Behaviors

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http://www.andrew.cmu.edu/course/15-491

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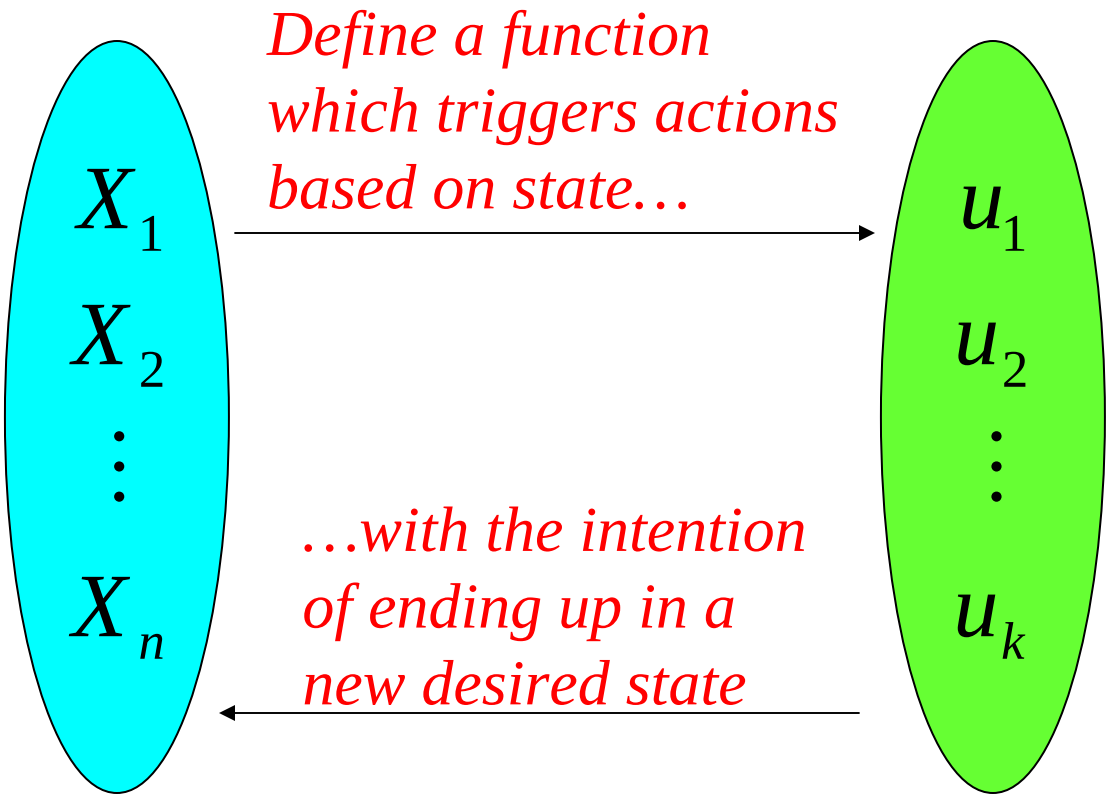
Behaviors as Functions



Domain of state space
(continuous or discrete)

Range of robot actions
(including those of the team)

“Thinking”… Selecting Actions

- Sensory data as input
- “Behaviors” as *processing of input to select actions*
- Actuators perform the actions

Behaviors Approaches

There are three main approaches to behaviors

- Reactive
  - Try to respond directly to the environment
- Deliberative
  - Think ahead about actions before deciding on one to execute (included Planning as special case)
- Hybrid
  - Combination of the above

Reactive Behaviors

- Reactive behaviors map from sensors to actions
  - No memory
- *State* becomes *Internal state:*
  - current sensory data + limited memory
- Advantages
  - Very responsive to changes in environment
  - Simple and easy to understand
  - Smooth control changes in response to smooth changes in sensor values
- Disadvantages
  - Can't perform different actions from the same state
  - Can get stuck
  - Don't scale well to complex tasks

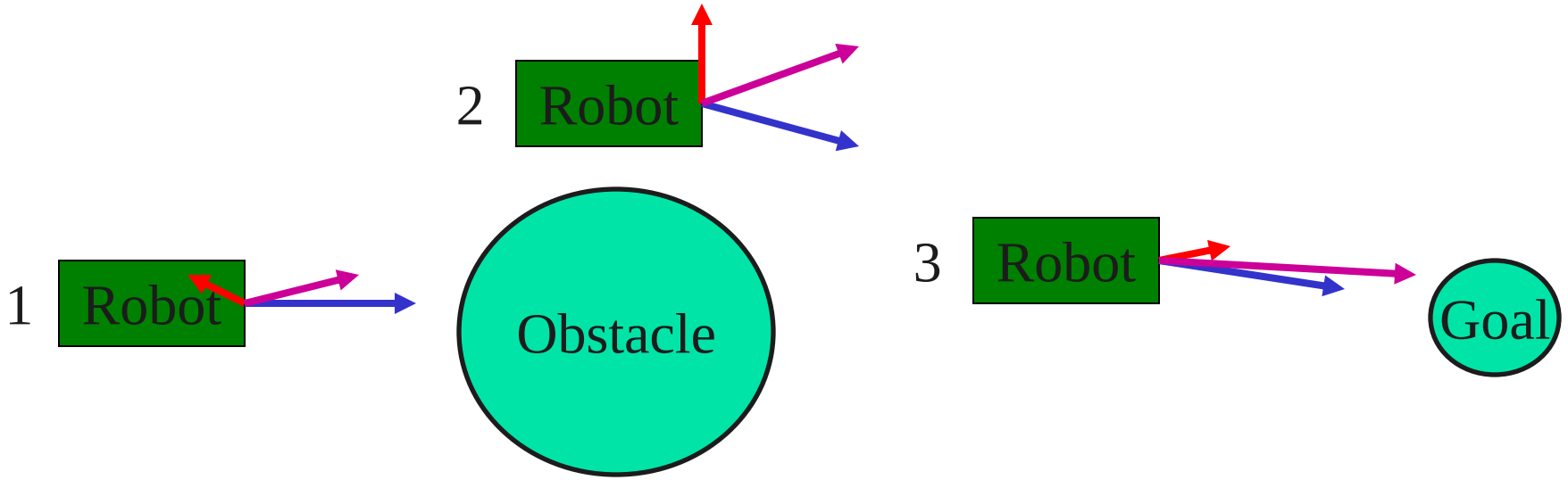
Types of Reactive Behaviors

- Reactive behaviors come under a wide variety of names
- Regardless of the names, they typically behave in the same general way
- An example behavior system:
  - Motor schemas

Motor Schemas

- A *motor schema* is a mapping from sensors to a *force vector* whose direction and value dictates the robot's next motion
- Each motor schema calculates a force on the robot due to some *constraint*
- The force vectors are summed to get the total force on the robot
- Example: navigation in the presence of obstacles
  - One motor schema produces force towards goal
  - Second motor schema produces force away from obstacles

Motor Schemas



Goal vector

Avoidance vector

Resulting vector

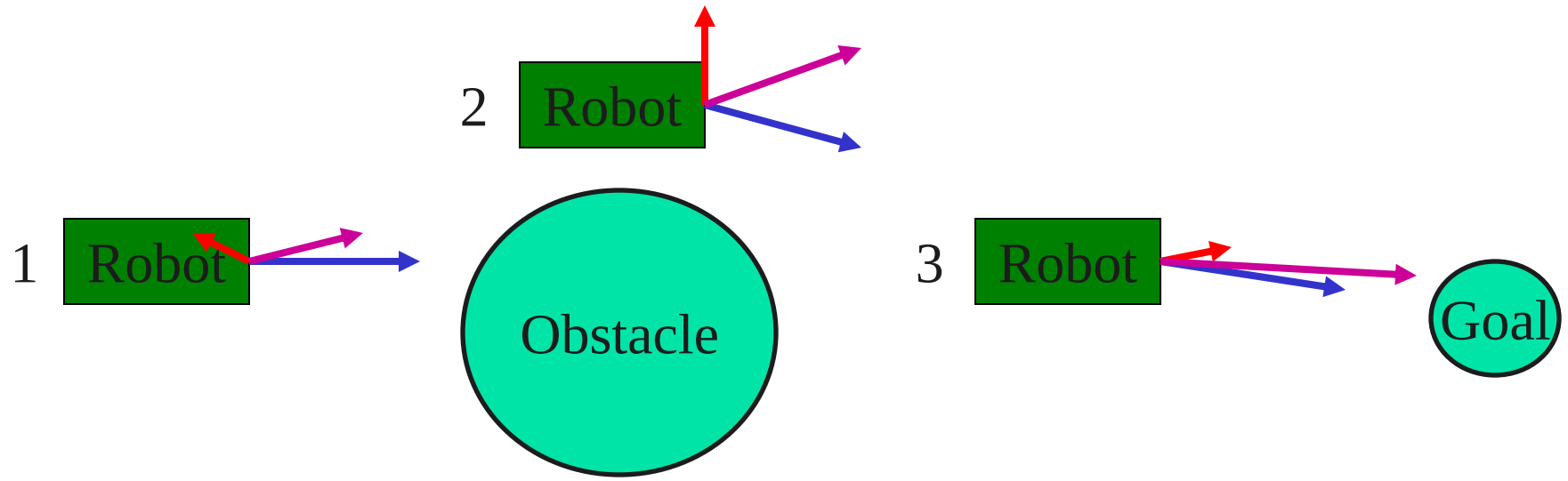
Combining Reactive Behaviors

- Reactive behaviors don't scale very well
- Reactive behaviors need to be combined into a larger behavior system
- Some combination ideas include:
  - Blending – motor schemas is an example of this
  - Competition – behaviors compete for control
  - Subsumption – reactive behaviors selectively take control
  - Sequencing – reactive behaviors are executed in a sequence based on a higher-level controller

Blending

- Behaviors output an activation magnitude and direction
- Multiple behaviors have their activation values merged into a single unified value
- Easy to implement as long as sensor values can be described by “forces” with direction and magnitude
- Problem: equal but opposing forces can cancel each other out

Blending – Same as Motor Schemas



Goal vector

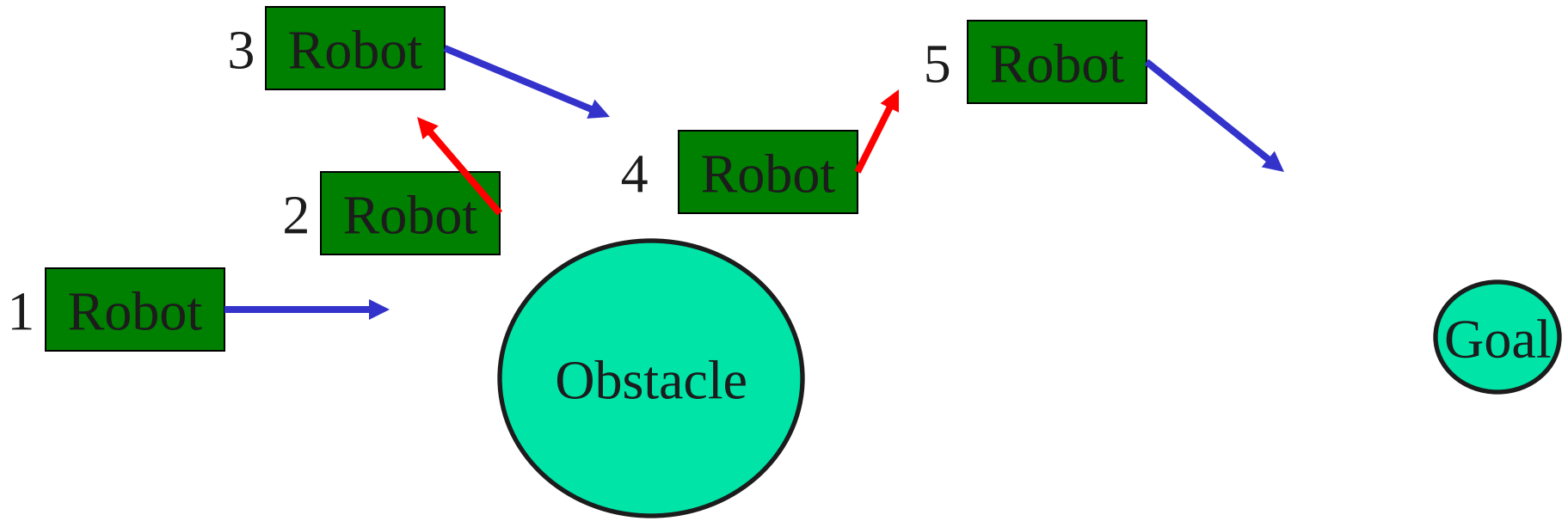
Avoidance vector

Resulting vector

Competition

- Similar to blending, but uses “winner-take-all” for activation
- Reactive behaviors compete for control of the robot
- Very responsive and adaptable to different behavior sets
- Problem: oscillations could occur when two behaviors have very similar strengths

Competition



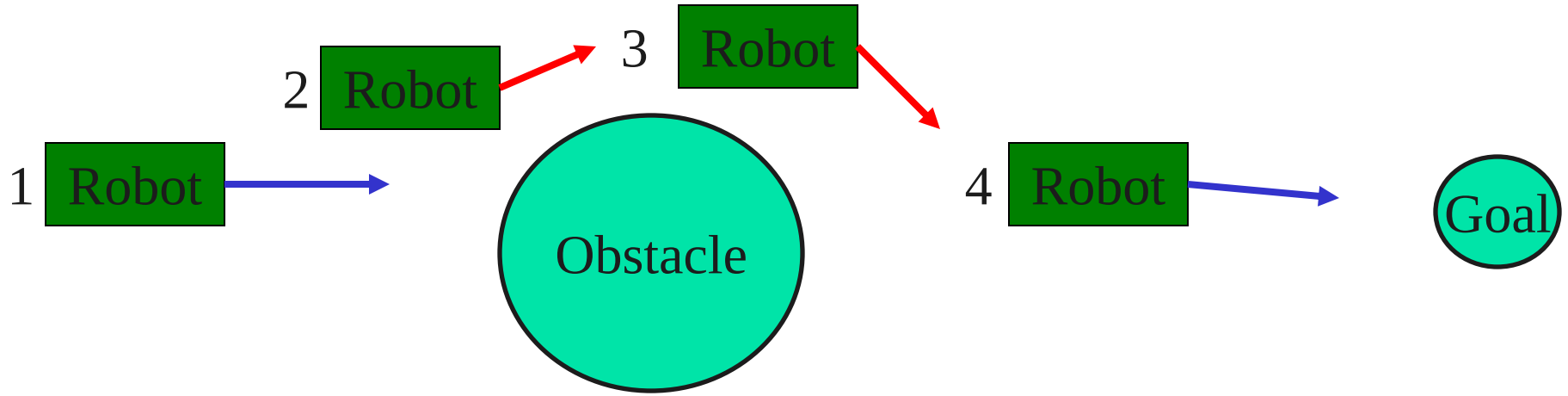
Goal vector

Avoidance vector

Subsumption

- Provide a strict priority ordering for the behaviors
- All behaviors read from sensors and output values to actuators
- Higher priority behaviors override the outputs from lower-level behaviors
- Better scalability due to strict ordering and notion of abstraction

Subsumption



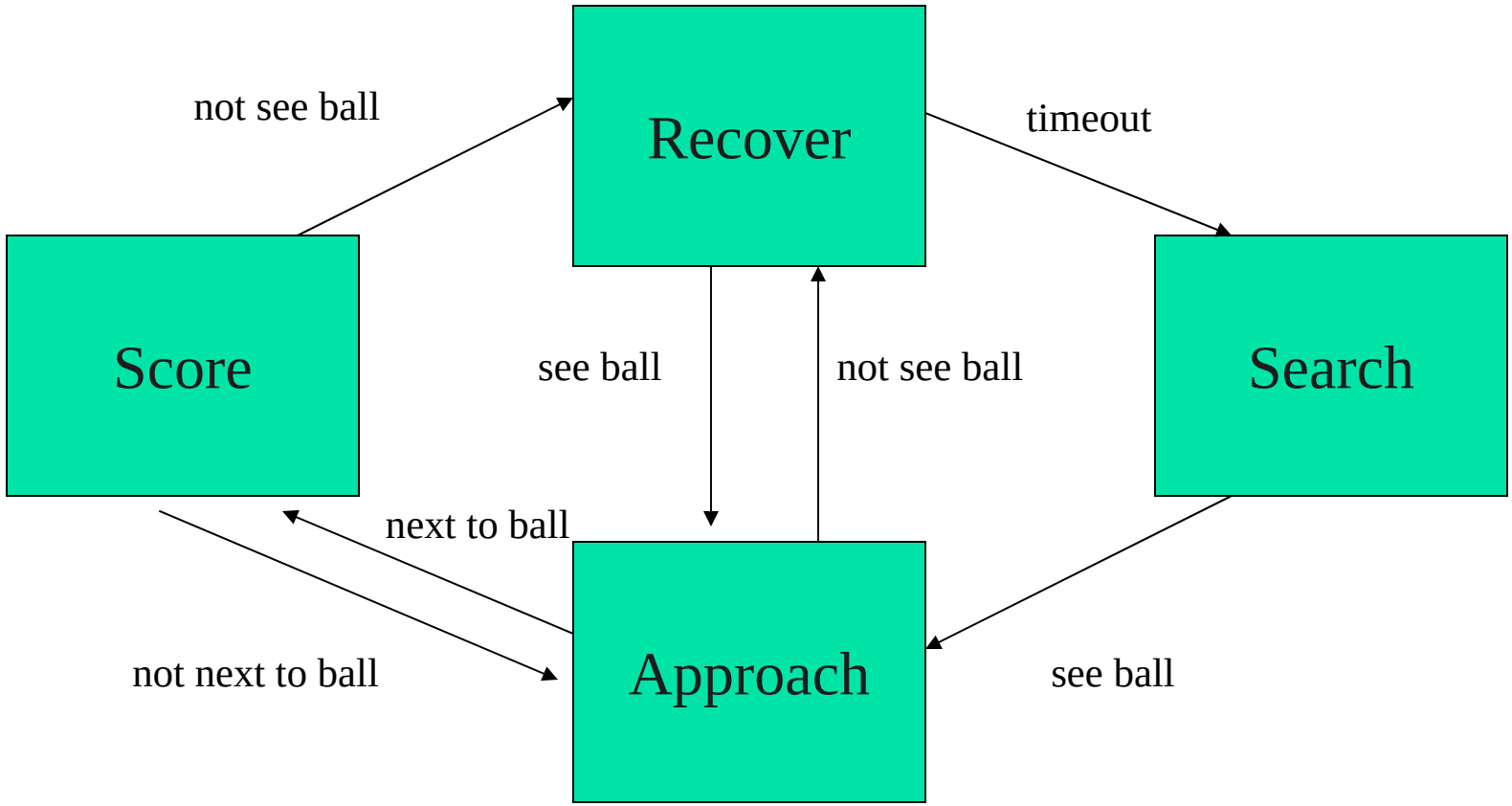
Goal vector

Wall follow vector

Sequencing

- Run only a single reactive behavior at a time and switch the active behavior based on change in robot/environment state
- Convenient notation for sequencing the behavior is a finite state machine (FSM)
- Each state of the FSM has an associated reactive behavior
- Each transition of the FSM has a rule that must be satisfied before a transition can occur
- Approach used by CMRoboBits code

Behaviors as Finite State Machines



Behavior FSM Semantics

- Each behavior is a function which must return a value every time new sensor data is called
- Takes as input the sensor features and returns the actuator commands
- Inside the function is the FSM
  - First, remember which state the FSM is in
  - Do computations on persistent values
    - Time in state, as an example
  - Decide whether to exit the function or whether to transition to a new state
    - Why shouldn't the FSM make the transition state and then exit?

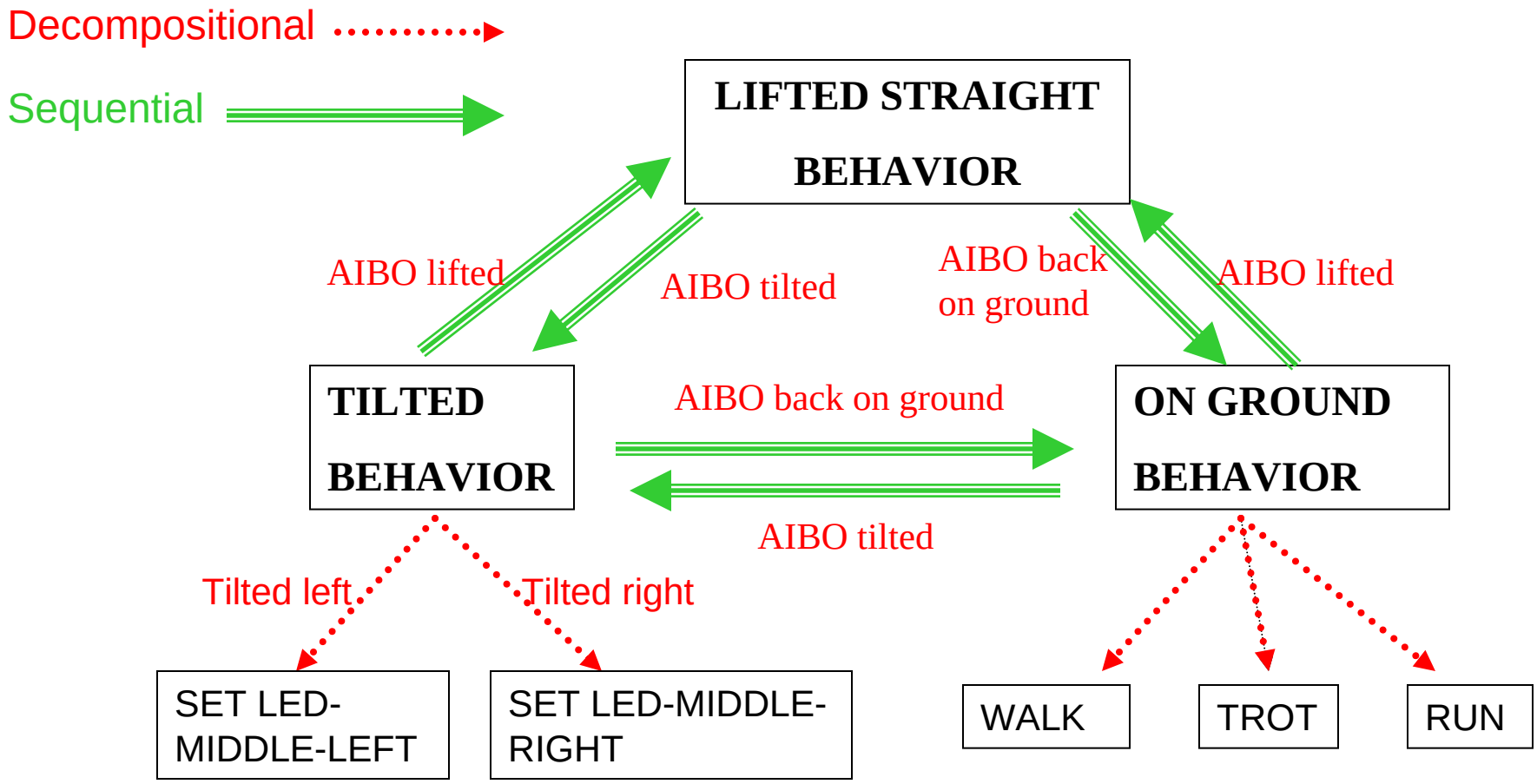
Sequencing Advantages

- Problems with oscillation are greatly reduced by the transition rules
- Can be very reactive to environment
- Can select different actions from same perceptions using context and memory
- Easy to chain together into larger actions

Hierarchy – Adding Scale

- In order to scale to large behaviors, we can reuse collections of lower-level behaviors
  - Libraries of lower-level behaviors form the building blocks for all robot behaviors
- Each state of FSM can be either a single reactive behavior, or another FSM with its own behaviors (or FSMs)

Example of Behavior/FSM



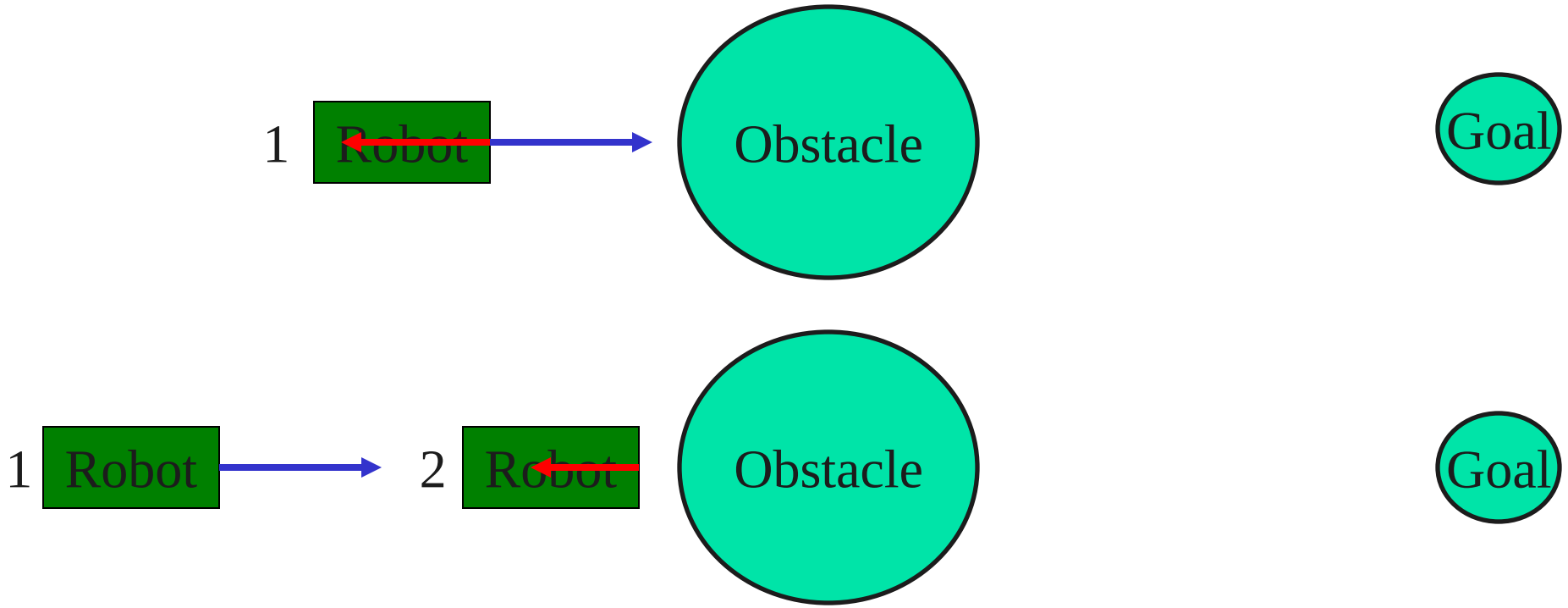
Implementation Details

- Behavior design is more of an art
- Good behaviors produce smoothly varying control signals
- Control signals that oscillate lead to poor control performance
  - Control target changes before controller can achieve the previous target
- Oscillation in behaviors needs to be avoided because it will lead to oscillations in control signals

Problems of Oscillation

- Behavior design can feel like more of an art
- Good behaviors produce smoothly varying control signals
- Control signals that oscillate lead to poor control performance
  - E.g. Control target changes before controller can achieve the previous target
- Oscillation in behaviors needs to be avoided because it will lead to oscillations in control signals

Oscillation



Goal vector

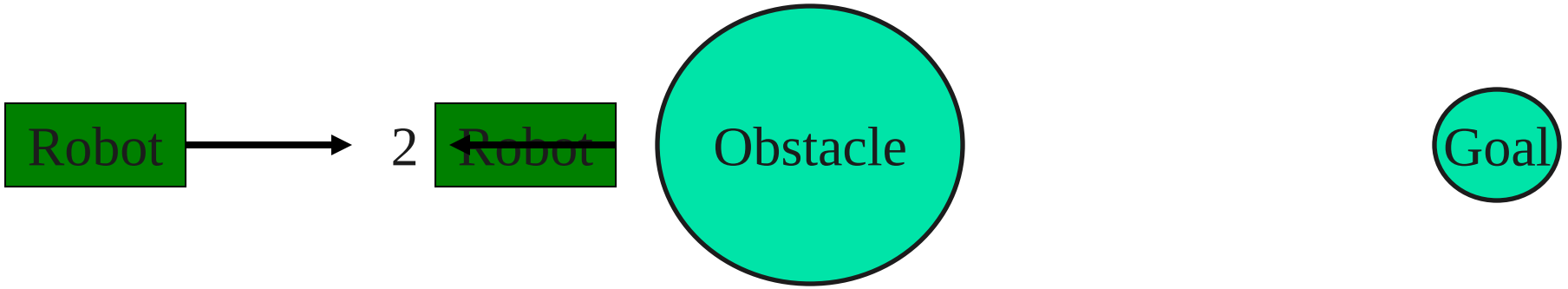
Avoidance vector

Avoiding Oscillation

- If oscillation occurs, one choice is to merge the states where the oscillation is occuring
- A more general solution is to add *hysteresis* to the transition rules
  - A system exhibits hysteresis when the behavior depends not only on the current state but also on its history
  - This refers to the creation of a buffer zone between states
- Important for first sensors homework

Example: When to Invoke the Different Behaviors?

Challenge: sensors are ***noisy*** , actuation can be noisy



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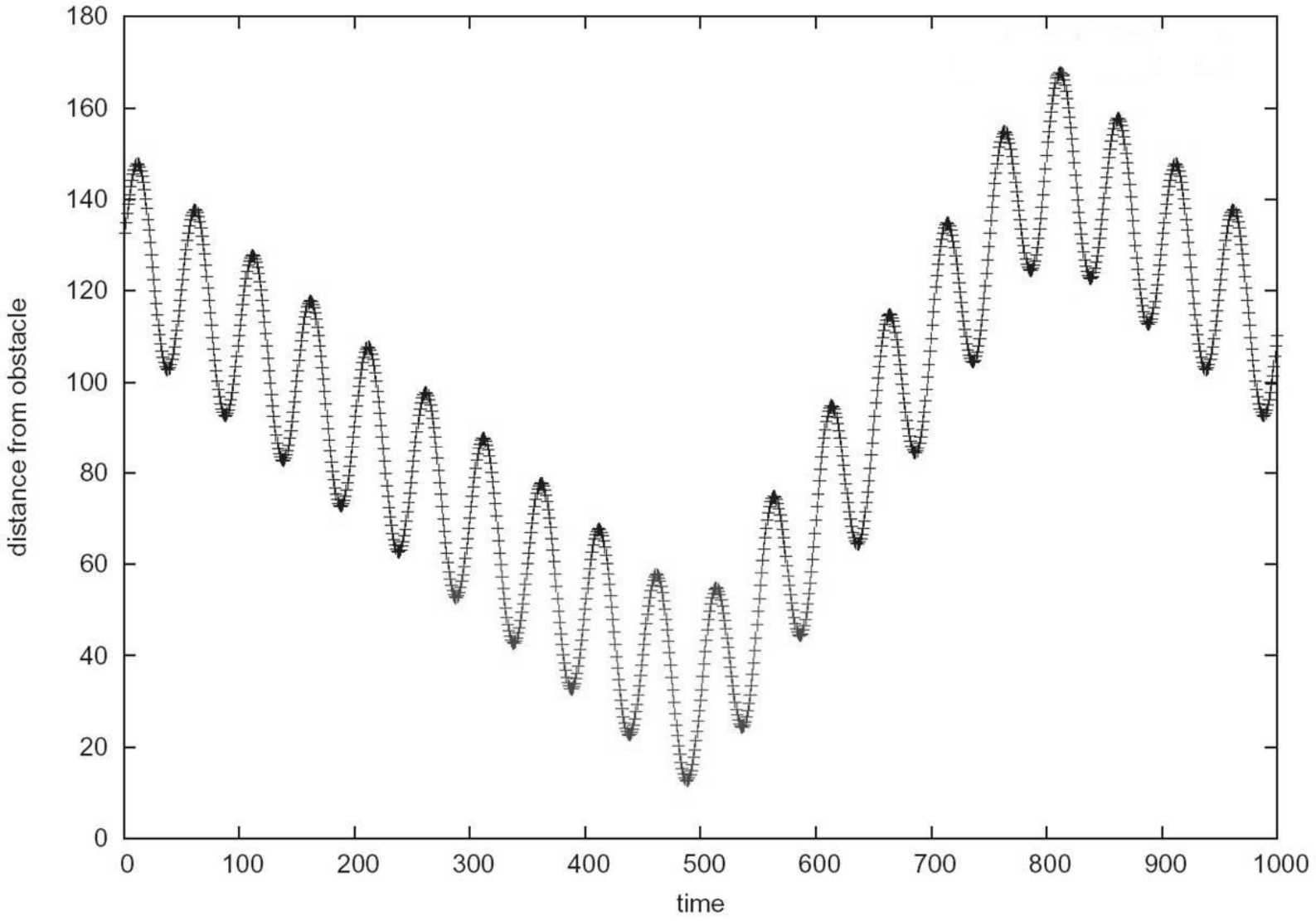
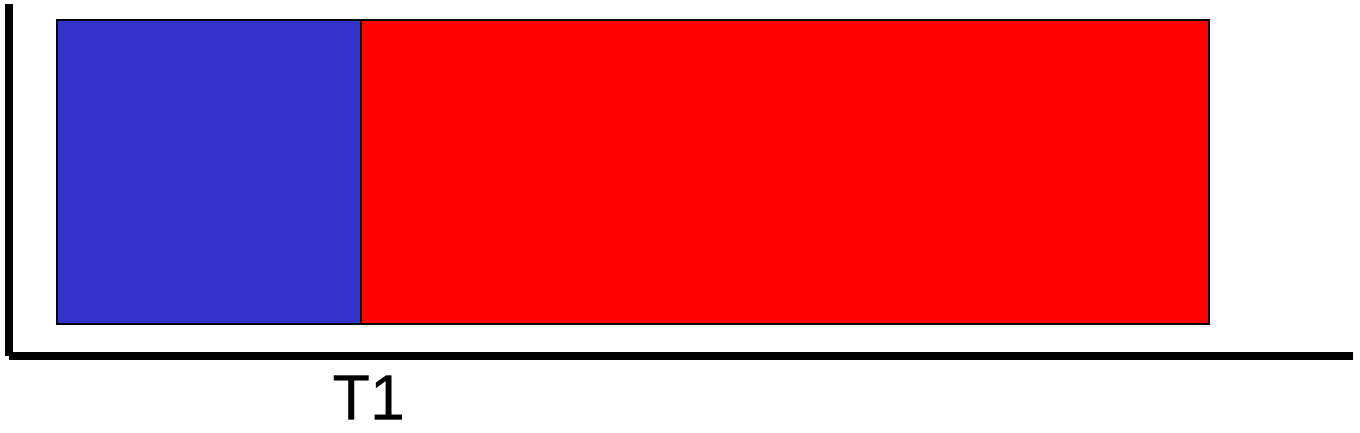
Let's collect some data from a robot driving towards and away from an obstacle.

Raw Data


distance from obstacle
time
0
20
40
60
80
100
120
140
160
180
0
100
200
300
400
500
600
700
800
900
1000

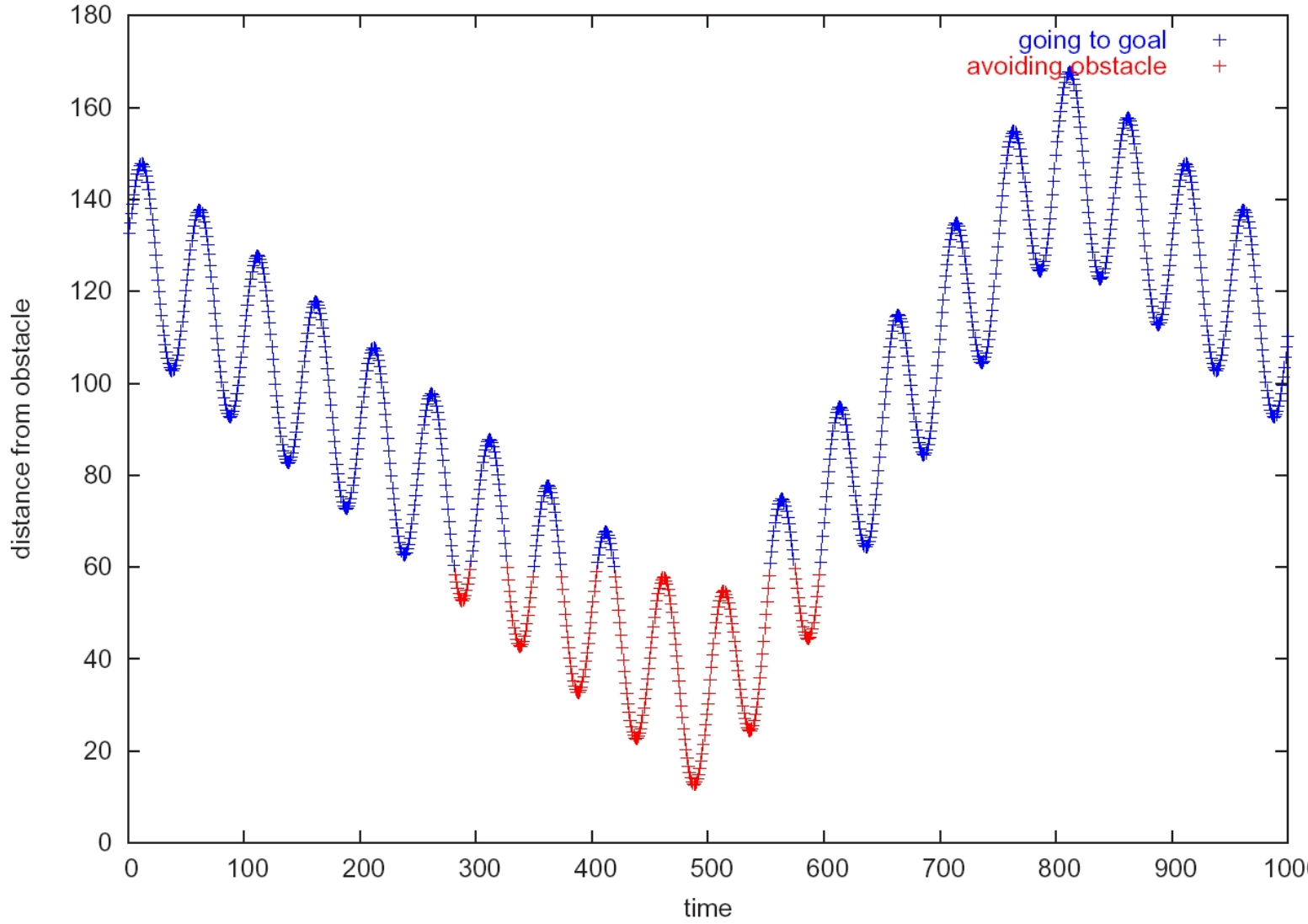
Handling Uncertainty

- Sensory data is noisy
  - How to decide between two conflicting sensor readings?
  - One solution is thresholding



Question: is a single value a good solution?

Naïve Control



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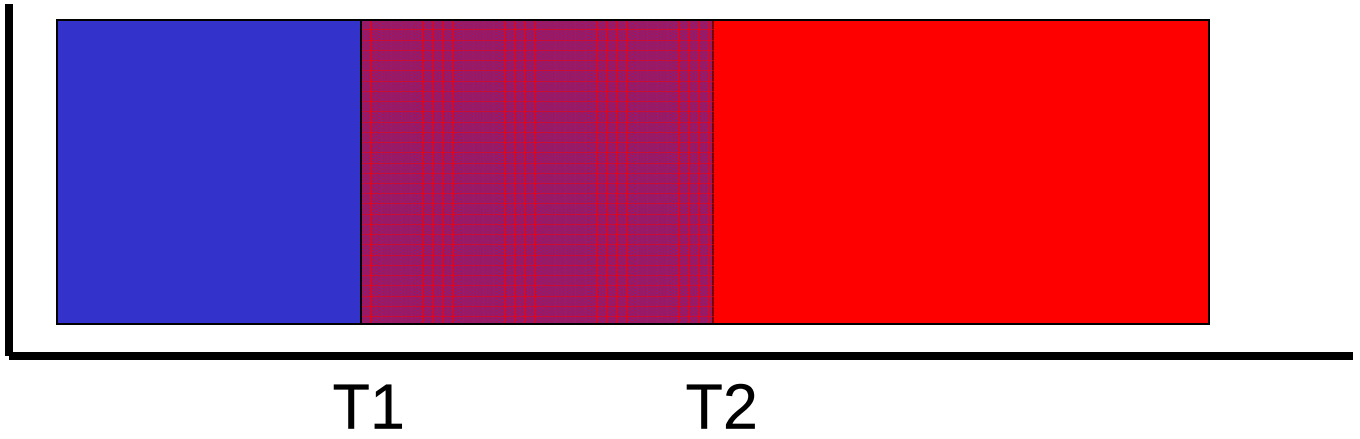
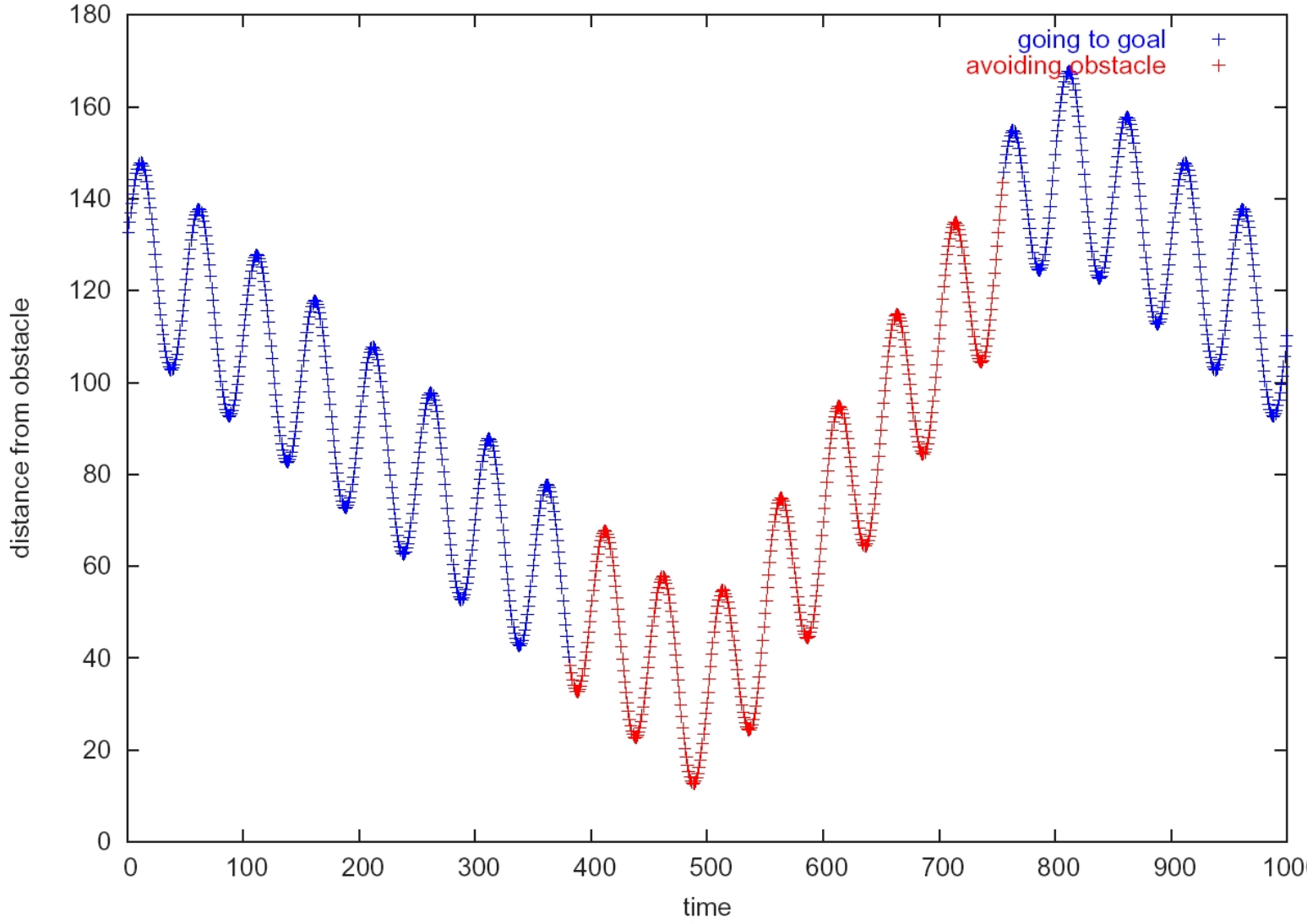
Handling Uncertainty

- Two threshold method: hysteresis
  - The lagging of an effect behind its cause



- The state switches from blue to red when values rise above T2. It switches from red to blue when values fall below T1.

Hysteresis



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Behavior Design Principles

- Design behavior in stages
  - Work on only one state at a time
- Start with initial “entry” state
  - Continue with each successive state
  - Test and debug one transition at a time
- Make one change at a time and thoroughly test the states and transitions
- Debug in which state the robot is
  - Robot should “say” where it is, both control state and sensing

Behaviors: Working within the Perception/Cognition/Action Loop

- Sensors obtain data at a fast rate
- One pass through the loop should not slow this processing down
  - Too much time in cognition might cause data data be missed or lost
- Computation cannot take “too much” time…

Summary – Next Class

- Behaviors map sensors to actuators
- Reactive behaviors
- Next class – deliberative behaviors, planning