ROBOT BEHAVIOR

Maslab ‘09

Overview

- The Big Picture
  - Your Goal
- The Wrong Way
- The Right Way
  - Model Plan Act
  - Emergent Behavior
  - Finite State Machines

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The Big Picture… Literally

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Your Goal

- Find balls
- Pick up balls
- Dump balls in goals

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- Navigate the robot out if its corner, through the small gap

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- Navigate the robot out if its corner, through the small gap
- Don’t overload robot

Your Goal

- Find balls
- Pick up balls
- Dump balls in goals
- Navigate the robot out if its corner, through the small gap
- Don’t overload robot
- Avoid walls

The Game

- More complicated than just picking up balls
- Find all the caveats at:
  - http://maslab.mit.edu/2009/wiki/Playing_field
  - http://maslab.mit.edu/2009/wiki/Rules

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The Wrong Way – An Example

```
void moveForward( int time ) {

  while ( t < time ) {

    // Drive forward a bit
    ---------------------------------------
    ---------------------------------------

  }
}
```

The Wrong Way – An Example

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void moveForward( int time ) {

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    ---------------------------------------

    // Need to find some balls
    ---------------------------------------
    ---------------------------------------

    // Somehow pick up a ball
    ---------------------------------------
    ---------------------------------------

    // What if there is more than one ball?
    ---------------------------------------
    ---------------------------------------

  }
}
```

The Wrong Way – An Example

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    // Need to find some balls
    ---------------------------------------
    ---------------------------------------

    // Somehow pick up a ball
    ---------------------------------------
    ---------------------------------------

    // What if there is more than one ball?
    ---------------------------------------
    ---------------------------------------

  . . .
```

```
    . . .

    // Need to find some goals
    ---------------------------------------
    ---------------------------------------

    // What if there are no goals visible?
    ---------------------------------------
    ---------------------------------------

    // Drop off some balls
    ---------------------------------------
    ---------------------------------------

    // Find more balls I guess
    ---------------------------------------
    ---------------------------------------

    // Make sure to ignore balls in goal
    ---------------------------------------
    ---------------------------------------

    // Try to go somewhere new
    ---------------------------------------
    ---------------------------------------

  }
}
```

The Wrong Way

- Monolithic code
  - Monster to maintain
  - Hard to debug
  - Confusing
- There's a better way…

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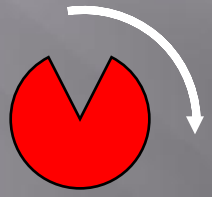
Behaviors

- Defined as: a set or series of acts regarded as a unified whole
- Should be simple, well-defined, self-contained, and independently testable

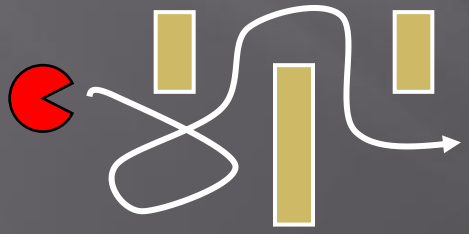
Behaviors



Turn right 90°

Go forward until reach obstacle

Capture a ball



Explore playing field

Complex Behaviors

- Composed of primitive behaviors acting as building blocks.

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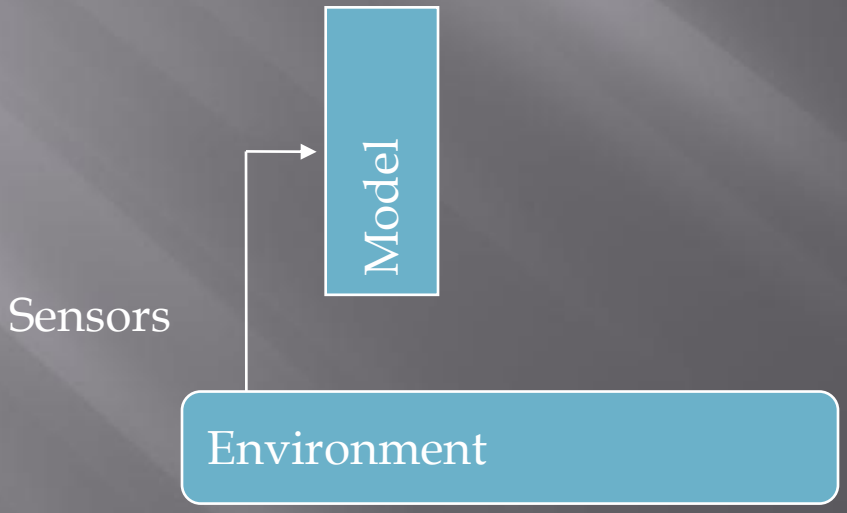
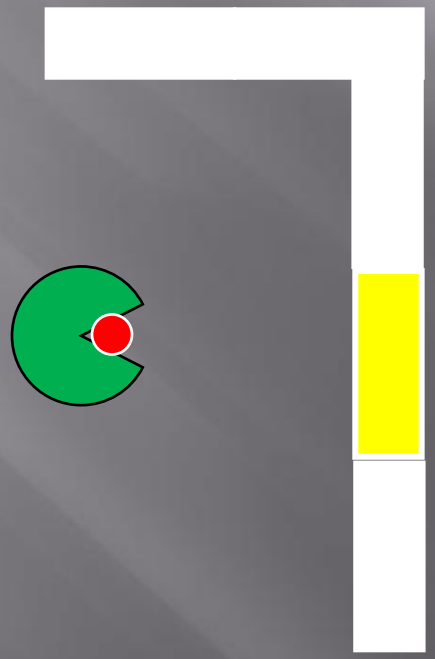
Model Plan Act

- Use sensors to create a model of the world.



Model – Outside Perspective

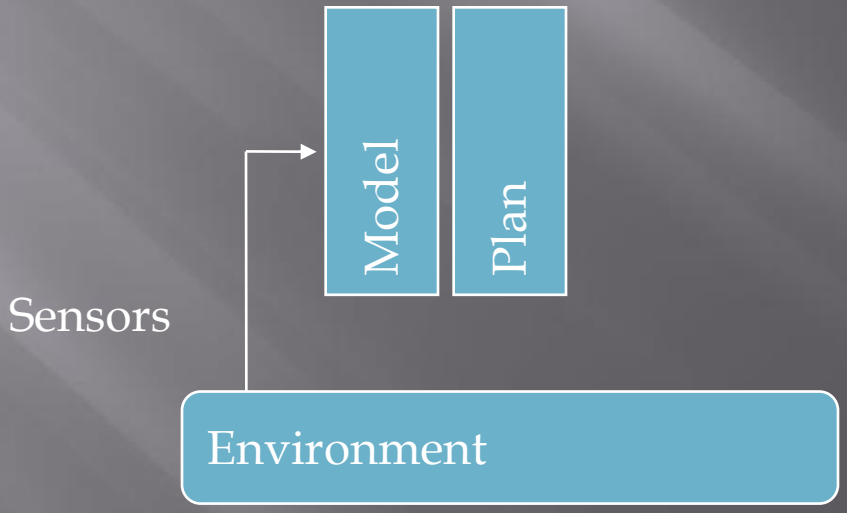


Model – Robot Perspective

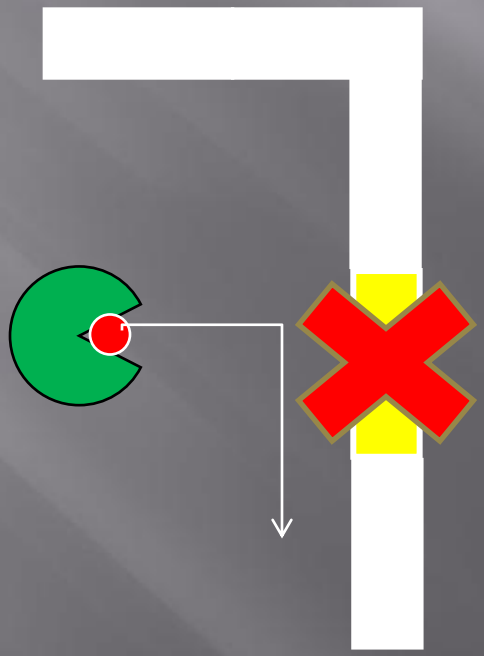
- I have 1 red ball.
- I see a yellow goal in front of me.
- I see a wall 30 cm to my left.
- I see open space to my right.
- I have traveled 3 ft since my last observation
- …
- …
- …

Model Plan Act

- Use sensors to create a model of the world
- Create a plan



Plan – Outside Perspective

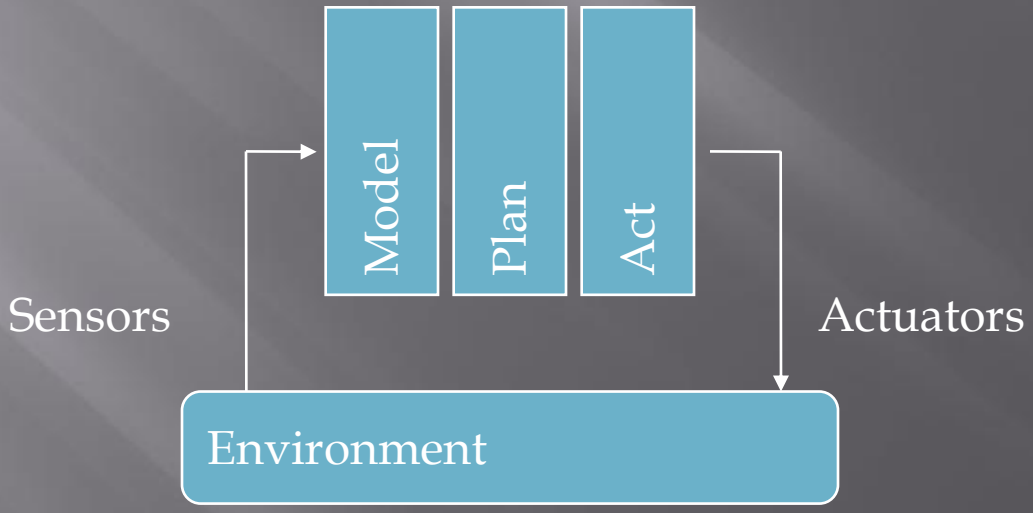


Plan – Robot Perspective

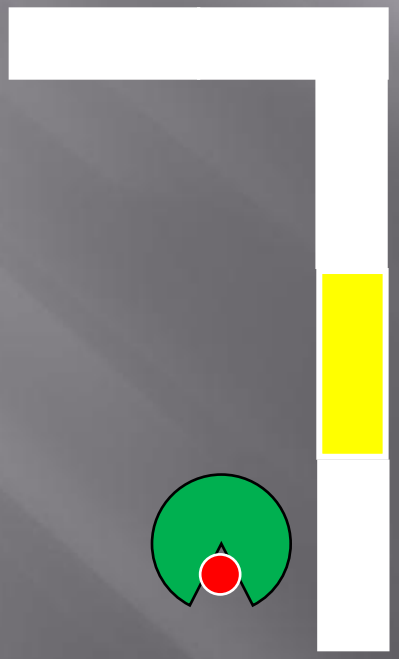
- I don't want to dump my ball, I'll get negative points
- Can't go left
- I just came from behind me
- Wall follow the wall in front of me!

Model Plan Act

- Use sensors to create a model of the world
- Create a plan
- Act on it by stringing together behaviors



Act – Outside Perspective

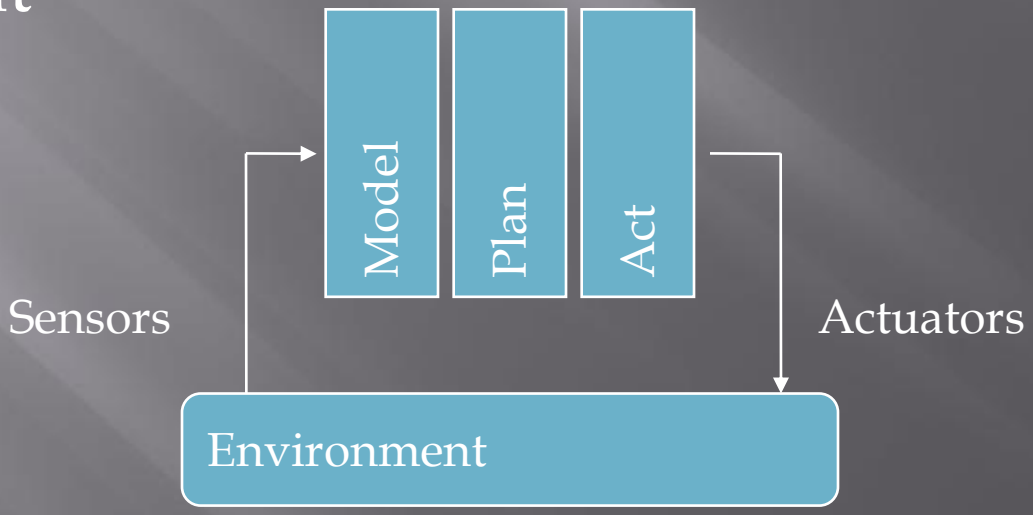


Act – Robot Perspective

- Go forward until IR reports wall is 15 cm away
- Turn 90° right
- Wall follow

Model Plan Act

- Use sensors to create a model of the world
- Create a plan
- Act on it by stringing together behaviors
- Repeat



Advantages and Disadvantages

- Advantages
  - Global knowledge in the model enables optimization
  - Can make provable guarantees about the plan

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- Advantages
  - Global knowledge in the model enables optimization
  - Can make provable guarantees about the plan
- Disadvantages
  - Must implement all functional units before any testing
  - Computationally intensive
  - Requires very good sensor data for accurate models
  - Models are inherently an approximation
  - Works poorly in dynamic environments

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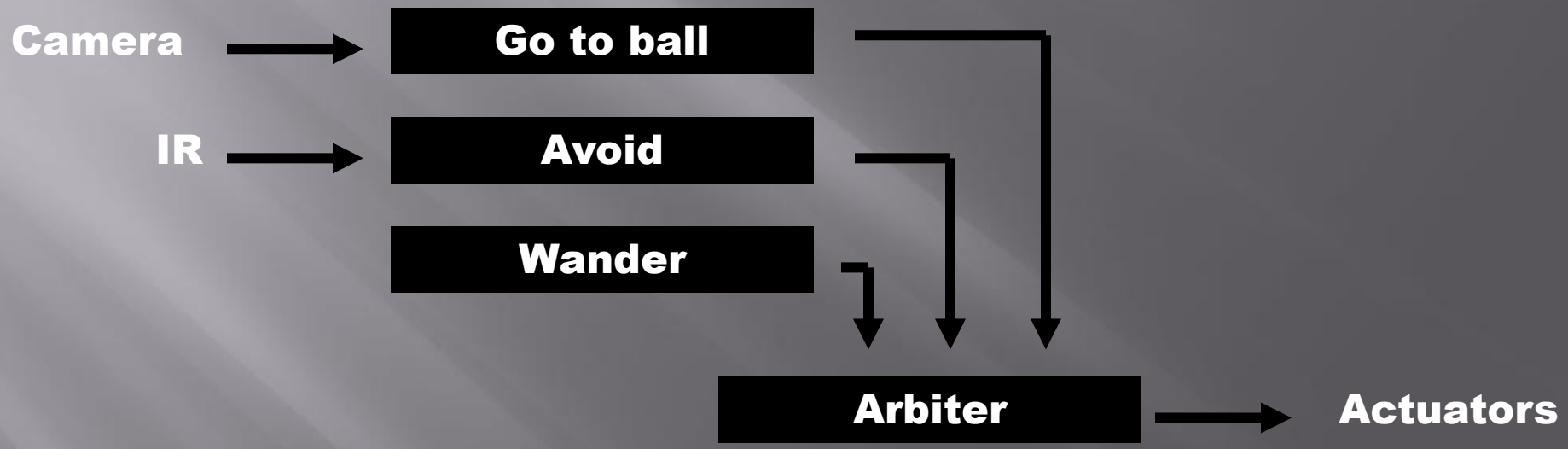
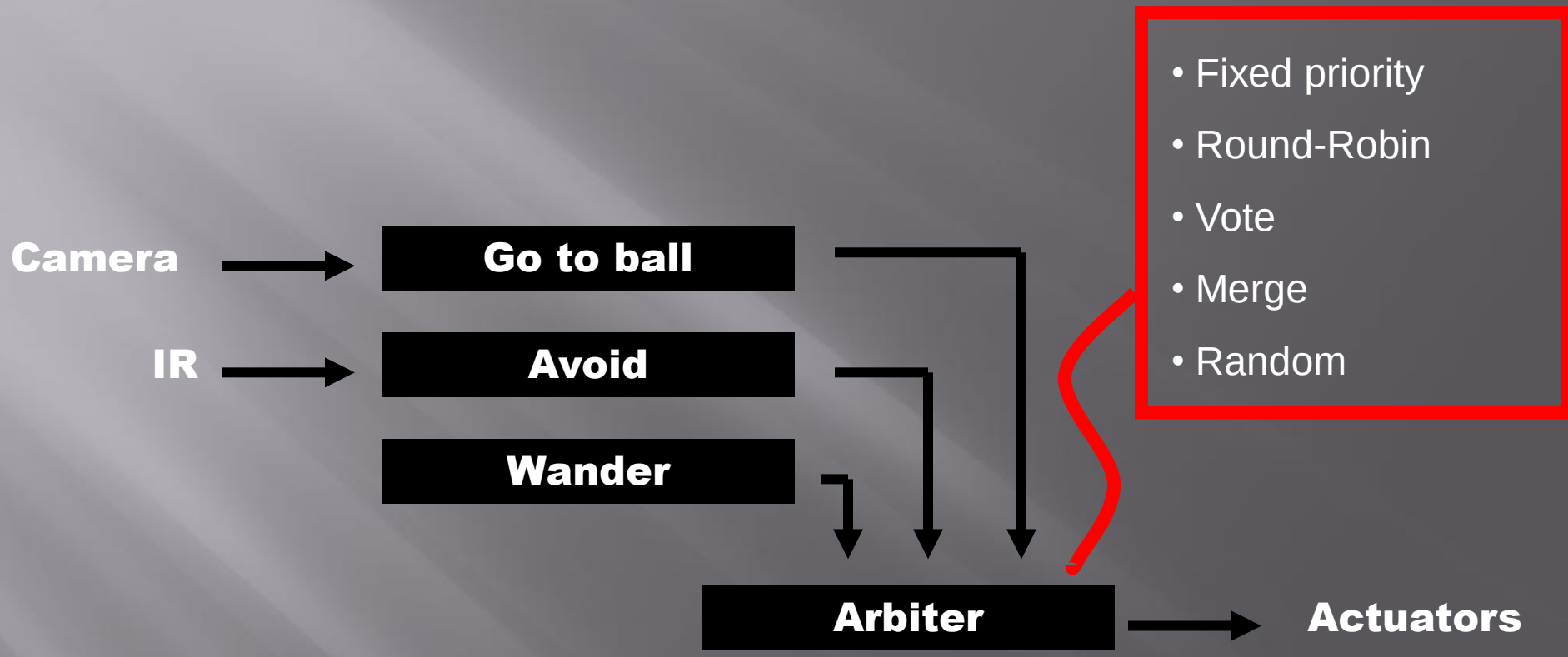
Emergent Behavior

- Sensors feed data into behaviors
- Behaviors decide what to do based on given sensor input
- Arbiter decides which behavior gets priority
- Arbiter passes command to actuators

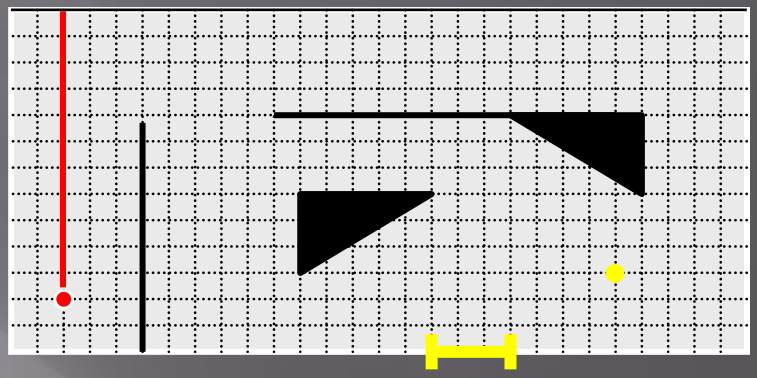
Emergent Behavior



Emergent Behavior

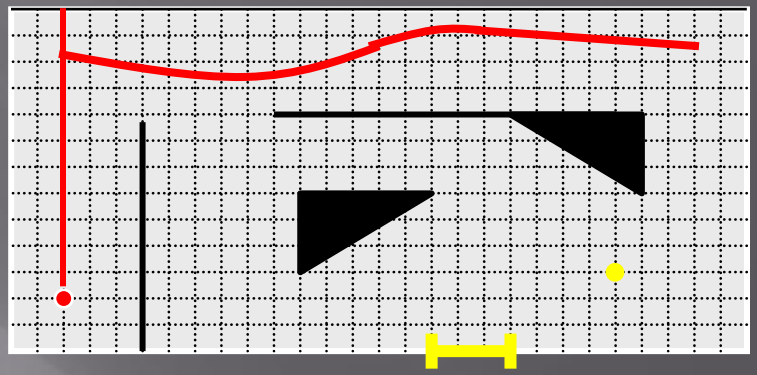


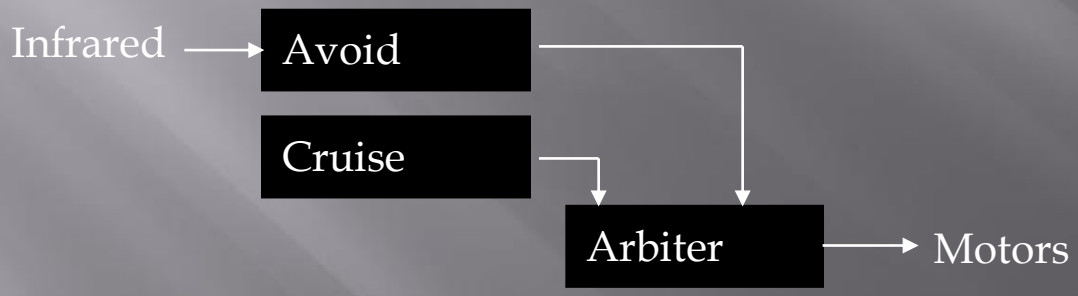
Emergent Behavior - Example



Cruise behavior simply moves robot forward

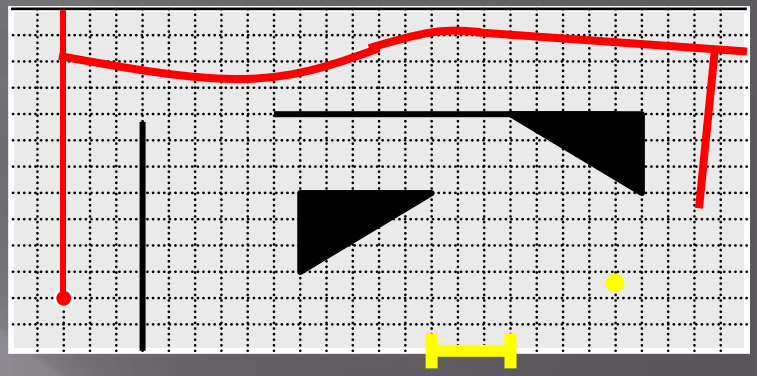
Emergent Behavior - Example

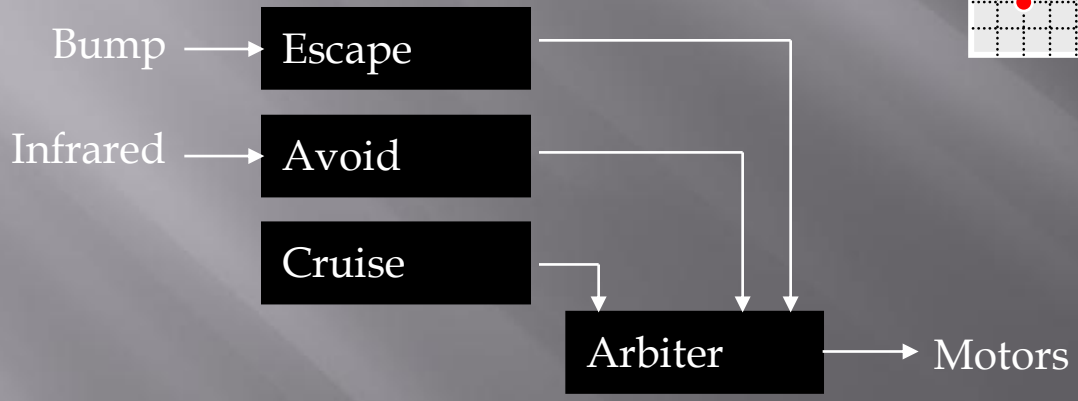




Left motor speed inversely proportional to left IR range
Right motor speed inversely proportional to right IR range
If both IR < threshold stop and turn right 120 degrees

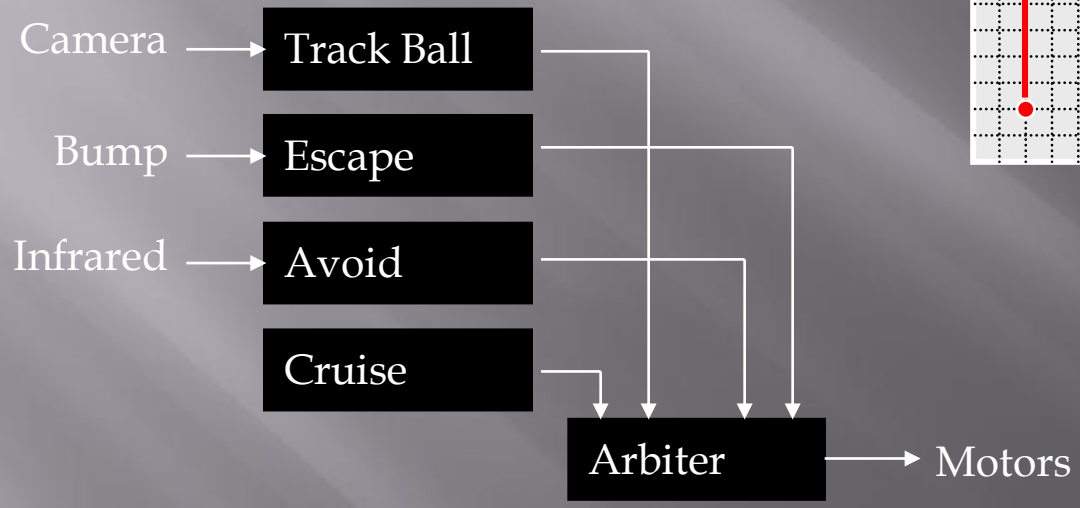
Emergent Behavior - Example

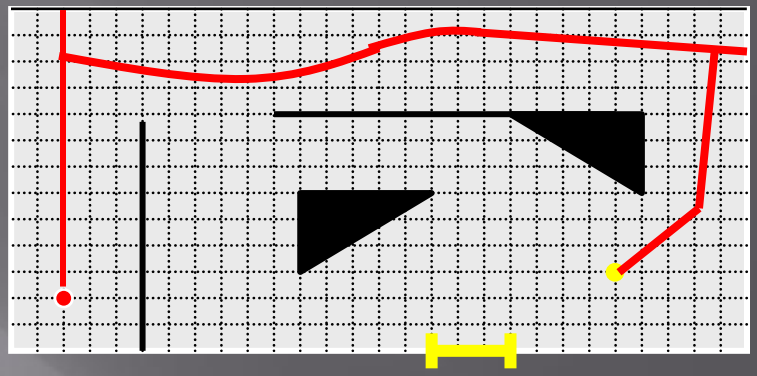




Escape behavior stops motors,
backs up a few inches, and turns right 90 degrees

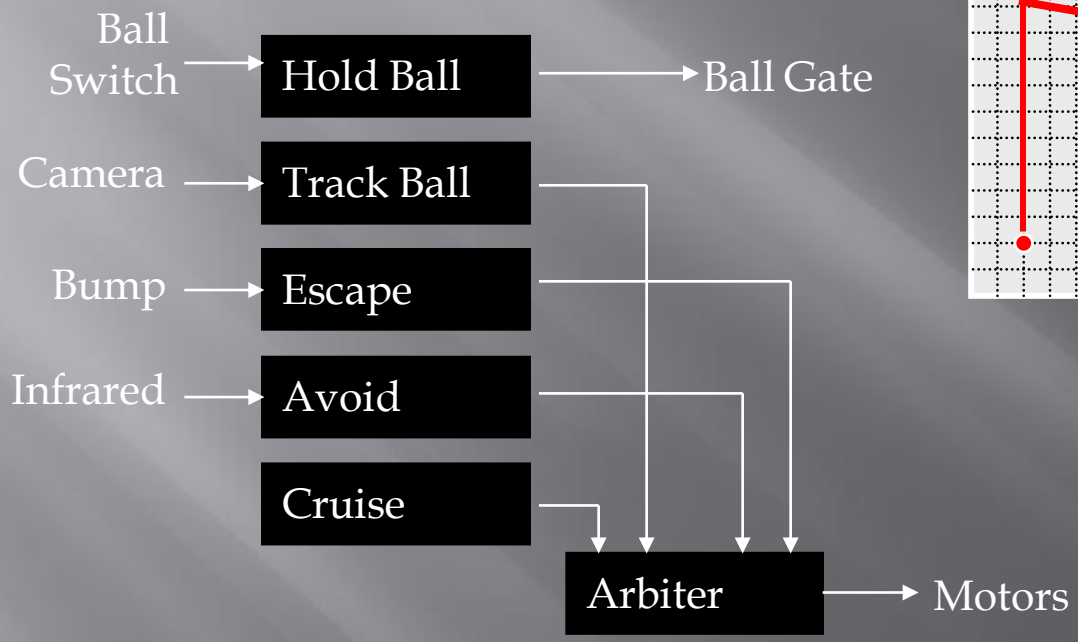
Emergent Behavior - Example

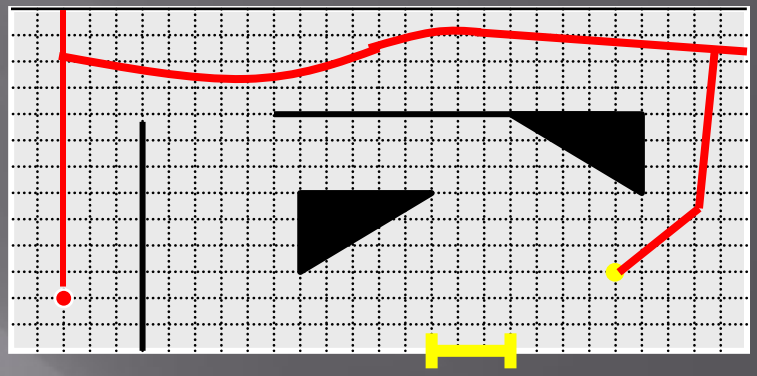




The track ball behavior adjusts the
motor differential to steer the robot towards the ball

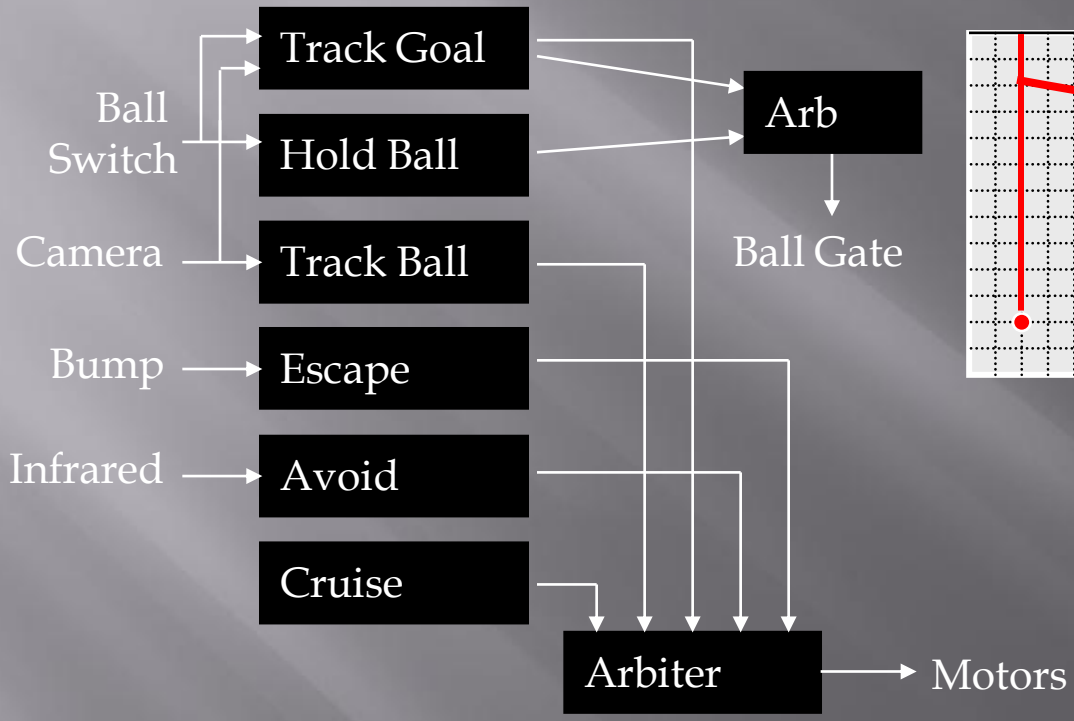
Emergent Behavior - Example

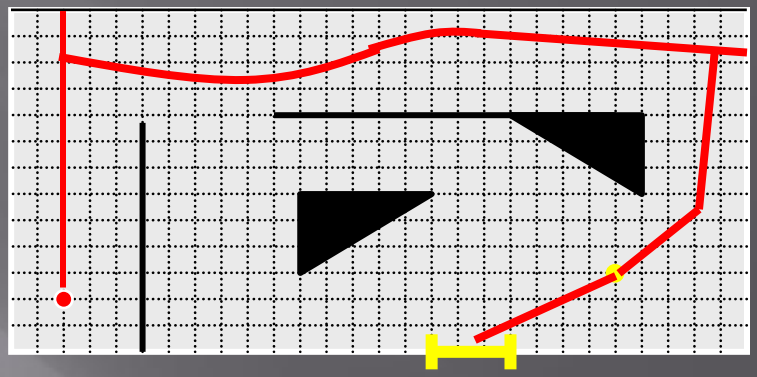




Hold ball behavior simply closes ball gate when ball switch is depressed

Emergent Behavior - Example





The track goal behavior opens the ball gate and adjusts the motor differential to steer the robot towards the goal

Advantages and Disadvantages

- Advantages
  - Incremental development is very natural
  - Modularity makes experimentation easier
  - Cleanly handles dynamic environments
  - Arbiter can easily shut down robot

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- Advantages
  - Incremental development is very natural
  - Modularity makes experimentation easier
  - Cleanly handles dynamic environments
  - Arbiter can easily shut down robot
- Disadvantages
  - Not predictable
  - No performance or completeness guarantees
  - Debugging can be very difficult

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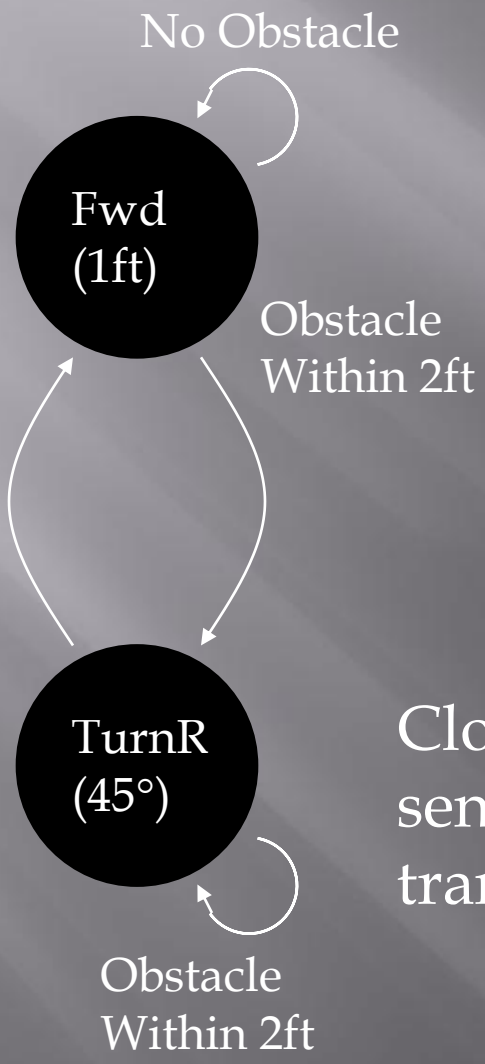
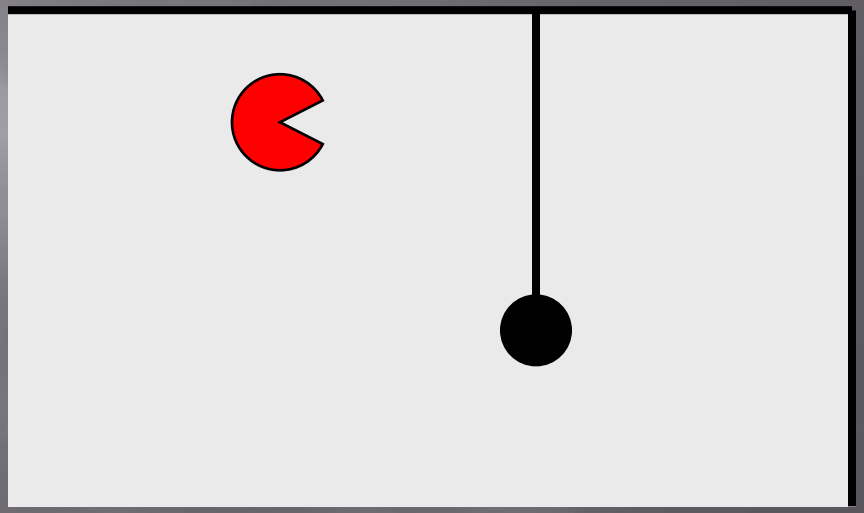
Finite State Machines

- A state is an instance of a behavior
- A state can only transition into certain other states
- Combines static and dynamic behavior

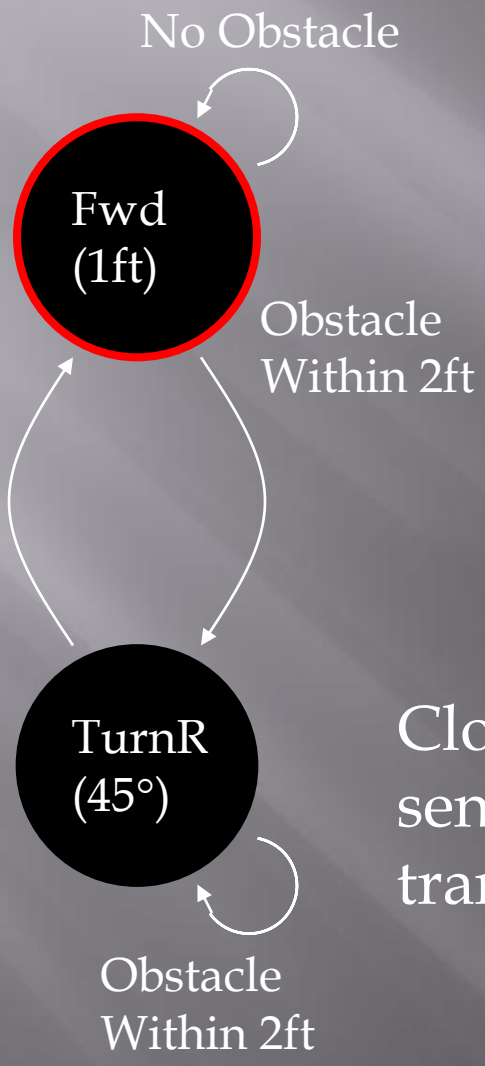
Simple Example

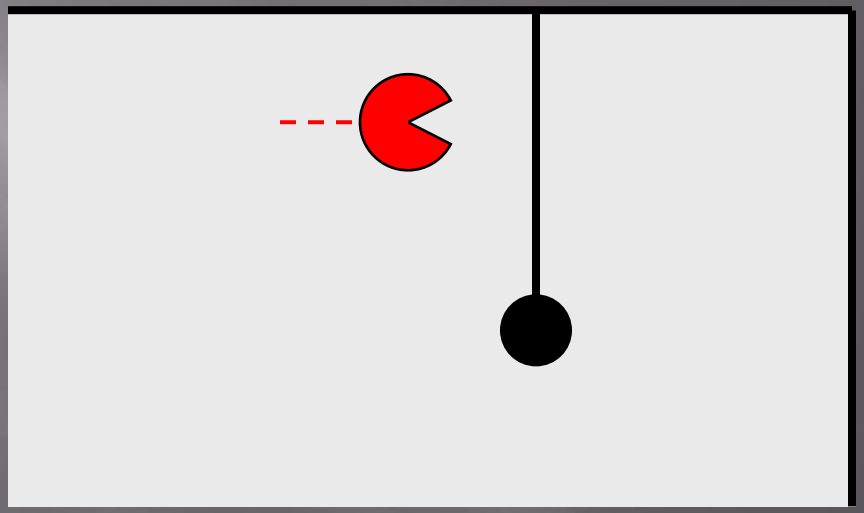




Closed loop finite state machines use sensor data as feedback to make state transitions

Simple Example





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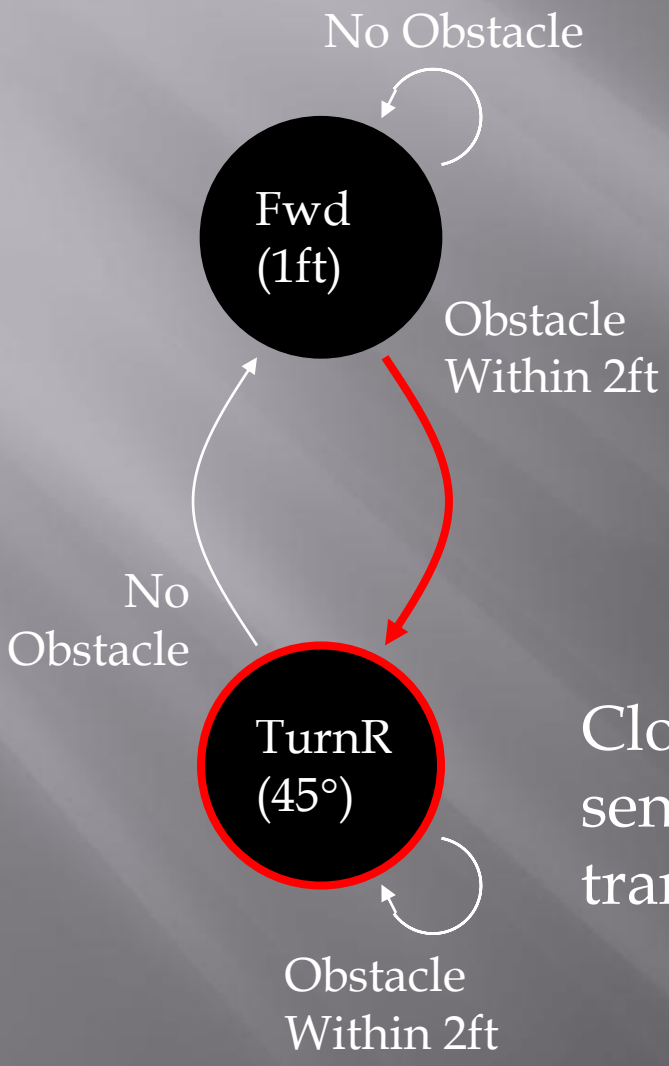

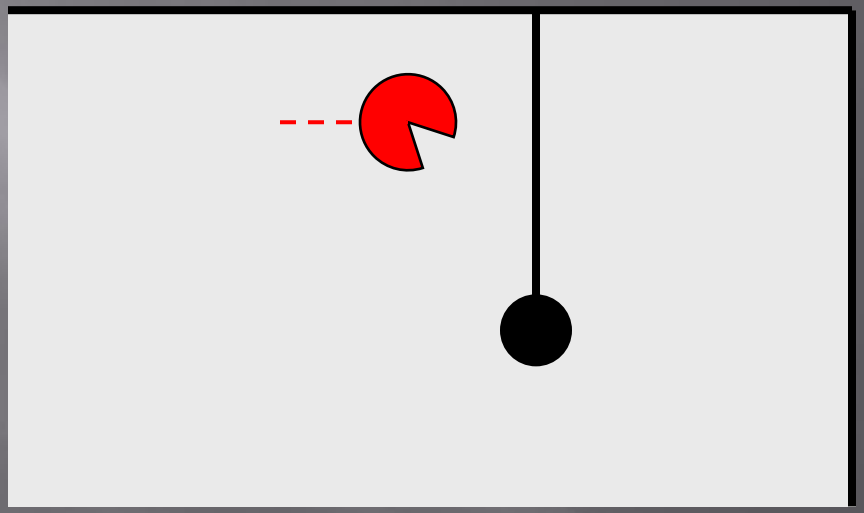

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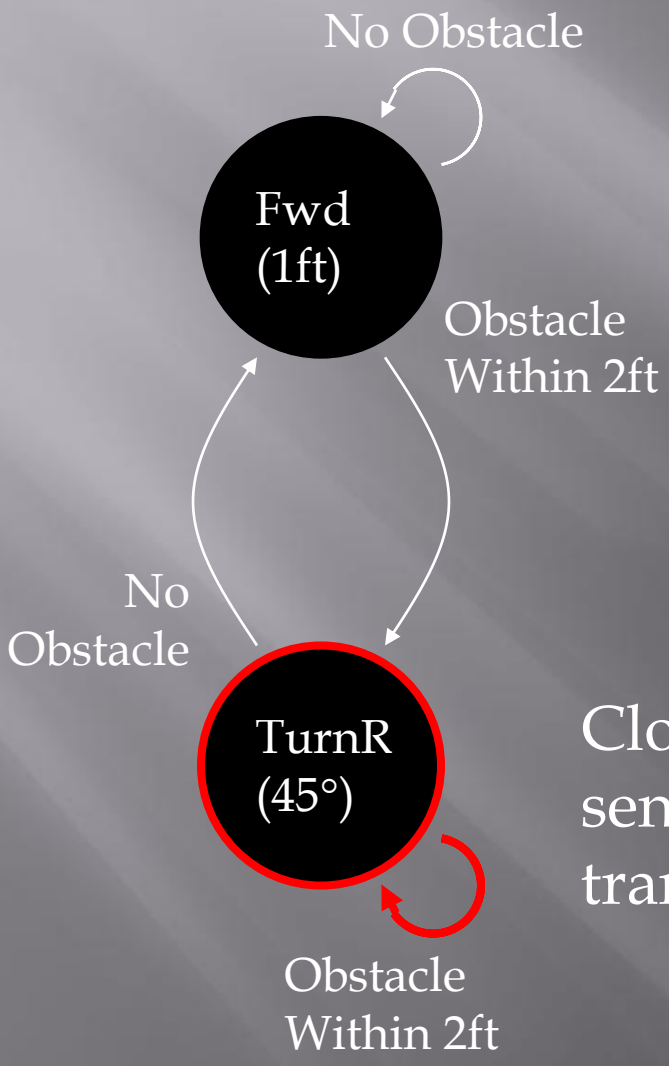

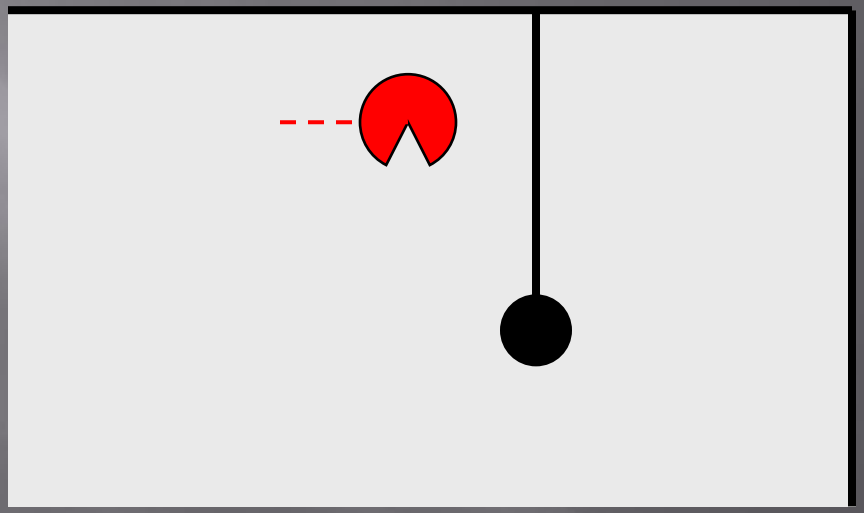

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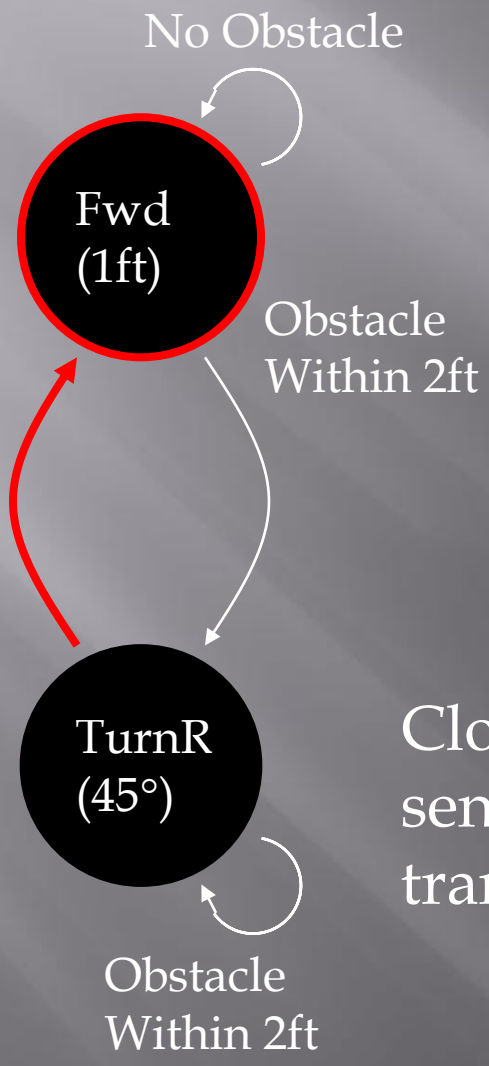

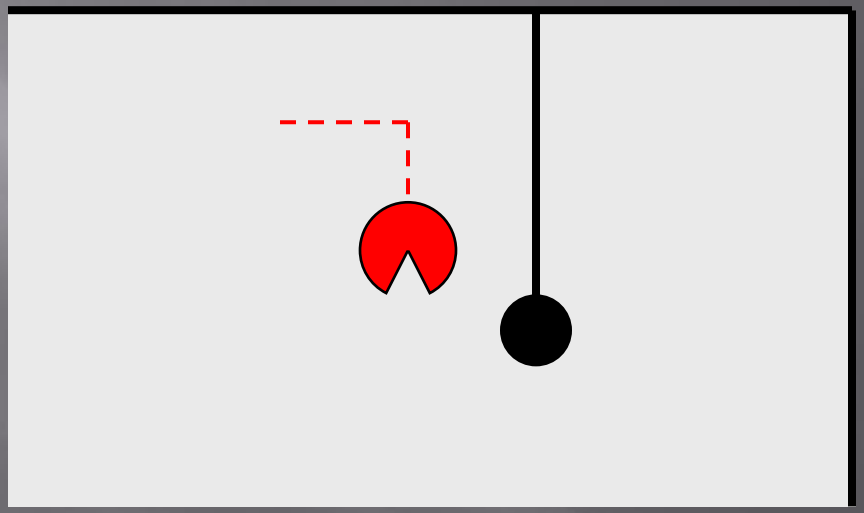

Closed loop finite state machines use sensor data as feedback to make state transitions

Implementing in Java

- Can use an enum to hold the value of the state and then switch on it

```
switch ( state ) {

  case States.Fwd_1 :
    moveFoward(1);
    if ( distanceToObstacle() < 2 )
      state = TurnR_45;
    break;

  case States.TurnR_45 :
    turnRight(45);
    if ( distanceToObstacle() >= 2 )
      state = Fwd_1;
    break;

}
```

Implementing in Java Method 2

- Define a state interface

```
public interface IState{
  public IState performAction();
}
```

Implementing in Java Method 2

- Each state then becomes a class that implements the interface

```
public class Fwd implements
IState{

  private int dist;
  private IState nextState;
  public Fwd(int dist){
    this.dist = dist;
  }
  public IState performAction(){
    moveForward(dist);
    if (distanceToObstacle()<2){
      nextState = new TurnR(45d);
    }else{
      nextState = this;
    }
  return nextState;
}
```

```
public class TurnR implements
IState{

  private double angle;
  private IState nextState;
  public TurnR(double angle){
    this.angle = angle;
  }
  public IState performAction(){
    turnRight(angle);
    if (distanceToObstacle()>=2){
      nextState = new Fwd(1);
    }else{
      nextState = this;
    }
  return nextState;
}
```

Implementing in Java Method 2

- The states are run by a loop in the main thread

```
public static void Main(String[] args){

  IState currentState = new Fwd(1);
  while (time < 5min){
    currentState = currentState.performAction();
  }
}
```

Implementing in Java Method 2

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- Can anyone see something wrong with this?

Implementing in Java Method 2

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  while (time < 5min){
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  }
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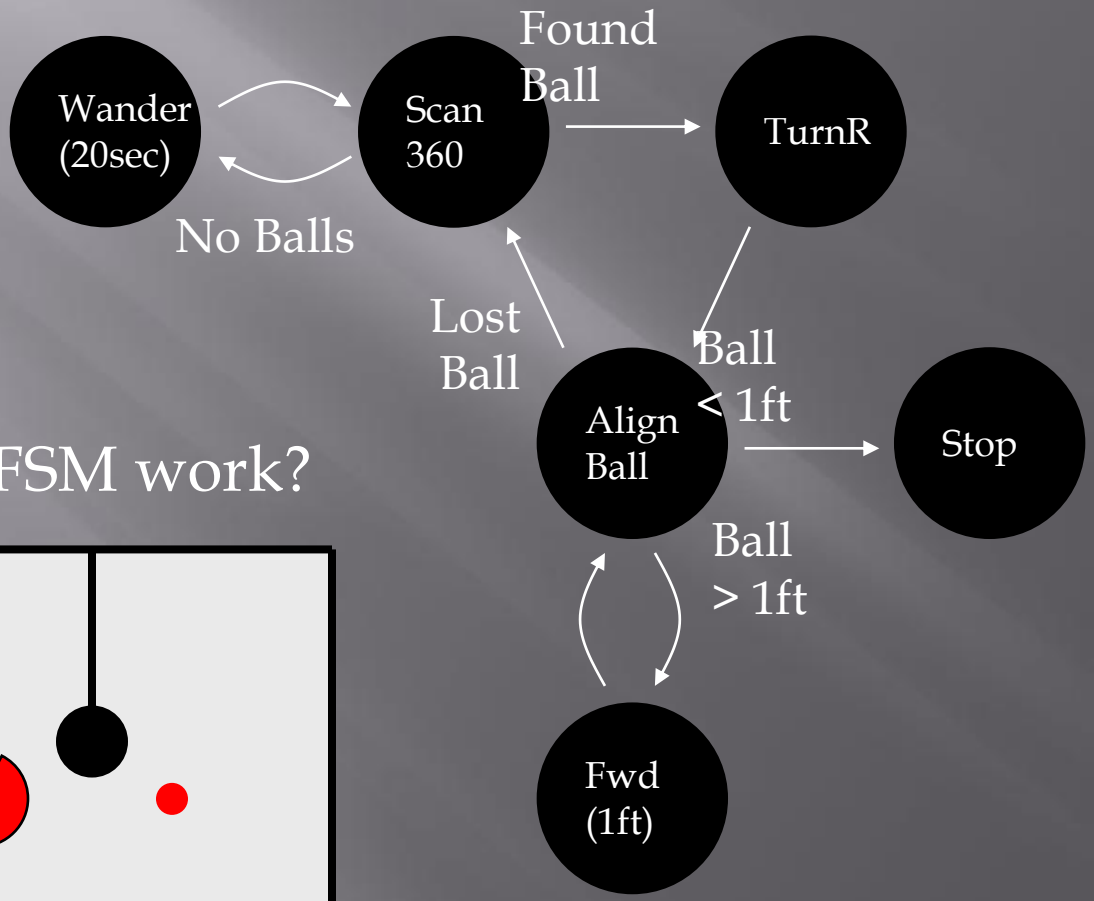
```

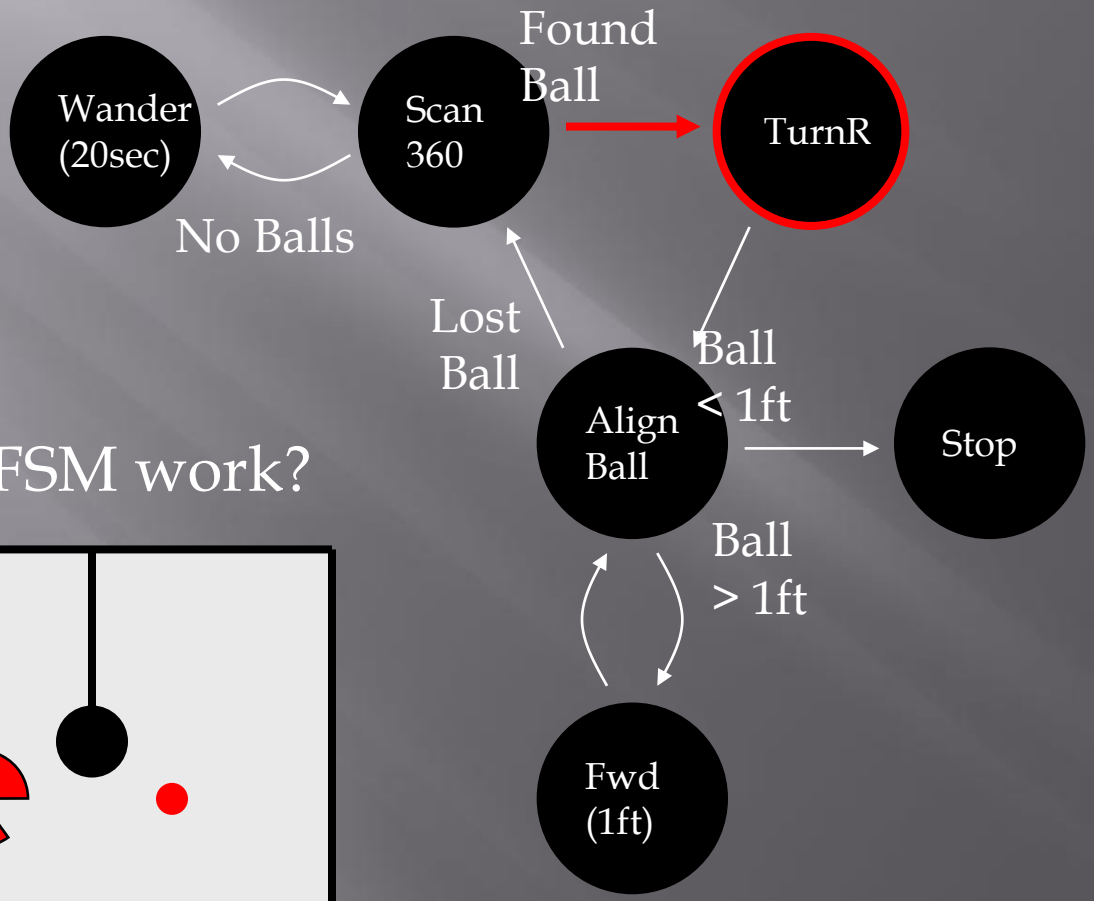
- Can anyone see something wrong with this?
- What if a state doesn't finish its task until 5:20 into the competition?

Complex Example



Does this FSM work?

Complex Example



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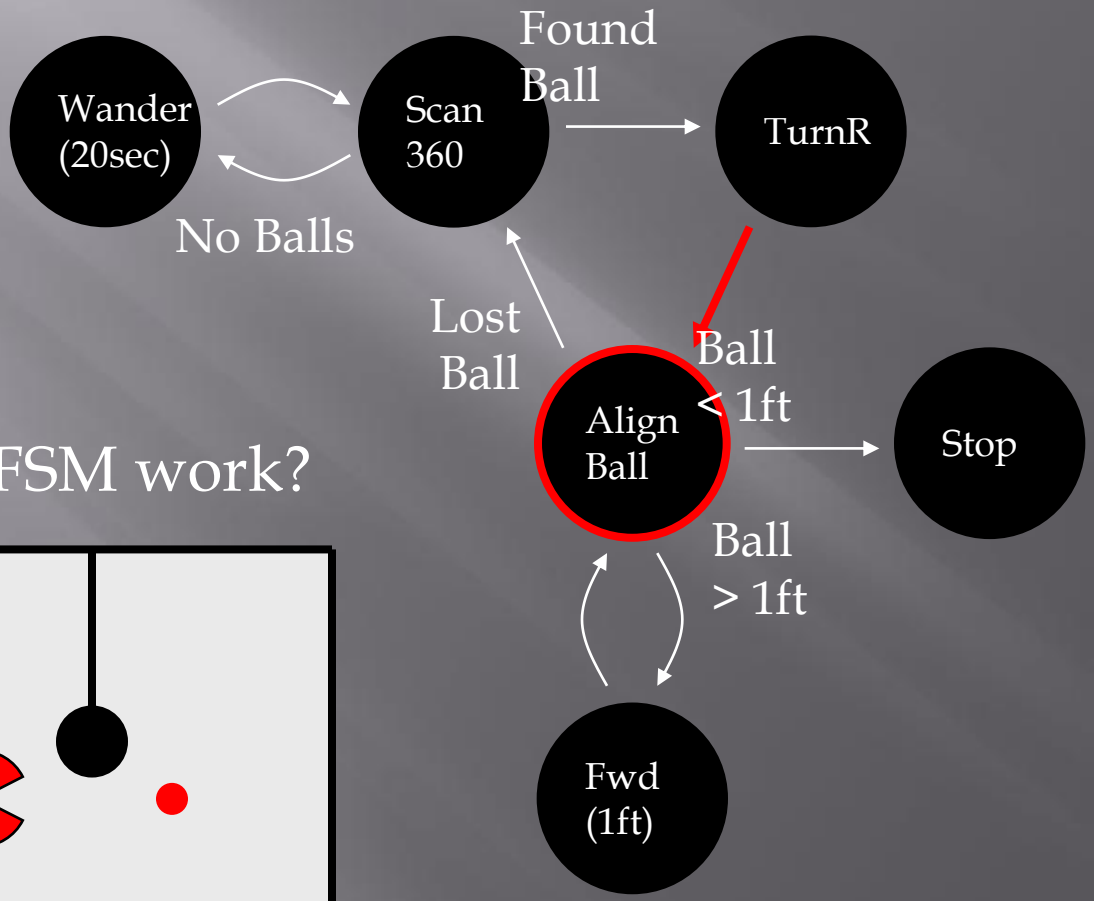

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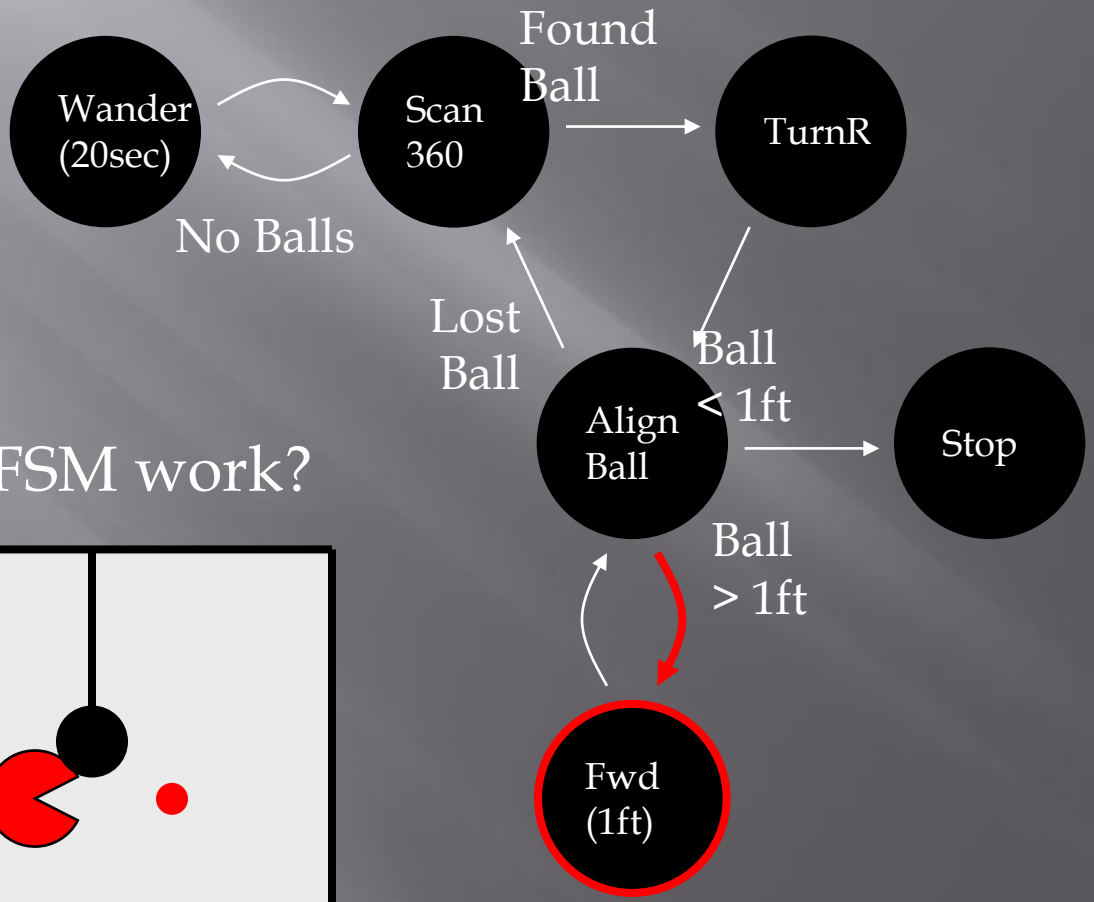
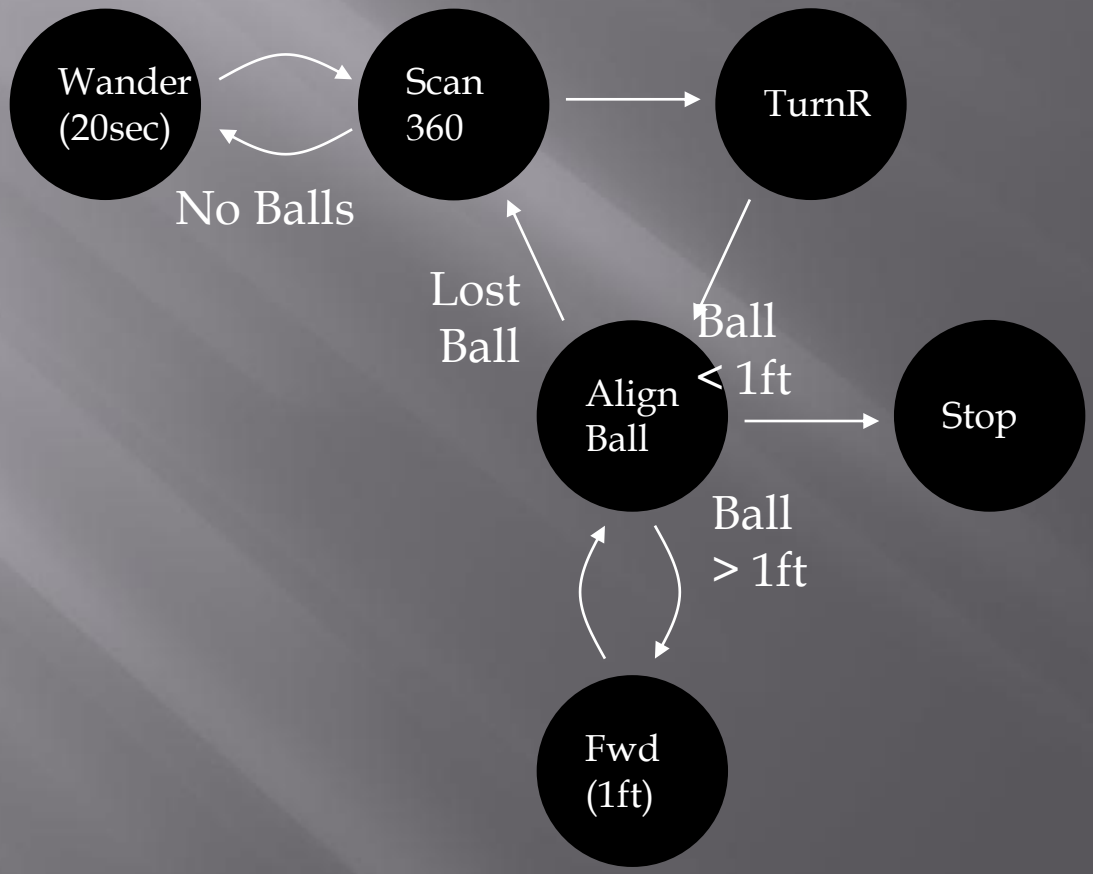


Does this FSM work?

Complex Example

- It doesn't work. How do we improve it?



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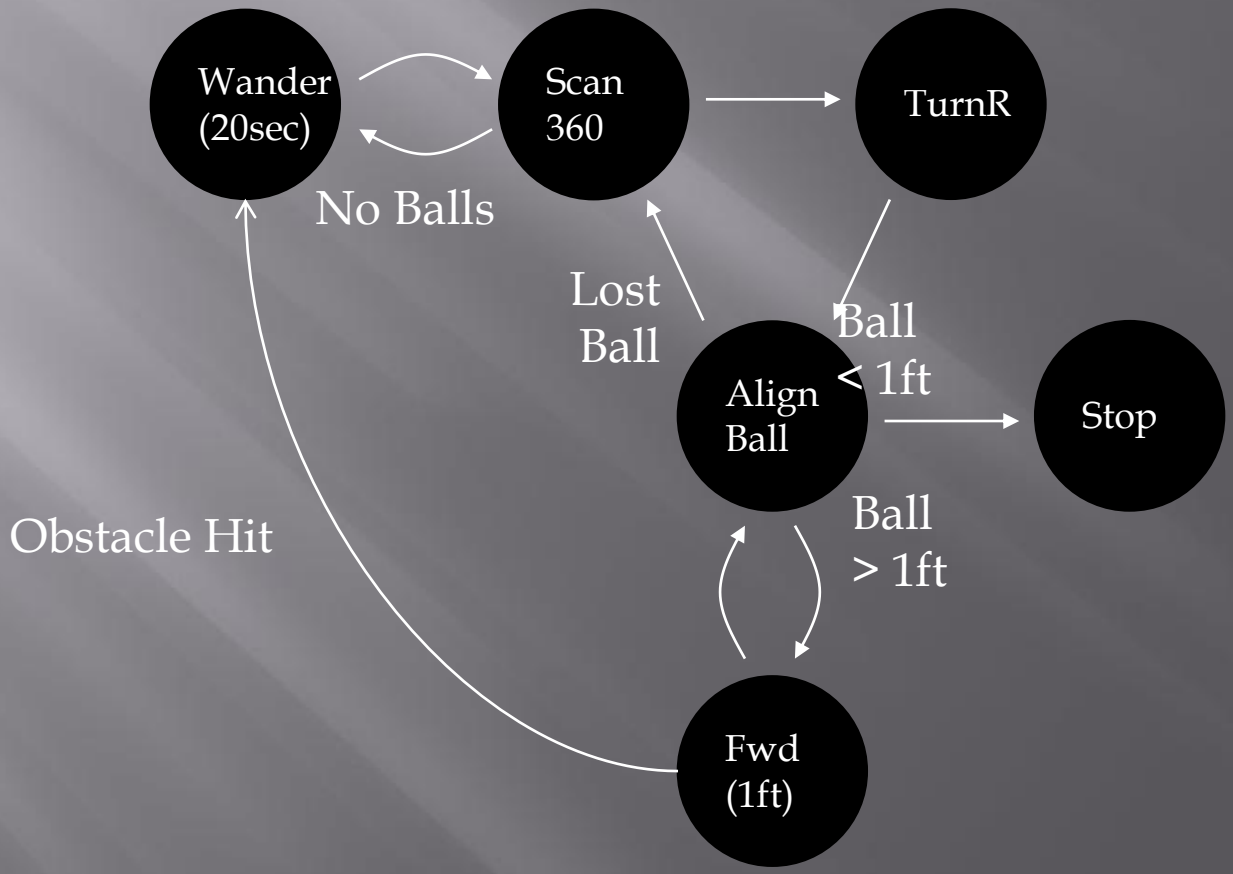
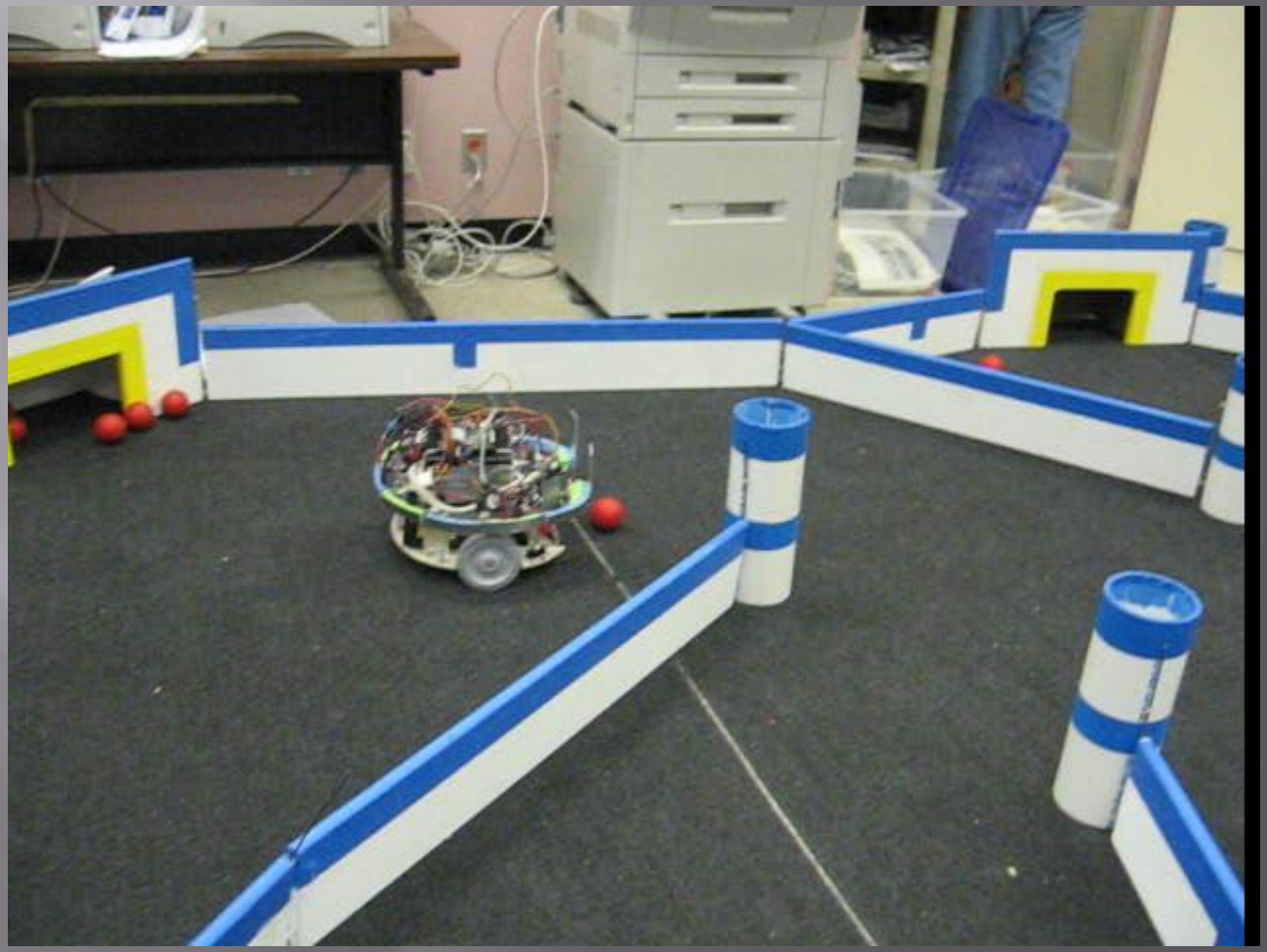


Advantages and Disadvantages

- Advantages
  - Combine Model Plan Act and Emergent Behavior
  - Predictable
  - Very Modular
  - Simple
- Disadvantages
  - Not as “free-flowing” as Emergent Behavior
  - Not as optimum as Model Act Plan

Video



Further Resources

- 6.005 Lecture Notes
  - http://stellar.mit.edu/S/course/6/fa07/6.005/
- Previous years' lecture notes

Thanks to:

- Valorie Morash
- Christopher Batten

Reminder

- Start thinking about Assignment 4 now!