15 & 16: High-level and detailed design (FSMs)

V model

Next week!

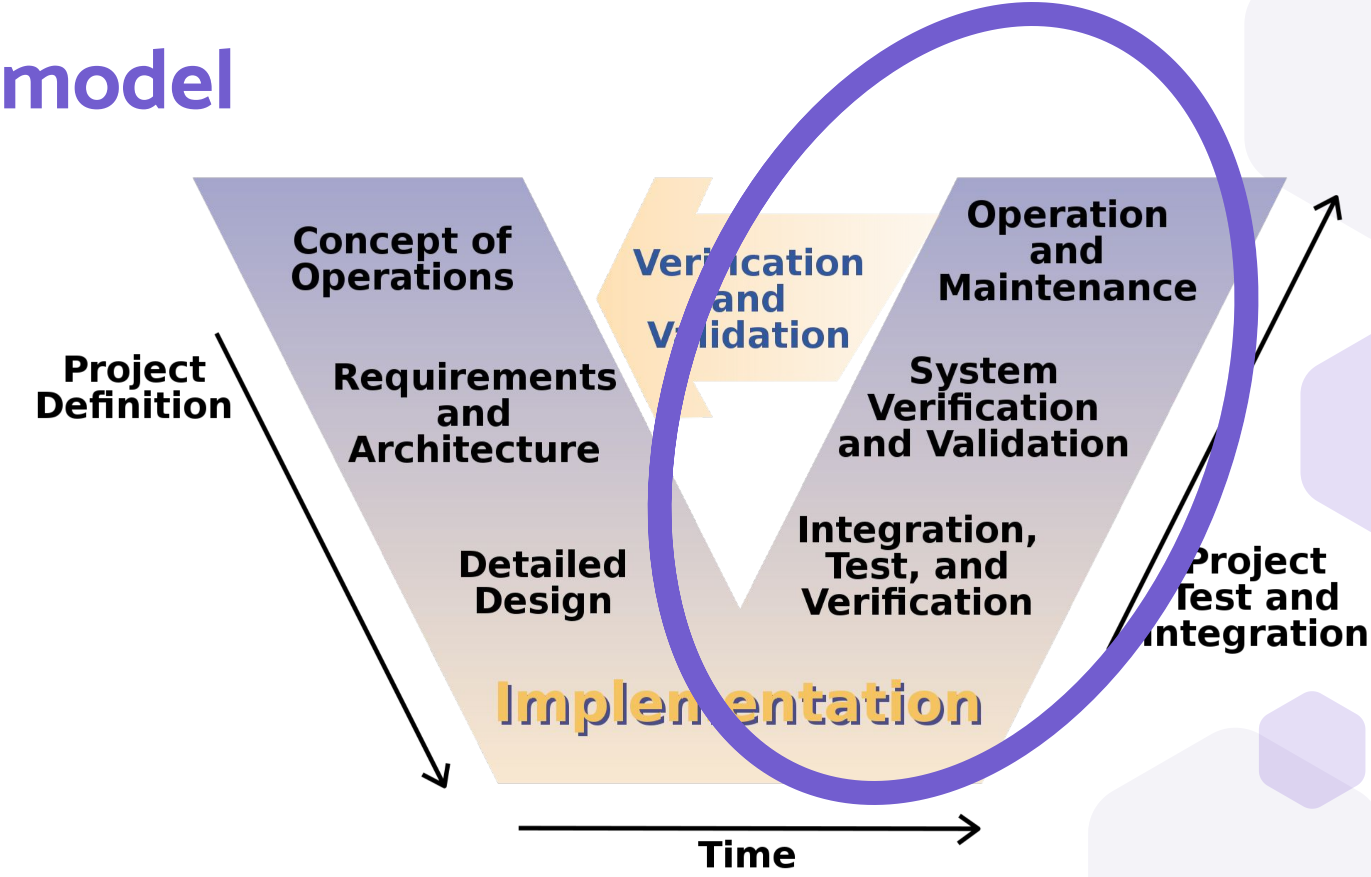
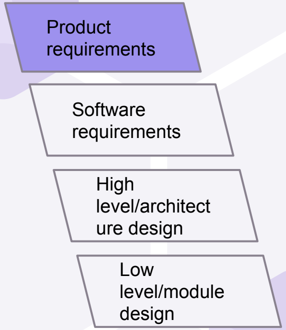

Concept of Operations
Requirements and Architecture
Detailed Design
Project Definition
Verification and Validation
Operation and Maintenance
System Verification and Validation
Integration, Test, and Verification
Project Test and Integration
Implementation
Time

Image source

Left side of V model

Product requirements	What the product does from the customer POV
Software requirements	What the product does from the SW POV (high-level, not the "how")
High level/architecture design	What modules there are in the system, which module performs which function, how modules communicate
Low level/module design	Flowcharts, statecharts/finite state machines, algorithms...



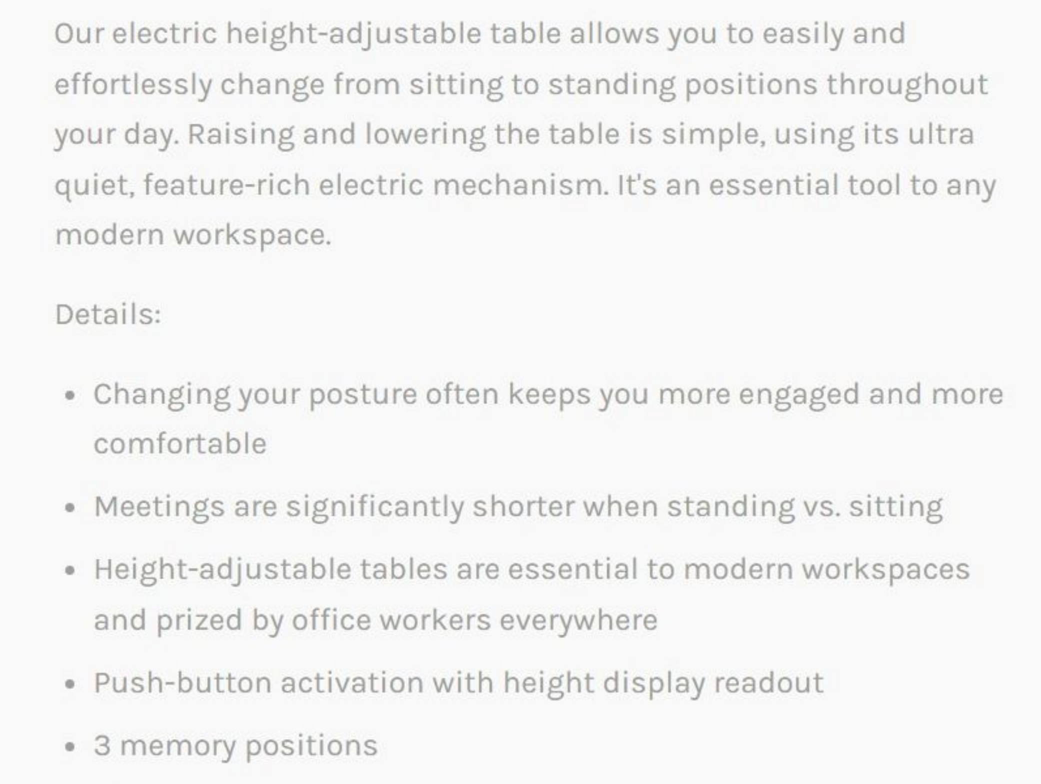
Product requirements

Software requirements

High level/architecture design

Low level/module design

Product requirements



Our electric height-adjustable table allows you to easily and effortlessly change from sitting to standing positions throughout your day. Raising and lowering the table is simple, using its ultra quiet, feature-rich electric mechanism. It's an essential tool to any modern workspace.

Details:

- Changing your posture often keeps you more engaged and more comfortable
- Meetings are significantly shorter when standing vs. sitting
- Height-adjustable tables are essential to modern workspaces and prized by office workers everywhere
- Push-button activation with height display readout
- 3 memory positions

Customer-facing
Can be a list of features
Used in marketing

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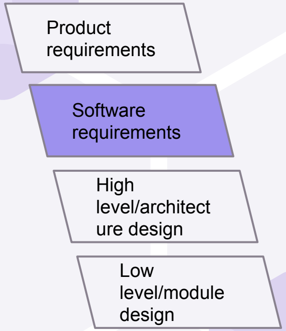


Software requirements

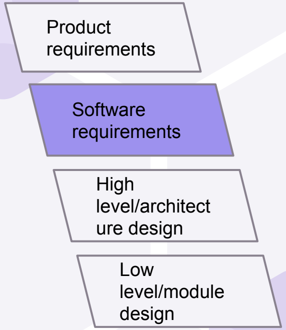
Written with specific wording and format

- "Shall" - the software **must** do this to meet requirements
- "Should" - the software has this goal
- Labeled or numbered (RS-1, RS-2, RS-2.a...)

Precise and measurable

- Quantitative over qualitative
- Can be tested

What the software does, not *how*



Product requirements

Software requirements

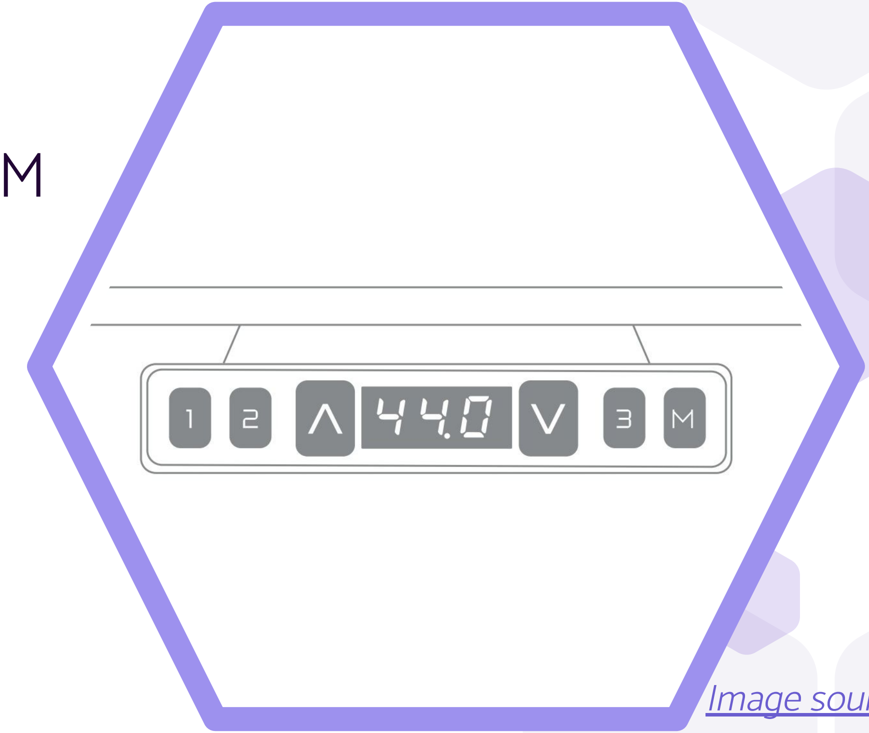
High level/architecture design

Low level/module design

Adjustable height desk inputs

Current height*

Buttons: 1, 2, 3, up, down, M



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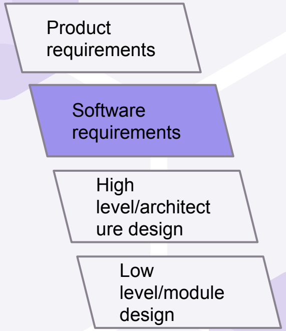
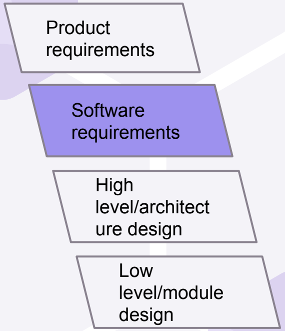


Adjustable height desk outputs

Motor command (stopped, up, down)

Display

Adjustable height desk requirements



Product requirements

Software requirements

High level/architecture design

Low level/module design

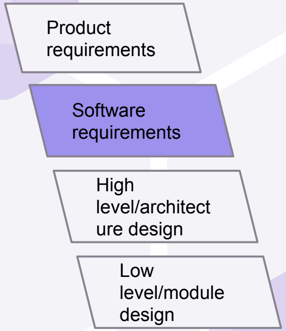
R1: If the desk is not at its maximum height, and the up button is held, the motor shall be commanded UP

R2: If the M button is pressed and released, and one of the numbered buttons [1, 2, 3] is pressed and released within 10 seconds, then the current height shall be stored as a preset for the corresponding numbered button

R3: If one of the numbered buttons [1, 2, 3] is held, the motor should be commanded such that the desk height moves to the corresponding preset height

Come up with additional requirement(s) that refine the preset behavior

R3: If one of the numbered buttons [1, 2, 3] is held, the motor should be commanded such that the desk height moves to the corresponding preset height



Product requirements

Software requirements

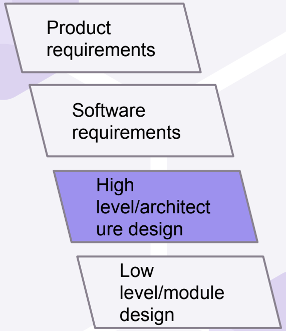
High level/architecture design

Low level/module design

Refined requirements

R3: If one of the numbered buttons [1, 2, 3] is held, the motor should be commanded such that the desk height moves to the corresponding preset height

> R3-A: If the corresponding preset is not stored, the motor shall be commanded STOPPED
>
> R3-B: If the desk height is at the preset height, the motor shall be commanded STOPPED
>
> R3-C: If the desk height is higher/lower than the preset height, the motor shall be correspondingly commanded DOWN/UP as long as the numbered button is held and the desk has not yet reached the preset height.



High-level/architecture design

How components fit together and what the interfaces are

- Boxes-and-arrows diagram: **boxes** are components, **arrows** are interfaces

General rule: should fit on one page

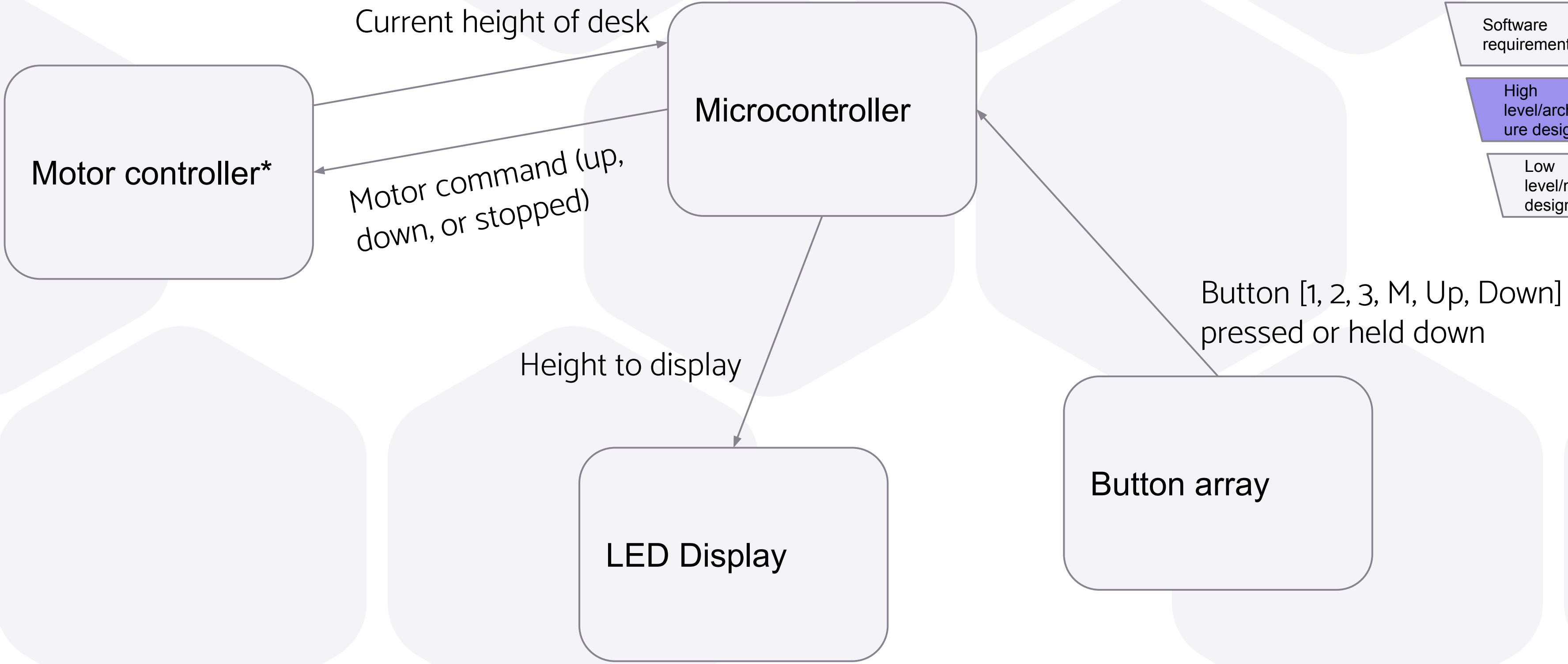
- Details of components are left to detailed design

Product requirements

Software requirements

High level/architecture design

Low level/module design



Current height of desk

Microcontroller

Motor controller*

Motor command (up, down, or stopped)

Height to display

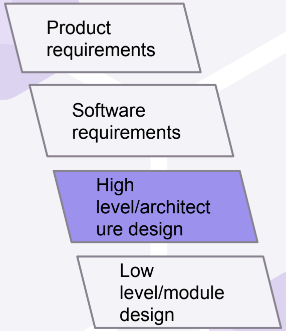
Button [1, 2, 3, M, Up, Down] pressed or held down

LED Display

Button array

Boxes-and-arrows for adjustable height desk

Sequence diagrams



Shows interaction between components

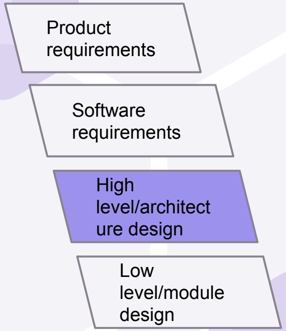
Columns: components

Arrows between columns: data sent across interfaces

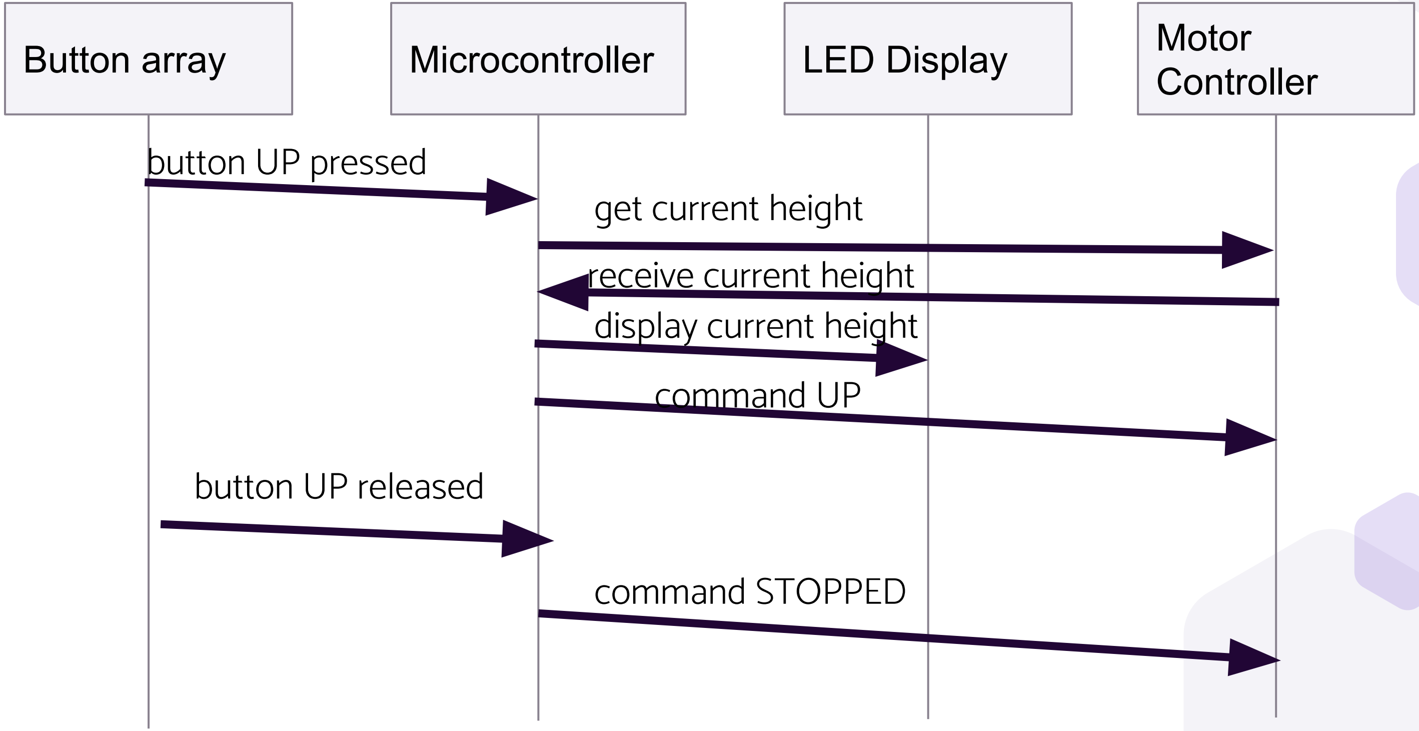
Temporally arranged (lower is later)

Usually one for each customer **scenario**

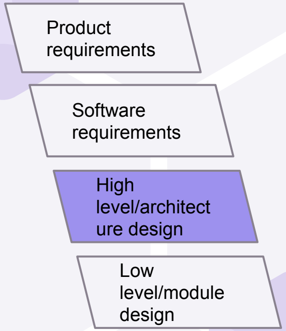
- Scenario is variant of a **use case**

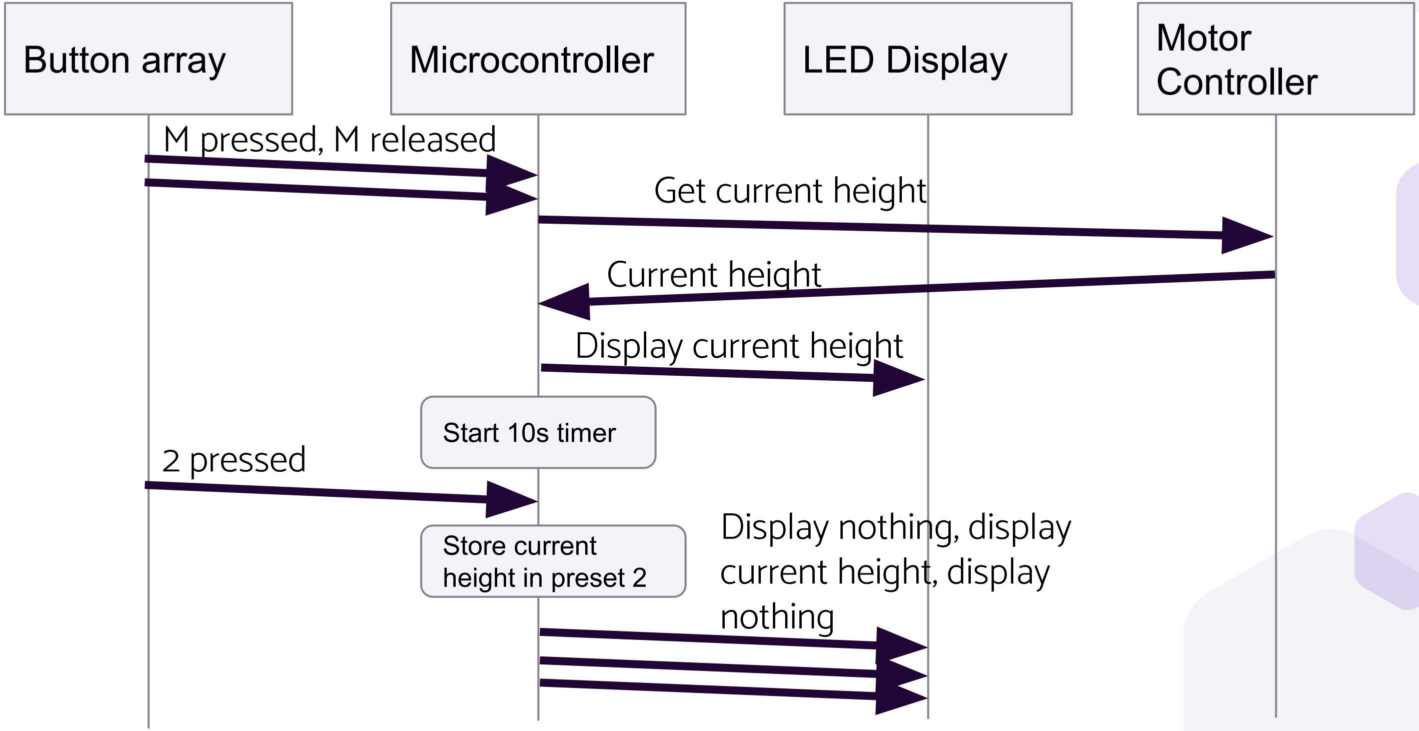


Scenario: user wants to raise desk, presses up button and desk rises

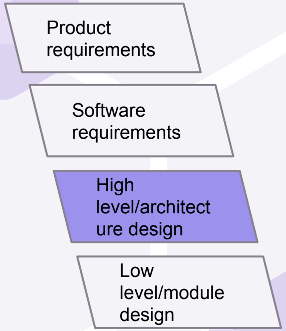


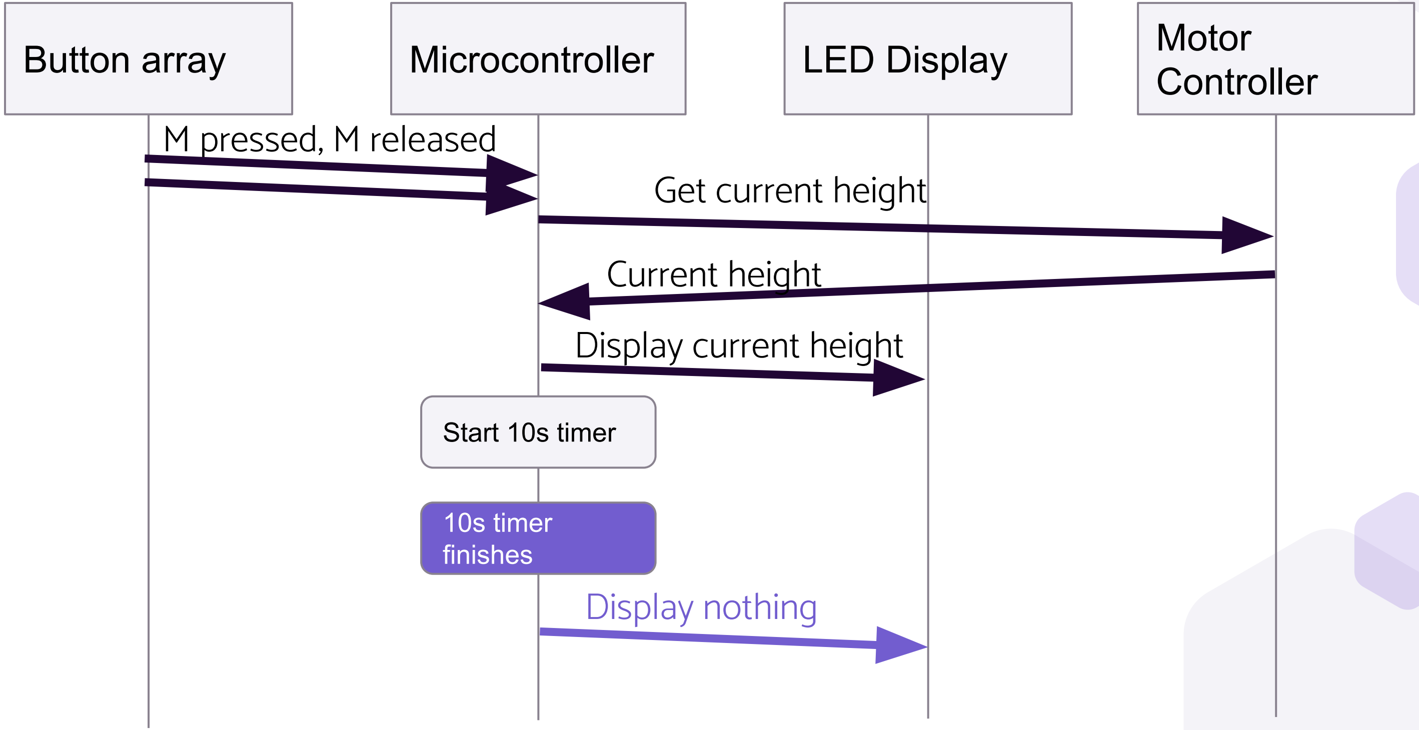
Scenario: store current height as preset 2

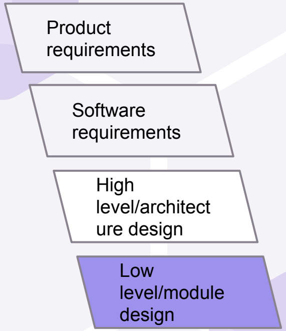




Alternative scenario for same use case







Product requirements

Software requirements

High level/architecture design

Low level/module design

Finite state machines

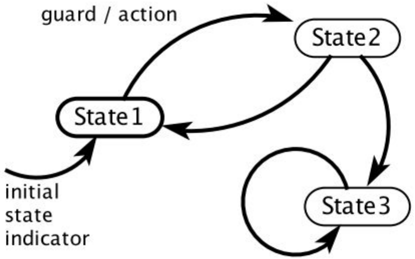
Low-level design for a module

Shows the change in state of a module

- Contrast with **flowchart**, which just shows flow of computation

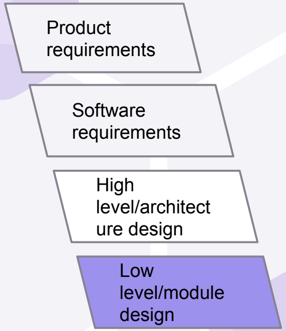
At basic level, composed of:

- States (one state is initial state)
- Guards (predicates on inputs)
- Actions (setting outputs)



Lee/Seshia chapter 3

Figure 3.3: Visual notation for a finite state machine.



Product requirements

Software requirements

High level/architecture design

Low level/module design

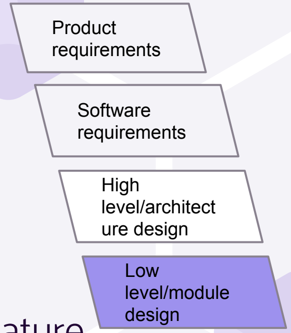
Variants

Multiple ways to define statecharts/FSMs

- Mealy vs. Moore, deterministic vs non-deterministic, etc
- Extended FSMs: state variables (variables that are **not** inputs or outputs) can appear in guards and actions

We will use **deterministic, extended** FSMs as defined by Lee/Seshia

- Will be useful when we talk about modeling
- Translate well to coding



Product requirements

Software requirements

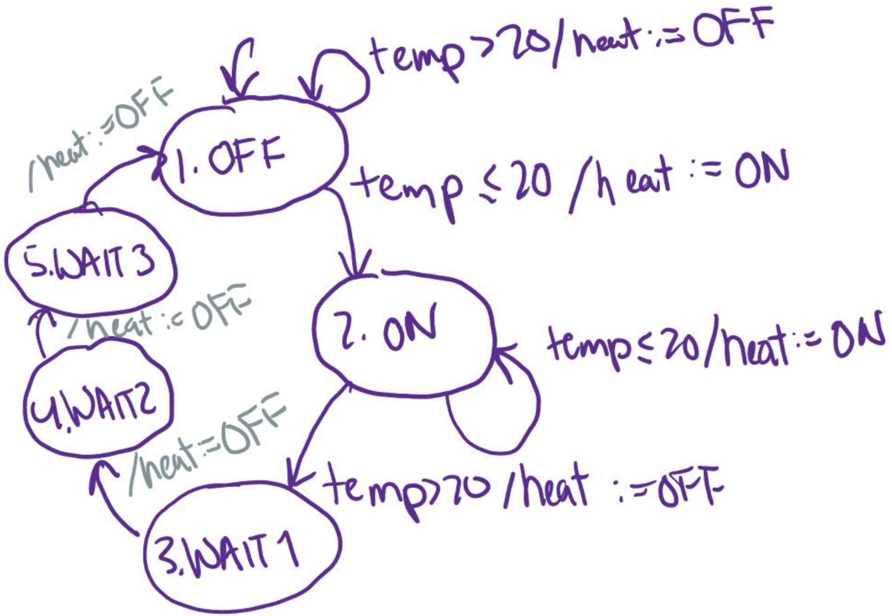
High level/architecture design

Low level/module design

FSM example: HW problem

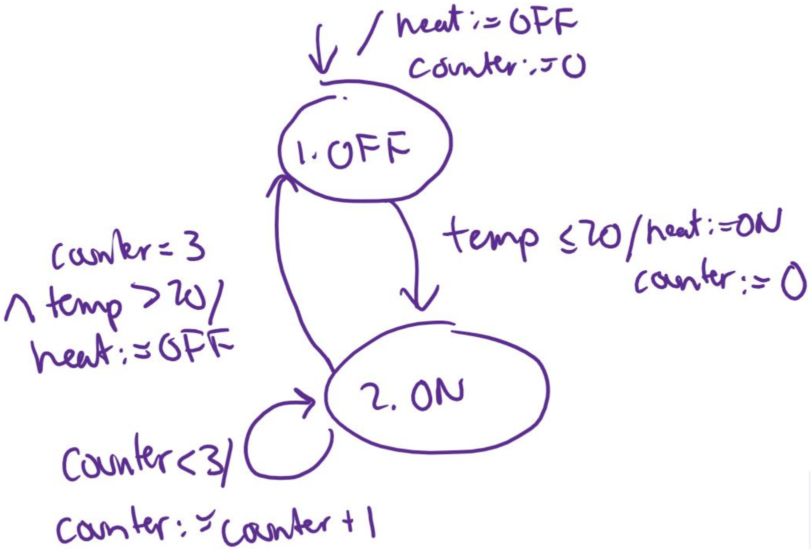
Consider a variant of the thermostat of example 3.5. In this variant, there is only one temperature threshold, and to avoid chattering the thermostat simply leaves the heat on or off for at least a fixed amount of time. In the initial state, if the temperature is less than or equal to 20 degrees Celsius, it turns the heater on, and leaves it on for at least 30 seconds. After that, if the temperature is greater than 20 degrees, it turns the heater off and leaves it off for at least 2 minutes. It turns it on again only if the temperature is less than or equal to 20 degrees

Design an FSM that behaves as described, assuming it reacts exactly once every 30 seconds.



Inputs:
temp

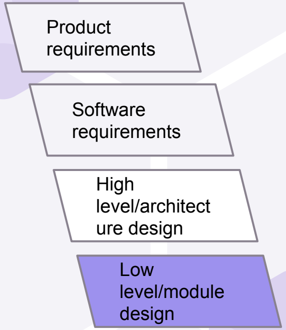
Outputs:
heat (ON/OFF); initially OFF



Extended FSM (alternative design)
Inputs:
Current temp

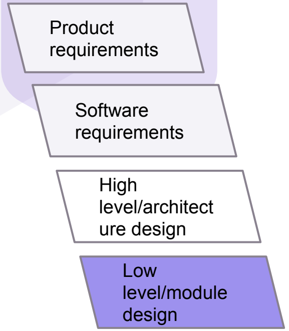
Outputs:
Heater (ON/OFF); initially OFF

Variables: counter; initial value doesn't matter



FSM conventions/rules

- Define inputs, outputs, and variables
  - Define initial values for outputs/variables
- Label each state with a number and a short, descriptive name
  - Label the start state
- Guards for transitions out of a state:
  - should be mutually exclusive
  - should only be predicated on inputs and variables
- Outputs on transitions should only set outputs and variables



Product requirements

Software requirements

High level/architect ure design

Low level/module design

Adjustable-height desk FSM

Whiteboard

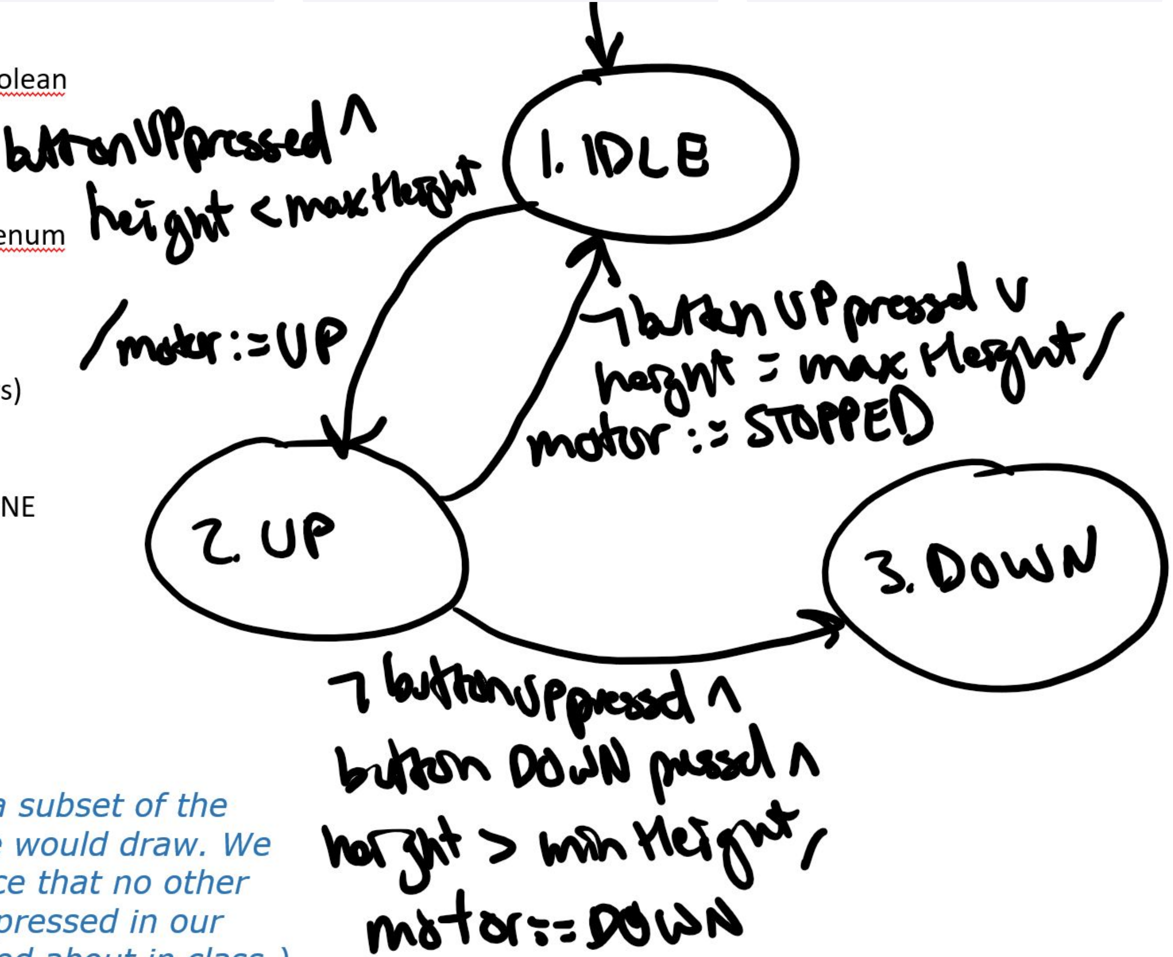
Inputs:
Button (1, 2, 3, UP, DOWN, M) pressed: boolean
Current desk height: fixed-point number

Outputs:
Motor command: (UP, DOWN, STOPPED): enum
LED display: fixed-point number or NONE

Constants:
maxHeight, minHeight (fixed point numbers)

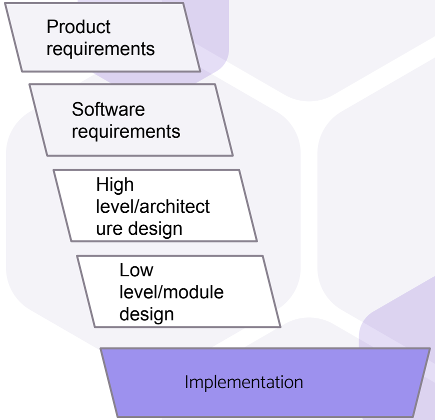
Variables (for extended FSM):
Presets 1, 2, 3 (fixed-point numbers) or NONE

Initial values:
Motor command: STOPPED
LED display: NONE
Presets 1, 2, 3: NONE


1. IDLE
2. UP
3. DOWN
buttonUPpressed ∧ height < maxHeight
/motor:=UP
¬buttonUPpressed ∨ height = maxHeight/
motor := STOPPED
¬buttonUPpressed ∧ buttonDOWNpressed ∧ height > minHeight/
motor:=DOWN

(note: this is just a subset of the entire FSM that we would draw. We also need to enforce that no other buttons are being pressed in our guards, as we talked about in class.)

Implementation of FSM


Product requirements

Software requirements

High level/architecture design

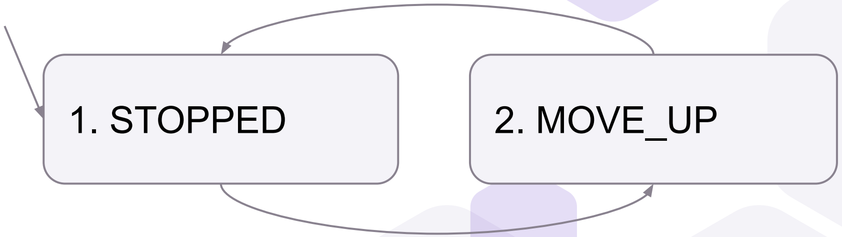
Low level/module design

Implementation

```
typedef enum { STOPPED = 1, MOVE_UP = 2 } state;

state updateFSM(state currentState, bool buttonUPpressed, …) {
    state nextState = currentState; // stay in same state by default
    switch(currentState) {
    case STOPPED:
        if (buttonUPpressed && (deskHeight != maxHeight)) {
            nextState = MOVE_UP;
            setMotorControl(UP);
        }
        break;
    case MOVE_UP:
        if (!buttonUPpressed || (deskHeight == maxHeight) {
            nextState = STOPPED;
            setMotorControl(STOPPED);
        }
        break;
    default:
        error(“invalid state!”);
    }
    return nextState;
}
```

¬ buttonUPpressed v (deskHeight = maxHeight) / motorControl := STOPPED


1. STOPPED

2. MOVE_UP

buttonUPpressed ^ ¬ (deskHeight = maxHeight) / motorControl := UP

When should updateFSM be called?

```
state updateFSM(state currentState,
    bool buttonUPpressed, ...)
```

Time-triggered vs. event-triggered design

Time-triggered: computation to (potentially) change state happens every x ms, regardless if inputs have changed

Timer interrupt OR schedule in loop

e.g.

```
void loop() {
  static state S = STOPPED;
  state = updateFSM(...);
  delay(100);
}
```

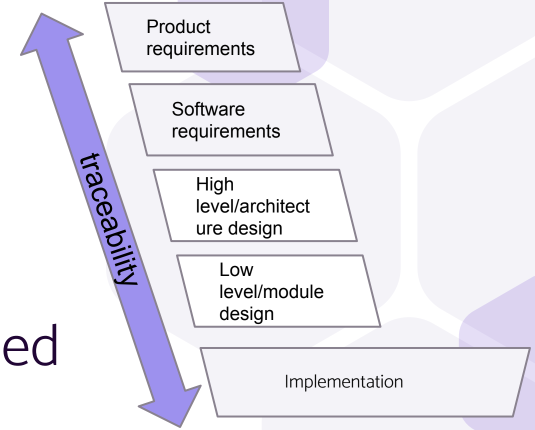
Event-triggered: computation to (potentially) change state happens when an input changes

Call `updateFSM` in every interrupt/task that polls input

Pros/cons of time- vs. event-triggered design?

How do we know that our design has met our requirements?

Traceability



Ensures that all requirements have been implemented and tested

Often done using a **traceability matrix**

- Example: each column is a requirement; each row is a transition
- “x” in a cell if the transition helps meet the requirement
- If a column has no x’s, means requirement isn’t being met
- If a row has no x’s, means transition is unnecessary (or requirement is missing/wasn’t stated!)

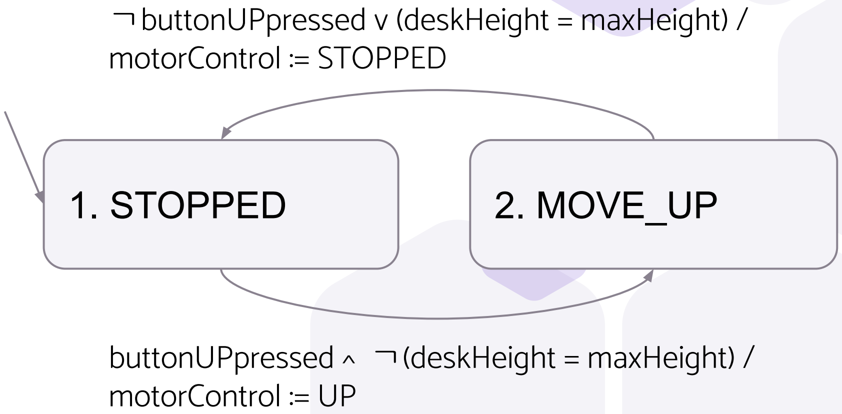
Example: requirements to FSM traceability

R1: If the desk is not at its maximum height, and the up button is held, the motor shall be commanded UP

R2: If the M button is pressed and released, and one of the numbered buttons [1, 2, 3] is pressed and released within 10 seconds, then the current height shall be stored as a preset for the corresponding numbered button

…

	R1	R2	R3
T 1-2	X		
T 2-1			



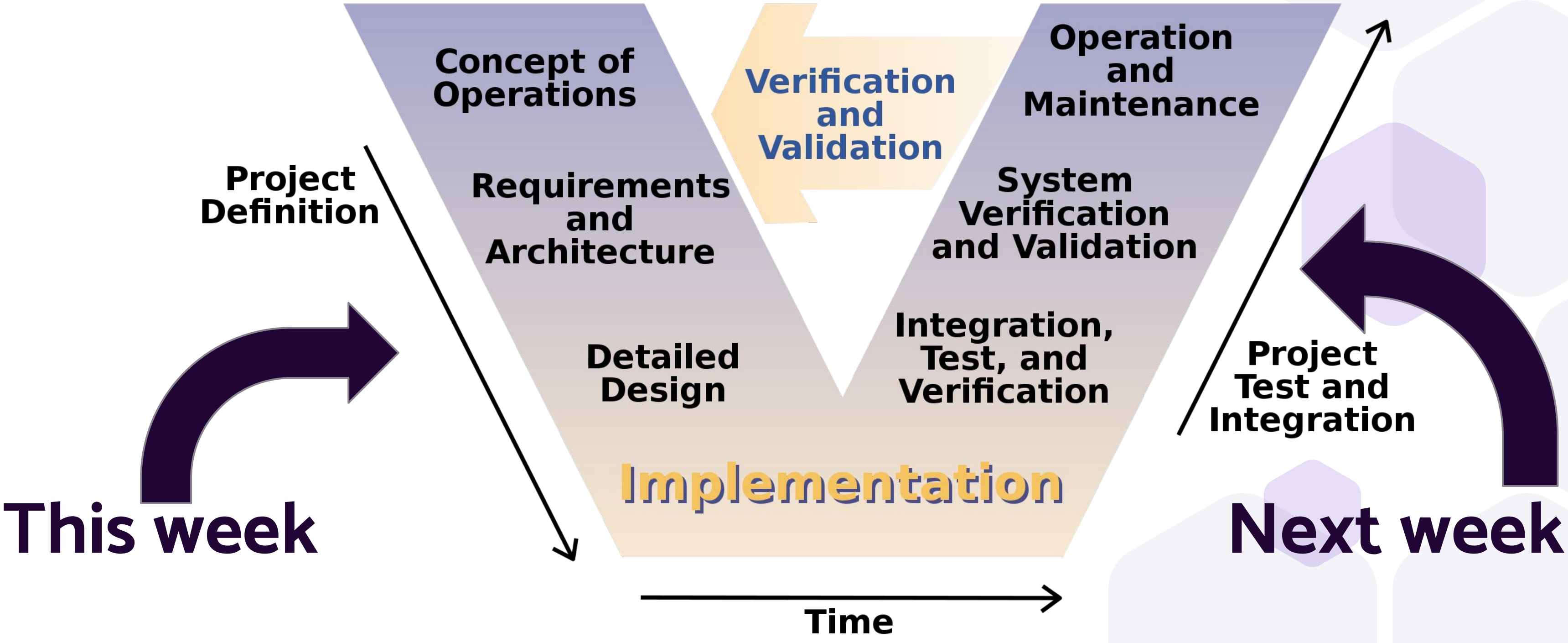
¬buttonUPpressed ∨ (deskHeight = maxHeight) /
motorControl := STOPPED

1. STOPPED

2. MOVE_UP

buttonUPpressed ∧ ¬(deskHeight = maxHeight) /
motorControl := UP

Summary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