DEVS as State/output Equation Form

DES Dynamic Equations

$$\begin{cases} q' = (s', r') = \delta_{int}(q) \oplus \delta_{ext}(q, x) \\ \qquad\qquad = \delta_{int}(s, r) \oplus \delta_{ext}((s, r), x) \\ y = \lambda(s, r) \end{cases}$$

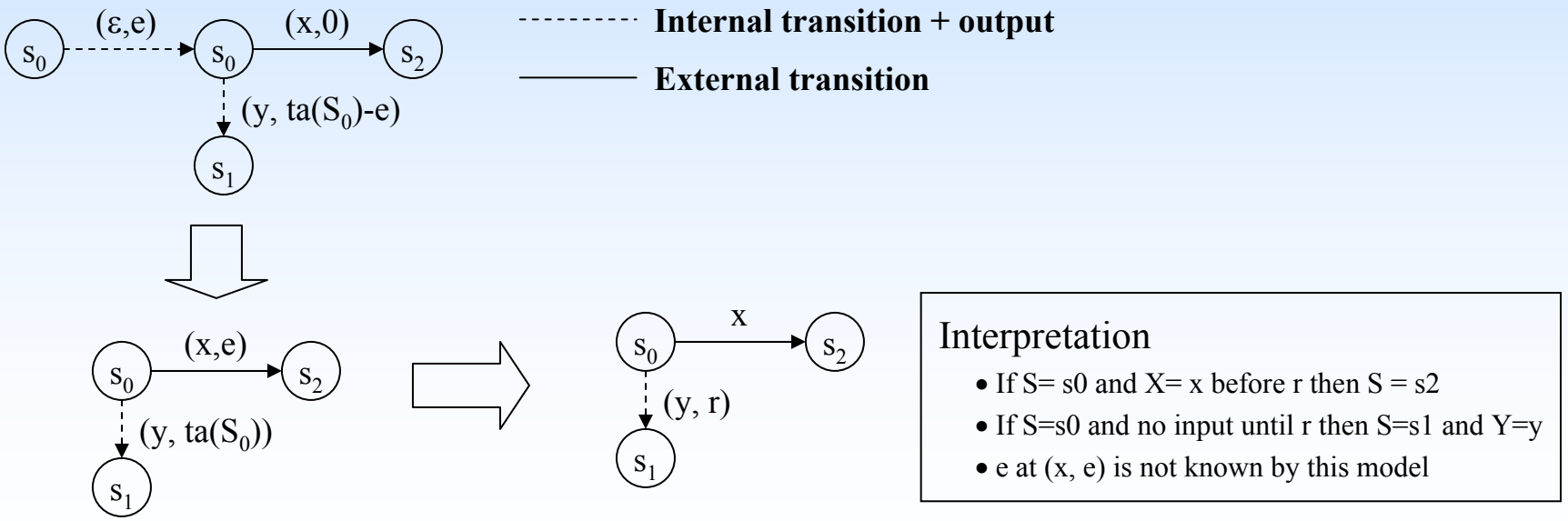
Interpretation

$$q' = \underbrace{\delta_{int}(s, r)}_{\text{Input-free transition}} \oplus \underbrace{\delta_{ext}((s, r), x)}_{\text{inputted transition}} = \begin{cases} \delta_{int}(s, r) \text{ if only } \delta_{int} \text{ occurs} \\ \delta_{ext}((s, r), x) \text{ if only } \delta_{ext} \text{ occurs} \\ \text{Not happen both } \delta_{int} \text{ and } \delta_{ext} \text{ occur} \end{cases}$$

$y = \lambda(s, r)$: always occurs with $\delta_{int}(s, r)$

DEVS Graph

- DEVS graph G = < V, E >
  - Visual representation of DEVS atomic model in a labeled graph
  - V represents DEVS sequential (discrete) state
    - V = S
  - E represents internal or external transition with labels on E
    - $E \subseteq V \times V$ with a label $(X \cup Y \cup \{\varepsilon\}) \times \mathbf{R}$
    - X: input; Y:output; ε: empty input; R: elapsed time
- **Representation Example**

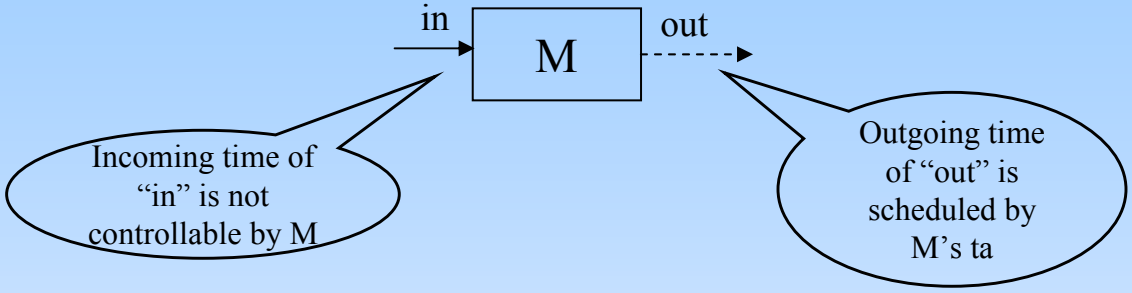


Interpretation

- If S= s0 and X= x before r then S = s2
- If S=s0 and no input until r then S=s1 and Y=y
- e at (x, e) is not known by this model

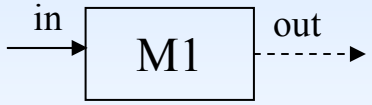
Schedule Conflict(Tie)

- Event scheduling: Only for output event by ta after each state transition

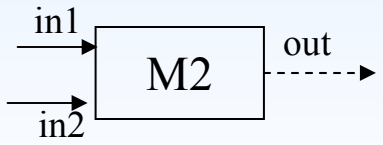


- Assumptions on Atomic DEVS Modeling
  - A-1: Transition either by input or by input-free, but not both :: $q' = \delta_{int}(q) \oplus \delta_{ext}(q, x)$
  - A-2: Arriving one input event at a time :: $\delta_{ext}(q, x)$

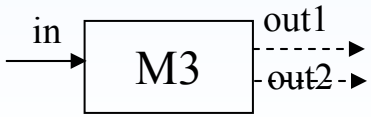
- Schedule Conflict Case: Violation of assumptions
  - Internal(out) and External(in) Events
    - ➔ Violation of A-1



  - External(in1) and External(in2) Events
    - ➔ Violation of A-2



  - Internal(out1) and Internal(out2) Events
    - ➔ Never happen (because one output for a state)

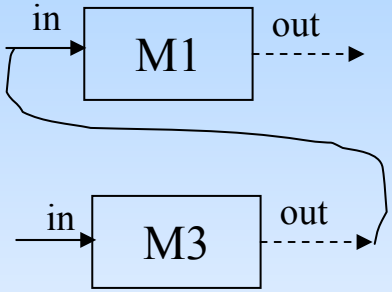


Schedule Tie-Break: *Select function*

◆ **Tie-break ==> Select : $2^{\{Mi\}} \rightarrow \{M_i\}$**

conflict resolution: priority of internal transitions of models that cause conflict.

❖ Case A-1: For M1, Internal and external transitions are conflict



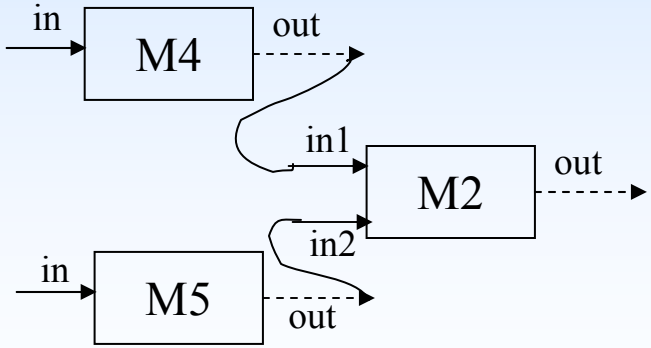
Tie-break:: Select ({M1, M3}) = M1

↓

δ_{int} ((s, r)) for M1 is applied first

Then, δ_{int} ((s, r)) for M3

❖ Case A-2: For M2, two inputs are conflict



Tie-break:: Select ({M4, M5}) = M4

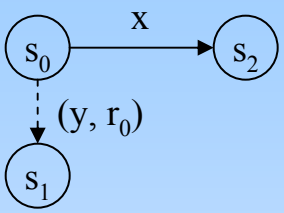
↓

For M2 δ_{ext} ((s, r), in1) is applied first

Then, δ_{ext} ((s, r), in2)

➔ *Select* decides order of q' = $\delta_{int}(q) \oplus \delta_{ext}(q, x)$ when both transition occur

Schedule continuation or override



Assume: $ta(s_0) = r_0$

current simulation time: t

case 1: no input is arrived in next r0 time unit

at $(t + r_0)$, internal transition :: $(s_0, r_0) \rightarrow (s_1, 0)$

generate output y

new schedule $r_1 = ta(s_1)$

case 2: an input x is arrived in next $e < r_0$ time unit

at $(t + e)$, external transition :: $((s_0, e), x) \rightarrow (s_2, 0)$

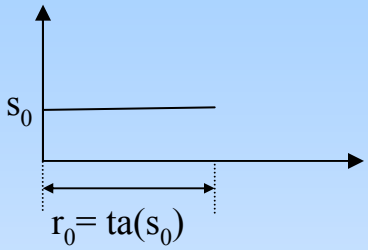
case 2-1: continuation of previous schedule

$ta(s_2) = r_2 = r_0 - e$

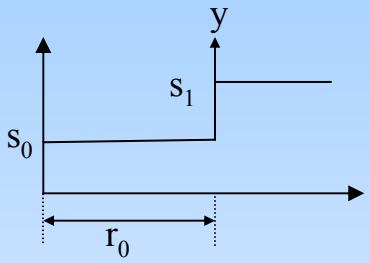
case 2-2: cancel previous schedule and make a new one

$ta(s_2) = r_2$ = new value

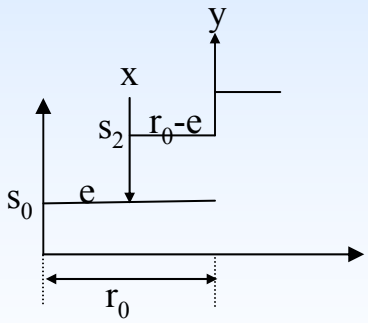
Time chart for schedule continuation/override



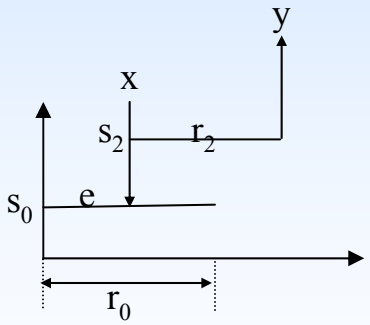
Initial Schedule



Case 1: no input before scheduled time



Case 2-1: continuation of previous schedule

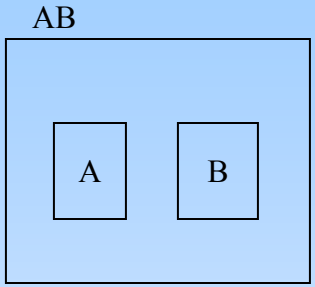


Case 2-2: make a new schedule

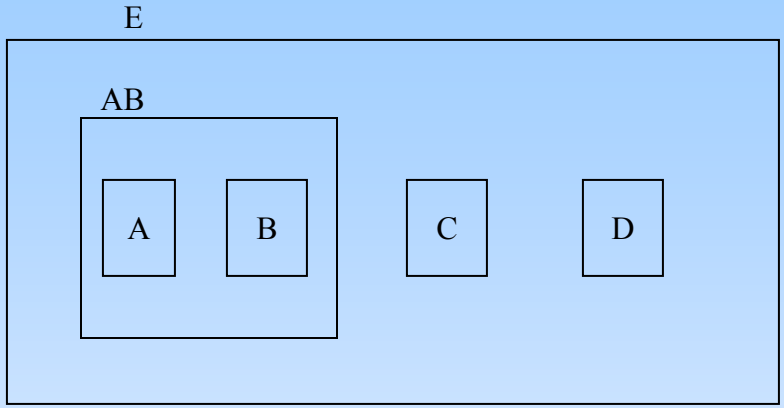
Continuation in DEVSim++

- Time advance : ta(s)
  - ta is decided based only on the current discrete state
  - Executed after both internal(input-free) and external(inputted) state transitions
  - Time advance after internal transition
    - A new schedule for a new state is required: ta(current-state) = new-value
  - Time advance after external transition
    - Schedule at the previous state (ta-old) may exist
    - ta(current-state) after external transition is either continuation of old one or new one.
- Time advance after external transition
  - For continuation extra state variables (ta-old, e) may be required
    (ta-old: existing schedule; e: time elapsed after existing schedule)
  - Time advance at current state
    - ta(current-state) = ta-old – e for continuation of existing schedule
      = new-value otherwise
- Macro *continue* in DEVSim++
  - *continue* :: ta(current-state) = ta-old – e
  - DEVSim++ *continue* can be used within external transition function without extra state vars by users

Select in General Case

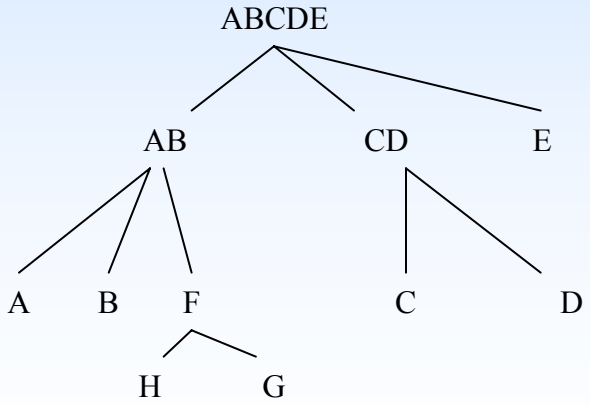


Sel ({A, B}):: Priority between A and B



In AB, Priority between A and B is specified

In E, Priority among AB, C and D is specified



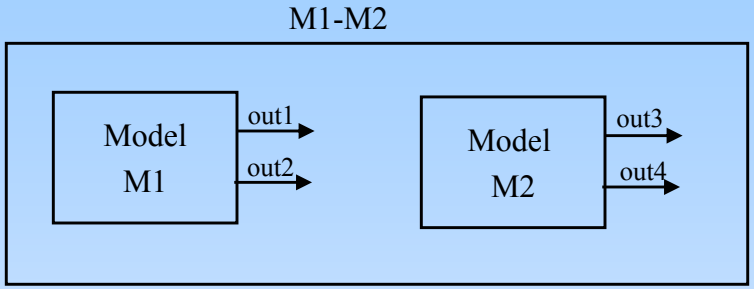
ABCDE = < …….. Sel> : Priority among AB, CD, E

AB = < ……Sel> : Priority among A, B, F

CD = <……..Sel> : Priority between C, D

F = < ……Sel> : Priority between H, G

Limitation of Select function



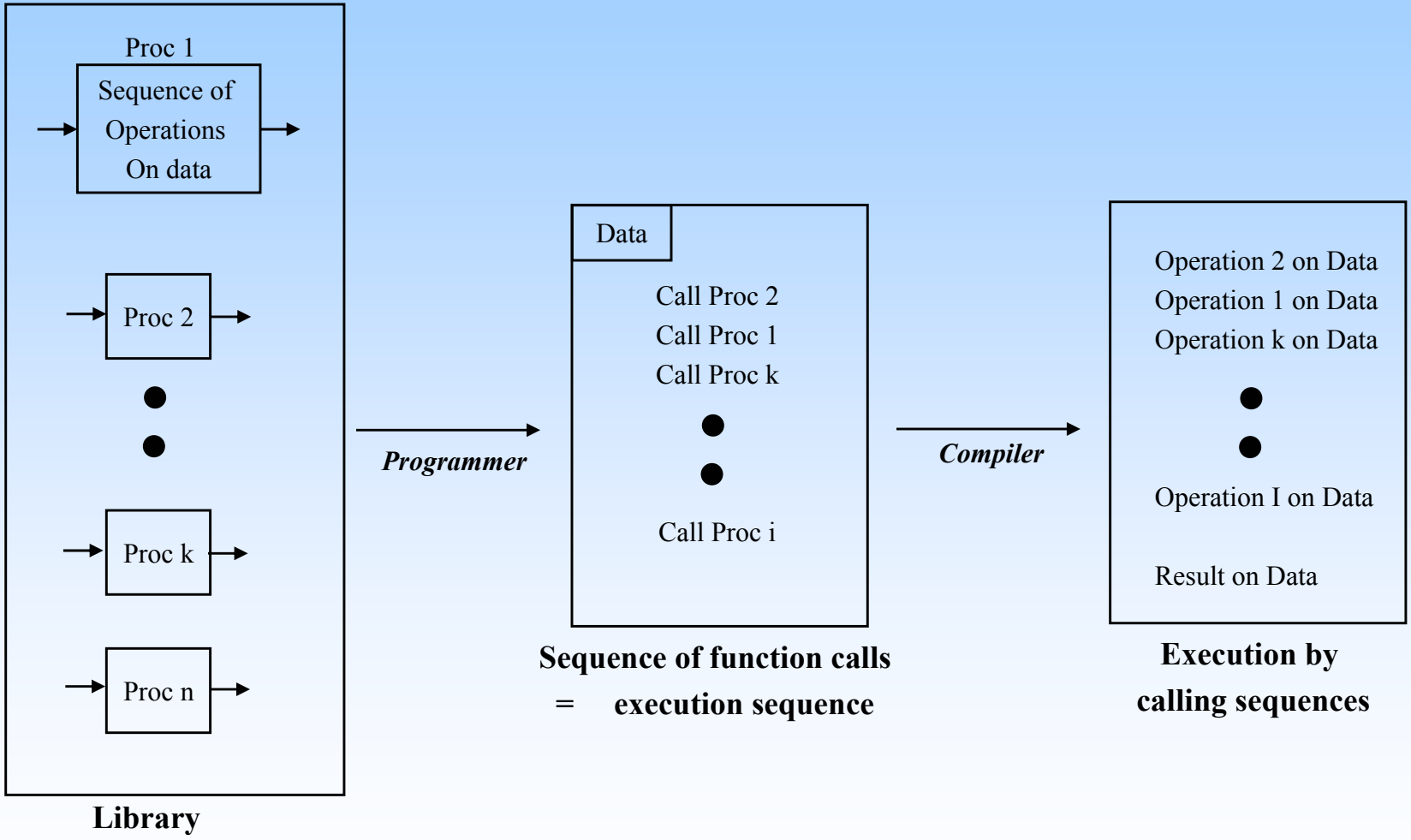
- Assume the following priority between outputs
  - M1.out1 > M2.out4 and M2.out3 > M1.out2
    - M1.out1 > M2.out4 ➔ sel ({M1, M2}) = M1
    - M2.out3 > M1.out2 ➔ sel ({M1, M2}) = M2

  } Conflict

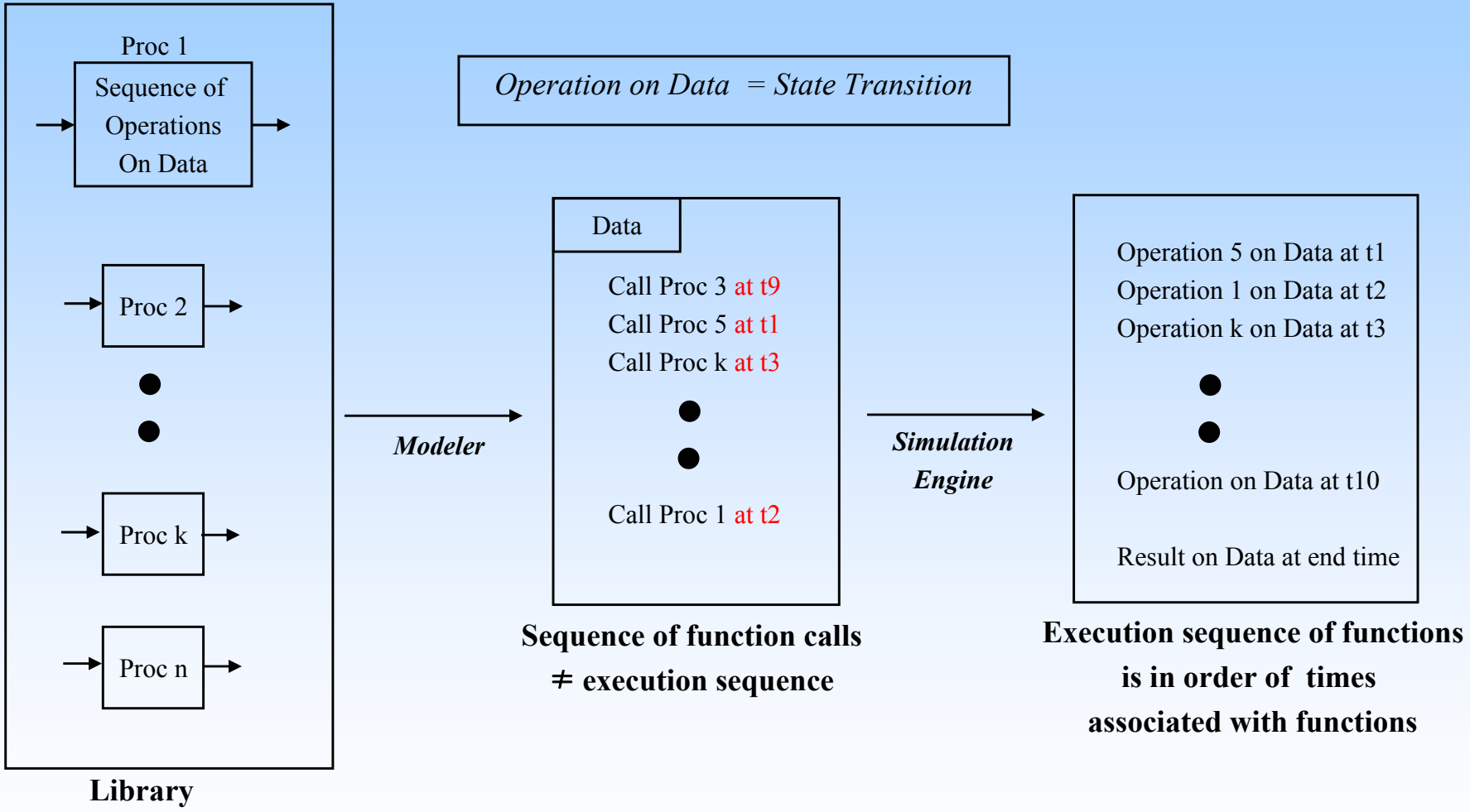
➔ DEVS *Sel* function cannot be used for specification of the above conflict case.

- Solution
  - Sol 1: Break each of M1 and M2 into two models, each with one output only.
  - Sol 2: Modify selection function
    - sel : $2^Y \rightarrow Y$, $Y = \bigcup_i Y_i$: set of all output ports within a coupled model

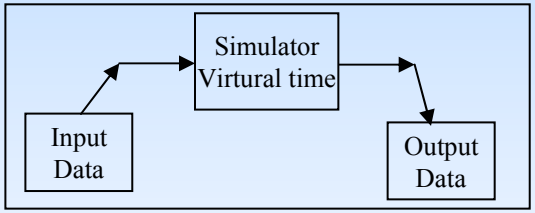
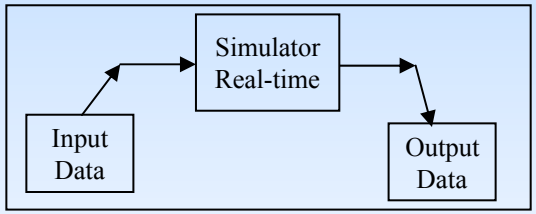
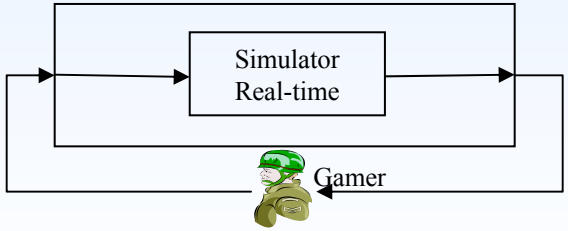
Execution Sequence of General Program: Calling order

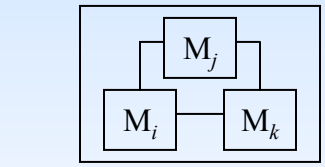


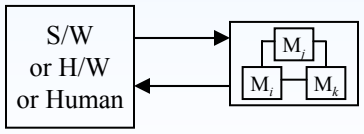
Execution Sequence of Simulation Program: Time order



Simulation Clock: Virtual vs Real-time

Simulation Clock / Model Boundary	Simulation clock ➔ value of the variable (clock variable) used in simulation program Simulation time advance ➔ updating clock variables (independent of execution time)	
	Virtual Time	**Real-time (Wall) Time**
	No relation between clock variable and real-time	Clock variable is related to real-time C.V = real-time ➔ Game Ratio 1:1
	Local time / Global time	Local time / Global time
No interaction with external environment	 **Performance Simulator**	 **Timing Verifying Simulator**
Interaction with external environment	**N/A** **Response time required from external world** **<< Simulation execution time**	 **Training Simulator** **Hardware-in-The-Loop Simulator**





External world **model**