18-642: Modal Systems & Statecharts

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

– Yogi Berra
State Intensive Systems

- **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?

```c
// SPDBUTTON: input true on cycle when speed 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(SPDBUTTON == 1 || ONOFF == 1) { speed = 1; }
} else if (SPDBUTTON == 1)
{
    if (speed == 1) { speed = 2; }
    else if (speed == 2) { speed = 3; }
    else { speed = 0; }
} else if (ONOFF == 1)
{ speed = 0; }
```
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

- (Next slide has graphic)
- Define a state for each fan speed
- Define transitions
- Easier to understand? Any bugs?
Convert to StateChart Exercise: 3-speed fan

- Define initial state, side effects, transitions

![StateChart Diagram]

- S1. OFF
  Speed $\leftrightarrow$ Stop
- S2. SLOW
  Speed $\leftrightarrow$
- S3. MEDIUM
  Speed $\leftrightarrow$
- S4. FAST
  Speed $\leftrightarrow$
Corrected Statechart

- This is a controller for a multi-speed motor or other similar application

- Inputs: SPDBUTTON, ONOFF
- Outputs: Speed = {Stop, Slow, Med, Fast}
- State names (arbitrary labels): {OFF, SLOW, MEDIUM, FAST}
- System Reset is to state s1
static enum CurrState {OFF, SLOW, MEDIUM, FAST}; // 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

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

Half-Duplex Serial Port Example

RDRF = “Receive Data Register Full” → Data byte arrived
TDRE = “Transmit Data Register Empty” → Done sending

SCDR = “Serial Comms. Data Reg.”
XON/XOR → Flow Control

[Valvano 2006]
Best Practices for Statecharts

- 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

- 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://goo.gl/ocnSRS
How to Write Good Code:

1. Start project.
2. Do things right or do them fast? (fast)
3. Code fast
4. Does it work yet? (no)
5. Code well
6. Are you done yet? (no)
7. Almost, but it's become a mass of kludges and spaghetti code.
8. No, and the requirements have changed.
9. Throw it all out and start over.

Good code.