Verification of UML models with timing constraints using IF

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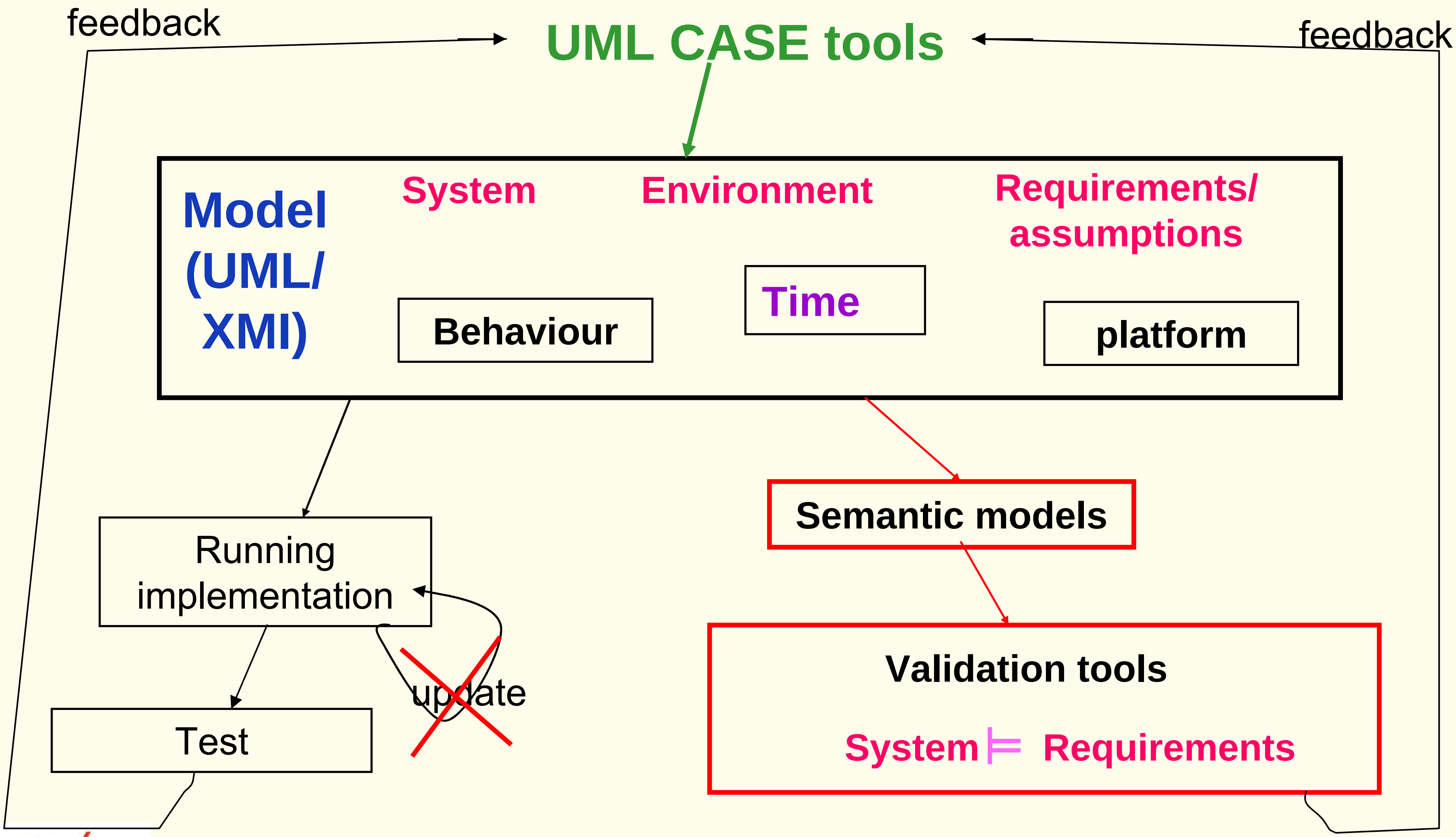
Verimag

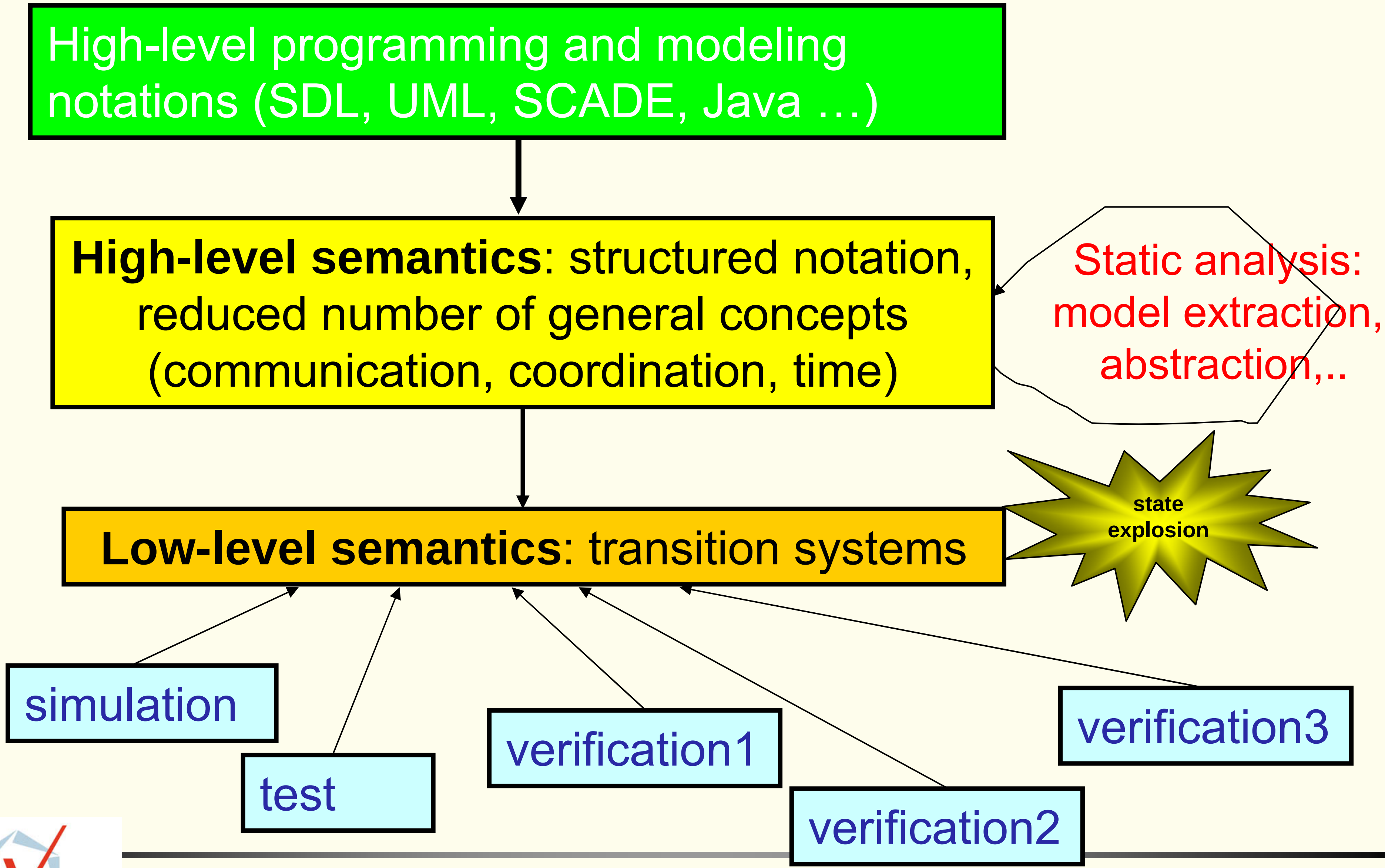
http://www-if.imag.fr/

http://www-omega.imag.fr/

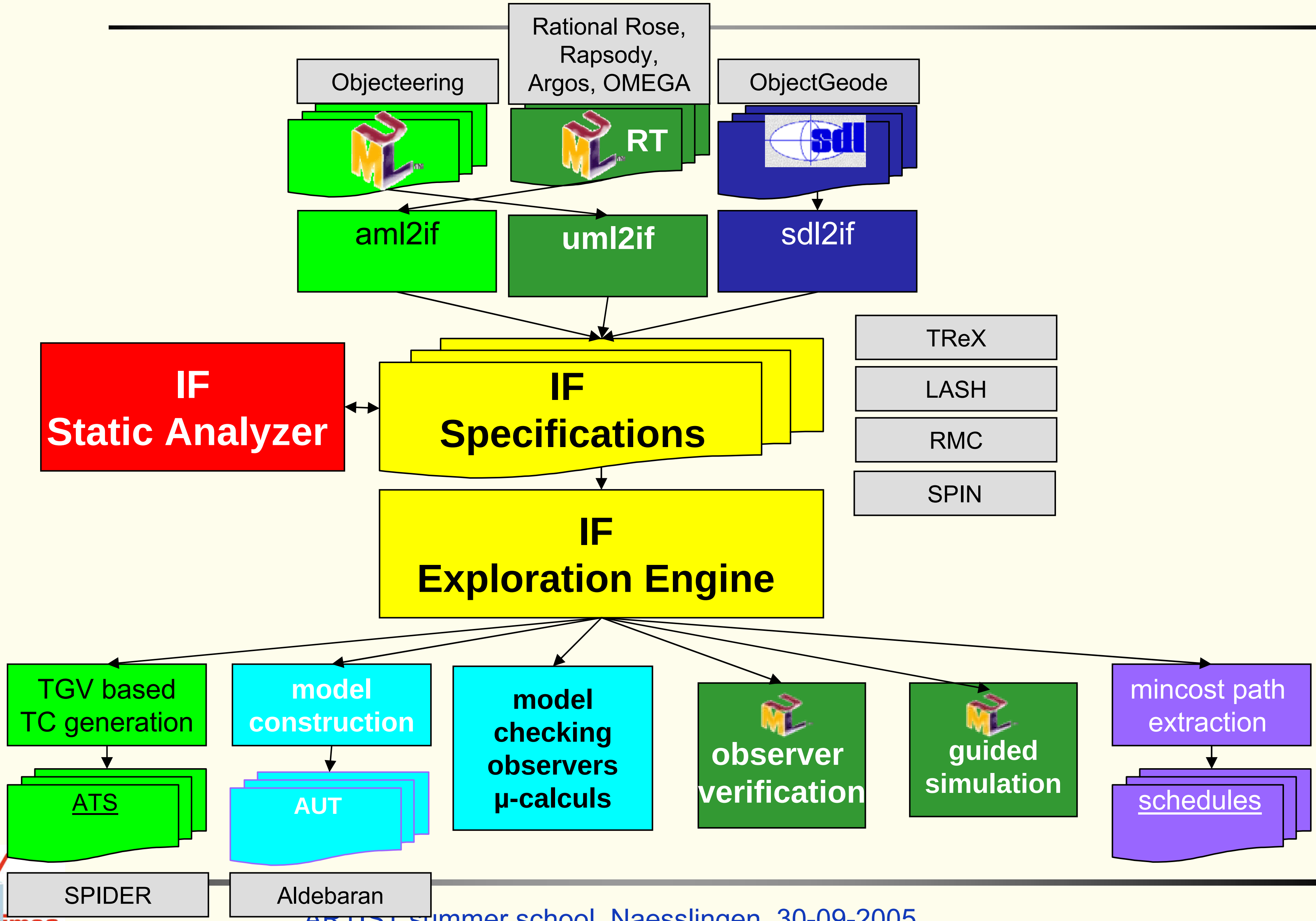
IST OMEGA: validation in the context of model-based development of real-time systems



The IF toolbox: approach



IF tool-set: overview



Outline

IF language

System =

Set of **concurrent processes**

- **timed automata with urgency**
- hierarchical automata
- complex + abstract data types
- dynamic creation
- non-determinism

Communication

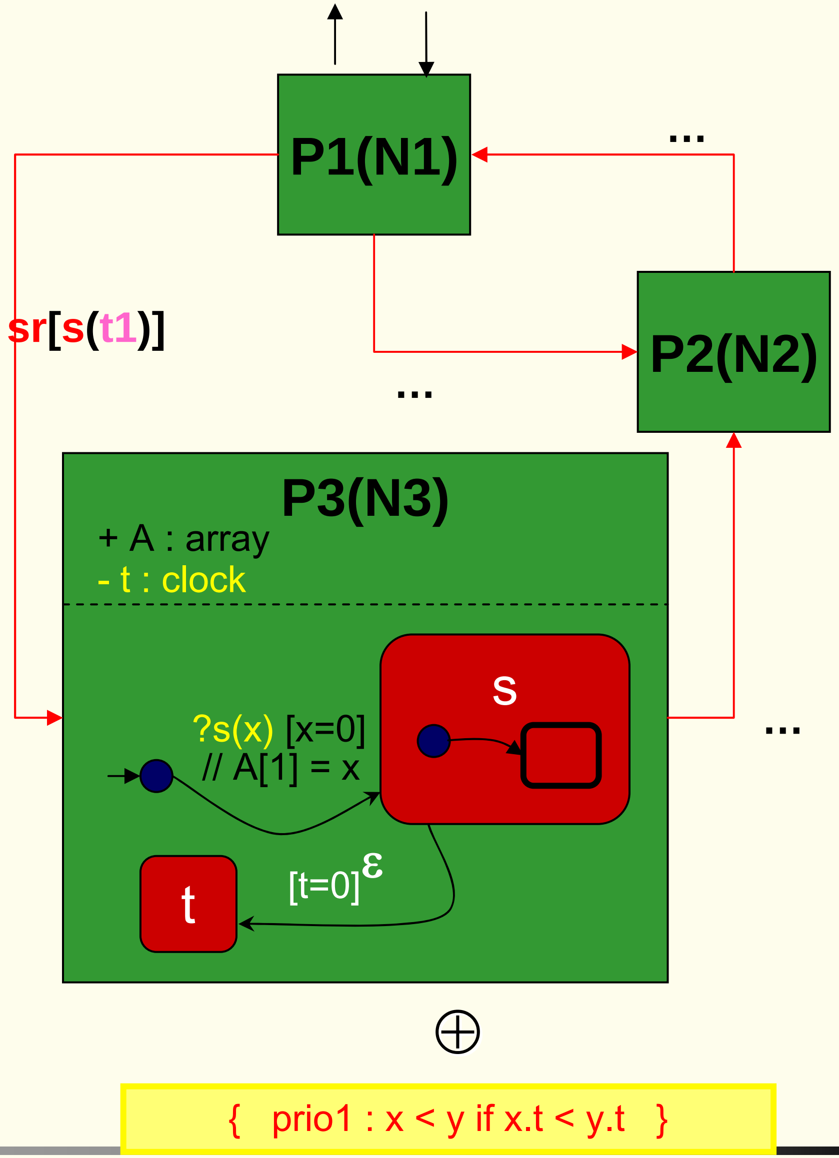
- asynchronous channels
- various routing / delay / loss models
- shared variables

Execution control

- dynamic priorities

Assumptions and Requirements

- observers (weak synchronization)



System description

Processes (components)

Extended *hierarchical timed automata*

(non-determinism, dynamic creation)

Data

- predefined data types (basic types, arrays, records)
- abstract data types

Interactions

- asynchronous channels
- shared variables

Execution control

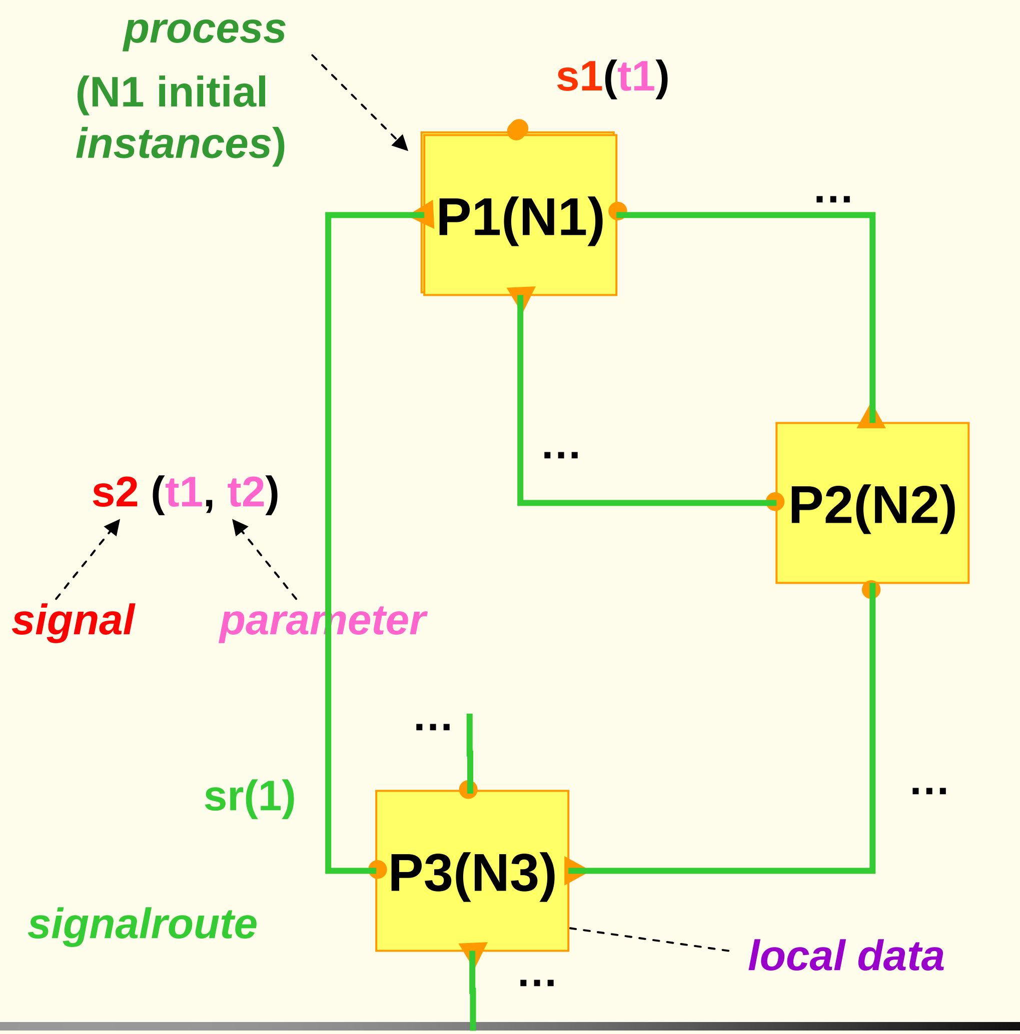
- priority rules
- *resources* (mutex, preemption)

IF: system description

// processes
process P1(N1)
...
endprocess;
...
process P3(N3)
...
endprocess;

// signalroutes
signalroute sr1(1) ...
from P1 to P3 ;

// signals
signal s1(t1)
signal s2(t1, t2),



IF: process description

Process = hierarchical timed automaton

process P1(N1);
fpar … ;

parameters

local data

// types, variables, constants, procedures

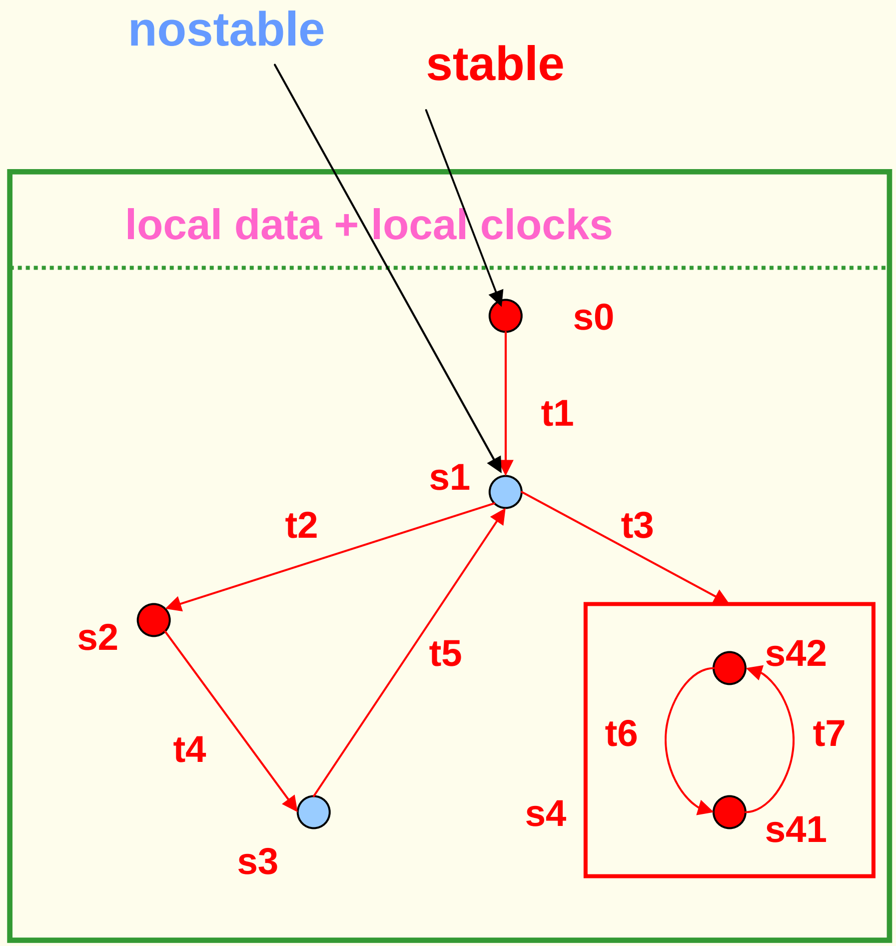
state

state s0 …;
… // transition t1
endstate;

outgoing transitions

state s1 #unstable…;
… // transitions t2, t3
endstate;

… // states s2, s3, s4
endprocess;



P1(N1)

transition = *urgency* + trigger + body

state s0
…

t1

urgency *eager*
provided x!=10;
when c2 >= 4;
input update(m);
body ….
nextstate s1;

…
endstate;

urgency

untimed guard

timed guard

signal consumption from the process buffer

= **trigger**

statement list, ext. proc.

sequential. conditional, or iterative composition

statement = data assignment
message sending,
process or signalroute creation or destruction, …

signal route = connector = process to process communication channel with ***attributes,*** can be ***dynamically*** created

route name

initial instance number

attributes

signal set

signalroute s1(1) **#unicast #lossy #fifo**

from server **to** client **with** grant, fail;

endpoints

attributes:

- queuing policy: **fifo** | **multiset**
- reliability: **reliable** | **lossy**
- delivery policy: **peer** | **unicast** | **multicast**
- *delay policy: urgent | delay[l,u] | rate[l,u]*

IF: dynamic priorities

- priority order between process instances p1, p2
  (free variables ranging over the active process set)

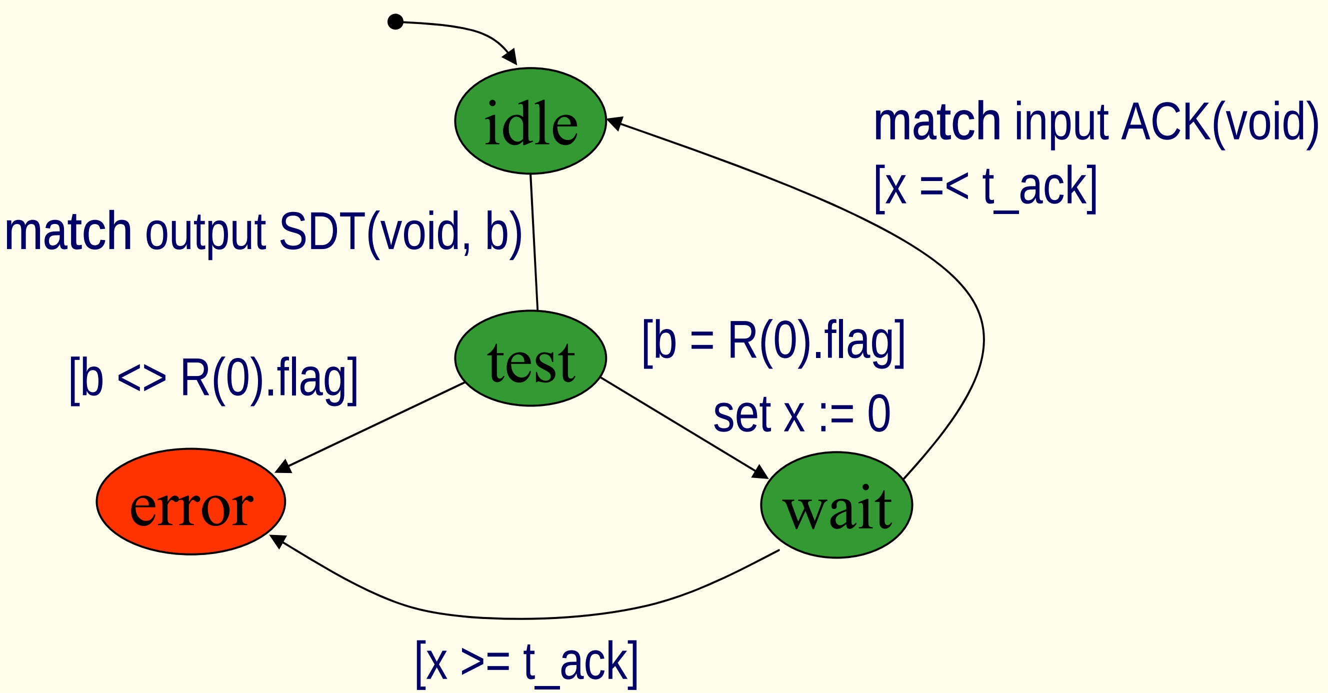
priority_rule_name: p1 < p2 **if** *condition*(p1,p2)

- semantics: *only maximal enabled processes can execute*

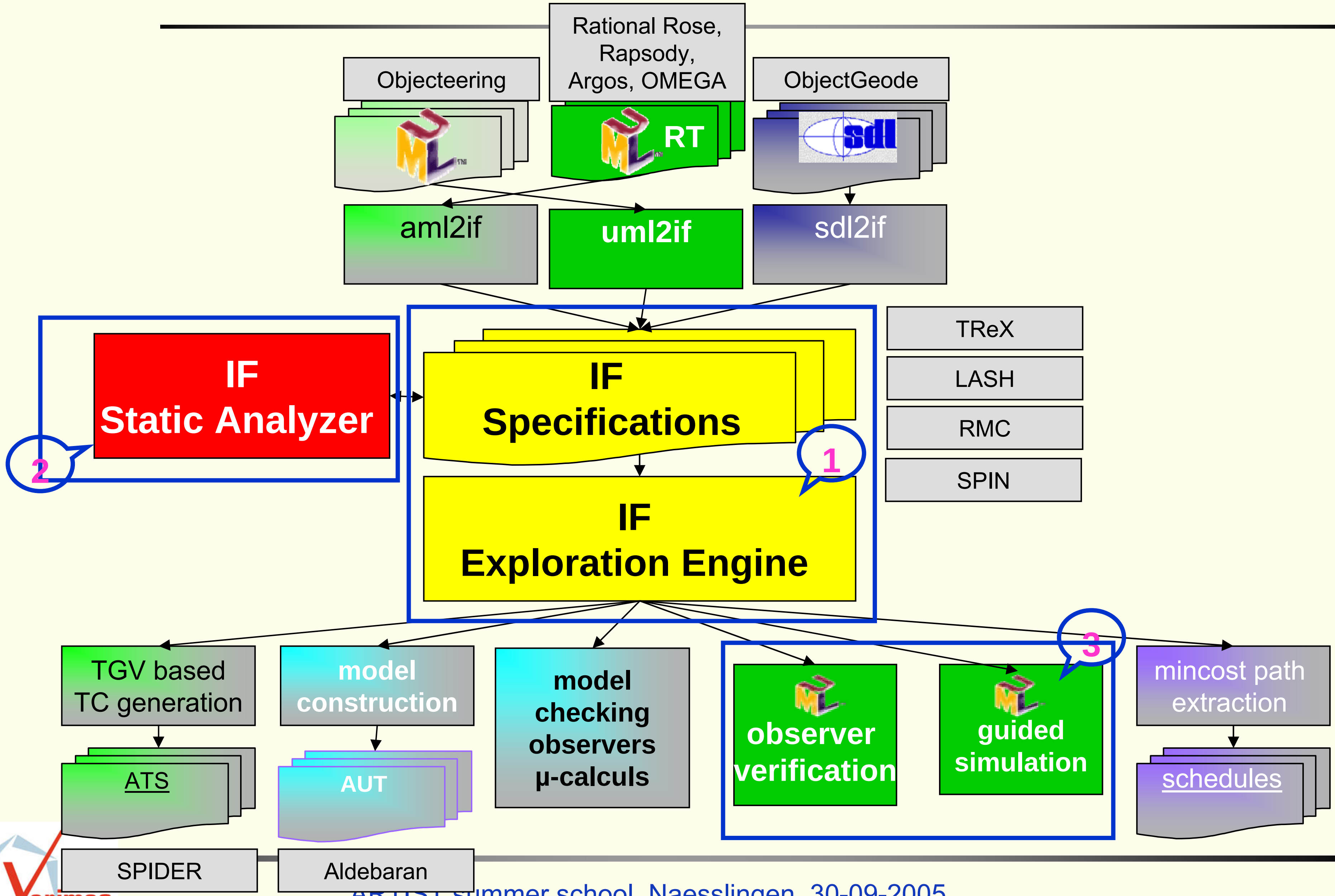
- examples of scheduling policies
  - **fixed priority**: p1 < p2 if p1 instanceof T and p2 instanceof R
  - **EDF**: p1 < p2 if Task(p2).timer < Task(p1).timer
  - **run-to-completion**: p1 < p2 if p2 = manager(0).running

IF: observer for the expression of properties

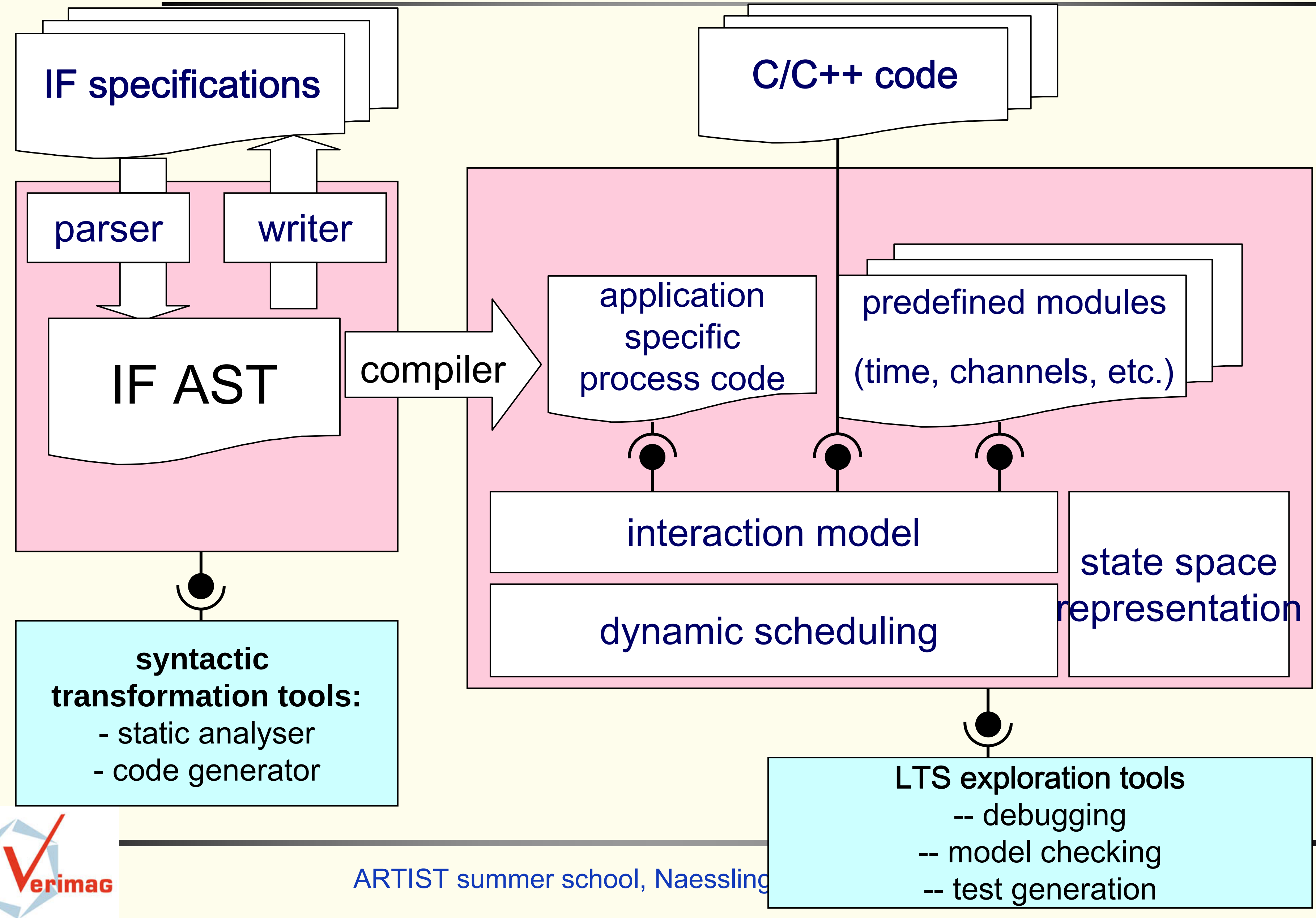
- ***Observers*** specify safety properties (assumptions and requirements)
- Event language acceptors: processes with specific triggers for monitoring events, system state, elapsed time
- 3 types of states : normal / error / success
- *Semantics*:
  - transitions triggered by monitored events are executed with highest priority
  - Reaching a success state = reaching un uninteresting part (assumption)



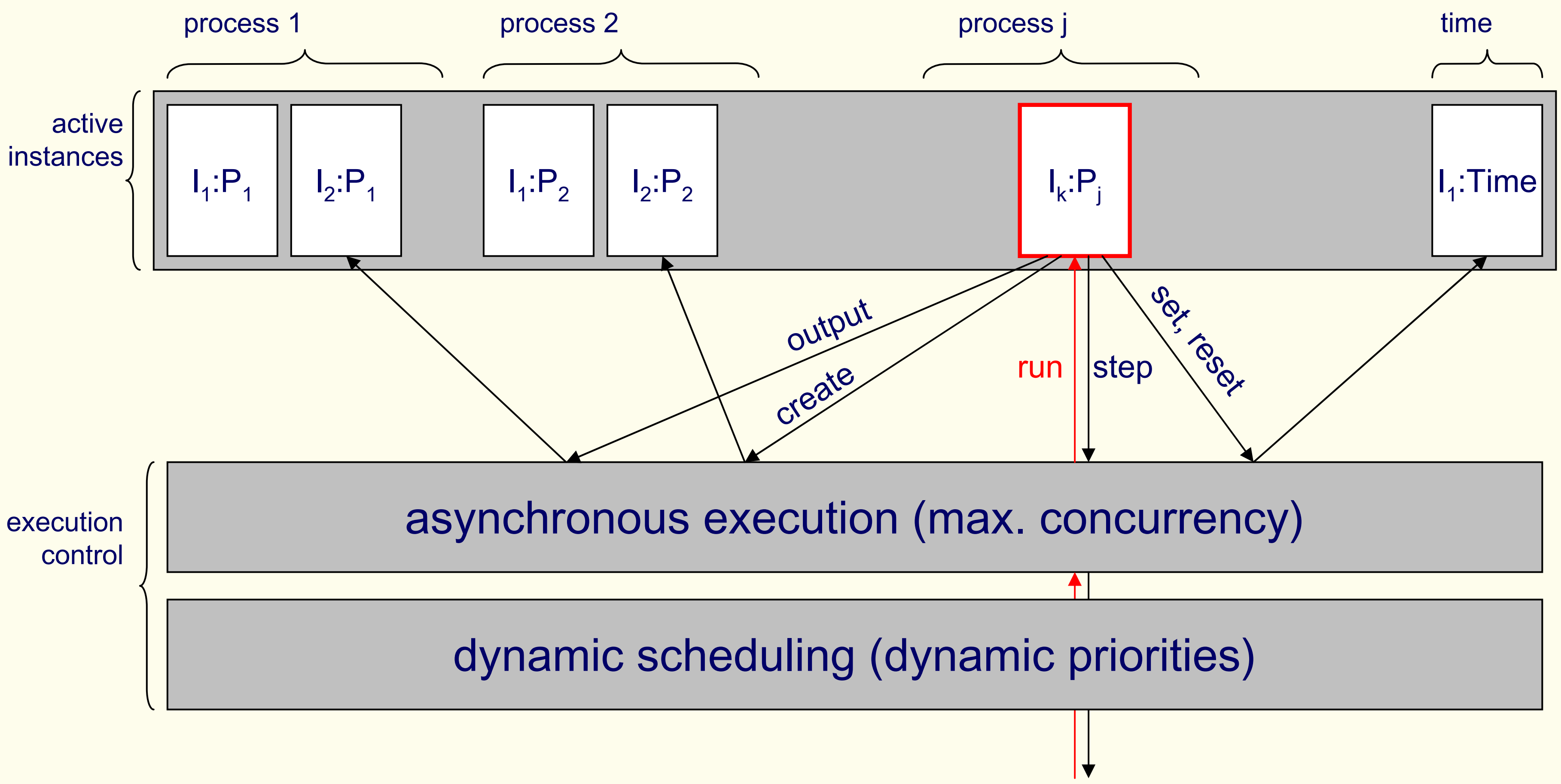
IF tool-set: overview



IF: core components



IF: exploration engine

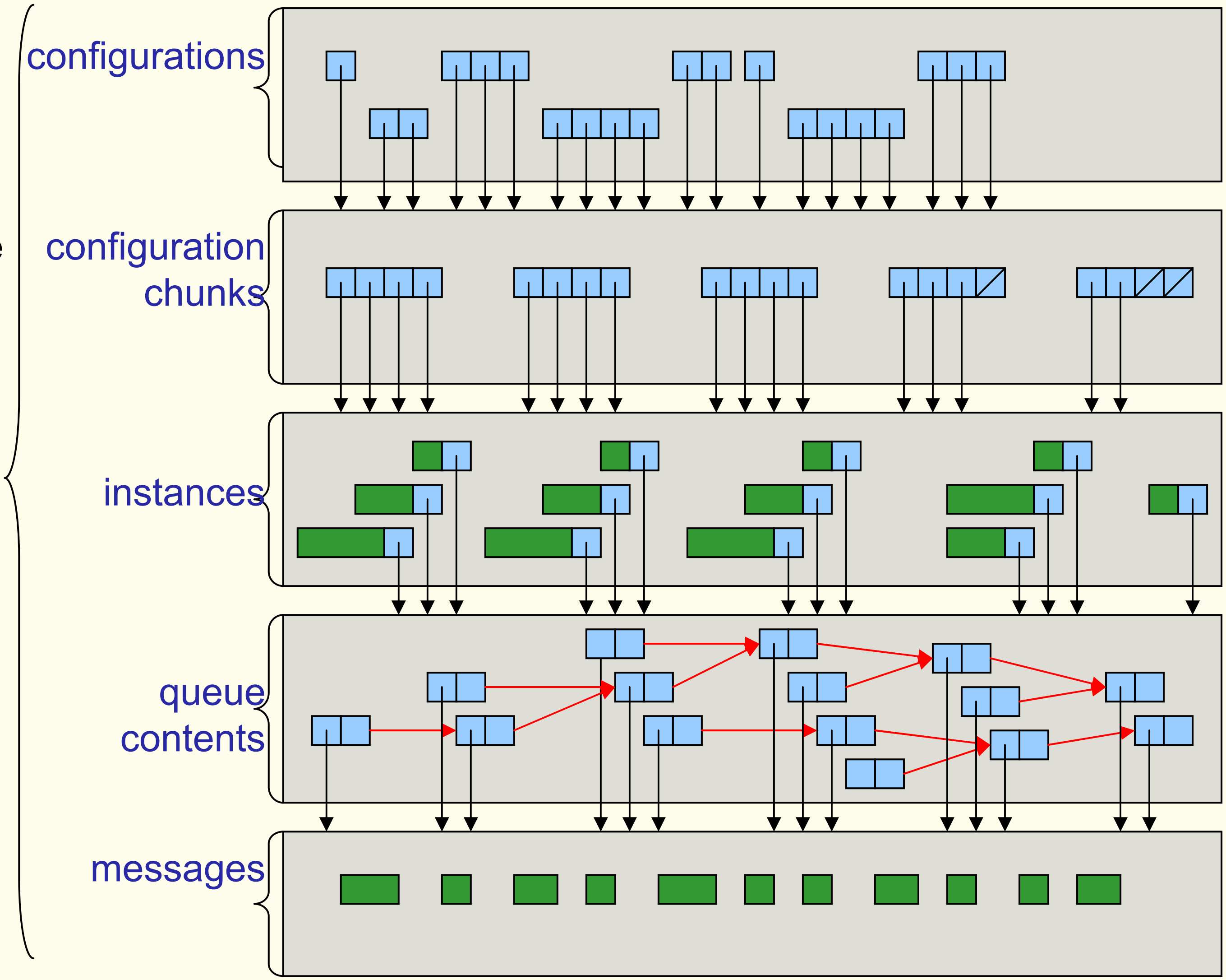


IF: state space representation

state storage is completely done by the simulator

structural representation of configurations offering maximal sharing

unique tables implemented as hash tables with collision or search trees (splay trees or 2-3 trees)



IF: representation of time

Time represented by a dedicated process instance handling:

- dynamic clock allocation (set, reset)
- representation of clock valuations
- checking time constraints (time guards)
- computation of time progress conditions w.r.t. actual deadlines
- firing time progress transitions, if enabled

Two concrete implementations are available (others can be easily added)

i) *discrete time*

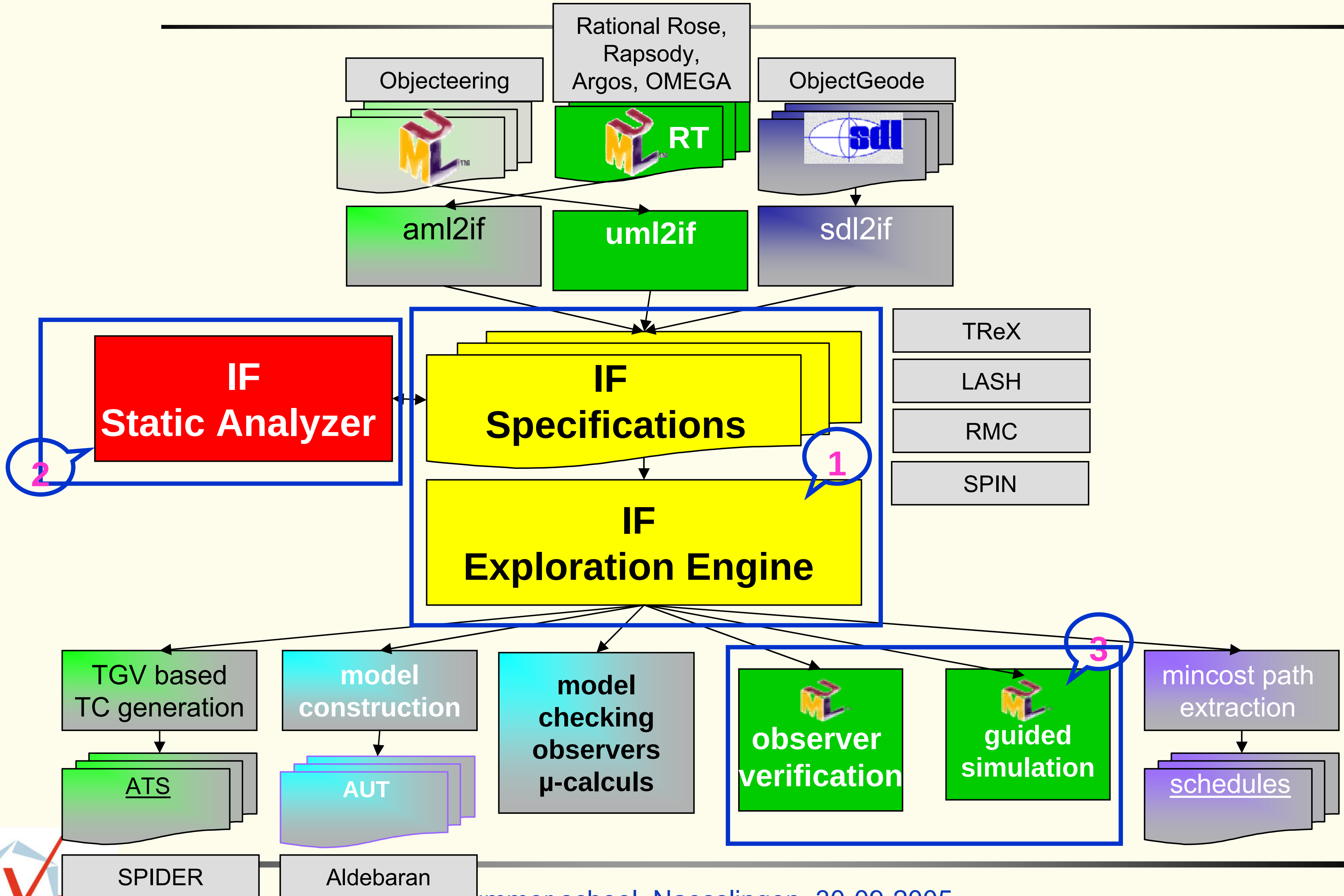
- clock valuations represented as integer values
- time progress by an explicit *tick transition* to the next deadline

ii) *symbolic time*

- clock valuations represented by (varying size) difference bound matrices (DBMs)
- time progress is implicit: State = state + time constraint
- non convex time zones may arise due to urgency: represented implicitly by unions of DBMs

KRONOS, UPPAAL

IF tool-set: overview



IF: Static analysis

- **Approach**
  - source code transformations for model reduction
  - code optimization methods

- **Particular techniques implemented** so far
  - live variable analysis: remove dead variables and/or reset variables when useless in a control state
  - slicing: remove unreachable code, model elements w.r.t. a property, e.g. assumptions about the environment
  - variable abstraction: extract the relevant part after removing some variables
  - queue reduction: static analysis of queues

- Result: usually, ***impressive state space reduction***

Outline

Omega UML profile: general features

Structure

- class diagrams distinguishing active and passive classes
- structuring concepts : inheritance, associations, compositions
- architecture and components (UML 2.0-like, not available in UML 1.4)

Behavior

- state machines with action language (compatible to UML1.4 A.S.)
- operations defined by methods (action body) → polymorphic
- concurrency : active/passive objects ➔ activity groups
- interactions: primitive/triggered operations, asynchronous signals

Requirements and assumptions

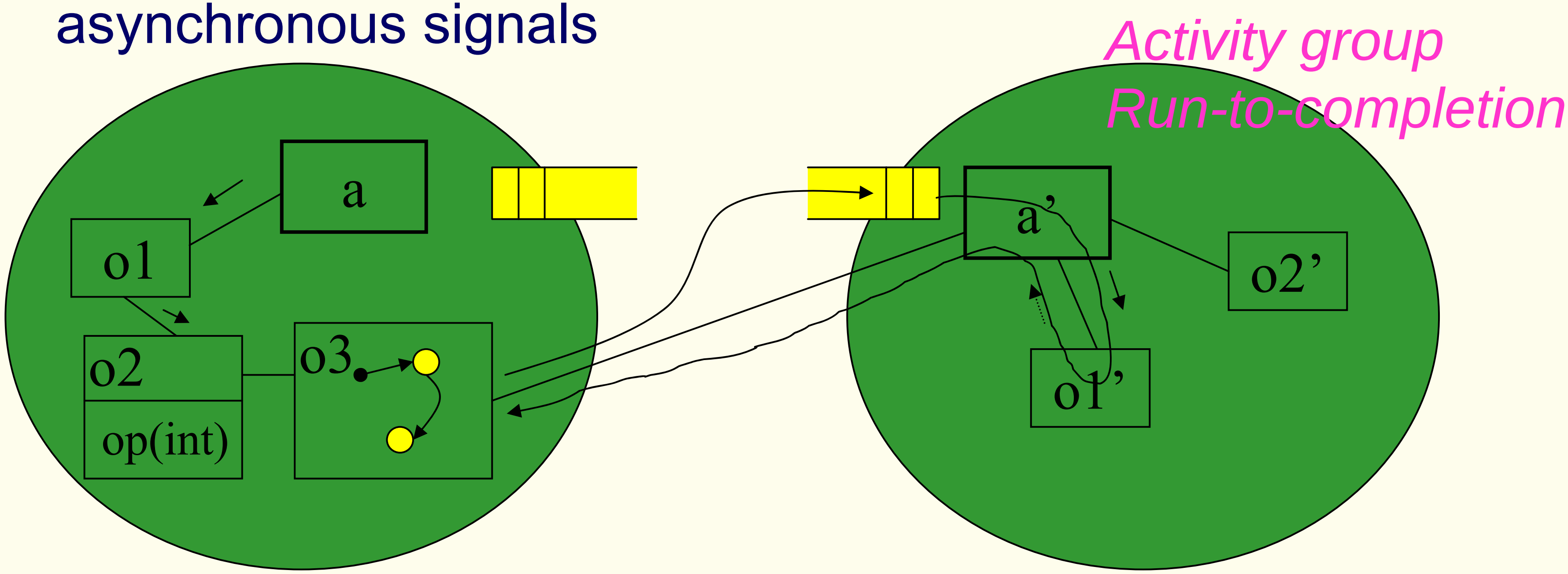
- operational : *observers*, *Live Sequence Charts*
- declarative : *OCL* constraints on event histories

Timing constraints (in requirements, structure and design)

- declarative : timed events, linear (duration) constraints
- imperative : timers, clocks

Omega UML profile: interaction model & semantics

- active/passive objects define ***activity groups***
- interactions: primitive/triggered operations, asynchronous signals



- [Damm, Josko, Pnueli, Votintseva 2002 & Hooman, Zwaag 2003] – based on the Rhapsody tool semantics

Omega UML profile: Time extensions

Compatible SPT profile and UML 2.0

- **Basics**
  - A notion of global time, *time progress non-deterministic, but controllable* by the model
  - Time primitive types: *Time*, *Duration* with operations
  - *Timed Events*: instants of occurrences of identified state changes in executions

- **Operational time access** (UML 2.0)
  - *time dependent behavior*
  - Mechanisms for measuring durations: *timers, clocks*
  - Corresponding actions: *set, reset*,…

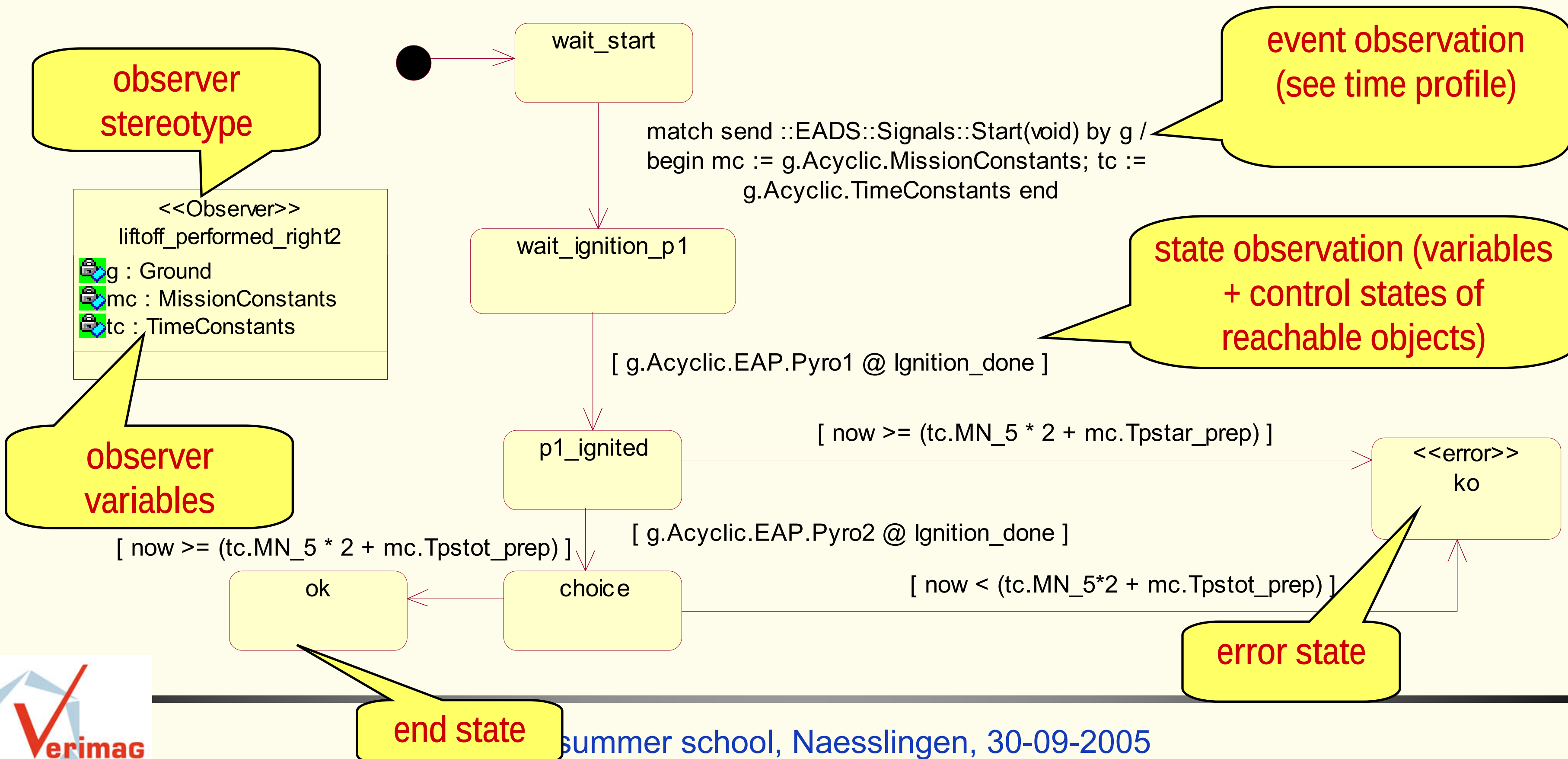
Omega UML profile: Time extensions

- **Time constraints**
  - **Constraints on durations** between *occurrences of events*
    - OCL based
    - Patterns for constraining durations between occurrences of 2 events
    - SPT like derived patterns associated with syntactic entities
      - response time, duration of actions → deadline constraints,
      - duration in state, delay of channel, ...
  - **Observers** with time guards

- **Scheduling**
  - *Resources* accessed in mut. excl. and consuming execution time and actions for associating behavior with resources (deployment)
  - *Execution time* of actions
  - *Dynamic priorities* for expressing scheduling policies

Omega UML profile : requirements as *observers*

- special objects monitoring the system state / events
- example (Ariane-5) : ***If the Pyro1 object enters state "Ignition_done", then the Pyro2 object shall enter the state "Ignition_done" in not less than TimeConstants.MN_5*2 + Tpstot and not more than TimeConstants.MN_5*2 + Tpstar time units.***



Omega UML profile : *observables*

- observable events
  - for signals : send, receive, accept
  - for operations : invoke, receive, accept, invokereturn, …
  - for states : entry, exit
  - for actions : start, end, start-end (for instantaneous actions)
- observable state
  - all entities reachable by navigation from already known entities (e.g. obtained from events)
  - can be stored in the observer
- observing time
  - use clocks local to an observer
  - read clocks of visible part of the model

Omega UML profile : requirements as constraints

- Define explicit events and constraints
- example (Ariane-5) : ***If the Pyro1 object enters state "Ignition_done", then the Pyro2 object shall enter the state "Ignition_done" in not less than TimeConstants.MN_5*2 + Tpstot and not more than TimeConstants.MN_5*2 + Tpstar time units.***

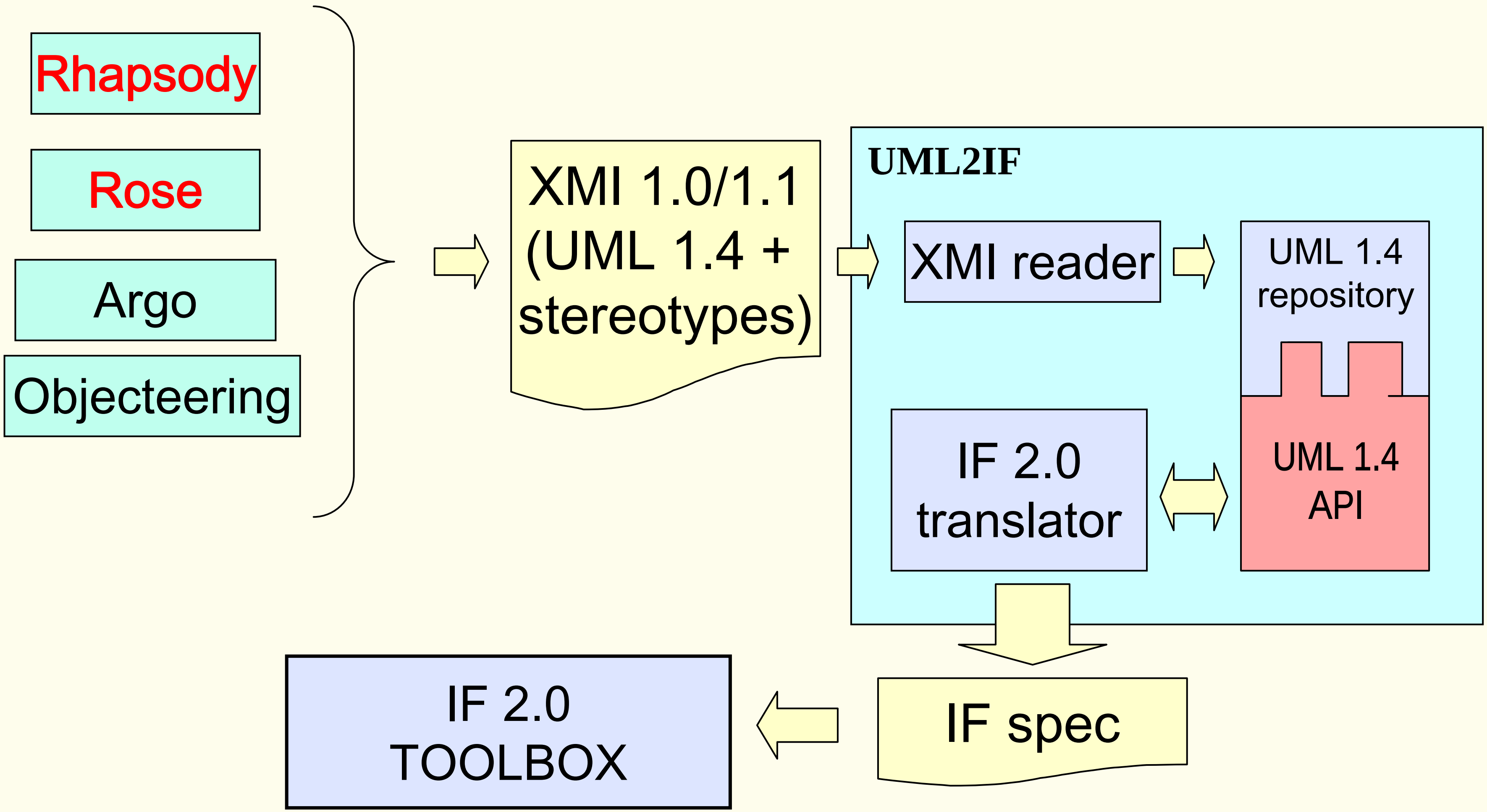
<<TimedEvent>>
IgnPyro1
p : Pyro
{ match enter Pyro @ Ignition_done by p
when p = p.EAP.Pyro1 }

<<TimedEvent>>
IgnPyro2
p : Pyro
{ match enter Pyro @ Ignition_done by p
when p = p.EAP.Pyro2 }

<<TimedAssert>>
liftoff_performed_right
i1 : IgnPyro1
i2 : IgnPyro2
{ duration(i1,i2) >=
TimeConstants.MN_5*2 + Tpstot_prep
duration(i1,i2) <=
TimeConstants.MN_5*2 + Tpstar_prep
}

Outline

IFx: overview

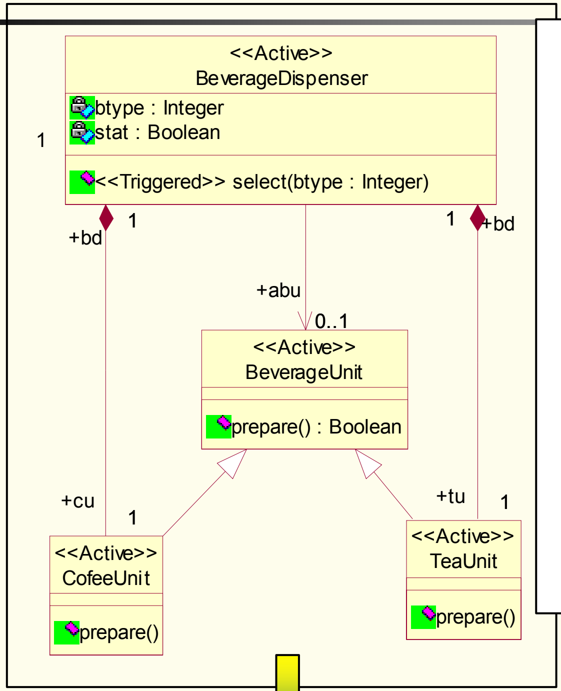


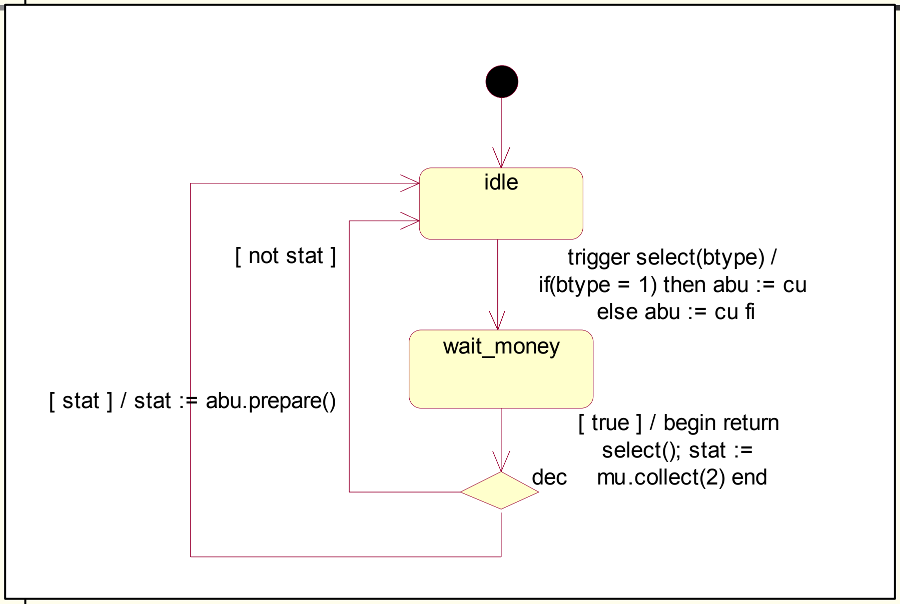
IFx: mapping UML to IF

Mapping OO concepts to (extended) communicating automata

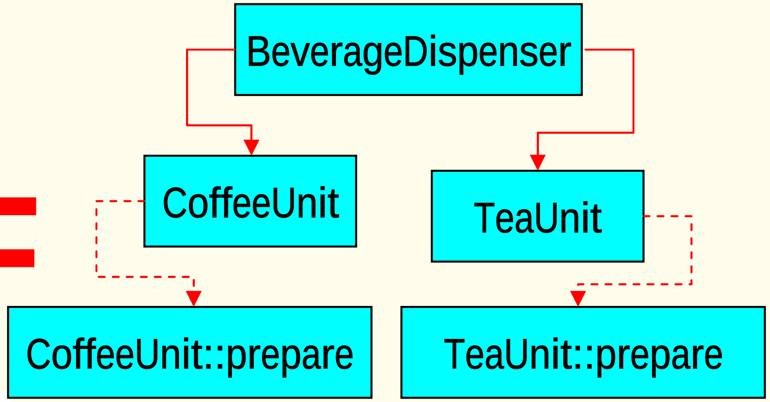
- Structure
  - class → process type
  - attributes & associations → variables
  - inheritance → replication of features
  - signals, basic data types → direct mapping
- Behavior
  - state machines (with restrictions) → IF hierarchical automata
  - action language → IF actions, automaton encoding
  - operations:
    - operation call/return → signal exchange
    - procedure activations → process creation
    - polymorphism → untyped PIDs
    - dynamic binding → destination object automaton determines the executed procedure
- Observers and events: direct mapping

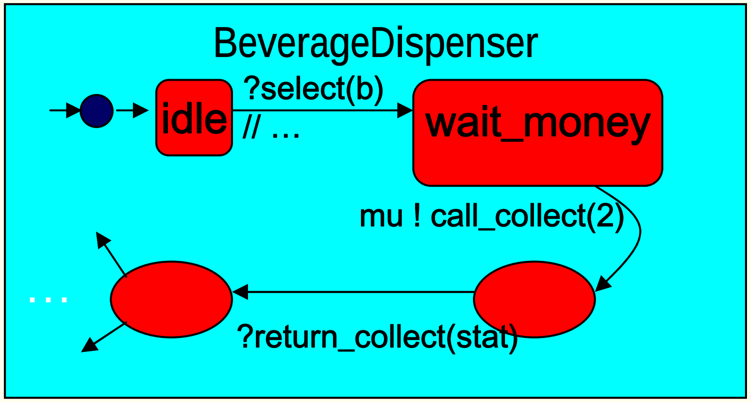
IFx: example of mapping



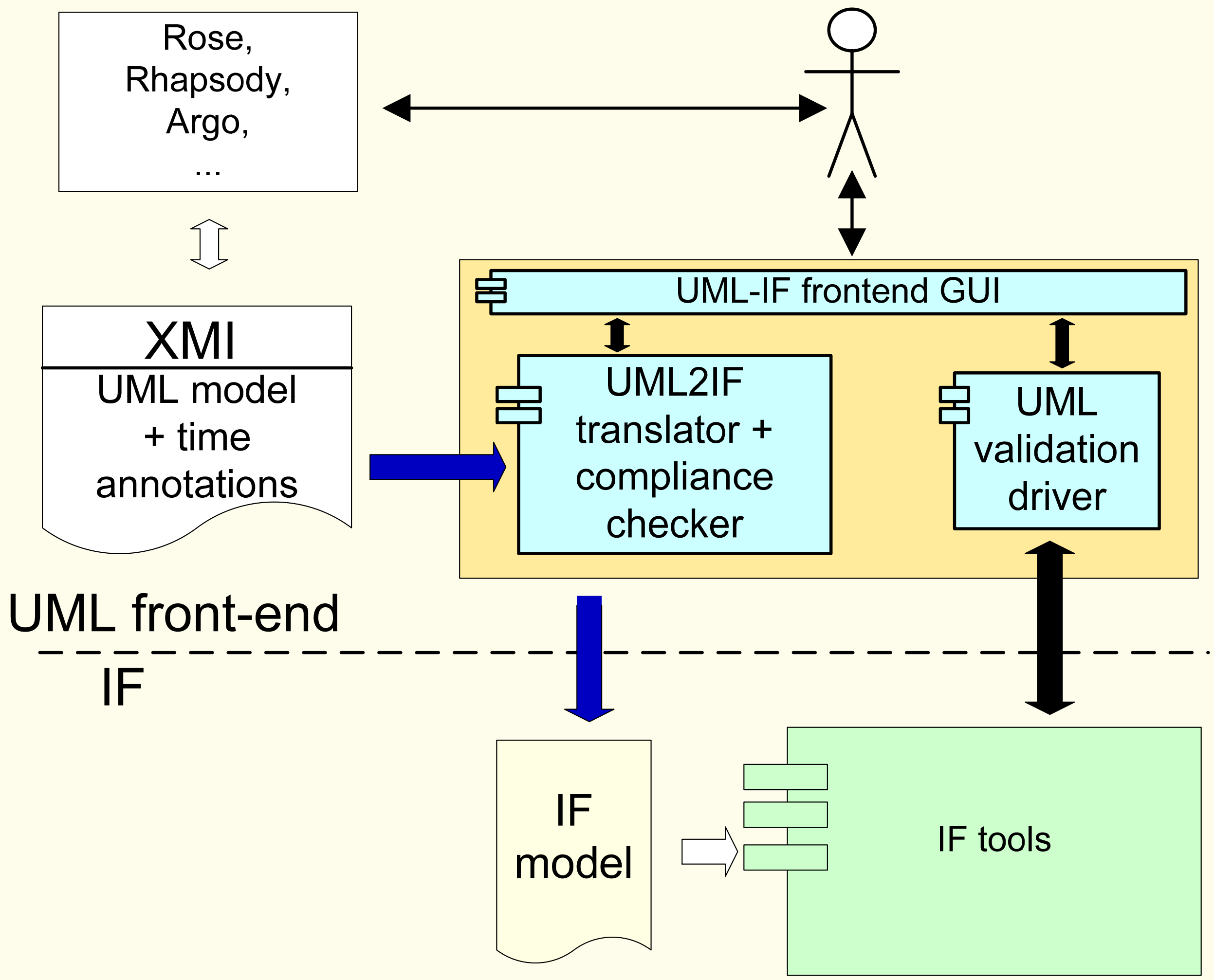


IF

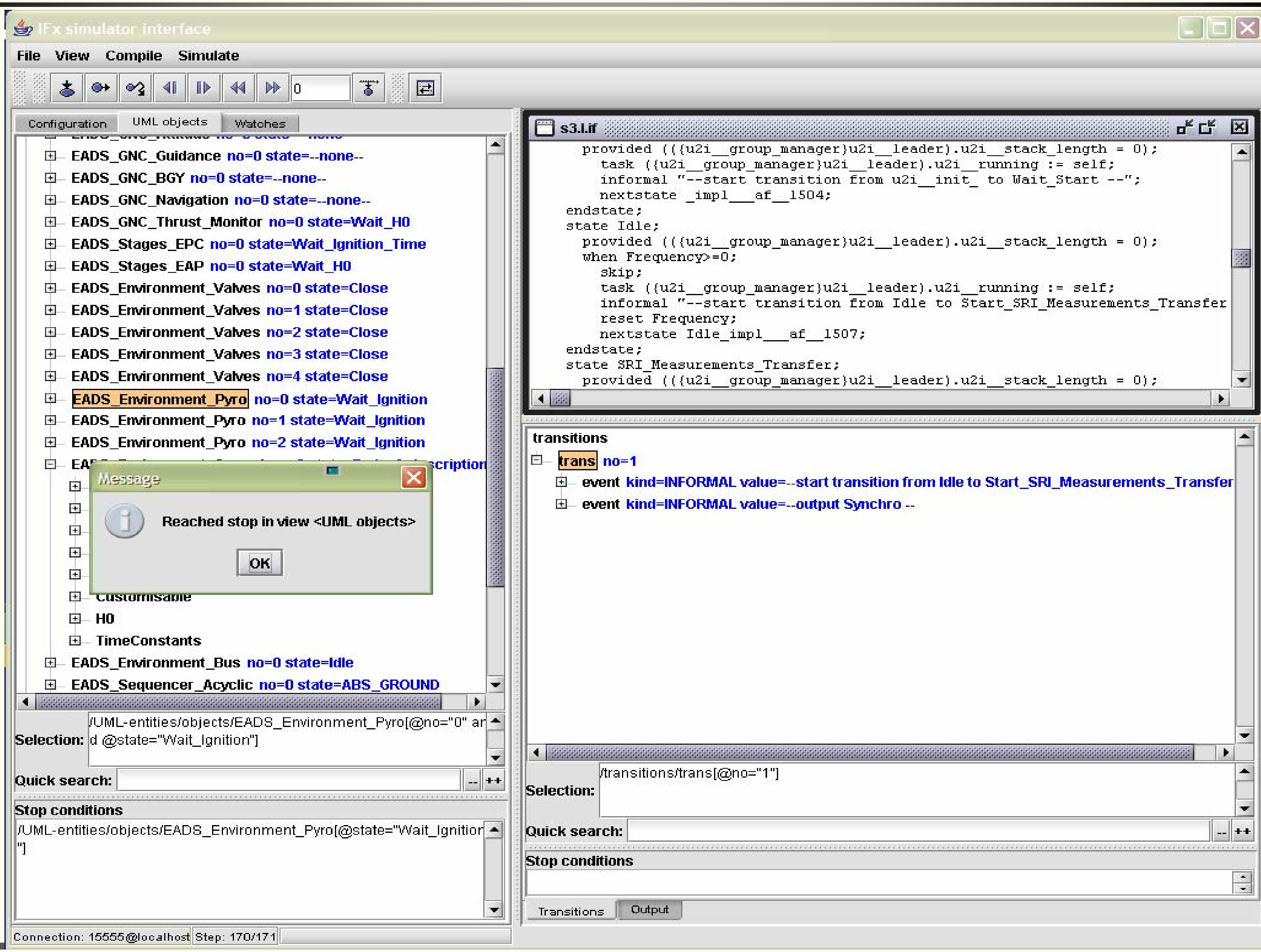




IFx: global architecture



IFx: simulation/verification interface



- user friendly simulation
  - rewind/reply
  - conditional breakpoints
  - …
- customizable presentation of results for UML users

Outline

- IF notation and tool-set (8)
- Omega Real-time profile (7)
- IFx: IF frontend for UML (5)
- Case studies (x)

IFx: case studies

Ariane-5 flight program (together with EADS) – Rational Rose

- statically validate the well formedness of the model wrt the Omega profile,
- 9 safety properties of the flight regulation and configuration components,
- analyzed the schedulability of the cyclic / acyclic components under the assumption of fixed priority preemptive scheduling policy,
- safety properties concerning bus read/write access under this policy

MARS bus monitor (together with NLR) – I-Logix Rhapsody

- static validation
- proved 4 safety properties concerning the correctness of the MessageReceiver,
- discover reactivity limits of the MessageReceiver and to fine-tune its behavior in order to improve reactivity.

Sensor Voting (together with IAI) – Rational Rose

- static validation
- proved 4 safety properties concerning the timing of data acquiring by the three Sensors: end-to-end duration, duration between consecutive reads, etc.

A depannage service specification (done FT) – Rational Rose and IF

- showed service level timing properties

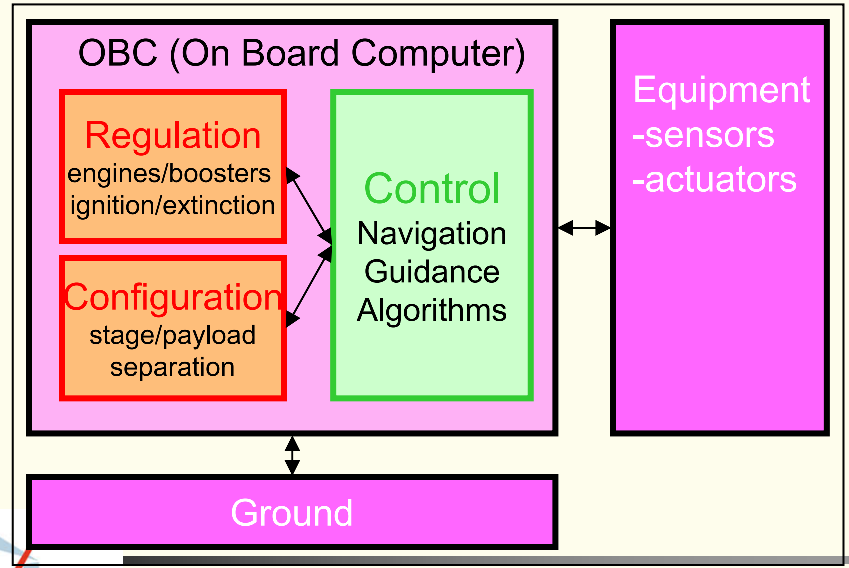
Ariane 5 flight program

Joint work with EADS SPACE Transportation

flight program specification

built by reverse engineering by EADS
high level, non-deterministic, abstracts the whole program as a OMEGA UML model

23 classes, 27 runtime objects
~7000 lines of IF code



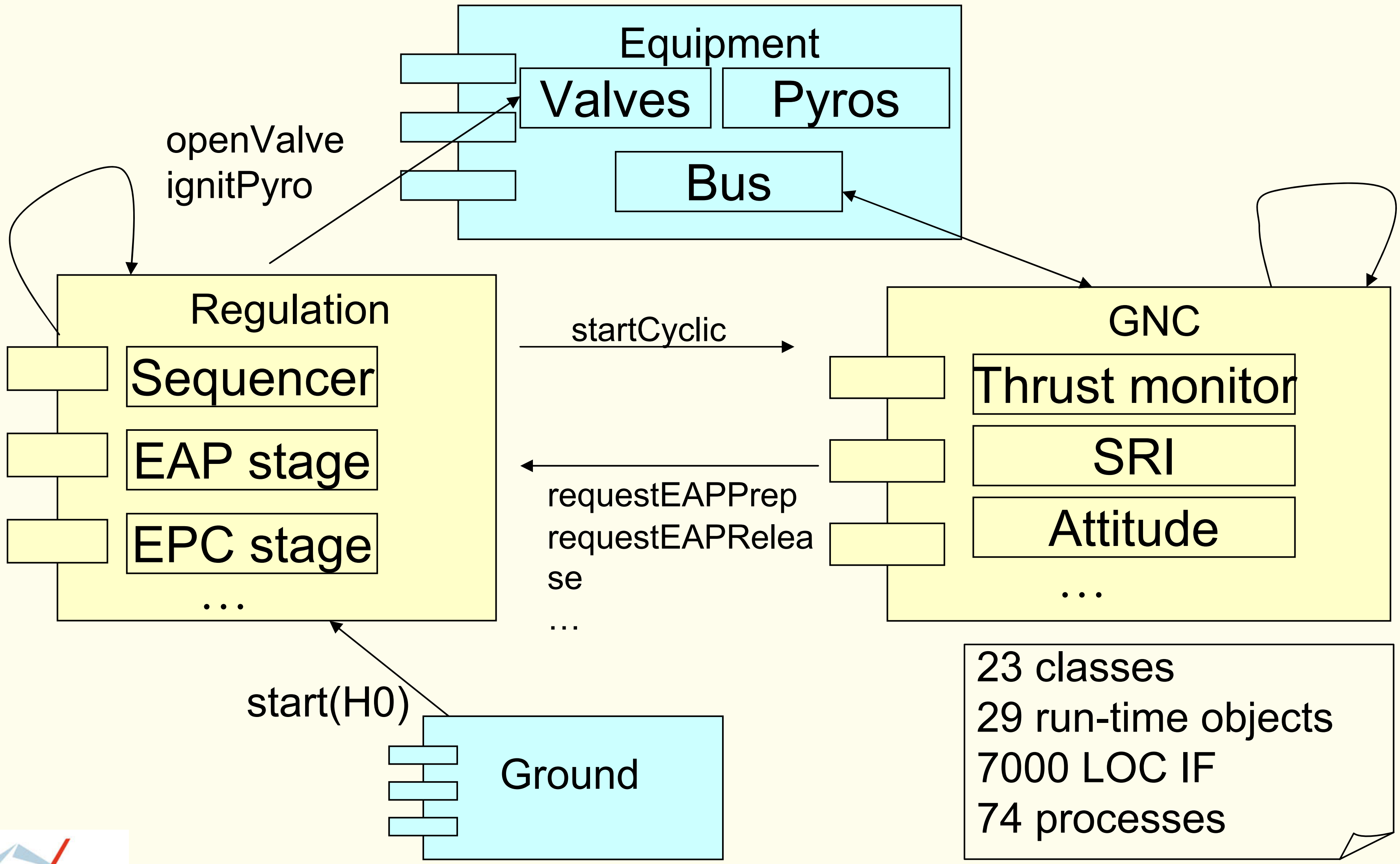
flight program requirements

General requirements
- no deadlock, no timelock
- no implicit signal consumption

Overall system requirements
- flight phase order
- stop sequence order

Local requirements of components
- activation signals arrive in some predefined time interval

Ariane 5: Model architecture



Ariane 5: techniques applied

translation

- Mapping of complete UML specification into IF with **uml2if**
- fixed static errors (typing, naming)

model generation

partial order reduction needed

the full state space cannot be constructed

use some conservative abstractions

model exploration

random or guided simulation

several inconsistencies found

model checking

9 safety properties about the correct sequencing of sub-phases

- concern only the acyclic part
- abstraction of GNC part

schedulability analysis

- concerns the entire system
- abstraction of mission duration

static analysis

live variable analysis

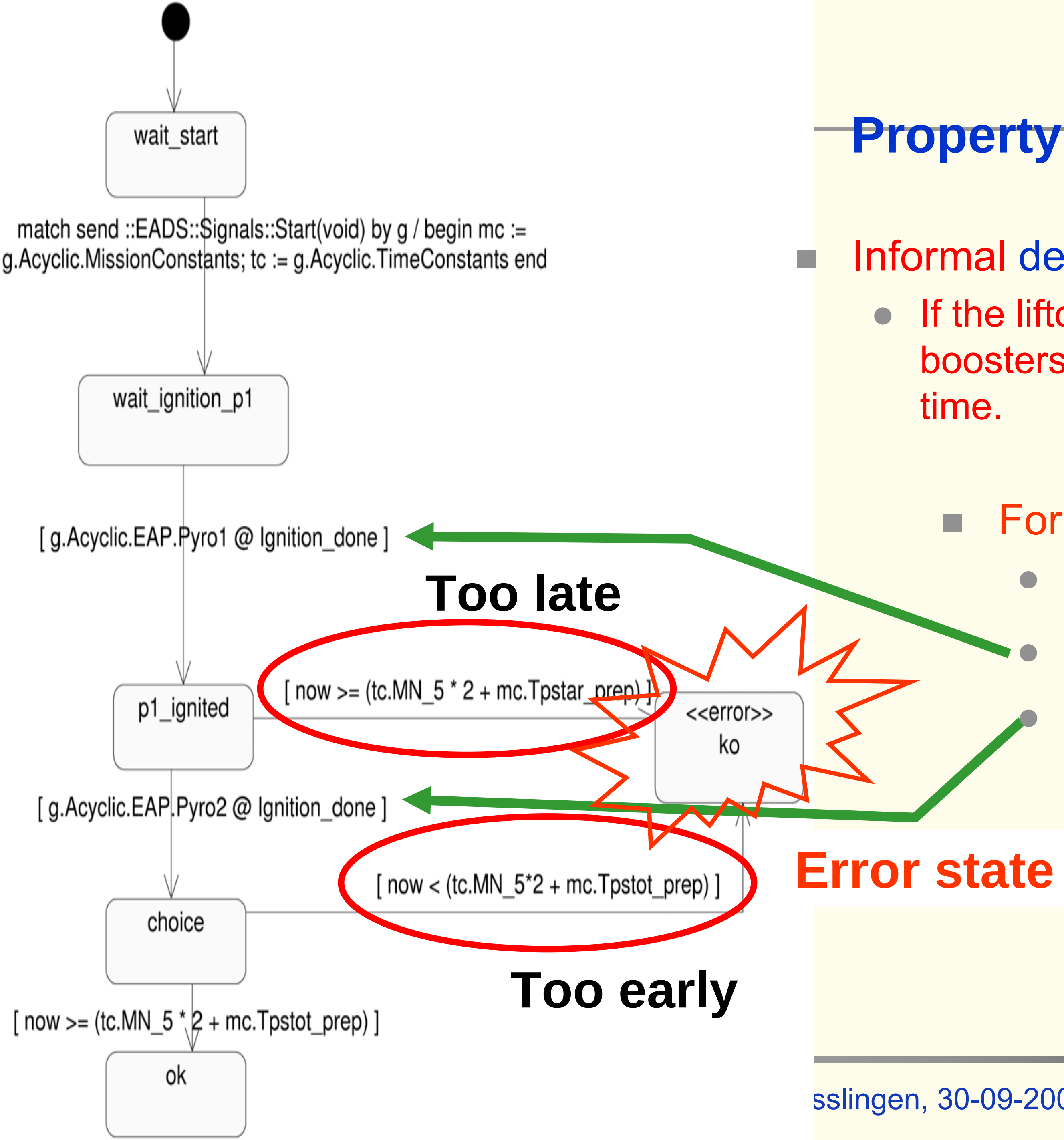
20% of all variables are dead in each state

- *9 safety properties about the correct sequencing of sub-phases:*
  - *between any two commands sent by the flight program to the valves there should elapse at least 50ms*
  - *a valve should not receive signal Open while in state Open, nor signal Close while in state Closed.*
  - *if some instance of class Valve fails to open (i.e. enters the state Failed Open) then*
    - No instance of the Pyro class reaches the state Ignition done.
    - All instances of class Valve shall reach one of the states Failed Close or Close after at most 2 seconds since the initial valve failure.
    - The events EAP Preparation and EAP Release are never emitted.
  - *…*

Property example (timed)

- Informal description
  - If the liftoff is performed, the boosters shall be released at due time.

- Formal description
  - Using an observer
  - Liftoff = pyro1.ignition
  - Boosters release = pyro2.ignition



- pre-emptive fixed priority scheduling
  - one processor
  - three tasks :

Regulation
- sporadic
- E = 2-5ms (func)
- priority : 0

NC
- periodic 72ms
- E = 37-64ms (f)
- priority : 1

Guidance
- periodic 576ms
- E = ? ms
- priority : 2

why we cannot abstract functionality