Introduction to Embedded Systems

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EECS 149/249A
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Chapter 5: Composition of State Machines

Composition of State Machines

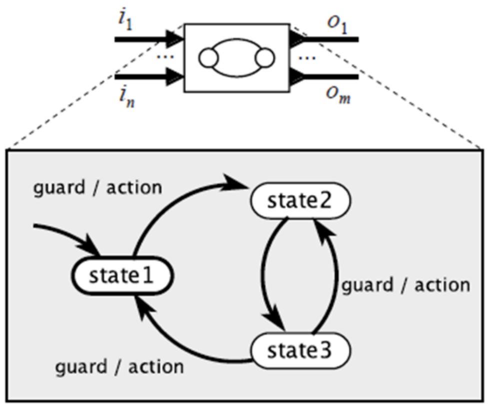
How do we construct complex state machines out of simpler "building blocks"?

Two kinds of composition:

1. **Spatial**: how do the components communicate between each other?
2. **Temporal**: when do the components execute, relative to each other?

Actor Model for State Machines

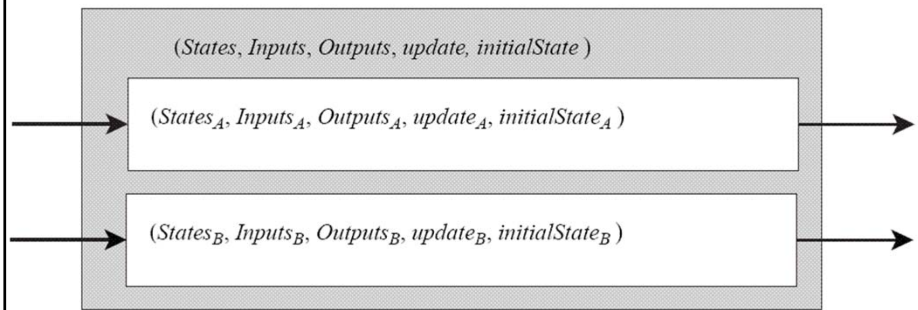
Expose inputs and outputs, enabling composition:



Spatial Composition of State Machines

- Side-by-side composition
- Cascade composition
- Feedback composition

Side-by-Side Composition



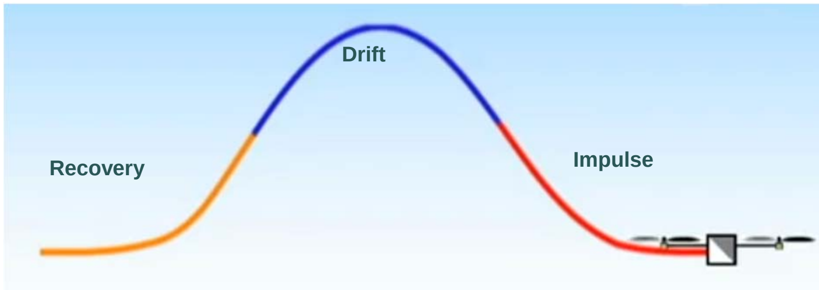
A key question: When do these machines react?

Temporal Composition of State Machines

Sequential vs. Parallel

Asynchronous vs. Synchronous

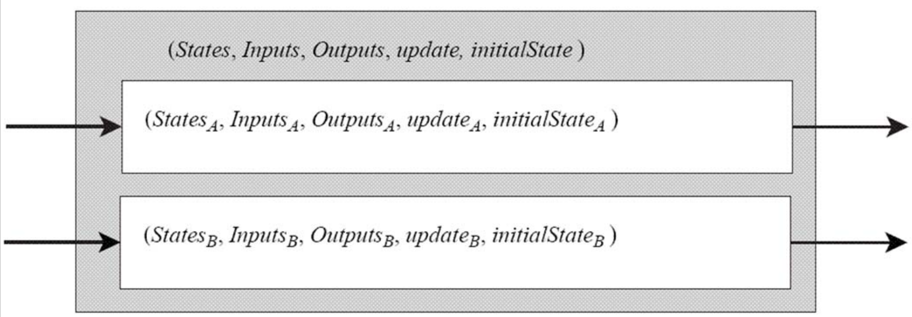
Example of Sequential Composition



https://www.youtube.com/watch?v=iD3QgGpzzIM

[Tomlin et al.]

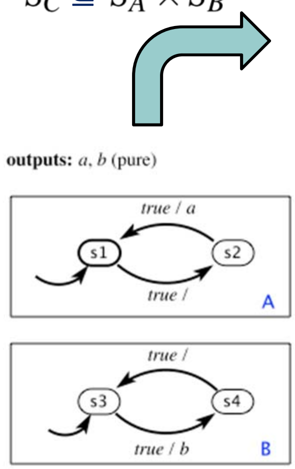
Side-by-Side, Parallel Composition



When do these machines react?
Two possibilities:
- Together, in lock step (synchronous, parallel composition)
- Independently (asynchronous, parallel composition)

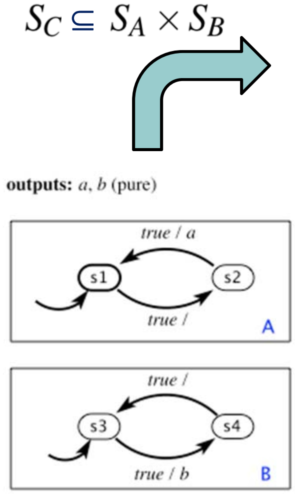
Synchronous Composition

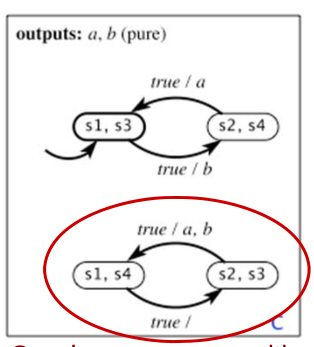
$S_C \subseteq S_A \times S_B$



Synchronous Composition

$S_C \subseteq S_A \times S_B$



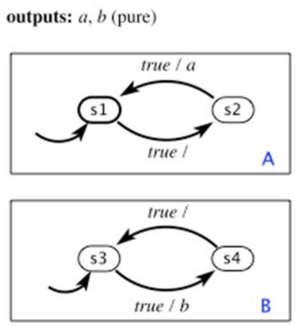


Synchronous composition

Note that these two states are not reachable.

Asynchronous Composition

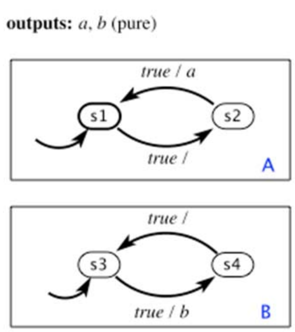
$S_C \subseteq S_A \times S_B$

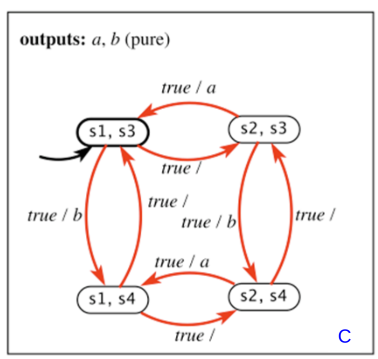


Asynchronous composition using <u>interleaving</u> semantics

Asynchronous Composition

$S_C \subseteq S_A \times S_B$

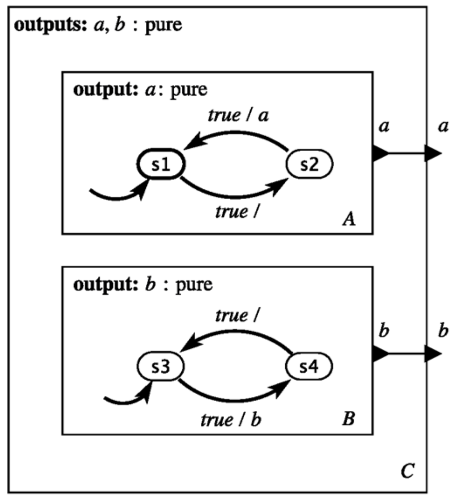




Asynchronous composition using <u>interleaving</u> semantics

Note that now all states are reachable.

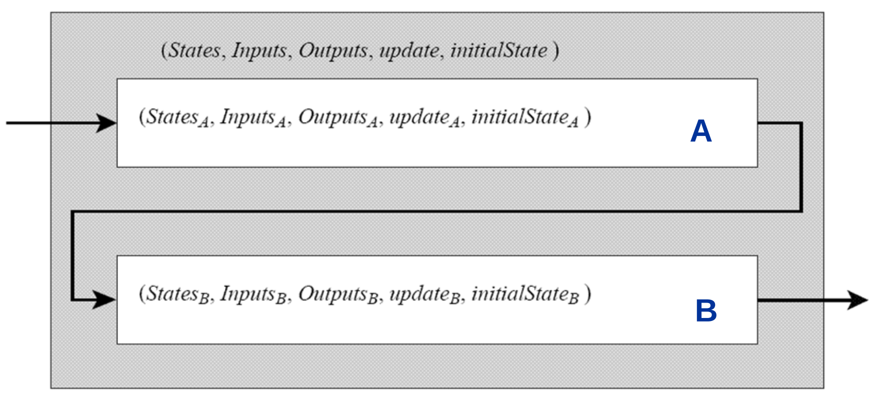
Syntax vs. Semantics



Synchronous or Asynchronous composition?

If asynchronous, does it allow simultaneous transitions in A & B?

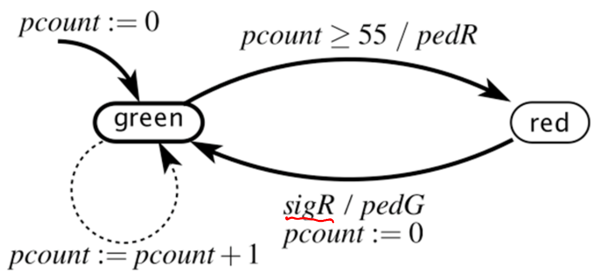
Cascade Composition



Output port(s) of A connected to input port(s) of B

Example: Pedestrian Light

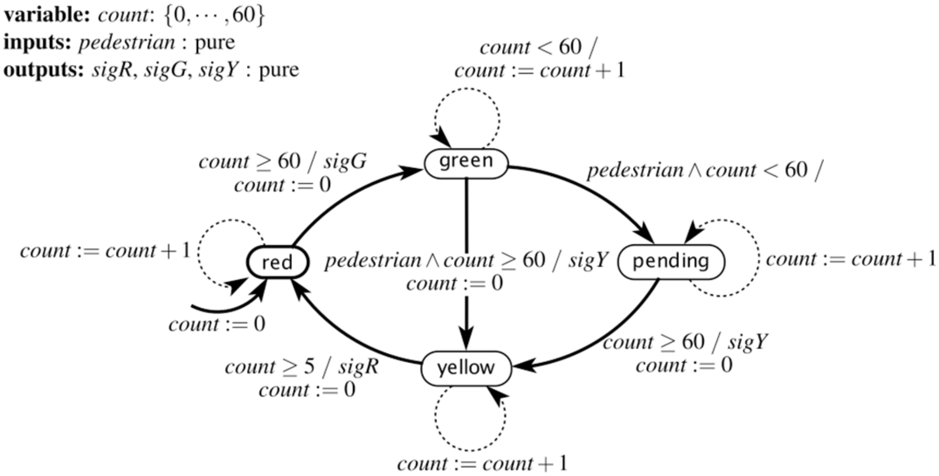
variable: *pcount*: $\{0, \cdots, 55\}$
input: *sigR* : pure
outputs: *pedG*, *pedR* : pure



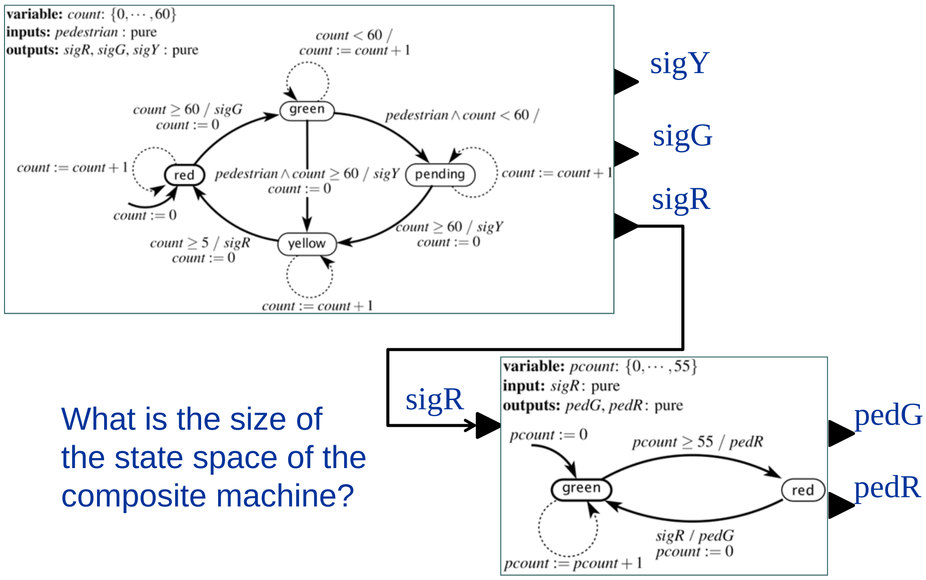
This light stays green for 55 seconds, then goes red.
Upon receiving a sigR input, it repeats the cycle.

Example: Car Light

variable: *count*: $\{0, \cdots, 60\}$
inputs: *pedestrian* : pure
outputs: *sigR*, *sigG*, *sigY* : pure

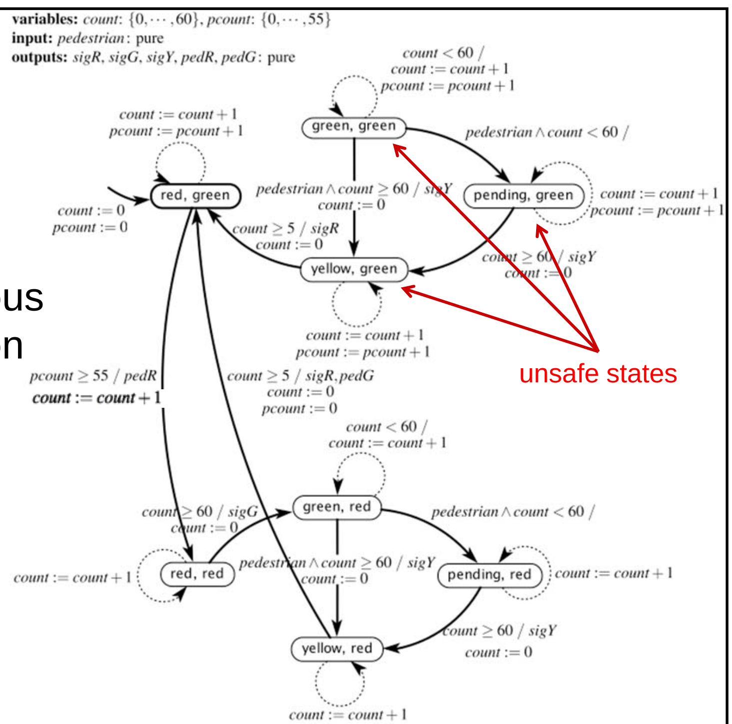


Pedestrian Light with Car Light

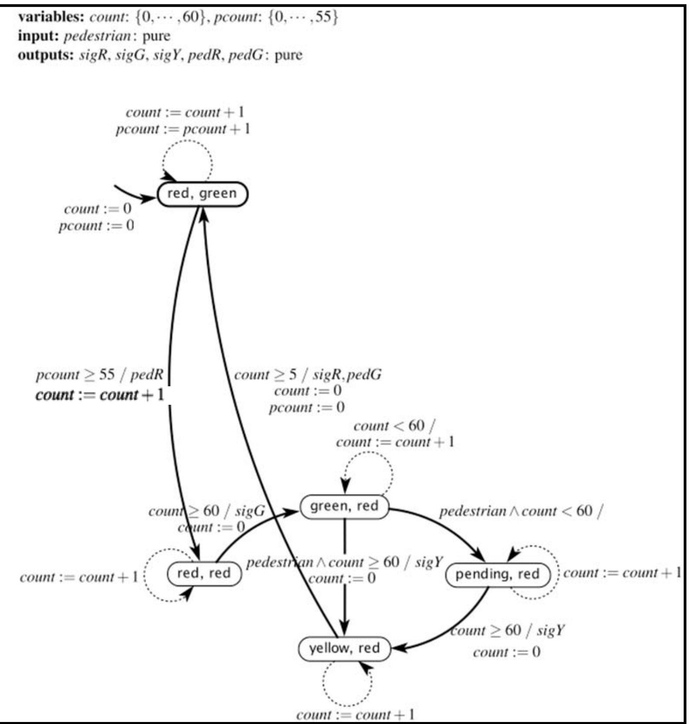


What is the size of the state space of the composite machine?

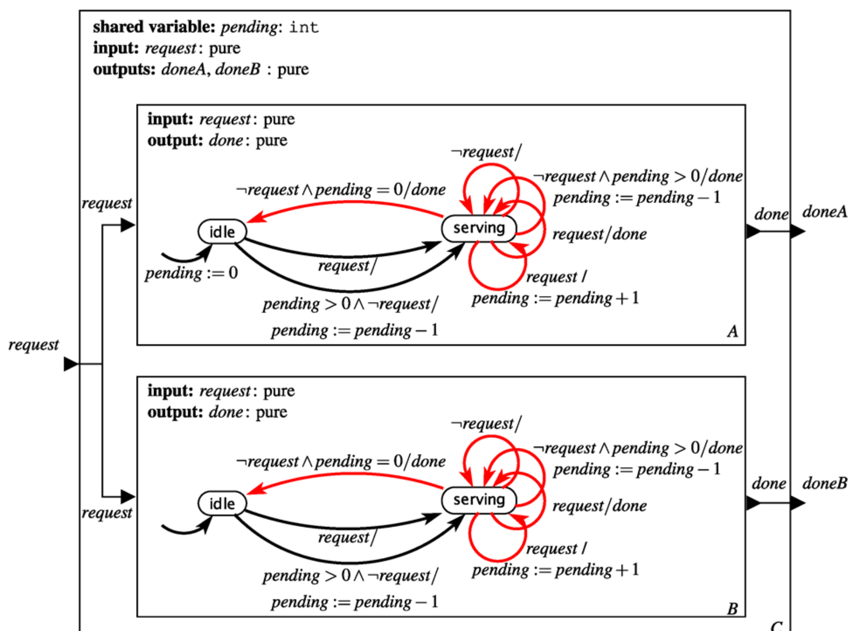
Synchronous composition



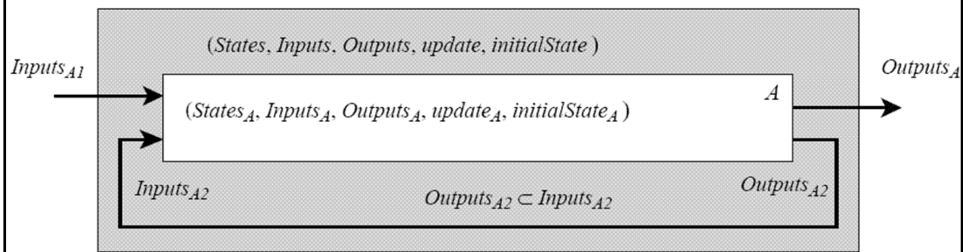
Synchronous composition with unreachable states removed



Shared Variables: Two Servers



Feedback Composition



Reasoning about feedback composition can be very subtle.
(this topic is out of scope for EECS149/249A)