Real time system modeling with UML: *current status and some prospects*

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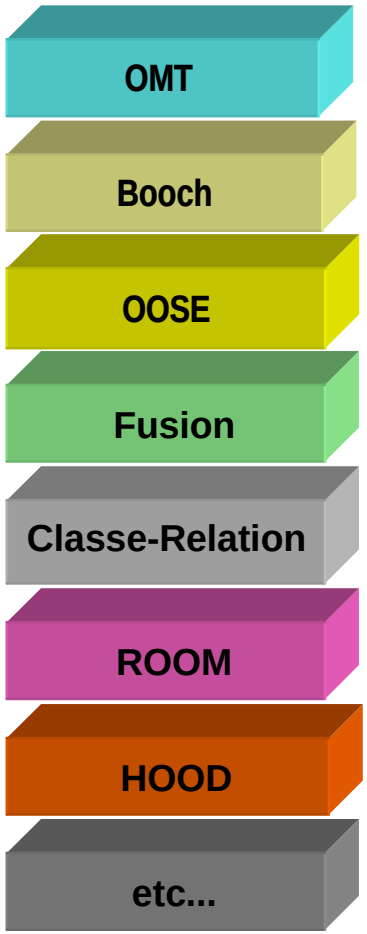
Embedded systems soon > 50 % of market

- ✓ **With more and more importance of software**
- ☞ How to master…

Use of a « universal » modeling standard

☞ **We must go from artisanal practices to industrial production solutions**



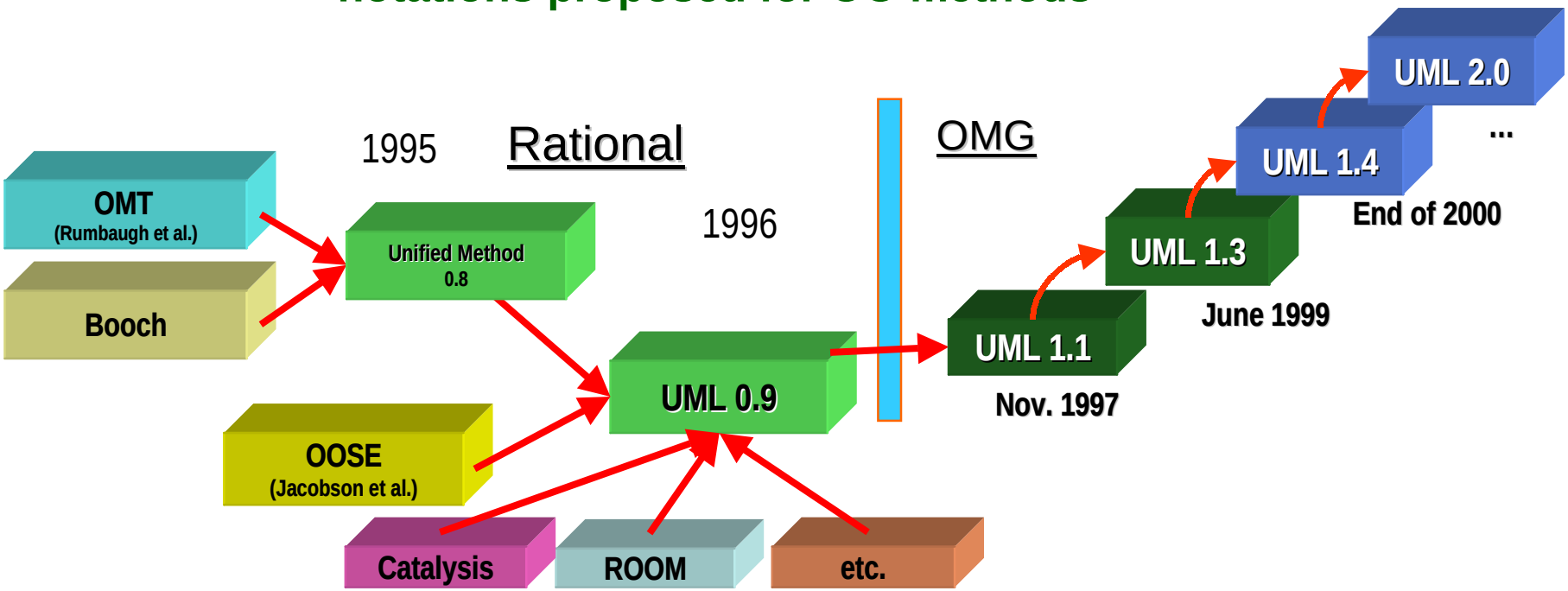
Fin 1990

- high level modeling and component based development
- Idea integration of complementary/concurrent modeling notations proposed for OO methods

Use of a « universal » modeling standard

☞ **We must go from artisanal practices to industrial production solutions**

- ❖ **high level modeling and component based development**
- ❖ **Idea integration of complementary/concurrent modeling notations proposed for OO methods**



But what about real-time systems ?

- **Importance of dynamic in such system requires the specialization of the modeling language**

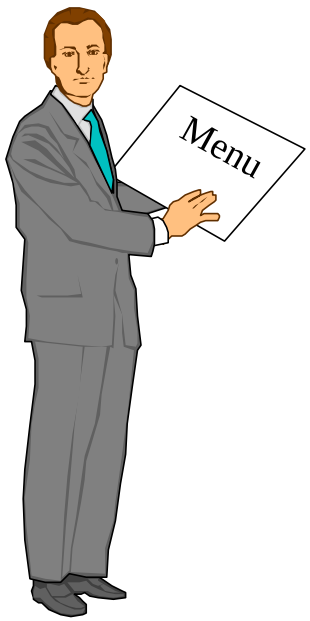
- **Solutions have been developed to integrate current practices into the UML OO framework:**

  - ✓ **More or less advanced levels of integration of real time and object paradigms**

- **Variability of the practices of real time domain depending on the context:** ***small embedded system or installation control and command, production automaton, distributed systems, safety critical systems, telecom, high performance computing…***

  - ❖ *Low level of automatic integration of the « good practices »*

Plan of the presentation

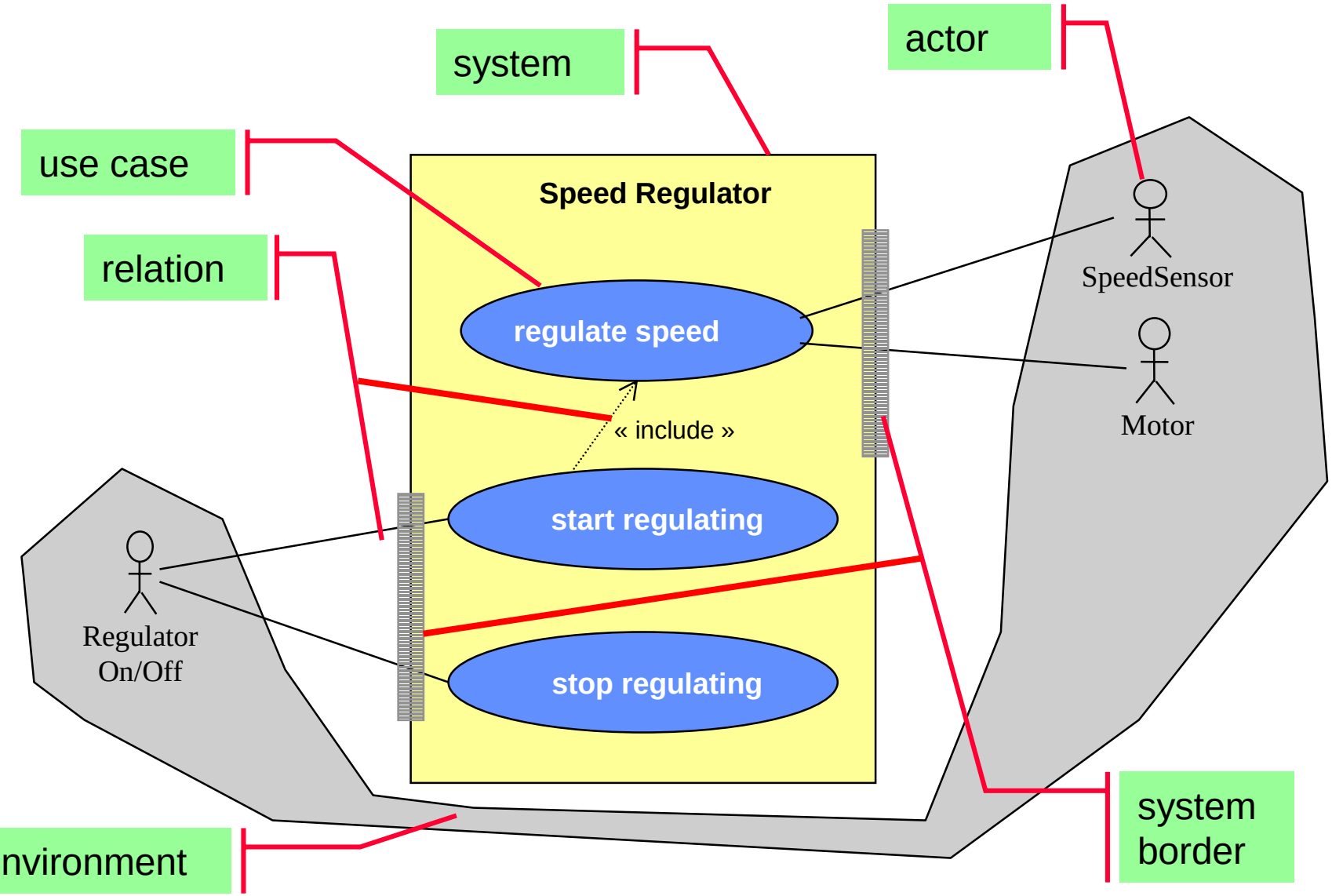


- Current status of UML 1.3
- ARTiSAN proposal
- RT-UML / Rhapsody tool
- UML/SDL tools association
- UML-RT / ROSE-RT tool
- Toward a stronger paradigm integration
- Some open points

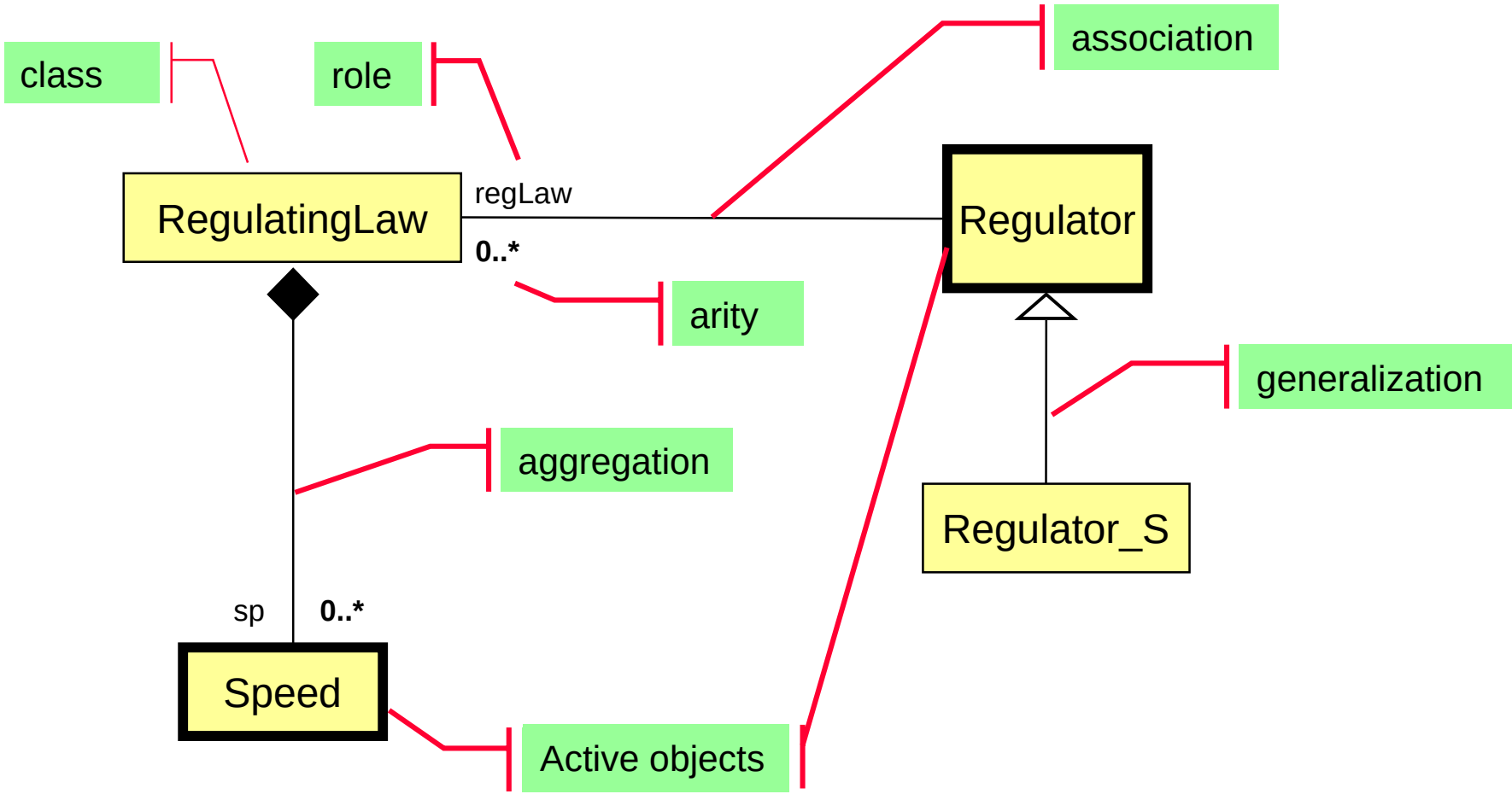
UML 1.3: essential models

- Use case diagram
  - Requirement modeling
- Class diagrams
  - Static structure
- Activity, sequence or collaboration diagrams
  - Interaction
- State machine diagrams
  - Behavior view
- Component, deployement diagram
  - Structure of material implantation

Use case diagram

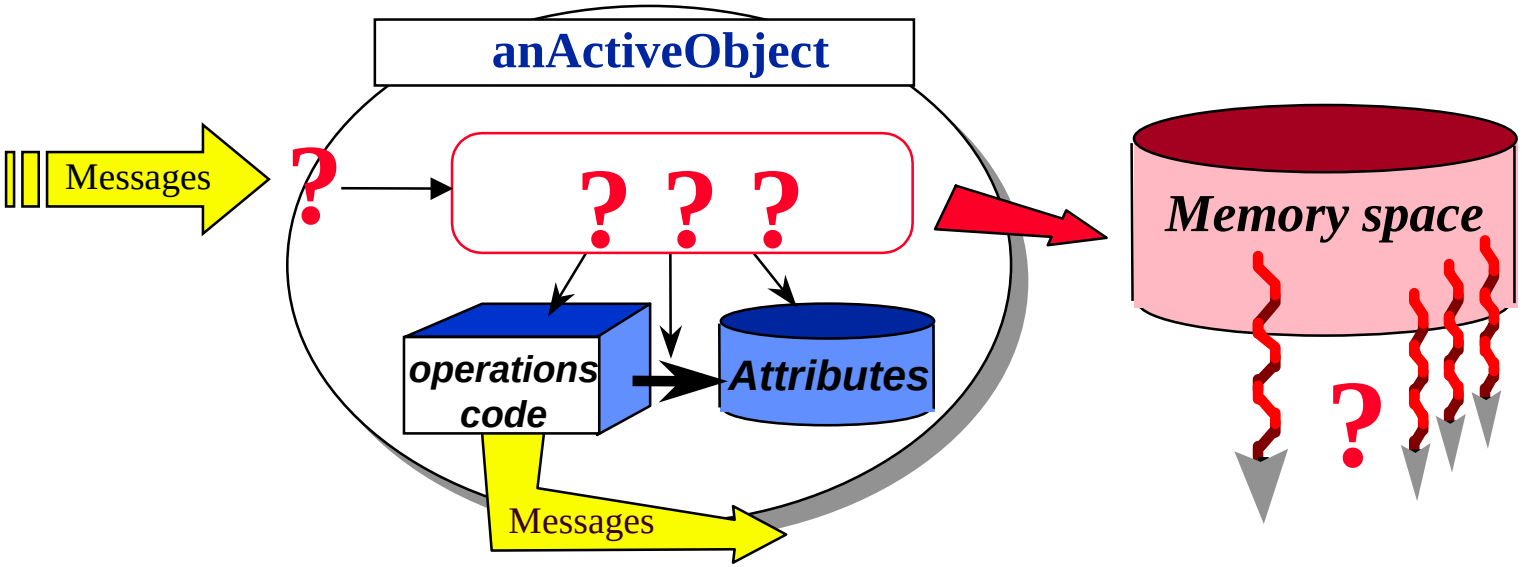


Class diagram



The UML concept of active object

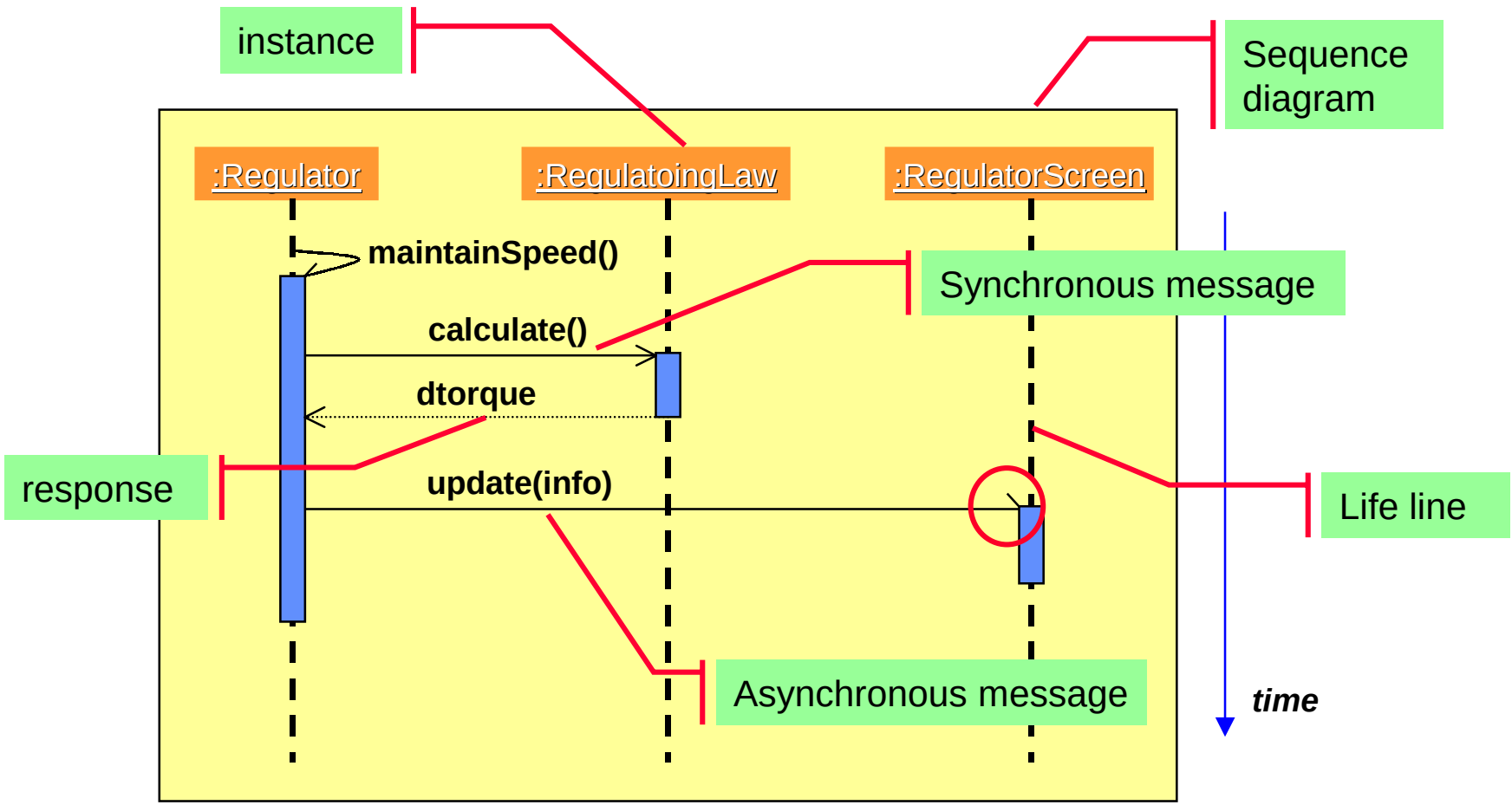
- They are objects having an *(only ?)* independent processing resource (« thread », « process » or other)



- Behavior not well defined: *connection between messages processing and use of the processing resource are not defined*

are they just an Object Oriented view of « tasks » ?

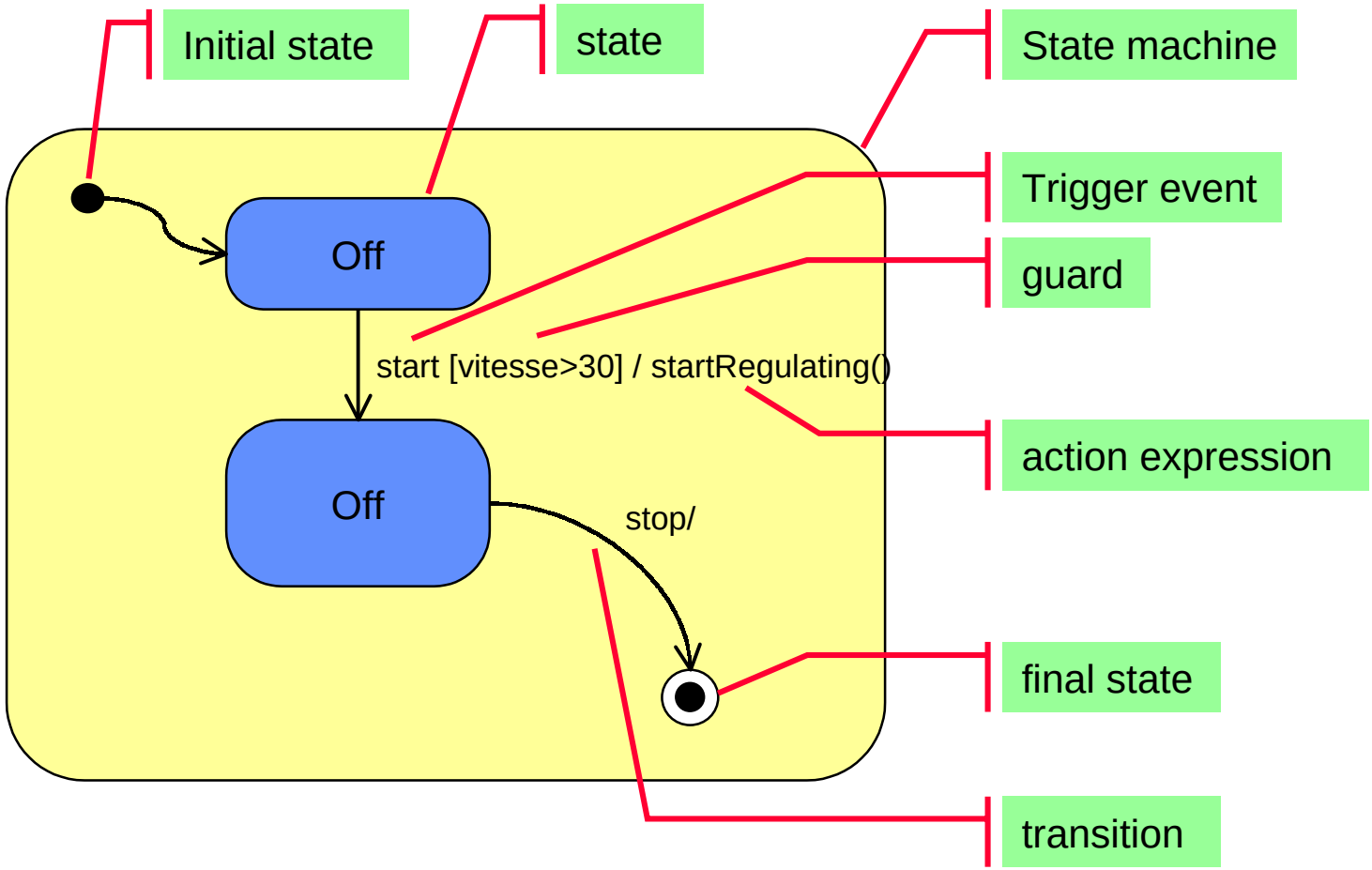
Sequence diagram



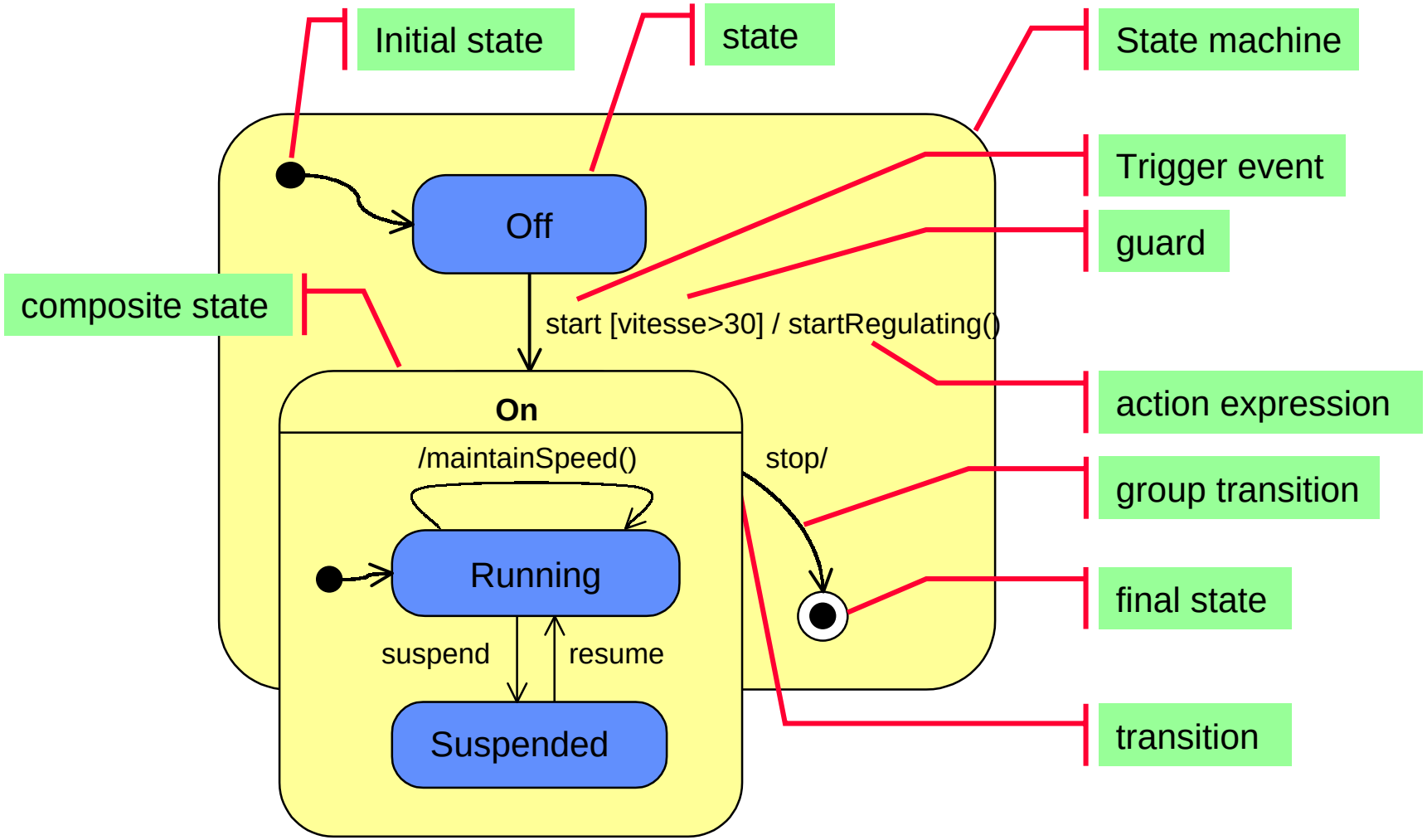
UML communication mechanisms

- Communication: only by message passing
  - A message = an action + an event
    - Point to point communication, possibility to have a set of targets
- Two types of messages
  - Operation call (CallAction + CallEvent)
    - Synchronous/asynchronous, input and output parameters
  - Signal sending (SendAction + SignalEvent)
    - Asynchronous communication, input parameters only
- No specific communication mechanisms for the active objects…

State machine diagram



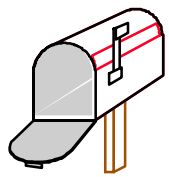
State machine diagram



UML state machines

- Each object can have a state machine (or even several)
  - Transitions can have four triggering types of events (or none):
    - Object operation call: "CallEvent"
    - Signal receipt: "SignalEvent"
    - Condition becoming true: "ChangeEvent"
    - Date occurrence: "TimeEvent"

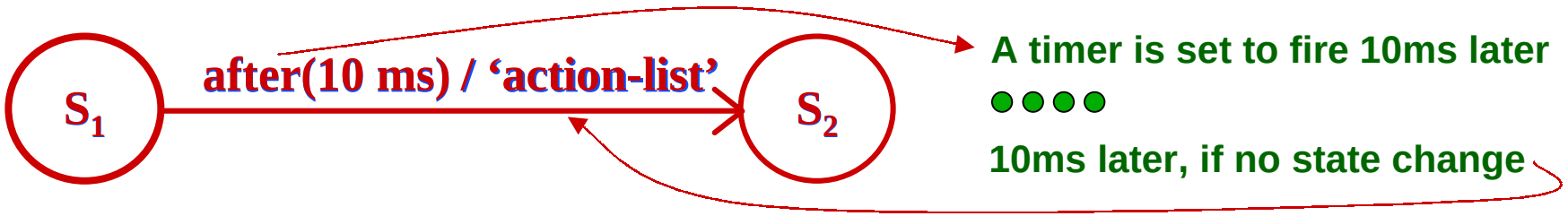
} *messages*



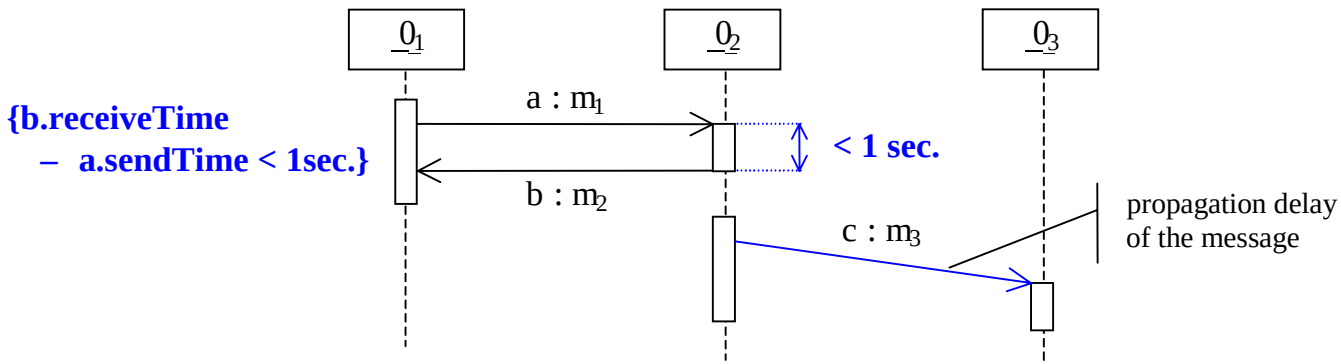
- A state machine has a queue to store incoming events
  - Storing mechanisms and its extraction protocol has to be defined (implemented) by developers
- Current event processing has to be completed before handling of next incoming event
  - Run To Completion (RTC) assumption
  - No distinction between internal and external events

UML 1.3 timing specifications

- Time can be expressed through two notations:
  - Timer setting on transitions of state machines (TimeEvent)

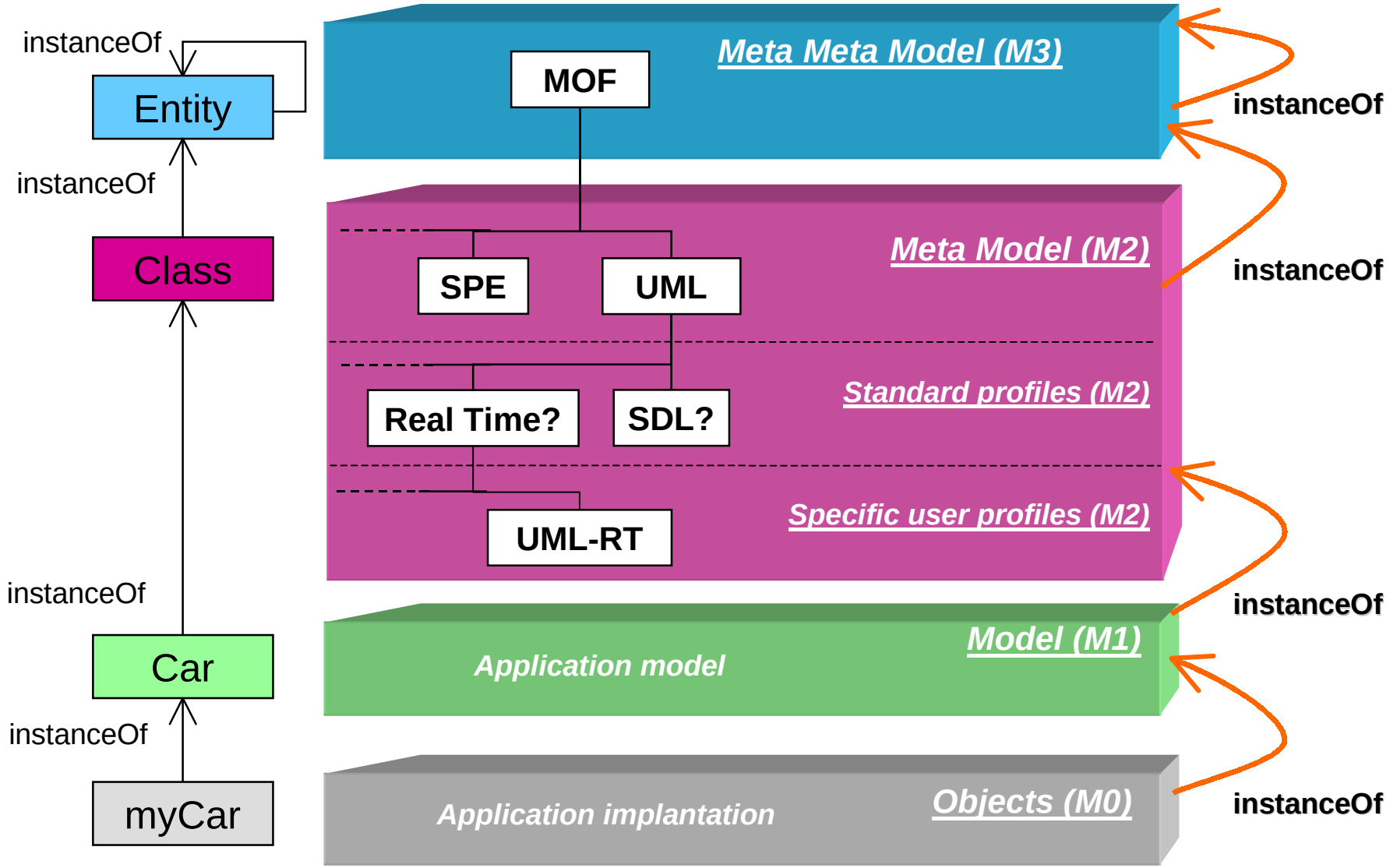


    - Specification is performed through implementation mechanisms
  - Dates definition in sequence diagrams



    - No relation is defined between these specifications neither with the rest of the model nor with the system scheduling policy

UML meta-model: four levels of instanciation



UML 1.3: specialization mechanisms

☞ Tagged value

✓ Properties added to a meta-class

- E.g., {documentation = “ … ” } on Element

☞ Constraint

✓ Addition of « Well-Formed ness Rules »

- E.g., {destroyed}, {new} or {transient} on Instance

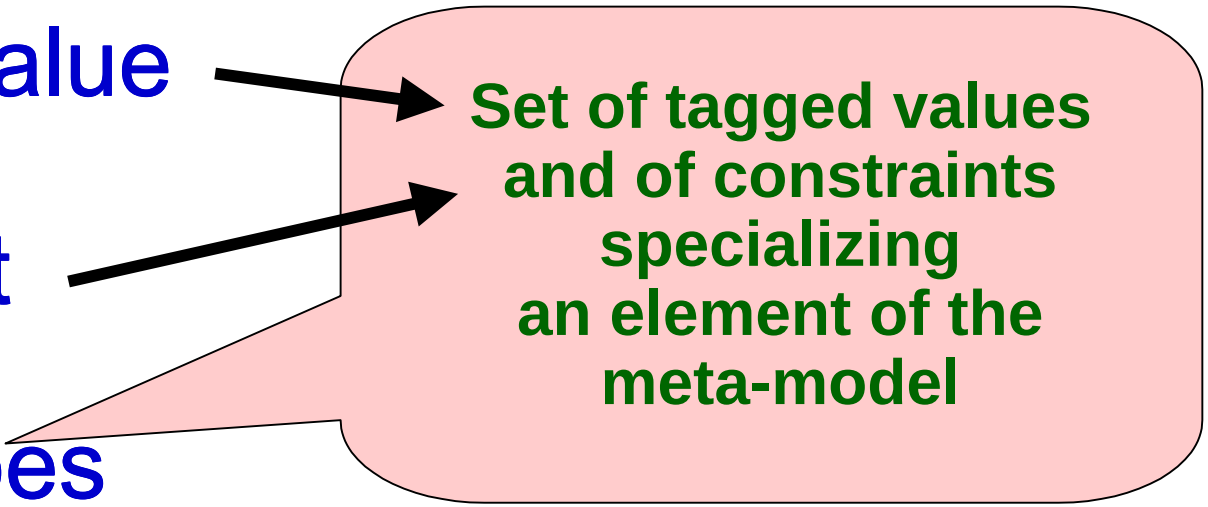
☞ Stereotypes

✓ Indirect add of elements to the meta-model

- E.g., « thread » or « process » on Classifier

UML 1.3: specialization mechanisms

- Tagged value
- Constraint
- Stereotypes



Organisation needs

⇨ notion of Profile in UML 1.3

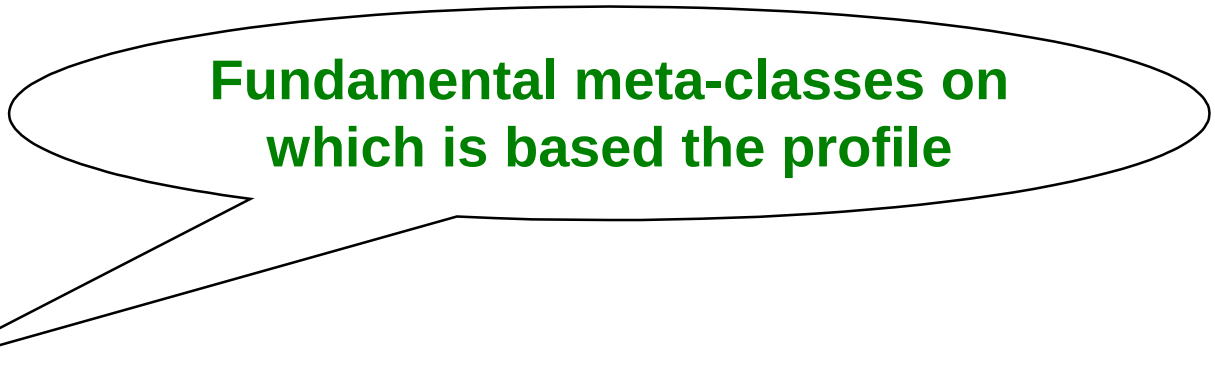
UML profile definition

☞ Objective

Specialization of a standard meta-model (e.g., UML) into a specific meta-model dedicated to a given application domain.

UML profile definition

☞ A profile can contain:



- ✓ **Selected elements of the reference meta-model**

UML profile definition

☞ A profile can contain:

- ✓ **Selected elements of the reference meta-model**
- ✓ **Extension mechanisms**

Stereotypes, tagged values, constraints added to the profile

UML profile definition

☞ A profile can contain:

- ✓ **Selected elements of the reference meta-model**
- ✓ **Extension mechanisms**

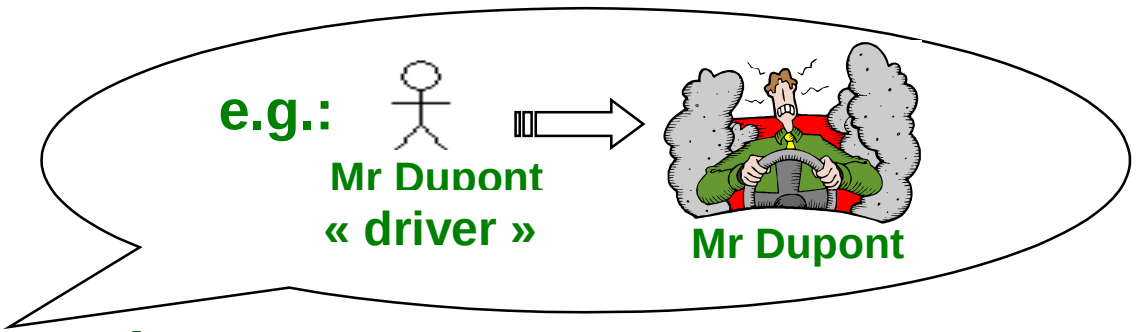
Clarification of
« Semantics Variation Points »
or UML ambiguities

- ✓ **Descriptions of the profile semantics**

UML profile definition

☞ A profile can contain:

- ✓ **Selected elements of the reference meta-model**
- ✓ **Extension mechanisms**
- ✓ **Descriptions of the profile semantics**

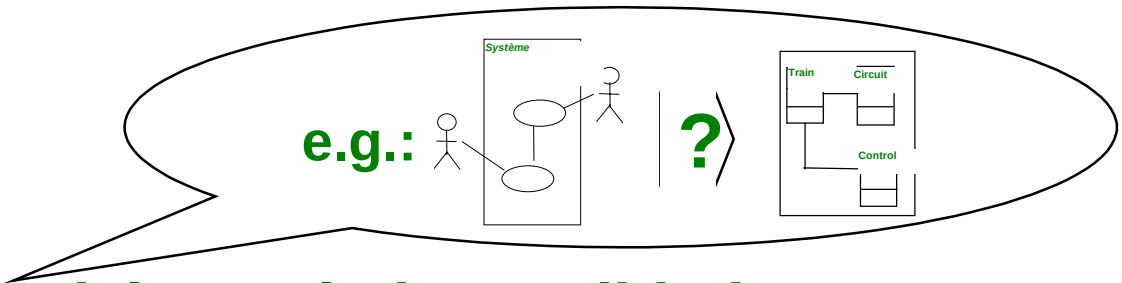


- ✓ **Additional notations**

UML profile definition

☞ A profile can contain:

- ✓ **Selected elements of the reference meta-model**
- ✓ **Extension mechanisms**
- ✓ **Descriptions of the profile semantics**
- ✓ **Additional notations**



- ✓ **Rules for model translation, validation, presentation**

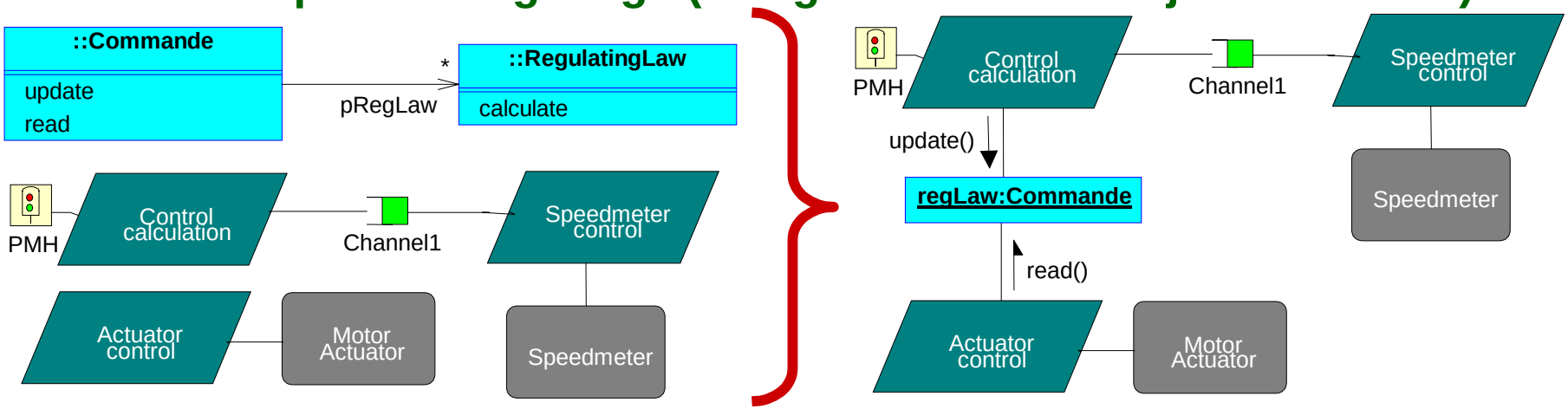
UML 1.3: lacks, ongoing works at the OMG

☞ Three points concerning real-time:

- Proposal of an « Action language semantics »
  - Must integrate proposals from all the submitters (« SDL » domain consortium, Rational and other tool vendors)
  - Standard only on semantics not on notations…
  - Several times postponed…
- Proposal of a real-time profile on
  - Time semantics, scheduling and real-time concepts at implementation level → a UML virtual machine…
- Works are also in progress on Profile formalization, and on pattern description and use…

ARTiSAN: two orthogonal models, weak integration

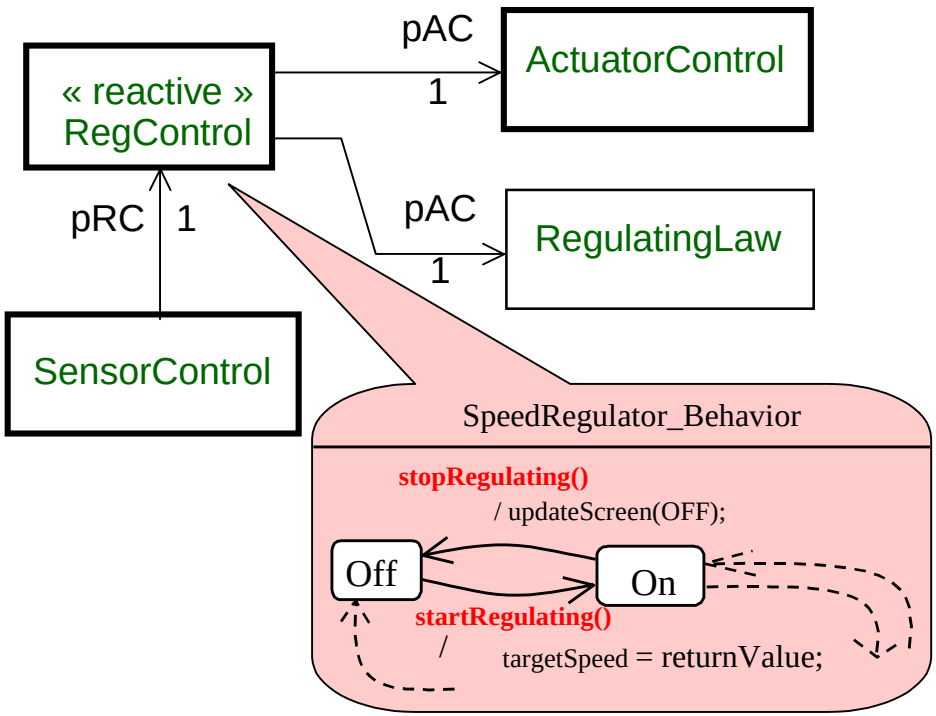
- This tool aims to offer in the same environment:
  - A classical UML modeling facilities
  - A classical task model called the concurrent model
  - An implementing stage (assignment of the objects to tasks)



- Task model has to be manually implemented
- Relation between task and object model is weak
- Timing constraints must be translated on the implementation
  - Communication between object of different tasks must be implemented by the user with low level concepts

RT-UML: two « orthogonal » but « integrated » models

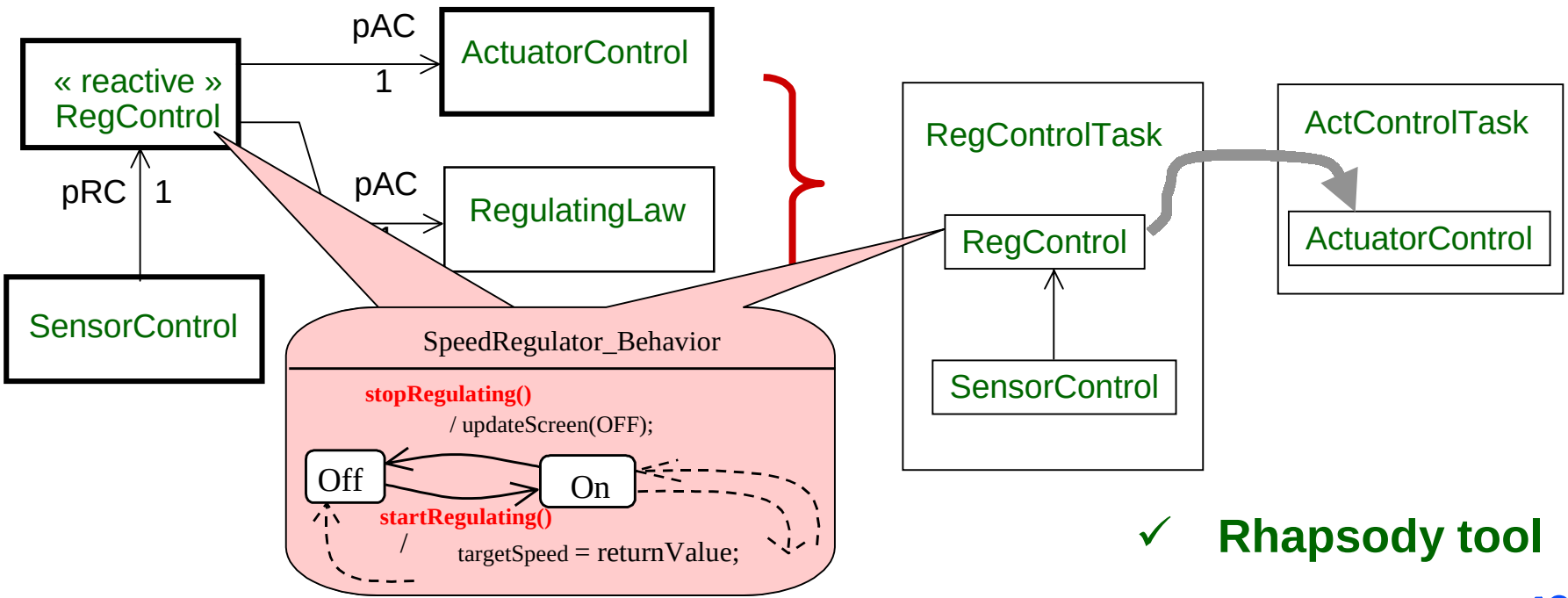
- Tasks are identified by declaration of active objects
  - Behavior specified by state machine of reactive objects



- ✓ **Rhapsody tool**

RT-UML: two « orthogonal » but « integrated » models

- Tasks are identified by declaration of active objects
  - Behavior specified by state machine of reactive objects
  - Reactive objects are assigned to active objects…
  - Communication by message between reactive objects



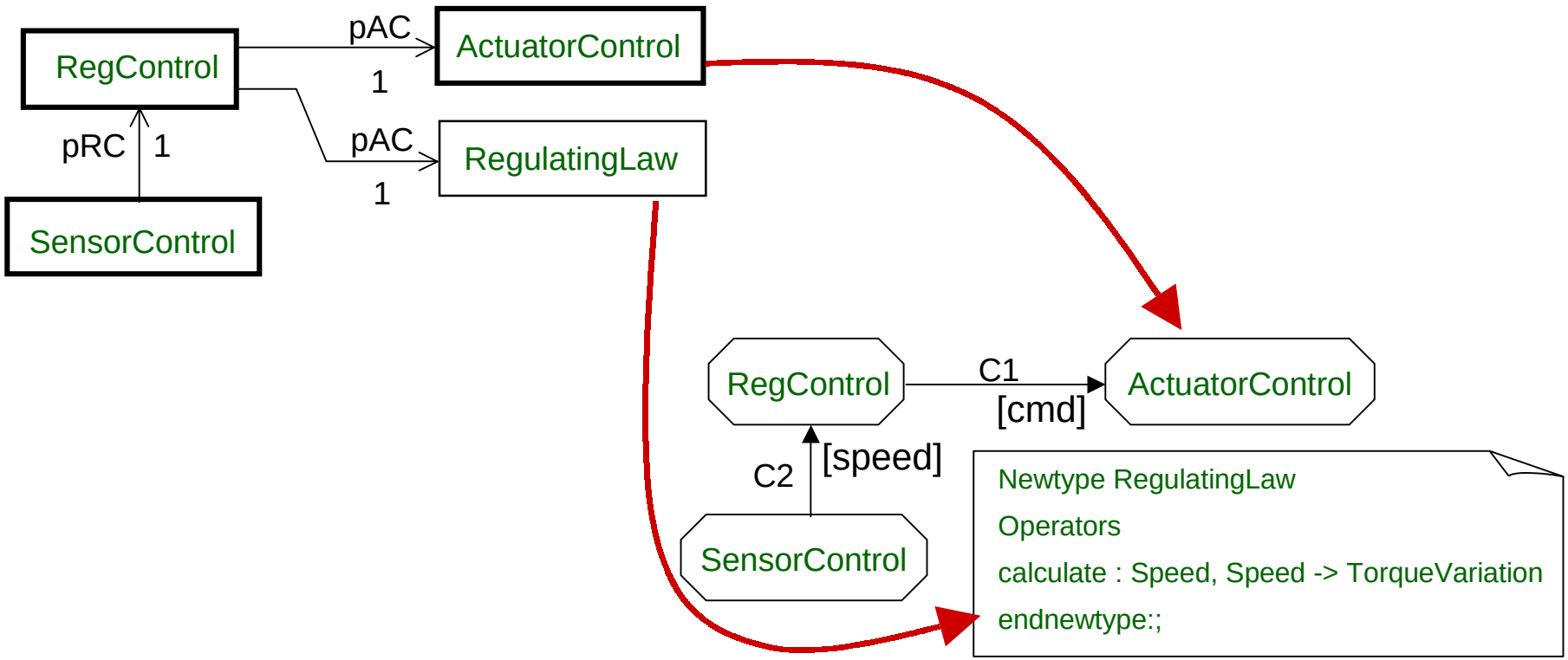
✓ **Rhapsody tool**

RT-UML: non homogenous features

- Different processing semantic between signals and operation calls
  - Signals: parallel execution in thread of receiver object
  - Operation calls: execution in thread of sender object
    - Under control of the object state machine « triggered op. call »
    - Without control of the object state machine…
  - Concurrency is only managed through RTC assumption
  - Return value of operation call can be defined… under responsibility of the caller
- Priorities can be assigned to the active objects
  → Not on the event themselves…
- Timing constraints must be implemented

UML/SDL: association of UML analysis and SDL design

- UML modeling is used at the first modeling stage
  - Use cases, sequence and class diagrams are defined
  - Active object declarations → SDL processes
  - Passive objects → Abstract Data Types of SDL



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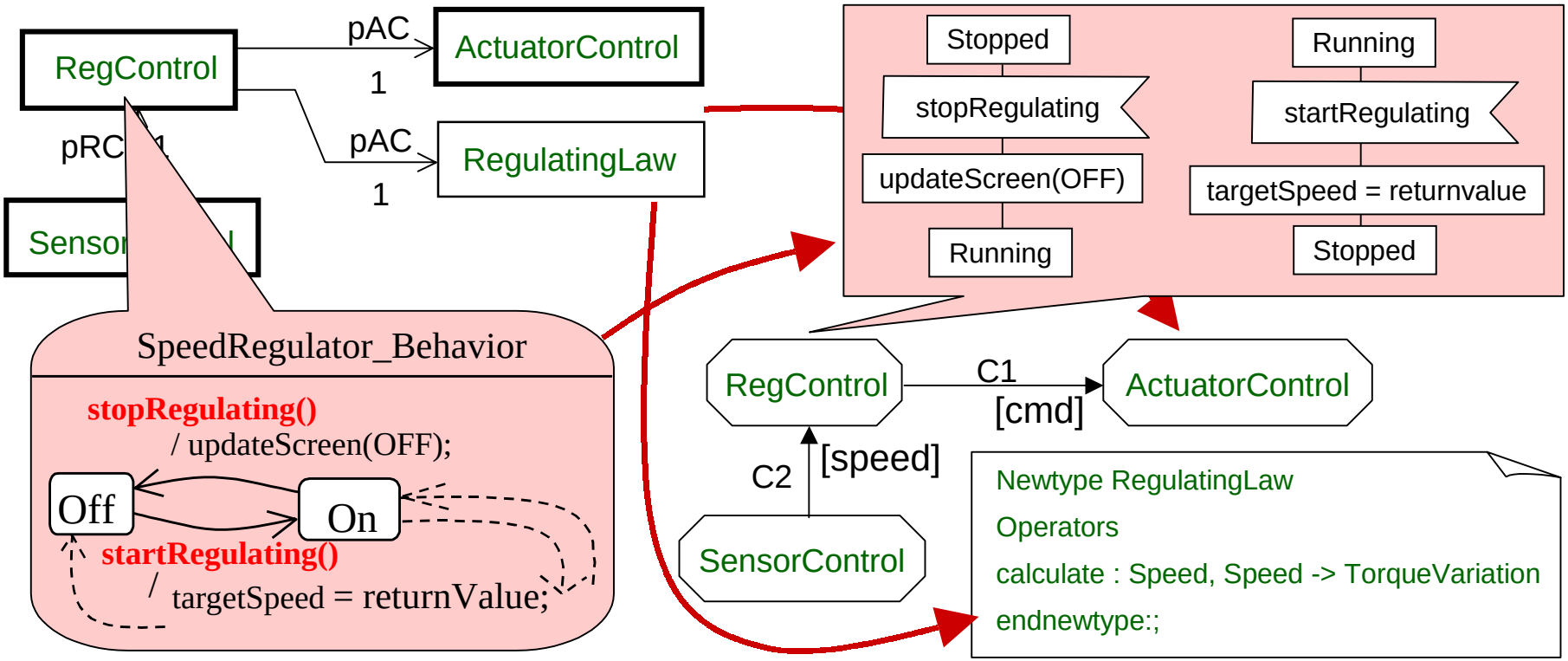
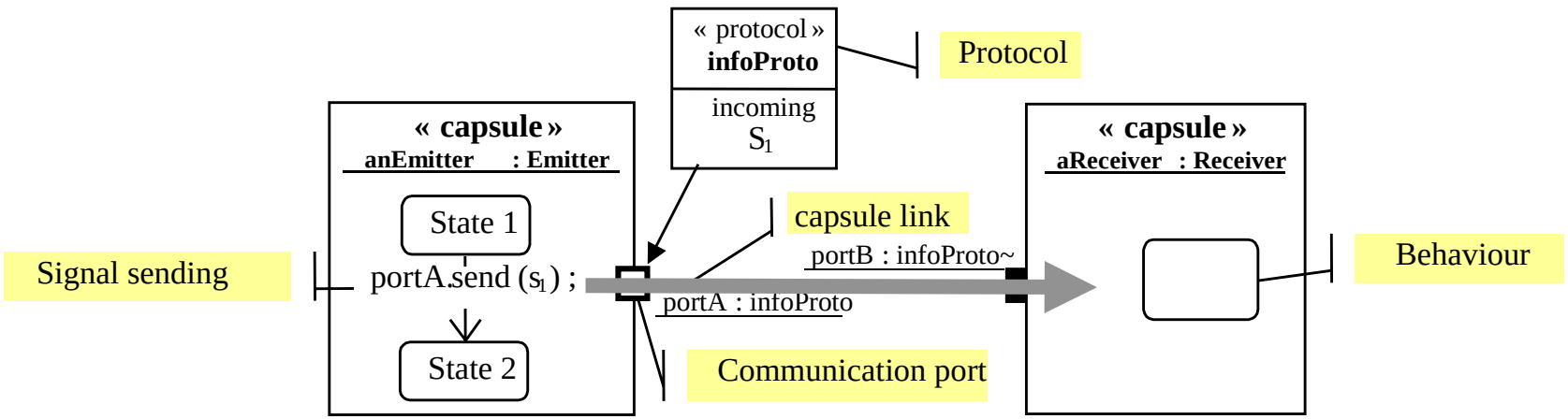


UML/SDL: mapping is under user responsibility

- The developer has to clarify the mapping of:
  - UML state machines → SDL specifications
  - Use of shared passive objects in UML model → SDL
  - Active object communication → SDL signal exchange
- Independency between model and implementation? implementation?
- Timing specifications:
  - → only with low level implementation mechanisms
    - Timers, SDL priorities…

UML-RT: attempt to integrate task and object paradigms

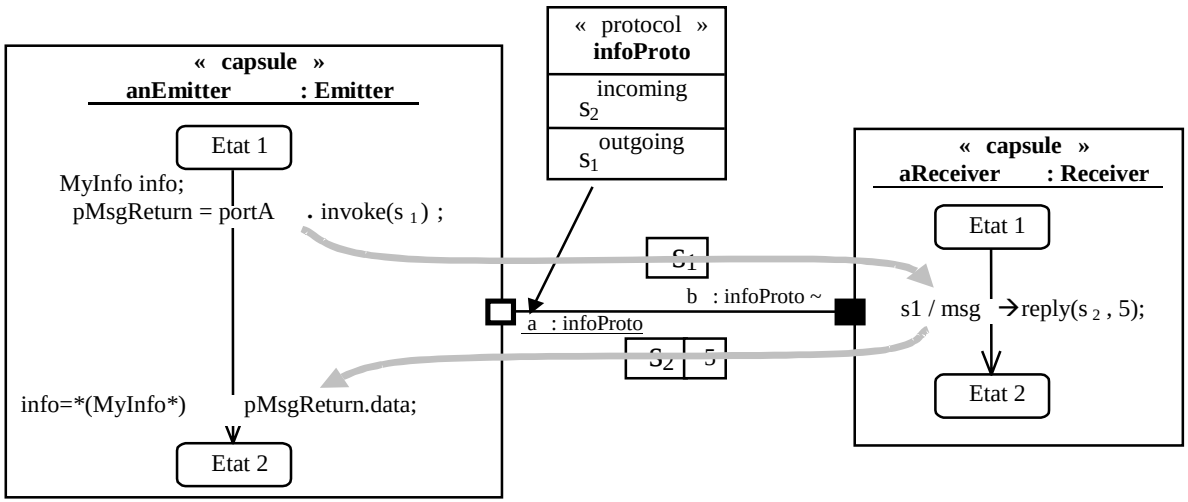
- « capsule » stereotype identifies active objects
  - They will be assigned to task at implementation stage
  - They have state automaton
- Communication is performed through « ports »
  - Sending of signal via port of communication



- ✓ Defines the set and protocol of the exchanged messages

UML-RT (ROOM/ObjecTime → ROSE-RT): Synthesis

- Communication based on specific concepts
  - Output parameters: return values managed by sender



- Priorities can be assigned on messages
  - One message queue by priority (five levels) :

    At implementation level mapping with task priorities must be managed by hand

- Timing specification through low level mechanisms

Synthesis on current offers

☞ Weak integration of object and real time…

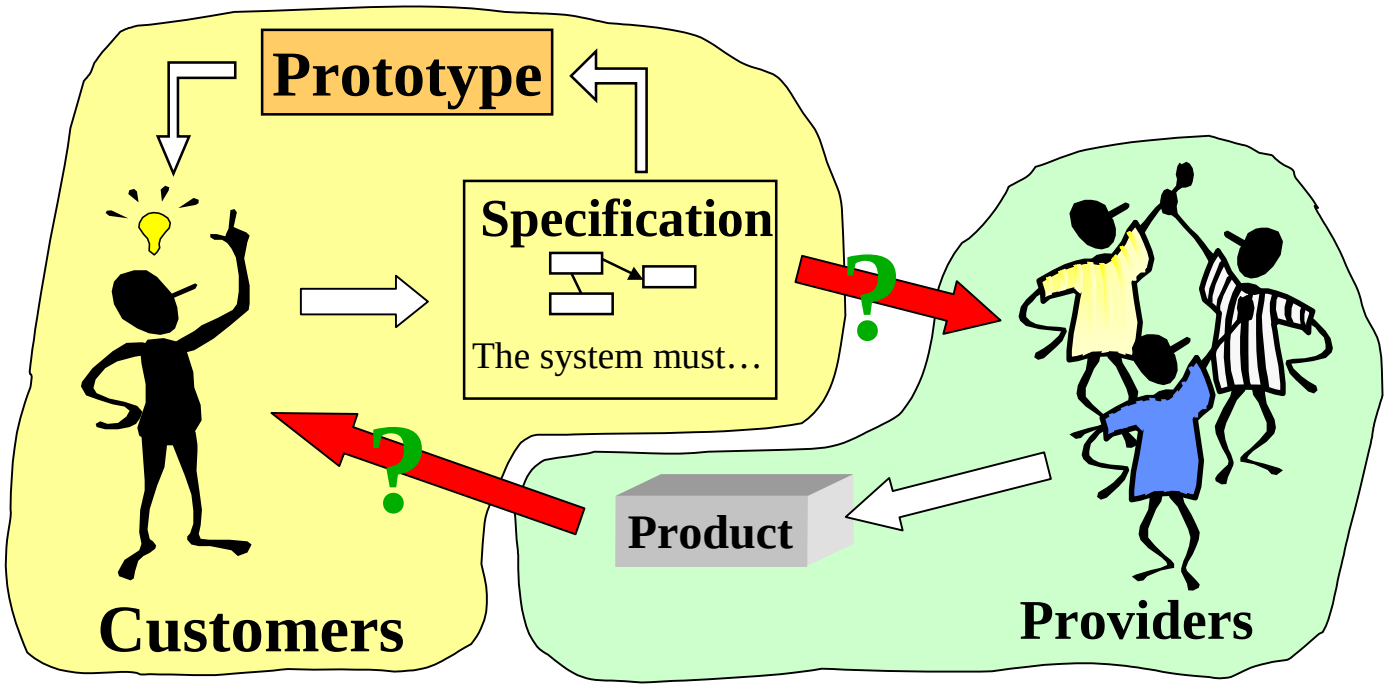
- Two very different models (e.g., ARTiSAN, UML/SDL)
- Behavior lies on operation and signal processing but with poor links to the usual object interface
- Focus is made more on signal than on operations that leads to behavior specification mixing up control action at object level and processing actions at operation level
- Output parameters often hard to manage

☞ Poor facilities to express timing constraints

- Specification of timers or of priorities
- Implementation of real time constraints kept to the users
- Sometimes difficulties to map model constraints on RT-OS → model / task priorities with OS priority management policies

Larger market → New users → New needs

- **Customers want to specify good RT models**
  - **They want also to be able to prototype/develop the systems**



- **Notations are not sufficient: method of use is required**
  - **Continuity and "tracability" of the model is mandatory**
  - **Availability of Model and application validation is critical**

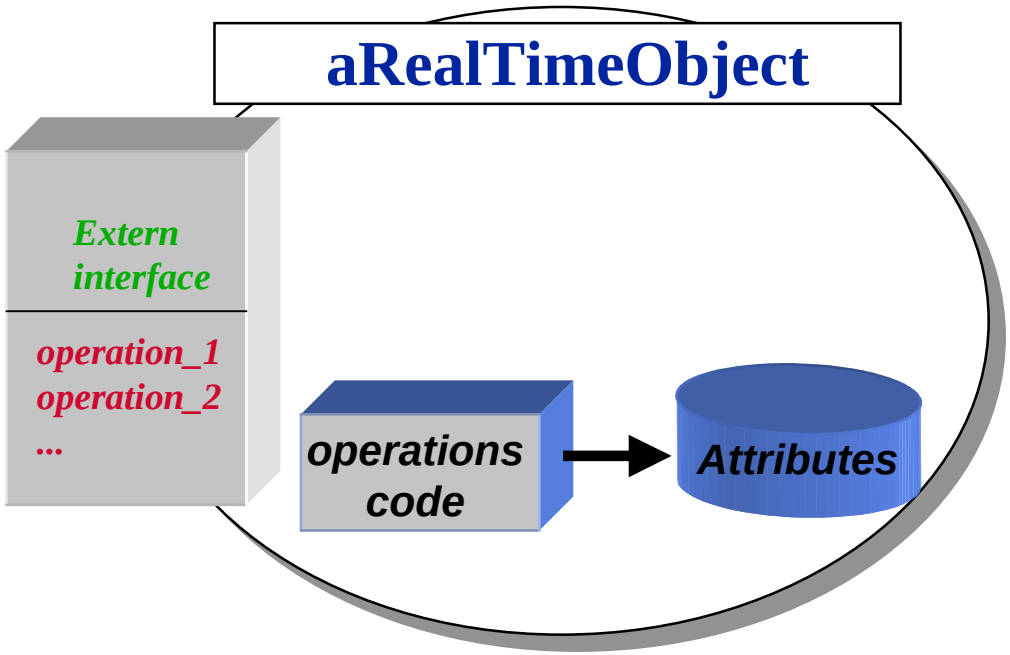
ACCORD/UML: introduction of real-time objects

- High level specification of real time behavior
  - Declarative expression of the real-time constraints
  - Hide RT-OS implementation concepts
- « Formal » models
  - Validation on model
  - Automatic prototyping code generation
  - Tuning of implementation through directives, patterns…
- Keep the usual object programming practices

ACCORD/UML: « task » model

- Task are attached to implementation of RT objects
  → support parallel processing of the messages they receive

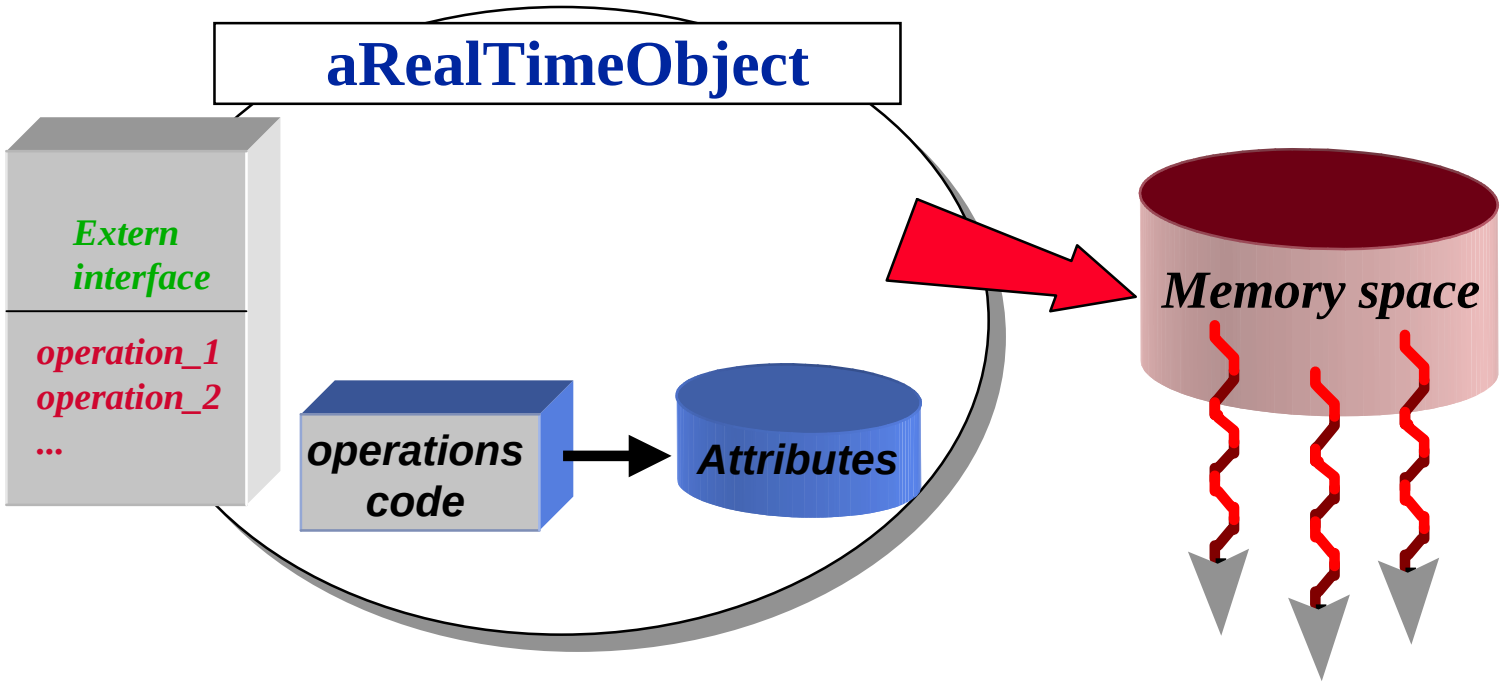
- User point of view :
  an object encapsulating data & processing



ACCORD/UML: « task » model

- Task are attached to implementation of RT objects
  → support parallel processing of the messages they receive

- User point of view :
  an object with its own processing resources

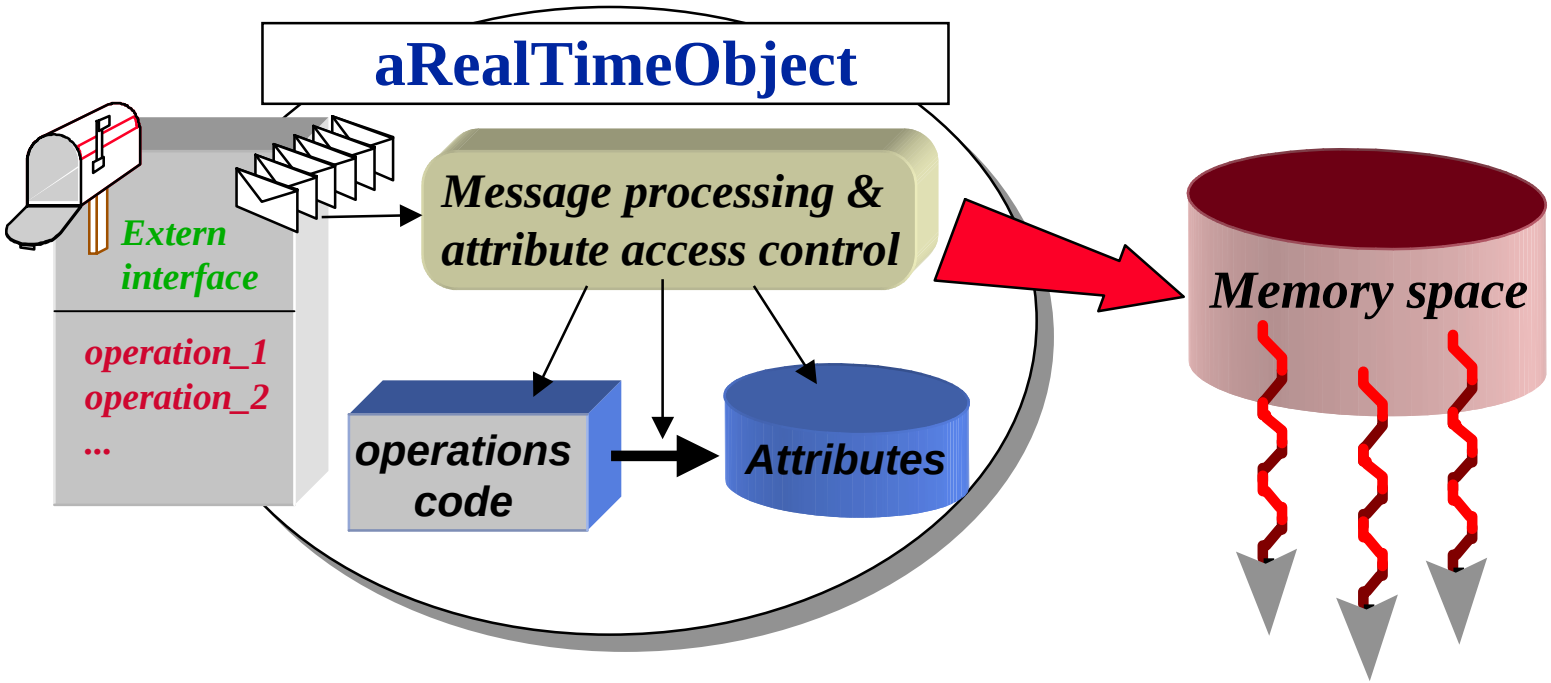


ACCORD/UML: « task » model

- Task are attached to implementation of RT objects
  → support parallel processing of the messages they receive

- User point of view :

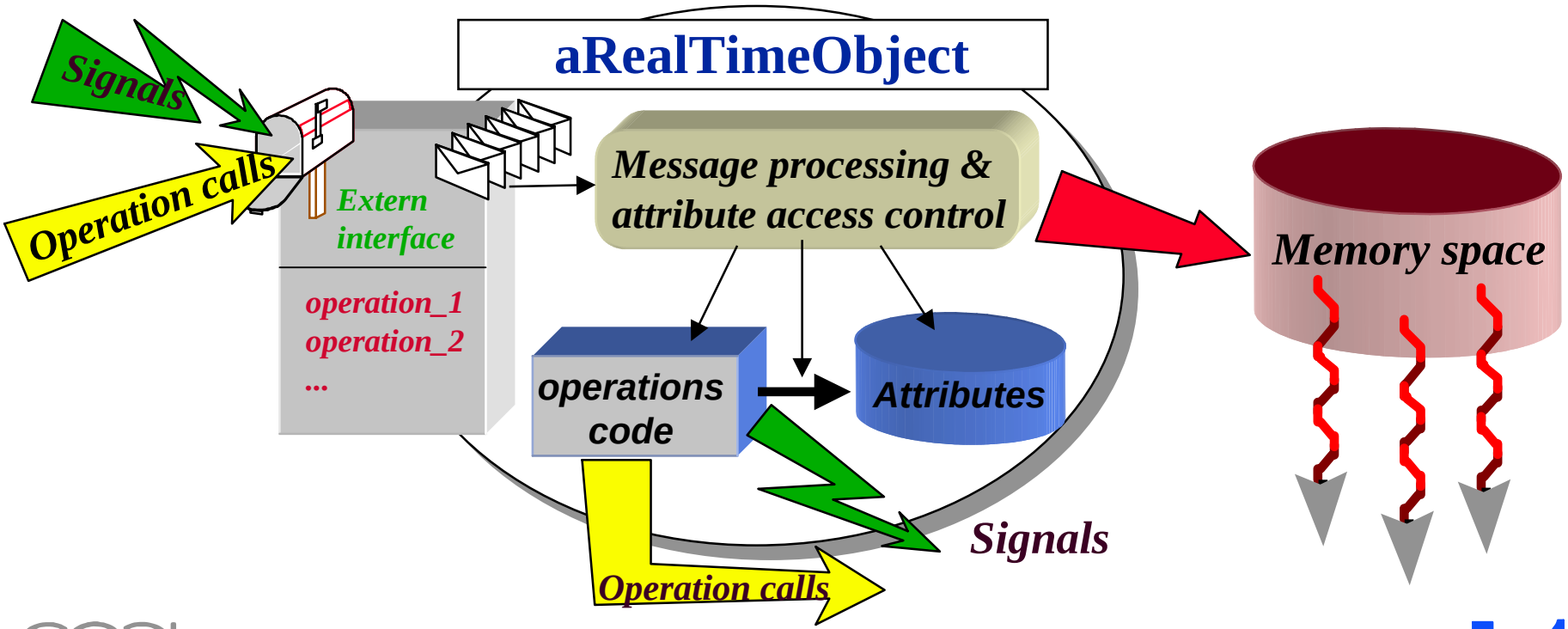
an object performing itself the control of its processing



ACCORD/UML: « task » model

- Task are attached to implementation of RT objects
  → support parallel processing of the messages they receive

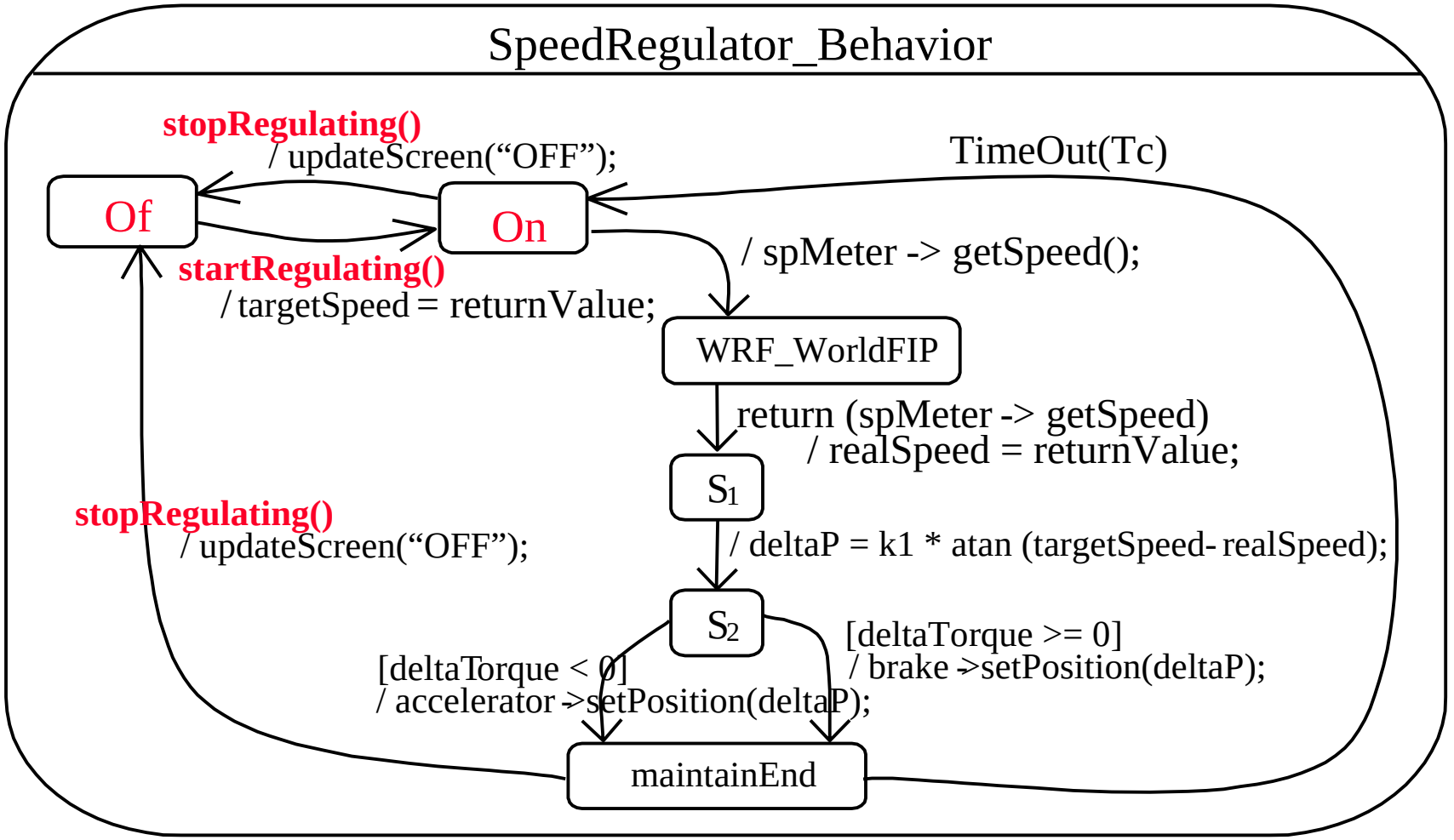
- User point of view : an autonomous computing entity with a standard UML object interface



ACCORD/UML: communication with RTO

- By messages that convey real-time constraints
  - Deadlines, priorities…
  - Operation calls: Asynchronous message passing
    - Output parameters create synchronization on their use
  - Signals: Asynchronous anonymous broadcast (atomic)
    - Only input parameters → signal attributes
- Shared passive object can be defined
  - Concurrency control is added

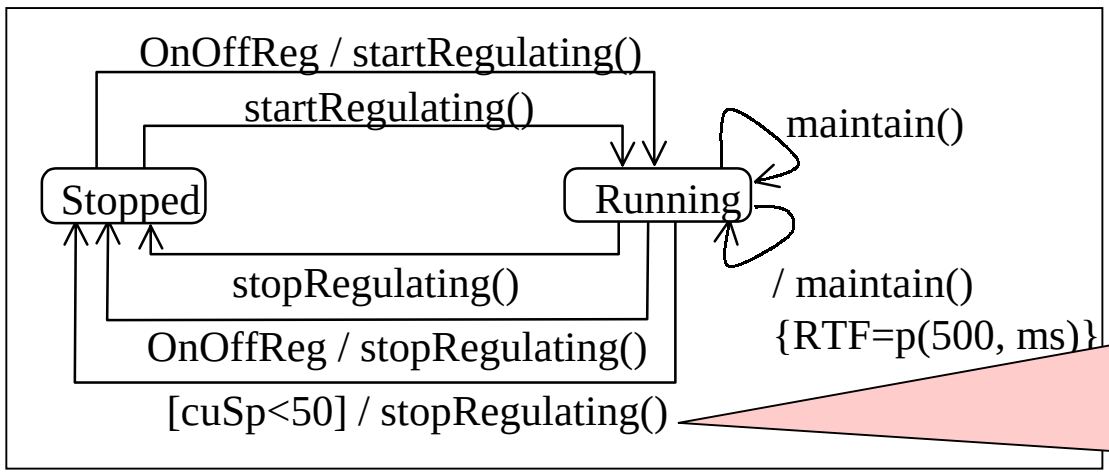
ACCORD/UML: two levels of state machines

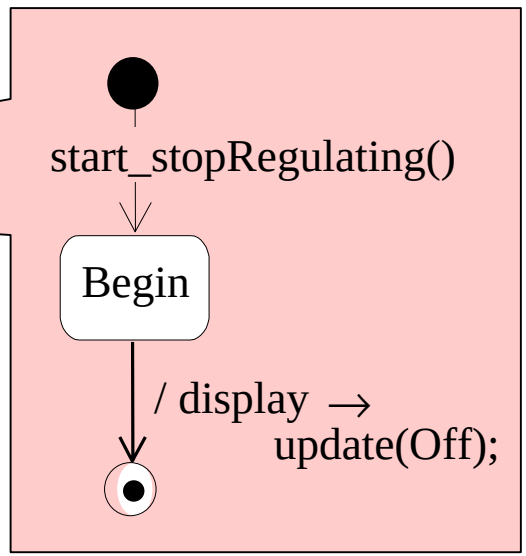


☞ Instead of having one single state machine…

ACCORD/UML: two levels of state machines

- Object behavior is structured at two levels
  - Global object control: protocol state machine
    - Transition only triggers processing of an object operation
      → clear link with object interface is maintained





  - Detailled specification of operations
    - Formal description of main actions performed by an operation

ACCORD/UML: Real-Time implementation

- Assignment of task to message processing by RTO
  - Default: reaction on signal and internal processing
    (always defined by the execution of an object operation)
  - User: implementation directives on message processing
  - Constraints specification only (deadline, period, priority)
    - Associated, when possible, to operation properties like execution times
- Scheduling mechanisms are provided
  - Event queue management based on message RT constraints
  - Concurrency management based on operation constraint declaration declaration

ACCORD/UML: synthesis

- Keeps to modeling concepts the common OO view
  - It can be used by non real-time specialists
- Provides models without implementation details
  - They can be changed without changing the structure of the models (nor in class, or sequence or state diagrams)
- Facilitate automatic generation of prototype code
- Allows model validation
  - through simulation or formal analysis (execution model can be deduced from the specification)

Some open points

- Definition of development methods…
- Improvement of formal validation of models…
  - Lot of work to do for integration of existing solutions
- Integration of new paradigms:
  - Links between discrete and continuous models…
  - Links with « data flow » based modeling (high performance embedded parallel computing)
  - Links with hardware: « co-design »
- What about the next versions of UML standard ?

Some web sites

- AIT-WOODDES: *« Workshop for Object Oriented Design and Development of Embedded Systems », IST project of the 5th PCRD*
  http://wooddes.intranet.gr/project.htm
- SIVOES: *ECOOP'2000 workshop on « Specification, Implementation and Validation of Object-oriented Embedded Systems »*
  http://www-dta.cea.fr/leti/UK/Pages/Tech_info/Sivooes.htm
- UML'2000: http://www.cs.york.ac.uk/uml2000
  Workshop on Formal Design Techniques for Real-Time UML
  http://wooddes.intranet.gr/workshop.htm
- Action semantics: *AD/98-11-01,* http://www.omg.org, http://uml.simware.com
  http://people.ce.mediaone.net/weigert/actionsemantics/home.html
- ARTiSAN: http://www.artisansw.com
- RT-UML (Rhapsody): http://www.ilogix.com
- UML-SDL (ObjectGEODE): http://www.csverilog.com, http://www.telelogic.com
- UML-RT (ROSE-RT): http://www.rational.com