Logical Time at Work:

Capturing Data Dependencies and Platform Constraints

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Semantics as *constrained logical time*

(Modeling) languages are defined by:

- syntax
- (behavioral) semantics

Semantics should be explicit

Clock Constraint Specification Language (CCSL)

- Define the semantics of syntactical models
- Makes the syntactical models executable

Outline

Semantics of data-flow formalisms: Synchronous Data-Flow (SDF), Multidimensional-SDF

- The description of all the possible system execution schedules
- Functional description: internal constraints = data dependencies
- Time refinement – enforce the constraints
- Environment/execution platform constraints

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Semantics of data-flow formalisms: Synchronous Data-Flow (SDF), Multidimensional-SDF

- The description of all the possible system execution schedules
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- Time refinement – enforce the constraints
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1. Define explicit semantics for SDF models
2. Translate data-dependencies to execution dependencies
3. Multi-dimensional semantics (MDSDF)
4. External constraints

Clock Constraint Specification Language

Modeling and Analysis of Real-Time and Embedded systems (MARTE)

- Companion of the **Time** Package
- Chronological relations between events
- **Clocks** = possibly infinite and possibly dense totally ordered sets of instants

CCSL relations:

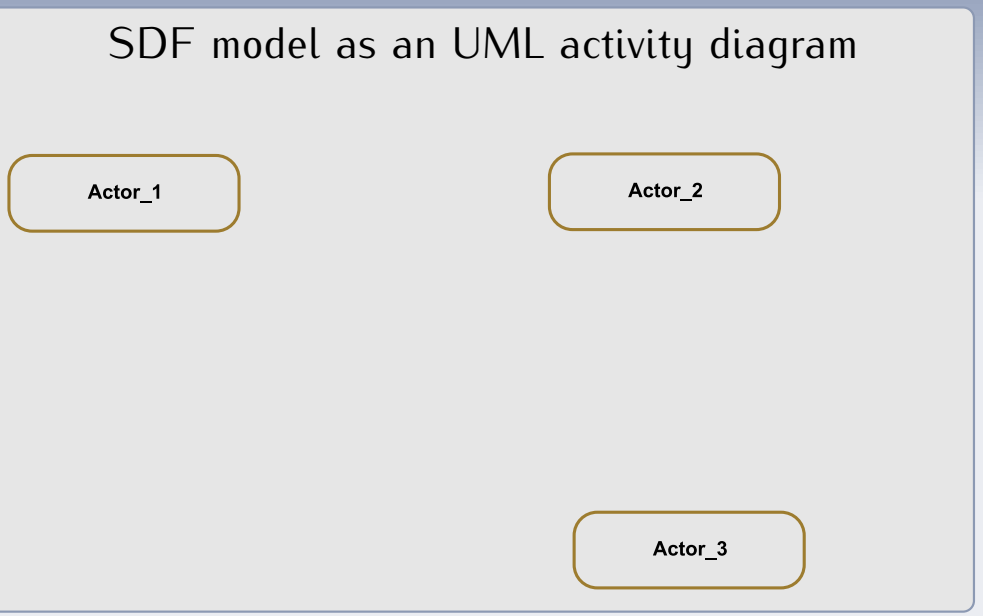
- **precedence** ($\prec$)
- **coincidence** ($\equiv$)
- **exclusion** (#)

CCSL clock expressions:

- **filteredBy** ($\blacktriangledown$) – by a binary periodic word
- **delay** ($) – by an integer value

Data-flow models

SDF model as an UML activity diagram



Syntax:

- computational elements
  - **actors**

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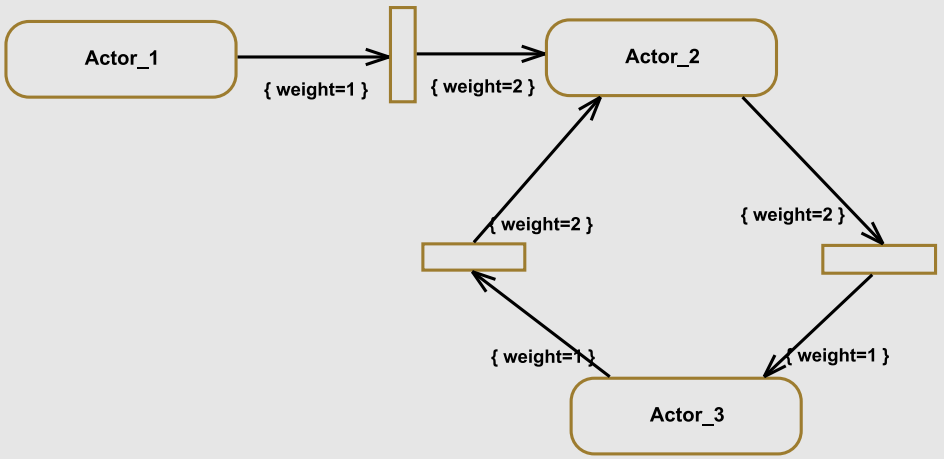

Syntax:

- computational elements – **actors**
- FIFO channels – **arcs**

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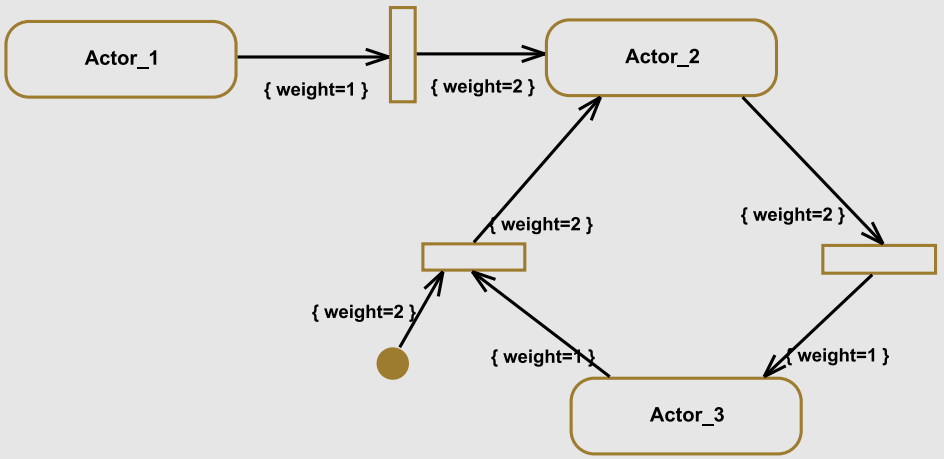

Syntax:

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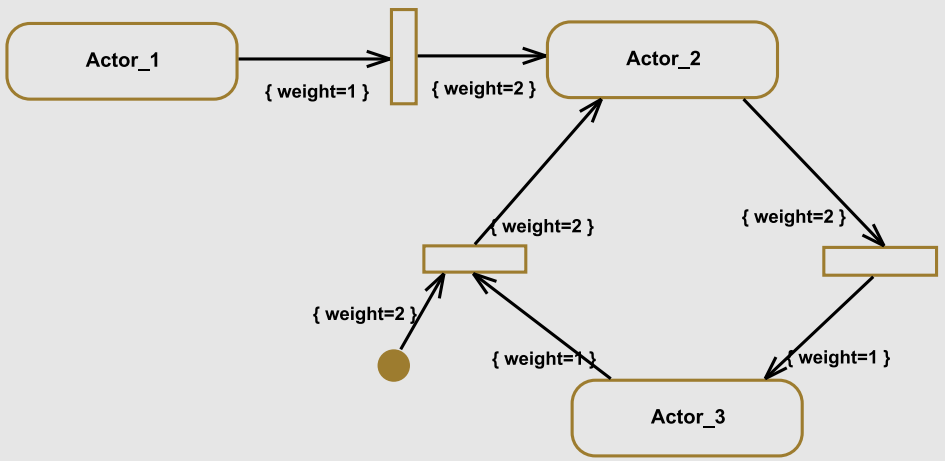


Syntax:

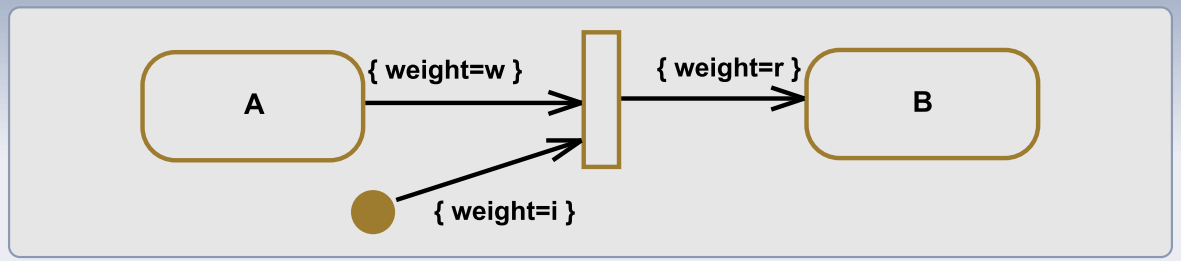
- computational elements – **actors**
- FIFO channels – **arcs**
- initial values – **delays**

Synchronous data-flow semantics:

- **fixed amount** of data elements produces/consumed at each firing
- local **producer/consumer rules** defined by each arc

SDF: data dependency semantics

General representation of a SDF arc



Relevant events in the system:

- Actor **firings**
- Element-wise **write** and **read** events on arcs

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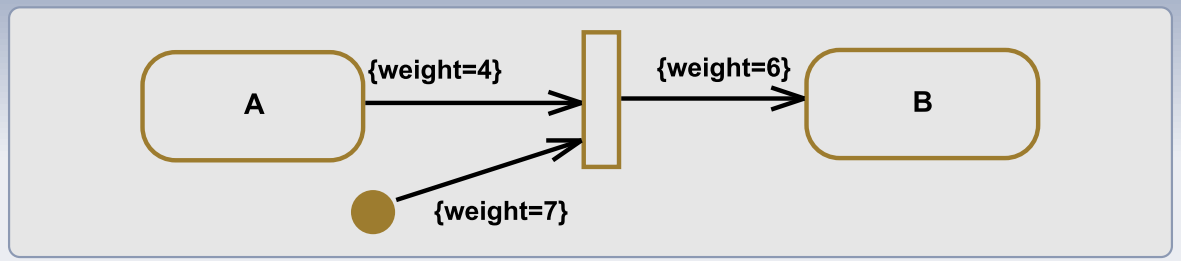

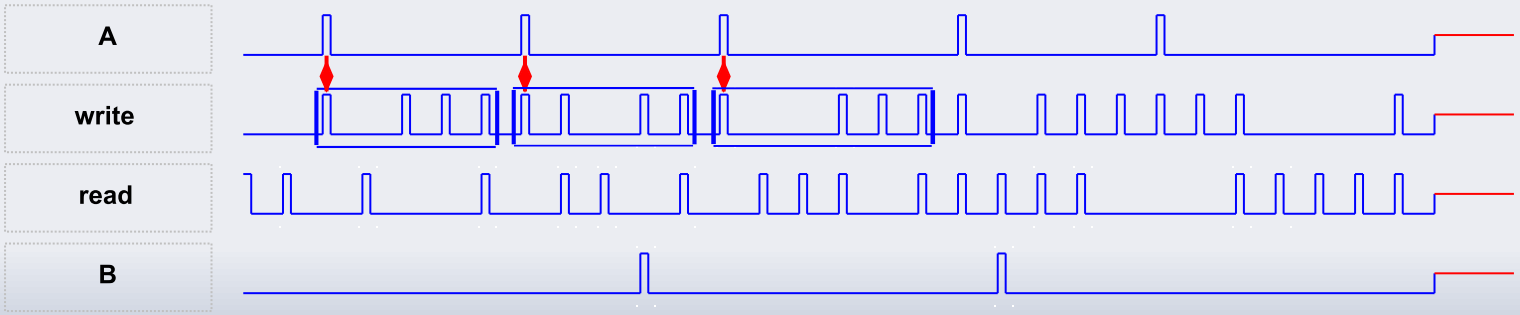

- Each actor firing is followed by $write_{weight}$ write events on each outgoing arc

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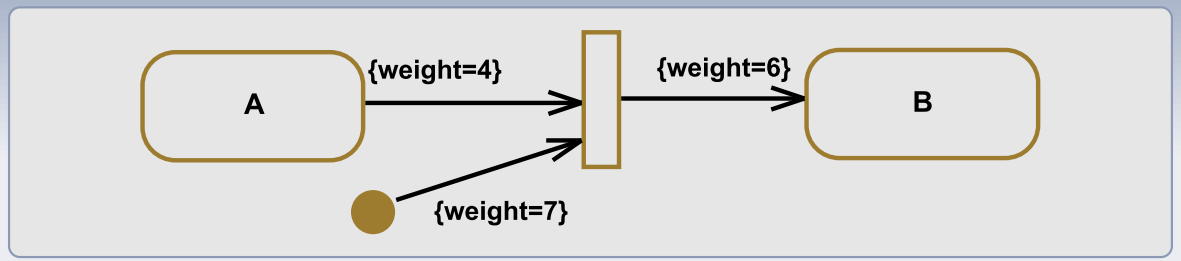

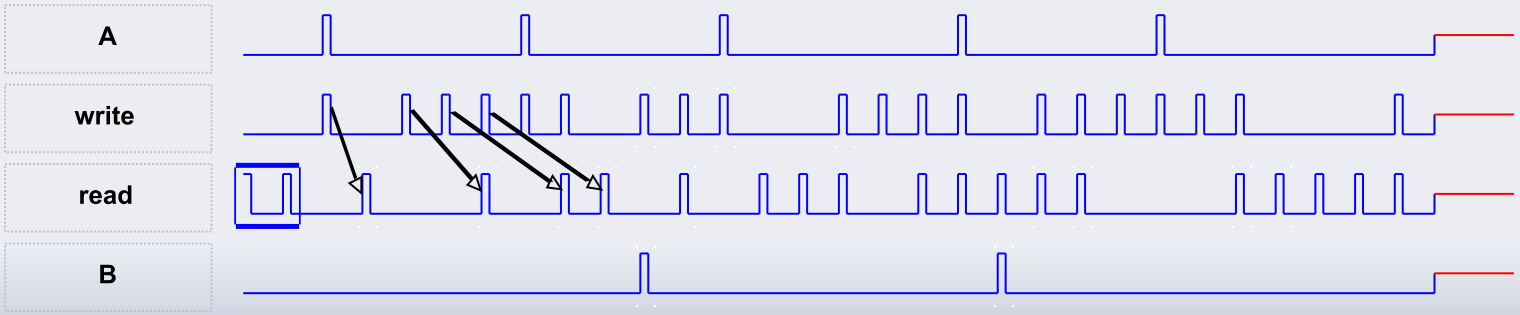

- On each arc, read events (delayed by the initial value) must follow write events

SDF: data dependency semantics

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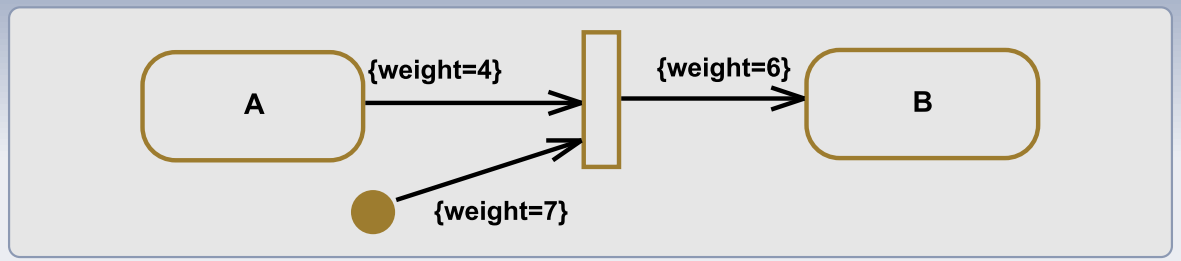

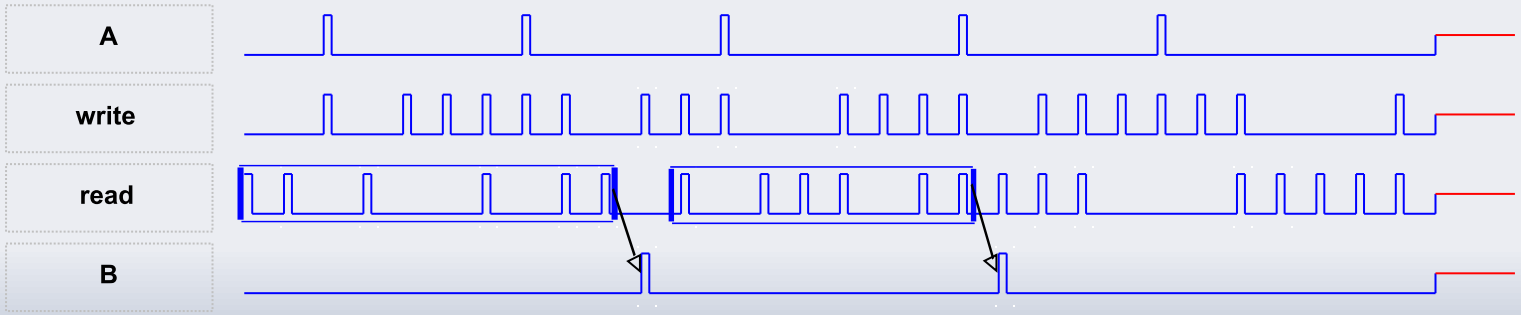

- $read_{weight}$ read events on each of its ingoing arc precede an actor firing

SDF: data dependency semantics

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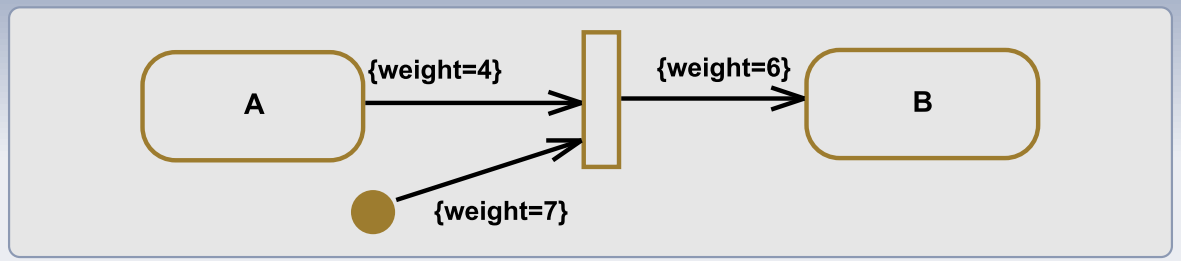
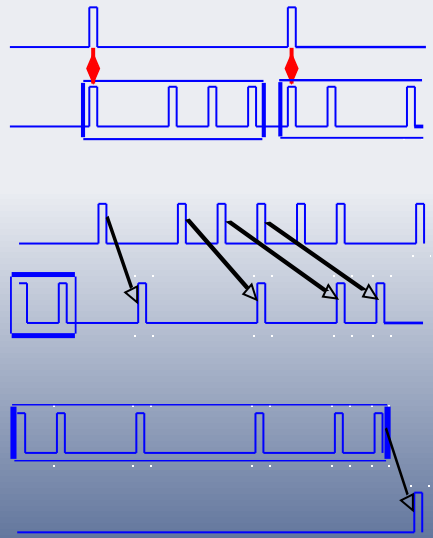
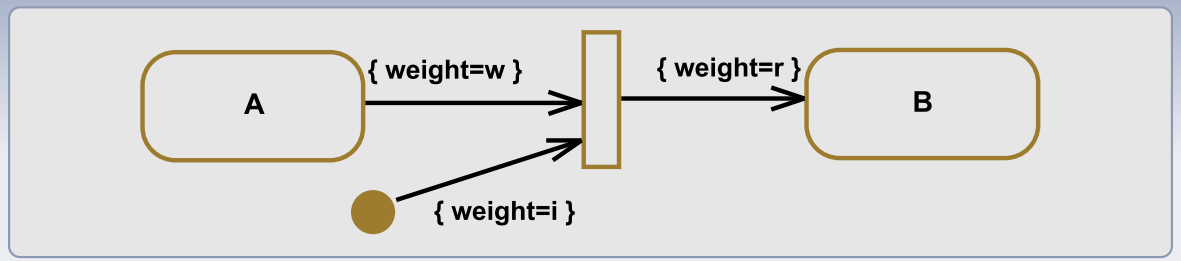


1. *actor* $\boxed{=}$ $\left(write \blacktriangledown \left(1.0^{weight-1}\right)^{\omega}\right)$
2. *write* $\boxed{\prec}$ $(read\ \$\ delay)$
3. $\left(read \blacktriangledown \left(0^{weight-1}.1\right)^{\omega}\right)$ $\boxed{\prec}$ *actor*



SDF: execution dependency semantics

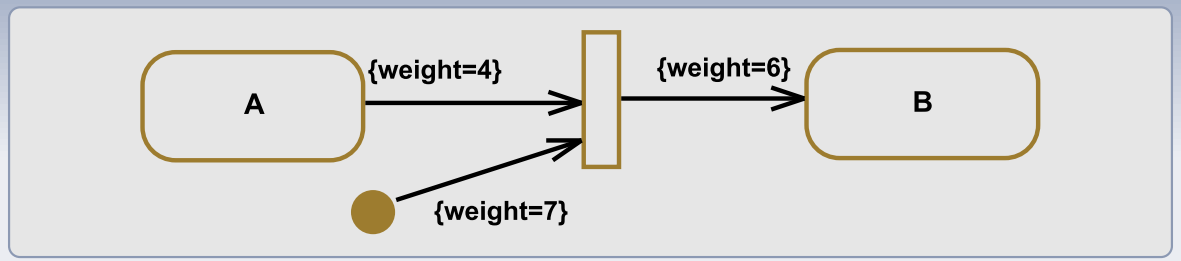
General representation of a SDF arc



Direct precedence (**computed**) between the two clocks

SDF: execution dependency semantics

Example of SDF arc



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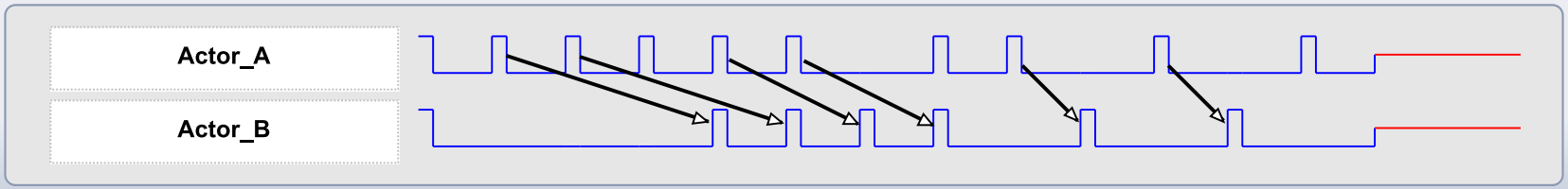

$$(Clock_{master} \blacktriangledown (011)^{\omega}) \prec (Clock_{slave} \$ 1)$$

Direct precedence computation algorithm

Iterative algorithm to compute the parameters of the general **execution precedence** relation:

$$(Clock_{master} \blacktriangledown M) \boxed{\prec} ((Clock_{slave} \$ d) \blacktriangledown S)$$

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$$initial = delay_{\text{weight}} \bmod read_{\text{weight}}$$

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Iterative algorithm to compute the parameters of the general **execution precedence** relation:

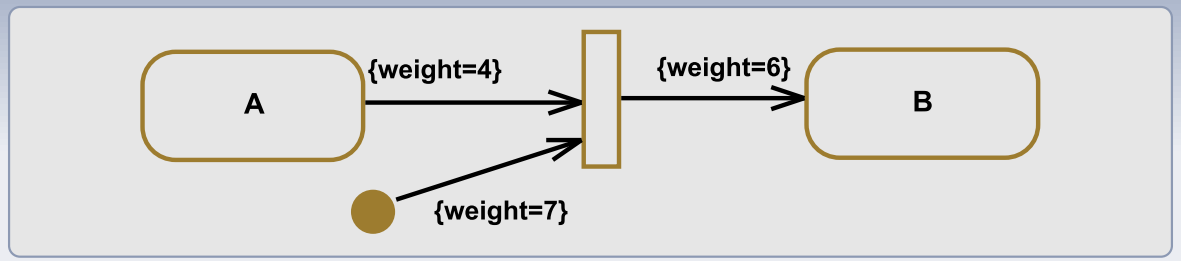
$$(Clock_{master} \blacktriangledown M) \boxed{\prec} ((Clock_{slave} \$ d) \blacktriangledown S)$$

$$d = \lfloor delay_{\text{weight}} / read_{\text{weight}} \rfloor \quad = \lfloor 7/6 \rfloor = 1$$

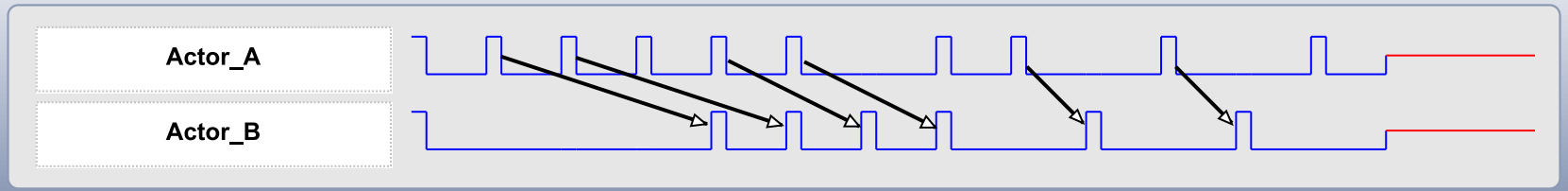
$$initial = delay_{\text{weight}} \bmod read_{\text{weight}} \quad = 7 \bmod 6 = 1$$

	initial		+4	+4	-6+4	-6+4
tokens	1		5	9	7	5
			< 6	> 6	> 6	done
binary		(	0	1	1	)

Local rules – global functionality



$$(Actor_A \blacktriangledown (011)^{\omega}) \prec (Actor_B \$ 1)$$



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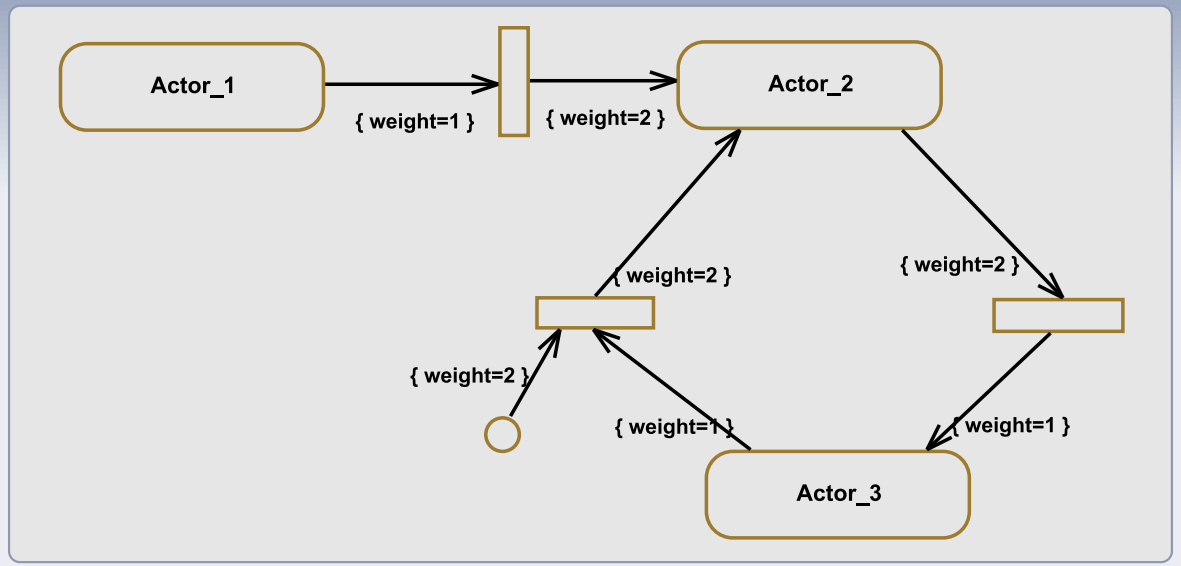
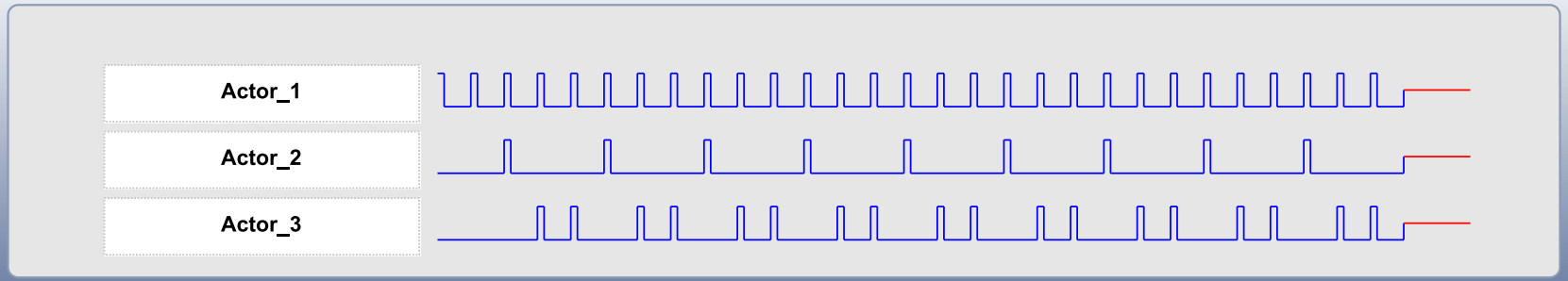
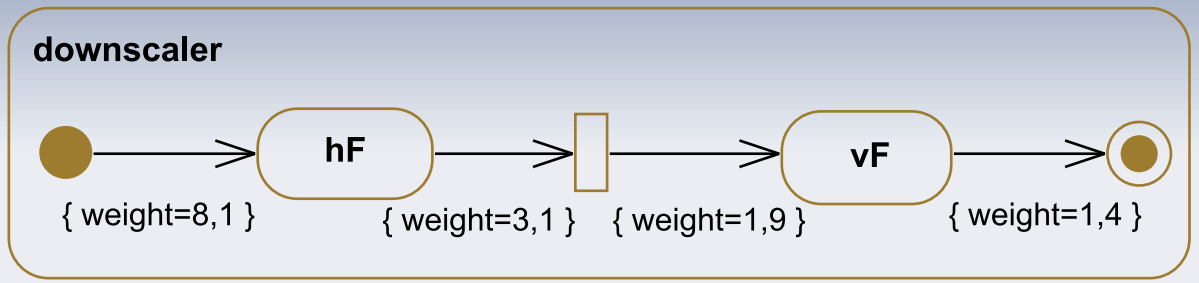




Encoding MDSDF in CCSL

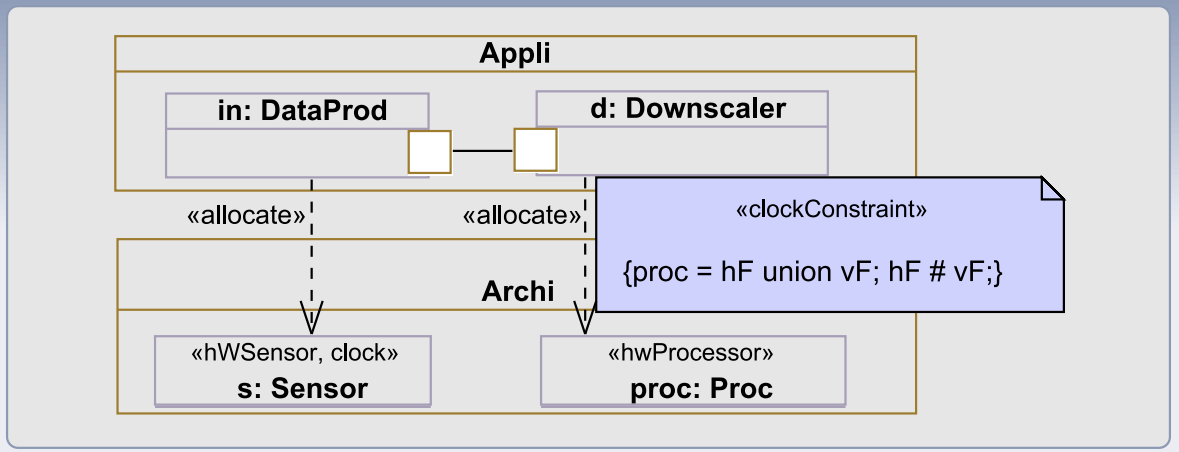


- straightforward multi-D extension of 1-D SDF
- quasi-independent relations producer/consumer by dimension

$in_1 \boxed{\prec} (hF_1 \blacktriangledown (1.0^2)^\omega)$
$in_2 \boxed{\prec} hF_2$

$hF_1 \boxed{\prec} (vF_1 \blacktriangledown (1.0^2)^\omega)$
$(hF_2 \blacktriangledown (0^8.1)^\omega) \boxed{\prec} vF_2$

External constraints



- multidimensional order – environment constraints

$$in_1 = (s \blacktriangledown 1.(0)^{\omega}) \qquad in_2 = s$$
$$hF_1 = (hF \blacktriangledown 1^3.(0)^{\omega}) \qquad hF_2 = (hF \blacktriangledown (0^2.1)^{\omega})$$
$$vF_1 = (vF \blacktriangledown 1^9.(0)^{\omega}) \qquad vF_2 = (vF \blacktriangledown (1.0^8)^{\omega})$$

- execution platform constraints

$$proc = hF + vF \qquad hF \# vF$$

System refinement

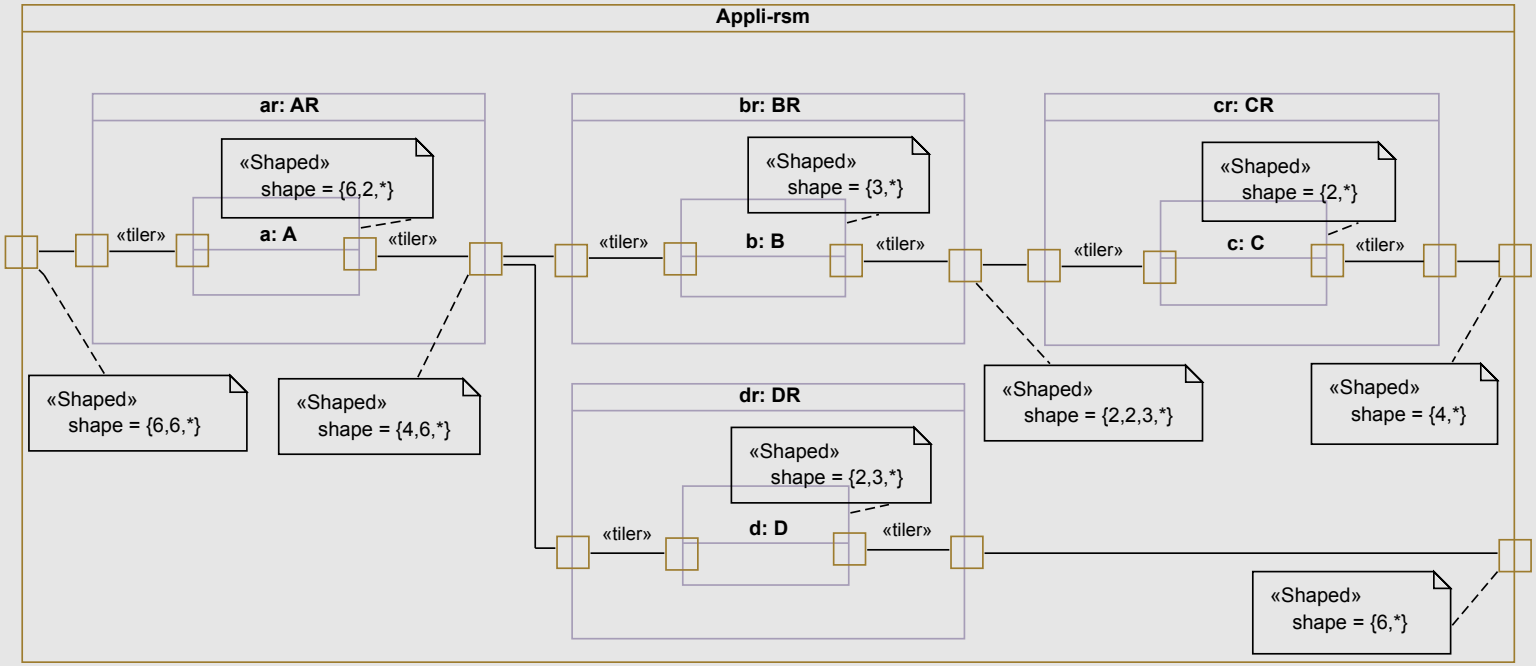
Formal specification encoding the entire set of schedules corresponding to a correct execution

Enforce the constraints:

- internal (data dependencies)
- external (environment or execution platform)
- buffer capacities - reverse constraints
- physical time – durations: execution, communication, ...

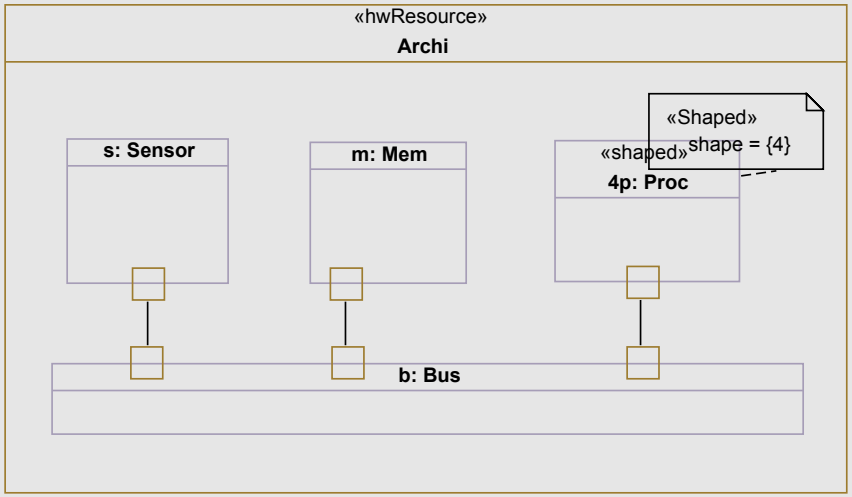
Repetitive Structure Modeling

Application – data dependencies



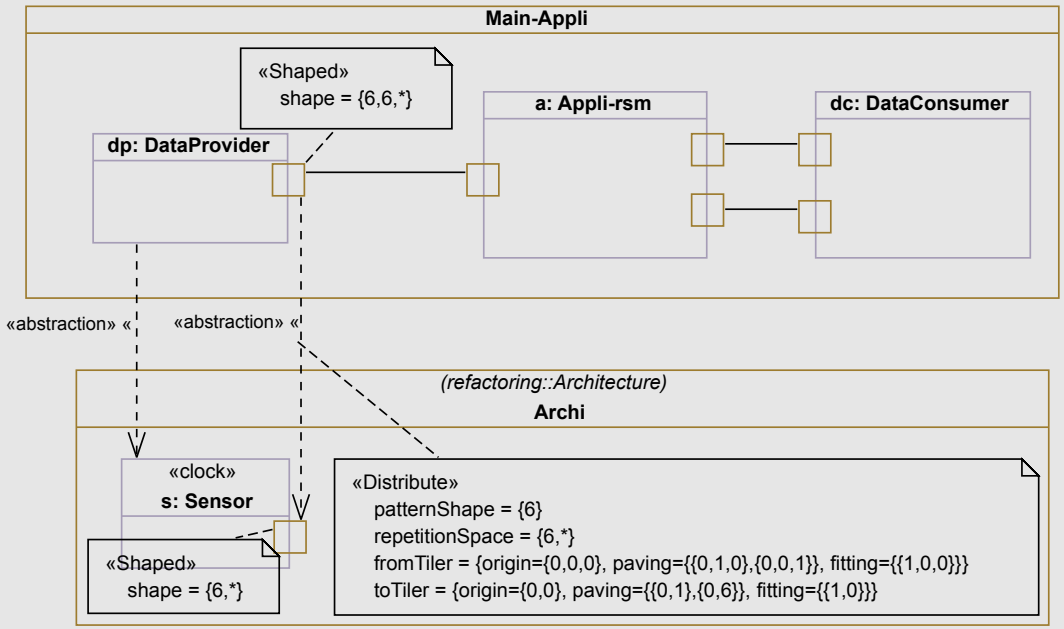
Repetitive Structure Modeling

Architecture – execution platform



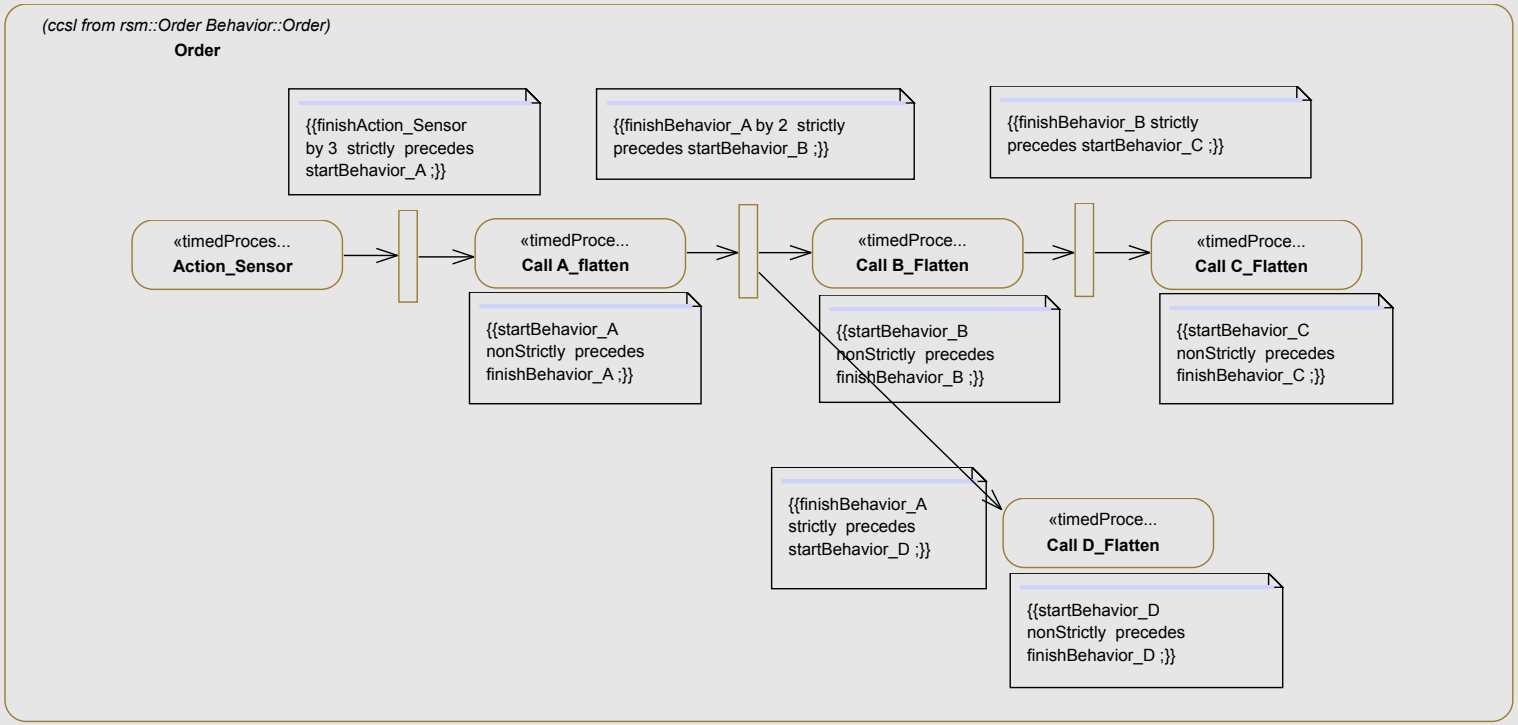
Repetitive Structure Modeling

Multi-D structures – projection in time and space



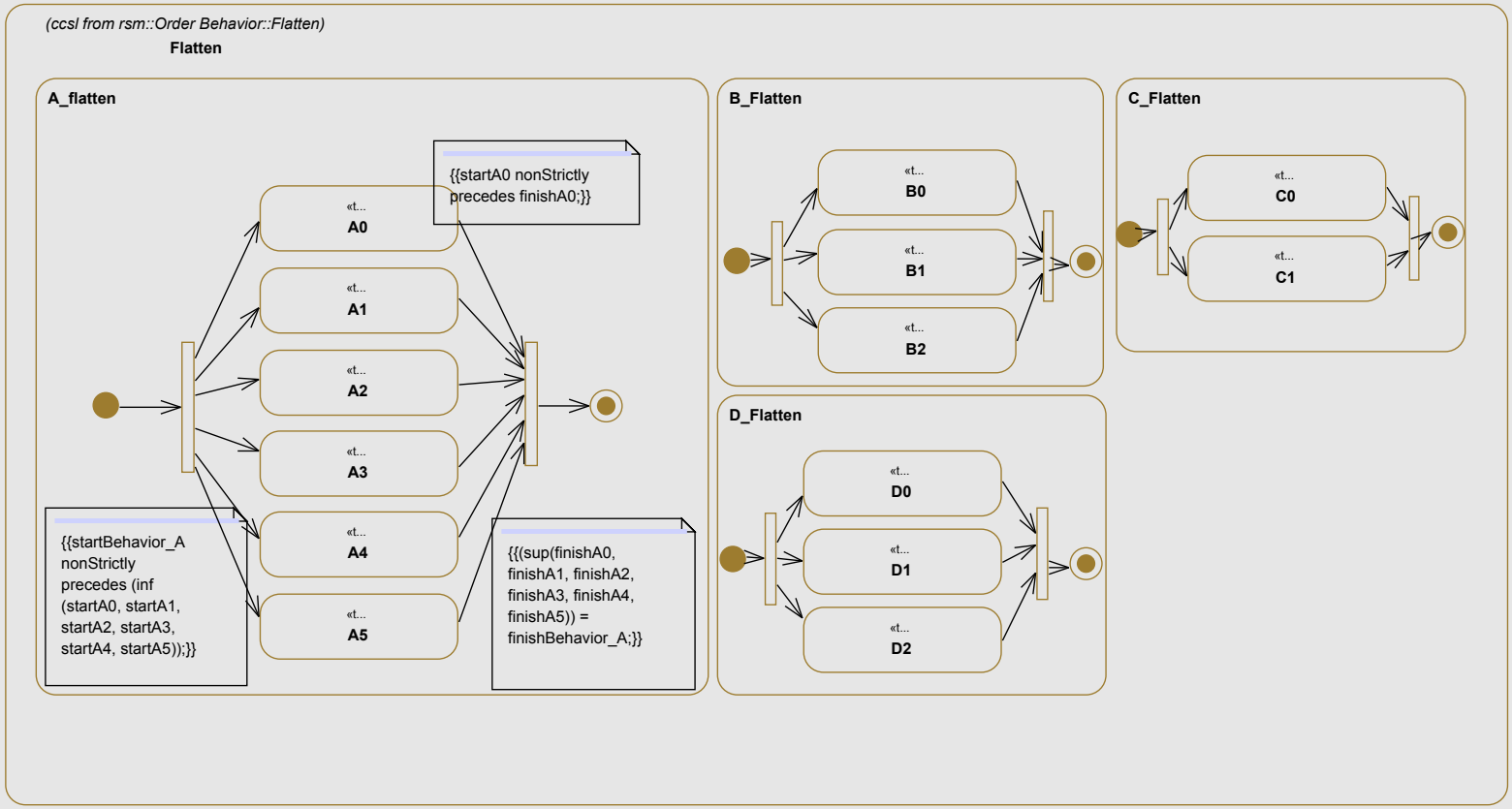
Internal constraints

Execution dependencies : precedence



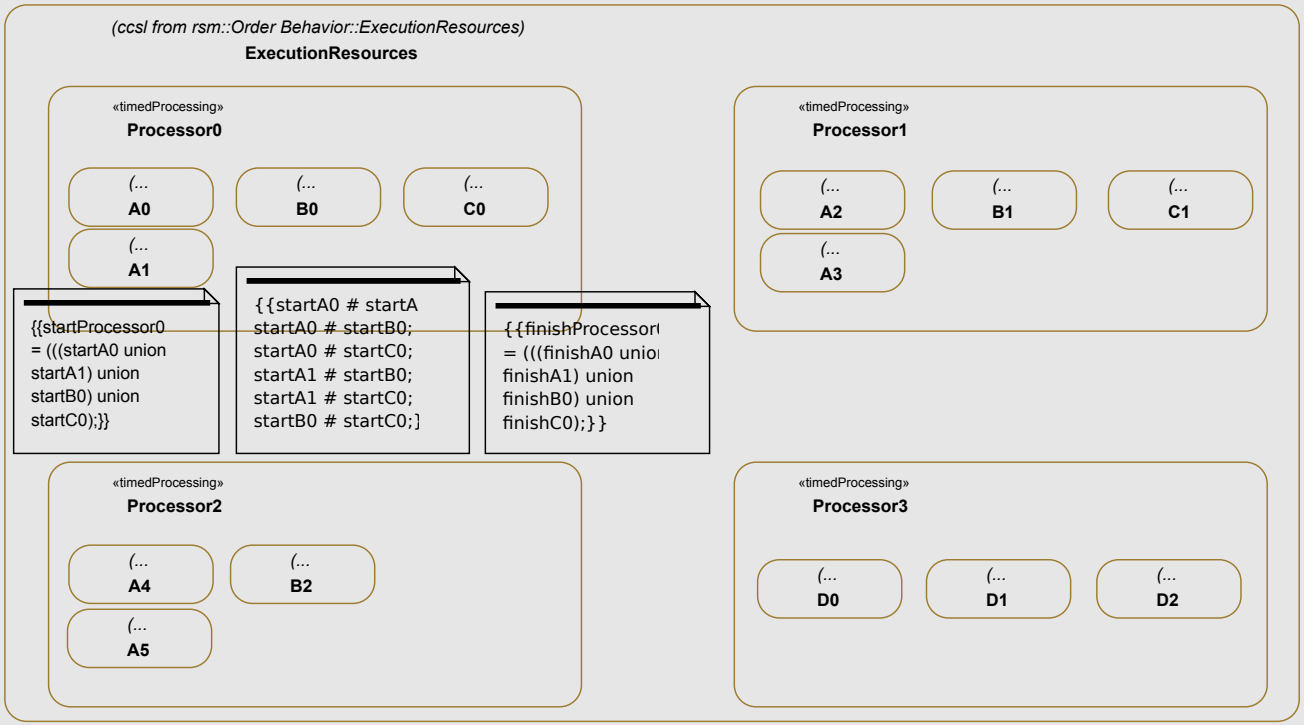
Internal constraints

Task parallelism – unbounded resources



External constraints

Execution resources



Time Model & CCSL (MARTE)

Logical Time:

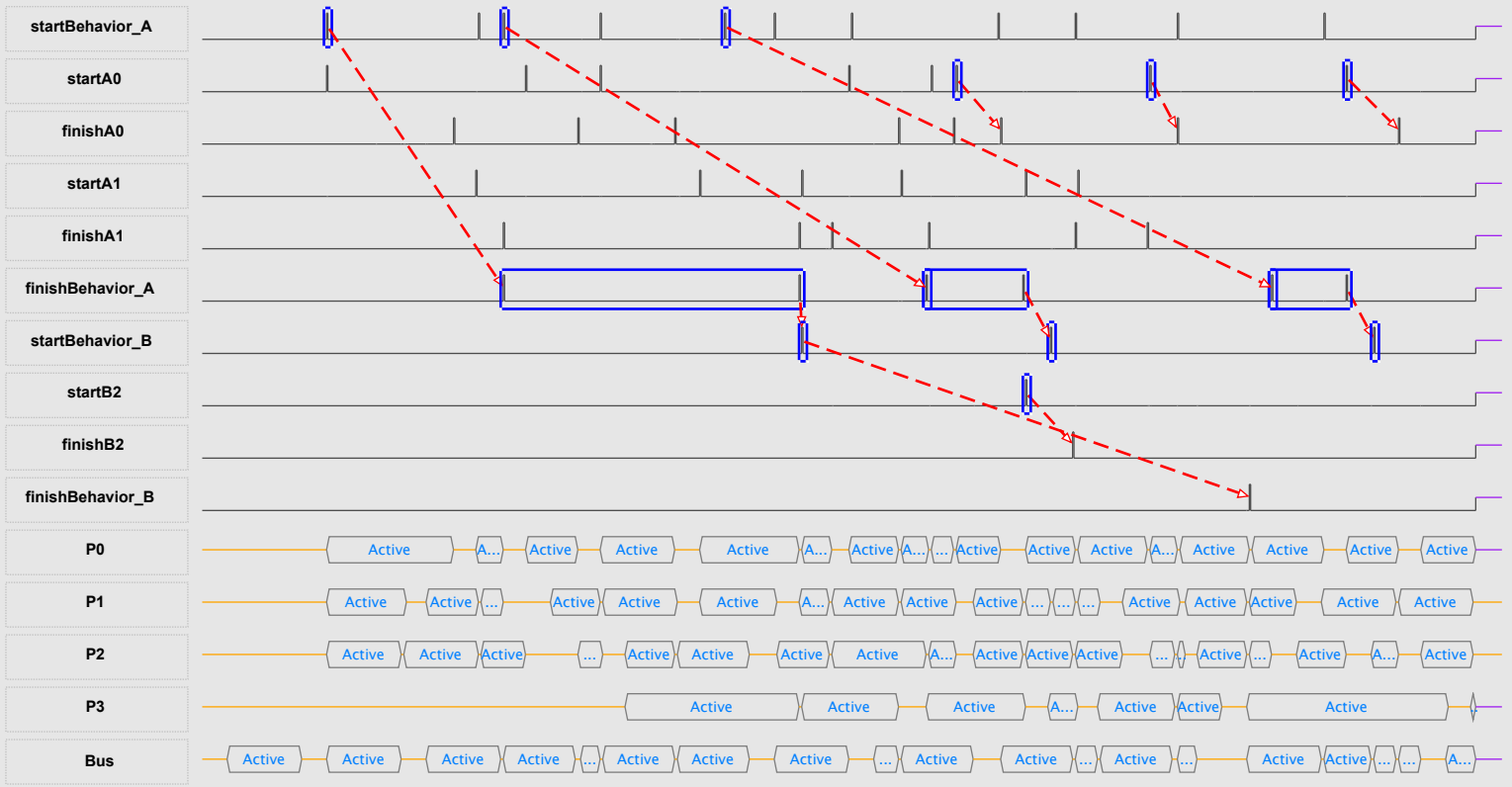
- Dependencies (data, execution)
- Parallelism
- Concurrence (resources: execution, communication, storage)

Projection into **Physical Time**

- Physical clocks
- Durations
- Delays
- ...

Schedule constraints

TimeSquare simulation



Conclusion

Results:

- Define explicit semantics
- For analysis, static scheduling, state space exploration
- Simulation in TimeSquare[1]

More complex languages:

- Array-OL: no predefined order
- Uniform loop nests: complex dependence analysis

Heterogeneous systems

[1] http://www-sop.inria.fr/aoste/dev/time_square