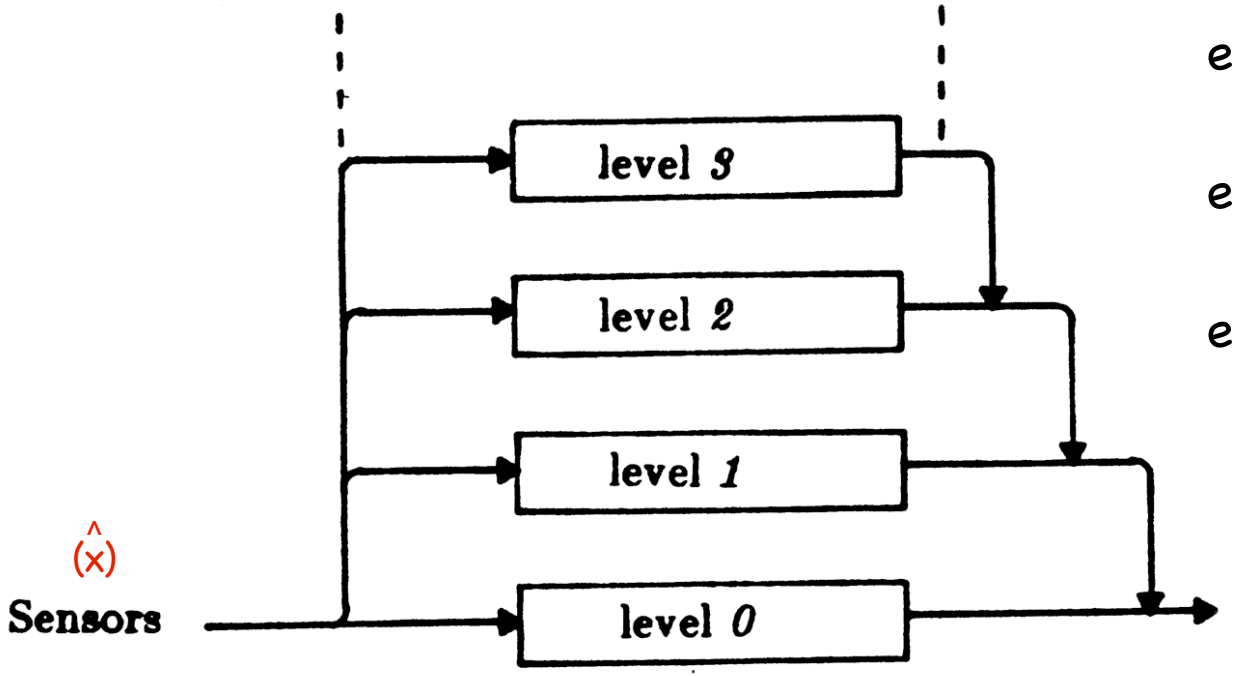
Let’s generalize FSMs for robot control

Subsumption Architecture

[Brooks 1986]

- Generalization of FSM-based control
- Collection of modular reactive controllers in a priority hierarchy
- Controllers can be FSMs
- Large nested if-else statement
- Most robots are controlled by some form of subsumption

Subsumption Architecture



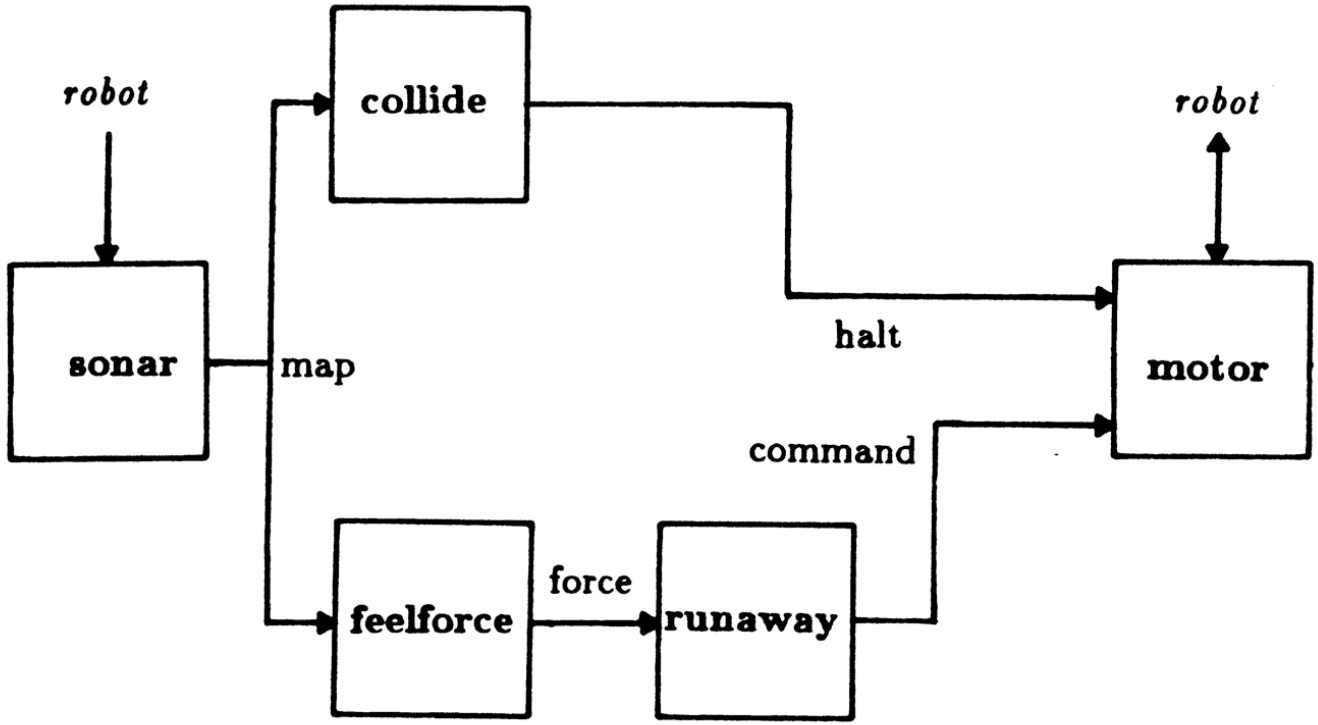

```
if (level3_condition)
  u ← level3_control
else if (level2_condition)
  u ← level2_control
else if (level1_condition)
  u ← level1_control
else
  u ← level0_control
```

Subsumption Design Process

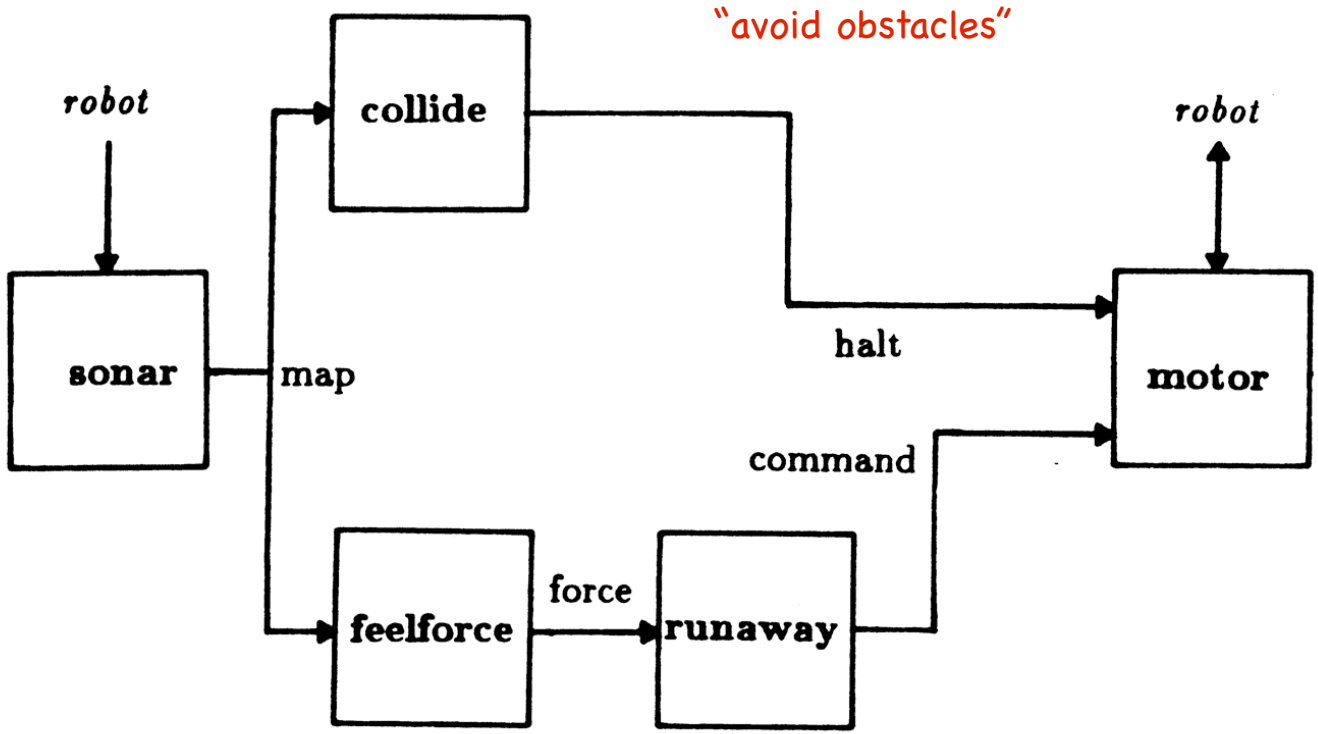
1. Divide your problem into basic competencies ordered simple to more complex. Designate a level for each basic competency.
2. Further subdivide each level into multiple simple components which interact through shared variables. Limit the sharing of variables among levels to avoid incomprehensible code.
3. Implement each module as a separate light-weight thread. You might think of setting the priorities for these threads so that modules in a given level have the same priority.
4. Implement suppression and inhibition as one or more separate "arbitration" processes that serve to control access to shared variables. You might want to control access using semaphores.

http://www.cs.brown.edu/~tld/courses/cs148/02/architectures.html

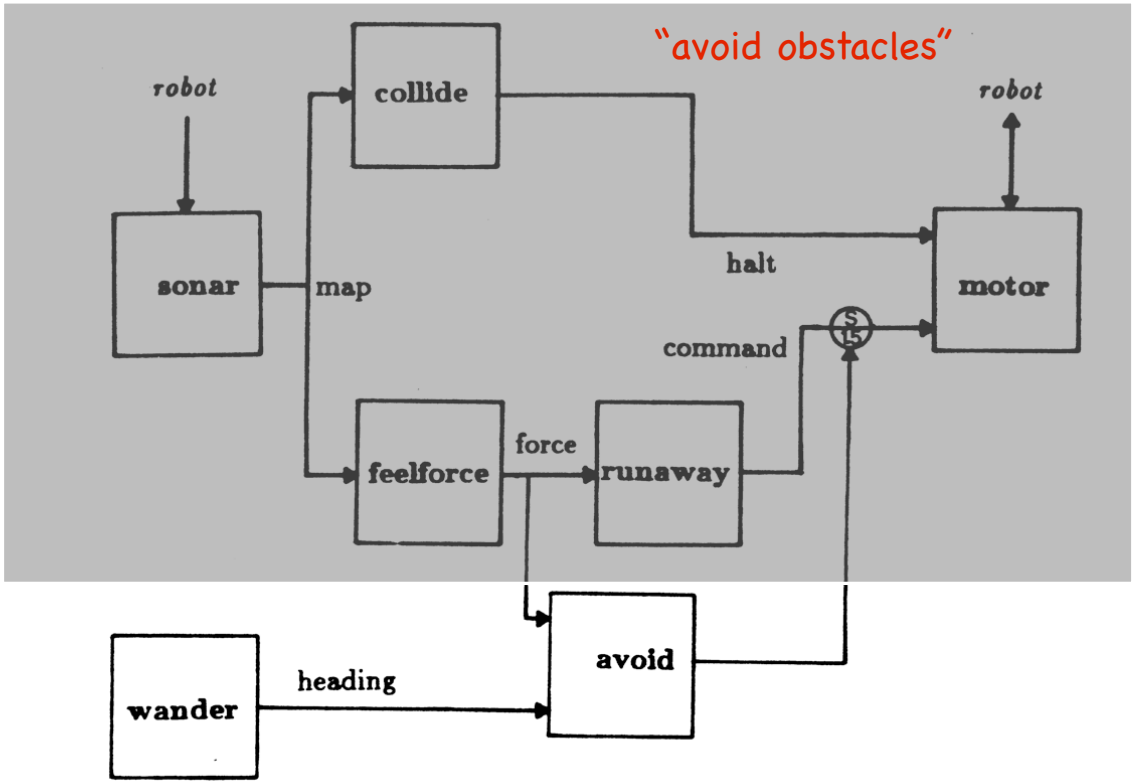
What will this do?



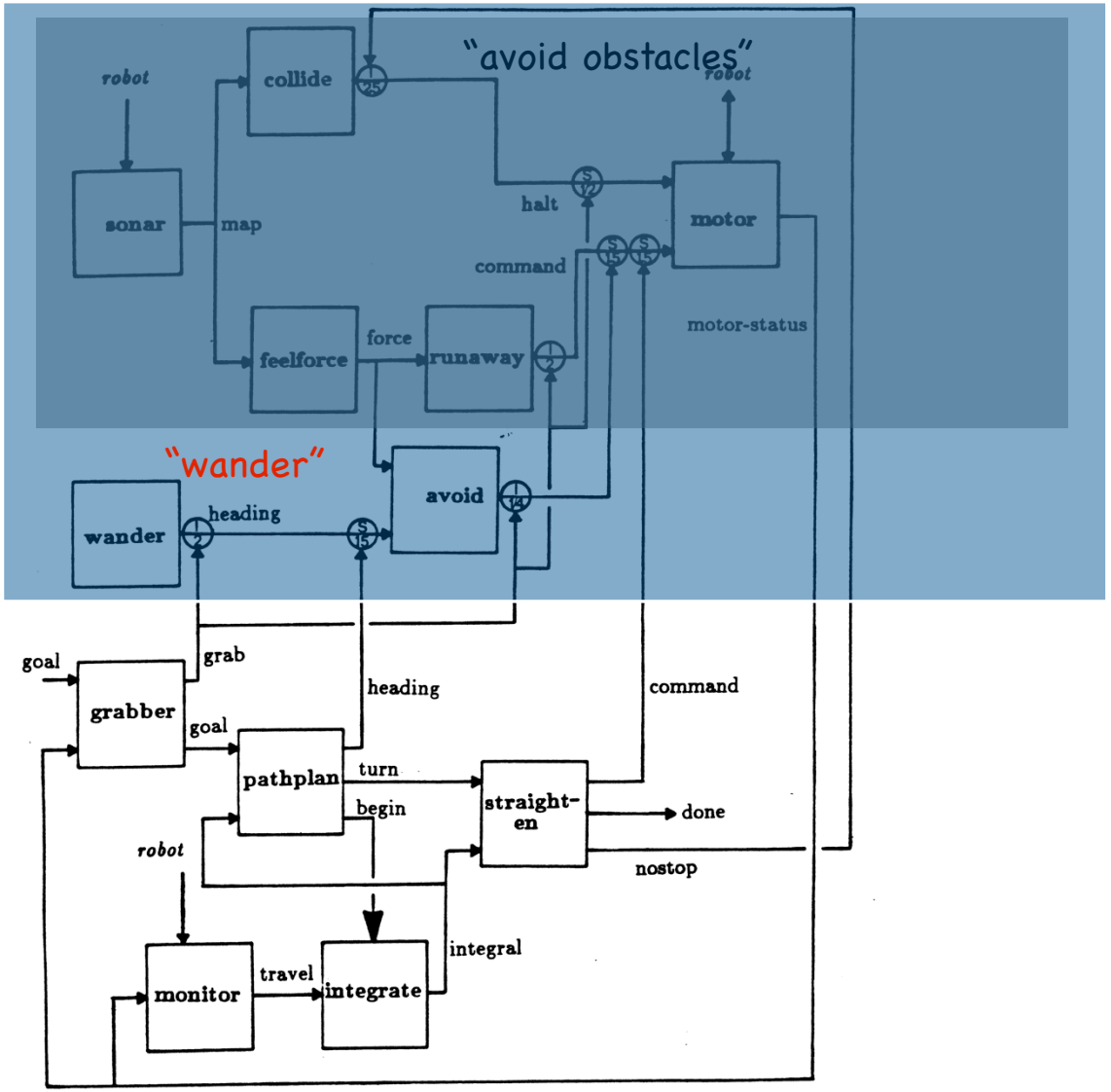
What will this do?



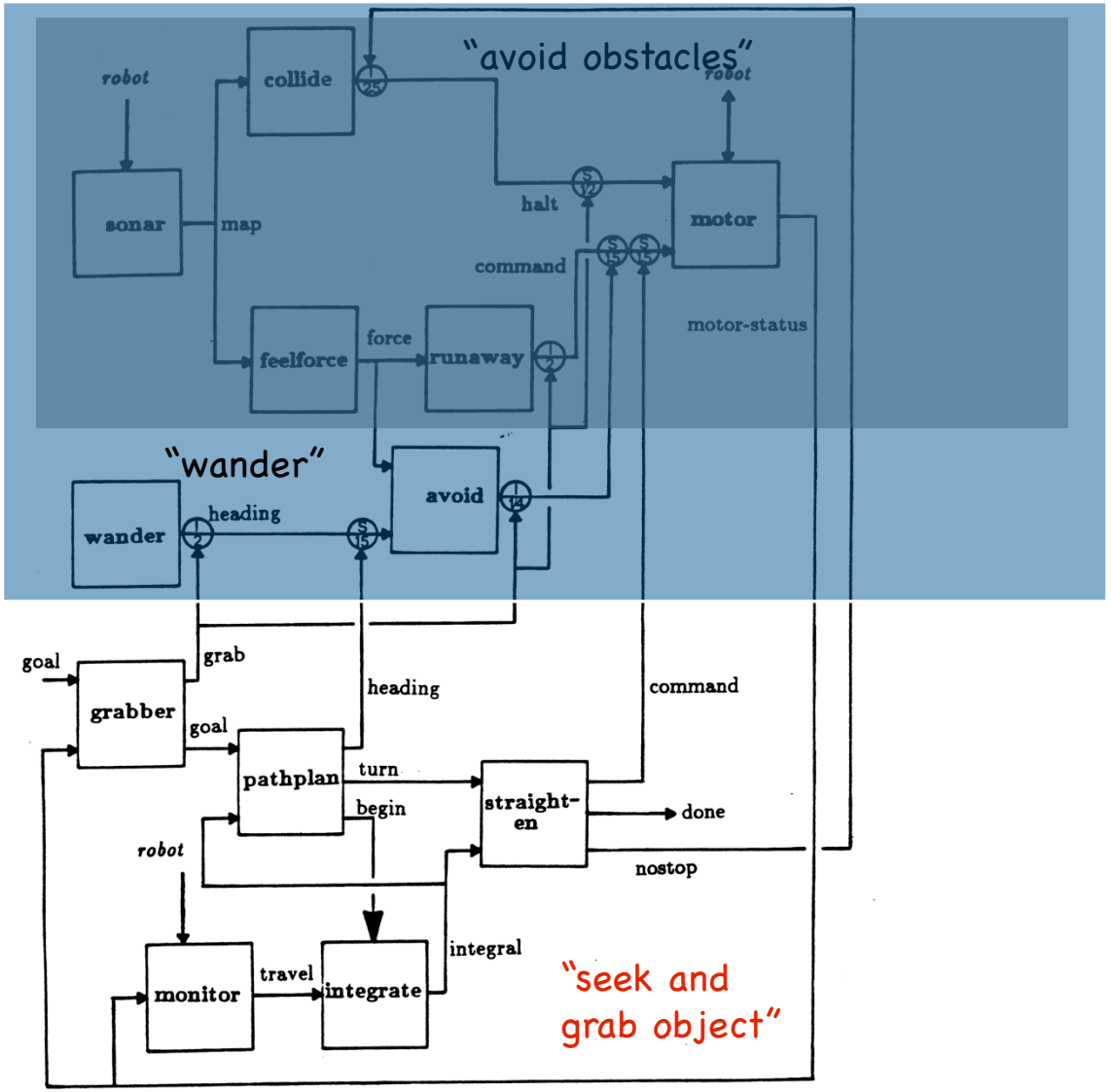
What will this do?



What will this do?



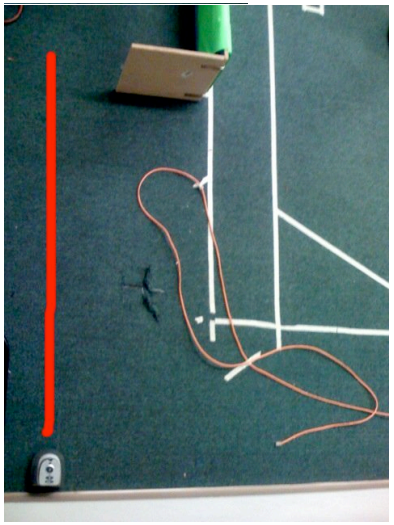
What will this do?

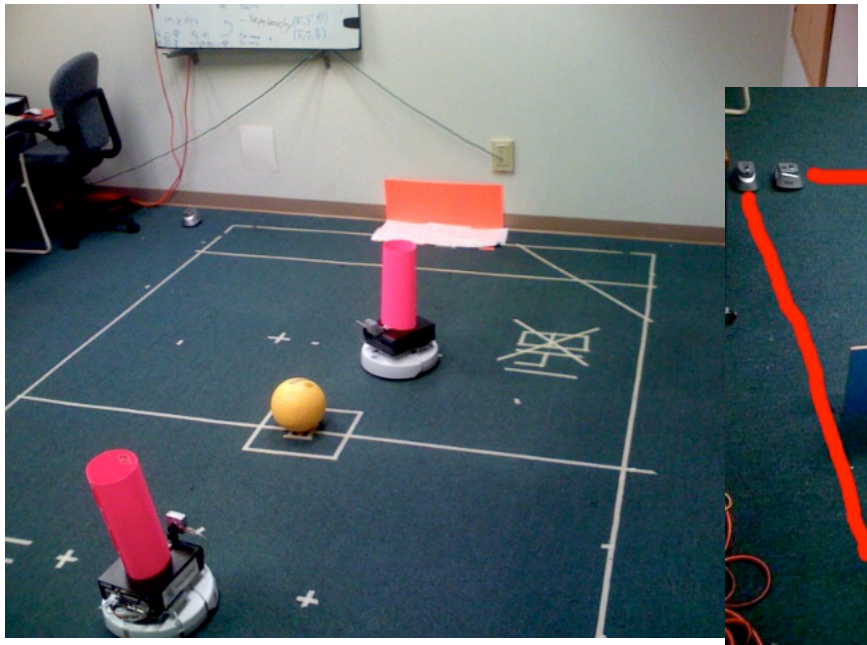


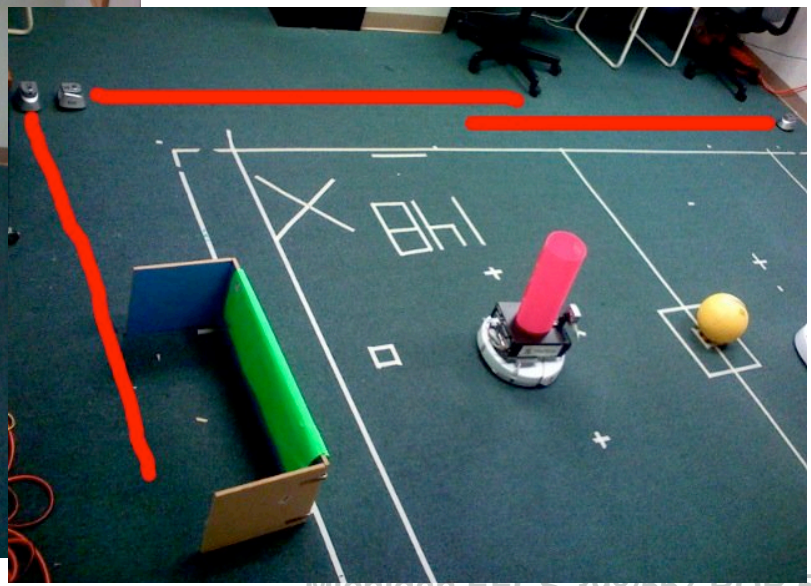
2010: Assignment 5

Subsumption for robot soccer

- Propose modules and priority?

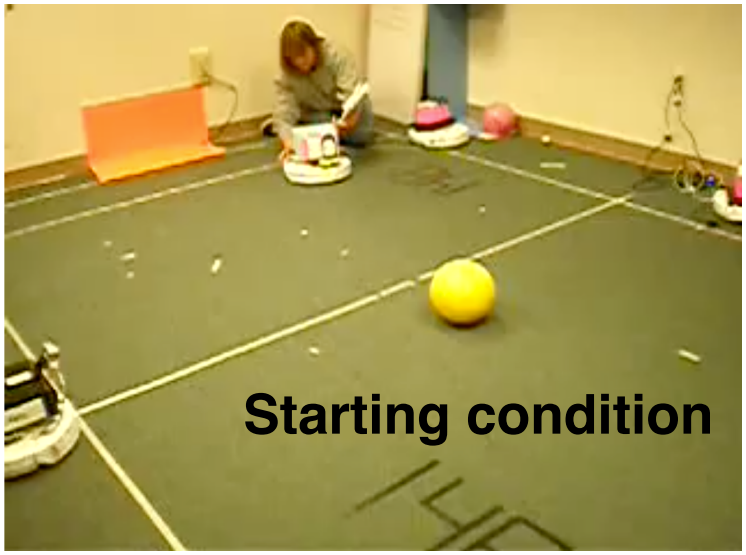


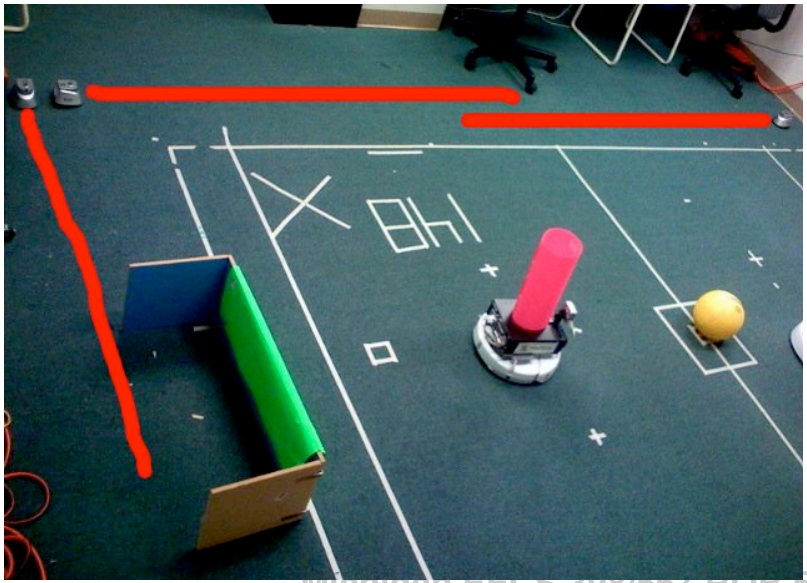




What behavior will result?

1. Avoid IR Wall
2. Avoid Robot
3. Avoid Fiducial
4. Bumper Hit
5. Go To Opposite Goal
6. Go To Any Goal
7. Line Up On Ball
8. Go To Ball
9. Score Goal
10. At Ball
11. Look For Ball





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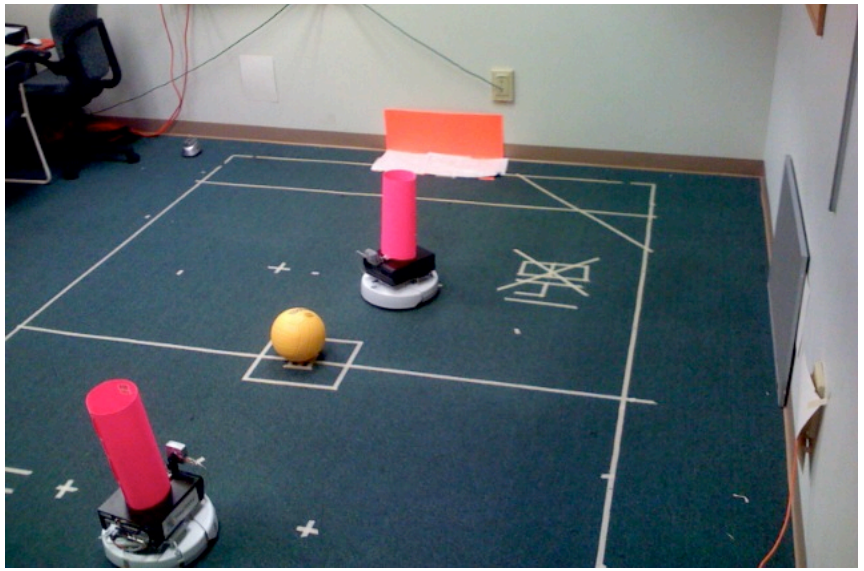

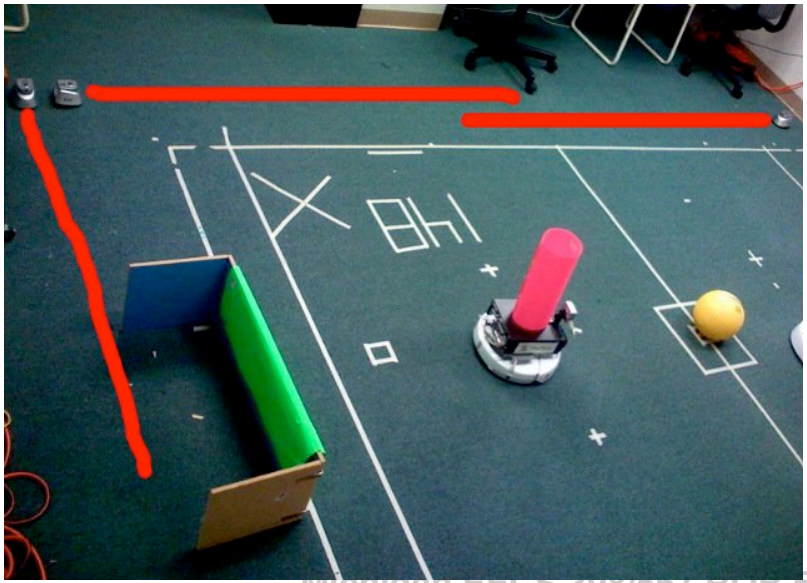

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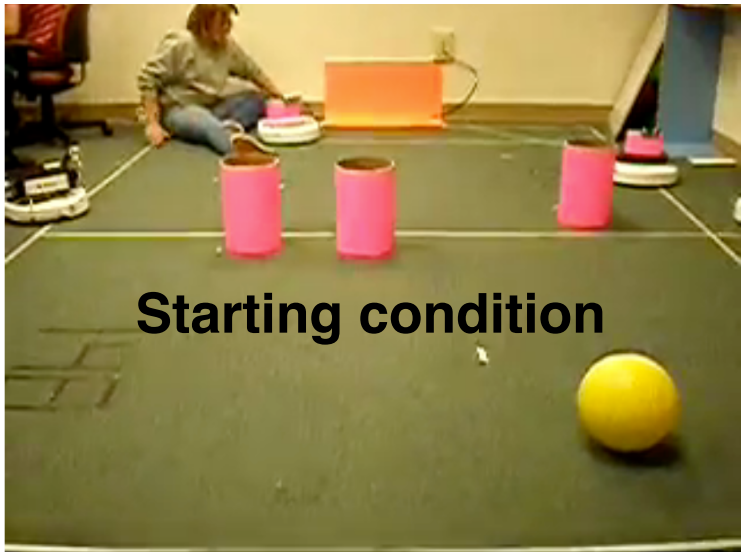
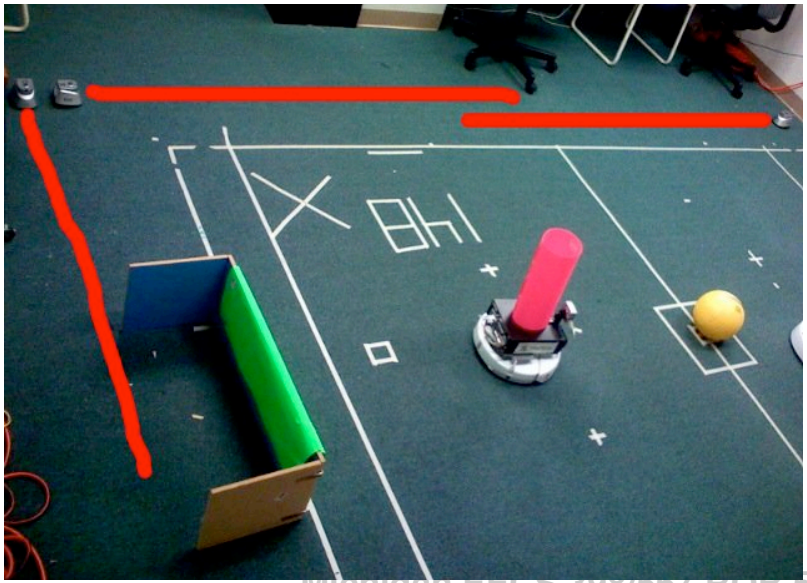




Snappy's Subsumption: Navigate to Ball

1. Avoid IR Wall
2. Avoid Robot
3. Avoid Fiducial
4. Bumper Hit
5. Go To Opposite Goal
6. Go To Any Goal
7. Line Up On Ball
8. Go To Ball
9. Score Goal
10. At Ball
11. Look For Ball

Navigation Challenge - Navigate to Ball

Snappy in competition

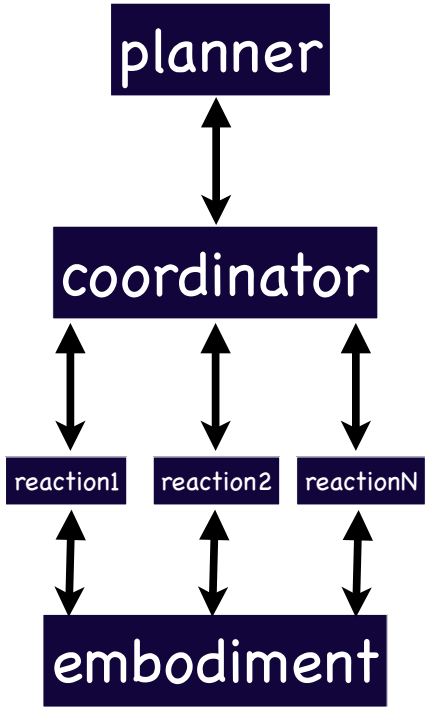
Are there other methods of decision making?

Types of Decision Making

- Deliberative (Planner-based) Control
  - "Think hard, act later."
- Reactive Control
  - "Don't think, (re)act."
- Hybrid Control
  - "Think and act separately & concurrently."
- Behavior-Based Control
  - "Think the way you act."

Hybrid systems

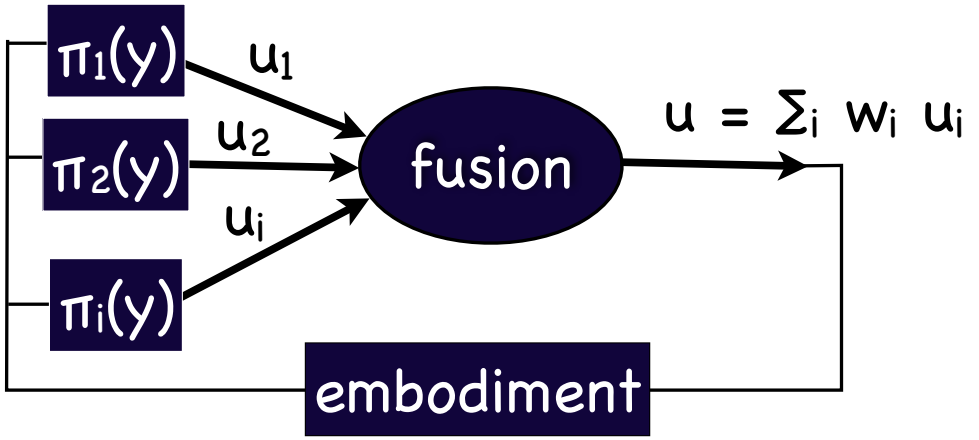
- Top-down planner for high-level goals
- Reaction for low-level immediate execution
- Interface layer to coordinate
  - how to balance long and short term
- Modern cost maps?
- Not discrete-continuous hybrid control



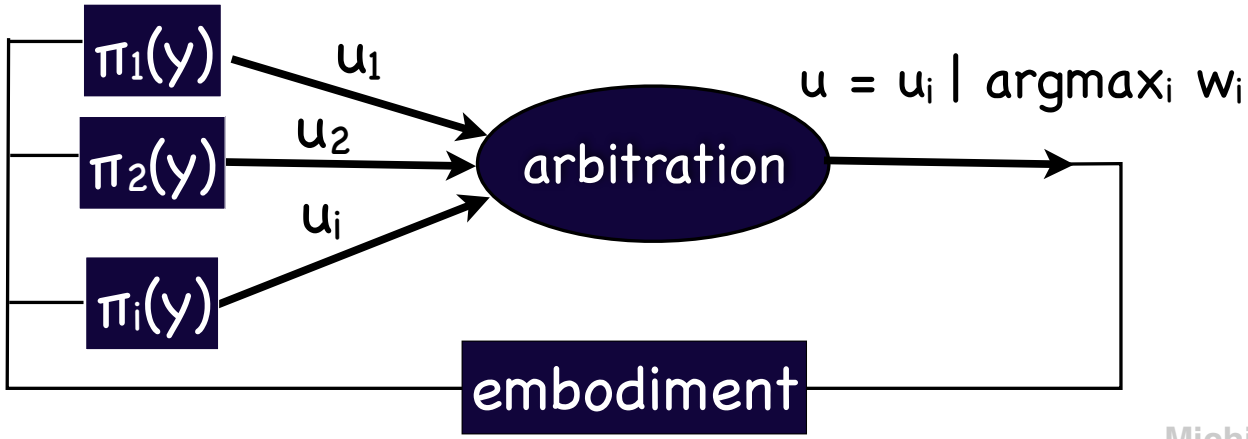
Behavior-based systems

- All modules have equal priority, access to sensing, and output motor commands
- Modules can be deliberative, reactive, or whatever
- Commands merged through arbitration or fusion
- Potential fields?

Arbitration vs. Fusion



Fusion:
linearly combine
$u = \sum_i w_i u_i$



Arbitration:
winner-take-all
$u = u_i \mid \text{argmax}_i\ w_i$


Next class:
Inverse Kinematics