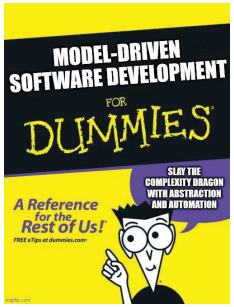
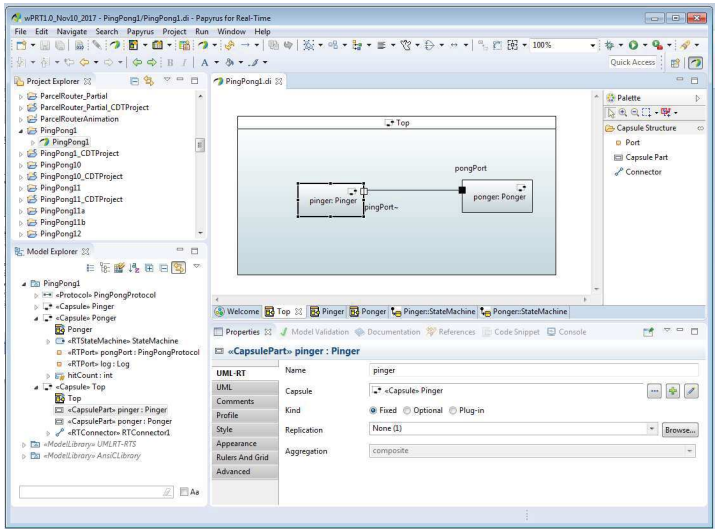
Beyond Code:
An Introduction to Model-Driven Software Development (CISC 844)



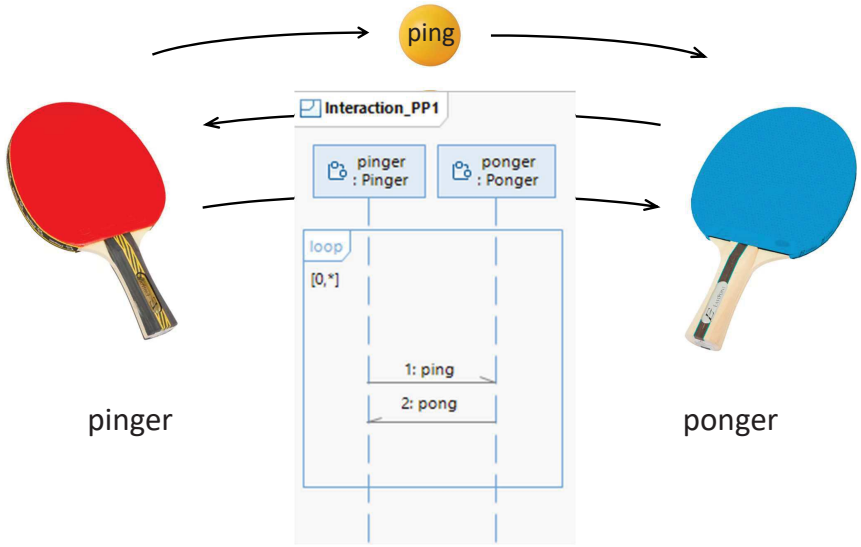
UML-RT and HCL Model RealTime: Part I

Juergen Dingel
Winter 2025

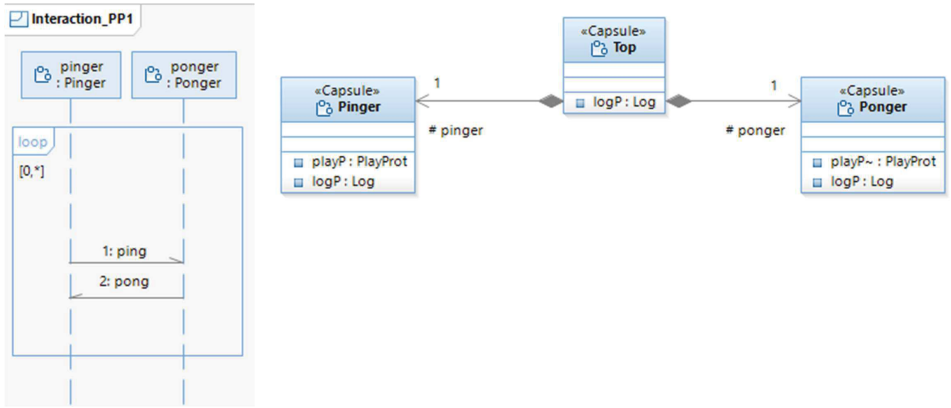
UML-RT and Model RealTime: Sneak Peek



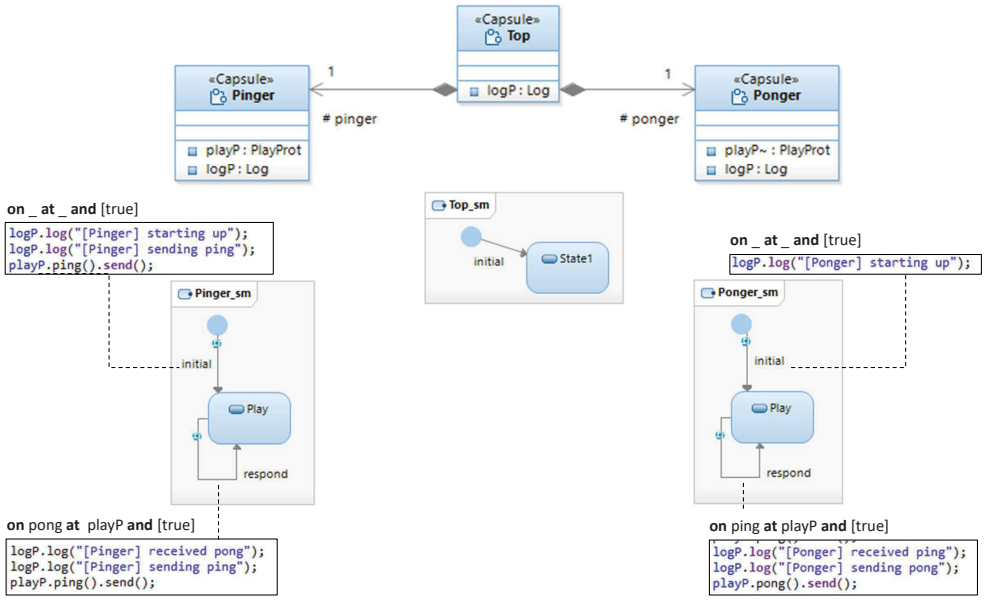
Example 1: Forever PingPong (1)



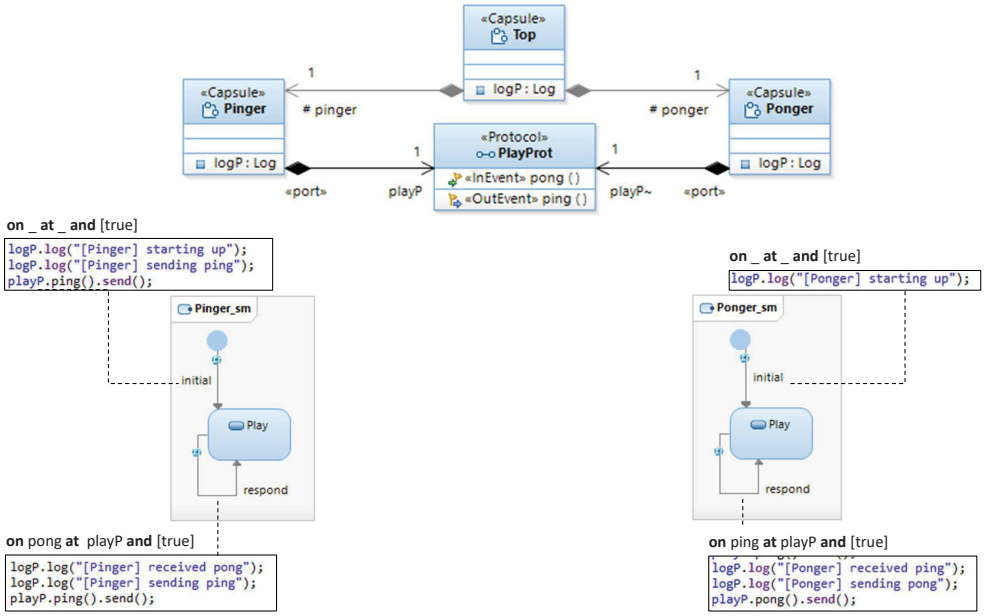
Example 1: Forever PingPong (2)



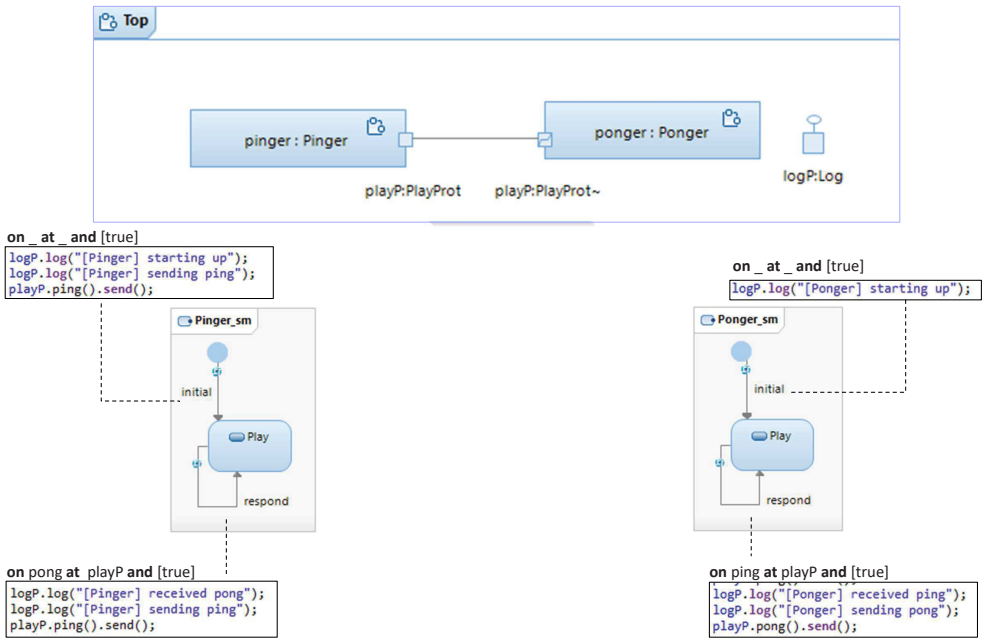
Example 1: Forever PingPong (3)



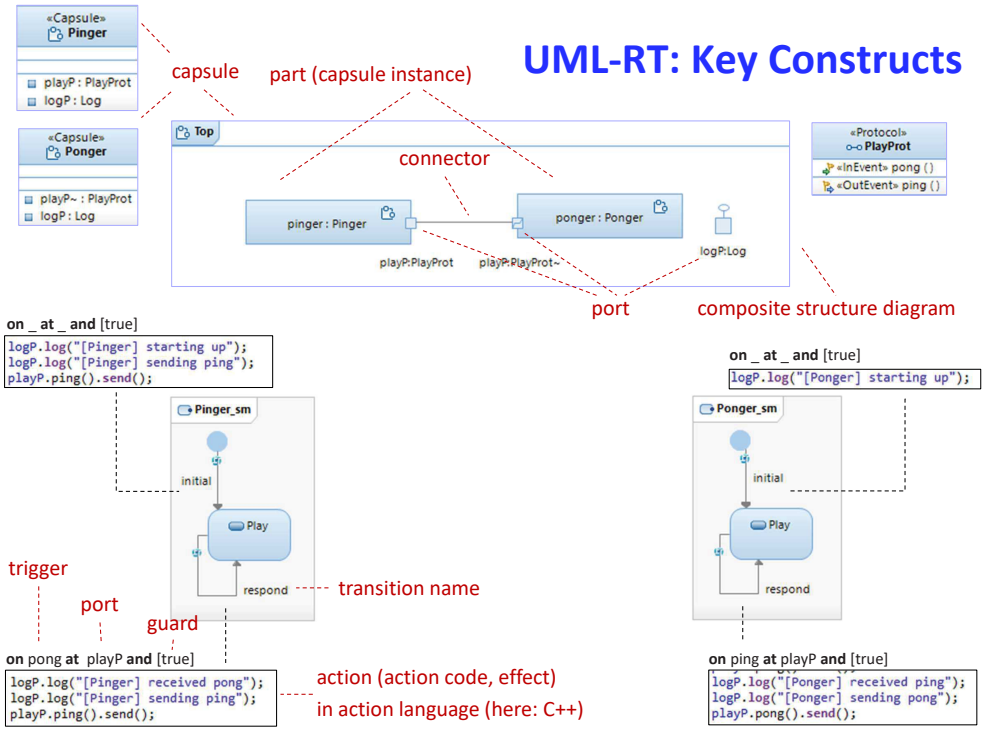
Example 1: Forever PingPong (4)



Example 1: Forever PingPong (5)



UML-RT: Key Constructs



UML-RT: Tools

- Commercial
  - IBM RSARTE
  - HCL Model RealTime (as Eclipse plugin)
  - HCL Code RealTime (as VS Code or Eclipse Theia extension)
  - Protos eTrice
- Open source
  - Eclipse Papyrus-RT

Model RealTime Demo: Forever PingPong

```
$ ./executable.exe -URTS_DEBUG=quit

RT C++ Target Run Time System - Release 7.0.07

targetRTS: observability listening not enabled
  Task 0 detached
[Pinger] starting up
[Pinger] sending ping
                                        [Ponger] starting up
                                        [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
                                        [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
```

- Showing: editing, building, executing
- Variations
  - In Pinger: No initial 'ping' message
  - In Ponger: 'pong' sent 1 second after receipt of 'ping'

Modeling Languages

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

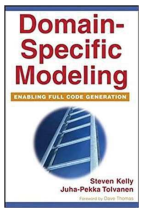
UML-RT
- Embedded, real-time
- State-machine-based

AADL
- Embedded, real-time

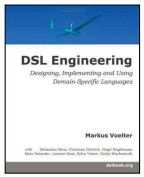
UML

UML MARTE
- Embedded, real-time

Examples in



[Kelly, Tolvanen 2008]



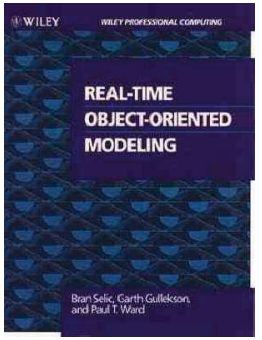
[Voelter 2013]

increasing generality

increasing domain-specifity

UML-RT: History

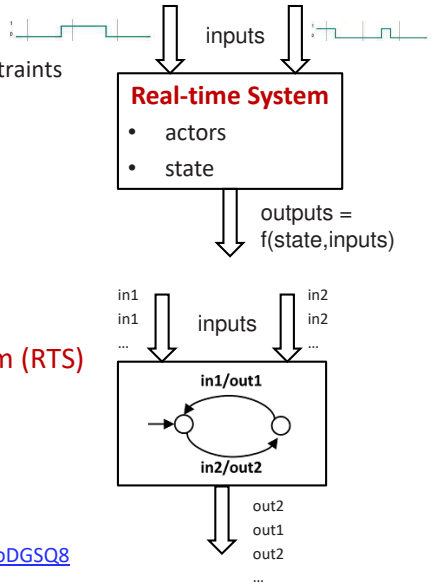
- Real-time OO Modeling (ROOM)
  - ObjecTime, early 1990 ties
- Major influence on UML 2
  - E.g., StructuredClassifier
- "RT subset of UML"
- Tools
  - ObjecTime Developer
  - IBM Rational RoseRT
  - IBM RSA-RTE
  - Eclipse Papyrus-RT
  - Protos eTrice



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

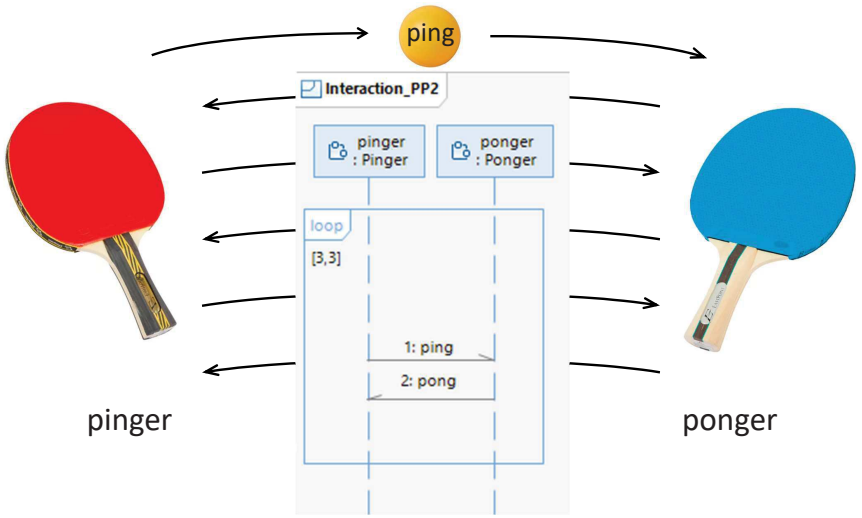
UML-RT: Characteristics I

- Domain-specific
  - Embedded systems w/ soft real-time constraints
- Graphical, but textual syntax exists
- Small, cohesive set of concepts
- Strong encapsulation
  - Actors (active objects)
  - Explicit interfaces
  - Message-based communication
- Resources managed by runtime system (RTS)
  - Message passing, logging, timers, capsule instantiation, …

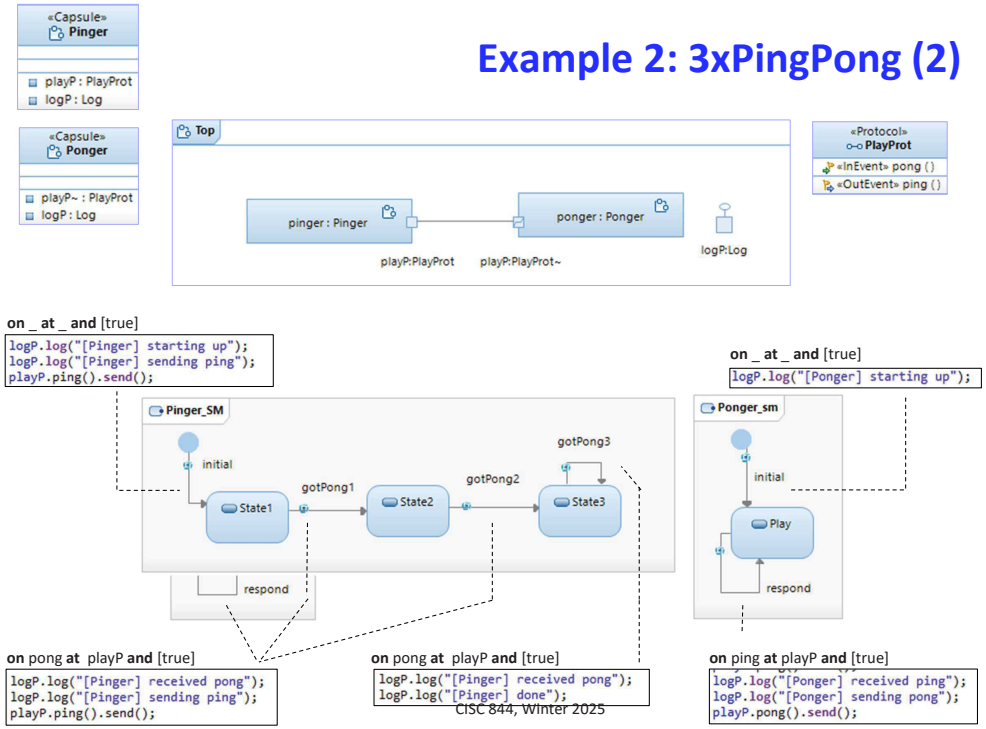


Animation: https://www.youtube.com/watch?v=6kgg_oDGSQ8

Example 2: 3xPingPong (1)



Example 2: 3xPingPong (2)



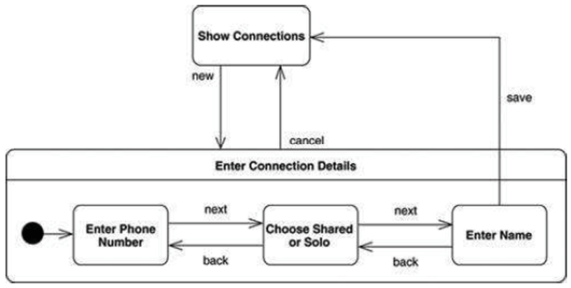
Example 2: 3xPingPong (3)

```
$ ./executable.exe -URTS_DEBUG=quit

RT C++ Target Run Time System - Release 7.0.07

targetRTS: observability listening not enabled
  Task 0 detached
[Pinger] starting up
[Pinger] sending ping 1
                                        [Ponger] starting up
                                        [Ponger] received ping
                                        [Ponger] sending pong
[Pinger] received pong
[Pinger] sending ping 2
                                        [Ponger] received ping
                                        [Ponger] sending pong
[Pinger] received pong
[Pinger] sending ping 3
                                        [Ponger] received ping
                                        [Ponger] sending pong
pinger(1)@State3 received unexpected message: playP[1]%pong data: void
```

- Variations
  - Remove trigger in 'gotPong3' transition in 'pinger'

UML-RT: Characteristics 2

- Event-driven execution
  - Every execution step by capsule C is caused by a message delivered to C (including, e.g., timeout messages)
  - Challenge: when message m is delivered to state machine of C, C is able to handle m
    - group transitions (out of composite states)
    - defer/recall



M. Fowler. UML Distilled. 3rd Ed. 2004.

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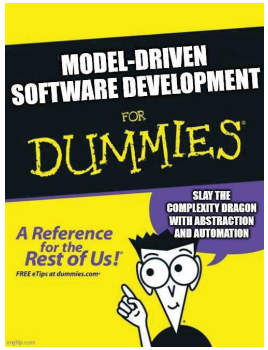


UML-RT and Model RealTime: Part II

Juergen Dingel
Winter 2025

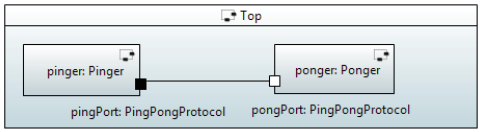
UML-RT w/ RTist: Part II

- Core concepts
  - Structural modeling
  - Behavioural modeling

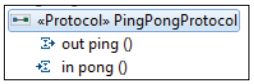
UML-RT: Core Concepts (1)

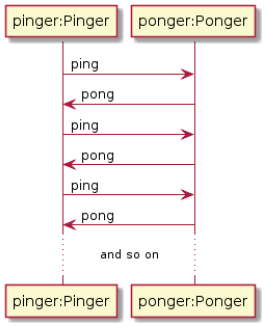
- Types
  - Capsules (active classes)
    - Capsule instances (parts)
  - Passive classes (data classes)
    - Objects
  - Protocols
  - Enumerations
- Structure
  - Attributes
  - Ports
  - Connectors
- Behaviour
  - Messages (events)
  - State machines
- Grouping
  - Package
- Relationship
  - Generalization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

UML-RT: Core Concepts (2)



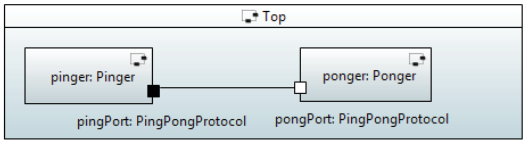
- Model
  - Collection of capsule definitions
  - 'Top' capsule containing collection of capsule instances (parts)
- Capsules
  - May contain
    - Attributes, ports, or other capsule instances (parts)
  - Behaviour defined by state machine
- Ports
  - Typed over protocol defining input and output messages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



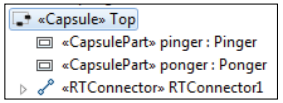


Capsules (1)

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

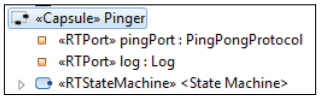


- May also contain
  - Ports over which messages can be sent and received
  - Parts (instances of other capsules) and connectors



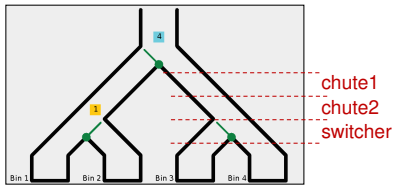
- Creation, use of instances tightly controlled
  - Created by runtime system (RTS)
  - Cannot be passed around
  - Stored in attribute of another capsule (part)
  - Information flow only via messages sent to ports

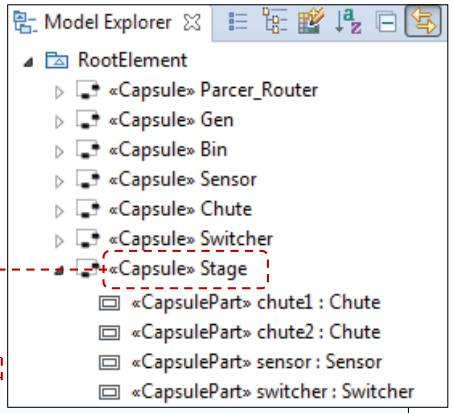
  ⇒ better concurrency control and encapsulation

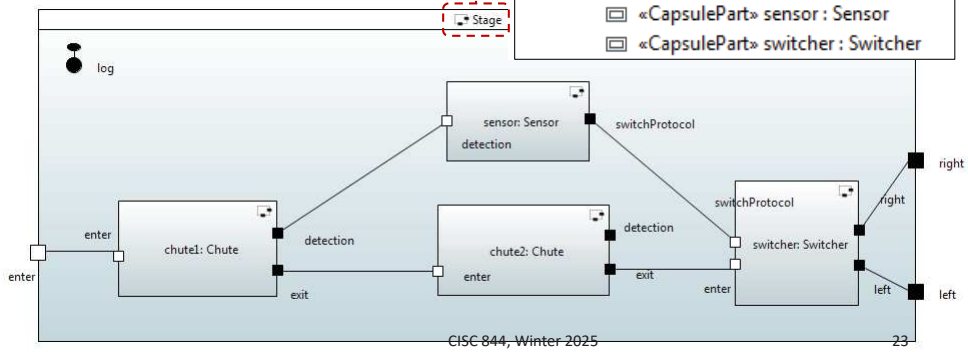


- Behaviour defined by state machine

Example: Capsules and Capsule Parts

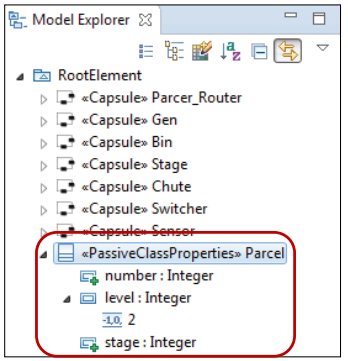






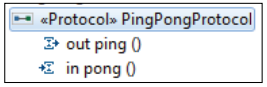
Passive Classes/Data Classes

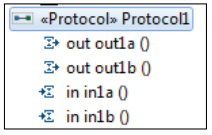
- Similar to regular classes
- Do not have independent flow of control
- Behaviour defined through operations
- Used to define data structures and operations on them

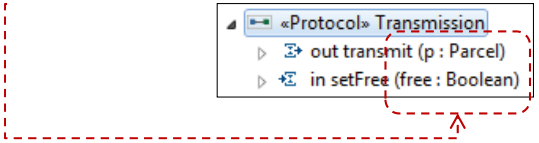


Protocols

- 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





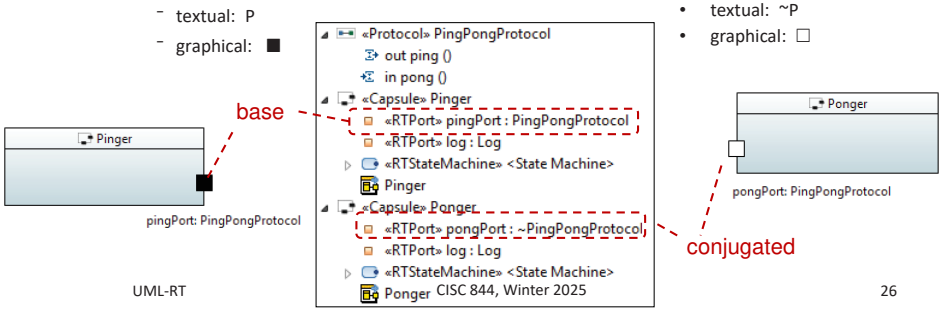


Ports

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

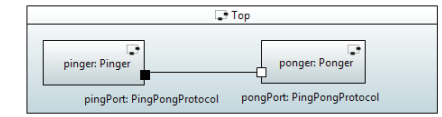
```
portName.msg(arg).send()
```

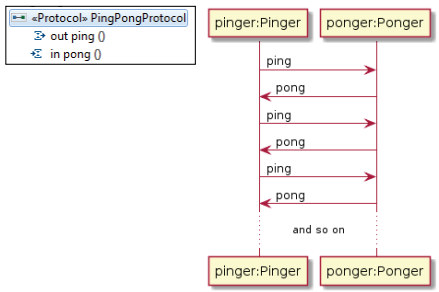
- Can be
  - base (not conjugated)
    - Direction of messages is as declared in protocol
    - Notation:
      - textual: P
      - graphical: ■
  - conjugated
    - Direction of messages declared in protocol is reversed
    - Notation
      - textual: ~P
      - graphical: □

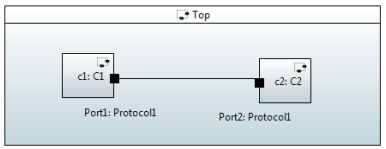


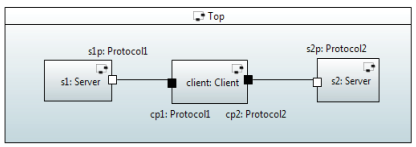
Connectors

- 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



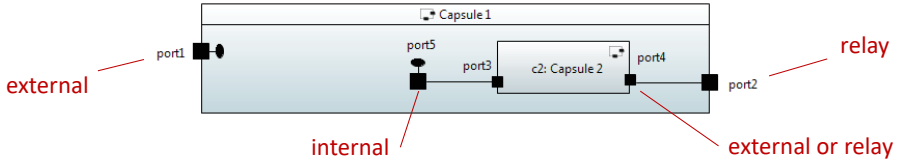




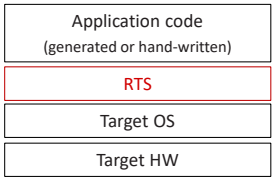


Ports: External, Internal, Relay

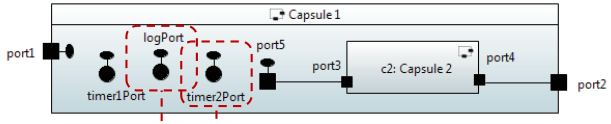
- External behaviour
  - Provides (part of) externally visible functionality (isService=true)
  - Incoming messages passed on to state machine (isBehaviour=true)
  - Must be connected (isWired=true)
- Internal behaviour
  - As above, but not externally visible (isService=false)
  - Connect state machine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



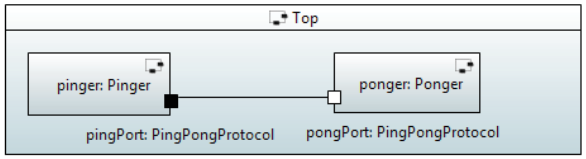
Ports: System

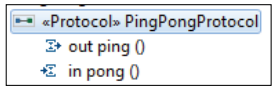


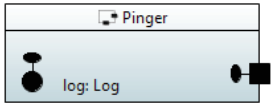
- Connects capsule to Runtime System (RTS) library via corresponding system protocol
- Provides access to RTS services such as
  - Timing: setting timers, time out message
    - `timer2Port.informIn(RTTimespec(10, 2));`
      `// set timer that will expire in 10 secs and 2 nanosecs`
    - When timer expires, '`timeout`' message will be sent over `timer2Port`
  - Log: sending text to console
    - `logPort.log("Ready to self-destruct")`
  - Frame: incarnate, destroy capsule instances



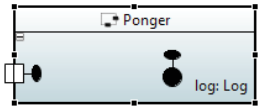
Example: PingPong





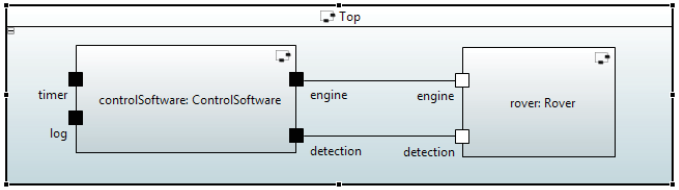


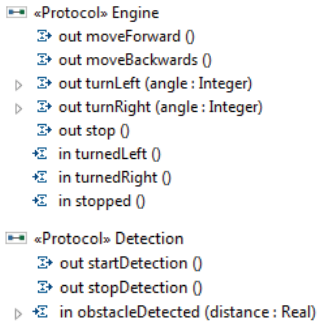
pingPort: PingPongProtocol

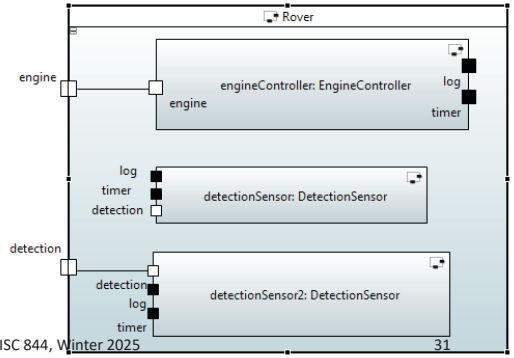


pongPort: PingPongProtocol

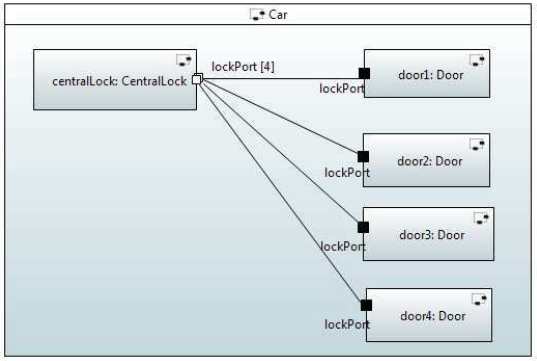
Example: Rover

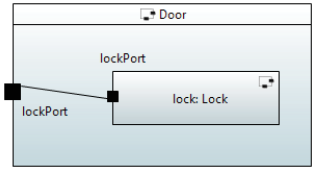




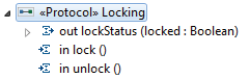


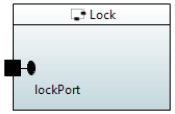
Example: Door Lock System

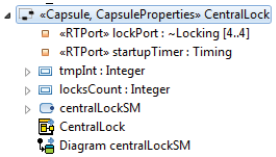




lockPort [4]







UML-RT w/ Model RealTime: Part II

- 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

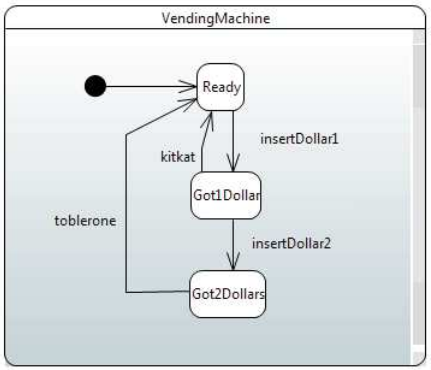
Pseudo states

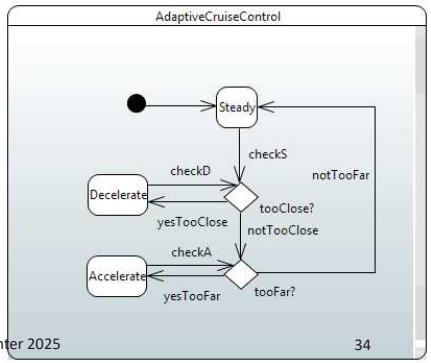
- Don't belong to description of lifetime of object

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

Transitions

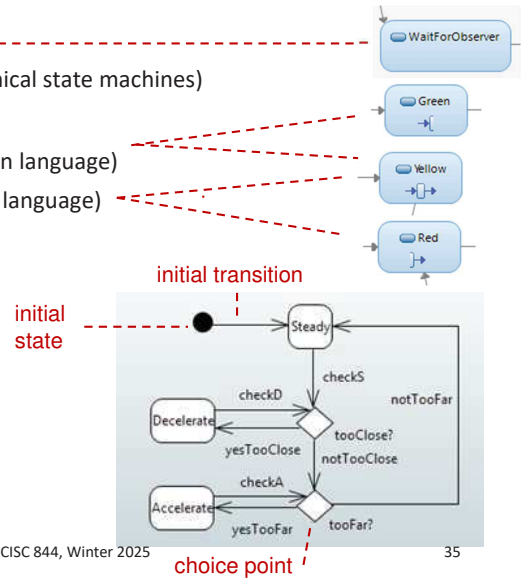
- Describe how object can move from one state to next in response to message input





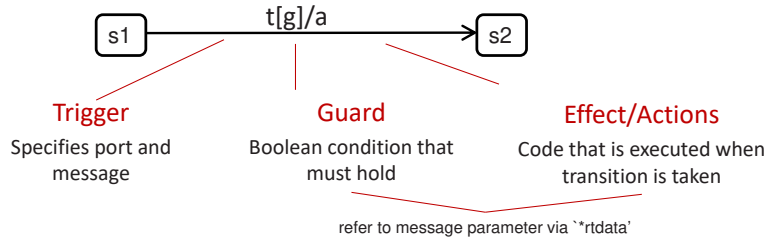
States I: Simple and Pseudo

- States
  - Kinds:
    - Simple
    - Later: composite (in hierarchical state machines)
  - May contain
    - Entry action (written in action language)
    - Exit action (written in action language)
- Pseudo states I
  - initial
  - choice point



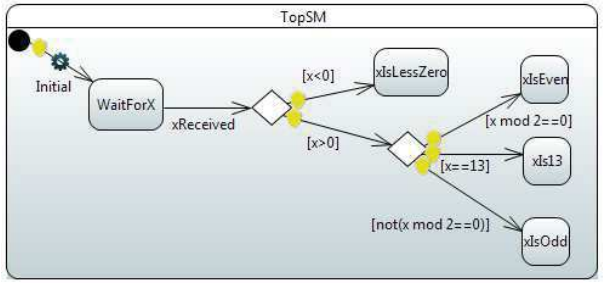
Transitions

- Kinds:
  - Basic
  - Later: 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)
    - Transitions out of initial state should not have guards
  - Effect/Actions (optional, written in action language)

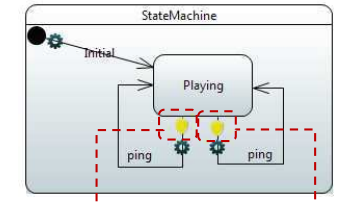


Transitions Into and Out of Pseudo States

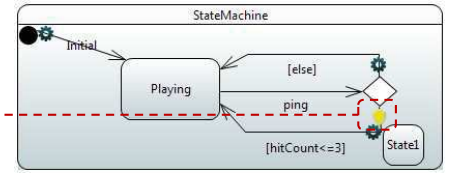
- Initial
  - Incoming transition: impossible
  - Outgoing transition: no guard, no trigger, but can have action code
- Choice point
  - Incoming transitions: can have guard, triggers, action code
  - Outgoing transitions:
    - No trigger, but should have guard
    - Guards should be pairwise disjoint (i.e., non-overlapping)
    - Collection of guards should be exhaustive



Guards on Transitions out of Basic States




```
return (hitCount>4);
```

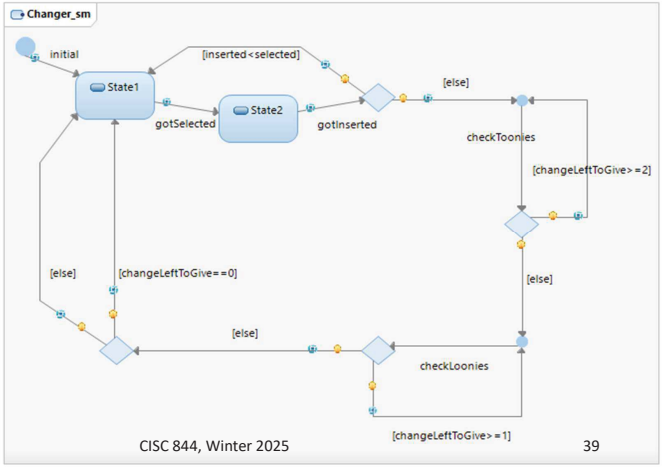



```
return (hitCount<=3);
```

- Better to use choice points
  - Make branching in control flow more explicit

UML-RT: Characteristics 3

- State machines
  - pseudo states (e.g., choice, junction, history) => transition chains
- Transition chains



Action Language

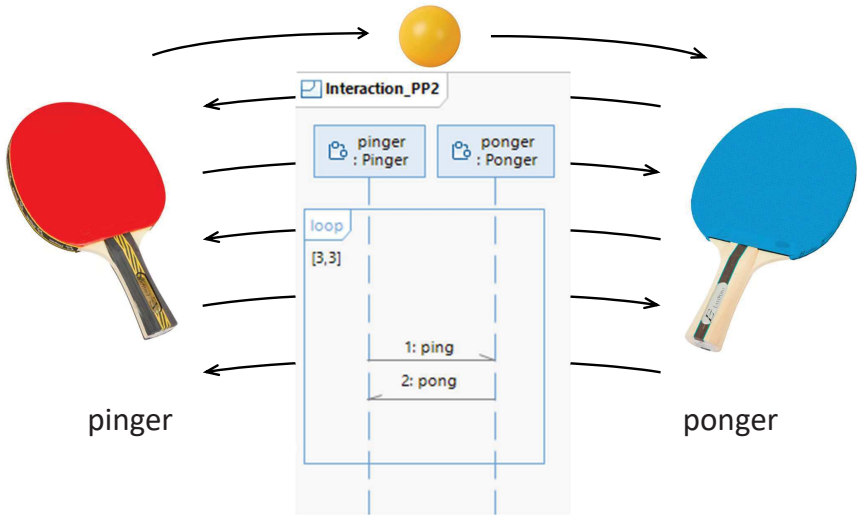
- Language used in
  - guards to express Boolean expressions
  - entry action, exit action, transition effects to read and update attribute values, send messages
- Typically: C/C++, Java

⇒ State machines are a hybrid notation combining
  - graphical notation for state machines and
  - textual notation for source code in actions

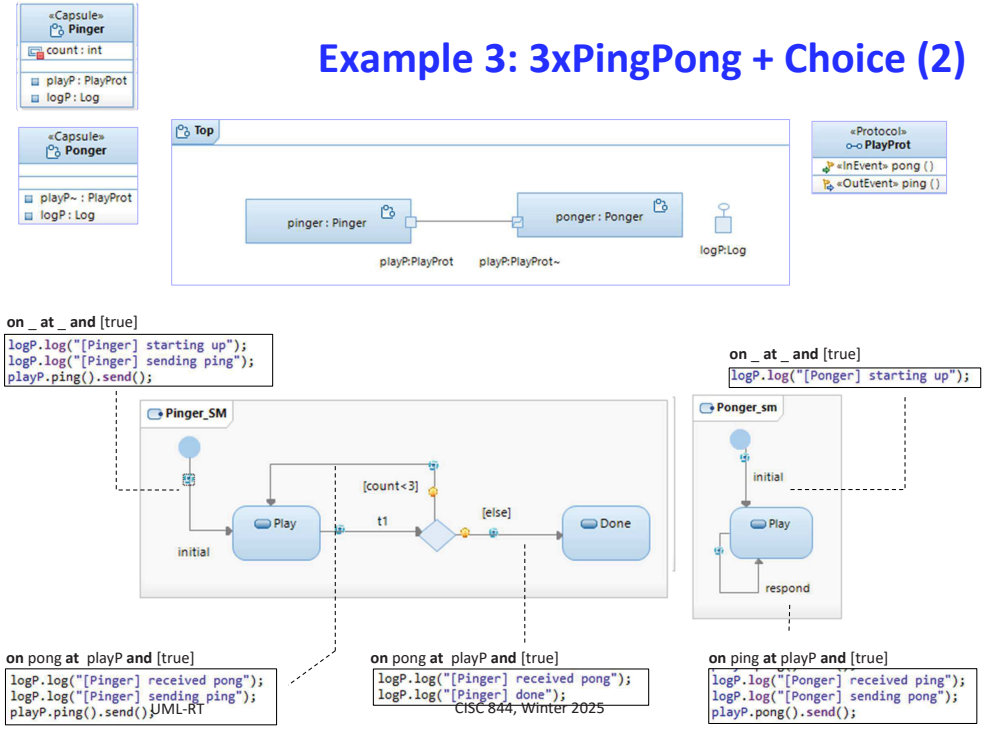
⇒ UML and UML-RT State Machines
  - different from, e.g., Finite Automata
  - closer to 'extended hierarchical communicating state machines' [6]

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

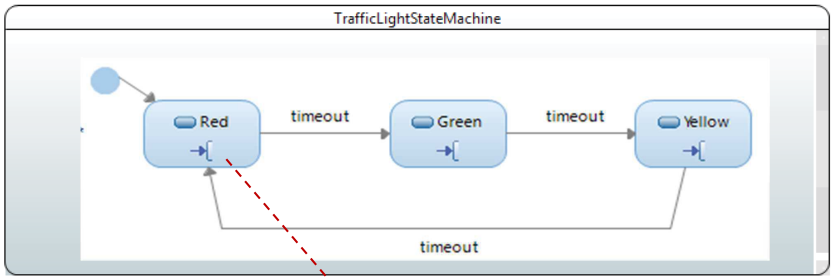
Example 3: 3xPingPong + Choice (1)



Example 3: 3xPingPong + Choice (2)

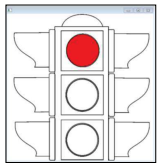


Example: Action Code, Timers, Logging




```
$ ./TopMain.exe
Controller "DefaultController" running.
address: localhost, port: 8080
Switched to red
Switched to green
Switched to yellow
Switched to red
Switched to green
Switched to yellow
Switched to red
```

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



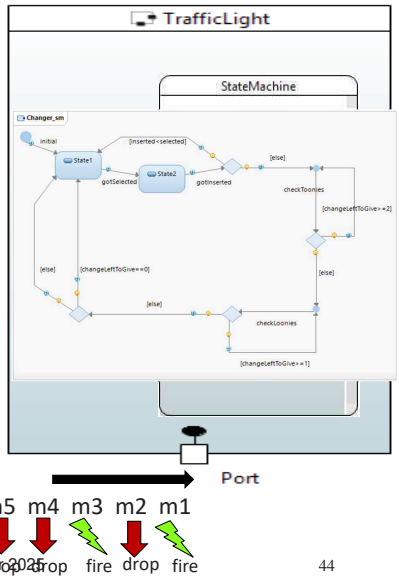
Execution Semantics I

// SM is in stable state, i.e., ready to process messages

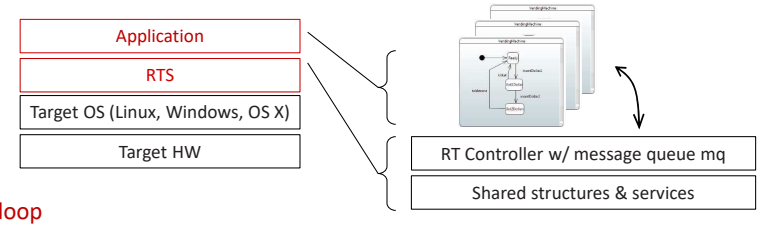
1. Message m has arrived and is delivered to SM
2. If SM has no transition that is enabled, m is 'dropped'
3. If transition t enabled in SM, i.e.,
   1. source state of t is active,
   2. trigger of t matches m, and
   3. guard (if any) of t evaluates to 'true'

   then execute transition chain tc starting at t:
   1. execute exit action of source state of t, if any
   2. execute action code along tc while checking guards if any
   3. execute entry code of target state of tc, if any

// SM is in stable state



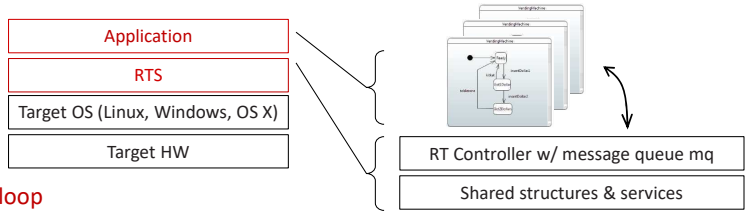
Execution Semantics I (Cont'd)



Controller main loop

```
WHILE (1) {
  <m,sm> = dequeue(mq);
  IF can find transition t in sm such that enabled(m,t,currRTState) THEN
     currRTState = execChain(t,currRTState);
  ELSE
     report 'Unexpected message m';
}

WHERE
  currRTState is …?
```


Execution Semantics I (Cont'd)

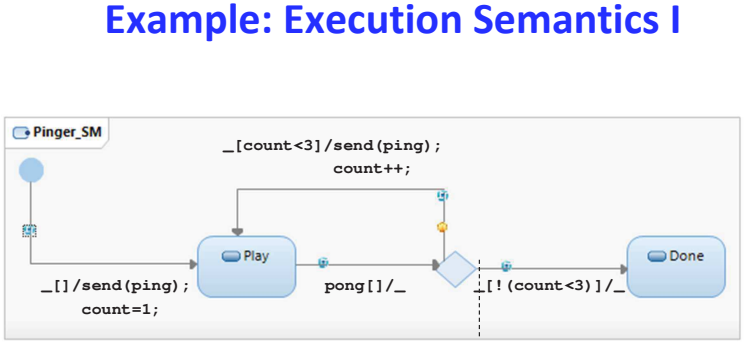


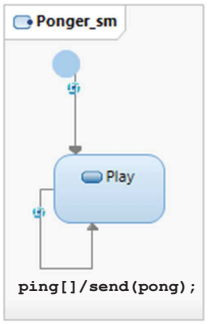
Controller main loop

How to add support for entry/exit actions? For junction/join points?

```
<actStates,vars,mq> := execInits();
WHILE (1) {
  <m,sm> = dequeue(m);
  IF can find transition t in sm such that enabled(m,t,<actStates,vars,mq>) THEN
     <actStates,vars,mq> = execChain(t,<actStates,vars,mq>);
  ELSE
     report 'Unexpected message m';
}
WHERE
enabled(m,t,<actStates,vars,mq>) =
             source(t) in actStates, trigger(t) matches m, and eval(guard(t),vars)='true'
execChain(t,<actStates,vars,mq>) =
             <actStates,vars,mq> := exec(effect(t),<actStates,vars,mq>);
             WHILE target(t) is choice point {
                 find t' such that source(t')=target(t) and eval(guard(t'),vars)='true';
                 <actStates,vars,mq> := exec(effect(t'),<actStates,vars,mq>);
                 t = t';
             }
             RETURN <actStates,vars,mq>;
```


Example: Execution Semantics I





actStates	vars	mq
_,_	count=_	[]
Play,Play	count=1	[ping]
		[pong]
	count=2	[ping]
		[pong]
	count=3	[ping]
		[pong]
Done,Play		[]

pinger, ponger
ponger
pinger

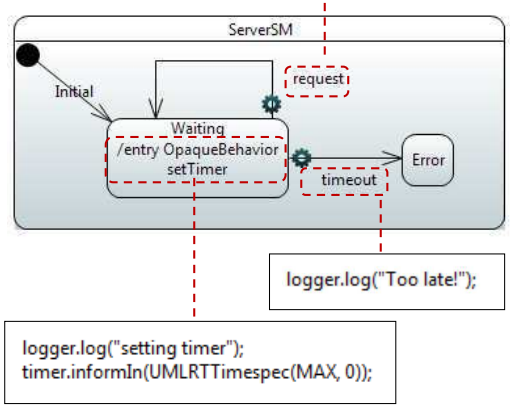
Example: Execution Semantics I (Cont'd)

```
$ ./executable.exe -URTS_DEBUG=quit

RT C++ Target Run Time System - Release 7.0.07

targetRTS: observability listening not enabled
  Task 0 detached
[Pinger] starting up
[Pinger] sending ping 1
                                        [Ponger] starting up
                                        [Ponger] received ping
                                        [Ponger] sending pong
[Pinger] received pong
[Pinger] sending ping 2
                                        [Ponger] received ping
                                        [Ponger] sending pong
[Pinger] received pong
[Pinger] sending ping 3
                                        [Ponger] received ping
                                        [Ponger] sending pong
[Pinger] received pong
[Pinger] done
```

- Things to try
  - In its initial transition, pinger sends 2 'ping' messages

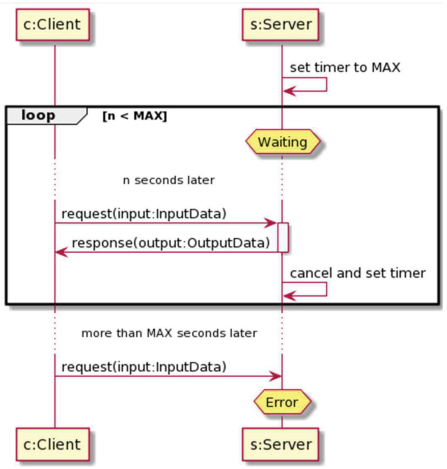
Example: Timers

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




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

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



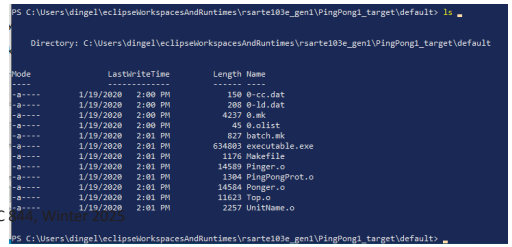
HCL Model RealTime

- Download and installation
  - Queen's version
  - Java 21, 64 bits
- Q&A forums
  - CISC 844 forum on Discourse server

Model RealTime (Cont'd)

- Use
  - (model, generate, build, run)^*
- Generated code
  - `<workspace>/<projectName>_target/`
- RTS
  - `<RTist installation dir>/rsa_rt/C++/TargetRTS/`
- Building generated code
  - executable:
    - `<workspace>/<projectName>_target/default`
- Running generated code
  - from inside RTist
  - from command line

```
>> ./executable.exe -URTS_DEBUG=quit
```



Model RealTime (Cont'd)

- Tips and tricks
  - Common mistakes
    - Forgot: 'send' statement or trigger

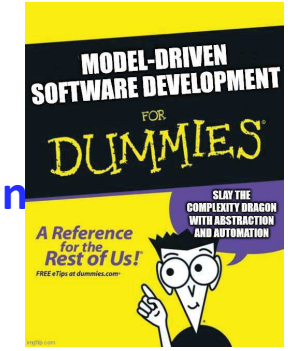
```
logP.log("[Pinger] sending first ping");
pingP.ping();
```

    - Execution results in a 'stackdump'? C++ issue in action code, e.g.,

```
int delay = 500000000;
logP.log("[%s] twiddling for %d nanoseconds", delay, "Pinger");
// wait for 0.5 seconds; 10^9 nsec = 1 sec
timingP.informIn(RTTimespec(0, delay));
```

    - When using 'Code View':
      - don't confuse tabs:
        - for transitions: 'effect' vs 'guard'
        - for states: 'entry' vs 'exit'
      - ensure changes saved properly
- Examples
  - See 'Sample models' page

Beyond Code:
An Introduction to Model-Driven Software Development (CISC 844)



UML-RT and HCL Model RealTime: Part III

Juergen Dingel
Winter 2025

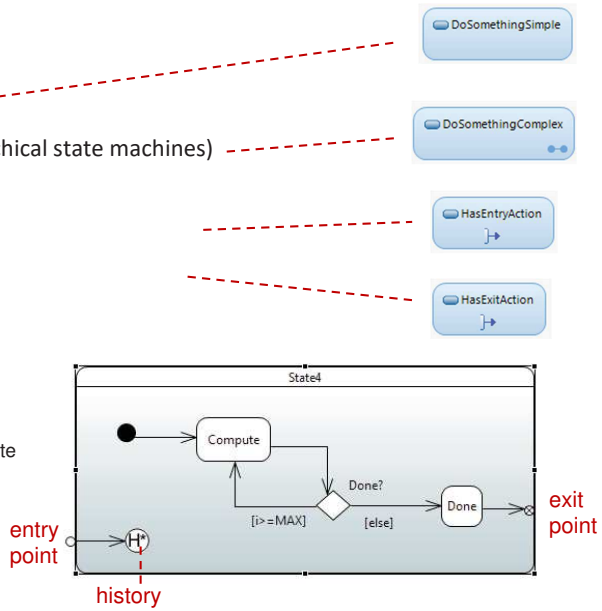
UML-RT w/ HCL Model RealTime : Part III

- More on
  - State machines
    - States
      - Simple
      - Composite
    - Pseudo states
      - Initial
      - Choice point
      - Entry point
      - Exit point
      - History
      - Junction
  - Execution semantics
    - Run-to-completion
- Design guidelines

States II: Composite and Pseudo

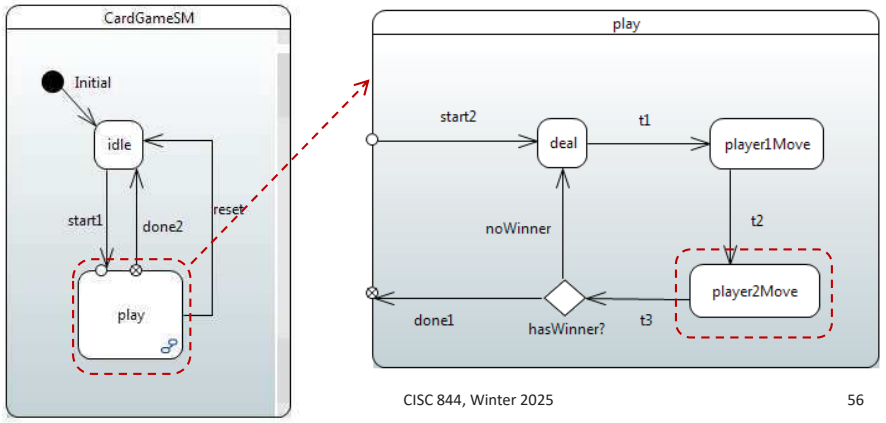
- States
  - Kinds:
    - Simple
    - Composite (in hierarchical state machines)
  - May contain
    - Entry action
    - Exit action
- Pseudo states
  - initial
  - choice point
  - history
  - entry point
  - exit point
  - junction point

in composite states only



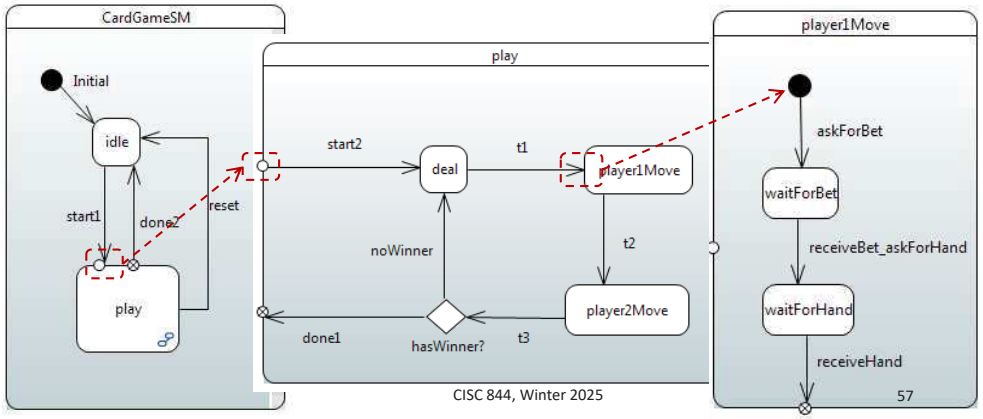
Group Transitions

- 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'>



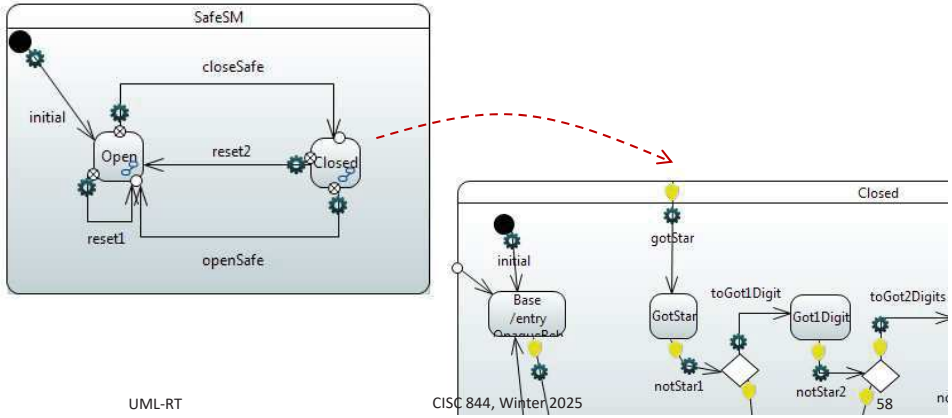
State Configuration

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



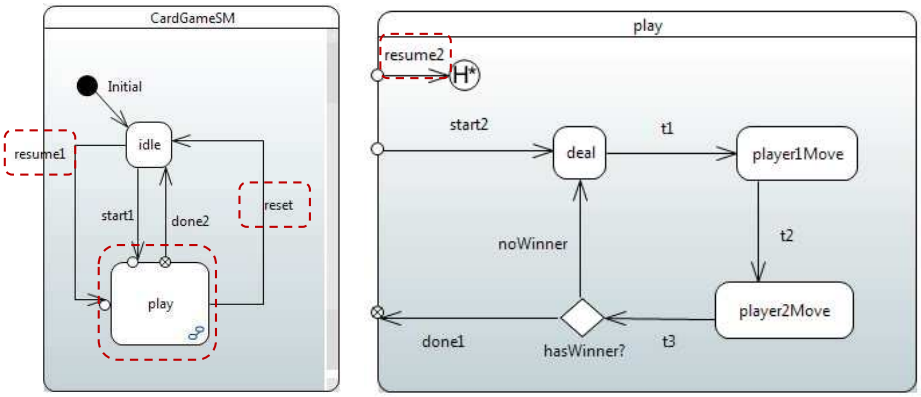
Entry and Exit Points

- Required boundary pseudo states for transitions crossing boundaries of composite states
- Transition ending at entry point w/o outgoing transitions: implicit return to history



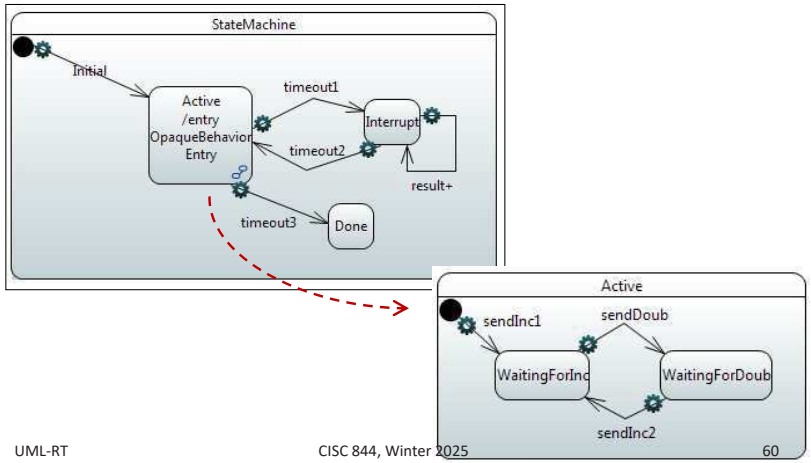
History

- Re-establish full state configuration that was active when containing state was active most recently
- If entering state for first time, go to initial state
- Example: from <'play', s> to <'play', s> with 'reset' 'resume1'

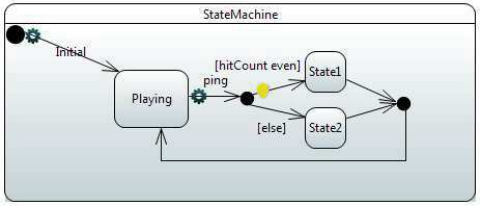


History (Cont'd)

- History pseudo state does not need to be given explicitly
- Transition ends at boundary of composite state: Implicit return to history

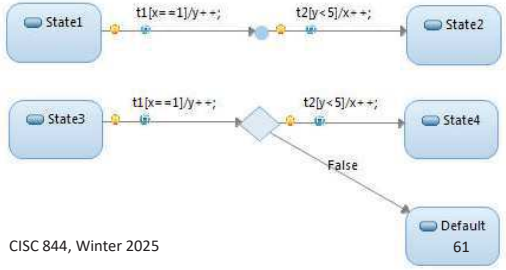


Junction Points



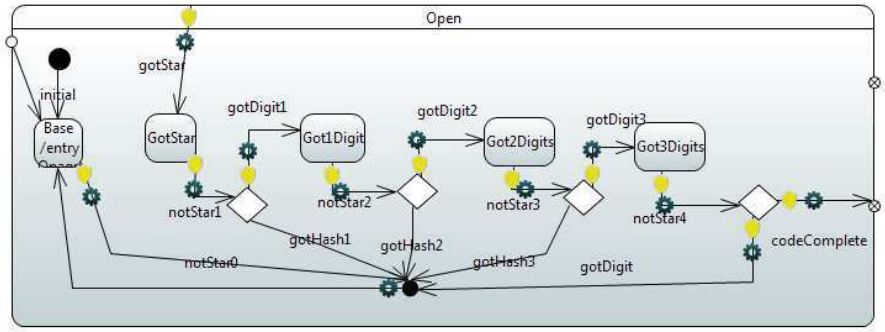
- Can be used to split and merge control flow
- Warning:
  - Static evaluation: All guards on transitions connected by junction points evaluated BEFORE first transition is taken
  - Transitions taken only when fully enabled path exists
- Choice points
  - Dynamic evaluation:

  Guards evaluated as transitions are executed
- Pros/cons?



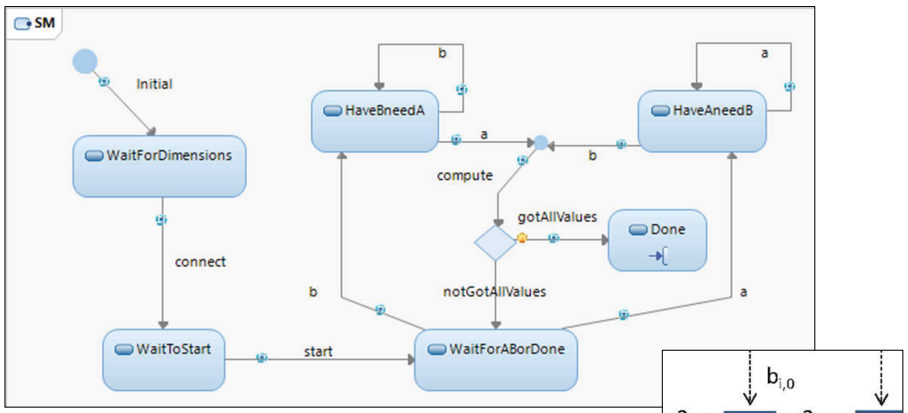
Junction Points (Cont'd)

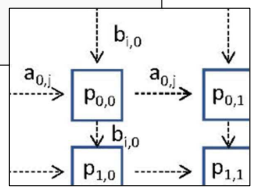
- Merge useful to avoid duplication of action code



Junction Points (Cont'd)

- State machine of processor in matrix multiplication:





Run-to-Completion

- Event processing of state machines follows run-to-completion semantics
- Dispatching of message triggers execution of possibly chain of transitions ('`exec`' 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

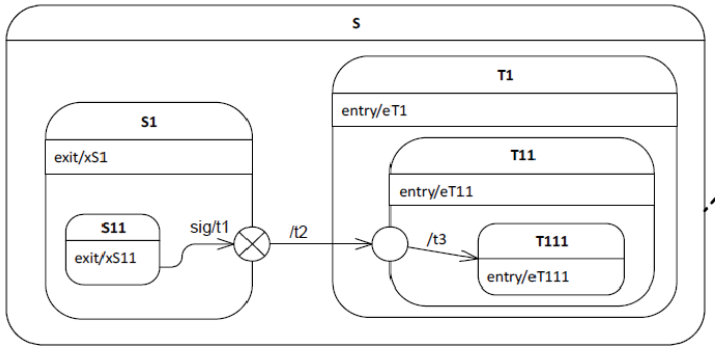
⇒ execution triggered by message treated as one unit

⇒ no 'interleaved' processing of messages

⇒ less potential for bugs (e.g., 'race conditions')

Example

- Assume
  - State configuration: <S,S1,S11>
  - Message 'sig' dispatched to state machine
- What happens?

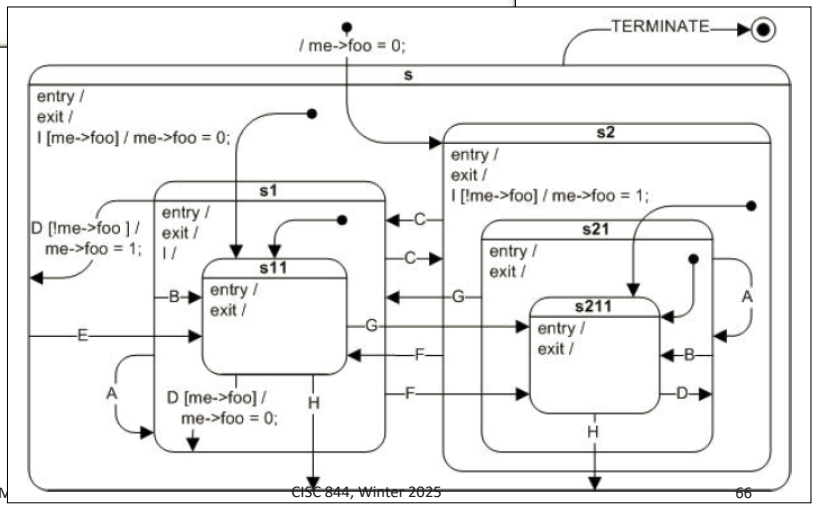


[UML2.5.1] UML Specification v2.5.1. Dec 2017. Page 381
https://www.omg.org/spec/UML/2.5.1/PDF

Example (Cont'd)

```
QHsmTst example, built on Sep 25 2007 at 09:11:31,
QEP/C: 3.4.01.
Press ESC to quit...
top-INIT;s-ENTRY;s2-ENTRY;s2-INIT;s21-ENTRY;s211-ENTRY;
>G: s21-G;s211-EXIT;s21-EXIT;s2-EXIT;s1-ENTRY;s1-INIT;s11-ENTRY;
>I: s1-I;
>A: s1-A;s11-EXIT;s1-EXIT;s1-ENTRY;s1-INIT;s11-ENTRY;
>D: s1-D;s11-EXIT;s1-EXIT;s-INIT;s1-ENTRY;s11-ENTRY;
>D: s11-D;s11-EXIT;s1-INIT;s11-ENTRY;
>C: s1-C;s11-EXIT;s1-EXIT;s2-ENTRY;s2-INIT;s21-ENTRY;s211-ENTRY;
>E: s-E;s211-EXIT;s21-EXIT;s2-EXIT;s1-ENTRY;s11-ENTRY;
>E: s-E;s11-EXIT;s1-EXIT;s1-ENTRY;s11-ENTRY;
>G: s11-G;s11-EXIT;s1-EXIT;s2-ENTRY;s21-ENTRY;s211-ENTRY;
>I: s2-I;
>I: s-I;
>+: Bye, Bye!
```

[Sam09] M. Samek.
A Crash Course in UML State Machines.
Article based on Chapter 2 of the book
Practical UML Statecharts in C/C++
2nd Edition.
March 2009.



Execution Semantics II

Controller main loop

```
WHILE (1) {
  m = dequeue(mq);
  IF can find transition t such that enabled(ssc,m,t) THEN rts = exec(ssc,t);
  ELSE report 'Unexpected message m';
}
WHERE
enabled(<ssc,vars>,m,t) = (1) source(t) is active in ssc, (2) trigger(t) matches m,
                  (3) eval(guard(t),vars)='true', and
                  (4) source(t) does not contain any other state satisfying (1),(2),(3)
exec(<ssc,vars>,t) =
                LET ssc=<s1, …, si-1, si, si+1, …, sn> where si=source(t) IN
                FOR j=n to i+1 {execute exit of sj};
                <targetOfChain,vars> = execChain(t,vars);
                sk = leastCommonAncestor(source(t), targetOfChain);
                LET <sk, s'1, …, s'm> be containment hierarchy where s'm=targetOfChain IN
                  RETURN <<s1, …, sk-1, sk, s'1, …, s'm>,vars>
execChain(t,vars) =
              execute exit of source(t), if any;
              execute effect of t, if any;
              execute entry of target(t), if any;
              WHILE target(t) is pseudo state {
                 find t' such that source(t')=target(t) and eval(guard(t'))='true';
                 execute exit of state(source(t')), if any;
                 execute effect of t', if any;
                 execute entry of state(target(t')), if any;
                 t = t';
              RETURN <target(t),vars>;    }
```

UML2.5.1 Spec, Section 14.2.3
http://www.omg.org/spec/UML/2.5.1/PDF

UML-RT: Design Guidelines

- General
  - Names
    - Descriptive, correct (syntactically and semantically), consistent
  - Readable, clear layout of models
  - Remove/cancel what is not needed anymore (timers, capsule parts)
  - Avoid duplication (through, e.g., operations, junction points for merging, entry and exit code)
- Capsules
  - Low coupling, high cohesion (look at connectors, message traffic, protocols)
  - Avoid overly deeply nested capsule definitions
- State machines
  - Avoid unreachable states and transitions
  - Avoid overly deeply nested composite states
  - Avoid composite states with only one substate

UML-RT: Design Guidelines (Cont'd)

- Action code
  - Short, simple, terminating, readable, reachable (i.e., not dead)
  - Avoid 'hidden' states (e.g., flags and complex control flow)
- Junction points
  - Only use for merging
- Transitions
  - Guards: short, simple, readable, side-effect-free
  - Out of choice points: at least two, guards exhaustive and exclusive, no trigger
  - Out of initial, entry, exit, junction: no guard, no trigger
  - Out of non-pseudo state: no guards
  - Use different kinds (external, local, internal) appropriately
  - Avoid dropped, 'unexpected' messages
  - Make copy of complex message parameters upon receipt
  - Can't cross 'state boundaries' w/o going through an entry or exit point

UML-RT: Design Guidelines (Cont'd)

- Correct use of constructs and services offered by UML-RT, RTS or C++
  - Random number generator
    - Initialize once at startup (e.g., using `srand(time(0))`)
  - Replication
- Observability
  - Insert informative log statements at suitable places to facilitate reasoning about the model (debugging, error localization)

    Format:

    `logP.log("[Name of capsule part](Name of state)…(Name of substate) info")`

    where 'info' describes
    - message and/or data received, or
    - attribute values
  - Consider use of command-line parameters to facilitate testing