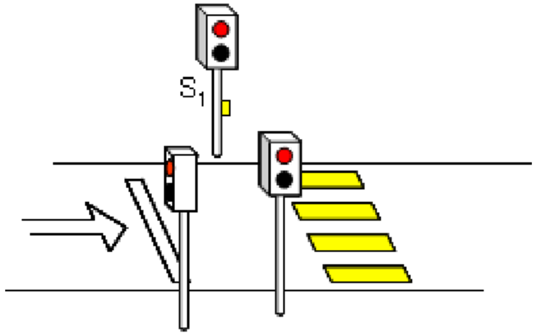
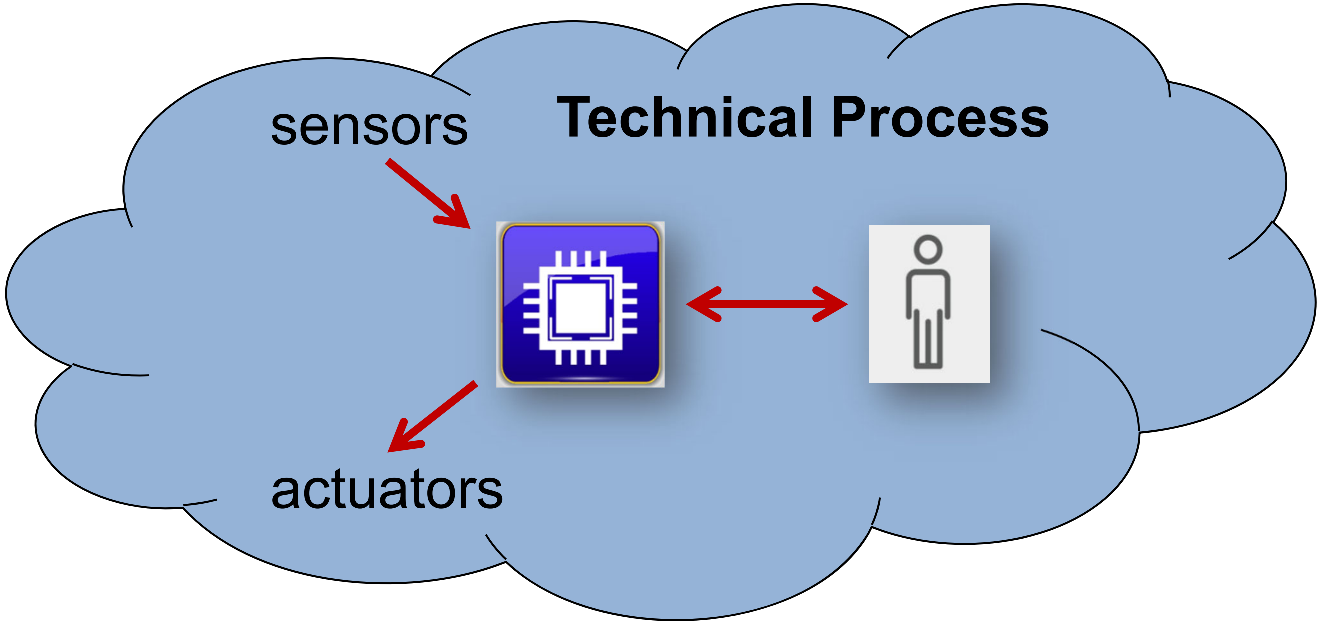
Software State Machines

Computer Engineering 2

Motivation

- **Embedded Systems**
  - Embedded in technical context / process
  - Application specific
- **How is a Finite State Machine (FSM) modeled in software?**





Agenda

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- **Repetition: FSM in Hardware**
- **FSM in Software**
- **Modeling State Machines in UML**
- **Implementation in C**
- **Interaction of FSMs**

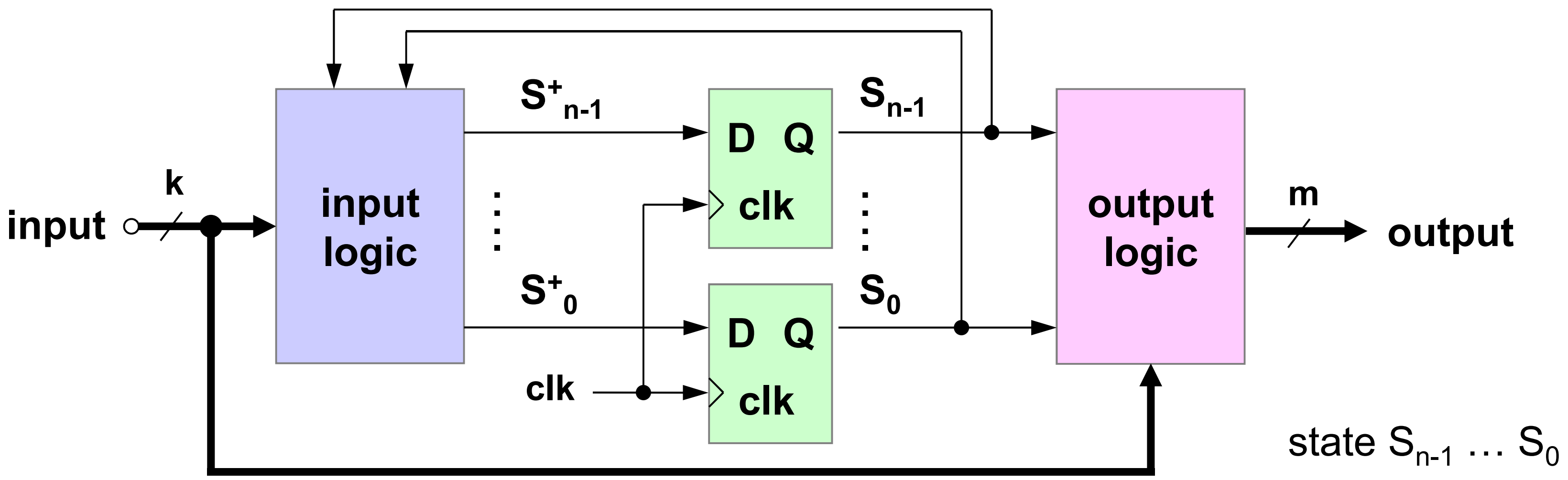
Learning Objectives

At the end of this lesson you will be able

- to explain the term «Finite State Machine» (FSM)
- to outline why FSMs in software are often modeled in a different way than in hardware
- to explain the concept of a reactive system (state-event model)
- to correctly use the related terms and to interpret a UML state diagram with the basic elements
- to correctly model/describe an FSM using the basic elements of a UML state diagram
- to name and describe the semantics of an UML FSM
- to translate a simple FSM modeled in UML into C-Code

Repetition: FSM in Hardware

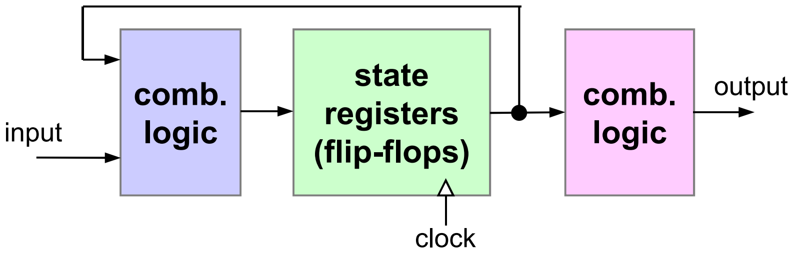
- **Finite State Machine (FSM) in hardware**
  - Flip-flops store internal state
  - Clock-driven
    - Inputs are evaluated[1] at each clock edge
    - State can only change on a clock edge

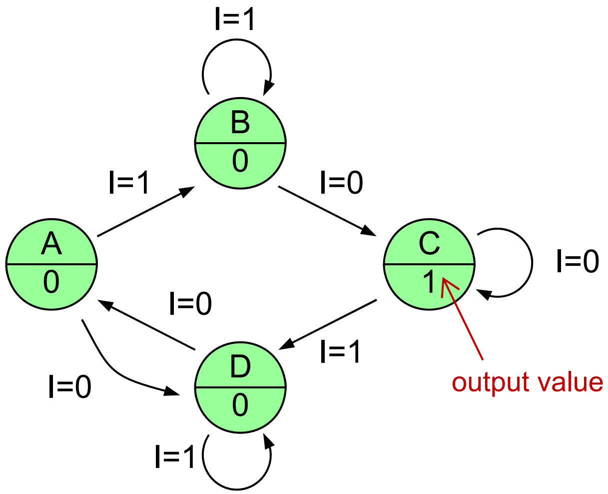


[1] Evaluation of inputs → interpretation of signal levels: '0' vs. '1'

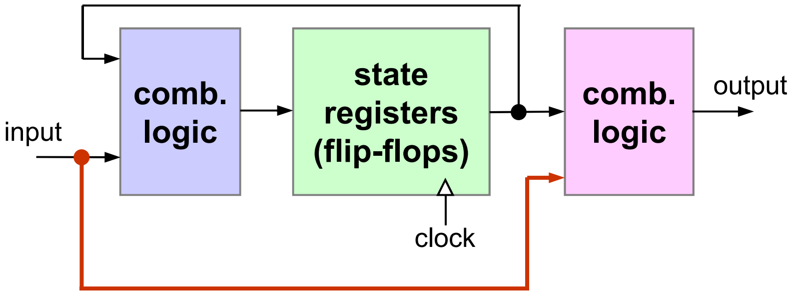
Repetition: FSM in Hardware

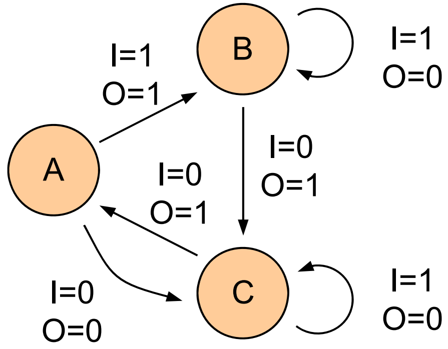
- **Moore**
  - Input signals influence state only





- **Mealy**
  - Input signals influence state AND output signals





FSM in Software

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Why software is different

- Hardware is intrinsically parallel
  - Several FSMs can be processed in parallel using the same clock – Large number of flip-flops and gates evaluate simultaneously
  - Use of common clock as the only event
  - Evaluate signal levels of inputs at clock edges
  - Unchanged signal levels of inputs do not create overhead

- Software is intrinsically sequential
  - CPU has to process one FSM after the other
  - "HW approach" would require a function call on each clock edge
  - All FSM inputs would have to be evaluated on each function call even if they have not changed → creates a large processing load for CPU
  - Cooperating FSMs: Using a "synchronous clock approach" as in hardware creates a lot of synchronization issues in sequential system

→ use a different approach for software

FSM in Software

- **Reactive system → State-event model**
  - Responds to external events (input)
    - Event-driven
    - Only evaluate the FSM if an input changes
  - Internal state
    - Memory of what happened before
  - Actions
    - Influence the outside world
  - Each event may or may not
    - Change the internal state
    - Trigger actions

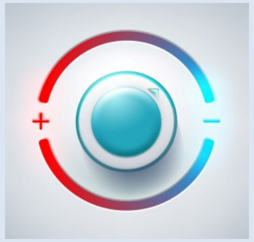
source www.thediligentadvisor.com

Depending on the current state an event may have a different effect.

FSM in Software

- **State-event applications**

Process control
- Washing machines
- Vending machines
- Heating systems



Communication protocols
- Opening and closing connection

Human-machine interface
- Recognition and validation of user inputs

Parsing
- Programming languages

image sources: colourbox, itflow.biz

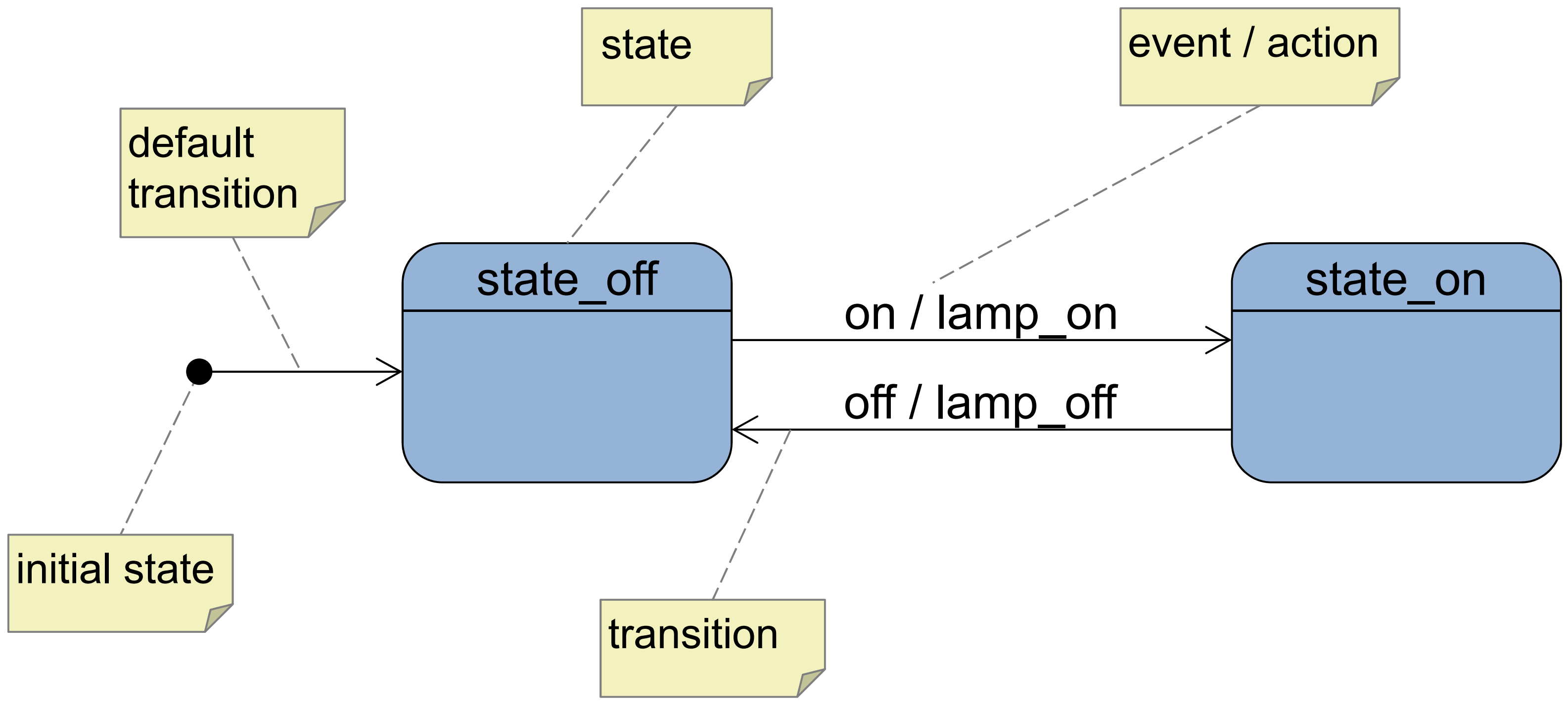
Modeling State Machines in UML

- **UML – Unified Modeling Language**
  - Graphical modeling of software systems
  - Object oriented concepts
  - Introduced in the 1990s
    - Since 1997 maintained
      by Object Management Group (OMG)
    - Since 2000 certified by ISO
  - State diagrams
    - Only a part of UML
    - Describe the reactive behavior of classes
    - Based on notation of Prof. David Harel

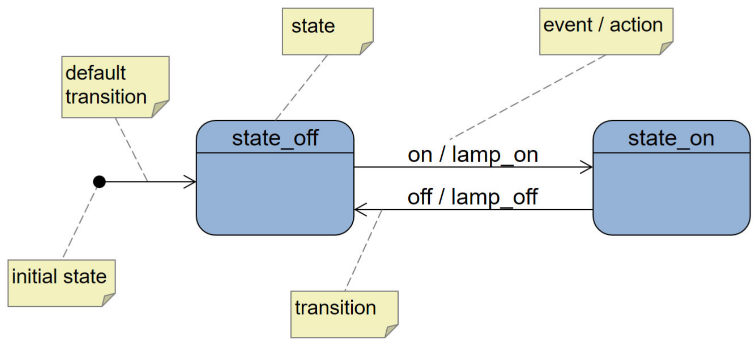
We only cover a small part of the available state diagram notations

Modeling State Machines in UML

- **UML state diagram example**



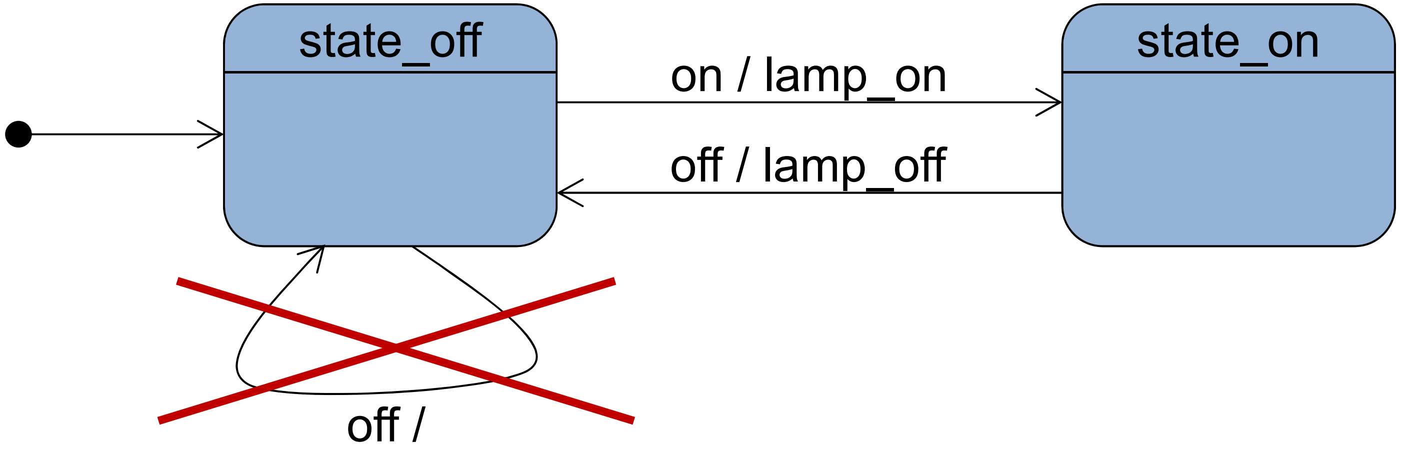
Modeling State Machines in UML



- **Terminology**
  - State
    - Internal state of the system in which it is awaiting the next event
  - Event
    - Asynchronous input that may cause a transition
  - Transition
    - Reaction to an event: May change the state and/or trigger an action
  - Action
    - Output associated with a transition
      - Either a directly carried out operation or a
      - Message to another FSM (seen as an event by the receiving FSM)
  - Finite State Machine (FSM)
    - Machine with a finite number of states and transitions

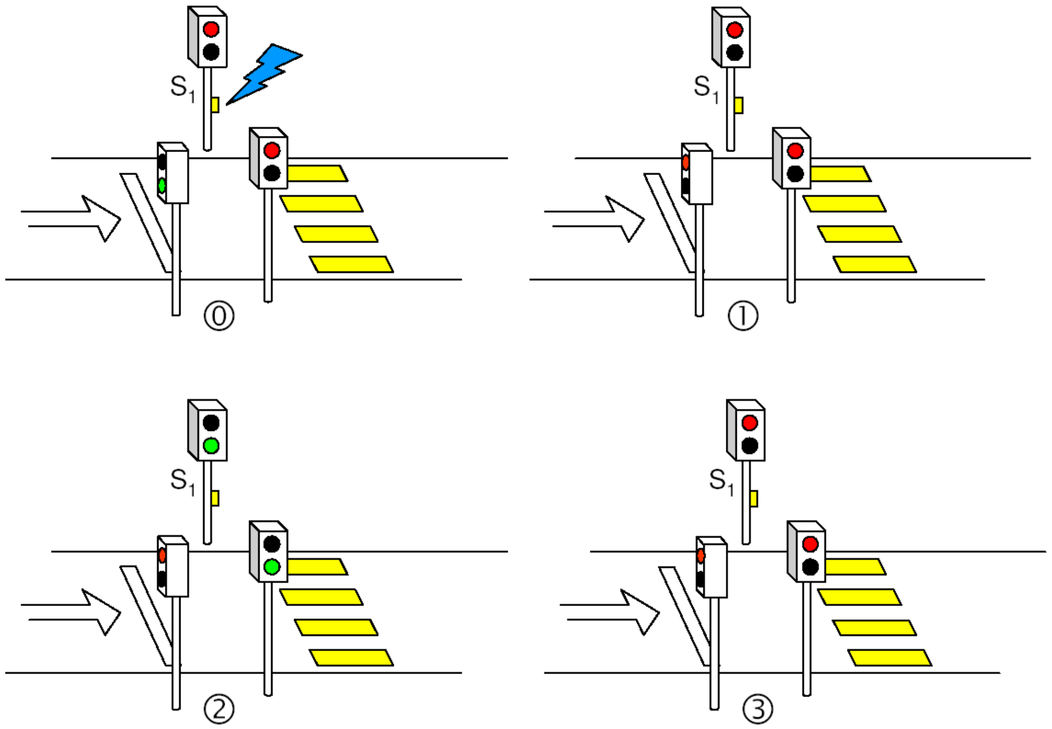
Modeling State Machines in UML

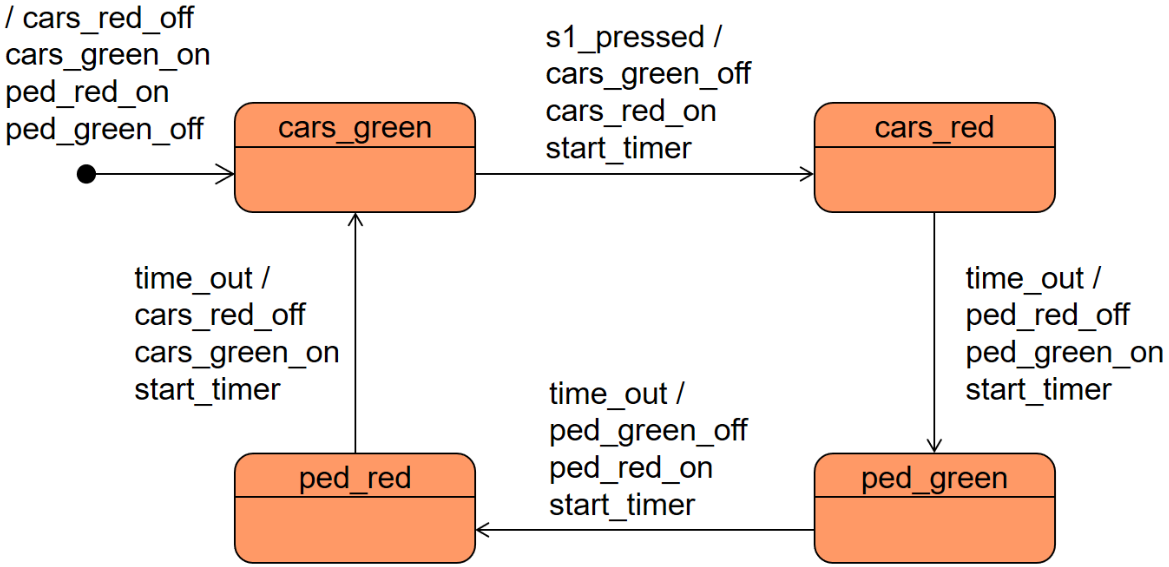
- **In contrast to Mealy notation**
  - Input asynchronous event
  - Output actions → interaction with outside world
  - Inputs without effect are omitted
    - If an event triggers neither a state transition nor an action it will not be drawn in the UML state diagram
    - Increases clarity of diagram
  - UML contains Mealy and Moore notations as a subset



Modeling State Machines in UML

- **Example: Traffic light**

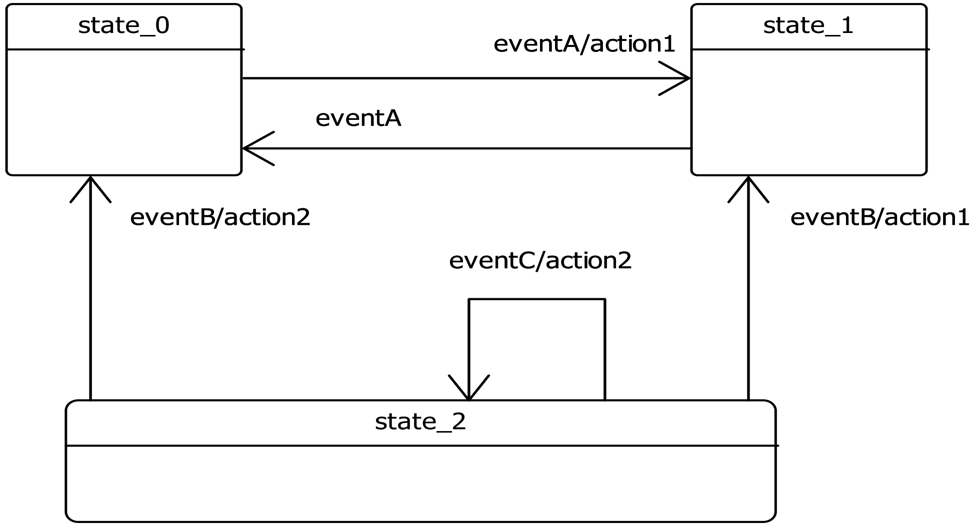




Modeling State Machines in UML

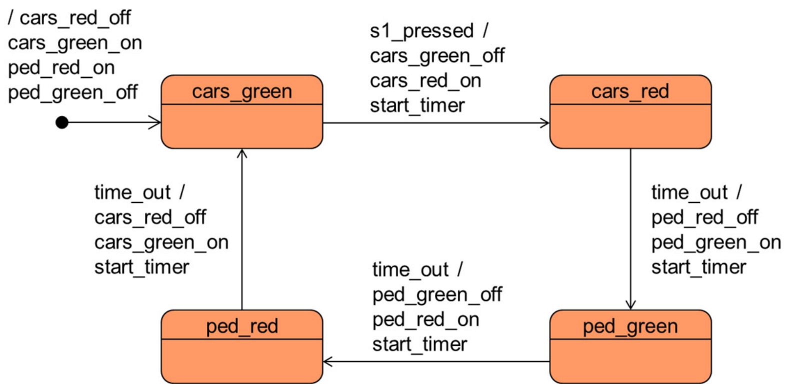
- **Rules for UML state machines**
  - Every state-diagram must have an initial state
  - Each state has to be reachable through a transition
  - The state-diagram has to be deterministic
    - I.e. for each event it has to be defined which transition is triggered

What's wrong?



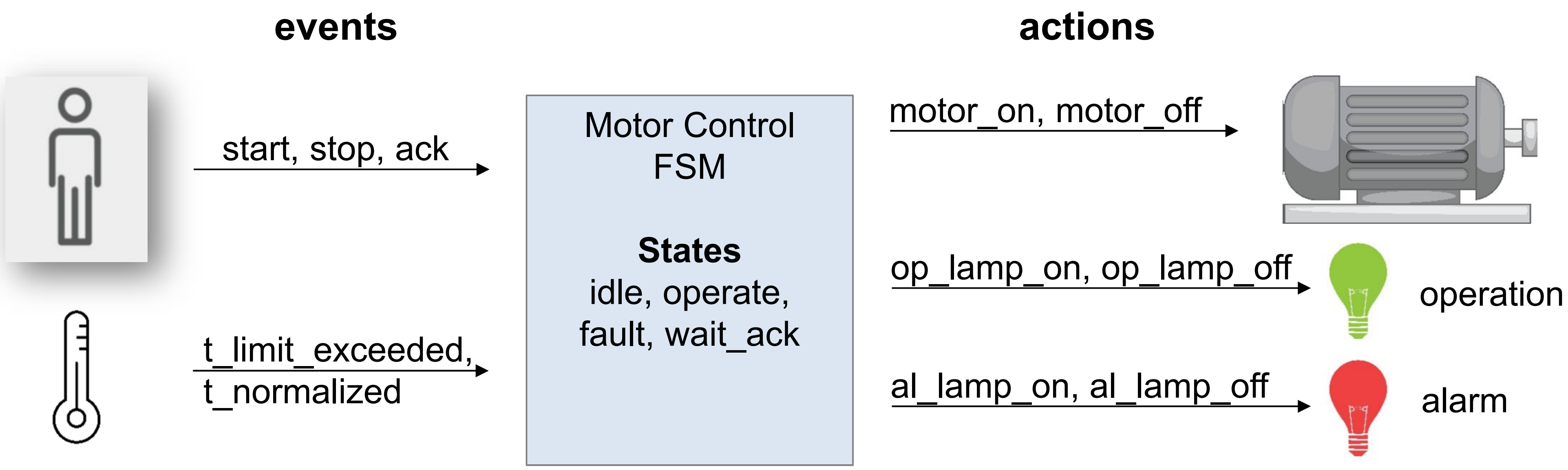
Modeling State Machines in UML

- **Semantics of an UML FSM → understanding the model**
  - FSM is passive
    - It only reacts to events from the outside
    - Does not initiate any actions on its own
  - Always has a defined state
  - Reaction to an event depends on the current state
    - State defines the corresponding transition for an event
    - Event is discarded (lost) if no transition for it exists in current state
  - Run-to-completion
    - Once started a transition cannot be interrupted
  - Strives to avoid querying additional input
    - The executed transition only depends on the event and not on additional inputs



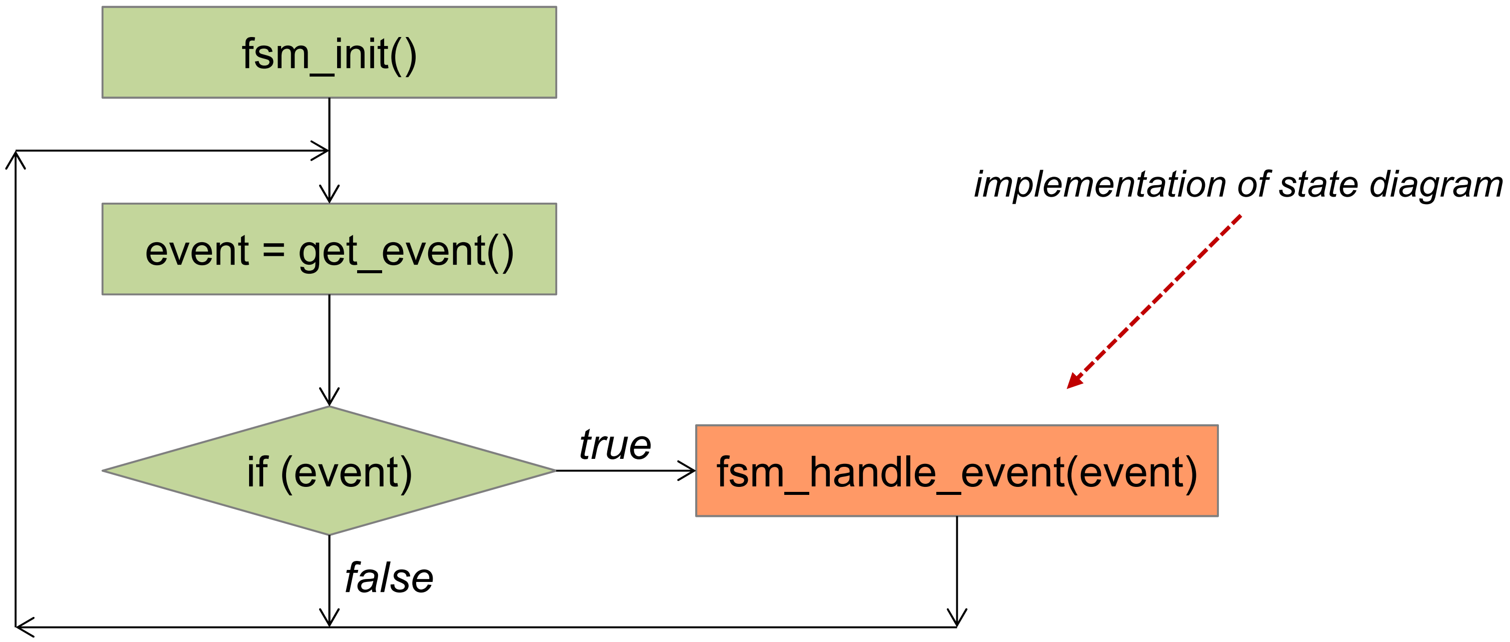
Modeling State Machines in UML

- **Exercise: Draw the UML-State-Diagram for “Motor Control”**
  - The operator shall be able to turn the motor on and off by pressing the start button and the stop button respectively.
  - Motor control shall switch the motor off if the temperature limit is exceeded.
  - Restarting the motor after a temperature shutdown shall require pressing the acknowledge button before pressing the start button.
  - Normal operation shall be indicated with an operation lamp whereas an alarm condition shall be indicated with an alarm lamp.



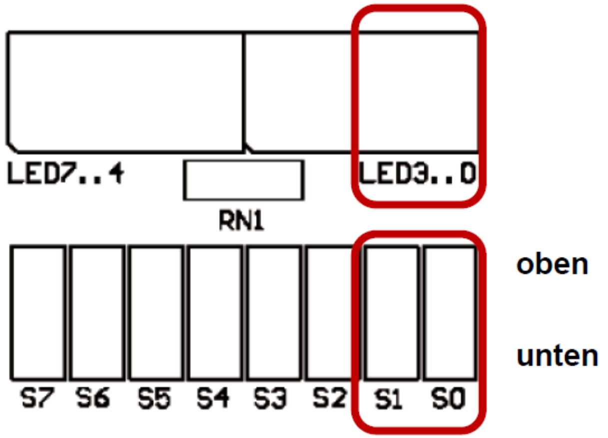
Implementation in C

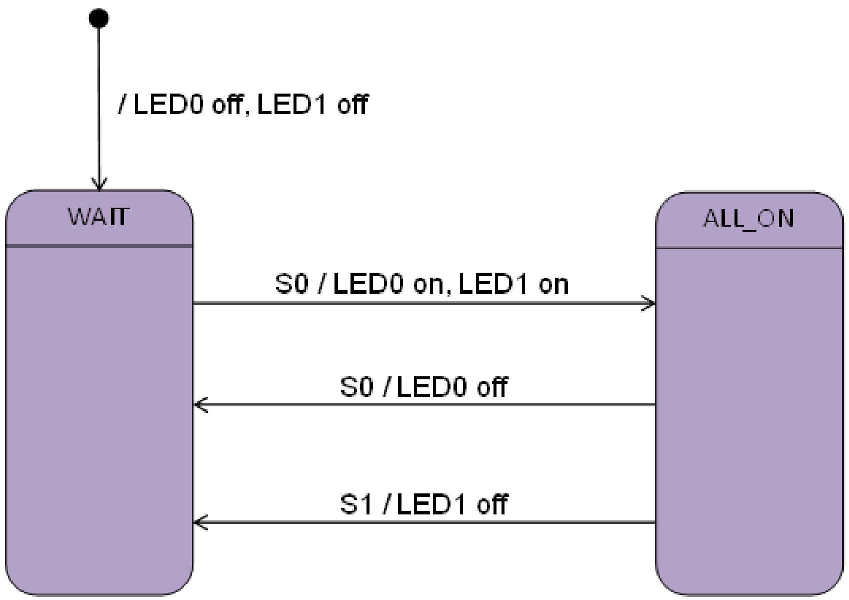
- **Simple FSM System**



Implementation in C

- **Example: LED control on CT-board**
  - Shifting switch Sx from 'unten' to 'oben' → event Sx
  - x ∈ { 0, 1 }





Implementation in C

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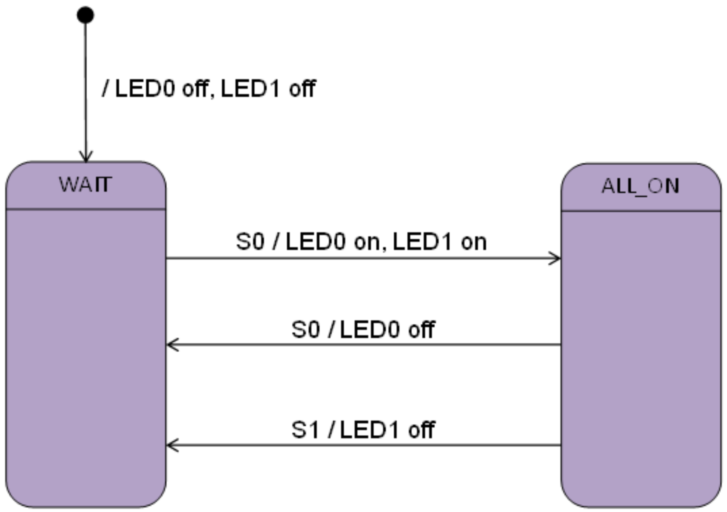
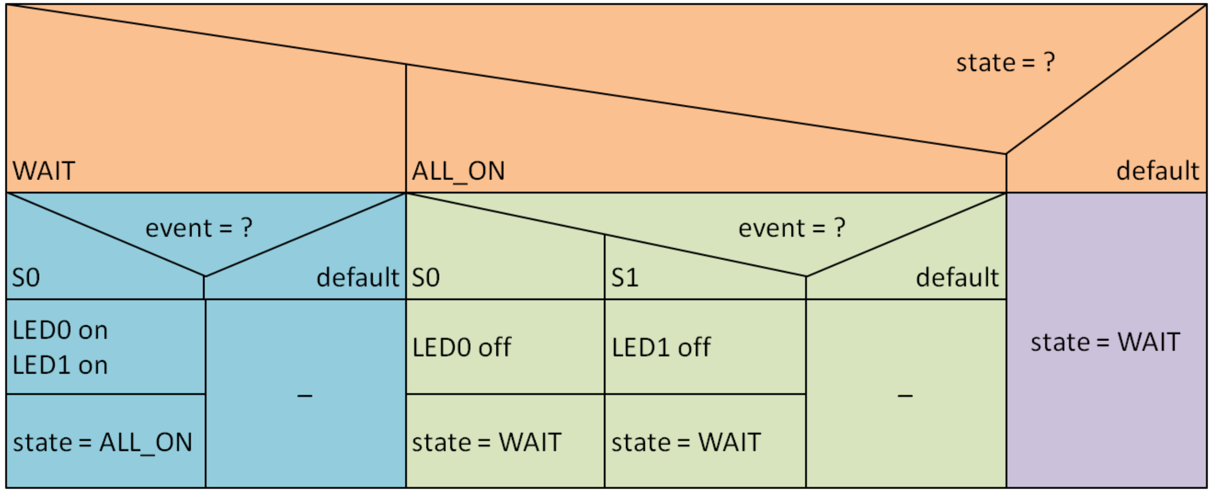
- **Example: LED control**

```c
int main(void)
{
    event_t event;

    fsm_init();
    while (1) {
        event = get_event();
        if (event != NO_SWITCH){
            fsm_handle_event(event);
        }
    }
}
```

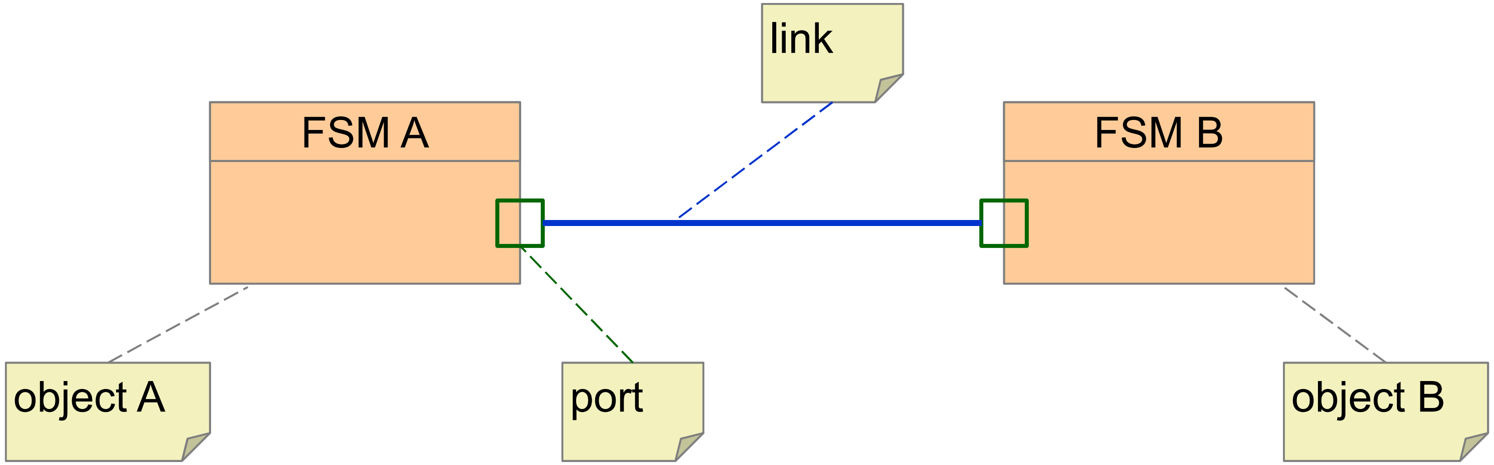
→ see code example





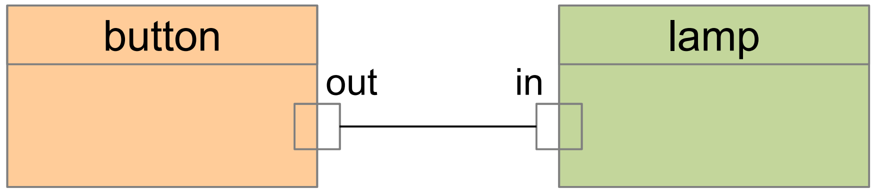
Interaction of FSMs

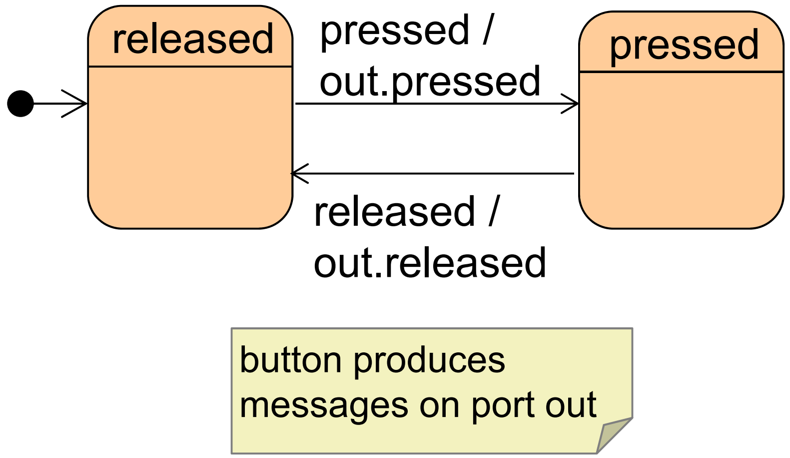
- **Port**
  - Defines the messages that can be sent and received by an FSM
    - Output message → action of the FSM
    - Input message → event of the FSM
- **Link**
  - Defines a connection for sending messages

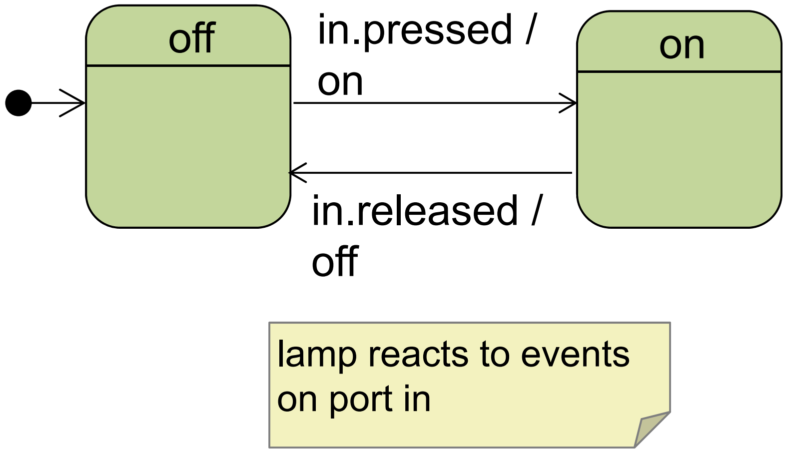


Interaction of FSMs

- **Example**
  - Reactive system partitioned into two FSMs
  - Interaction of FSMs happens through event-messages

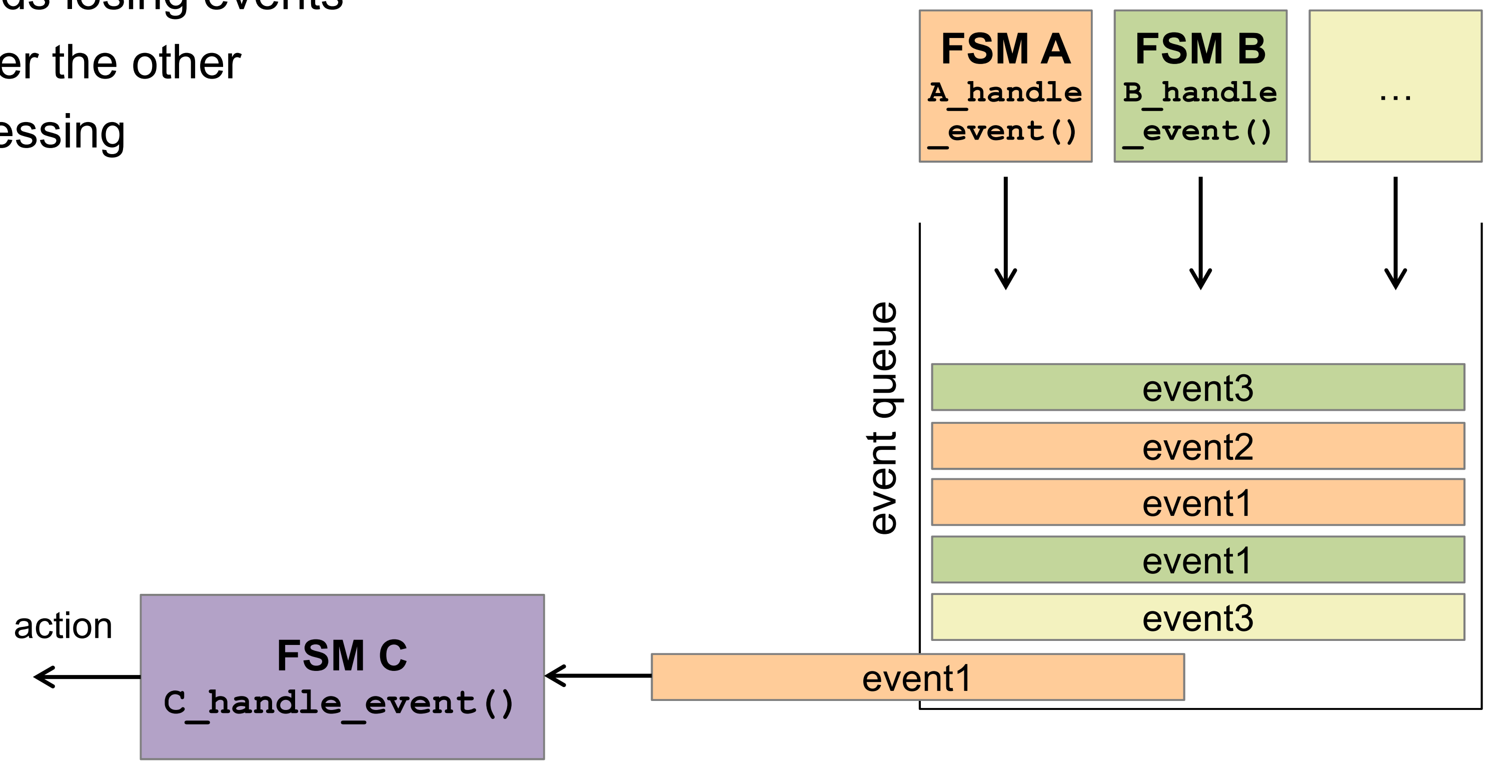






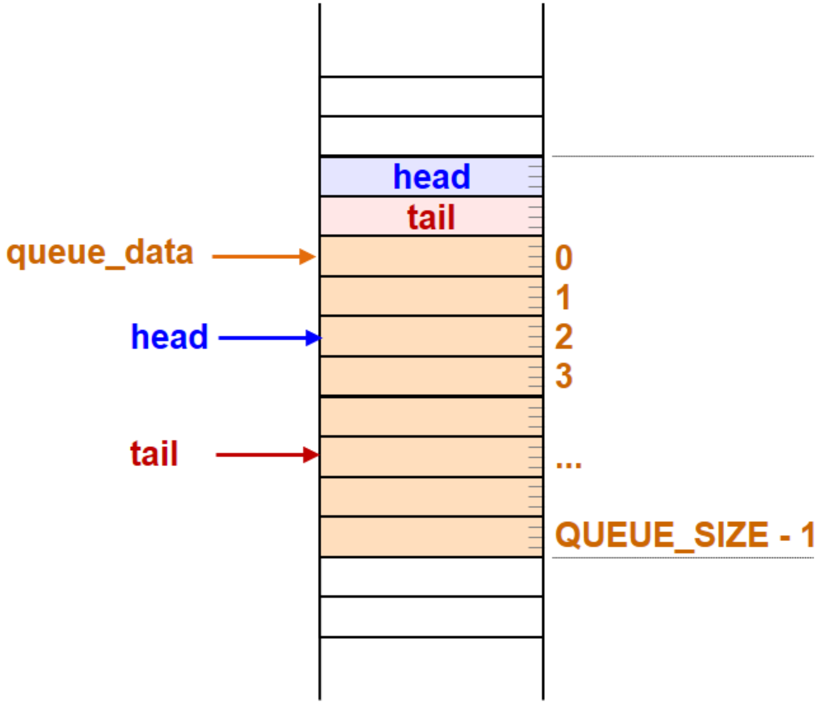
Interaction of FSMs

- **Event queue**
  - Collect events generated by different objects
  - Buffered in event queue: Avoids losing events
  - FSM processes one event after the other
  - Events are deleted after processing



Interaction of FSMs

- **Event queues**
  - Covered in Microcomputer Systems 1 (MC1)




```c
#define QUEUE_SIZE 20

/**
 *  \brief  Defines a queue.
 */
typedef struct {
    uint32_t head;
    uint32_t tail;
    uint32_t queue_data[QUEUE_SIZE];
} queue_t;
```

Conclusion

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- **Finite State Machine (FSM)**
  - Allows modeling of reactive systems
  - Hardware vs. software
    - Digital logic → clock driven
    - Software → event driven
  - Modeling in UML
    - State / Event / Transition / Action
  - Implementation in C
    - Switch case
  - Interaction of FSMs
    - (Output-) actions of one FSM become (input-) events for other FSM
    - Event queue

```
switch (state) {
    case STATE_A:
        switch (event) {
            case S0:
                action();
                state = NEW_STATE;
                break;
            default:
                state = WAIT;
        }
        break;

    case STATE_B:
        switch (event)
```