Robot Control
(Planning and State Machines)

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Outline

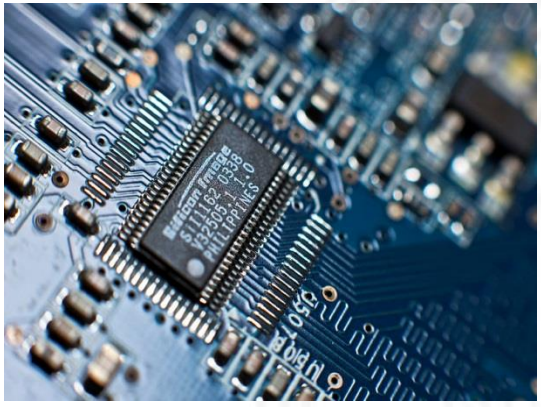
- Motivation
- Why is designing control system a complicated task?
- Control system and behaviors
- Approaches to control:
  - Hierarchical Approach
  - Behavioral Approach
  - Comparison of Hierarchical and Behavioral approaches
  - Hybrid
    - FSM
    - Subsumption architecture
    - SMACH
- Conclusion
- Bibliography

Motivation

- Early robotics dominated by machine tool industry
  - Limited sequence control (pick and place operations)
  - Playback with point to point control
  - Playback with continuous path control
  - Intelligent control

Why is designing control system a complicated task?

- Building a control system for robot: Complex task
  - Integrating mechanical, electrical and software components
  - Dynamic environment, sensor noise
  - Dynamic constraints of robot itself
  - Debugging and testing
  - Performance requirements
  - Maintainability
  - Performance improvement



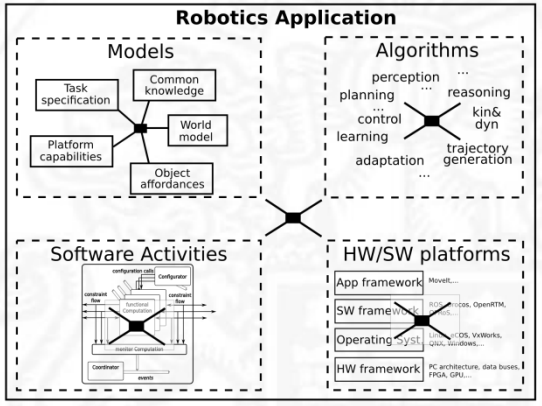


Figure 1: Hardware, Electrical and Software components [1,2]

Control system and behaviors

- Control system and collection of behaviors
  - Well defined, self-contained and independently testable
  - Integrate behaviors to achieve goals

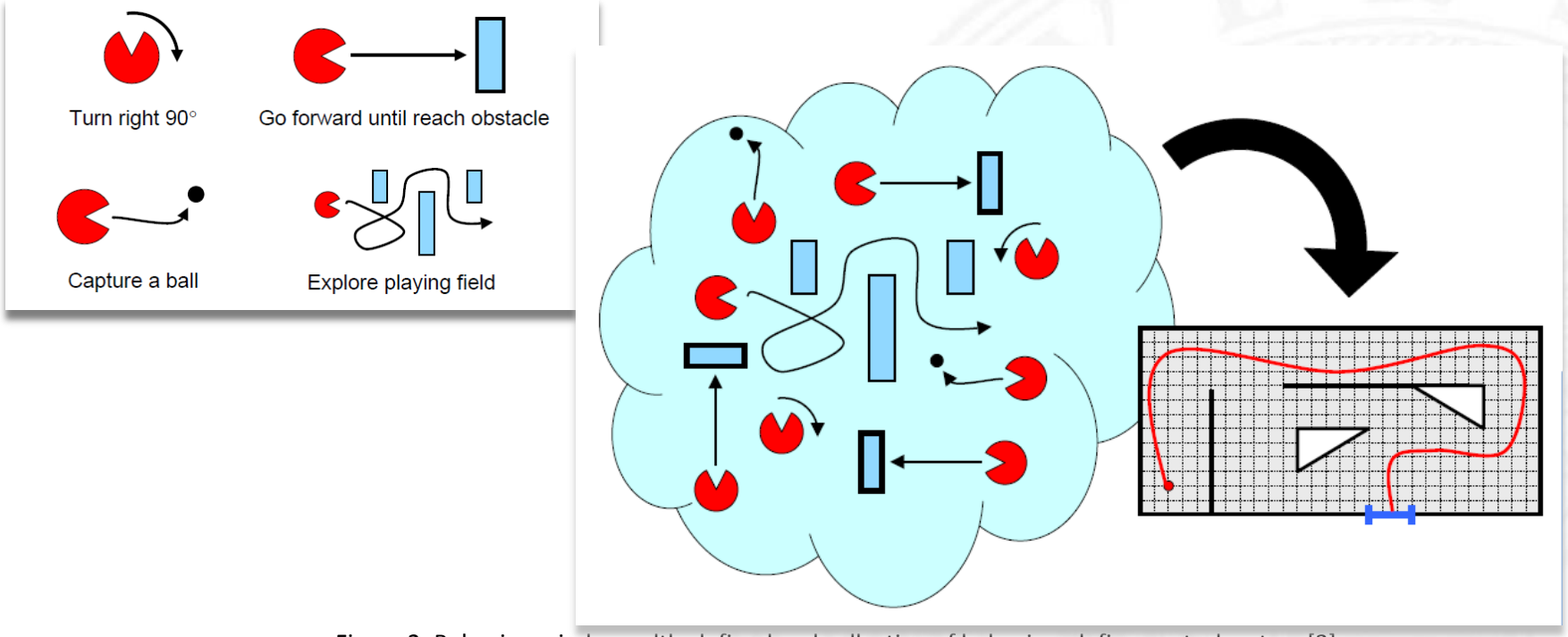


Figure 2: Behaviours independtly defined and collection of behaviors define control system [3]

Approaches to control

- Hierarchical: (Model-Plan-Act)
  - Top-down approach
  - Not very flexible
- Behavioral
  - Bottom-up approach
  - Organization is difficult, messy approach
- Hybrid (FSM, Subsumption architecture)
  - Deliberative at high level; reactive at low level

Figure 1: Hardware, Electrical and Software components [1,2]

High level control systems approaches: Model-Plan-Act

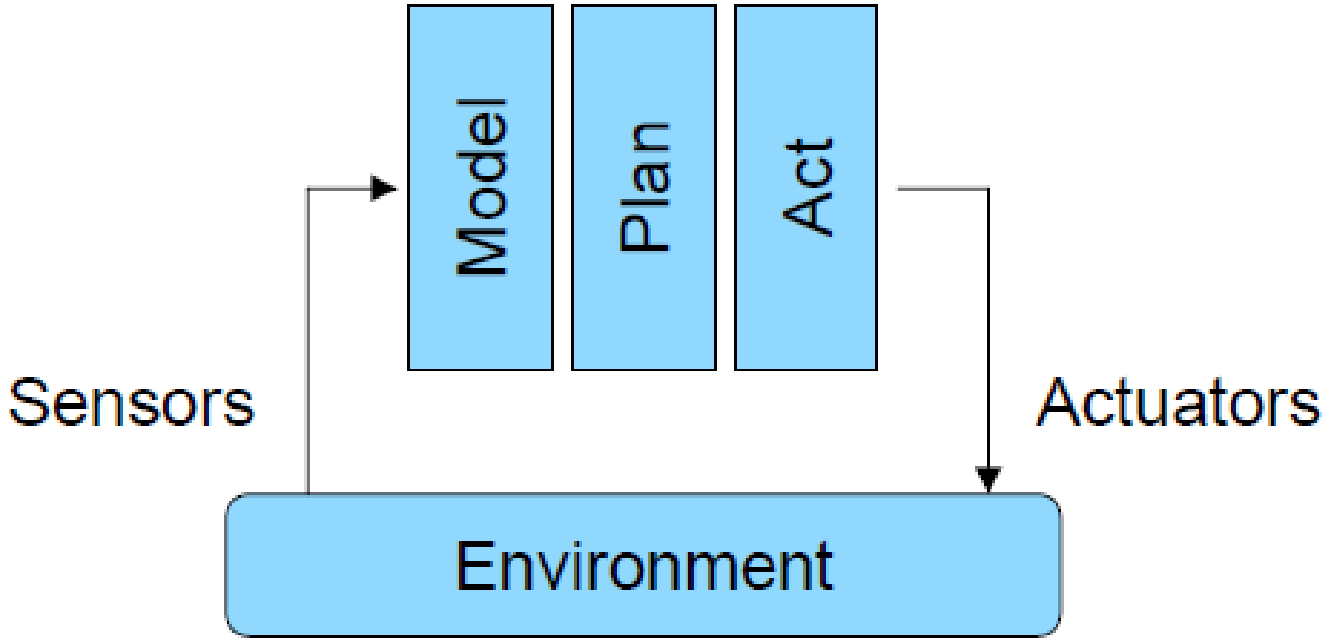


Figure 3: Model Plan Act Flowchart [3]

High level control systems approaches: Model-Plan-Act

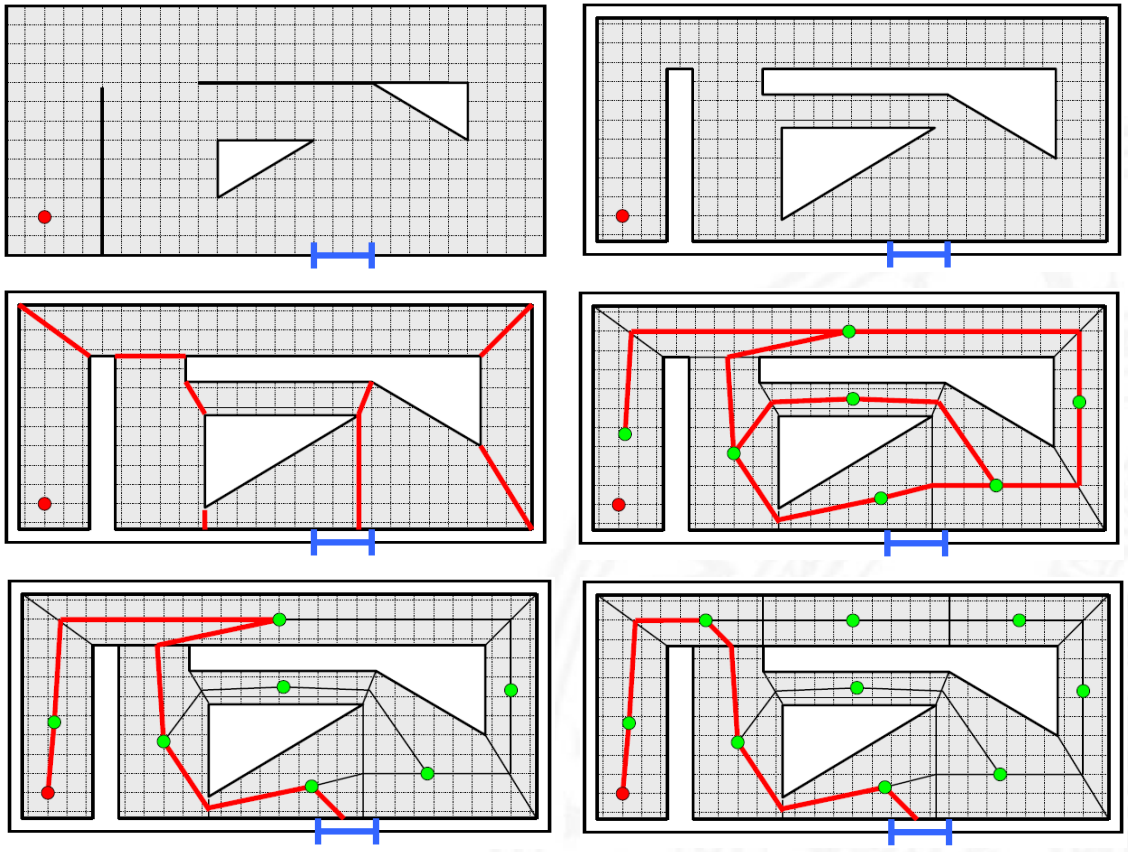
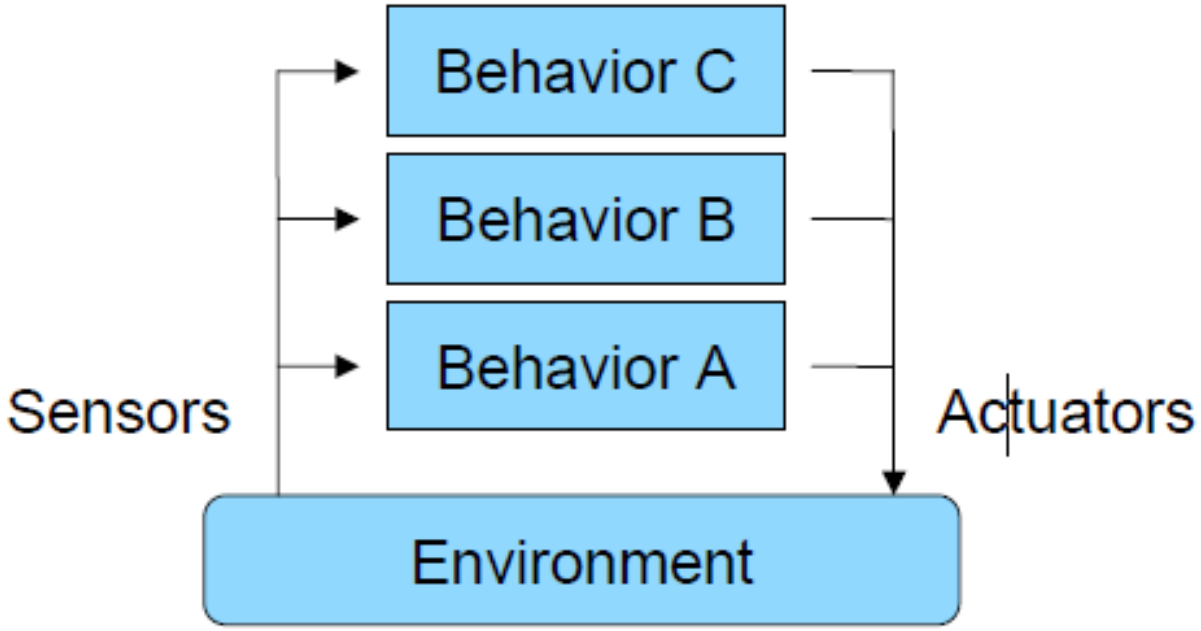


Figure 4: Finding the mouse-hole example [3]

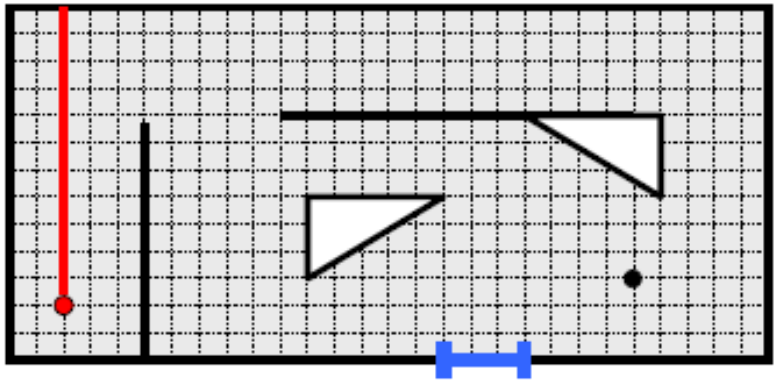
High level control systems approaches: Behavioral

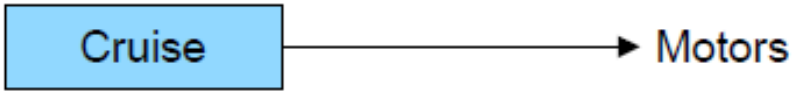


- Direct coupling of sensors and actuators
- Higher level behaviors are layered on top of lower level behaviors

Figure 5: Behavioural Approach Flowchart [3]

High level control systems approaches: Behavioral

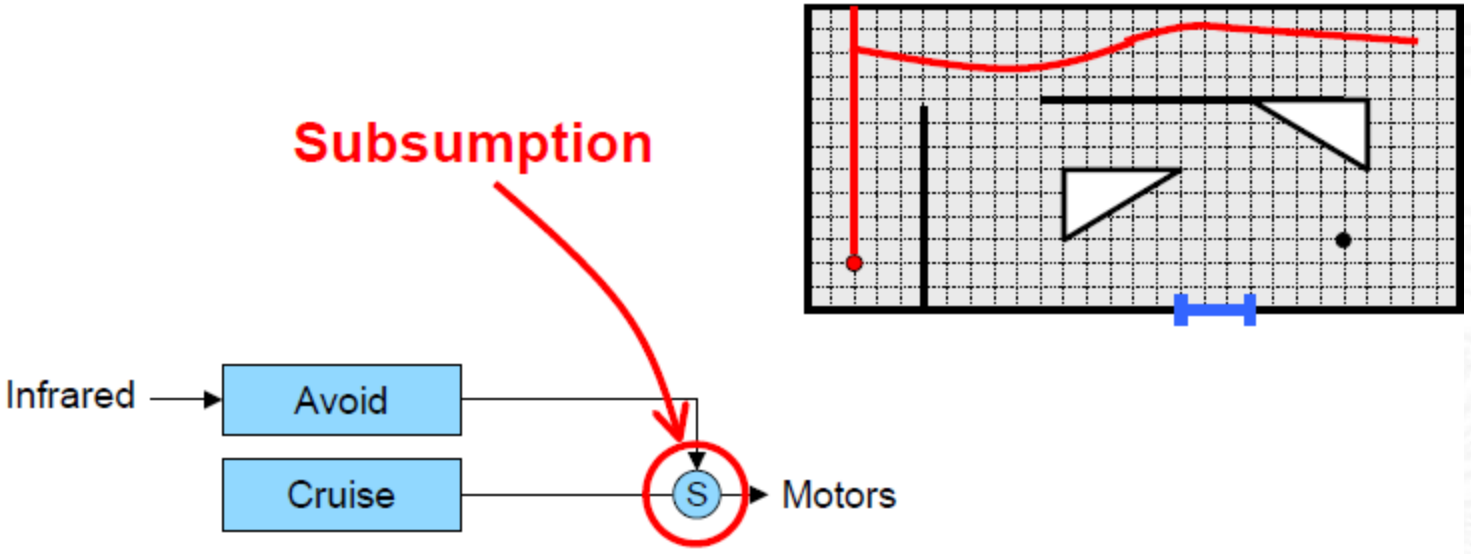




Cruise behavior simply moves robot forward

Figure 6: Behavioural approach example [3]

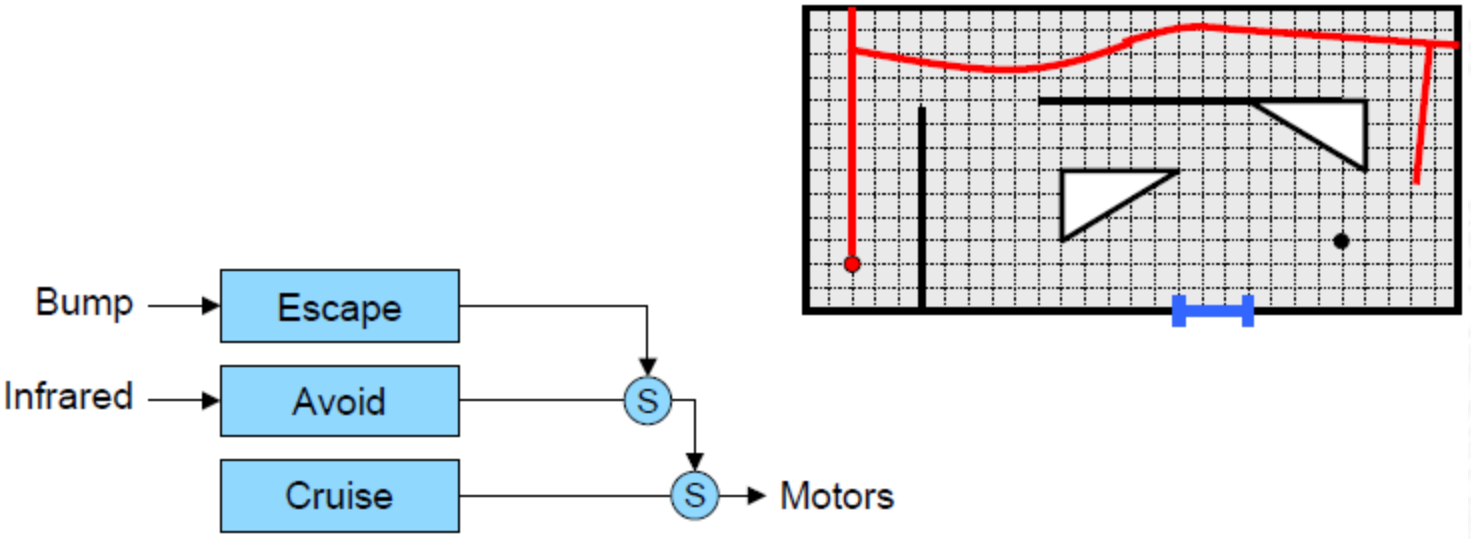
High level control systems approaches: Behavioral



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

Figure 7: Behavioural approach example [3]

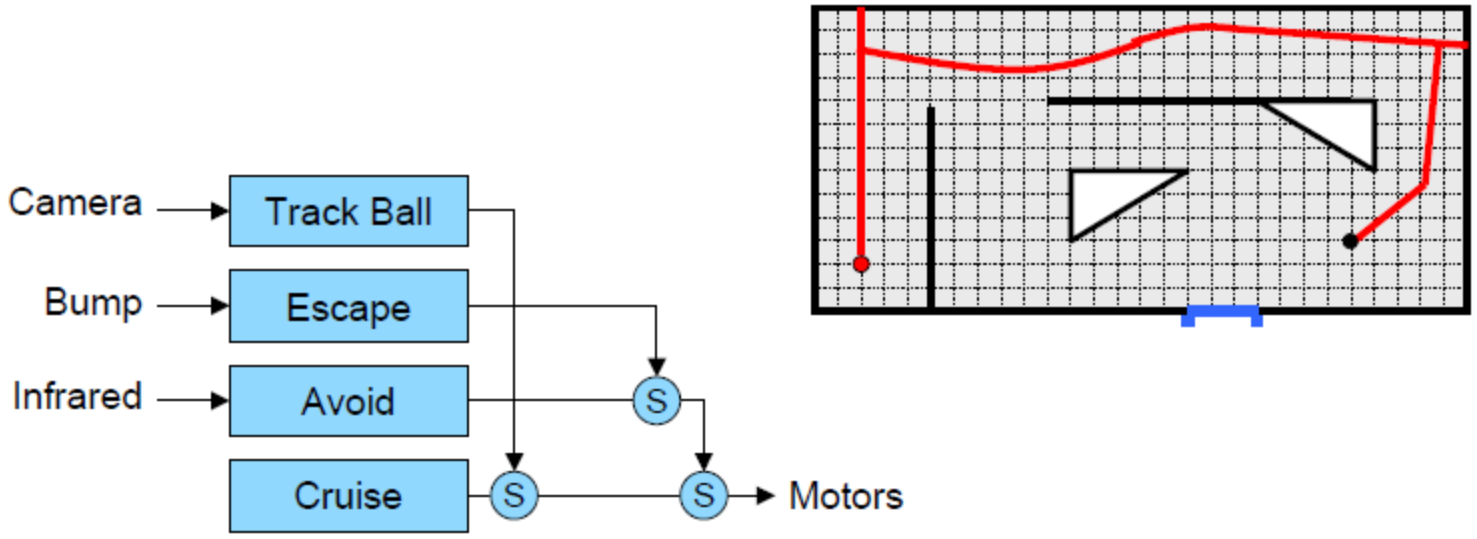
High level control systems approaches: Behavioral



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

Figure 8: Behavioural approach example [3]

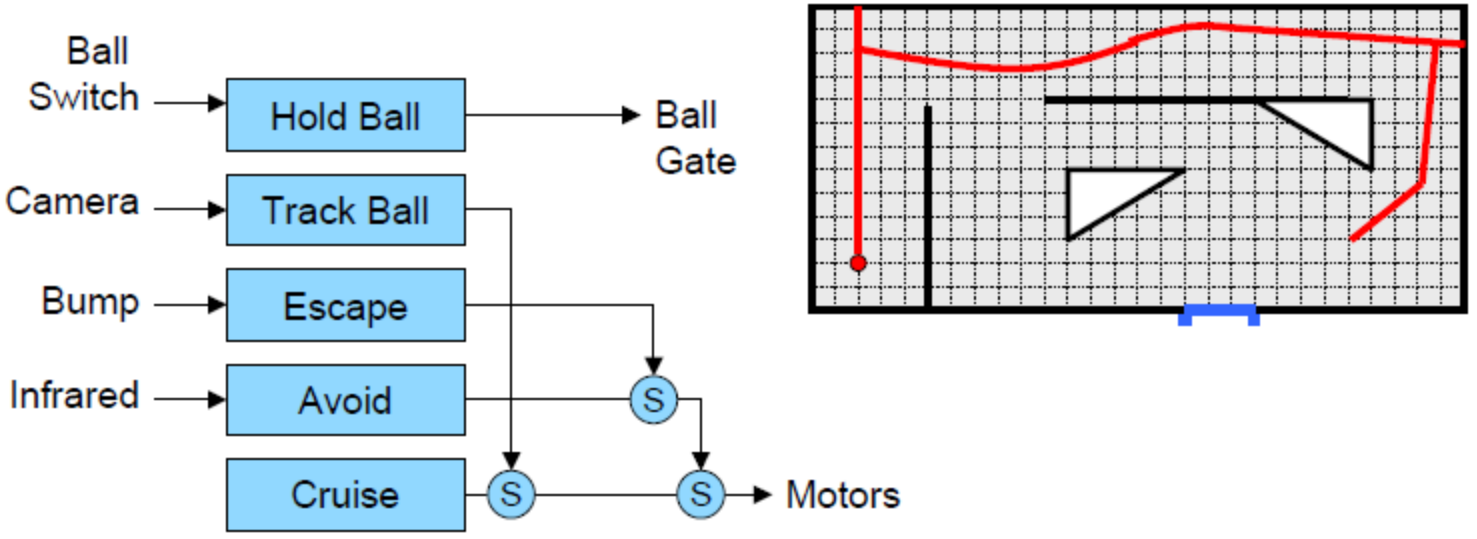
High level control systems approaches: Behavioral



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

Figure 9: Behavioural approach example [3]

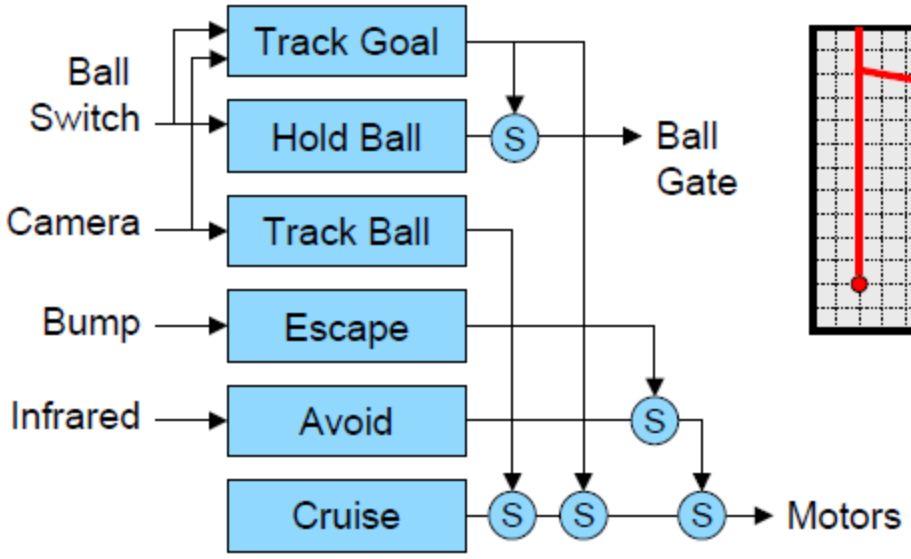
High level control systems approaches: Behavioral

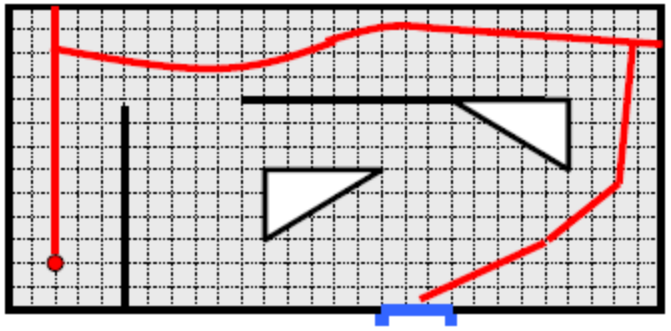


Hold ball behavior simply closes ball gate when ball switch is depressed

Figure 10: Behavioural approach example [3]

High level control systems approaches: Behavioral

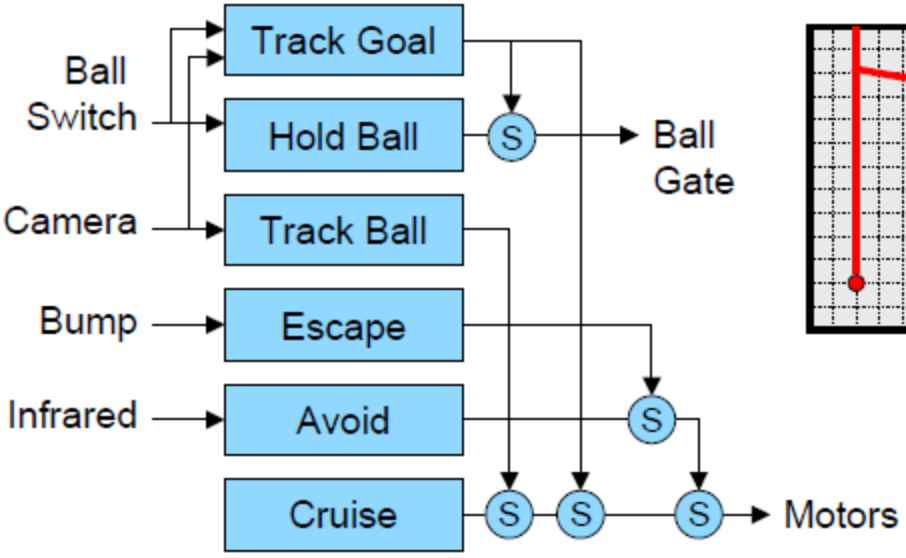


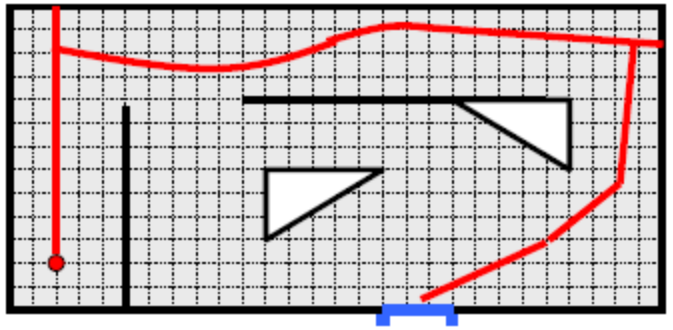


The track goal behavior opens the ball gate and adjusts the motor differential to steer the robot towards the goal

Figure 11: Behavioural approach example [3]

High level control systems approaches: Behavioral





All behaviors are always running in parallel and an arbiter is responsible for picking which behavior can access the actuators

Figure 12: Behavioural approach example [3]

Comparison of Model-Plan-Act & Behavioral Approaches

Model-Plan-Act	Behavioural
Speed of response: Slower	Speed of response: Faster (Real time response)
Symbolic	Reflexive
Adaptive	More robust but forgetful
Requires complete model of the world	Requires complete design of the system
High level intelligence	Low level intelligence

High level control systems approaches: Finite State Machines

- Combination of above approaches
- Each state is a behavior, linked to form a close loop control system
- Pre, post and end conditions of state
- Sensor data used as feedback for transition to next state
- Debug and verify states for improved behavior
- Software:
  - Implement behaviors as functions in code
  - Use switch statement to handle state transition and behaviors

High level control systems approaches: Finite State Machines

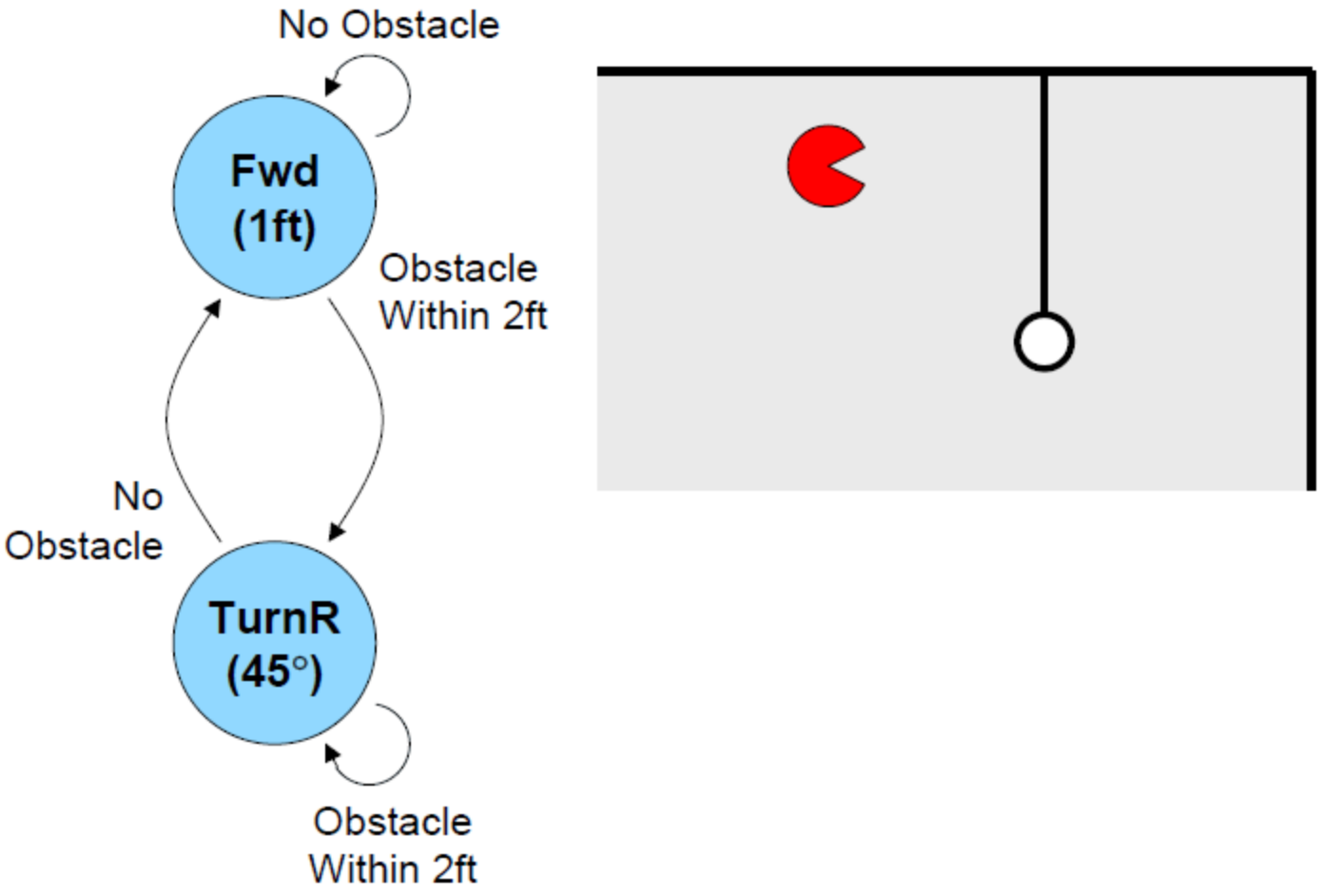


Figure 13: Finite state machine approach example [3]

High level control systems approaches: Finite State Machines

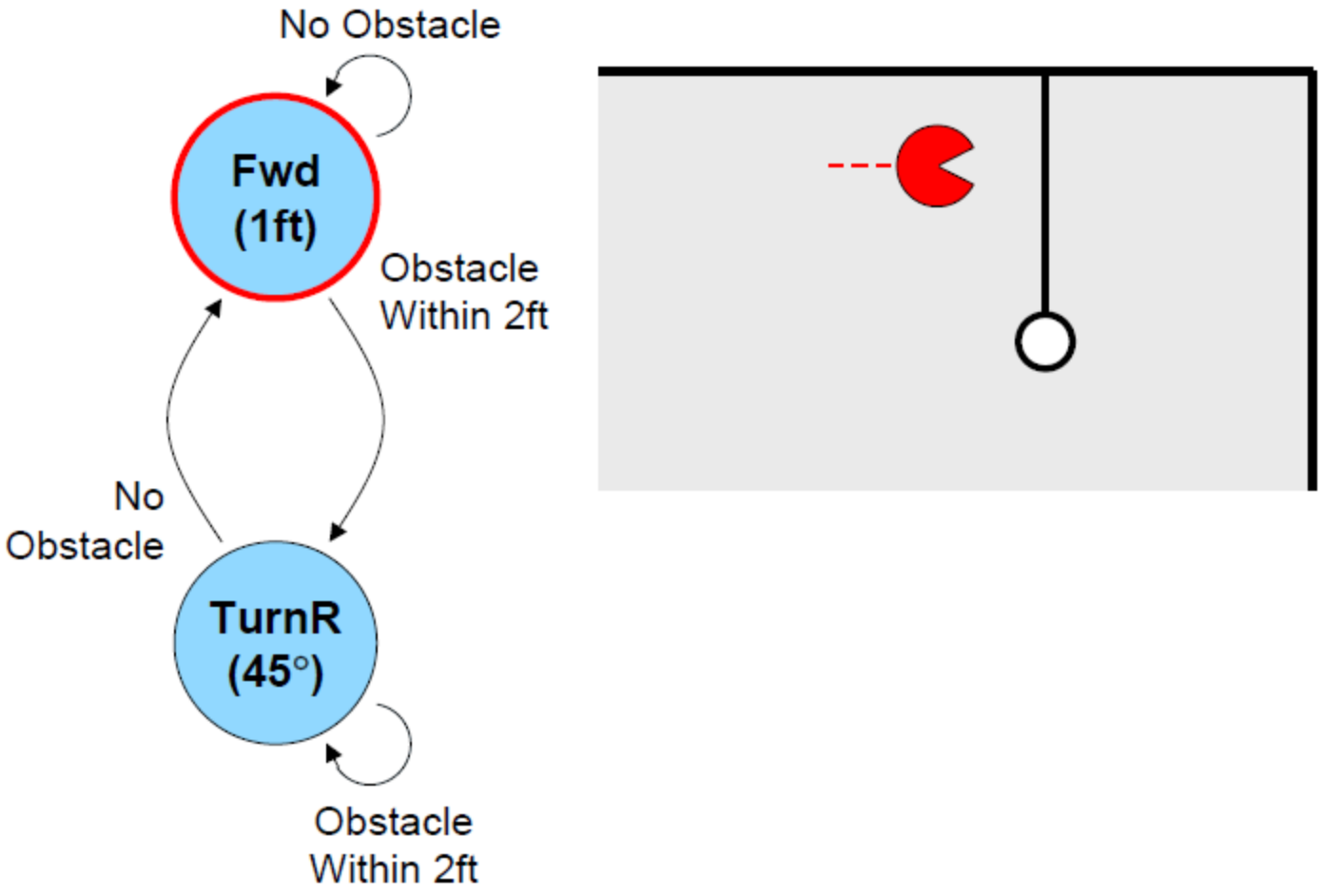


Figure 14: Finite state machine approach example [3]

High level control systems approaches: Finite State Machines

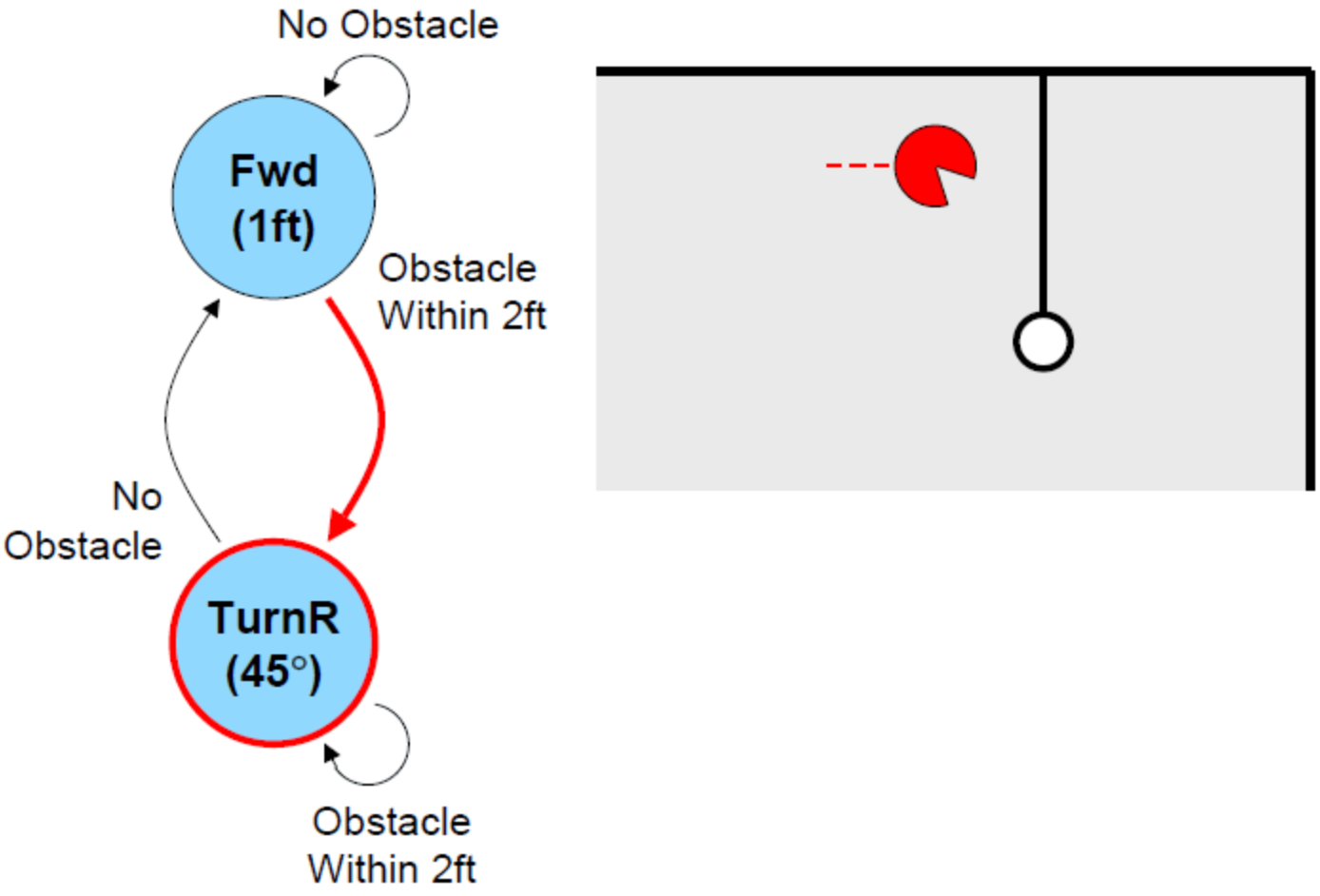


Figure 15: Finite state machine approach example [3]

High level control systems approaches: Finite State Machines

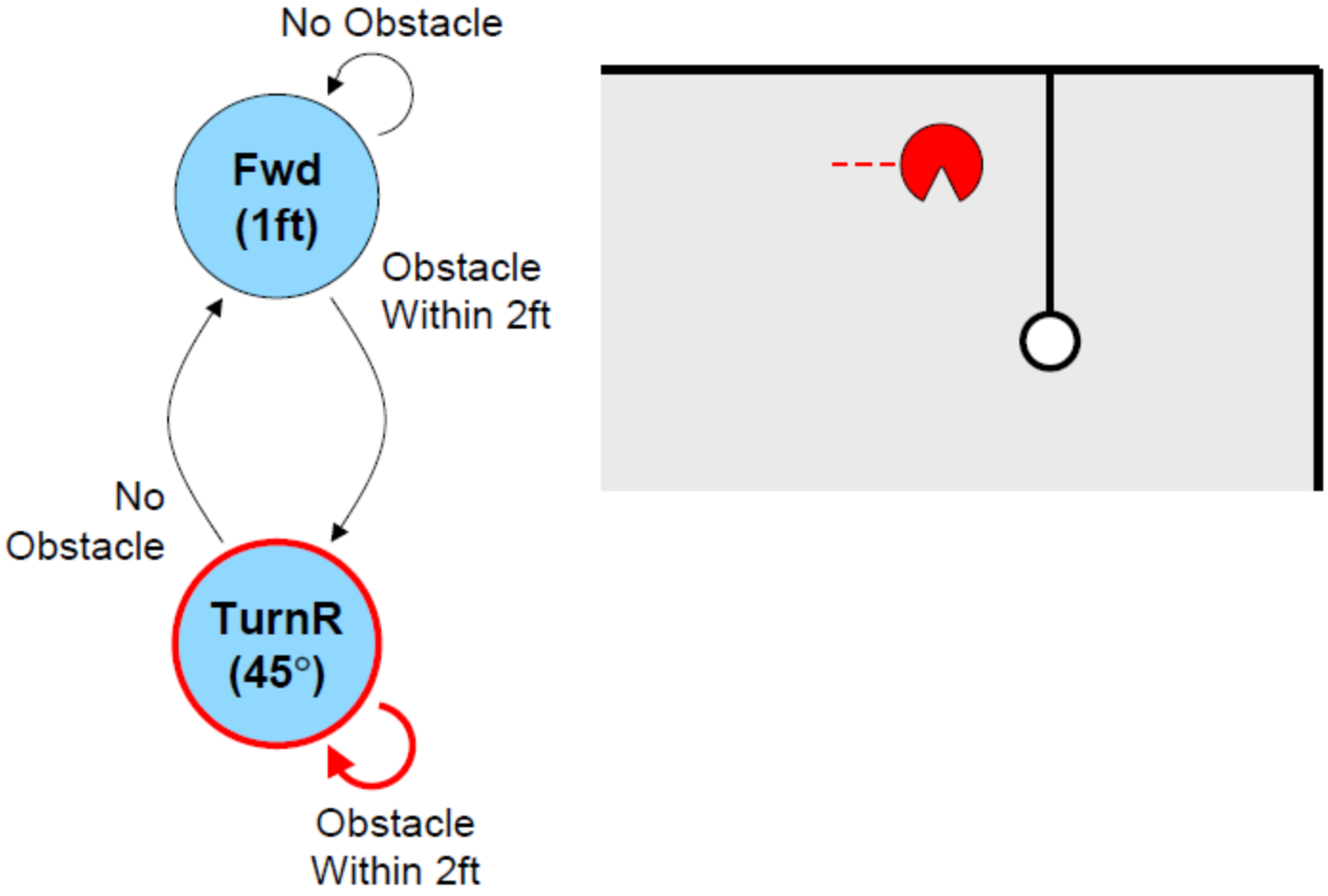


Figure 16: Finite state machine approach example [3]

High level control systems approaches: Finite State Machines

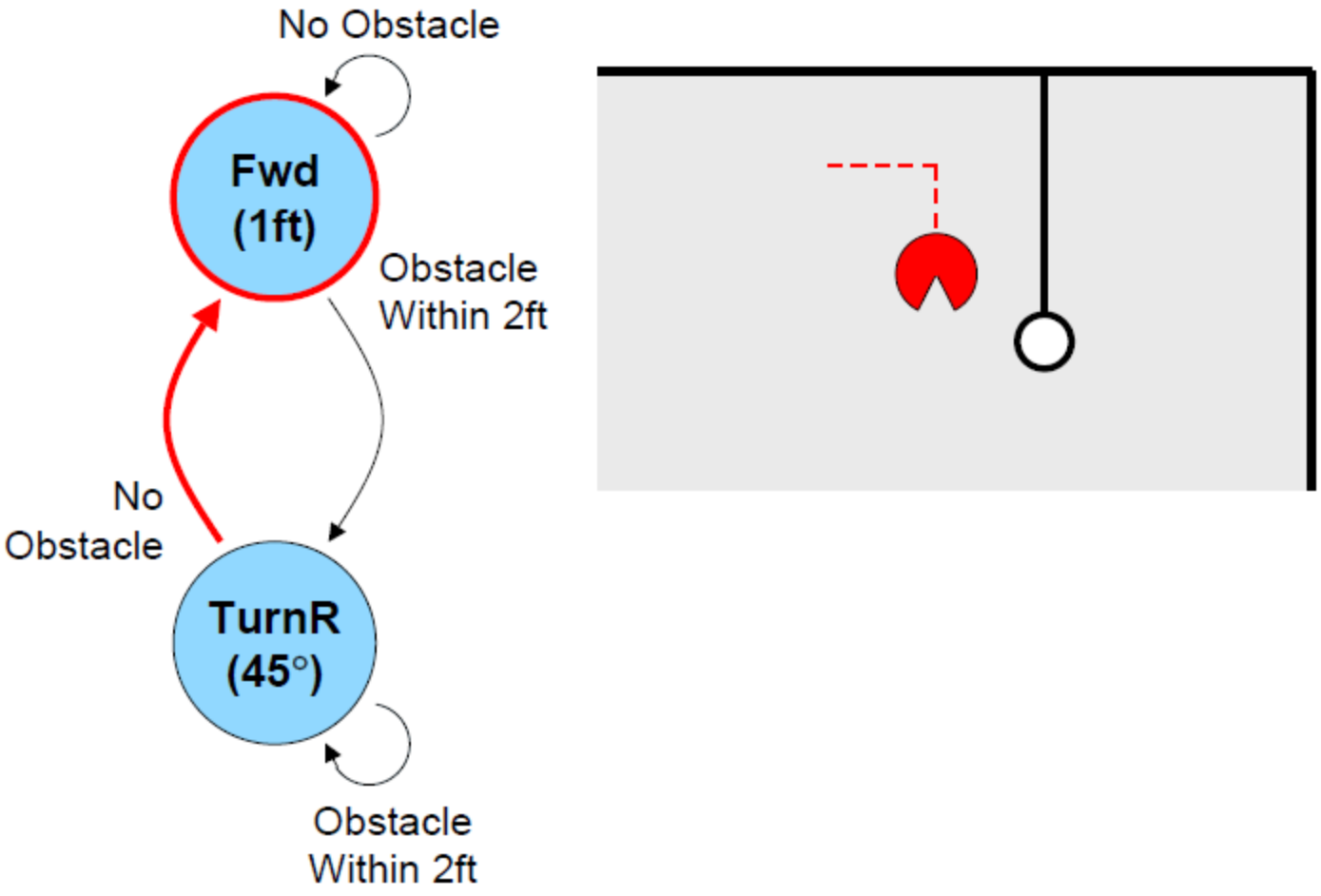


Figure 17: Finite state machine approach example [3]

High level control systems approaches: Finite State Machines

- Subsumption Architecture:
  - Generalization of finite state machine approach
  - Collection of modular controllers (FSMs) in a hierarchy where each module is treated as a light weight thread with priorities. These modules can share limited variables.
  - Implemented in code through nested if else statement
  - Common approach in many robots

High level control systems approaches: Finite State Machines

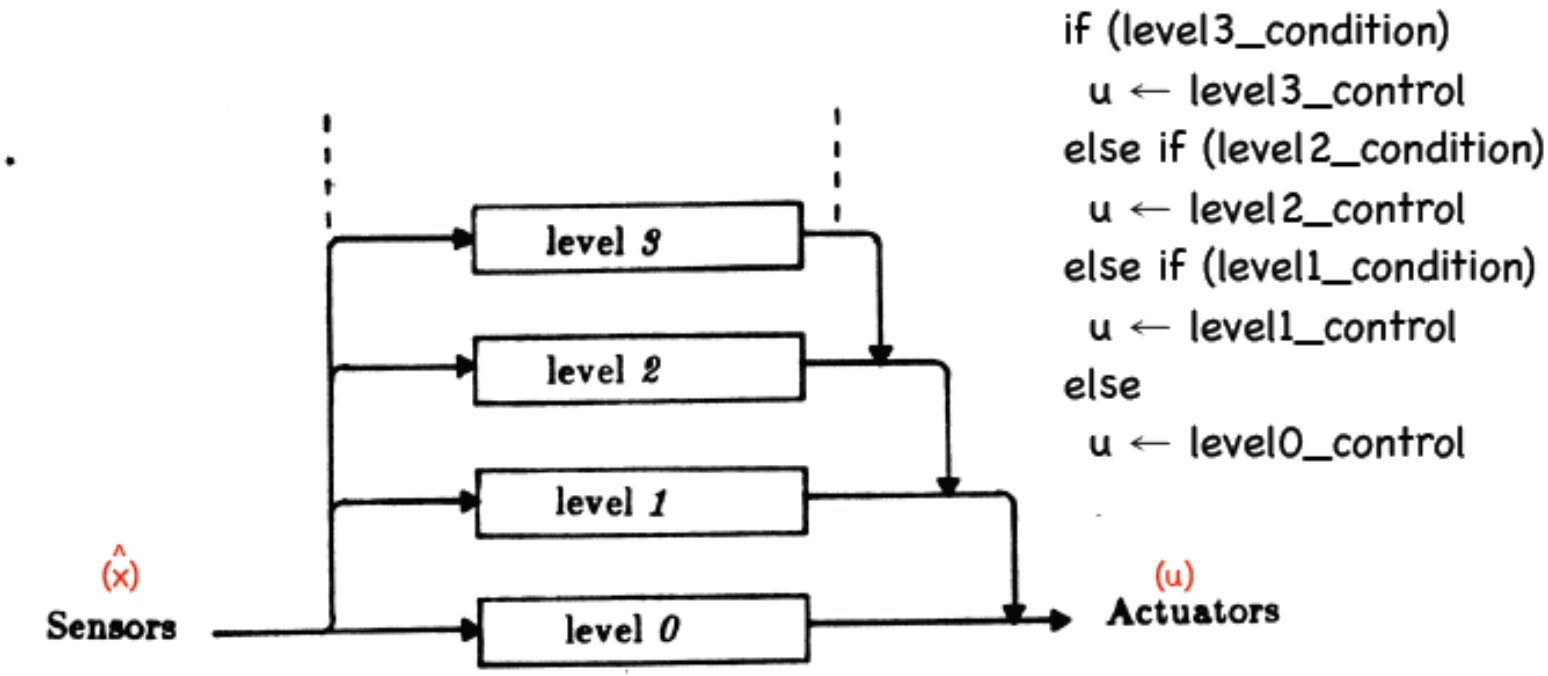


Figure 18: Finite state machine approach example [4]

Finite State Machines Implementation in ROS

- SMACH:
  - Python based – task level architecture
  - Each state is an executable task
  - Default outcome of each state:
    - Succeeded
    - Aborted
    - Preempted
  - States have database for calculations with input and output keys
  - Collection of containers and states
  - Aids in building complex behavior

Finite State Machines Implementation in ROS

- States of SMACH:
  - Generic State
  - CBState (Callback)
  - Simple Action State
  - Service State
  - Monitor State
- Containers of SMACH:
  - State Machine Container
  - Concurrence Container (Parallel execution, 2 callbacks)
  - Sequence Container
  - Iteration Container

Conclusion

- Many different types of control strategies exist for robots, choose one depending on complexity of the task to be achieved.
- Finite state machines can combine the model-sense-act and behavioral approaches and are modeled as closed loop control systems. FSMs offer a better approach for control.
- Finite state machines can be modularized and grouped into hierarchies to create a subsumption architecture.

Any Questions?

References

[1] : https://en.wikipedia.org/wiki/Robotics (Figure 1, Hardware and electrical component)
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[3] : “Control for mobile robots”, Cristopher Batten, Maslab IAP Robotics Course, January 7, 2005
[4] : “A robust layered control system for a mobile robot”, Brooks, 1985