POLITECNICO DI MILANO

AUTONOMOUS VEHICLES

S. Arrigoni

POLITECNICO
MILANO 1863

Finite State Machines

introduction

Introduction

What are Finite State Machines (FSM)?

<u>Definition</u>:
State machines are a ***method of modeling*** systems whose ***output depends on the entire history*** of their inputs, (and <u>not just on the most recent input</u>).

It can be used for:

✓ Design ***control logics*** based on:
  - Events
  - Time-based
  - External signals
- ***Model behavior*** of a system (due to environment interaction)
- ***Predict*** future behavior (based on past inputs)

Introduction

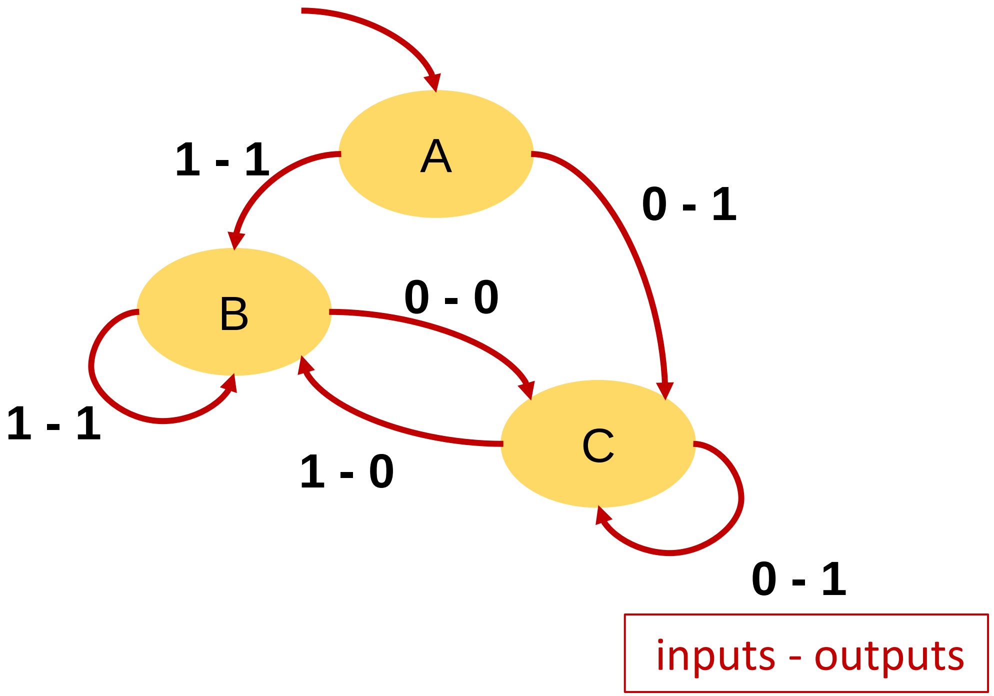
What are Finite State Machines (FSM)?

It is *mathematically* defined as a six-tuple (I, S, s_0, τ, o, O) where:

- ✓ $I \rightarrow$ inputs set (a finite, non-empty set of symbols) aka input vocabulary
- ✓ $S \rightarrow$ ***finite***, non-empty set of states
- ✓ $s_0 \rightarrow$ initial state at t_0 ($s_0 \in S$)
- ✓ $O \rightarrow$ outputs set (set of symbols) aka output vocabulary
- ✓ $\tau \rightarrow$ transition (next-state) function, $\tau(i_t, s_t) \rightarrow s_{t+1}$
- ✓ $o \rightarrow$ output function, $o(i_t, s_t) \rightarrow o_t$

Introduction

What are Finite State Machines (FSM)?

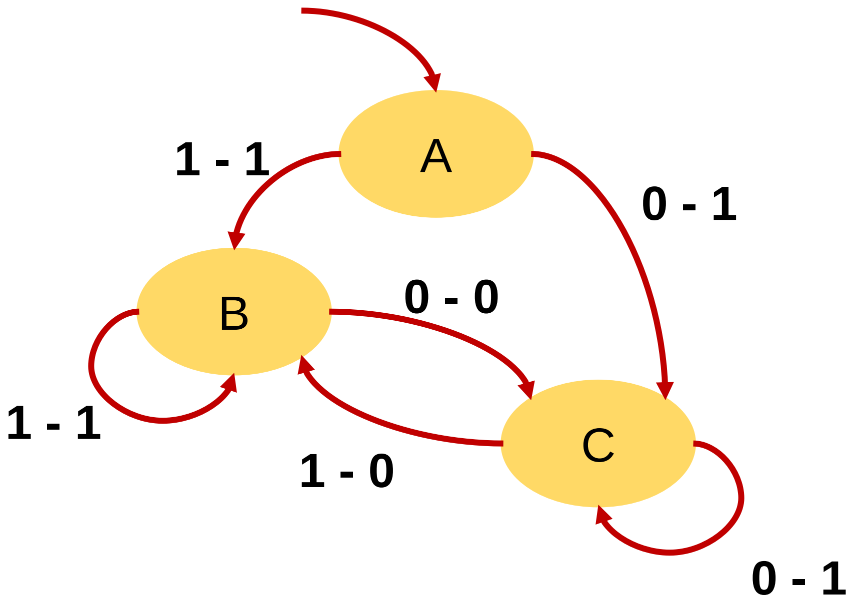


Let's look at the example:

- ✓ inputs set $I \rightarrow \{0,1\}$
- ✓ set of states $S \rightarrow \{A, B, C\}$
- ✓ $s_0 \rightarrow$ initial state at t_0 A
- ✓ outputs set $O \rightarrow \{0,1\}$

Introduction

What are Finite State Machines (FSM)?



Transition and outputs functions (τ, o) can be defined by a tabular:

- ✓ states on the rows
- ✓ inputs on the columns
- ✓ Each cell contains s_{t+1}, o_t

	0	1
A	B,1	C,1
B	C,0	B,1
C	C,1	B,0

Introduction

Example: Parking Gate Control

Gate positions:

- ✓ Top
- ✓ Middle
- ✓ Bottom

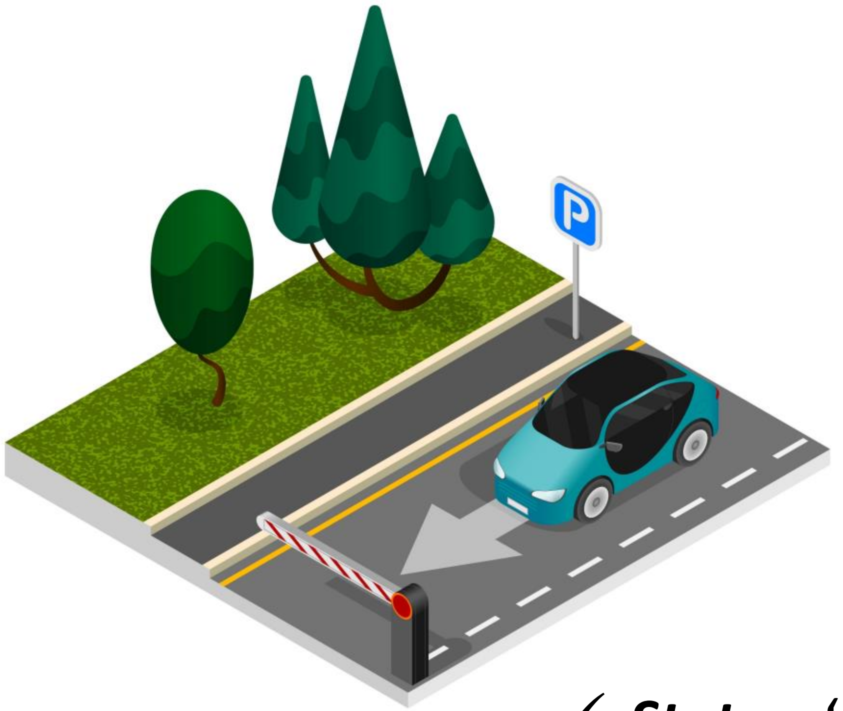
#sensor1: a car is waiting

#sensor2: a car has just passed through

Actions:

- ✓ raise the gate
- ✓ lower the gate
- ✓ no operation (nop).

Introduction



Example: Parking Gate Control

Expected behavior:

- If a car is close, need to raise the arm until ‘top’ position
- Gate has to stay up until the car has passed
- Gate has to lower after the car has gone

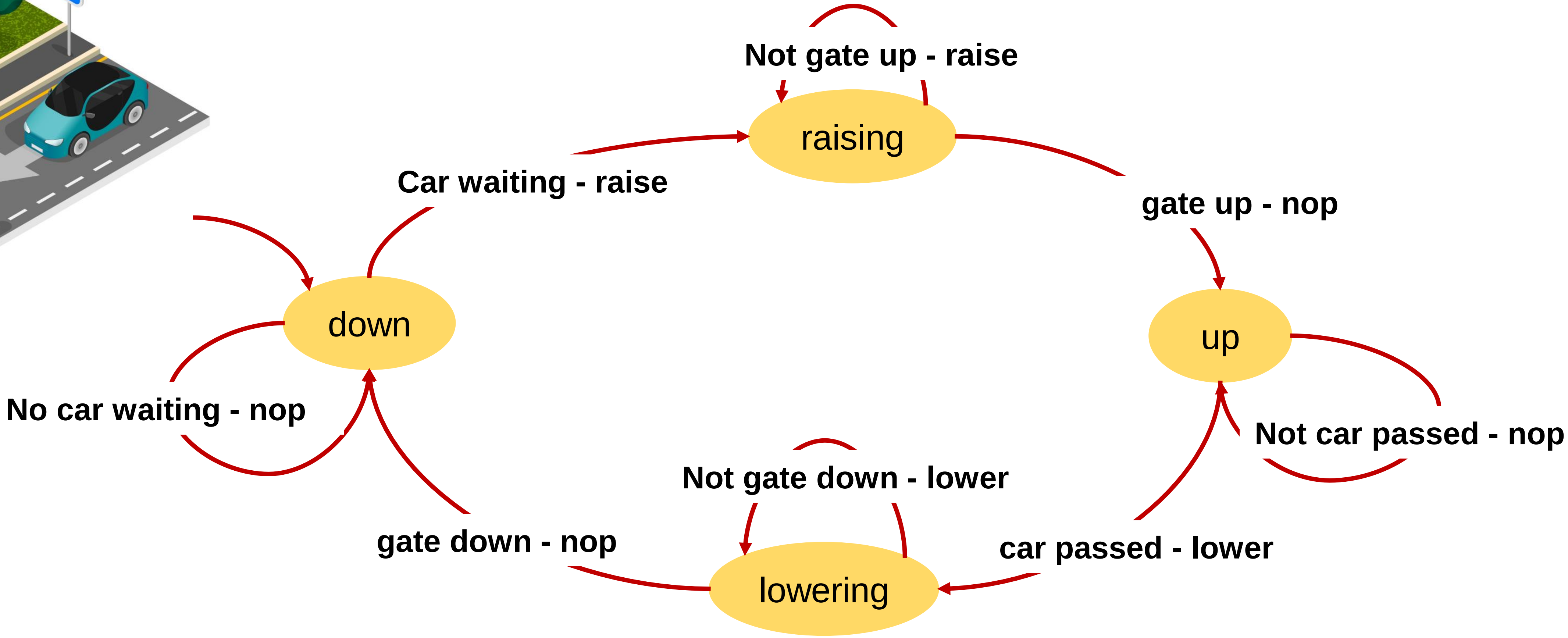
✓ ***States***: ‘down’, ‘raising’, ‘up’, ‘lowering’

✓ ***Input***: ‘no car waiting’, ‘car waiting’, ‘gate up’, ‘not gate up’, ‘gate down’, ‘not gate down’, ‘car passed’, ‘not car passed’

✓ ***Output***: ‘raise’, ‘lower’, ‘nop’

Introduction

Example: Parking Gate Control



Introduction

Control complexity in real world

The complexity of a finite state machine (FSM) can easily explode!
(new states can generate an exponential number of transitions).
The main strategies to keep the architecture tractable are:

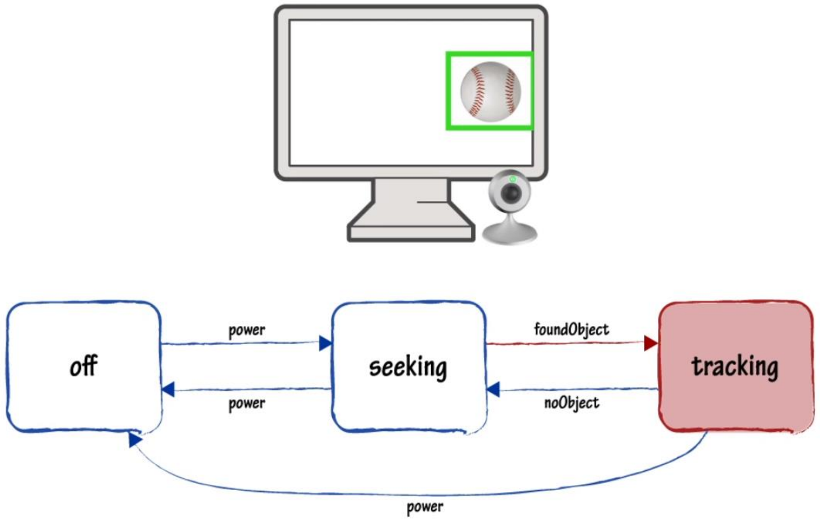
- ✓ Reduction of redundant states
- ✓ ***Hierarchical finite state machines***
- ✓ ***Composition using common patterns (decomposition)***

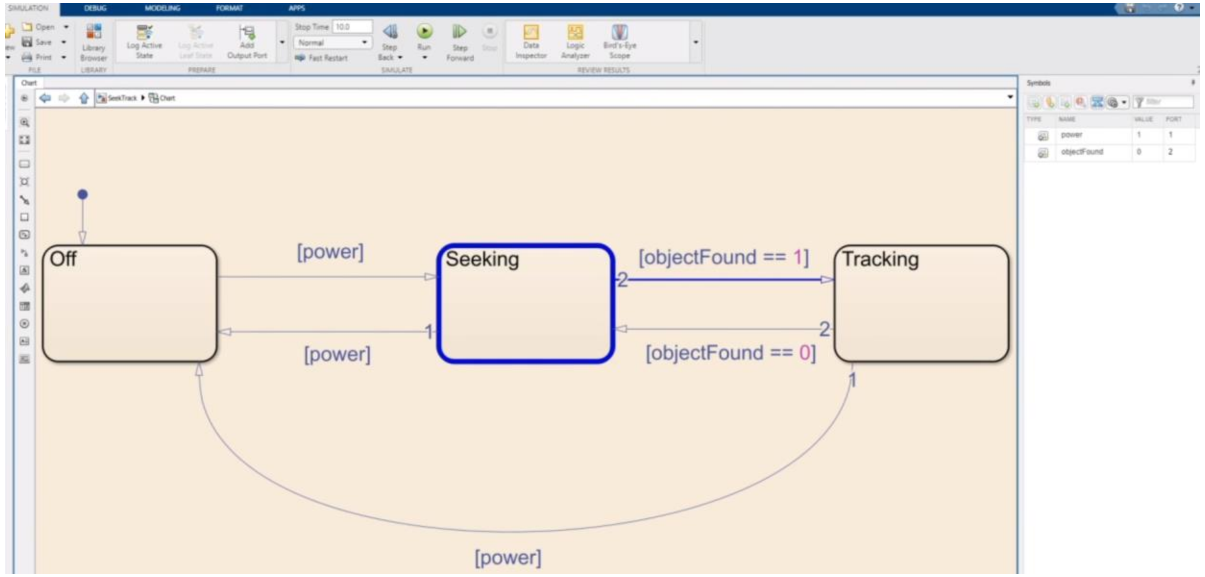
Software requirements

MATLAB®

FSM using Stateflow

Stateflow allows to easily design / test a state machine

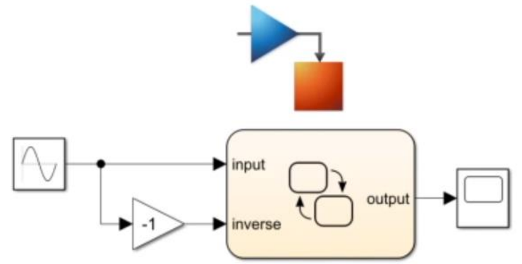


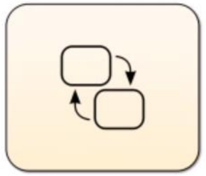


Ref: *stateflow onramp mathworks©*

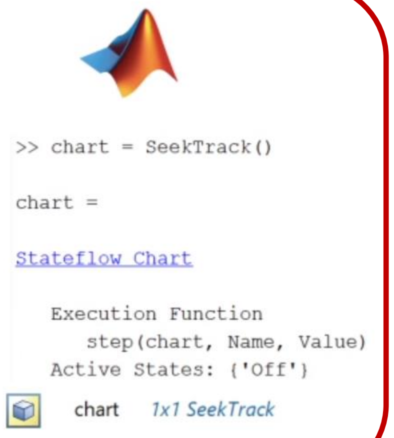
FSM using Stateflow

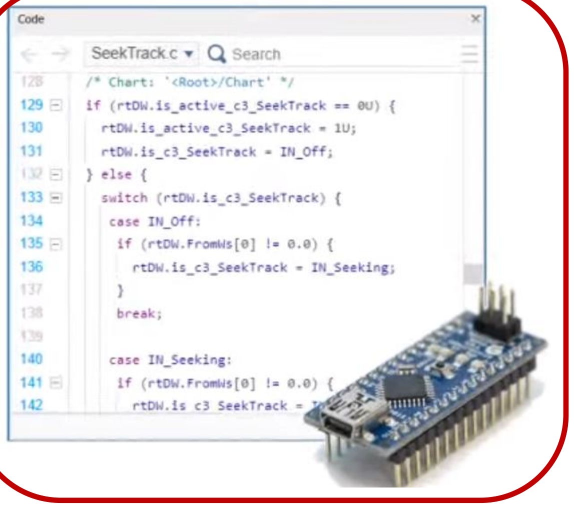
Stateflow allows to easily design / test a state machine





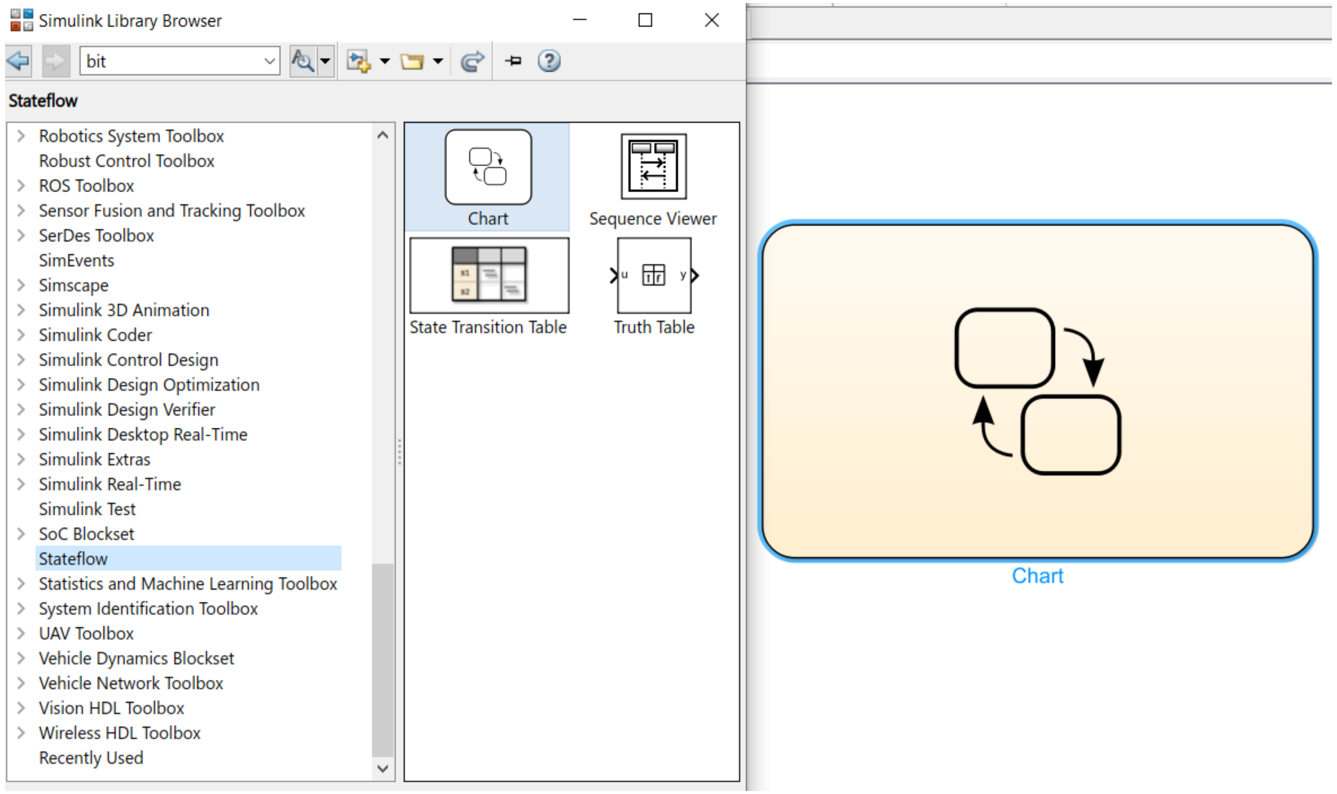
Stateflow





FSM using Stateflow

Stateflow is a graphical programming language that allows you to quickly create a runnable model of your system

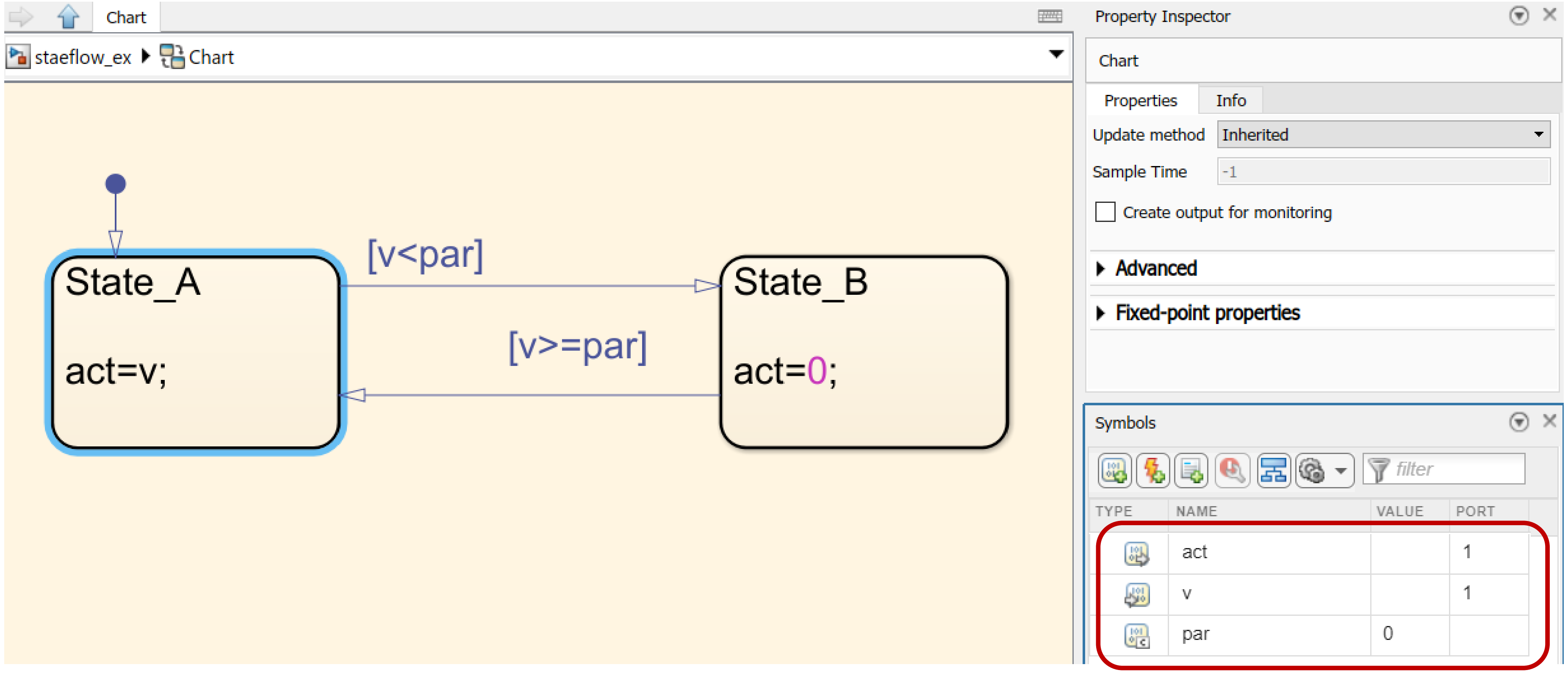


FSM using Stateflow

Main components:

Design panel: draw states, transitions, …

Symbols: add new data, fix unknown, …



FSM using Stateflow

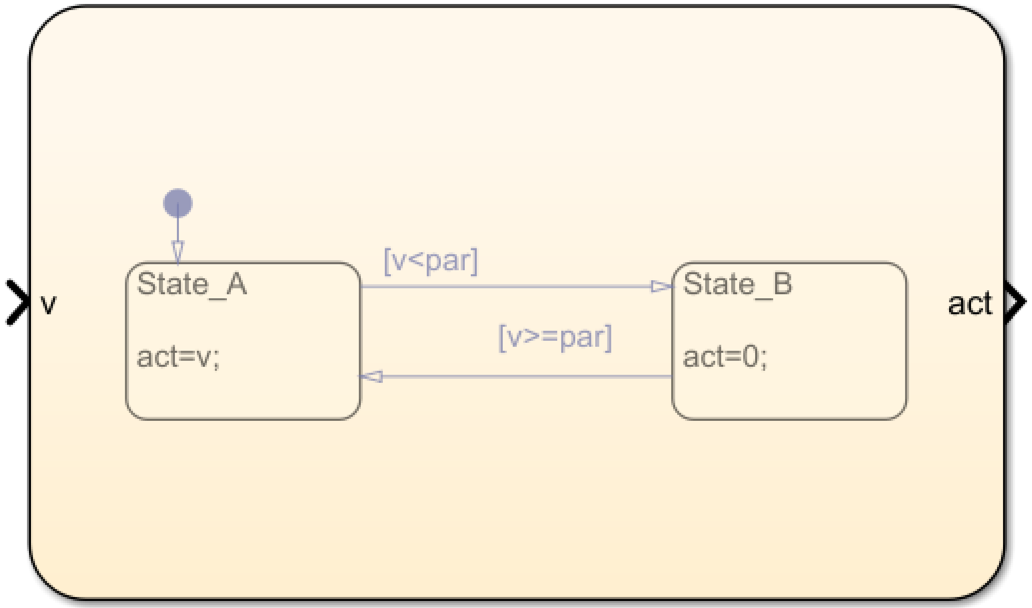
#example 1

Symbols

TYPE	NAME	VALUE	PORT
	act		1
	v		1
	par	0	

outputs
inputs
constant

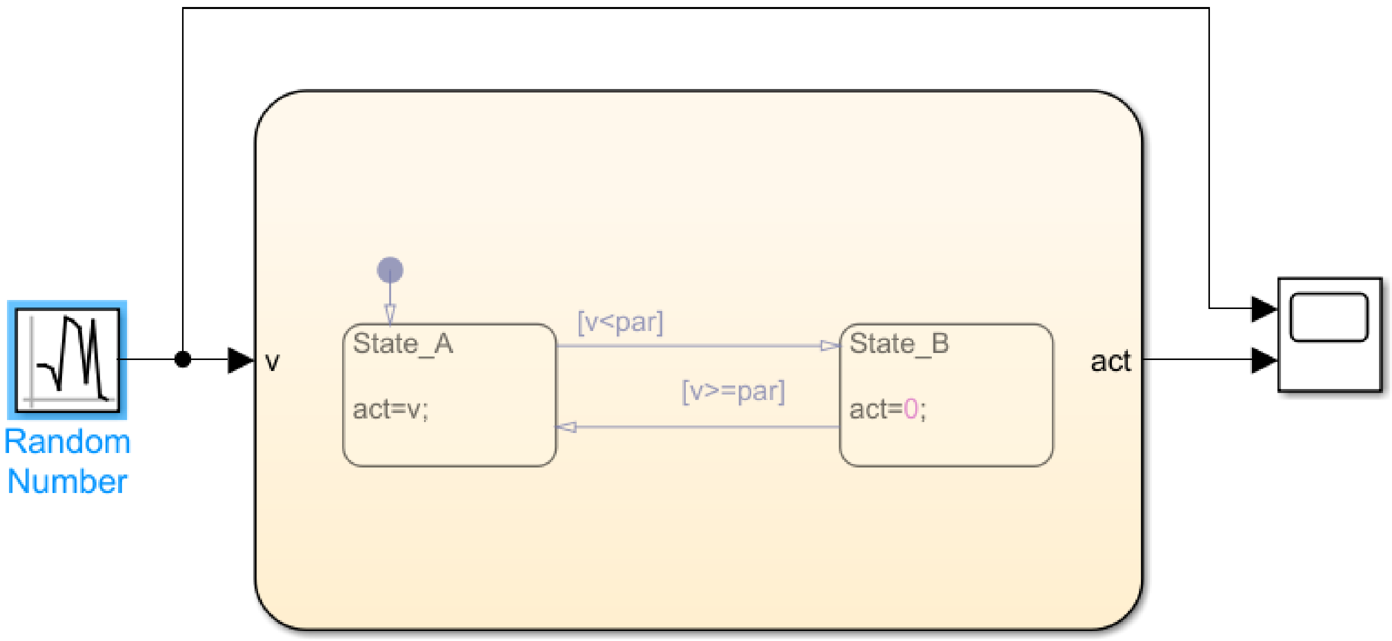
Fix data types

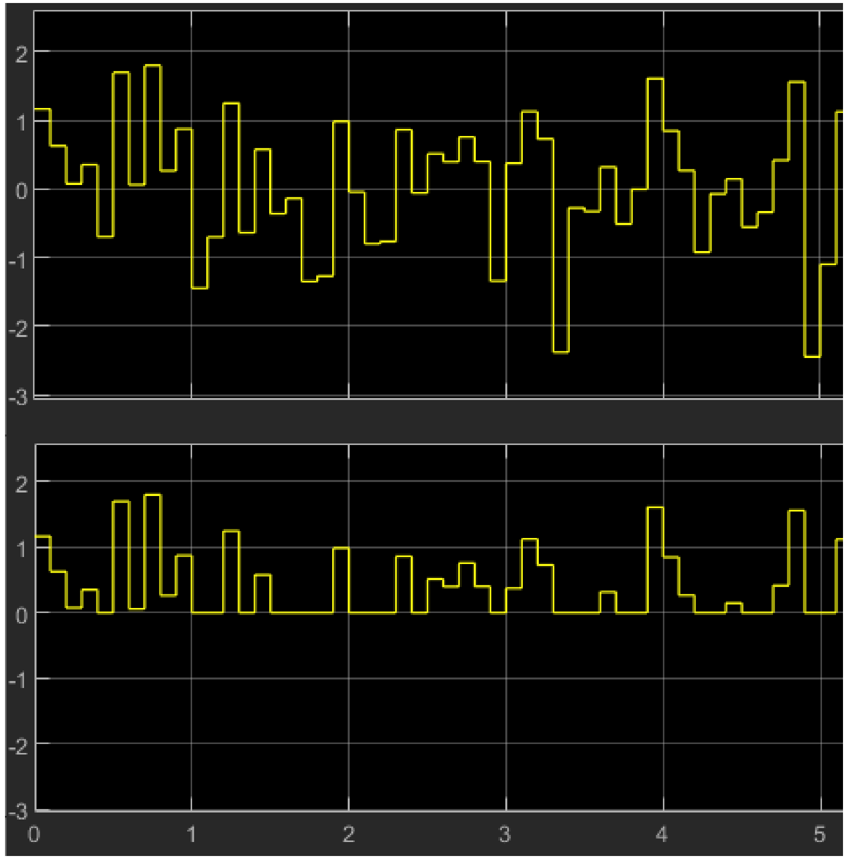


Chart

FSM using Stateflow

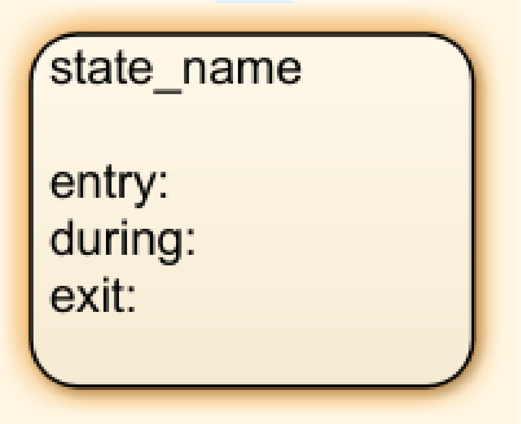
#example 1





FSM using Stateflow

State actions



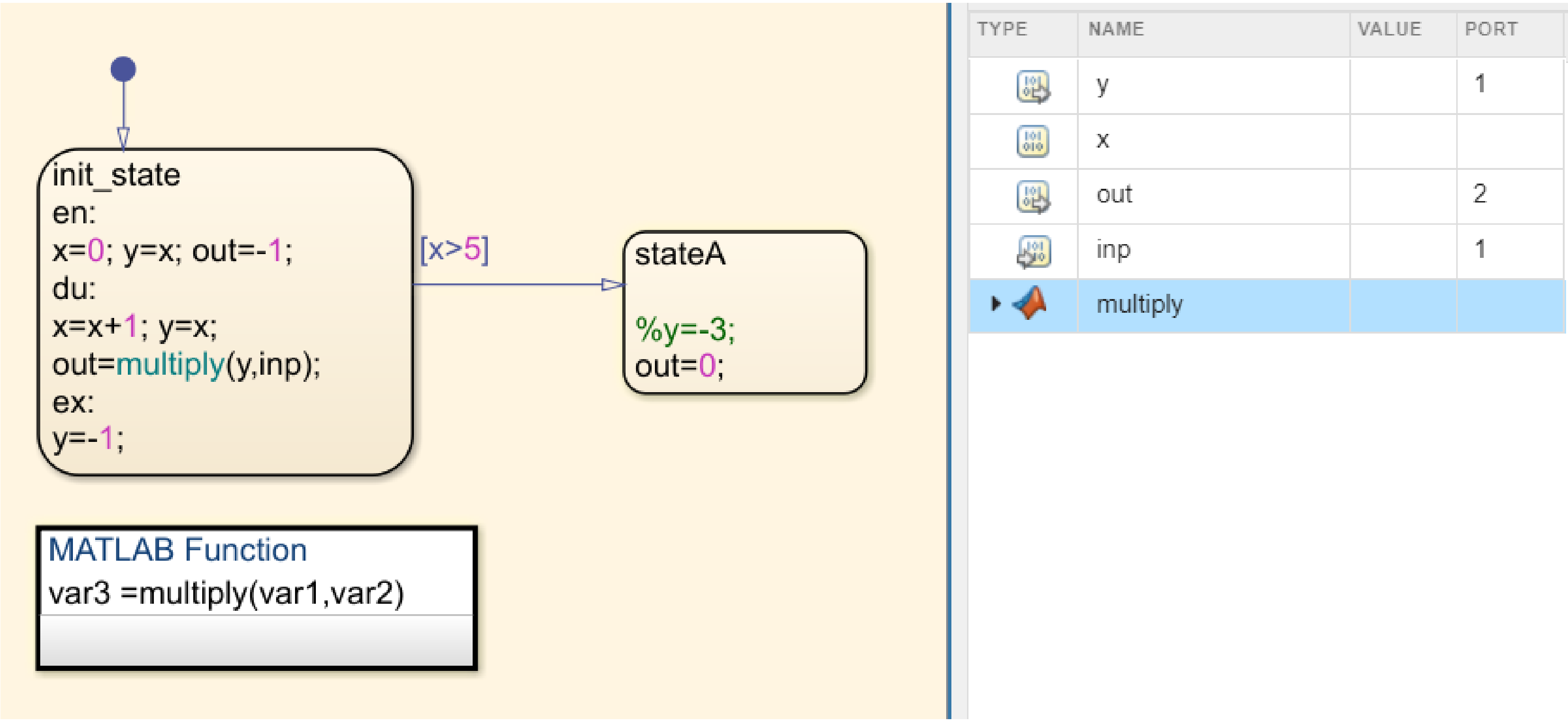
entry	en	Action occurs on a time step when the state becomes active.
during	du	Action occurs on a time step when the state is already active and the chart does not transition out of the state.
exit	ex	Action occurs on a time step when the chart transitions out of the state.

FSM using Stateflow

#example 2

entry
during

exit



FSM using Stateflow

#example 2

```
out=multiply(y,inp);
```

MATLAB Function
var3 =multiply(var1,var2)

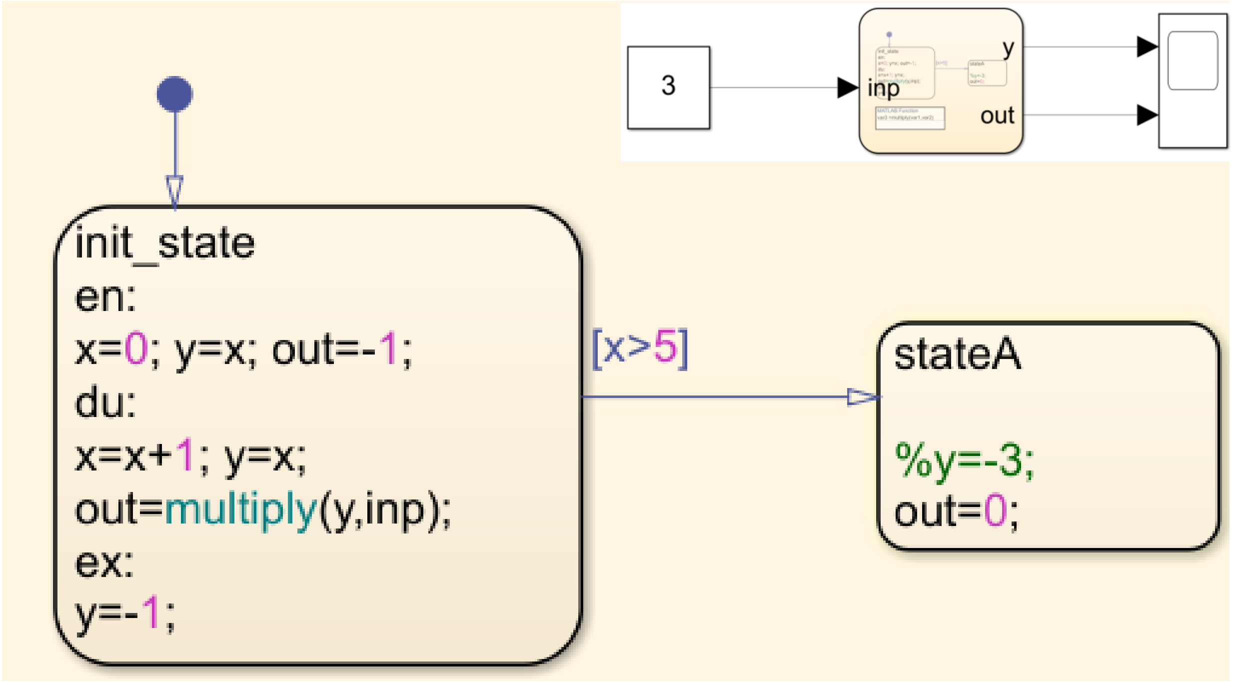
stateflow_ex2 ▸ Chart ▸ multiply

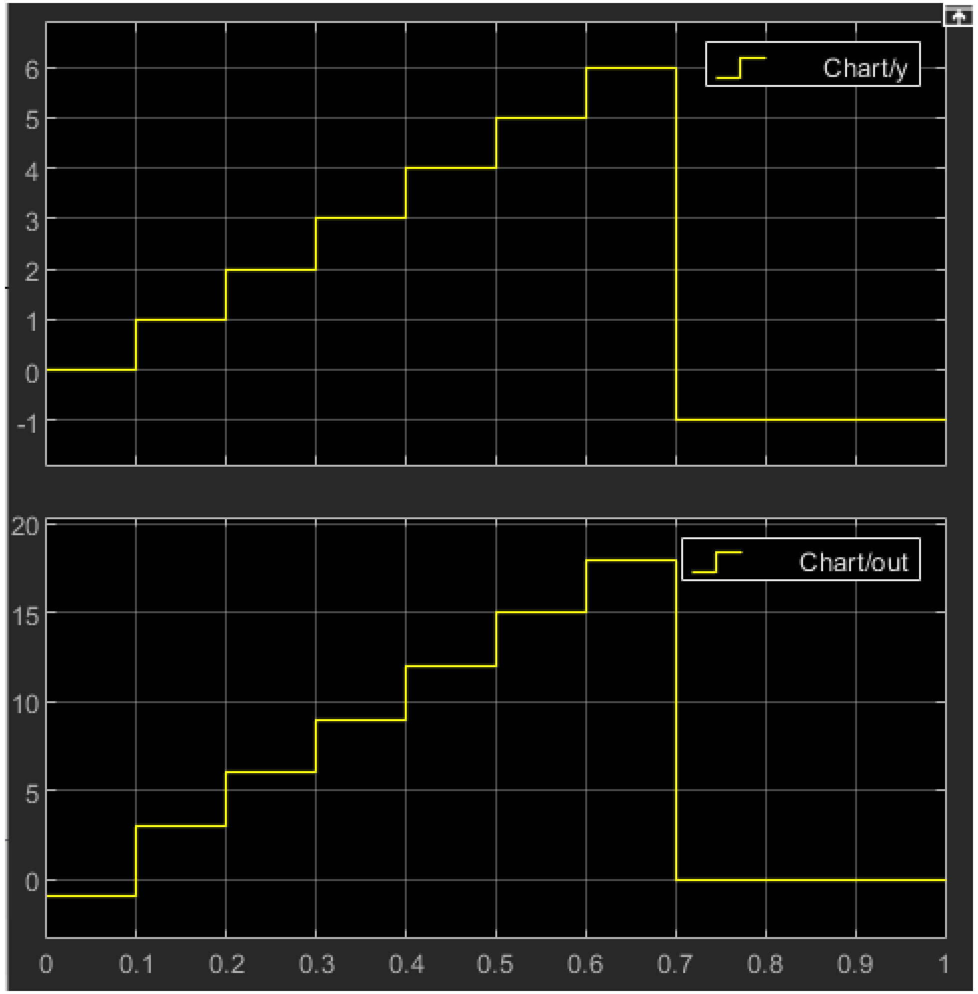
```
function var3 =multiply(var1,var2)

var3=var1*var2;
```

FSM using Stateflow

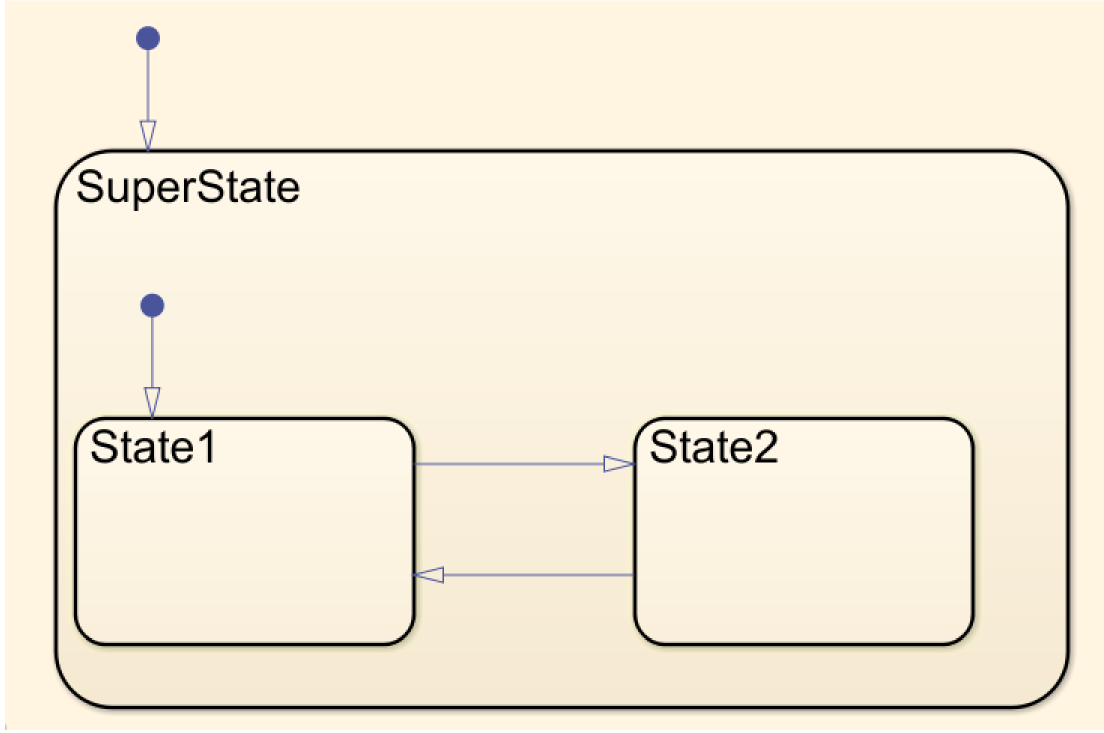
#example 2





FSM using Stateflow

State Hierarchy & parallelization (decomposition)

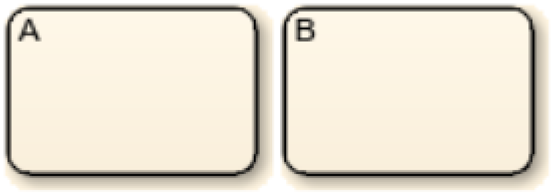


Hierarchy:

- When a parent state becomes active, one of its child states also becomes active.
- When the parent state becomes inactive, all of its child states become inactive.

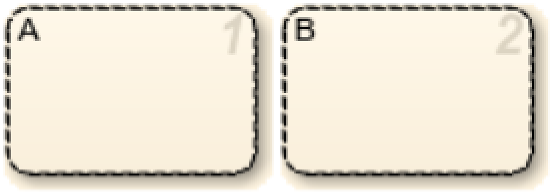
FSM using Stateflow

State Hierarchy & parallelization (decomposition)



Series (OR) : mutually exclusive modes of operation (default).

- Only one state active or execute at the same hierarchical simultaneously.
- Stateflow represents each exclusive state by a solid rectangle.

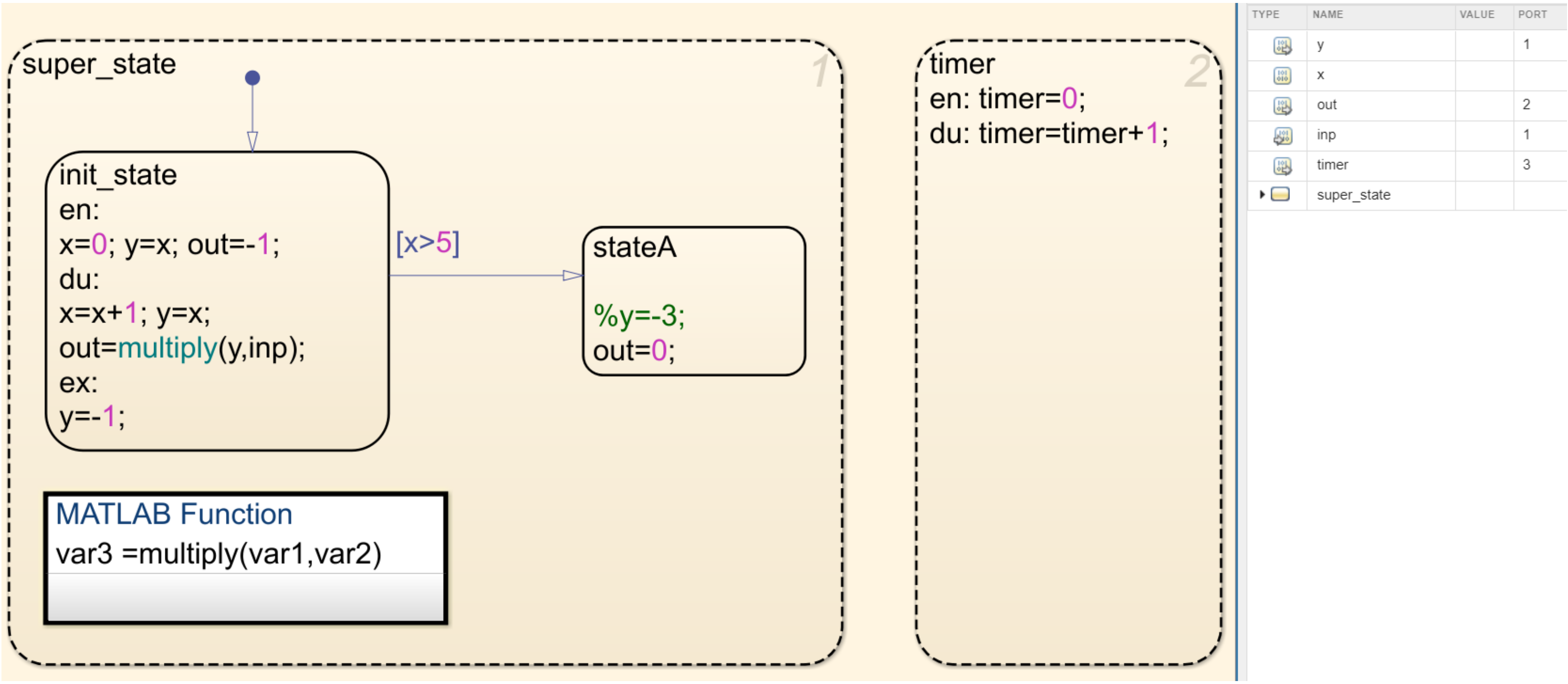


Parallels (AND) : independent modes of operation.

- Two or more parallel states can be active at the same time.
- Stateflow represents each parallel state by a dashed rectangle with a number indicating its execution order.

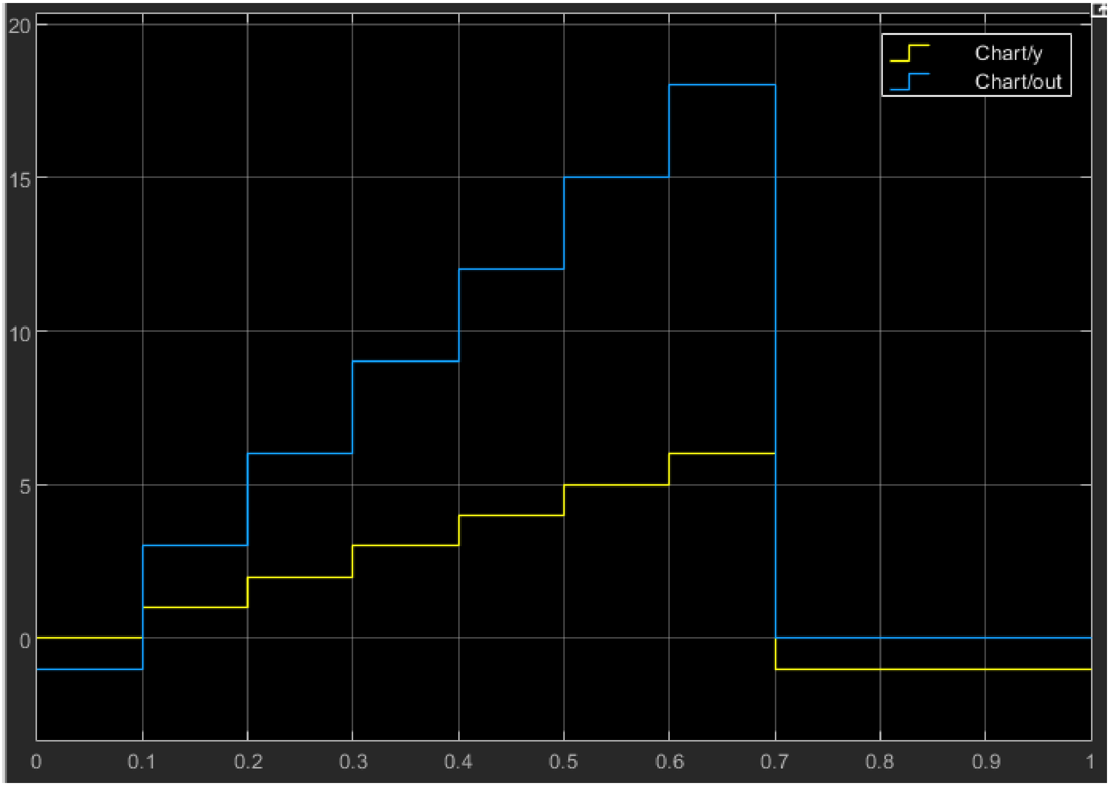
FSM using Stateflow

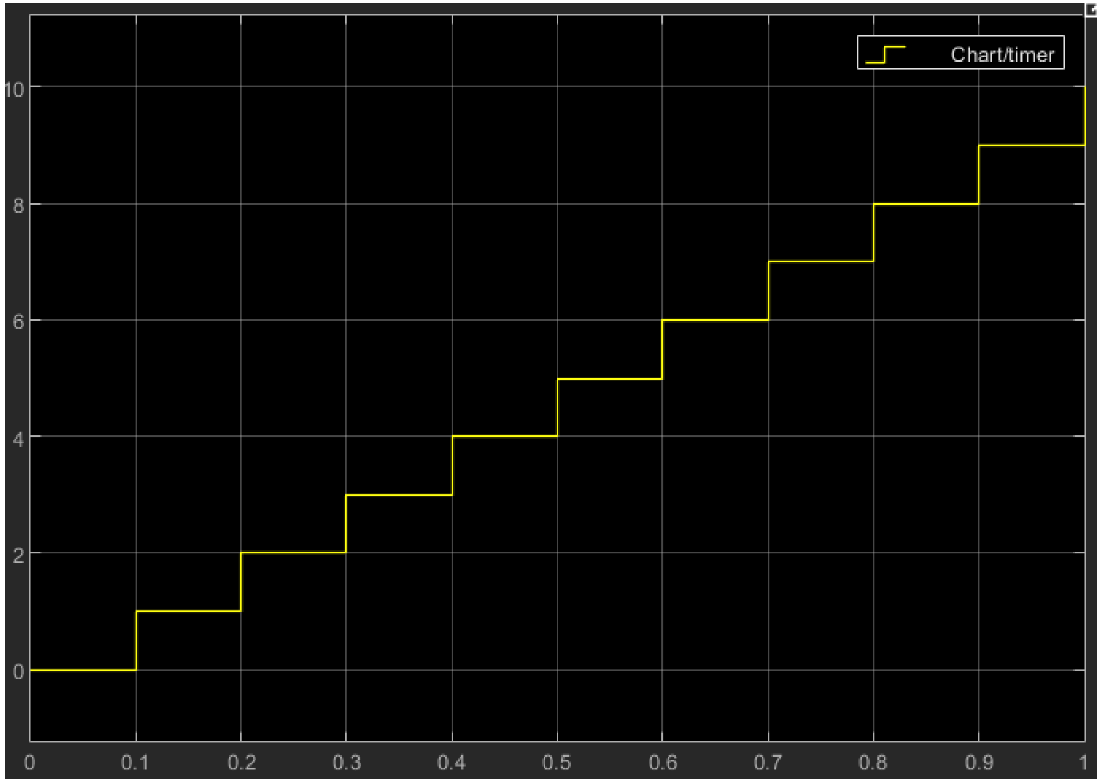
#example 3



FSM using Stateflow

#example 3





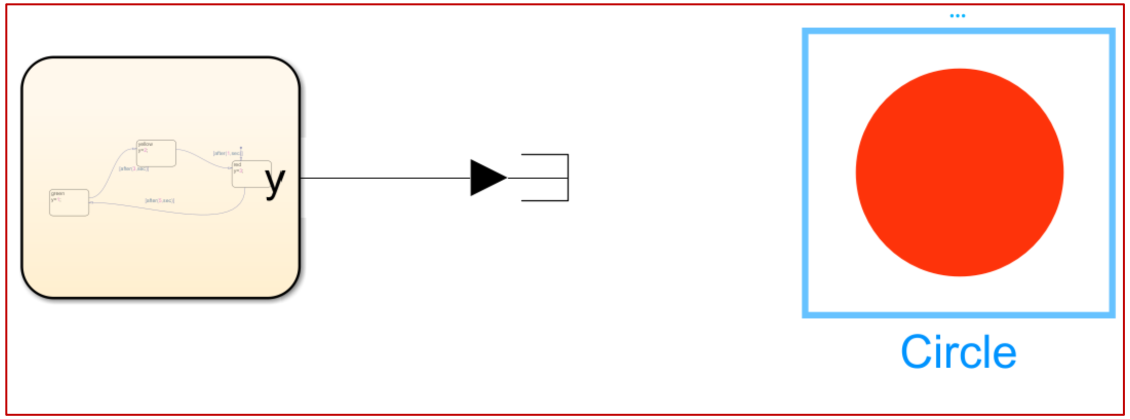
FSM using Stateflow

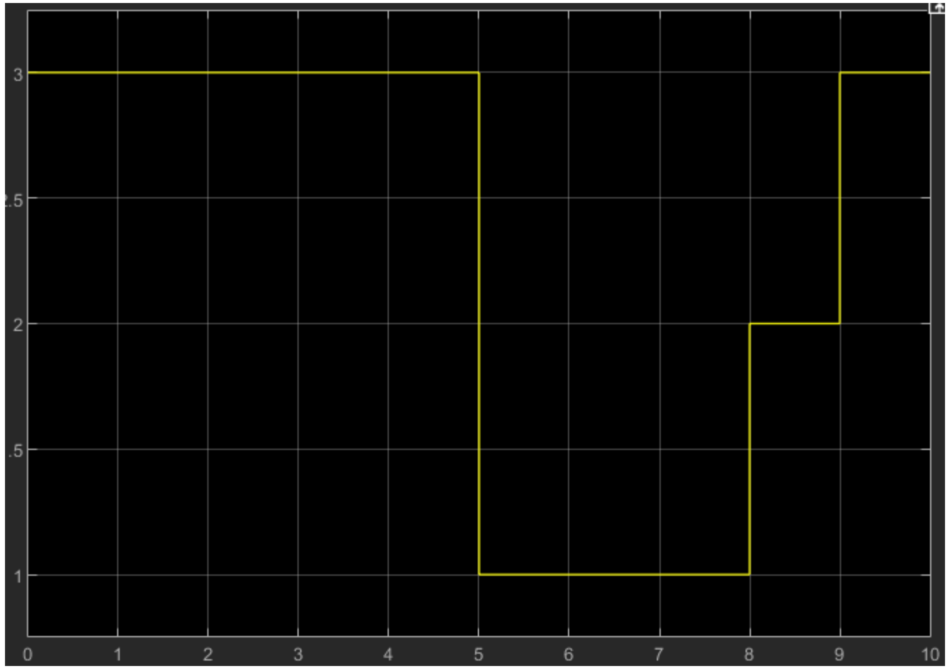
temporal logic operators

after(n,sec)	Returns ***true*** if **n** seconds of simulation time elapsed since the activation of the associated state.
elapsed(sec)	Returns the ***seconds*** of simulation time elapsed since the activation of the associated state.
duration(C)	Returns the ***seconds*** of simulation time that have elapsed since the Boolean condition **C** becomes true.

FSM using Stateflow

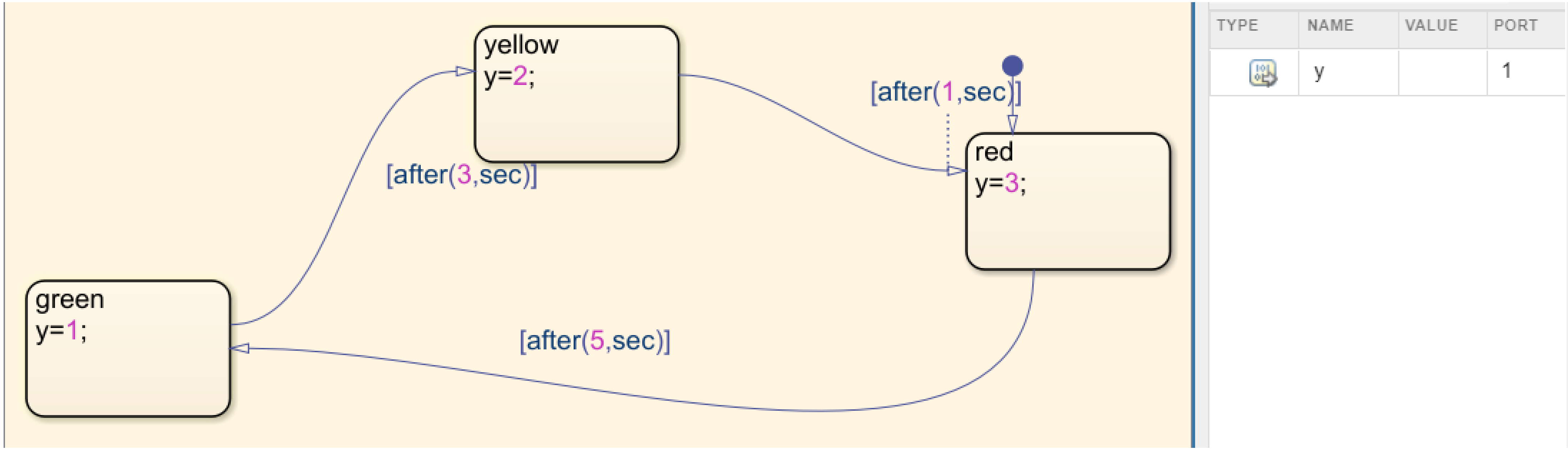
example 4





FSM using Stateflow

example 4



ROS

Assignment V

What we expect from you

Starting from the “parking gate control” example:

1. Analyze and learn how “vehicle FSM” provided works
2. Define “raise” & “lower” functions of the gate according to specifics (next page)
3. Define a FSM to model “parking gate control”
4. Integrate the 2 FSM and run it for 100s

What we expect from you

“raise” & “lower” functions:

1. Max angular speed = 4 deg/sec
2. Down=0°; up=90°
3. Max angular acc/dec = |1| deg/sec^2

Results

- What is mandatory for the report?
  - Plot of travelled distance of vehicles / gate motion in time;
  - Describe FSM designed;
  - Describe “raise” & “lower” functions;
  - (comment results)

That’s it for today…

See you next time!

S. Arrigoni