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Electrical & Computer ENGINEERING

Modal Systems & Statecharts

"When you come to a fork in the road – take it."

— Yogi Berra

State Intensive Systems

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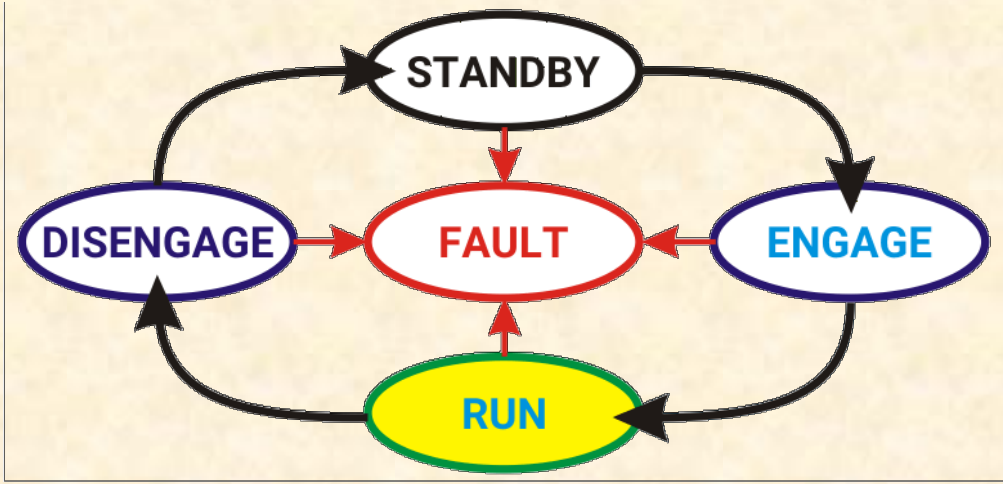
- Anti-Patterns:
  - No detailed design; just code
  - Deeply nested if statements instead of switch statements for state-full code
  - Mixing mode change logic with normal output sequences



- Detailed design of state-intensive behaviors
  - Operating modes, e.g., stop, start, run
  - Inputs that drive sequences of events
  - Key technique: statecharts (software finite state machine)

3-Speed Fan FlowChart

- Example code for 3-speed fan
  - Draw a flowchart -- how easy is it to understand this code?
  - Are there any bugs in this code?

```
// Change: input true on cycle when speed change button depressed
//    OnOff : input true one cycle when on/off switch depressed
static uint8_t speed; // 0=Off; 1=Slow; 2=Medium; 3=Fast
…..
if(speed == 0)
{ if(Change == 1 ||            OnOff   == 1) { speed = 1; }
} else if (Change == 1)
{ if (speed == 1) { speed = 2; }
    else if (speed == 2) { speed = 3;}
    else { speed = 0;}
} else if (         OnOff   == 1)
{ speed = 0;}
```


Elements of a Statechart

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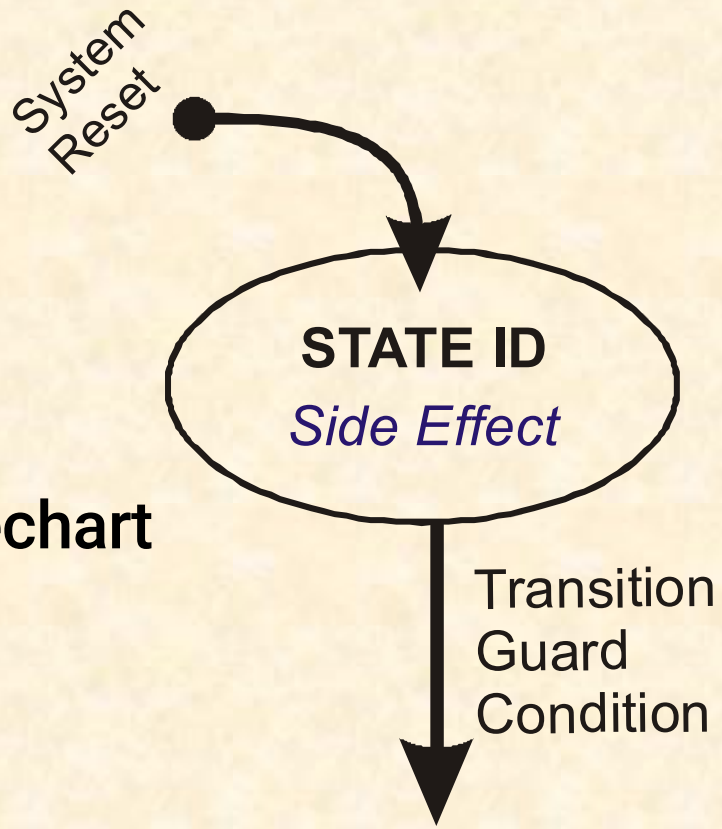
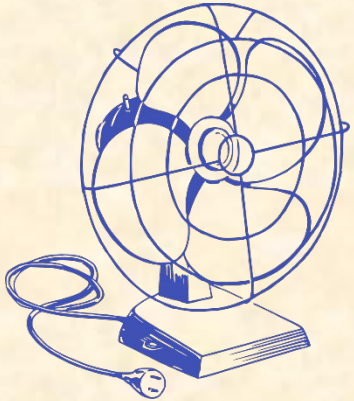
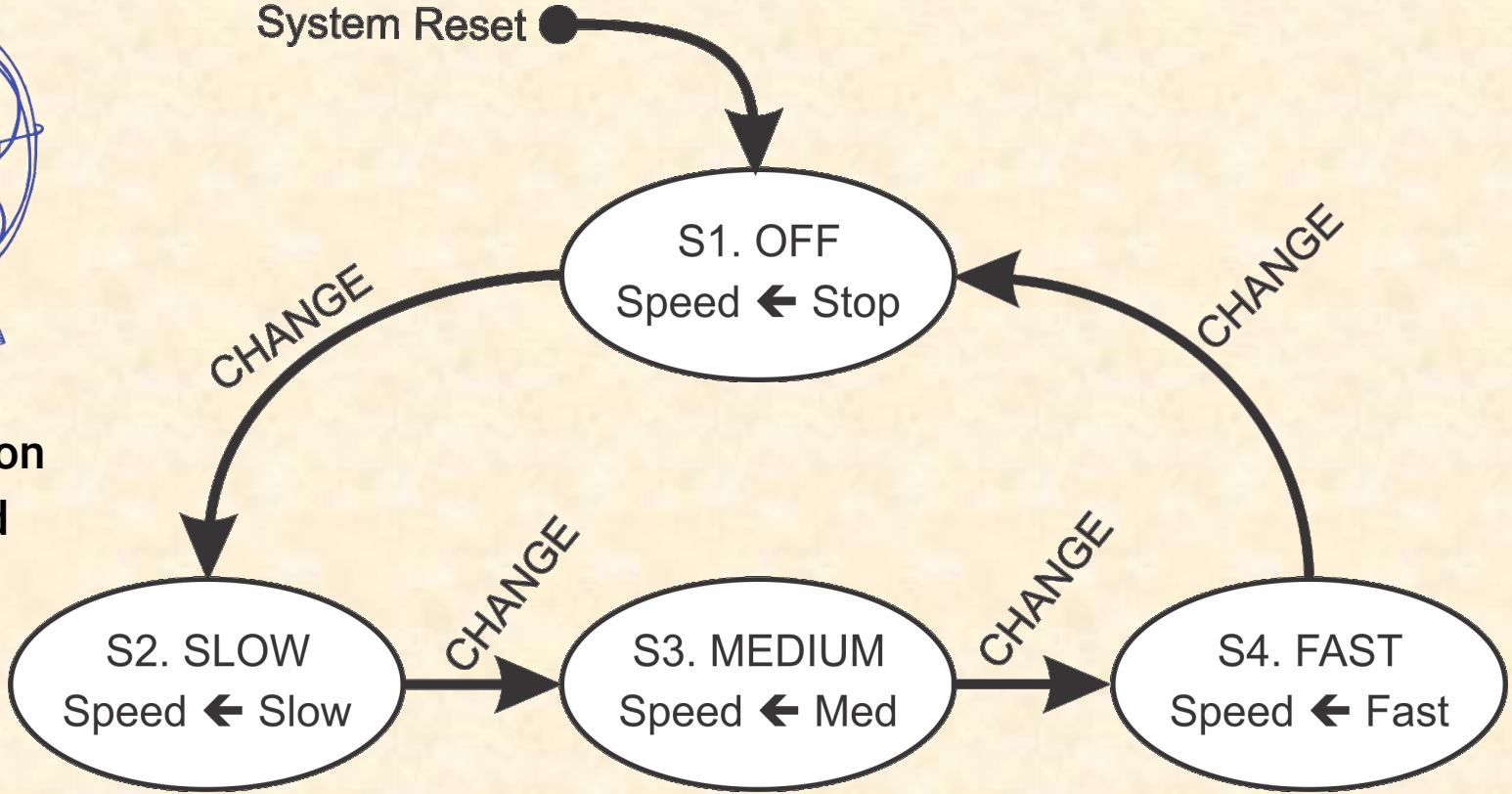
- A statechart is a software Finite State Machine:
  - Set of states with side effects
  - Set of guards that cause transitions
    - No side effects on transitions
  - Initial state
- Convert example fan code to statechart
  - (See following four slides)
  - Define a state for each fan speed
  - Define transitions
  - Easier to understand? Any bugs?



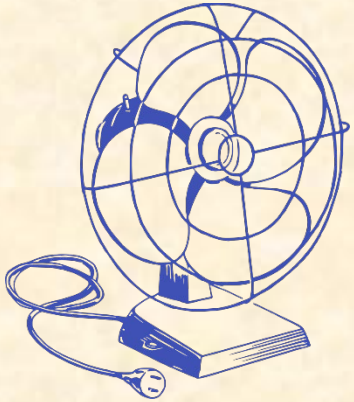
Exercise: One Button 3-speed Fan



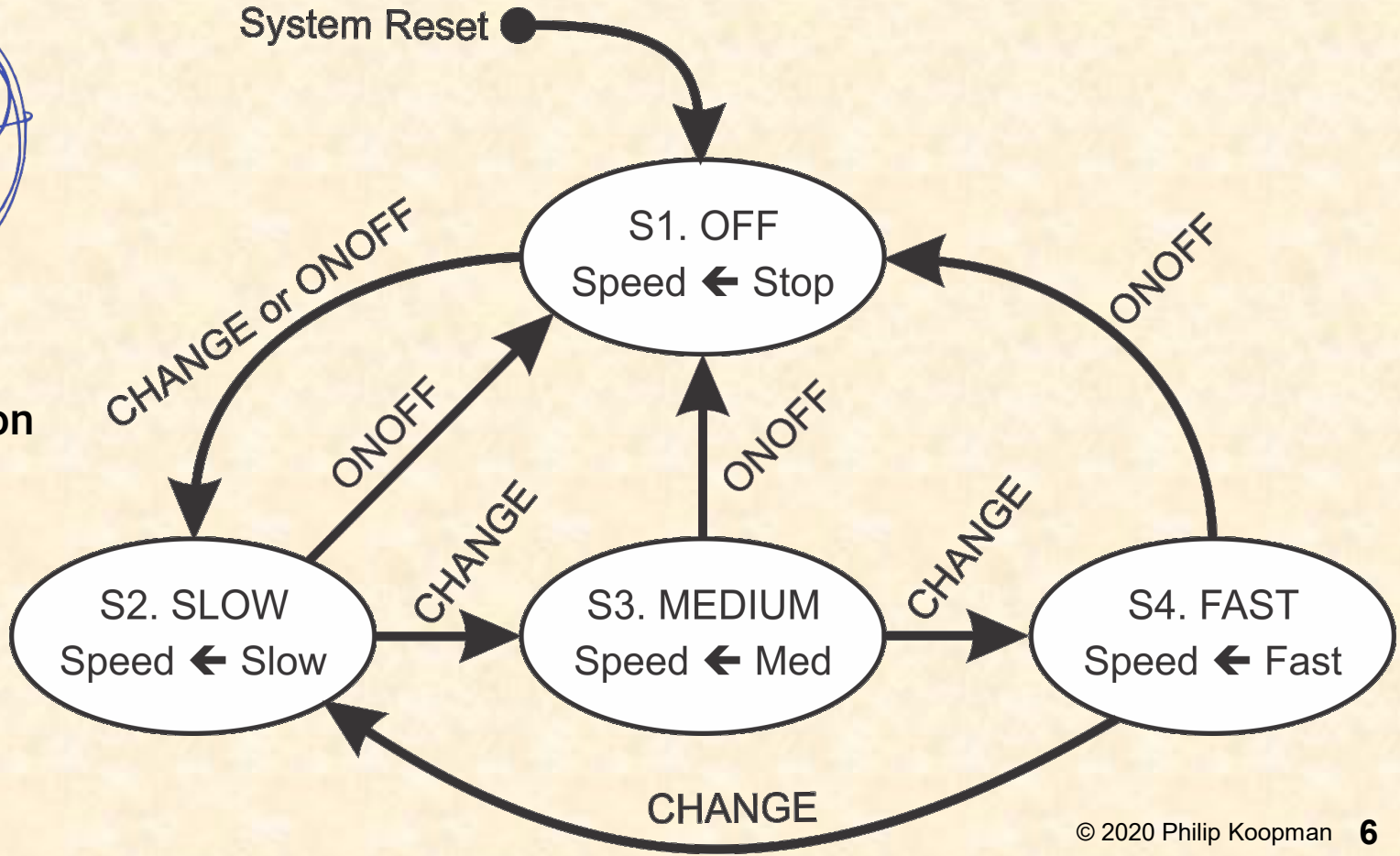
- CHANGE button
- Output: Speed



Exercise: Two Button 3-speed fan



- CHANGE button
- ONOFF button
- Output: Speed



Fan Example Code – part 1

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```
static      enum  { OFF, SLOW, MEDIUM, FAST  }   CurrState    ;   // define states
static      const    uint8_t      SpdOff  =0; // define speed constant values
static      const    uint8_t      SpdSlow =10;
static      const    uint8_t      SpdMed=15;
static      const    uint8_t      SpdFast  =25;
CurrState      = OFF; // initialize state machine to OFF
void    ProcessStates     (void) // run periodically from main loop
{ switch (       CurrState     )
   { case OFF: // State S1
         speed(  SpdOff  ); // Take action in state
         // Test arc guards and take transitions
         if (     SpdButton   () == TRUE ||        OnOffButton    () == TRUE) {      CurrState      = SLOW;}
         break; // go to end of switch statement
     case SLOW: // State S2
         speed(  SpdSlow ); // take action
         if (     SpdButton   () == TRUE) {      CurrState      = MEDIUM;}
         if (     OnOffButton    () == TRUE) {      CurrState      = OFF;}
         break;
```

Fan Example Code – part 2

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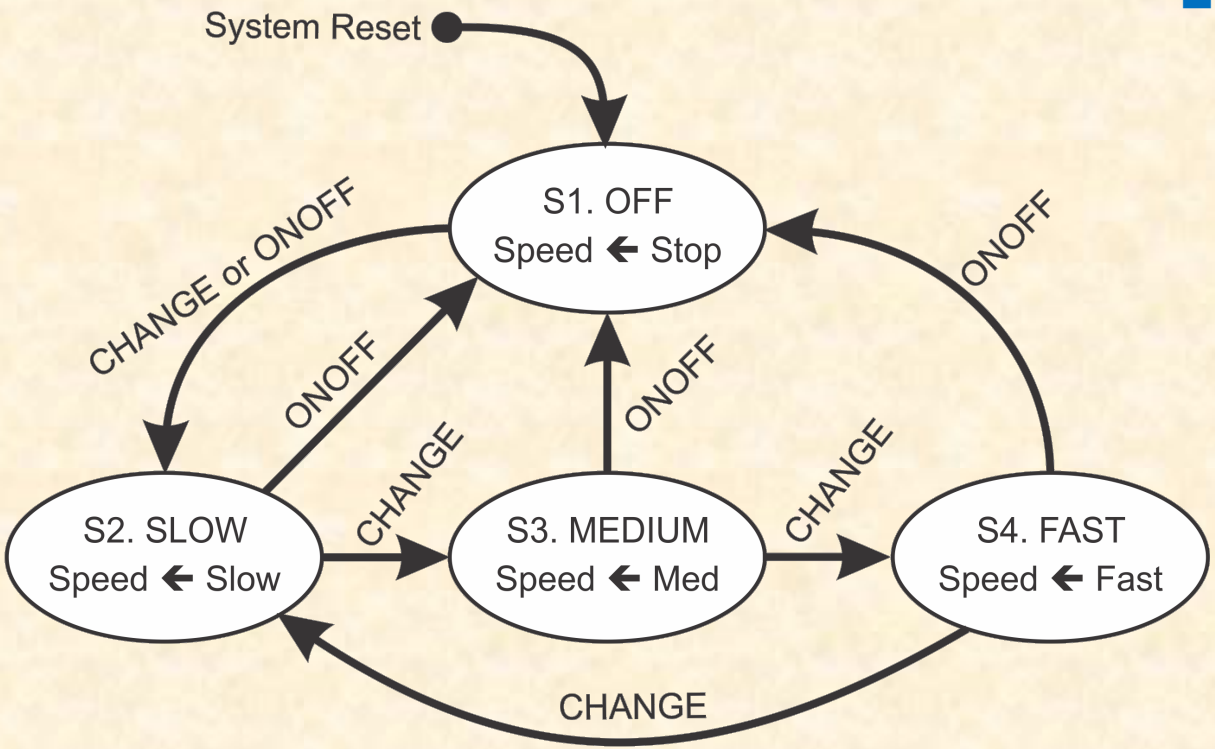
```
    case MEDIUM: // State S3
        speed(  SpdMed); // take action
        if (    SpdButton   () == TRUE) {     CurrState     = FAST;}
        if (    OnOffButton    () == TRUE) {     CurrState     = OFF;}
        break;
     case FAST: // State S4
        speed(  SpdFast  ); // take action
        if (    SpdButton   () == TRUE) {     CurrState     = SLOW;}
        if (    OnOffButton    () == TRUE) {     CurrState     = OFF;}
        break;
     default: // Error: invalid state
        error(INVALID_STATE_ERROR); // should never get here
   }
}
```

Finished Statechart



- Controller for a multi-speed motor or other similar application
  - Inputs: CHANGE, ONOFF
  - Outputs: Speed = {Stop, Slow, Med, Fast}
  - State names (arbitrary labels): {OFF, SLOW, MEDIUM, FAST}
  - System Reset is to state S1

Half-Duplex Serial Port Example

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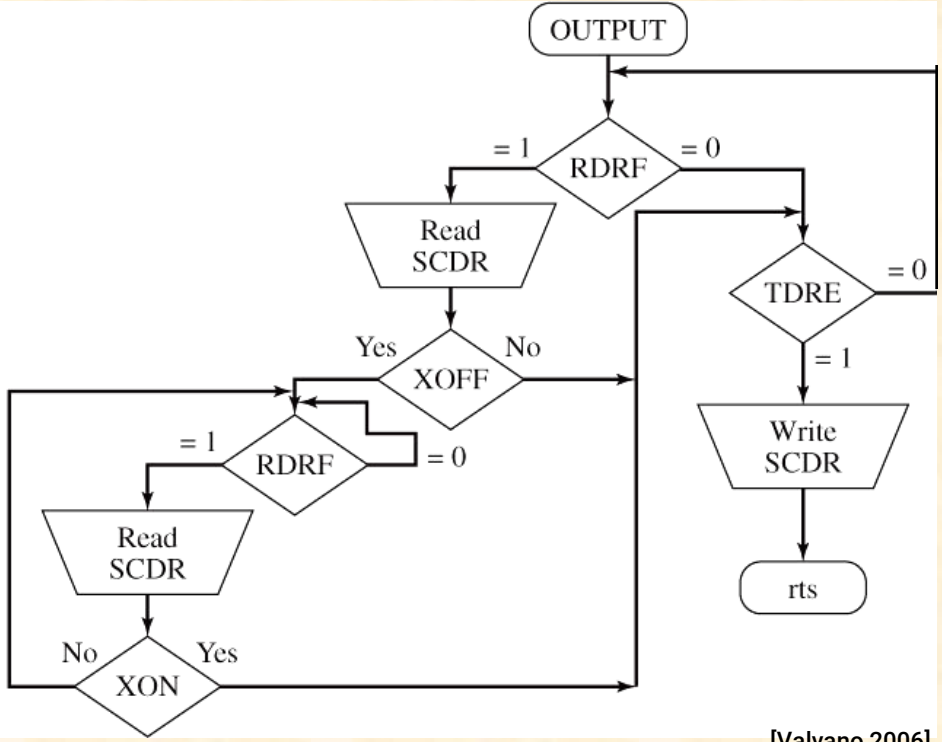
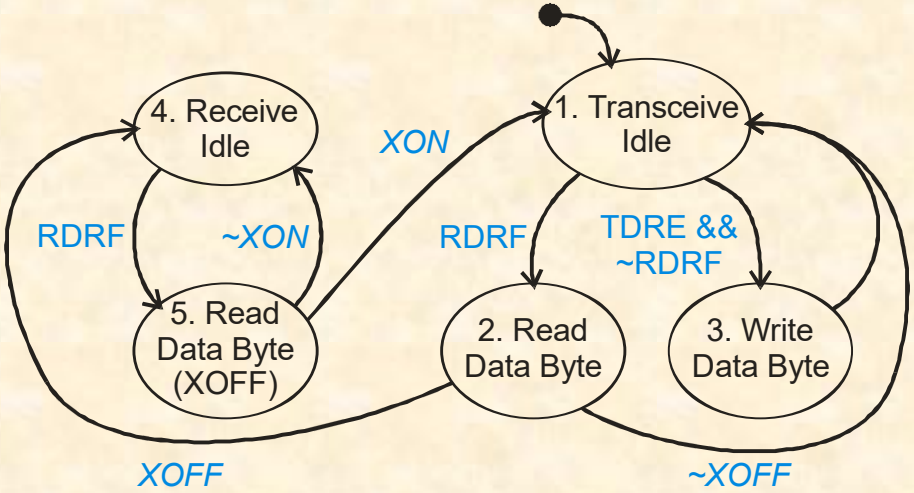
RDRF = "Receive Data Register Full" ➔ Data byte arrived
TDRE = "Transmit Data Register Empty" ➔ Done sending

SCDR = "Serial Comms. Data Reg."
XON/XOFF ➔ Flow Control



[Valvano 2006]



Best Practices for Statecharts

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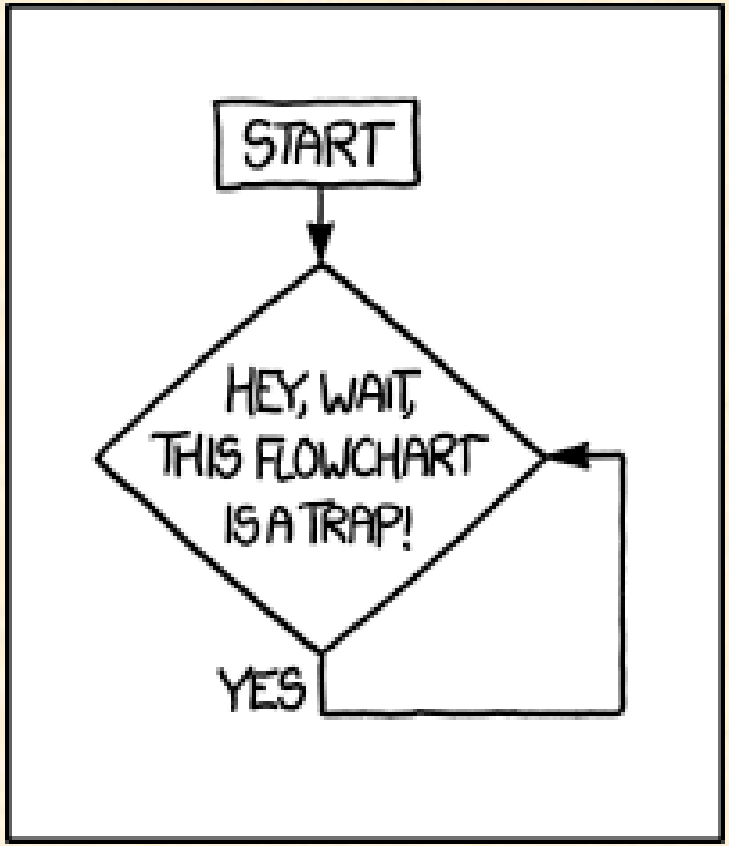
- Use statecharts for stateful code
  - Maps to easier-to-test switch statement
  - Avoid actions on arcs to simplify code
  - Move complex behaviors to per-state subroutine helper functions to limit cyclomatic complexity

https://goo.gl/ocnSRS

- Summary of pitfalls
  - Some code is better as flowchart if there is no state history
  - Don't let statechart get too complex
    - Might need to decompose into nested or parallel state machines



https://xkcd.com/1195/

Discussion Questions

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- What happens if multiple transition arcs from a state are true?
  - Need to have some way of prioritizing exits or requiring only-one-true
- Why should actions (“side effects”) be avoided on arcs?
  - How do you handle executes-once actions?
- Explain “mode confusion” and its cause
  - Hint: this is a contributing factor to some aviation mishaps
- When should you:
  - Use a flowchart, use a statechart, use model-based design approach, use pseudocode?

Exercises

- Find some code with deeply nested if statements and convert to a statechart
- List three everyday systems with modal behavior and briefly describe how mode affects user interface
  - For example, buttons change function depending upon mode

