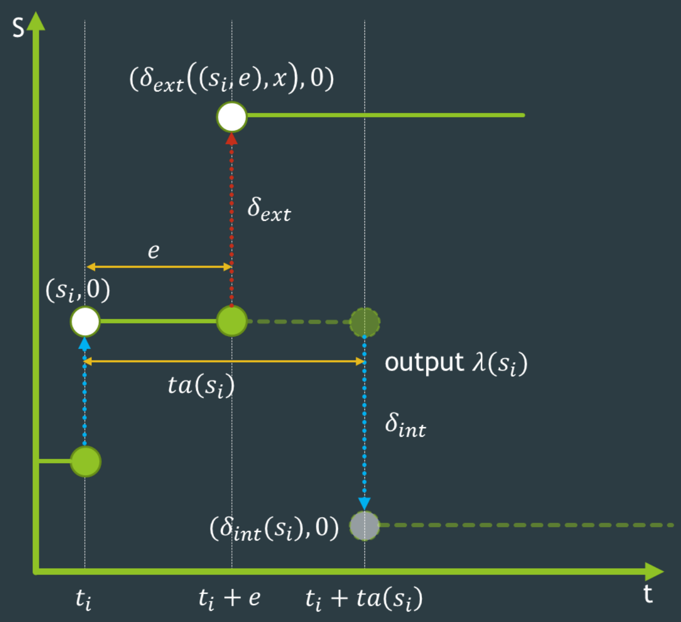


Classic DEVS

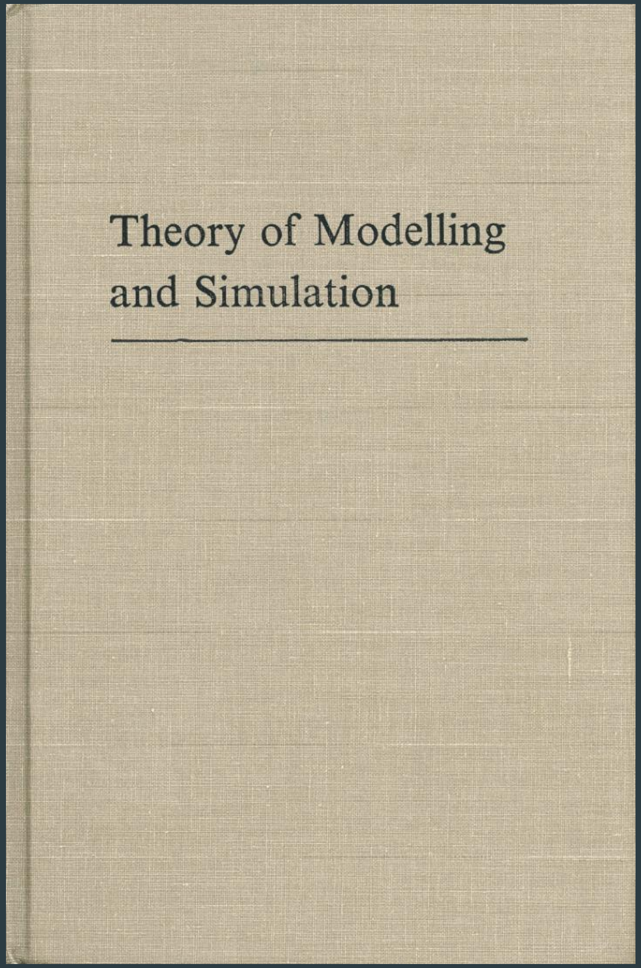
An Introduction Using PythonPDEVS

Yentl Van Tendeloo, Hans Vangheluwe

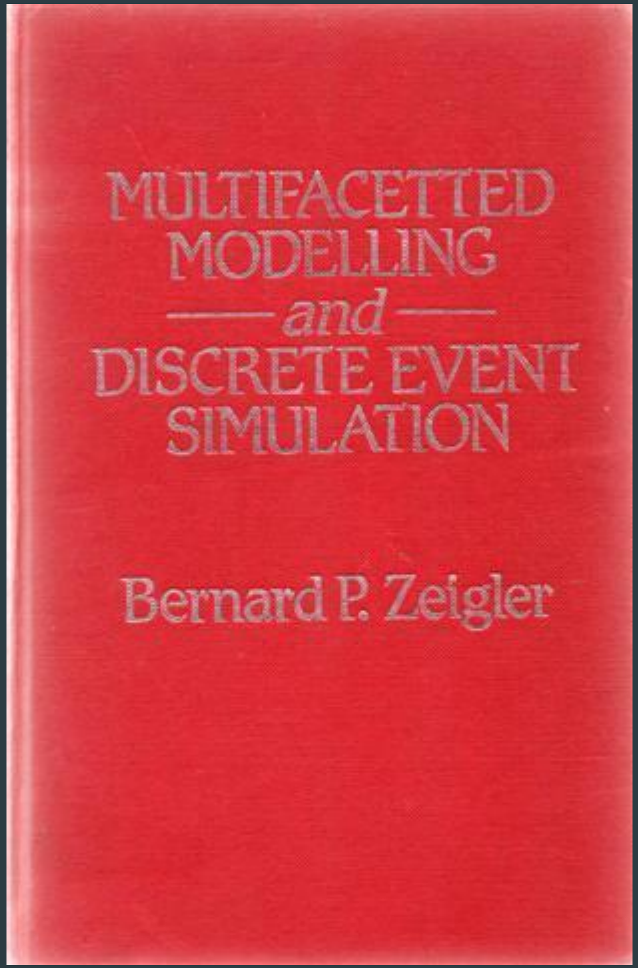
Universiteit Antwerpen

McGill

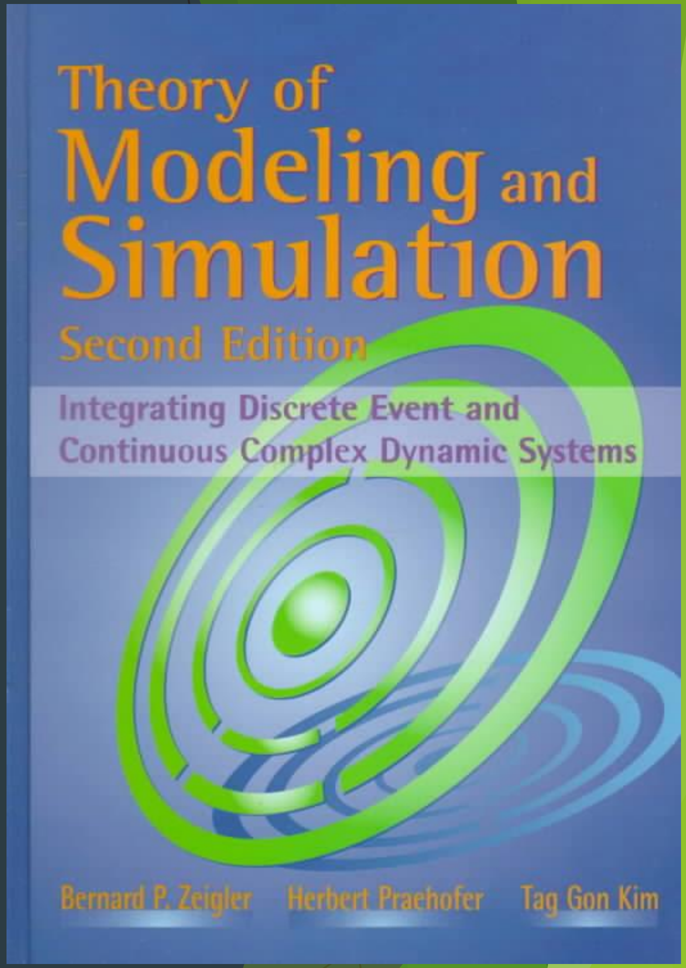
Introduction



Bernard P. Zeigler.
Theory Of Modelling And Simulation.
1st ed. Wiley, 1976.



Bernard P. Zeigler.
Multifacetted Modelling and Discrete Event Simulation.
1st ed. Academic Press, 1984.



Bernard P. Zeigler, Herbert Praehofer, and Tag Gon Kim.
Theory Of Modelling And Simulation.
2nd ed. Academic Press, 2000.

An overview of PythonPDEVS

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Methodology

Simulation

Simulation: Transactions of the Society for Modeling and Simulation International
1–19

DOI: 10.1177/0037549716678330
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An evaluation of DEVS simulation tools

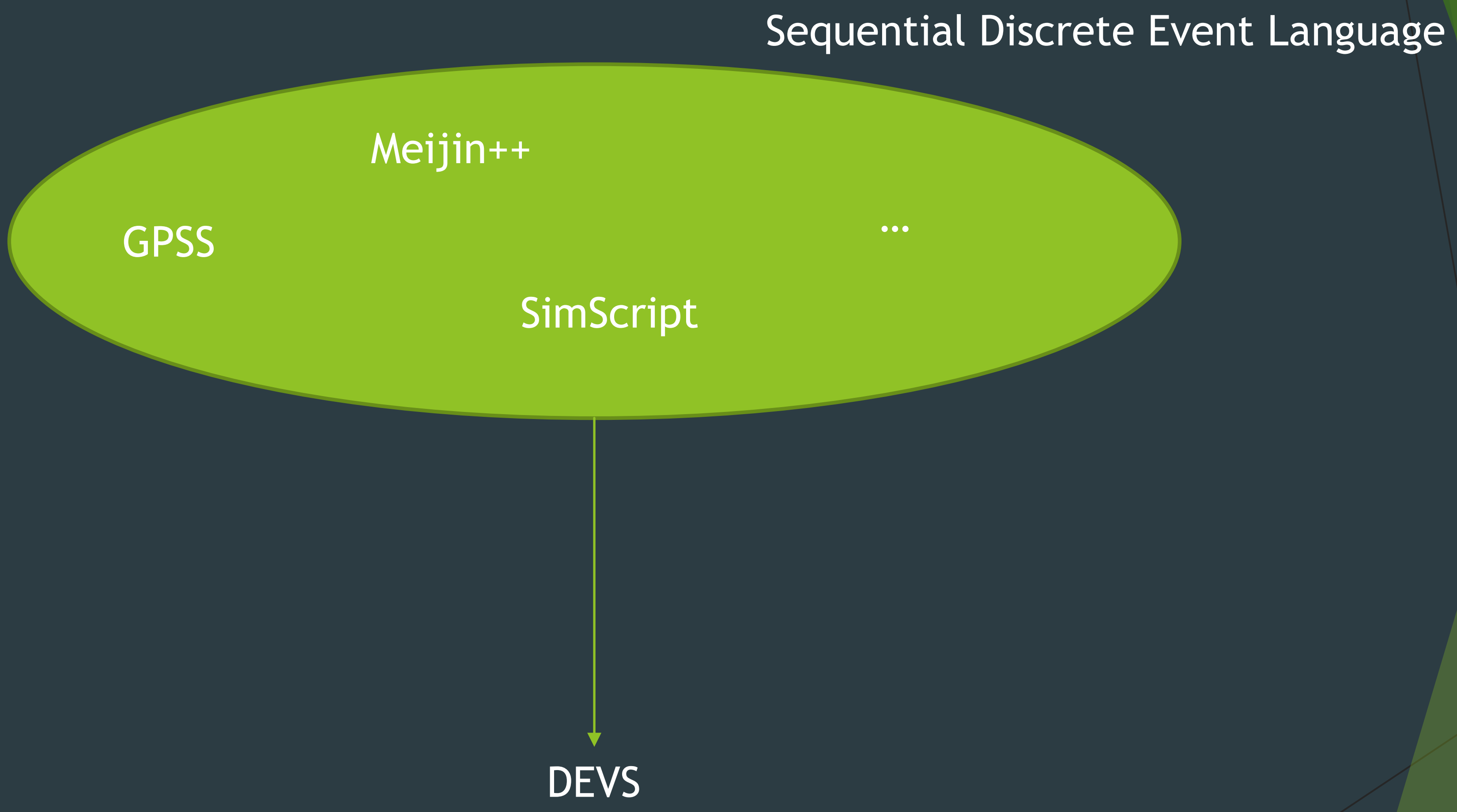
Yentl Van Tendeloo[1*] and Hans Vangheluwe[1,2,3*]

Abstract
DEVS is a popular formalism for modeling complex dynamic systems using a discrete-event abstraction. Owing to its popularity, and the simplicity of the simulation kernel, a number of tools have been constructed by academia and industry. However, each of these tools has distinct design goals and a specific programming language implementation. Consequently, each supports a specific set of formalisms, combined with a specific set of features. Performance differs significantly between different tools. We provide an overview of the current state of eight different DEVS simulation tools: ADEVS, CD++, DEVS-Suite, MS4 Me, PowerDEVS, PythonPDEVS, VLE, and X-S-Y. We compare supported formalisms, compliance, features, and performance. This paper aims to help modelers in deciding which tools to use to solve their specific problems. It further aims to help tool builders, by showing the aspects of their tools that could be extended in future tool versions.

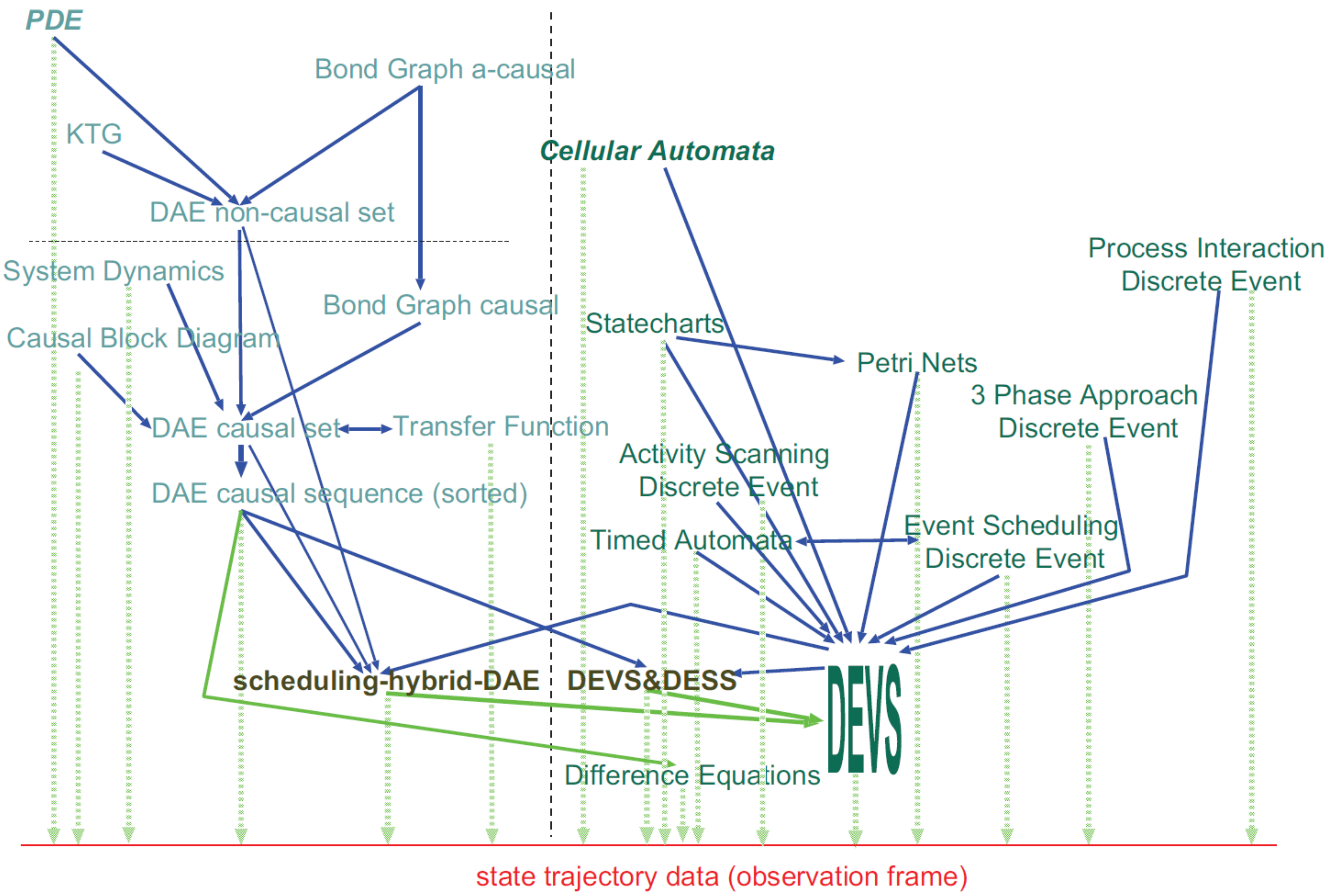
Yentl Van Tendeloo and Hans Vangheluwe.
An Overview of PythonPDEVS.
In Proceedings of Journées DEVS Francophones (JDF), pages 59-66, 2016.

Yentl Van Tendeloo and Hans Vangheluwe.
An Evaluation of DEVS Simulation Tools.
Simulation: Transactions of the Society for Modeling and Simulation International.
2017, 93(2): 103-121

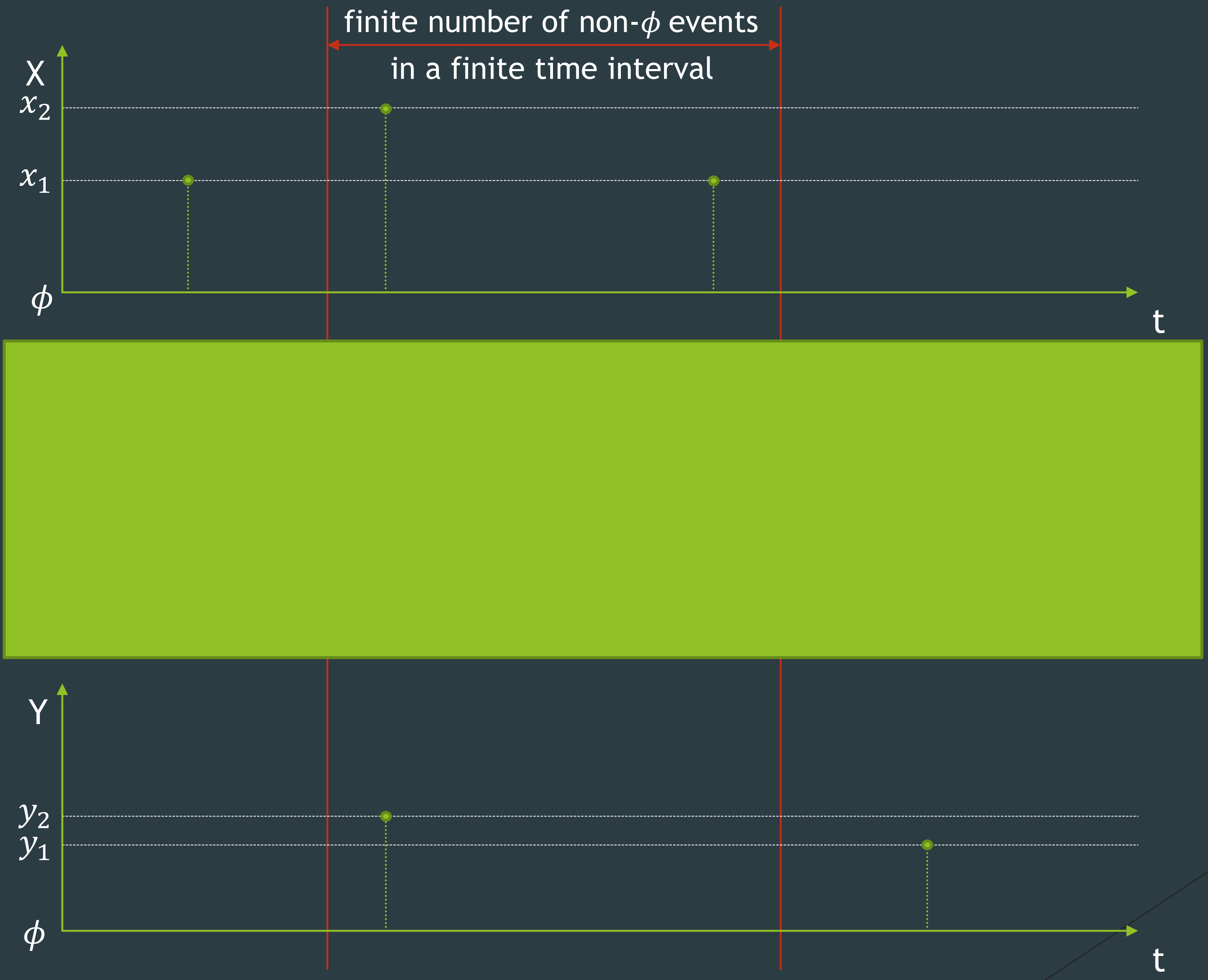
Our presentation uses initialized DEVS models, which contain an initial state. The initial state was left implicit in the original DEVS specification.

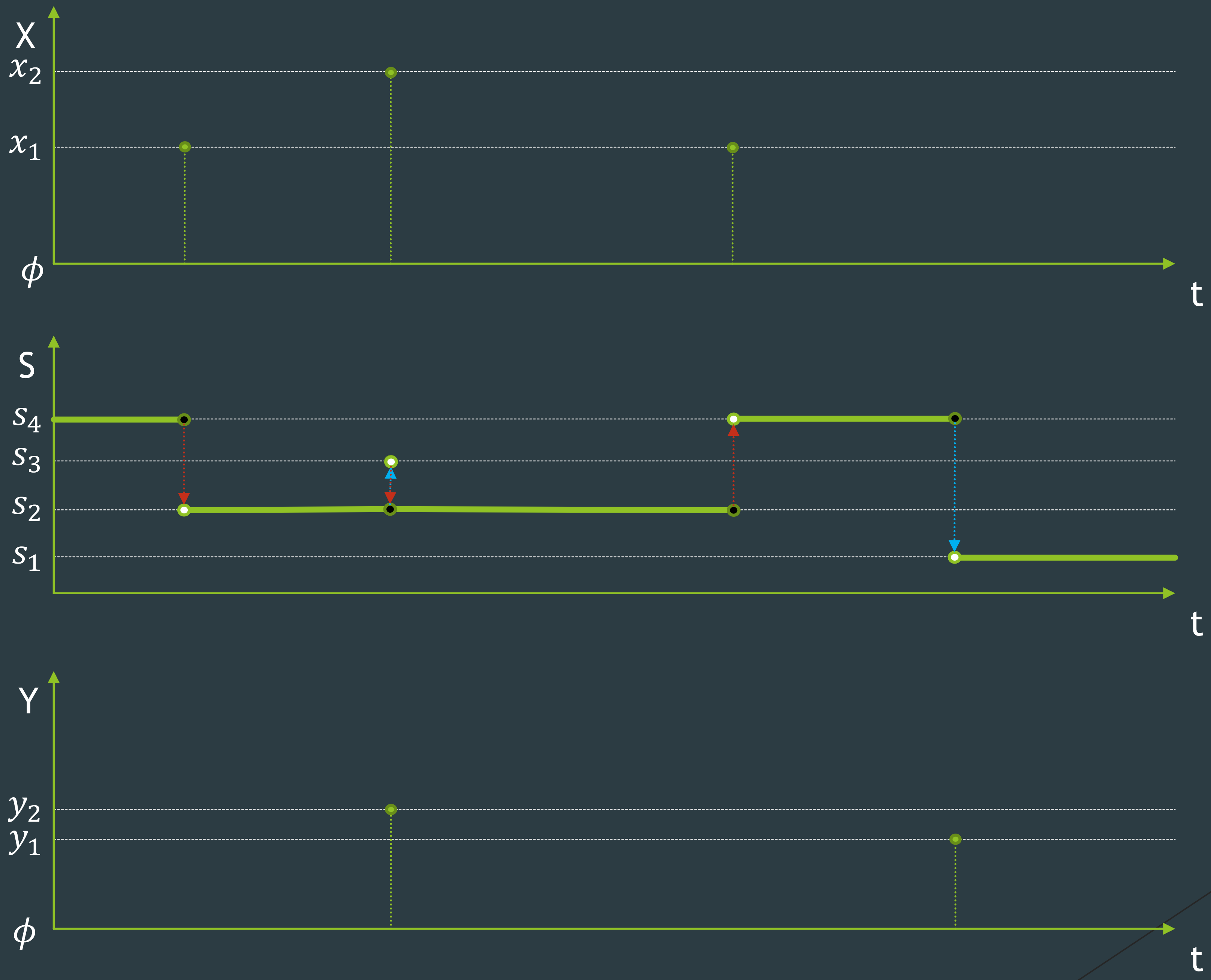


= modular simulation assembly language



Vangheluwe, Hans. DEVS as a common denominator for multi-formalism hybrid systems modelling.
In proceedings of the International Symposium on Computer-Aided Control System Design, pp. 129-134. 2000.

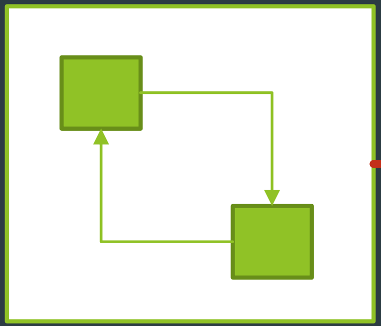

finite number of non-ϕ events
in a finite time interval
X
x_2
x_1
ϕ
t
Y
y_2
y_1
ϕ
t



X
x_2
x_1
ϕ
t
S
s_4
s_3
s_2
s_1
t
Y
y_2
y_1
ϕ
t

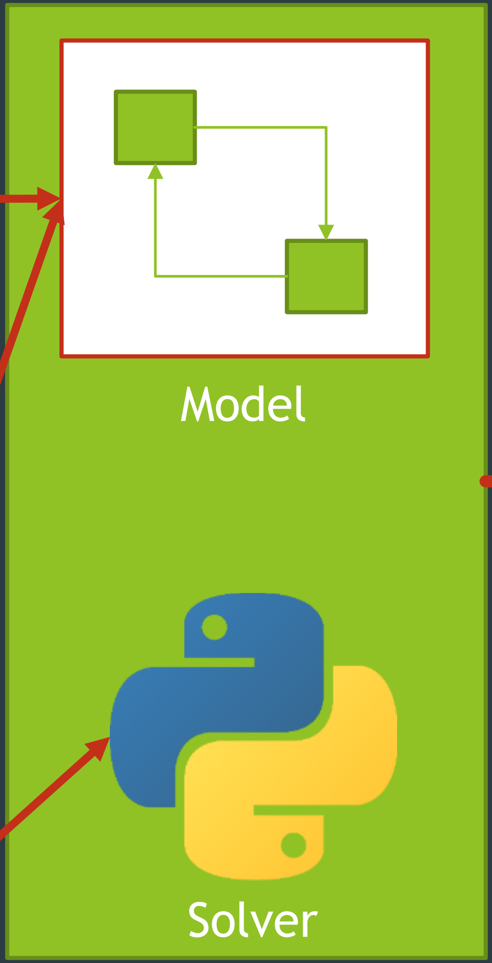
Experimentation

Simulation

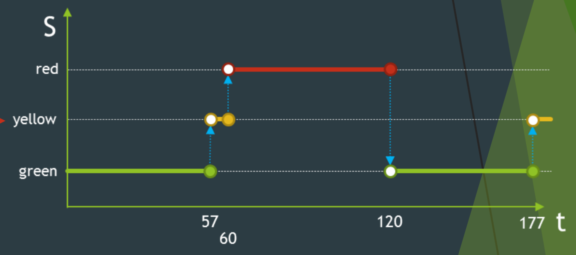


Model

$$delay_{red} = 60s$$
$$delay_{yellow} = 3s$$
$$delay_{green} = 57s$$
$$q_{init,light1} = (green, 0)$$
$$q_{init,pol1} = (idle, 280)$$
$$cond_{termination} = (t_{sim} \geq t_{end})$$
$$t_{end} = 24h$$



Simulator



Trace

Concrete Syntax

simple_experiment.py

```
from pypdevs.simulator import Simulator

from mymodel import MyModel

model = MyModel(\
            q_init_pol1 = (“idle”, 280),
            q_init_light1 = (“green”, 0),
            delay_red = 60,
            delay_yellow = 3,
            delay_green = 57
)
simulator = Simulator(model)

simulator.setTerminationTime(24*60*60)
simulator.setClassicDEVS()
simulator.setVerbose()

simulator.simulate()
```

__ Current Time: 0.00 ____

INITIAL CONDITIONS in model <system.light>

Initial State: green

Next scheduled internal transition at time 57.00

INITIAL CONDITIONS in model <system.policeman>

Initial State: idle

Next scheduled internal transition at time 20.00

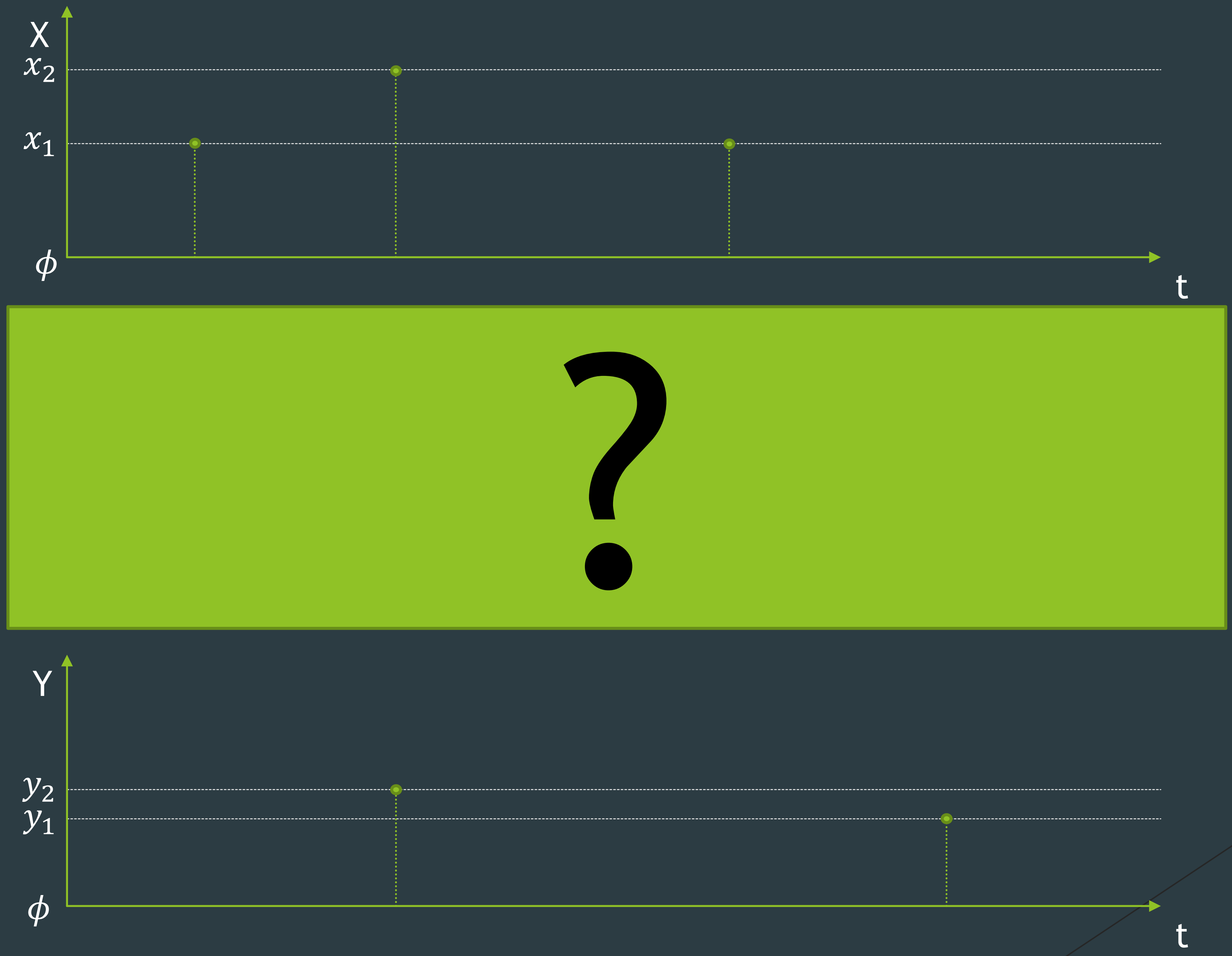
```
__  Current Time:      20.00 ____________________________________________

    EXTERNAL TRANSITION in model <system.light>
        Input Port Configuration:
            port <interrupt>:
                toManual
        New State: going_manual
        Next scheduled internal transition at time 20.0

    INTERNAL TRANSITION in model <system.policeman>
        New State: working
        Output Port Configuration:
            port <output>:
                go_to_work
        Next scheduled internal transition at time 3620.00
```

__ Current Time: 20.00 ____

INTERNAL TRANSITION in model <system.light>
Output Port Configuration:
port <observer>:
turn_off
New State: manual
Next scheduled internal transition at time inf

```
__  Current Time:     3620.00 ________________________________________

    EXTERNAL TRANSITION in model <system.light>
        Input Port Configuration:
            port <interrupt>:
                toAuto
        New State: going_auto
        Next scheduled internal transition at time 3620.00

    INTERNAL TRANSITION in model <system.policeman>
        New State: idle
        Output Port Configuration:
            port <output>:
                take_break
        Next scheduled internal transition at time 3920.00
```

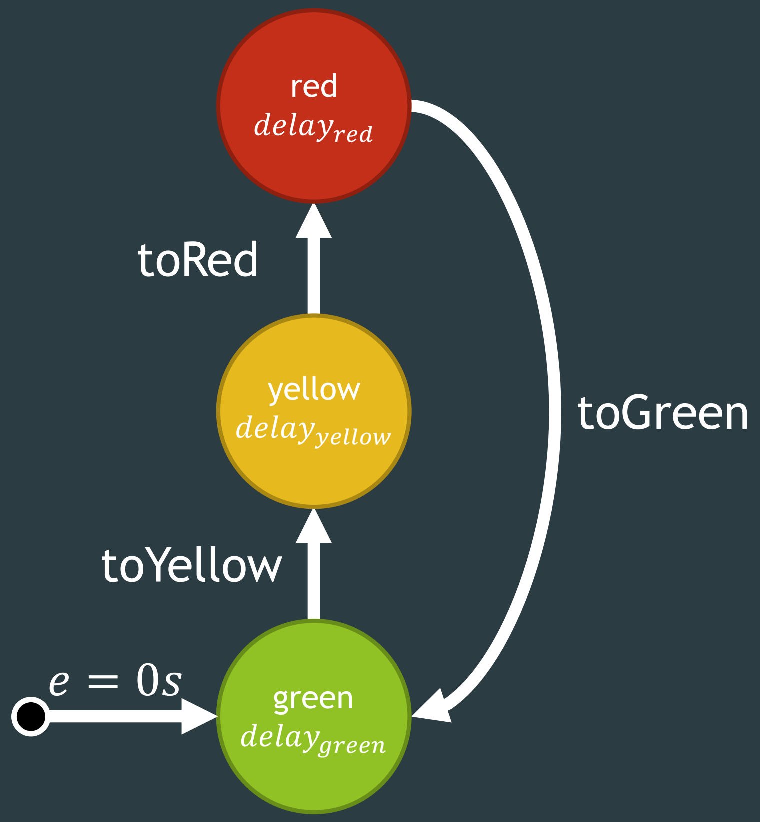
Atomic Models



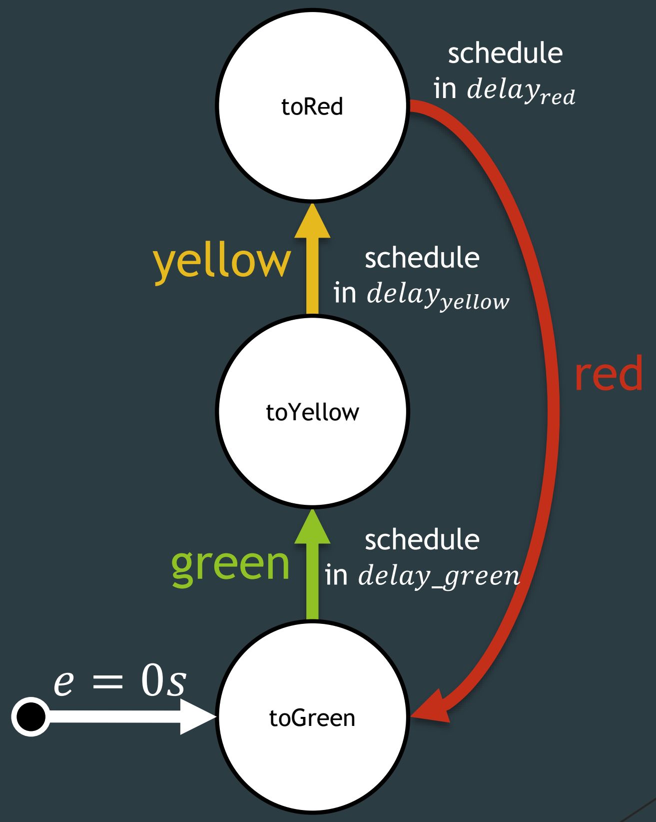
X
x_2
x_1
ϕ
t
?
Y
y_2
y_1
ϕ
t

Modelling Discrete Event Behaviour

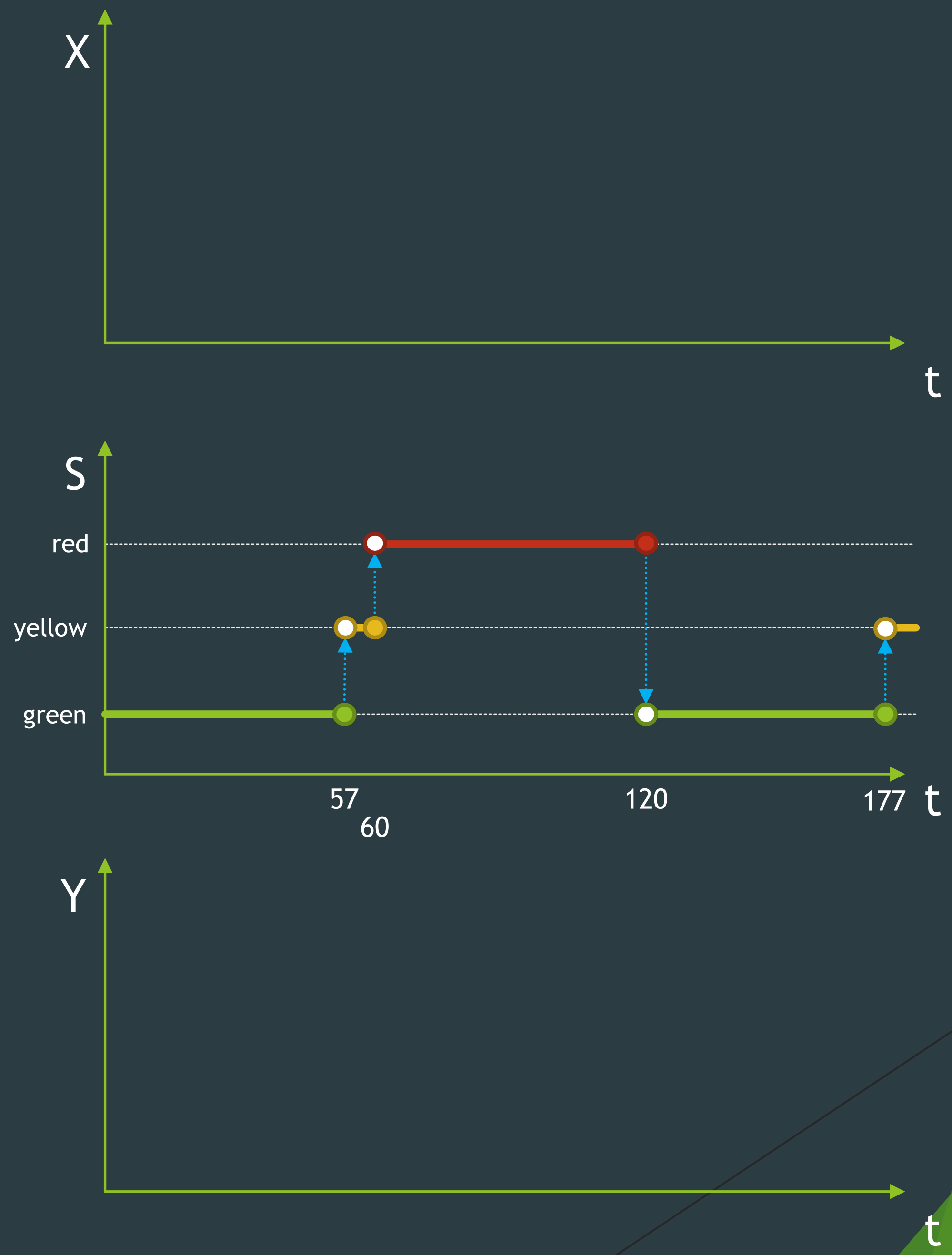
Finite State Automaton



Timed Event Scheduling Graph



red
$delay_{red}$
yellow
$delay_{yellow}$
green
$delay_{green}$



X
t
S
red
yellow
green
57
60
120
177
t
Y
t

Autonomous (no input)

$M = \langle S , \quad , \delta_{int} \ , ta \rangle$

S : set of sequential states

S = {red, yellow, green}

$\delta_{int} : S \rightarrow S$

δ_{int} = {red → green,
green → yellow,
yellow → red}

$ta : S \rightarrow \mathbb{R}^{+}_{0,+\infty}$

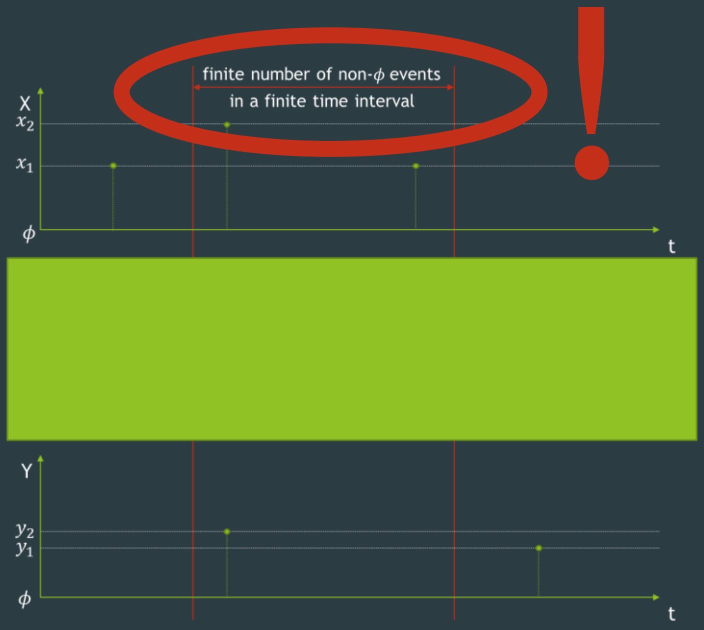
ta = {red → $delay_{red}$,
green → $delay_{green}$,
yellow → $delay_{yellow}$}

Time Advance: corner cases

$$ta : S \rightarrow \mathbb{R}^{+}_{0,+\infty}$$

$ta(s_i) = 0$

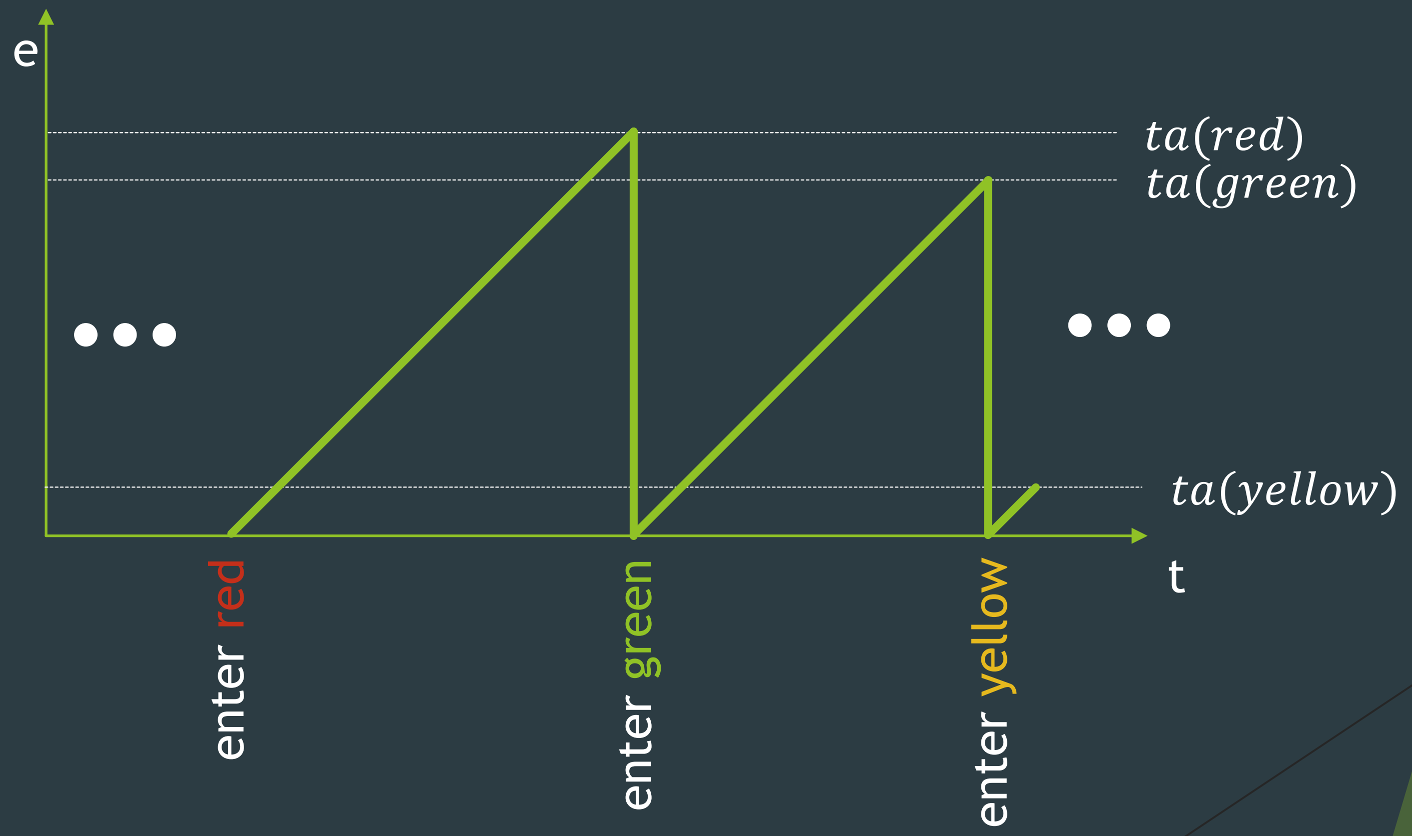
transient states



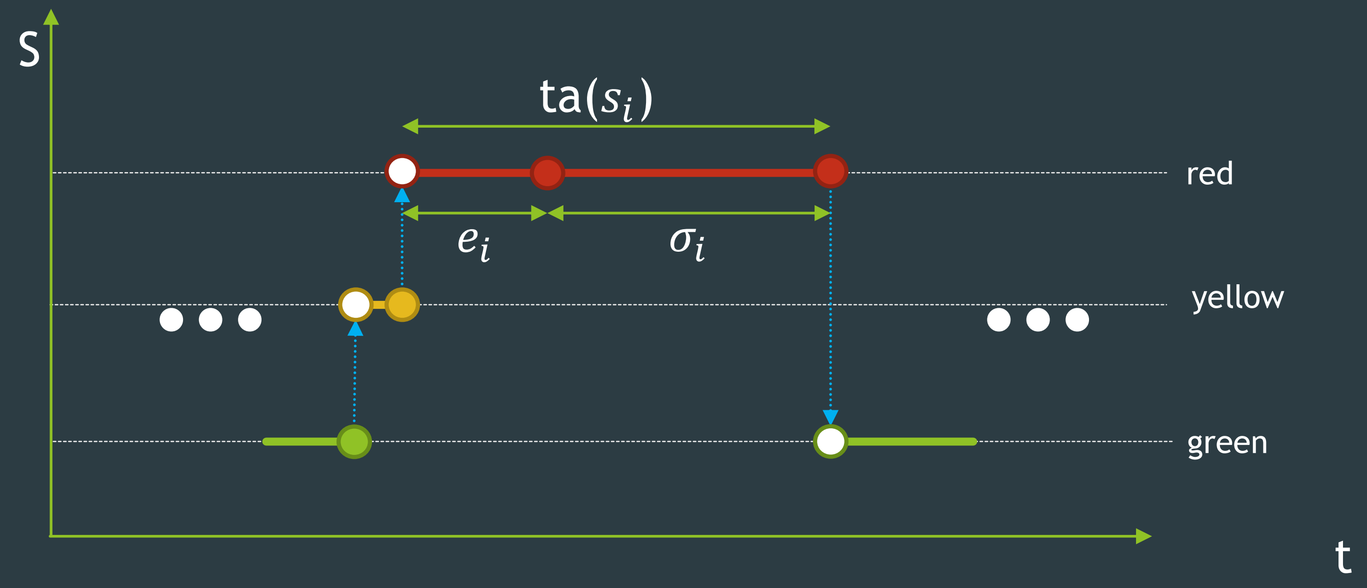
$ta(s_i) = +\infty$

passive states

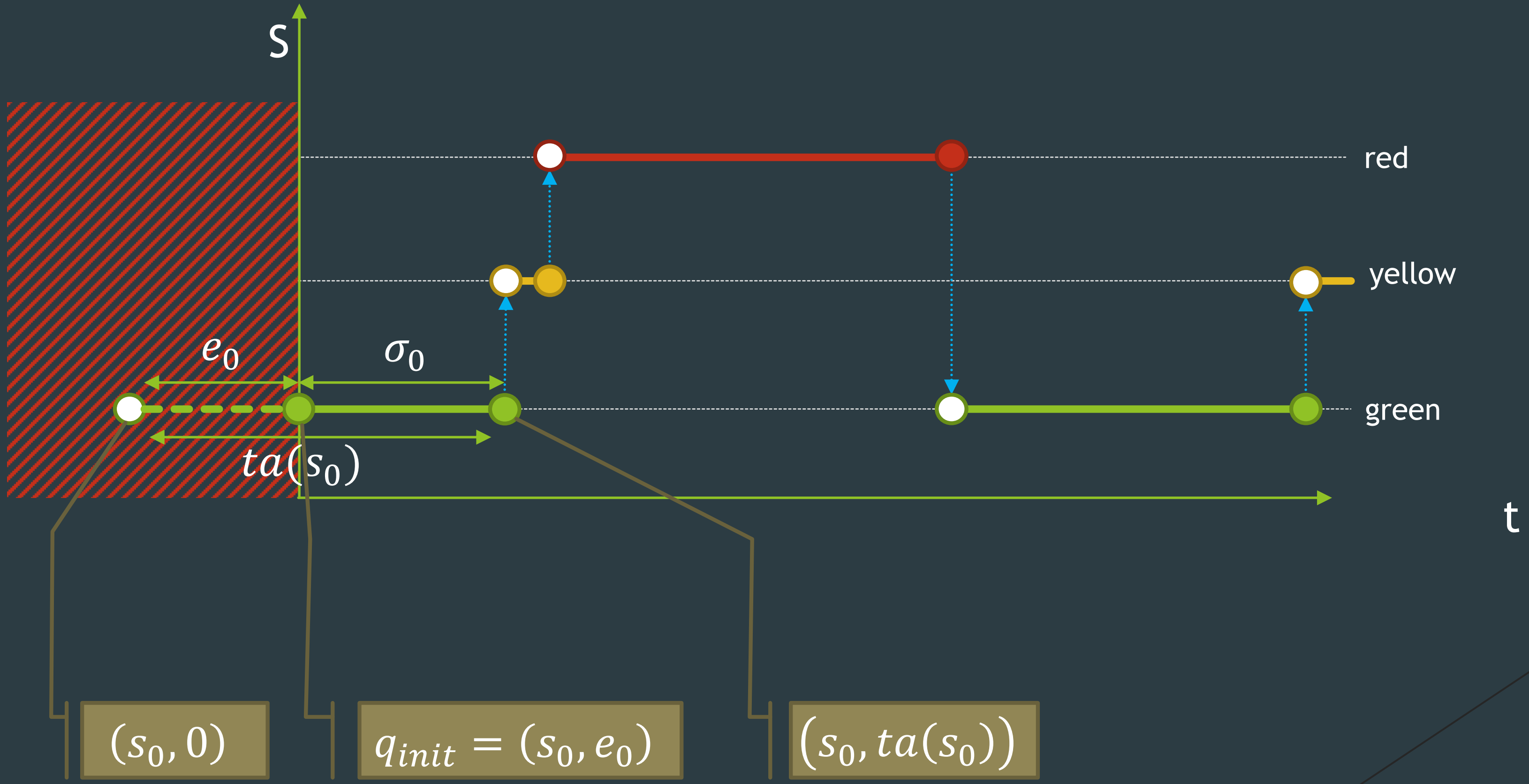
Elapsed time



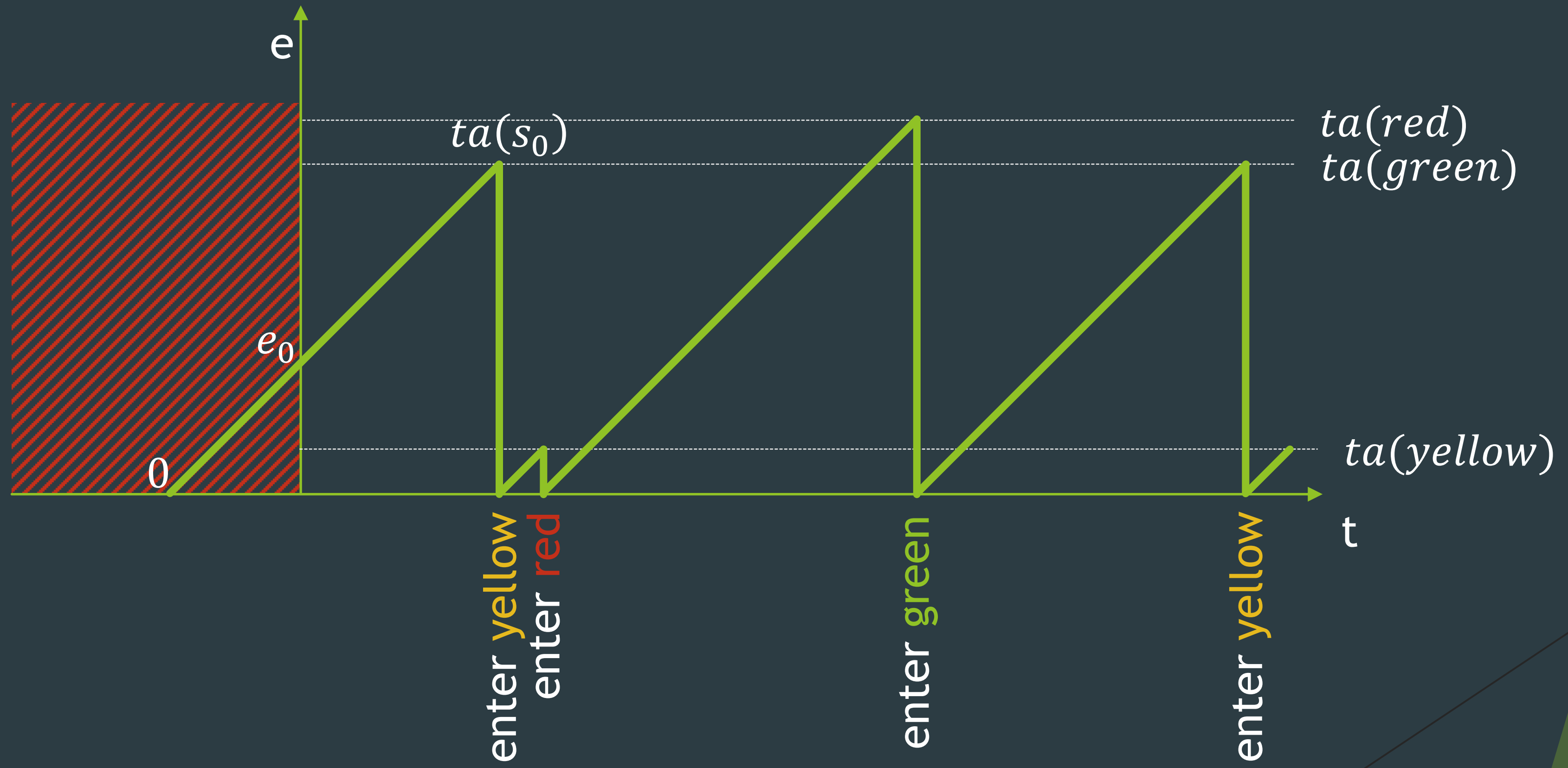
Elapsed time

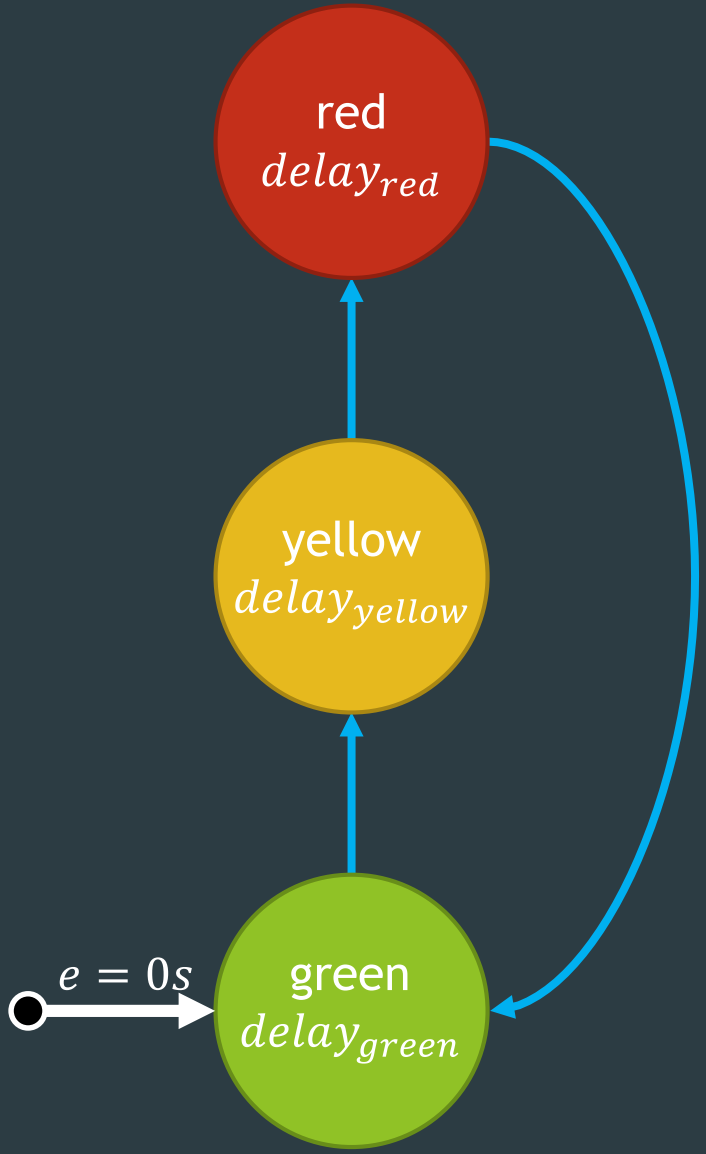


Initialization of Initial State



Elapsed time





Autonomous (no output)

$M = \langle S, q_{init}, \delta_{int}, ta \rangle$

S : set of sequential states

S = {red, yellow, green}

$\delta_{int} : S \rightarrow S$

δ_{int} = {red → green,
green → yellow,
yellow → red}

$ta : S \rightarrow \mathbb{R}^{+}_{0,+\infty}$

ta = {red → $delay_{red}$,
green → $delay_{green}$,
yellow → $delay_{yellow}$}

q_{init} : Q - set of total states

$Q = \{(s, e) | s \in S, 0 \leq e \leq ta(s)\}$

q_{init} = (green, 0)

Abstract Syntax

S = {red, yellow, green}

δ_{int} = { red → green,
green → yellow,
yellow → red}

ta = {red → $delay_{red}$,
green → $delay_{green}$,
yellow → $delay_{yellow}$}

q_{init} = (green, 0)

Operational Semantics

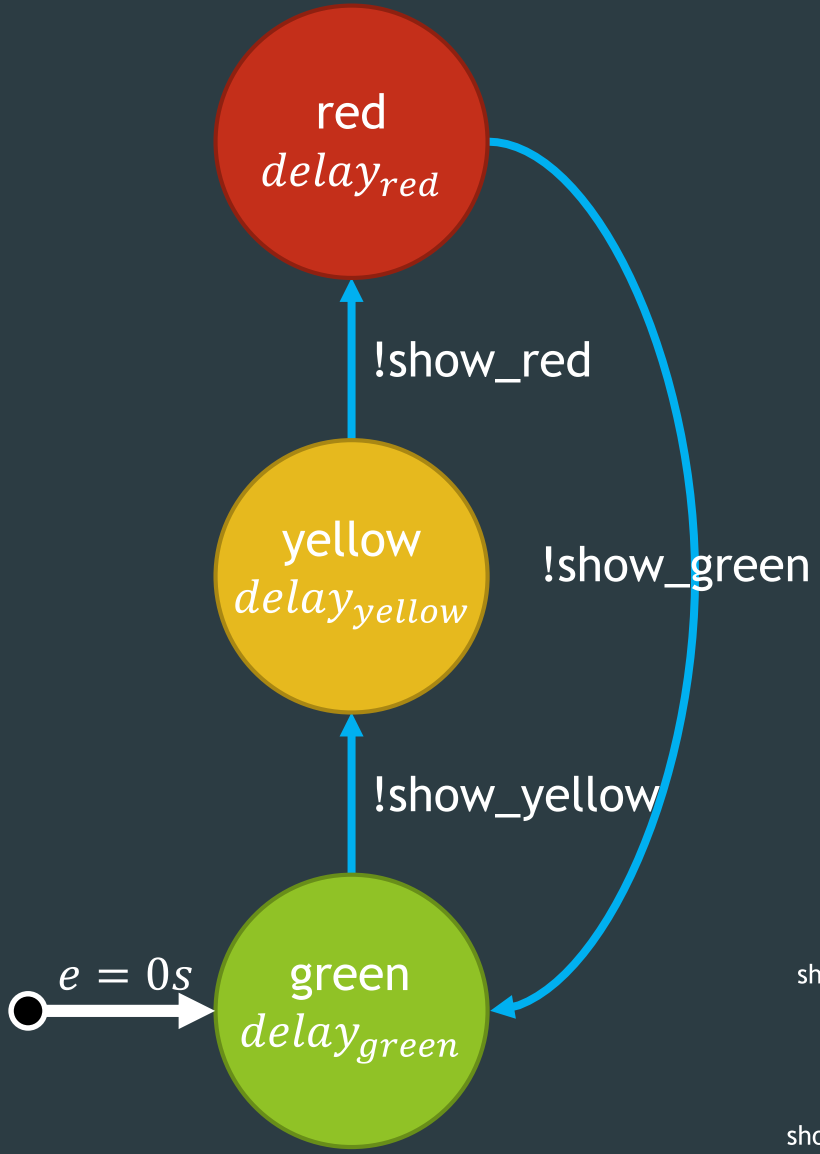
```
time = 0
current_state = initial_state
last_time = -initial_elapsed
while not termination_condition():
    time = last_time + ta(current_state)
    current_state = δint(current_state)
    last_time = time
```

Concrete Syntax

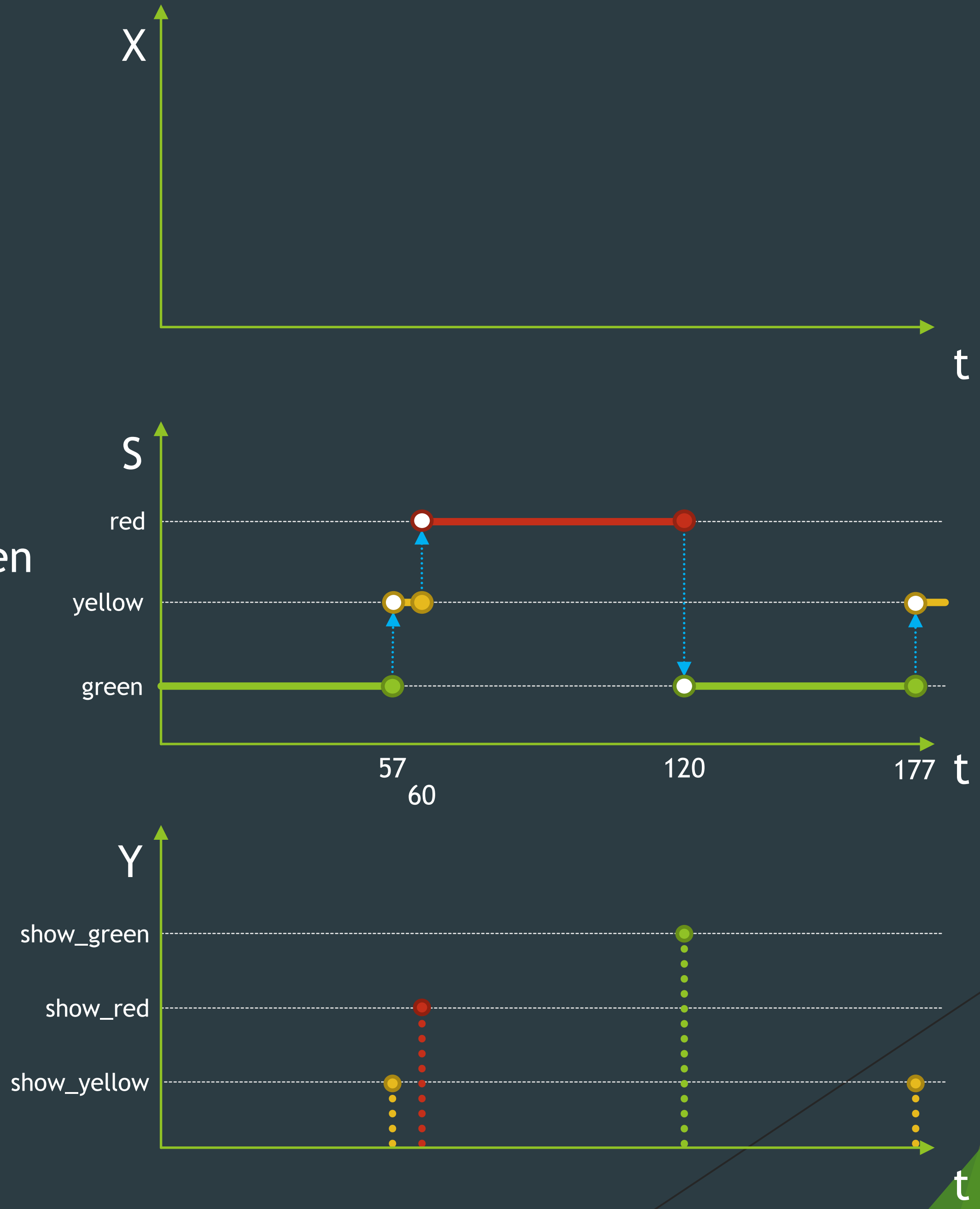
atomic_int.py

```python
from pypdevs.DEVS import *

class TrafficLightAutonomous(AtomicDEVS):
    def __init__(self, q_init, delay_green,
                     delay_yellow, delay_red):
        AtomicDEVS.__init__(self, "light")
        self.state, self.elapsed = q_init
        self.delay_green = delay_green
        self.delay_yellow = delay_yellow
        self.delay_red = delay_red

    def intTransition(self):
        state = self.state
        return {"red": "green",
                "yellow": "red",
                "green": "yellow"}[state]

    def timeAdvance(self):
        state = self.state
        return {"red": self.delay_red,
                "yellow": self.delay_yellow,
                "green": self.delay_green}[state]
```

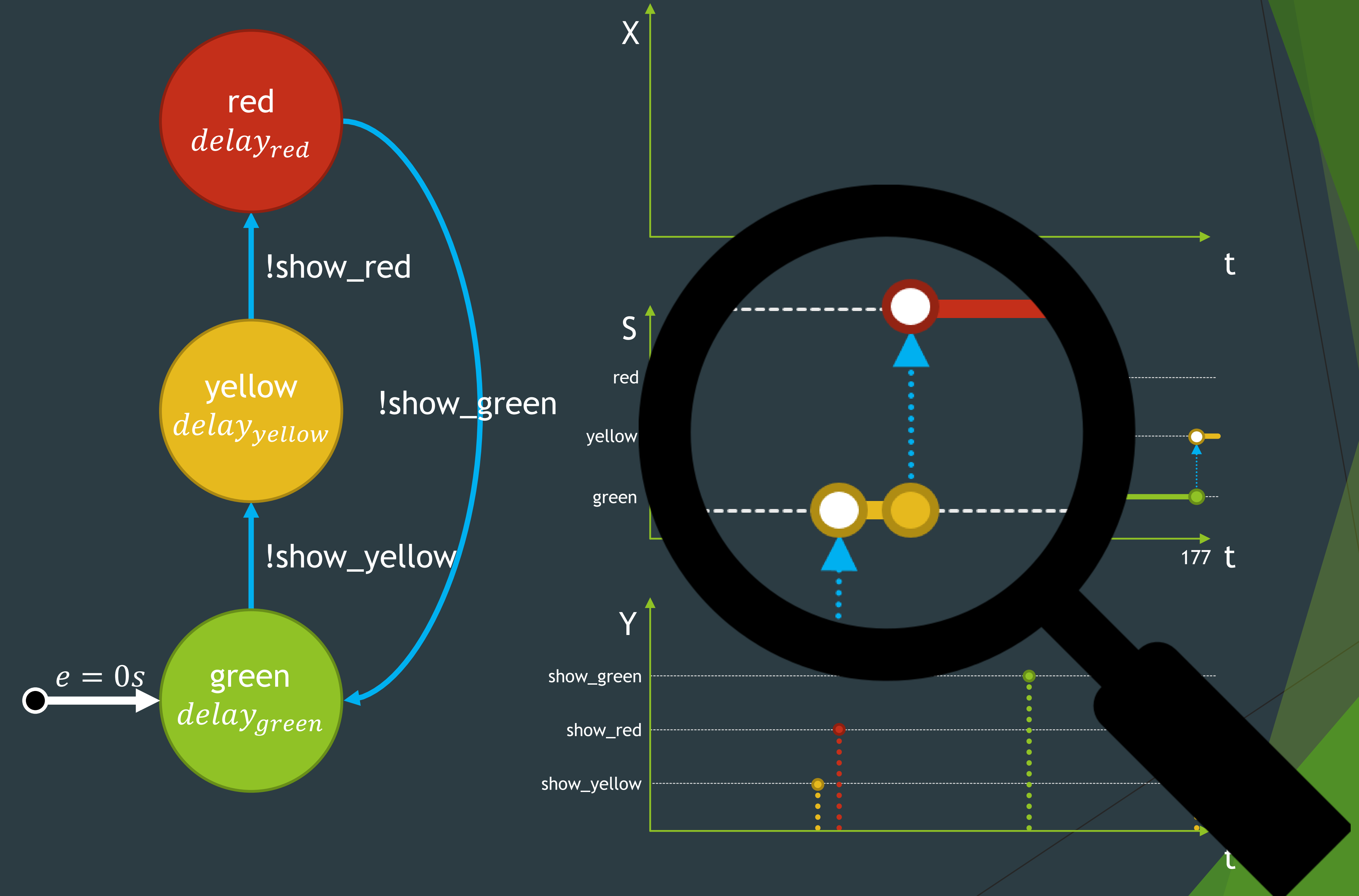
```
__  Current Time:       0.00 ____________________________________________

      INITIAL CONDITIONS in model <light>
              Initial State: green
              Next scheduled internal transition at time 57.00

__  Current Time:      57.00 ____________________________________________

      INTERNAL TRANSITION in model <light>
              New State: yellow
              Output Port Configuration:
              Next scheduled internal transition at time 60.00

__  Current Time:      60.00 ____________________________________________

      INTERNAL TRANSITION in model <light>
              New State: red
              Output Port Configuration:
              Next scheduled internal transition at time 120.00
```



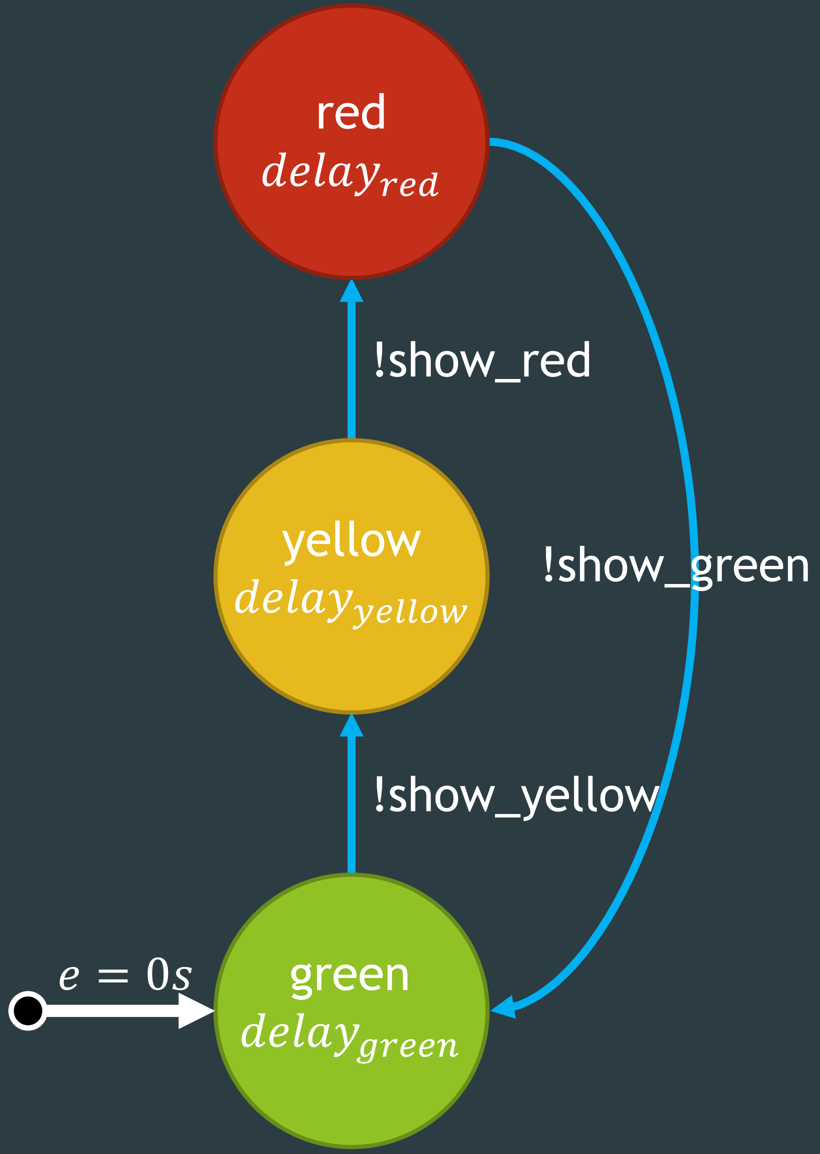
red
$delay_{red}$
!show_red
yellow
$delay_{yellow}$
!show_green
!show_yellow
green
$delay_{green}$
$e = 0s$



X
t
S
red
yellow
green
57
60
120
177
t
Y
show_green
show_red
show_yellow
t



red
$delay_{red}$
!show_red
yellow
$delay_{yellow}$
!show_green
!show_yellow
$e = 0s$
green
$delay_{green}$
X
t
S
red
yellow
green
177
t
Y
show_green
show_red
show_yellow
t



Autonomous (with output)

$M = \langle Y, S, q_{init}, \delta_{int}, \lambda, ta \rangle$

S = {red, yellow, green}

δ_{int} = { red → green,
green → yellow,
yellow → red}

q_{init} = (green, 0)

ta = {red → $delay_{red}$,
green → $delay_{green}$,
yellow → $delay_{yellow}$}

Y : set of output events

Y = {“show_red”, “show_green”, “show_yellow”}

$\lambda : S \rightarrow Y \cup \{\phi\}$

λ = { green → “show_yellow”,
yellow → “show_red”,
red → “show_green”}

Abstract Syntax

S = {red, yellow, green}
q_{init} = (green, 0)
δ_{int} = { red → green,
green → yellow,
yellow → red}
ta = {red → $delay_{red}$,
green → $delay_{green}$,
yellow → $delay_{yellow}$}
Y = {"show_red",
"show_green",
"show_yellow"}
λ = {green → "show_yellow",
yellow → "show_red",
red → "show_green"}

Operational Semantics

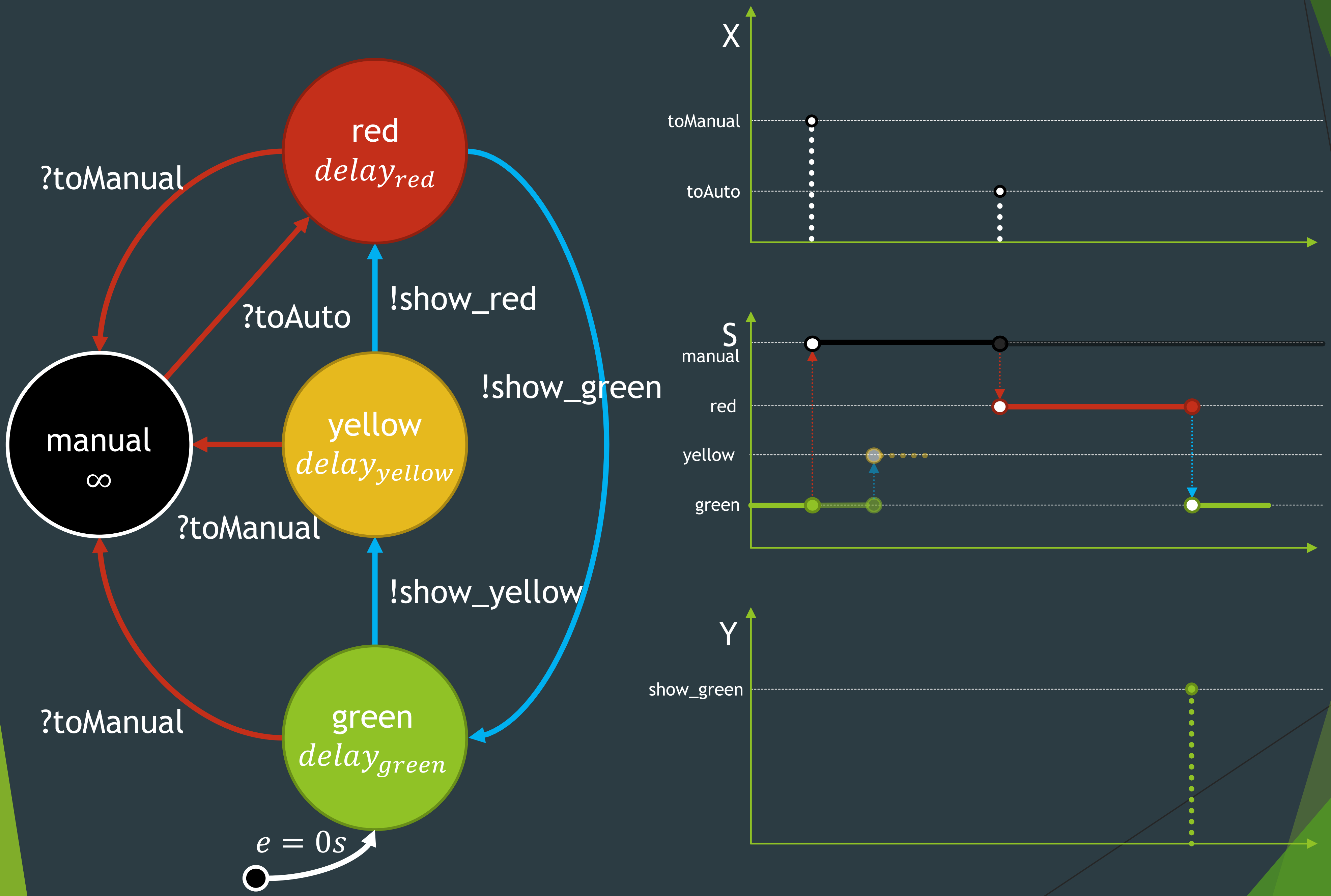
```
time = 0
current_state = initial_state
last_time = -initial_elapsed
while not termination_condition():
    time = last_time + ta(current_state)
    output(λ(current_state))
    current_state = δ_int(current_state)
    last_time = time
```

Concrete Syntax

atomic_out.py

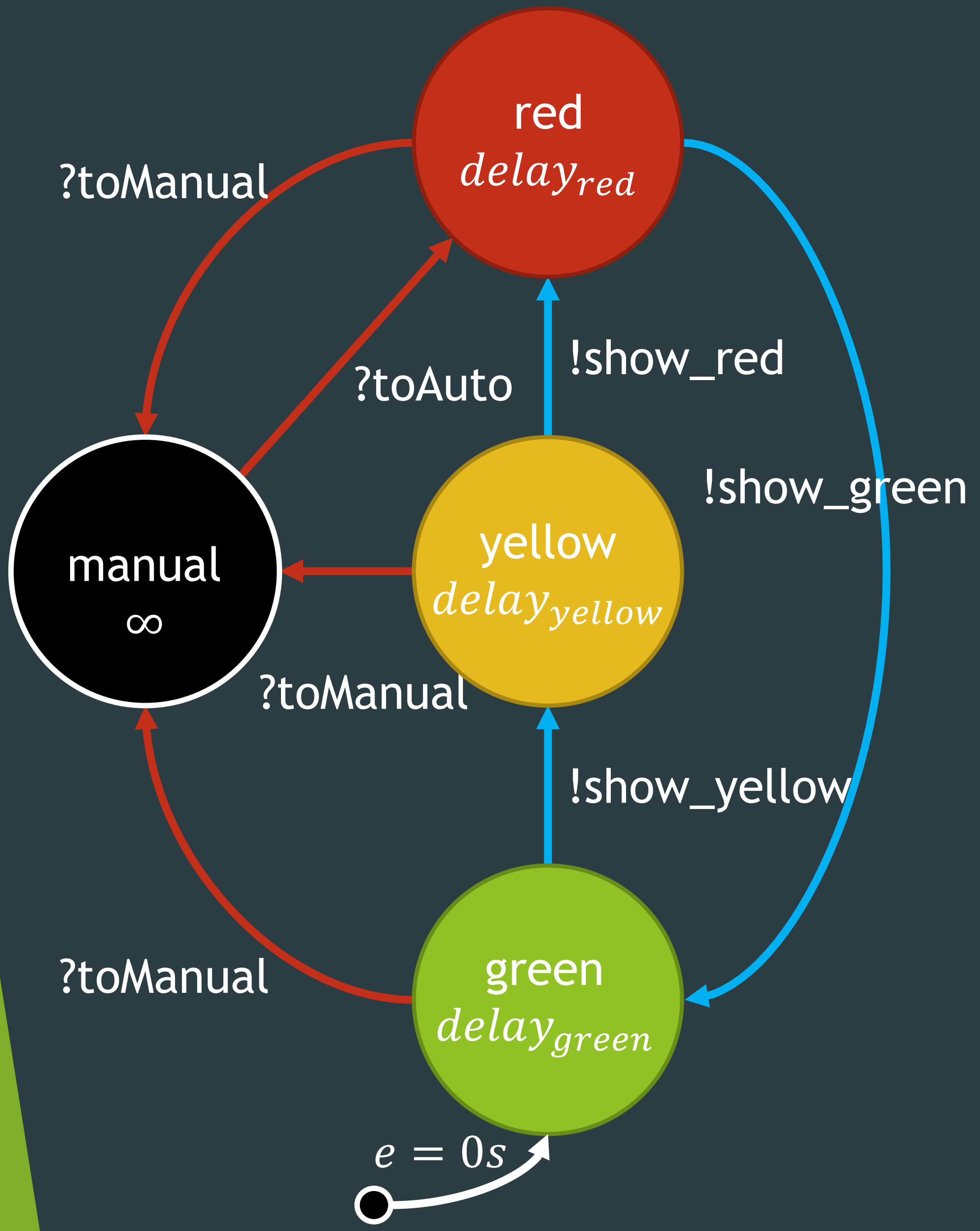
```python
from pypdevs.DEVS import *

class TrafficLightWithOutput(AtomicDEVS):
    def __init__(self, …):
        AtomicDEVS.__init__(self, "light")
        self.observe = self.addOutPort("observer")
        …
    …

    def outputFnc(self):
        state = self.state
        if state == "red":
            return {self.observe: "show_green"}
        elif state == "yellow":
            return {self.observe: "show_red"}
        elif state == "green":
            return {self.observe: "show_yellow"}
```

```
__  Current Time:      0.00 ______________________________________________

      INITIAL CONDITIONS in model <light>
            Initial State: green
            Next scheduled internal transition at time 57.00

__  Current Time:     57.00 ______________________________________________

      INTERNAL TRANSITION in model <light>
            New State: yellow
            Output Port Configuration:
                  port <observer>:
                        show_yellow
            Next scheduled internal transition at time 60.00

__  Current Time:     60.00 ______________________________________________

      INTERNAL TRANSITION in model <light>
            New State: red
            Output Port Configuration:
                  port <observer>:
                        show_red
            Next scheduled internal transition at time 120.00
```



red
$delay_{red}$
?toManual
?toAuto
!show_red
!show_green
manual
∞
yellow
$delay_{yellow}$
?toManual
!show_yellow
?toManual
green
$delay_{green}$
$e = 0s$
X
toManual
toAuto
t
S
manual
red
yellow
green
t
Y
show_green
t

Reactive



$M = \langle X, Y, S, q_{init}, \delta_{int}, \delta_{ext}, \lambda, ta \rangle$

Y = {"show_red", "show_green", "show_yellow"}
S = {red, yellow, green, manual}
q_{init} = (green, 0)
δ_{int} = {red → green,
green → yellow,
yellow → red}
λ = {green → "show_yellow",
yellow → "show_red",
red → "show_green"}
ta = {red → $delay_{red}$,
green → $delay_{green}$,
yellow → $delay_{yellow}$,
manual → +∞}

X : set of input events
X = {"toAuto", "toManual"}

$\delta_{ext} : Q \times X \to S$
$Q = \{(s, e) | s \in S, 0 \le e \le ta(s)\}$
δ_{ext} = {((*, *), "toManual") → "manual",
(("manual", *), "toAuto") → "red"}

Abstract Syntax

Y = {"show_red", "show_green", "show_yellow"}
S = {red, yellow, green, manual}
q_{init} = (green, 0)
δ_{int} = {red → green,
green → yellow,
yellow → red}
λ = {green → "show_yellow",
yellow → "show_red",
red → "show_green"}
ta = {red → $delay_{red}$,
green → $delay_{green}$,
yellow → $delay_{yellow}$,
manual → ∞}
X = {"toAuto", "toManual"}
δ_{ext} = {((*, *), "toManual") → manual,
((manual, *), "toAuto") → red}

Operational Semantics

```
time = 0
current_state = initial_state
last_time = -initial_elapsed
while not termination_condition():
    next_time = last_time + ta(current_state)
    if time_next_ev <= next_time:
        e = time_next_ev - last_time
        time = time_next_ev
        current_state = δ_ext((current_state, e), next_ev)
    else:
        time = next_time
        output(λ(current_state))
        current_state = δ_int(current_state)
    last_time = time
```

Abstract Syntax

Y = {"show_red", "show_green", "show_yellow"}
S = {red, yellow, green, manual}
q_{init} = (green, 0)
δ_{int} = {red → green,
green → yellow,
yellow → red}
λ = {green → "show_yellow",
yellow → "show_red",
red → "show_green"}
ta = {red → $delay_{red}$,
green → $delay_{green}$,
yellow → $delay_{yellow}$,
manual → ∞}
X = {"toAuto", "toManual"}
δ_{ext} = {((*, *), "toManual") → manual,
((manual, *), "toAuto") → red}

Concrete Syntax

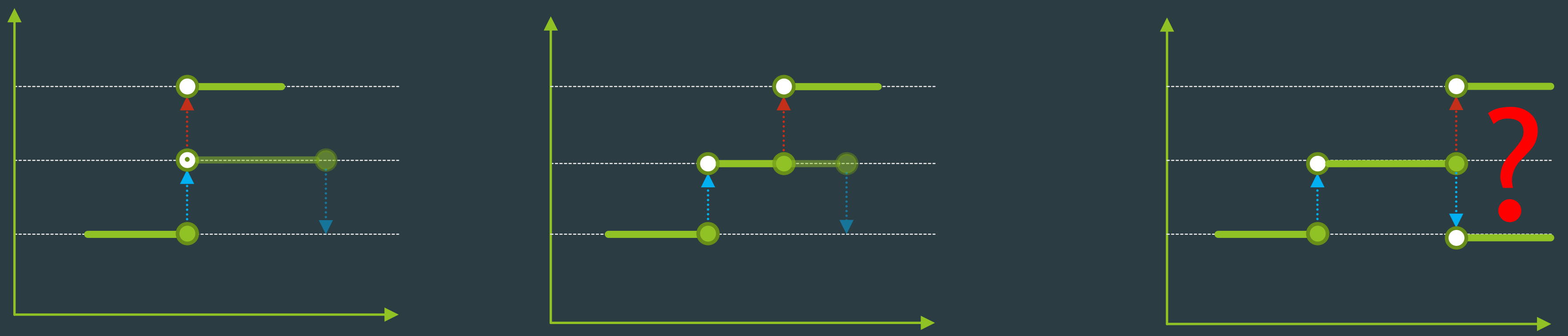
atomic_ext.py

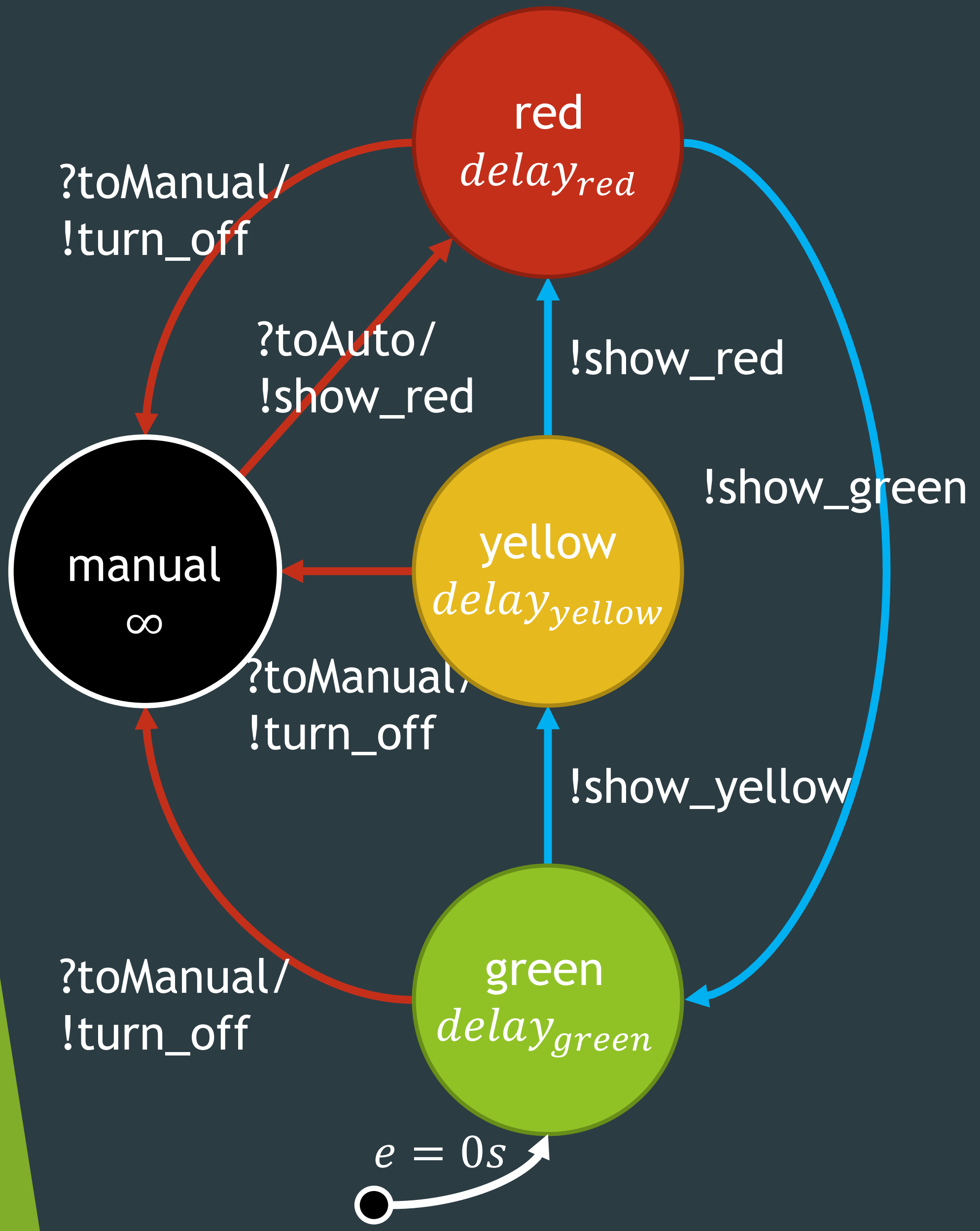
```
from pypdevs.DEVS import *

class TrafficLight(AtomicDEVS):
 def __init__(self, …):
       AtomicDEVS.__init__(self, "light")
       self.interrupt = self.addInPort("interrupt")
       …
   …

   def extTransition(self, inputs):
       inp = inputs[self.interrupt]
       if inp == "toManual":
           return "manual"
       elif inp == "toAuto":
           if self.state == "manual":
               return "red"
```

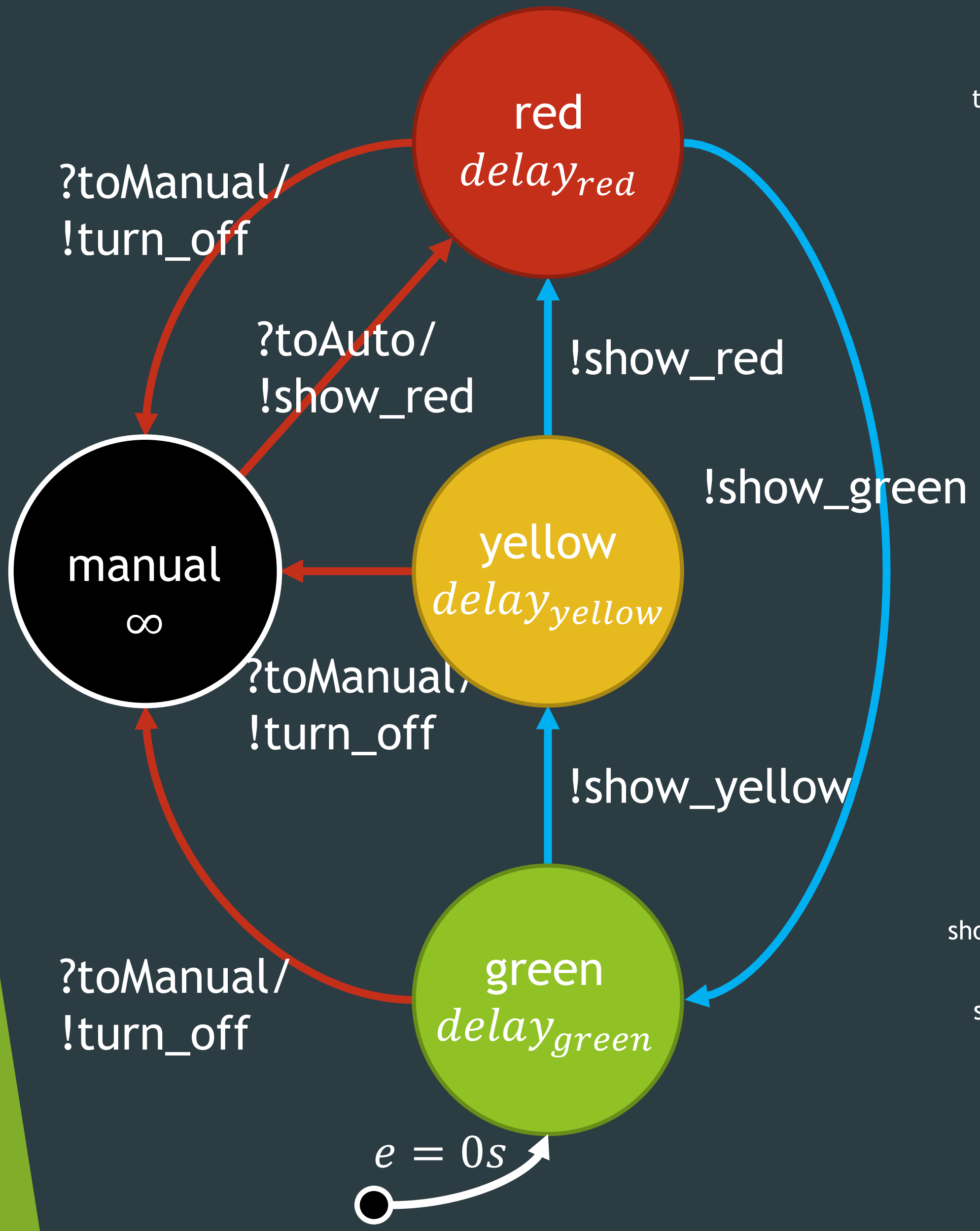
```
__  Current Time:       0.00 ____________________________________________

        INITIAL CONDITIONS in model <light>
                Initial State: green
                Next scheduled internal transition at time 57.00

__  Current Time:      57.00 ____________________________________________

        INTERNAL TRANSITION in model <light>
                New State: yellow
                Output Port Configuration:
                        port <observer>:
                                show_yellow
                Next scheduled internal transition at time 60.00

__  Current Time:      60.00 ____________________________________________

        INTERNAL TRANSITION in model <light>
                New State: red
                Output Port Configuration:
                        port <observer>:
                                show_red
                Next scheduled internal transition at time 120.00
```

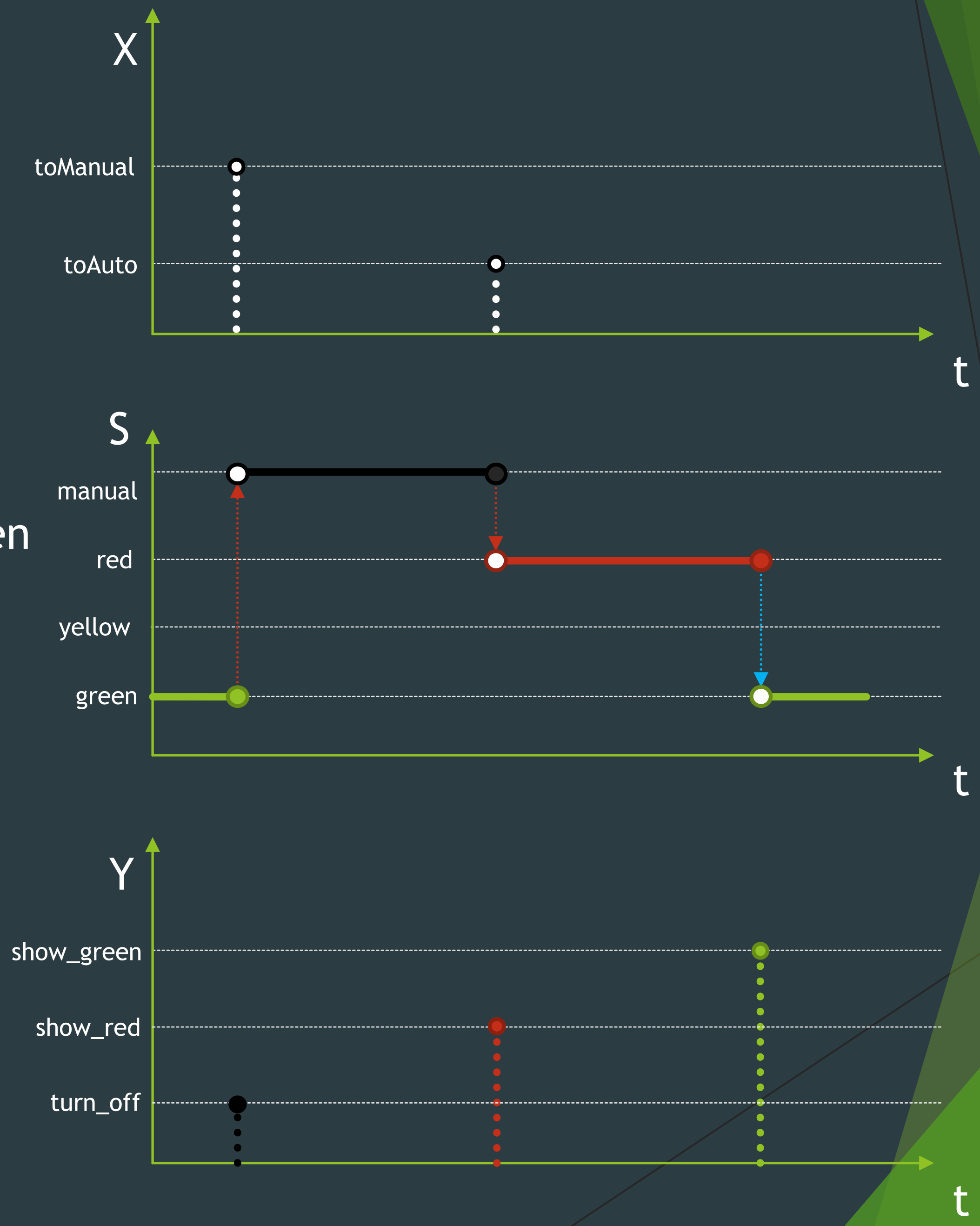
$$Q = \{(s,e) | s \in S, 0 \leq e \leq ta(s)\}$$

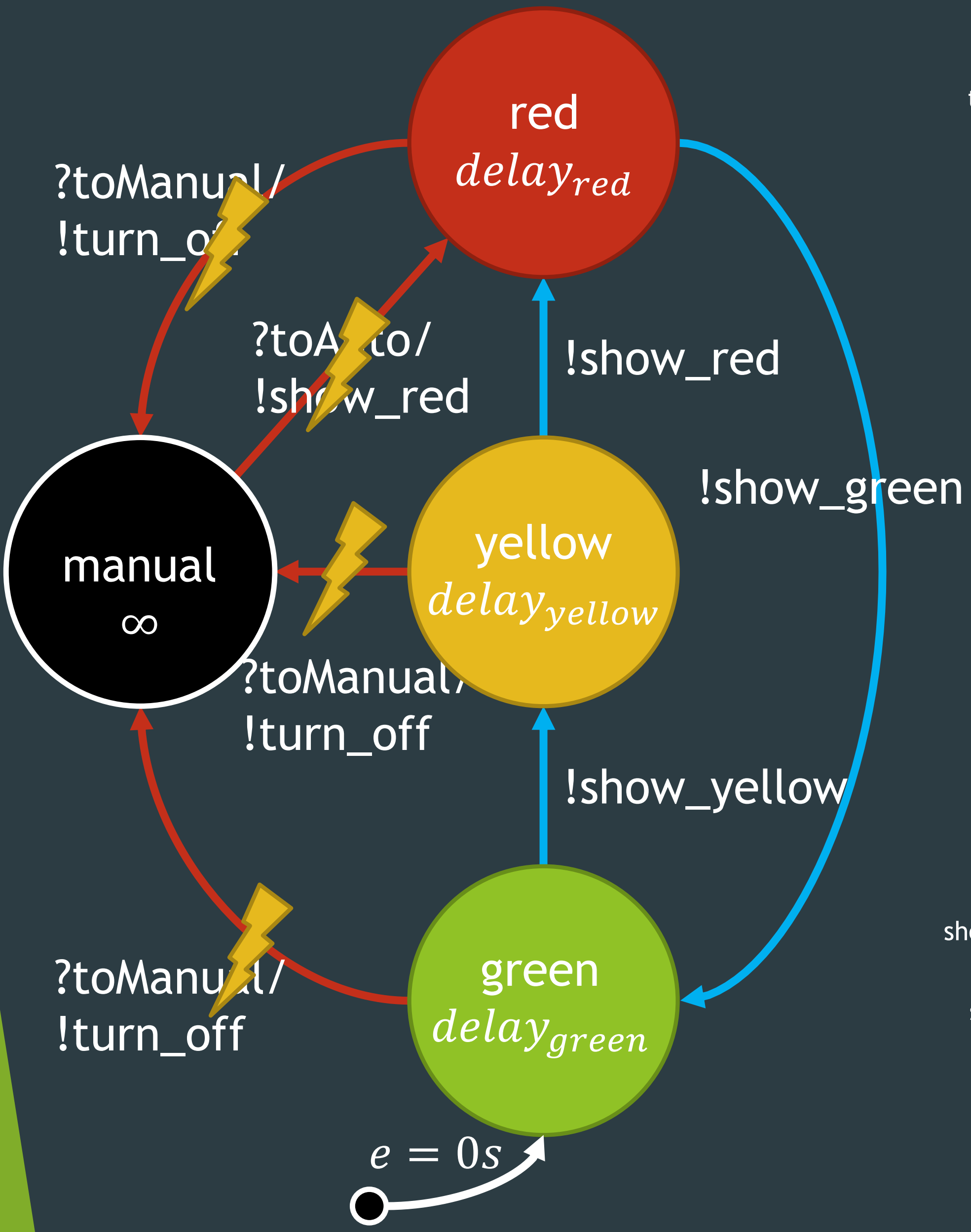
$e = 0$ | $0 < e < ta(s)$ | $e = ta(s)$

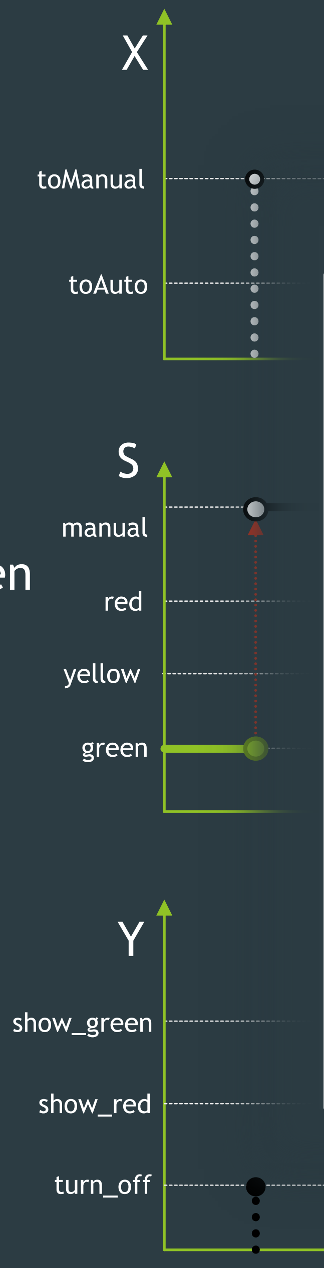



red
$delay_{red}$
?toManual/
!turn_off
?toAuto/
!show_red
!show_red
!show_green
manual
∞
yellow
$delay_{yellow}$
?toManual/
!turn_off
!show_yellow
?toManual/
!turn_off
green
$delay_{green}$
$e = 0s$

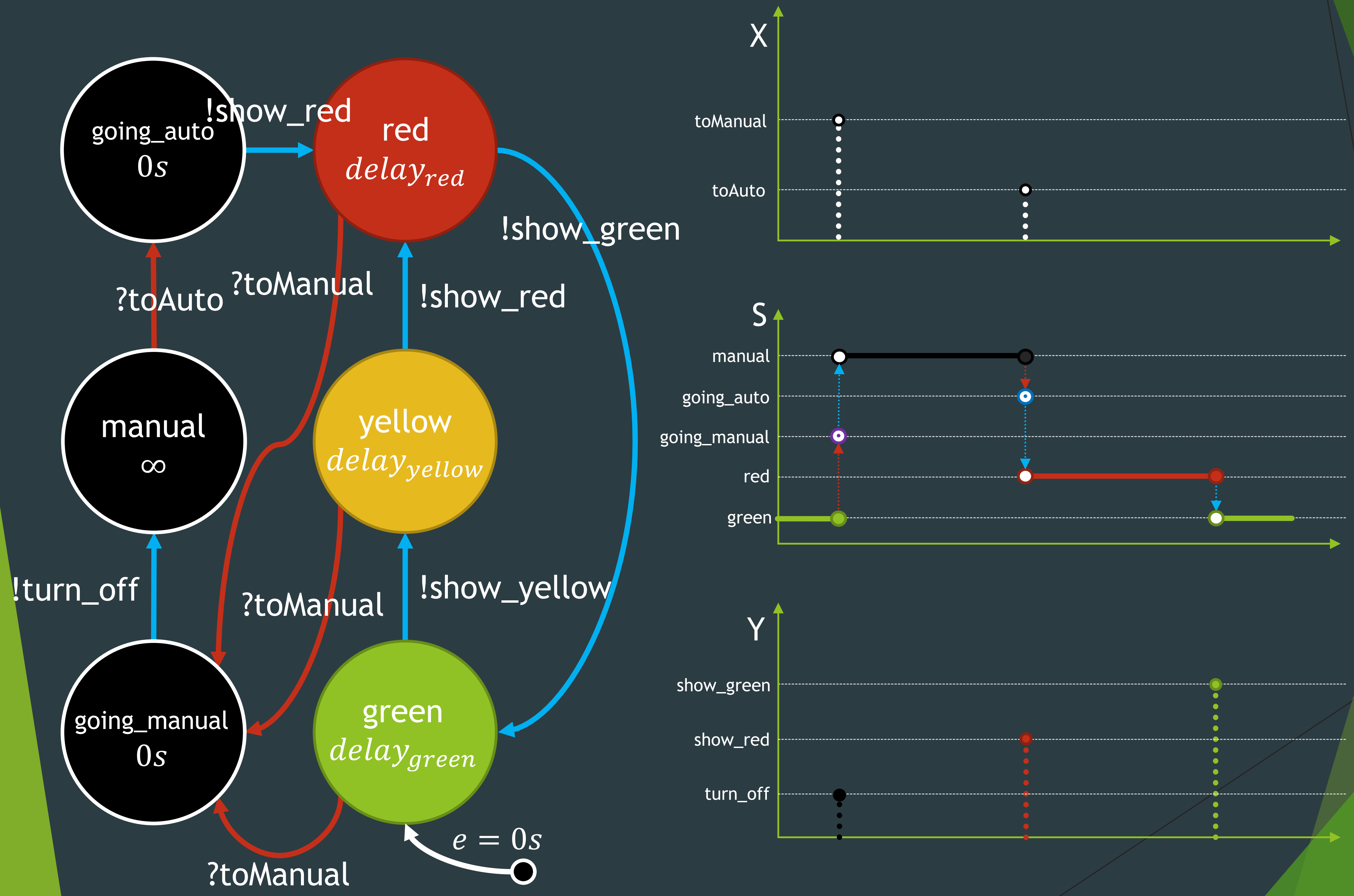

red
$delay_{red}$
?toManual/
!turn_off
?toAuto/
!show_red
!show_red
!show_green
manual
∞
yellow
$delay_{yellow}$
?toManual/
!turn_off
!show_yellow
?toManual/
!turn_off
green
$delay_{green}$
$e = 0s$


X
toManual
toAuto
t
S
manual
red
yellow
green
t
Y
show_green
show_red
turn_off
t






```
time = 0
current_state = initial_state
last_time = -initial_elapsed
while not termination_condition():
    next_time = last_time + ta(current_state)
    if time_next_ev <= next_time:
        e = time_next_ev - last_time
        time = time_next_ev
        current_state = δ_ext((current_state, e), next_ev)
    else:
        time = next_time
        output(λ(current_state))
        current_state = δ_int(current_state)
    last_time = time
```



going_auto
0s
!show_red
red
delay_red
!show_green
?toAuto
?toManual
!show_red
manual
∞
yellow
delay_yellow
!turn_off
?toManual
!show_yellow
going_manual
0s
green
delay_green
?toManual
e = 0s
X
toManual
toAuto
t
S
manual
going_auto
going_manual
red
green
t
Y
show_green
show_red
turn_off
t

Full Atomic DEVS Specification

$$M = \langle X, Y, S, q_{init}, \delta_{int}, \delta_{ext}, \lambda, ta \rangle$$

X : *set of input events*

Y : *set of output events*

S : *set of sequential states*

$q_{init} : Q$

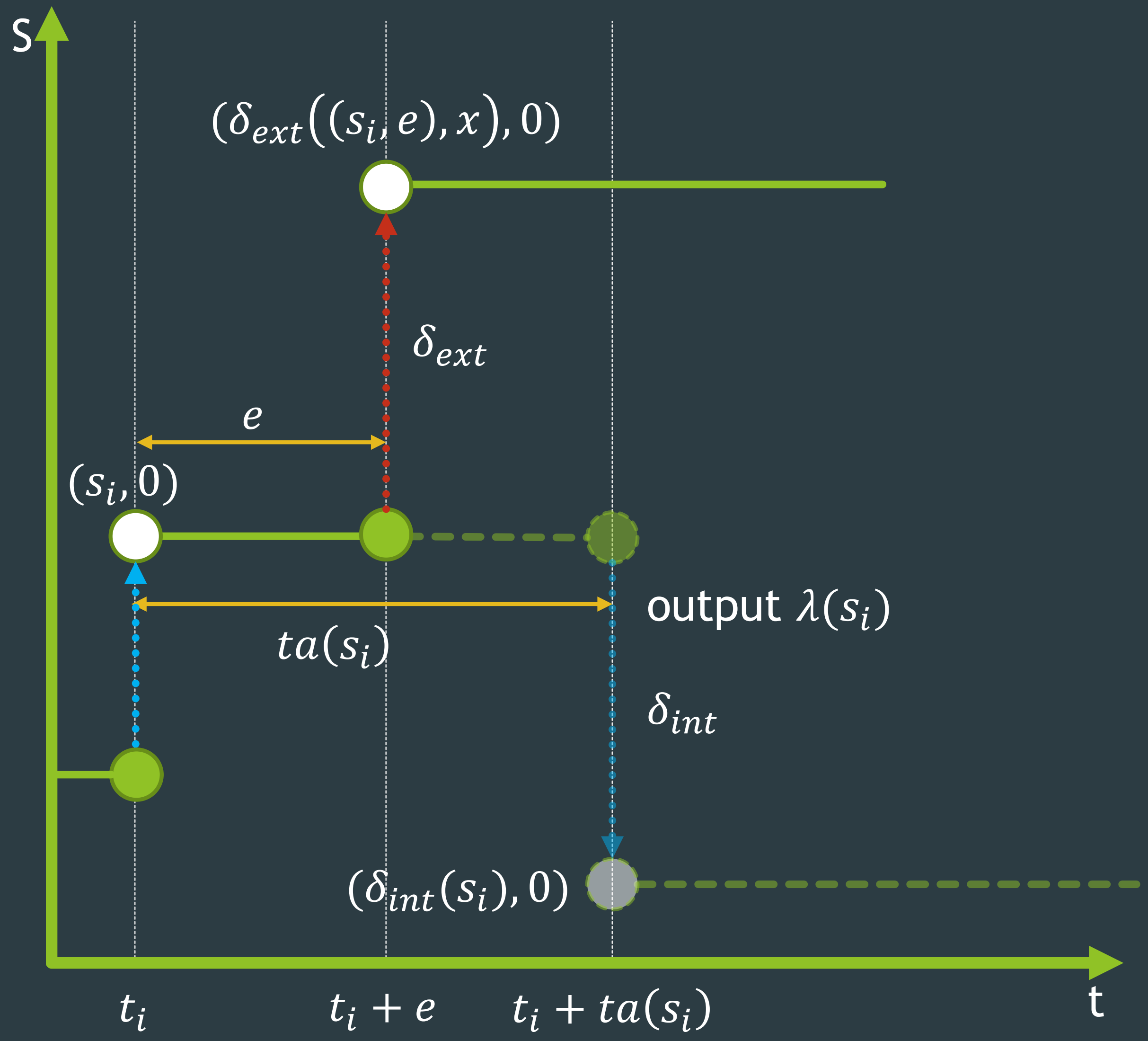
$$Q = \{(s,e) | s \in S, 0 \leq e \leq ta(s)\}$$

$\delta_{int} : S \rightarrow S$

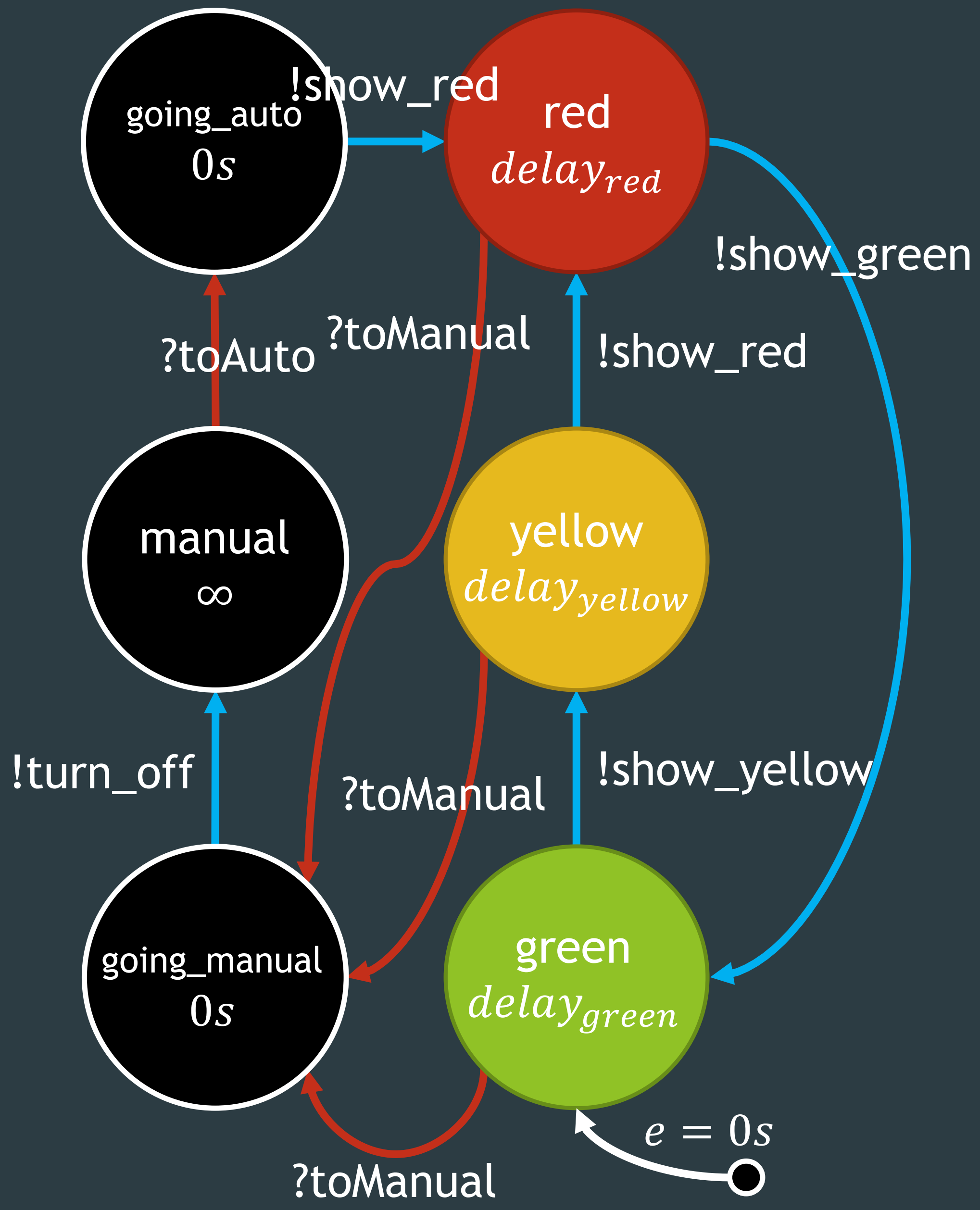
$\delta_{ext} : Q \times X \rightarrow S$

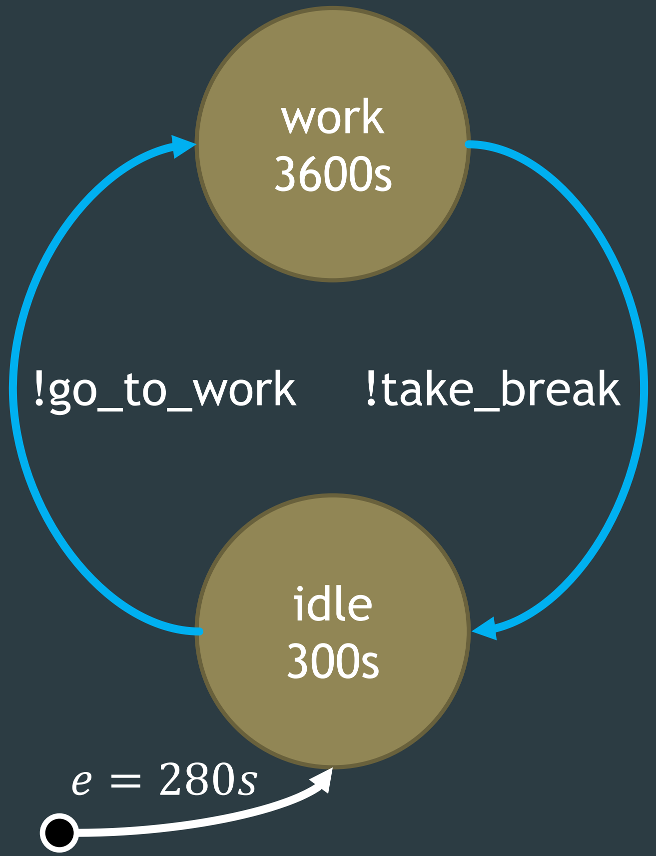
$\lambda : S \rightarrow Y \cup \{\phi\}$

$ta : S \rightarrow \mathbb{R}^{+}_{0,+\infty}$


S
$(\delta_{ext}((s_i, e), x), 0)$
δ_{ext}
e
$(s_i, 0)$
output $\lambda(s_i)$
$ta(s_i)$
δ_{int}
$(\delta_{int}(s_i), 0)$
t_i
$t_i + e$
$t_i + ta(s_i)$
t

Coupled Models


going_auto
$0s$
!show_red
red
$delay_{red}$
!show_green
?toAuto
?toManual
!show_red
manual
∞
yellow
$delay_{yellow}$
!turn_off
?toManual
!show_yellow
going_manual
$0s$
green
$delay_{green}$
$e = 0s$
?toManual

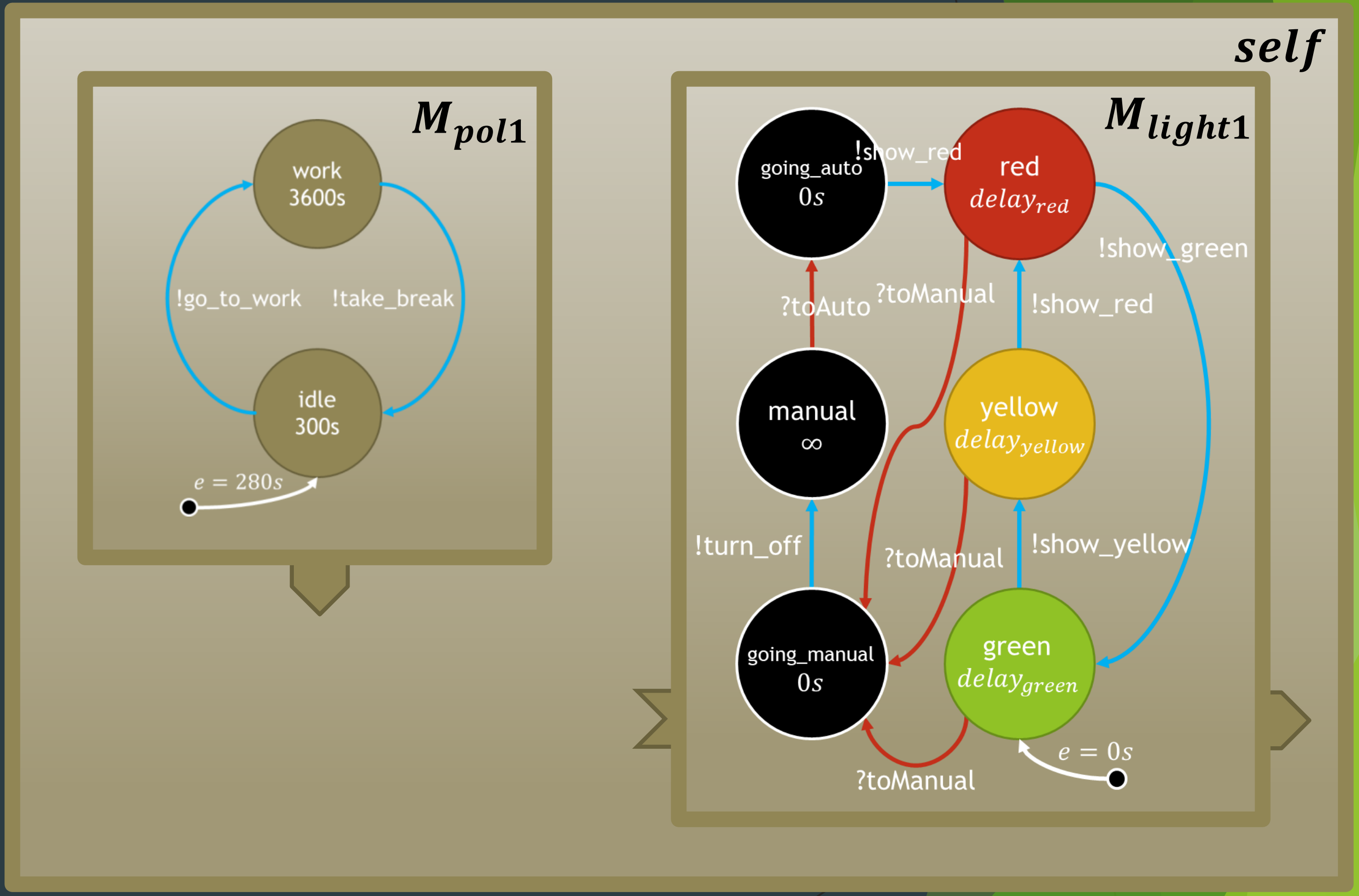

work
3600s
!go_to_work
!take_break
idle
300s
e = 280s


TRAFFIC

$$C = \langle D, MS \rangle$$

$$MS = \{M_i | i \in D\}$$

$$M_i = \langle X_i, Y_i, S_i, q_{init,i}, \delta_{int,i}, \delta_{ext,i}, \lambda_i, ta_i \rangle, \forall\, i \in D$$

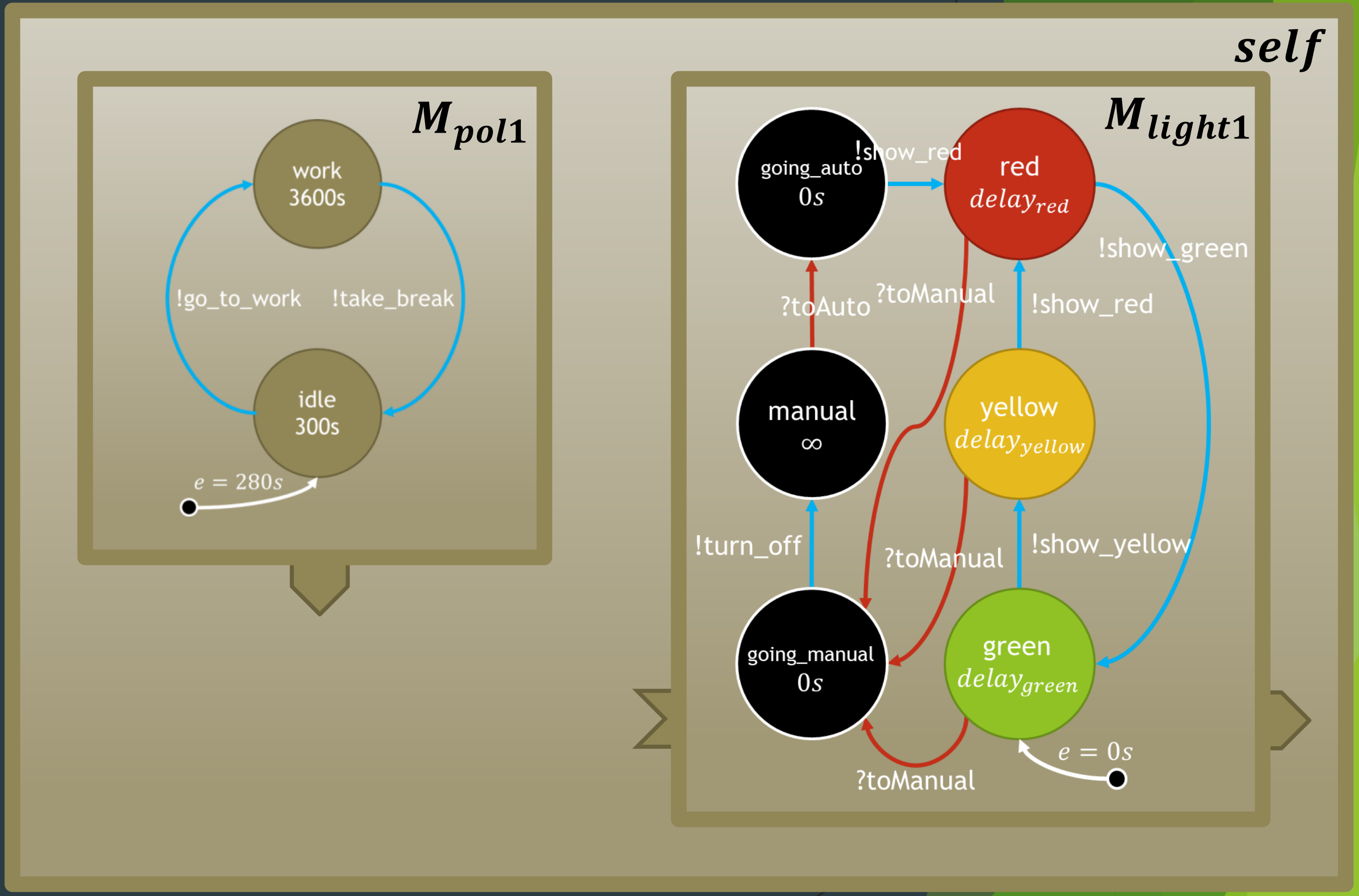


$D = \{light_1, pol_1\}$

$$C = \langle D, MS \rangle$$

$$MS = \{M_i | i \in D\}$$

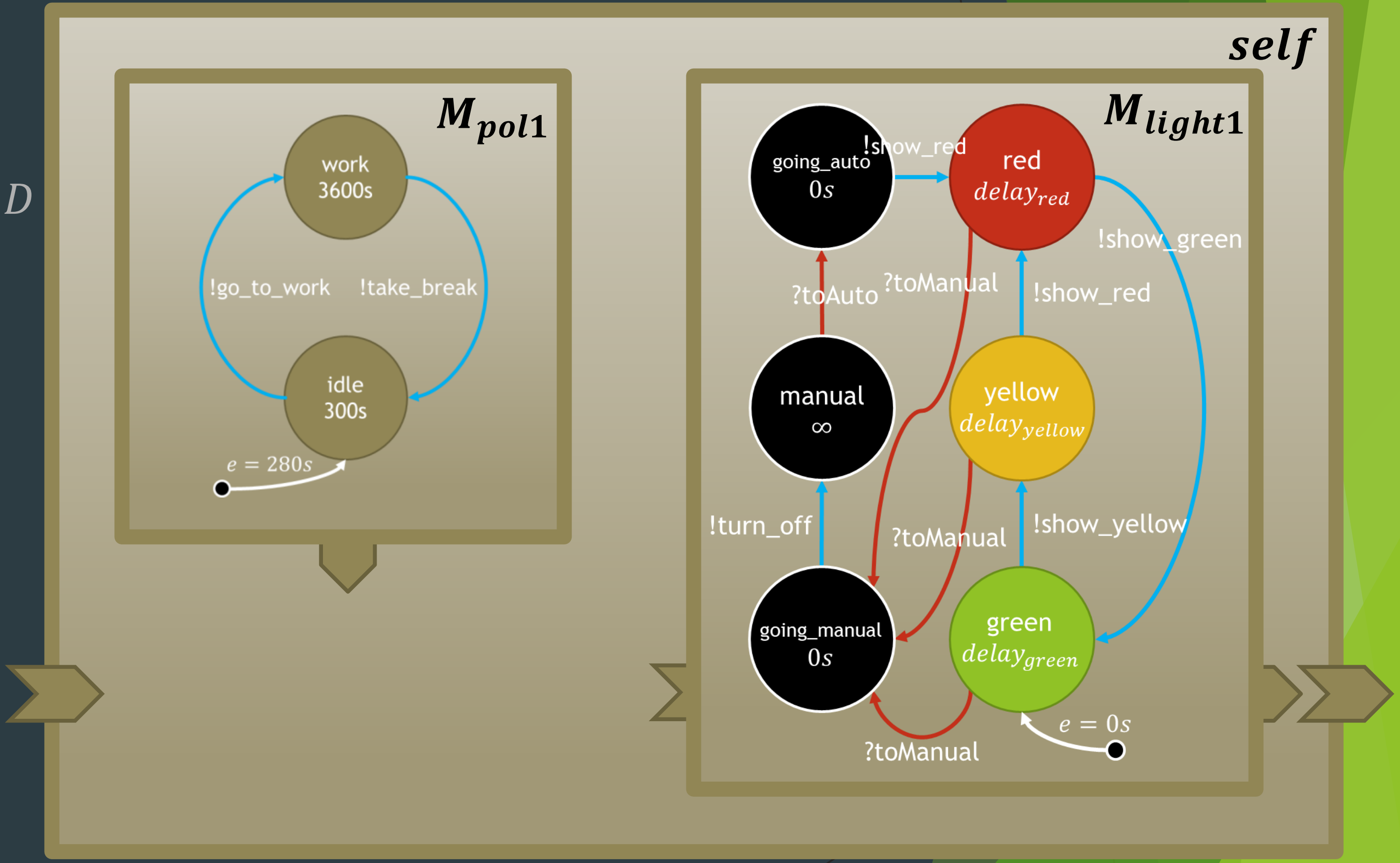
$$M_i = \langle X_i, Y_i, S_i, q_{init,i}, \delta_{int,i}, \delta_{ext,i}, \lambda_i, ta_i \rangle, \forall\, i \in D$$



$$C = \langle X_{self}, Y_{self}, D, MS \rangle$$

$$MS = \{M_i | i \in D\}$$

$$M_i = \langle X_i, Y_i, S_i, q_{init,i}, \delta_{int,i}, \delta_{ext,i}, \lambda_i, ta_i \rangle, \forall\, i \in D$$



$$C = \langle X_{self}, Y_{self}, D, MS, IS \rangle$$

$$MS = \{M_i | i \in D\}$$

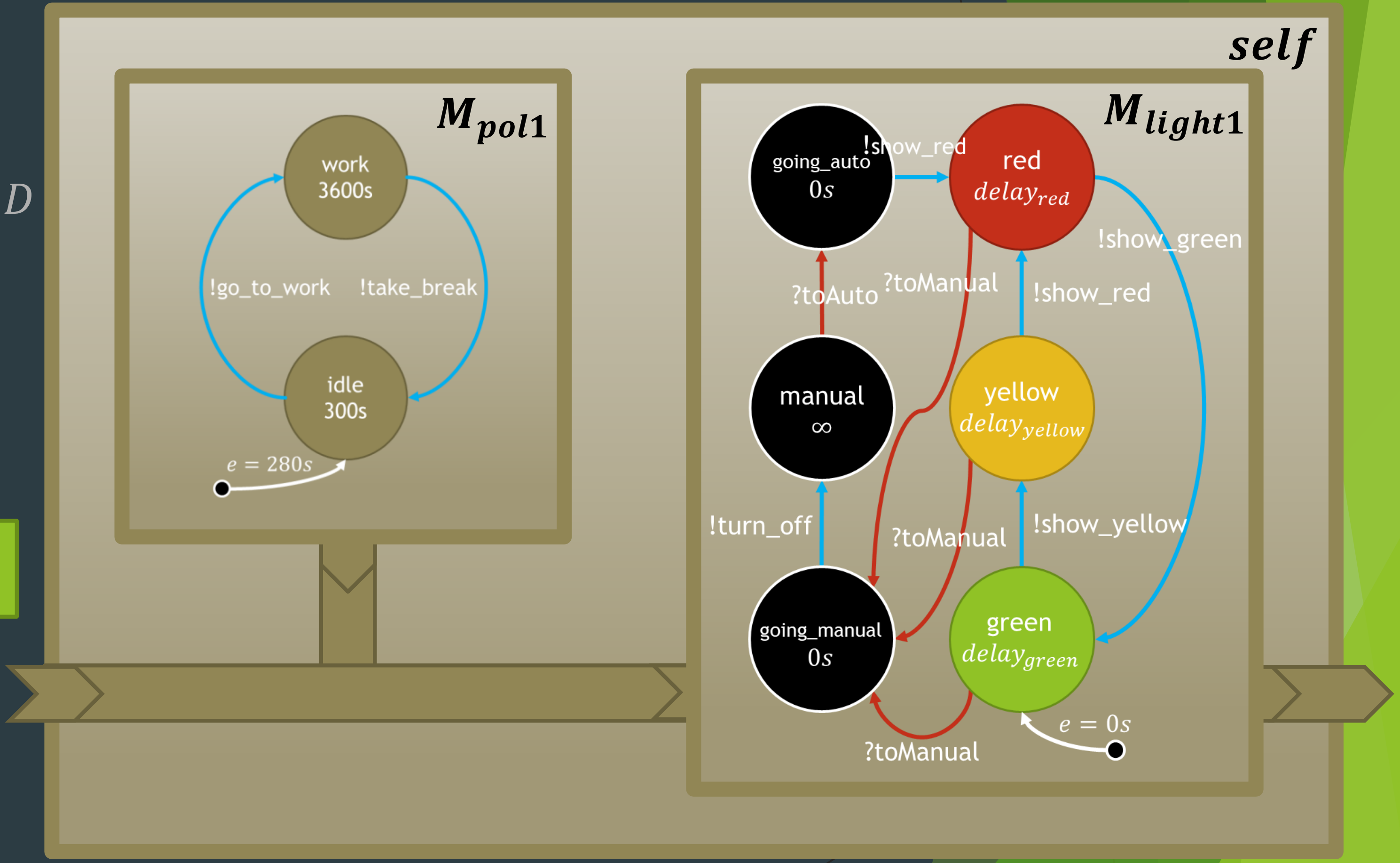
$$M_i = \langle X_i, Y_i, S_i, q_{init,i}, \delta_{int,i}, \delta_{ext,i}, \lambda_i, ta_i \rangle, \forall\, i \in D$$

$$IS = \{I_i | i \in D \cup \{self\}\}$$

$$\forall\, i \in D \cup \{self\} : I_i \subseteq D \cup \{self\}$$

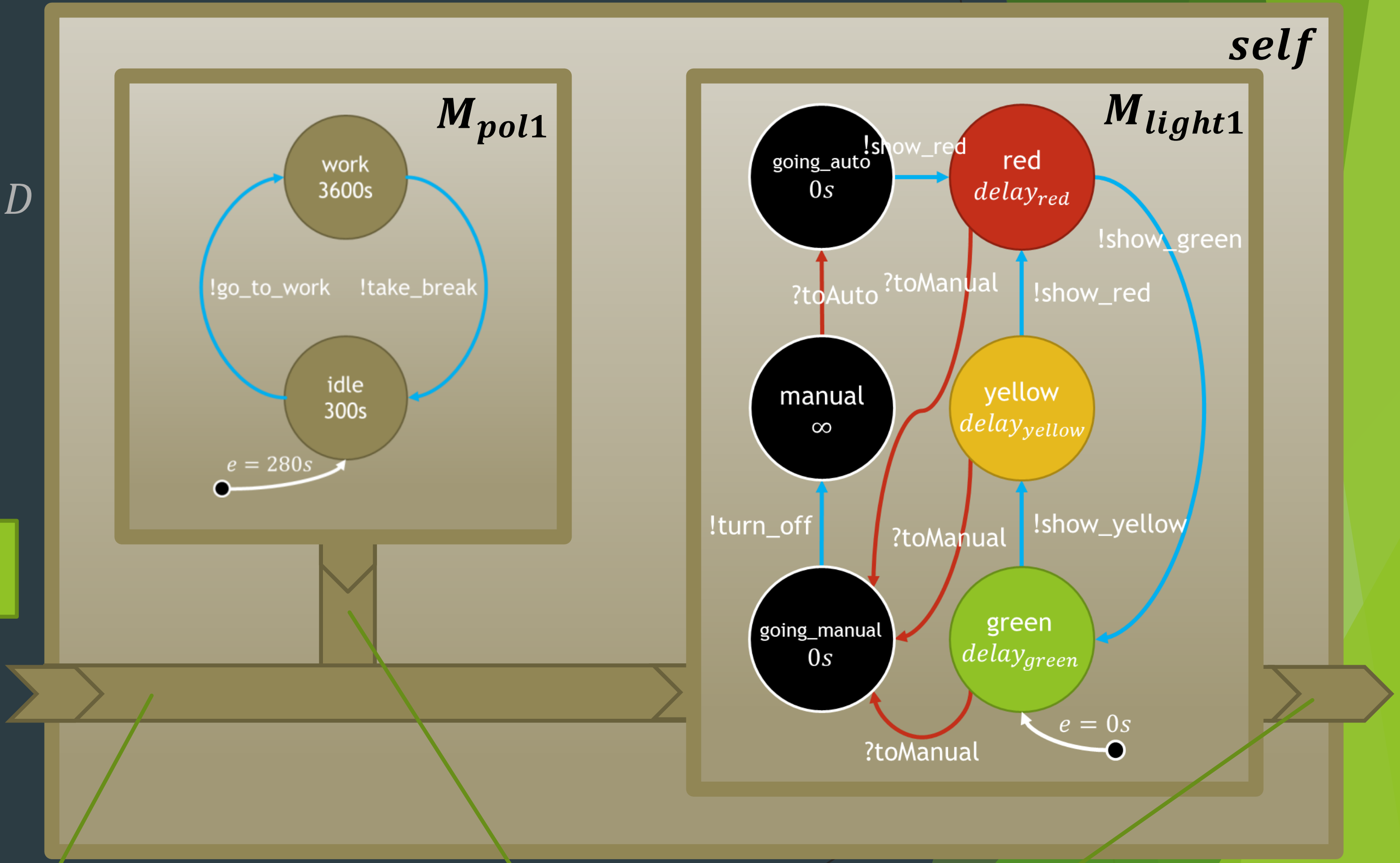
$$\forall\, i \in D \cup \{self\} : i \notin I_i$$

I_i :Influencees of i



$$C = \langle X_{self}, Y_{self}, D, MS, IS \rangle$$
$$MS = \{M_i | i \in D\}$$
$$M_i = \langle X_i, Y_i, S_i, q_{init,i}, \delta_{int,i}, \delta_{ext,i}, \lambda_i, ta_i \rangle, \forall\ i \in D$$
$$IS = \{I_i | i \in D \cup \{self\}\}$$
$$\forall\ i \in D \cup \{self\} : I_i \subseteq D \cup \{self\}$$
$$\forall\ i \in D \cup \{self\} : i \notin I_i$$

I_i :Influencees of i



$I_{self} = \{light1\}$

$I_{pol1} = \{light1\}$

$I_{light1} = \{self\}$

$$C = \langle X_{self}, Y_{self}, D, MS, IS, ZS \rangle$$

$$MS = \{M_i | i \in D\}$$

$$M_i = \langle X_i, Y_i, S_i, q_{init,i}, \delta_{int,i}, \delta_{ext,i}, \lambda_i, ta_i \rangle, \forall\ i \in D$$

$$IS = \{I_i | i \in D \cup \{self\}\}$$

$$\forall\ i \in D \cup \{self\} : I_i \subseteq D \cup \{self\}$$

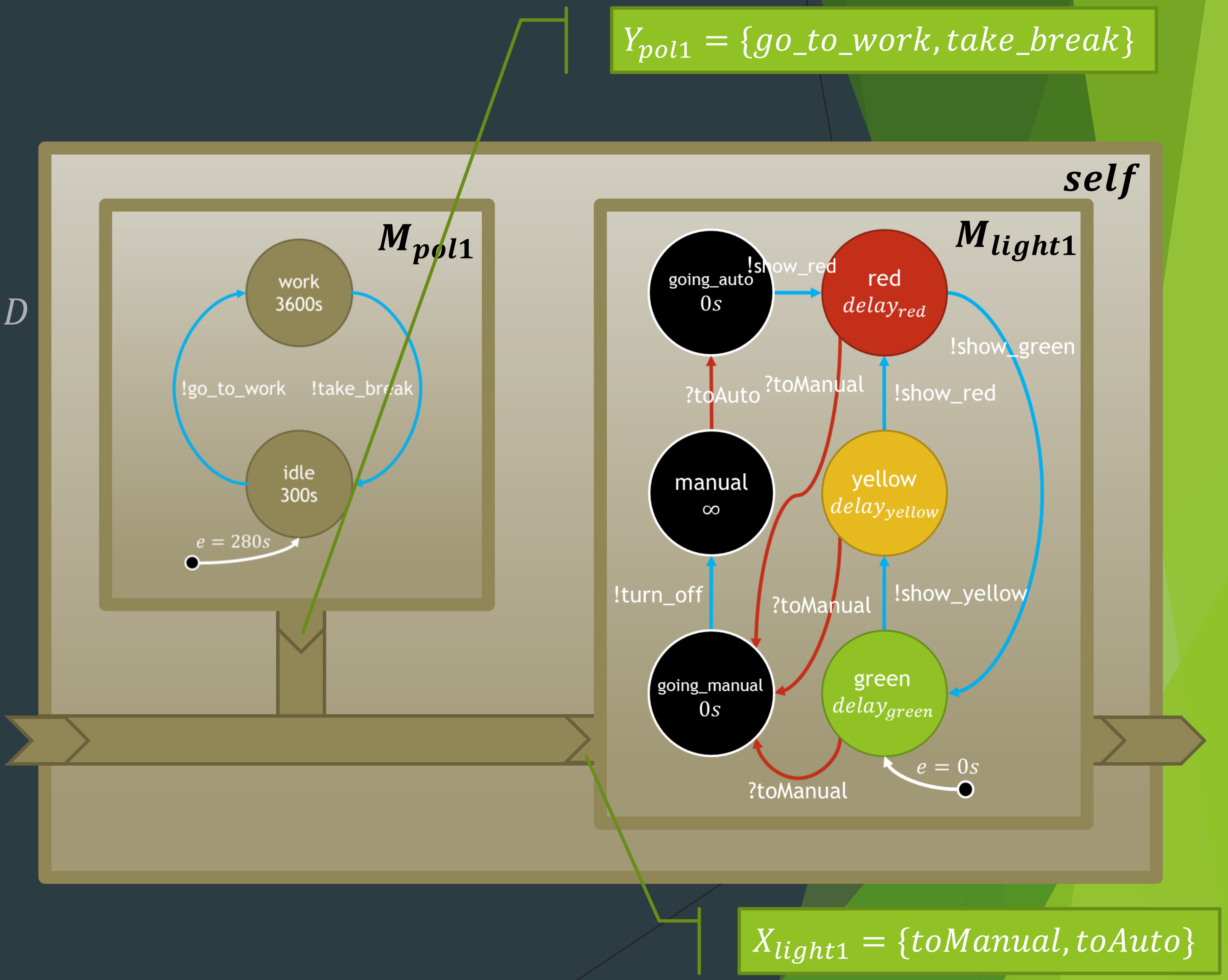
$$\forall\ i \in D \cup \{self\} : i \notin I_i$$

$$ZS = \{Z_{i,j} | i \in D \cup \{self\}, j \in I_i\}$$

$$Z_{self,j} : X_{self} \rightarrow X_j, \forall\ j \in D$$

$$Z_{i,self} : Y_i \rightarrow Y_{self}, \forall\ i \in D$$

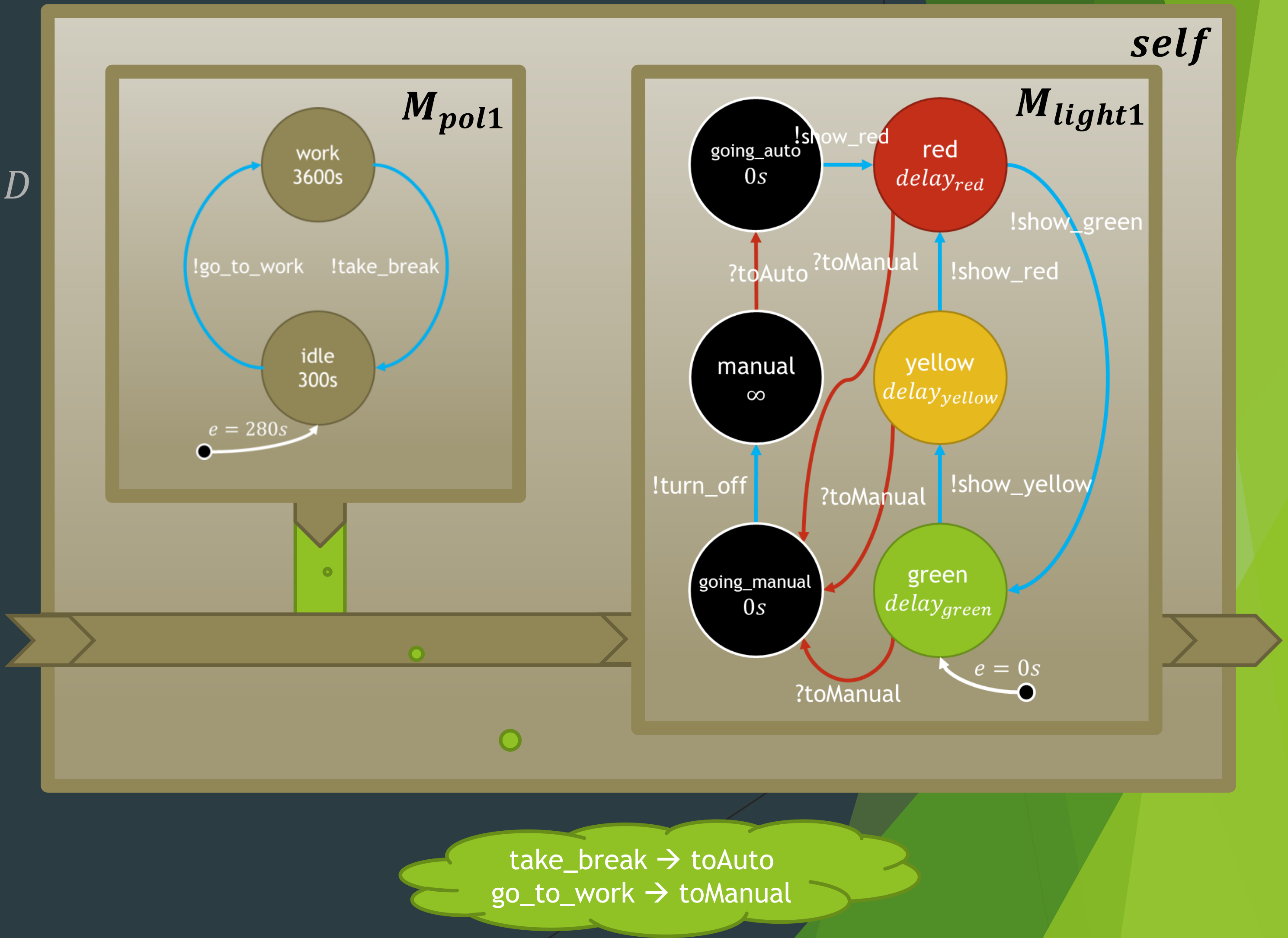
$$Z_{i,j} : Y_i \rightarrow X_j, \forall\ i, j \in D$$



$$C = \langle X_{self}, Y_{self}, D, MS, IS, ZS \rangle$$
$$MS = \{M_i | i \in D\}$$
$$M_i = \langle X_i, Y_i, S_i, q_{init,i}, \delta_{int,i}, \delta_{ext,i}, \lambda_i, ta_i \rangle, \forall\, i \in D$$

$$IS = \{I_i | i \in D \cup \{self\}\}$$
$$\forall\, i \in D \cup \{self\} : I_i \subseteq D \cup \{self\}$$
$$\forall\, i \in D \cup \{self\} : i \notin I_i$$

$$ZS = \{Z_{i,j} | i \in D \cup \{self\}, j \in I_i\}$$
$$Z_{self,j} : X_{self} \rightarrow X_j, \forall\, j \in D$$
$$Z_{i,self} : Y_i \rightarrow Y_{self}, \forall\, i \in D$$
$$Z_{i,j} : Y_i \rightarrow X_j, \forall\, i, j \in D$$



$$C = \langle X_{self}, Y_{self}, D, MS, IS, ZS, select \rangle$$

$$MS = \{M_i | i \in D\}$$

$$M_i = \langle X_i, Y_i, S_i, q_{init,i}, \delta_{int,i}, \delta_{ext,i}, \lambda_i, ta_i \rangle, \forall\, i \in D$$

$$IS = \{I_i | i \in D \cup \{self\}\}$$

$$\forall\, i \in D \cup \{self\} : I_i \subseteq D \cup \{self\}$$

$$\forall\, i \in D \cup \{self\} : i \notin I_i$$

$$ZS = \{Z_{i,j} | i \in D \cup \{self\}, j \in I_i\}$$

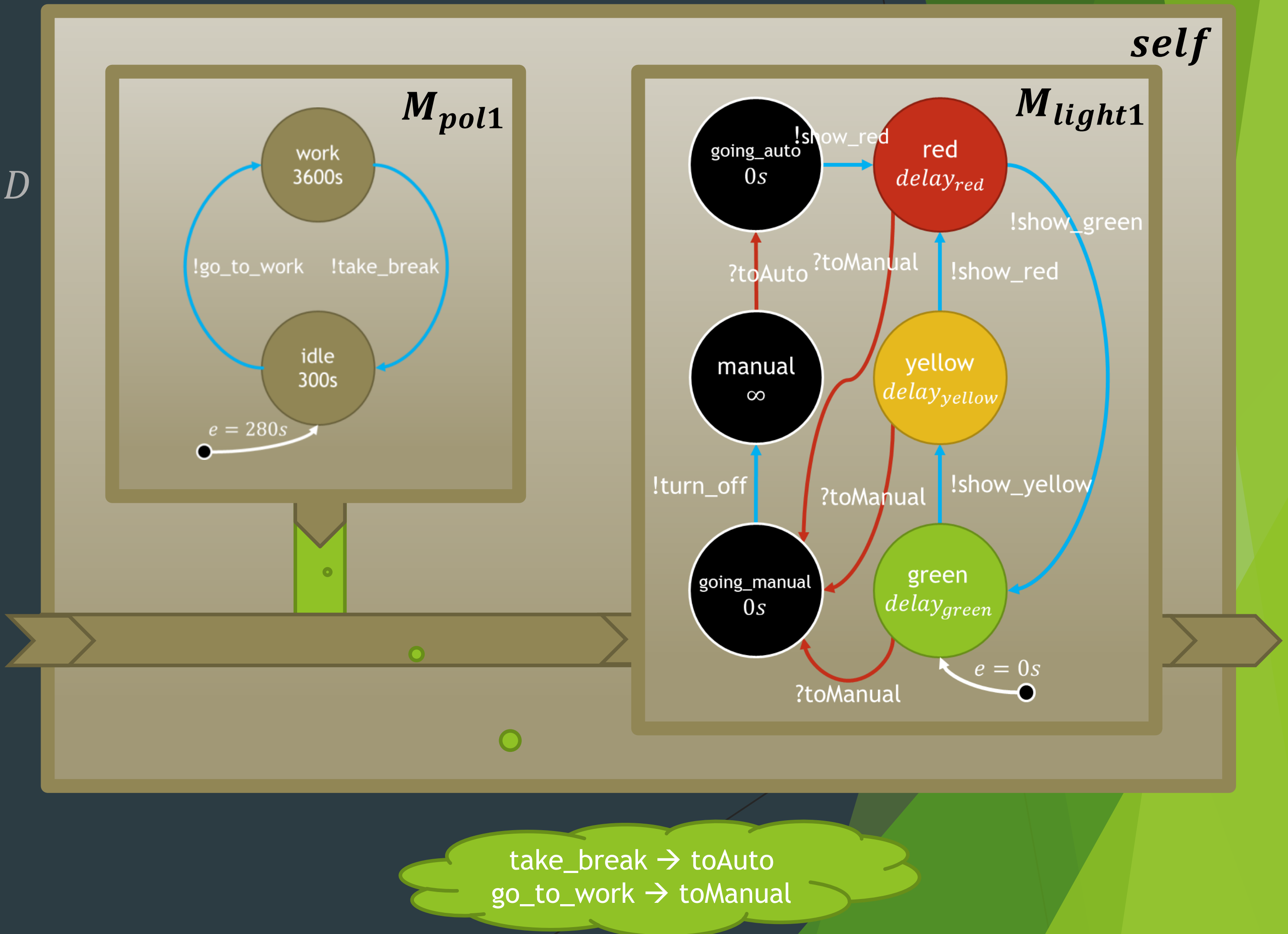
$$Z_{self,j} : X_{self} \rightarrow X_j, \forall\, j \in D$$

$$Z_{i,self} : Y_i \rightarrow Y_{self}, \forall\, i \in D$$

$$Z_{i,j} : Y_i \rightarrow X_j, \forall\, i,j \in D$$

$$select : 2^D \rightarrow D$$

$$\forall\, E \subseteq D, E \neq \emptyset : select(E) \in E$$



Concrete Syntax

trafficlight_system.py

```
from pypdevs.DEVS import *

from trafficlight import TrafficLight
from policeman import Policeman

def translate(in_evt):
    mapping = {“take_break”: “toAuto”,
                    “go_to_work”: “toManual”}
    return mapping[in_evt]

class TrafficLightSystem(CoupledDEVS):
    def __init__(self):
        CoupledDEVS.__init__(self, “system”)
        self.light = self.addSubModel(TrafficLight())
        self.police = self.addSubModel(Policeman())
        self.connectPorts(self.police.out, self.light.interrupt, translate)

    def select(self, immlist):
        if self.police in immlist:
            return self.police
        else:
            return self.light
```

__ Current Time: 0.00 ______________________________________

INITIAL CONDITIONS in model <system.light>

Initial State: green

Next scheduled internal transition at time 57.00

INITIAL CONDITIONS in model <system.policeman>

Initial State: idle

Next scheduled internal transition at time 20.00

```
__  Current Time:      20.00 ________________________________________

    EXTERNAL TRANSITION in model <system.light>
        Input Port Configuration:
            port <interrupt>:
                toManual
        New State: going_manual
        Next scheduled internal transition at time 20.0

    INTERNAL TRANSITION in model <system.policeman>
        New State: working
        Output Port Configuration:
            port <output>:
                go_to_work
        Next scheduled internal transition at time 3620.00
```

__ Current Time: 20.00 ____

INTERNAL TRANSITION in model <system.light>
Output Port Configuration:
port <observer>:
turn_off
New State: manual
Next scheduled internal transition at time inf

__ Current Time: 3620.00 ____

EXTERNAL TRANSITION in model <system.light>
Input Port Configuration:
port <interrupt>:
toAuto
New State: going_auto
Next scheduled internal transition at time 3620.00

INTERNAL TRANSITION in model <system.policeman>
New State: idle
Output Port Configuration:
port <output>:
take_break
Next scheduled internal transition at time 3920.00

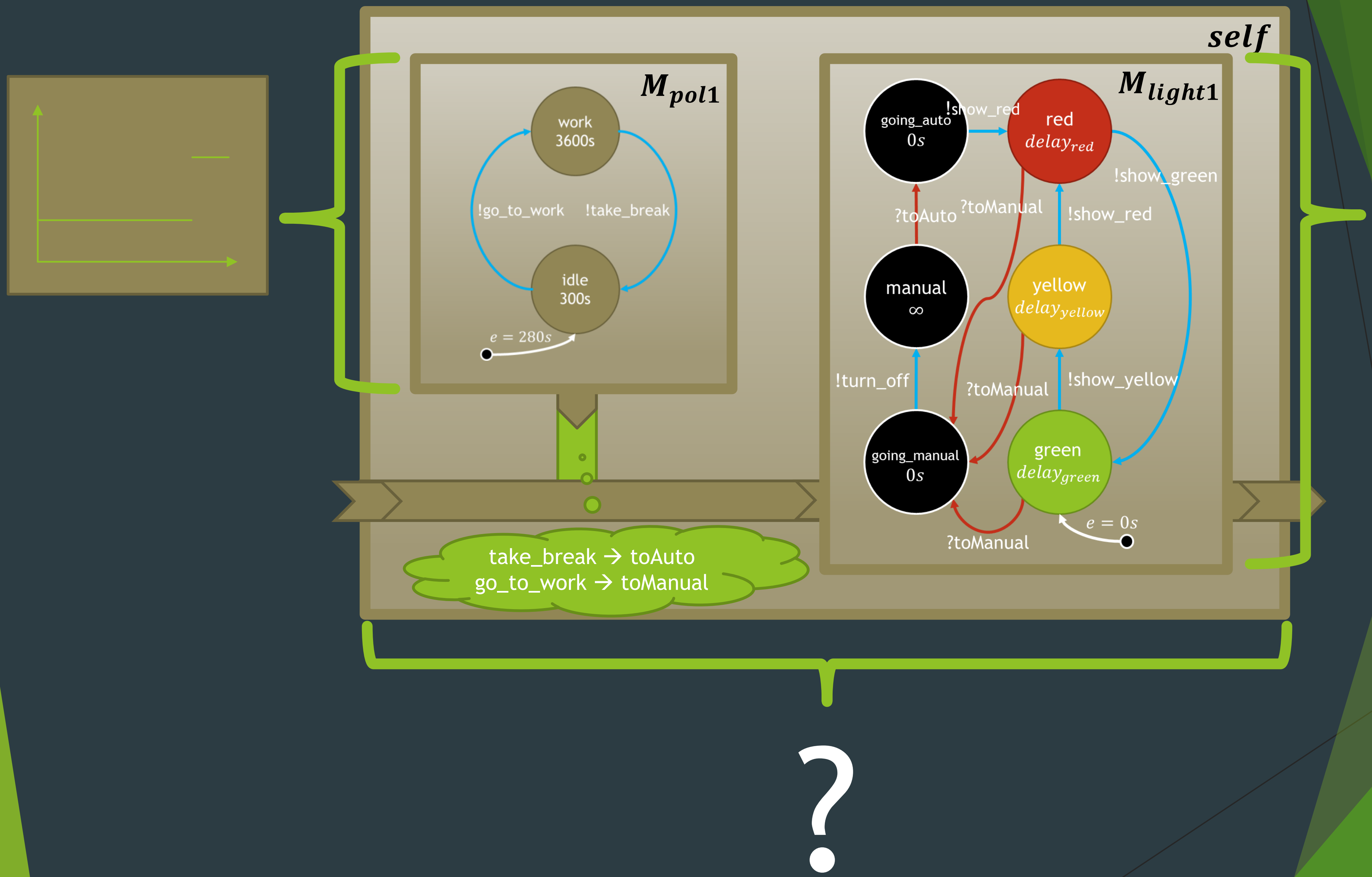
__ Current Time: 3620.00 ____

INTERNAL TRANSITION in model <system.light>
Output Port Configuration:
port <observer>:
show_red
New State: red
Next scheduled internal transition at time 3680.00

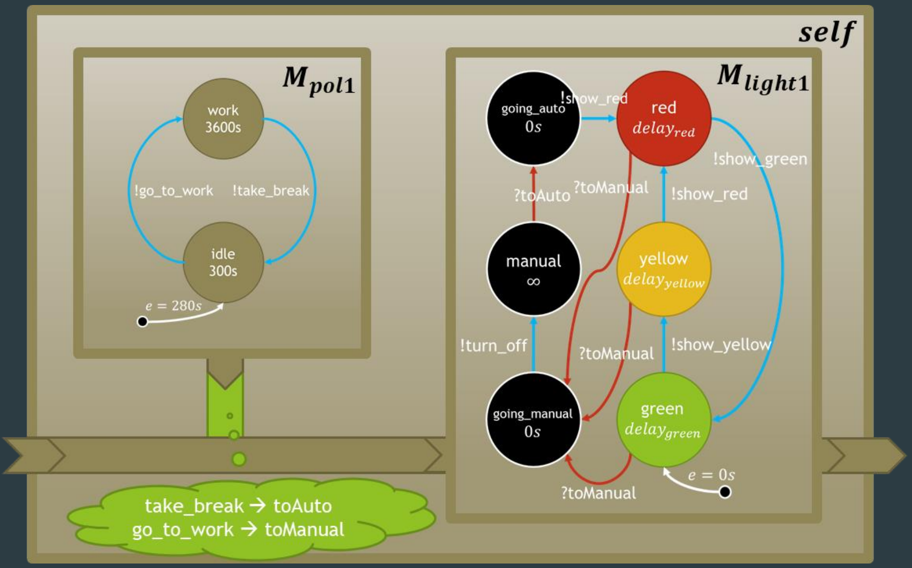
```
__  Current Time:     3620.00 ____________________________________________

    EXTERNAL TRANSITION in model <system.light>
        Input Port Configuration:
            port <interrupt>:
                toAuto
        New State: going_auto
        Next scheduled internal transition at time 3620.00

    INTERNAL TRANSITION in model <system.policeman>
        New State: idle
        Output Port Configuration:
            port <output>:
                take_break
        Next scheduled internal transition at time 3920.00
```

```
__  Current Time:     3920.00 ____________________________________________

        CONFLICT between models:
                <system.light>
              * <system.policeman>

        EXTERNAL TRANSITION in model <system.light>
                Input Port Configuration:
                        port <interrupt>:
                                toManual
                New State: going_manual
                Next scheduled internal transition at time 3920.00

        INTERNAL TRANSITION in model <system.policeman>
                New State: work
                Output Port Configuration:
                        port <output>:
                                go_to_work
                Next scheduled internal transition at time 7520.00
```

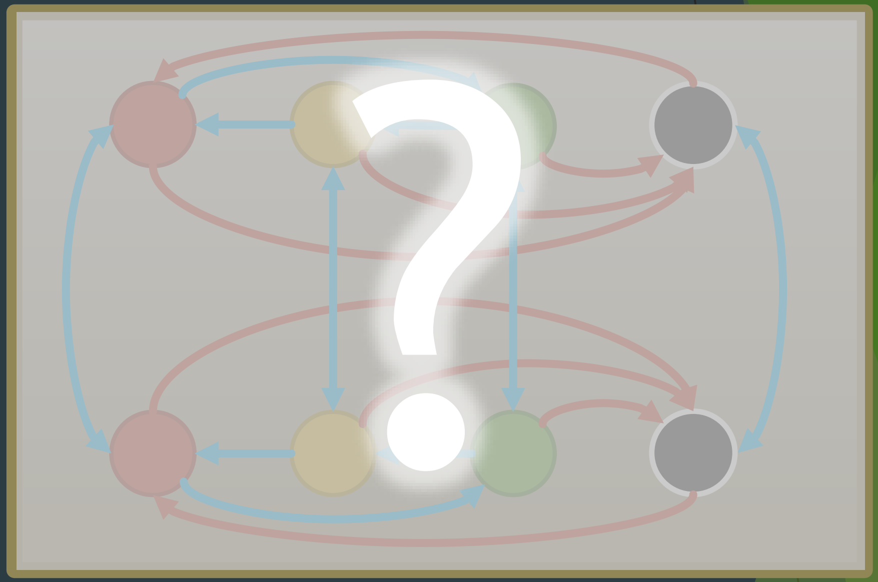
Closure under Coupling



self
M_{pol1}
work
3600s
!go_to_work
!take_break
idle
300s
$e = 280s$
take_break → toAuto
go_to_work → toManual
M_{light1}
going_auto
$0s$
!show_red
red
$delay_{red}$
!show_green
?toAuto
?toManual
!show_red
manual
∞
yellow
$delay_{yellow}$
!turn_off
?toManual
!show_yellow
going_manual
$0s$
green
$delay_{green}$
$e = 0s$
?toManual
?

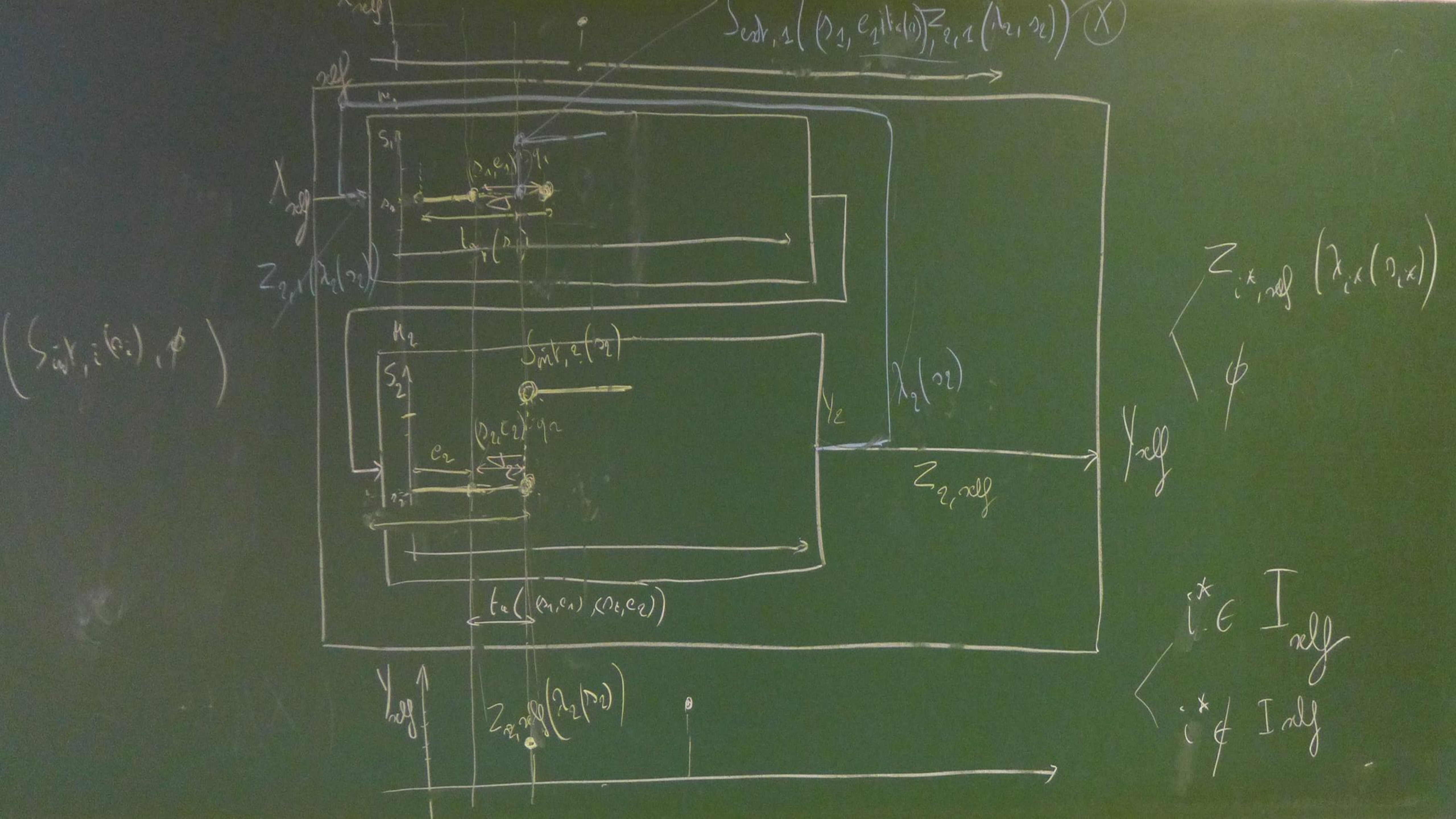


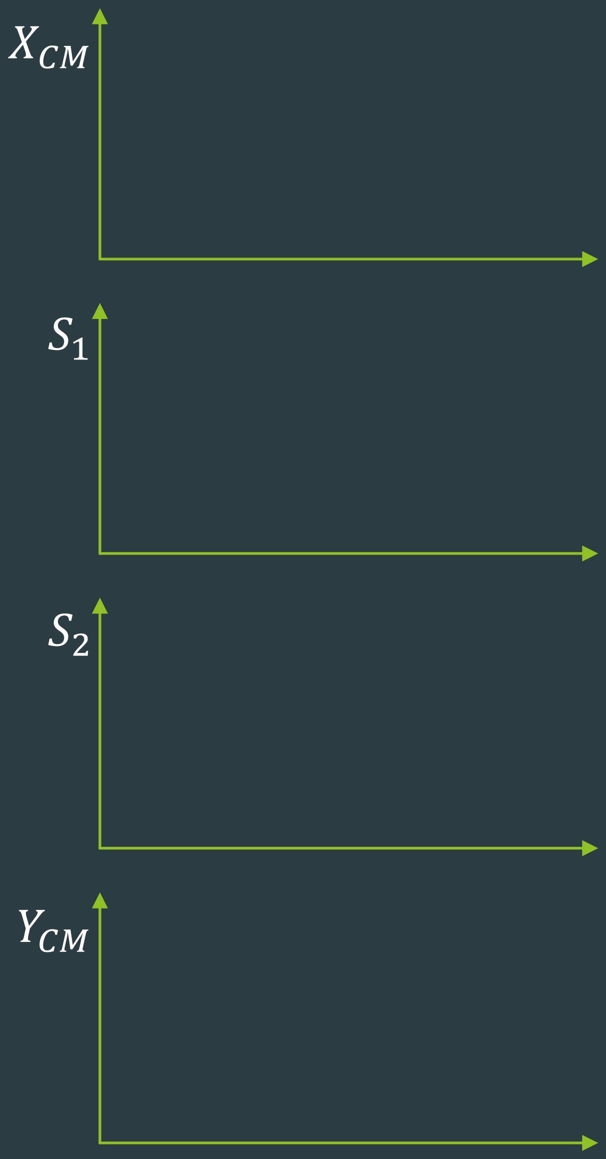
flatten

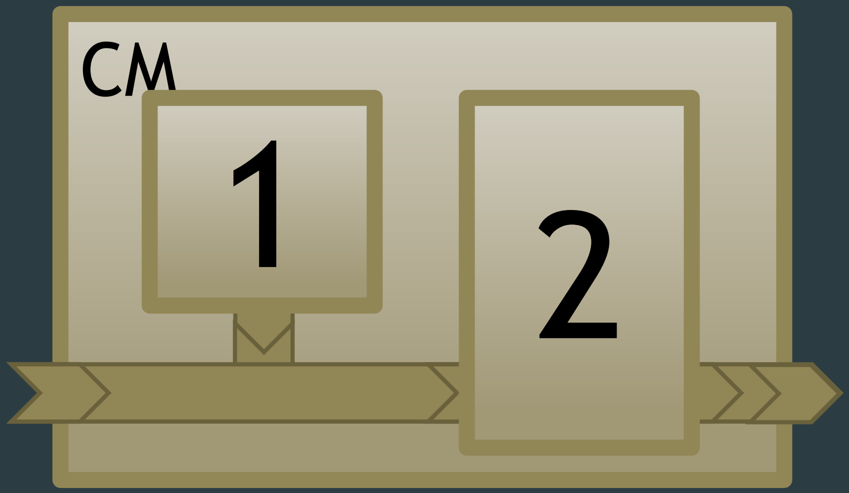


$CM = \langle X_{self}, Y_{self}, D, MS, IS, ZS \rangle$

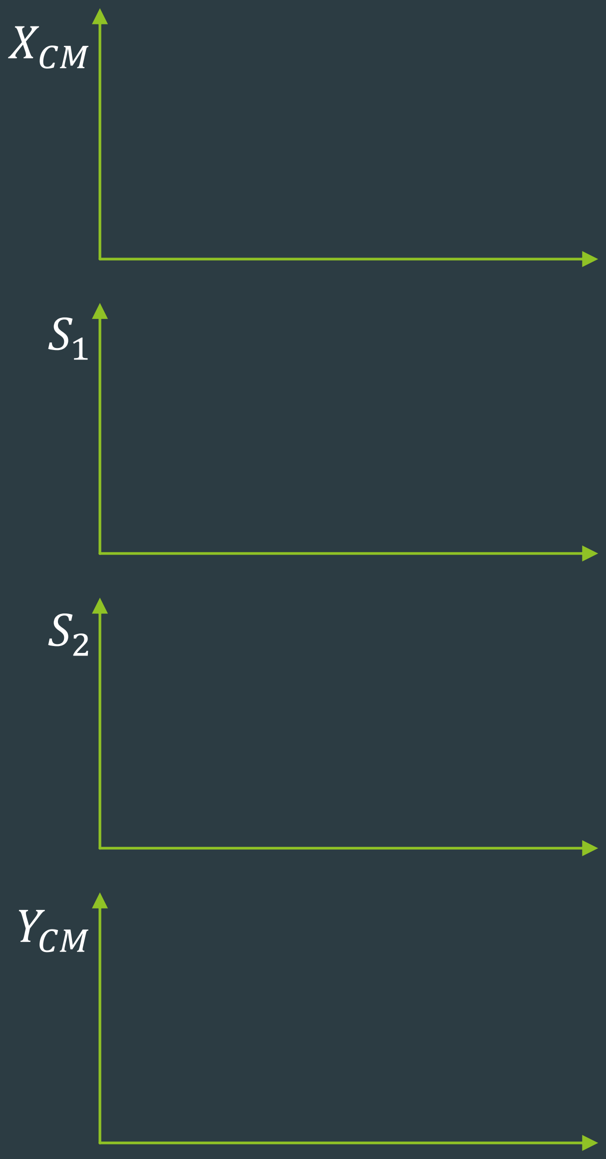
$flatten(CM) = \langle X, Y, S, q_{init}, \delta_{int}, \delta_{ext}, \lambda, ta \rangle$

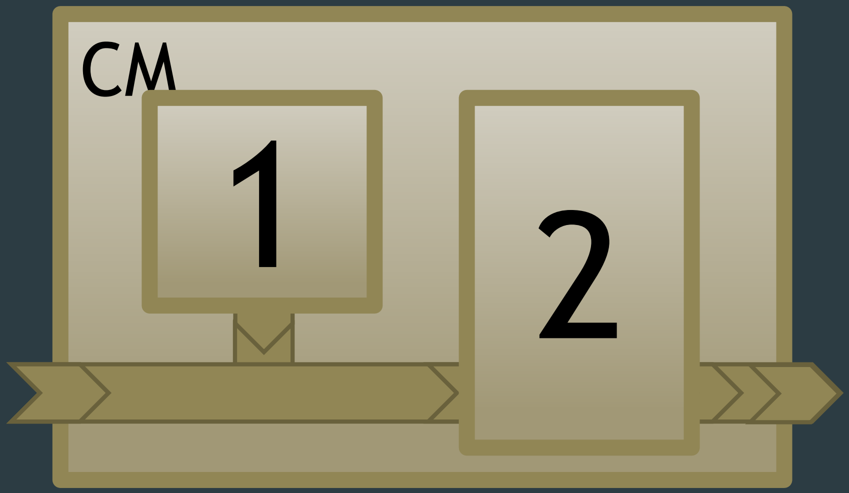

$S_{init,1}((r_1, e_1, t_{u}(r_1)), Z_{2,1}(\lambda_2, r_2))$
X_{rlf}
$Z_{2,1}(\lambda_2(r_2))$
$(S_{init,i}(r_i), \phi)$
$t_{ur}(r_1)$
(r_1, e_1)
$S_{init,2}(r_2)$
(r_2, e_2)
e_2
Y_2
$\lambda_2(r_2)$
$Z_{2,rlf}$
Y_{rlf}
$t_u((r_1, e_1), (r_2, e_2))$
$Z_{2,rlf}(\lambda_2(r_2))$
$Z_{i^*,rlf}(\lambda_{i^*}(r_{i^*}))$
ϕ
$i^* \in I_{rlf}$
$i^* \notin I_{rlf}$





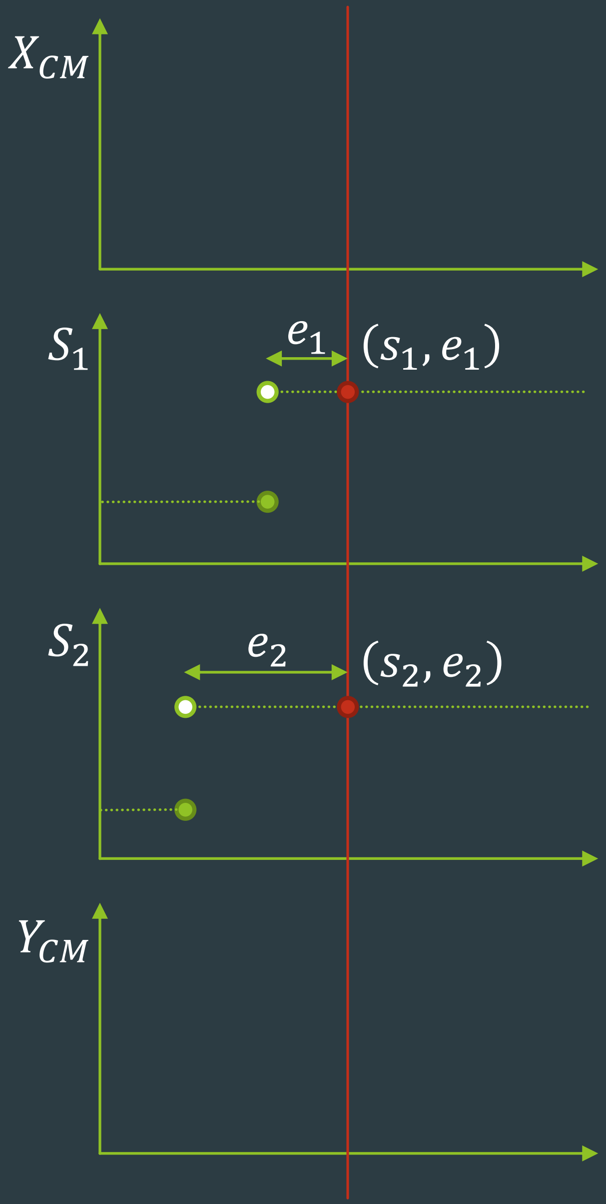
$$flatten(CM) = \langle X, Y, S, q_{init}, \delta_{int}, \delta_{ext}, \lambda, ta \rangle$$

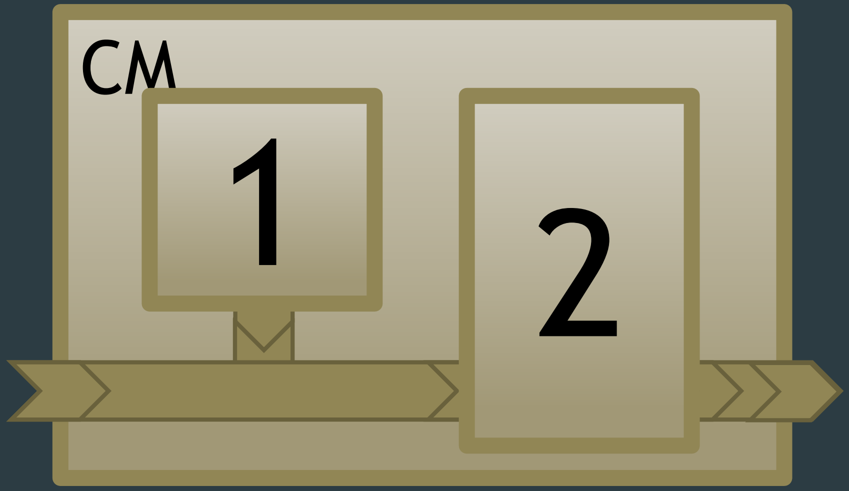




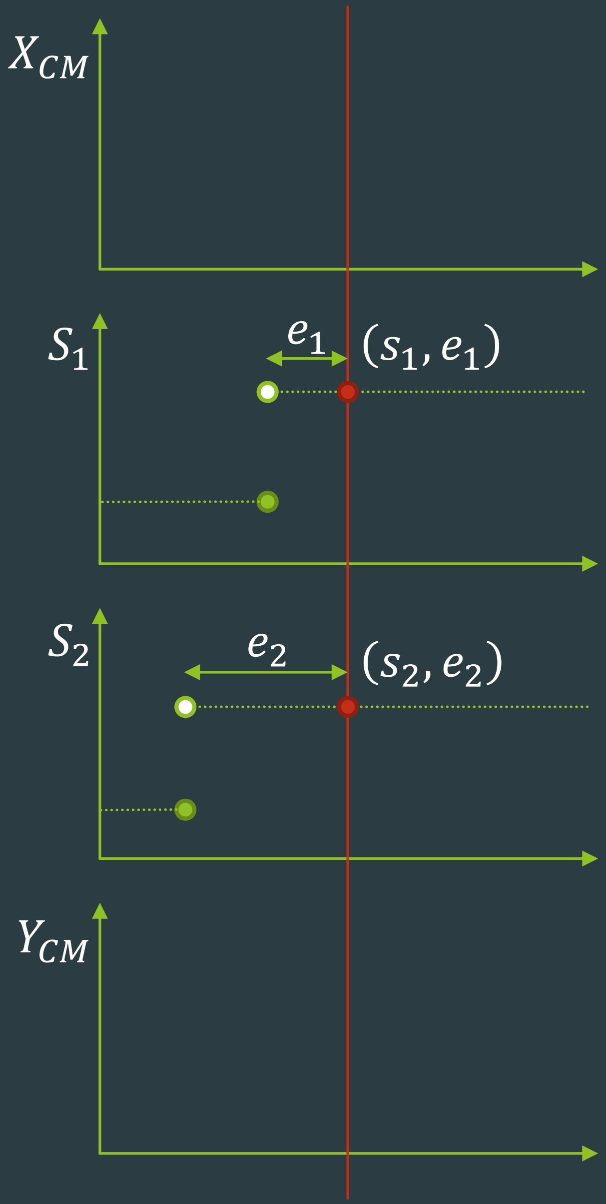
$$flatten(CM) = \langle X, Y, S, q_{init}, \delta_{int}, \delta_{ext}, \lambda, ta \rangle$$

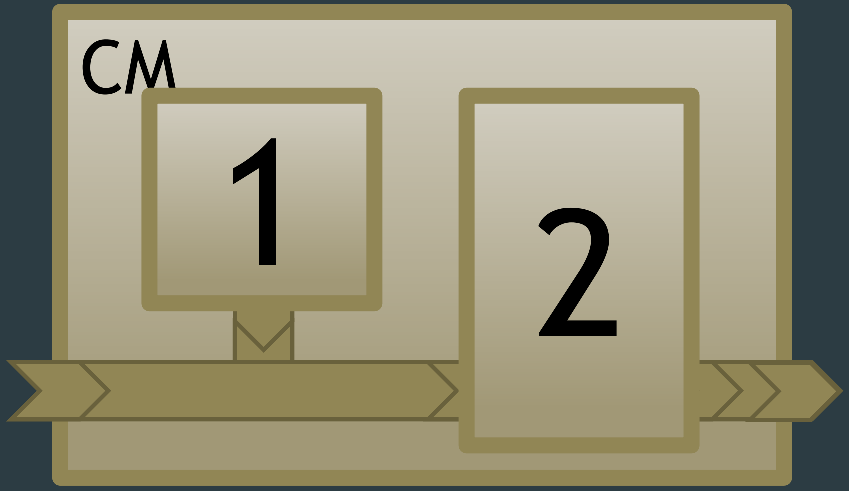
$$X = X_{CM}$$
$$Y = Y_{CM}$$





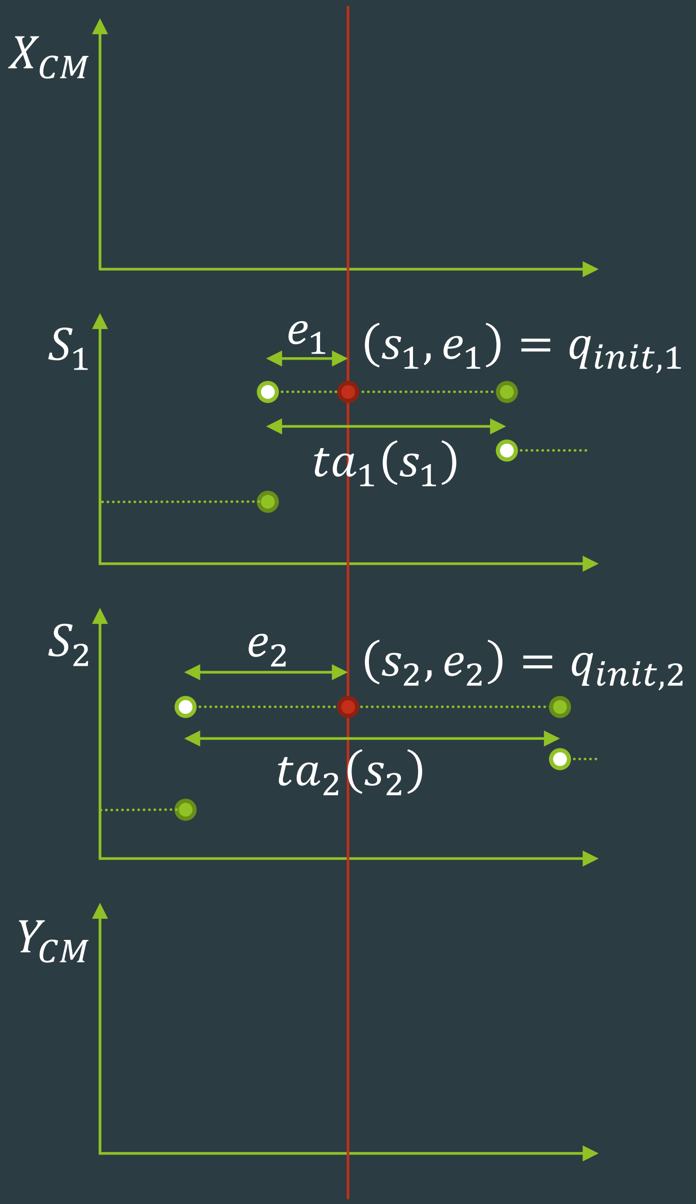
$$flatten(CM) = \langle X, Y, S, q_{init}, \delta_{int}, \delta_{ext}, \lambda, ta \rangle$$

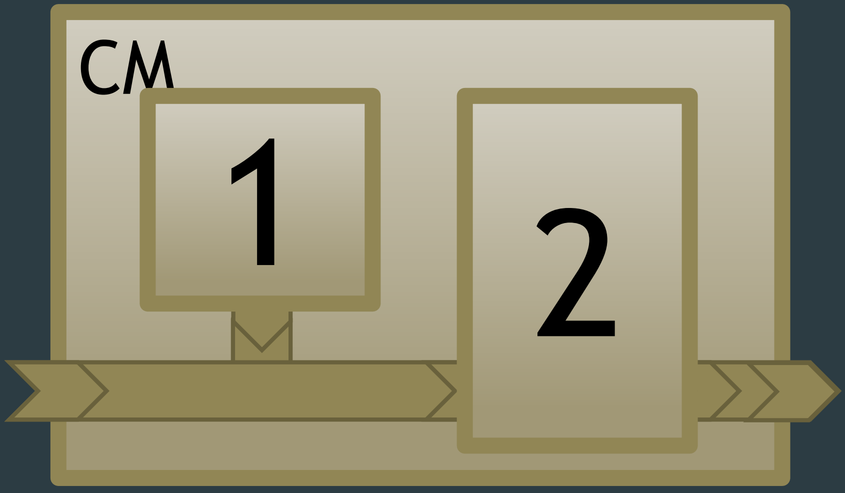




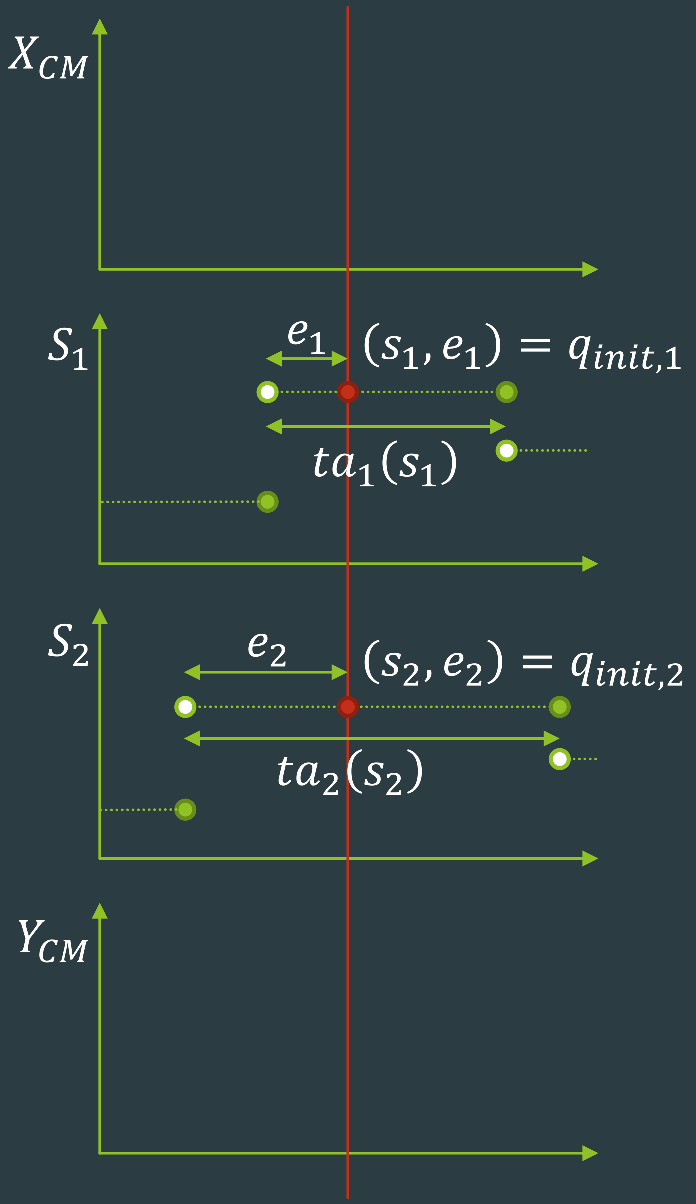
$$flatten(CM) = \langle X, Y, S, q_{init}, \delta_{int}, \delta_{ext}, \lambda, ta \rangle$$

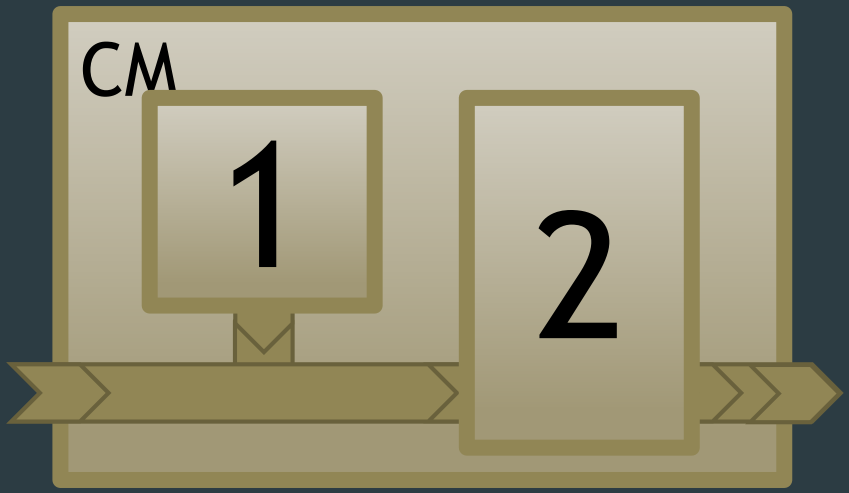
$$S = \times_{i \in D} Q_i$$





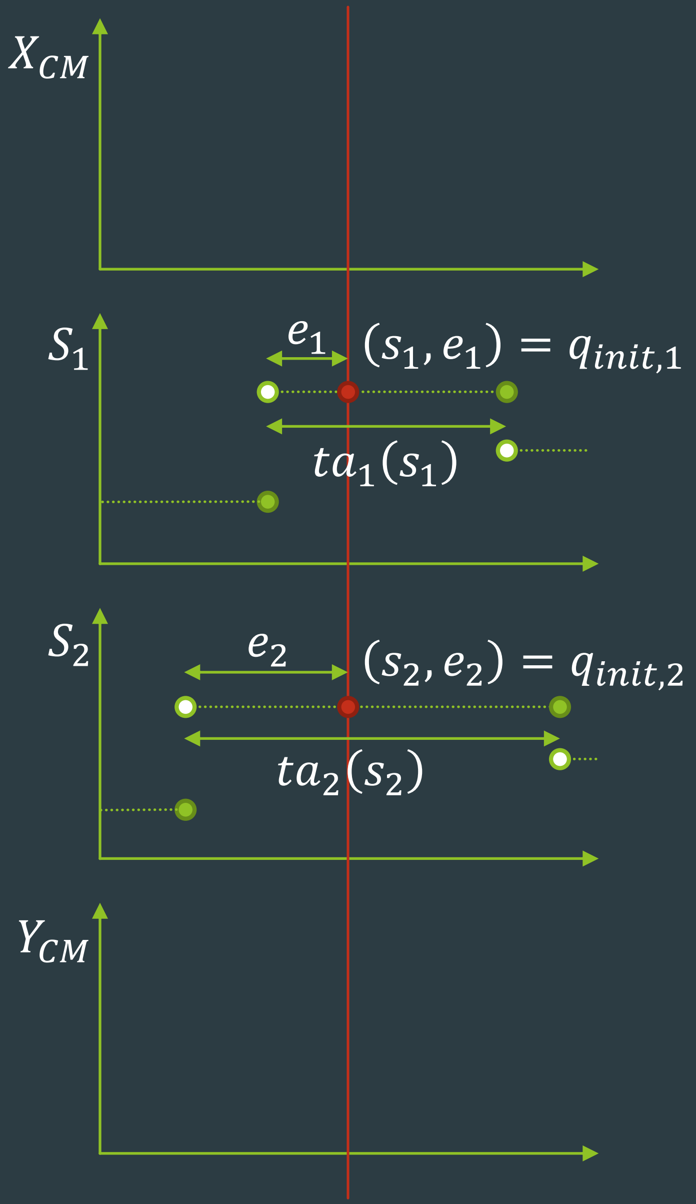
$$flatten(CM) = \langle X, Y, S, q_{init}, \delta_{int}, \delta_{ext}, \lambda, ta \rangle$$

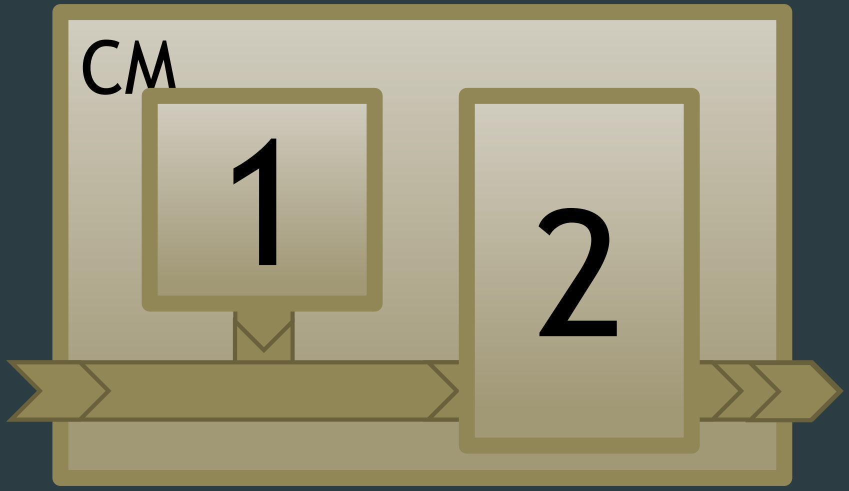




$$flatten(CM) = \langle X, Y, S, q_{init}, \delta_{int}, \delta_{ext}, \lambda, ta \rangle$$

$$q_{init} = (s_{init}, e_{init})$$

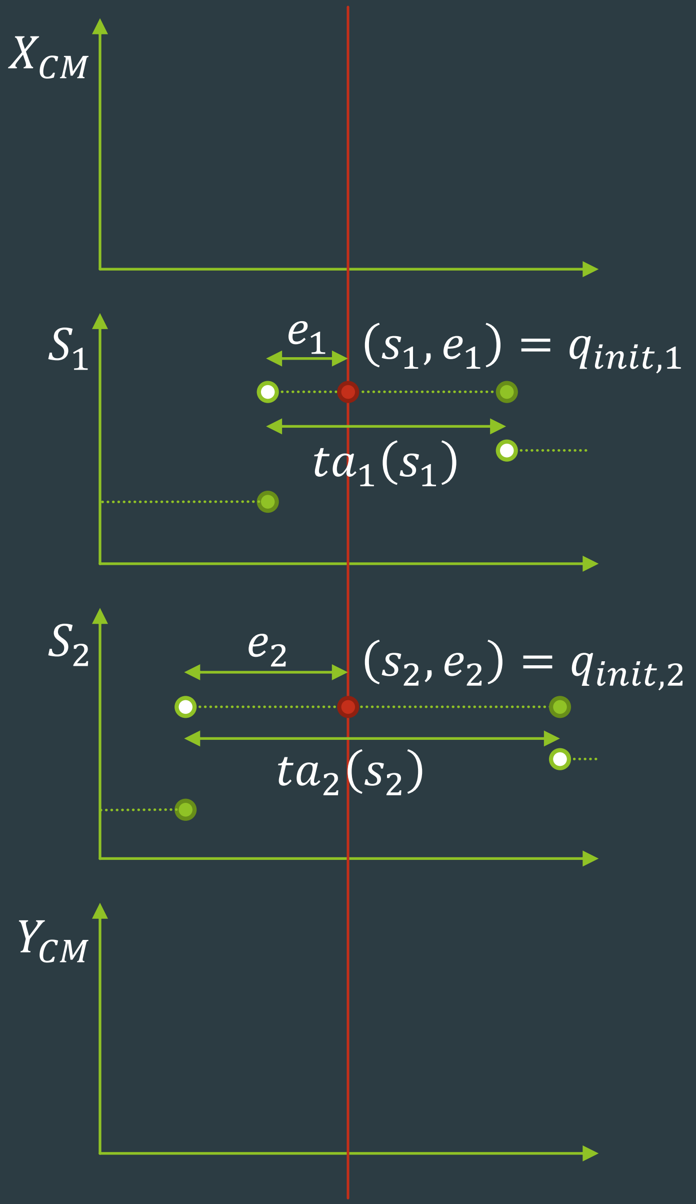


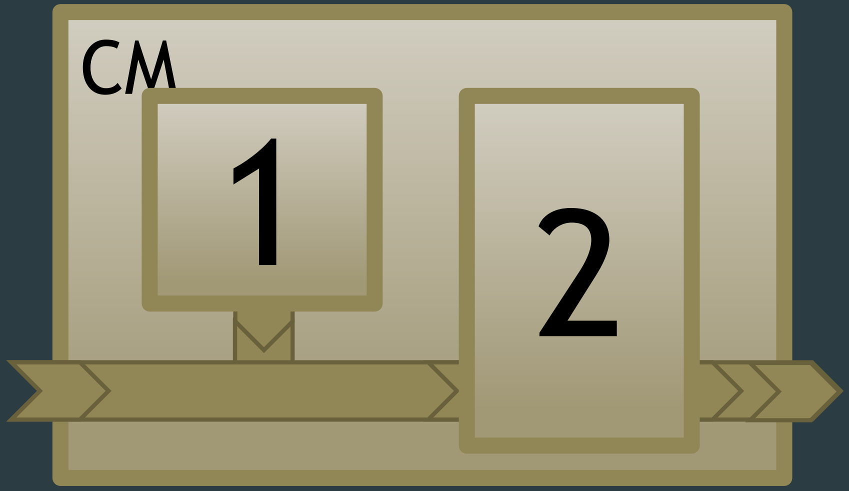


$$flatten(CM) = \langle X, Y, S, q_{init}, \delta_{int}, \delta_{ext}, \lambda, ta \rangle$$

$$q_{init} = (s_{init}, e_{init})$$

$$s_{init} = (\dots, (s_{init,i}, e_{init,i} - e_{init}), \dots)$$



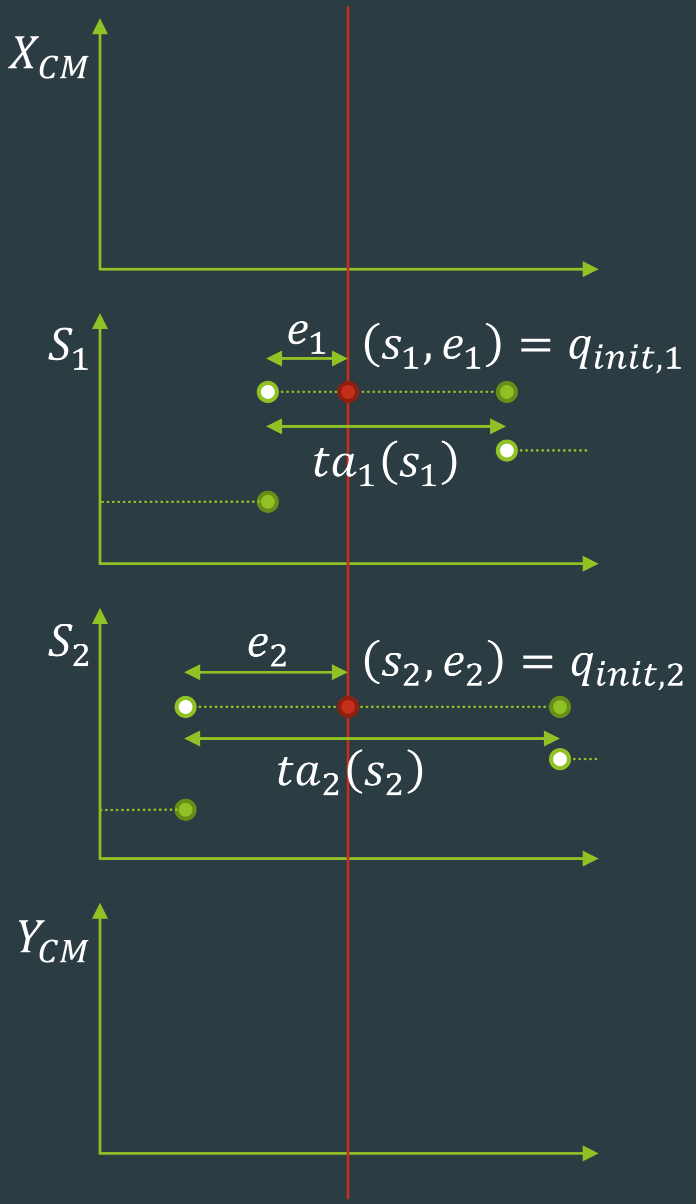


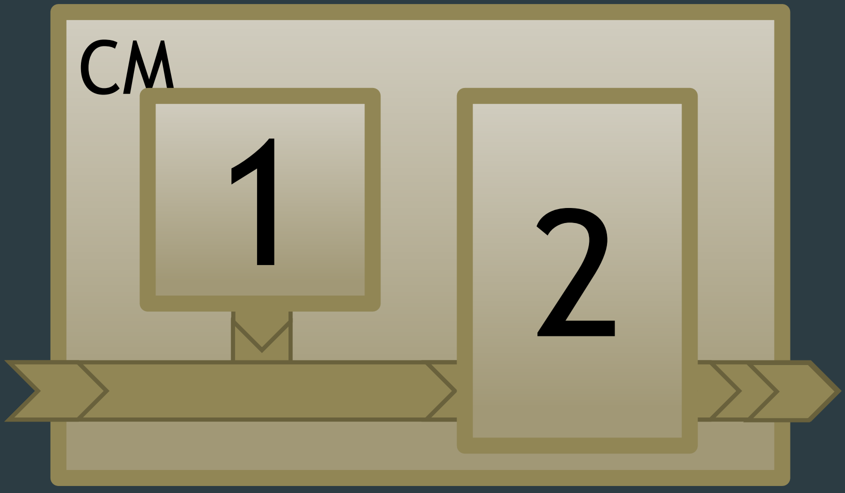
$$flatten(CM) = \langle X, Y, S, q_{init}, \delta_{int}, \delta_{ext}, \lambda, ta \rangle$$

$$q_{init} = (s_{init}, e_{init})$$

$$s_{init} = (\ldots, (s_{init,i}, e_{init,i} - e_{init}), \ldots)$$

$$e_{init} = \min_{i \in D}\{e_{init,i}\}$$





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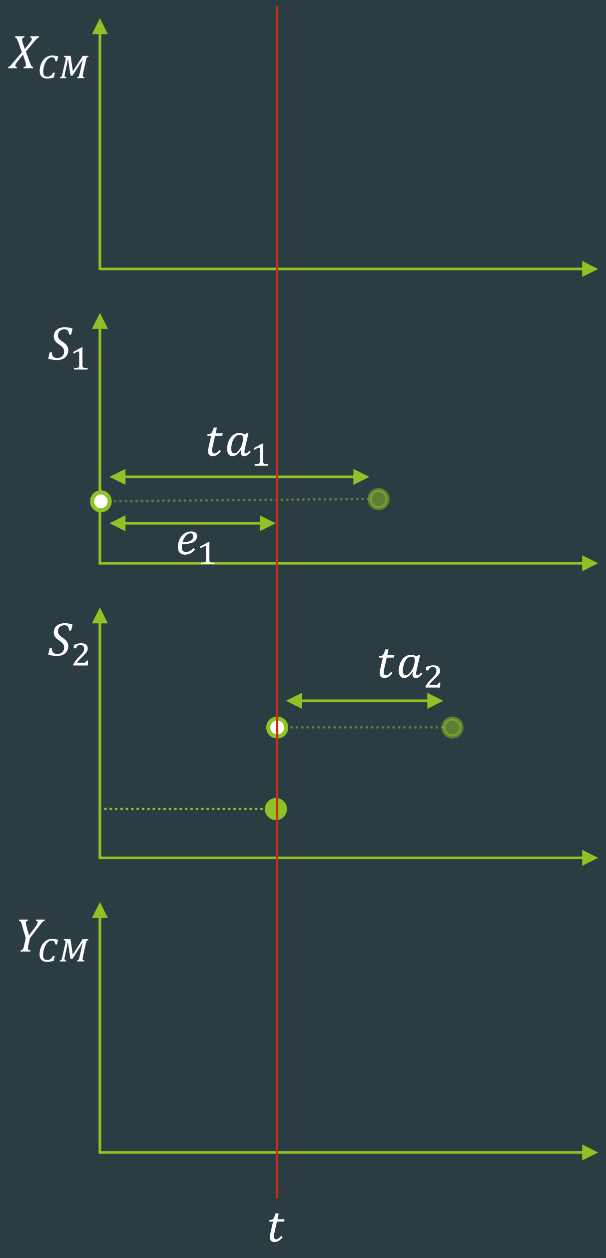
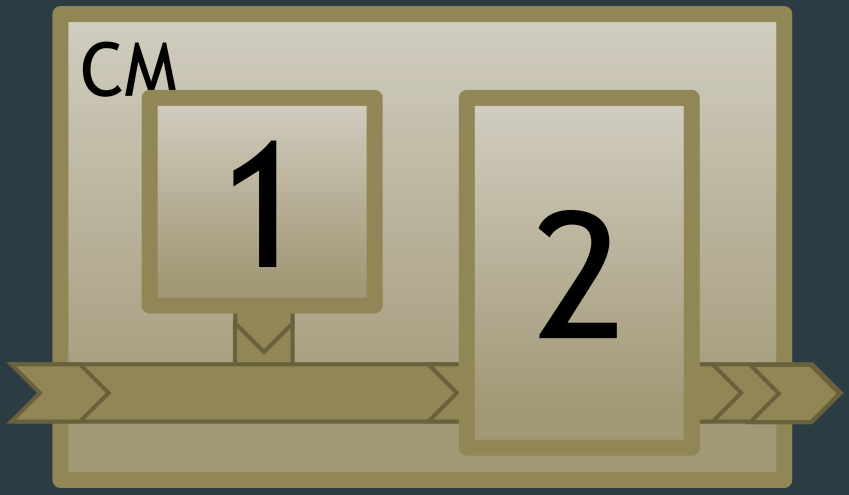
$$(s_{init,i}, e_{init,i}) = q_{init,i}$$





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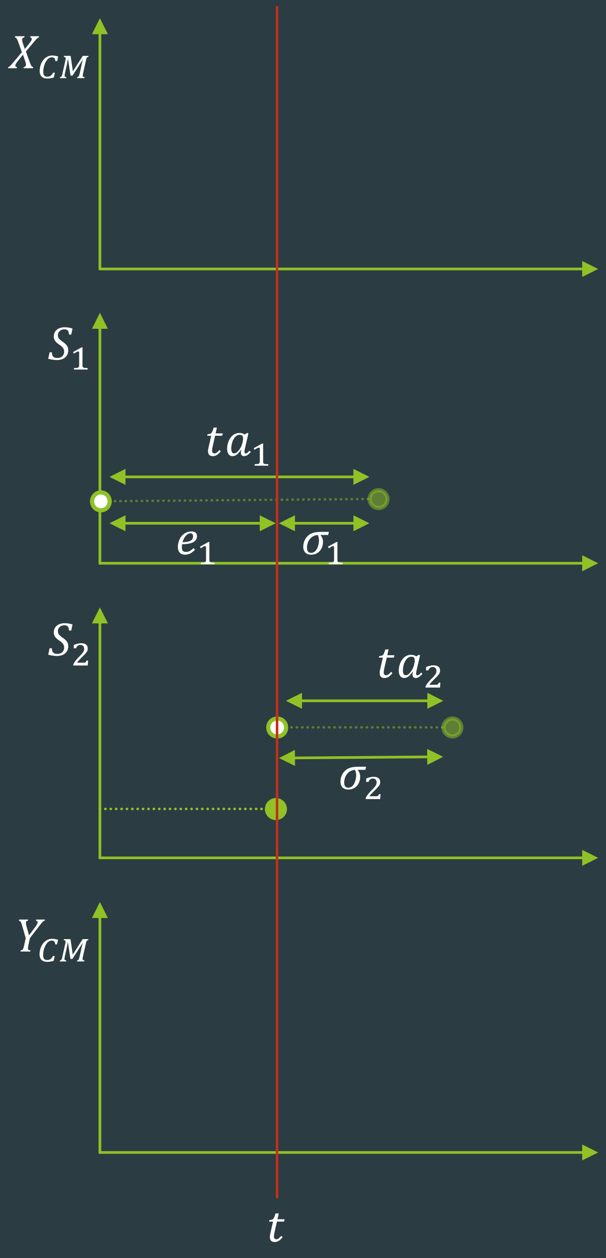
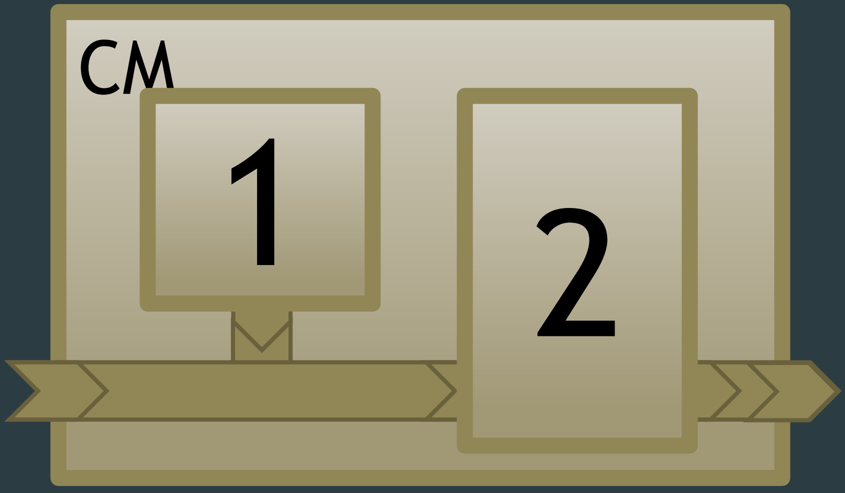
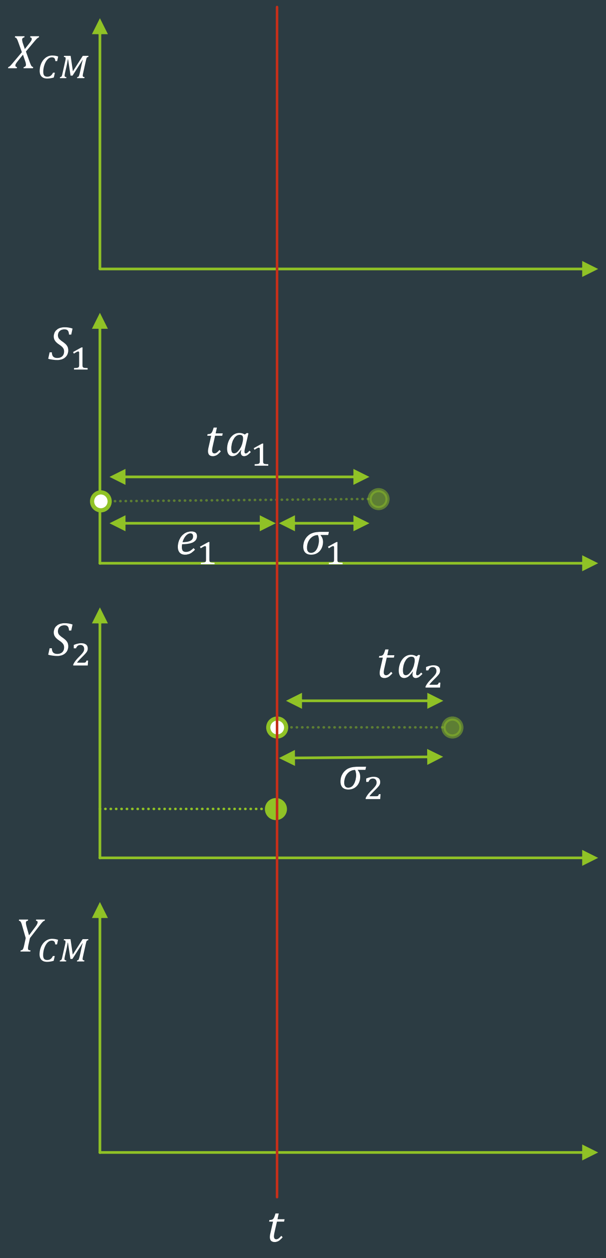


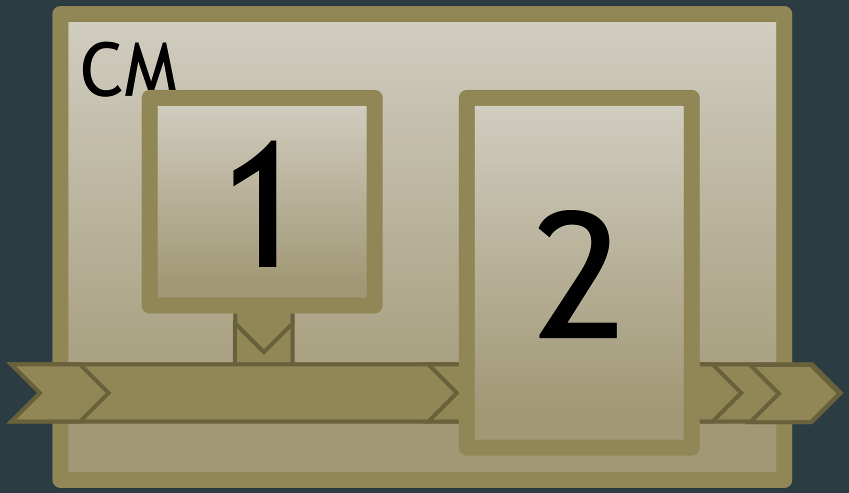


$$flatten(CM) = \langle X, Y, S, q_{init}, \delta_{int}, \delta_{ext}, \lambda, ta \rangle$$

$$ta : S \rightarrow \mathbb{R}^+_{0,+\infty}$$

$$ta(s) = \min_{i \in D}\{\sigma_i = ta_i(s_i) - e_i\}$$





$$flatten(CM) = \langle X, Y, S, q_{init}, \delta_{int}, \delta_{ext}, \lambda, ta \rangle$$

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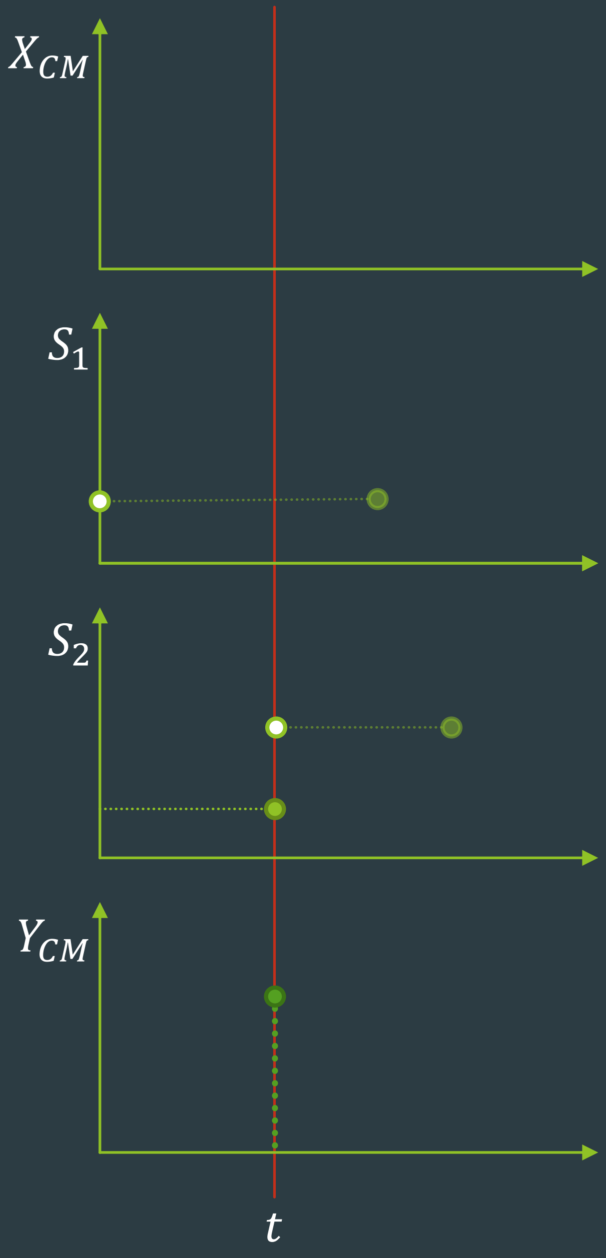
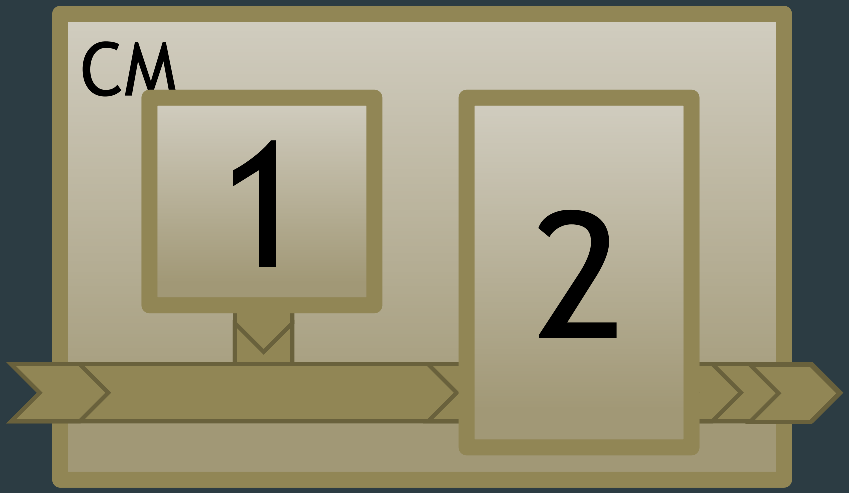
$$ta(s) = \min_{i \in D}\{\sigma_i = ta_i(s_i) - e_i\}$$

$$IMM(s) = \{i \in D | \sigma_i = ta(s)\}$$

$$select(IMM(s)) = i^*$$





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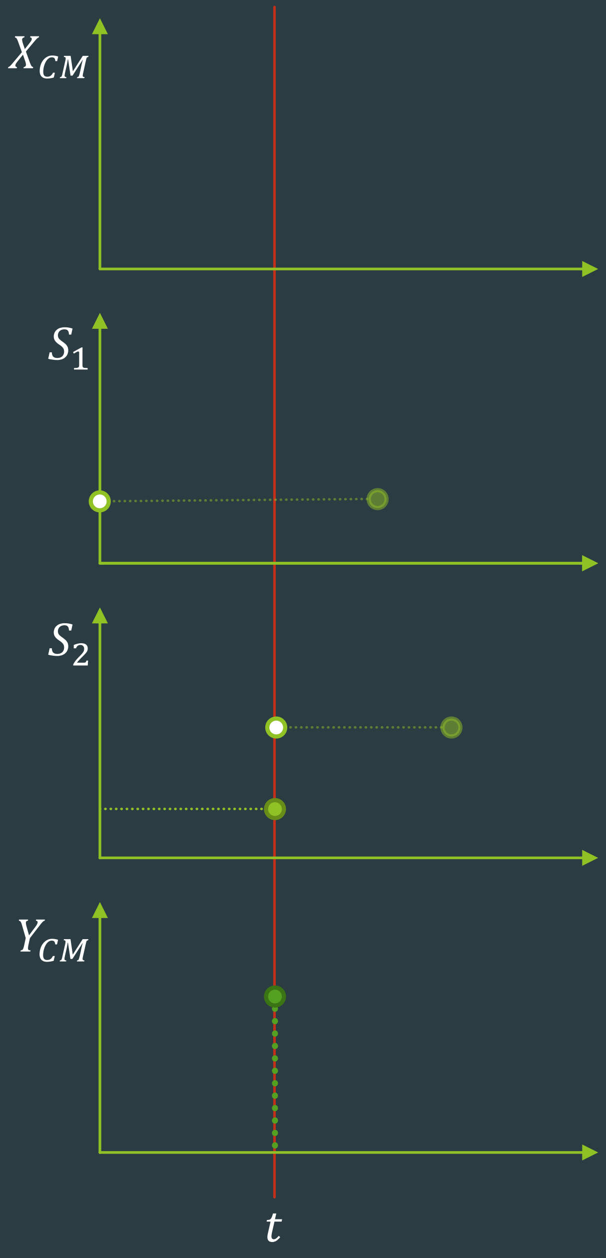
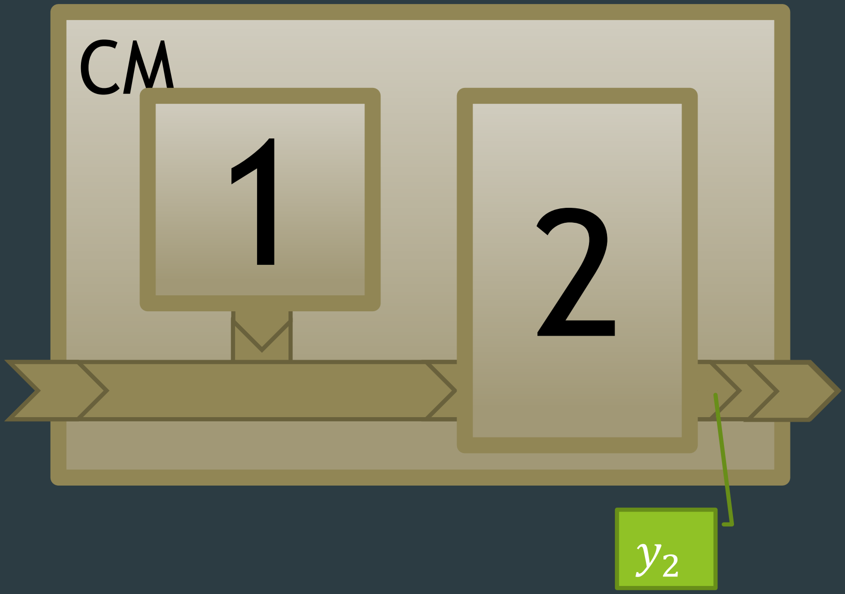
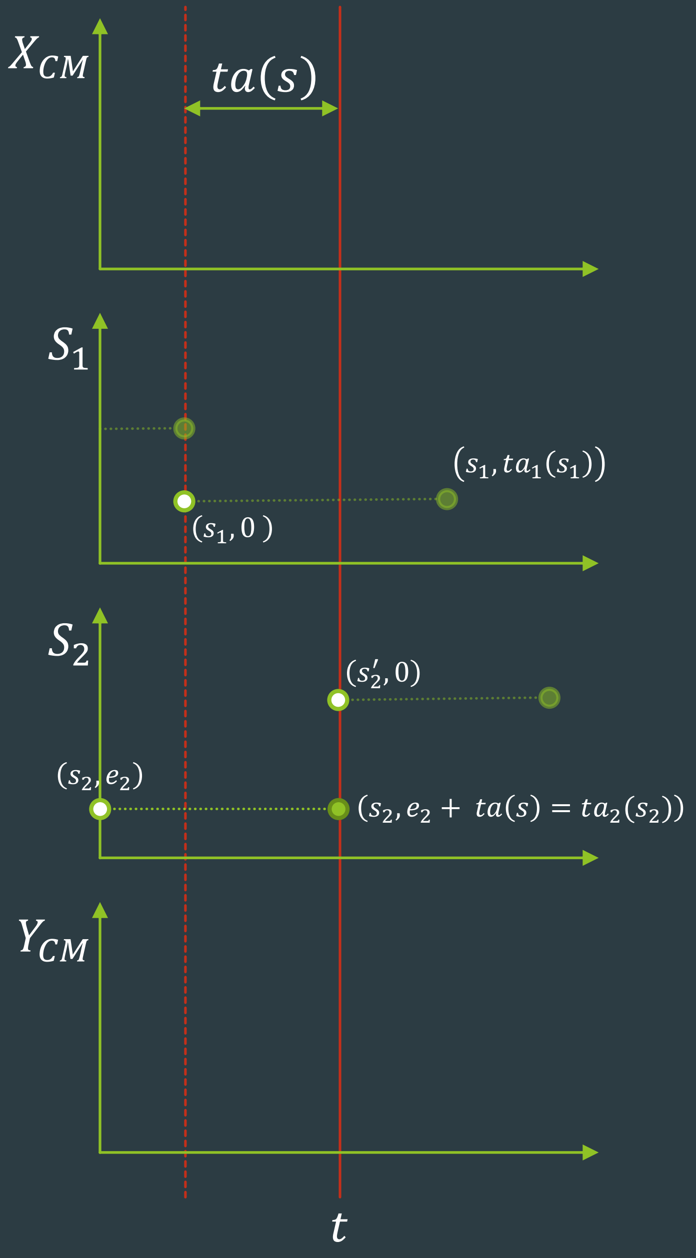
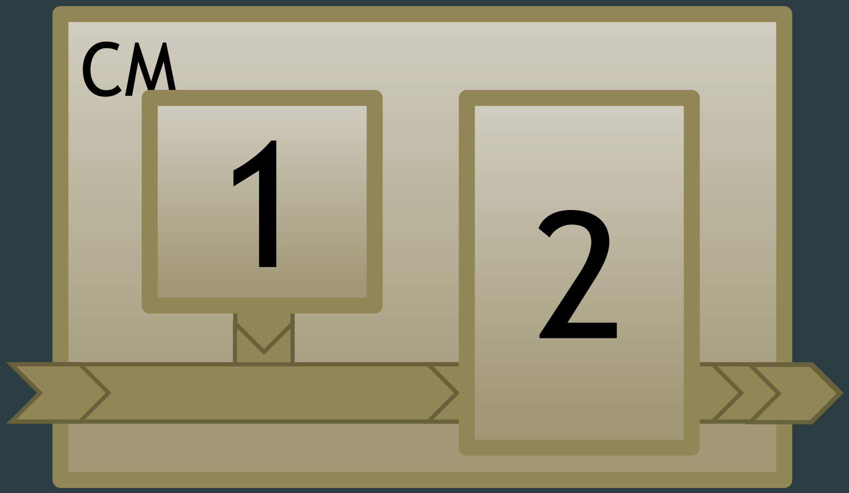




$$flatten(CM) = \langle X, Y, S, q_{init}, \delta_{int}, \delta_{ext}, \lambda, ta \rangle$$

$$\lambda(s) = \begin{cases} Z_{i^*,self}\left(\lambda_{i^*}(s_{i^*})\right) & if\ self \in I_{i^*} \\ \emptyset & if\ self \notin I_{i^*} \end{cases}$$





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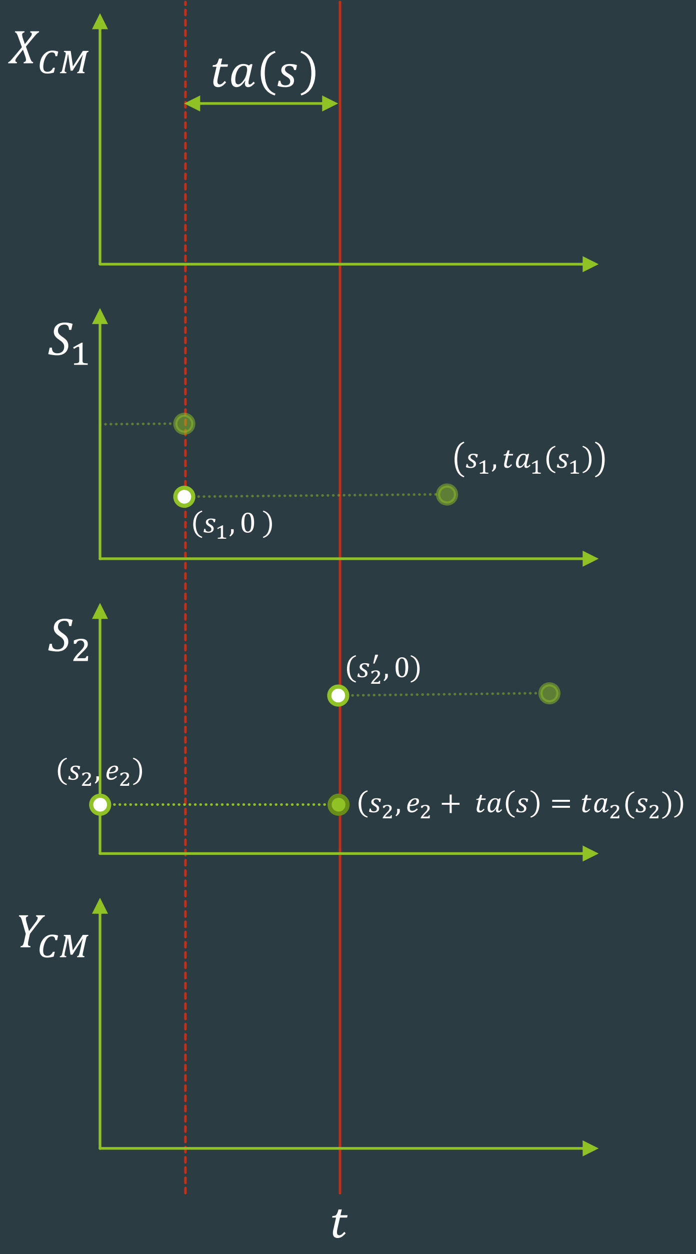
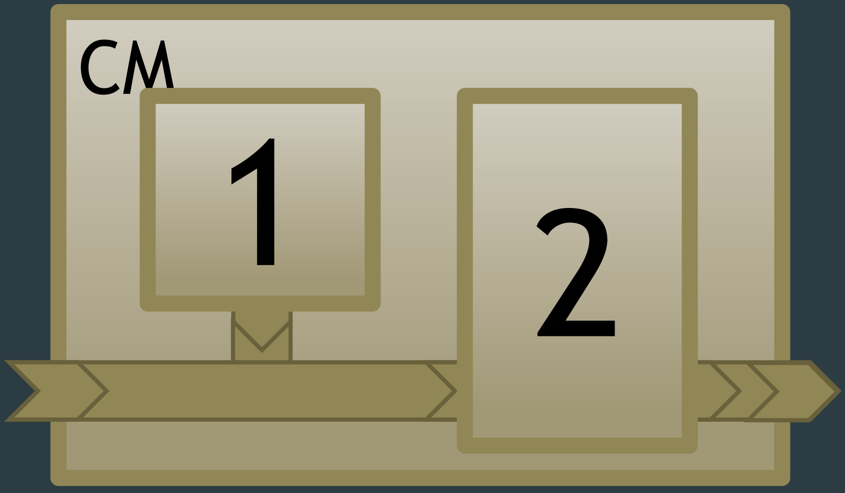
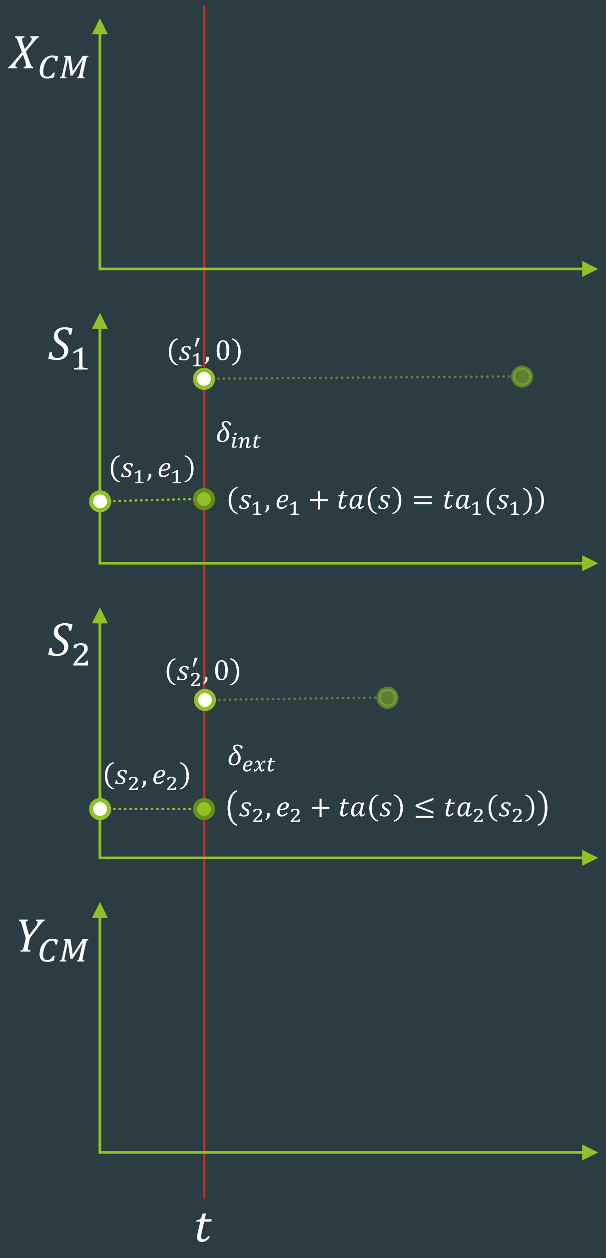


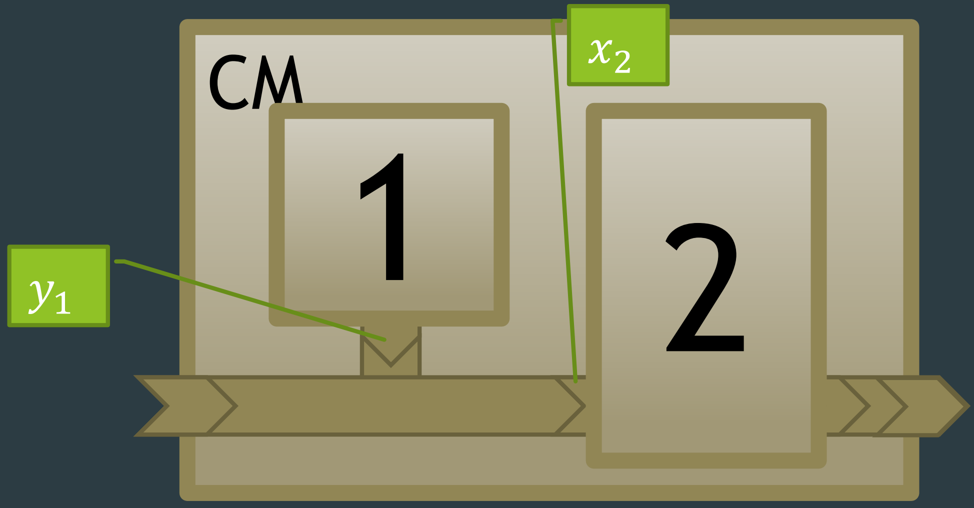


$$flatten(CM) = \langle X, Y, S, q_{init}, \delta_{int}, \delta_{ext}, \lambda, ta \rangle$$

$$\delta_{int}(s) = (\ldots, (s_j', e_j'), \ldots)$$

$$(s_j', e_j') = \begin{cases} (\delta_{int,j}(s_j), 0) & for\ j = i^* \\ ? & for\ j \in I_{i^*} \setminus \{self\} \\ (s_j, e_j + ta(s)) & else \end{cases}$$

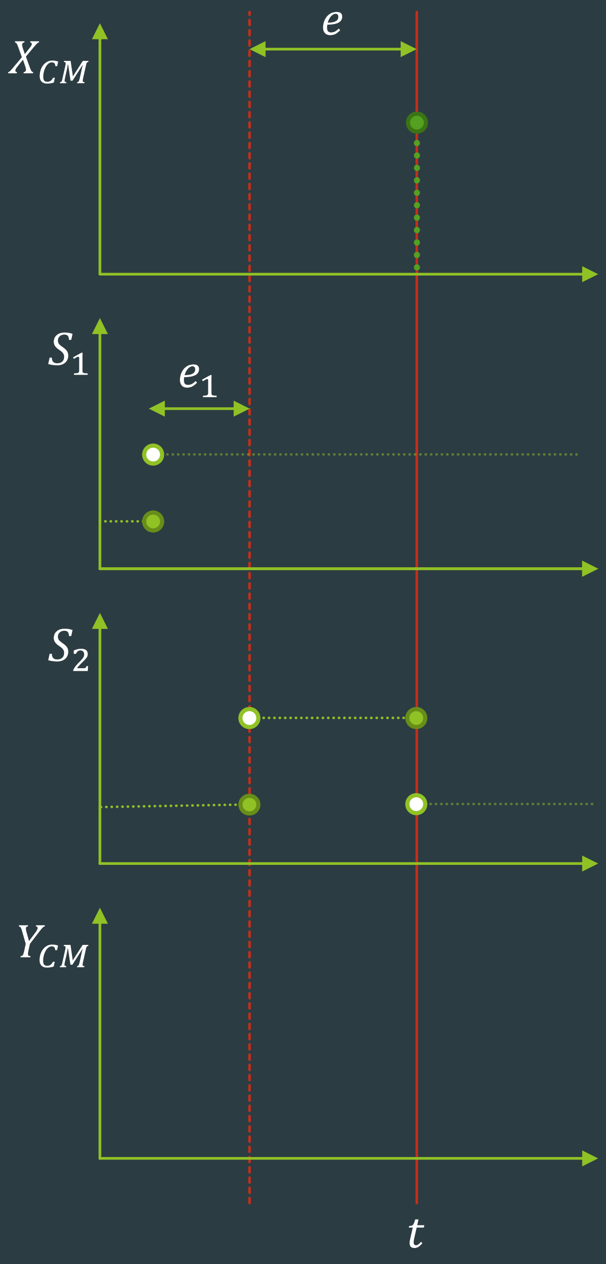


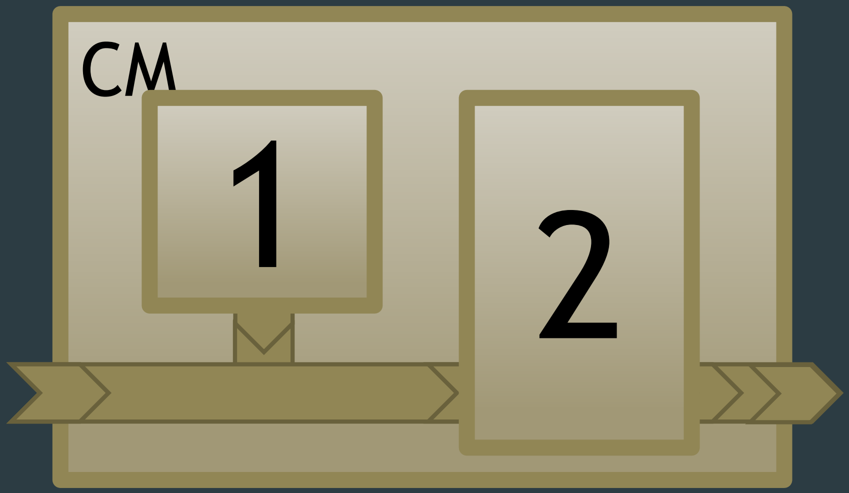


$$flatten(CM) = \langle X, Y, S, q_{init}, \delta_{int}, \delta_{ext}, \lambda, ta \rangle$$

$$\delta_{int}(s) = (\dots, (s'_j, e'_j), \dots)$$

$$(s'_j, e'_j) = \begin{cases} (\delta_{int,j}(s_j), 0) & for\ j = i^* \\ \left(\delta_{ext,j}\left(\left(s_j, e_j + ta(s)\right), Z_{i^*,j}(\lambda_{i^*}(s_{i^*}))\right), 0\right) & for\ j \in I_{i^*} \setminus \{self\} \\ \left(s_j, e_j + ta(s)\right) & else \end{cases}$$





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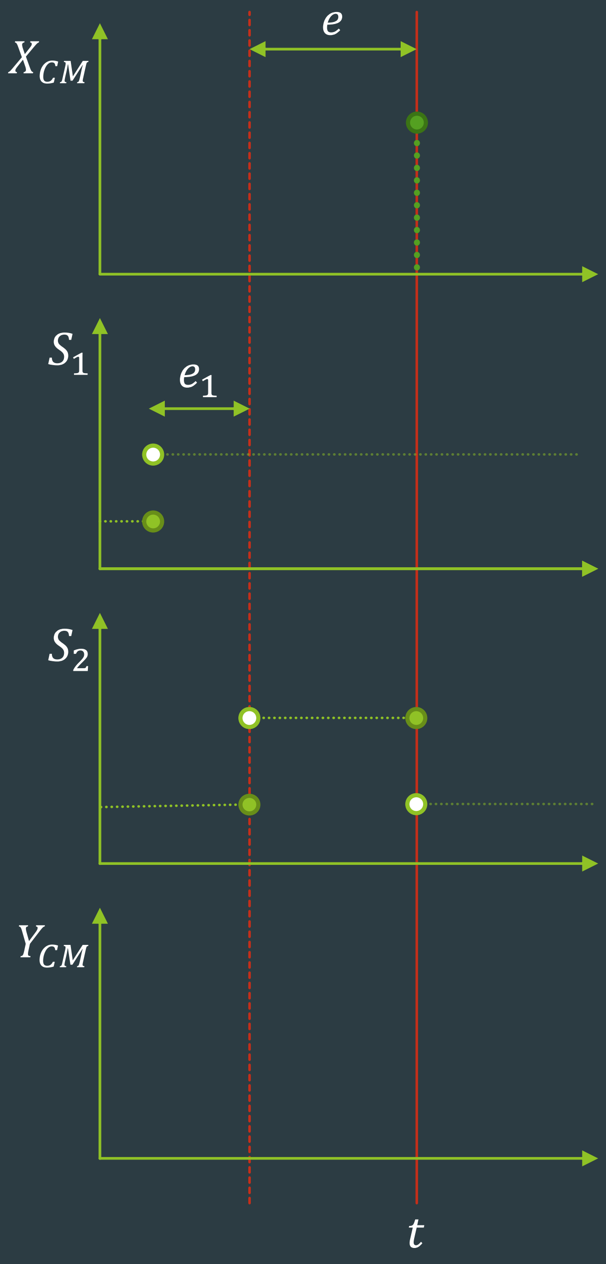
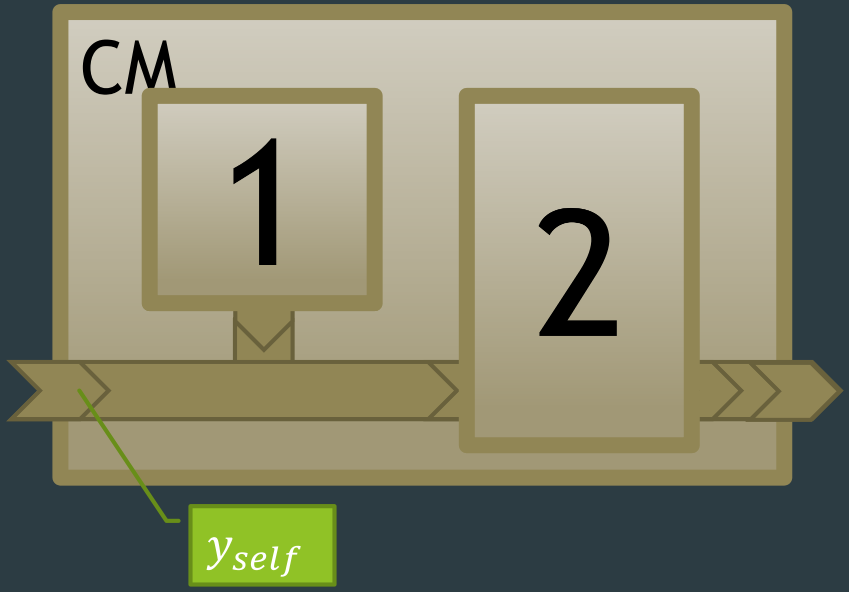




$$flatten(CM) = \langle X, Y, S, q_{init}, \delta_{int}, \delta_{ext}, \lambda, ta \rangle$$

$$\delta_{ext}((s,e),x) = (\dots, (s_i', e_i'), \dots)$$

$$(s_i', e_i') = \begin{cases} \left(\delta_{ext,i}\left((s_i, e_i + e), Z_{self,i}(x)\right), 0\right) & for\ i \in I_{self} \\ (s_i, e_i + e) & else \end{cases}$$

$$flatten(CM) = \langle X, Y, S, q_{init}, \delta_{int}, \delta_{ext}, \lambda, ta \rangle$$

$$X = X_{CM}$$

$$Y = Y_{CM}$$

$$S = \times_{i \in D} Q_i$$

$$Q = \{(s,e) | s \in S, 0 \le e \le ta(s)\}$$

$$q_{init} = (s_{init}, e_{init}) \in Q$$

$$s_{init} = (\ldots, (s_{init,i}, e_{init,i} - e_{init}), \ldots)$$

$$e_{init} = \min_{i \in D}\{e_{init,i}\}$$

$$(s_{init,i}, e_{init,i}) = q_{init,i}$$

$$\delta_{int}(s) = (\ldots, (s'_j, e'_j), \ldots)$$

$$(s'_j, e'_j) = \begin{cases} (\delta_{int,j}(s_j), 0) & for\ j = i^* \\ \left(\delta_{ext,j}\left((s_j, e_j + ta(s)), Z_{i^*,j}(\lambda_{i^*}(s_{i^*}))\right), 0\right) & for\ j \in I_{i^*} \\ (s_j, e_j + ta(s)) & else \end{cases}$$

$$\delta_{ext}((s,e), x) = (\ldots, (s'_i, e'_i), \ldots)$$

$$(s'_i, e'_i) = \begin{cases} \left(\delta_{ext,i}\left((s_i, e_i + e), Z_{self,i}(x)\right), 0\right) & for\ i \in I_{self} \\ (s_i, e_i + e) & else \end{cases}$$

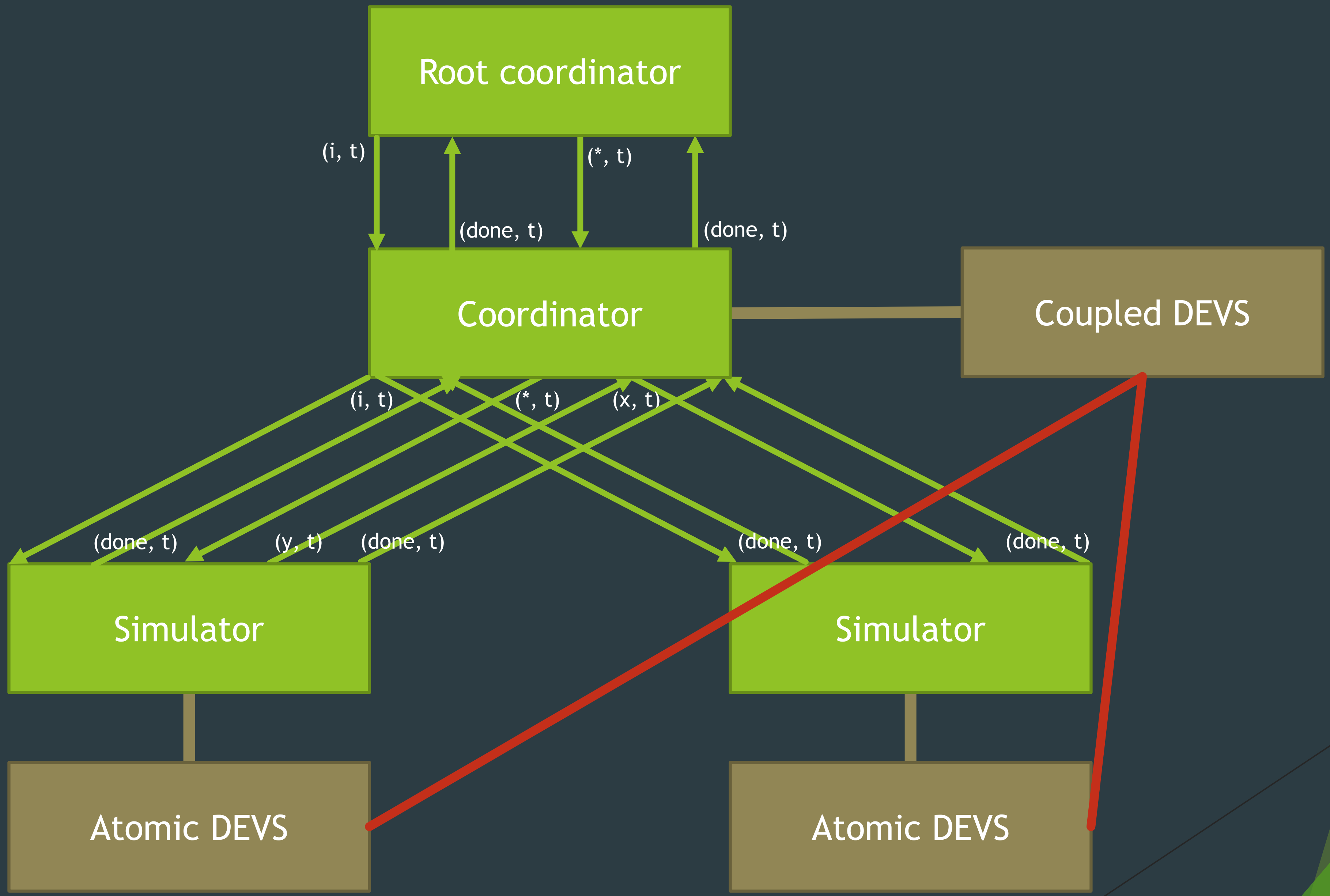
$$\lambda(s) = \begin{cases} Z_{i^*,self}(\lambda_{i^*}(s_{i^*})) & if\ self \in I_{i^*} \\ \phi & if\ self \notin I_{i^*} \end{cases}$$

$$i^* = select(IMM(s))$$

$$IMM(s) = \{i \in D | \sigma_i = ta(s)\}$$

$$ta(s) = \min_{i \in D}\{\sigma_i = ta_i(s_i) - e_i\}$$

Hierarchical Simulator


Root coordinator
(i, t)
(*, t)
(done, t)
(done, t)
Coordinator
Coupled DEVS
(i, t)
(*, t)
(x, t)
(done, t)
(y, t)
(done, t)
(done, t)
(done, t)
Simulator
Simulator
Atomic DEVS
Atomic DEVS

message m	**simulator**	**coordinator**
$(*, from, t)$	simulator correct only if $t = t_N$	
	$y \leftarrow \lambda(s)$	**send** $(*, self, t)$ to i^*, where
	if $y \neq \phi$:	$i^* = select(imm\_children)$
	send $(\lambda(s), self, t)$ to $parent$	$imm\_children = \{i \in D \mid M_i.t_N = t\}$
	$s \leftarrow \delta_{int}(s)$	$active\_children \leftarrow active\_children \cup \{i^*\}$
	$t_L \leftarrow t$	
	$t_N \leftarrow t_L + ta(s)$	
	send $(done, self, t_N)$ to $parent$	

message m	simulator	coordinator
$(x, from, t)$	simulator correct only if $t_L \leq t \leq t_N$ (ignore δ_{int} to resolve a $t = t_N$ *conflict*)	
	$e \leftarrow t - t_L$	$\forall i \in I_{self}$:
	$s \leftarrow \delta_{ext}(s, e, x)$	**send** $(Z_{self,i}(x), self, t)$ to i
	$t_L \leftarrow t$	$active\_children \leftarrow active\_children \cup \{i$
	$t_N \leftarrow t_L + ta(s)$	
	send $(done, self, t_N)$ to $parent$	

message m	simulator	coordinator
$(y, from, t)$		$\forall i \in I_{from} \setminus \{self\}$: **send** $(Z_{from,i}(y), from, t)$ to i $active\_children \leftarrow active\_children \cup \{i\}$ **if** $self \in I_{from}$: **send** $(Z_{from,self}(y), self, t)$ to $parent$
$(done, from, t)$		$active\_children \leftarrow active\_children \setminus \{from\}$ **if** $active\_children = \emptyset$: $t_L \leftarrow t$ $t_N \leftarrow min\{M_i.t_N \mid i \in D\}$ **send** $(done, self, t_N)$ to $parent$

$t \leftarrow t_N$ of topmost coordinator

repeat until $t \geq t_{end}$ (or some other termination condition)

  send $(*, main, t)$ to topmost coupled model top

  wait for $(done, top, t_N)$

  $t \leftarrow t_N$

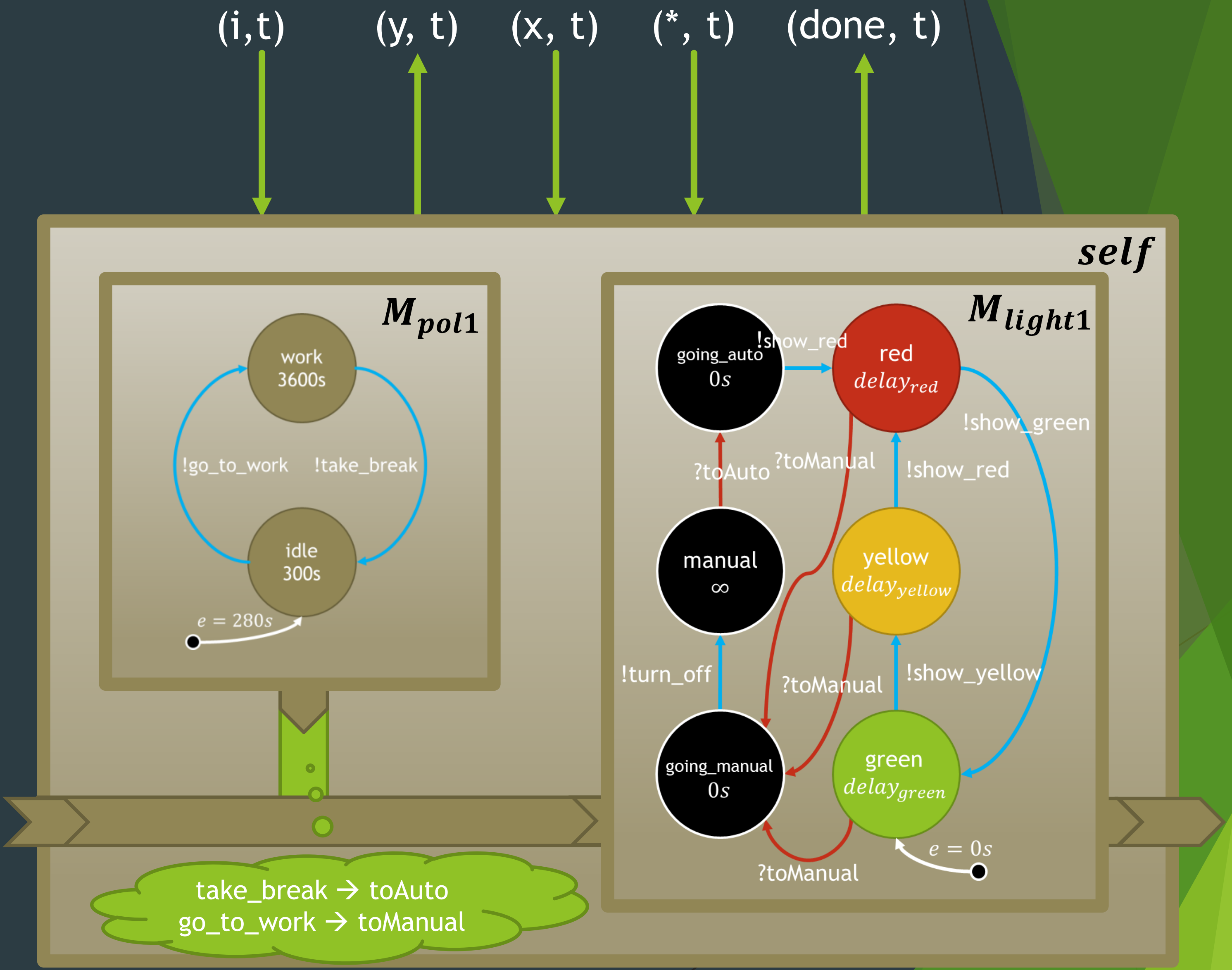
DEVS Semantics

	Operational Semantics	Denotational Semantics
Atomic DEVS	Abstract Simulator	[1]
Coupled DEVS	Hierarchical Simulator	Closure under Coupling

[1] Ashvin Radiya and Robert G. Sargent. A logic-based foundation of discrete event modeling and simulation. ACM Transactions on Modeling and Computer Simulation, 1(1):3-51, 1994.

Conclusions

- Atomic DEVS
- Coupled DEVS
- Closure under coupling
- Abstract Simulator



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Examples

A small *trafficModel* and corresponding *trafficExperiment* file is included in the *examples* folder of the PyPDEVS distribution. This (completely working) example is slightly too big to use as a first introduction to PyPDEVS and therefore this page will start with a very simple example.

For this, we will first introduce a simplified queue model, which will be used as the basis of all our examples. The complete model can be downloaded: `queue_example_classic.py`.

This section should provide you with all necessary information to get you started with creating your very own PyPDEVS simulation. More advanced features are presented in the next section.

Generator

Somewhat simpler than a queue even, is a generator. It will simply create a message to send after a certain delay and then it will stop doing anything.

Informally, this would result in a DEVS specification as:

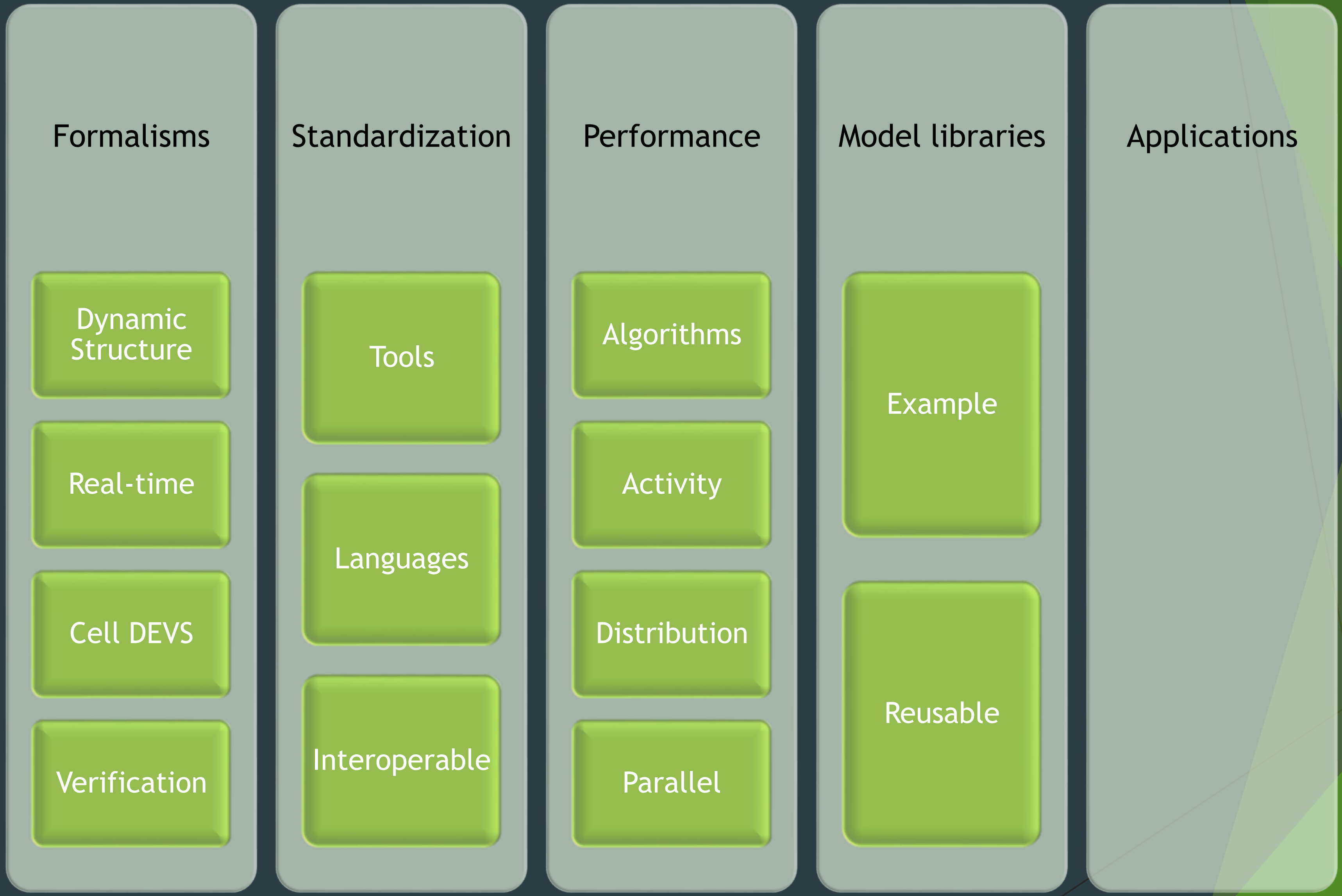
- Time advance function returns the waiting time to generate the message, infinity after the message was created
- Output function outputs the generated message
- External transition function will never happen (as there are no inputs)

http://msdl.cs.mcgill.ca/projects/PythonPDEVS

Limitations of Classic DEVS

- Parallel implementation
  - Parallel DEVS [1]
- Select function is artificial
  - Parallel DEVS [1]
- Dynamic Structure systems
  - Dynamic Structure DEVS [2]

[1] A.C.-H. Chow. Parallel DEVS: A parallel, hierarchical, modular modeling formalism and its distributed simulator. Transactions of the Society for Computer Simulation International, 13(2):55-68, 1996.
[2] F. Barros. The dynamic structure discrete event system specification formalism. Transactions of the Society for Computer Simulation International, 13(1):35-46, 1996.


Formalisms
Dynamic Structure
Real-time
Cell DEVS
Verification
Standardization
Tools
Languages
Interoperable
Performance
Algorithms
Activity
Distribution
Parallel
Model libraries
Example
Reusable
Applications

http://msdl.cs.mcgill.ca/projects/PythonPDEVS