EE 109 Unit 6

Software State Machines

What is state?

- It's late at night. You see a DPS officer approaching you. Are you happy?
  - _____
  - Your _____.
  - You've been _____.
- You press the PAUSE/PLAY button on a video player. What happens?
  - It _____ on what was happening _____.
  - We also want to stay in that mode _____ after the button is released.
  - This requires maintaining _____, which helps us _____ the necessary information for the system to operate correctly

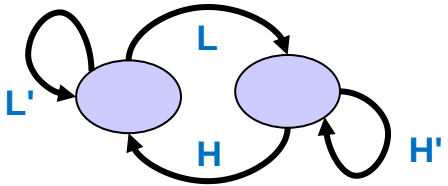
What is state?

- **State**: Everything that must be _____ to _____ **the inputs** (think the play/pause button) and/or to produce **outputs at appropriate** _____
  - Usually, state is required for _____**-dependent** behavior
- As a human:
  - Your "state" determines your interpretation of your senses and thoughts
  - The _____ of all your previous _____ is what is known as state
- In a circuit:
  - State refers to all the bits being remembered in _____ or _____
- In software:
  - State refers to all the _____ values that are being used

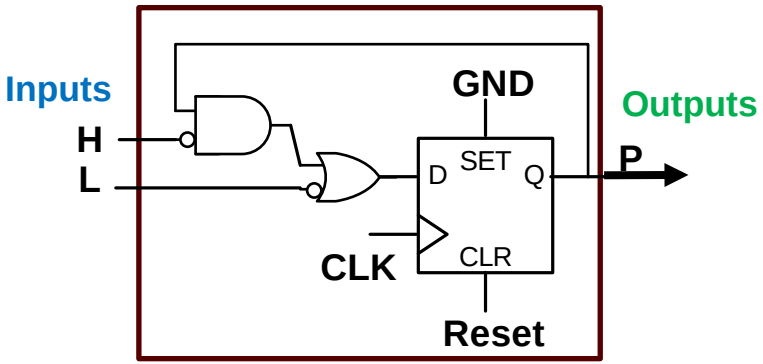
State Machines and State Diagrams

- Hardware and software components that utilize state are referred to as **state machines** (or FSMs = Finite State Machines)
- A state machine is modeled by a **state** _____ (i.e. a flow-chart)
- **FSMs are a very nice problem-solving approach/strategy**
  - If you can model your design with a state diagram, there are **straightforward** _____ to either software (what we'll study today) or hardware (later in the semester)

State Diagram
(Abstract representation of FSM operation)

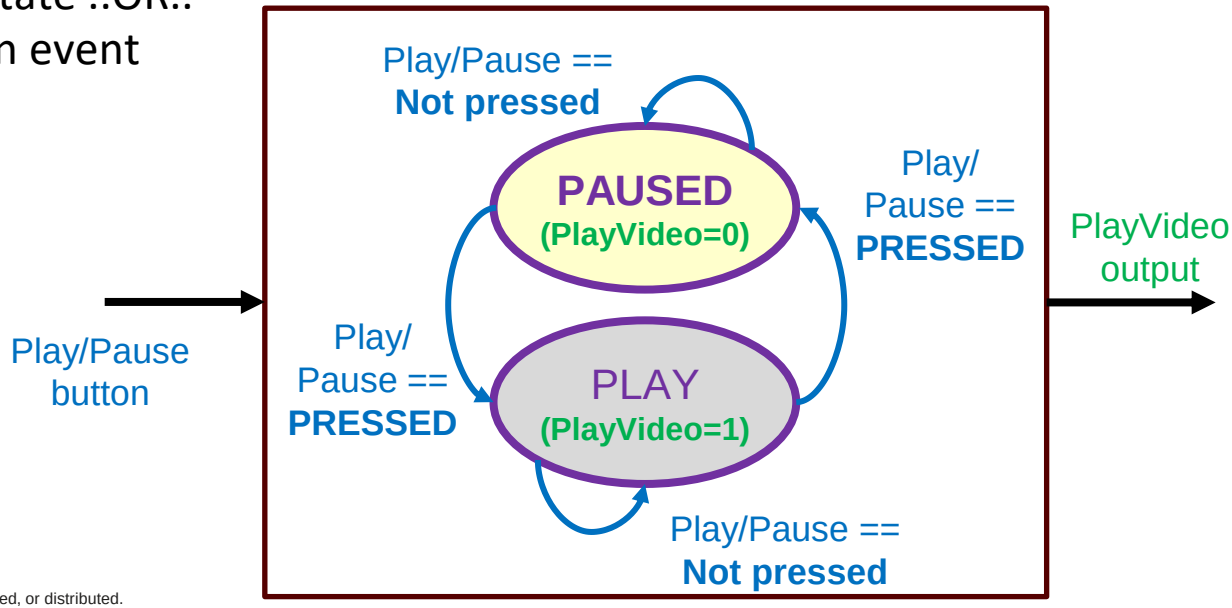


State Machine



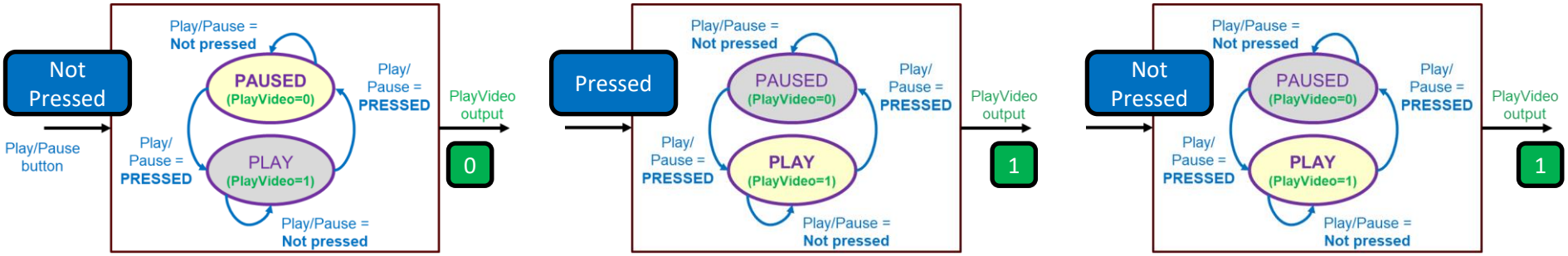
State Diagrams

- The **state diagram** should have 3 parts:
  - The _____ as circles or boxes
  - The _____ as arrows labeled by **input** conditions
  - The _____, which can be generated
    when in a particular state ..OR..
    on a specific transition event



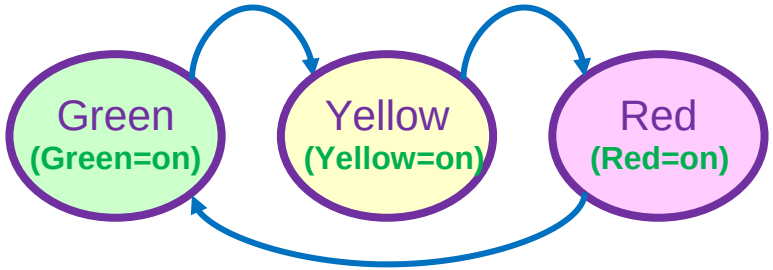
Operation

- **State** is used to _____ the **outputs** even while the **inputs** are not activated
- When an _____ is activated, the _____ can be updated…
- …and remembered after the **input** has deactivated



Another Example: Traffic Light

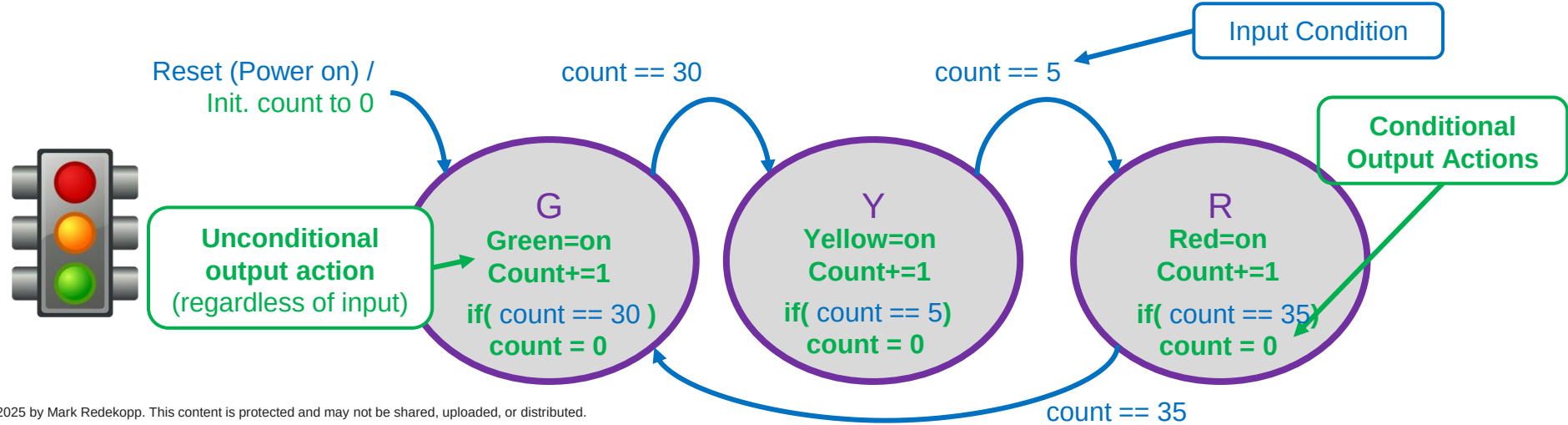
- State machines can be used to trigger **time-dependent** updates
  - Consider a system controlling the traffic lights at an intersection
  - There are no _____ inputs to indicate when the light should change
  - Instead, the **outputs** must change/transition based on _____.
  - The **state** helps determine what the next **output** should be.



If a transition does not have a condition, it means it is unconditional. Sometimes we may just label it with **1 (true)**

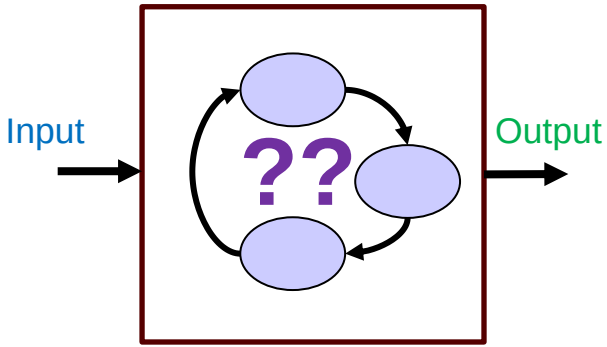
Time-Based Conditions

- Oftentimes we can use some kind of internal _____ to control when we transition states
  - Suppose our internal SW loop cycles every 1 second
- We can generate our **output/actions**
  - On each iteration, based on _____ (Green, Yellow, Red lights; increment counter)
  - On specific iterations based on other _____ (if count is 30, reset it to 0)



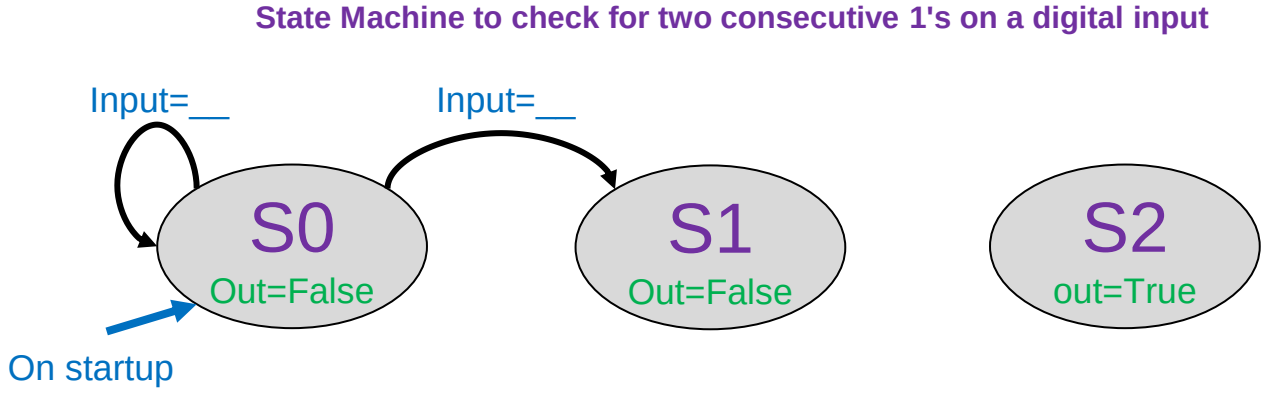
FSM Example 1-1

- Consider a system with one digital input and one output.
- The output should be true whenever the input is 1 for two consecutive time units
  - `Input:  0 1 0 1 1 0 1 1 1 0`
  - `Output: 0 0 0 0 0 1 0 0 1 1`
- Does this system need state?
- To help answer the question:
  - "The input is a 1 right now, should the output be true?"
  - _____whether the input was true _____ as well? We _____!



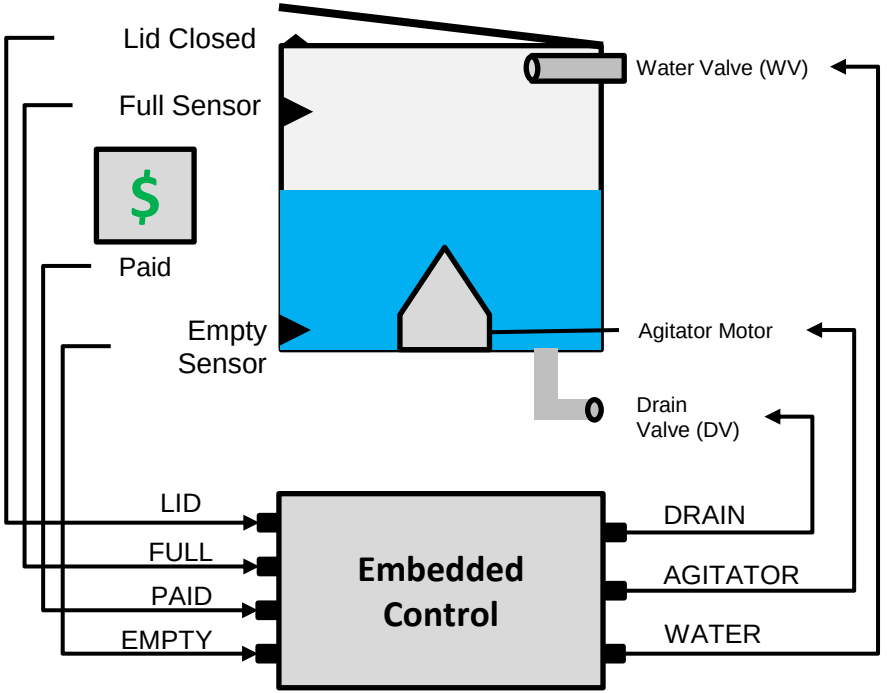
FSM Example 1-2

- Draw the state diagram for the system that outputs true (1) whenever the input has been 1 for two consecutive time periods



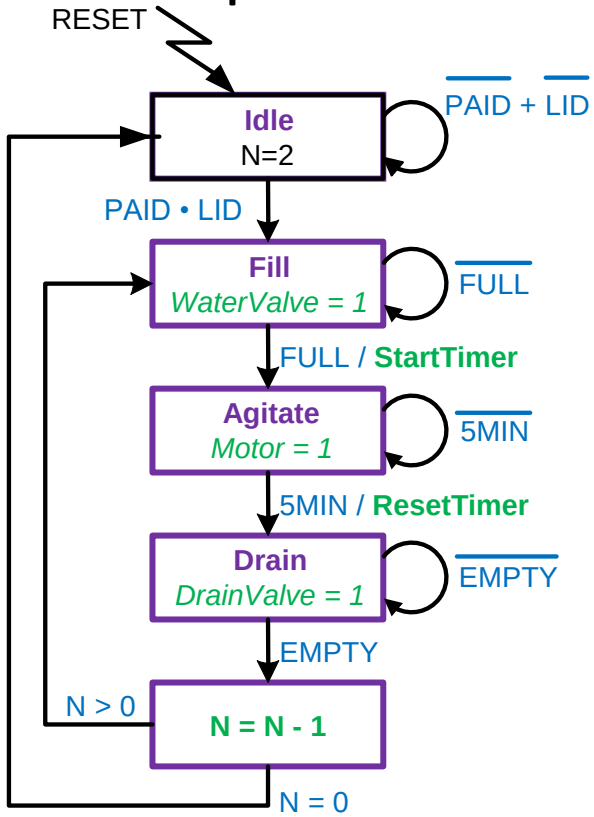
FSM Example 2: Washing Machine

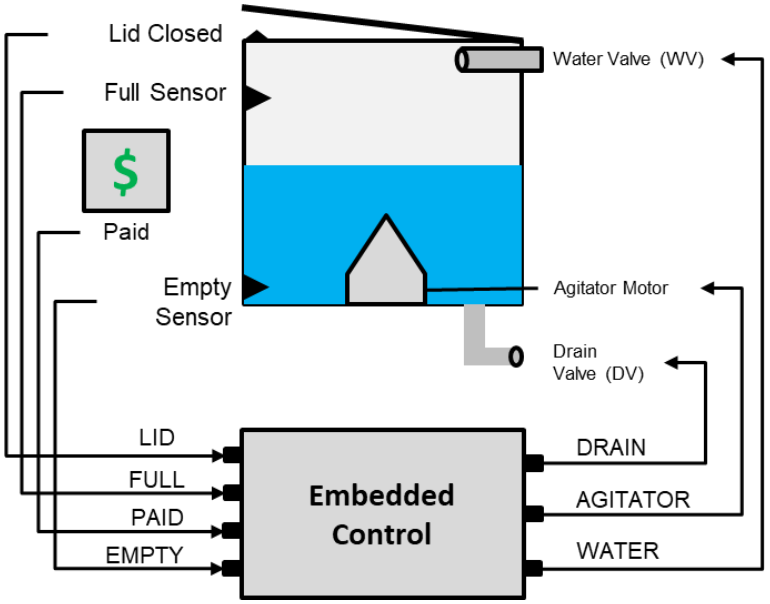
- Consider the design of an embedded controller for a coin/card-operated laundry machine.
- Consider the inputs and outputs



Washing Machine State Diagram

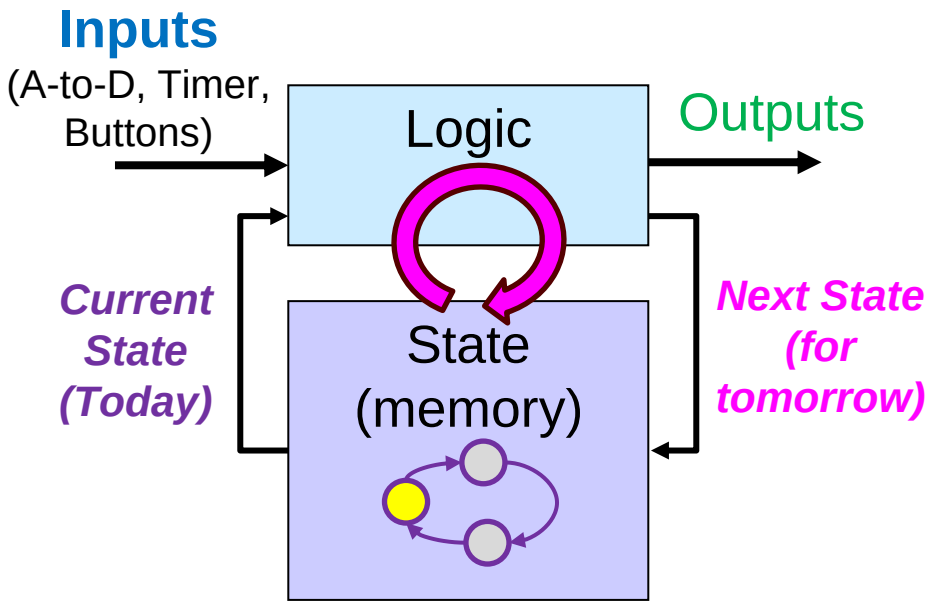
- Examine a potential state machine for this design.





A Day in the Life of a State Machine

- State machines operate time step by time step
  - **Human analogy: _____ (see inset)**
- Each time step, the state machine use current (today's) state to:
  - Determine which inputs to examine to determine the **next (tomorrow's) state**
  - Determine any **outputs** and **actions** to take (sometimes based on the inputs)

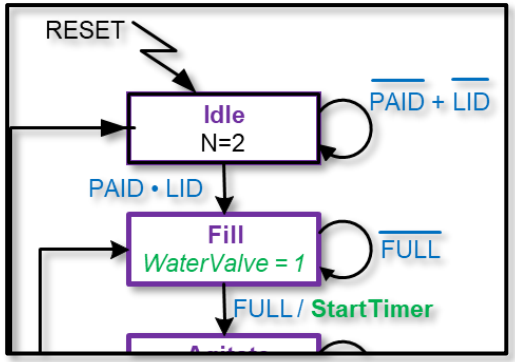


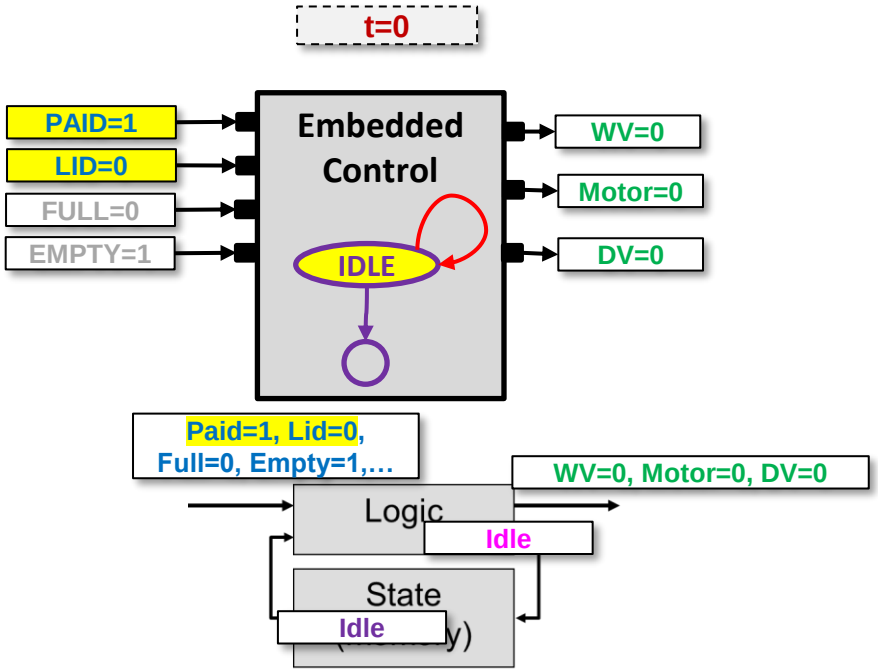
Human analogy: day-by-day

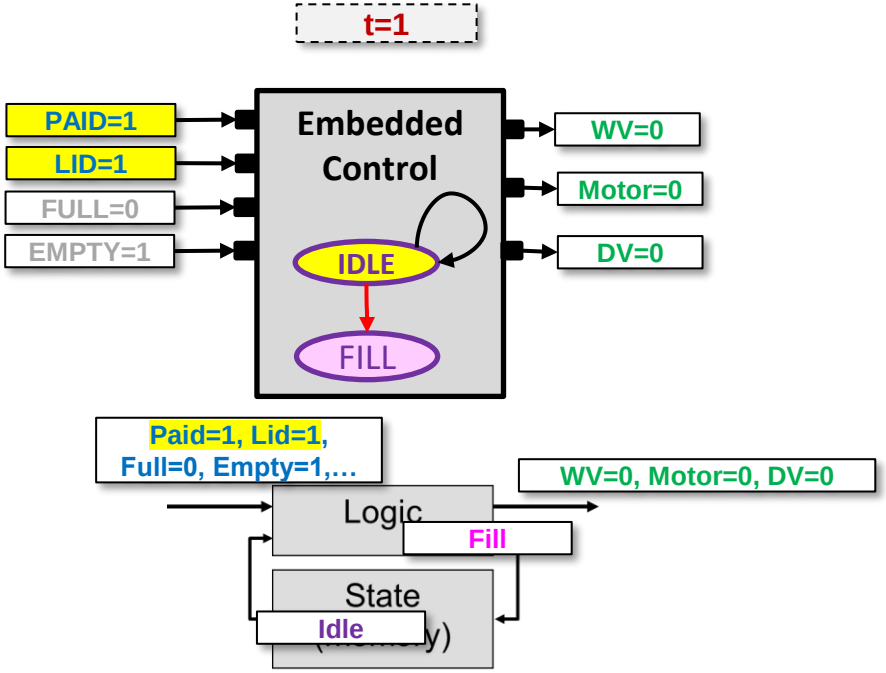
- Wake up with only a **memory** of the **current state**
- Use **current state** (and inputs) to determine **outputs** and **actions** for today
- Use **current state** and **inputs** to update state (i.e. determine state for tomorrow)
- Go to sleep and repeat same process tomorrow

State Machine Operation (1)

- Notice how the current state helps identify which inputs "matter" at specific times

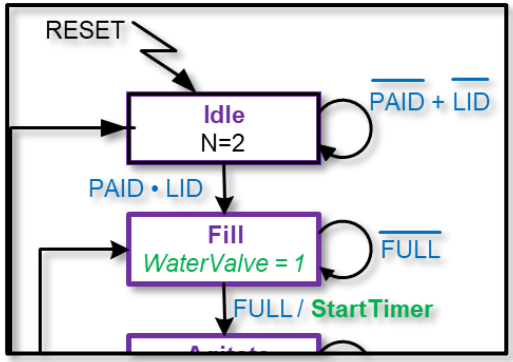


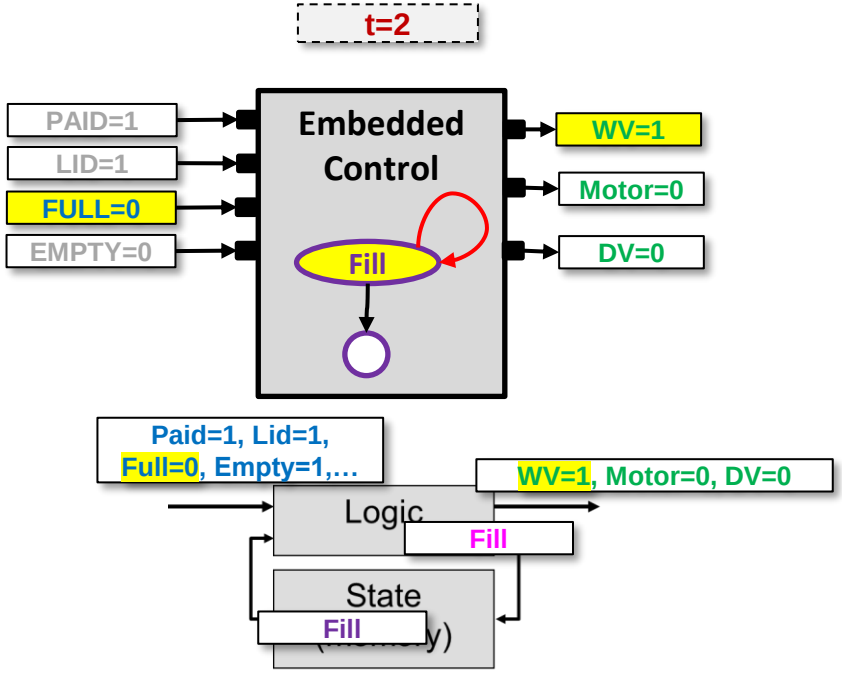


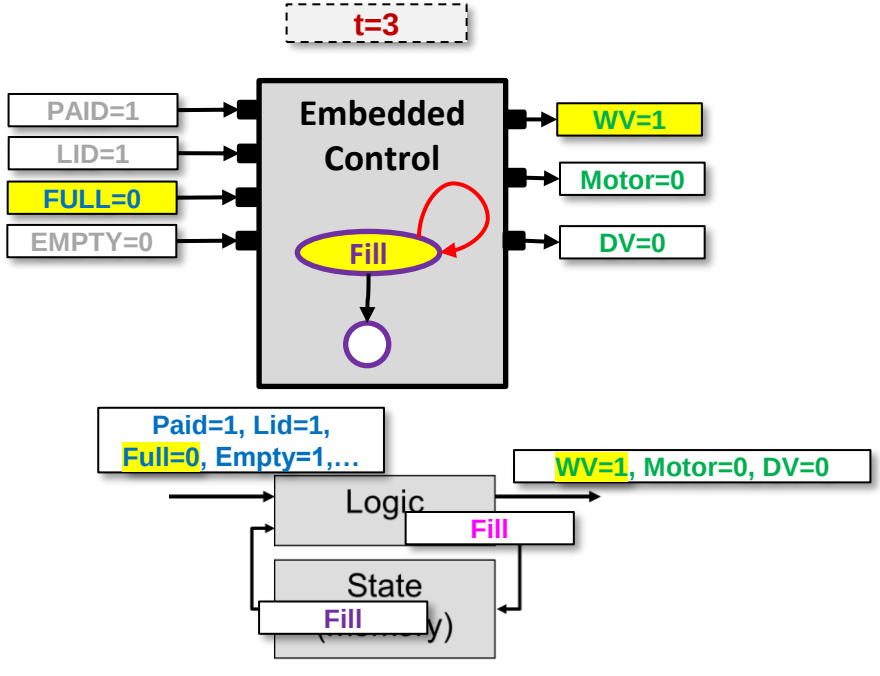


State Machine Operation (2)

- When the state changes, we produce new output values and may look at a new set of inputs

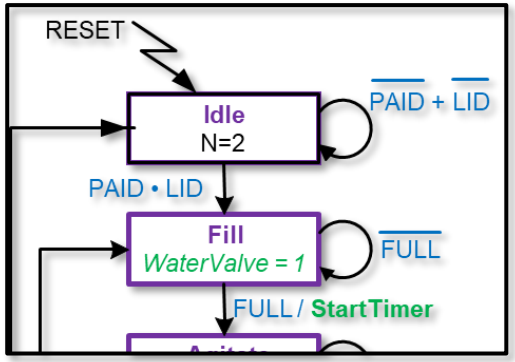


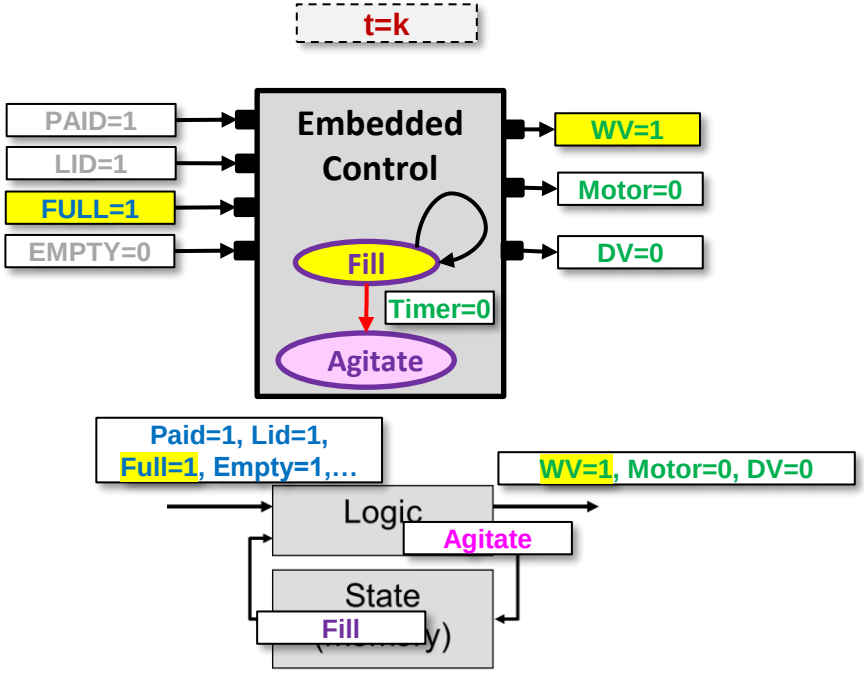


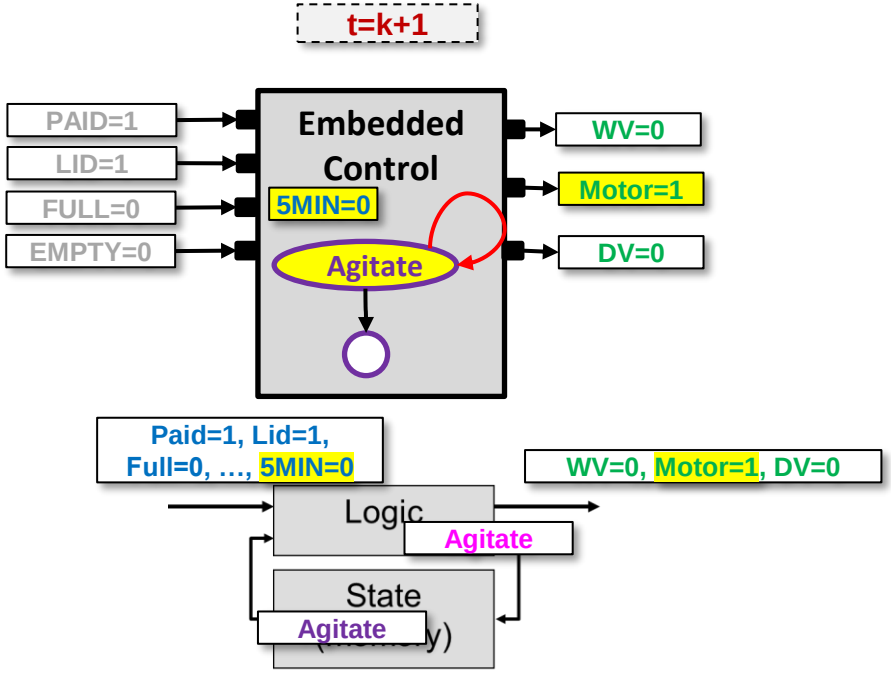


State Machine Operation (3)

- We can use internal "time" inputs to control when we change states.



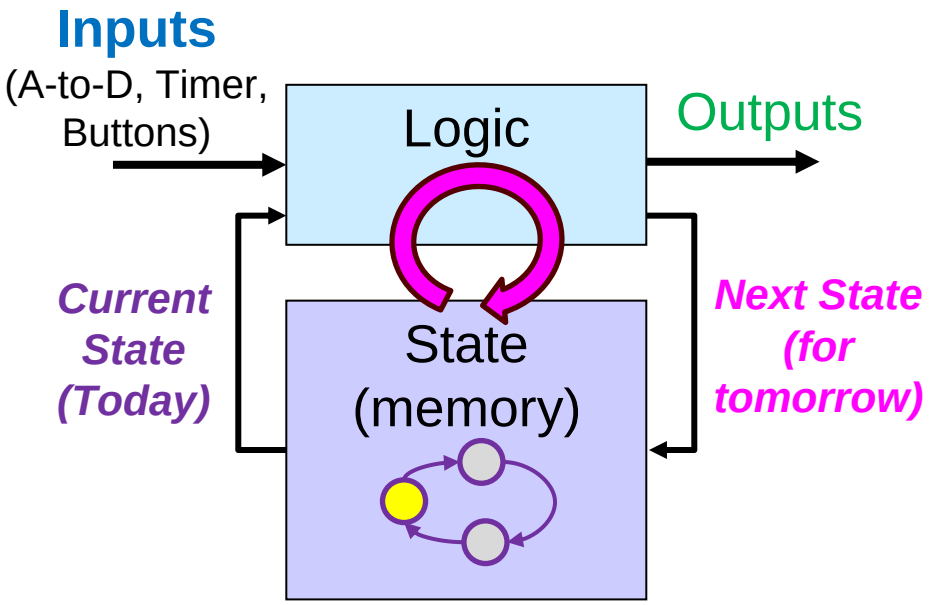




IMPLEMENTING STATE MACHINES IN SOFTWARE

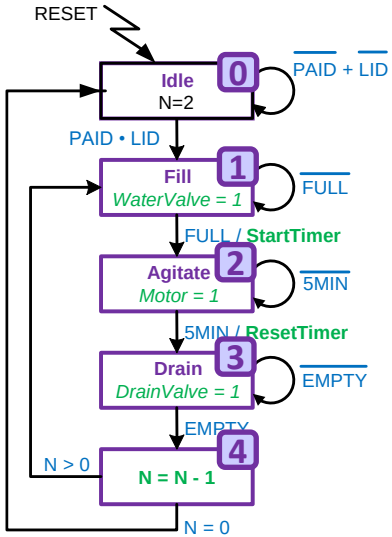
Software and Hardware Implementation

- Software Implementation
  - **Current State = just a _____**
  - **Input**/**output** Logic = ___ statements to update the next state or produce outputs
    - `if(state == 0 && input == 1) { state = 1; output = 0; }`
  - Transitions triggered by input or timers
  - **We'll start by implementing state machines in SW**
- Later in the semester we'll see how to implement state machines in hardware



Coding State Machines 1

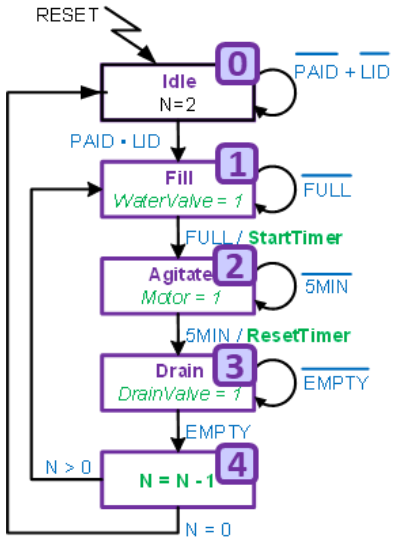
- Setup (declare and initialize) your state variable
  - Choose some numeric code for each state: 0=Idle, 1=Fill, 2 = Agitate, etc.
- Use **one while** loop and a single _____ (or timer) to repeat the "day-in-the-life" routine of a state machine




```
int main(){
  char currst = 0, n = 2; int timer;
  // other initialization
  while(1) {




    _delay_ms(100);
  }
  return 0;
}
```

Coding State Machines 2

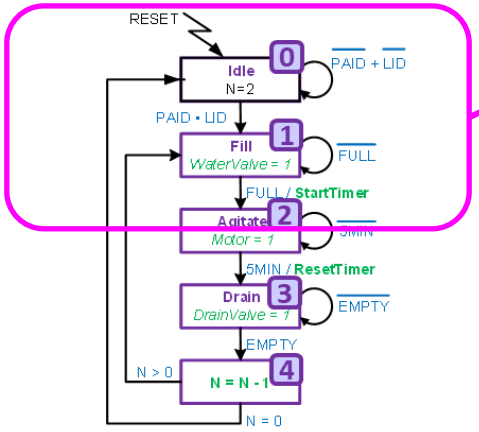
- In the while loop, setup a series of _____ statements to determine what state you are in "today"




```
int main(){
  char currst = 0, n = 2; int timer;
  // other initialization
  while(1) {

    if( currst == 0 ){ // Idle
      // code pertinent to Idle
    }
    else if( currst == 1 ){ // Fill
      // code pertinent to Fill
    }
    else if( currst == 2 ){ // Agitate
      // code pertinent to Agitate
    }
    else if( currst == 3 ){ // Drain
      // code pertinent to Drain
    }
    else { // Decrement
      // code pertinent to last state
    }
    _delay_ms(100);
  }
  return 0;
}
```

Coding State Machines 3a

- _____ the inputs at the start of each iteration (each day)
- In each if statement for the current state, use a **nested if statement** for the **input conditions** to determine **next state** and **output** actions

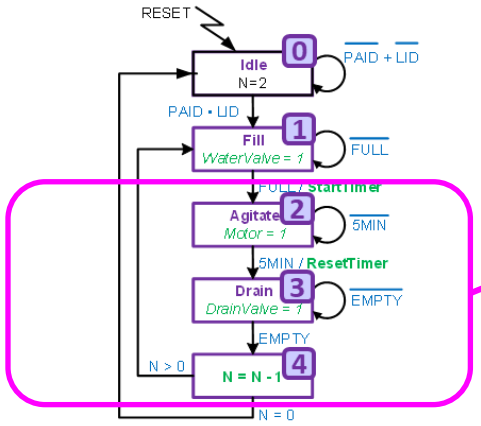



```
int main(){
  char currst = 0, n = 2; int timer;
  // other initialization
  while(1) {
    char paid = PIND & (1 << PD0);
    char lid = PIND & (1 << PD1);
    char full = PIND & (1 << PD2);
    if( currst == 0 ){ // Idle
      if(paid && lid)
       { currst = 1; /* Goto Fill */ }
    }
    else if( currst == 1 ){ // Fill
      PORTC |= (1 << PC0); // WV=1
      if(full)
        { currst = 2; timer = 0; }
    }
    else if( currst == 2 ){ // Agitate
      PORTC &= ~(1 << PC0); // WV=0
      PORTC |= (1 << PC1);  // Motor=1
      ...
    }
    ...
    _delay_ms(100);
  }
  return 0;
}
```

Notice the nested IF statement structure used for state machines.

Coding State Machines 3b

- Sample the inputs at the start of each iteration (each day)
- In each if statement for the current state, use a nested if statement for the input conditions to determine next state and output actions




```
int main(){
  char currst = 0, n = 2; int timer;
  while(1) {
    ...
    char full = PIND & (1 << PD2);
    char empty = PIND & (1 << PD3);
    ...
    else if( currst == 2 ){ // Agitate
      timer++;
      PORTC &= ~(1 << PC0); // WV=0
      PORTC |= (1 << 1); // Motor=1
      if(timer=3000) // 5 min
        { currst = 3; timer = 0; }
    }
    else if( currst == 3 ){ // Drain
      PORTC &= ~(1 << PC1); // Motor=0
      PORTC |= (1 << PC2); // DV = 1
      if(empty) { currst = 4; }
    }
    else { if(--n > 0) currst = 1;
           else        currst = 0;  }
    _delay_ms(100);
  }
  return 0;
}
```

The final "else" is equivalent to "else if (currst == 4)".

Notice the nested IF statement structure used for state machines.

Enumerations

- It would be nice to use _____ **names** for states, rather than numbers
- In C/C++, _____ associate an integer code (number) with a symbolic name
- Syntax:
  `enum [optional_collection_name] {SymName1, SymName2, … SymNameN}`
  - SymName1 = 0
  - SymName2 = 1
  - …
  - SymNameN = N-1
- Use symbolic item names in your code and compiler will replace the symbolic names with corresponding integer values…**makes the code much more _____!**

```
const int IDLE=0;
const int FILL=1;
const int AGITATE=2;
...
char state = IDLE;
...
if(state == FILL && full == true) {
  state = AGITATE;
}
```

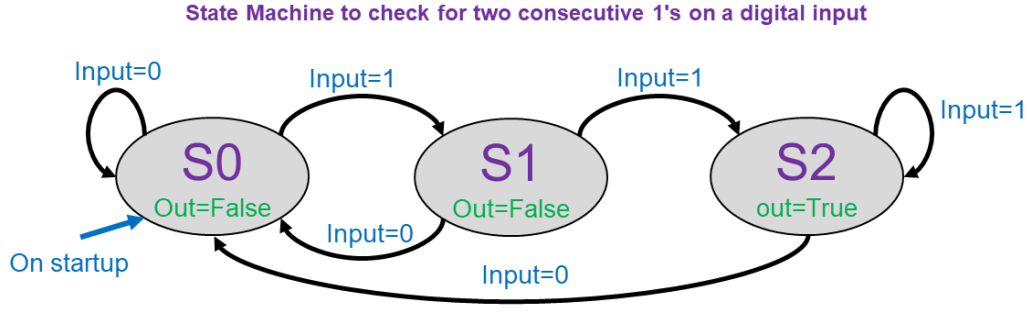
Option 1: Hard coding symbolic state names with given codes. Better than nothing, but enumerations (below) are often preferred.

```
// First enum item is associated with code 0
enum States {IDLE, FILL, AGITATE, DRAIN, DEC};
// auto-assign 0     1      2        3    4
char state = IDLE;    // same as state = 0;
...
if(state == FILL && full == true) {
   state = AGITATE;   // same as state = 2;
}
```

Option 2: Using enumeration to simplify state coding and make the code more readable!

Another Example: 2 Consecutive 1's FSM

- How would we begin to code the implementation of this state machine?
  - Start with an enum to list the states
  - Declare and initialize your state variable
  - Choose or determine the rate / delay at which transitions in state should be made or output actions must occur.
    - 1 iteration of the loop handles 1 time step (a "day")

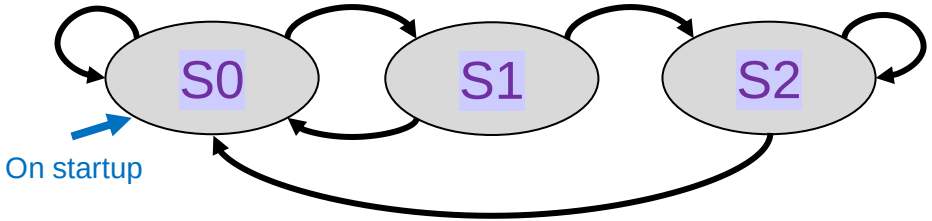



```
enum { S0, S1, S2 };
// input = PD0,  output = PD7
int main()
{ // be sure to init. state
  unsigned char state=S0, input;
  while(1)
  {
    _delay_ms(10); // use approp. Time
  } return 0;
}
```

Consecutive 1's FSM – State

- Again, notice the structure:
  - The purple 'if' statements determine which state we are in

State Machine to check for two consecutive 1's on a digital input

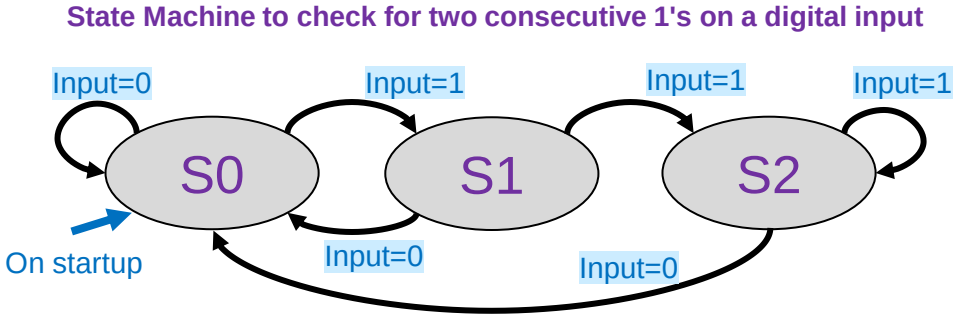


Select current state

```
enum { S0, S1, S2 };
// input = PD0,  output = PD7
int main()
{ // be sure to init. state
  unsigned char state=S0, input;
  while(1)
  {
    if(state == S0){


    }
    else if(state == S1){


    }
    else { // state == S2


    }
    _delay_ms(10); // use approp. Time
  } return 0;
}
```

Consecutive 1's FSM – Transitions

- Again, notice the structure:
  - The nested orange 'if' statements determine which **input conditions** are true to determine how we **update the state**



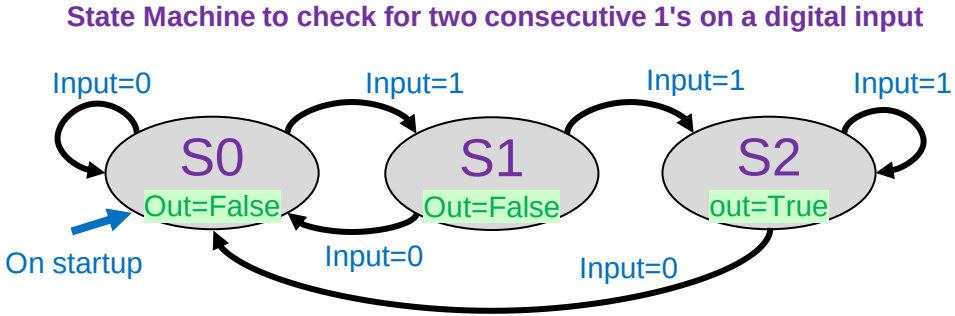

```
enum { S0, S1, S2 };
// input = PD0,  output = PD7
int main()
{ // be sure to init. state
  unsigned char state=S0, input;
  while(1)
  {
    input = PIND & (1 << PD0);
    if(state == S0){

      if( input ){ state = S1; }
    }
    else if(state == S1){

      if( input ){ state = S2; }
      else { state = S0; }
    }
    else { // state == S2

      if( !input ) { state = S0; }
    }
    _delay_ms(10); // use approp. Time
  } return 0;
}
```

Select current state

Select input val.

Consecutive 1's FSM – Output Actions

- Again, notice the structure:
  - We can add appropriate **output** actions




```
enum { S0, S1, S2 };
// input = PD0,  output = PD7
int main()
{ // be sure to init. state
  unsigned char state=S0, input;
  while(1)
  {
    input = PIND & (1 << PD0);
    if(state == S0){
      PORTD &= ~(1 << PD7);
      if( input ){ state = S1; }
    }
    else if(state == S1){
      PORTD &= ~(1 << PD7);
      if( input ){ state = S2; }
      else { state = S0; }
    }
    else { // state == S2
      PORTD |= (1 << PD7);
      if( !input ) { state = S0; }
    }
    _delay_ms(10); // use approp. Time
  } return 0;
}
```

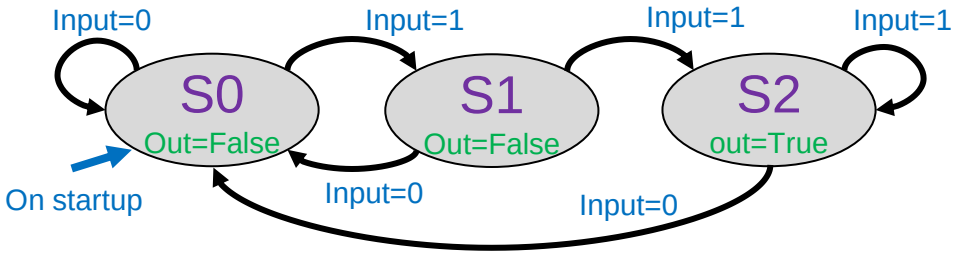
Select current state

Select input val.

Consecutive 1's FSM – Summary

- Again, notice the structure:
  - 1 iteration of the loop handles 1 time step (a "day")
  - The purple 'if' statements determine which **state** we are in and the nested orange 'if' statements determine which **input conditions** are true to determine how we **update the state** and what **output actions** we take
  - Some delay before the next iteration begins

State Machine to check for two consecutive 1's on a digital input



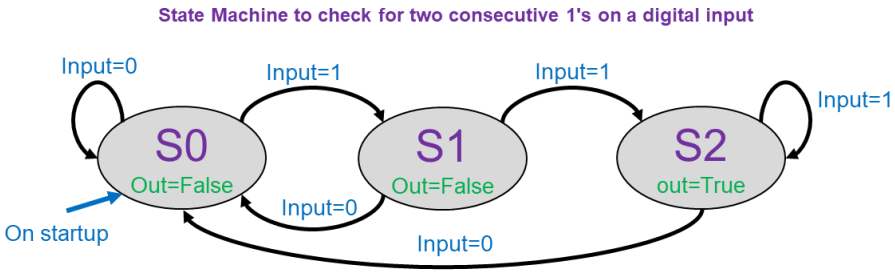
Select current state

Select input val.

```
enum { S0, S1, S2 };
// input = PD0,  output = PD7
int main()
{ // be sure to init. state
  unsigned char state=S0, input;
  while(1)
  {
    input = PIND & (1 << PD0);
    if(state == S0){
      PORTD &= ~(1 << PD7);
      if( input ){ state = S1; }
    }
    else if(state == S1){
      PORTD &= ~(1 << PD7);
      if( input ){ state = S2; }
      else { state = S0; }
    }
    else { // state == S2
      PORTD |= (1 << PD7);
      if( !input ) { state = S0; }
    }
    _delay_ms(10); // use approp. Time
  } return 0;
}
```

A Potential Alternate Structure

- Sometimes, it may be easiest to _____ :
  - the **state transition code** and
  - the **output action** code
- We can use separate ____ sequences.



State transitions

Outputs

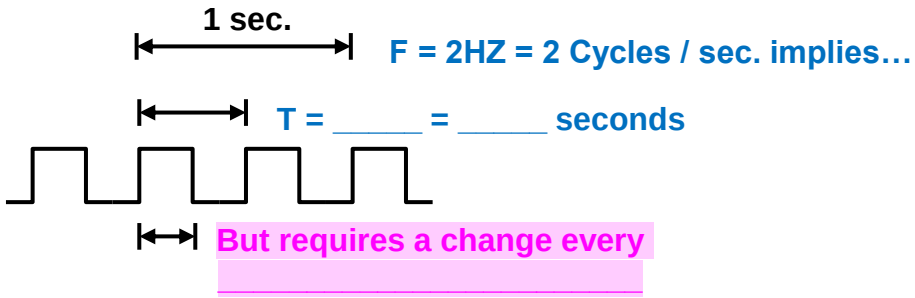
```
enum { S0, S1, S2 };
int main() {
  unsigned char state=S0, input;
  while(1) {
    // state transitions
    input = PIND & (1 << PD0);
    if(state == S0){
      if( input ){ state = S1; }
    }
    else if(state == S1){
      if( input ){ state = S2; }
      else { state = S0; }
    }
    else { // state == S2
      if( !input ) { state = S0; }
    }
    // output actions
    if( state == S2)
      PORTD |= (1 << PD7);
    else
      PORTD &= ~(1 << PD7);
    _delay_ms(10); // use approp. Time
  } return 0;
}
```

State Machines as a Problem-Solving Technique

- Modeling a problem as a state machine is a powerful problem-solving tool
- When you need to write a program, design HW, or solve a more abstract problem at least consider if it can be modeled with a state machine
  - Ask questions like:
    - What do I need to remember to interpret my inputs or produce my outputs? [e.g. Checking for two consecutive 1's]
    - Is there a distinct sequence of "_____" or "_____" that are used (each step/mode is a state) [e.g. Washing machine, etc.]

A Note About Timing

- Write a program to blink an LED at **2HZ**
- What delays should you use?




```
int main()
{
  // Initialization
  while(1)
  {
     PORTD |= (1 << 7);  // LED on PD7
     _delay_ms(_______);
     PORTD &= ~(1 << 7);
     _delay_ms(_______);
  }
  return 0;
}
```

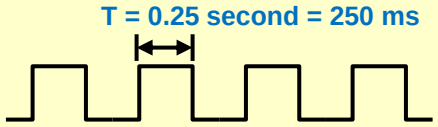
- If all we are doing is blinking, we can simplify to use an XOR to flip the output bit

```
int main()
{
  // Initialization
  while(1)
  {
     PORTD ^= (1 << 7); // LED on PD7
     _delay_ms(_______);
  }
  return 0;
}
```

Tunnel Vision (1)

- Consider a program that constantly monitors several inputs and takes appropriate actions:
  - If button1 is pressed it should blink an LED 10 times at a rate of 2 HZ
  - If button2 is pressed it should output something to the LCD screen
  - If button3 is pressed it should enable a motor
  - And even more tasks…
- To do something 10 times, it would be easiest to use a for loop, RIGHT?!?

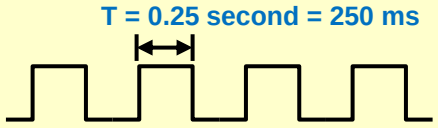
```
// Ad-hoc implementation
int main()
{
  while(1)
  {
     int i;
     if(checkInput(1) == 0) {
       for(i=0; i < 10; i++) {
          blink(250); // on for 250, off for 250
          // delays are in the blink() functions
       }
     }
     if(checkInput(2) == 0) {
       // output to LCD
     }
     if(checkInput(3) == 0) {
       // enable motor
     }
     if(...) {
       // even more tasks
     }
  }
  return 0;
}
```



Tunnel Vision (2)

- Consider a program that constantly monitors several inputs and takes appropriate actions:
  - If button1 is pressed it should blink an LED 10 times at a rate of 2 HZ
  - If button2 is pressed it should output something to the LCD screen
  - If button3 is pressed it should enable a motor
  - And even more tasks…
- To do something 10 times, it would be easiest to use a for loop, RIGHT?!?
- ____! When we are in the for loop, we would _____ be performing our _____ and miss actions.

```
// Ad-hoc implementation
int main()
{
  while(1)
  {
     int i;
     if(checkInput(1) == 0) {
       for(i=0; i < 10; i++) {
          blink(250); // on for 250, off for 250
          // what if button 2, 3, ... are pressed?
       }
     }
     if(checkInput(2) == 0) {
       // output to LCD
     }
     if(checkInput(3) == 0) {
       // enable motor
     }
     if(...) {
       // even more tasks
     }
  }
  return 0;
}
```



A Better Approach

To keep many things going at once, cycle through all the tasks doing only a short / small amount of the task at a time!

A Better Approach

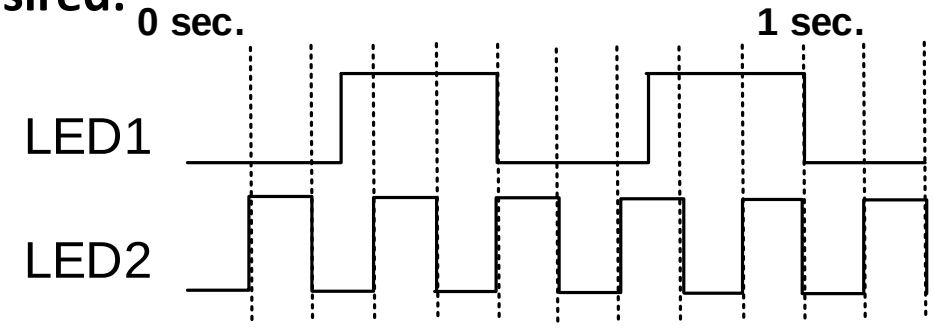
- Instead, perform _____ **per** iteration, tracking your _____!
- This allows other checks and actions to be performed after each single blink
- You can use your count as a "_____" variable:
  - cnt: 0-9 tracks how many blinks
  - cnt: 10 DONE/OFF
- …or use a separate state variable (**s=1**: counting, **s=0**: DONE/OFF) in combination with **cnt**
- Every time we press button 1, we _____ the cnt to start 10 more blinks

Other checks and actions

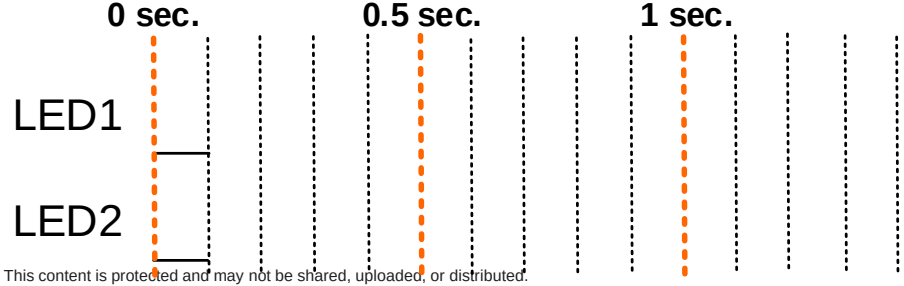
```
// Ad-hoc implementation
int main()
{
  int cnt=10;
  while(1)
  {
     if(checkInput(1) == 0) {
       cnt=0;
     }
     if(cnt < 10) {
       blink(250); // 1 blink per iter.
       cnt++;
     }
     if(checkInput(2) == 0) {
       // output to LCD
     }
     if(checkInput(3) == 0) {
       // enable motor
     }
     if(...) {
       // more tasks
     }
  }
  return 0;
}
```

Operations at Different Rates (1)

- Consider a program to blink one LED at a rate of 2 Hz and another at 5 Hz at the same time
- **Desired:**



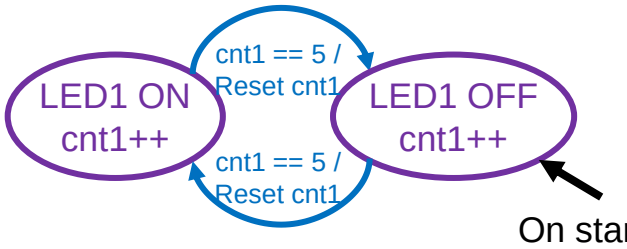
- **Problem**: Does the code to the right work correctly?
  - No! When one LED blinks the other will be off

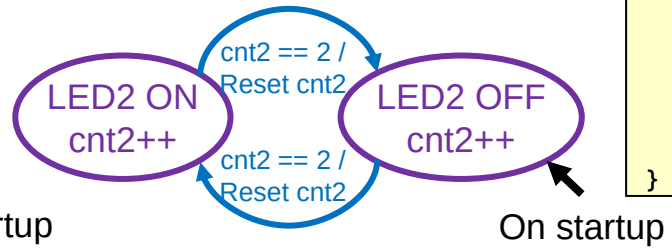



```
int main()
{
    while(1)
    {
        LED1_OFF();
        _delay_ms(250);
        LED1_ON();
        _delay_ms(250);

        LED2_OFF();
        _delay_ms(100);
        LED2_ON();
        _delay_ms(100);

    }

    return 0;
}
```

Operations at Different Rates (2)

- Use a _____ delay and separate state (**count**) variables to do work on each task at the "same time". This mimics "parallel" (aka multithreaded) execution.
- To determine that delay, find the _____ _____ of the _____ periods that action is needed for each task.
  - **Task 1**: Flip the LED every **250 ms**
  - **Task 2**: Flip the LED every **100 ms**
  - Use a delay of _____






```
int main()
{
    int cnt1 = 0, cnt2 = 0;

    // set initial state of LEDs as "off"
    LED1_OFF();
    LED2_OFF();

    while(1)
    {
        if(cnt1 == _____)
        {
            FLIP_LED1();
            cnt1 = 0;
        }
        cnt1++;
        if(cnt2 == _____)
        {
            FLIP_LED2();
            cnt2 = 0;
        }
        cnt2++;
        // Delay the minimum granularity
        _delay_ms(50);
    }
    return 0;
}
```

Operations at Different Rates (3)

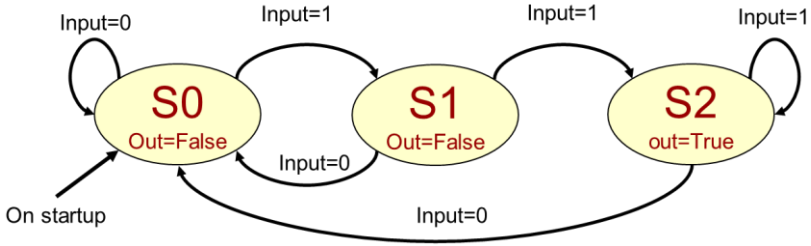
- To determine that delay, find the GCD (Greatest Common Divisor) of the minimum periods that action is needed for each task.
  - **Task 1**: Flip the LED every **250 ms;**
    Task 2: Flip the LED every **100 ms**
  - Use a delay of **50ms** = GCD (250, 100)

- We can use a _____ counter looking for multiples of the individual task periods (every 2 or every 5 iterations) using the modulo operator
- Can reset the count to 0 after the _____ _____ of the task periods
  - _____ **= 10 iterations.**

```
int main()
{
  int cnt = 0;

  // set initial state of LEDs as "on"
  LED1_ON();
  LED2_ON();

  while(1) {
    if(cnt % 5 == 0) {
      FLIP_LED1();
    }
    if(cnt % 2 == 0) {
      FLIP_LED2();
    }
    cnt++;
    if(cnt == 10)
      { cnt = 0; }
    // Delay the minimum granularity
    _delay_ms(50);
  }
  return 0;
}
```

Summary Definition

- To specify a state machine, we must specify 6 things:
  - A set of possible input values: {0, 1}
  - A set of possible states: {S0, S1, S2}
  - A set of possible outputs: {False, True}
  - An initial state = S0
  - A transition function:
    - {States x Inputs} -> the Next state
  - An output function:
    - {States x Inputs} -> Output value(s)



All the info in the state diagram is presented in the sets and tables to the right

Inputs: {0, 1}

States: {S0, S1, S2}

Outputs: {False, True}

Initial State: S0

	Inputs	
State	**0**	**1**
S0	S0	S1
S1	S0	S2
S2	S0	S2

State Transition Function

State	Outputs
S0	False
S1	False
S2	True

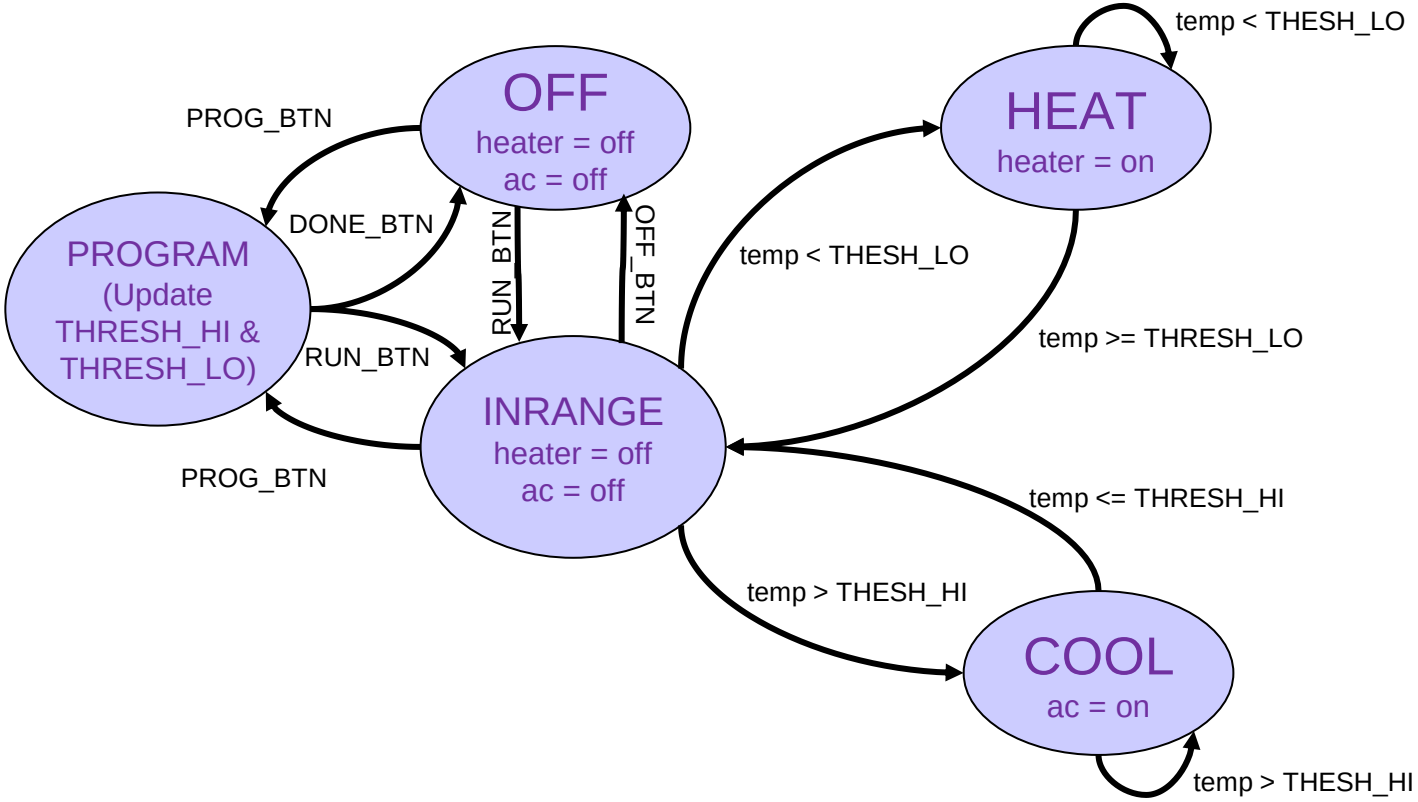
Output Function

HW (Instruction Cycle) & Software (String Matching)

MORE EXAMPLES IF TIME

Thermostat

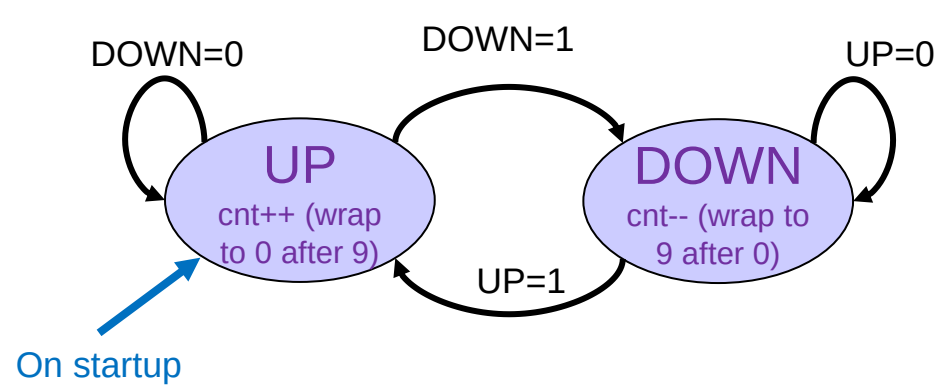
- Sample state machine to control a thermostat

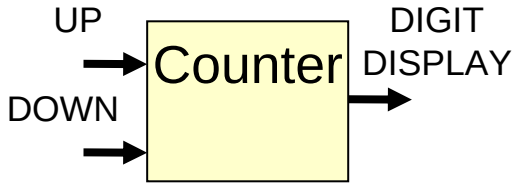


Counter Example

- Consider a system that has two button inputs: UP and DOWN and a 1-decimal digit display. It should count up or down at a rate of 500 milliseconds and change directions only when the appropriate direction button is pressed
- Every time interval we need to poll the inputs to check for a direction change, update the state and then based on the current state, increment or decrement the count

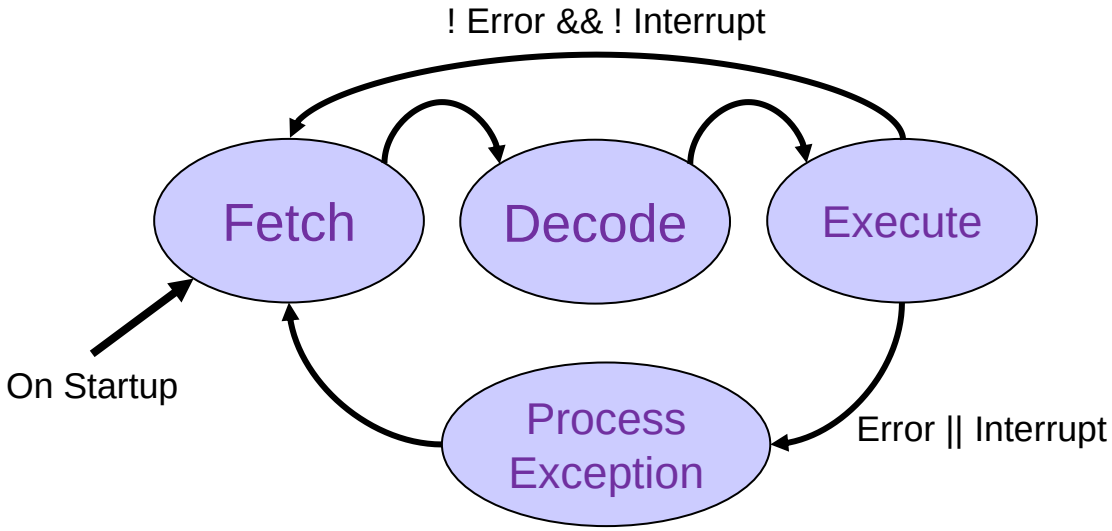
State Machine to count up or down (and continue counting) based on 2 pushbutton inputs: UP and DOWN





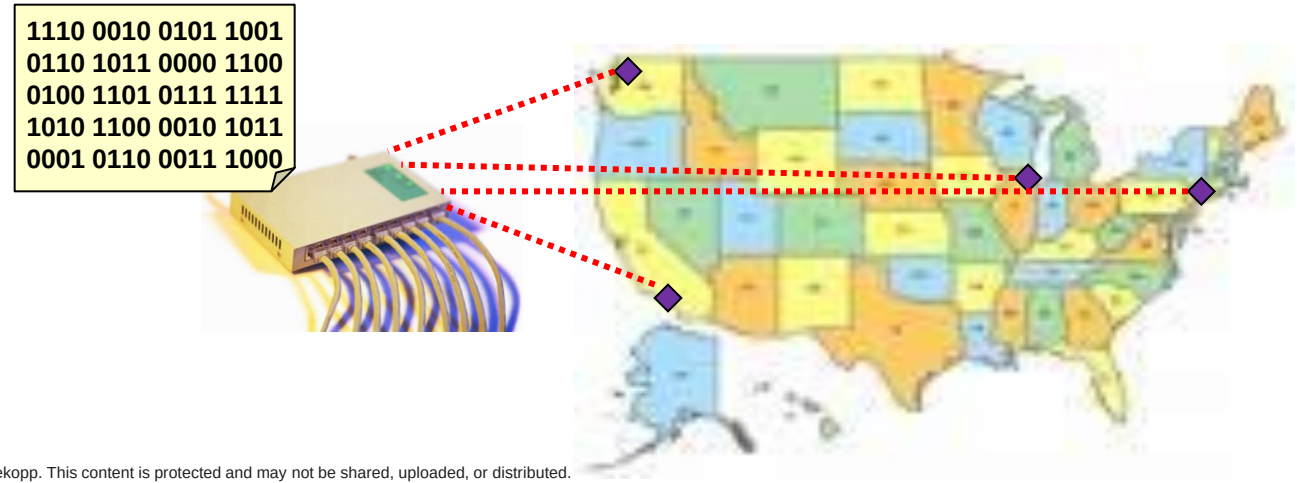
More State Machines

- State machines are all over the place in digital systems
- Instruction Cycle of a computer processor



Another Example

- On the Internet, packets of data are transferred between “router” devices
- Each router receives thousands of packet per second each of 100’s-1000’s of bytes of data
- These packets may contain viruses, spam, etc.
- Given patterns (common spam words or virus definitions), can we find these in the data and filter them out?



Looking for Signatures

- Look for specific patterns (i.e. signatures) such as data that would indicate a specific virus, words that are typically spam, etc.
- Databases of these signatures are available
- We take a packet and search for the presence of any of these signatures in our database
- If we find a signature we can drop the packet and not deliver it

String/Pattern Matching

- Given a large array of data (let's say text characters) how can we efficiently find the occurrence of specific strings (patterns)?

```
win
offer
cash
free
deceased
inherit
...
```

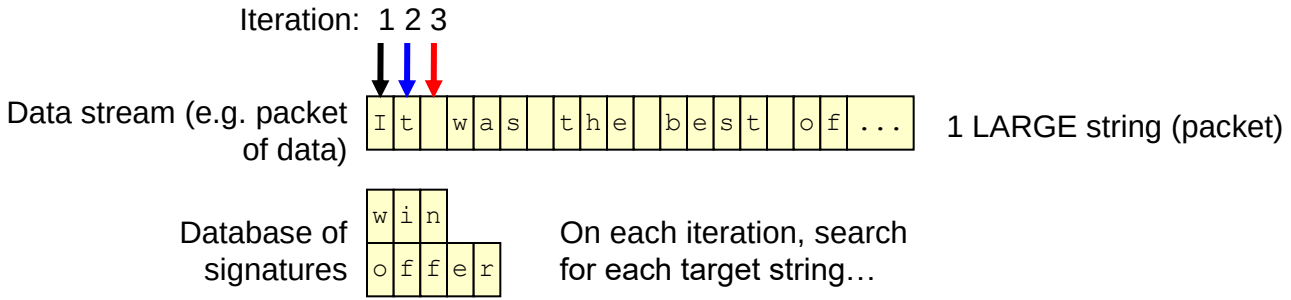
Database of signatures

```
Hello,

I am Barr. Phillip Butulezi, an attorney
of law to a deceased Immigrant property
Magnate, who was based in the U.K, also
referred to as my client.

On the 25th of July 2000, my client, his
wife, and their two Children died in the
Air France concord plane crash bound for
New York. They were on their way to a
world cruise.
```

Data stream (e.g. packet of data)

Brute Force

- Take each character in the data stream
  - Compare each string in the database to the string starting at the character in the data stream
  - Use strncmp()



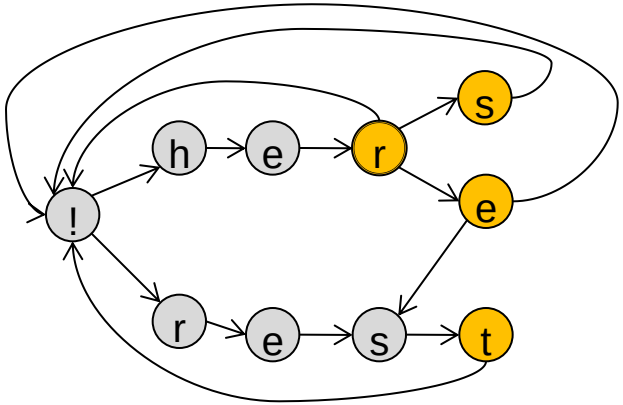
Data Stream = N chars with T Targets => Run Time proportional to N*T

A Better way

- Can we avoid checking each of the T target strings for each character in the data stream
- Can we take a letter from the data stream and simultaneously track possible (partial) target string matches
  - Example strings: her, hers, here, rest
  - Data Stream: heresthers
    - Don't check all 4 target strings, just grab 'h' and see what options are possible and which are ruled out… (i.e. keep track of all options simultaneously)
    - h [could be her or hers or here]
    - e [could still be her or hers or here]
    - r [found her! But could also be hers or here or start of rest]
    - e [found here! Could be start of rest]
    - s [Could be rest]
    - t [Found rest]
    - h [Could be start of her or hers or here]

Use a state machine

- '!' represents 'null' state
  - No part of a definition found
- Slightly different notation used
  - State label indicates the input character that would put you into that state
- What state you're in "tracks" what you've seen thus far AND what target strings you might be about to find…

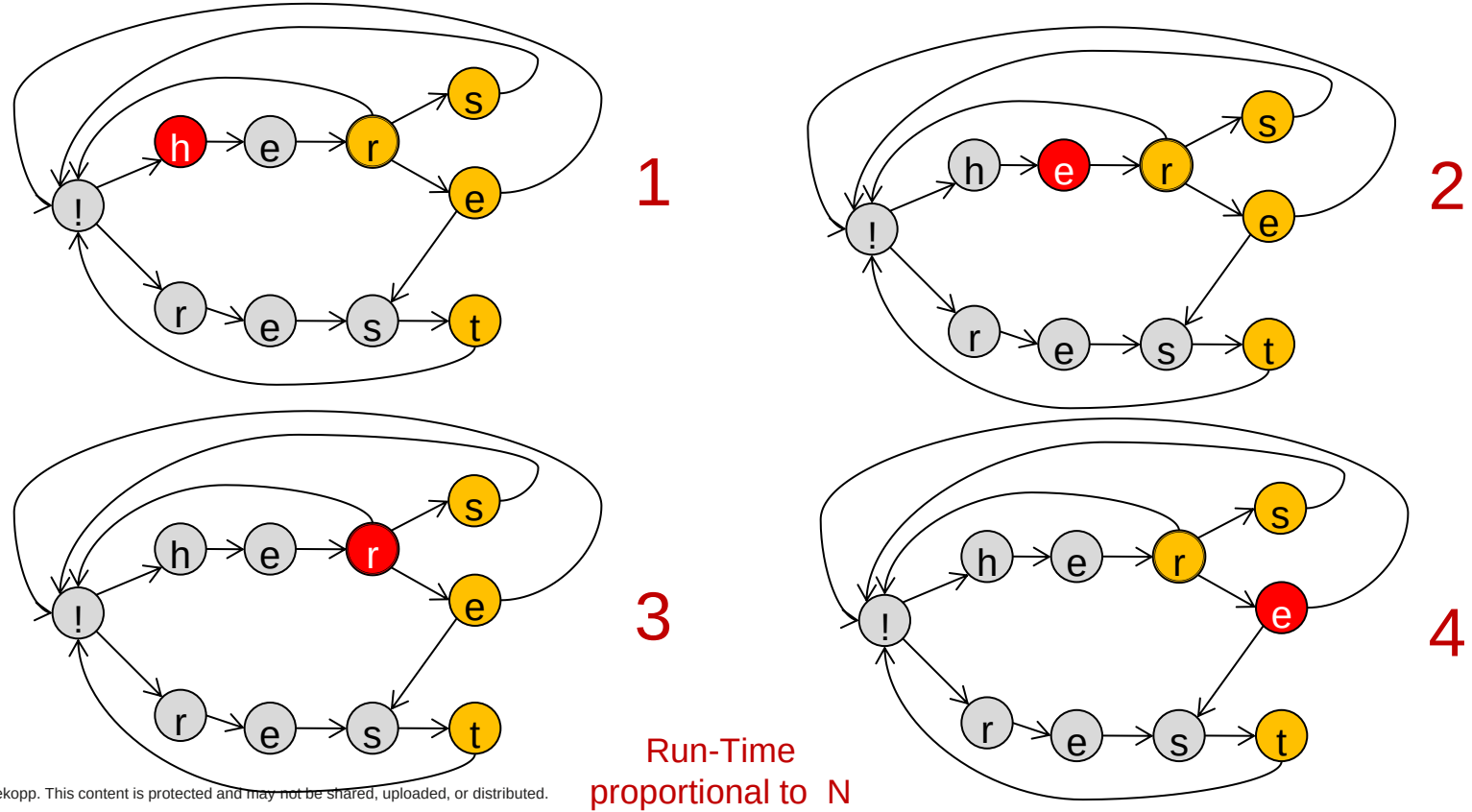


Internal state

Terminal / Pattern Found State (i.e. output should be True)

Finite State Automaton

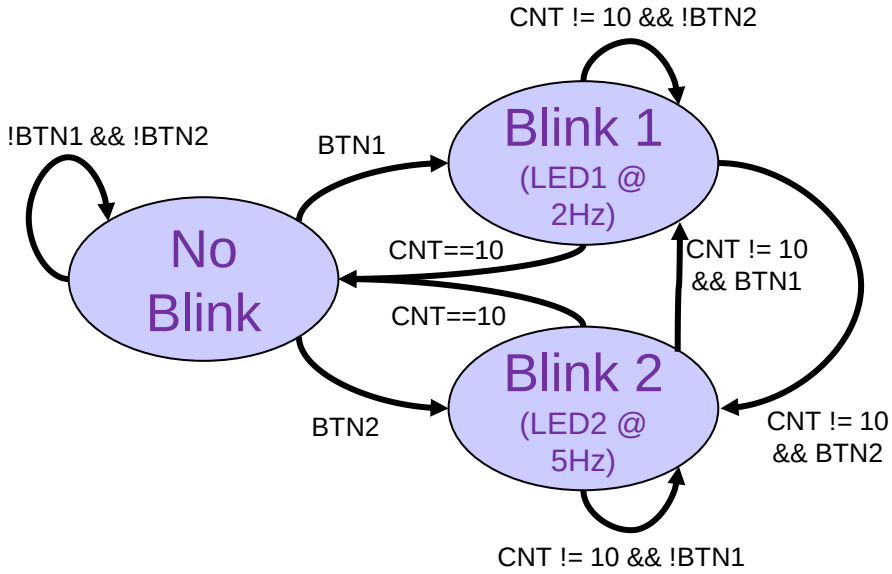
- Data Stream: heresthers



Run-Time proportional to N

BACKUP DRAWINGS AND OLD SLIDES

- Formulated as a state machine:
  - Separate code to update state and then perform actions based on state

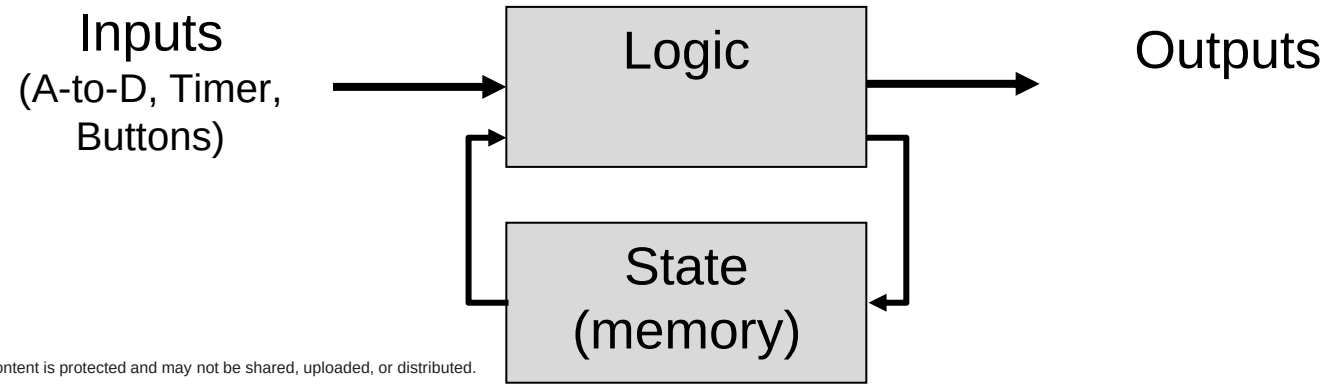


Assume if no transition it true, we

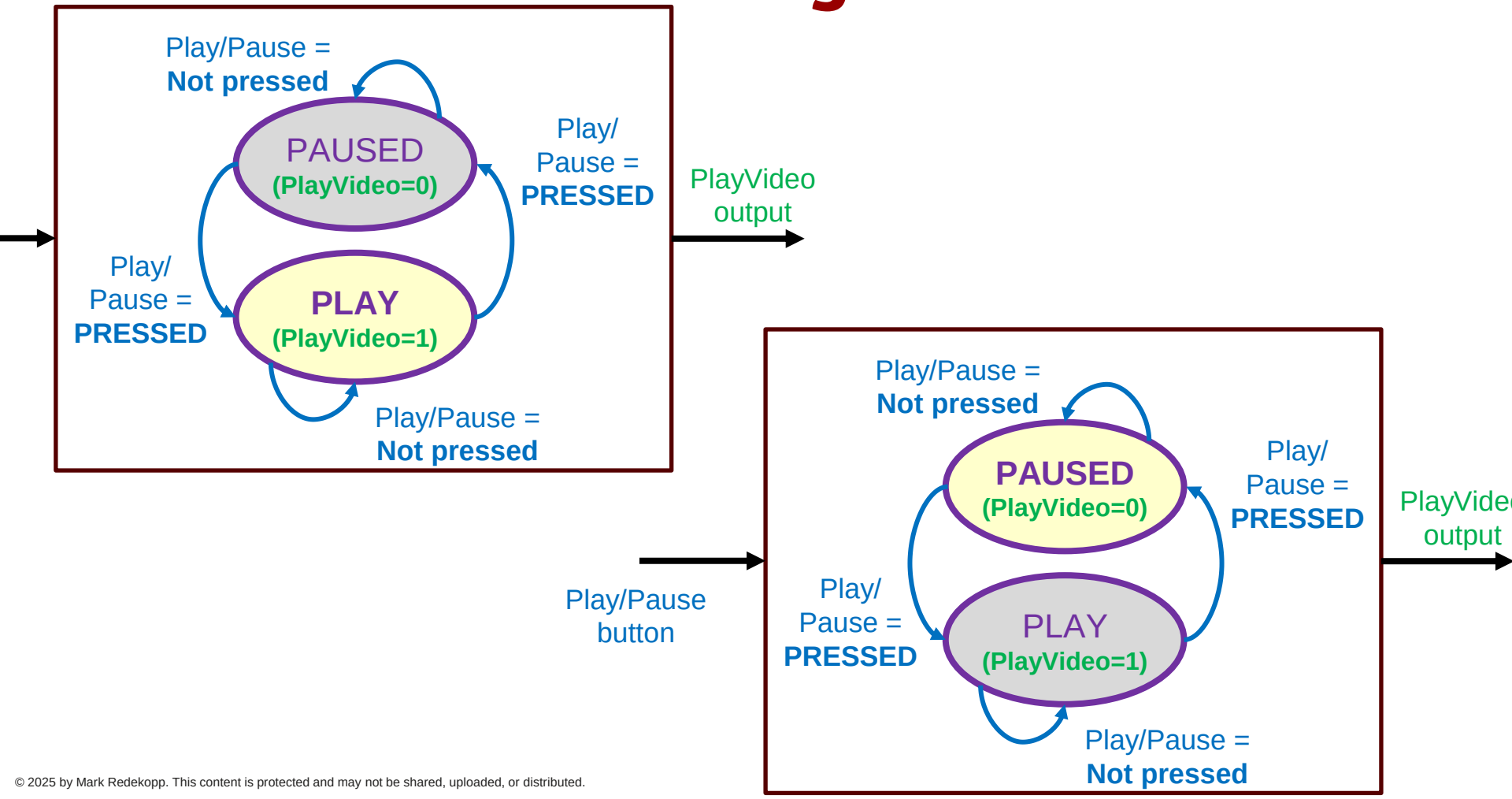
```
// State machine implementation
int main()
{
  int state = 0, cnt = 0;
  while(1)
  {
     // Update the state
     if(checkInput(1) == 0) {
        state = 1; cnt = 0;
     }
     else if(checkInput(2) == 0) {
        state = 2; cnt = 0;
     }

     // Use state to determine actions
     if(state == 1) {
        blink(250); // on for 250, off for 250
        cnt++;
        if(cnt == 10) {
           cnt = 0;
           state = 0;
        }
     }
     else if(state == 2) {
        blink(100); // on for 100, off for 100
        cnt++;
        if(cnt == 15) {
           cnt = 0;
           state = 0;
        }
     }
  }
  return 0;
}
```

State Machine Block Diagram

- A system that utilizes state is often referred to as a state machine
  - A.k.a. Finite State Machine [FSM]
- Most state machines can be embodied in the following form
  - Logic examines what's happening NOW (inputs) & in the PAST (state) to…
    - Produce outputs (actions you do now)
    - Update the state (which will be used in the future to change the decision)
- Inputs will go away or change, so state needs to summarize/capture anything that might need to be remembered and used in the future



State Diagrams



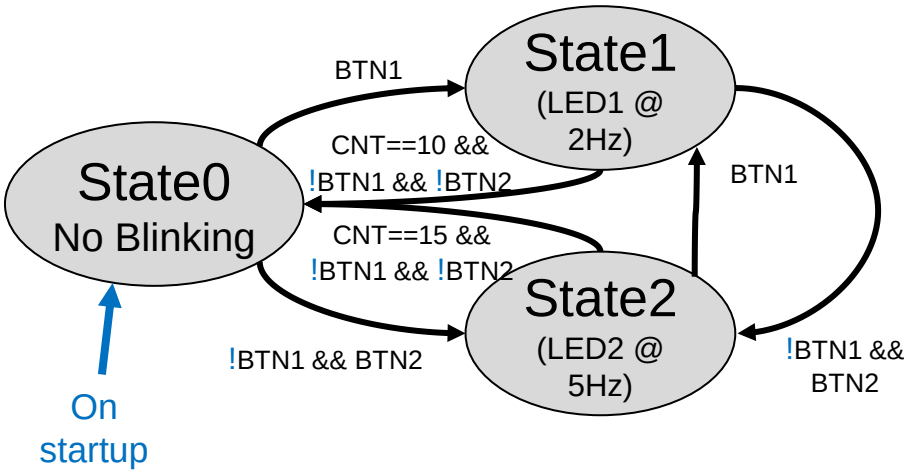
Example: Ad-hoc Implementation

- Could add checks after each blink but this becomes clunky in larger, more complex examples
- **Better approach**: Formulate the design as state machine and do NOT use additional loops (i.e. only the main while loop)

```
// Ad-hoc implementation
int main()
{
  while(1)
  {
     int i;
     if(checkInput(1) == 0){
       for(i=0; i < 10; i++)
       {
          blink(250); // on for 250, off for 250
          if(checkInput(2) == 0)
          {
               break;
          }
       }
     }
     if(checkInput(2) == 0){
       for(i=0; i < 15; i++)
       {
          blink(100);  // on for 100, off for 100
          if(checkInput(1) == 0)
          {
             break;
          }
       }
     }
     // delays are in the blink() functions
     // so no delay needed here

     // Problem:  what if button that caused
     // break from for  loop is released right
now
  }
  return 0;
}
```

Example: FSM implementation

- Formulated as a state machine:
  - Separate code to update state and then perform actions based on state
- Tip: Avoid loops other than the primary `while` and instead use state, counters, and `if` statements

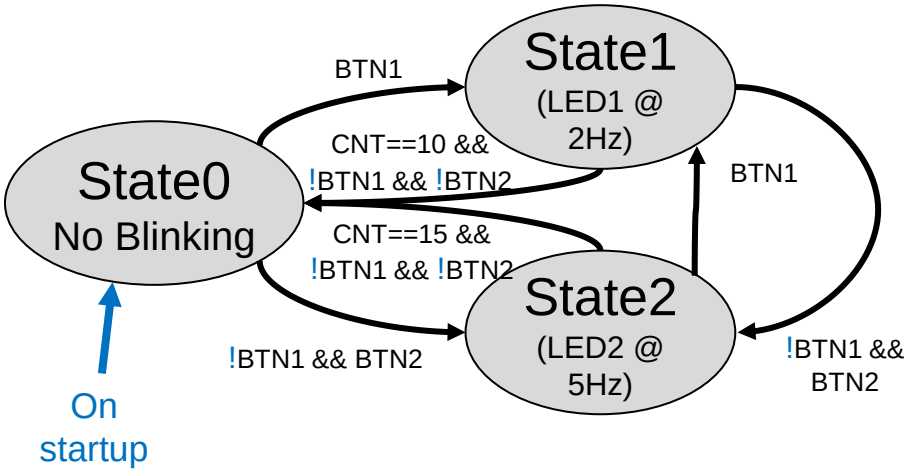



```
int main()
{
   int state = 0, cnt = 0;
   while(1)
   {
     // Update the state based on buttons.
     // Any button input, restarts the count
     if (checkInput(1) == 0) {
        state = 1; cnt = 0;
     }
     else if (checkInput(2) == 0) {
        state = 2; cnt = 0;
     }

     // Use state to determine output actions
     if(state == 1) {
        blink(250); // on for 250, off for 250
        cnt++;
        if( cnt == 10 ) { state = 0; cnt = 0; }
     }
     else if(state == 2) {
        blink(100); // on for 100, off for 100
        cnt++;
        if( cnt == 15 ) { state = 0; cnt = 0; }
     }
   }
   return 0;
}
```

Assume if no transition it true, we intend to stay in the same state.

Example: FSM implementation

- Formulated as a state machine:
  - Separate code to update state and then perform actions based on state
- Tip: Avoid loops other than the primary `while` and instead use state, counters, and `if` statements

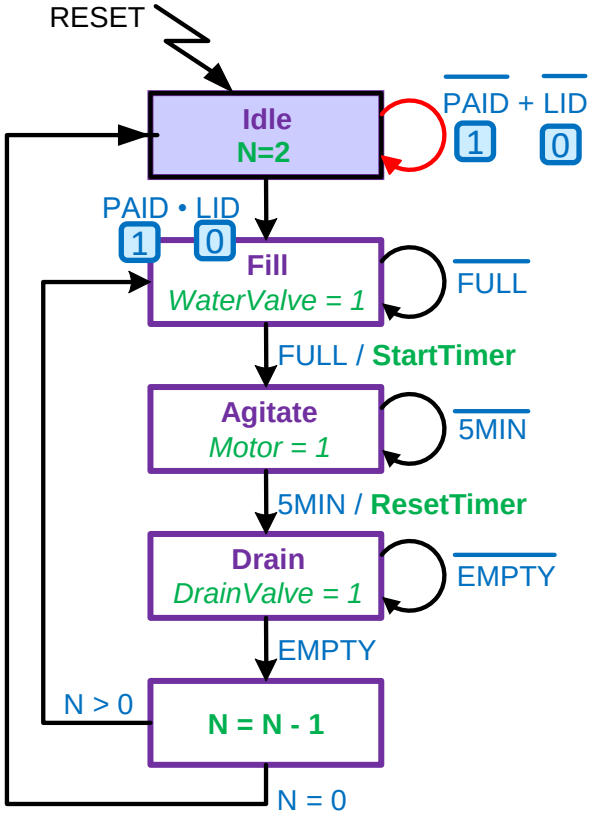


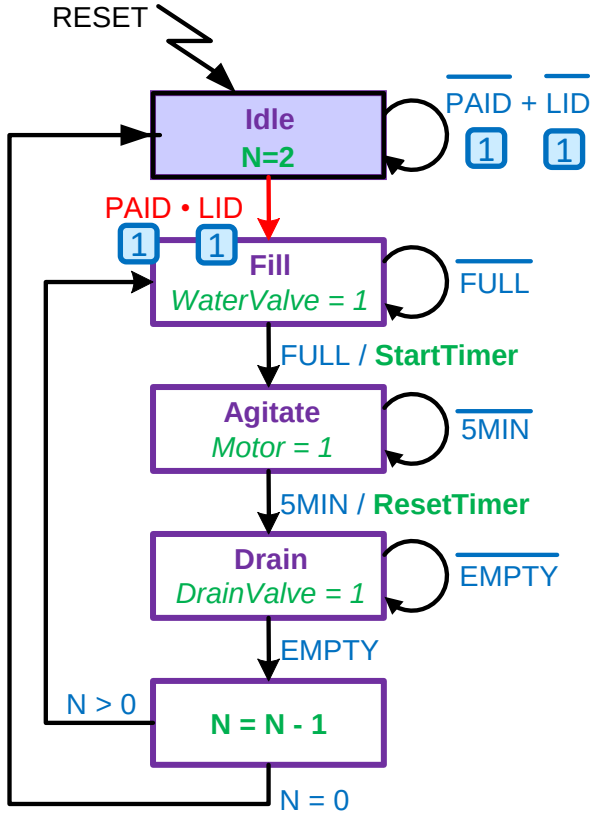
Assume if no transition it true, we intend to stay in the same state.

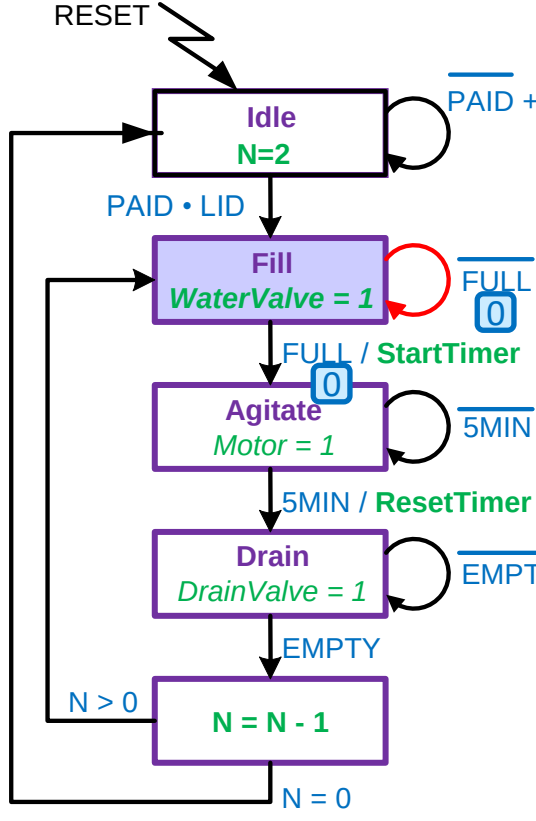
```
int main()
{
   int state = 0, cnt = 0;
   while(1)
   {
     // Update the state based on inputs
     if (checkInput(1) == 0) {
        state = 1; cnt = 0;
     }
     else if (checkInput(2) == 0) {
        state = 2; cnt = 0;
     }
     else if( (state == 1 && cnt == 10) ||
              (state == 2 && cnt == 15 ) ) {
        state = 0; cnt = 0;
     }

     // Use state to determine output actions
     if(state == 1) {
        blink(250); // on for 250, off for 250
        cnt++;
     }
     else if(state == 2) {
        blink(100); // on for 100, off for 100
        cnt++;
     }
   }
   return 0;
}
```

Washing Machine State Diagram

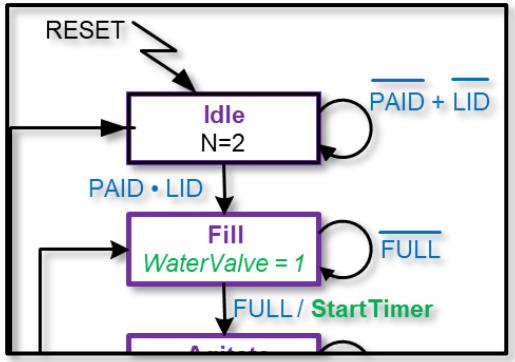
- Examine a potential state machine for this design.



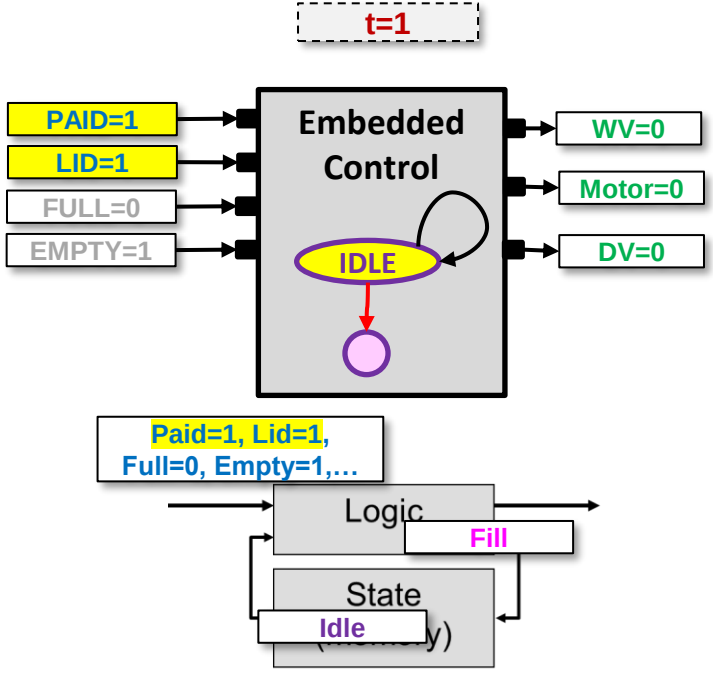


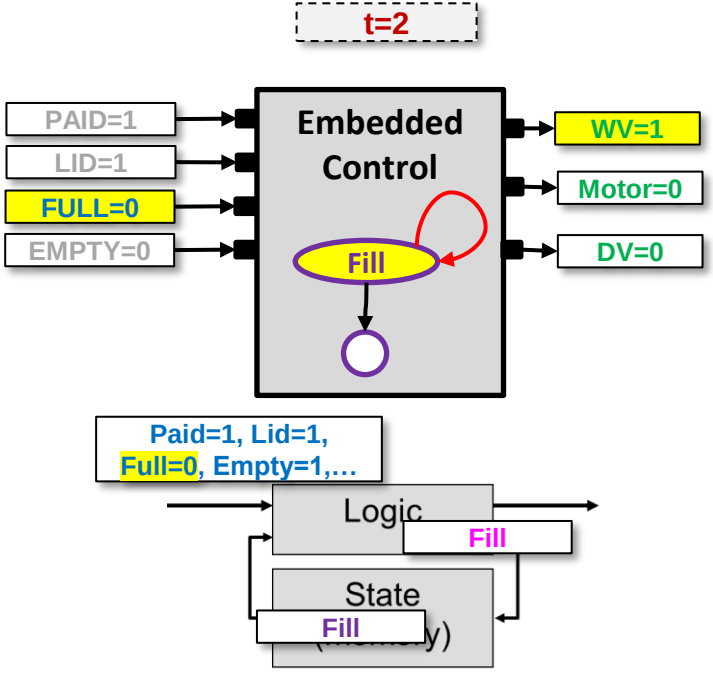


State Machine Operation (2)



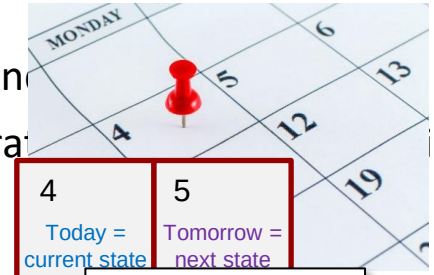
- When the state changes, we produce new output values and may look at a new set of inputs

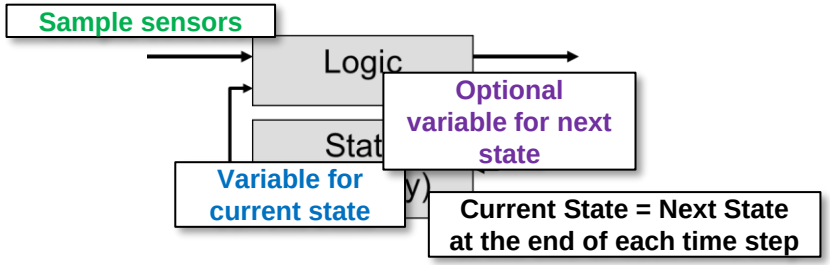


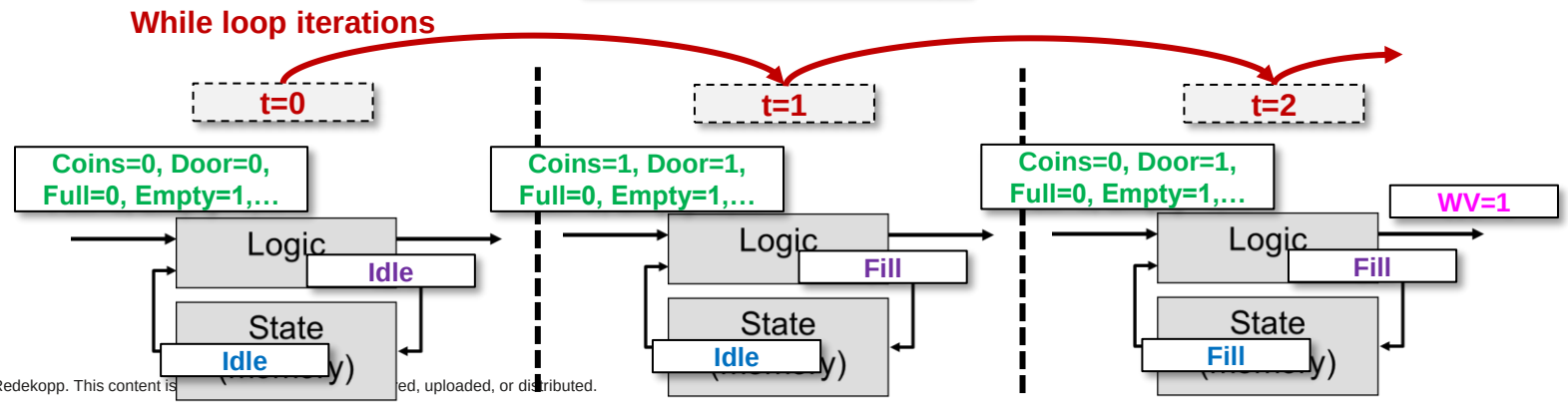


Coding State Machines 1

- Use a variable to store current state and, optionally, a secon state
- Use while loop where each iteration is one step in the opera ne





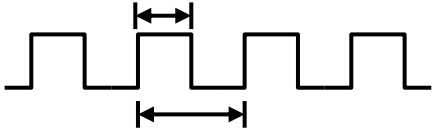


Tunnel Vision

- Consider a program that checks two buttons
  - When button 1 is pressed, blink an LED 10 times at 2 HZ
  - When button 2 is pressed, blink an LED 15 times at 5 HZ
- **Desired behavior**: If during the blinking of one LED the other button is pressed, immediately stop the current blink cycle and start the blink cycle of the other button.
- Problem: Will using the for loops to the right allow the desired behavior?

```
// Ad-hoc implementation
int main()
{
  while(1)
  {
     int i;
     if(checkInput(1) == 0){
       for(i=0; i < 10; i++)
       {
          blink(250); // on for 250, off for 250
          // What if other button is now pressed
       }
     }
     if(checkInput(2) == 0){
       for(i=0; i < 15; i++)
       {
          blink(100);  // on for 100, off for 100
          // What if other button is now pressed
       }
     }
     // delays are in the blink() functions
     // so no delay needed here
  }
  return 0;
}
```

T = 0.25 second = 250 ms



1 cycle

F = 2 Hz implies

T = ½ = 0.5 seconds

Example: Ad-hoc Implementation

- Could add checks after each blink but this becomes clunky in larger, more complex examples

- **Better approach**: Formulate the design as state machine using a state or count variable and do NOT use additional loops (i.e. **only** the main **while** loop)

```
// Ad-hoc implementation
int main()
{
  while(1)
  {
     int i;
     if(checkInput(1) == 0){
       for(i=0; i < 10; i++)
       {
          blink(250); // on for 250, off for 250
          if(checkInput(2) == 0)
            break;
       }
     }
     if(checkInput(2) == 0){
       for(i=0; i < 15; i++)
       {
          blink(100);  // on for 100, off for 100
          if(checkInput(1) == 0)
            break;
       }
     }
     // delays are in the blink() functions
     // so no delay needed here

     // Problem:  what if button that caused
     // break from for loop is released right now
  }
  return 0;
}
```