Embedded System Design and Modeling

VI. Composition of State Machines

Composition of state machines

- How to combine multiple smaller FSMs into a bigger one?
- What problems arise?
- Two types of compositions:
  1. **Spatial** composition: how are the components connected?
  2. **Temporal** composition: how do the components react in time?

Spatial composition

- **Spatial** composition = how are two components connected, how does the information flow between the components
  - **Side-by-side** composition = no common inputs/outputs, no shared data
  - **Cascade** composition = Outputs of one FSM are inputs to another one
  - **Feedback** composition = (Some) outputs of a FSM are inputs to the same FSM, or to some other component which is in front

Side-by-side composition

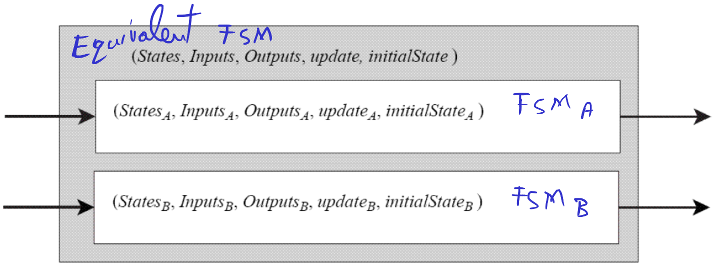


Figure 1: Side-by-side composition

Cascade composition

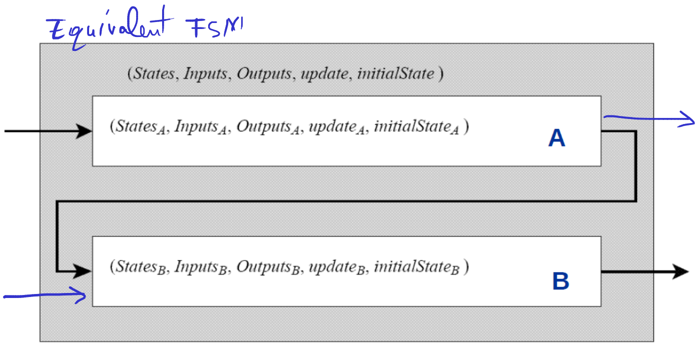
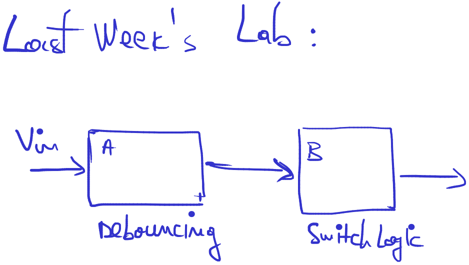


Figure 2: Cascade composition



- Outputs of FSM A are inputs to FSM B

Feedback composition

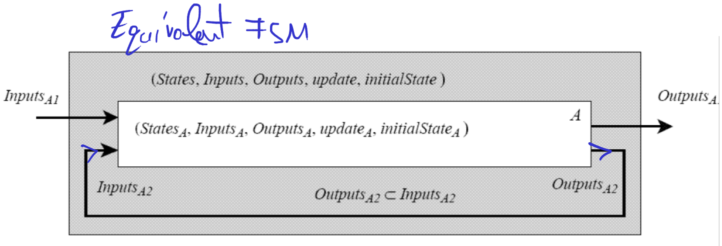
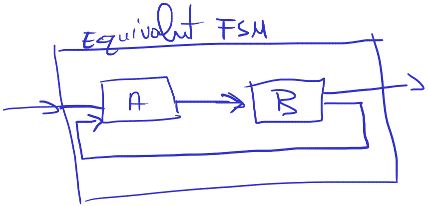


Figure 3: Feedback composition

- Some outputs of the FSM are coming back as inputs



Feedback + Cascade

Temporal composition

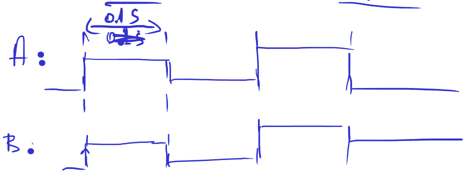
Seq.

Parallel

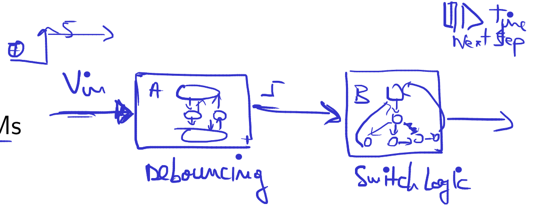
Synch.

Async.

- **Temporal** composition = when do two components react?
  - **Sequential vs Parallel** composition:
    - **Sequential** = the two FSM do not work at the same time
    - **Parallel** = the two FSM work at the same time
  - **Asynchonous vs Synchronous** composition = only for parallel composition
    - **Synchronous** = transitions are taken at the same time in both FSMs
    - **Asynchronous** = transitions are taken at independent times in the FSMs



Last Week's Lab:



- Parallel
- Synchronous

Sequential composition

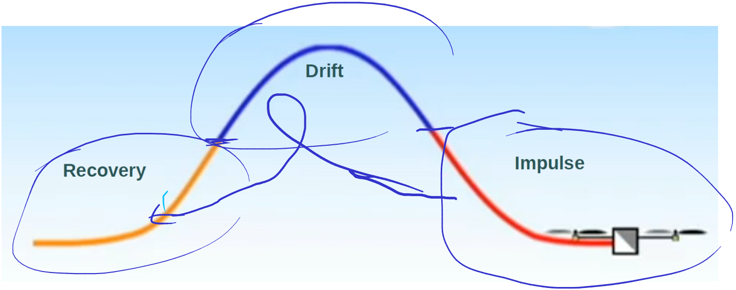
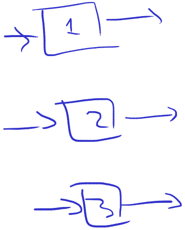


Figure 4: Example of Sequential composition



- https://www.youtube.com/watch?v=iD3QgGpzzIM
- The drone has three modes of operation, working **in sequence**

Parallel composition

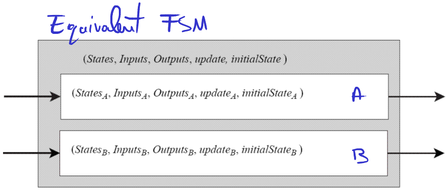


Figure 5: Side-by-side composition

- The two FSMs form an **equivalent model**
- When do the transitions in these FSM take place?
  - Synchronous: simultaneously
  - Asynchronous: independently

Synchronous composition

- Consider the two FSM on the left (A and B)
- The equivalent model is on the right

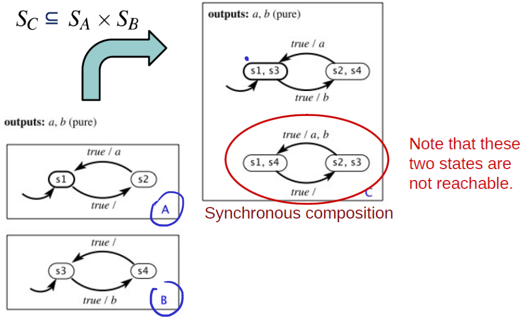
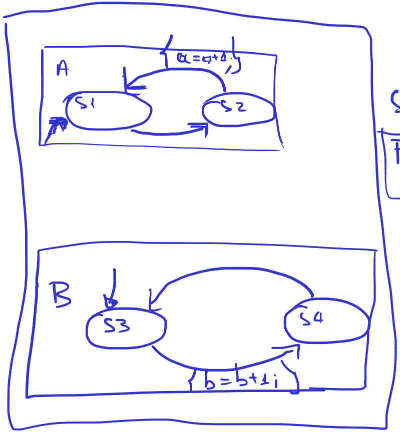


Figure 6: Synchronous composition

Synchronous composition

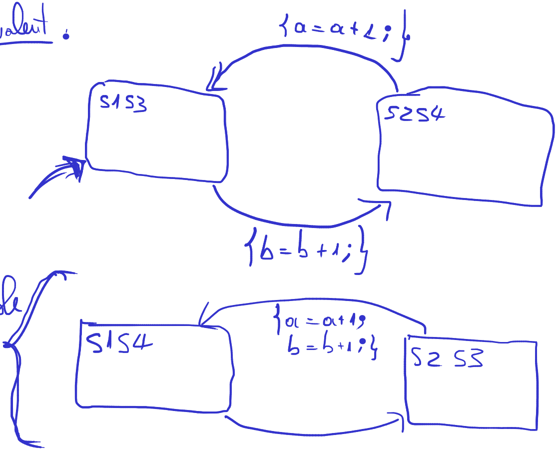
Equiv. FSM

Redraw here



Side-by-side
parallel and
Synchronous

Equivalent:



Unreachable
states

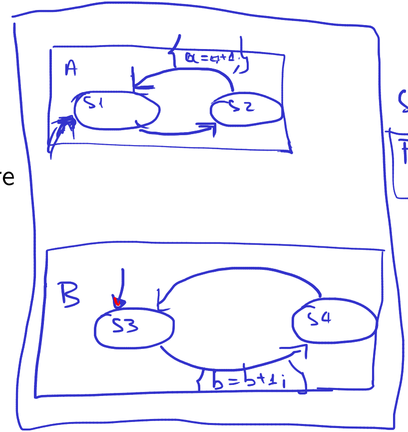
Synchronous composition

- In the equivalent model:
  - States = combination of states of the two FSMs
  - Transition = transition in FSM A and FSM B, happening simultaneously.
  - There might exist unreachable states in the equivalent model (states that will never be reached)

Asynchronous composition

Equiv. FSM

Draw here



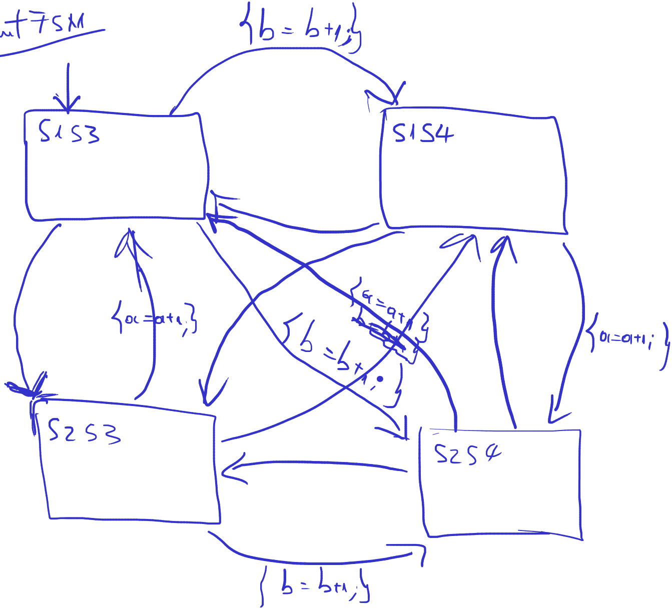
Side-by-side

parallel and ~~synchronous~~

Asynchronous

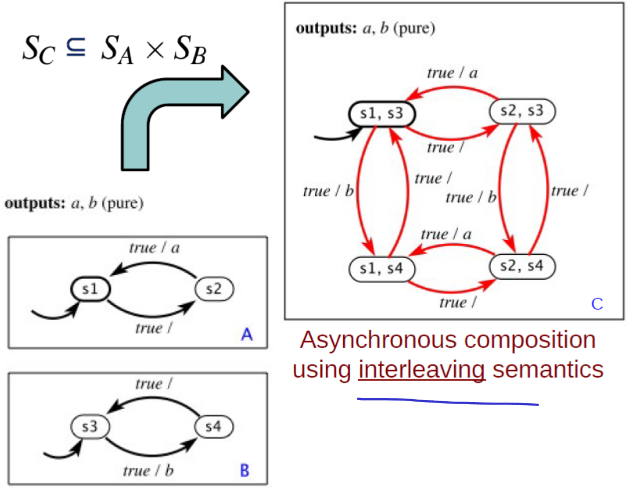
(Simultaneous semantics)

Equivalent FSM



Asynchronous composition

$S_C \subseteq S_A \times S_B$



Asynchronous composition
using interleaving semantics

Note that now
all states are
reachable.

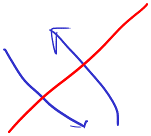


Figure 7: Asynchronous composition

Asynchronous composition

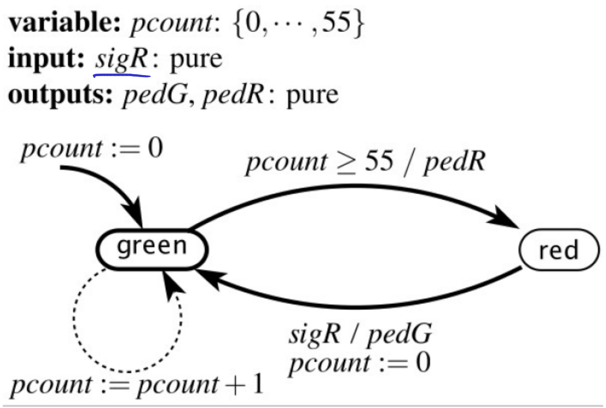
- In the equivalent model:
  - States = combination of states of the two FSMs
  - Transitions in the two FSMs can take place at irregular and independent (not synchronized) times
  - All states are reachable
    - because one model can be much faster than the other

Asynchronous composition

Flavors of asynchronous composition

- How are simultaneous transitions handled?
- **Interleaving** semantics:
  - simultaneous transition in models A and B is not allowed (we may have either a transition in model A, or a transition in B)
  - i.e. transition from A takes place first, then transition from B takes place after a non-zero time delay (or vice-versa)
- **Simultaneous** semantics:
  - simultaneous transition in models A and B is allowed
  - for example, we may have either
    - transition only in model A
    - transition only in model B
    - Simultaneous transition in models A and B

Example



This light stays green for 55 seconds, then goes red.
Upon receiving a sigR input, it repeats the cycle.

Figure 8: Composition - Pedestrian Light

Example

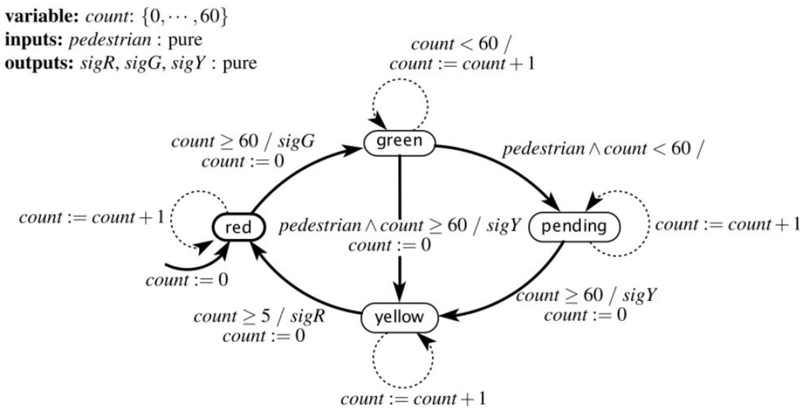


Figure 9: Composition - Car Light

Example

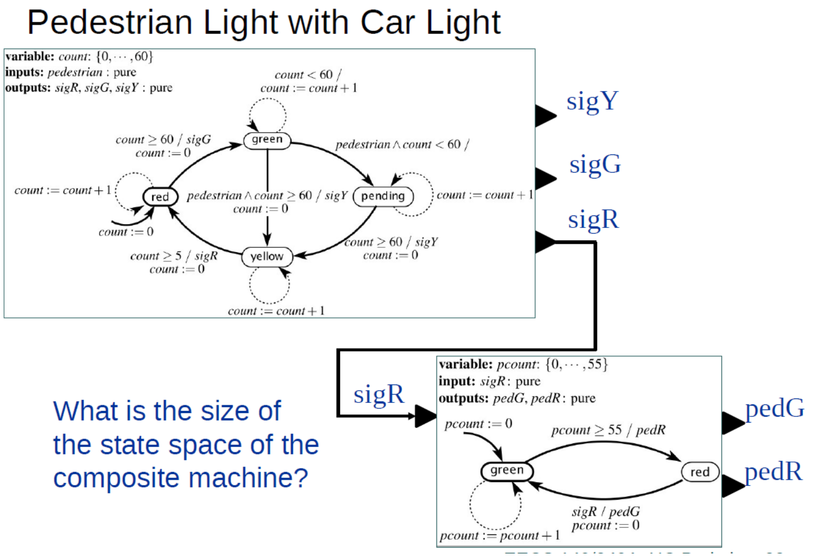
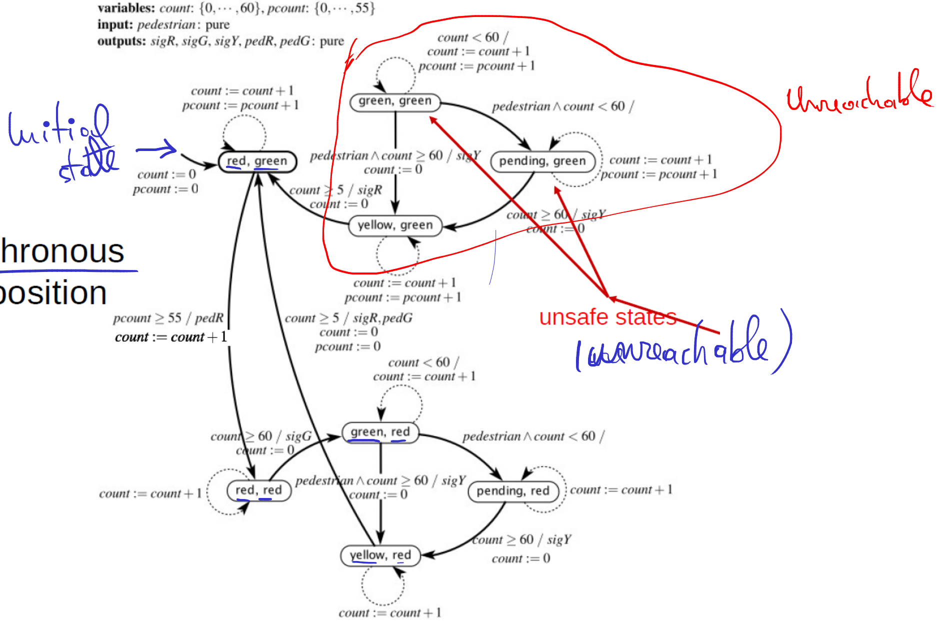


Figure 10: Cascade Composition - Both Lights

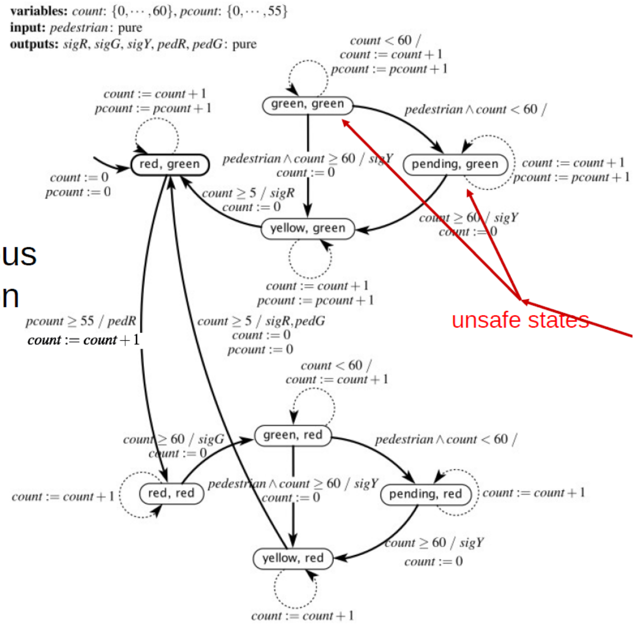
Example



Synchronous composition

Example

Synchronous composition



Shared variables

Other possibilities for model composition:

- **Shared** variables = variables which can we written / read by both models
  - Analysis much harder
  - Potential problems: What happens if both models try to access (read or write) the variable at the same time?
    - Answer: something bad. Might end up with an incorrect value
    - Solution: access to shared variable must be via **atomic operations** and guarded with a **mutex**

Shared variables

- **Atomic** operation = an operation that is indivisible (once it starts, it can't be interrupted until it ends)
- **Mutex** = a mechanism for ensuring only one process accesses a given resource (e.g. variable) at one time
  - A process first **acquires** the mutex, if it is available
  - Only afterwards it accesses the variable
  - While the mutex is acquired, no other process can access it
  - The process **releases** the mutex when it's done with the variable