Finite State Machines (FSMs)

Pure FSM form is composed of:

• A set of states
• A set of possible inputs (or events)
• A set of possible outputs
• A transition function:
  – Given the current state and an input: defines the output and the next state
Finite State Machines (FSMs)

States:
• Represent all possible “situations” that must be distinguished
• At any given time, the system is in exactly one of the states
• There is a finite number of these states
FSMs and Control

How do we relate FSMs to Control?

• States are our memory of recent inputs

• Inputs are?
FSMs and Control

How do we relate FSMs to Control?

• States are our memory of recent inputs

• Inputs are some processed representation of what the sensors are observing

• Outputs are ?
FSMs and Control

How do we relate FSMs to Control?
• States are our memory of recent inputs

• Inputs are some processed representation of what the sensors are observing

• Outputs are the control actions
FSMs: A Control Example

Suppose we have a vending machine:
• Accepts dimes and nickels
• Will dispense one of two things once $.20 has been entered: Jolt or Buzz Water
  – The “user” requests one of these by pressing a button
• Ignores select if < $.20 has been entered
• Immediately returns any coins above $.20
Vending Machine FSM

What are the states?
Vending Machine FSM

What are the states?

• $0
• $.05
• $.10
• $.15
• $.20
Vending Machine FSM

What are the inputs/events?
Vending Machine FSM

What are the inputs/events?

• Input nickel (N)
• Input dime (D)
• Select Jolt (J)
• Select Buzz Water (BW)
Vending Machine FSM

What are the outputs?
Vending Machine FSM

What are the outputs?
• Return nickel (RN)
• Return dime (RD)
• Dispense Jolt (DJ)
• Dispense Buzz Water (DBW)
• Nothing (Z)
Vending Machine Design

What is the initial state?
Vending Machine Design

What is the initial state?
• $S = 0$
Vending Machine Design

What can happen from $S = 0$?

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<th>Event</th>
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Vending Machine Design

What can happen from $S = \$0$?

What does this part of the diagram look like?

<table>
<thead>
<tr>
<th>Event</th>
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<tbody>
<tr>
<td>N</td>
<td>$.05</td>
<td>Z</td>
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<td>D</td>
<td>$.10</td>
<td>Z</td>
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<tr>
<td>J</td>
<td>$0</td>
<td>Z</td>
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<tr>
<td>BW</td>
<td>$0</td>
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Vending Machine Design

A piece of the state diagram:
Vending Machine Design

What can happen from $S = $0.05?

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Vending Machine Design

What can happen from $S = \$0.05$?

What does the modified diagram look like?

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<tr>
<th>Event</th>
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<tbody>
<tr>
<td>N</td>
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<td>BW</td>
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Vending Machine Design

A piece of the state diagram:
Vending Machine Design

What can happen from $S = $0.10?

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Vending Machine Design

What can happen from $S = 0.10$?

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<tr>
<th>Event</th>
<th>Next State</th>
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</thead>
<tbody>
<tr>
<td>N</td>
<td>$0.15$</td>
<td>Z</td>
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<td>D</td>
<td>$0.20$</td>
<td>Z</td>
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<td>J</td>
<td>$0.10$</td>
<td>Z</td>
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<td>BW</td>
<td>$0.10$</td>
<td>Z</td>
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Vending Machine Design

A piece of the state diagram:
Vending Machine Design

What can happen from S = $0.15?

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Vending Machine Design

What can happen from $S = \$0.15$?

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<tbody>
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<td>N</td>
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<td>$.20</td>
<td>RN</td>
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<tr>
<td>J</td>
<td>$.15</td>
<td>Z</td>
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<tr>
<td>BW</td>
<td>$.15</td>
<td>Z</td>
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Vending Machine Design

A piece of the state diagram:

[State diagram image]
Finally: what can happen from $S = 0.20$?

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Vending Machine Design

Finally, what can happen from $S = \$0.20$?

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<td>RD</td>
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<td>J</td>
<td>$0</td>
<td>DJ</td>
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<tr>
<td>BW</td>
<td>$0</td>
<td>DBW</td>
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Vending Machine Design

The complete state diagram:
FSMs in C

```c
int state = 0;    // Initial state
while(1) {
    <do some processing of the sensory inputs>
    switch(state) {
        case 0:
            <handle state 0>
            break;
        case 1:
            <handle state 1>
            break;
        case 2: ... 
    }
}
```
Finite State Machines

• Very useful tool to describe sequential behavior.
• But – when used for control, we deviate from the theory in several key ways
FSMs As Controllers

• Need code that translates sensory inputs into FSM events
• An FSM output can require an arbitrary amount of time
  – We will often implement this control action as a separate function call
• Control actions will not necessarily be fixed (but could be a function of sensory input)
FSMs As Controllers (cont)

- We might choose to leave some events out of the implementation
  - Only some events may be relevant to certain states

- When in a state, the FSM may also issue control actions (even when a new event has not arrived)
  - Again, this may be implemented as a function call
int state = 0; // Initial state
while(1) {
    // do some processing of the sensory inputs
    switch(state) {
        case 0:
            // handle state 0
            break;
        case 1:
            // handle state 1
            break;
        case 2: ...
    }
}
FSMs in C (some other possibilities)

```c
int state = 0;    // Initial state
while(1) {
    <do some processing of the sensory inputs>
    switch(state) {
        case 0:
            <handle state 0>
            break;
        :
        default:
            <handle default case>
            break;
    }
    <do some low-level control>
}
```
FSMs in C: Processing for Individual States

```c
case STATE_10cents:
    // $.10 has already been deposited
    switch(event) {
        case EVENT_NICKEL: // Nickel
            state = STATE_15cents; // Transition to $.15
            break;
        case EVENT_DIME: // Dime
            state = STATE_20cents; // Transition to $.2
            break;
        case EVENT_JOLT: // Select Jolt
        case EVENT_BUZZ: // Select Buzzwater
            display_NOT_ENOUGH();
            break;
        case EVENT_NONE: // No event
            break; // Do nothing
    }
};
break;
```
A Note on “Style” in C

- The numbers that we assigned to the different states are arbitrary (and at first glance, hard to interpret)
- Instead, we can define constant strings that have some meaning

- Replace: 0, 1, 2, 3, 4, 5
- With: STATE_00, STATE_05, STATE_10, STATE_15, STATE_20
A Note on “Style” in C

In C, this is done by adding some definitions to the beginning of your program (either in the .c file or the .h file):

```c
#define STATE_00   0
#define STATE_05   1
#define STATE_10   2
#define STATE_15   3
#define STATE_20   4
```