Technical Briefing:

Modeling and Code Generation for Real-Time Systems using UML-RT and Papyrus-RT

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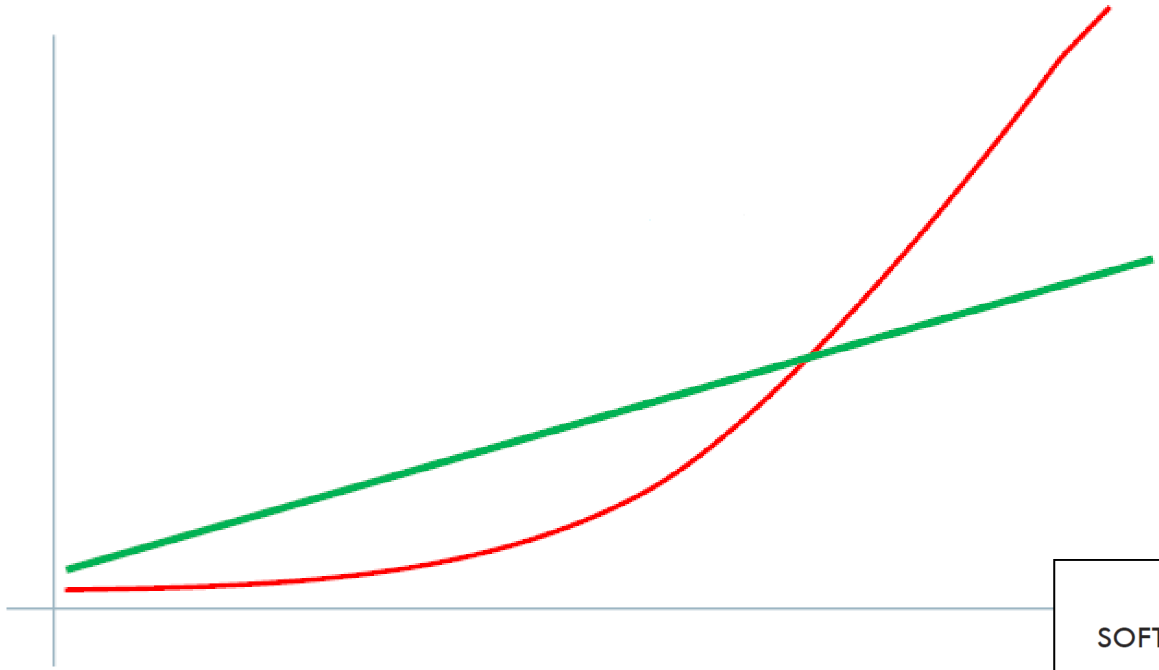
ICSE

May 23, 2017

All material available at

http://flux.cs.queensu.ca/mase/research/tutorials/icse17-technical-briefing/

49 Years Ago at 1st NATO SW Eng Conference



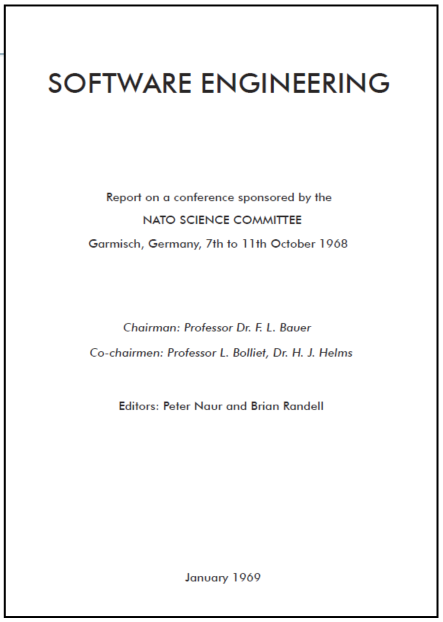
HW computing power ⇑

⇒ Complexity of tasks SW asked to do ⇑

⇒ Complexity of SW ⇑

⇒ Existing SW development capabilities strained

⇒ **"Software crisis"**



SOFTWARE ENGINEERING

Report on a conference sponsored by the
NATO SCIENCE COMMITTEE
Garmisch, Germany, 7th to 11th October 1968

Chairman: Professor Dr. F. L. Bauer
Co-chairmen: Professor L. Bolliet, Dr. H. J. Helms

Editors: Peter Naur and Brian Randell

January 1969

Since Then: LOTS of Progress

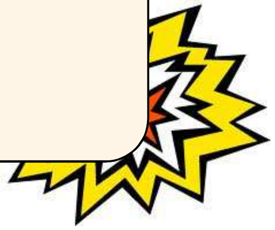
- **Hardware**
  - **Computing power** (2016 vs 1969) [Paul Ledak on quora.com]:
    - Number of transistors:
      - iPhone 6 = Apollo 11 GC x 180,000
    - Clock frequency:
      - iPhone 6 = Apollo 11 GC x 32,000
    - Instructions per second:
      - iPhone 6 = Apollo 11 GC x 80 million
    - Overall:
      - iPhone 6 = Apollo 11 GC x 120 million
  - **Cost of 1 MB of memory** in US$ [www.jcmit.com]:
    - Dec 2015 = 1957 / 100 billion

Since Then: LOTS of Progress

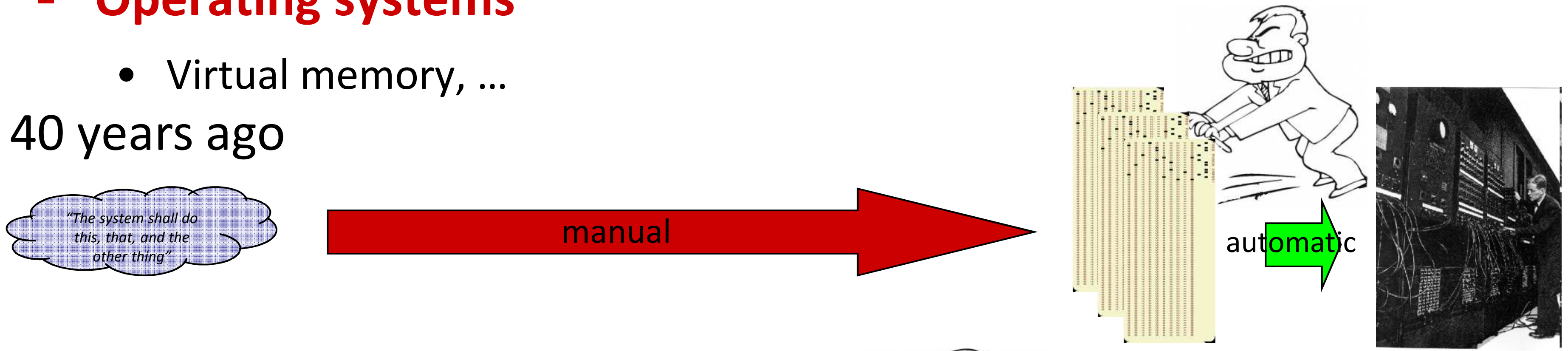
- **Software engineering**
  - Information hiding via modularization, encapsulation, interfaces, MDE, …
- **Pro**
  - (
- **Dat**
  - Relational model, …
- **Operating systems**
  - Virtual memory, …

Key general techniques:

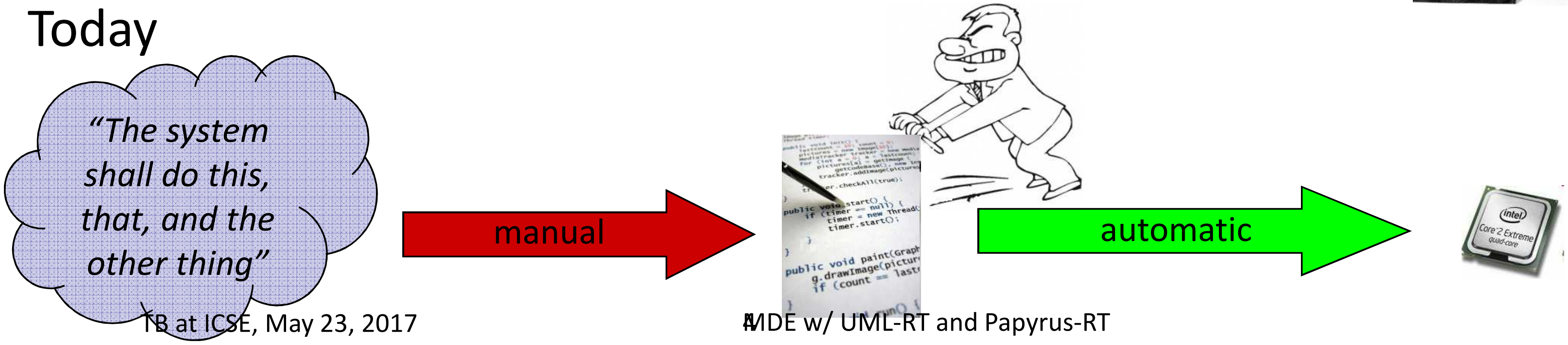
Abstraction, automation, and analysis



40 years ago



Today



Model-Driven Engineering (MDE)

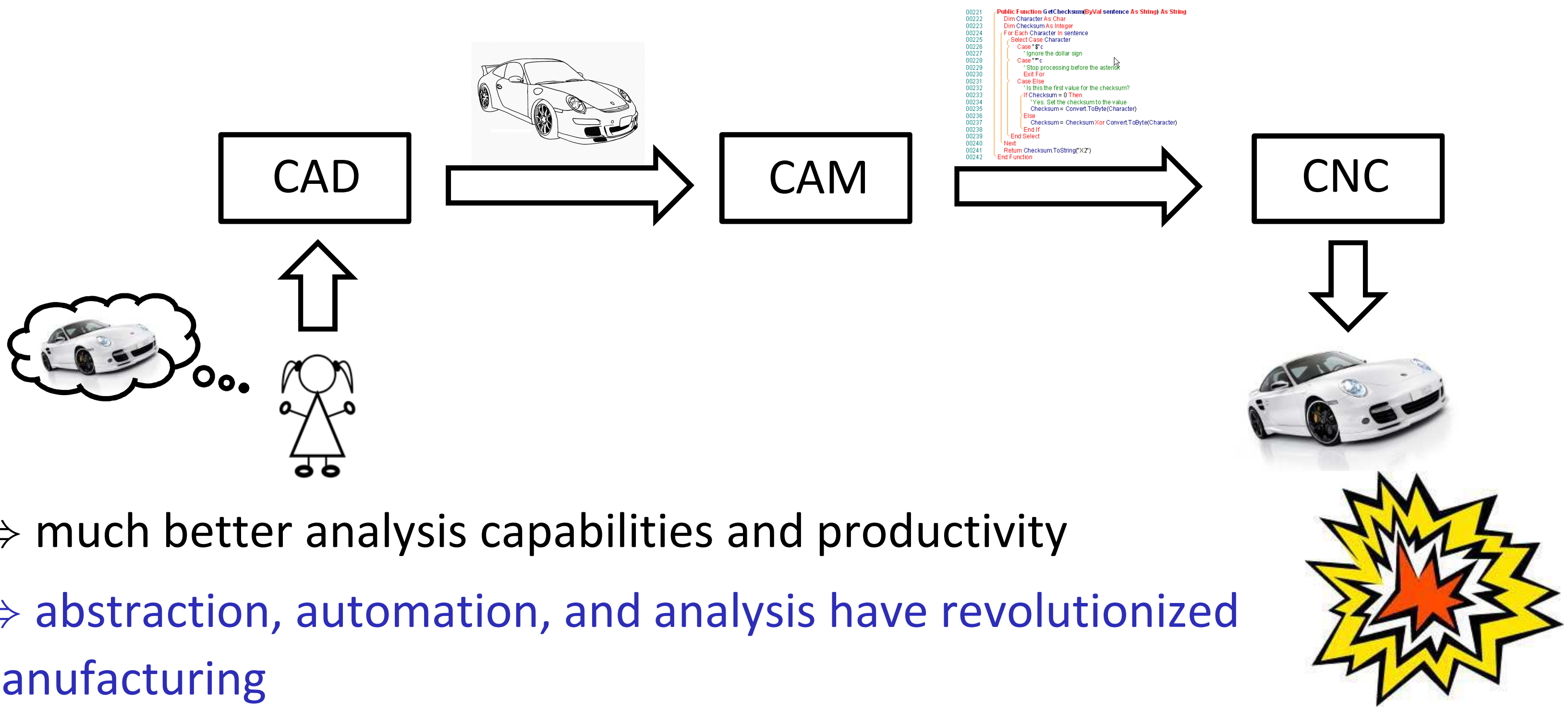
- Improve productivity, quality, and ability to handle complexity by
  - increasing level of **abstraction**
    - through use of ‘models’
  - leveraging **automation**
    - e.g., via code generation from models, model transformation, …
  - improving **analysis** capabilities
    - e.g., through constraint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

MDE = Abstraction + Automation + Analysis

- Inspired by use of models in engineering and science

Abstraction, Automation, and Analysis in Manufacturing

- Mechanical design till early 1970ties: paper drawings, …
- Mechanical design from about 1972: CAD/CAM
  1. Create drawings w/ computer (CAD)
  2. Computer automatically generates milling/CNC programs (CAM)



```
Public Function GetChecksum(ByVal sentence As String) As String
    Dim Character As Char
    Dim Checksum As Integer
    For Each Character In sentence
        Select Case Character
            Case "$"c
                ' Ignore the dollar sign
            Case "*"c
                ' Stop processing before the asterisk
                Exit For
            Case Else
                ' Is this the first value for the checksum?
                If Checksum = 0 Then
                    ' Yes. Set the checksum to the value
                    Checksum = Convert.ToByte(Character)
                Else
                    Checksum = Checksum Xor Convert.ToByte(Character)
                End If
        End Select
    Next
    Return Checksum.ToString("X2")
End Function
```

⇒ much better analysis capabilities and productivity

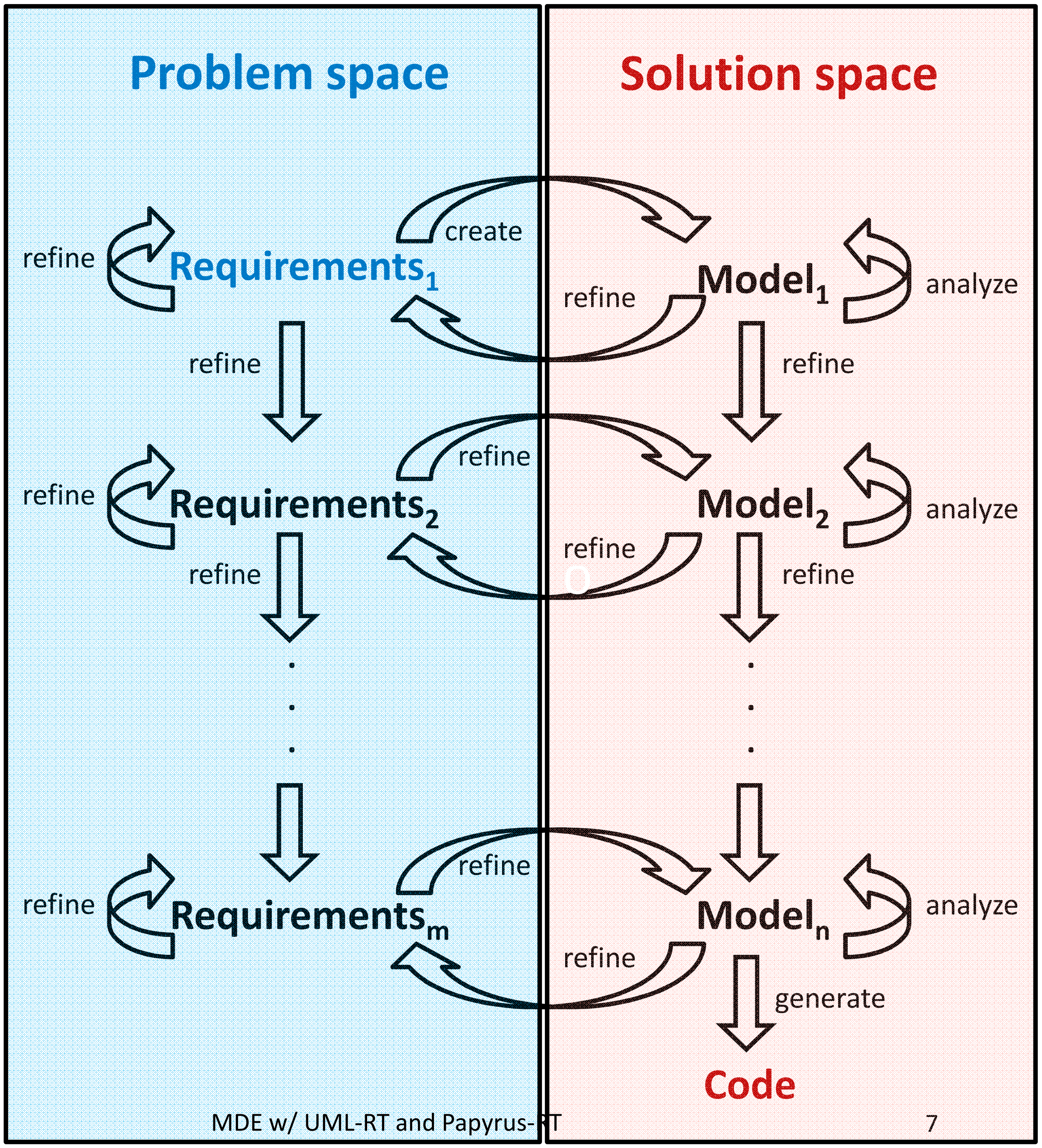
⇒ abstraction, automation, and analysis have revolutionized manufacturing

MDE Process

Elements in solution space exist in **same medium:** the computer

⇒ Model can evolve into system it is modeling!

⇒ fewer discontinuities



MDE for Embedded Systems: Context

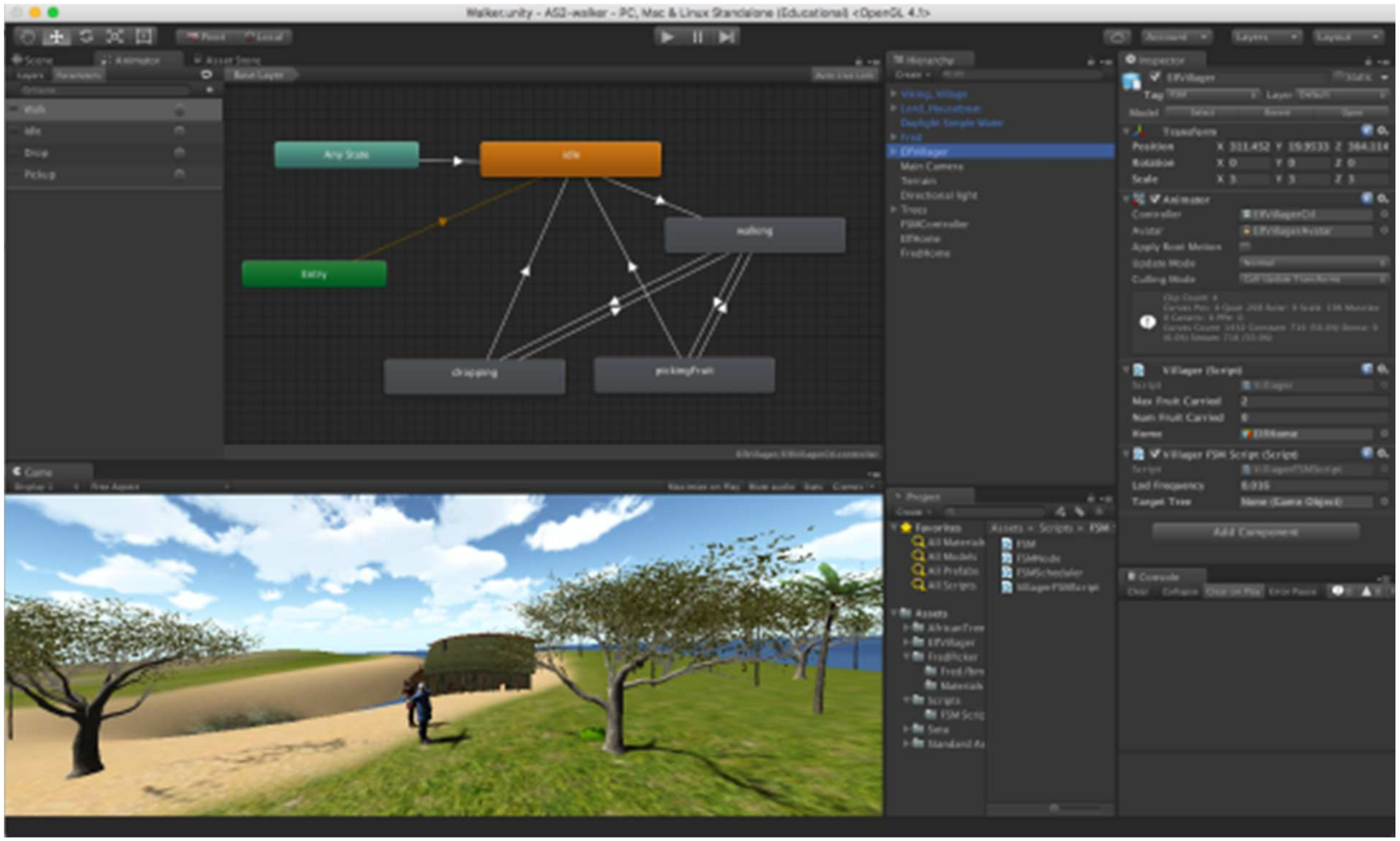
- Some vendors
  - Mathworks: Stateflow/Simulink
  - IBM: Rational RoseRT, Rational Rhapsody, RSA-RTE
  - National Instruments: LabVIEW
  - Esterel Technologies: SCADE
  - IAR Systems: IAR Visual State
- Some standards
  - DO-178C, DO-331

[Radio Technical Commission for Aeronautics (RTCA). DO-178C: Software Considerations in Airborne Systems and Equipment Certification. Jan 2012] [https://en.wikipedia.org/wiki/DO-178C]

[Radio Technical Commission for Aeronautics (RTCA). DO-331 "Model-Based Development and Verification Supplement to DO-178C and DO-278A]

Even the Game Industry is Using MDE Now

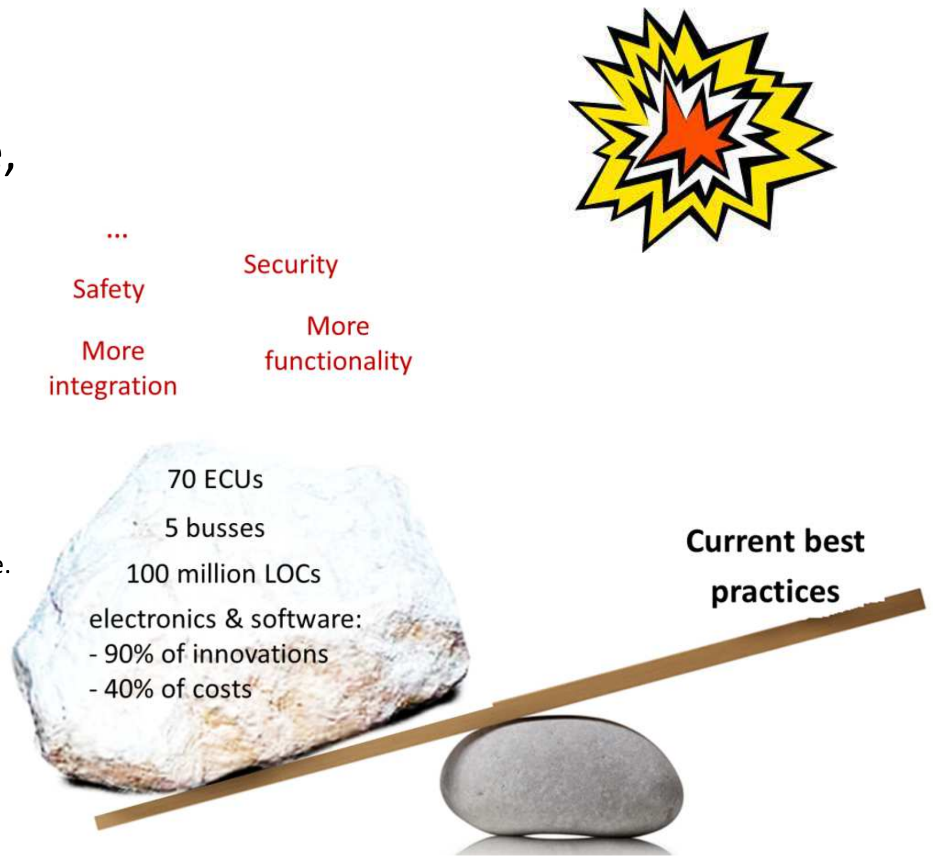
[http://docs.unity3d.com/Manual/Animator.html]



Screenshot courtesy Nick Graham

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]



[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.

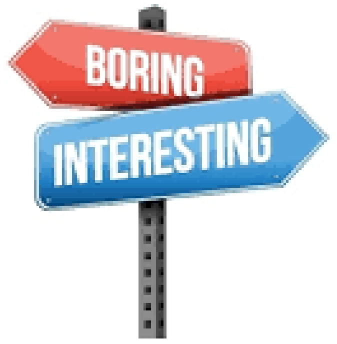
[2] Whittle, Hutchinson, Rouncefield. The state of practice in model-driven engineering. IEEE Software 31 (3), 79-85. 2014.

[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.

Goal of TB

- Inform
  - Intro to MD with UML-RT and Papyrus-RT
  - Pointers to resources, related work, etc
- Inspire
  - We need more abstraction, automation, analysis!
  - UML-RT
    - small, cohesive set of concepts

      "UML-RT has features which appeal to the formalist, but some are severely underused by practioners. The primary reason is undoubtedly that there is nothing within the Rose RealTime toolset that can take advantage of the extra information, relegating it instead to a documentary role" [4]
    - successful track record, but work needed on, e.g.,
      - static analysis, user experience, deployment, interpretation, testing, verification, simulation, …



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

Overview

1. MDE	(10 mins)	(10 slides)
2. Overview	(1 min)	(1 slide)
3. Papyrus-RT	(5 mins)	(3 slides)
4. UML-RT: Part I	(25 mins)	(24 slides)
• Core concepts		
5. Demo I	(10 mins)	
6. Hands on session	(10 mins)	
7. UML-RT: Part II	(15 mins)	(14 slides)
• More advanced concepts		
8. Demo II	(10 mins)	
9. Conclusion	(5 min)	(3 slides)

All material available at
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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

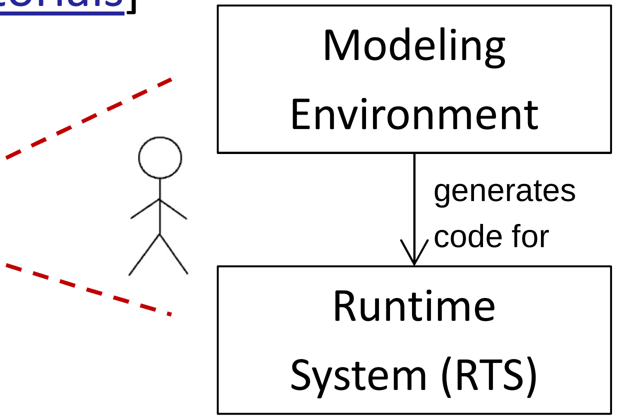
[https://wiki.eclipse.org/Papyrus-RT]

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]



Modeling Languages

UML

AADL
- Embedded, real-time

UML MARTE
- Embedded, real-time

Modelica
- Physical systems
- Equation-based

Simulink
- Continuous control, DSP
- time-triggered dataflow

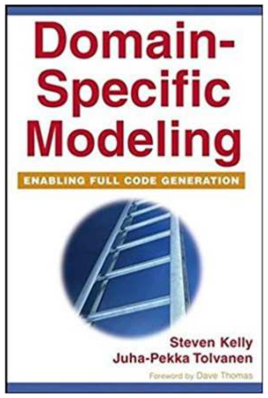
Stateflow
- Reactive systems
- Discrete control
- State-machine-based

Lustre/SCADE
- Embedded real-time
- Synchronous dataflow

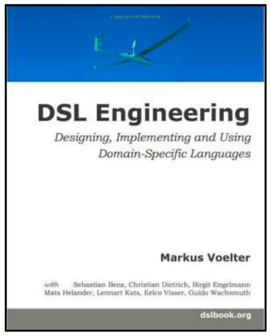
UML-RT
- Embedded, real-time
- State-machine-based

increasing generality ⟷ increasing domain-specifity

Examples in



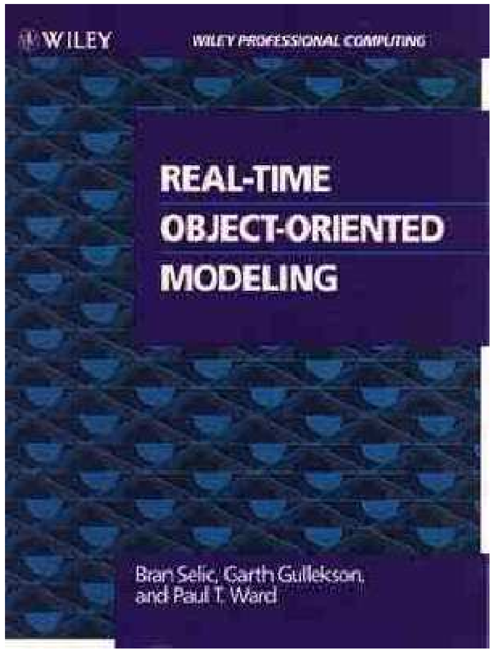
[Kelly, Tolvanen 2008]



[Voelter 2013]

UML-RT: History

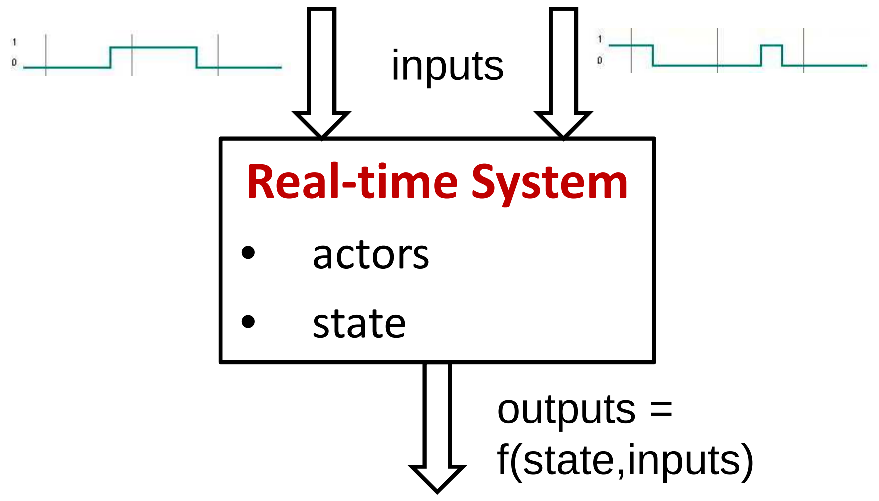
- Real-time OO Modeling (ROOM)
  - ObjecTime, early 1990 ties
- Major influence on UML 2
  - E.g., StructuredClassifier
- "RT subset of UML"
- Tools
  - ObjecTime Developer
  - IBM Rational RoseRT
  - IBM RSA-RTE
  - Eclipse Papyrus-RT

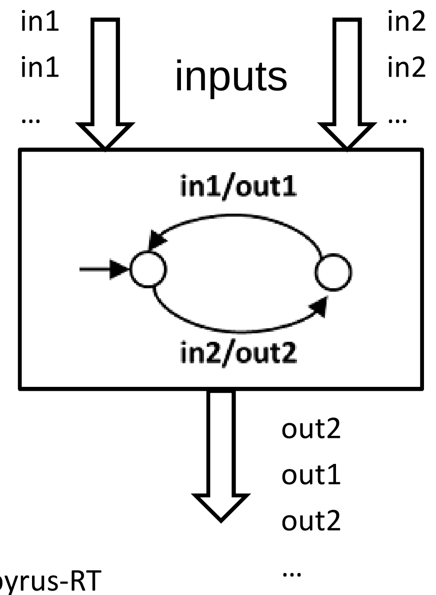

WILEY
WILEY PROFESSIONAL COMPUTING
REAL-TIME OBJECT-ORIENTED MODELING
Bran Selic, Garth Gullekson, and Paul T. Ward

[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 interfaces
  - Message-based communication
- Event-driven execution
  - State machines





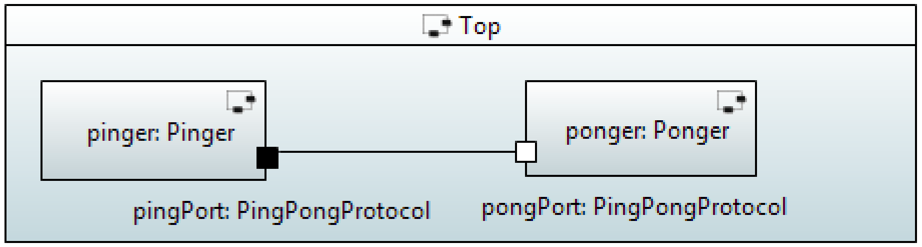
UML-RT Part I

- Core concepts
  - Structural modeling
  - Behavioural modeling

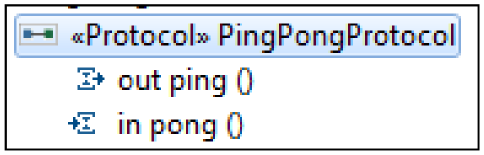
UML-RT: Core Concepts (1)

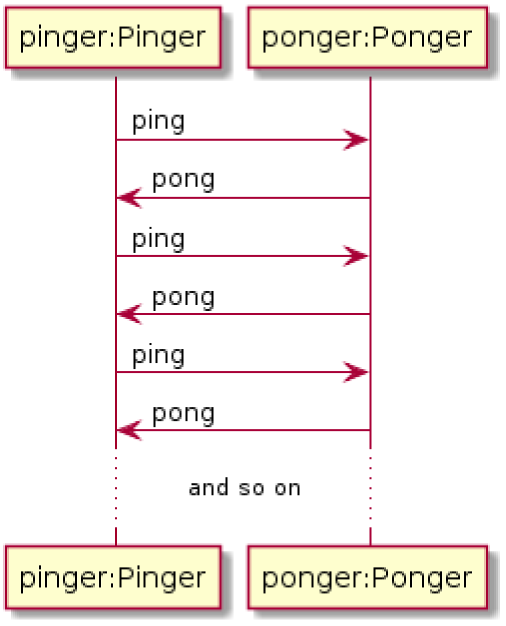
- Types
  - Capsules (active classes)
    - Capsule instances (parts)
  - Passive classes (data classes)
    - Objects
  - Protocols
  - Enumerations
- Structure
  - Attributes
  - Ports
  - Connectors
- Behaviour
  - Messages (events)
  - State machines
- Grouping
  - Package
- Relationship
  - Generalization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

UML-RT: Core Concepts (2)



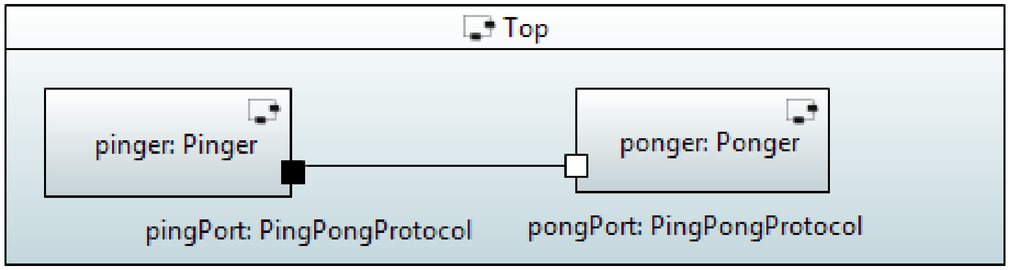
- Model
  - Collection of capsule definitions
  - 'Top' capsule containing collection of capsule instances (parts)
- Capsules
  - May contain
    - Attributes, ports, or other capsule instances (parts)
  - Behaviour defined by state machine
- Ports
  - Typed over protocol defining input and output messages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

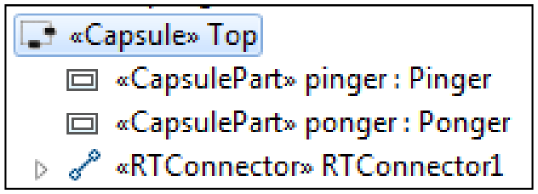


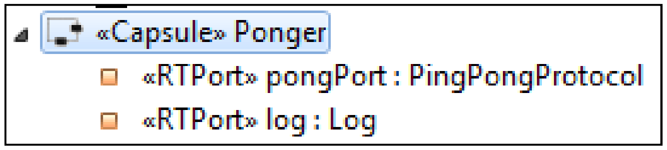


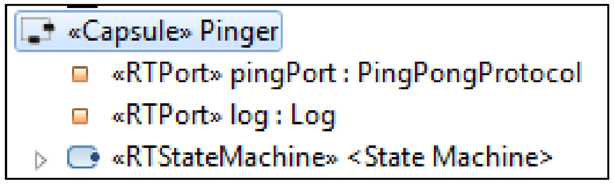
Capsules (1)

- Kind of active class
  - Attributes, operations
  - Own, independent flow of 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

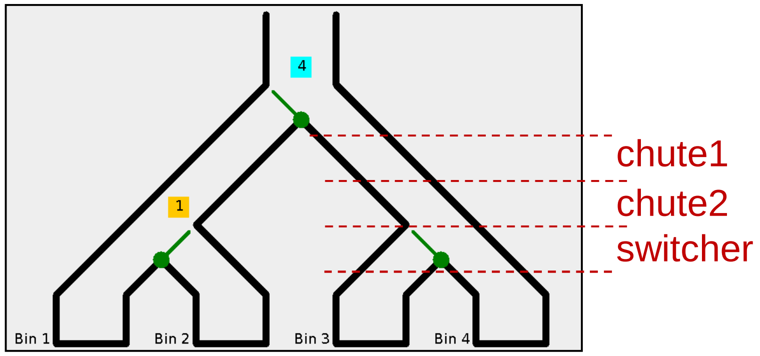


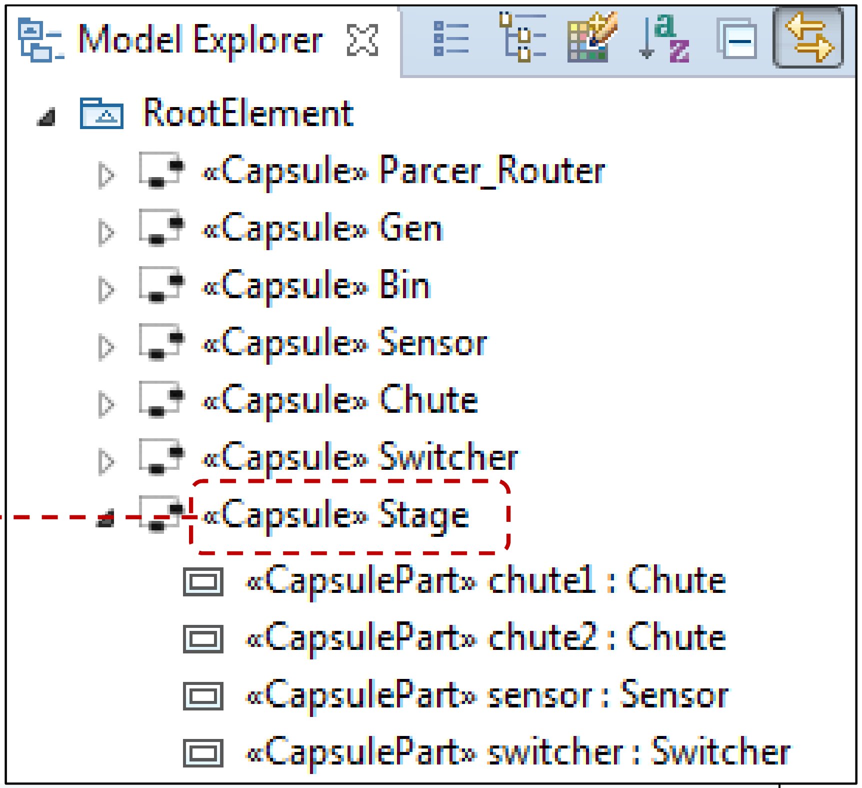

«Capsule» Top
«CapsulePart» pinger : Pinger
«CapsulePart» ponger : Ponger
«RTConnector» RTConnector1


«Capsule» Ponger
«RTPort» pongPort : PingPongProtocol
«RTPort» log : Log

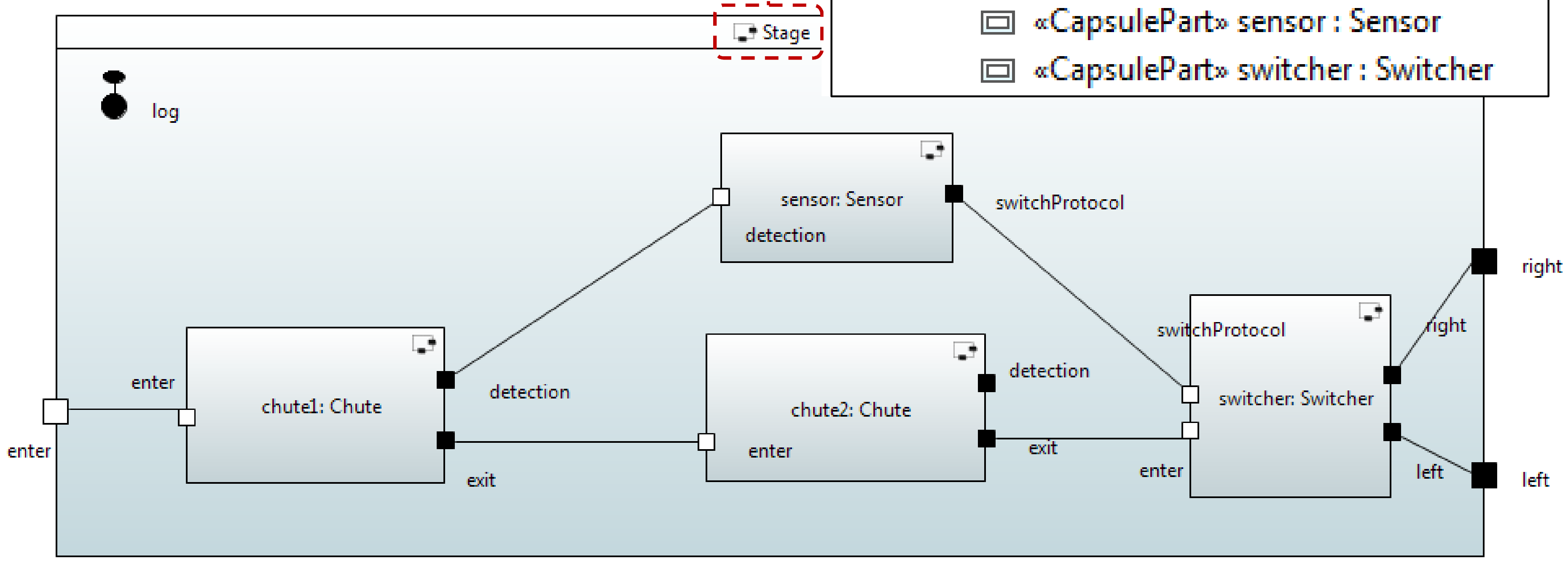

«Capsule» Pinger
«RTPort» pingPort : PingPongProtocol
«RTPort» log : Log
«RTStateMachine» <State Machine>

Example: Capsules and Capsule Parts



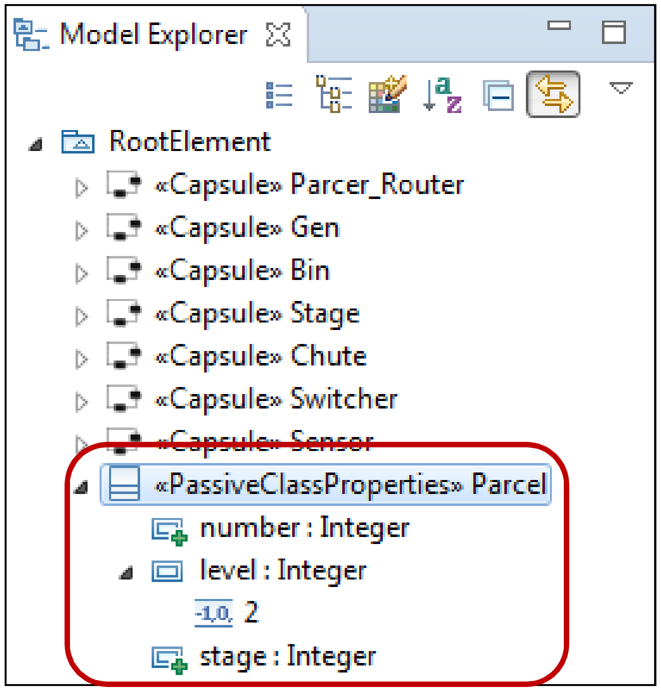

Model Explorer

- RootElement
  - «Capsule» Parcer_Router
  - «Capsule» Gen
  - «Capsule» Bin
  - «Capsule» Sensor
  - «Capsule» Chute
  - «Capsule» Switcher
  - «Capsule» Stage
    - «CapsulePart» chute1 : Chute
    - «CapsulePart» chute2 : Chute
    - «CapsulePart» sensor : Sensor
    - «CapsulePart» switcher : Switcher



Passive Classes/Data Classes

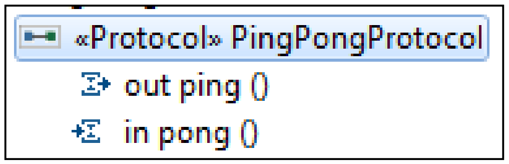
- Similar to regular classes
- Do not have independent flow of control
- Behaviour defined through operations
- Used to define data structures and operations on them

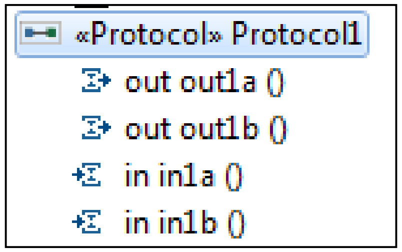

Model Explorer

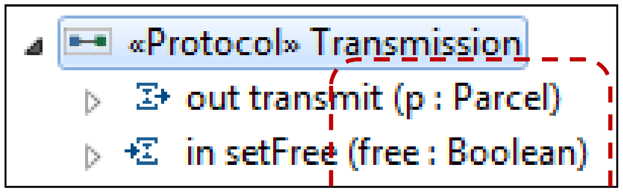
RootElement
- «Capsule» Parcer_Router
- «Capsule» Gen
- «Capsule» Bin
- «Capsule» Stage
- «Capsule» Chute
- «Capsule» Switcher
- «Capsule» Sensor
- «PassiveClassProperties» Parcel
  - number : Integer
  - level : Integer
    - 2
  - stage : Integer

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

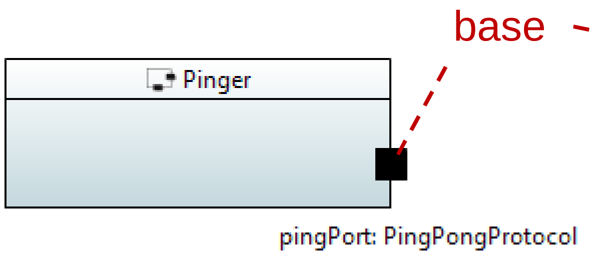

«Protocol» PingPongProtocol
out ping ()
in pong ()

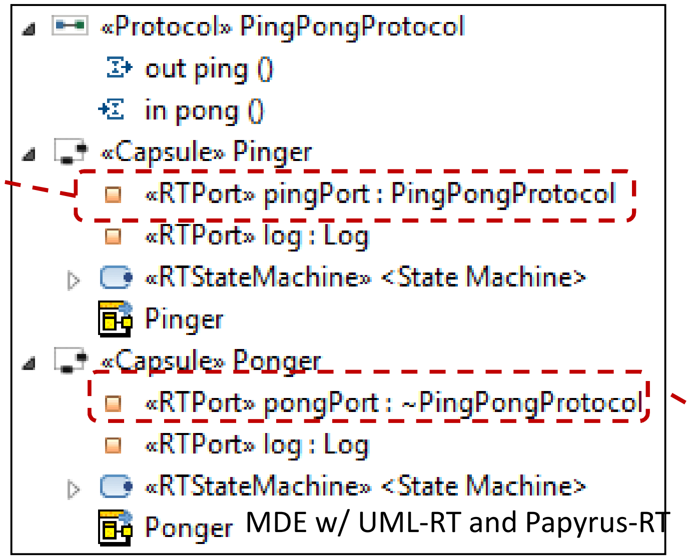

«Protocol» Protocol1
out out1a ()
out out1b ()
in in1a ()
in in1b ()

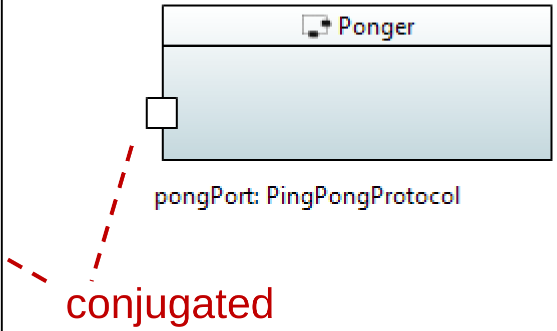

«Protocol» Transmission
out transmit (p : Parcel)
in setFree (free : Boolean)

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: □

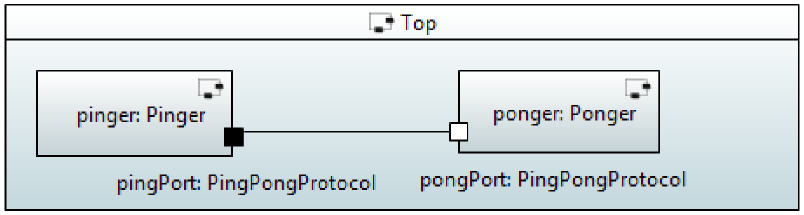


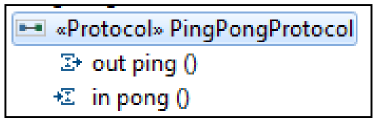

```
◢ «Protocol» PingPongProtocol
      out ping ()
      in pong ()
◢ «Capsule» Pinger
      «RTPort» pingPort : PingPongProtocol
      «RTPort» log : Log
   ▷ «RTStateMachine» <State Machine>
      Pinger
◢ «Capsule» Ponger
      «RTPort» pongPort : ~PingPongProtocol
      «RTPort» log : Log
   ▷ «RTStateMachine» <State Machine>
      Ponger
```

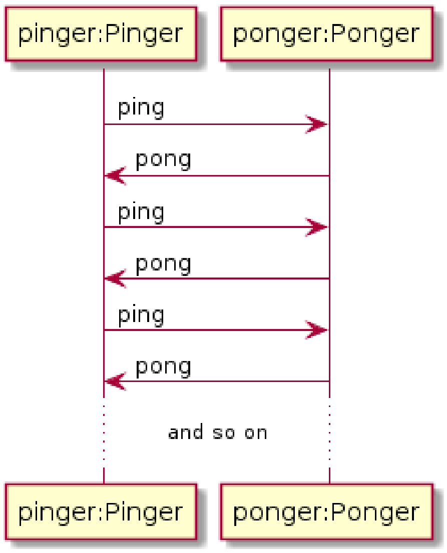


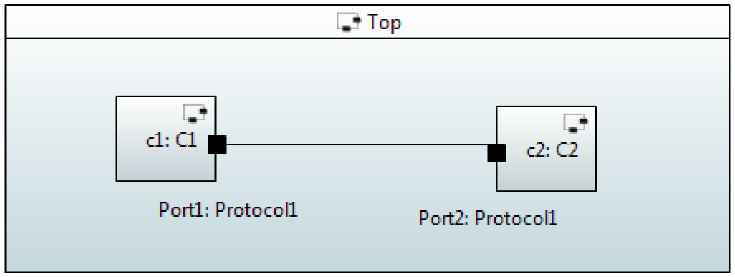
Connectors

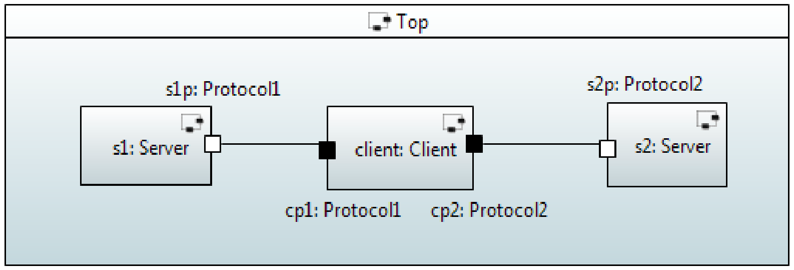
- Connect two ports
- Ports must be compatible
  - Both are instances of same protocol
  - Either (asymmetric)
    - one is 'base' (i.e., not 'conjugated')
      - typically owned by 'client'
    - and the other is 'conjugated'
      - typically owned by 'server'
  - Or (symmetric)
    - only InOut messages





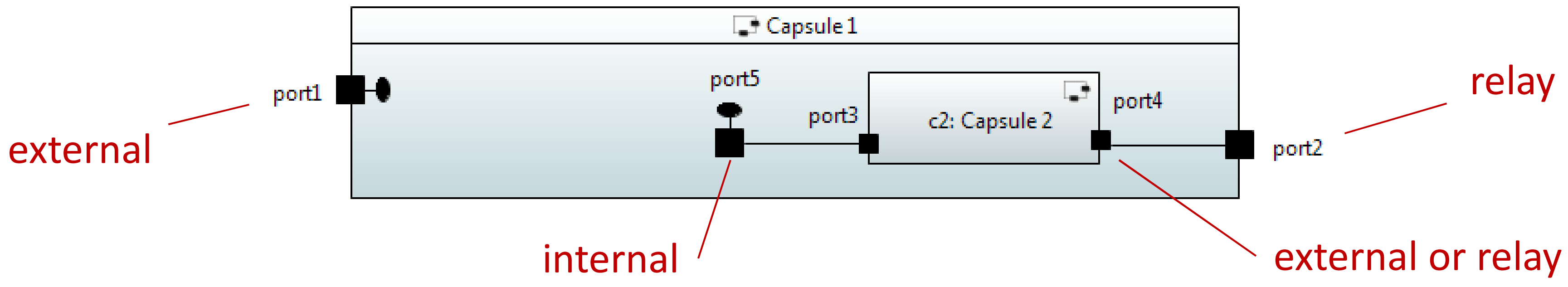




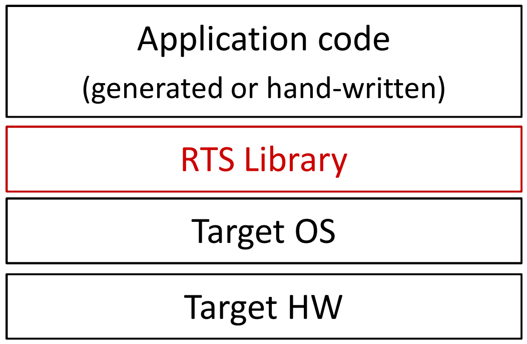


Ports: External, Internal, Relay

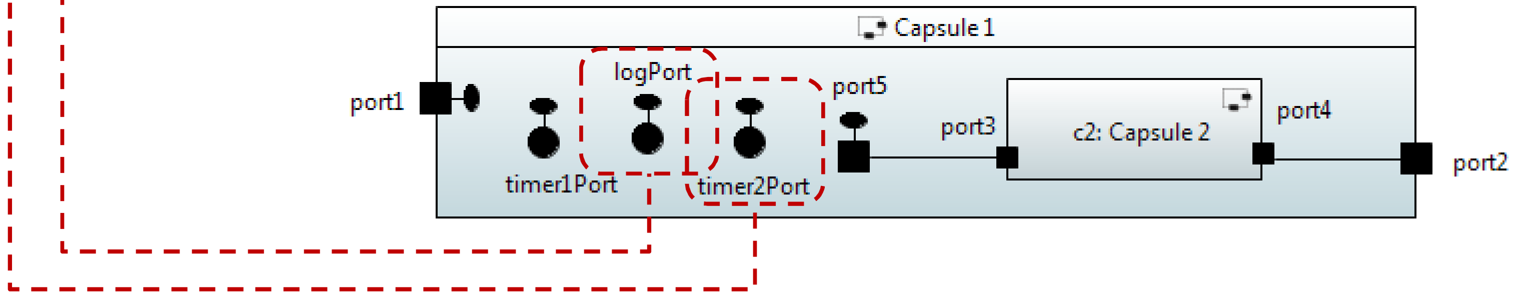
- External behaviour
  - Provides (part of) externally visible functionality (isService=true)
  - Incoming messages passed on to state machine (isBehaviour=true)
  - Must be connected (isWired=true)
- Internal behaviour
  - As above, but not externally visible (isService=false)
  - Connect state machine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



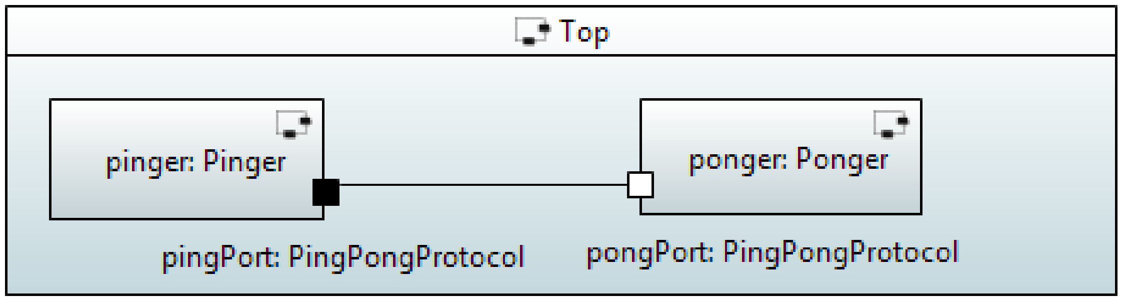
Ports: System

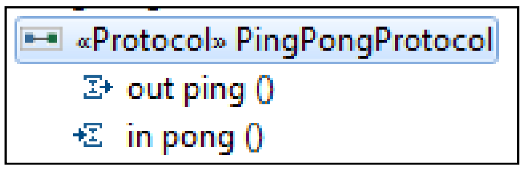


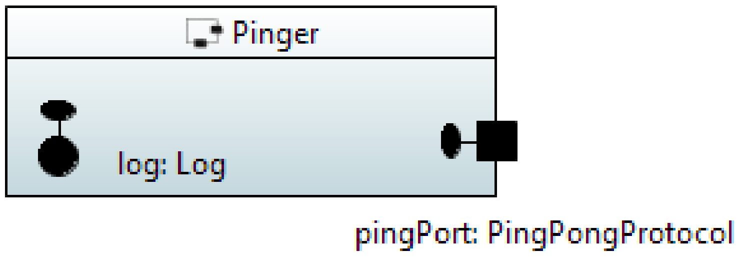
- Connects capsule to Runtime System (RTS) library via corresponding system protocol
- Provides access to RTS services such as
  - Timing: setting timers, time out message
    - `timer2Port.informIn(UMLRTTimespec(10, 0));`
      `// set timer that will expire in 10 secs and 0 nanosecs`
    - When timer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

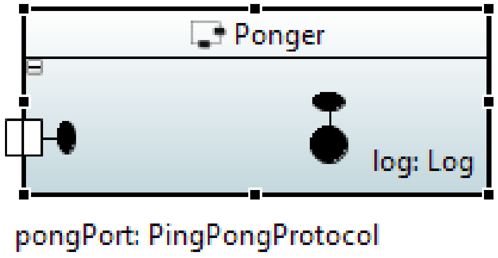


Example: PingPong

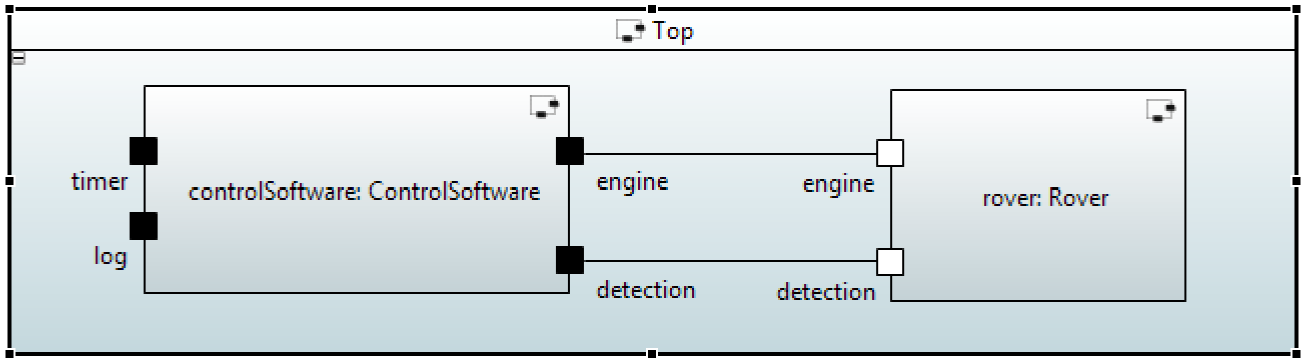


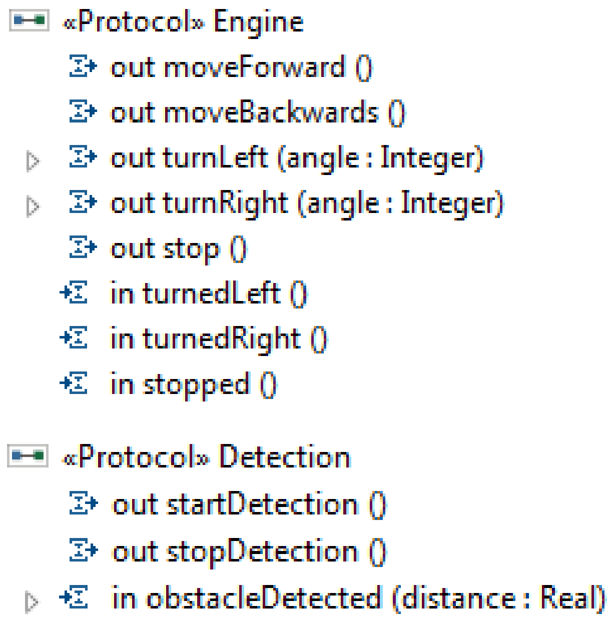




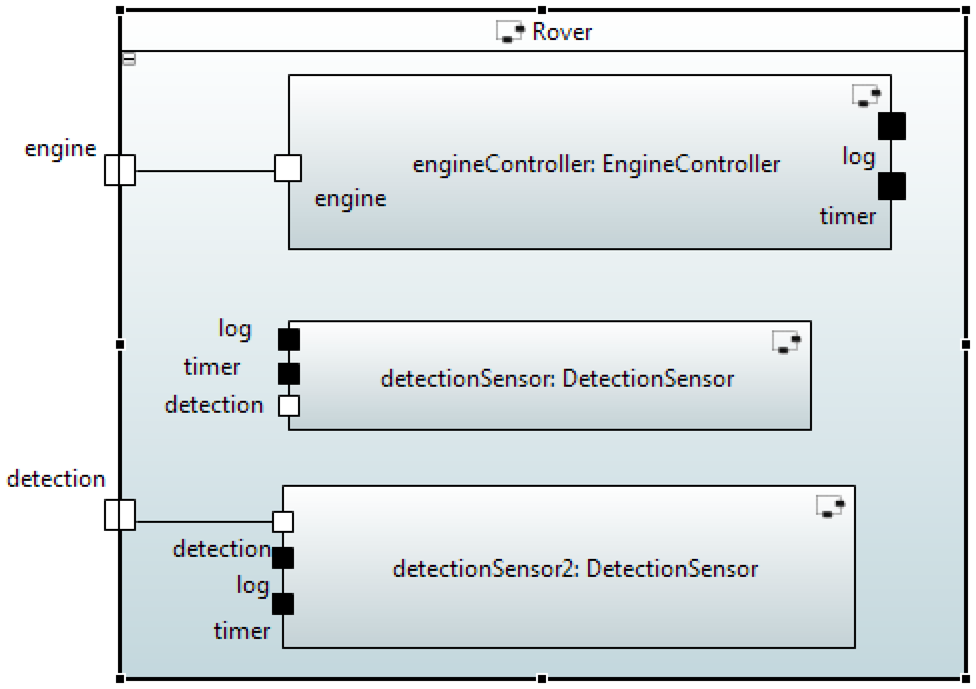


Example: Rover

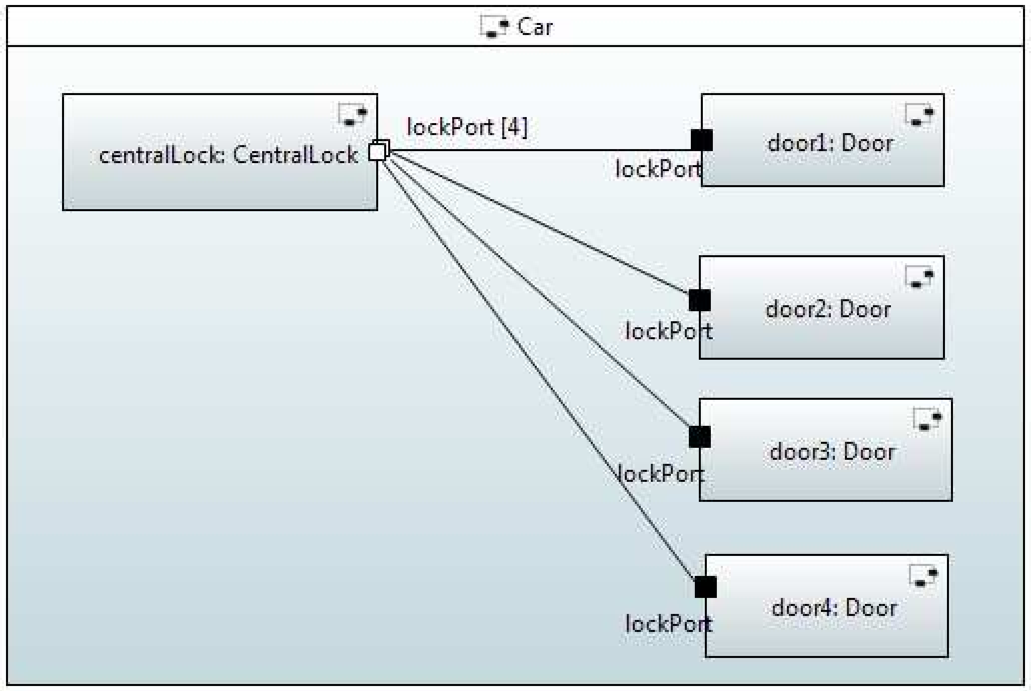


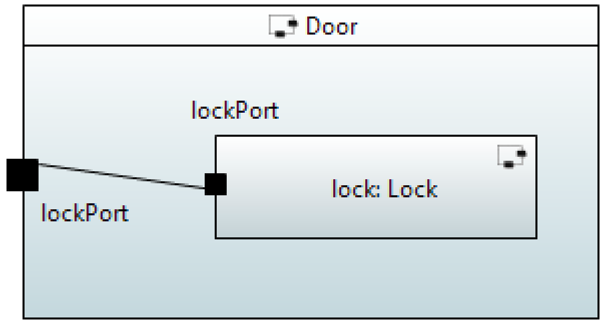

«Protocol» Engine
- out moveForward ()
- out moveBackwards ()
- out turnLeft (angle : Integer)
- out turnRight (angle : Integer)
- out stop ()
- in turnedLeft ()
- in turnedRight ()
- in stopped ()

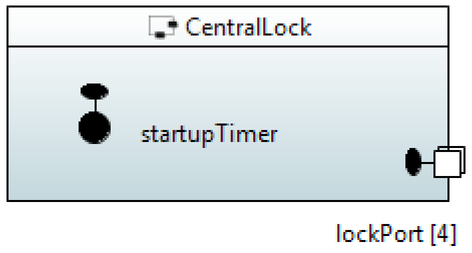
«Protocol» Detection
- out startDetection ()
- out stopDetection ()
- in obstacleDetected (distance : Real)

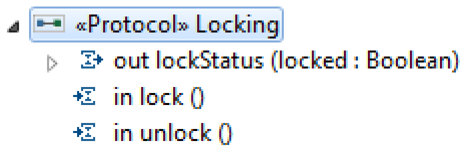

Rover
engine
engine
engineController: EngineController
log
timer
log
timer
detection
detectionSensor: DetectionSensor
detection
detection
log
timer
detectionSensor2: DetectionSensor

Example: Door Lock System

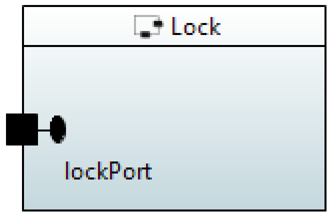


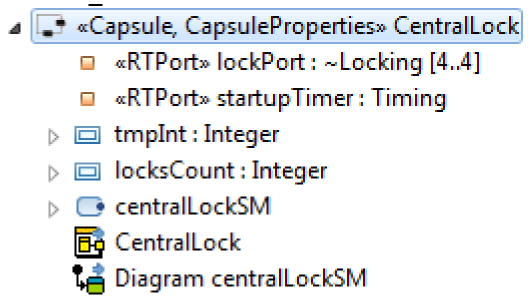






«Protocol» Locking
- out lockStatus (locked : Boolean)
- in lock ()
- in unlock ()





«Capsule, CapsuleProperties» CentralLock
- «RTPort» lockPort : ~Locking [4..4]
- «RTPort» startupTimer : Timing
- tmpInt : Integer
- locksCount : Integer
- centralLockSM
- CentralLock
- Diagram centralLockSM

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

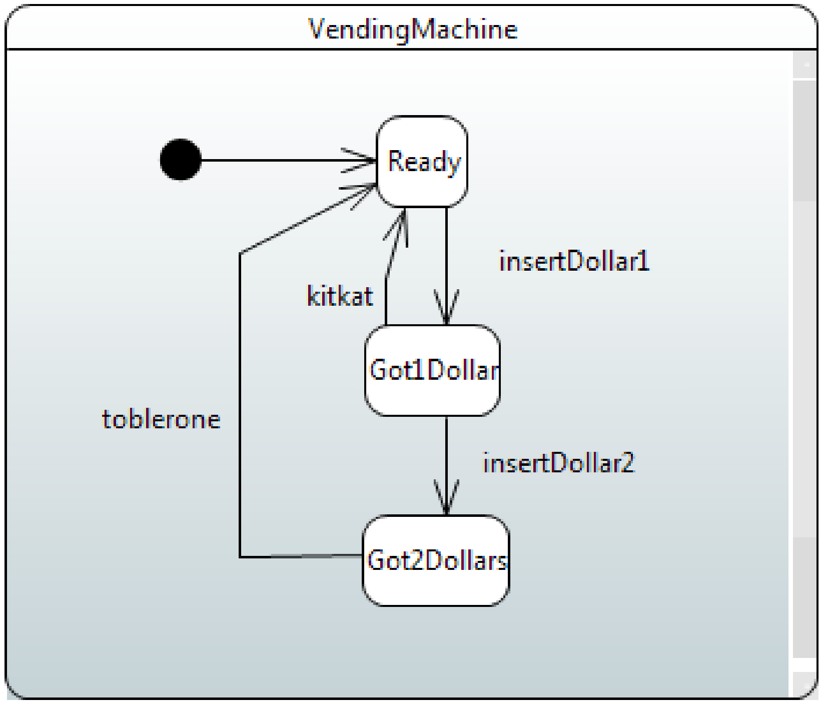
Pseudo states

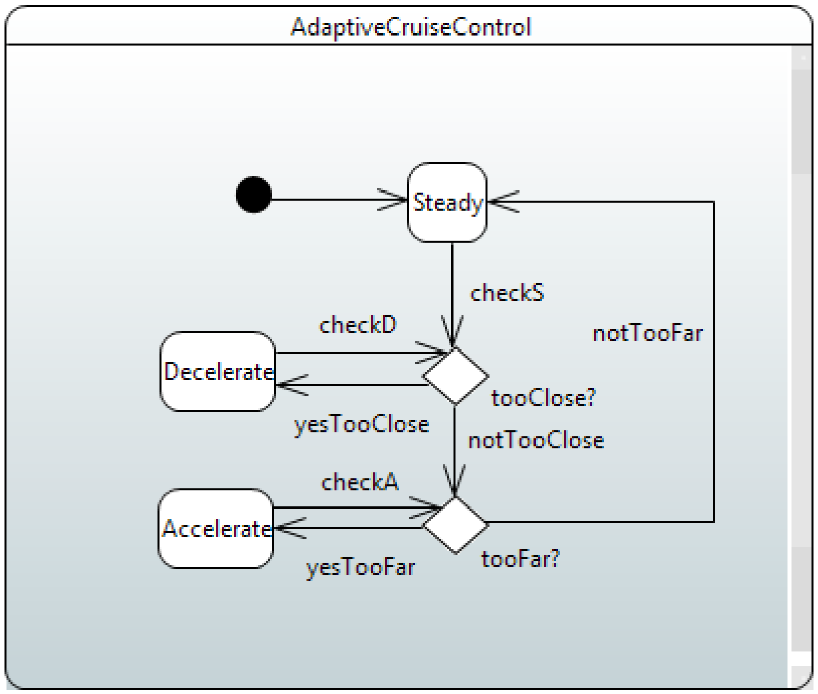
- Don't belong to description of lifetime of object

  ⇒ 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

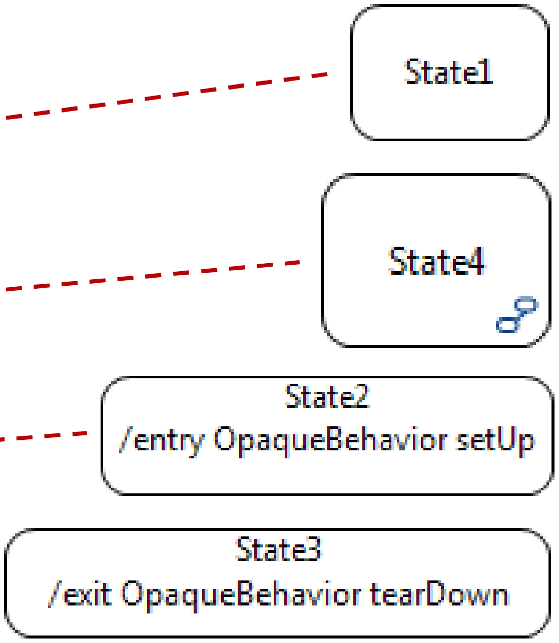


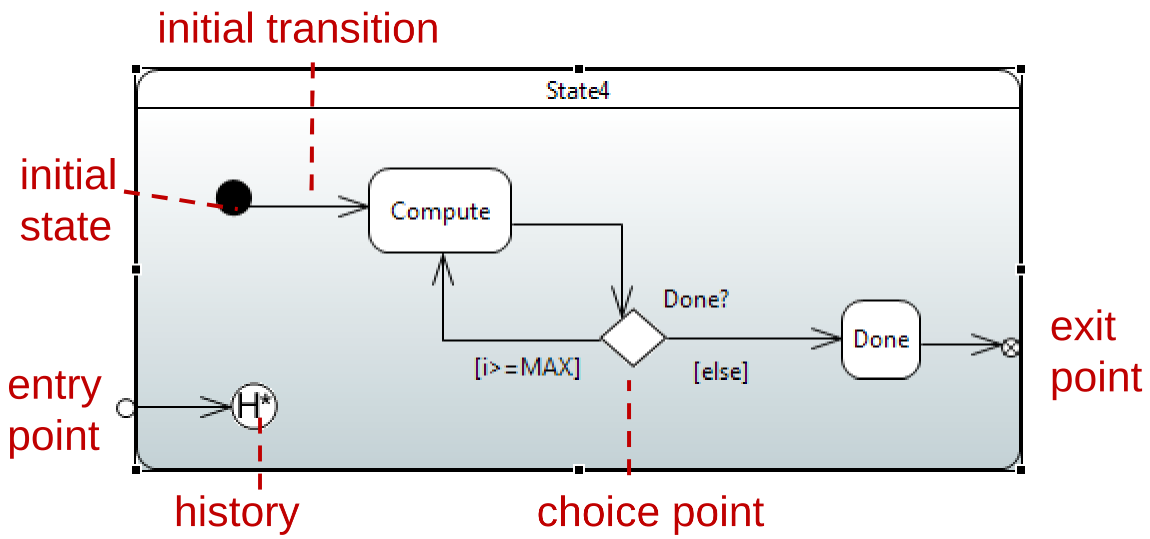


States and Pseudo States

- 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

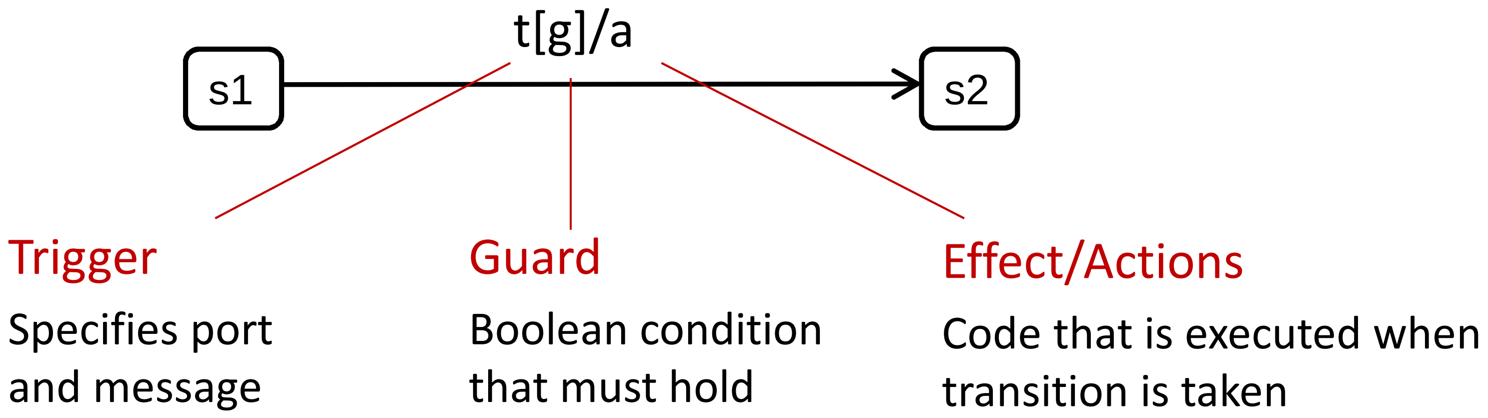
in composite states only





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)


t[g]/a
s1
s2
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

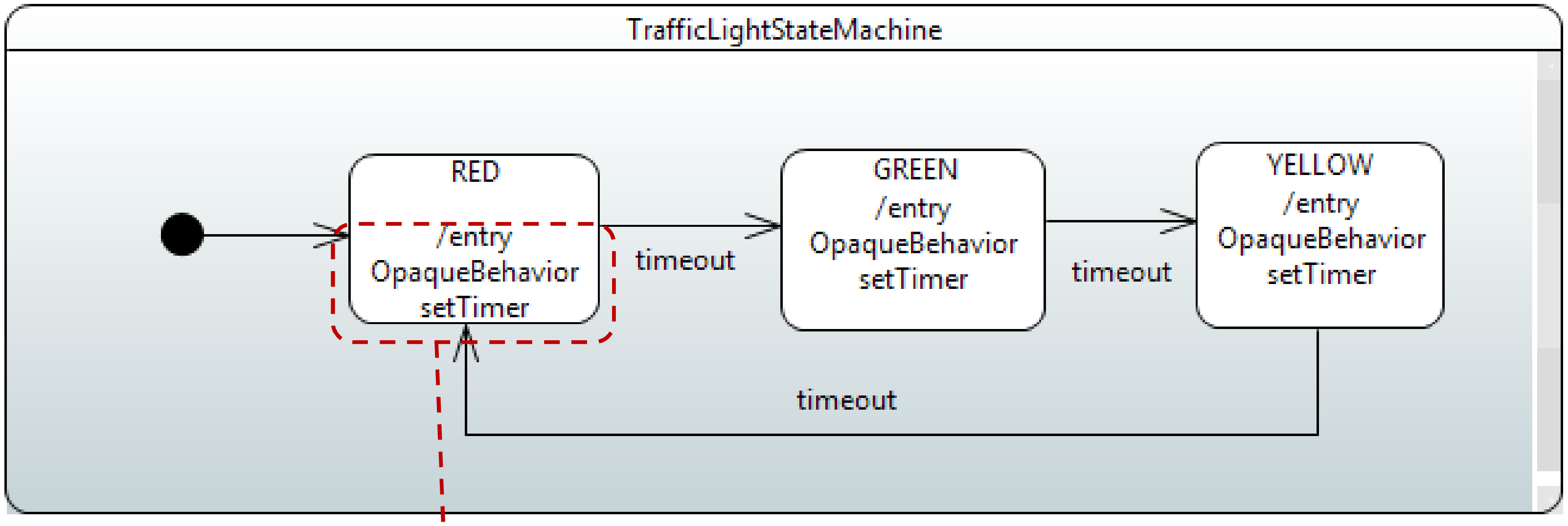
- graphical notation for state machines and
- textual notation for source code in actions

⇒ UML and UML-RT State Machines

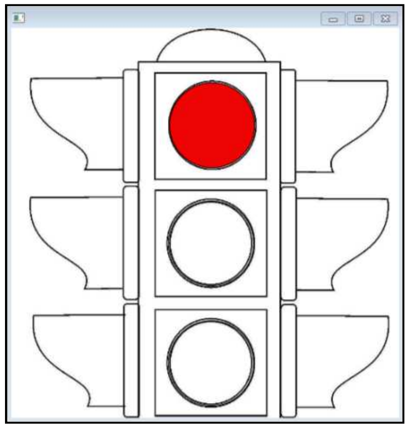
- different from, e.g., Finite Automata
- closer to 'extended hierarchical communicating state machines' [5]

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

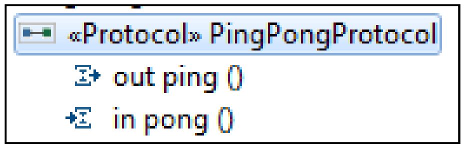
Example: Action Code, Timers, Logging

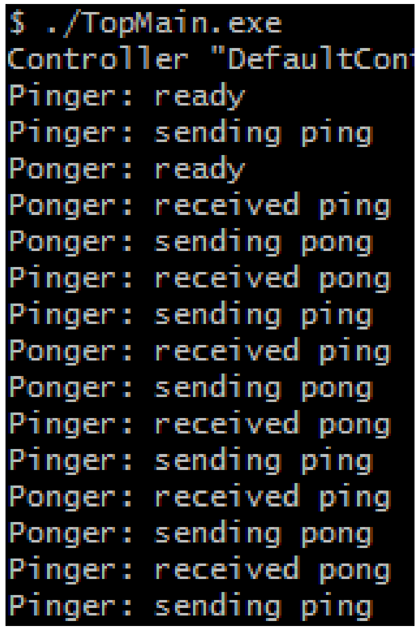


```
timer.informIn(UMLRTTimespec(5,0));
log.log("Switched to red");
```

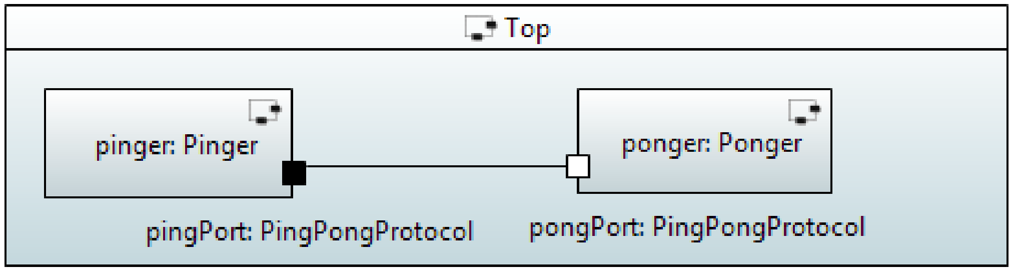


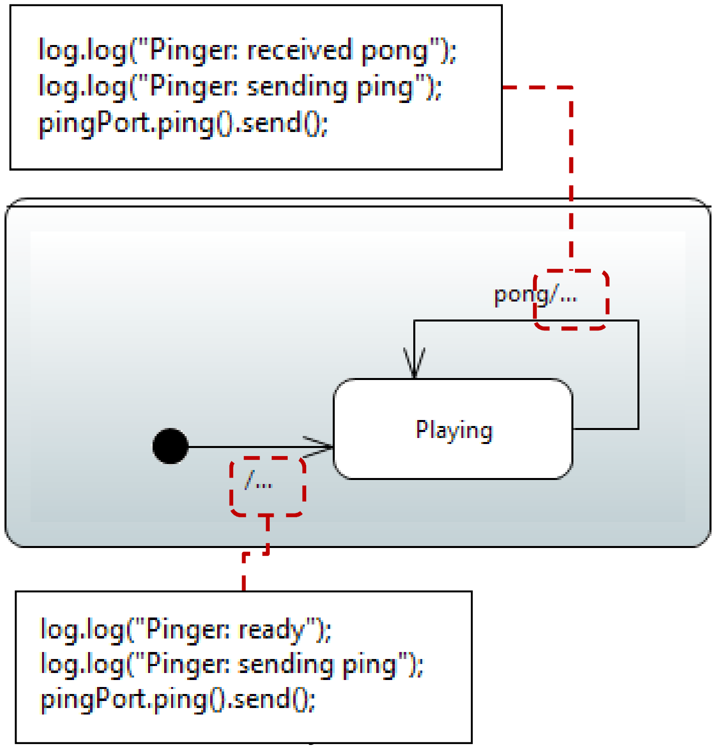
Example: Ping Pong





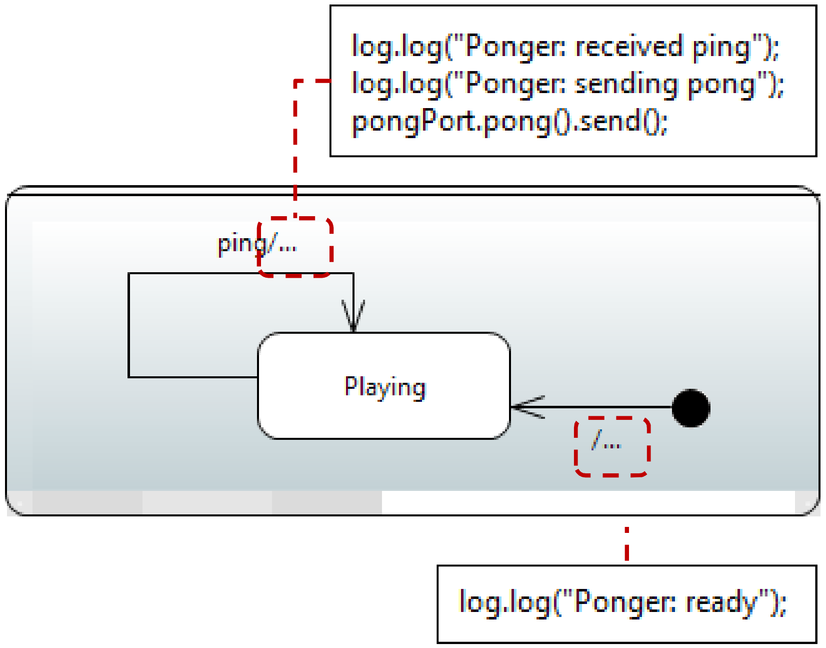
```
$ ./TopMain.exe
Controller "DefaultCon
Pinger: ready
Pinger: sending ping
Ponger: ready
Ponger: received ping
Ponger: sending pong
Pinger: received pong
Pinger: sending ping
Ponger: received ping
Ponger: sending pong
Pinger: received pong
Pinger: sending ping
Ponger: received ping
Ponger: sending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





```
log.log("Pinger: received pong");
log.log("Pinger: sending ping");
pingPort.ping().send();
```

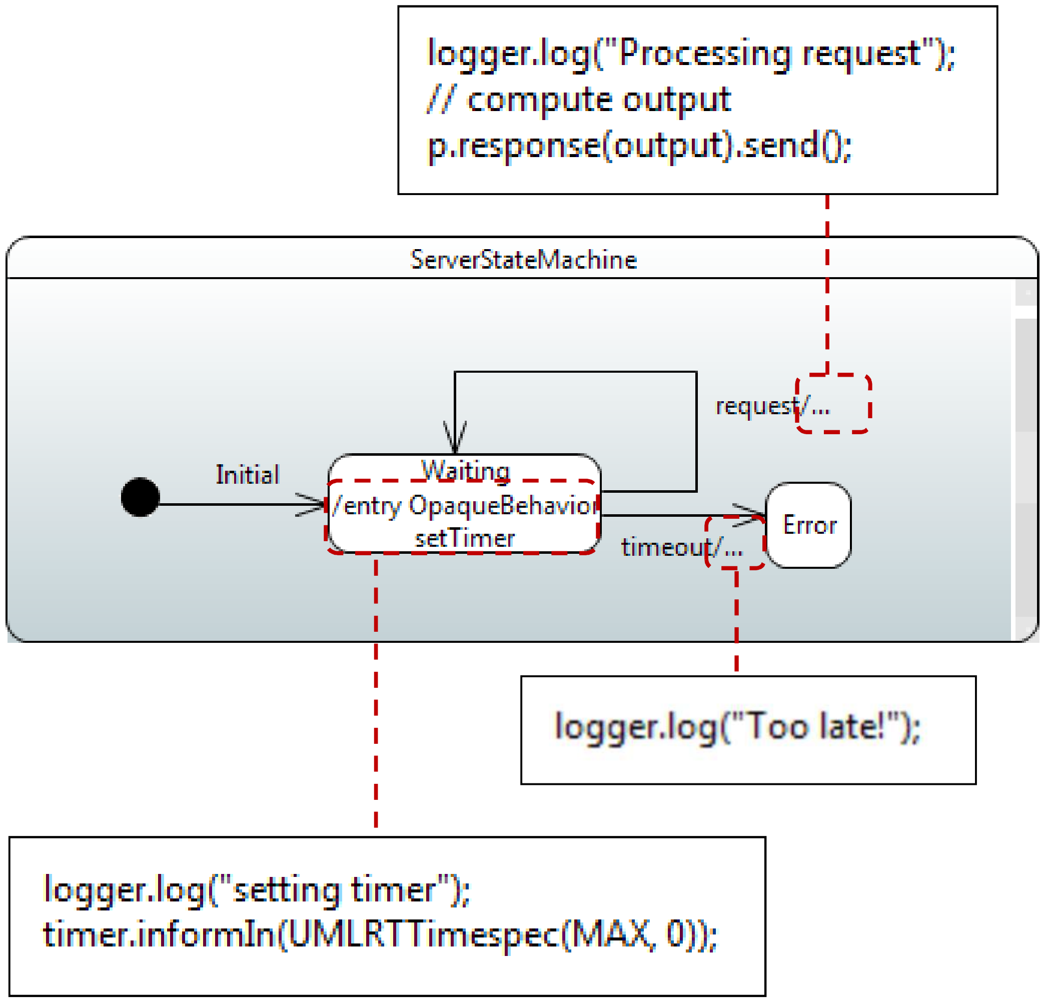
```
log.log("Pinger: ready");
log.log("Pinger: sending ping");
pingPort.ping().send();
```



```
log.log("Ponger: received ping");
log.log("Ponger: sending pong");
pongPort.pong().send();
```

```
log.log("Ponger: ready");
```

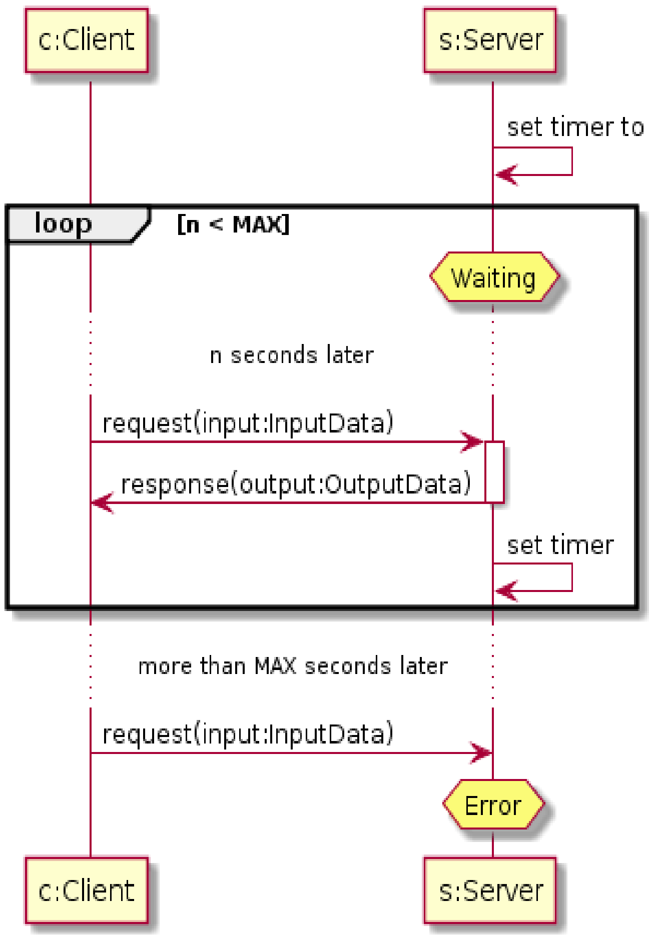
Example: Timers



```
logger.log("Processing request");
// compute output
p.response(output).send();
```

```
logger.log("Too late!");
```

```
logger.log("setting timer");
timer.informIn(UMLRTTimespec(MAX, 0));
```



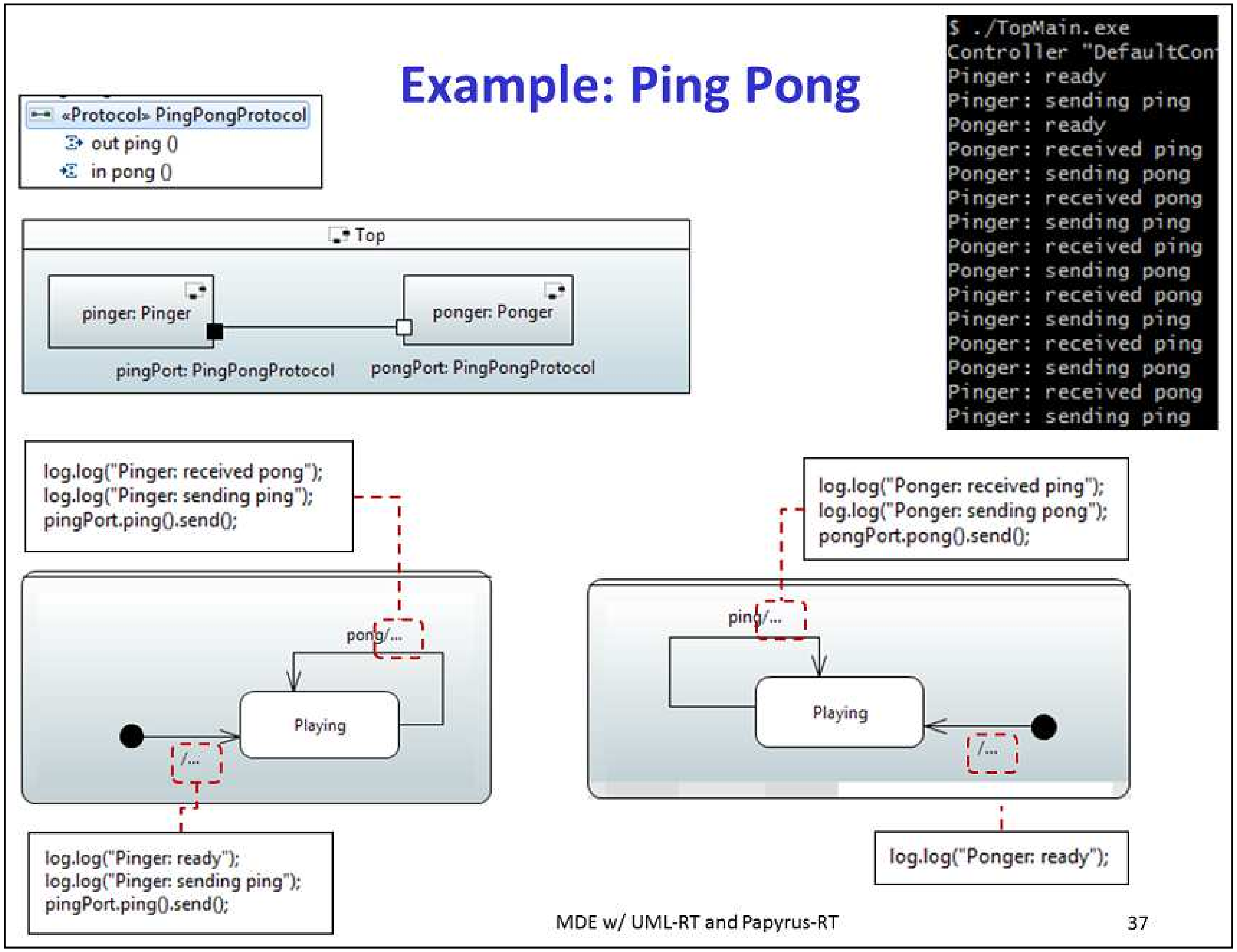
Overview

1.	MDE	(10 mins)	(10 slides)
2.	Overview	(1 min)	(1 slide)
3.	Papyrus-RT	(5 mins)	(3 slides)
4.	UML-RT: Part I	(25 mins)	(24 slides)
	• Core concepts		
5.	Demo I	(10 mins)	
6.	Hands on session	(10 mins)	
7.	UML-RT: Part II	(15 mins)	(14 slides)
	• More advanced concepts		
8.	Demo II	(10 mins)	
9.	Conclusion	(5 min)	(3 slides)

All material available at

http://flux.cs.queensu.ca/mase/research/tutorials/icse17-technical-briefing/

Demo and Handson



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
```

```
log.log("Pinger: received pong");
log.log("Pinger: sending ping");
pingPort.ping().send();
```

```
log.log("Ponger: received ping");
log.log("Ponger: sending pong");
pongPort.pong().send();
```

```
log.log("Pinger: ready");
log.log("Pinger: sending ping");
pingPort.ping().send();
```

```
log.log("Ponger: ready");
```

MDE w/ UML-RT and Papyrus-RT 37

Overview

1. MDE	(10 mins)	(10 slides)
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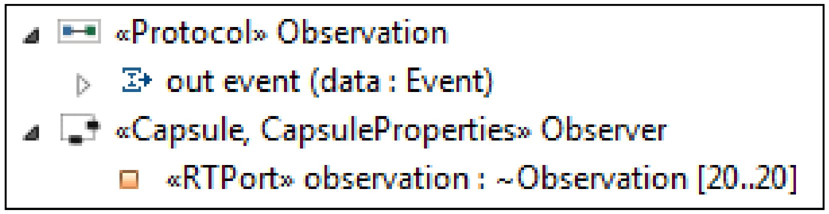
UML-RT Part II

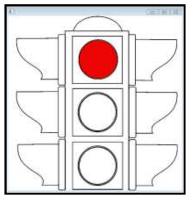
- More on ports
- More on state machines

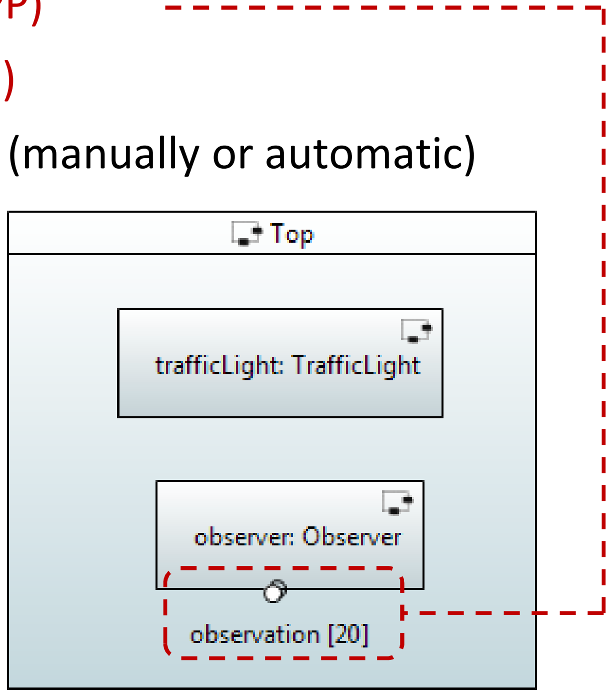
Ports: SPP and SAP

- 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)



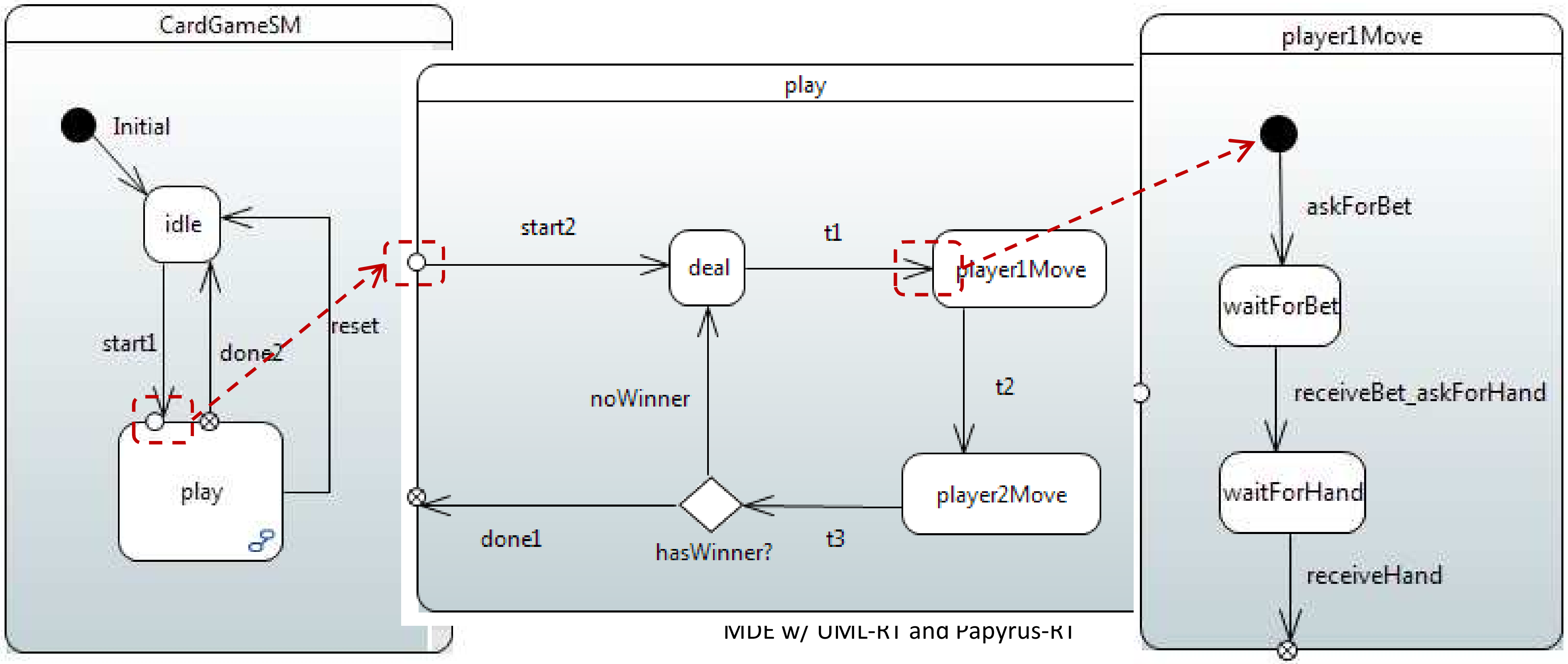
```
◢ «Protocol» Observation
    ▷ out event (data : Event)
◢ «Capsule, CapsuleProperties» Observer
      «RTPort» observation : ~Observation [20..20]
```





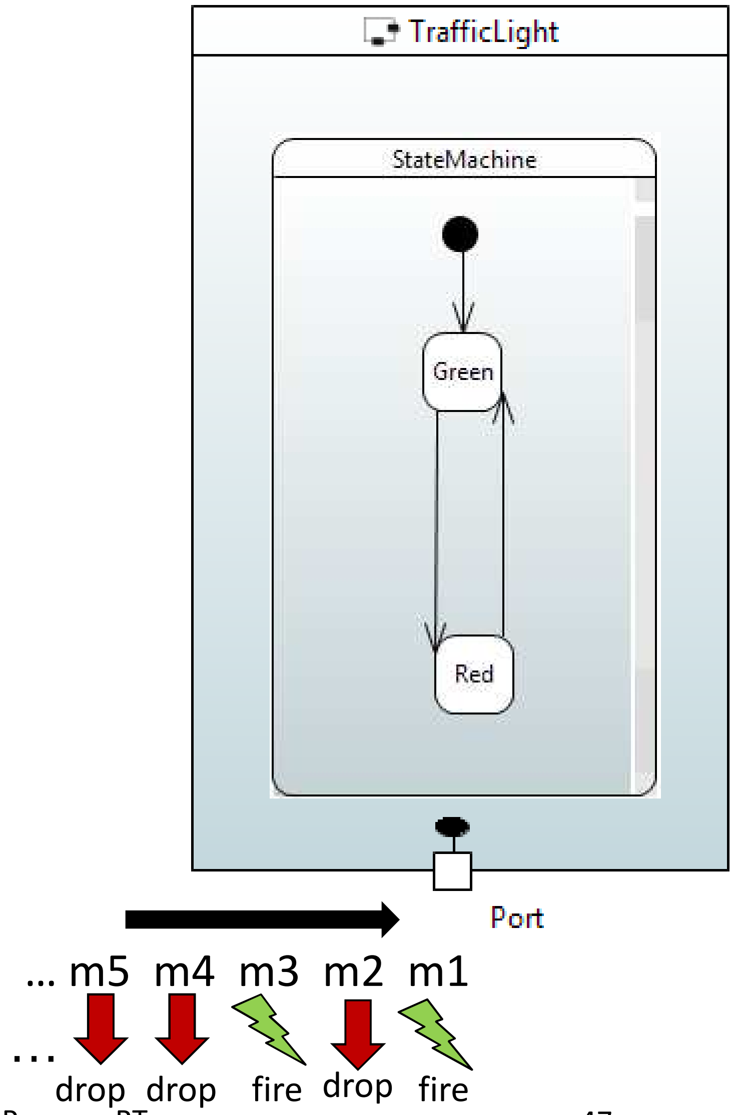
State Configuration

- 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



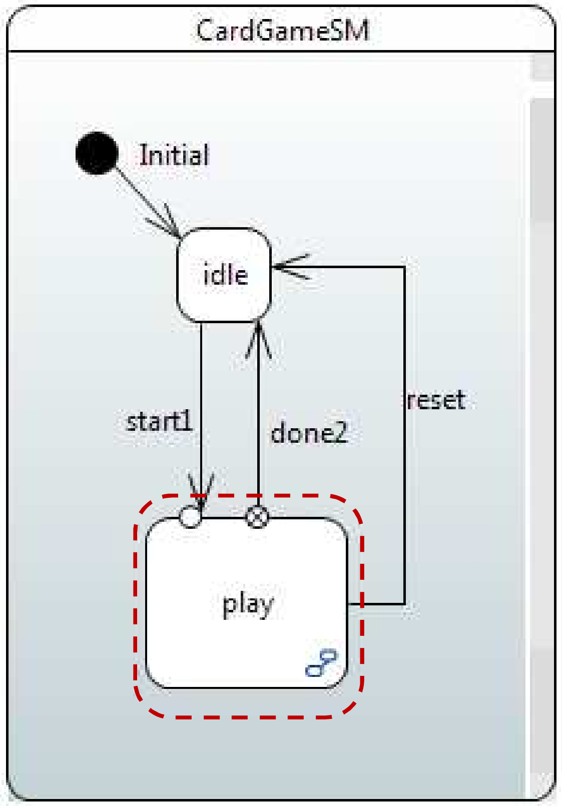
Run-to-Completion

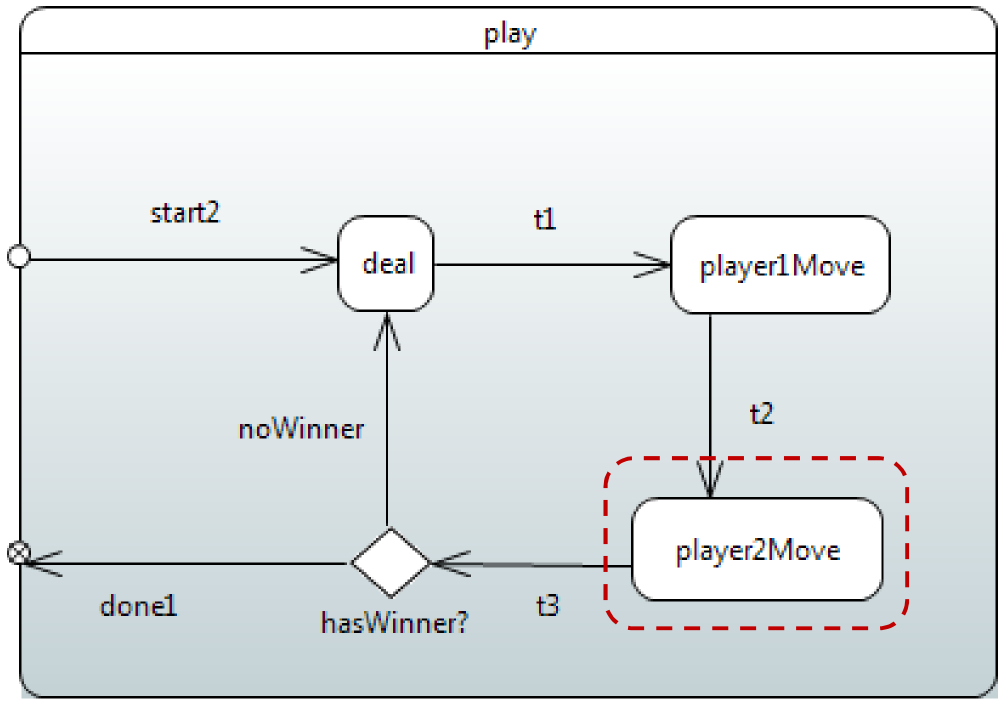
- The event processing of state machines follows ‘run-to-completion’ semantics
- Dispatching of message triggers execution of possibly entire chain of transitions (Steps 5 and 6 on previous slide)
- Execution lasts until stable state configuration has been reached (last state in transition chain not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

$\Rightarrow$ better concurrency control

Group Transitions

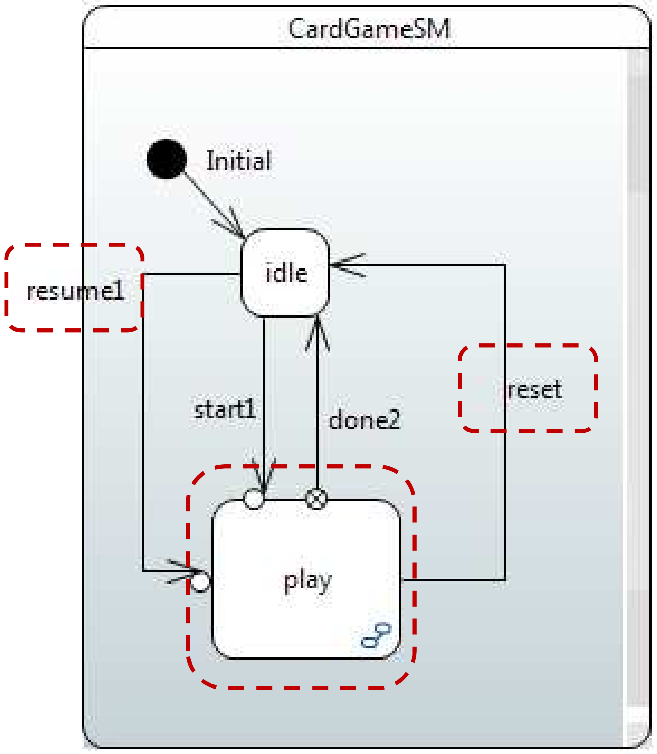
- Source state is composite
- Example:
  - Start configuration <‘play’,’player2Move’>
  - Execute transition ‘reset’:
    - exit code ‘player2Move’, exit code ‘play’, effect ‘reset’, entry code ‘idle’
  - End configuration <‘idle’>

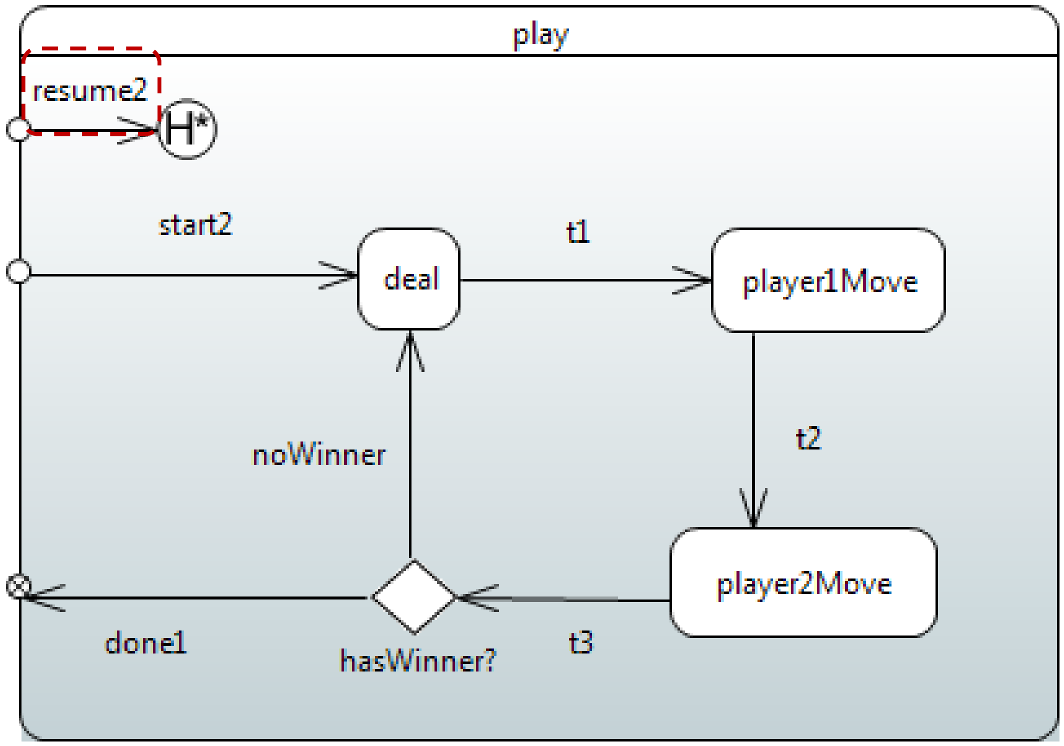




History

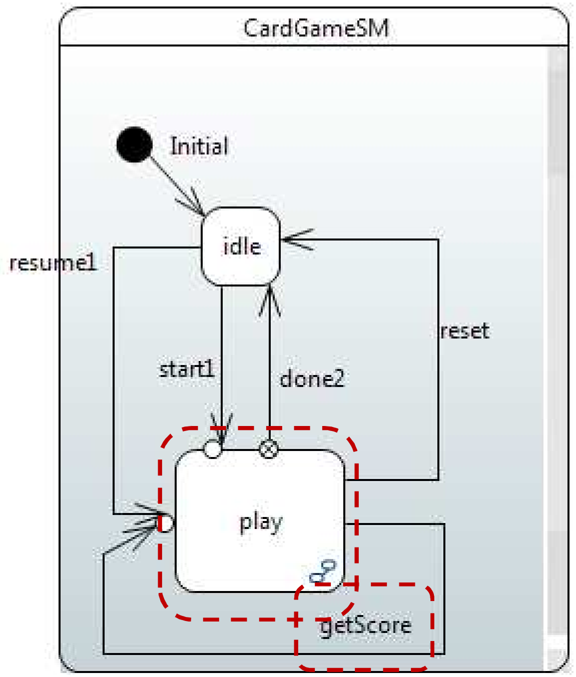
- Re-establish full state configuration that was active when containing state was active most recently
- Example: from <'play', s> to <'play', s> with 'reset' 'resume1'

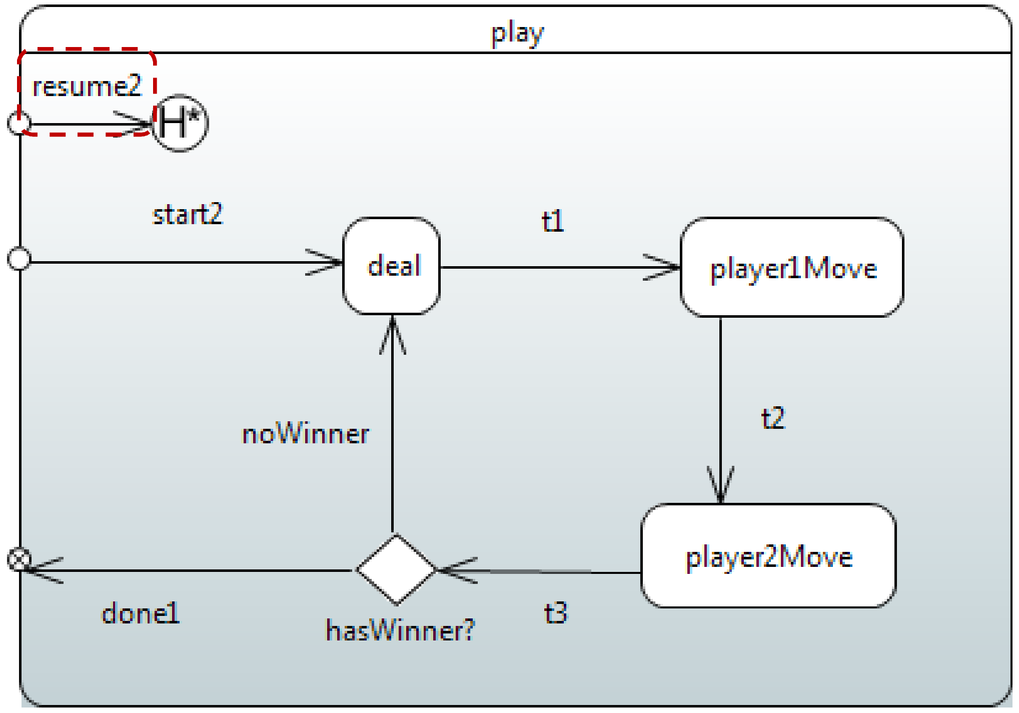


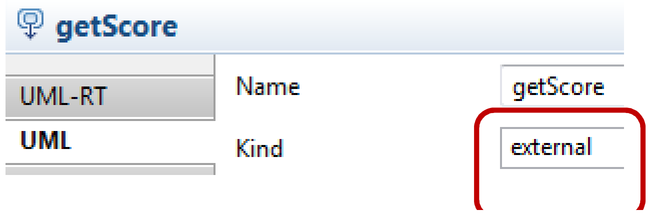


Self Transitions

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



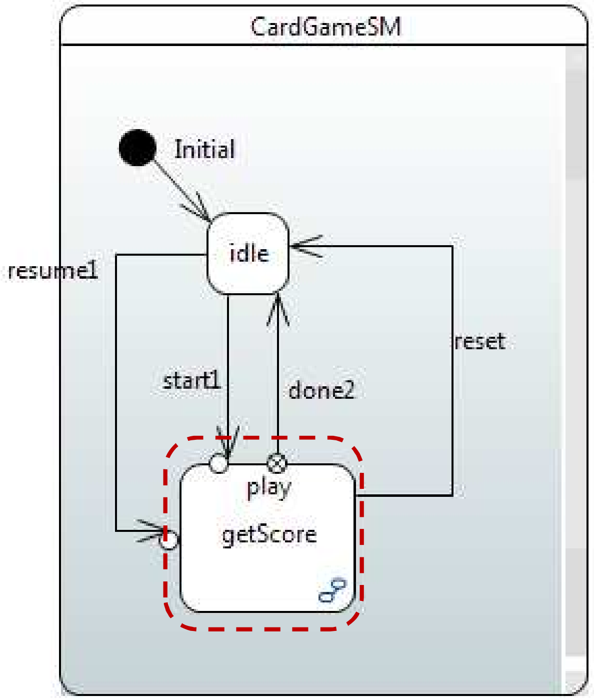


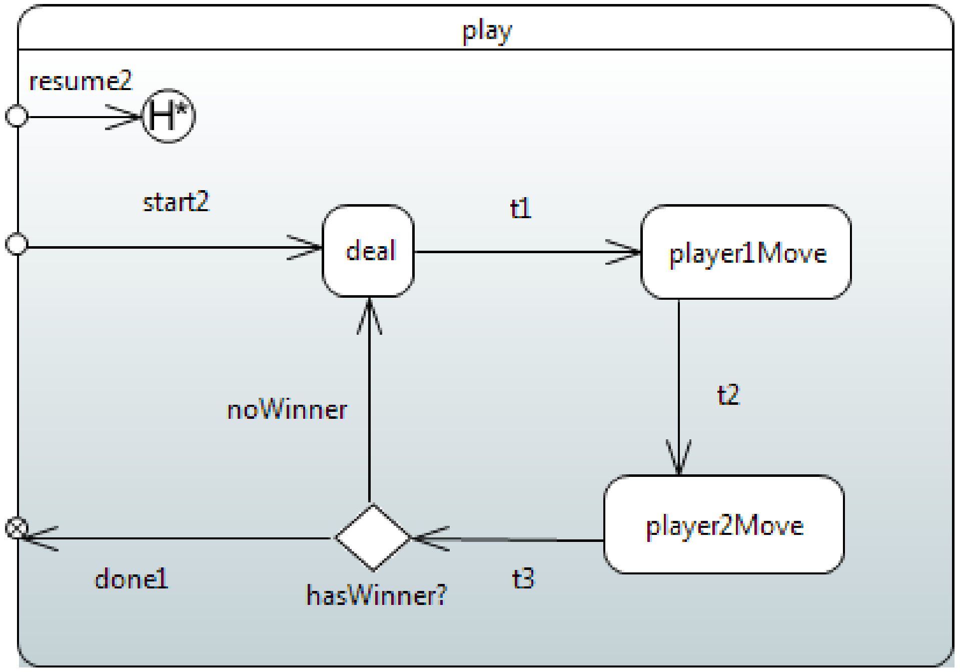

getScore

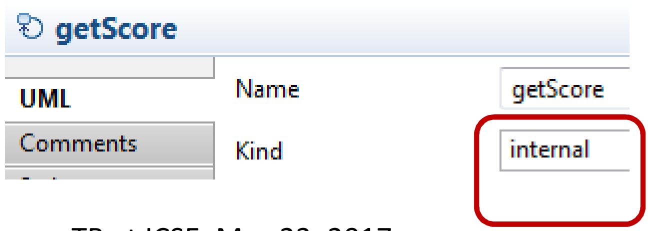
UML-RT	Name	getScore
UML	Kind	external

Self Transitions: Internal

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

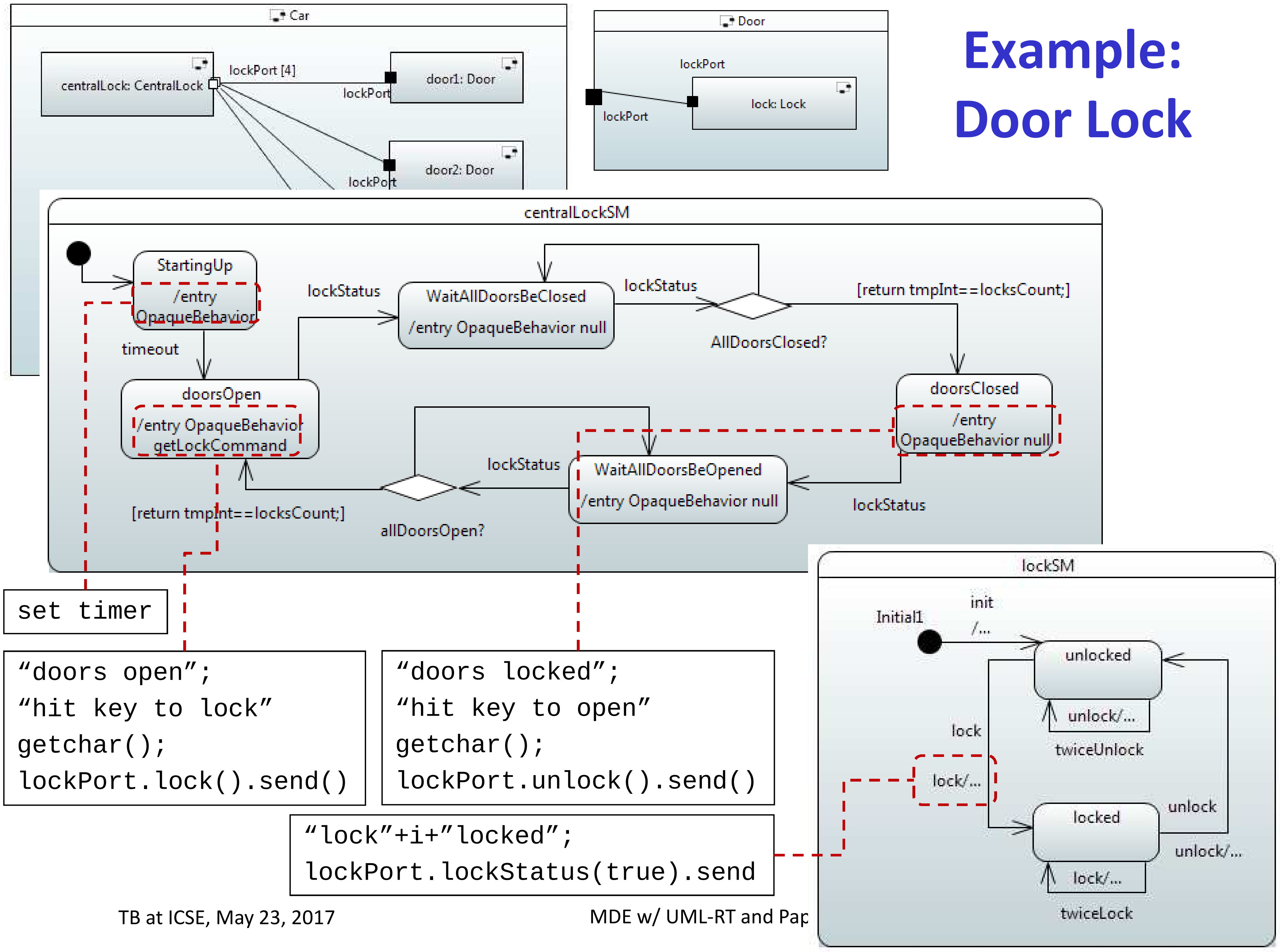





getScore

UML	Name	getScore
Comments	Kind	internal

Example: Door Lock



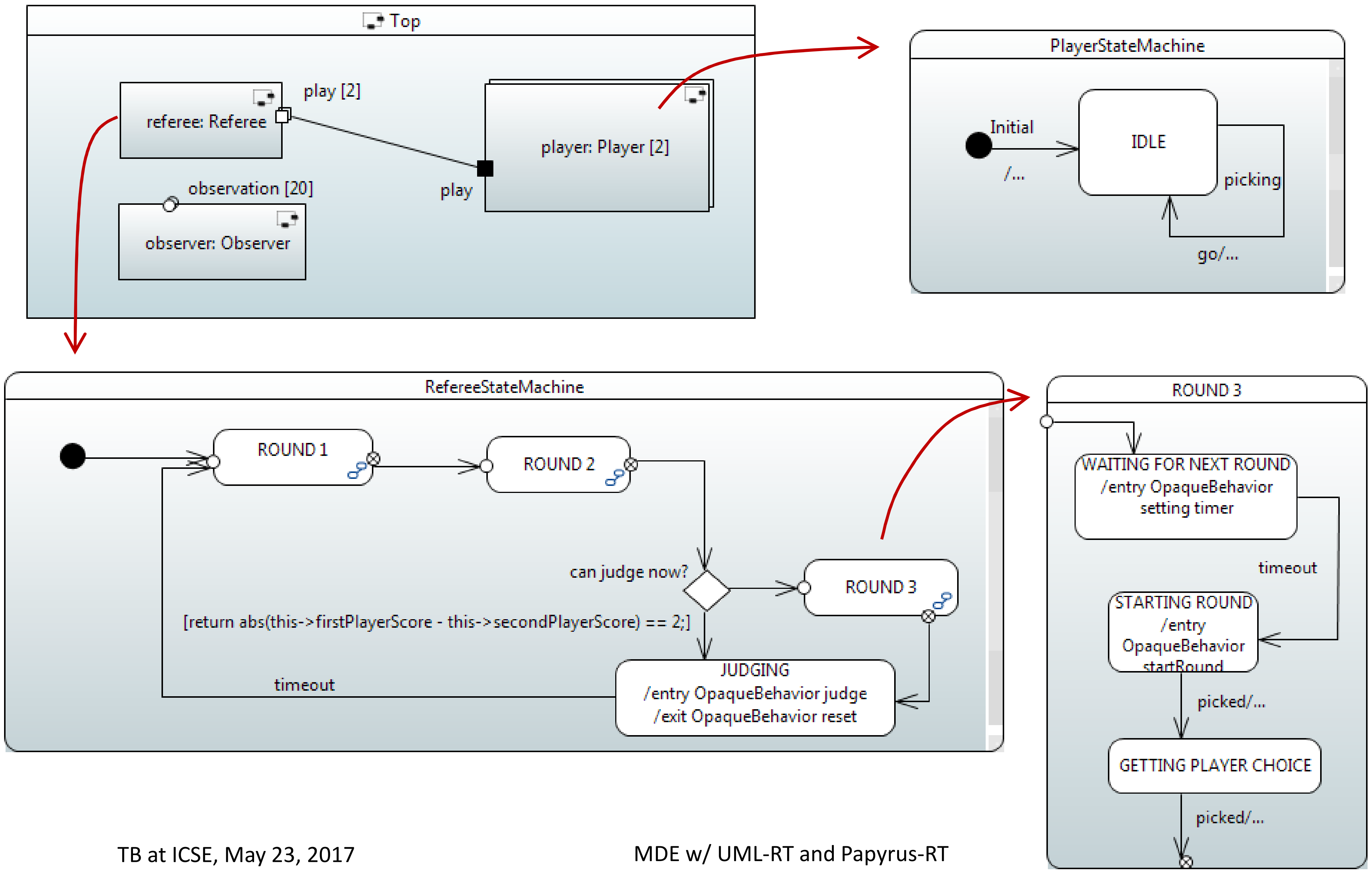
```
set timer
```

```
"doors open";
"hit key to lock"
getchar();
lockPort.lock().send()
```

```
"doors locked";
"hit key to open"
getchar();
lockPort.unlock().send()
```

```
"lock"+i+"locked";
lockPort.lockStatus(true).send
```

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

Conclusion

- Intro to
  - MDE
    - Abstraction, Automation, Analysis
    - Core techniques to deal with complexity
  - UML-RT
    - small, proven subset of UML for real-time systems
  - Papyrus-RT
    - open-source MDE tool w/ full code generation
- Lots of opportunity to use, research, contribute
- More questions?
  - dingel@cs.queensu.ca
  - hili@cs.queensu.ca

Resources and References

- Links
  - TB resources: http://flux.cs.queensu.ca/mase/research/tutorials/icse17-technical-briefing
  - 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.

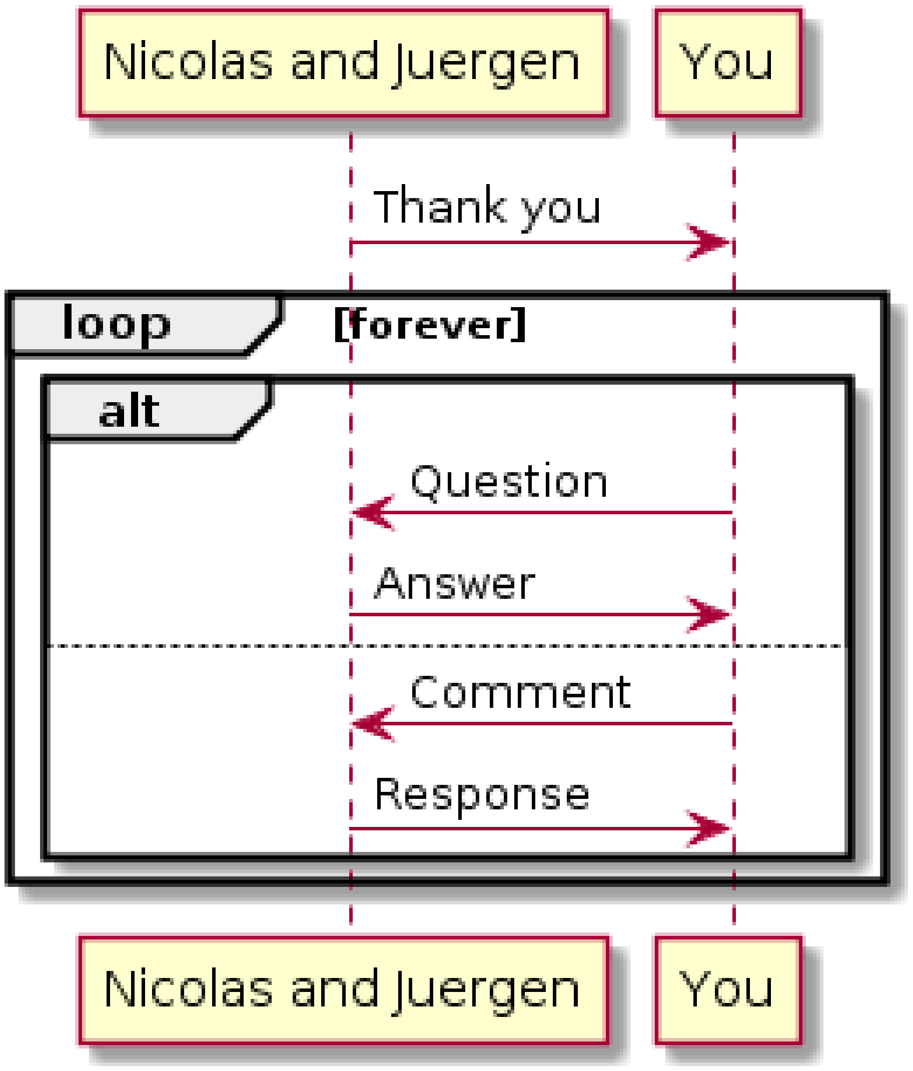
[3] Dingel. Complexity is the Only Constant: Trends in Computing and Their Relevance to Model Driven Engineering. Proceedings ICGT'16. LNCS 9761:79-85. 2016..

[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.

The End


Nicolas and Juergen
You
Thank you
loop
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Question
Answer
Comment
Response
Nicolas and Juergen
You