

UPPAAL - Present and Future

Gerd Behrmann¹, Alexandre David², Kim G. Larsen¹, M. Oliver Möller³,
Paul Pettersson², Wang Yi²

¹ Aalborg University, ² Uppsala University, ³ BRICS Århus

Outline:

- 1 Model-checking Timed Automata
- 2 Internal Optimizations
- 3 Applications: Protocols & Controllers
- 4 Extensions of the Modeling Language

Collaborators

@ UPPsala

Wang Yi
Johan Bengtsson
Paul Pettersson
Fredrik Larsson
Alexandre David
Tobias Amnell
Elena Fersmann

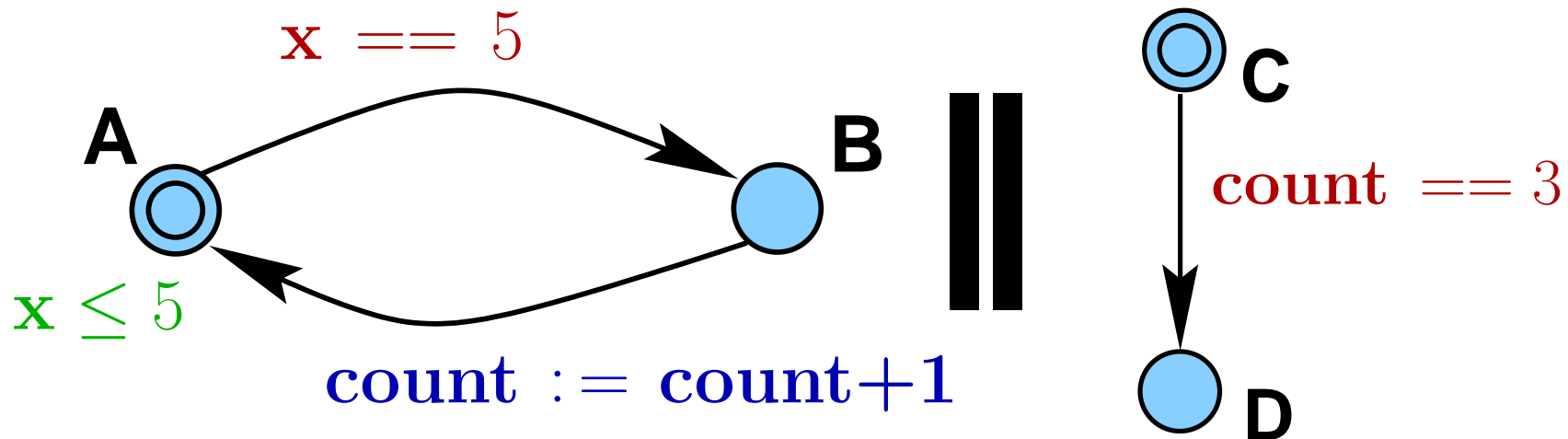
@ AALborg

Kim G. Larsen
Arne Skou
Carsten Weise
Kåre J. Kristoffersen
Gerd Behrmann
Thomas Hune
M. Oliver Möller

@ many other places

David Griffioen, Ansgar Fehnker, Frits Vandraager, Klaus Havelund, Theo Ruys, Pedro DArgenio, J-P Katoen, J. Tretmans, Judi Romijn, Ed Brinksma, Franck Cassez, Magnus Lindahl, Francois Laroussinie, Patricia Bouyer, Augusto Burgueno, H. Bowmann, D. Latella, M. Massink, G. Faconti, Kristina Lundqvist, Lars Asplund, Justin Pearson, ...

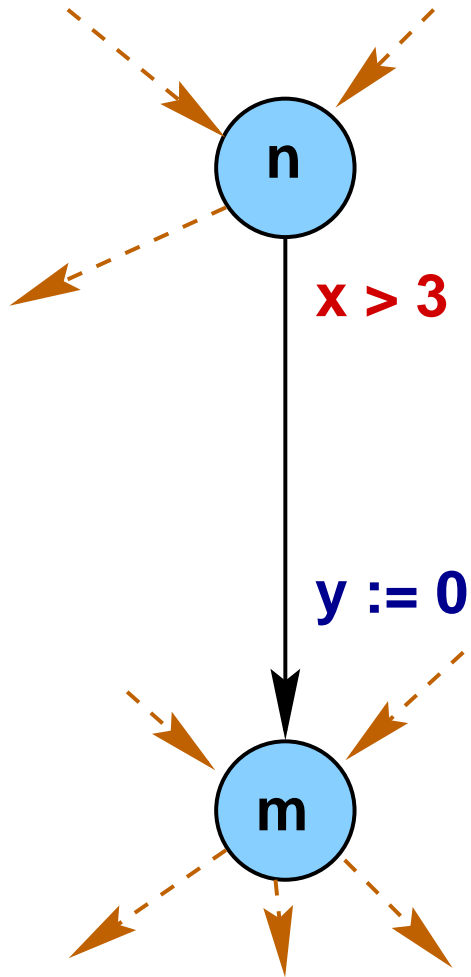
UPPAAL: Model checking Timed Automata



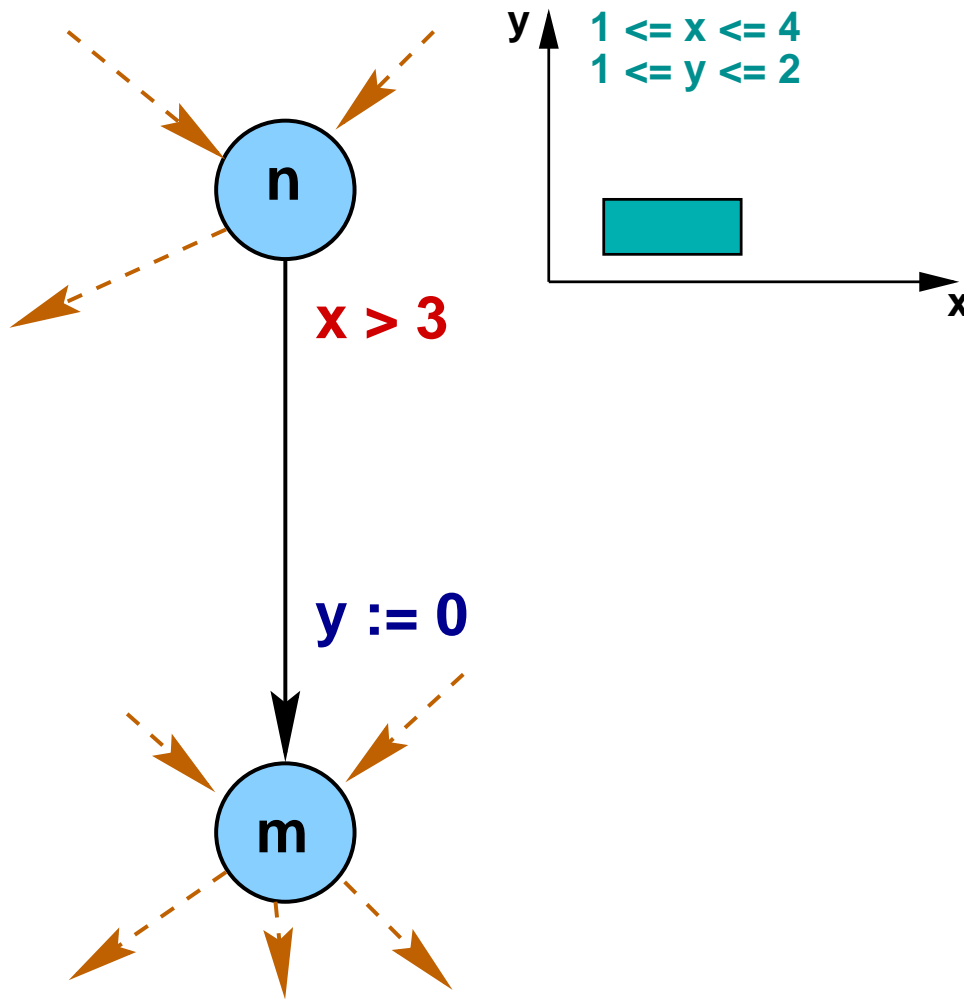
```
clock x; int count
```

- network of timed automata
- discrete data types
- arrays
- hand-shake synchronization
- urgency
- template mechanism
- committed locations
- **forward** state-space exploration

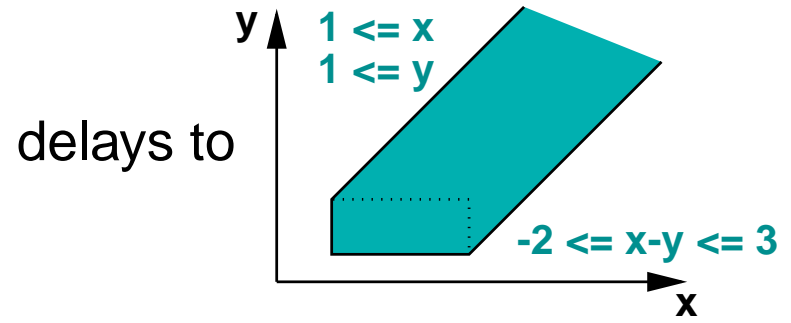
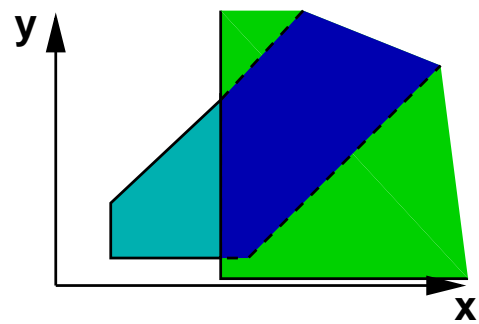
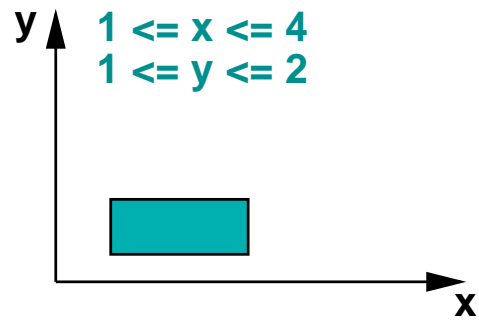
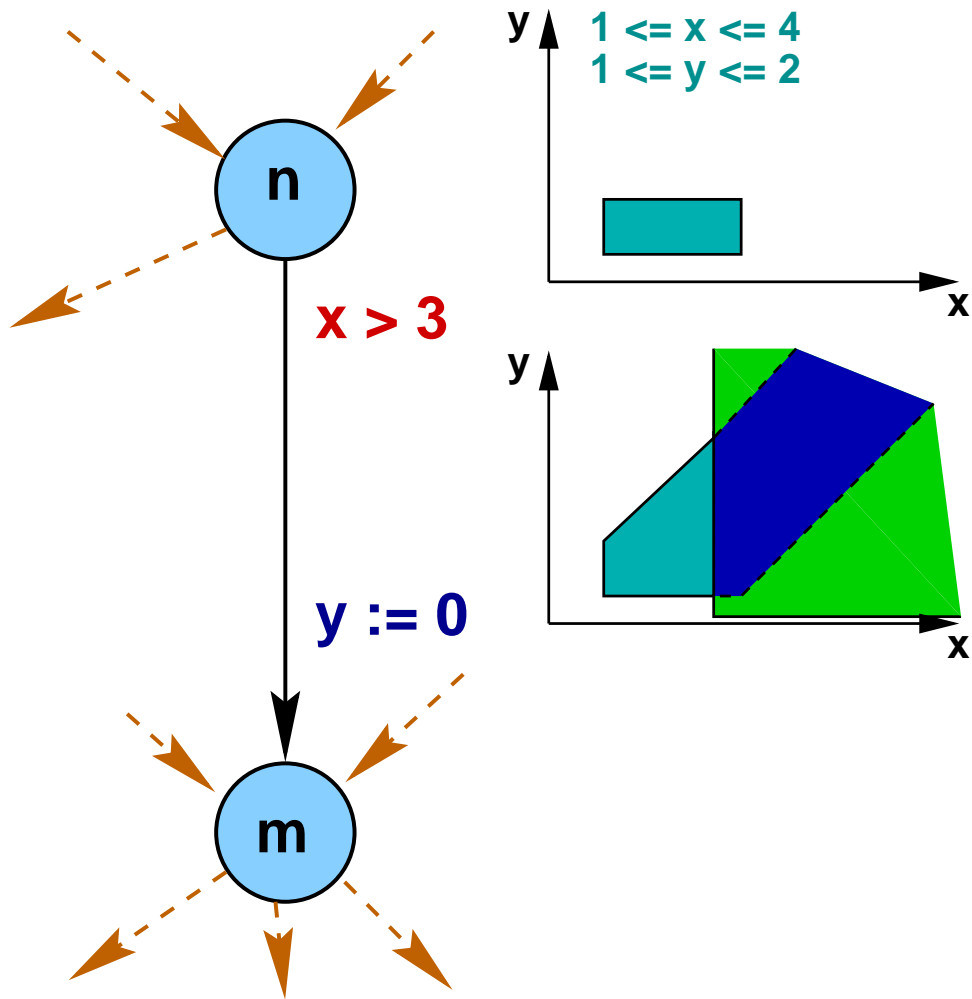
Symbolic Transitions



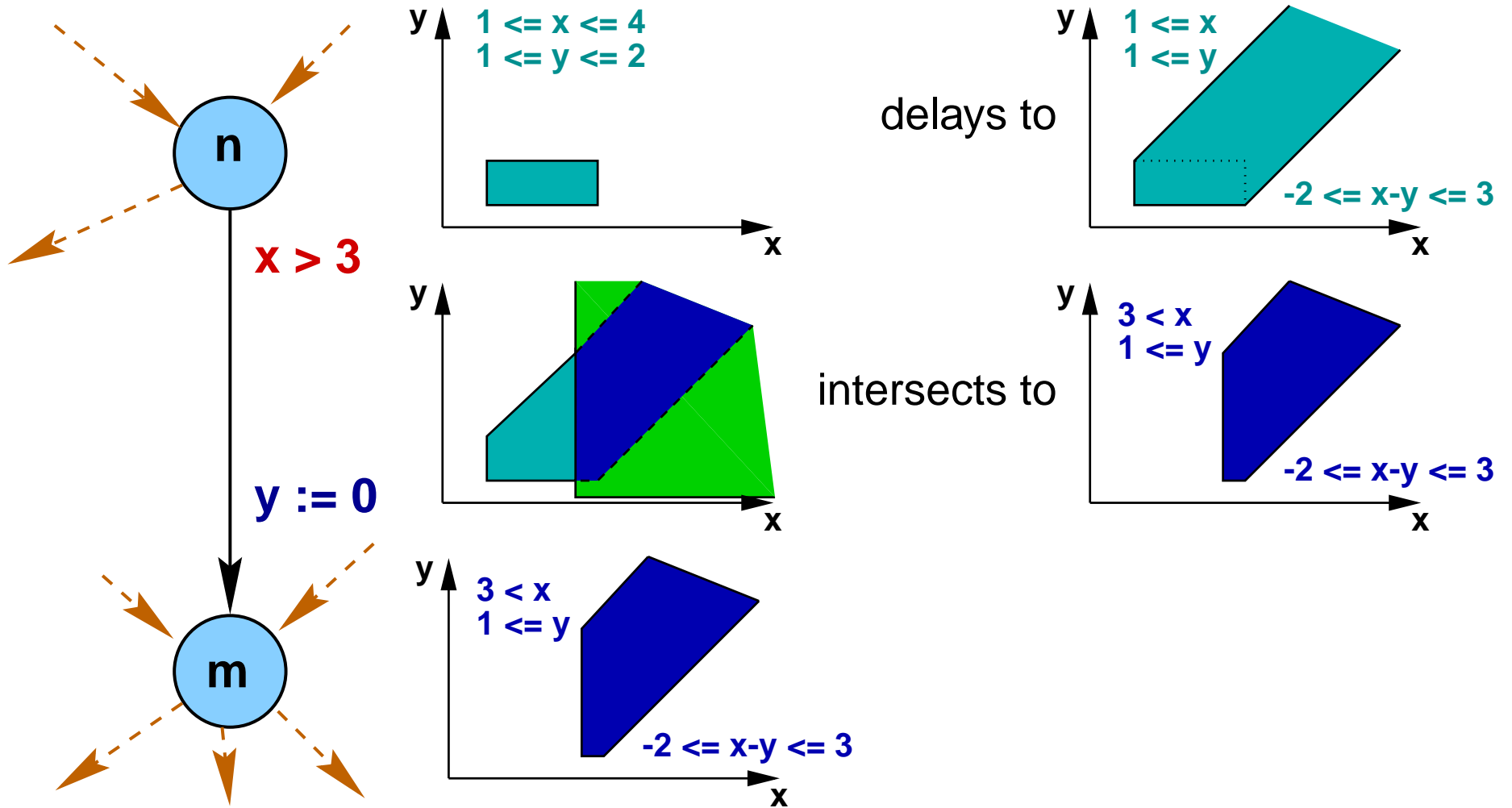
Symbolic Transitions



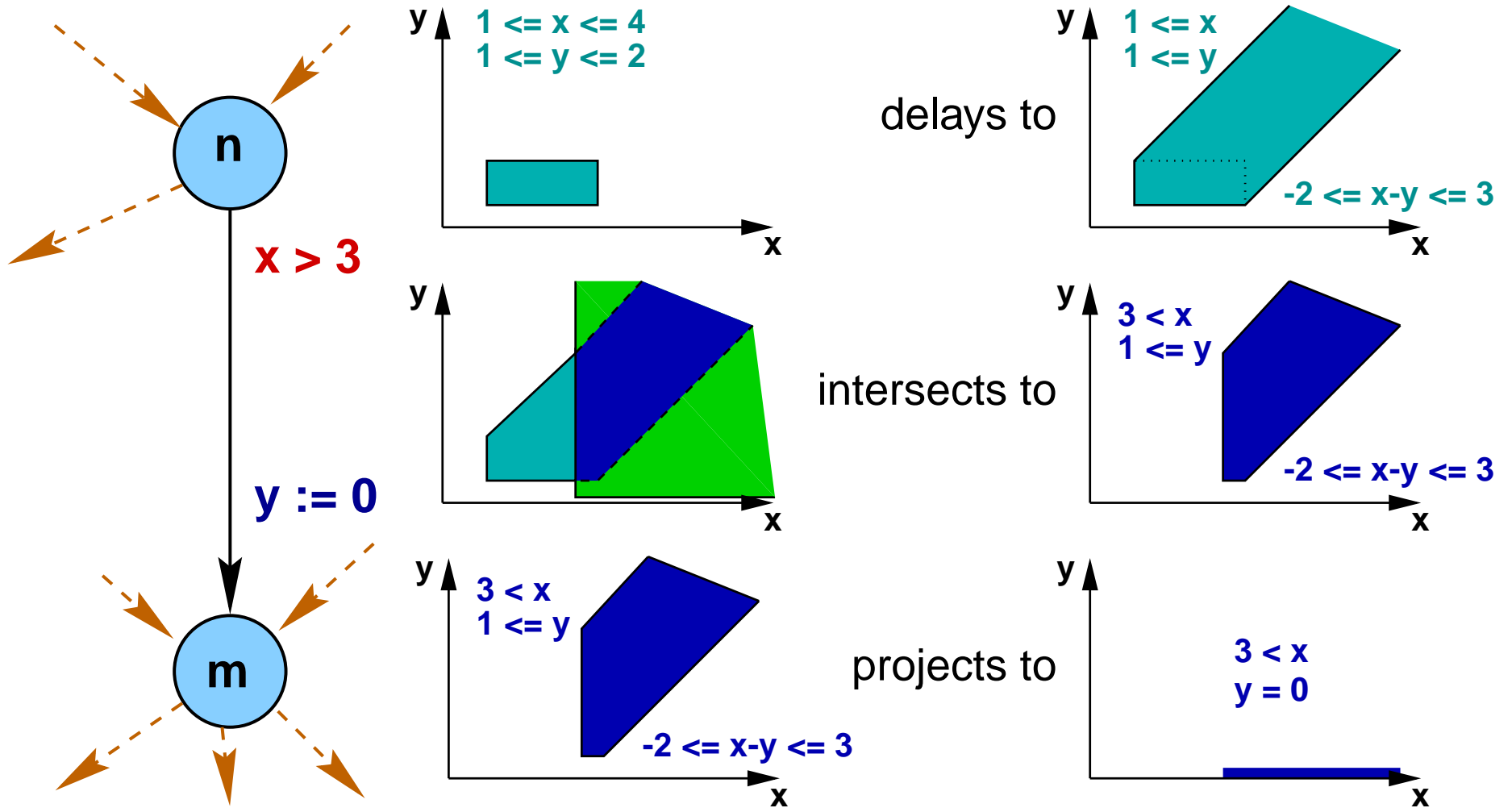
Symbolic Transitions



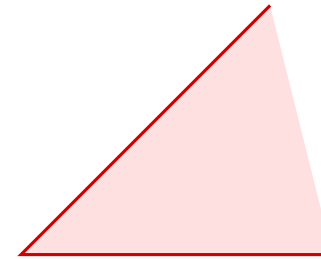
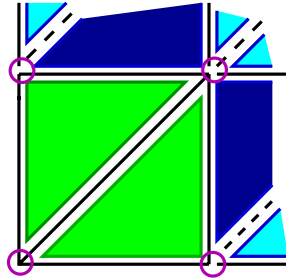
Symbolic Transitions



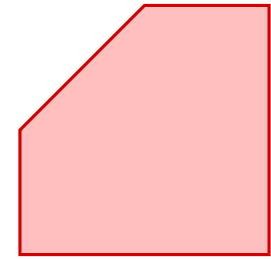
Symbolic Transitions



Sets of Clock-Evaluations



$$y - x \leq 0$$

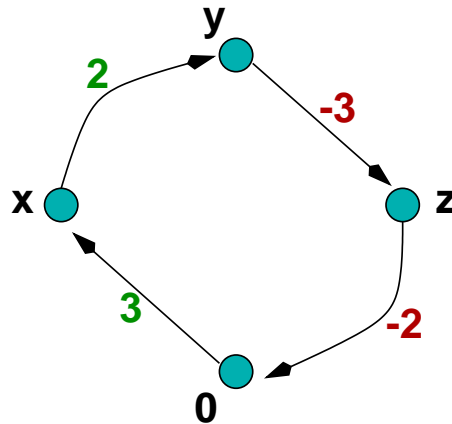


$$1 \leq x < 3 \wedge y \leq 2 \wedge y - x \leq 0$$

regions: smallest distinguishable sets

zones: convex unions of regions

representing (unions of) zones: DBMs, CDDs, DDDs, ...

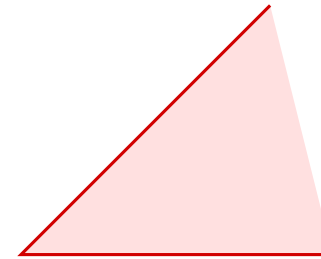
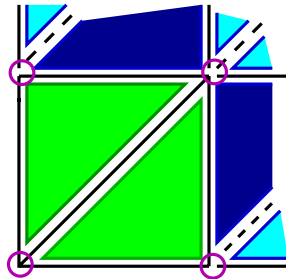


difference-bounded matrices

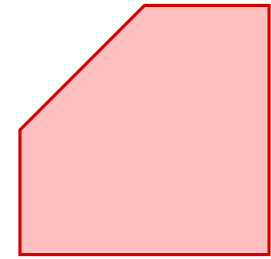
canonical

static

Sets of Clock-Evaluations



$$y - x \leq 0$$

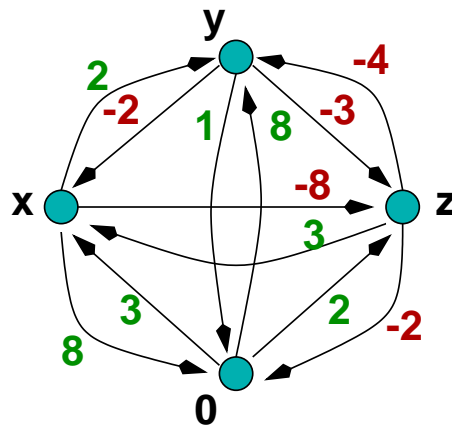


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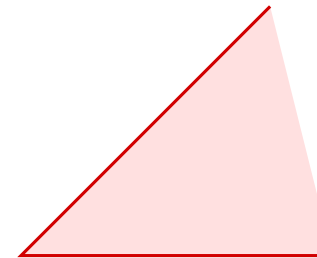
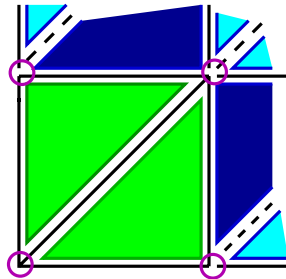


difference-bounded matrices

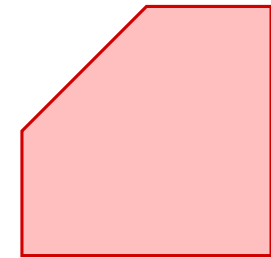
canonical

static

Sets of Clock-Evaluations



$$y - x \leq 0$$

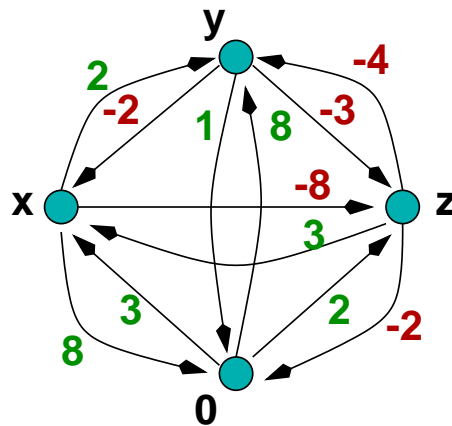


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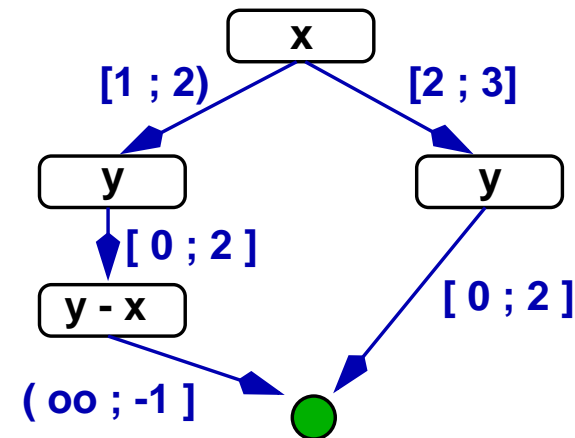
representing (unions of) zones: DBMs, CDDs, DDDs, ...



difference-bounded matrices

canonical

static

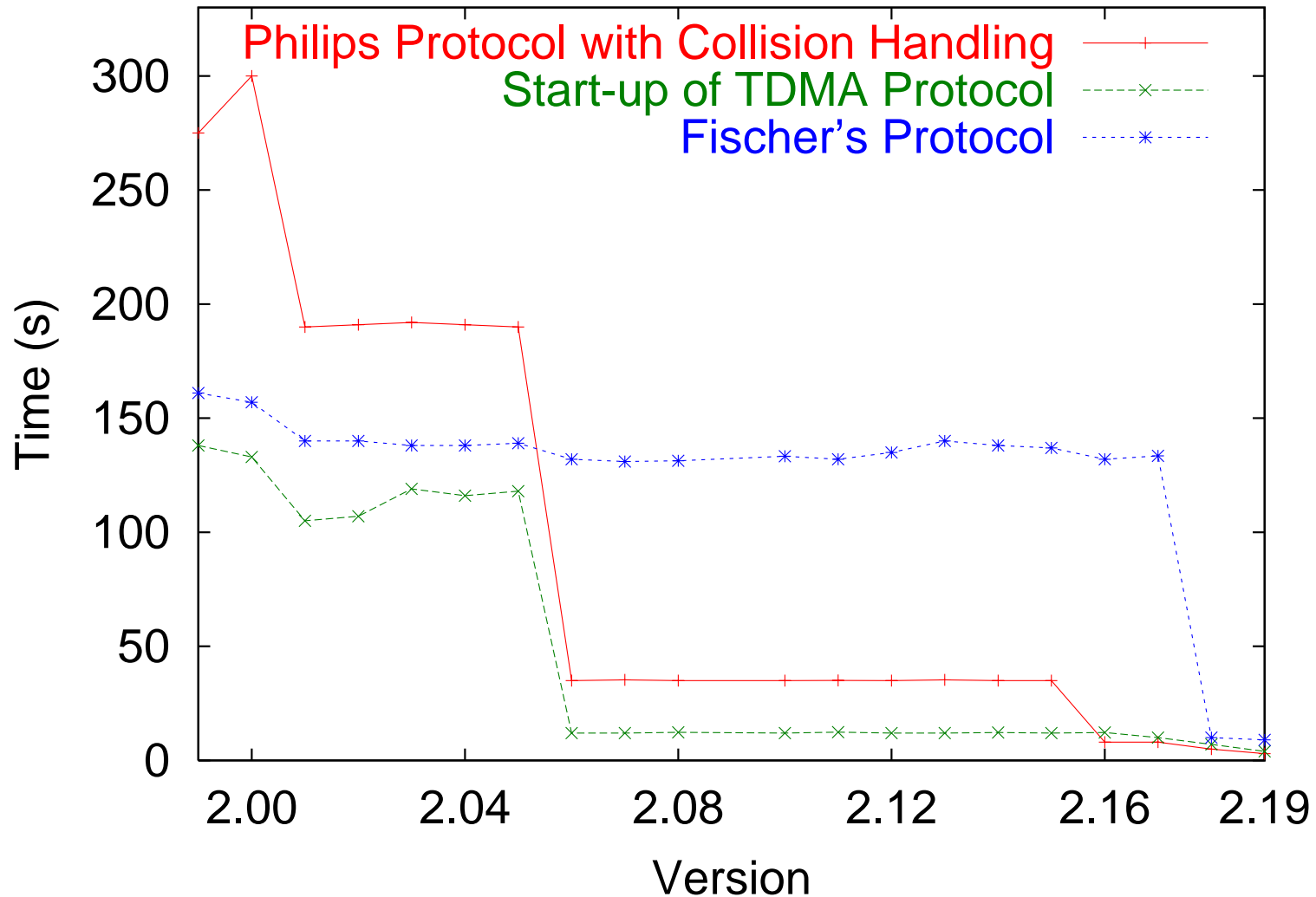


clock difference diagrams

non-canonical

flexible

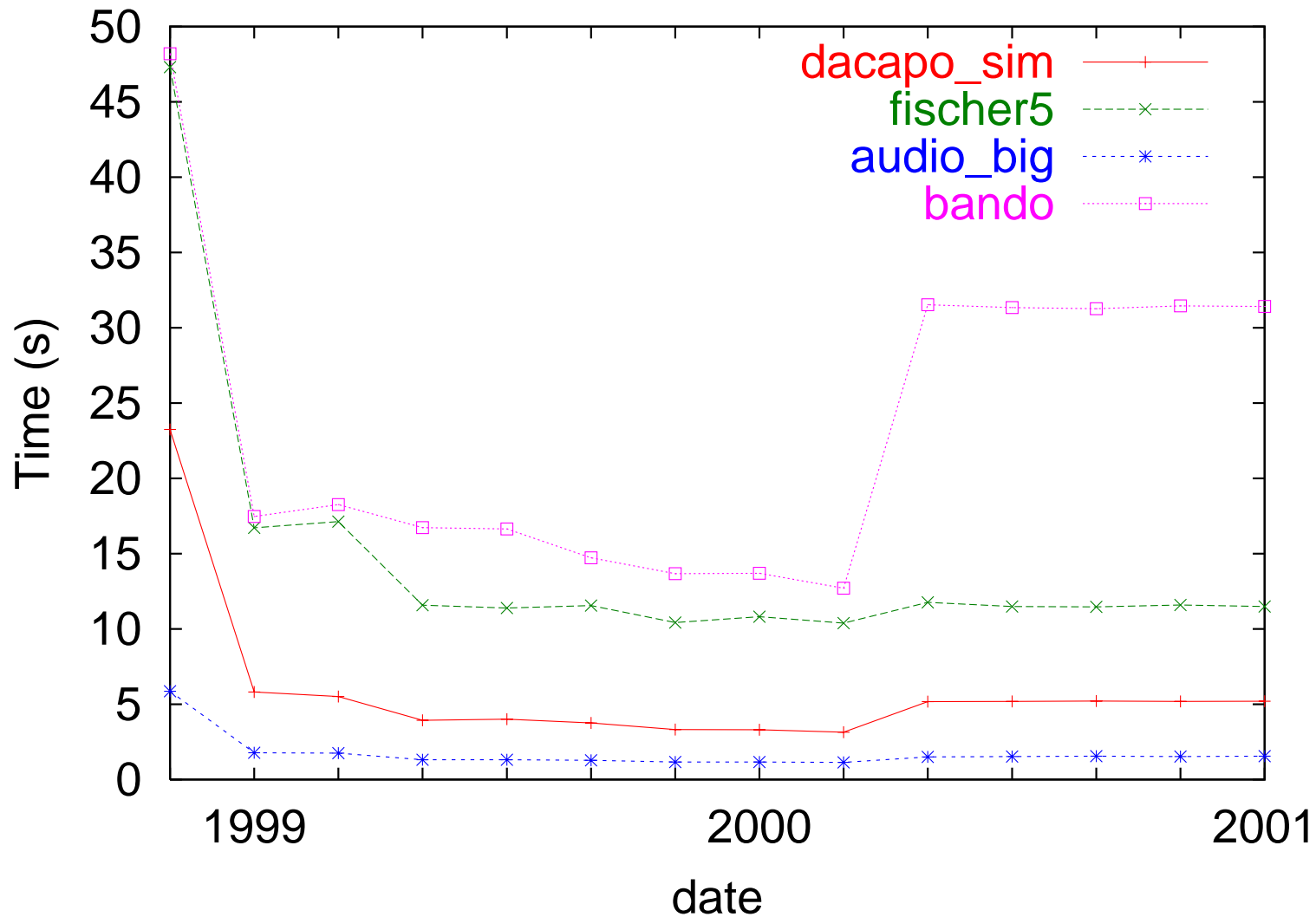
Engineering Improvements Dec '96 - Sept '98



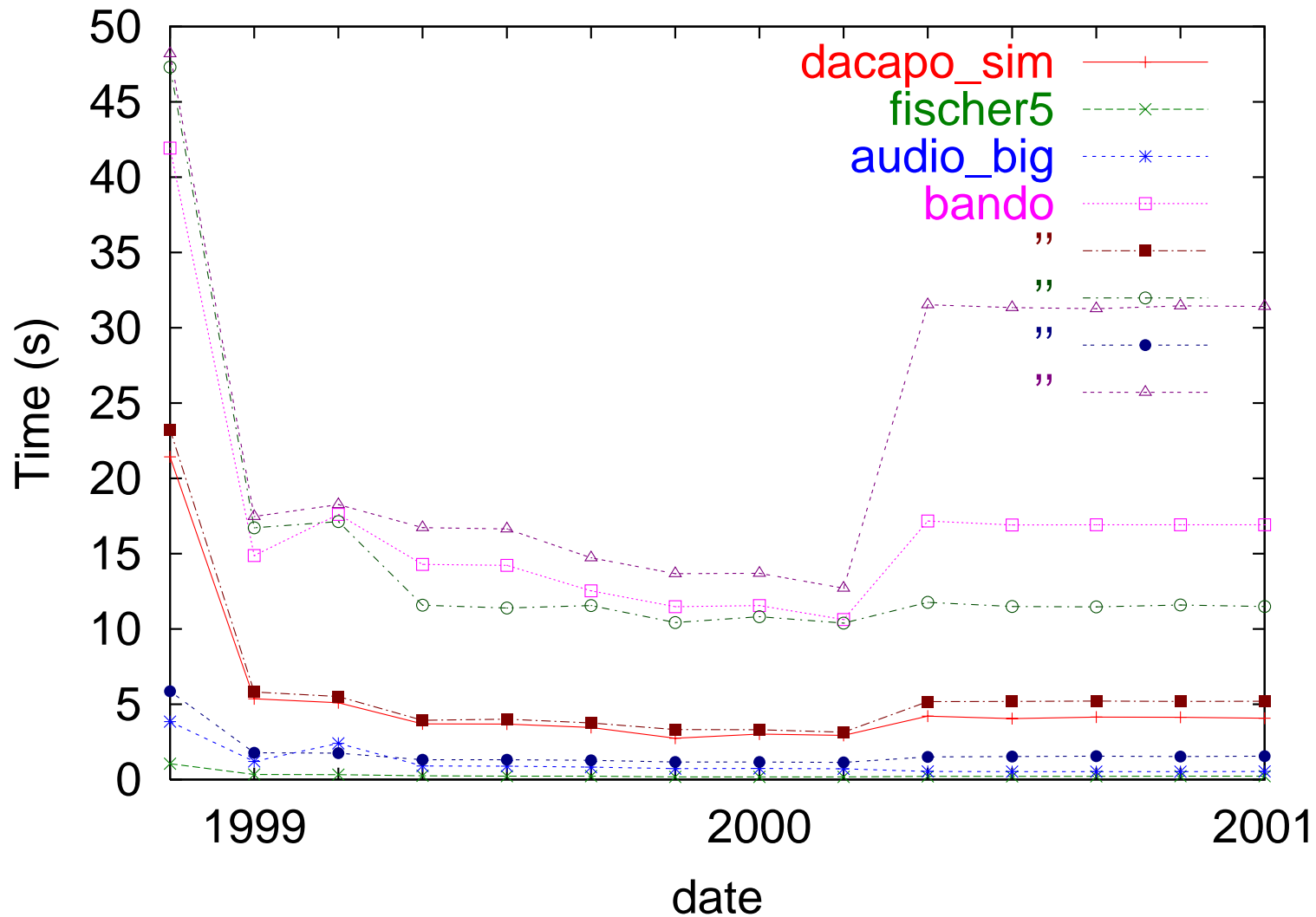
Internal Optimizations

- × committed locations (to reduce interleavings)
 - × active clock reduction
 - × variation of search order
 - × local reduction (compact DBM representation)
 - × global reduction (remove covered states from *Passed*)
 - ≈ convex hull over-approximation [safe]
 - ≈ bit-state hashing [sound]
- ... and of course: *a lot of software engineering!*

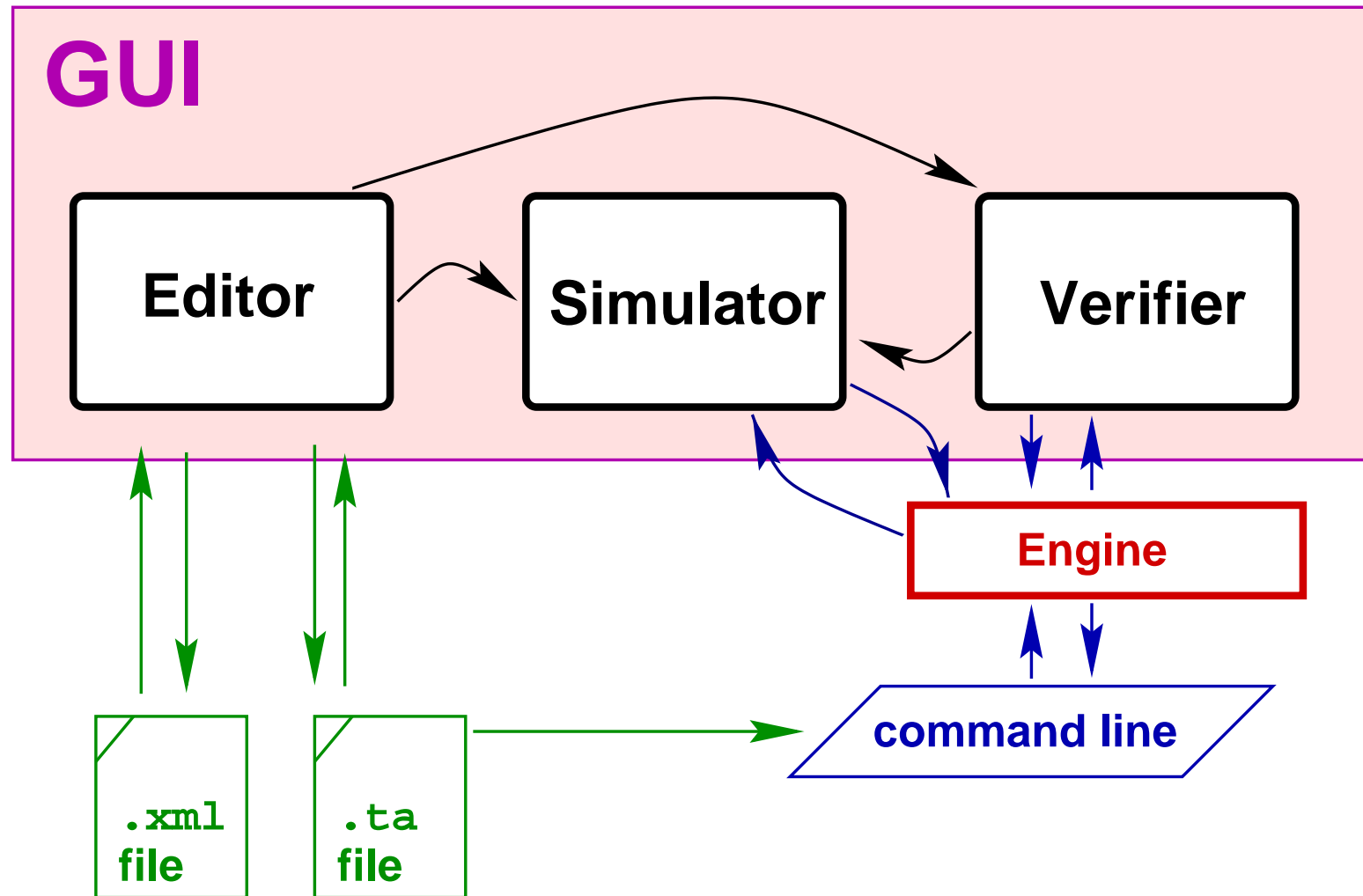
Benchmarks (without optimizations)



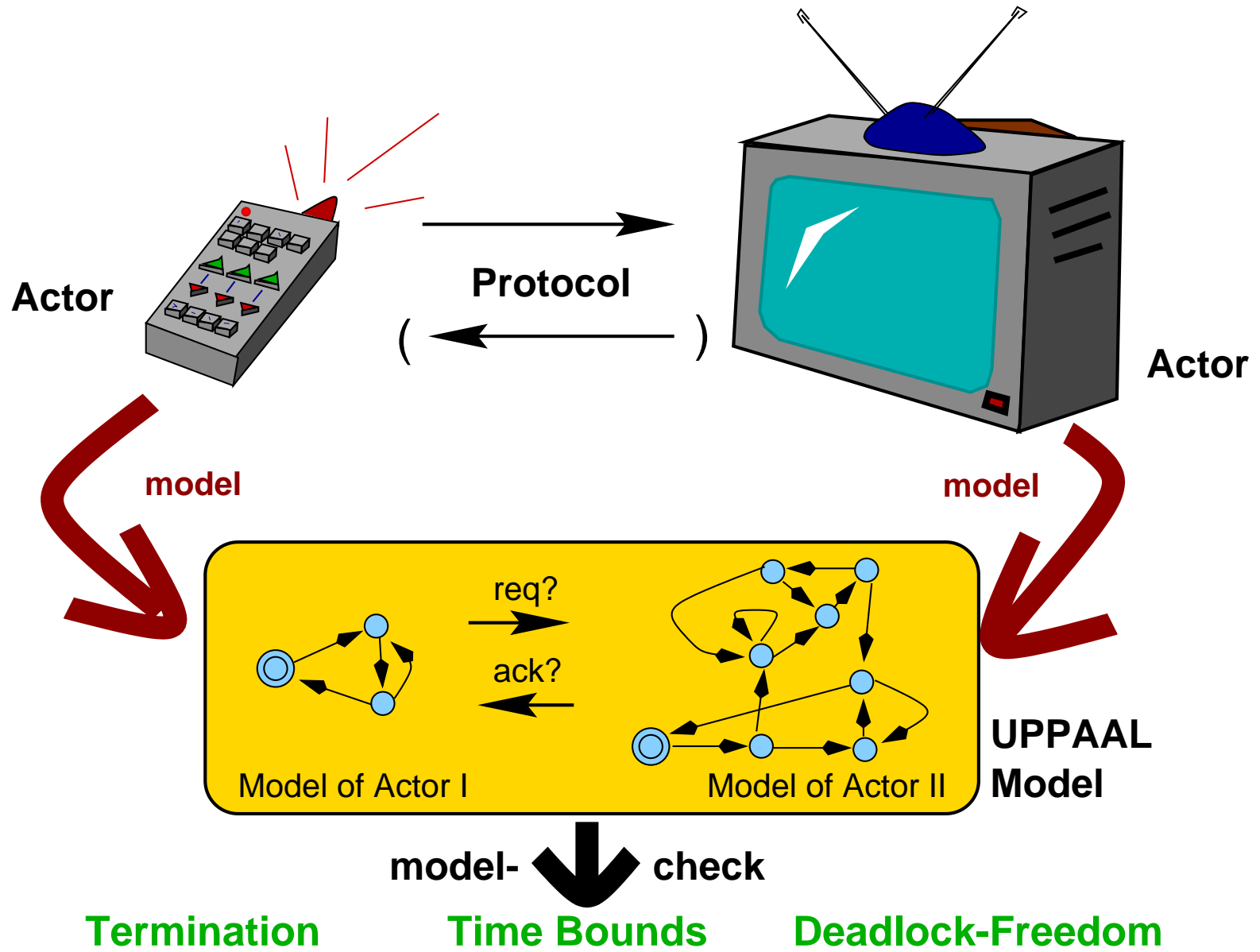
Benchmarks (with optimizations)



Architecture of UPPAAL



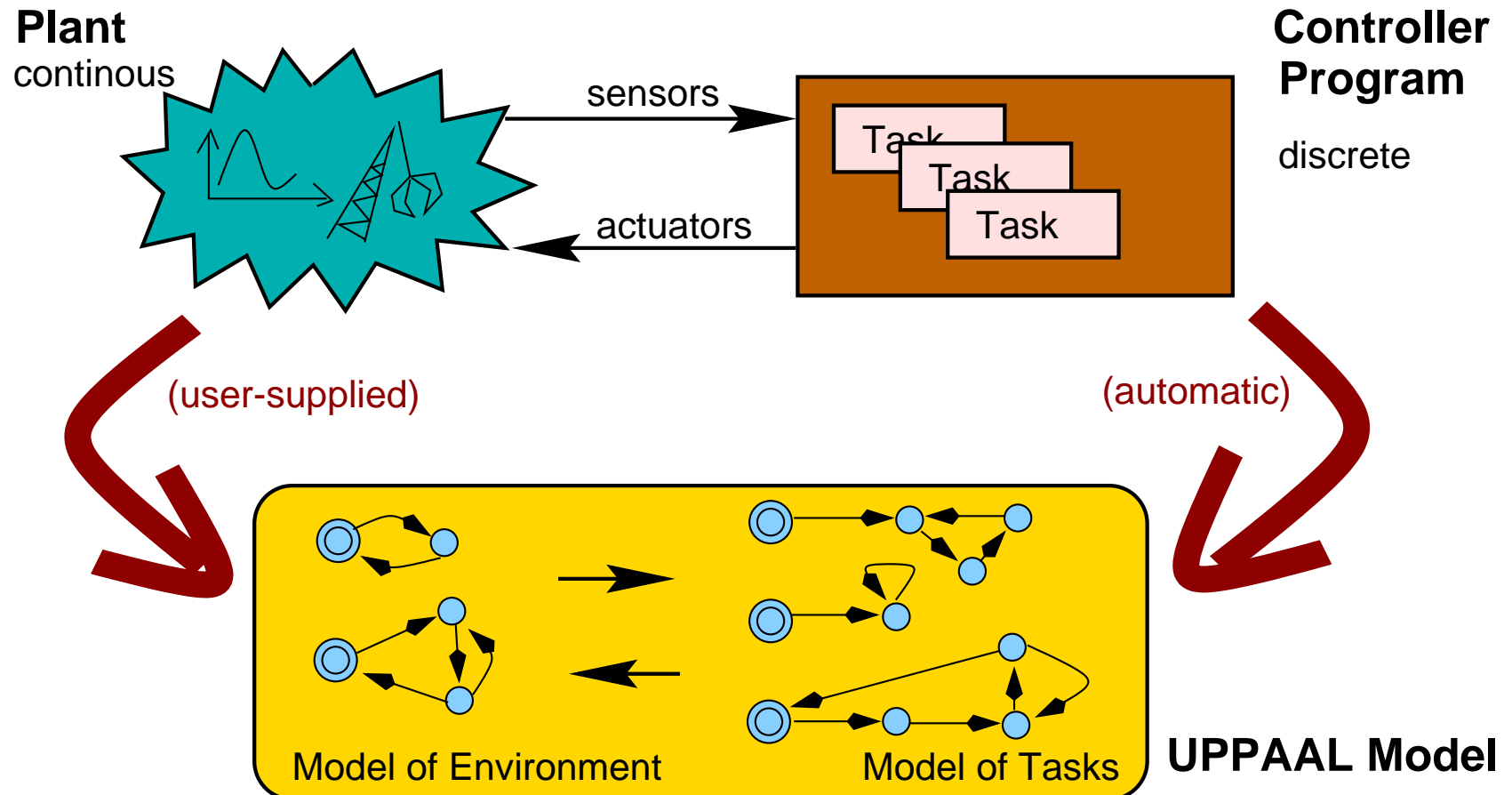
Communication Protocols



Case Studies: Protocols

- Philips Audio Protocol [HS95, CAV95, RTSS95, CAV96]
- Collision-Avoidance Protocol [SPIN95]
- Bounded Retransmission Protocol [TACAS97]
- Bang & Olufsen Audio/Video Protocol [RTSS97]
- TDMA Protocol [PRFTS97]
- Lip-Synchronization Protocol [FMICS97]
- Multimedia Streams [DSVIS98]
- ATM ABR Protocol [CAV99]
- ABB Fieldbus Protocol [ECRTS2k]
- IEEE 1394 Firewire Root Contention [STTT'01]

Composing the Embedded System Model



Case Studies: Controllers

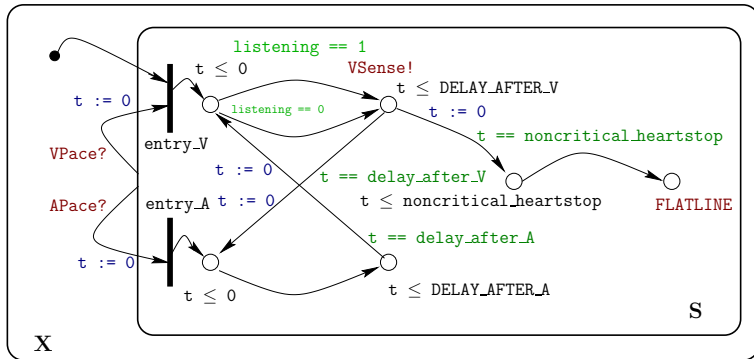
- Gearbox Controller [TACAS98]
- Bang & Olufsen Power Controller [RTPS99, FTFT2k]
- SIDMAR Steel Production Plant [RTCSA99, DSVV2k]
- Real-Time RCX Control-Programs [ECRTS2k]
- RCX Production Cell (2000)
- Experimental Batch Plant [ICDCS'01]
- Saab Car Locking System [RT-TOOLS'01]

Extensions of the Modeling Language

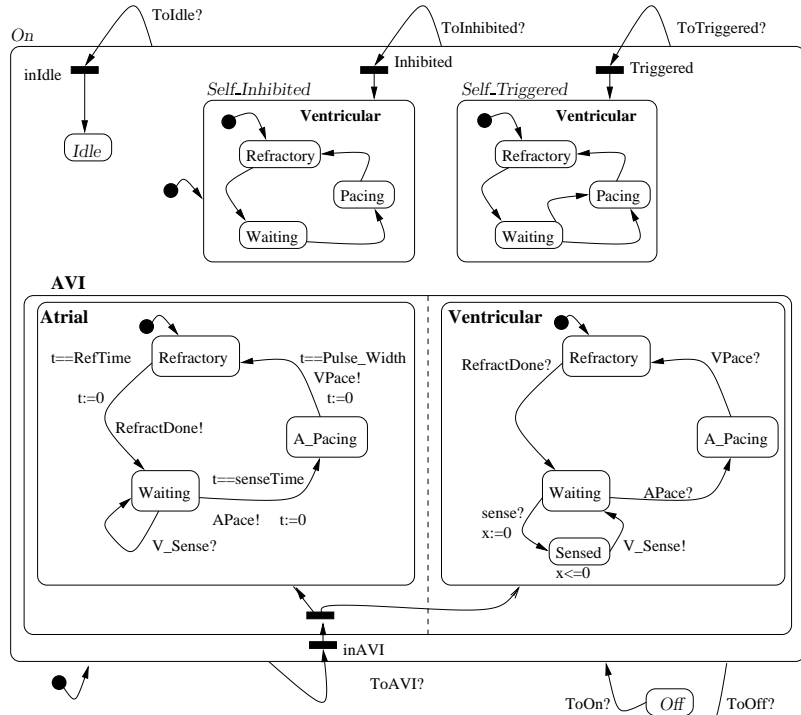
- ➔ **Stopwatch** extension
- ➔ **Probabilistic** timed automata
- ➔ **Hierarchical** timed automata
- ➔ **Parameters** on clock constraints
- ➔ **Cost-Optimal** timed automata
- ➔ **Executable** timed automata

Hierarchical UPPAAL

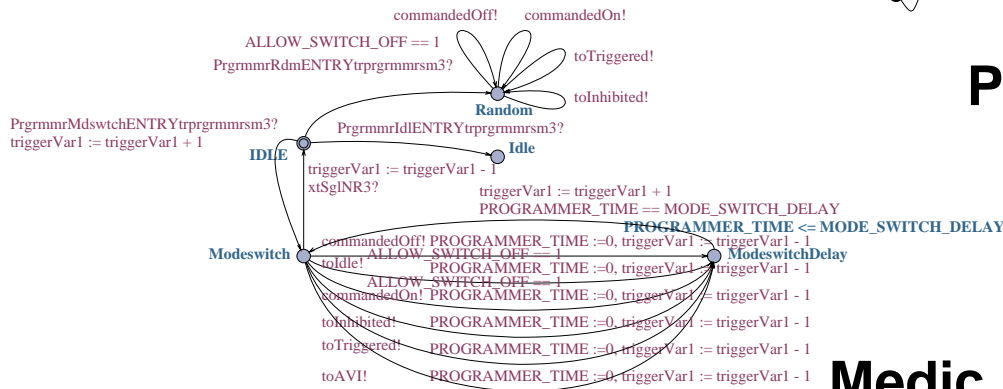
Use **hierarchical** timed automata:



Human Heart



Pacemaker



Medic

Flattened Version of the Pacemaker

HTA model	# XML tags	564	→	1191	UPPAAL model
	# proper control locations	35	→	45	

- SAFETY:

$A[] \neg \text{heart stops}$

- LIVENESS:

$A[] V\text{contract} \Rightarrow A\langle\rangle A\text{contract}$

Parameters:

REFRACTORY_TIME = 50

SENSE_TIMEOUT = 15

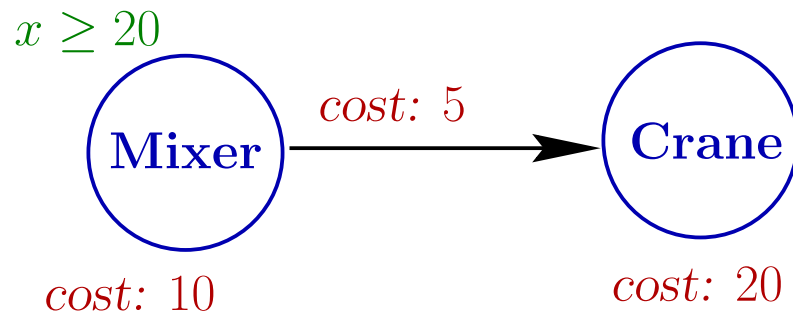
DELAY_AFTER_V = 50

DELAY_AFTER_A = 5

MODE_SWITCH_DELAY = 66

E.g. for $\text{MODE_SWITCH_DELAY} = 65$, $A[] \neg \text{heart stops}$ is violated

Cost-Optimality



Idea: Add *cost* to locations and actions

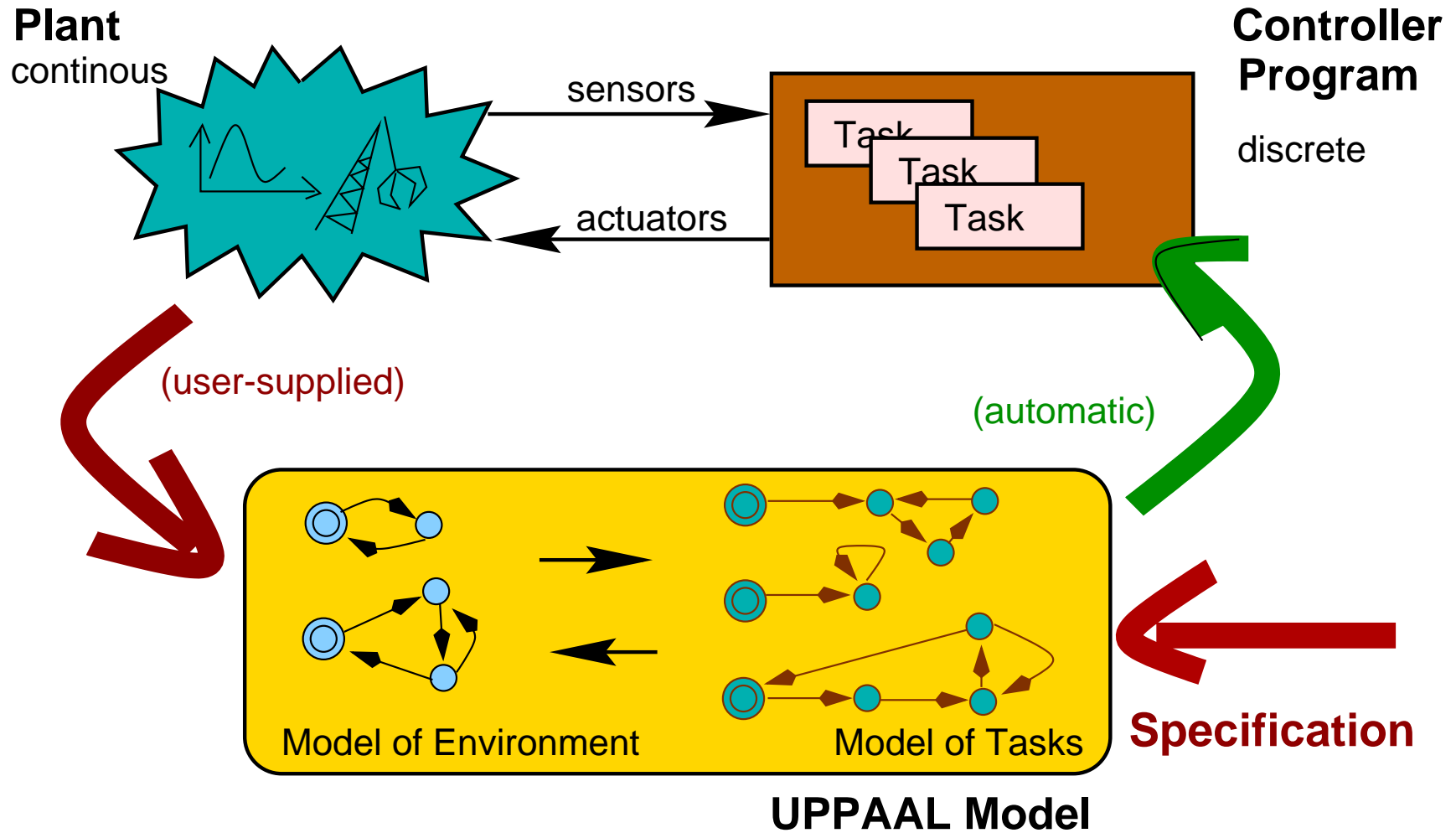
Starting Point: 'cost' not necessarily uniform

Approach: attach different (integer) prices to locations
treat algorithmically with *priced zones*

Applied: compute schedule for a steel batch plant in Gent
and a LEGO model of it [Feh99, HLP00]

Fact: Cost-Optimal trace is computable

Controller Synthesis



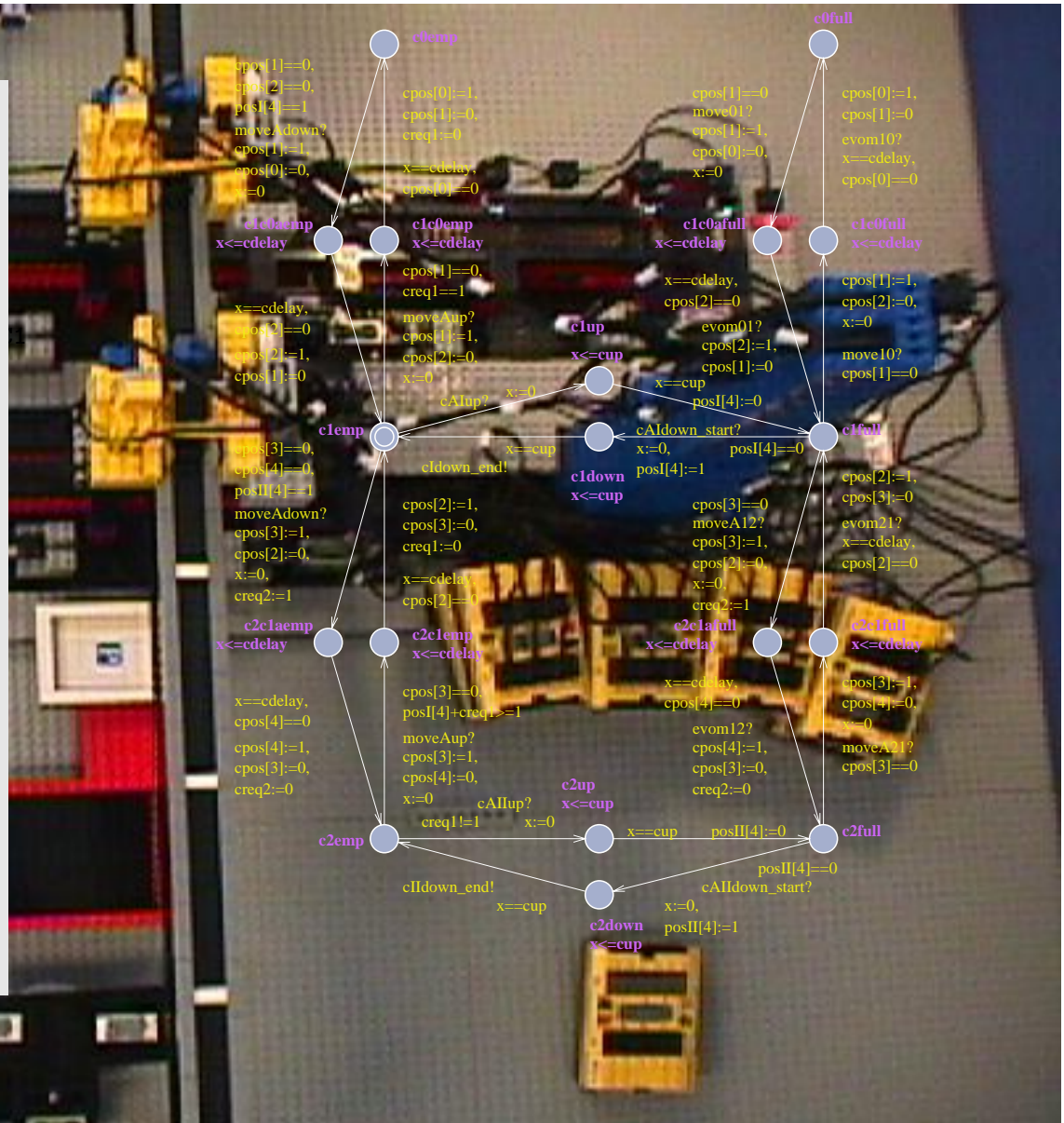
SIDMAR Steel Production Plant (LEGO Version)

```

'''Delay 15
PB.Wait 2, 1500

'''cAIup();
'''Crane A - Pick UP
PB.PlaySystemSound 1
PB.SendPBMMessage 2, 97 'Pick up, on
PB.SetVar 1, 15, 0 'Wait for ack
PB.While 0, 1, 3, 2, 97
PB.Wait 2, 20
PB.SetVar 1, 15, 0 'Read the message
PB.ClearPBMMessage
PB.SumVar 2, 2, 1
PB.If 0, 2, 2, 2, 20
'If looped 20 times
PB.PlaySystemSound 1
PB.SendPBMMessage 2, 97 'Then Send
'message, again same as sendig 0
PB.SetVar 2, 2, 0
PB.EndIf
PB.EndWhile

'''Delay 10
PB.Wait 2, 1000
    
```



Cost-Optimal Extension: Summary

- completely random schedules not analyzable
→ guides/optimality *restrict* behavior
- the LEGO model helped *debugging* the UPPAAL model

Compared to traditional (LP) methods:

- reasonably efficient
- more **flexible**
- *aircraft landing* case study:
computed schedules either **better** or **substantially worse**

Completed Parts

- ✓ cost-optimal extension
- ✓ parametric extension
- ✓ stopwatch extension
- ✓ distributed UPPAAL

Work in Progress

- probabilistic extension
- hierarchical extension
- executable UPPAAL

Work Planned

- ★ dynamic partitioning
- ★ hybrid animation

Go, Get It!

UPPAAL2k (3.2.1) available for

Linux, SunOS, and MS Windows

<http://www.uppaal.com/>

Since July 1999: > 1'000 downloads (from different users)

> 60 countries

Open mailing list: <http://groups.yahoo.com/group/uppaal>

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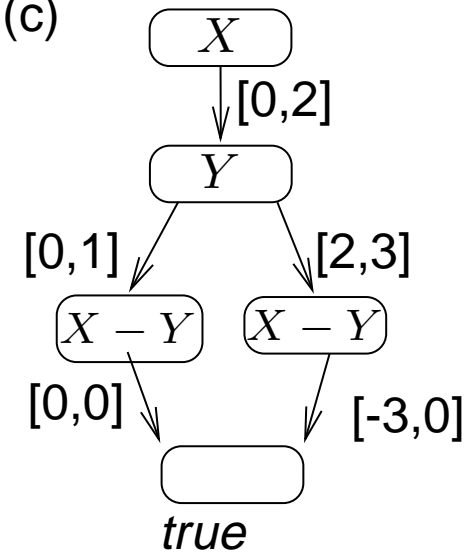
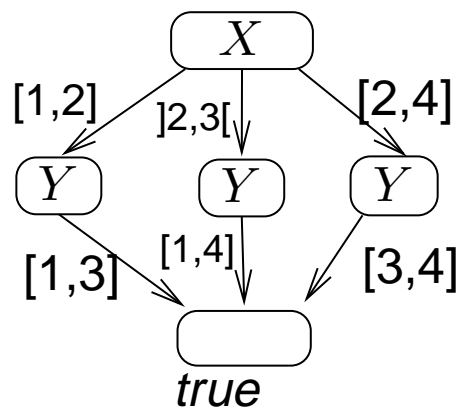
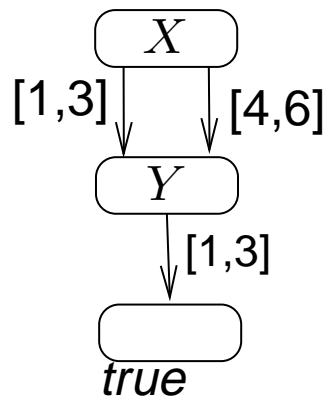
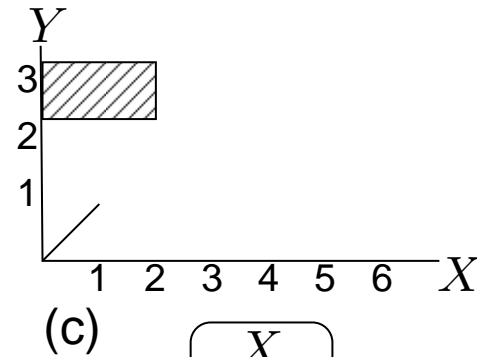
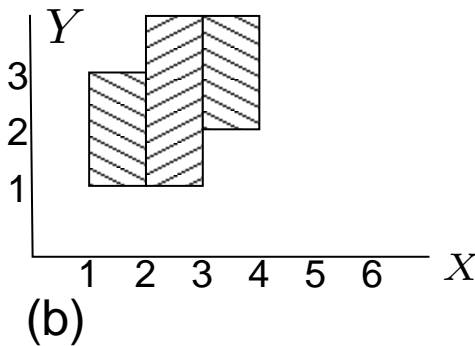
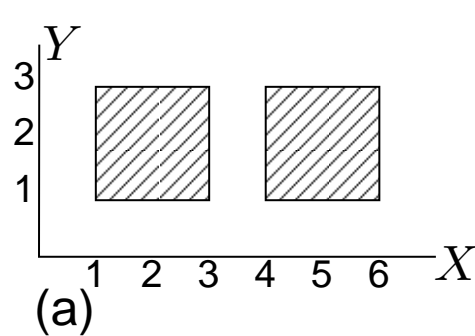
Clock Difference Diagrams (CDDs)

Data structure to express disjunction of zones

- similar to BDDs
- rooted, directed, acyclic graph
- every node labeled x or $x - y$
- every edge labeled with an interval
- order of labels fixed
- one terminal node: true
- missing edges lead to false

 *not canonical*

Clock Difference Diagrams (CDDs) (2)



Stopwatch UPPAAL

timed automaton + stopwatches = SWA

Fact: Any *timed language* accepted by a *linear hybrid automaton* can also be accepted by a *stopwatch automaton*

linear hybrid automaton *—translate→* **SWA**

Problem: reachability analysis of SWA is undecidable

Observation: often it suffices to *over-approximate* reachability

Approach: run DBM-based SWA, with *approximative future*
(only differences of *two* stop-watches considered)

Notes: way to *translate* effects accuracy
more sophisticated translations could preserve *termination*

Probabilistic UPPAAL

Example Problem:

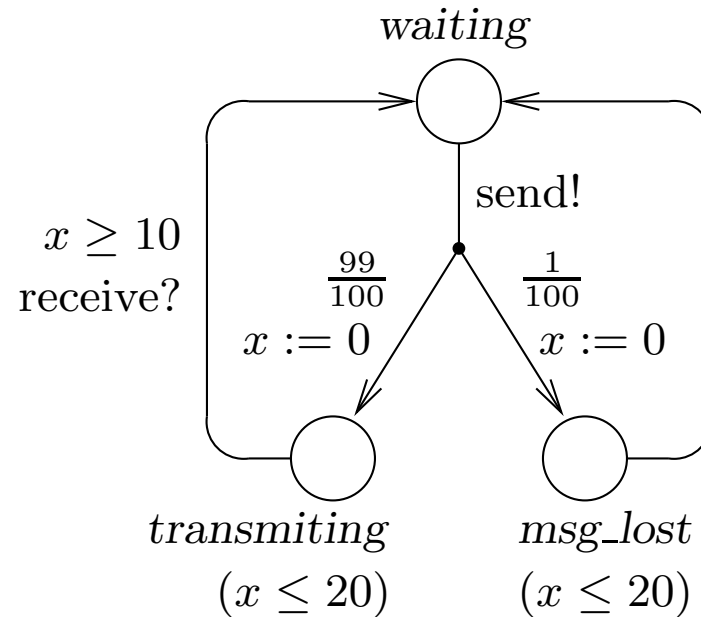
Lossy channel with known probabilities

Cannot prove:

in time X , message will arrive

But:

$P_{\geq 95\%}(\forall \square_{\leq 1000} \text{received})$



existing Approaches: Jensen 96, Kwiatkowska et al. 99

Problem: based on region graph construction

new Approach: use minimization techniques to obtain

stable probabilistic zone graphs

use matching data structure

Determining Parameters: *Parametric-Uppaal*

Parameters: in clock guards $x \bowtie p, x - y \bowtie p$
 $\bowtie \in \{<, \leq, =, \geq, >\}, p$ a linear expression

Fact: parameterized timed reachability undecidable for systems with ≥ 3 clocks [AHV93]

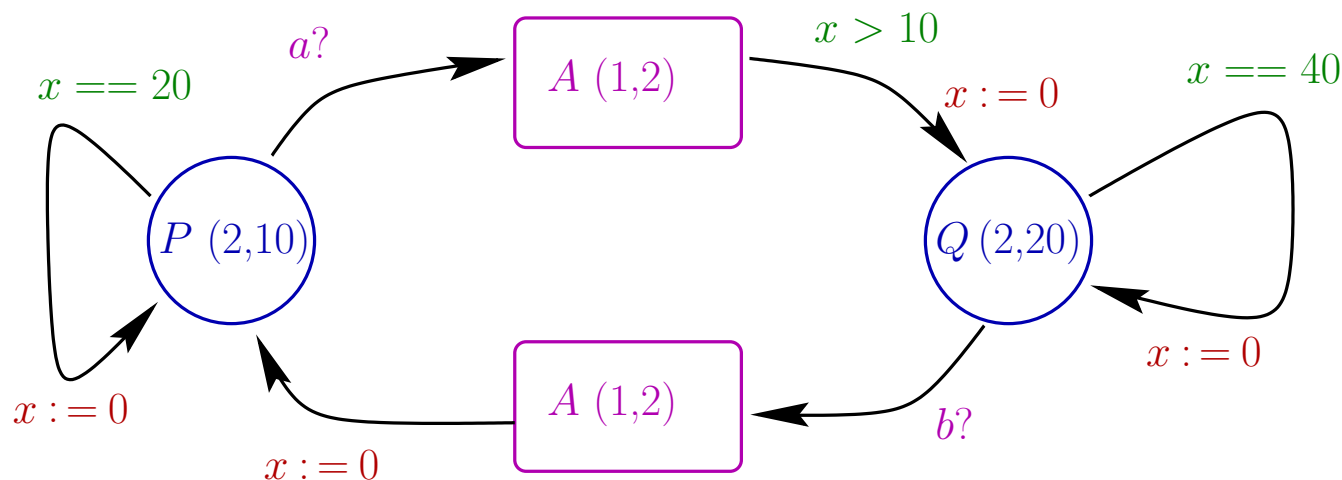
UPPAAL + LP solver (from PMC tool) = *semi-algorithm*

data-structure: parametric DBMs

modified algorithm: split, if the outcome of a comparison is dependent
on parameter values

not guaranteed to terminate \Rightarrow output partial solutions

Executable Timed Automata



Periodic Tasks P, Q

Spontaneous Tasks A, B

Parameters: **worst-case execution time**, **deadline**

Delay transition \equiv execute task with earliest deadline

Action transition \equiv releases a new task

Automaton schedulable \Leftrightarrow every $a!, b!$ -sequence schedulable

Fact: added *Preemption* is as expressive as TAs with stop watches

UPPAAL in the European WOODDES project

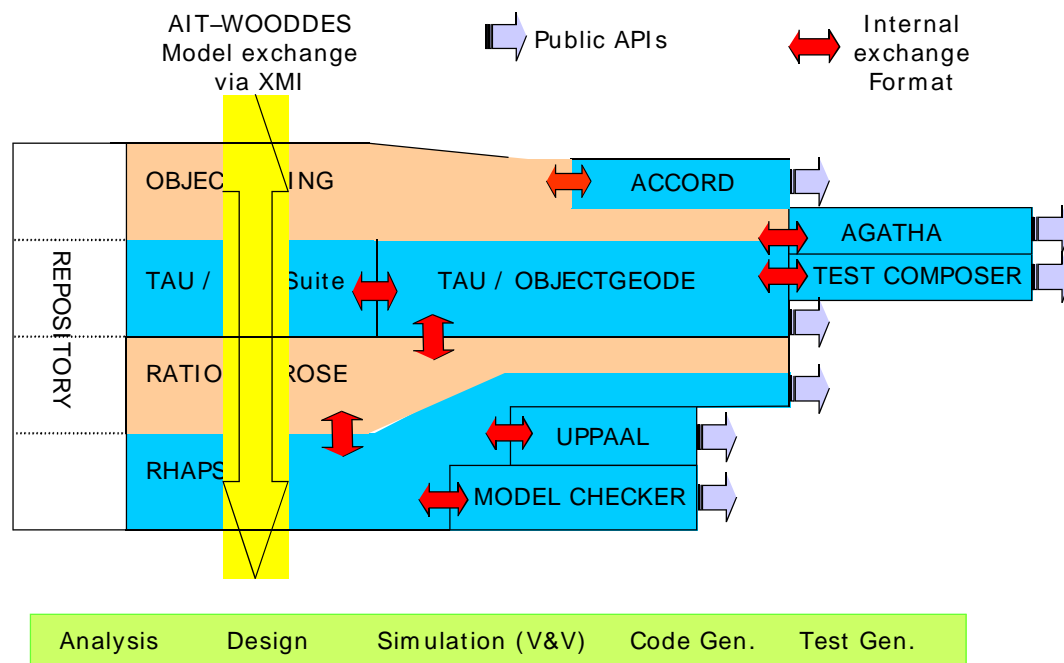
Workshop for Object-Oriented Design and Development of Embedded Systems

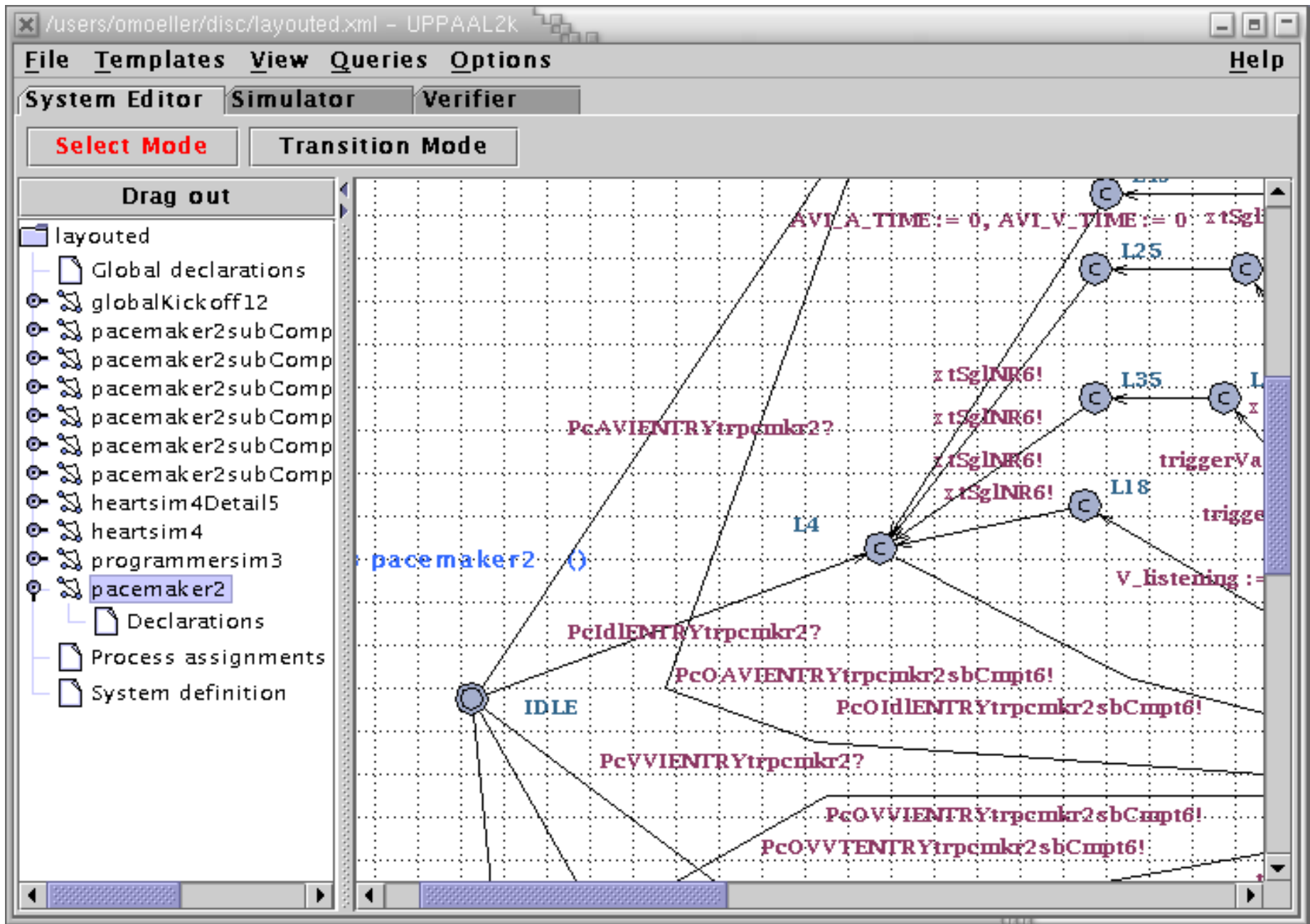
Partners:

-  PSA
-  Mecel
-  CEA
-  SOFTEAM
-  I-Logix
-  Intracom
-  Offis
-  Uppsala
-  Aalborg

Objectives:

- UML Real-Time profile
- WOODDES methodology & tool platform





/users/omoeller/disc/layouted.xml - UPPAAL2k
 File Templates View Queries Options Help

System Editor Simulator Verifier

Drag out
Enabled Transitions
 (pacemaker2subComponent6AVIMode9.1, ...
 Next Reset

Simulation Trace
 (heartsim4.2, heartsim4Detail5.1)
 (Detail, AContraction, Modeswitch, L7, ID
 (pacemaker2.5, pacemaker2subCompon
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 (Detail, AContraction, Modeswitch, subC
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 Trace File: _____
 Prev Next Replay
 Open Save Random
 Slow Fast

Drag out
Variables
 wasSwitchedC
 V_listening =
 A_LISTENING_
 triggerVar1 =
 triggerVar2 =
 triggerVar3 =
 triggerVar4 =
 triggerVar5 =
 triggerVar7 =
 VVI_TIME = 0
 VVT_TIME = 0
 AVI_A_TIME =
 AVI_V_TIME =
 HEART_TIME =
 PROGRAMMER
 VVT_TIME = V
 AVI_A_TIME =
 AVI_V_TIME =
 HEART_TIME =
 PROGRAMMER
 AVI_A_TIME =
 AVI_V_TIME =
 HEART_TIME =
 PROGRAMMER
 HEART_TIME =
 PROGRAMMER
 HEART_TIME =
 PROGRAMMER

L57
 x tSgINR9!
 triggerVar7 := triggerVar7 - 1
 x tSgINR11?
 IMd9VPrt11?
 IDLE
 r7 := triggerVar7 - 1
 x tSgINR11?
 Refractory
 AVI_A_Pace_Done
 AVI_Refracto
 V_listening :=
 Ventri
 AVI_
 x tSgINR11?
 triggerVar7 := triggerVar7 - 1

