EclipseCon 2017:
Developing Robotic Applications Using Model-Driven Engineering Techniques

With UML-RT and Papyrus-RT

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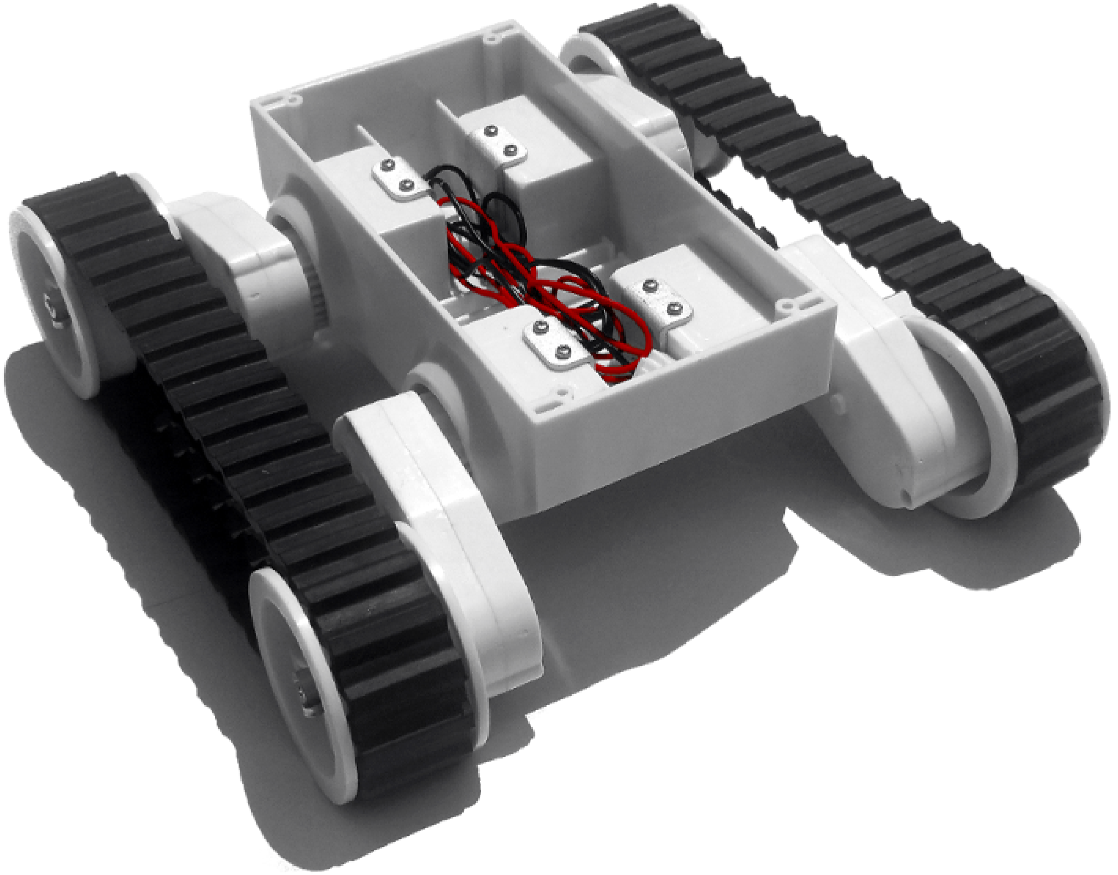
June, 2017

Intro



Model-Driven Engineering (MDE)

- Improve productivity, quality, and ability to handle complexity by
  - increasing level of **abstraction**
    - through use of ‘models’
  - leveraging **automation**
    - e.g., via code generation from models, model transformation, ...
  - improving **analysis** capabilities
    - e.g., through constraint solving, simulation, state space exploration, …

MDE = Abstraction + Automation + Analysis

- Inspired by use of models in engineering and science

MDE: Challenges, Opportunities

- Challenges [1],[2]
  - Technical: user experience, model analysis, …
  - Social: education/training, …
- Opportunities
  - Emerging eco-system: open source, standards, forums, repositories, …
  - Abstraction, automation, and analysis will continue to be key [3]

…

Safety

Security

More integration

More functionality

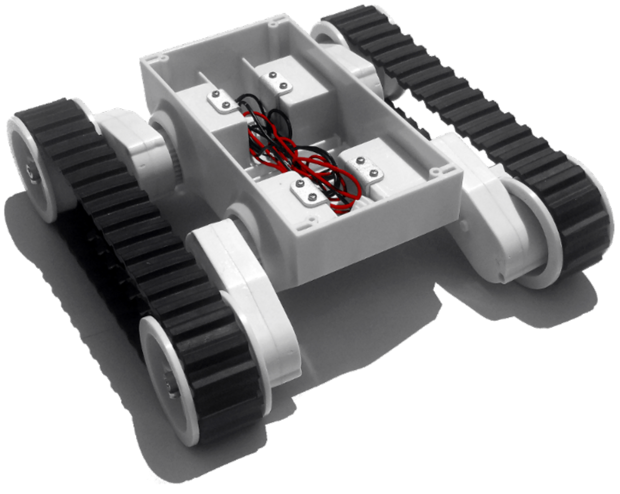
[1] Selic. What will it take? A view on adoption of model-based methods in practice. Software and Systems Modeling (SoSyM) 11(4):513-526. October 2012.

[2] Whittle, Hutchinson, Rouncefield. The state of practice in model-driven engineering. IEEE Software 31 (3), 79-85. 2014.

[3] Dingel. Complexity is the Only Constant: Trends in Computing and their Relevance to Model Driven Engineering. Proceedings ICGT'16. LNCS 9761:79-85. 2016.

Domain-specific languages (DSLs) for robotic applications

- Many different DSLs
  - RobotML,
  - SmartSoft,
  - BCM,
  - V3CMM
- Quite domain-specific:
  - Function modelling
  - Mission planning
  - Deployment modelling



Modeling Languages

Modelica

- Physical systems
- Equation-based

Simulink

- Continuous control, DSP
- time-triggered dataflow

Stateflow

- Reactive systems
- Discrete control
- State-machine-based

AADL

- Embedded, real-time

Lustre/SCADE

- Embedded real-time
- Synchronous dataflow

Examples in [Voe13, Kel08]

UML

UML MARTE

- Embedded, real-time

UML-RT

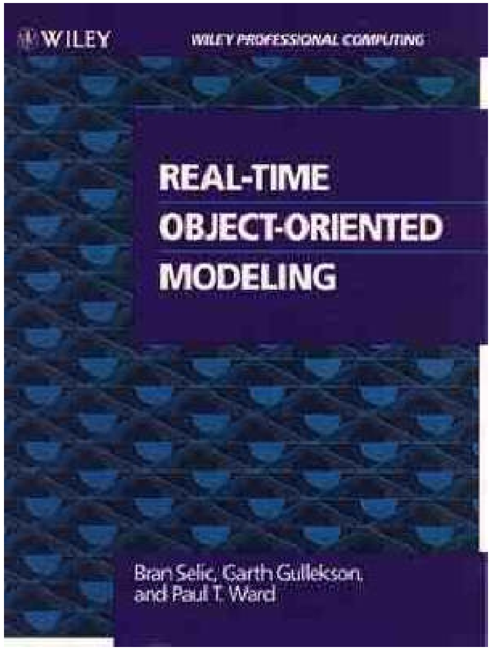
- Embedded, real-time
- State-machine-based

EGGG [Orw00]

increasing generality ⟷ **increasing domain-specifity**

UML-RT: History

- Real-time OO Modeling (ROOM)
  - ObjecTime, early 1990 ties
- Major influence on UML 2
  - E.g., StructuredClassifier
- "RT subset of UML"
- Tools
  - ObjecTime Developer
  - IBM Rational RoseRT
  - IBM RSA-RTE
  - Eclipse Papyrus-RT



[Selic, Gullekson, Ward. *Real-Time Object-Oriented Modellng*. Wiley. 1994]

Goal of the Workshop

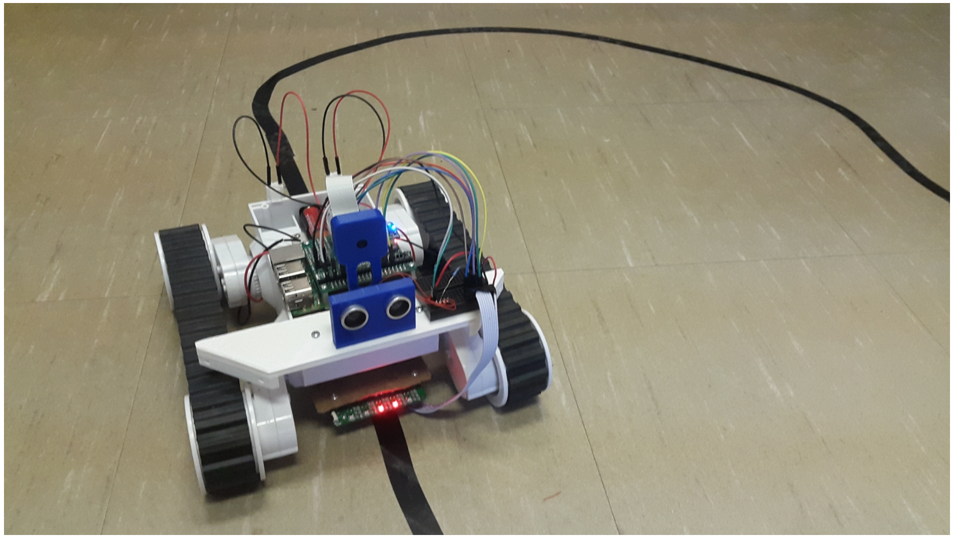
- Inform
  - Intro to robotic development for the PolarSys Rover
  - Intro to MD with UML-RT and Papurys-RT
- Combine
  - MDE for robotic applications
  - Application to the PolarSys Rover
- Inspire
  - We need more abstraction, automation, and analysis !
  - UML-RT
    - Small, cohesive set of concepts
    - Successful track record, but work needed on, e.g.,
      - static analysis, user experience, deployment, interpretation, testing, verification, simulation, …

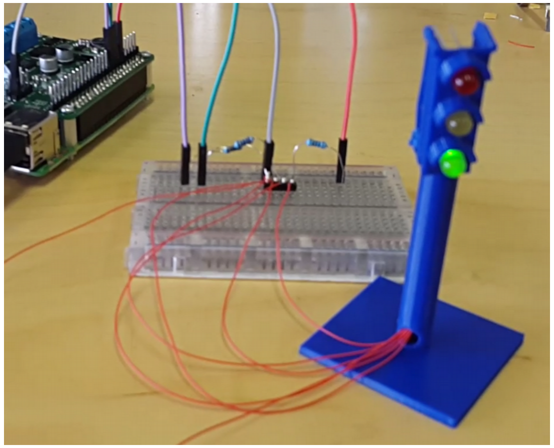
Overview

1.	Intro / MDE	(10 mins)	(8 slides)
2.	Overview	(1 min)	(1 slide)
3.	PolarSys Rover	(15 mins)	(16 slides)
4.	Demo I	(5 mins)	
5.	Hands on session	(20 mins)	(2 slides)
6.	UML-RT: Part I • Core concepts	(25 mins)	(26 slides)
7.	Demo II	(10 mins)	(3 slides)
8.	Hands on session	(20 mins)	(1 slide)
9.	UML-RT: Part II • More advanced concepts	(10 mins)	(14 slides)
10.	Hackaton	(90 mins)	(3 slides)
11.	Conclusion	(5 mins)	(2 slides)

PolarSys Rover development

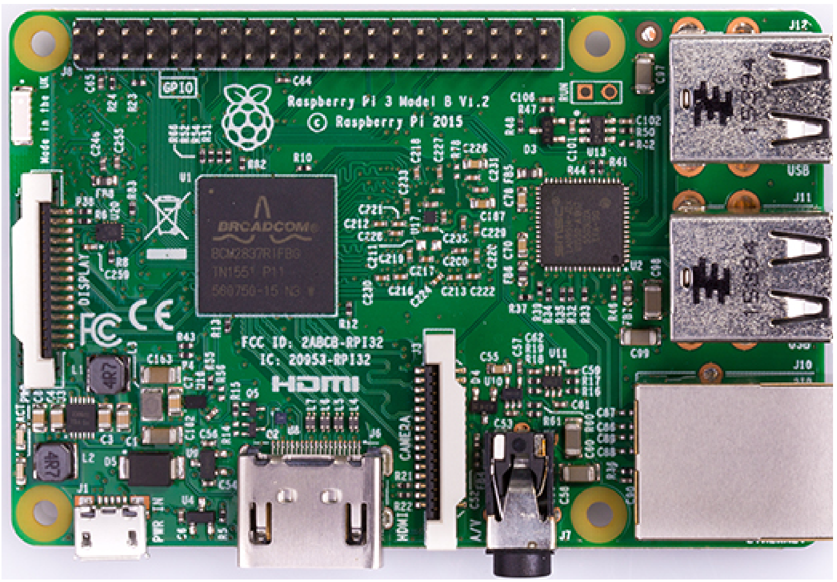
- PolarSys Rover
  - Pololu Dagu Rover 5 Tracked Chassis
  - Auto-calibrating line sensor LSS05
  - Ultrasonic detection sensor SR04
  - Raspicam
  - 3D printed extensions





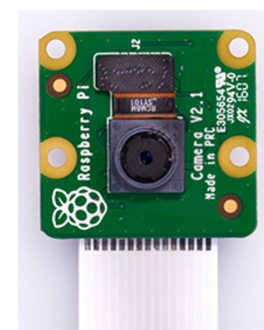
- Traffic Light
  - Raspicam-powered
  - 3D printed model of the traffic light

Raspberry PI 3 Model B



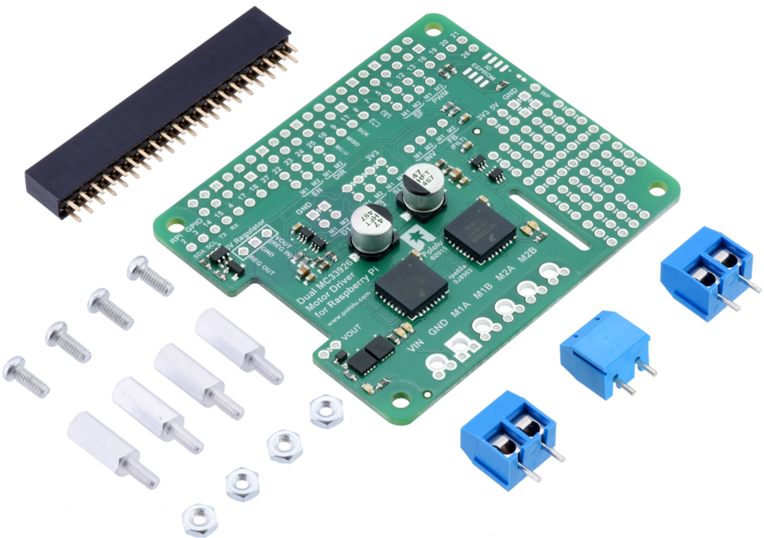
- 4 USB ports
- 40 GPIO pins
- HDMI port
- Ethernet port
- Camera interface (CSI) for camera module
- Micro SD card slot
- VideoCore IV 3D graphics core

- 1.2GHz 64-bit quad-core ARMv8 CPU
- 1GB RAM
- Built-in 802.11n Wireless LAN
- Built-in Bluetooth 4.1



Source: https://www.raspberrypi.org/products/raspberry-pi-3-model-b/

Pololu Dual MC33926 Motor Driver for Raspberry Pi



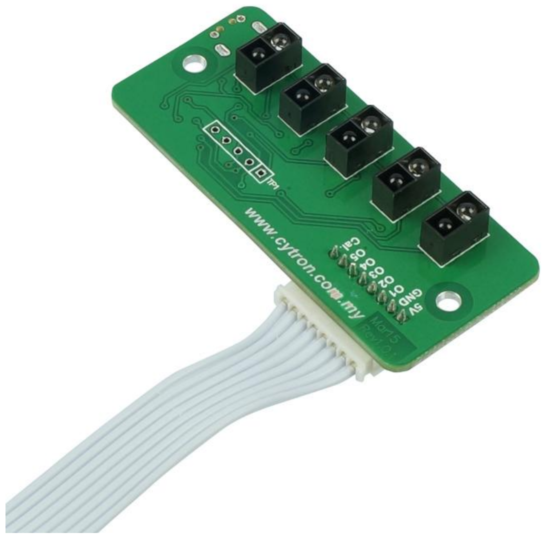
Motor driver mounted on top of the Raspberry PI

- Add-on for Raspberry PI
- Can control up to two bidirectional brushed DC motors
- All GPIO ports are available
- 8 GPIOs are used for controlling the two motors (can be re-wired)

- Must be supplied with 5V to 28V
- **Do not power the Raspberry PI (by default)**
  - A voltage regulator can be added to power the Raspberry PI
  - Otherwise, the Raspberry must be powered independently through its USB receptacle

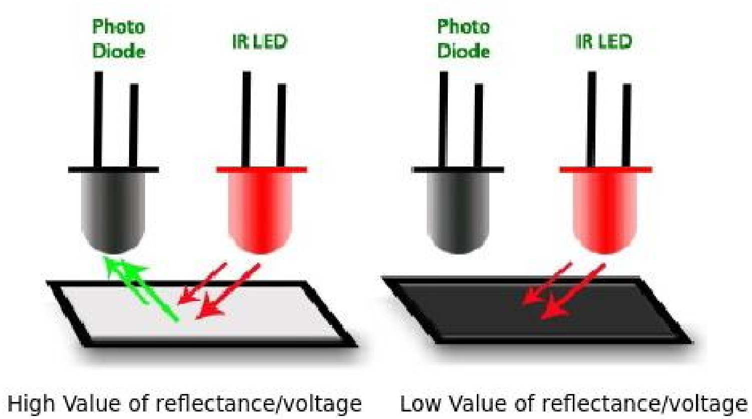
Source: https://www.pololu.com/product/2755

Auto calibrating line follower LSS05



- Easy-to-use line follower
- Powered with 5V supply
- 5 pairs of IR transmitter and receiver
- LEDs for visual feedback
- Line detection of 1cm to 3cm
- Auto calibrate
- Dark and bright mode selection

Principle:

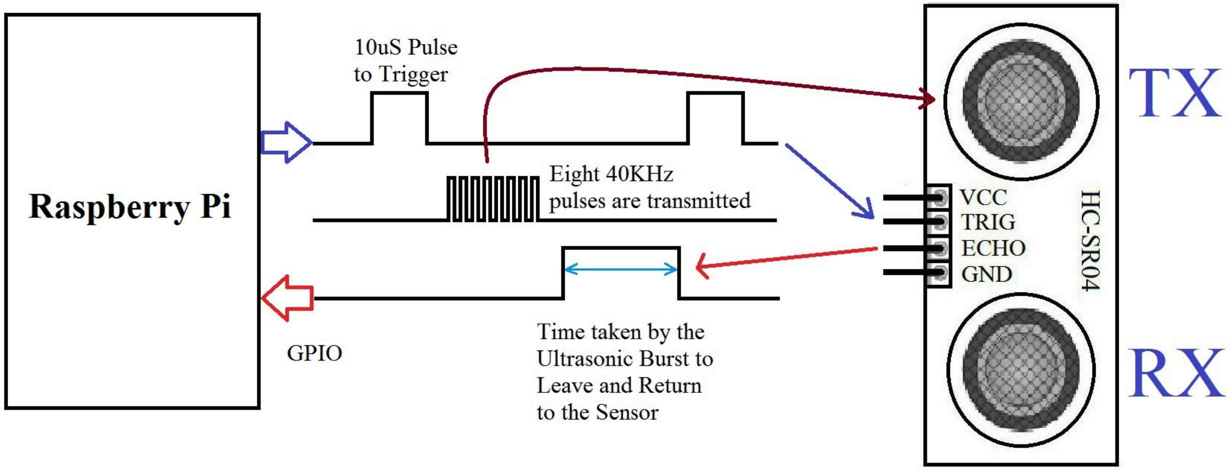


Source: https://www.cytron.com.my/p-lss05

Ultrasonic SR04

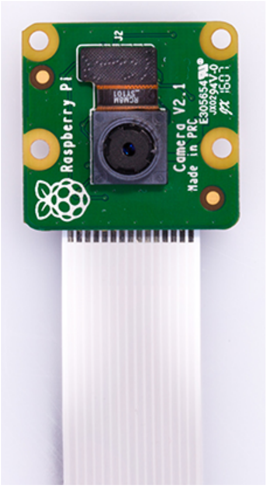
- Most commonly used sensor for detecting distances
- Unexpansive (less than 5$)
- Range: 2cm to 400cm
- Two GPIOs:
  - trigger (output)
  - echo (input)
- **Attention: the echo pin delivers a 5V voltage**

Principle:

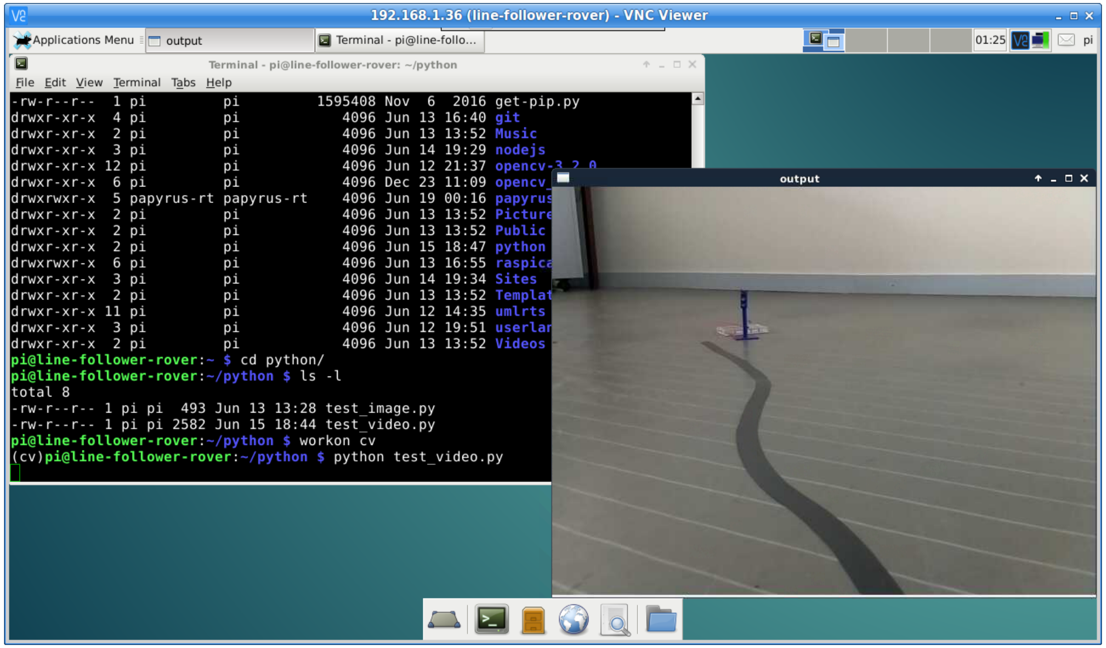


Source: https://electrosome.com/hc-sr04-ultrasonic-sensor-raspberry-pi/

Camera module



- Camera module for Raspberry PI
- Sony IMX219 8-megapixel sensor
- Connected to the CSI port using a 15cm ribbon cable



Raspberry PI 3 Built-in applications:

- `raspistill / raspistillyuv`
- `raspivid`

Different libraries to use:

- Raspicam available for Python / C++
- OpenCV

Sources:

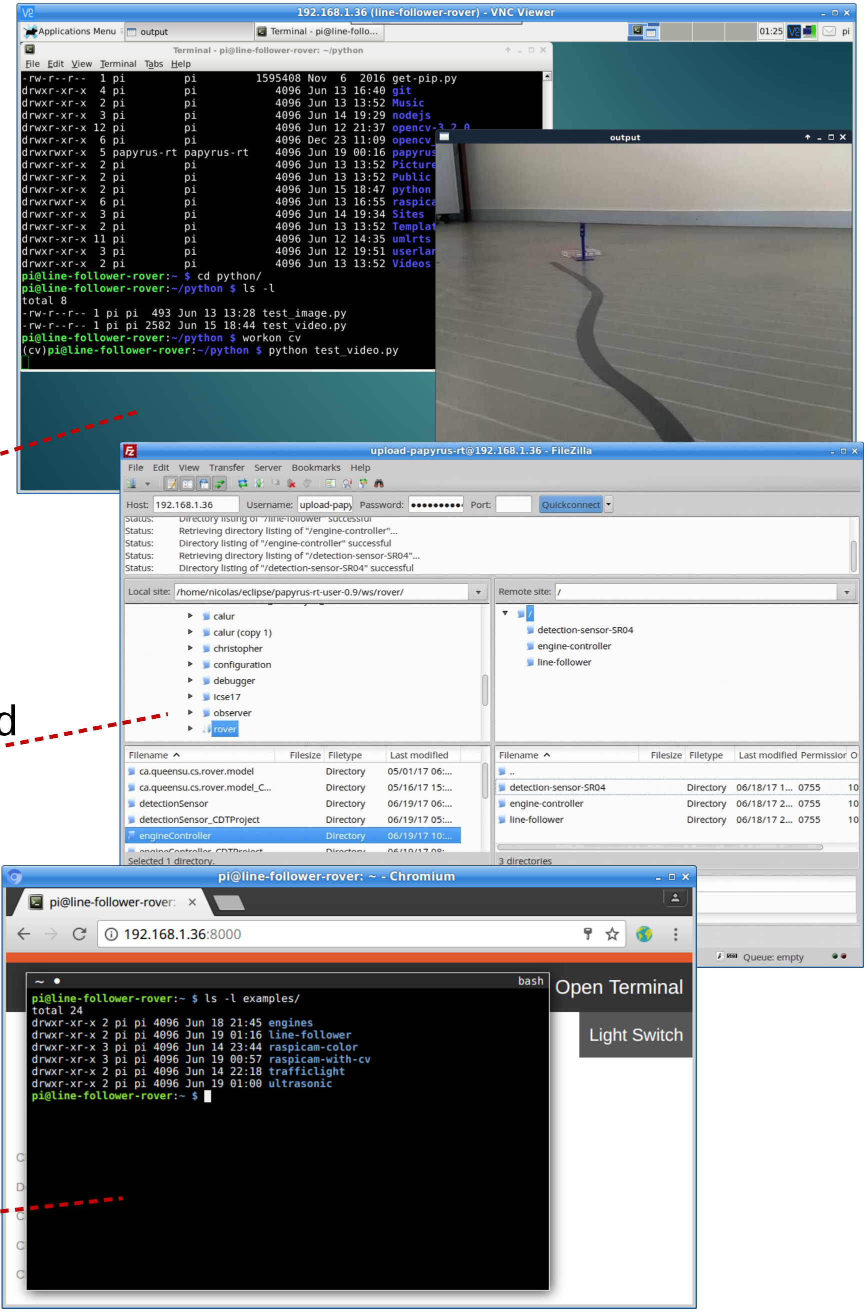
- https://www.raspberrypi.org/products/camera-module-v2/
- https://www.raspberrypi.org/documentation/raspbian/applications/camera.md

Accessing the Raspberry PI 3

- Common ways for accessing the Raspberry PI:
  - Using a monitor, keyboard and mouse
  - SSH
    - Comand-line interface (CLI)
    - Putty for Windows
  - Virtual Network Computing (VNC)
    - VNC viewer, …
    - Requires a Desktop manager to be installed
  - File Transfer Protocol (FTP)
    - Raspberry PI 3 : pure-ftp, …
    - Client: FileZilla, …
- SSH, VNC, and FTP are disabled by default on Raspberry PI. To enable them:

```
$ raspi-config
```

- Also available for this workshop:
  - TTy.js



Connecting your Raspberry PI 3

- Connecting your Raspberry PI 3:
  - Ethernet cable
  - Built-in Wi-fi
    - Wicd applet / Wicd-curse
    - NetworkManager
    - Configuring the Wifi network:
      - /etc/wpa_supplicant/wpa_supplicant.conf

```
…
network={
     ssid="MySSID"
     key_mgmt=WPA-EAP
     Identity="..."
     Password="..."
     id_str="home"
}
…
```

- Discovering your Raspberry PI 3:

```
$ nmap 192.168.1.0/24
```

```
Nmap scan report for line-follower-rover
(192.168.1.36)
Host is up (0.010s latency).
Not shown: 997 closed ports
PORT      STATE SERVICE
21/tcp    open  ftp
22/tcp    open  ssh
5900/tcp  open  vnc
```

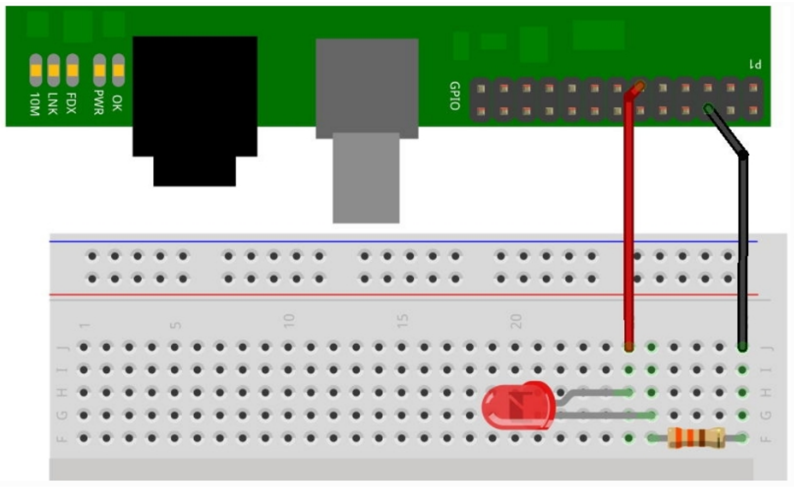
- Turning your Raspberry PI 3 into a Wi-fi hotspot
  - Hostapd, …

Your first Application

- Turning a LED on
  - Led connected via a breadboard
  - Different ways for accessing the GPIO
    - System calls:

```
echo 11 > /sys/class/gpio/export
echo out > /sys/class/gpio/gpio11/direction
echo 1 > /sys/class/gpio/gpio11/value
```

    - GPIOClass (no longer maintained ?)
    - Gpio utility (provided by the wiringPI library)



Source: http://wiringpi.com/examples/blink/

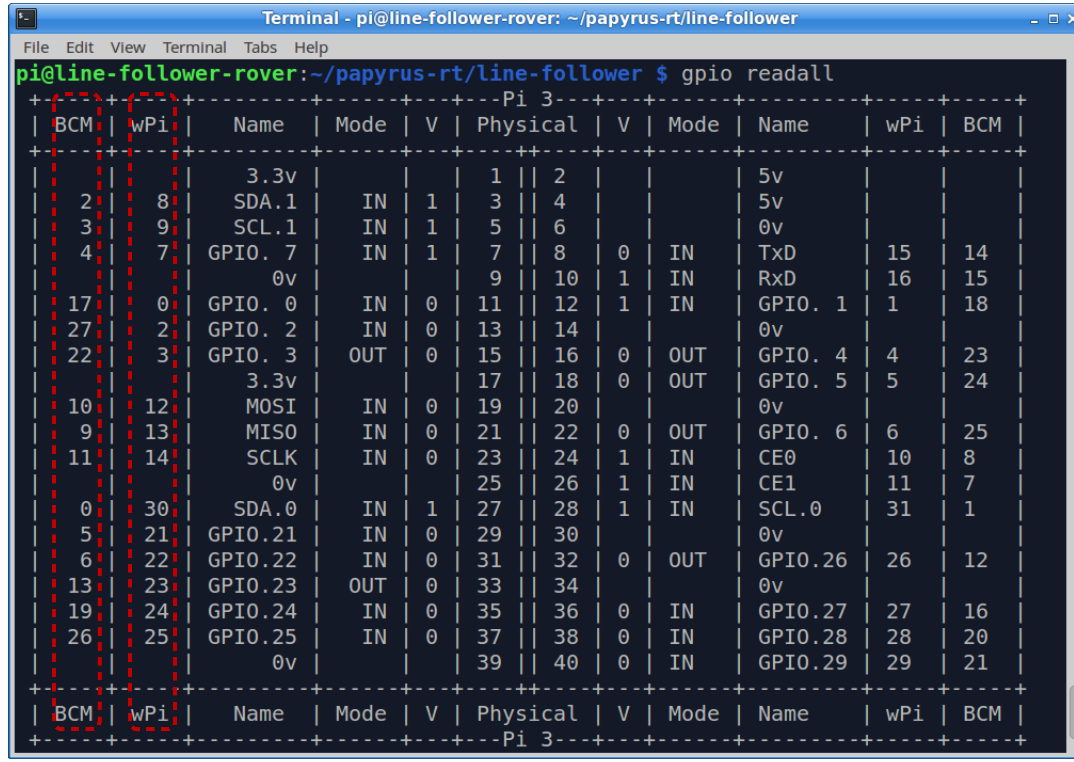
WiringPI library

- Provide an easy-to-use access to the GPIOs of the Raspberry PI
- Compatible with Raspberry PI 1, 2, 3 model A and B
- Provides a gpio utility
- Initially developed for C/C++, but some wrappers exist in Python, Java, …
- Advanced features:
  - Timer, interrupts, delays
  - Support Pulse-Width Modulation (PWM)
    - SoftPWM
  - I2C, SPI libraries
  - …

Source: http://wiringpi.com

Gpio utility

- An easy way for testing your system
- Different functions:
  - `gpio readall`
    - ➔ Display a table of GPIO mode and value
  - `gpio mode 2 output`
    - ➔ Set the mode of GPIO #2 to output
  - `gpio write 2 1`
    - ➔ Set the GPIO #2 to high
- **WiringPI uses its own mapping !**
  - Portability among the different versions of Raspberry PI
  - May cause confusion
  - Still possible to use the Raspberry PI GPIO pin numbers




```
pi@line-follower-rover:~/papyrus-rt/line-follower $ gpio readall
 +-----+-----+---------+------+---+---Pi 3---+---+------+---------+-----+-----+
 | BCM | wPi |   Name  | Mode | V | Physical | V | Mode | Name    | wPi | BCM |
 +-----+-----+---------+------+---+----++----+---+------+---------+-----+-----+
 |     |     |    3.3v |      |   |  1 || 2  |   |      | 5v      |     |     |
 |   2 |   8 |   SDA.1 |   IN | 1 |  3 || 4  |   |      | 5v      |     |     |
 |   3 |   9 |   SCL.1 |   IN | 1 |  5 || 6  |   |      | 0v      |     |     |
 |   4 |   7 | GPIO. 7 |   IN | 1 |  7 || 8  | 0 | IN   | TxD     | 15  | 14  |
 |     |     |      0v |      |   |  9 || 10 | 1 | IN   | RxD     | 16  | 15  |
 |  17 |   0 | GPIO. 0 |   IN | 0 | 11 || 12 | 1 | IN   | GPIO. 1 | 1   | 18  |
 |  27 |   2 | GPIO. 2 |   IN | 0 | 13 || 14 |   |      | 0v      |     |     |
 |  22 |   3 | GPIO. 3 |  OUT | 0 | 15 || 16 | 0 | OUT  | GPIO. 4 | 4   | 23  |
 |     |     |    3.3v |      |   | 17 || 18 | 0 | OUT  | GPIO. 5 | 5   | 24  |
 |  10 |  12 |    MOSI |   IN | 0 | 19 || 20 |   |      | 0v      |     |     |
 |   9 |  13 |    MISO |   IN | 0 | 21 || 22 | 0 | OUT  | GPIO. 6 | 6   | 25  |
 |  11 |  14 |    SCLK |   IN | 0 | 23 || 24 | 1 | IN   | CE0     | 10  | 8   |
 |     |     |      0v |      |   | 25 || 26 | 1 | IN   | CE1     | 11  | 7   |
 |   0 |  30 |   SDA.0 |   IN | 1 | 27 || 28 | 1 | IN   | SCL.0   | 31  | 1   |
 |   5 |  21 | GPIO.21 |   IN | 0 | 29 || 30 |   |      | 0v      |     |     |
 |   6 |  22 | GPIO.22 |   IN | 0 | 31 || 32 | 0 | OUT  | GPIO.26 | 26  | 12  |
 |  13 |  23 | GPIO.23 |  OUT | 0 | 33 || 34 |   |      | 0v      |     |     |
 |  19 |  24 | GPIO.24 |   IN | 0 | 35 || 36 | 0 | IN   | GPIO.27 | 27  | 16  |
 |  26 |  25 | GPIO.25 |   IN | 0 | 37 || 38 | 0 | IN   | GPIO.28 | 28  | 20  |
 |     |     |      0v |      |   | 39 || 40 | 0 | IN   | GPIO.29 | 29  | 21  |
 +-----+-----+---------+------+---+----++----+---+------+---------+-----+-----+
 | BCM | wPi |   Name  | Mode | V | Physical | V | Mode | Name    | wPi | BCM |
 +-----+-----+---------+------+---+---Pi 3---+---+------+---------+-----+-----+
```

Blink

```
#include <wiringPi.h>
int main (void)
{
 wiringPiSetup () ;

 pinMode (0, OUTPUT) ;
 for (;;)
 {
  digitalWrite (0, HIGH) ; delay (500) ;
  digitalWrite (0,  LOW) ; delay (500) ;
 }
 return 0 ;
}
```

Initialisation

Setting pin mode
(INPUT or OUTPUT)

Setting values of output GPIOs
(LOW or HIGH)

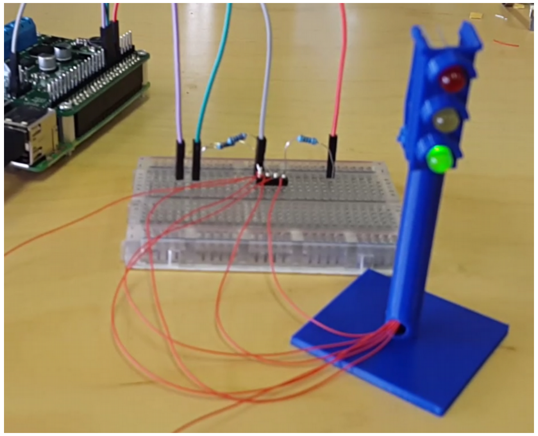
To compile :

```
$ gcc -Wall -o traffic-light traffic-light.c -lwiringPi
```

Source: http://wiringpi.com/examples/blink/

Traffic Light

```
#include <wiringPi.h>

#define GREEN 2
#define ORANGE 3
#define RED 0

int main(void)
{
  wiringPiSetup();

  pinMode(GREEN, OUTPUT);
  pinMode(ORANGE, OUTPUT);
  pinMode(RED, OUTPUT);

  for (;;)
  {
        digitalWrite(RED, LOW);
        digitalWrite(GREEN, HIGH);
        delay(4000);

        digitalWrite(GREEN, LOW);
        digitalWrite(ORANGE, HIGH);
        delay(2000);

        digitalWrite(ORANGE, LOW);
        digitalWrite(RED, HIGH);
        delay(4000);
  }
  return 0 ;
}
```



Engine Controller

```
...
int main (void)
{
  wiringPiSetup () ;

  pinMode(MOTOR_LEFT_ENABLE, OUTPUT);
  pinMode(MOTOR_LEFT_DIRECTION, OUTPUT);
  pinMode(MOTOR_RIGHT_ENABLE, OUTPUT);
  pinMode(MOTOR_RIGHT_DIRECTION, OUTPUT);

  int result = 0;

  softPwmCreate (MOTOR_LEFT_PWM, 0, 100) ;
  softPwmCreate (MOTOR_RIGHT_PWM, 0, 100) ;

  digitalWrite(MOTOR_LEFT_DIRECTION, 0);
  digitalWrite(MOTOR_RIGHT_DIRECTION, 0);

  for (;;)
  {
    delay (5000) ;              // mS
    digitalWrite(MOTOR_LEFT_ENABLE, 1);
    softPwmWrite(MOTOR_LEFT_PWM, 100) ;
    digitalWrite(MOTOR_RIGHT_ENABLE, 1);
    softPwmWrite(MOTOR_RIGHT_PWM, 100) ;
    printf("Accelerating\n");

    delay (5000) ;
    digitalWrite(MOTOR_LEFT_ENABLE, 0);
    softPwmWrite(MOTOR_LEFT_PWM, 0) ;
    digitalWrite(MOTOR_RIGHT_ENABLE, 0);
    softPwmWrite(MOTOR_RIGHT_PWM, 0) ;
    printf("Stopping\n");
  }
  return 0 ;
}
```

Pulse-width Modulation (PWM) creation

Setting a value to PWMs

To compile :

```
$ gcc -Wall -o traffic-light traffic-light.c -lwiringPi -lpthread
```

Line Follower

```
…
int main (void)
{
  wiringPiSetup () ;

  //LSS05 Auto-Calibrating Line Sensor Pin Setup
  pinMode(LeftSen,INPUT);
  pinMode(LeftMSen,INPUT);
  pinMode(MidSen,INPUT);
  pinMode(RightMSen,INPUT);
  pinMode(RightSen,INPUT);

  for (;;)
  {
        int leftSen = digitalRead(LeftSen);
        int leftMSen = digitalRead(LeftMSen);
        int midSen = digitalRead(MidSen);
        int rightMSen = digitalRead(RightMSen);
        int rightSen = digitalRead(RightSen);

        if(leftSen == 0 && leftMSen == 0 && midSen == 1 && rightMSen == 0 && rightSen == 0) {
            softPwmWrite(MOTOR_RIGHT_PWM, 80) ;
            softPwmWrite(MOTOR_LEFT_PWM, 80) ;
        }
        else if(leftSen == 0 && leftMSen == 1 && midSen == 1 && rightMSen == 0 && rightSen == 0) {
            softPwmWrite(MOTOR_RIGHT_PWM, 30) ;
            softPwmWrite(MOTOR_LEFT_PWM, 80) ;
        }
        ...
        delay(200);
  }
  return 0 ;
}
```

Reading GPIO value

Resources and References

- Links
  - PSysRoverInitialContrib (by Gaël Blondelle): https://github.com/gaelblondelle/PSysRoverInitialContrib/tree/master/documentation/c_getting_started
  - WiringPI: http://wiringpi.com
  - How to use GPIOs on Raspberry: https://sites.google.com/site/semilleroadt/raspberry-pi-tutorials/gpio
  - Ultrasonic detection sensor SR04: https://www.modmypi.com/blog/hc-sr04-ultrasonic-range-sensor-on-the-raspberry-pi
  - Raspbian + OpenCV: http://www.pyimagesearch.com/2016/04/18/install-guide-raspberry-pi-3-raspbian-jessie-opencv-3/
  - Guide Raspbian Lite with PIXEL/LXDE/XFCE/Mate/i3 gui: https://www.raspberrypi.org/forums/viewtopic.php?f=66&t=133691
  - VNC: https://www.raspberrypi.org/documentation/remote-access/vnc/
  - FTP: https://www.raspberrypi.org/documentation/remote-access/ftp.md

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10.	Hackaton	(90 mins)	(3 slides)
11.	Conclusion	(5 mins)	(2 slides)

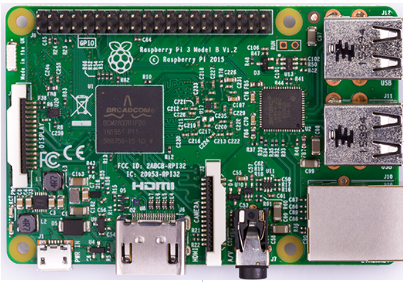
Hand-on session

- Connecting to the Raspberry PI 3
  - SSH
    - $ ssh pi@<Raspberry-IP>
    - PuTTy for Windows users
  - TTy.js
    - Browser : http://<Raspberry-IP>:8000
  - Don't know the IP of a Raspberry PI ?

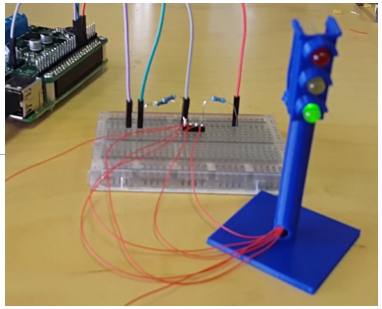
```
Nmap scan report for line-follower-rover
(192.168.1.36)
Host is up (0.010s latency).
Not shown: 997 closed ports
PORT     STATE SERVICE
21/tcp   open  ftp
22/tcp   open  ssh
5900/tcp open  vnc
```

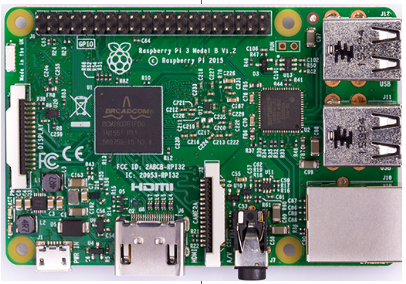
- Using the gpio utility
  - Displaying the list of GPIOs
  - Turning on a LED (Traffic Light)
  - Reading the detection sensor values (Rover)
- Using wiringPI
  - C/C++ applications folder: ~/examples/
    - trafficlight.c (Traffic light)
    - ultrasonic.c (Rover)
    - engine.c (Rover)
    - line-follower-sensor.c (Rover)
- **Please get closer to the Raspberry PI you wanna test**
  - When executing an application, please be sure no one else is doing it
  - Concurrent executions may cause unpredicted behaviour and damage the Raspberry PI

Hand-on session (cont'd)

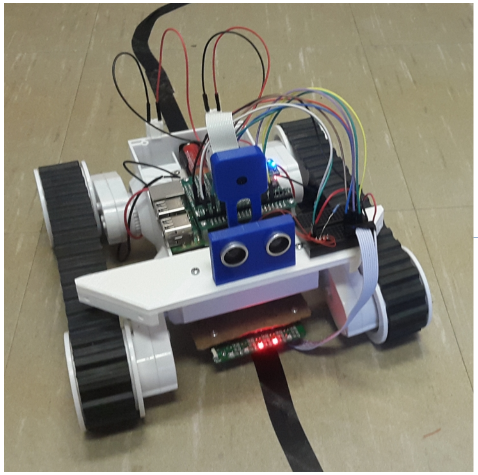


host: 192.168.1.54
hostname: traffic-light-blue
login: pi / EclipseCon2017





Host: ???
hostname: traffic-light-white
login: pi / EclipseCon2017



host: 192.168.1.36
hostname: line-follower-rover
login: pi / EclipseCon2017

Router connection:
SSID: UMLRT-2017
WPA2: EclipseCon2017

Overview

1.	Intro / MDE	(10 mins)	(8 slides)
2.	Overview	(1 min)	(1 slide)
3.	PolarSys Rover	(15 mins)	(16 slides)
4.	Demo I	(5 mins)	
5.	Hands on session	(20 mins)	(2 slides)
6.	UML-RT: Part I • Core concepts	(25 mins)	(26 slides)
7.	Demo II	(10 mins)	(3 slides)
8.	Hands on session	(20 mins)	(1 slide)
9.	UML-RT: Part II • More advanced concepts	(10 mins)	(14 slides)
10.	Hackaton	(90 mins)	(3 slides)
11.	Conclusion	(5 mins)	(2 slides)

Papyrus-RT: Overview

- Papyrus for Real-Time industrial-grade, complete modeling environment for the development of complex, software intensive, real-time, embedded, cyber-physical systems.
- Part of PolarSys
  - Eclipse Working Group
  - Open source for embedded systems
- Building on
  - Eclipse Modeling Framework (EMF), Xtext, Papyrus
- History
  - 2015: V0.7.0
  - March 2017: v0.9
  - Fall 2017: v1.0

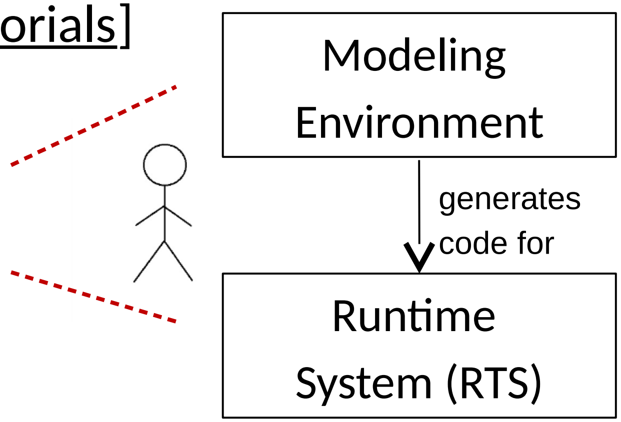
[https://wiki.eclipse.org/Papyrus-RT]

Papyrus-RT: Installation

- Easiest: as RCP
- From web:
  - [https://eclipse.org/papyrus-rt/content/download.php]
  - Download RCP for your platform
  - Extract downloaded file into a folder of your choice
- From USB stick:
  - In ‘Papyrus-RT’ folder:
    - Archive: Copy/paste, unpack
  - In ‘Models’ folder:
    - Models: Import in Papyrus-RT
  - In ‘Doc’ folder:
    - Installation instructions

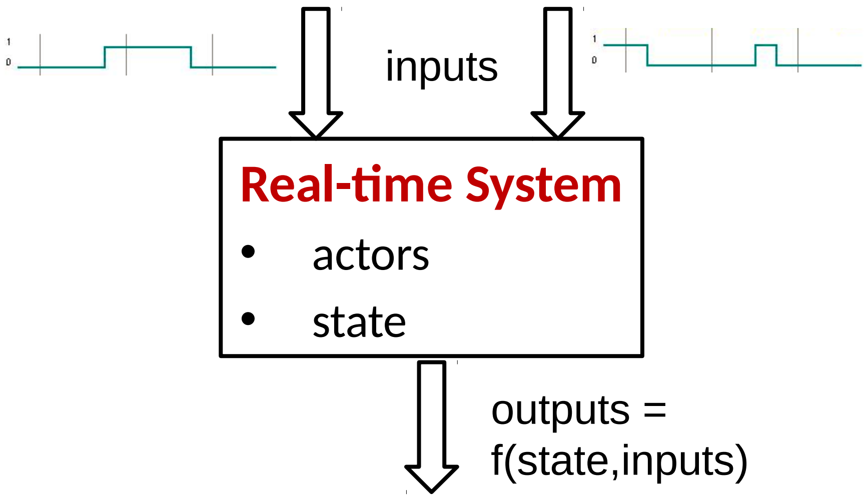
Papyrus-RT: Use

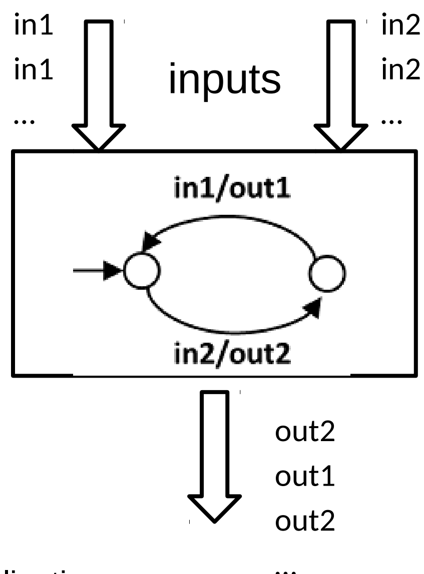
- Tutorials
  - [https://wiki.eclipse.org/Papyrus-RT/User#Tutorials]
- 2 parts
  1. Editing, building the model, generate code
  2. Compiling and running generated code
     - Linux: easy
       - [https://wiki.eclipse.org/Papyrus-RT/User/User_Guide/Getting_Started#Execute_the_model]
     - MacOS: use VirtualBox/Vagrant
     - Windows: use Cygwin, or VirtualBox/Vagrant
       - [https://wiki.eclipse.org/Papyrus-RT/User_Guide/Vagrant_Setup]



UML-RT: Characteristics

- Domain-specific
  - Embedded systems with soft real-time constraints
- Graphical, but textual syntax exists
- Small, cohesive set of concepts
- Strong encapsulation
  - Actors (active objects)
  - Explicit interfaces
  - Message-based communication
- Event-driven execution
  - State machines





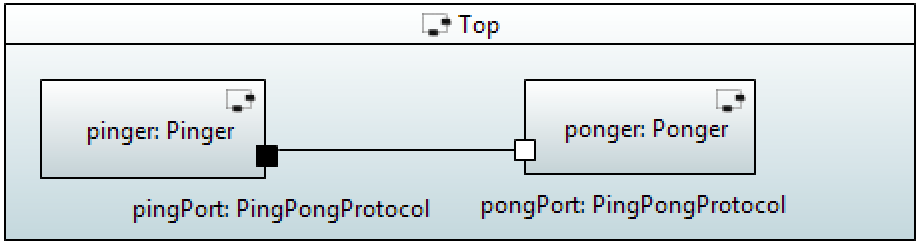
UML-RT Part I

- Core concepts
  - Structural modeling
  - Behavioural modeling

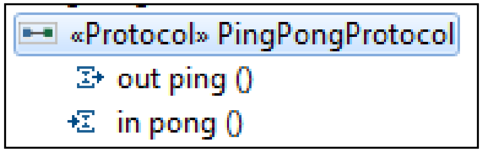
UML-RT: Core Concepts (1)

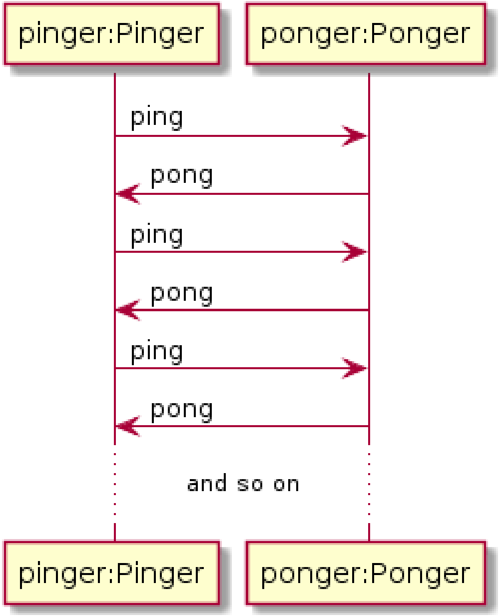
- Types
  - Capsules (active classes)
    - Capsule instances (parts)
  - Passive classes (data classes)
    - Objects
  - Protocols
  - Enumerations
- Structure
  - Attributes
  - Ports
  - Connectors
- Behaviour
  - Messages (events)
  - State machines
- Grouping
  - Package
- Relationship
  - Generalization
  - Associations

UML-RT: Core Concepts (2)



- Model
  - Collection of capsule definitions
  - ‘Top’ capsule containing collection of capsule instances (parts)
- Capsules
  - May contain
    - Attributes, ports, or other capsule instances (parts)
  - Behaviour defined by state machine
- Ports
  - Typed over protocol defining input and output messages
- State machine
  - Transition triggered by incoming messages
  - Action code can contain send statements that send messages over certain ports

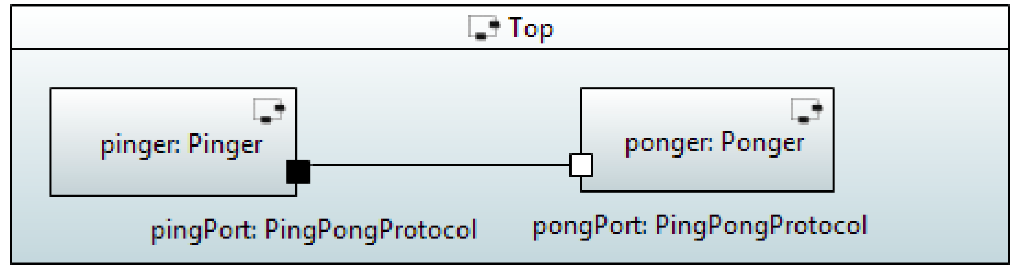


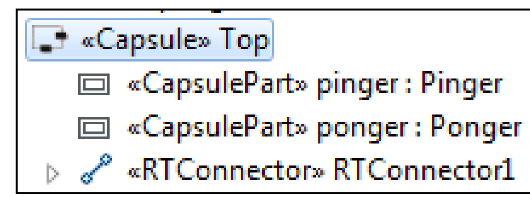


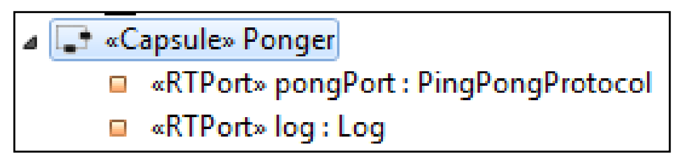
Capsules (1)

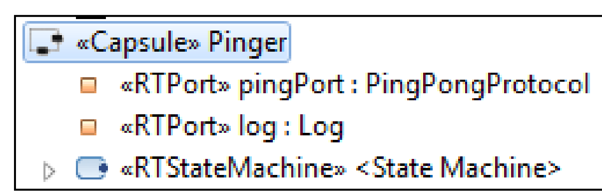
- Kind of active class
  - Attributes, operations
  - Own, independent flow control (logical thread)
- May also contain
  - Ports over which messages can be sent and received
  - Parts (instances of other capsules) and connectors
- Creation, use of instances tightly controlled
  - Created by runtime system (RTS)
  - Cannot be passed around
  - Stored in attribute of another capsule (part)
  - Information flow only via messages sent to ports

  ⇒ better concurrency control and encapsulation
- Behaviour defined by state machine

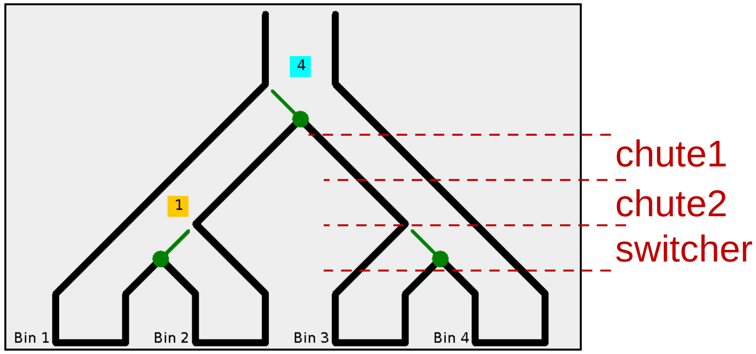


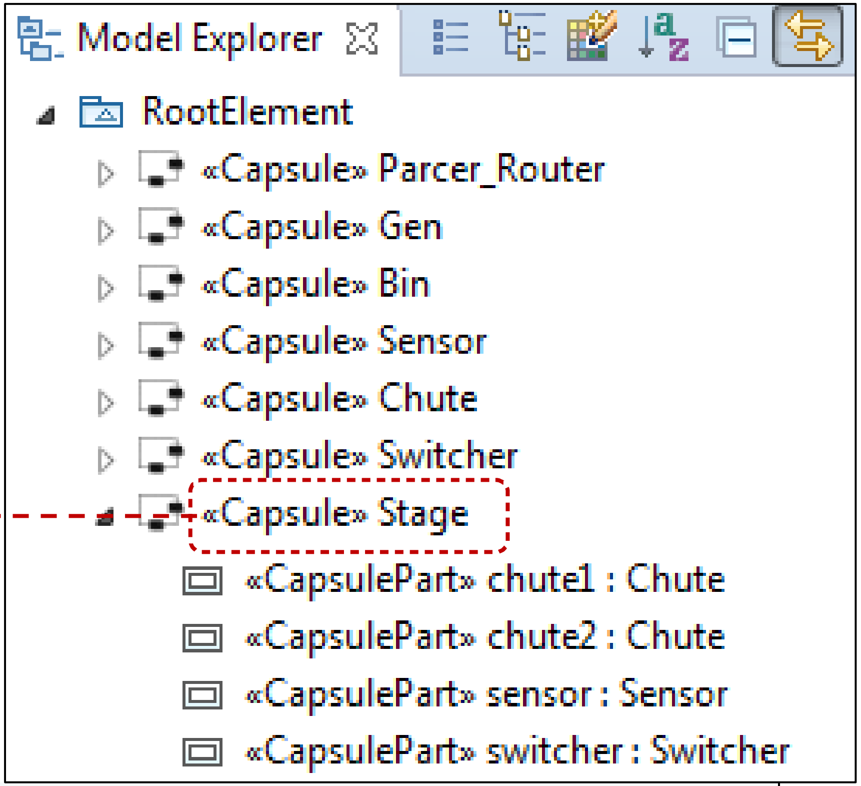


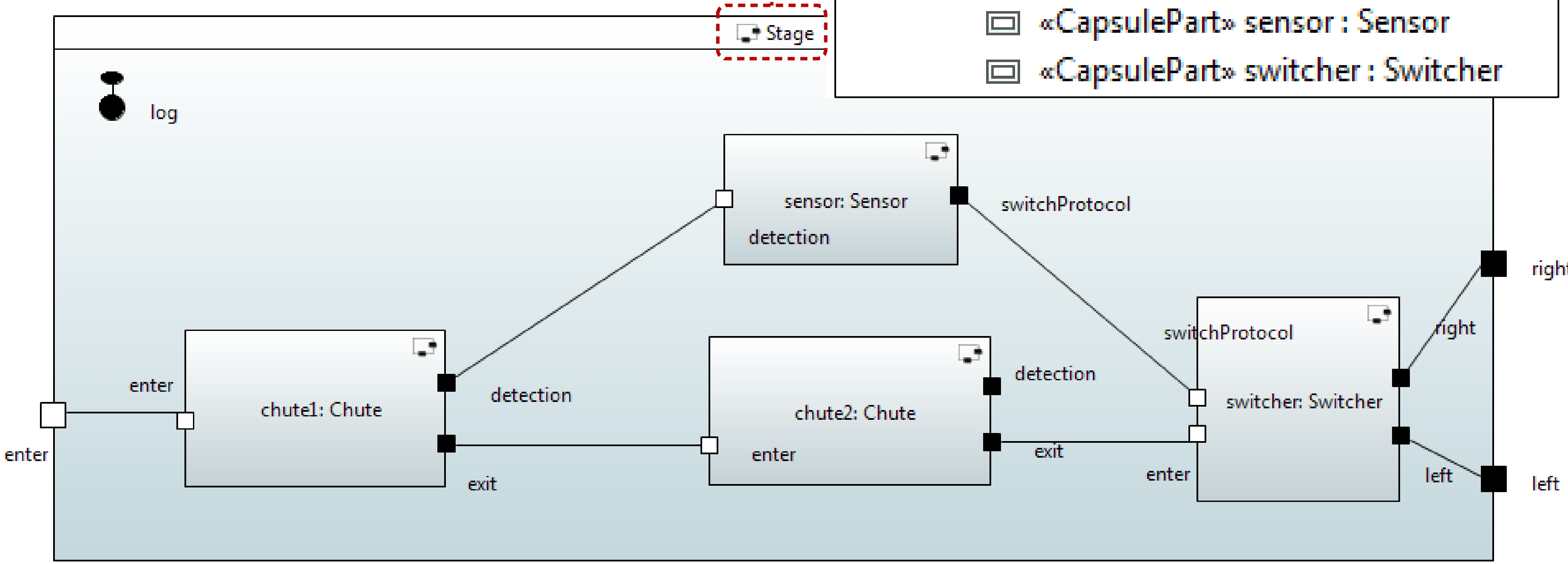




Example: Capsules and Capsule Parts

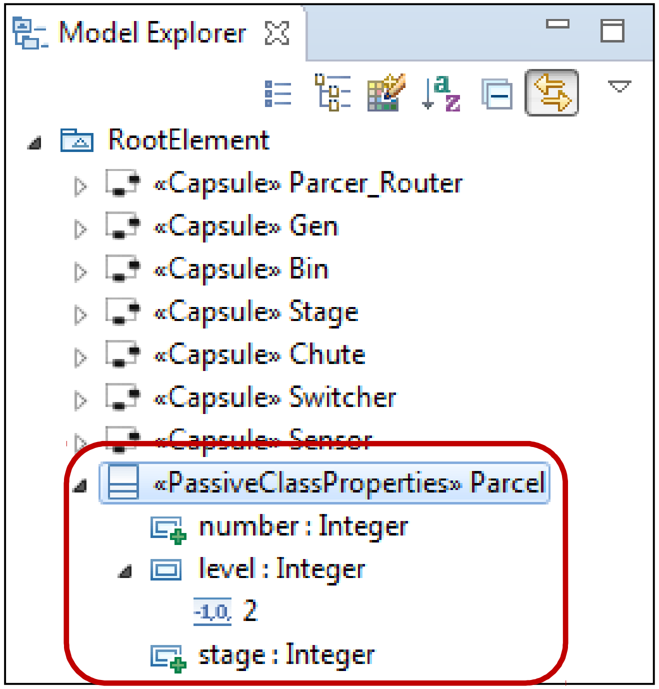






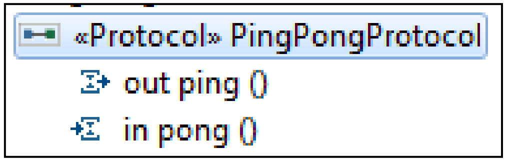
Passive Classes/Data Classes

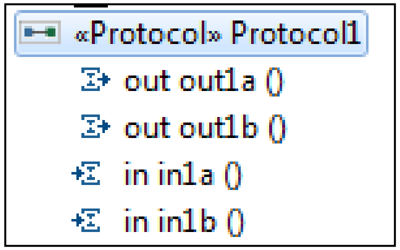
- Similar to regular classes
- Do not have independent flow of control
- Behaviour defined through operations
- Used to define data structures and operations on them

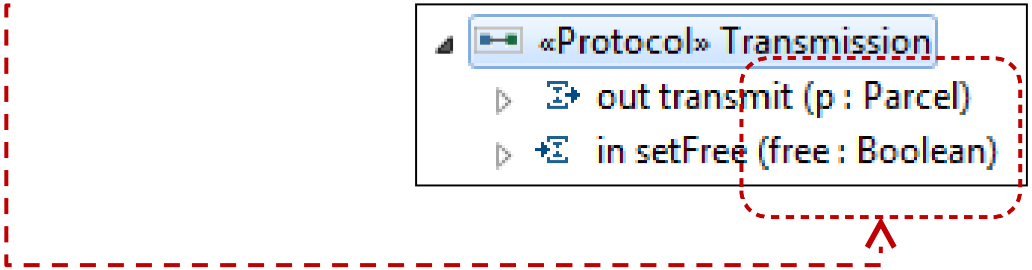


Protocols

- Provide types for ports
- Define
  - Input messages
    - Services provided by capsule owning port
  - Output messages
    - Services required by capsule owning port
  - Input/output messages
- Messages can carry data

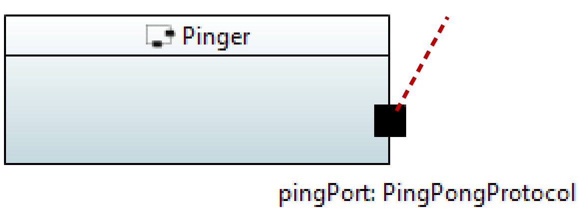


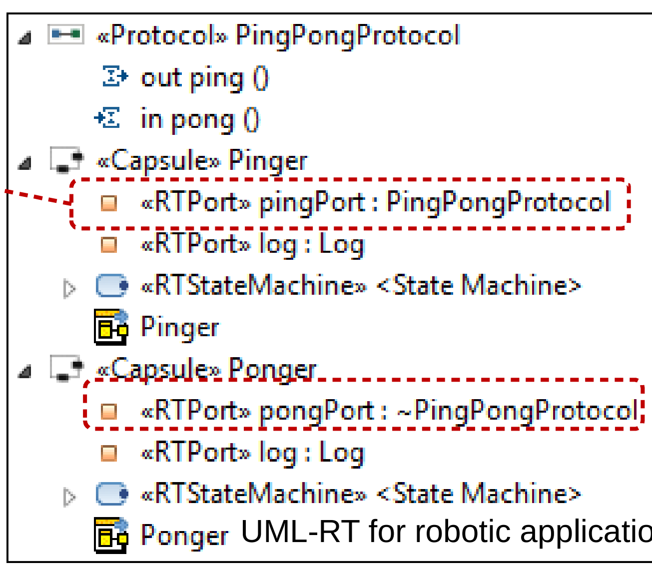


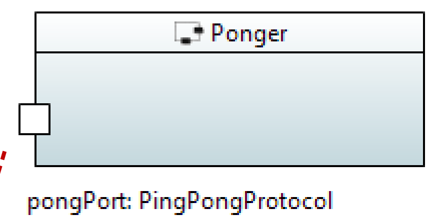


Ports

- "Boundary objects" owned by capsule
- Typed over a protocol P
- Have '**send**' operation
  - `portName.msg(arg1,...,argn).send()`
- Can be
  - base (not conjugated)
    - Direction of messages is as declared in protocol
    - Notation:
      - textual: P
      - graphical: ■
  - conjugated
    - Direction of messages declared in protocol is reversed
    - Notation
      - textual: ~P
      - graphical: □

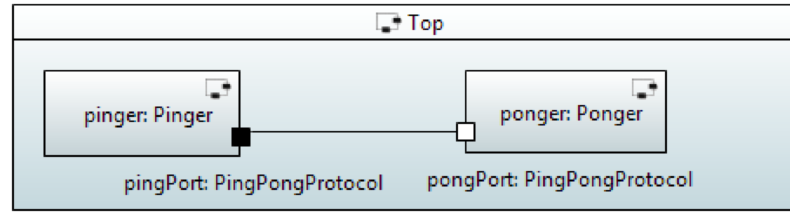


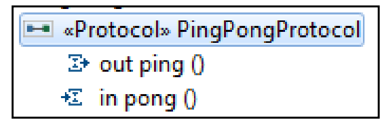


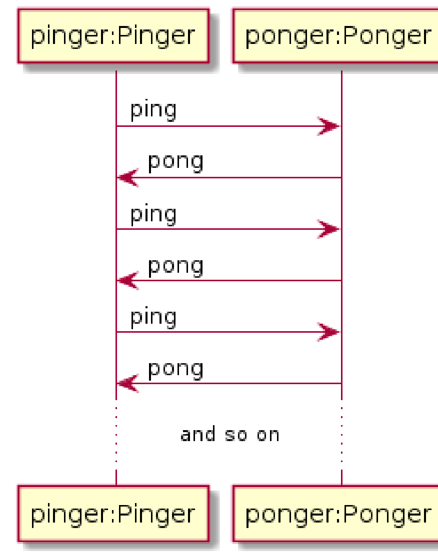


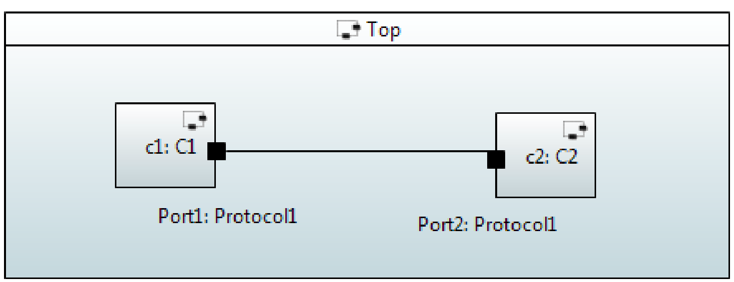
Connectors

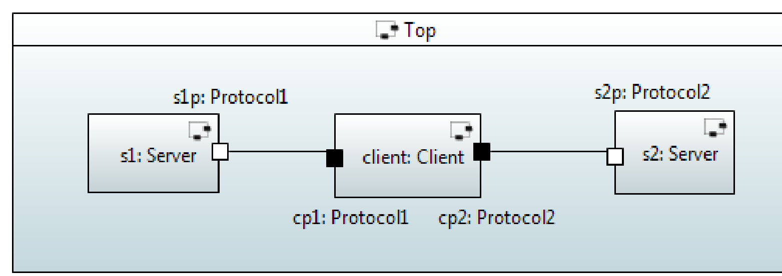
- Connect two ports
- Ports must be compatible
  - Both are instances of same protocol
  - Either (asymmetric)
    - one is 'base' (i.e., not 'conjugated')
      - typically owned by 'client'
    - and the other is 'conjugated'
      - typically owned by 'server'
  - Or (symmetric)
    - only InOut messages





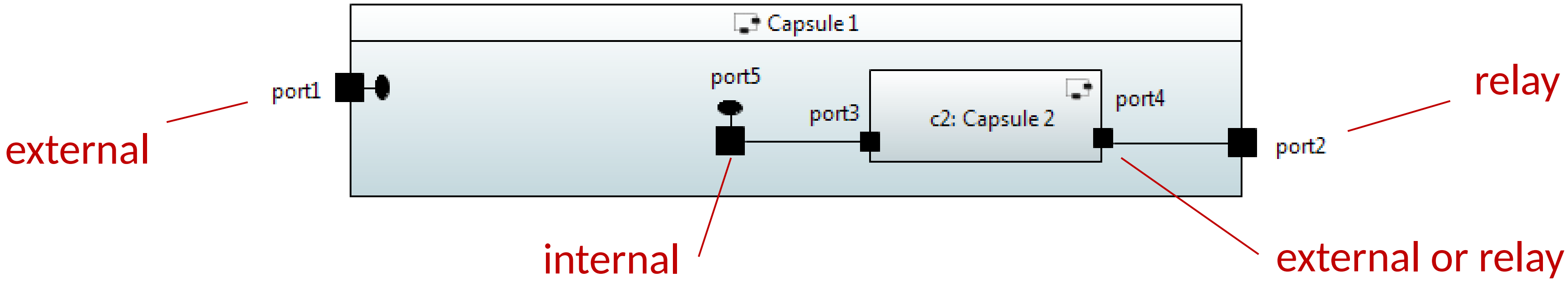




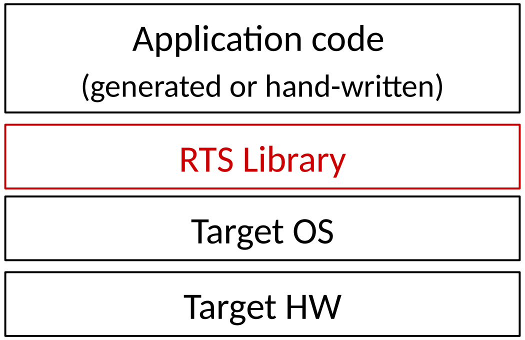


Ports: External, Internal, Relay

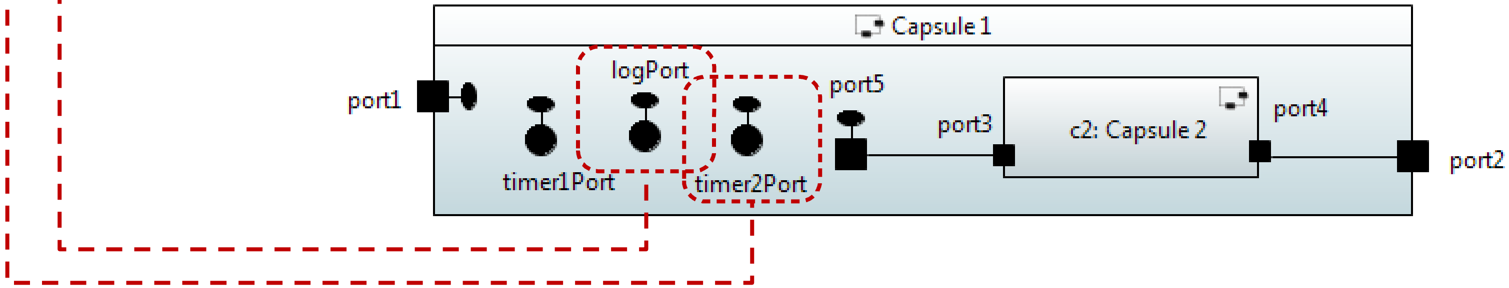
- External behaviour
  - Provides (part of) externally visible functionality (isService=true)
  - Incoming messages passed on to state machine (isBehaviour=true)
  - Must be connected (isWired=true)
- Internal behaviour
  - As above, but not externally visible (isService=false)
  - Connect state machine with a capsule part
- Relay
  - Pass external messages to and from capsule parts



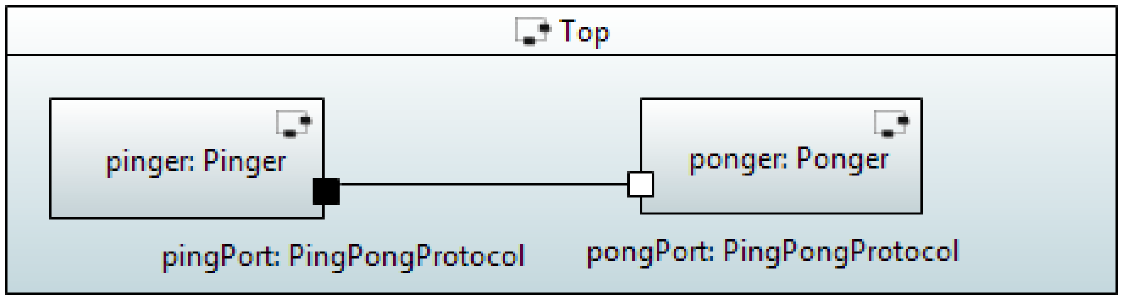
Ports: System

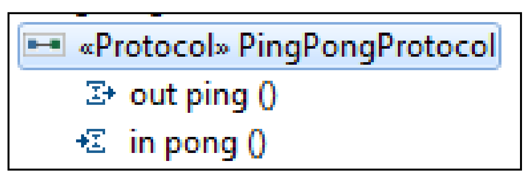


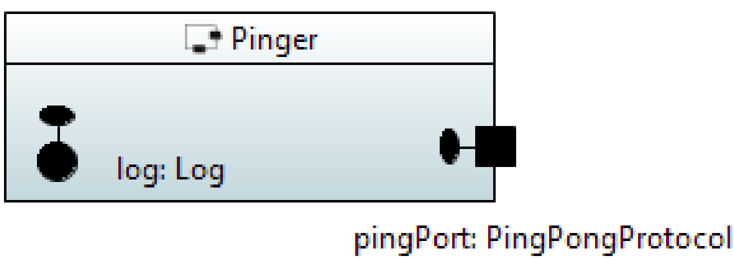
- Connects capsule to Runtime System (RTS) library via corresponding system protocol
- Provides access to RTS services such as
  - Timing: setting timers, time out message
    - `timer2Port.informIn(UMLRTTimespec(10, 0));`
      `// set timer that will expire in 10 secs and 0 nanosecs`
    - When timer expires, ‘`timeout`’ message will be sent over `timer2Port`
  - Log: sending text to console
    - `logPort.log(“Ready to self-destruct”)`
  - Frame: incarnate, destroy capsule instances

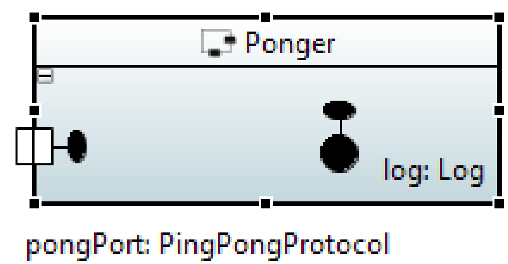


Example: PingPong

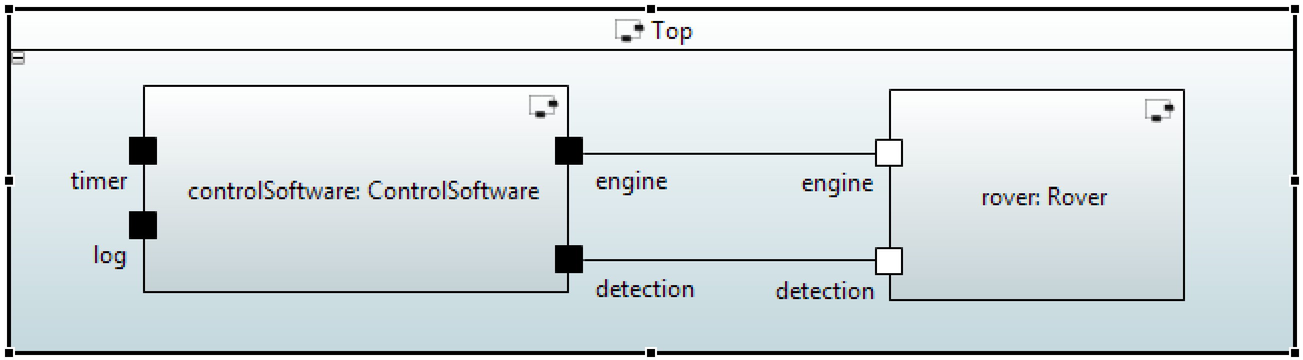






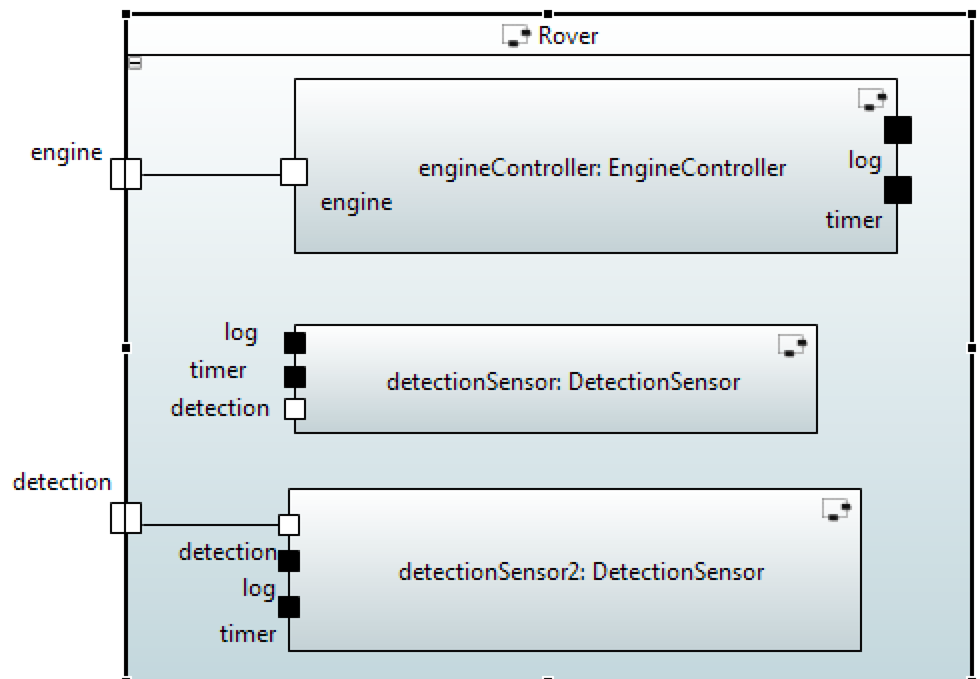


Example: Rover

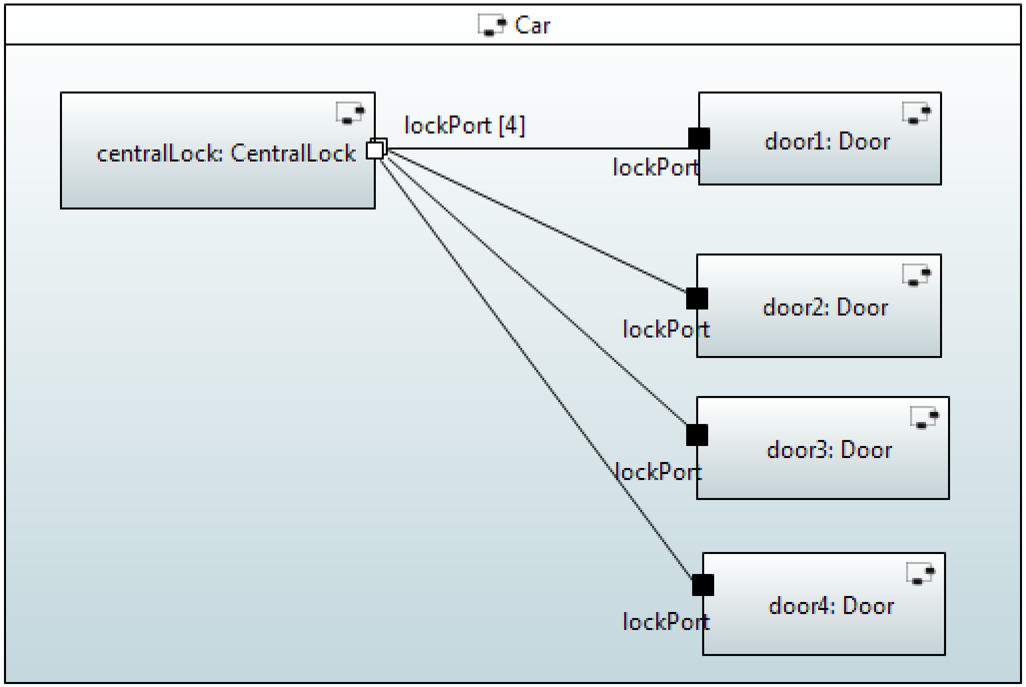


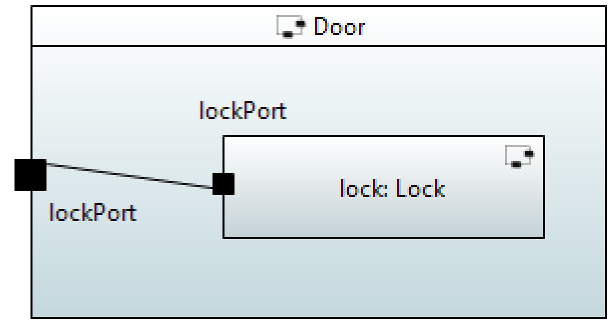
«Protocol» Engine
- out moveForward ()
- out moveBackwards ()
- out turnLeft (angle : Integer)
- out turnRight (angle : Integer)
- out stop ()
- in turnedLeft ()
- in turnedRight ()
- in stopped ()

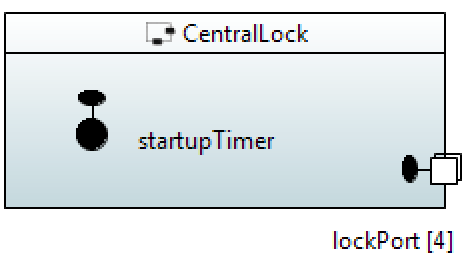
«Protocol» Detection
- out startDetection ()
- out stopDetection ()
- in obstacleDetected (distance : Real)

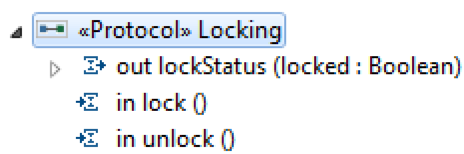


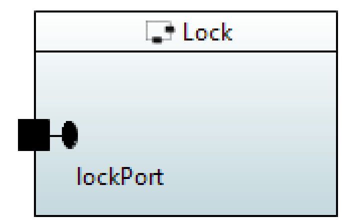
Example: Door Lock System

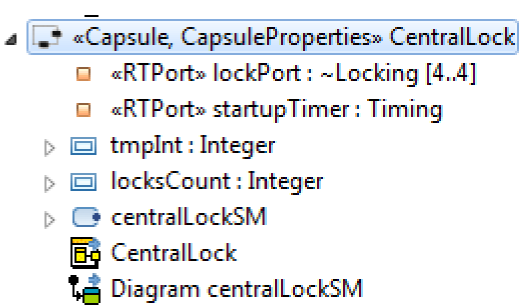












UML-RT Part I

- Core concepts
  - Structural modeling
  - Behavioural modeling

State Machines

States

- Capture relevant aspects of history of object
- Determine how object can respond to incoming messages
- May have invariants associated with them

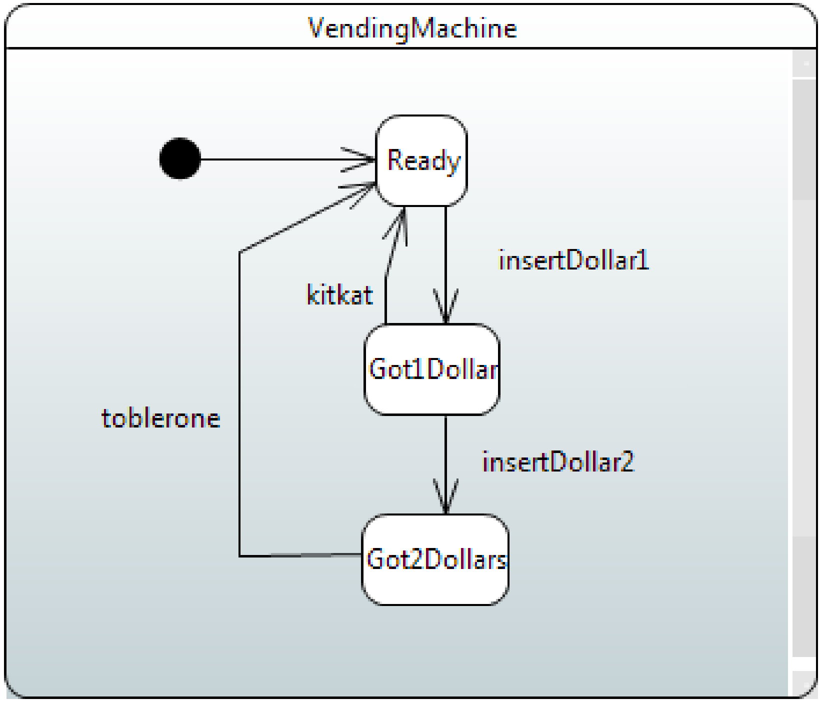
Pseudo states

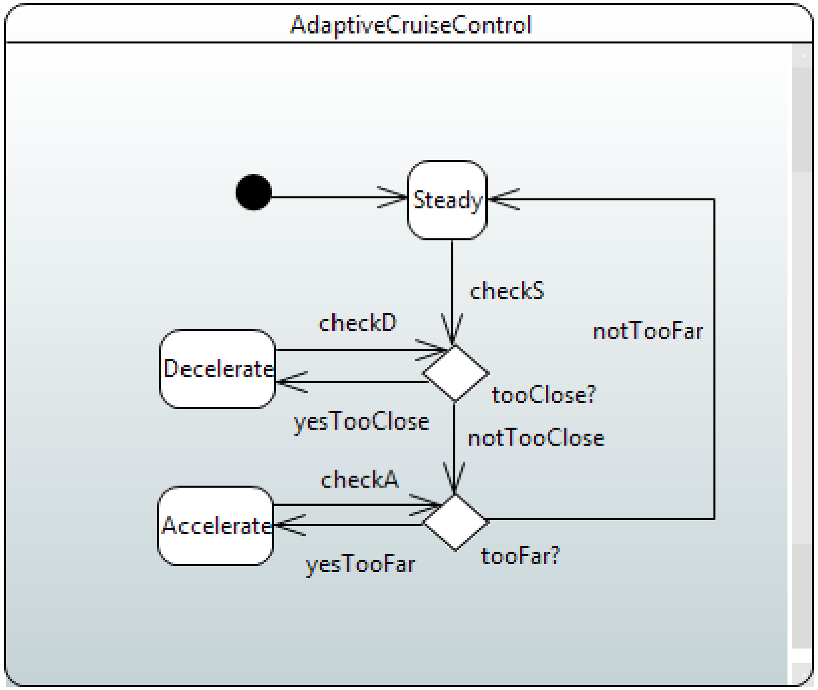
- Don't belong to description of lifetime of object

  ⇒ object cannot be 'in' a pseudo state
- Helper constructs to define complex state changes

Transitions

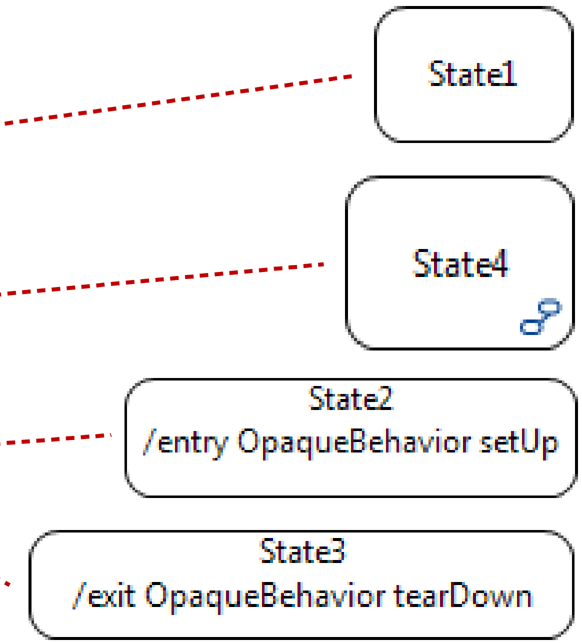
- Describe how object can move from one state to next in response to message input





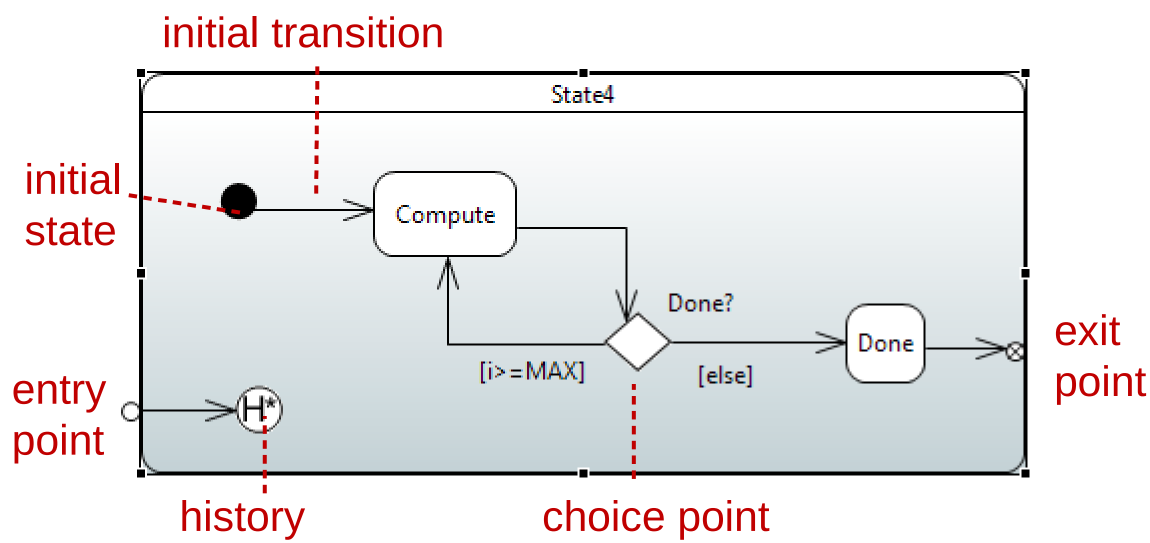
States and Pseudo States

- **States**
  - Kinds:
    - Basic
    - Composite (in hierarchical state machines)
  - May contain
    - Entry action (written in action language)
    - Exit action (written in action language)



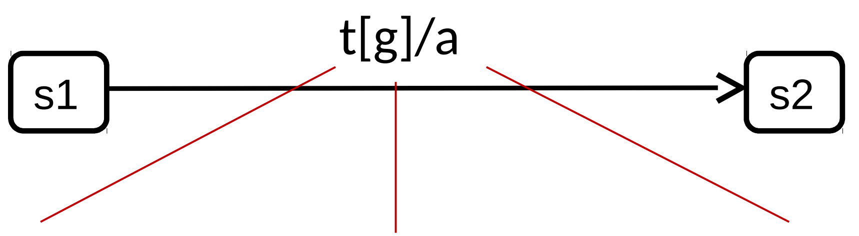
- **Pseudo states**
  - Initial
  - choice point
  - history
  - entry points
  - exit point

in composite states only



Transitions

- Kinds:
  - Basic
  - Group (in hierarchical state machines)
- Consists of
  - Triggers
    - Transitions out of pseudo states (initial, choice) don't have triggers
    - Transitions out of non-pseudo state should have at least one trigger
  - Guards (optional, written in action language)
  - Effect/Actions (optional, written in action language)



Trigger
Specifies port and message

Guard
Boolean condition that must hold

Effect/Actions
Code that is executed when transition is taken

Action Language

- Language used in
  - guards to express Boolean expressions
  - entry action, exit action, transition effects to read and update attribute values, send messages
- Typically: C/C++, Java

⇒ State machines are a hybrid notation combining

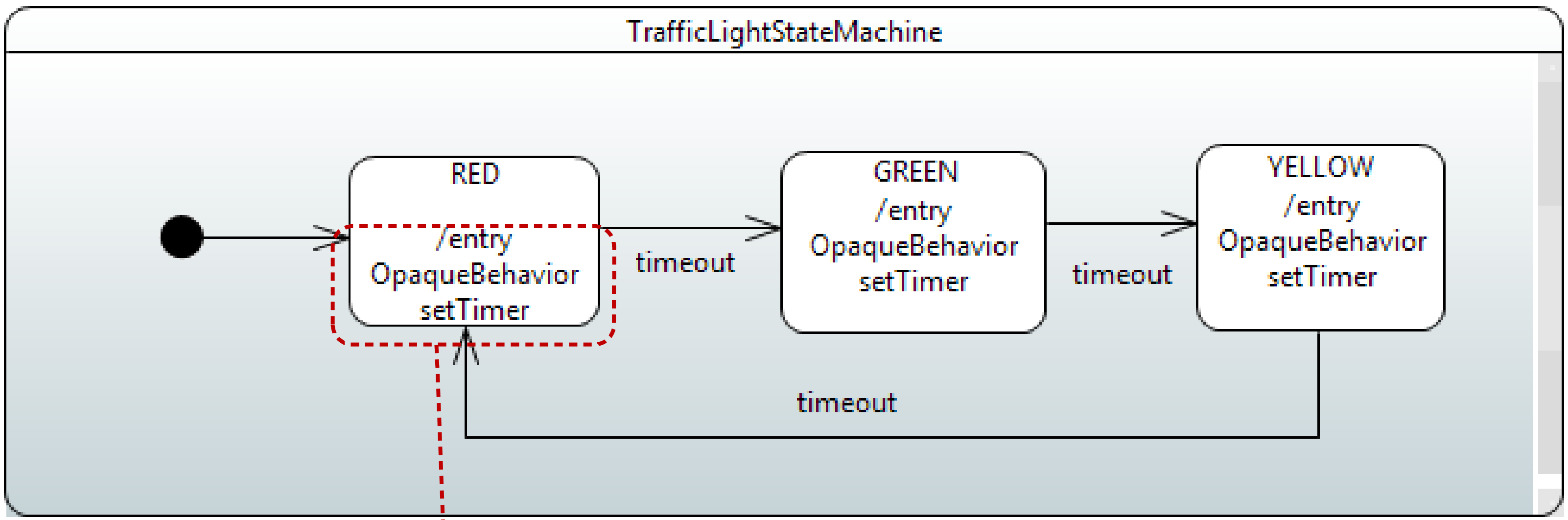
- graphical notation for state machines and
- textual notation for source code in actions

⇒ UML and UML-RT State Machines

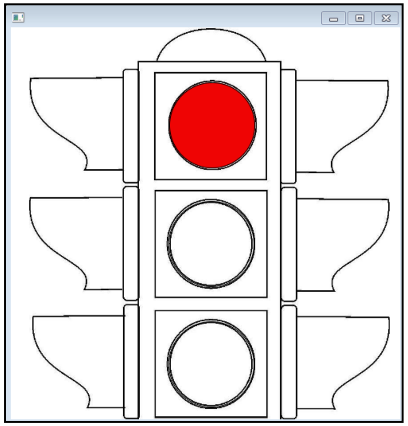
- different from, e.g., Finite Automata
- closer to 'extended hierarchical communicating state machines' [5]

[5] R. Alur. Formal Analysis of Hierarchical State Machines. Verification: Theory and Practice. 2003.

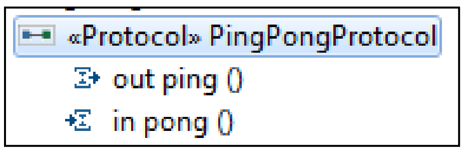
Example: Action Code, Timers, Logging



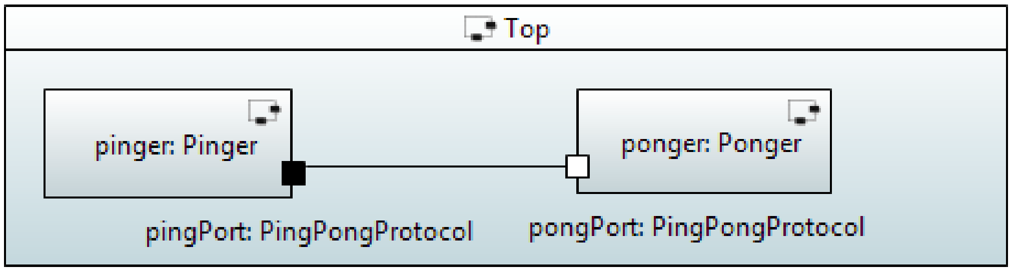

```
timer.informIn(UMLRTTimespec(5,0));
log.log("Switched to red");
```

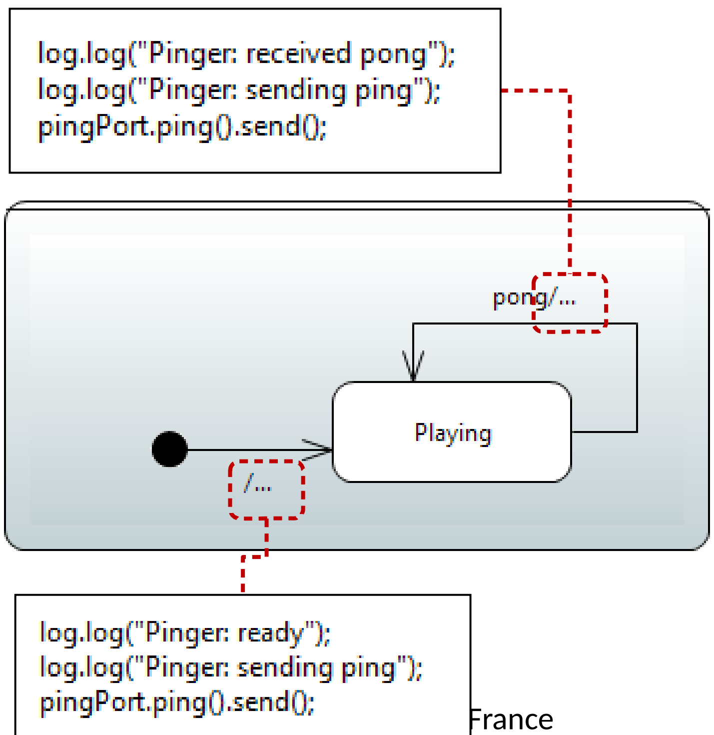


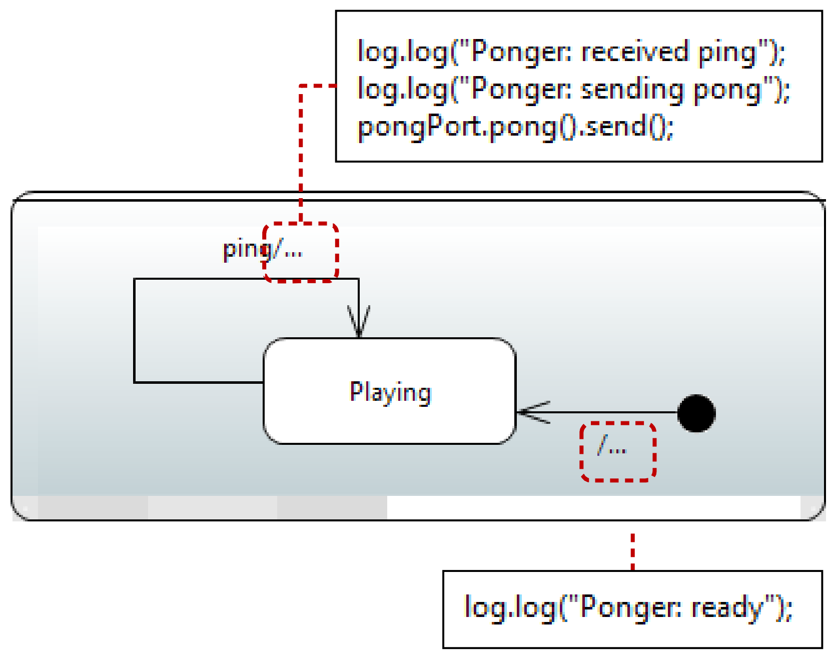
Example: Ping Pong



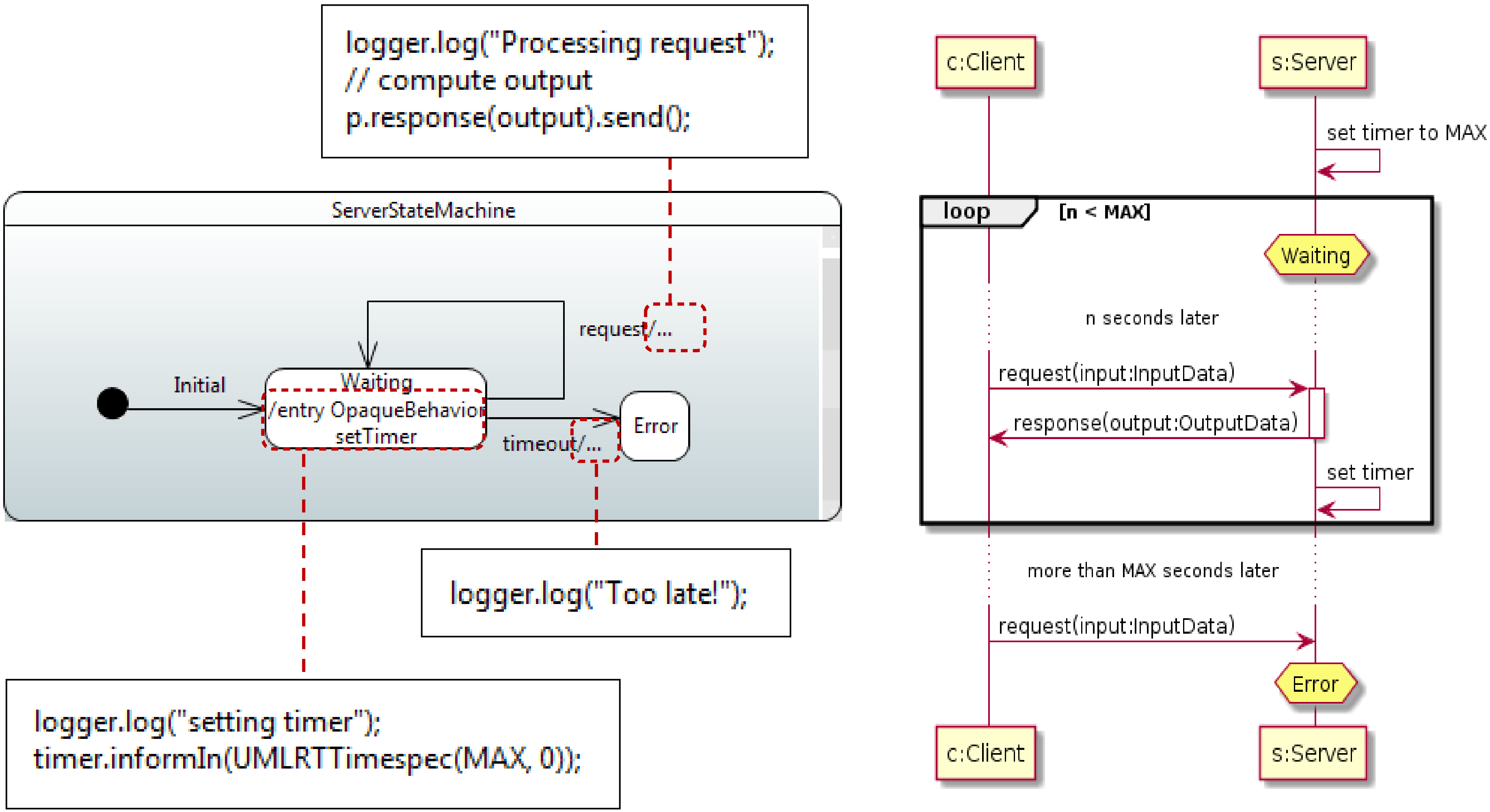

```
$ ./TopMain.exe
Controller "DefaultCon
Pinger: ready
Pinger: sending ping
Ponger: ready
Ponger: received ping
Ponger: sending pong
Pinger: received pong
Pinger: sending ping
Ponger: received ping
Ponger: sending pong
Pinger: received pong
Pinger: sending ping
Ponger: received ping
Ponger: sending pong
Pinger: received pong
Pinger: sending ping
```







Example: Timers



Demo II: Models for the PolarSys Rover

- Copying the RTS on the RaspberryPI
  - Locating the RTS in your Papyrus-RT installation

    ```
    $ cd ...
    ```

  - Copying the RTS into the Raspberry PI 3

    ```
    $ scp ...
    ```

  - Compiling the RST

    ```
    $ make clean && make
    ```

- Adding the WiringPI library

  ```
  $ cd ...
  $ vim ...
  ```

- You Raspberry PI is ready !
- **All these steps are already done for this workshop**

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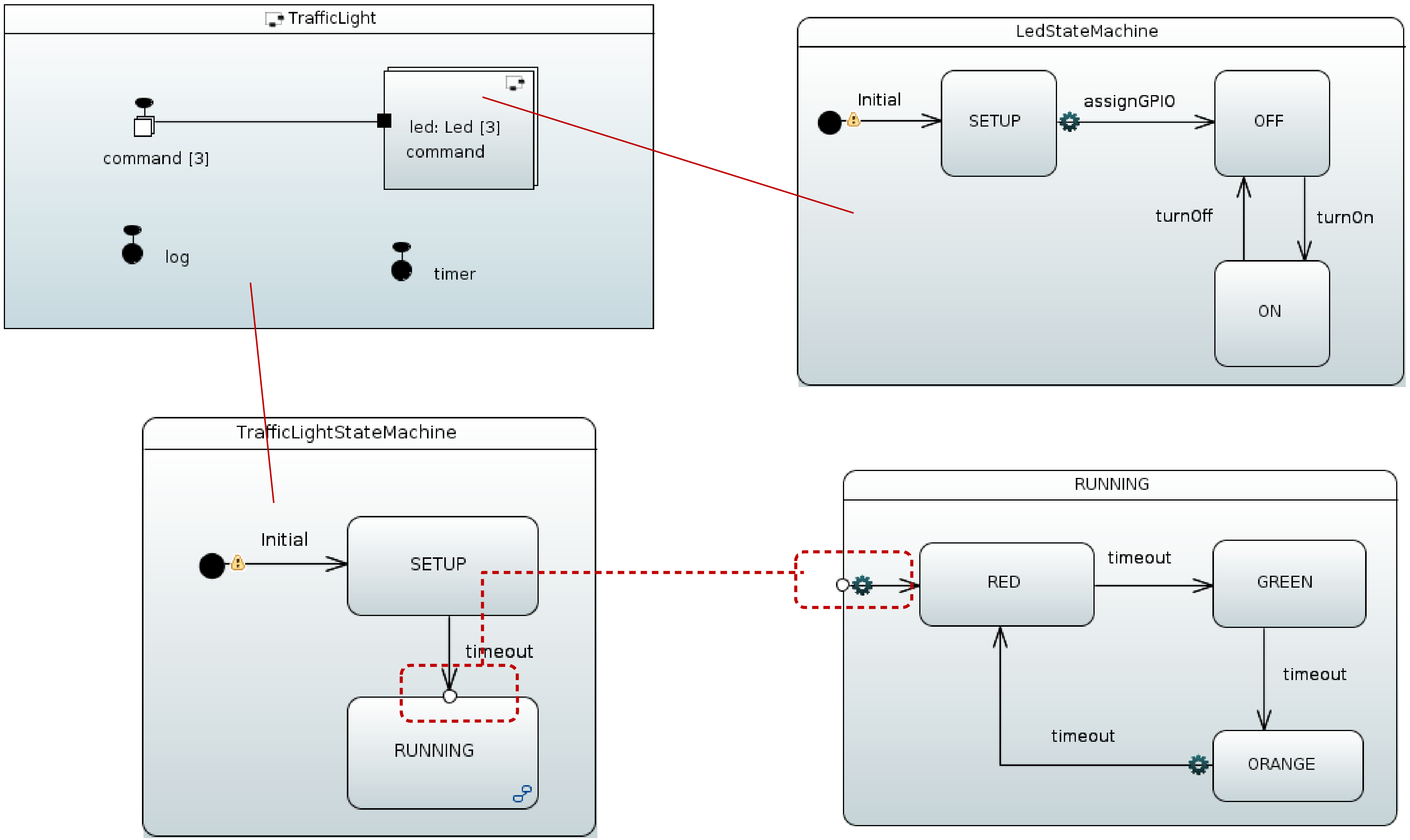
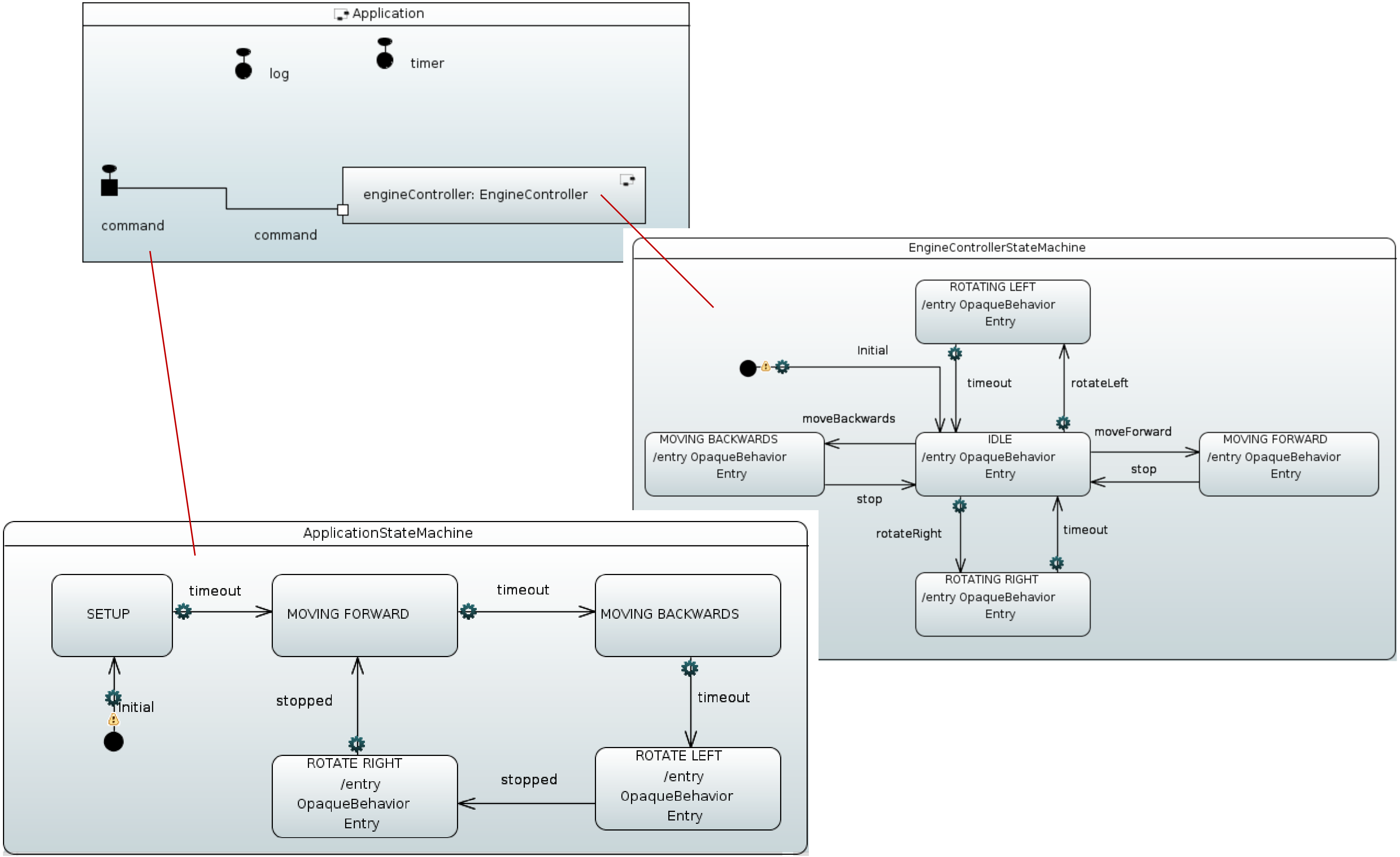
10.	Hackaton	(90 mins)	(3 slides)
11.	Conclusion	(5 mins)	(2 slides)

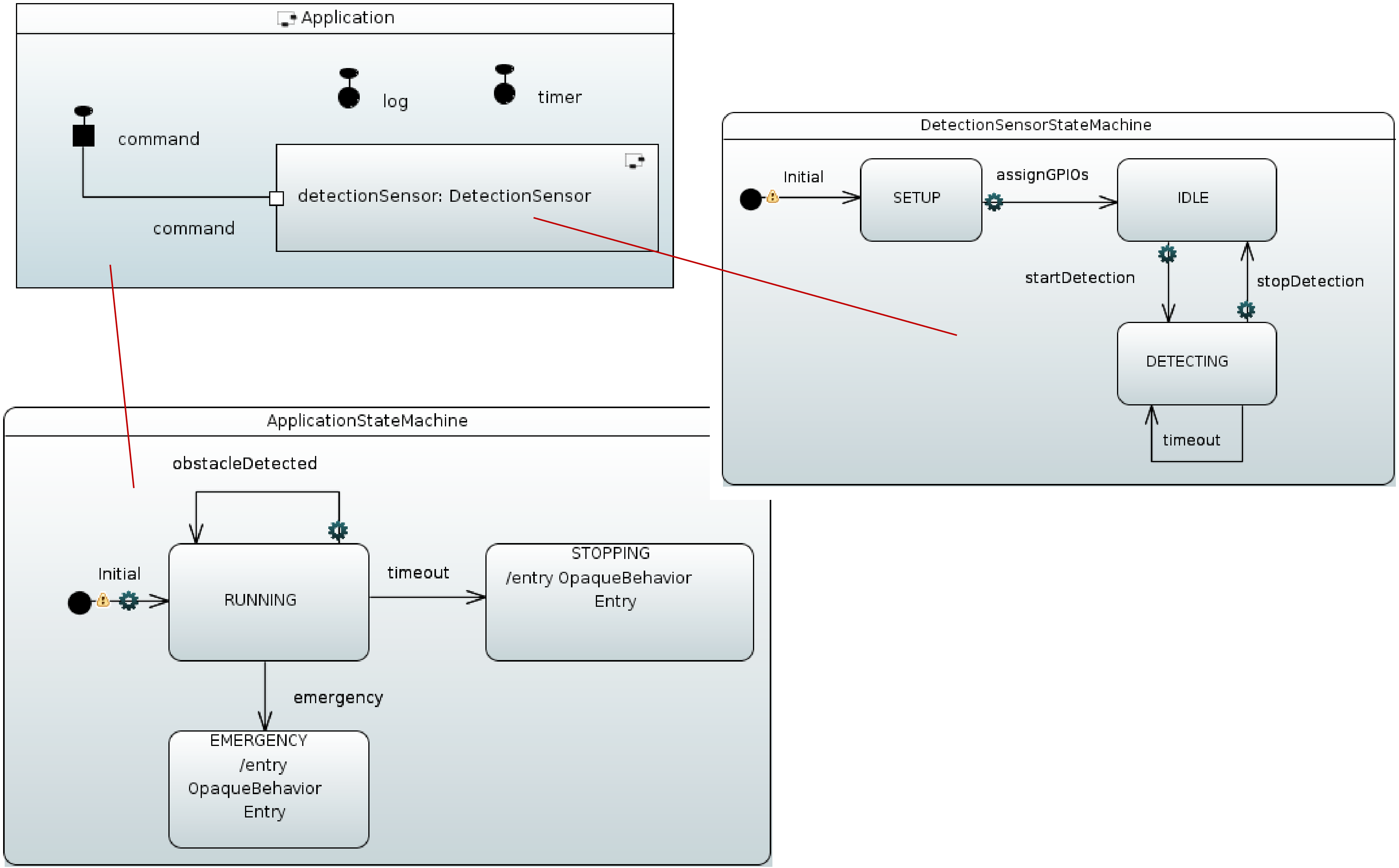
Demo II: TrafficLight



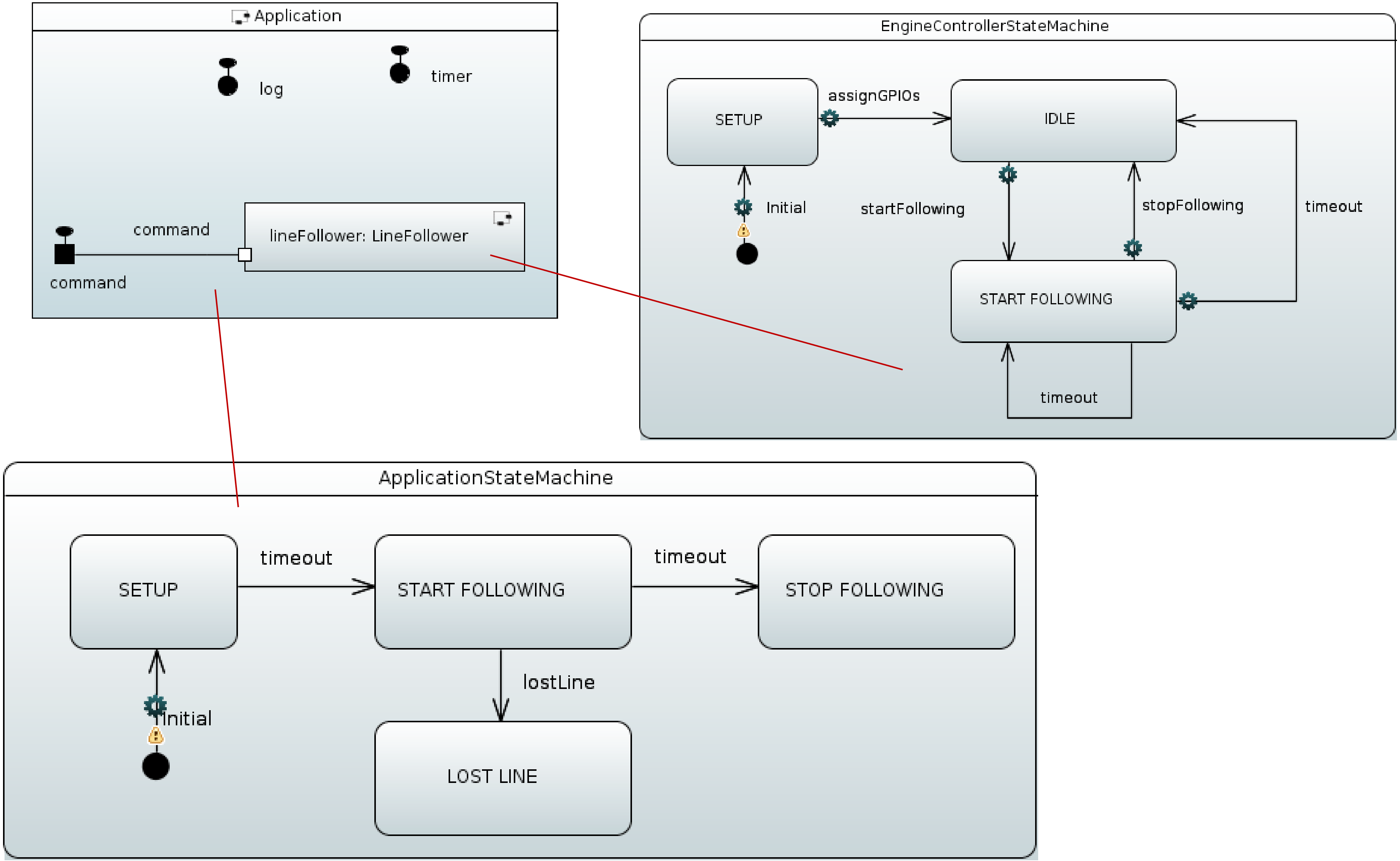
Demo II: EngineController



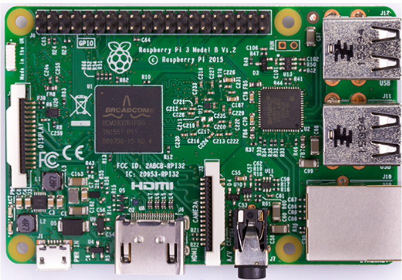
Demo II: DetectionSensor

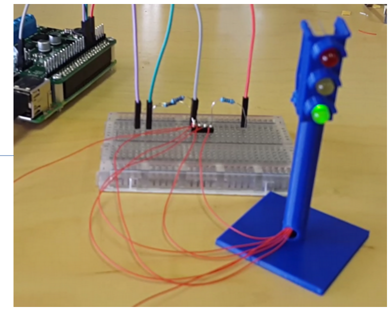


Demo II: LineFollower

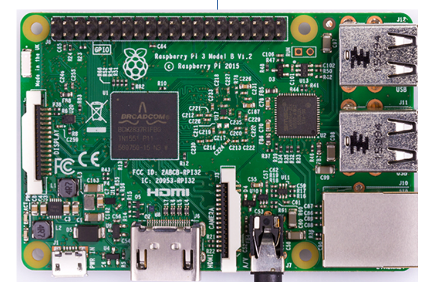


Hand-on session

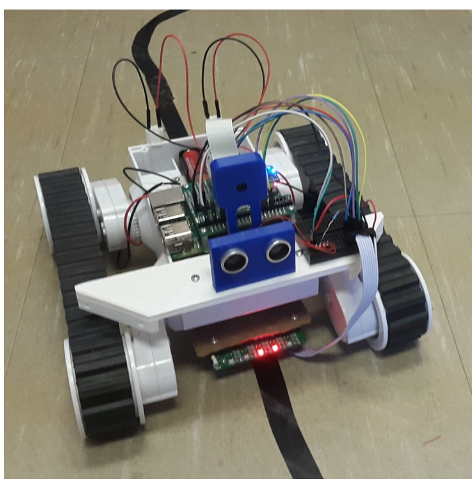




host: 192.168.1.54
hostname: traffic-light-blue
login: pi / EclipseCon2017



Host: ???
hostname: traffic-light-white
login: pi / EclipseCon2017



host: 192.168.1.36
hostname: line-follower-rover
login: pi / EclipseCon2017

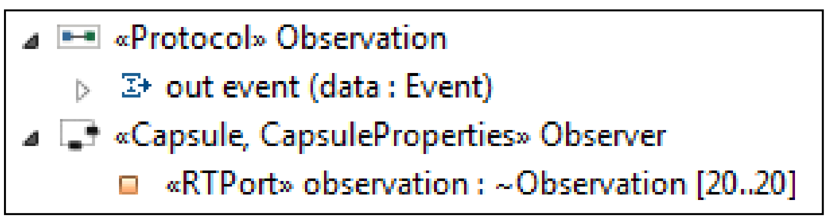
Router connection:
SSID: UMLRT-2017
WPA2: EclipseCon2017

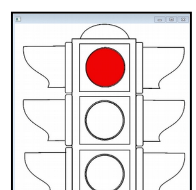
UML-RT Part II

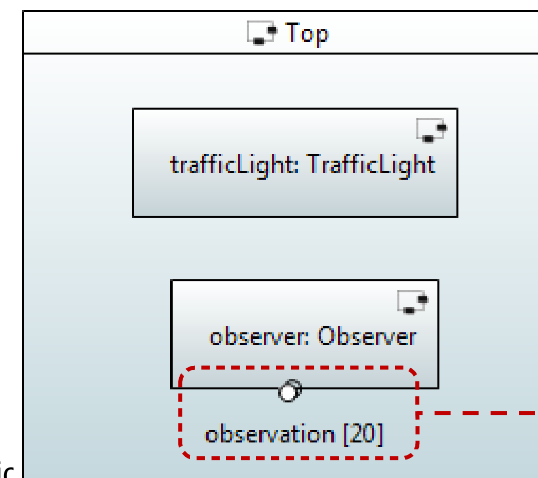
- More on ports
- More on state machines

Ports: SPP and SAP

- So far, only wired ports
  - Connected automatically when instances are created
- Unwired ports
  - Connected at run-time
  - Publish/subscribe
    - Port on publisher: Service Provision Point (SPP)
    - Port on subscriber: Service Access Point (SAP)
    - Register with RTS using unique service name (manually or automatic)

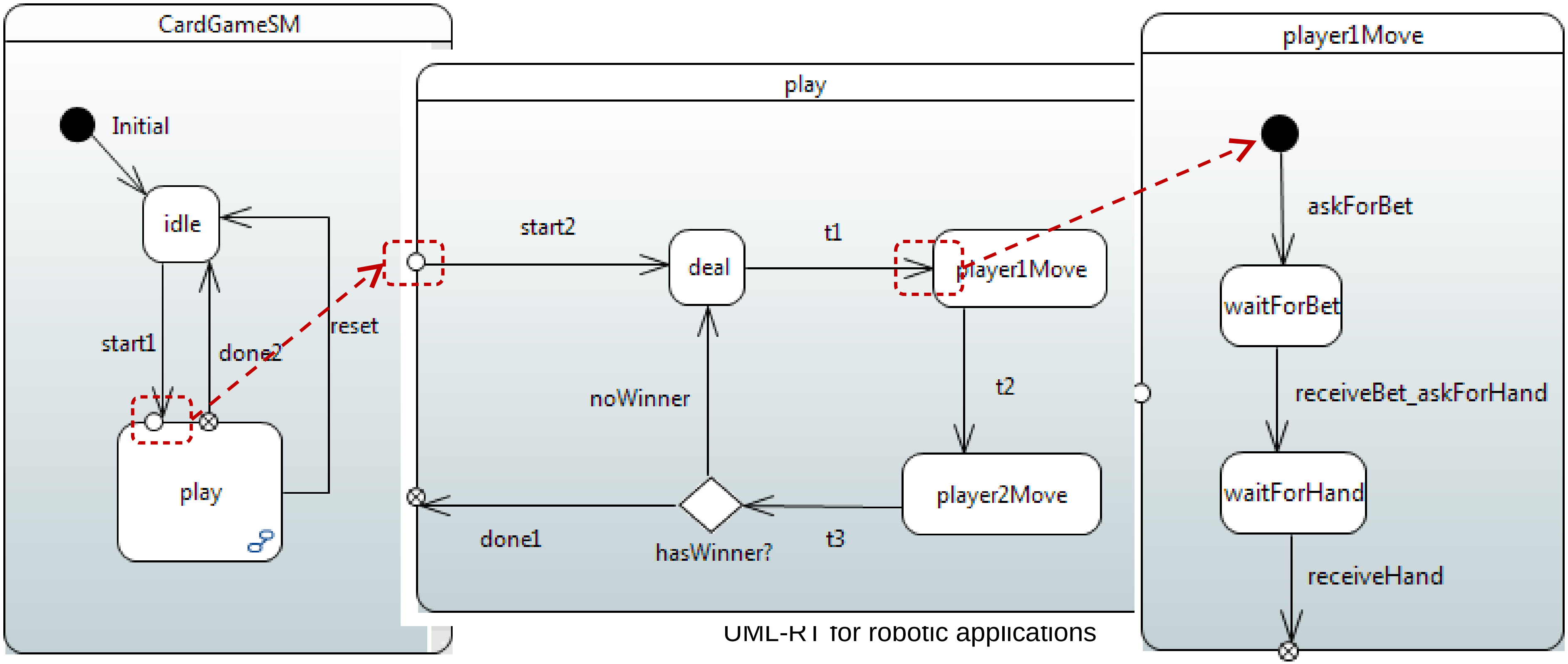






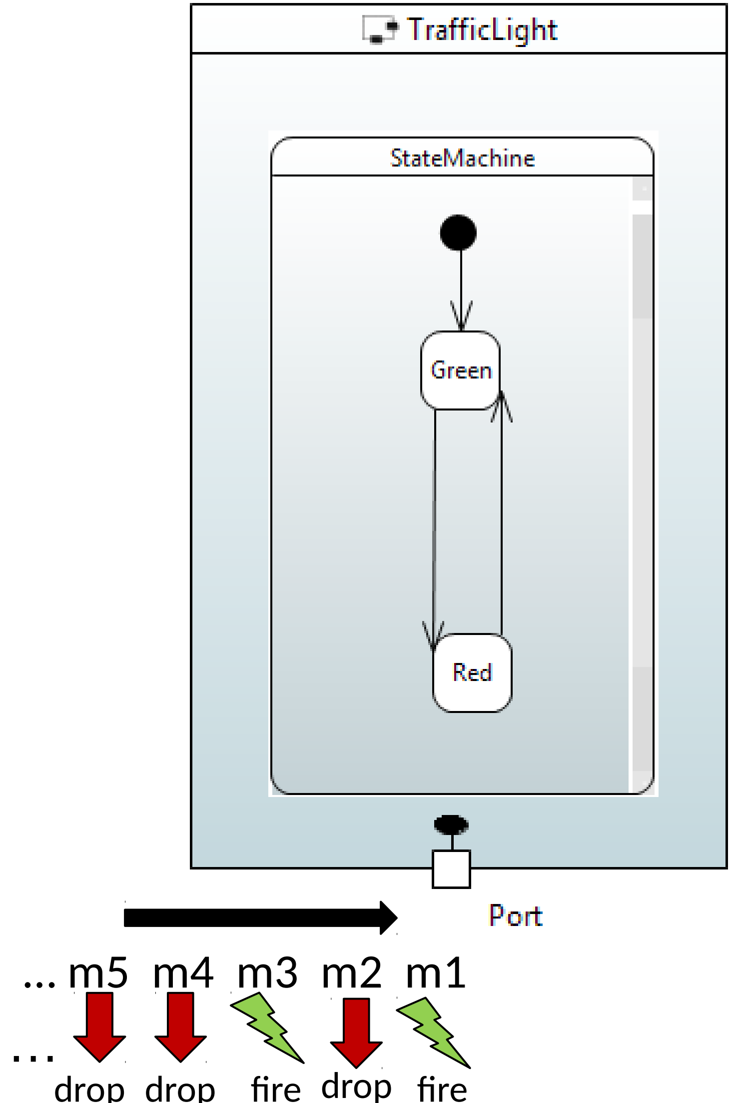
State Configuration

- States can be active: flow of control resides at state
- If a substate is active, its containing superstate is, too
- State configuration: list of active states
- Stable state configuration: no pseudo states and ends in basic state
- Example: <'play', 'player1Move', 'waitForHand'>



Transition Execution

1. Machine in stable state configuration
2. Message m1 has arrived and is dispatched
3. If dispatching enables no transition, m1 is 'dropped'
4. If dispatching enables transition t,
   - source state of t active,
   - message matches trigger of t, and
   - guard evaluates to 'true'
5. then transition t executed
   a. execute exit action of source state of t (if any)
   b. execute action code of t (if any)
   c. execute entry code of target state of t (if any)
6. If target of t is pseudo state
   a. continue by choosing and executing outgoing transition (i.e., goto 5.)
7. Machine in stable state configuration



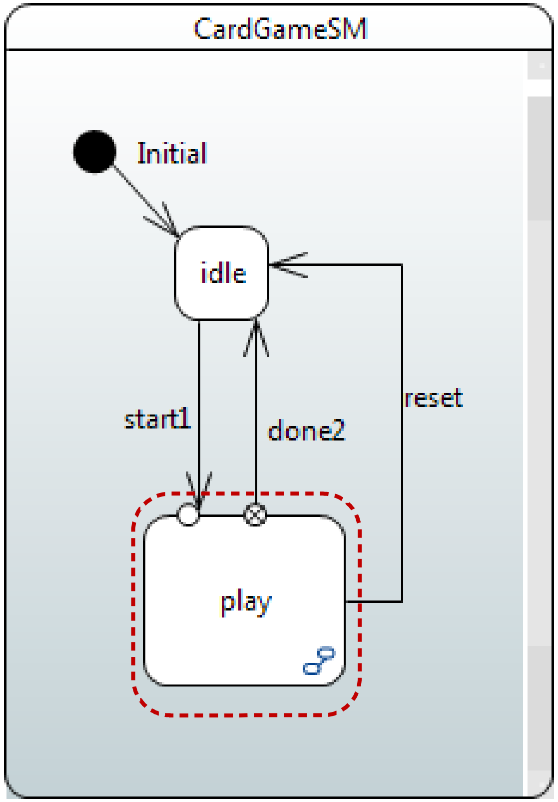
Run-to-Completion

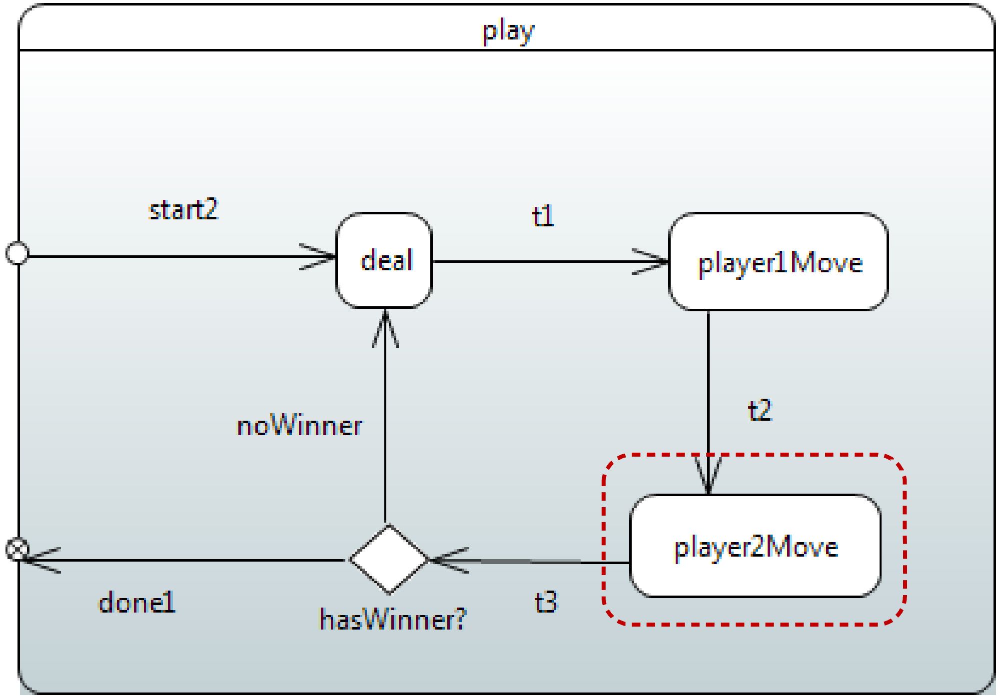
- The event processing of state machines follows 'run-to-completion' semantics
- Dispatching of message triggers execution of possibly entire chain of transitions (Steps 5 and 6 on previous slide)
- Execution lasts until stable state configuration has been reached (last state in transition chain not a pseudo state)
- During transition execution, no other message will be dispatched

$\Rightarrow$ better concurrency control

Group Transitions

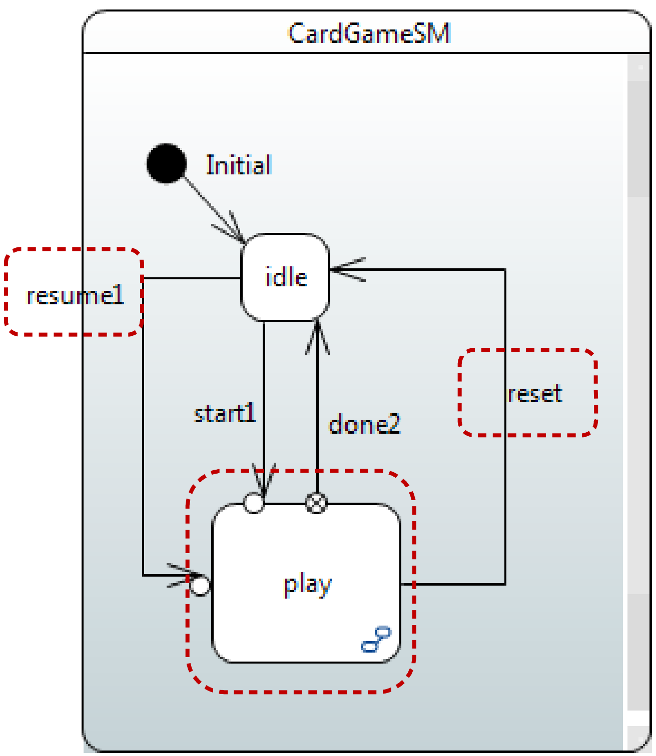
- Source state is composite
- Example:
  - Start configuration <'play','player2Move'>
  - Execute transition 'reset':
    - exit code 'player2Move', exit code 'play', effect 'reset', entry code 'idle'
  - End configuration <'idle'>

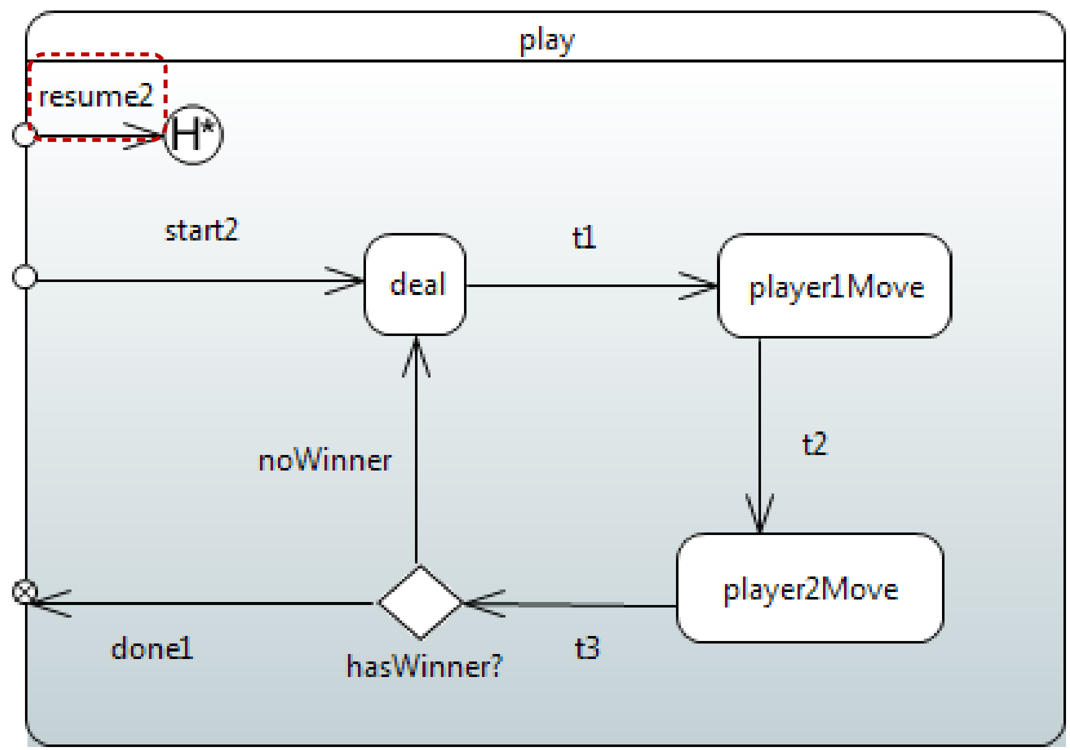




History

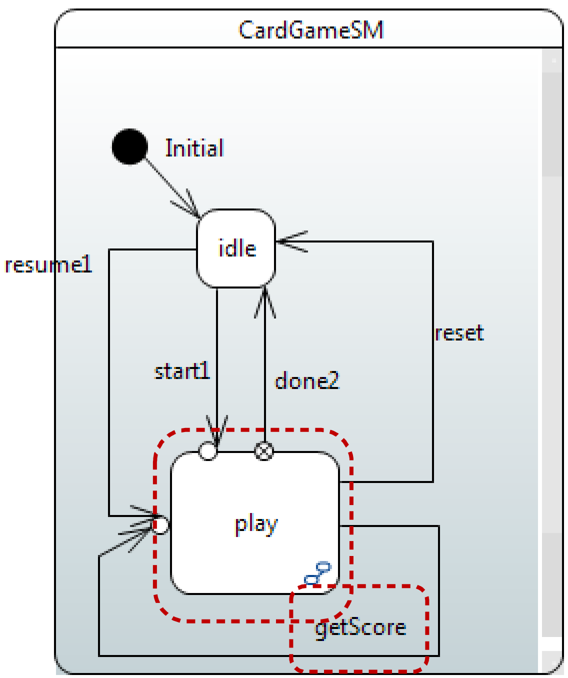
- Re-establish full state configuration that was active when containing state was active most recently
- Example: from <‘play’, s> to <‘play’, s> with ‘reset’ ‘resume1’

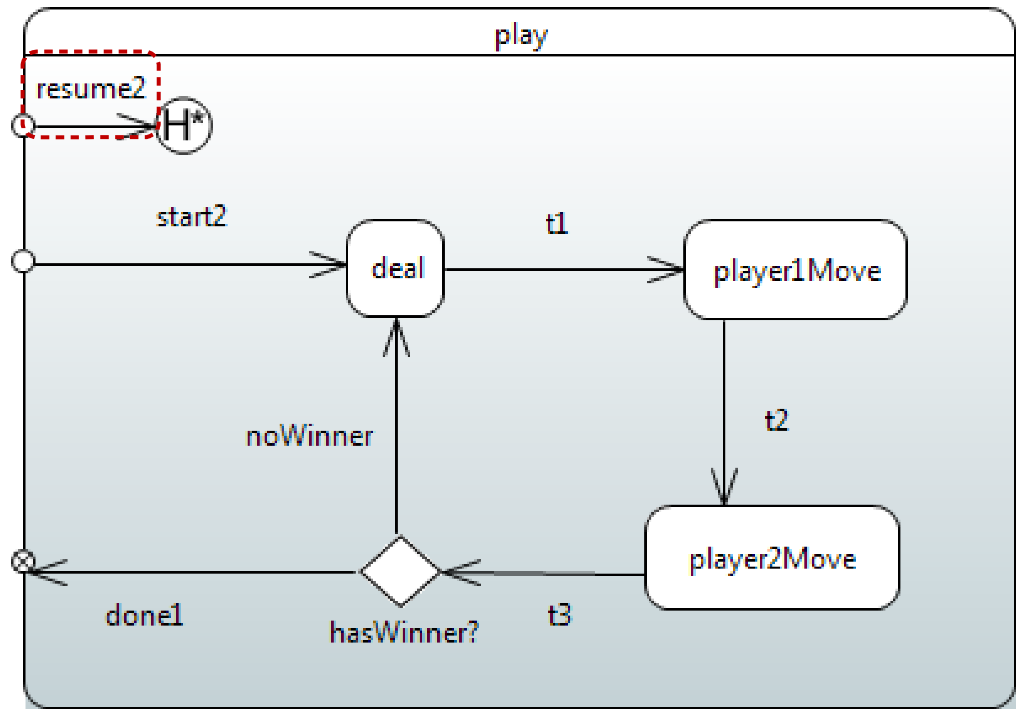


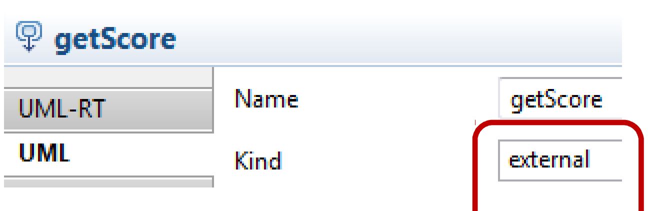


Self Transitions

- Source and target states are the same
- 2 kinds: external, internal
- External: source state (and all substates) exited and target state entered

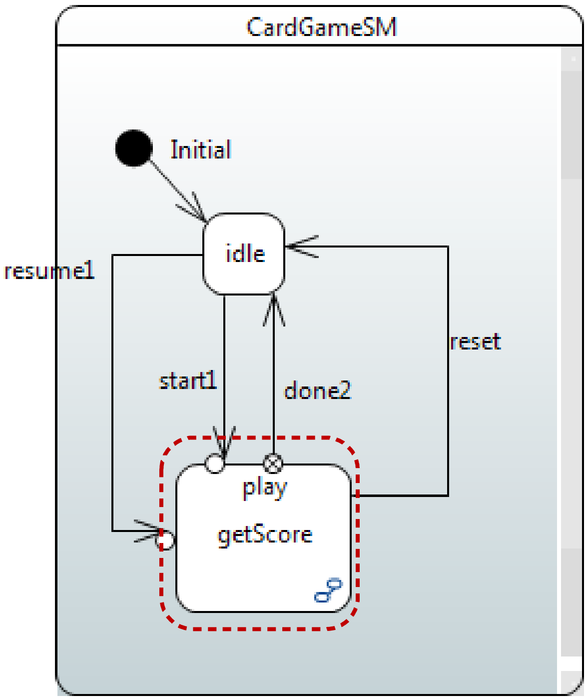


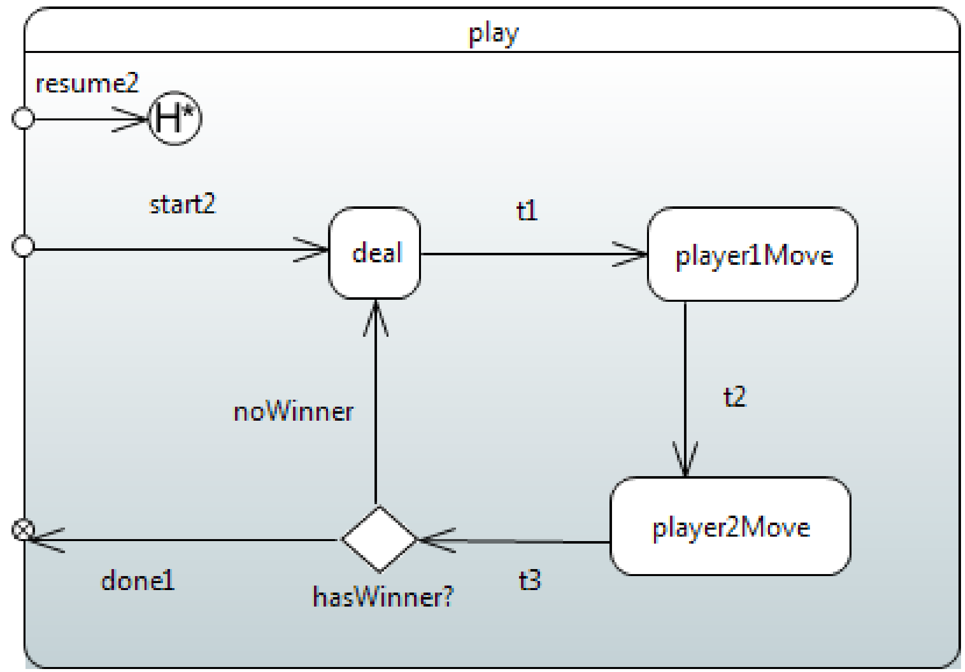


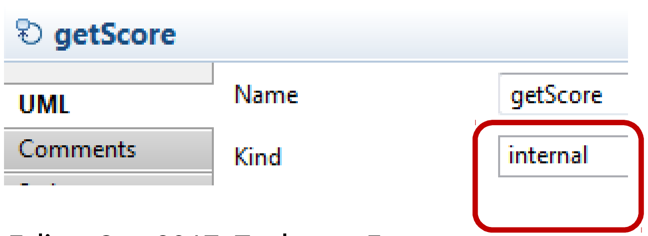


Self Transitions: Internal

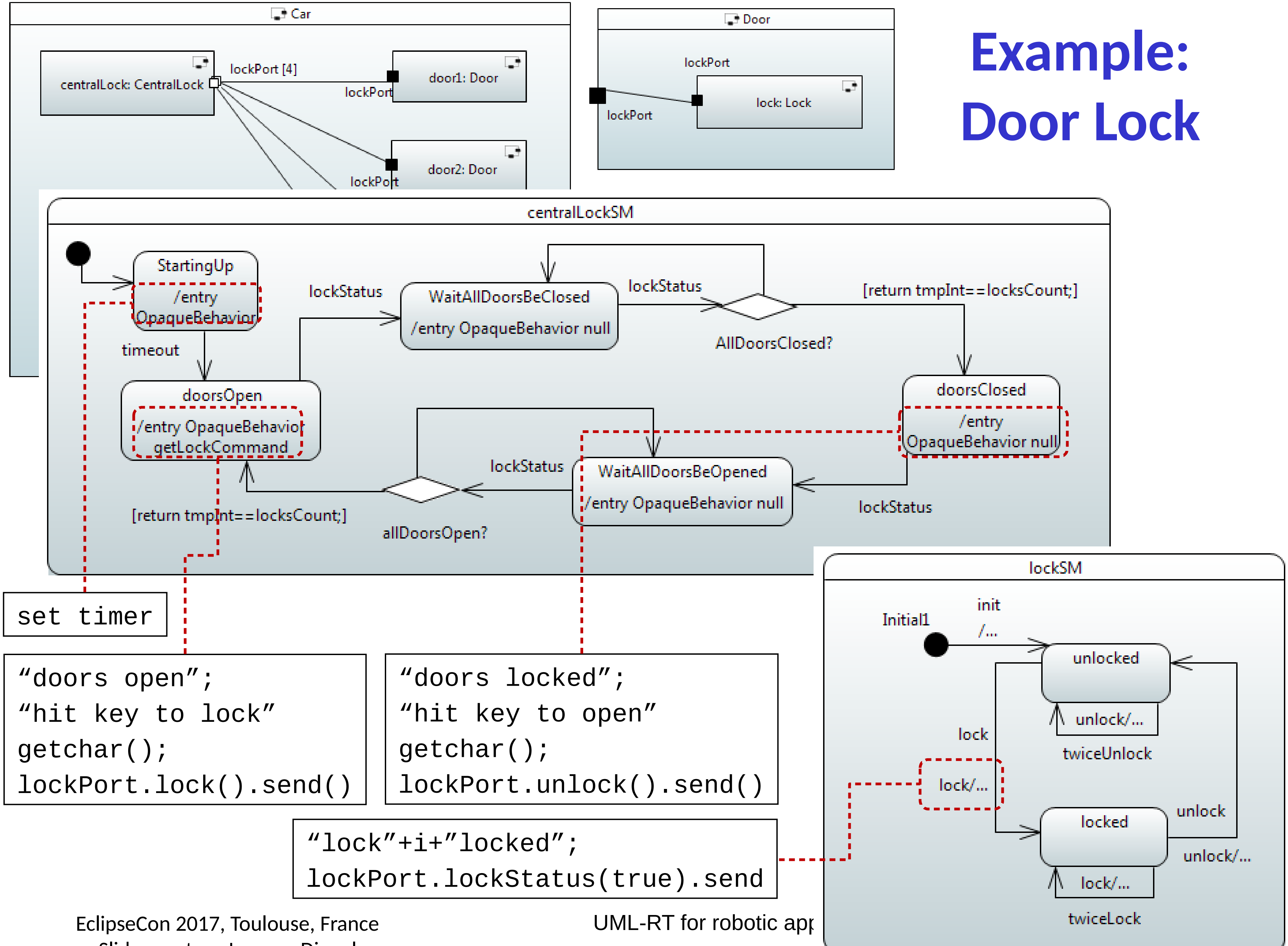
- Source state (and all substates) remain active; no exit or entry actions executed



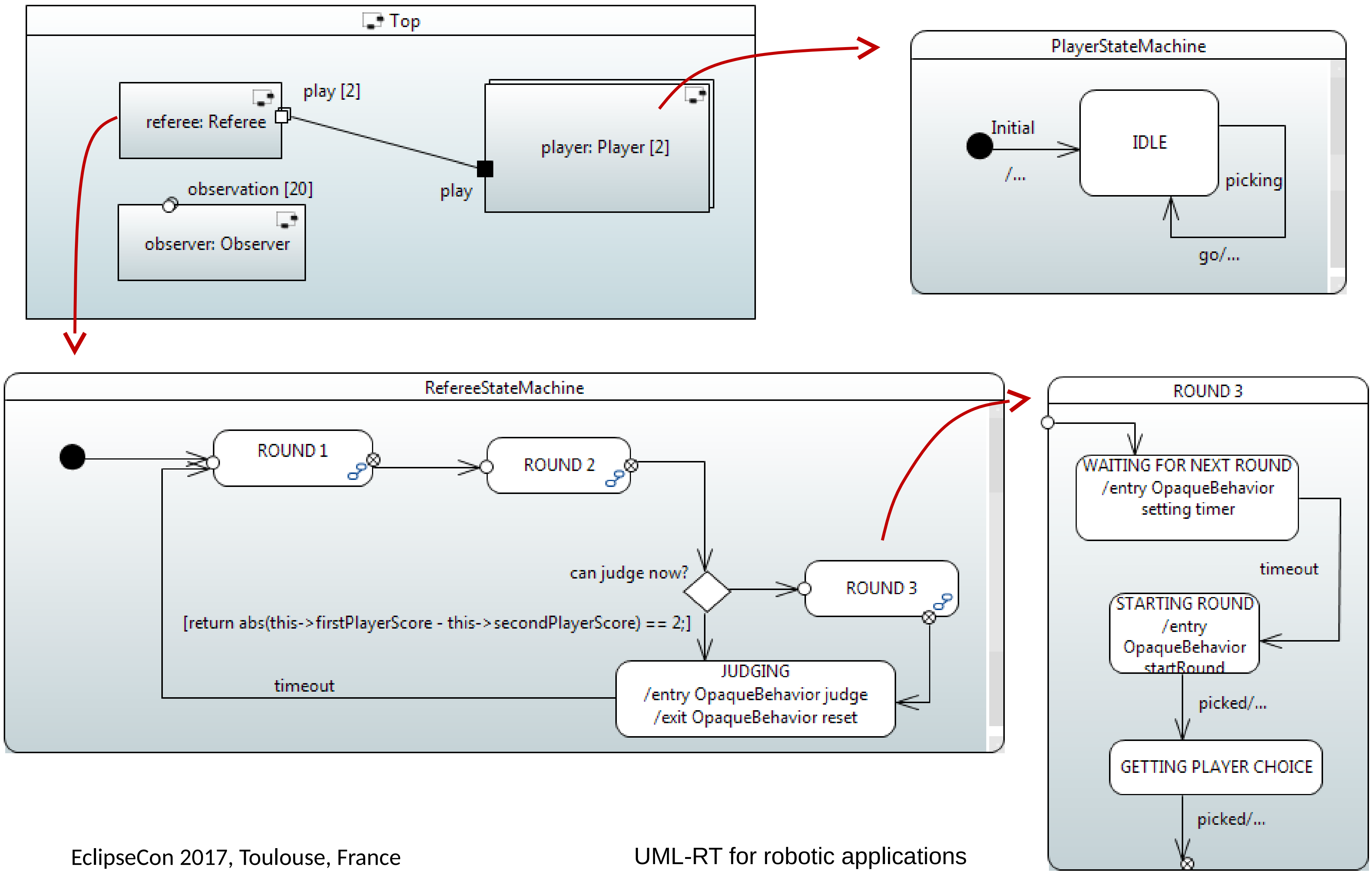




Example: Door Lock



Example: Rock/Paper/Scissors



Additional UML-RT Features

- Structure
  - Optional capsules
  - Inheritance
- Behaviour
  - Junction pseudo state
  - Defer/recall
  - Synchronous communication
  - Message priorities

Additional Papyrus-RT Capabilities

- Generation of multi-threaded code
  - Logical thread
    - = flow of control for capsule instance
  - Physical thread
    - Executes RTS controller
      - Oversees execution of all capsules assigned to physical thread
  - Generating single threaded code
    - 1 physical thread executing one controller executing all capsules
  - Generating multi threaded code
    - Several physical threads each executing their own controller
- Graphical/textual hybrid modeling (prototype)
  - Fully synchronized
- Legacy model import
- Observer service

Papyrus-RT: What's Missing?

- Model-level analysis
  - Model execution/interpretation
  - Debugging (ongoing)
  - Testing (ongoing)
  - Static analysis
- Integration with external tools (ongoing)
  - Animation, simulation (Unity)
- Sequence diagram integration
- Graphical/textual hybrid modeling (ongoing)
- Action language (ongoing)
- User experience
- Deployment

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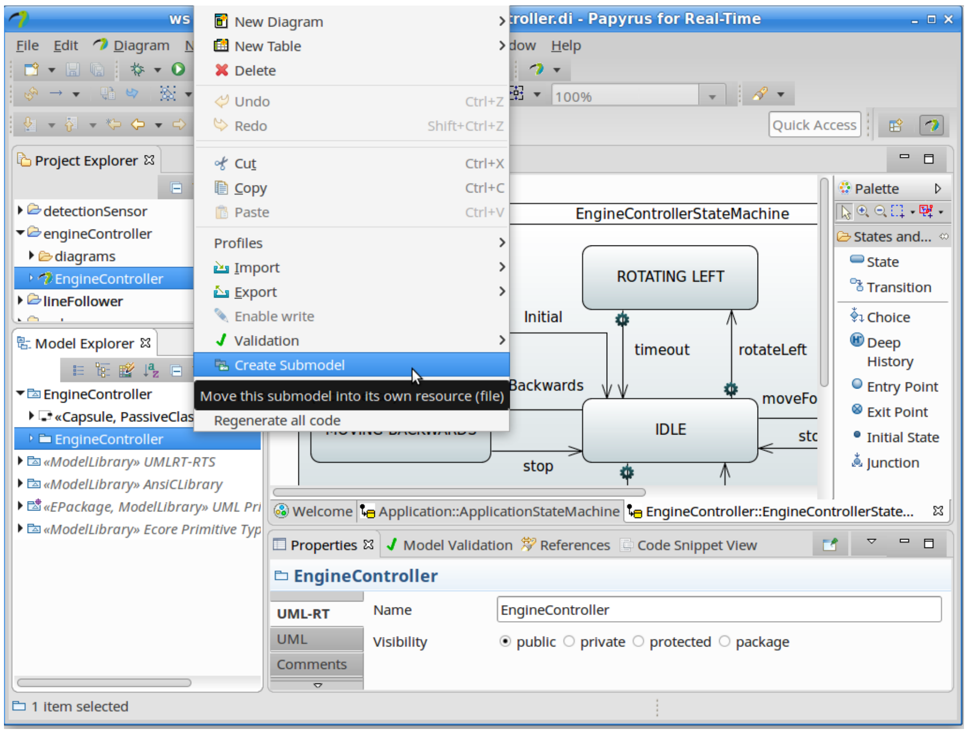
Hackaton !

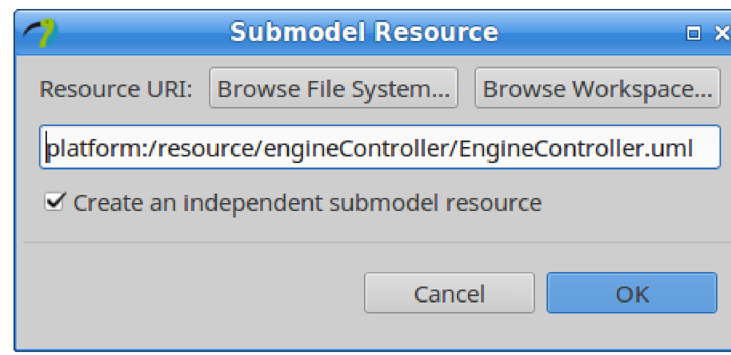
- Discovery
  - Move forward and take pictures
  - Record a video
  - Detect obstacle and stops
  - Change direction
- Line-following robot
  - Follow a line
  - Stop when detecting an obstacle
  - Brake whenever a front obstacle is too close
  - Stop when the traffic light turns red
- Traffic light
  - Red, green, orange
  - Detect the presence of a vehicle
  - Push button to detect pedestrians

Papyrus-RT: Sharing models

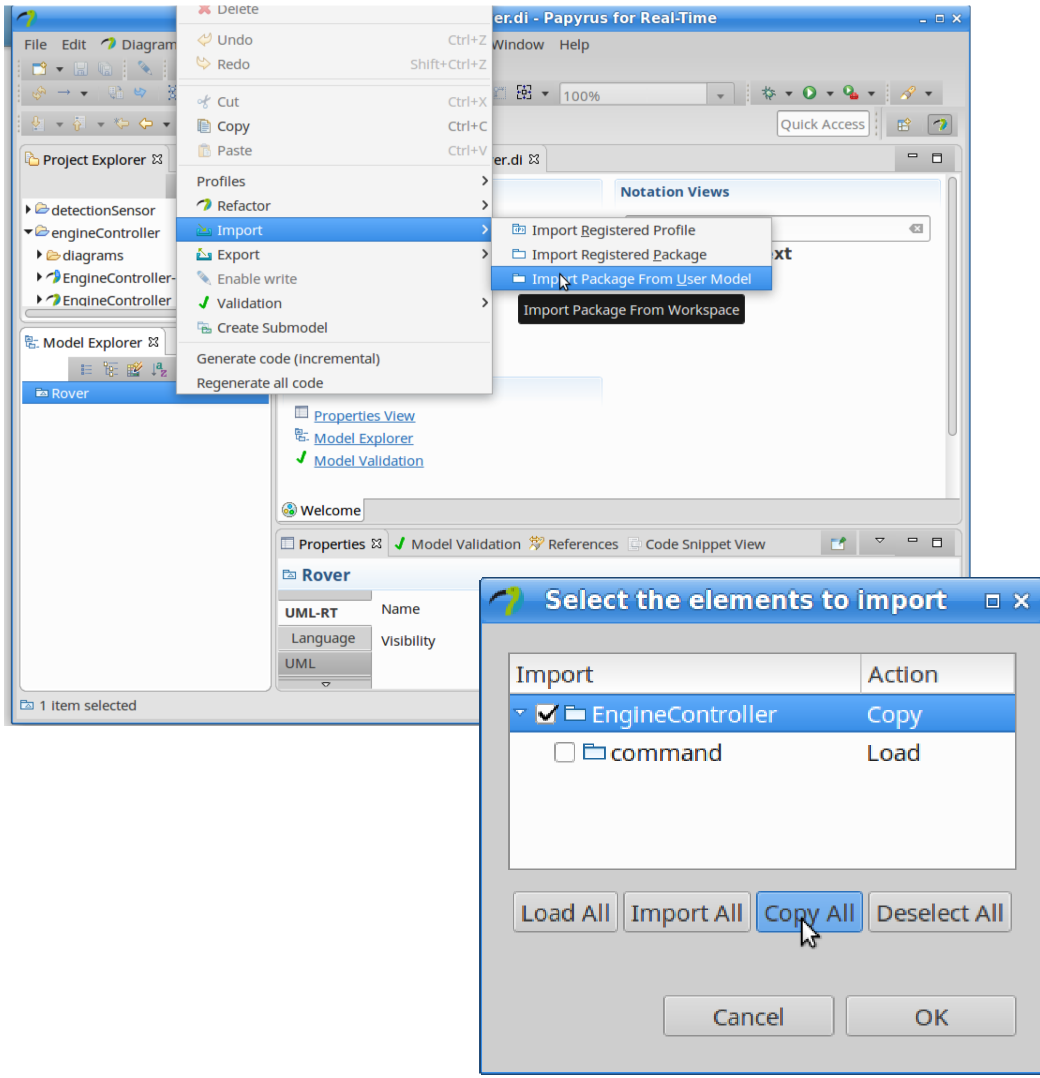


To export a package as a submodel :

- Right click on the package to export in the model explorer
- Click on Create Submodel
- Set the resource URI
- Hit 'OK' and save



Papyrus-RT: Sharing models (cont’d)

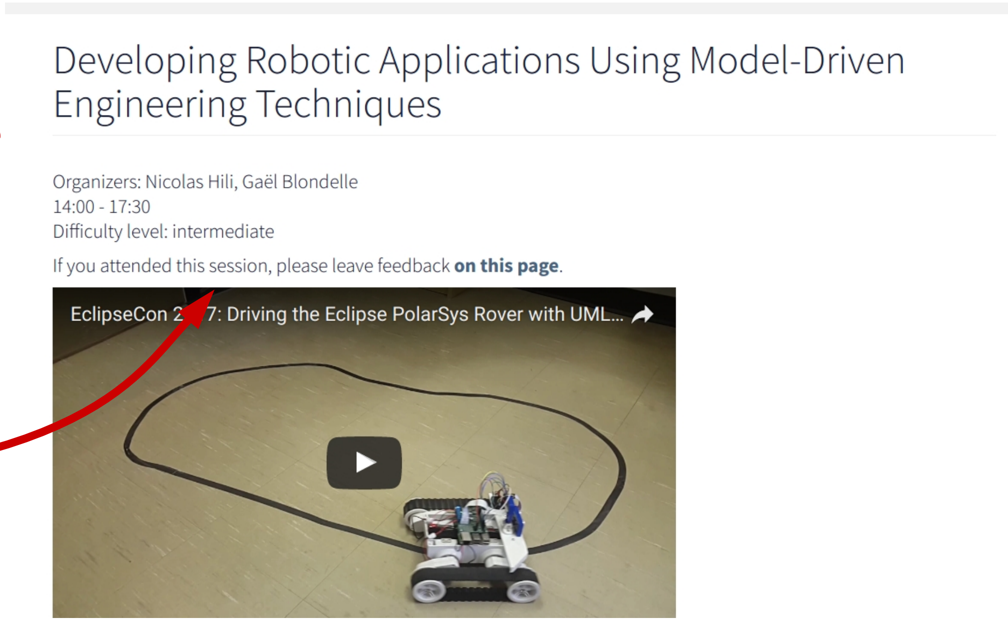


To import a package in another model:

- Right click on the root element of the model you want to import your submodel in the model explorer
- Select ‘Import / Import Package from User Model’
- Browse your workspace and find your submodel
- Click on the ‘Copy All’ button to import

Conclusion

- Intro to
  - UML-RT
    - small, proven subset of UML for real-time systems
  - Papyrus-RT
    - open-source MDE tool w/ full code generation
  - PolarSys Rover / Wiring PI
- Lots of opportunity to use research, contribute
- More questions?
  - hili@cs.queensu.ca
- Feedback ?



Acknowledgments

With the active and huge participation of:

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Harshith Vasanth Gayathri	MSc at Queen's University
Sudharshan Gopikrishnan	MSc at Queen's University

Special thanks to:

Gaël Blondelle	Director European Ecosystem Development at Eclipse foundation	for helping us bootstraping the project with the PolarSys Rover
Aaron Vissier	System analyst at Queen's University	for his huge help with all the "soldering" and "tooling" questions I have had (and for the future ones :))
Michal Pasternak	MSc at Queen's University	for spending hours 3D-printing the extensions for the Rover

Resources and References

- Links
  - Resources: http://flux.cs.queensu.ca/mase/eclipsecon17-unconference/
  - Papyrus-RT: https://eclipse.org/papyrus-rt
    - Installation, tutorial, etc: https://wiki.eclipse.org/Papyrus-RT/User
    - Wiki: https://wiki.eclipse.org/Papyrus-RT
    - Forum: https://www.eclipse.org/forums/index.php/f/314/
  - Papyrus: https://eclipse.org/papyrus/
    - Papyrus industrial Consortium: https://wiki.polarsys.org/Papyrus_IC
  - PolarSys: https://www.polarsys.org/
- References

[1] Selic. What will it take? A view on adoption of model-based methods in practice. Software and Systems Modeling (SoSyM) 11(4):513-526. October 2012.

[2] Whittle, Hutchinson, Rouncefield. The state of practice in model-driven engineering. IEEE Software 31 (3), 79-85. 2014.

[3] Dingel. Complexity is the Only Constant: Trends in Computing and Their Relevance to Model Driven Engineering. Proceedings ICGT'16. LNCS 9761:79-85. 2016..

[4] Whittaker, Goldsmith, Macolini, Teitelbaum, "Model Checking UML-RT Protocols", *Proc. Workshop Formal Design Techniques for Real-Time UML*, 2000-Nov.

[5] R. Alur. Formal Analysis of Hierarchical State Machines. Verification: Theory and Practice. 2003.

[6] Selic, "Using UML for modeling complex real-time systems," in Workshop on Languages, Compilers, and Tools for Embedded Systems (LCTES'98), 1998, pp. 250–260.