COEN-4720 Embedded Systems Design
Lecture 2
Flowcharts, Algorithmic State Machines

Cristinel Ababei
Dept. of Electrical and Computer Engr., Marquette University


A. Flowcharts

Flowcharts

- Flowcharts: a tool for precise description of algorithms/procedures.
- Specify tasks to perform and their sequencing.
- Main symbols:
  1. Operation box: contains tasks/operations to perform.
  2. Decision box: alternative actions based on decisions to be taken.
  3. Arrows: indicate appropriate sequencing.

1. Operation Box
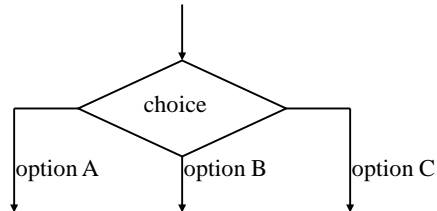
- An operation box is rectangular in shape, and is used to specify one or more subtasks to be performed. It has at most one entry point and one exit point.

Sub-task or operation to perform
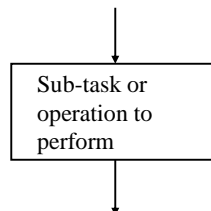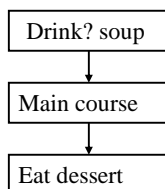
2. Decision Box

- A decision box is diamond-shaped. It has one entry point and multiple (but mutually exclusive) exit points.

```
                    │
                    ▼
              ◇ choice ◇
         ┌────┘        └────┐
    option A      option B      option C
         │            │            │
         ▼            ▼            ▼
```

3. Arrows

- Sequential flow: simplest type of sequencing; tasks are done in sequential order.

- An example: Eating a 3-course meal.

```
        ┌─────────────┐
        │ Drink? soup │
        └─────────────┘
               │
               ▼
        ┌─────────────┐
        │ Main course │
        └─────────────┘
               │
               ▼
        ┌─────────────┐
        │ Eat dessert │
        └─────────────┘
```

- ❖ Boxes are connected by lines with arrows. Lines without arrows are sometimes used. In the absence of arrows, the default flow direction is top-to-bottom and left-to-right.
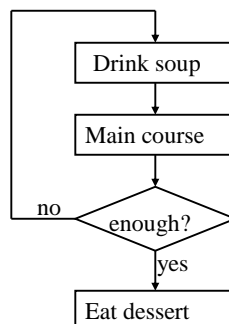
Flowcharts

- Iteration: some tasks/operations may be repeatedly/iteratively done.
- This is achieved through the loop-back in the flowchart.
- Decision box is used to determine when to terminate the loop.

Flowcharts

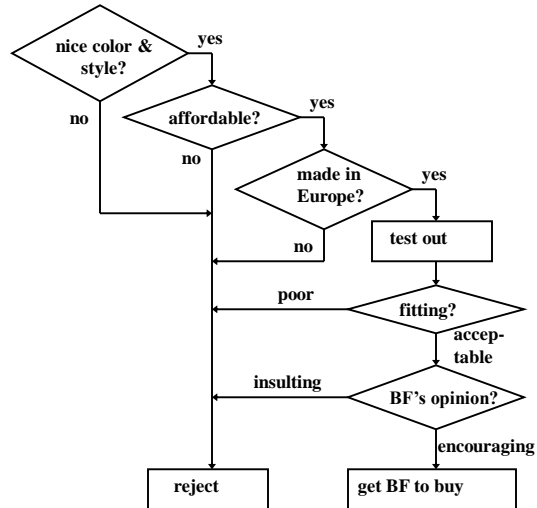- An example: meal in a different (buffet?) style.

Flowcharts

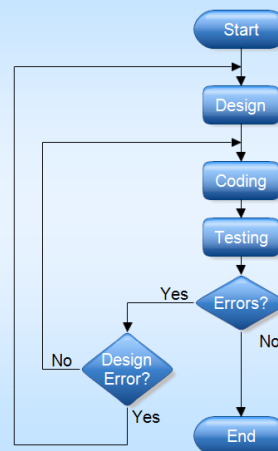- Flowcharts can be used to implement complex decisions ☺.

Flowcharts

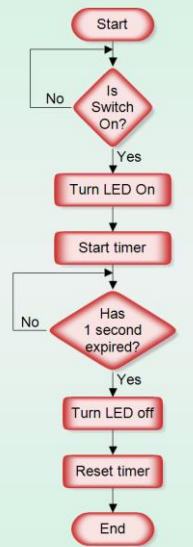- You can use flowcharts even for the software development process itself!

Software Development

Flowcharts: more examples
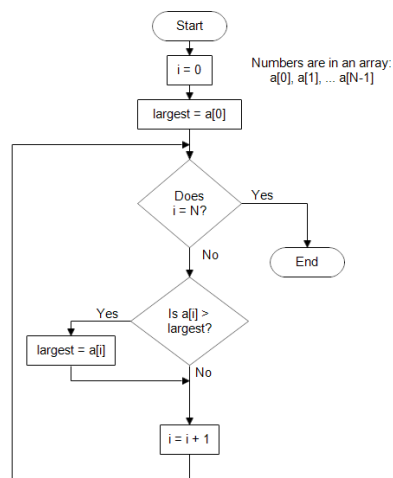
- LED on for 1 second as response to a switch event.

Flowchart of a One Second Response to a Switch

Start

No — Is Switch On?

Yes

Turn LED On

Start timer

No — Has 1 second expired?

Yes

Turn LED off

Reset timer

End

Flowcharts: more examples

- Sometimes Start and End are included inside ovals too.

Finding the Largest Number in a List of Numbers

Start

i = 0

Numbers are in an array: a[0], a[1], ... a[N-1]

largest = a[0]

Does i = N? — Yes → End

No

Is a[i] > largest? — Yes → largest = a[i]

No

i = i + 1

Flowcharts: more examples

- Additional blocks aside from rectangles, diamonds, and ovals.

Fibonacci Numbers

Finding the First N Fibonacci Numbers

Start

i = 0

j = 1

k = 0

fib = 0

i < N? — No → end

Yes

Output "Fibonacci(i) = fib"

Output carriage return and linefeed

fib = j + k

j = k

k = fib

i = i + 1
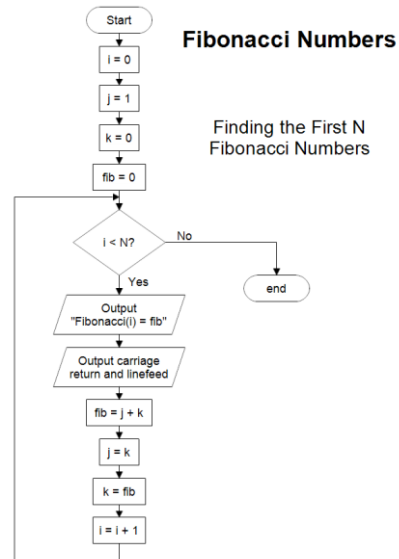
B. Finite State Machines (FSMs)

1. State Graphs: general form
2. Algorithmic State Machine (ASM) charts

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State Graph ←→ ASM chart

- State graph (or state diagram):
  - Nodes: unique states of the FSM
  - Transitional arcs: labeled with the condition that causes the transition
- Algorithmic State Machine (ASM) chart is an alternative representation
  - Composed of a network of ASM blocks
  - ASM block:
    - State box: represents a state in the FSM
    - Optional network of decision boxes and conditional output boxes
- **A state diagram can be converted to an ASM chart and vice-versa**

ASM Charts

- Algorithmic State Machine (ASM) Chart is a popular high-level flowchart-like graphical model (or notation) to specify the (hardware) algorithms in digital systems.
- Major differences from flowcharts are:
  - ❖ uses 3 types of boxes: state box (similar to operation box), decision box, and conditional box
  - ❖ contains exact (or precise) timing information; flowcharts impose a relative timing order for the operations.
- From the ASM chart it is possible to obtain
  - ❖ the control
 - ❖ the architecture (data processor)

Components of ASM Charts

- The state box is rectangular in shape. It has at most one entry point and one exit point and is used to specify one or more operations which could be simultaneously completed in one **clock cycle**.

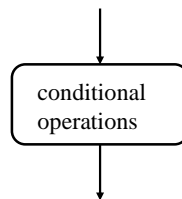state   binary code

one or more operations
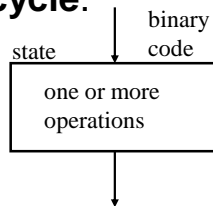
Components of ASM Charts

- The decision box is diamond in shape. It has one entry point but multiple exit points and is used to specify a number of alternative paths that can be followed.
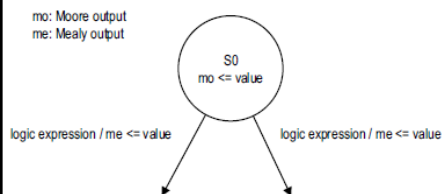
deciding factors

deciding factors
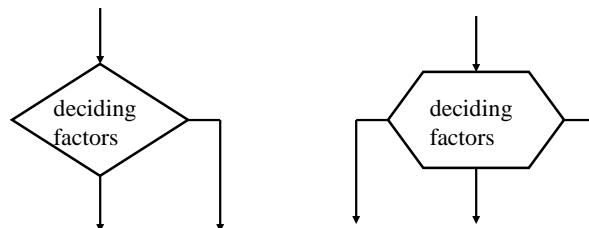
Components of ASM Charts

- The conditional box is represented by a rectangle with rounded corners. It always follows a decision box and contains one or more *conditional operations* that are only invoked when the path containing the conditional box is selected by the decision box.
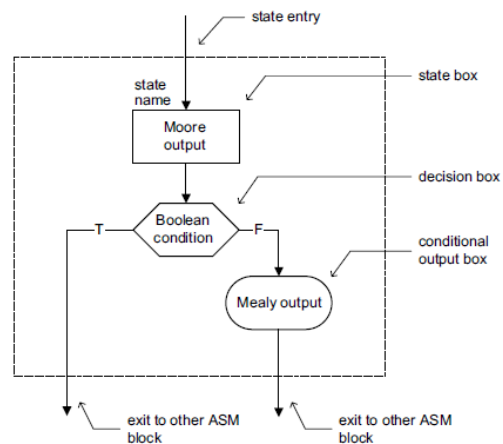
```
conditional
operations
```

State Graph ←→ ASM chart

State of State Graph

ASM Block

mo: Moore output
me: Mealy output

S0
mo <= value

logic expression / me <= value   logic expression / me <= value

state entry

state box

state name

Moore output

decision box

Boolean condition   T   F

conditional output box

Mealy output

exit to other ASM block   exit to other ASM block
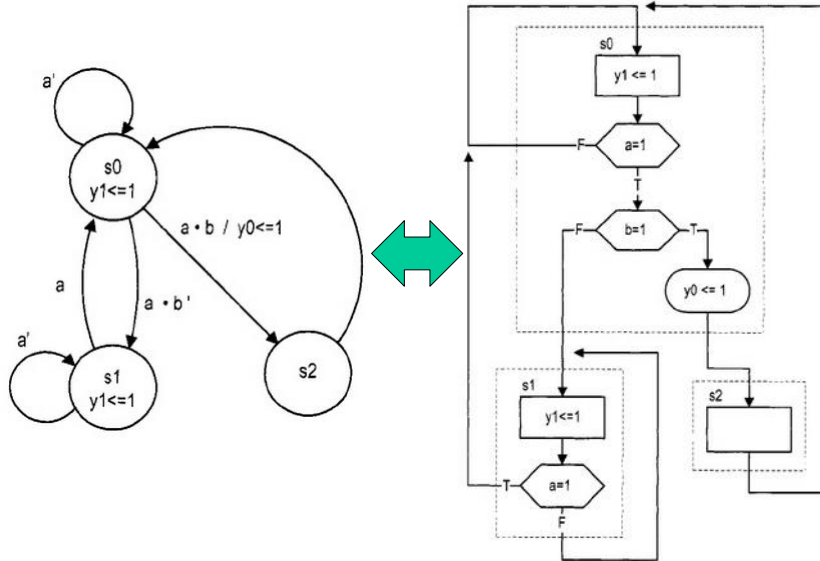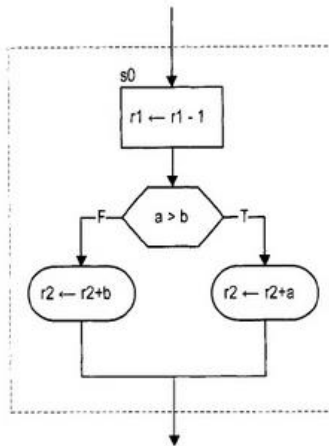
Example

C. Algorithmic State Machine with Datapath (ASMD)

Location of RT operation inside ASM block

- Extend ASM chart to incorporate RT operations and call it ASMD (ASM with data-path).
- Some people call them all just ASMs.

ASM block

Decision box with a register

- RT operation in an ASMD chart is controlled by an embedded clock signal
- Destination register is updated when the machine exits the current ASMD block, but not within the block!
- Example: $r \leftarrow r - 1$ means
  - r_next <= r_reg – 1;
  - r_reg <= r_next at the rising edge of the clock (when machine exits current block)

Timing in ASM(D) Charts

- In the context of designing sequential digital circuits: precise timing is implicitly present in ASM/ASMD charts.

- Each state box, together with its immediately following decision and conditional boxes, occurs within one clock cycle.
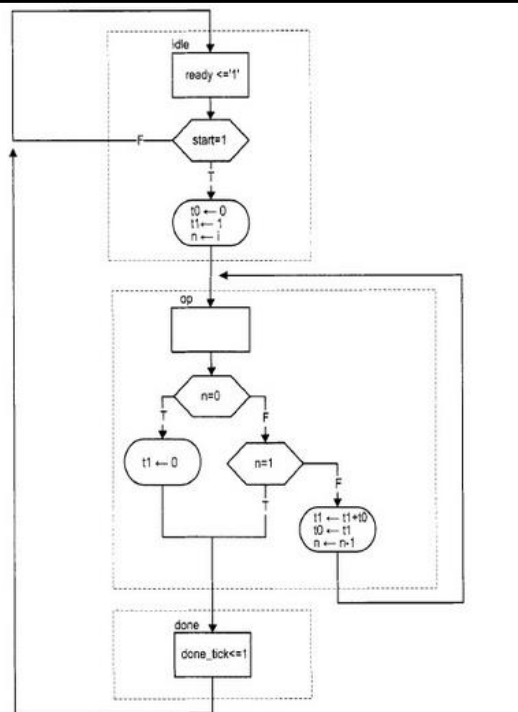
Timing in ASM Charts

3 ASM blocks
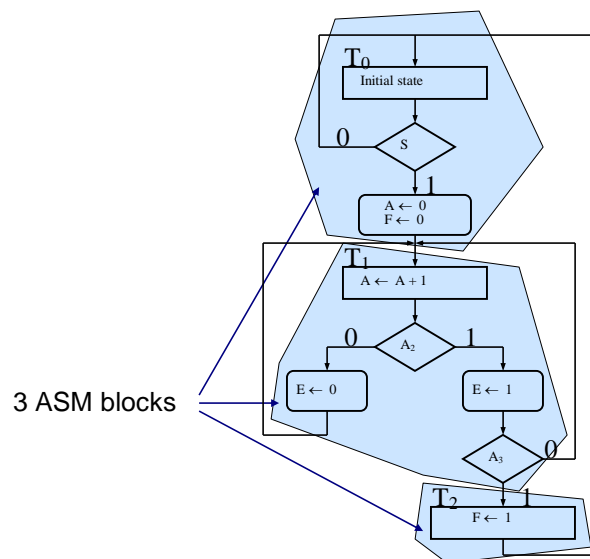
Example: Fibonacci numbers

- Fibonacci number circuit
- A sequence of integers
- fib(i) =
 0, if i = 0
  1 if i = 1
  fib(i-1) + fib(i-2), if i > 1

ASMD chart

Example: Period counter

- Measure the period of a periodic input waveform
- One solution: count the number of clock cycles between two rising edges of the input signal
- Use a rising-edge detection circuit
- Frequency of clock signal is known → easy to find the period of input signal: *N*1/f_{CLK}*
- Assume: $T_{CLK} = (1/f_{CLK}) = 20$ ns
- Register t counts for 50,000 clock cycles from 0 to 49,999 then wraps around; it takes 1ms to circulate through 50,000 cycles
- Register p counts in terms of milliseconds

ASMD chart
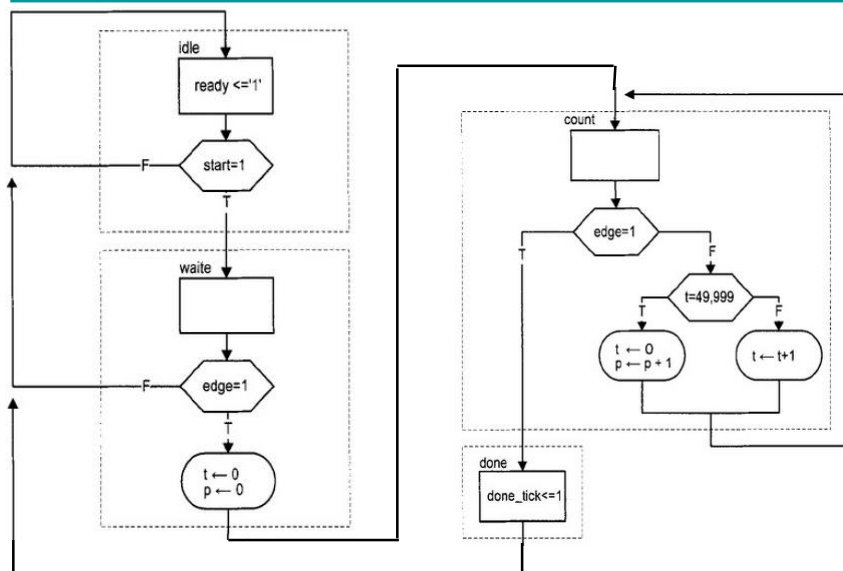
Summary

- Flowcharts are useful all the time.
- ASMs are really handy when you want to write code for a FSM type algorithm. They can make writing the code easier than when state-graphs are used.
- Use ASMs for portions of your application/program that you can specify as a FSM. Great for controller implementation (UART controller, I2C controller, USB controller, etc. controller).