Towards an open source MDE tool infrastructure for the Internet of Things

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The Internet of Things (IoT)

Technology for collection, aggregation, and analysis of data from range of devices to optimize operation of a system in different domains, including buildings, traffic, health care, energy, business, industry

And, please, don’t forget to buy milk ***again****!*

You should walk these short distances in the future.

Can you turn me around?
I look fuller from the other side.

IoT: Core Characteristics

timed
reactive
concurrent

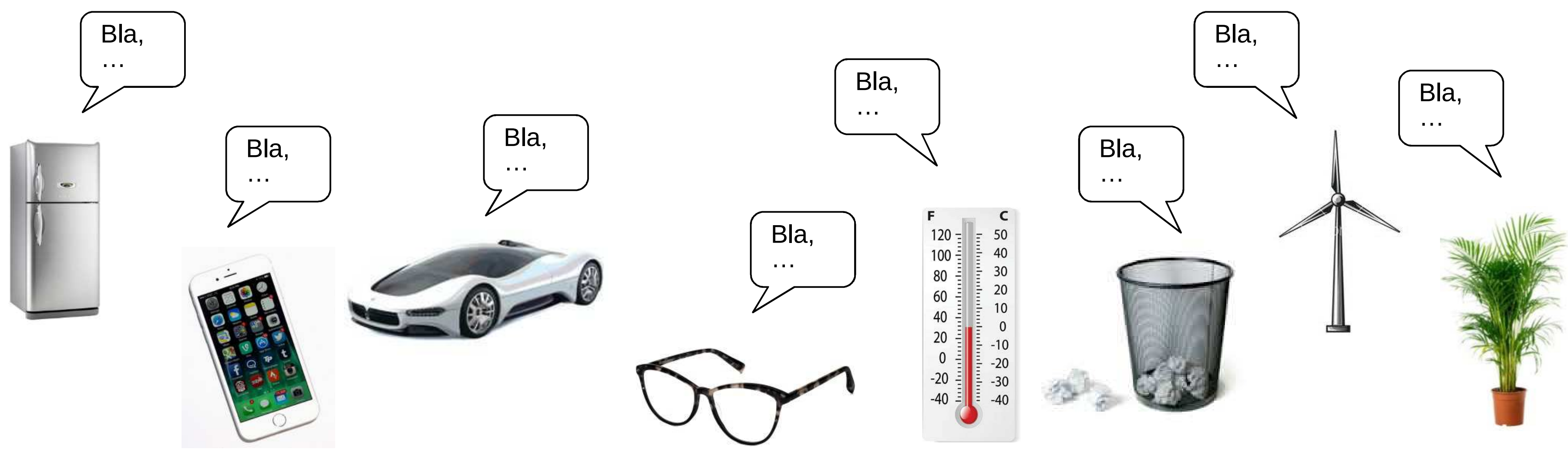
distributed

open
heterogenous

self-optimizing
context-aware
autonomous
adaptive

large scale

available
reliable



MDE

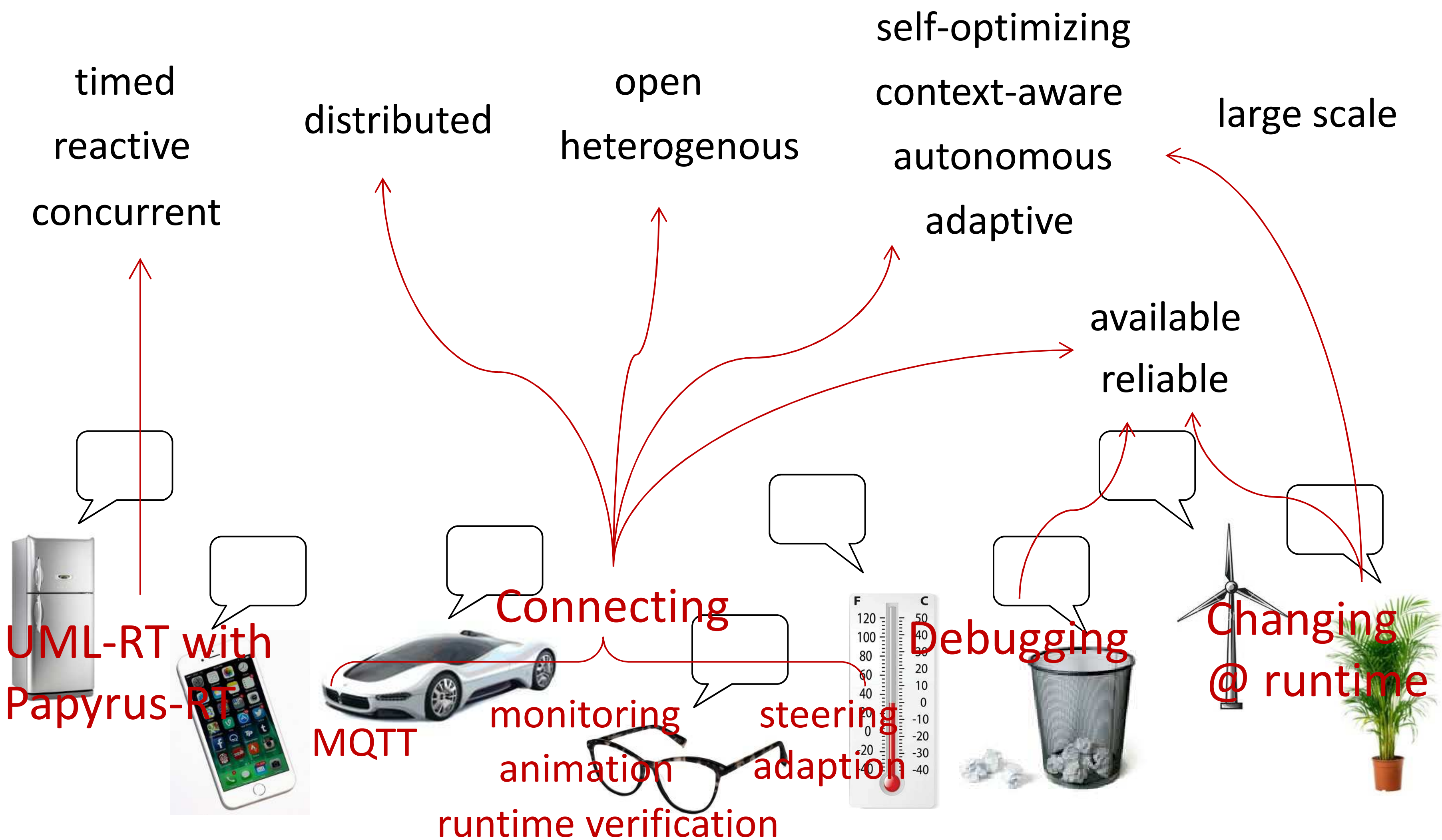
- MDE = notations, techniques, tools to leverage abstraction and automation for system development
- Examples for abstraction and automation
  - Virtual memory [Denning 1970]
  - Internet Protocol [Cerf 2017]
- Examples for MDE
  - Robotics software [SPARC 2016]
  - Industrial DSLs (e.g., at Ericsson)
  - Game development (e.g., in Unity)

[Denning 1970] P. Denning. Virtual Memory. ACM Computing Surveys 2(3):153-189. 1970

[Cerf 2017] V.G. Cerf. In Praise of Underspecification? CACM 60(8):7. Aug 2017

[SPARC 2016] SPARC. Robotics 2020 Multi-Annual Roadmap: For Robotics in Europe, Horizon 2020 Call ICT-2017 (ICT-25, ICT-27 & ICT-28). Dec 2016.

Overview of Talk



Goal of Talk

- Inform
  - MDE with UML-RT and Papyrus-RT and extensions
- Inspire
  - Use, extend, participate

Open Source!

Background

MDE with UML-RT
and Papyrus-RT

Overview of Talk

timed
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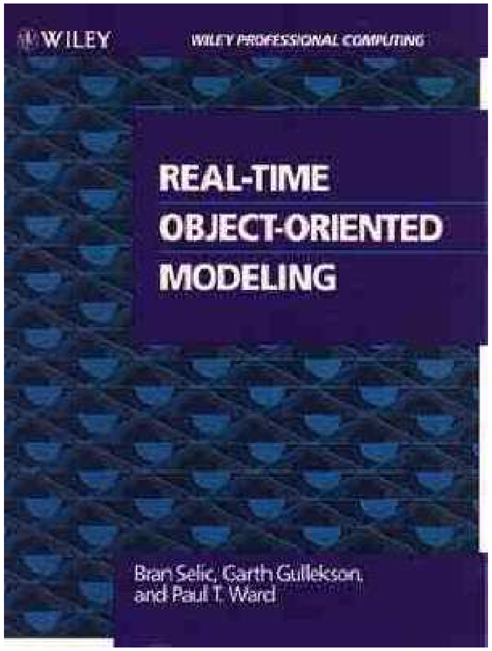
UML-RT with
Papyrus-RT

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
  - Protos ETrice
  - Eclipse Papyrus-RT

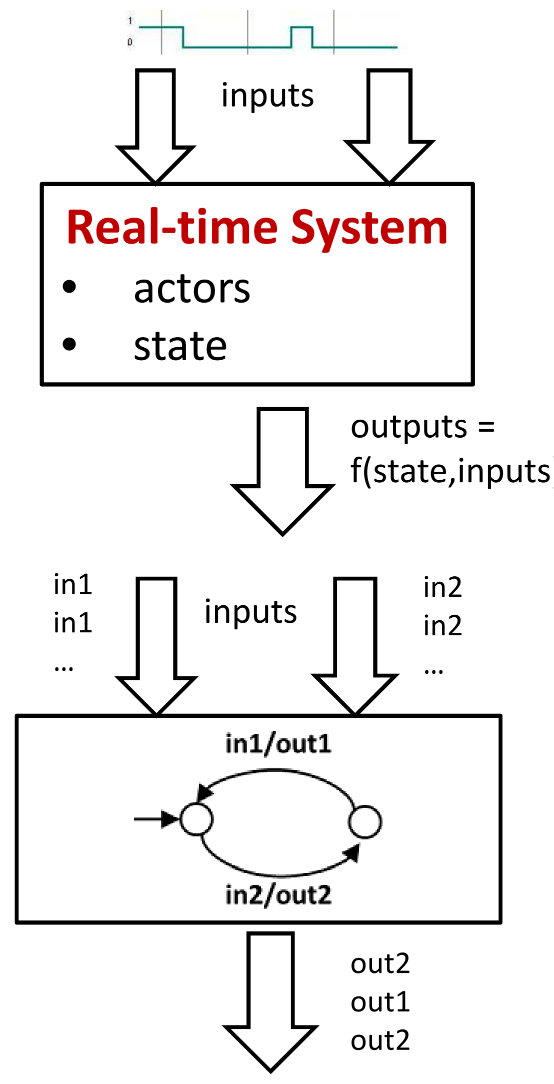


[Selic, Gullekson, Ward. *Real-Time Object-Oriented Modellng*. Wiley. 1994]

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, typed interfaces
  - Message-based communication
- Event-driven execution
  - State machines
- Lots of analysis opportunities

"UML-RT has features that appeal to the formalist"
[Whittaker et al 2000]

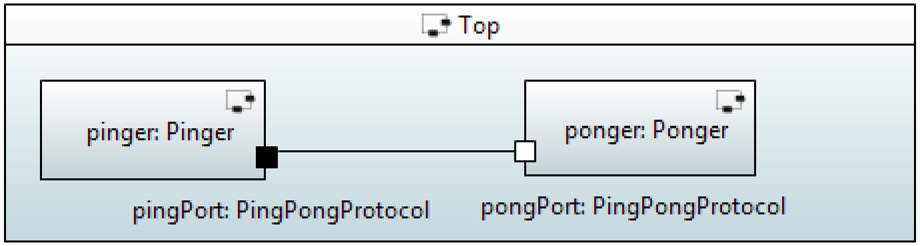


[Whittaker et al 2000] P. Whittaker, M. Goldsmith, K. Macolini, T. Teitelbaum. "Model checking UML-RT protocols". Workshop on Formal Design Techniques for Real-Time UML. York, UK. Nov. 2000.

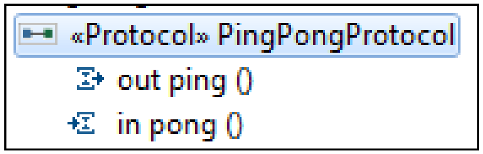
UML-RT: Core Concepts (1)

- 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

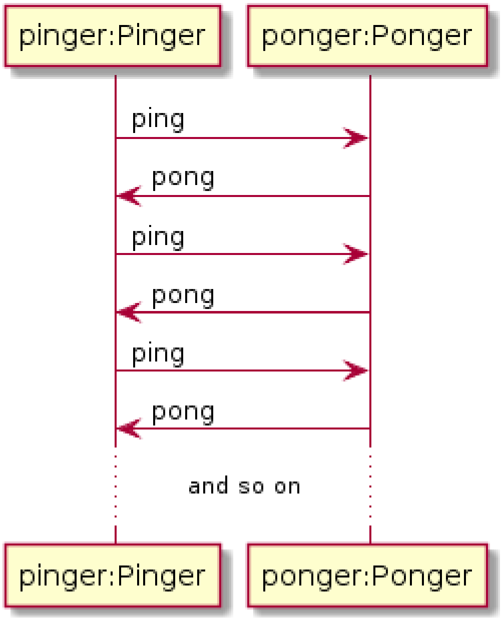
UML-RT:
Core Concepts (2)



- Model
  - Collection of capsule definitions
  - ‘Top’ capsule containing collection of parts (capsule instances)



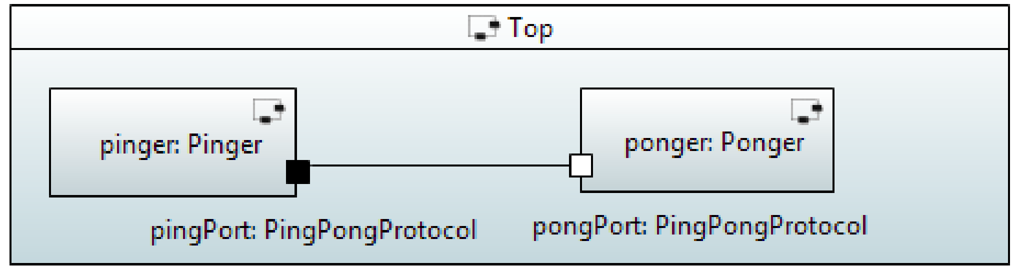
- Capsules
  - May contain
    - Attributes, ports, or other parts
  - Behaviour defined by state machine



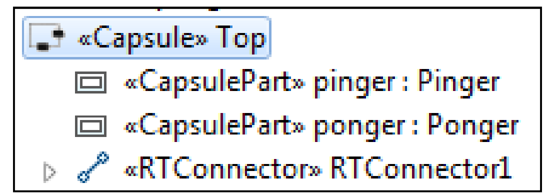
- Ports
  - Typed over protocol defining input and output messages
- State machine
  - Transition triggered by incoming messages
  - Action code can contain send statements that send messages over certain ports

Capsules (1)

- Kind of active class
  - Attributes, operations
  - Own, independent flow of control (logical thread)

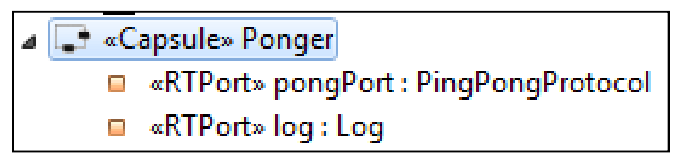


- May also contain
  - Ports over which messages can be sent, received
  - Parts (instances of other capsules) and connectors

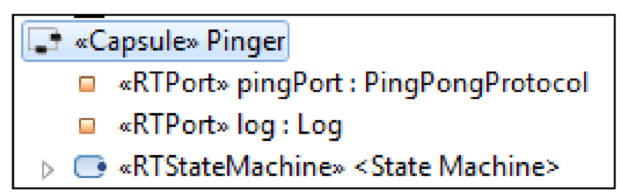


- Creation, use of instances tightly controlled
  - Created by runtime system (RTS)
  - Cannot be passed around
  - Stored in attribute of another capsule (part)
  - Information flow only via messages sent to ports

  ⇒ better concurrency control and encapsulation

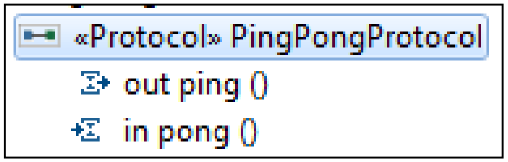


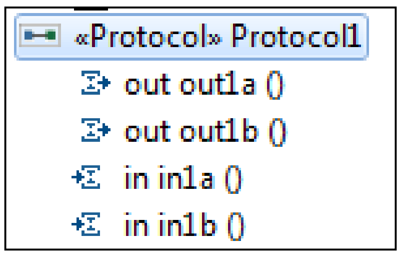
- Behaviour defined by state machine

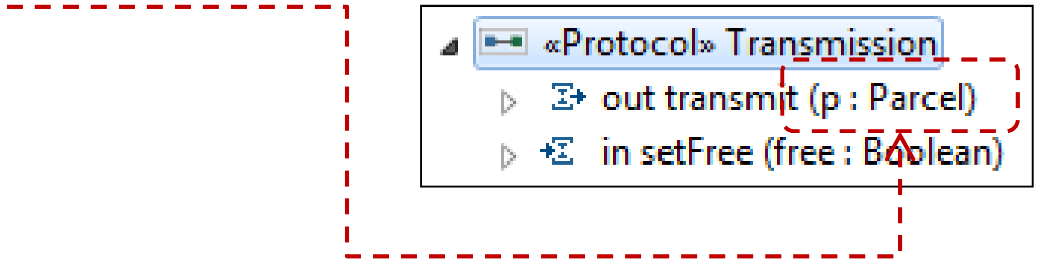


Protocols

- 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







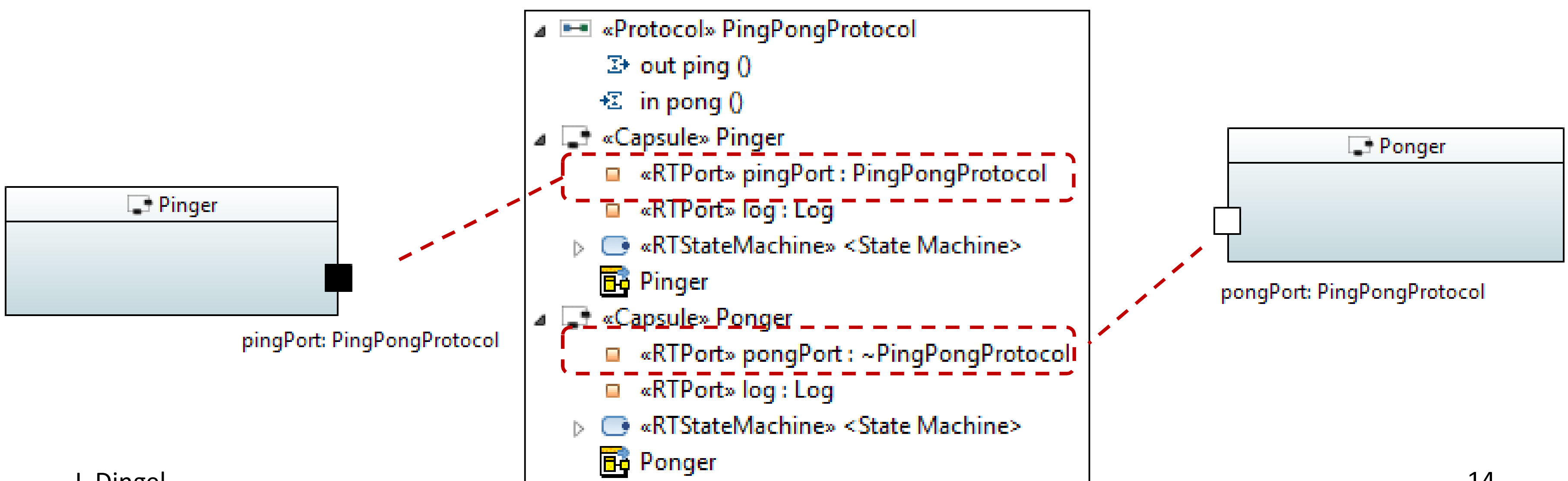
Ports

- "Boundary objects" owned by capsule
- Typed over a protocol P
- Have '**send**' operation

```
portName.msg(arg1,...,argn).send()
```

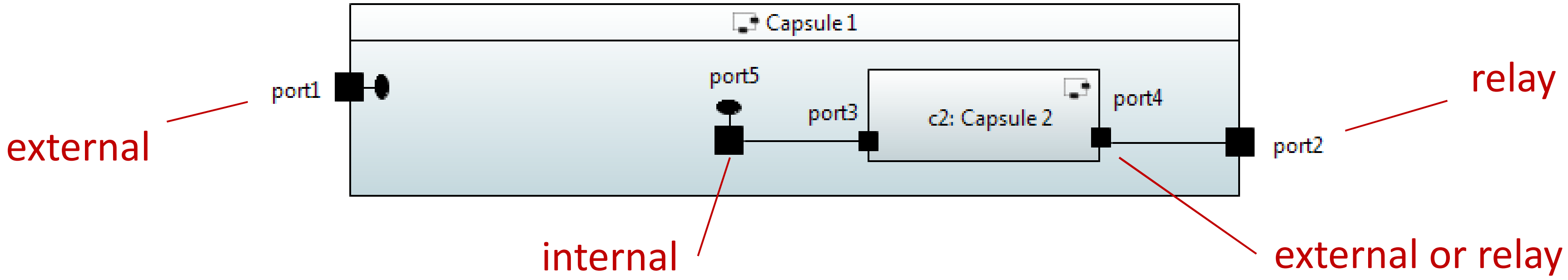
- E.g., in **`Pinger`**

```
pingPort.ping().send()
```

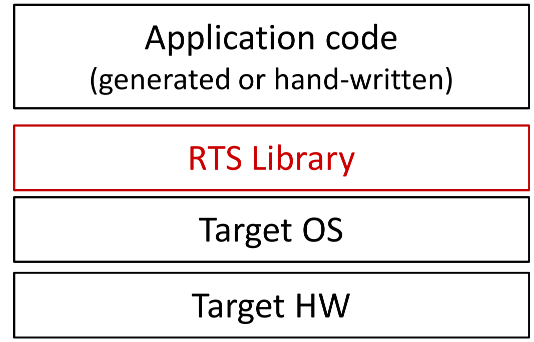


Ports: External, Internal, Relay

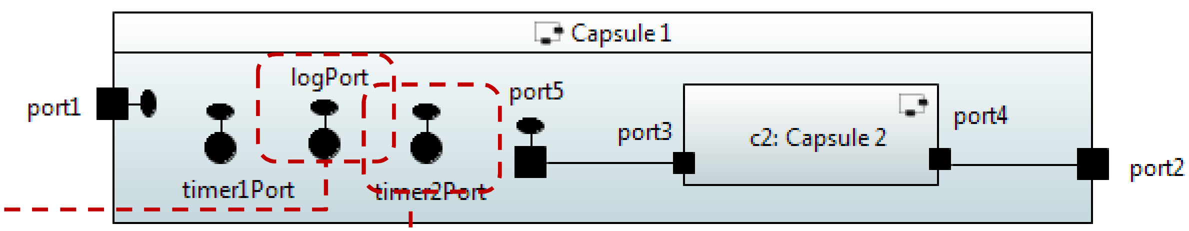
- External behaviour
  - Provides (part of) externally visible functionality (isService=true)
  - Incoming messages passed on to state machine (isBehaviour=true)
  - Must be connected (isWired=true)
- Internal behaviour
  - As above, but not externally visible (isService=false)
  - Connect state machine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



Ports: System

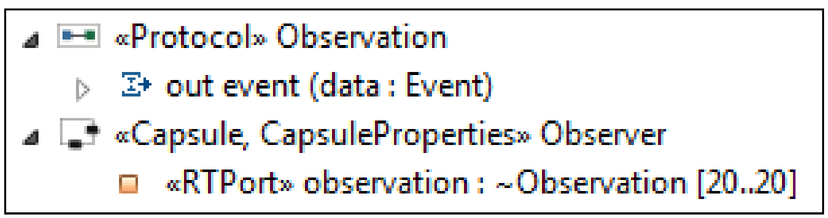


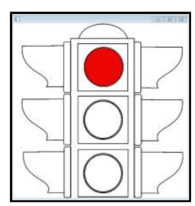
- Connects capsule to Runtime System (RTS) library via corresponding system protocol
- Provides access to RTS services such as
  - Timing: setting timers, time out message
    - `timer2Port.informIn(UMLRTTimespec(10, 0));`
      `// set timer that will expire in 10 secs and 0 nanosecs`
    - When timer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

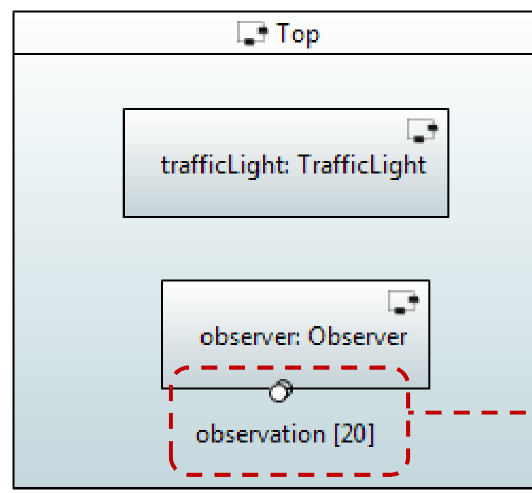


Ports: SPP and SAP

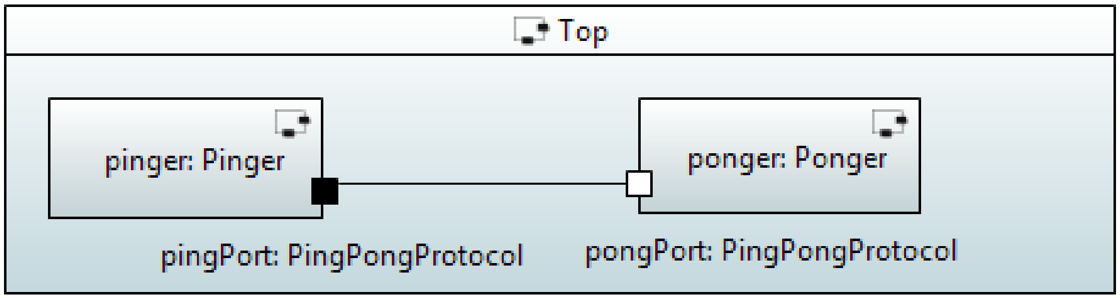
- So far, only wired ports
  - Connected automatically when instances are created
- Unwired ports
  - Original intent: ‘layered’ design
  - Connected at run-time
    - Port on provider: Service Provision Point (SPP)
    - Port on user: Service Access Point (SAP)
    - Register with RTS using unique service name (manually or automatic)

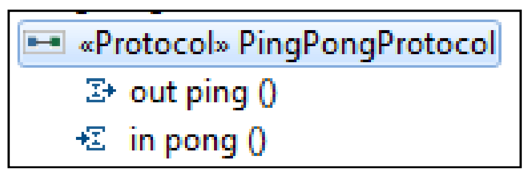


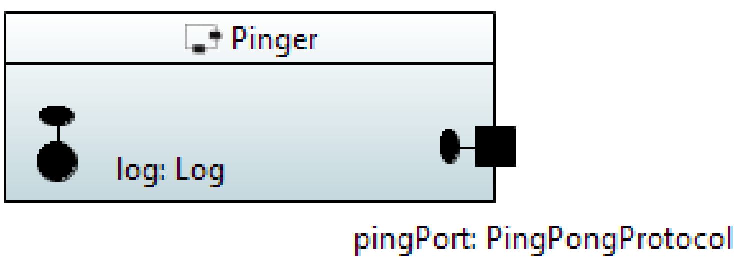


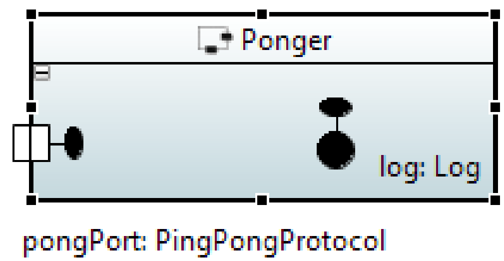


Example: Ping Pong









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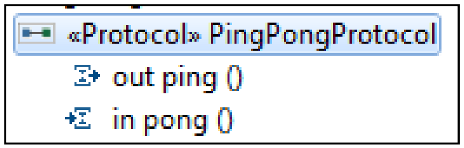
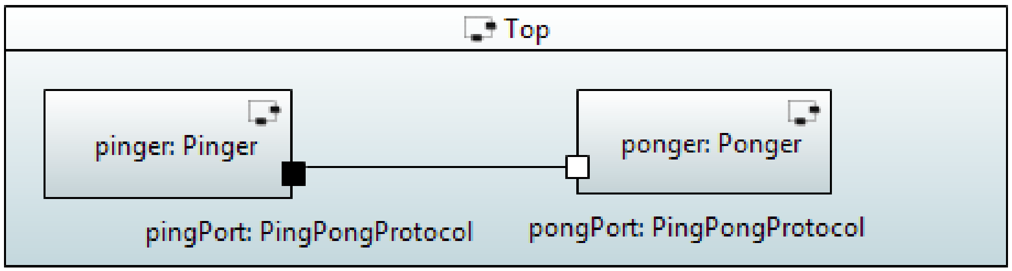
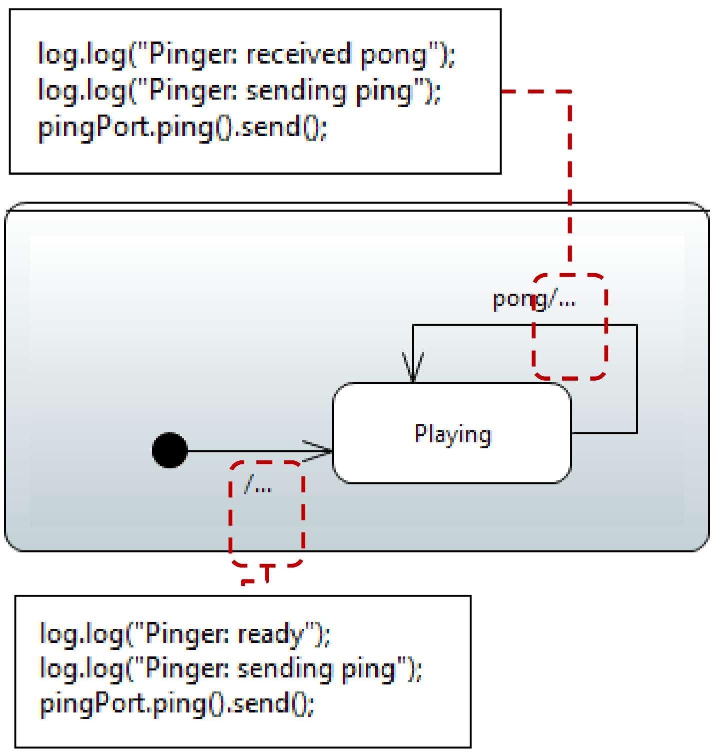
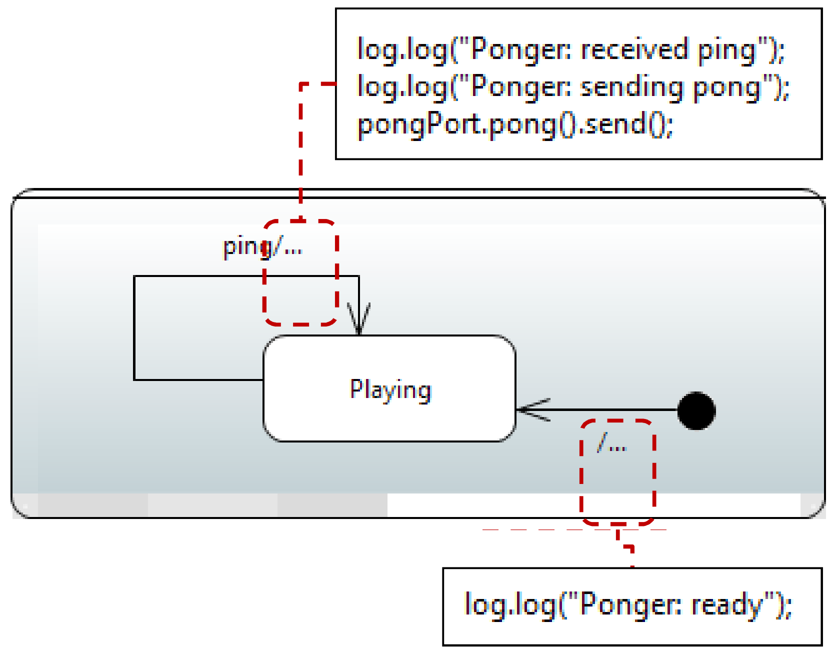





```
$ ./TopMain.exe
Controller "DefaultCon
Pinger: ready
Pinger: sending ping
Ponger: ready
Ponger: received ping
Ponger: sending pong
Pinger: received pong
Pinger: sending ping
Ponger: received ping
Ponger: sending pong
Pinger: received pong
Pinger: sending ping
Ponger: received ping
Ponger: sending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





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

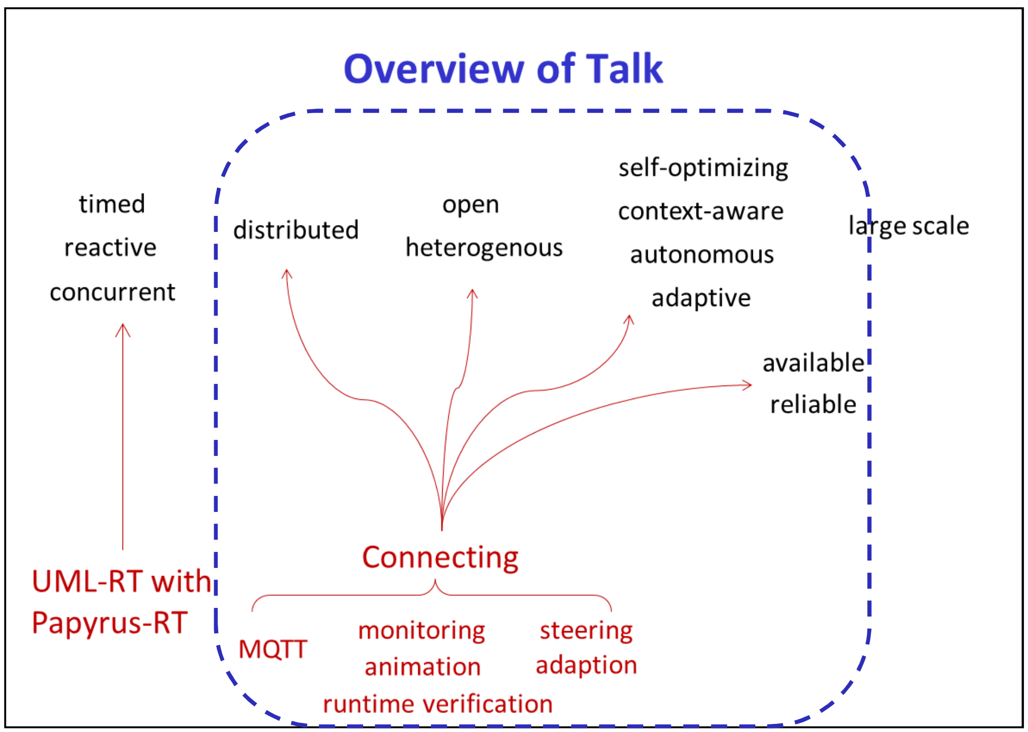
[https://wiki.eclipse.org/Papyrus-RT]

Resources: UML-RT and Papyrus-RT

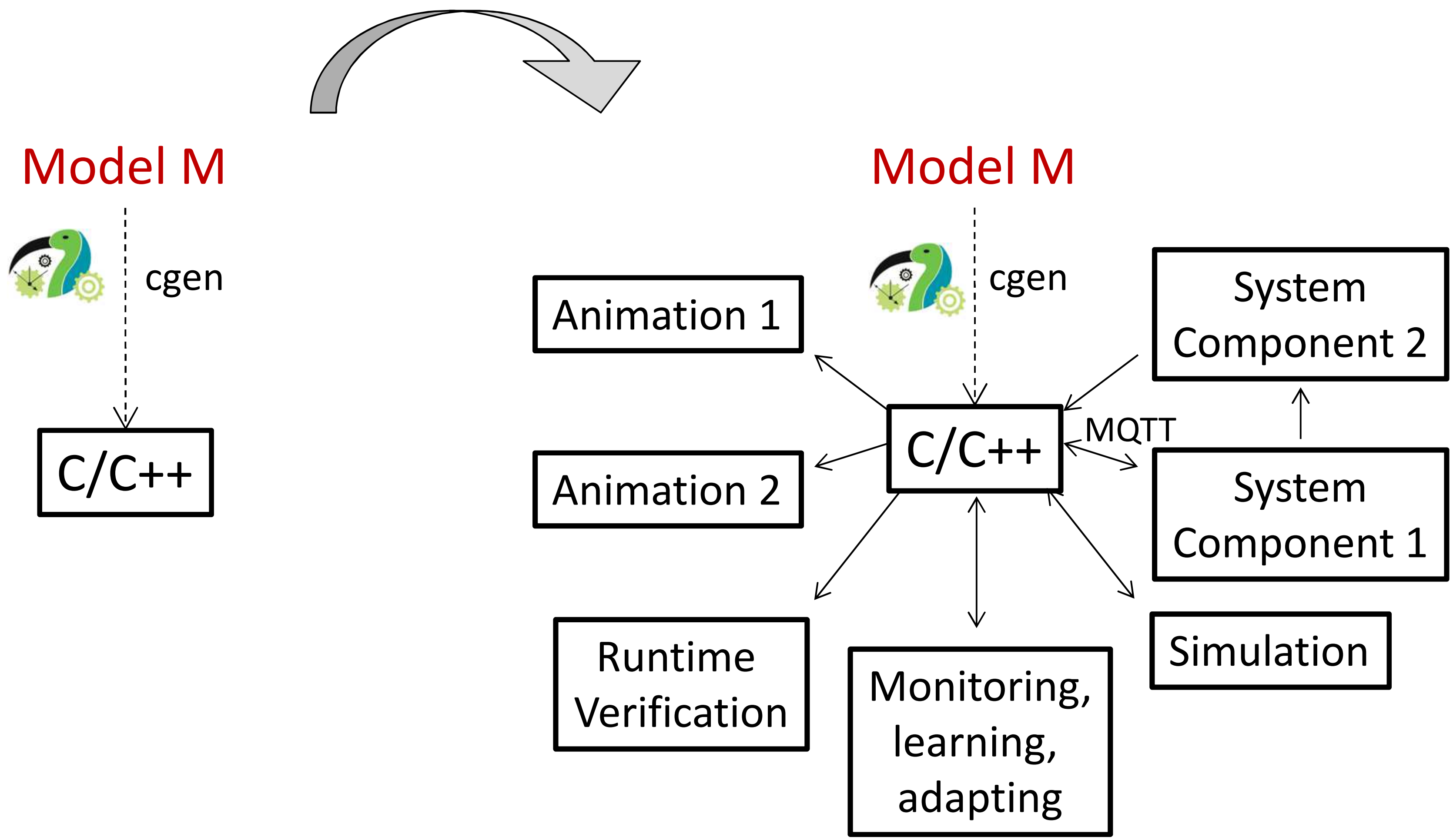
- UML-RT
  - Papers:
    - B. Selic. Using UML for Modeling Complex Real-time Systems. Workshop on Languages, Compilers, and Tools for Embedded Systems (LCTES'98)
    - E. Posse, J. Dingel. An Executable Semantics for UML-RT. SoSyM 15(1):179-217. 2016
  - Tutorials:
    - MODELS'17, http://flux.cs.queensu.ca/mase/papyrus-rt-resources/supporting-material-for-the-models17-tutorial/ ← This afternoon!
    - EclipseCon'17, http://flux.cs.queensu.ca/mase/papyrus-rt-resources/supporting-material-for-eclipsecon17-unconference/
- Papyrus-RT
  - Distribution: https://eclipse.org/papyrus-rt
  - Wiki: https://wiki.eclipse.org/Papyrus-RT
  - Overview: https://www.youtube.com/watch?v=UqefL7-ZPYo

Ongoing Research 1

Connecting

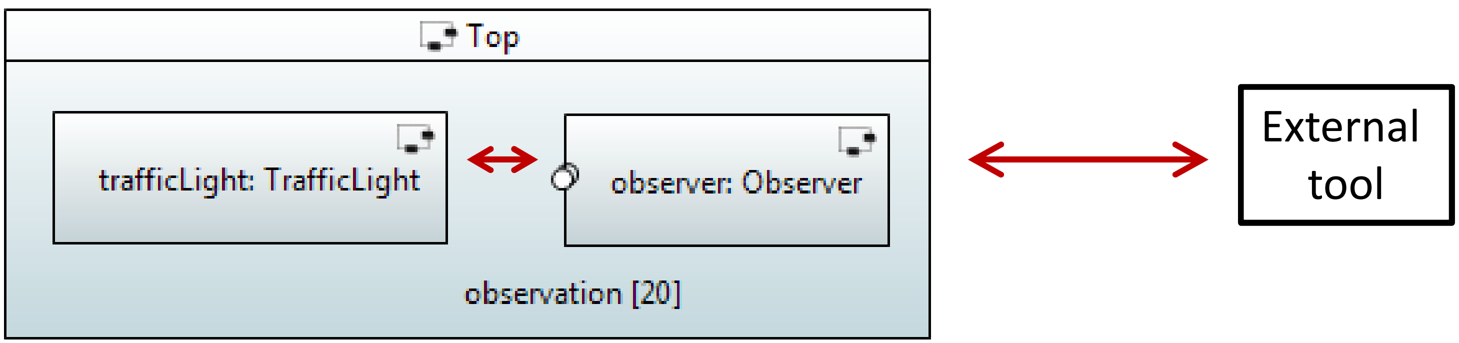


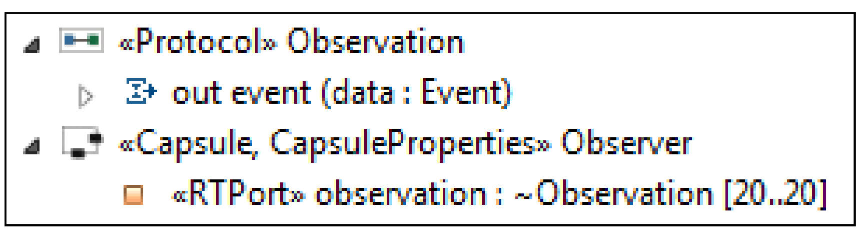
From Isolated to Connected



Mechanism 1: Gateway Capsule

- Using SAP/SPP
  - Protocol defines incoming/outgoing messages
  - Automatic registration
- Bi-directional
  - Incoming messages can trigger transitions

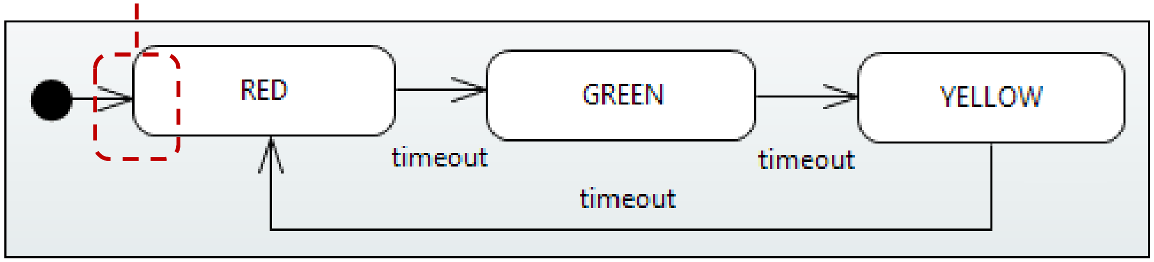


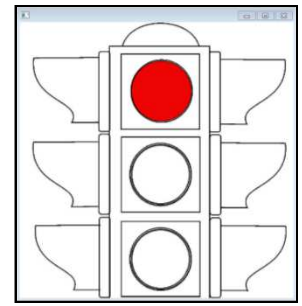


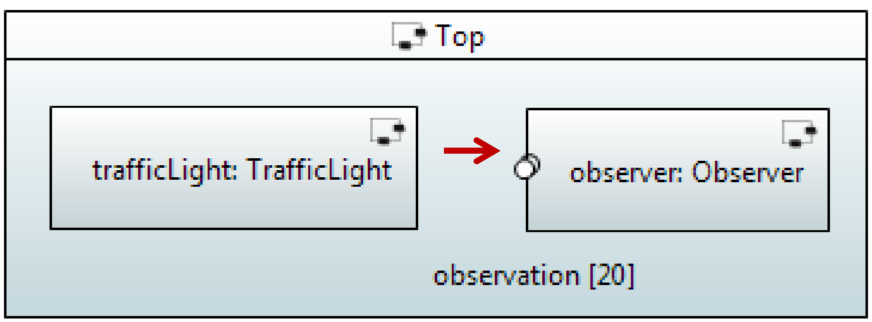
Gateway Capsule: Example

```
Event e1;
e1.setParam("id", "top");
e1.setParam("color", "#ef0404");
e1.setParam("cmd", "set_color");
observation.event(e1).send();

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





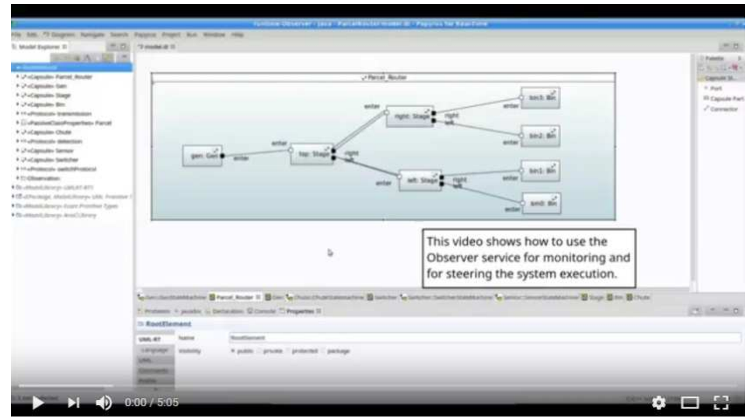


- hotpatching.animation
  - Controller.java
  - Interpreter.java
  - Main.java
  - SocketServer.java
  - TrafficCommandListener.java

- «Protocol» Observation
  - out event (data : Event)
- «Capsule, CapsuleProperties» Observer
  - «RTPort» observation : ~Observation [20..20]

Gateway Capsule: Examples

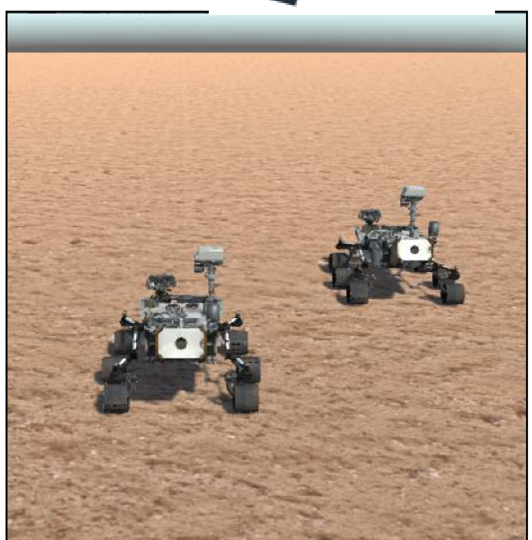
- Monitoring and steering
  - Parcel routing system
  - https://www.youtube.com/watch?v=EbMIgEX9O58




```
Object Wally : Rover {

    config {
        posx = 0
        posy = 1
        posz = 0
        size = 1
        brake = 20
        power = 100
        network = true
    }
}

Object Eva : Rover {
    config {
        posx = 5
        posy = 1
        posz = 5
        size = 1
        brake = 20
        power = 100
        network = true
    }
}
Env simulation {
    Instance plane : land
    Instance eva : Eva
    Instance ourRover: Wally
    Channel myChannel direction inout type TCP (port : 8888) assign ourRover
}
```



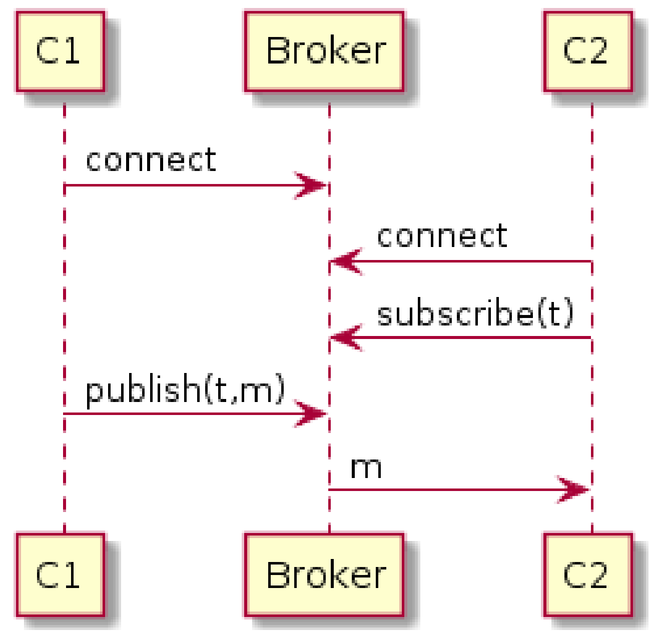
- Animation and simulation using Unity

[Diagrams courtesy Michal Pasternak]

Mechanism 2: MQTT

- Message Queue Telemetry Transport (MQTT)
  - Publish/subscribe protocol
  - Light-weight, low resource requirements
  - Easy to use:

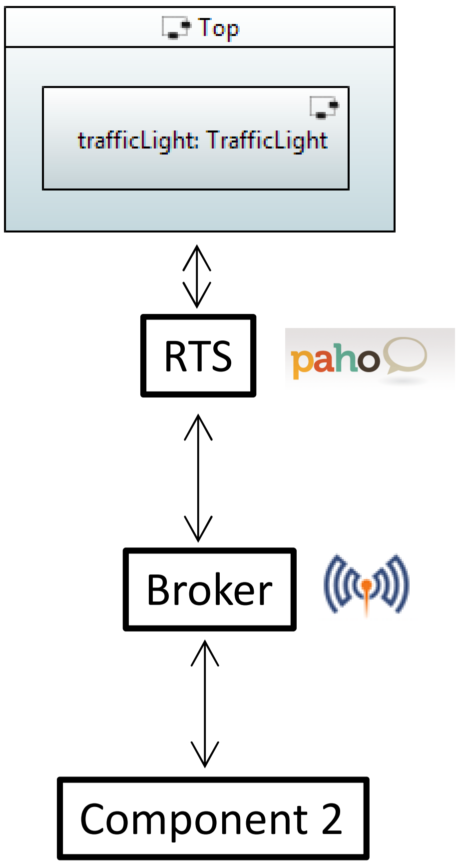
    (dis-)connect, (un-)subscribe, publish
  - Standardized
- Implementations
  - E.g., Eclipse Paho
- Brokers
  - E.g., Eclipse Mosquitto



Topic	Subscribers
“Temperature/bedroom”	Component 2
…	…

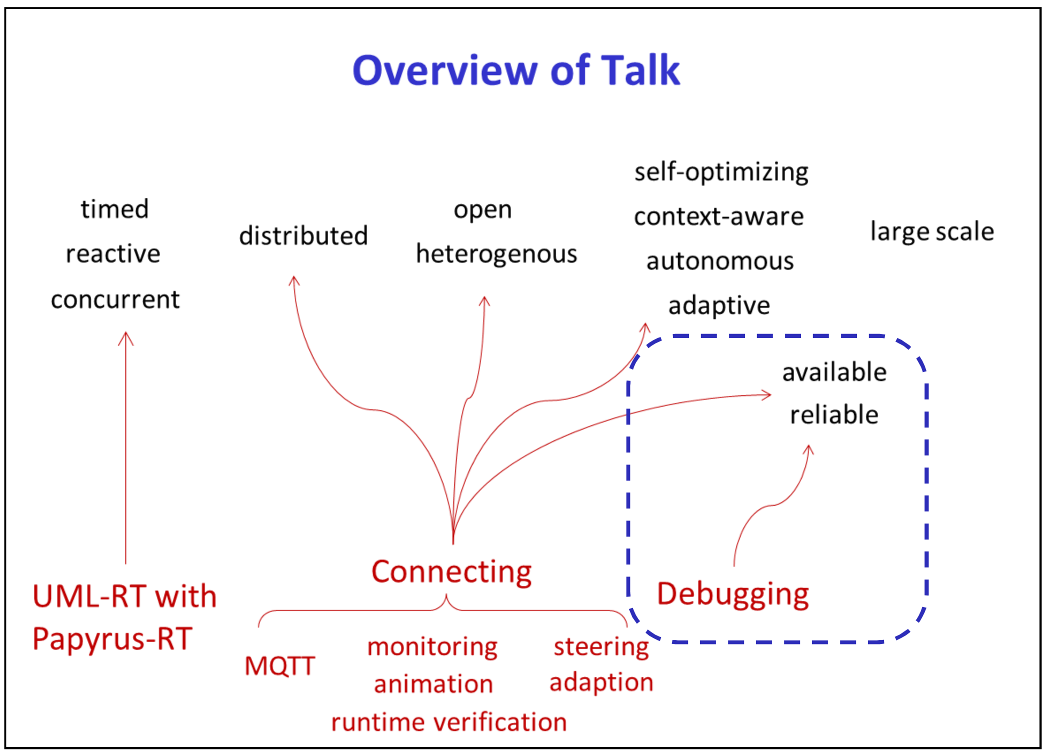
MQTT Support in Papyrus-RT

- In model
  - Subscribe(t) in capsule C
    - register unwired port of C as SAP under name t
  - Publish(t,m) in capsule C
    - send m to port of C associated with t
- RTS
  - Maintains connection to broker(s) and topic/broker table
  - Sends published messages to corresponding broker(s)
  - Periodically checks brokers for incoming messages
  - Sends incoming message m to port associated with m



Ongoing Research 2

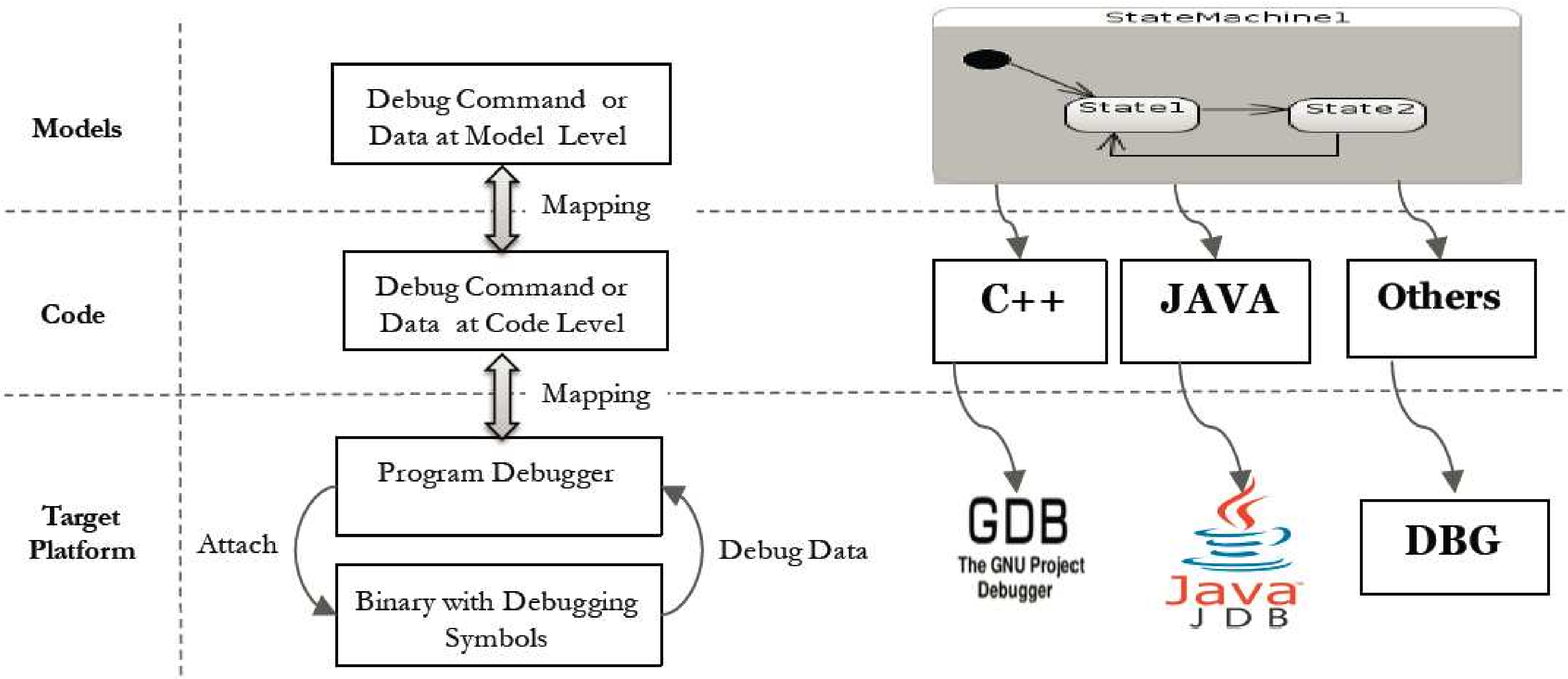
Debugging



Model Debugging: Two Approaches

1. Interpretation
   - Pros
     - Easier to integrate into MDE environment
   - Cons
     - Two semantics: Interpreter vs code generator
     - Two platforms: Modeling platform vs target platform
2. Executing generated code on target platform
   - Pros
     - One semantics, one platform
   - Cons
     - How to implement?

Existing Approaches



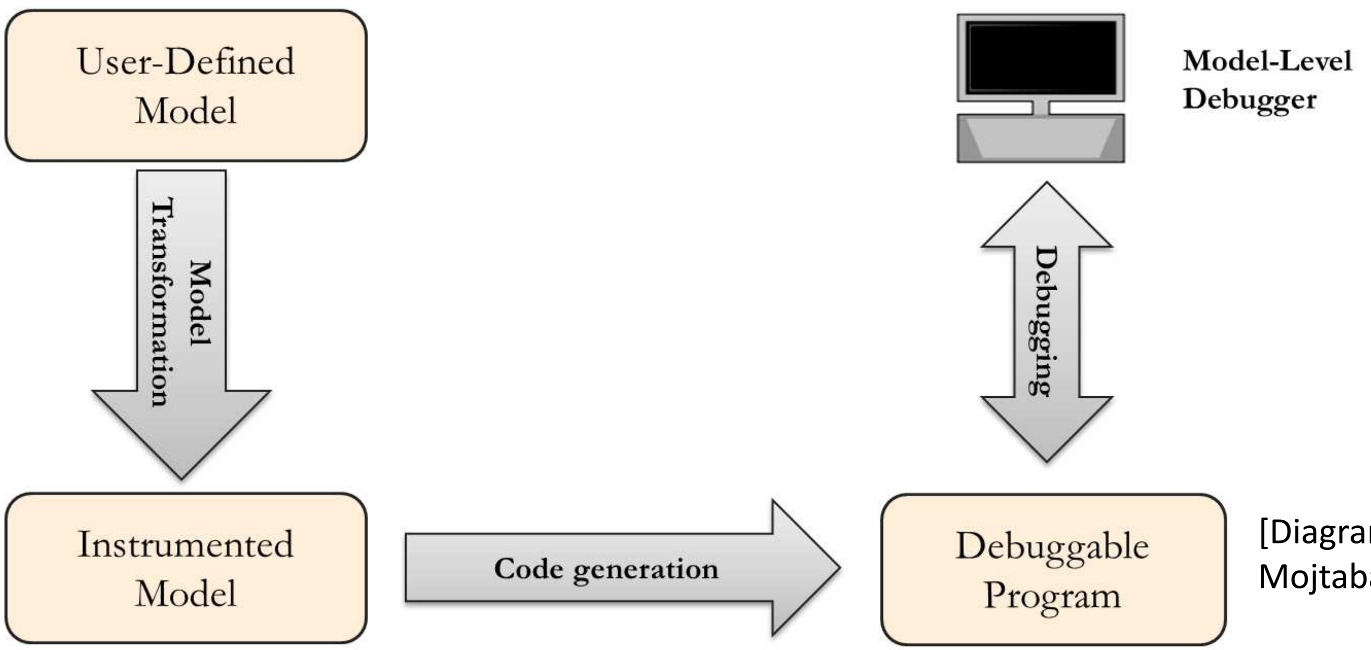
[Diagram courtesy Mojtaba Bagherzadeh]

Consequences?

Our Approach

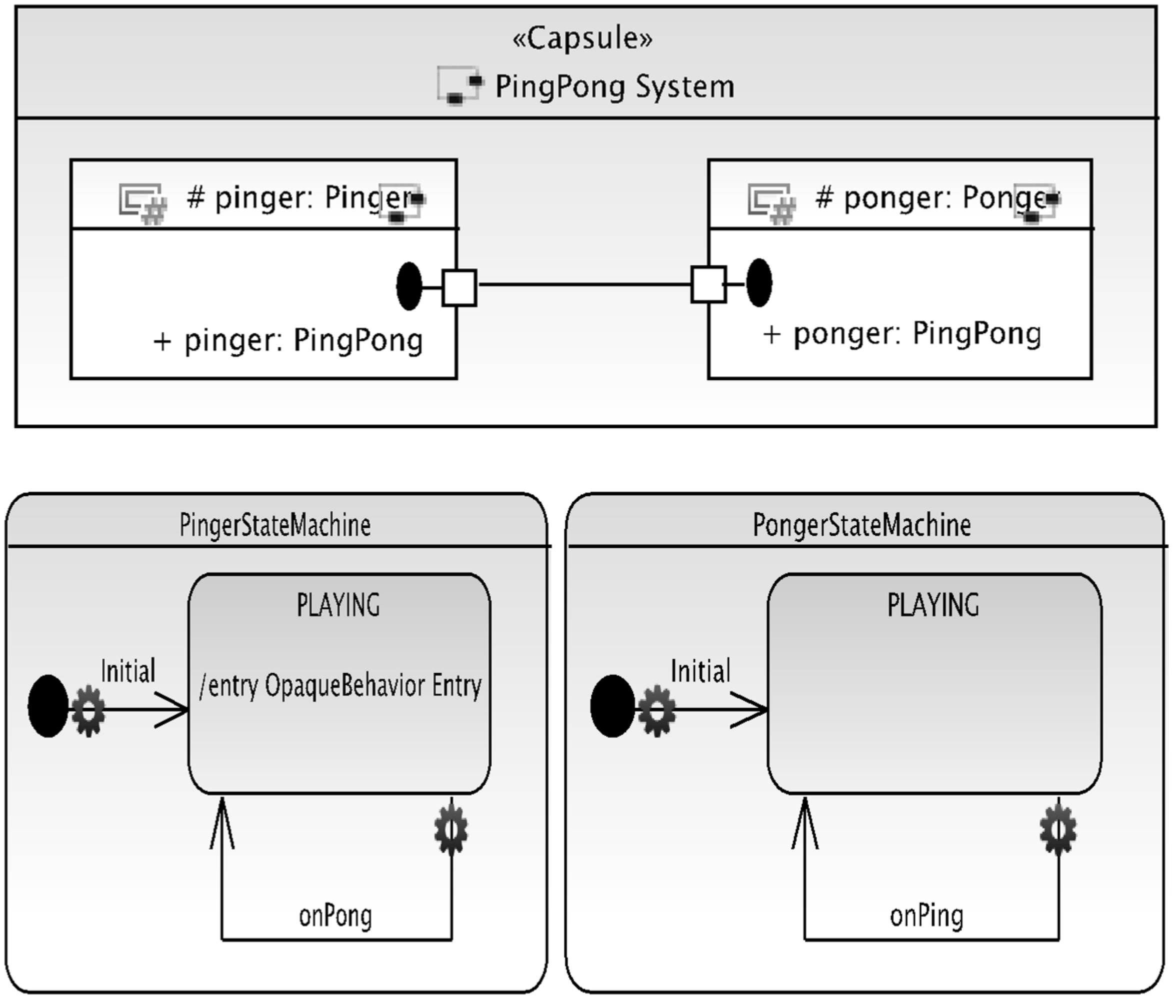
Key idea: Use model transformation to enrich model to allow it to support debugging operations:

- Execution stop and resume (breakpoints),
- variable access,
- collection of execution traces



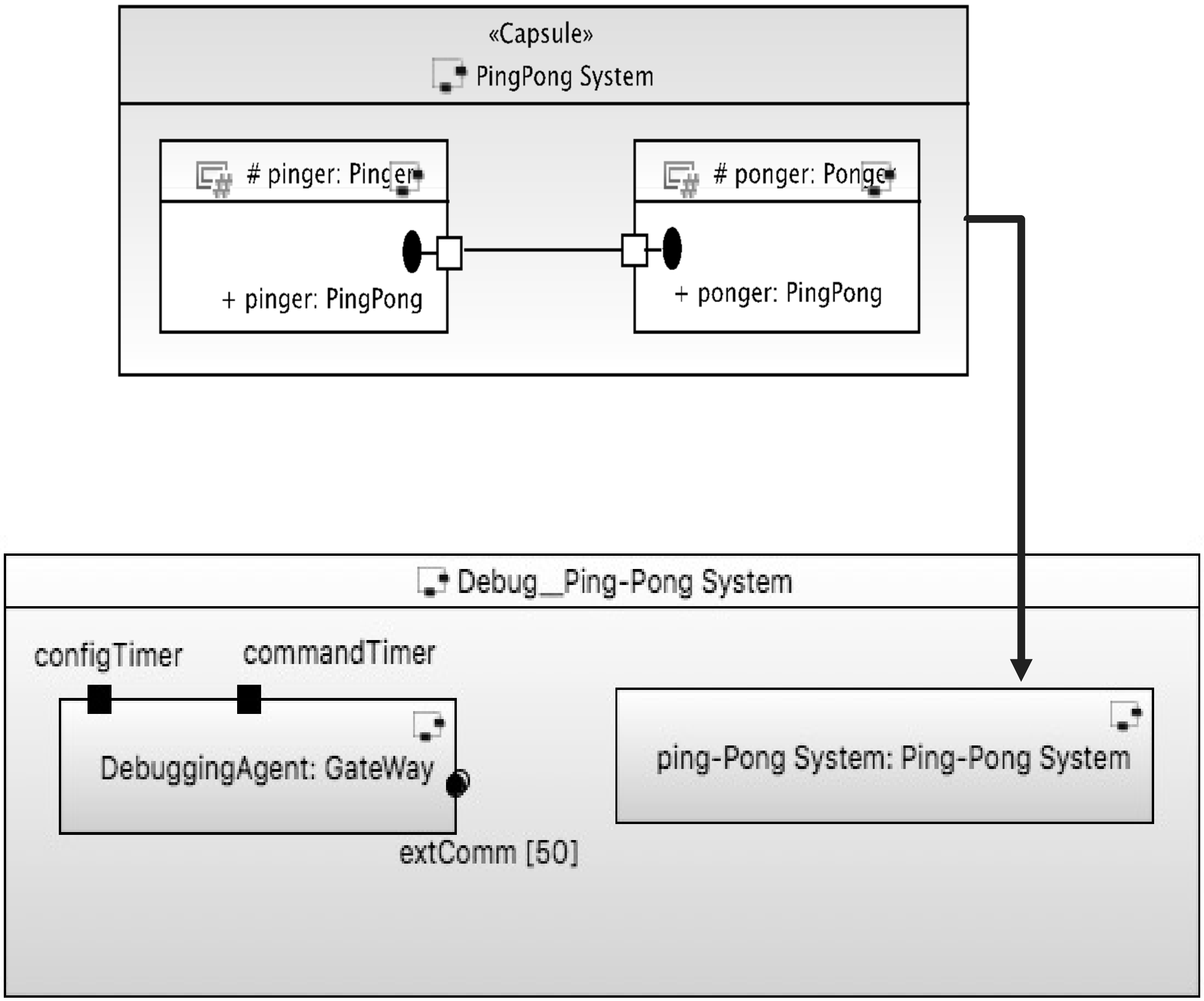
[Diagram courtesy Mojtaba Bagherzadeh]

Example: Ping Pong



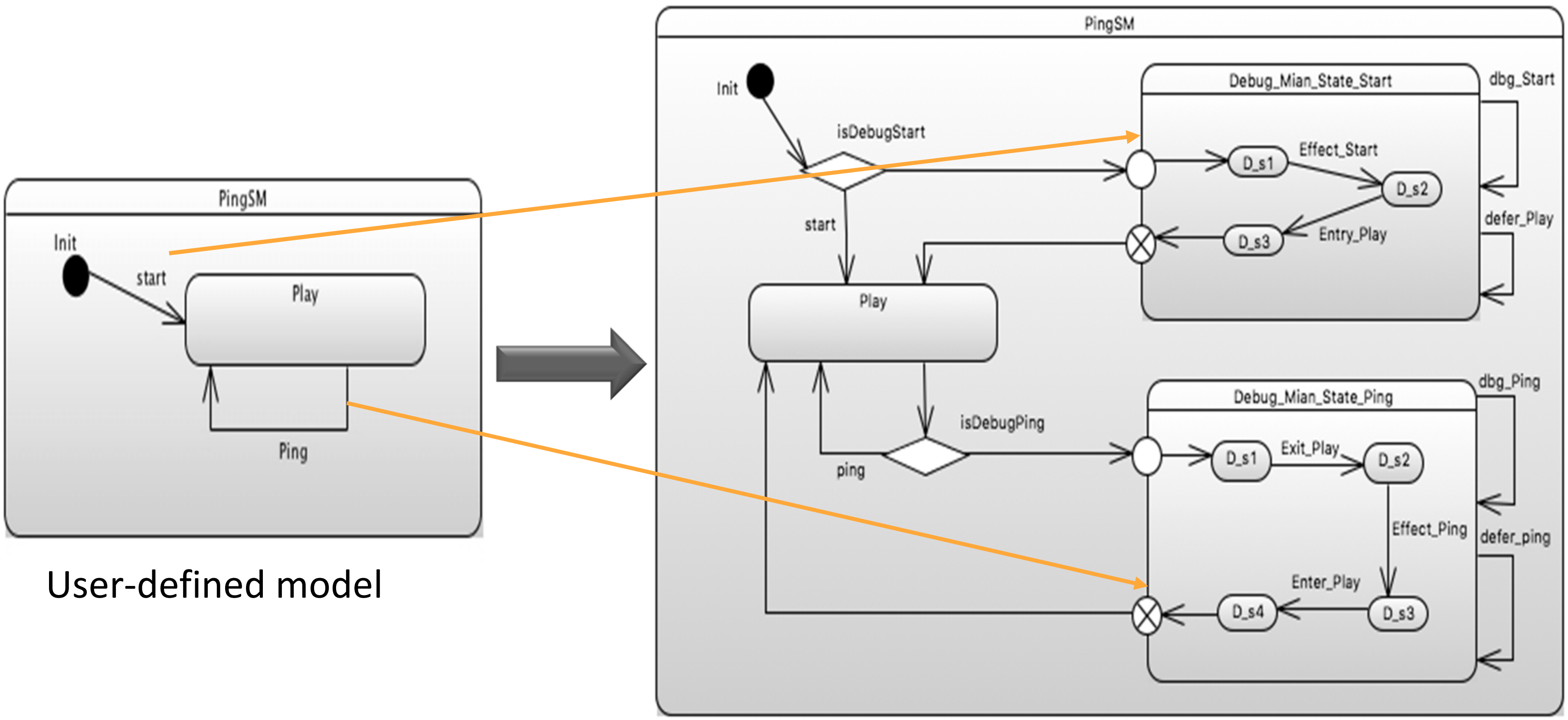
[Diagram courtesy Mojtaba Bagherzadeh]

Transformation of Structure



[Diagram courtesy Mojtaba Bagherzadeh]

Transformation of Behaviour

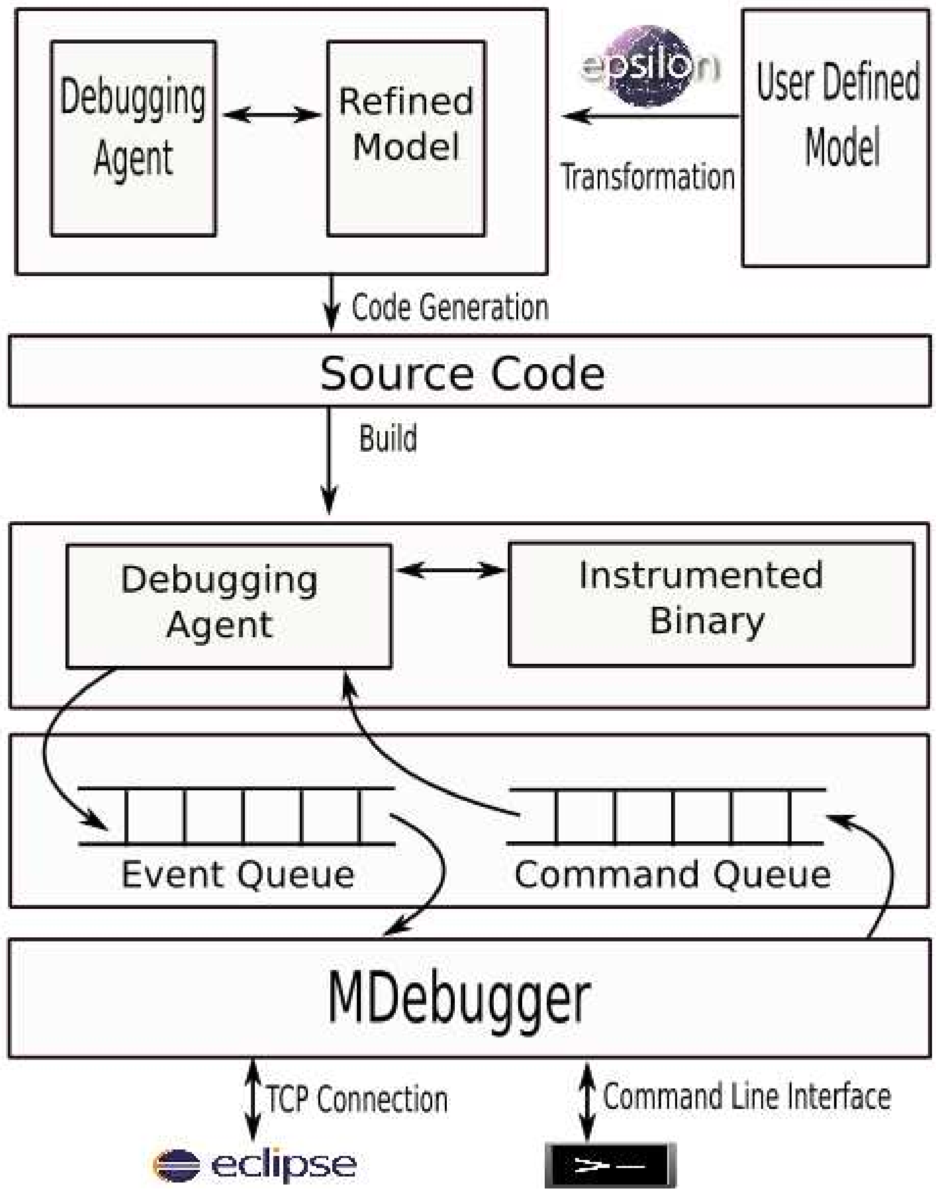


User-defined model

Instrumented model

[Diagram courtesy Mojtaba Bagherzadeh]

Overview



Pre runtime

At runtime

[Diagram courtesy Mojtaba Bagherzadeh]

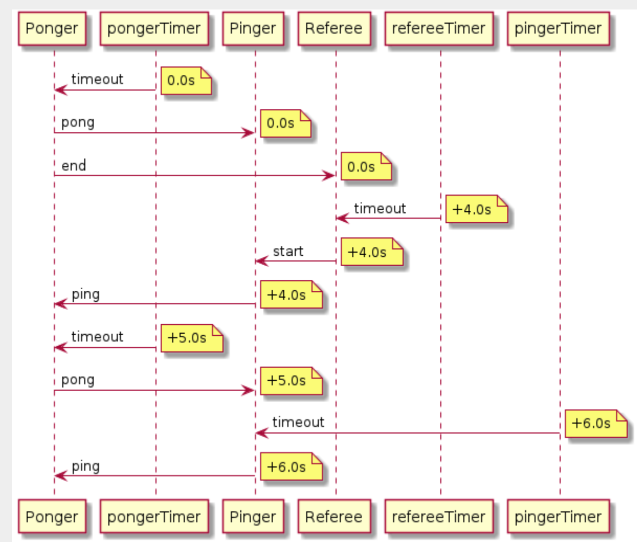
Example: Command Line Interface

List running capsules:
`#list`

Step execution
`#next –c capsule1`

View last 10 events
`#view –c capsule1 –n 10`

Generate sequence diagram:
`#seq –c capsuleName`



[Diagram courtesy Mojtaba Bagherzadeh]

Evaluation

- Instrumentation time

  ~40sec for model with 400 transitions

- Program size

  comparable with existing approaches

- Runtime performance overhead

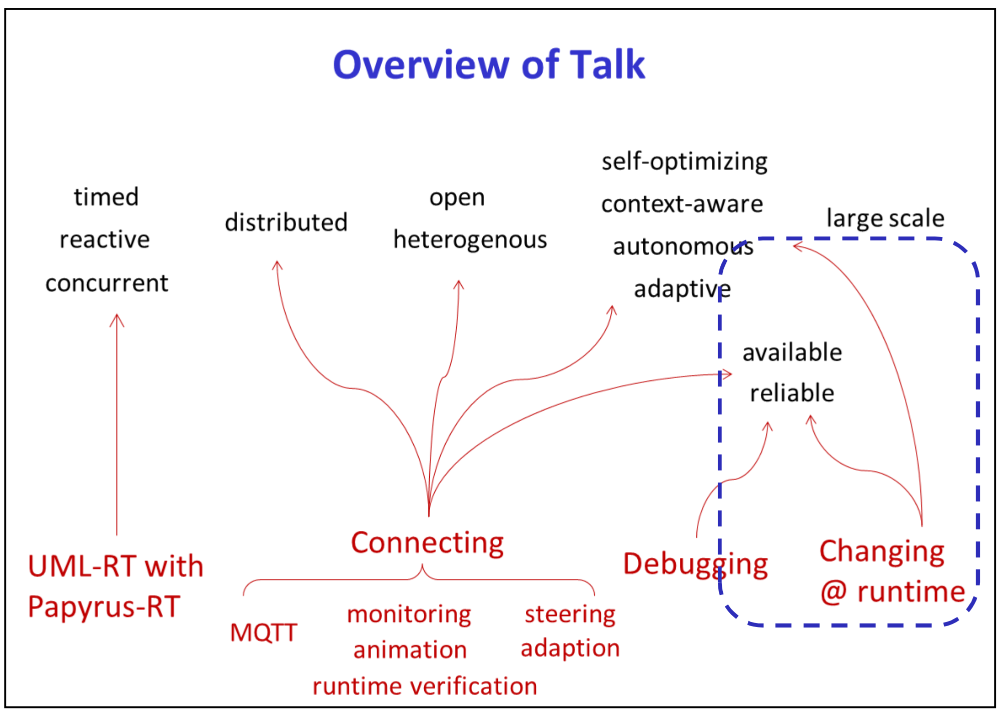
  microseconds per transition

Resources: Model-level Debugging

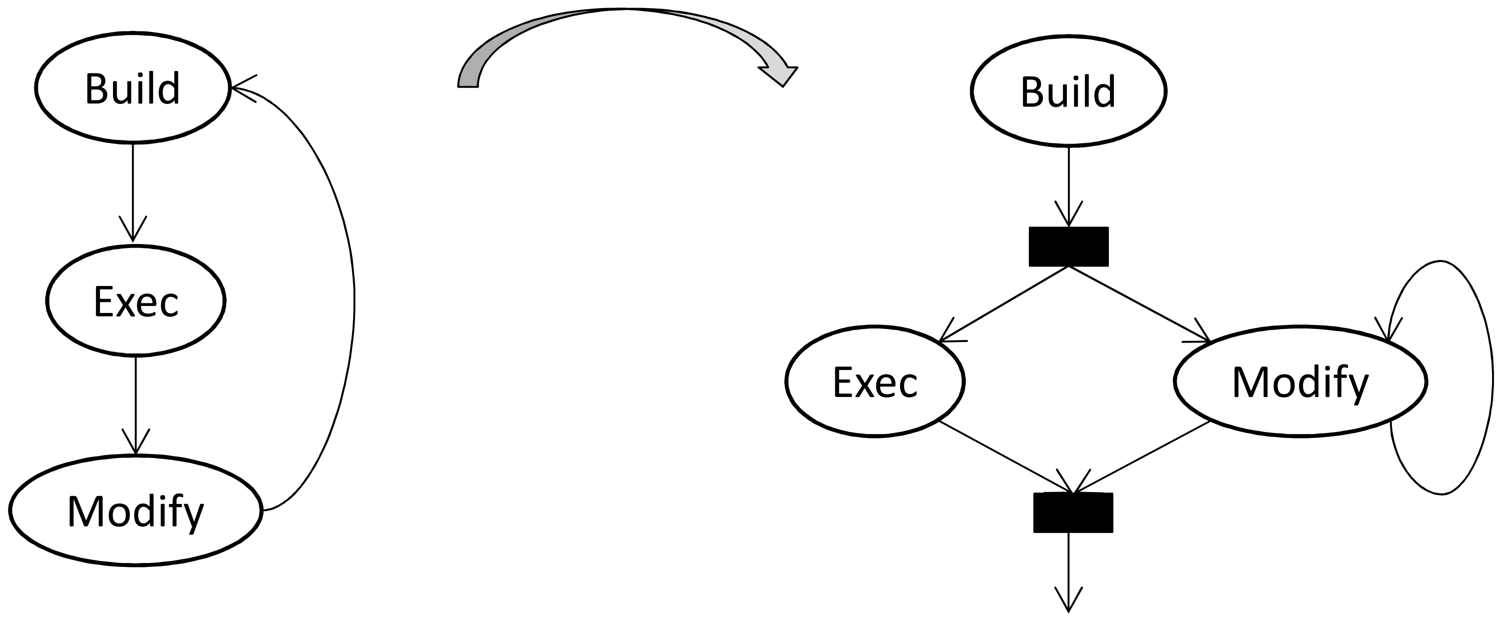
- Paper
  - M. Bagherzadeh, N. Hili, J. Dingel. Model-level, Platform-independent Debugging in the Context of the Model-driven Development of Real-time Systems. ESEC/FSE'17.
- Videos
  - CLI: https://www.youtube.com/watch?v=UJ4BYSOrTOQ
  - GUI: https://www.youtube.com/watch?v=PvPbV5QkQ9Y&t=8s
- Code with tutorial
  - https://github.com/moji1/MDebugger
- Virtual Box image
  - https://github.com/moji1/MDebugger

Ongoing Research 3

Changing @ runtime



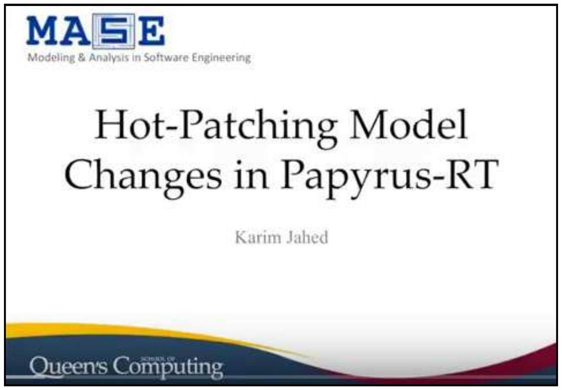
Supporting Modifications at Runtime



- A.k.a., "hot patching/loading", dynamic software updating
- As in, e.g., Erlang, Java Hotswap, Unreal engine, MS VS Recode

Supporting Modifications at Runtime (Cont'd)

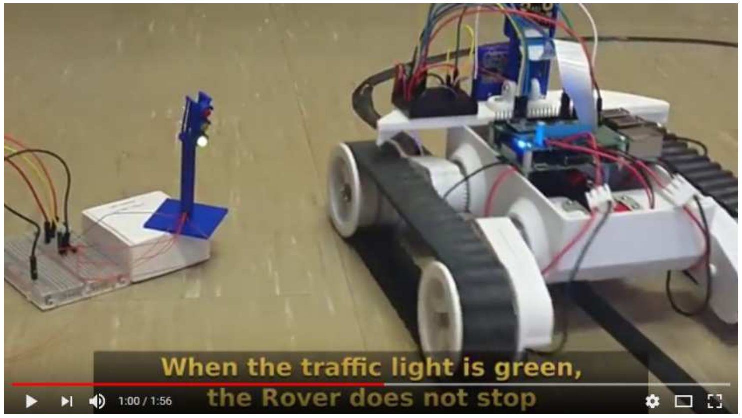
- Use shared, dynamically loaded and linked objects
  - Compile dynamically modifiable capsules into shared objects
  - Whenever capsule changes,
    - recompile and relink, and
    - transfer state
- Challenge
  - State transfer can lead to inconsistencies
- Demo
  - https://youtu.be/FrJm9NTR-bc
- Ongoing
  - Minimizing inconsistencies
  - Roll back



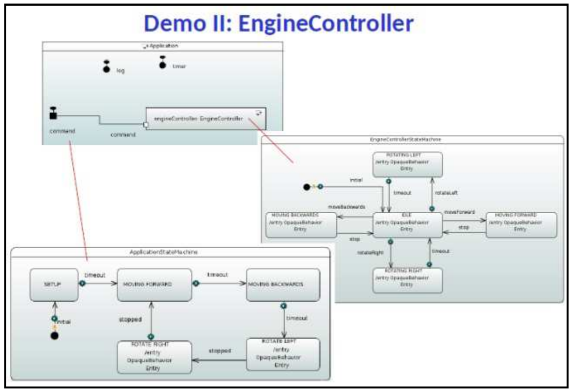
Ongoing Research 4

Demonstrator:
PolarSys Rover

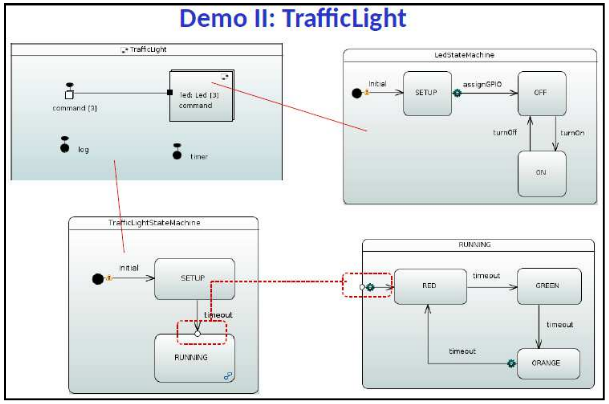
- PolarSys Rover
  - 2 motors, motor controller
  - Line sensor, ultrasonic detection sensor, camera
  - https://www.polarsys.org/projects/polarsys.rover
- Raspberry Pi 3 Model B
  - 1.2GHz 64-bit Quad-core, 1GB RAM
  - WLAN, Bluetooth, 4 USB, HDMI, Ethernet

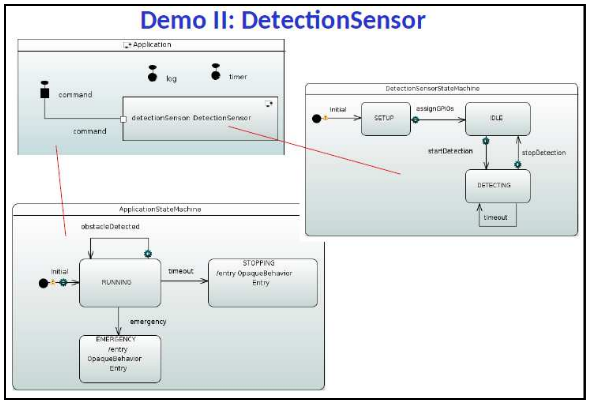


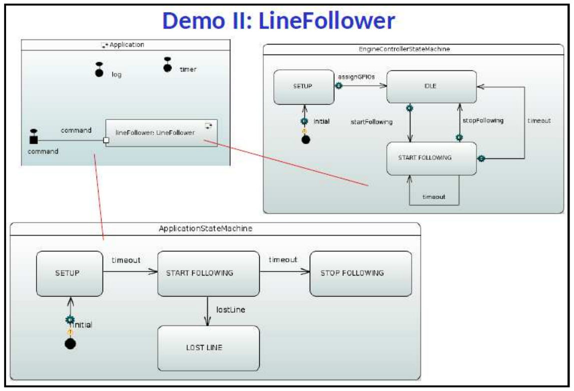
https://www.youtube.com/watch?v=2kLhRUHGLB4



[UML-RT slides courtesy of Nicolas Hili]







Conclusion

Conclusion

MDE with UML-RT and Papryrus-RT

+ Connecting (gateway, MQTT)
+ Debugging
+ Change at RT
+ Distribution
+ Deployment (MARTE)
+ Schedulability
+ Testing
+ ?

Open Source!

This talk

Future work

= Open source MDE tool infrastructure for (certain kinds of) IoT applications

Resources

- http://flux.cs.queensu.ca/mase/papyrus-rt-resources/

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- Nicolas Hili, PDF
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- Harshith Vasanth Gayathri, MSc
- Sudharshan Gopikrishnan, MSc

Thank you …

… for your attention

Hey you shrub, do you always have to have the last word?