Overview

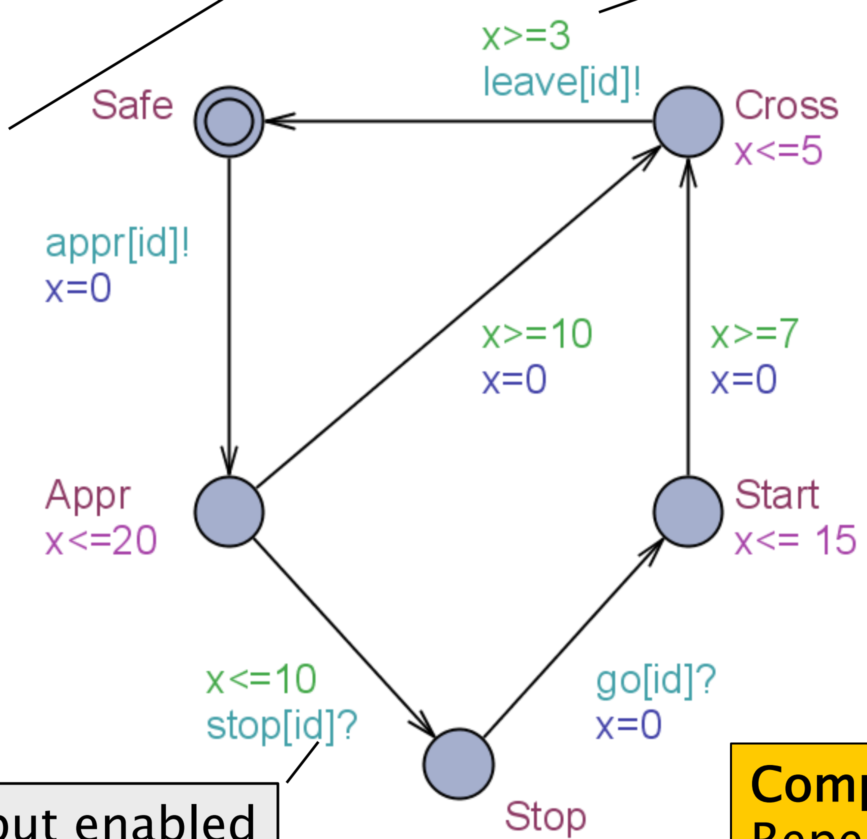
- Timed Automata / UPPAAL
  - Verification
- Priced Timed Automata / UPPAAL CORA
  - Optimal Scheduling (multicore applications)
  - Optimal Infinite Scheduling
  - Multi objective optimization
- Schedulability Analysis & Scheduling
  - Single Core, Multi Core
  - Dynamic voltage Scheduling
  - Energy Automata
- Stochastic Priced Timed Automata / UPPAAL SMC
  - Statistical Model Checking
  - Low Power Medium Access Protocol
  - Stochastic Hybrid Automata
  - Energy-Aware Buildings
  - Battery-Aware Scheduling
- Stochastic Priced Timed Games / UPPAAL STRATEGO
  - Optimal & Safe Synteses
  - Energy-Aware and Optimal Satelitte Scheduling
- Conclusion

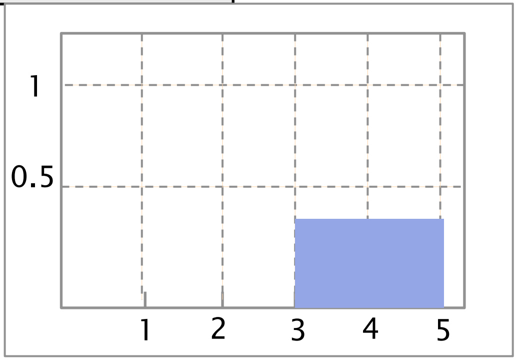
Stochastic Timed Automata

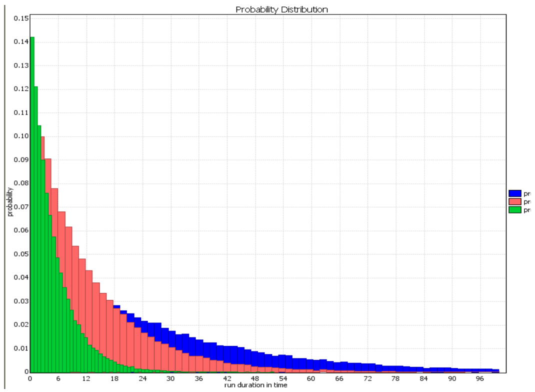
Stochastic Semantics of TA

Exponential Distribution

Uniform Distribution



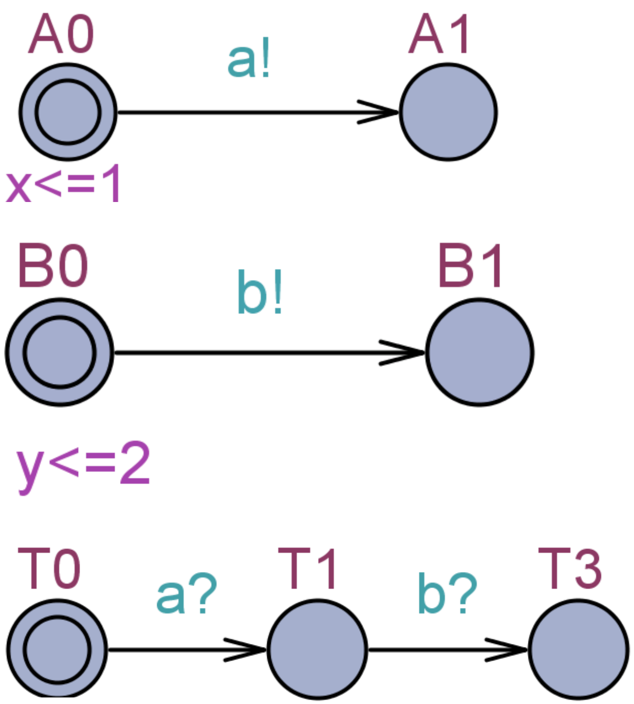




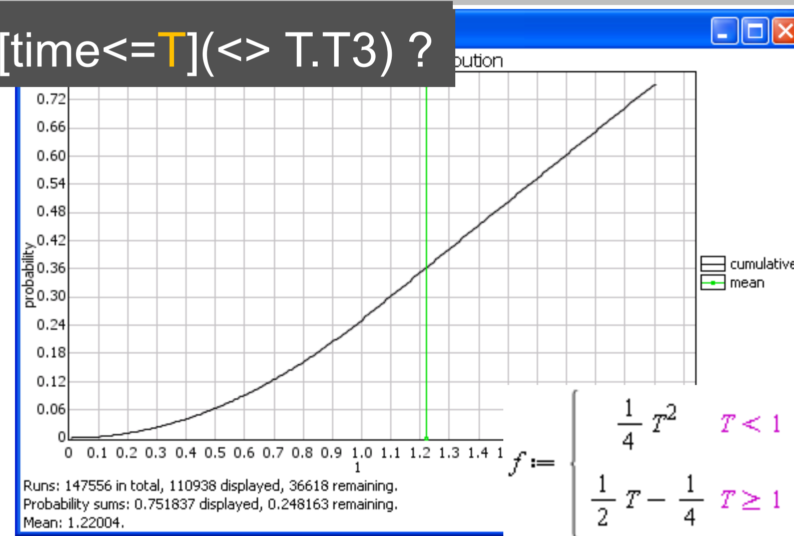
Input enabled

Composition =
Repeated races between components for **outputting**

Stochastic Semantics of Timed Automata

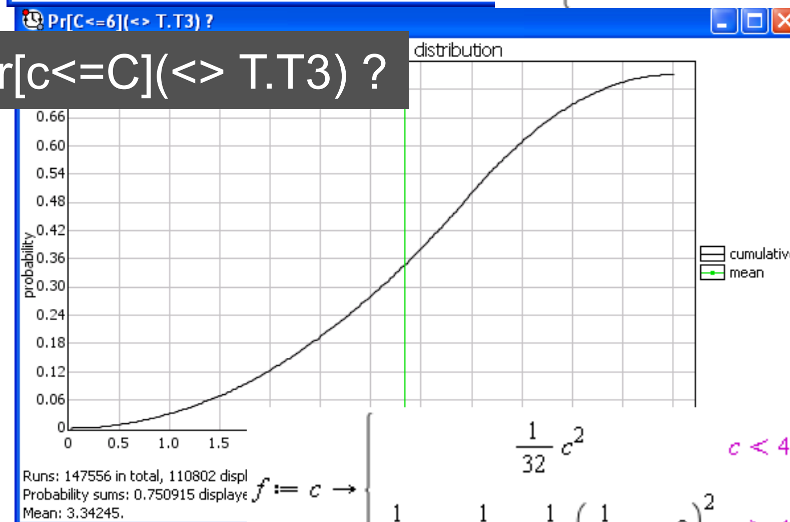


Pr[time<=T](<> T.T3) ?



$$f := \begin{cases} \frac{1}{4} T^2 & T < 1 \\ \frac{1}{2} T - \frac{1}{4} & T \geq 1 \end{cases}$$

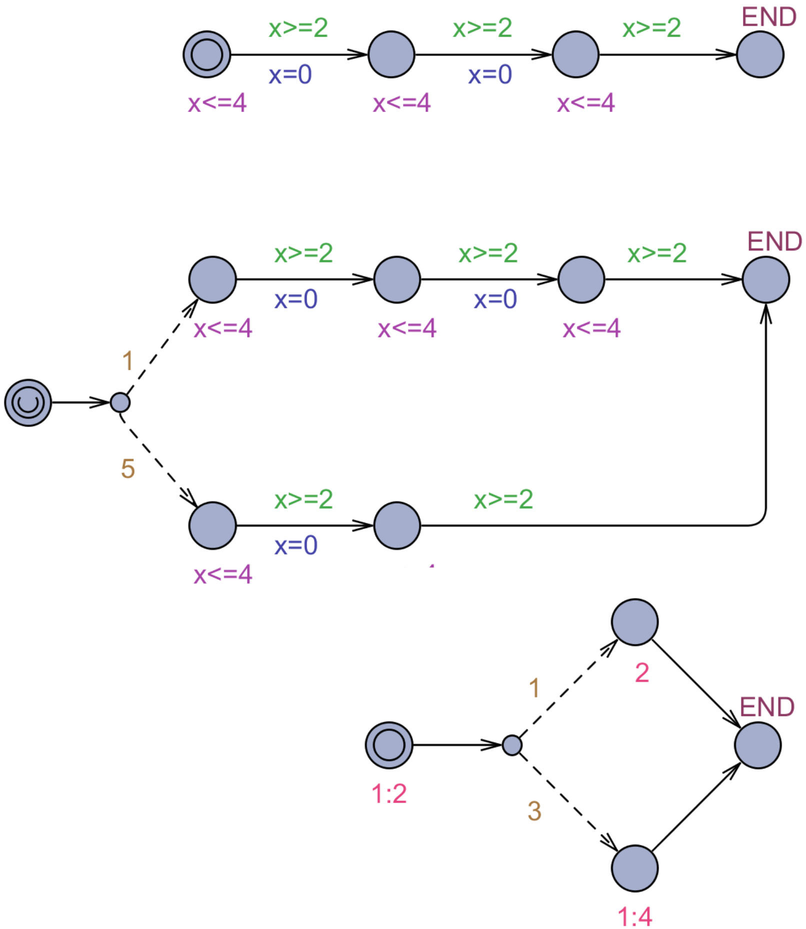
Pr[c<=C](<> T.T3) ?

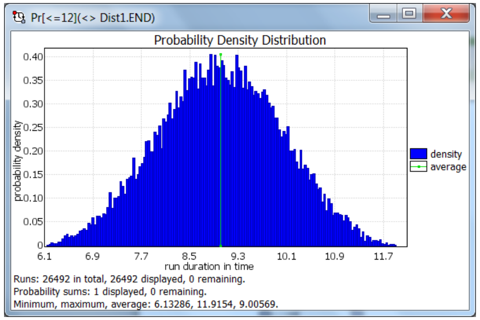


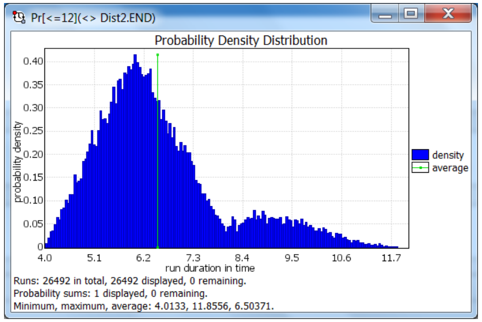
$$f := c \rightarrow \begin{cases} \frac{1}{32} c^2 & c < 4 \\ \frac{1}{4} c - \frac{1}{2} - \frac{1}{4}\left(\frac{1}{2} c - 2\right)^2 & c \geq 4 \end{cases}$$

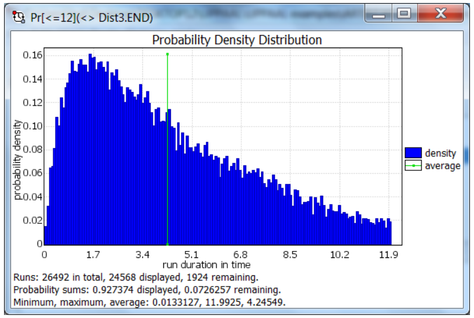
Composition = Race between components for outputting

Beyond Uniform / Exponential Dist.







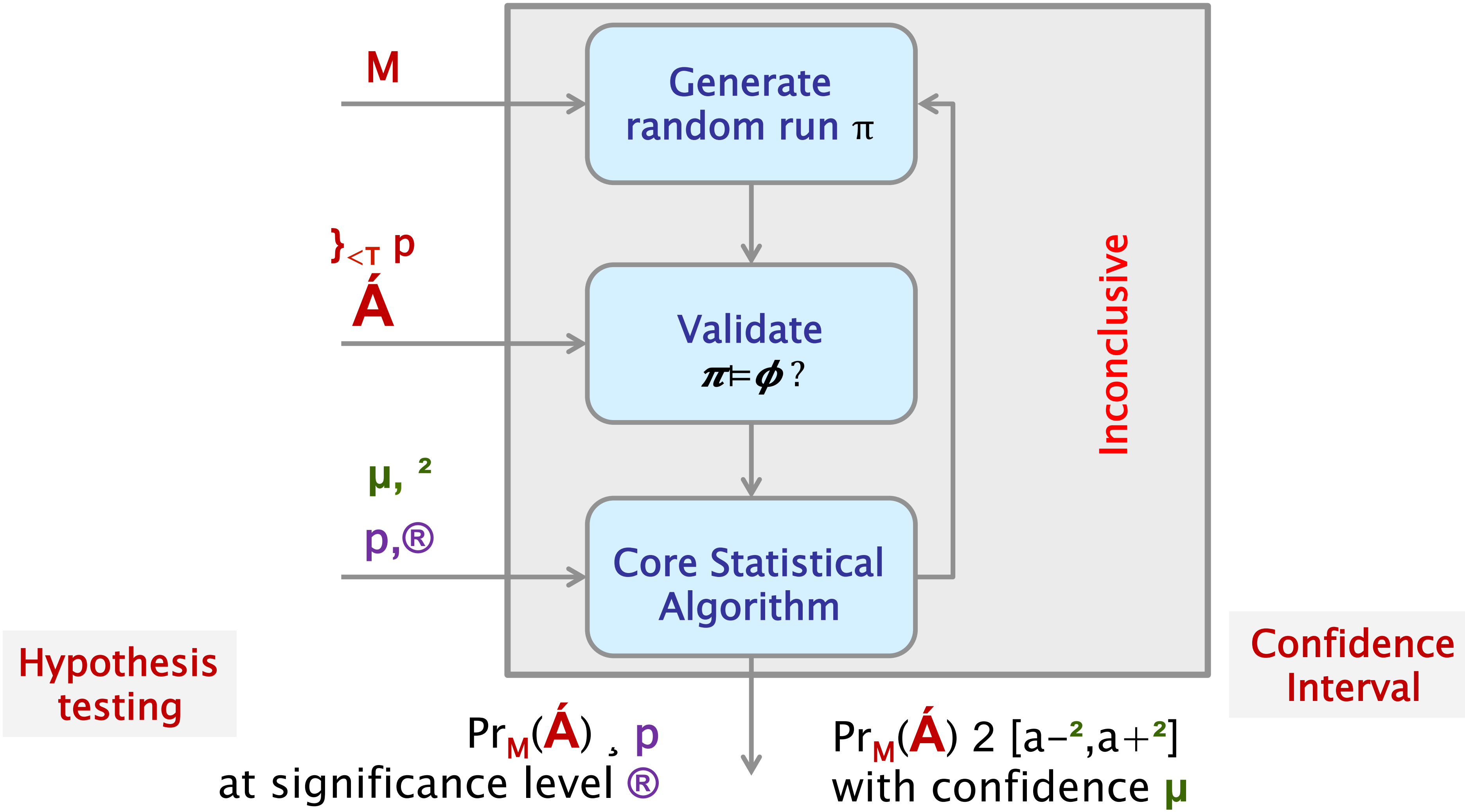


Includes all Phase-Type Distributions.

Can encode any distribution with arbitrary precision.

Statistical Model Checking

[FORMATS11, LPAR12, RV12]



Queries in UPPAAL Syntax

- Evaluation

  `Pr[<=100](<> expr)`
- Hypothesis testing

  `Pr[<=100](<> expr)>=0.1`

  `c<=100 #<=50 [] expr <=0.5`
- Comparison

  `Pr[<=20](<> e1)>=Pr[<=10](<> e2)`
- Expected value

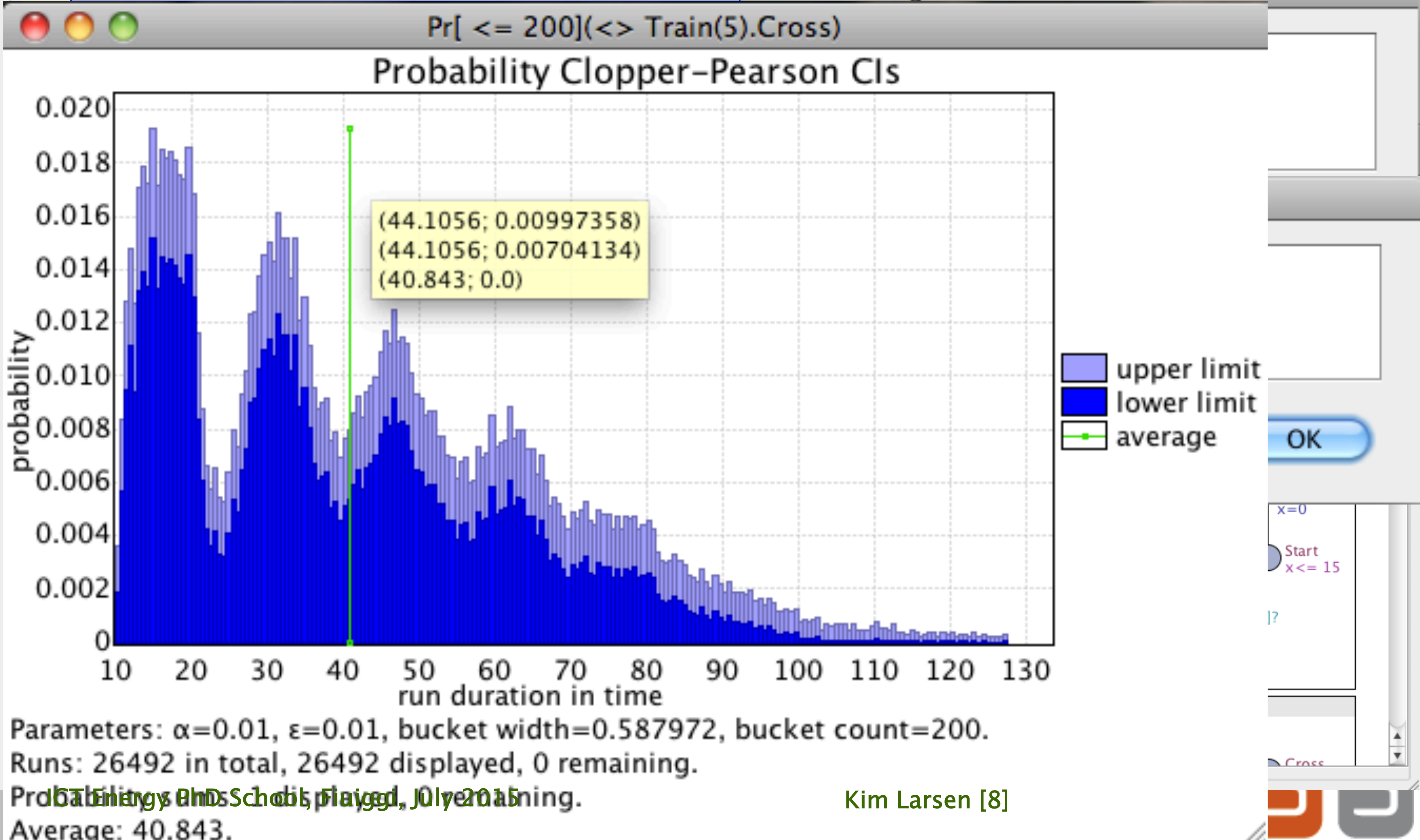
  `E[<=10;1000](min: expr)`

  Explicit number of runs. Min or max.
- Simulations

  `simulate 10 [<=100]{expr1,expr2}`

Queries in UPPAAL SMC

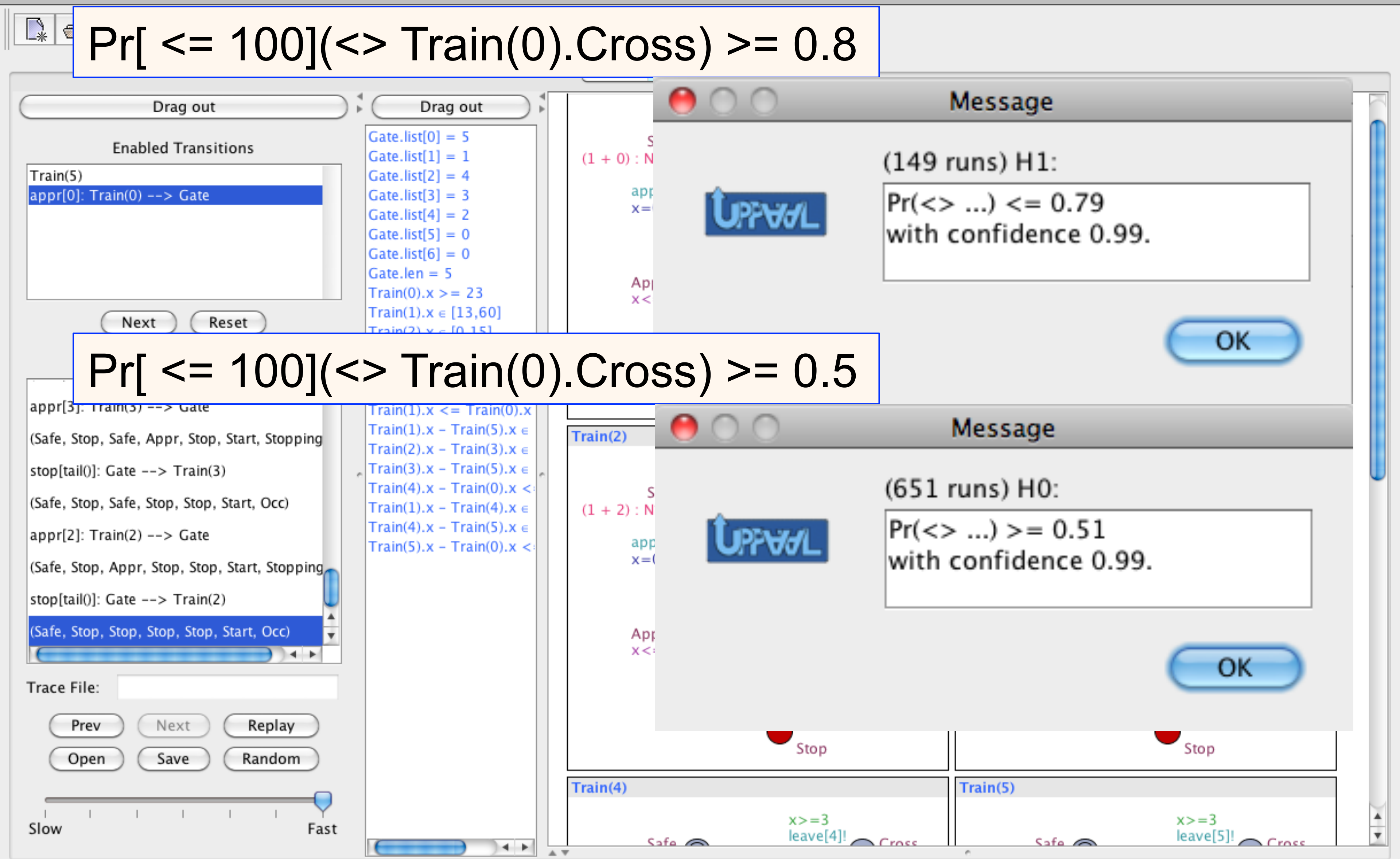
Pr[<= 200](<> Train(5).Cross)



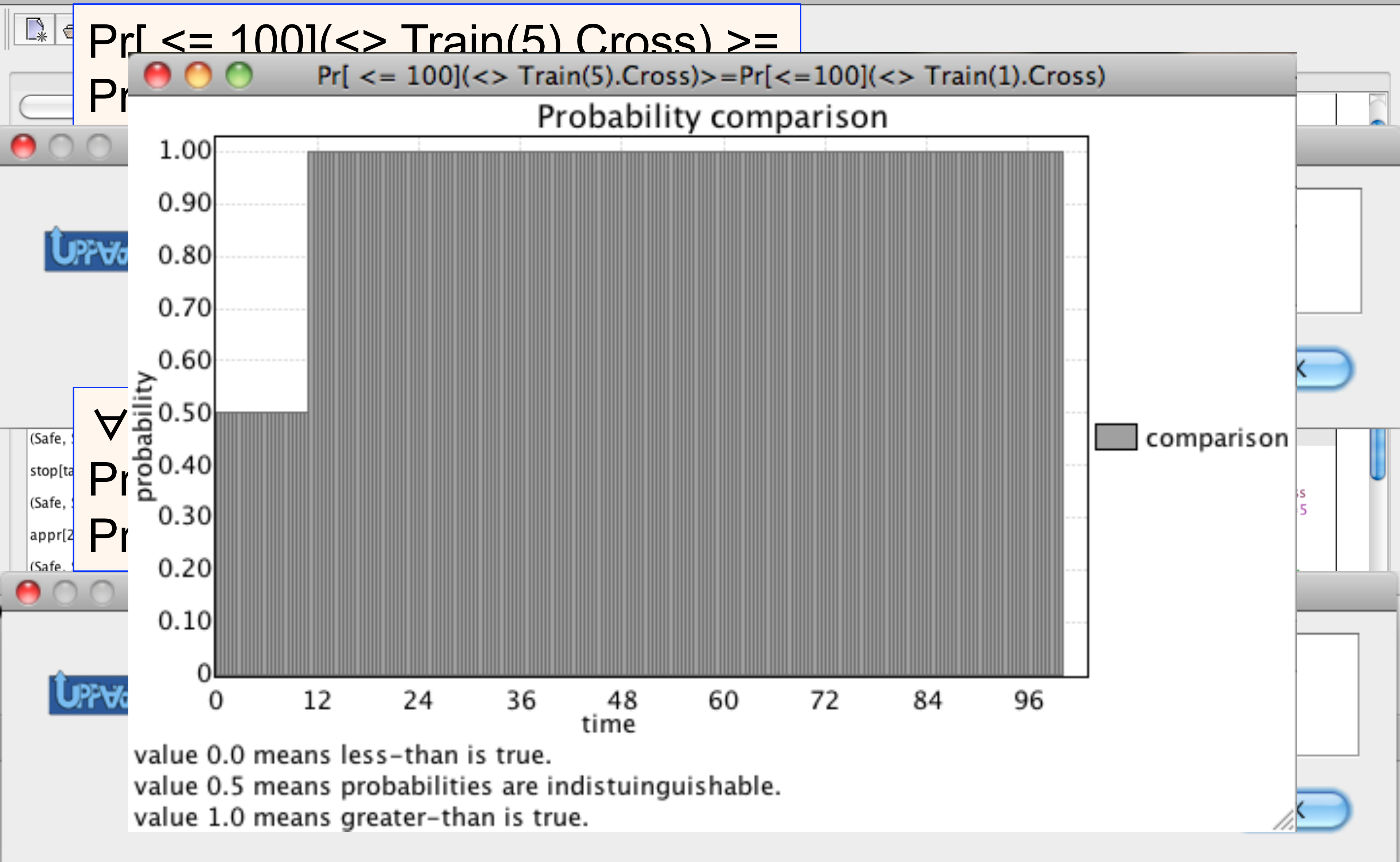
Queries in UPPAAL SMC

Pr[<= 100](<> Train(0).Cross) >= 0.8

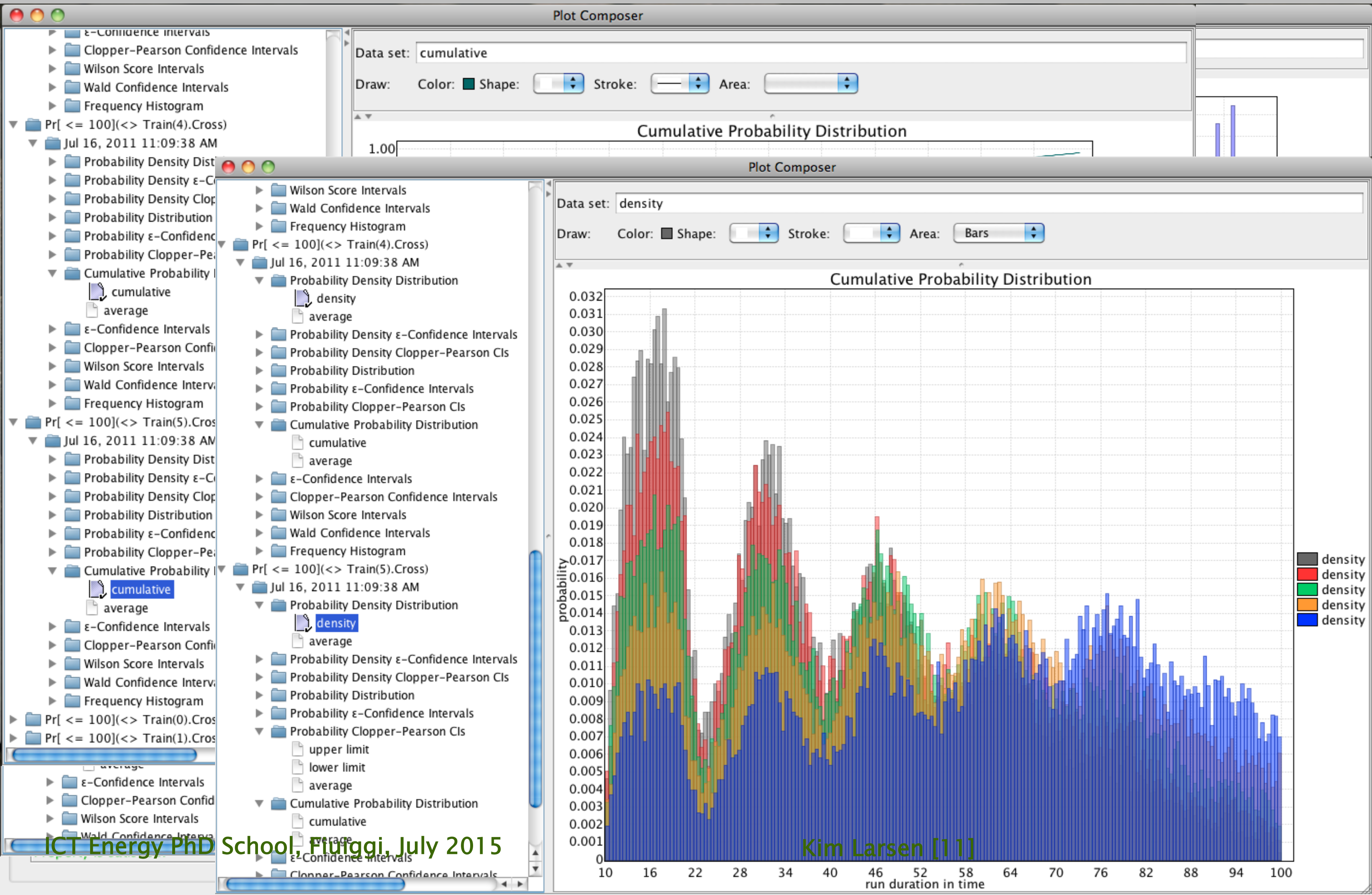
Pr[<= 100](<> Train(0).Cross) >= 0.5



Queries in UPPAAL SMC



Analysis Tool: Plot Composer



DEMO

LMAC

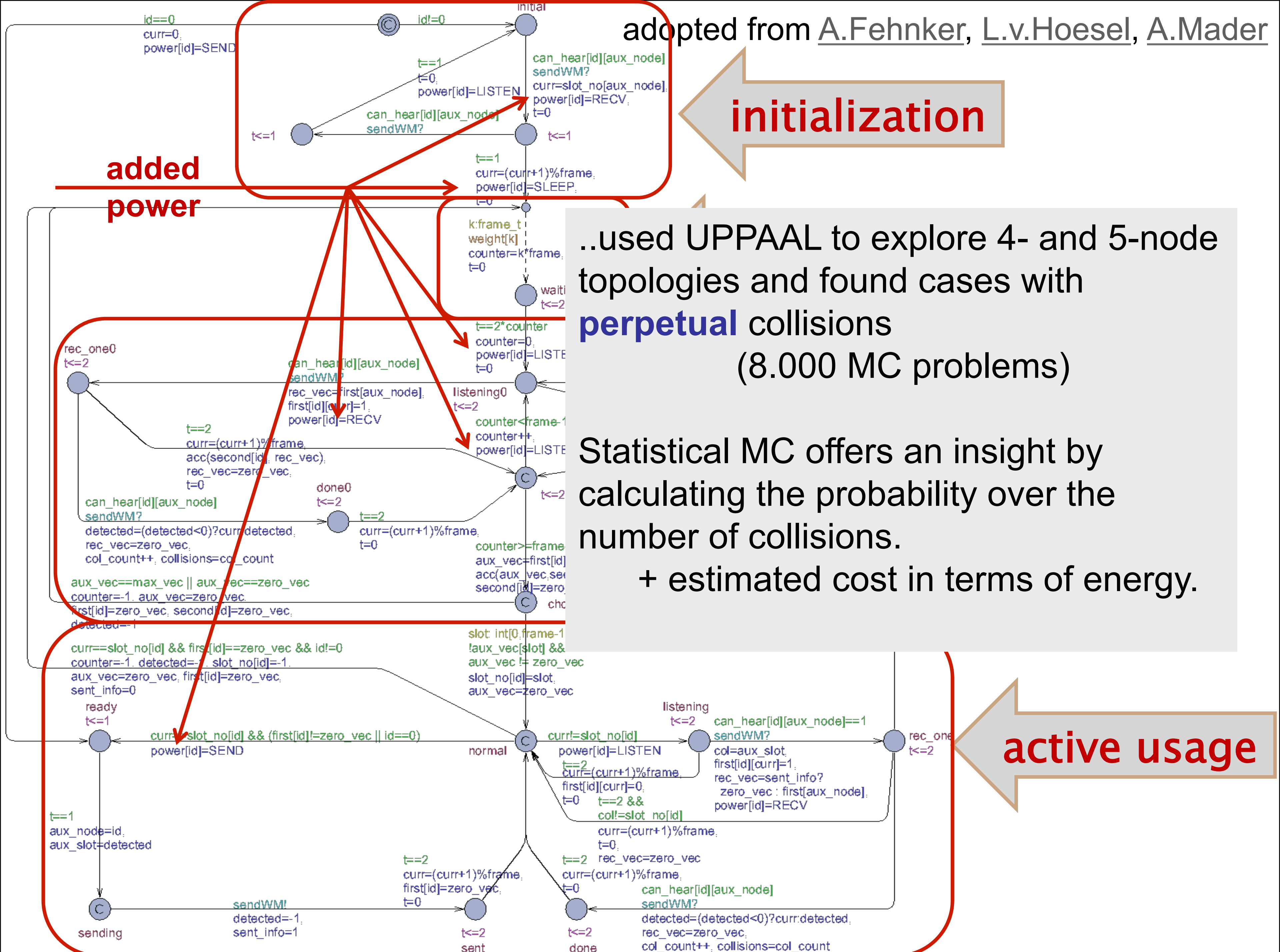
node																																			
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	d	d	d	d	d	3	3	3	3	3	3	3
1	i	d	d	d	d	d	1	1	1	1	1	d	d	d	d	d	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2	i	d	d	d	d	d	1	1	1	1	1	d	d	d	d	d	2	2	2	2	2	d	d	d	d	d	3	3	3	3	3	3	3	3	3
3	i	i	i	i	i	i	i	w	w	w	w	w	d	d	d	d	d	0	0	0	0	0	0	d	d	d	d	d	4	4	4	4	4	4	4
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34

Lightweight Media Access Control

- Problem domain:
  - communication scheduling
- Targeted for:
  - self-configuring networks,
  - collision avoidance,
  - low power consumption
- Application domain:
  - wireless sensor networks

- Initialization (listen until a neighbor is heard)
- Waiting (delay a random amount of time frames)
- Discovery (wait for entire frame and note used slots)
- Active
  - choose free slot,
  - use it to transmit, including info about detected collisions
  - listen on other slots
  - fallback to Discovery if collision is detected
- Only neighbors can detect collision and tell the user-node that its slot is used by others

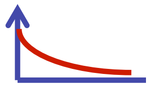
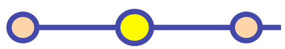
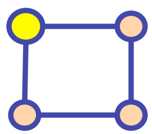
adopted from A.Fehnker, L.v.Hoesel, A.Mader

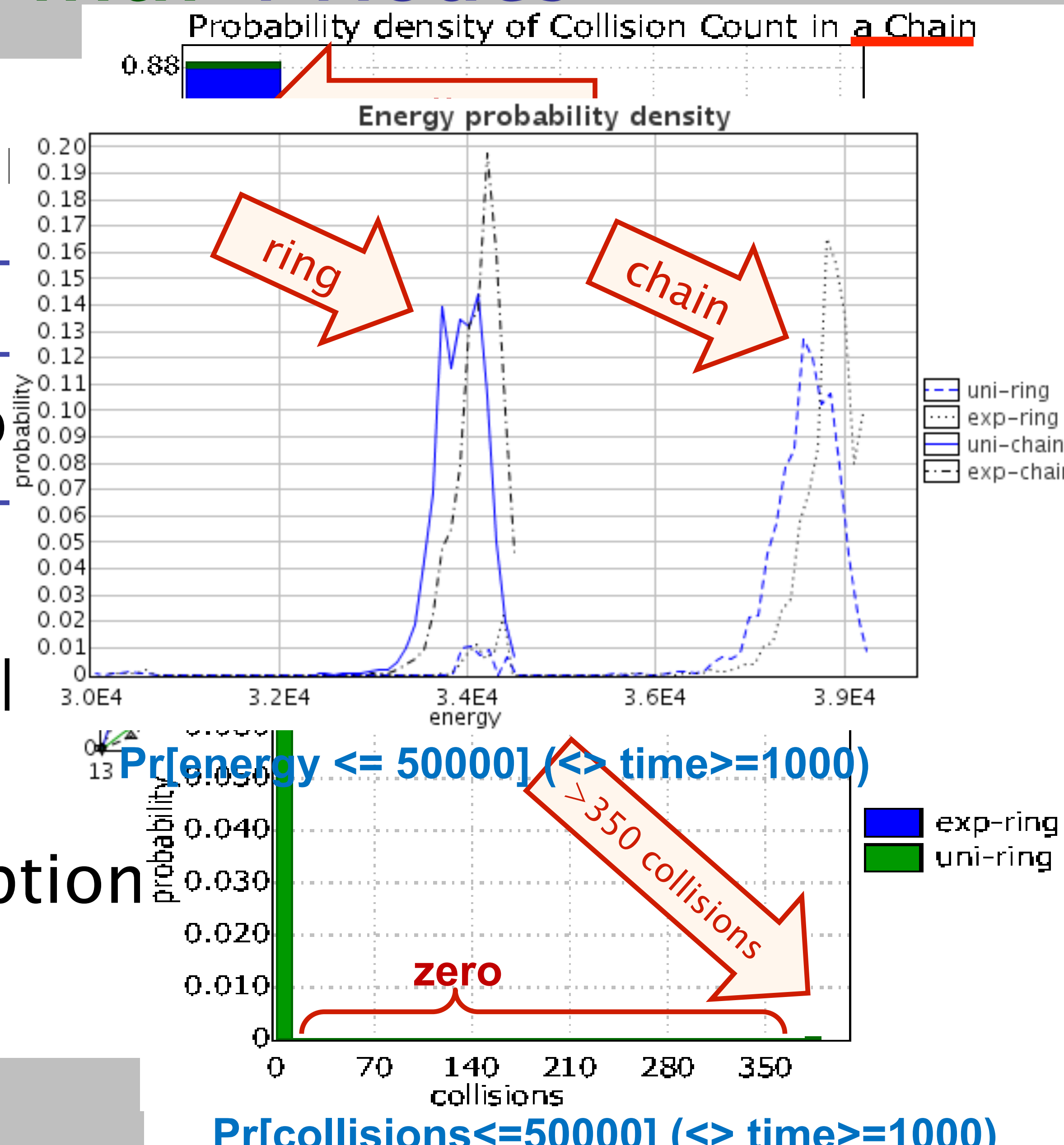


..used UPPAAL to explore 4- and 5-node topologies and found cases with **perpetual** collisions
(8.000 MC problems)

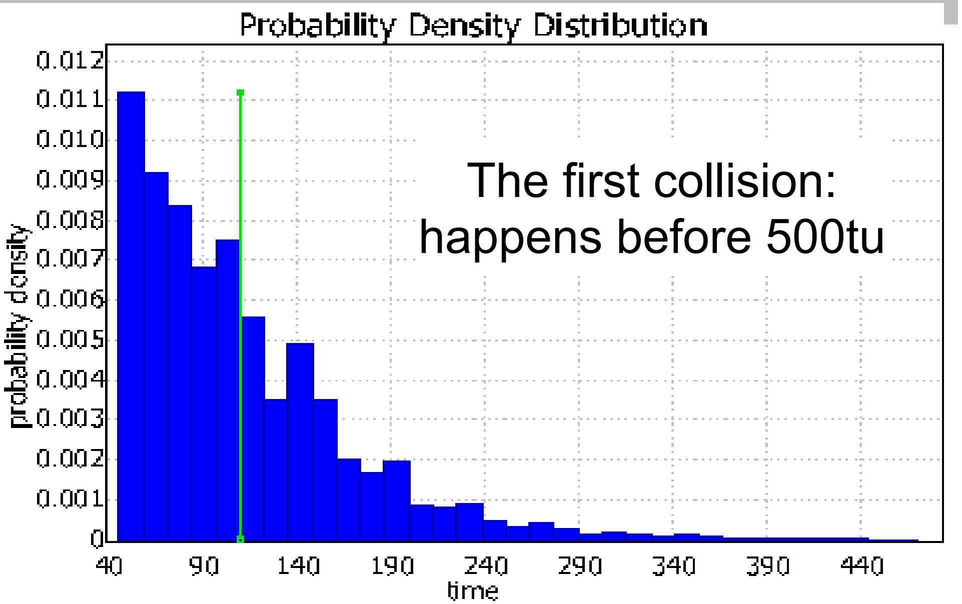
Statistical MC offers an insight by calculating the probability over the number of collisions.
+ estimated cost in terms of energy.

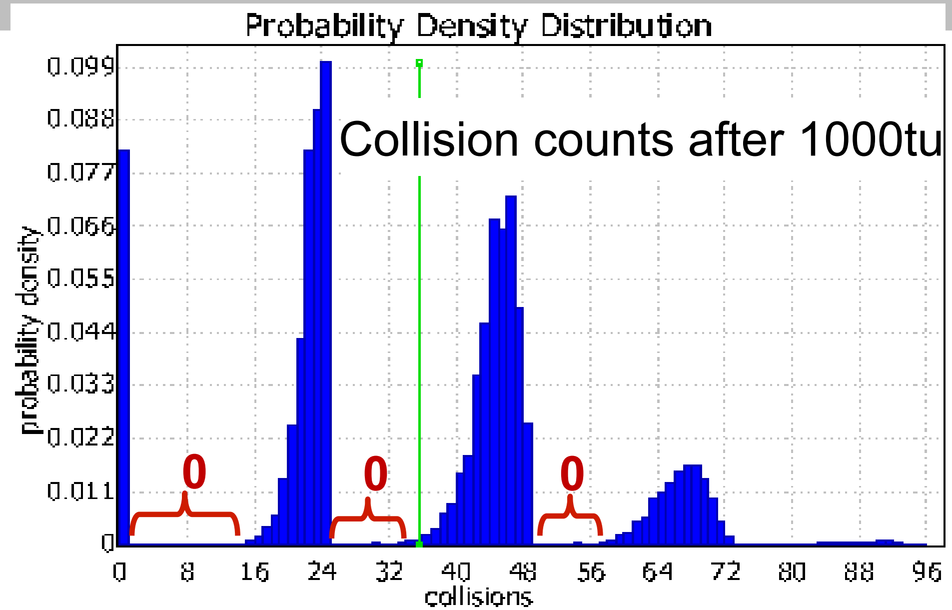
SMC of LMAC with 4 Nodes

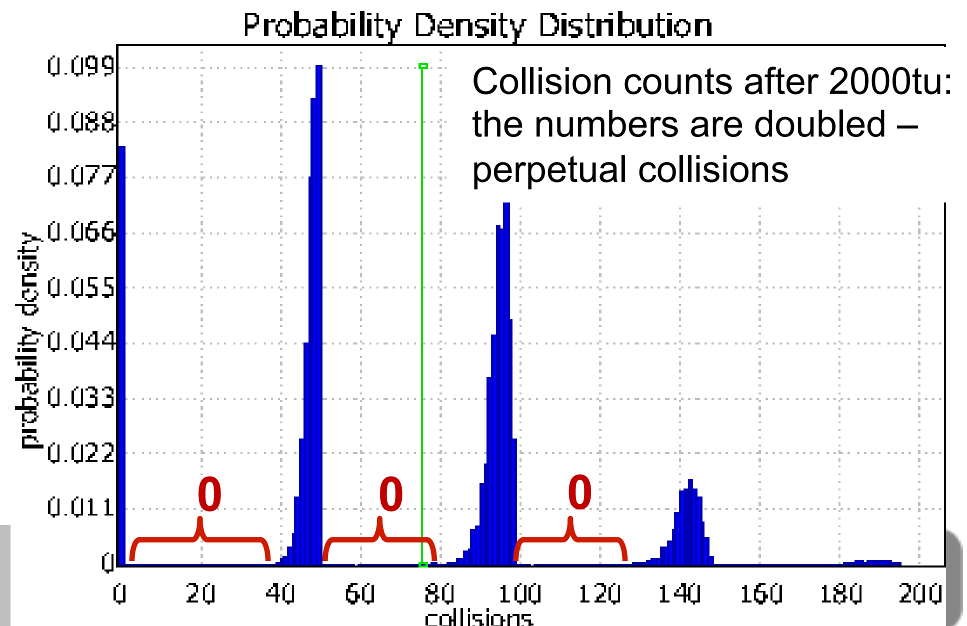
- Wait distributio
  - geometric 
  - uniform 
- Network topolo
  - chain 
  - ring 
- Collision probal
- Collision count
- Power consumption



10-Node Star

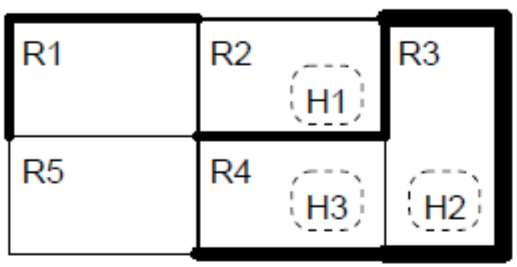






- The first collisions happen before **500**tu.
- It is unlikely (**8.2%**) that there will be **0** collisions.
- And if they happen, they are perpetual.

Energy Aware Buildings



Fehnker, Ivancic.
Benchmarks for Hybrid Systems Verification.
HSCC04

With Alexandre David,
Dehui Du
Marius Mikucionis
Arne Skou

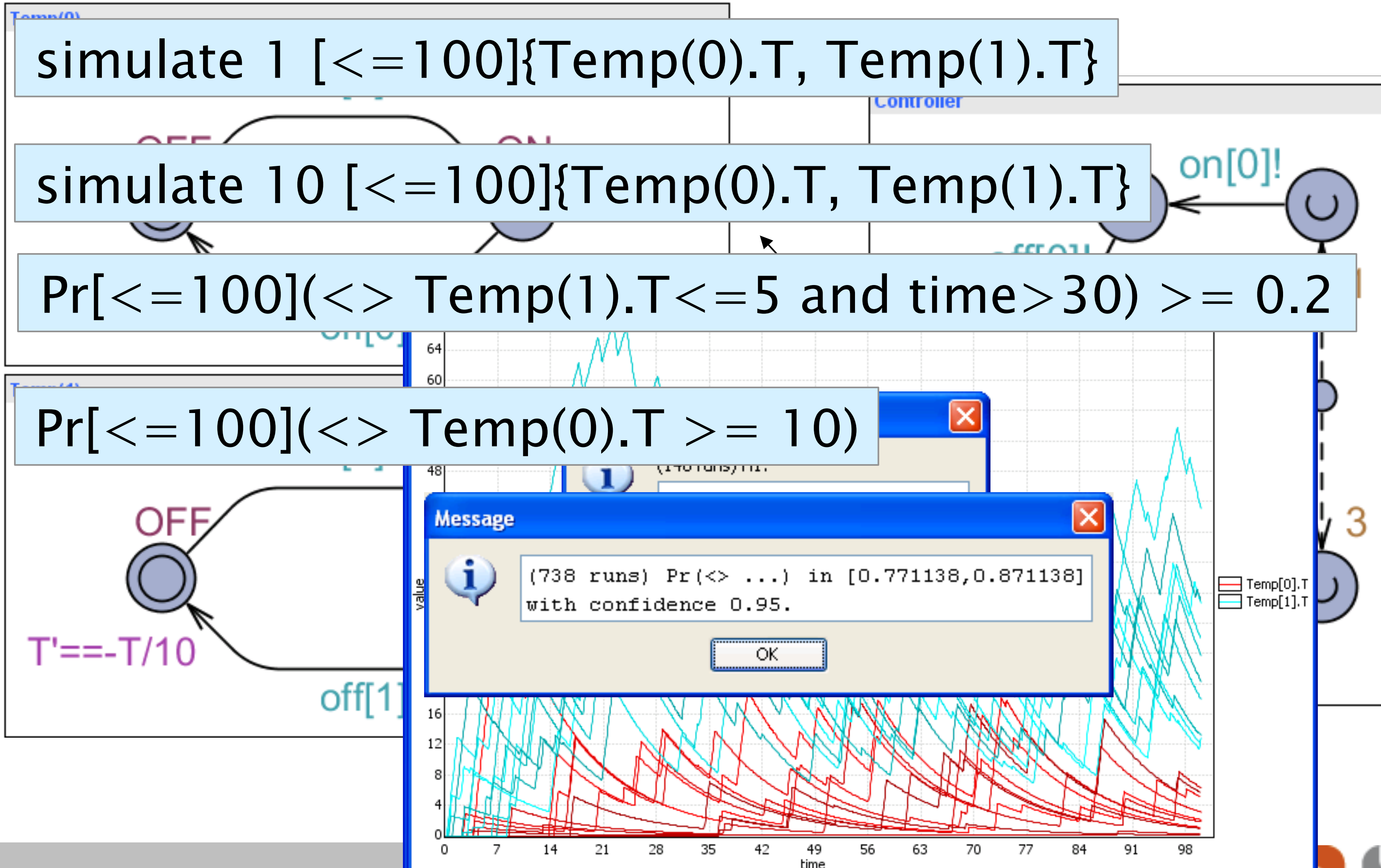
Stochastic Hybrid Systems

simulate 1 [<=100]{Temp(0).T, Temp(1).T}

simulate 10 [<=100]{Temp(0).T, Temp(1).T}

Pr[<=100](<> Temp(1).T<=5 and time>30) >= 0.2

Pr[<=100](<> Temp(0).T >= 10)



Stochastic Hybrid Systems

Pr[<=20](<>(time>=12 && Ball.p>4))

UPPAAL SMC

Uniform distributions (bounded delay)
Exponential distributions (unbounded delay)
Syntax for discrete probabilistic choice
Distribution on next state by use of `random`
GUI for plot composing and exporting
Hybrid flow by use of ODEs
+ usual stuff (structured variables, user-defined types user-defined functions, ….)

MITL

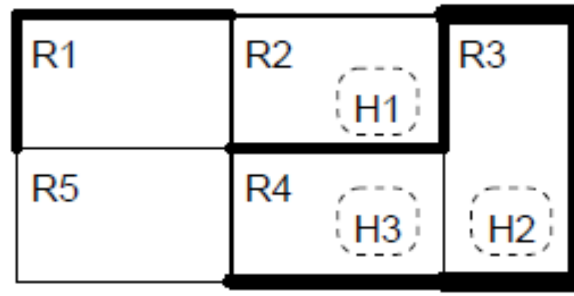
Networks

Repeated races between components for outputting

time

Energy Aware Buildings

Danish National Defense Building Administration
Pilot – Sjælland's Odde



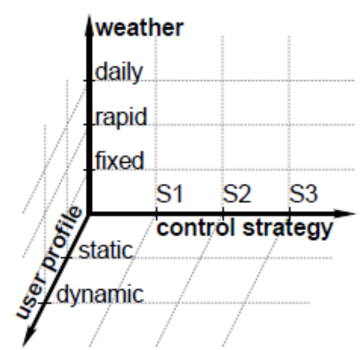
Modeling components
- building layout
- room temperature
- heater controler
- central controler
- weather temperature
- user profiles

Properties
- discomfort
- confortable time
- energy consumption comparison

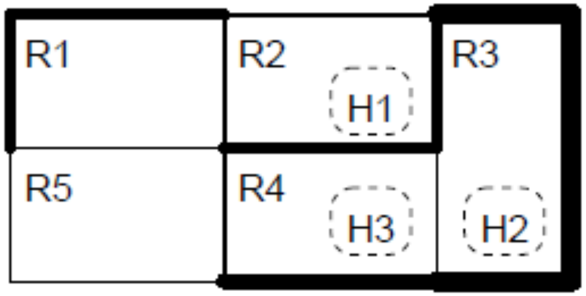
→ **Uppaal SMC** →

Results
- Probability estimate
- Probability distribution
  - ...over time
  - ...over energy
- Distribution comparison

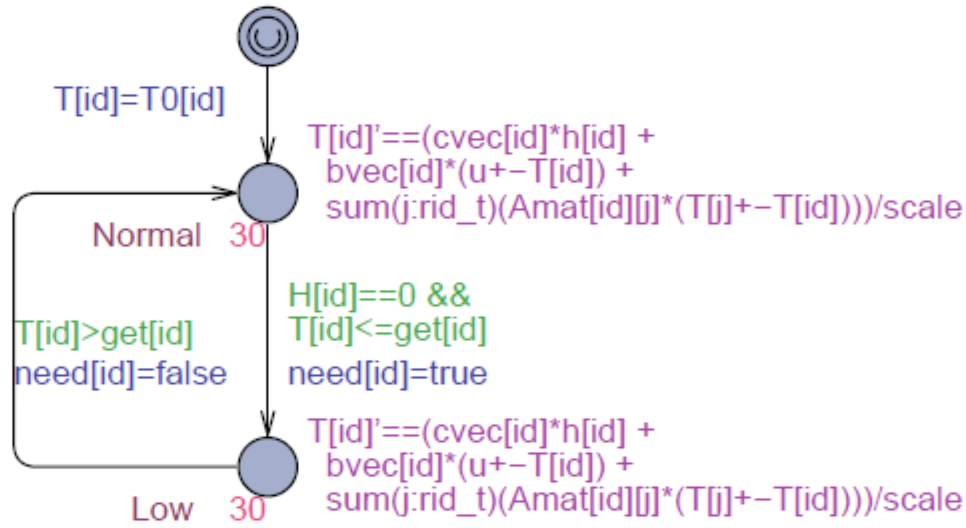
$$T_i' = \sum_{j \neq i} a_{i,j}(T_j - T_i) + b_i(u - T_i) + c_i h_i$$



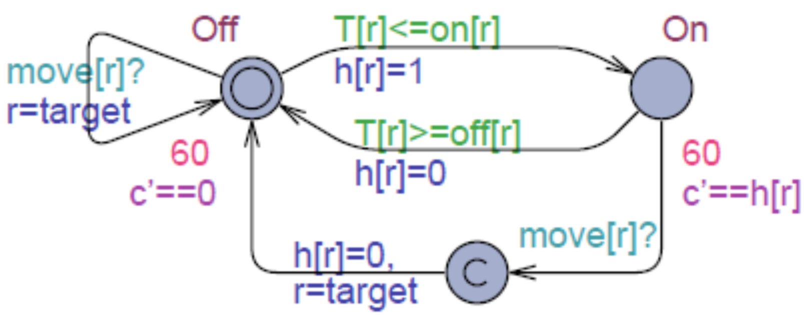
Rooms & Heaters – MODELS



$$T_i' = \sum_{j \neq i} a_{i,j}(T_j - T_i) + b_i(u - T_i) + c_i h_i$$



(a) Template for Room temperature.



(b) Template for Heater control.

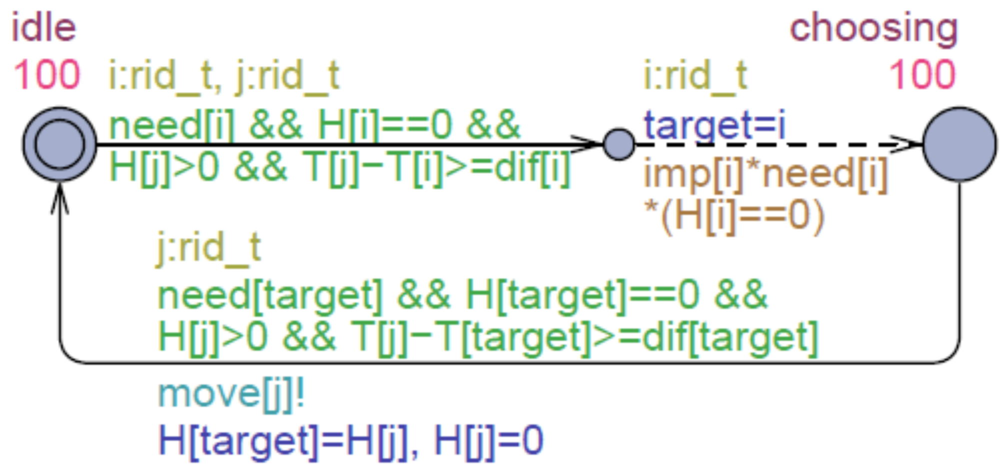
$$\begin{pmatrix} 10.0 & 7.0 & 10.0 & 11.0 & 9.0 \end{pmatrix}$$

(d) Heating vector c.

Control Strategies – MODELS

room	1	2	3	4	5
off	21	21	21	21	21
on	19	19	19	19	19
get	16	17	18	17	16
low	15	16	16	16	15
dif	1.0	1.0	1.0	1.0	1.0
imp	1	30	2	3	4
pow	5	5	5	5	5

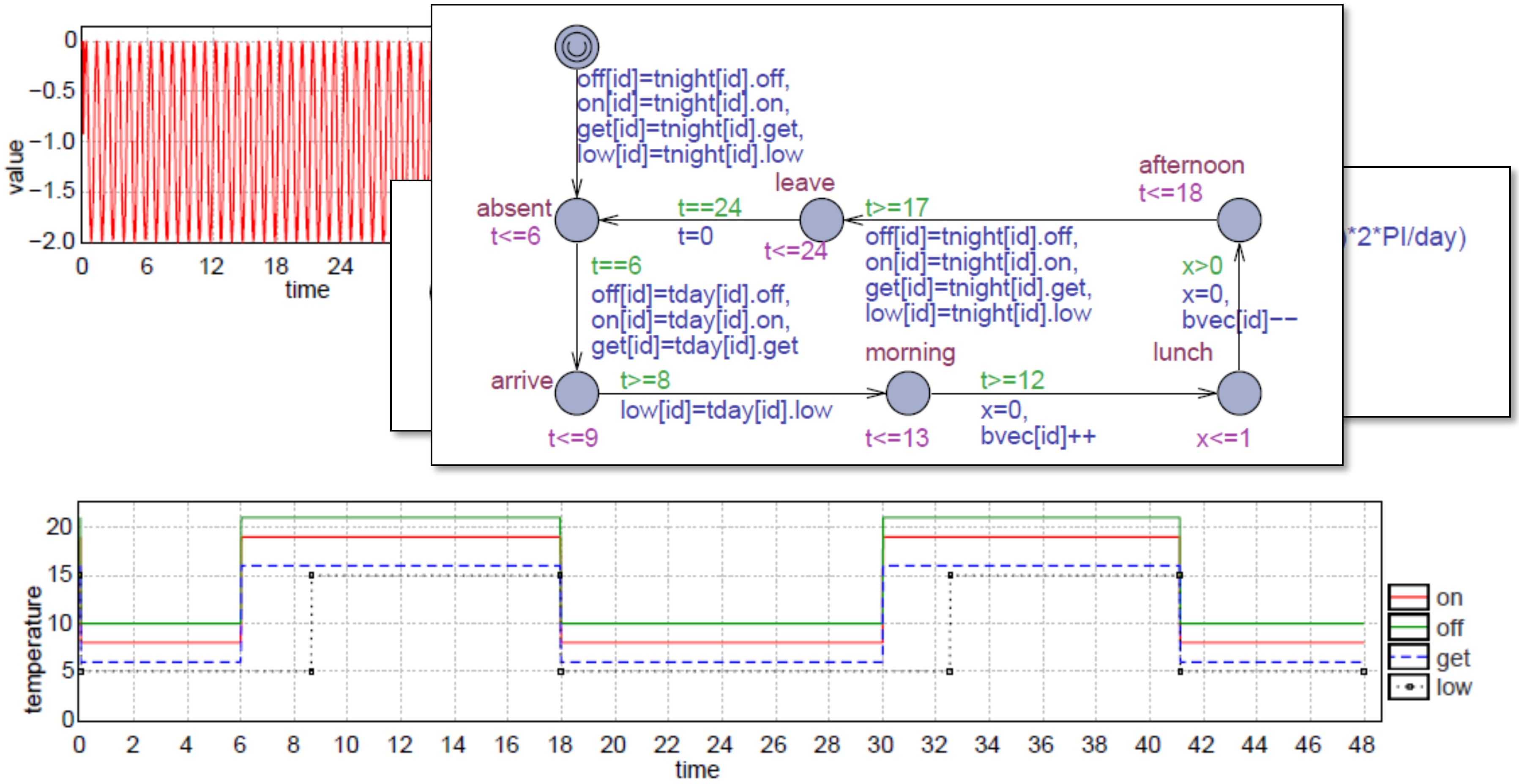
Te



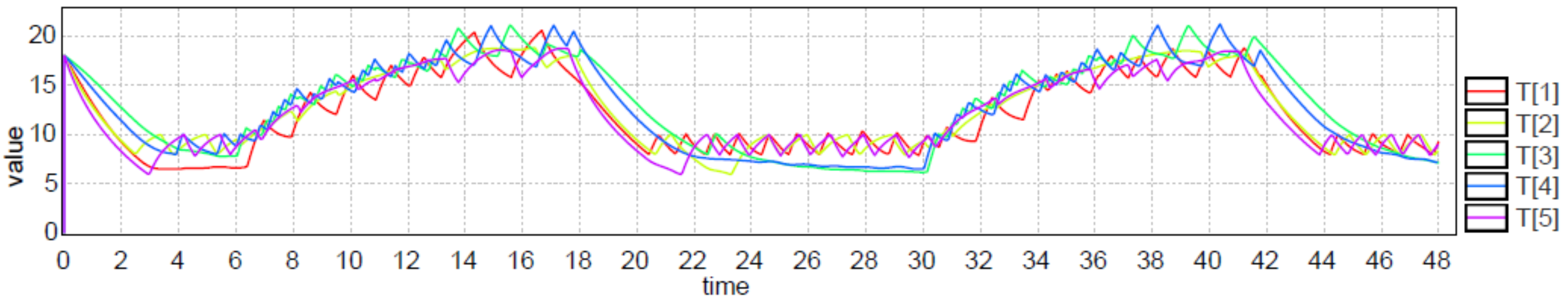
(a) Strategy 1 (as in [FI04b]).

Strategy 1	Strategy 2	Strategy 3
room i has no heater	room i has no heater	room i has no heater
room j has a heater	room j has a heater	room j has a heater
temperature $T_i \leqslant get_i$	temperature $T_i \leqslant get_i$	temperature $T_i \leqslant get_i$
difference $T_j - T_i \geqslant dif_i$	threshold $T_j \geqslant get_j$	threshold $T_j \geqslant on_j$

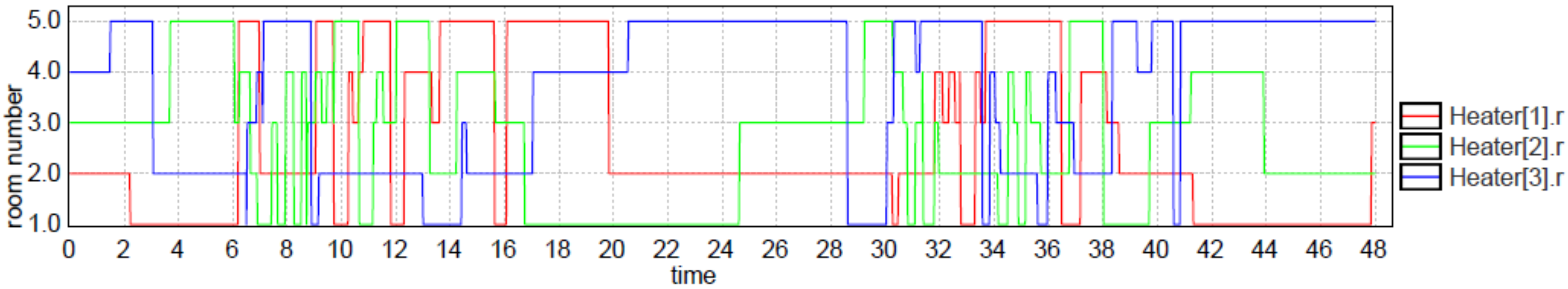
Weather & User Profile – MODELS



Results – Simulations



simulate 1 [<=2*day] { T[1], T[2], T[3], T[4], T[5] }



simulate 1 [<=2*day] { Heater(1).r, Heater(2).r, Heater(3).r }

Results – Comfort

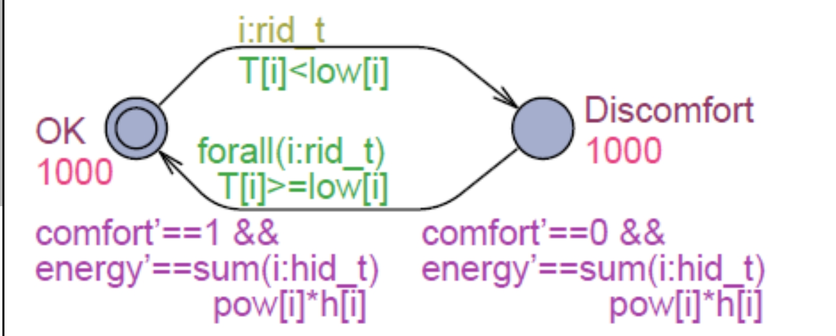
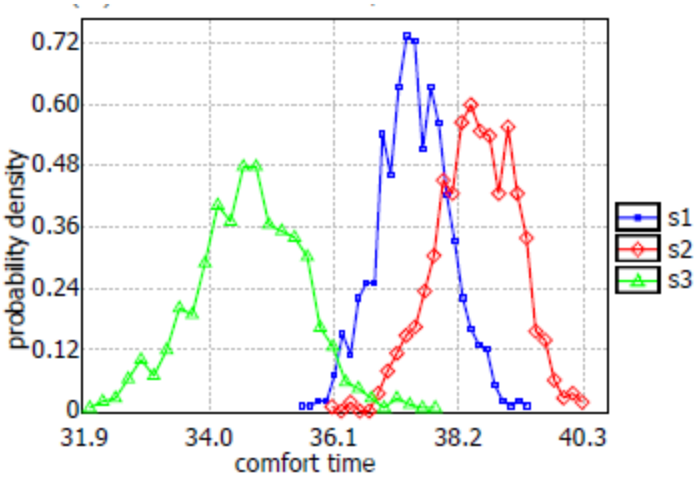
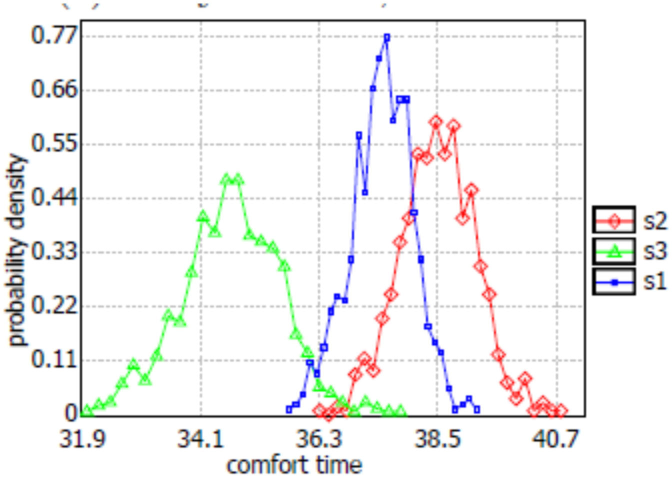


Figure 16: Monitor for comfort and energy.

Pr[comfort<=2*day] (<> time>=2*day)



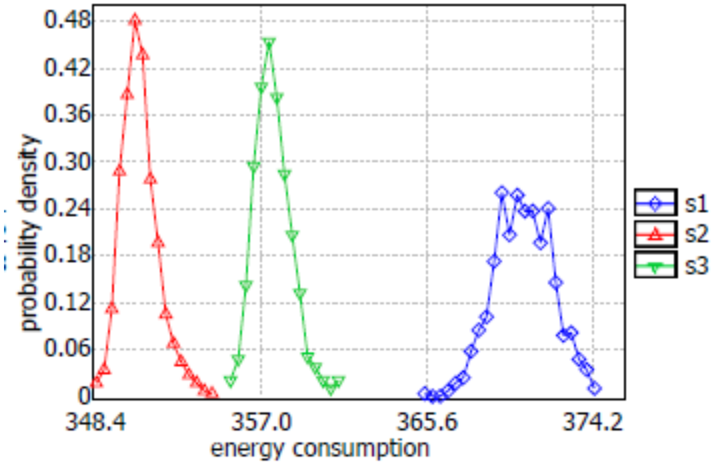
(d) Flat weather, Dynamic user.



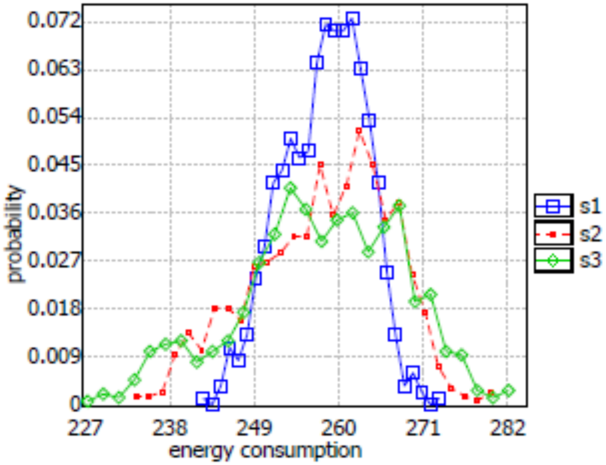
(f) Daily weather, Dynamic user.

Results – Energy

Pr[Monitor.energy<=1000000](<> time>=2*day)

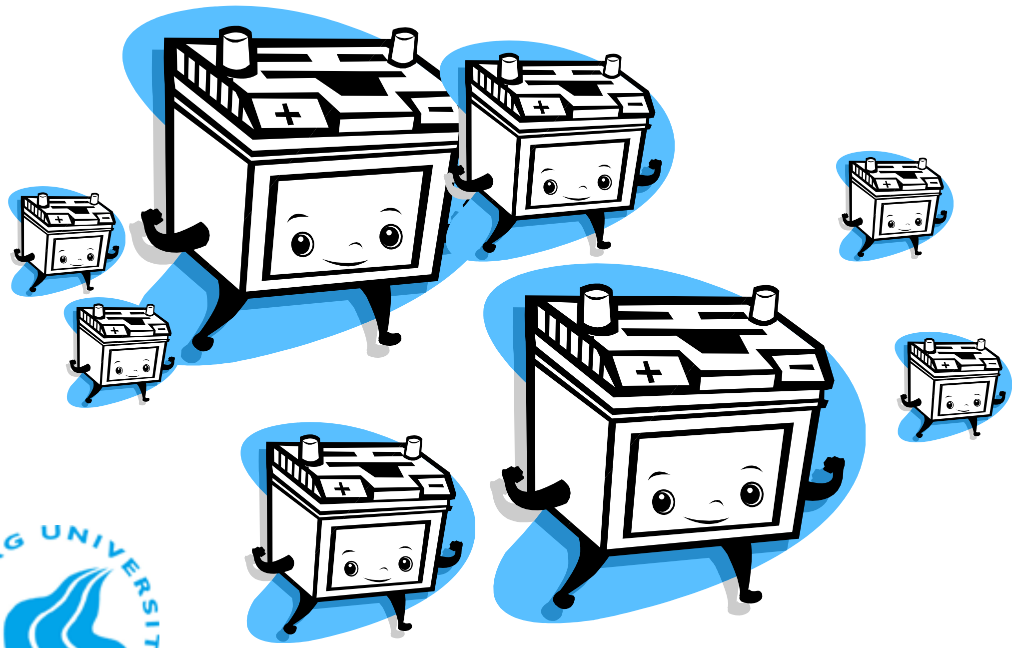


(c) Dail weather, Static user.



(f) Daily weather, Dynamic user.

Battery-Aware Soft Real-Time Scheduling



With Erik Wogensen
René R Hansen

SENSATION Project

Batteries

- CPS often have to operate independently (batteries)
- Unpredictable load (stochasticity)
- Battery state and lifetime depend non–linearly on workload (hybrid)

- Electrochemical Cell

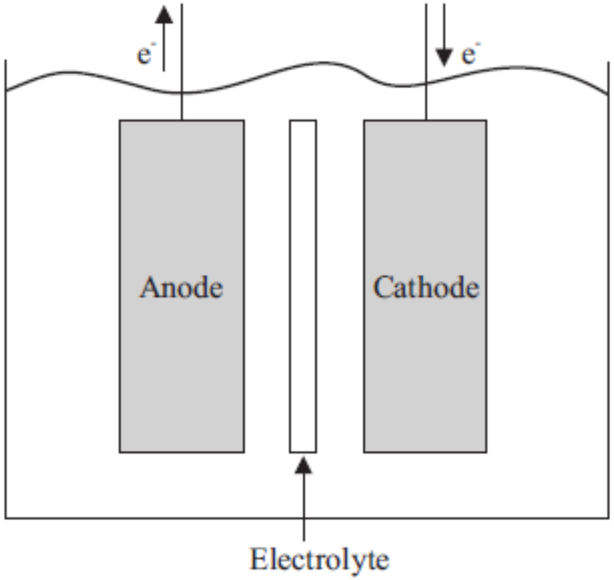
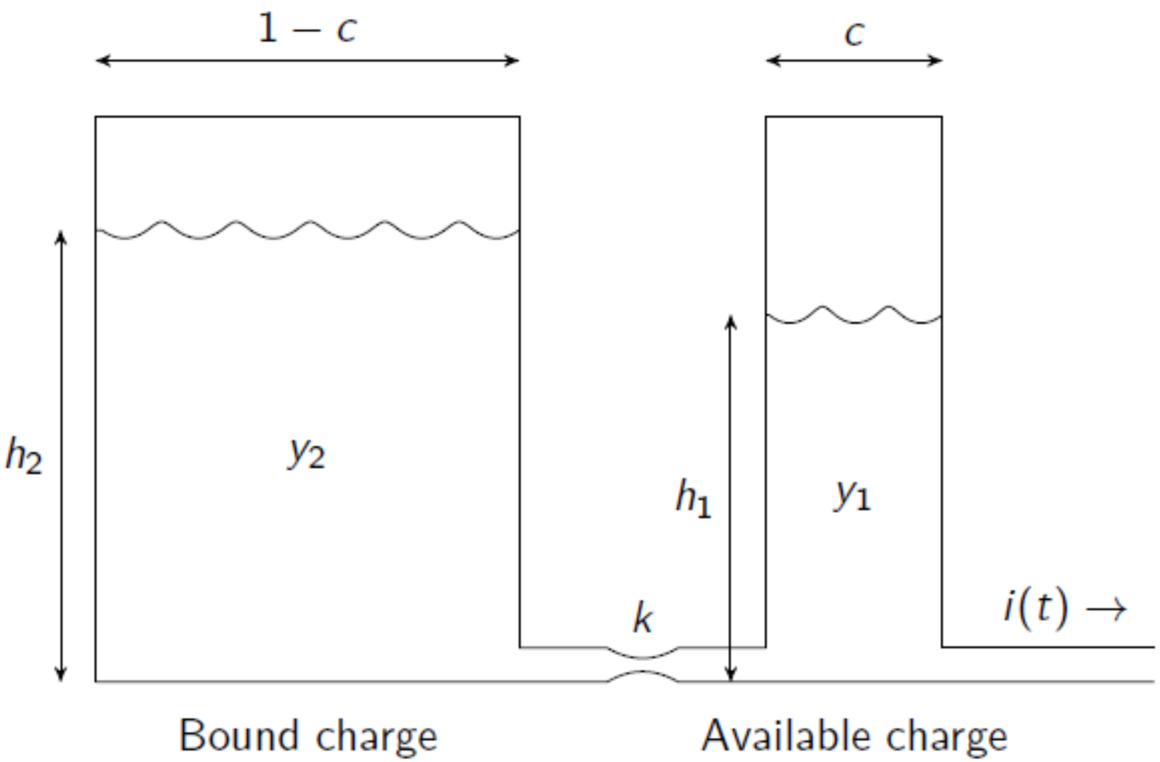


Figure from [Jongerden, 2010]

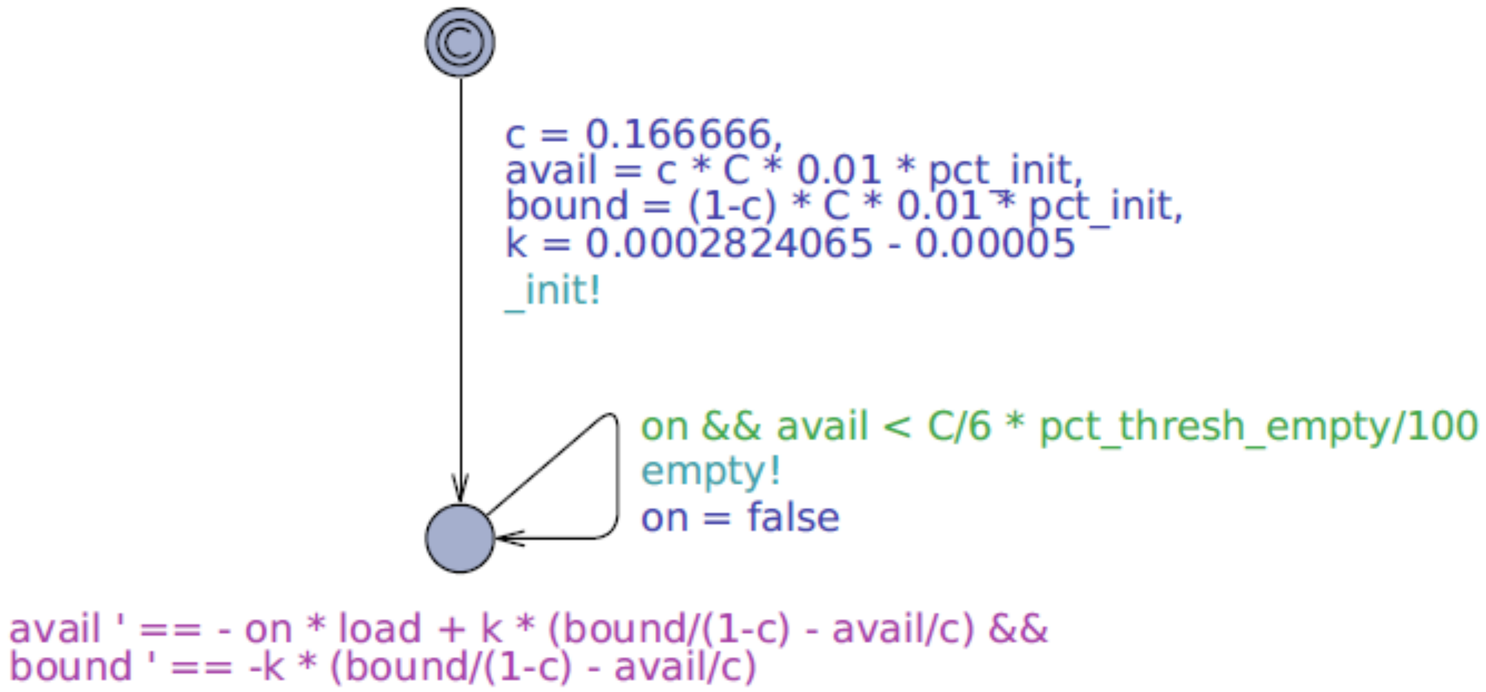
The Kinetic Battery Model
(Manwell and McGowan, 1993–1994)



Available charge: $\frac{dy_1}{dt} = -i + k(h_2 - h_1)$ $\quad h_1 = \frac{y_1}{c}$

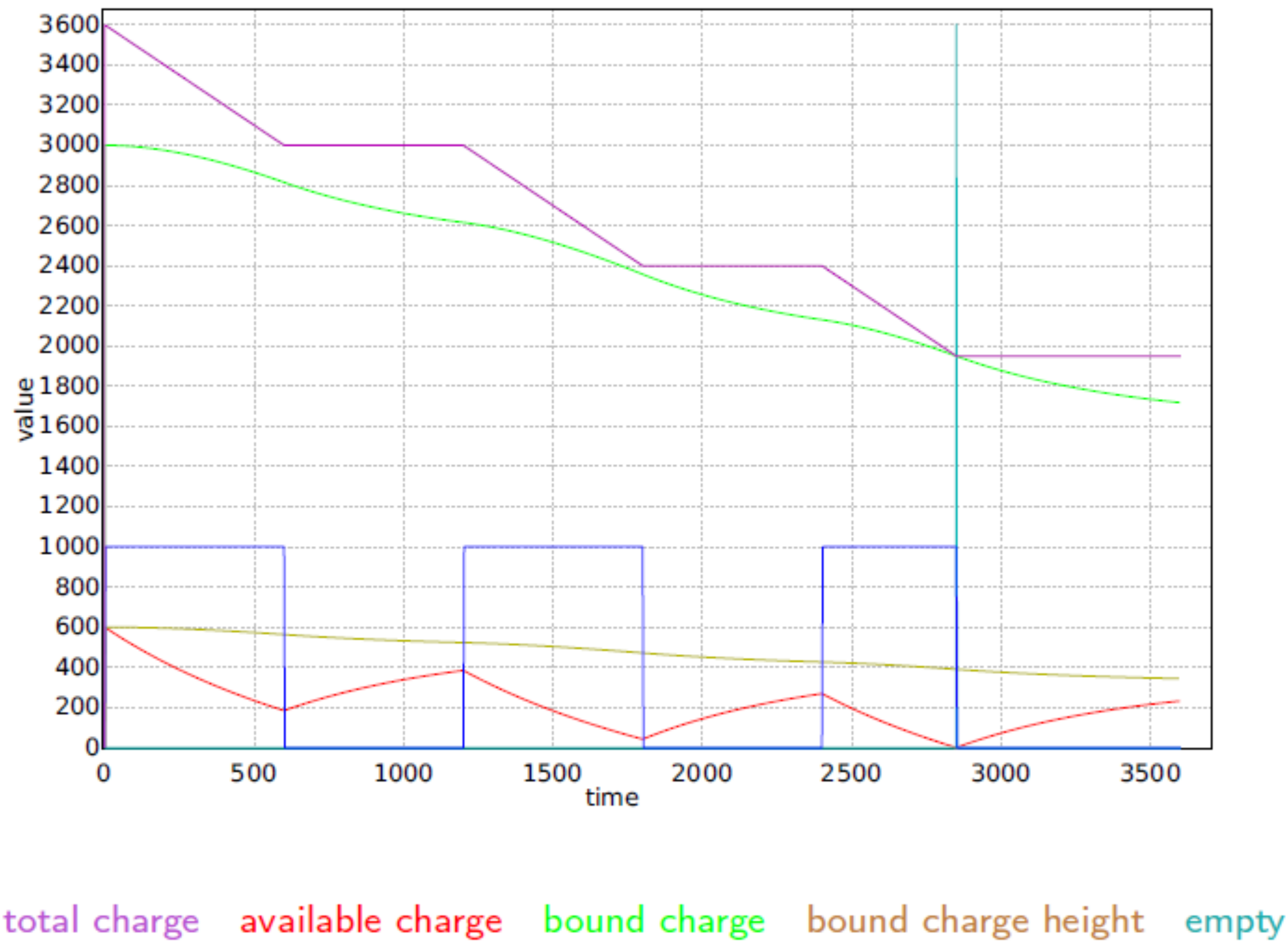
Bound charge: $\frac{dy_2}{dt} = -k(h_2 - h_1)$ $\quad h_2 = \frac{y_2}{(1-c)}$

The Kinetic Battery Model
(Manwell and McGowan, 1993–1994)

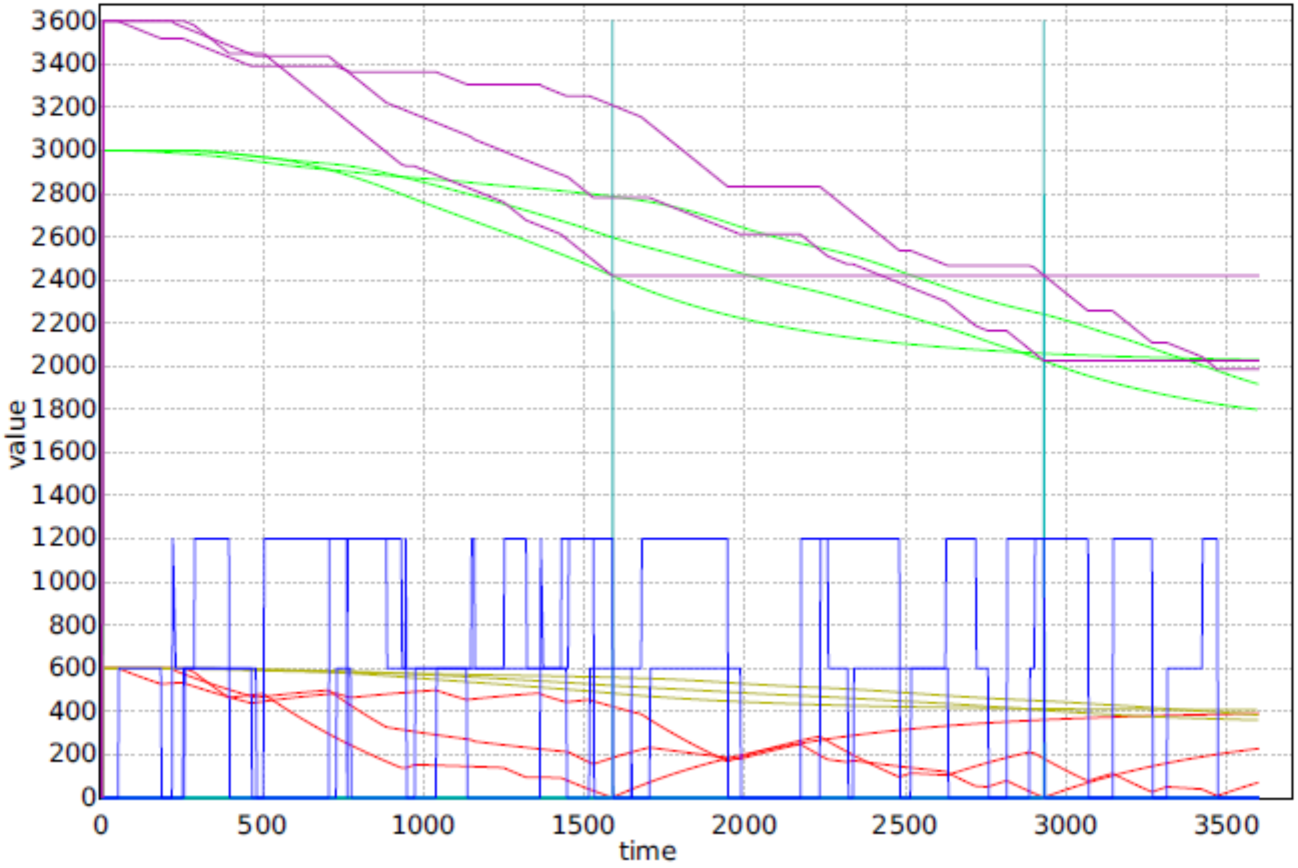


Realistic constants (e.g. Li-ion battery)

Example UPPAAL simulation

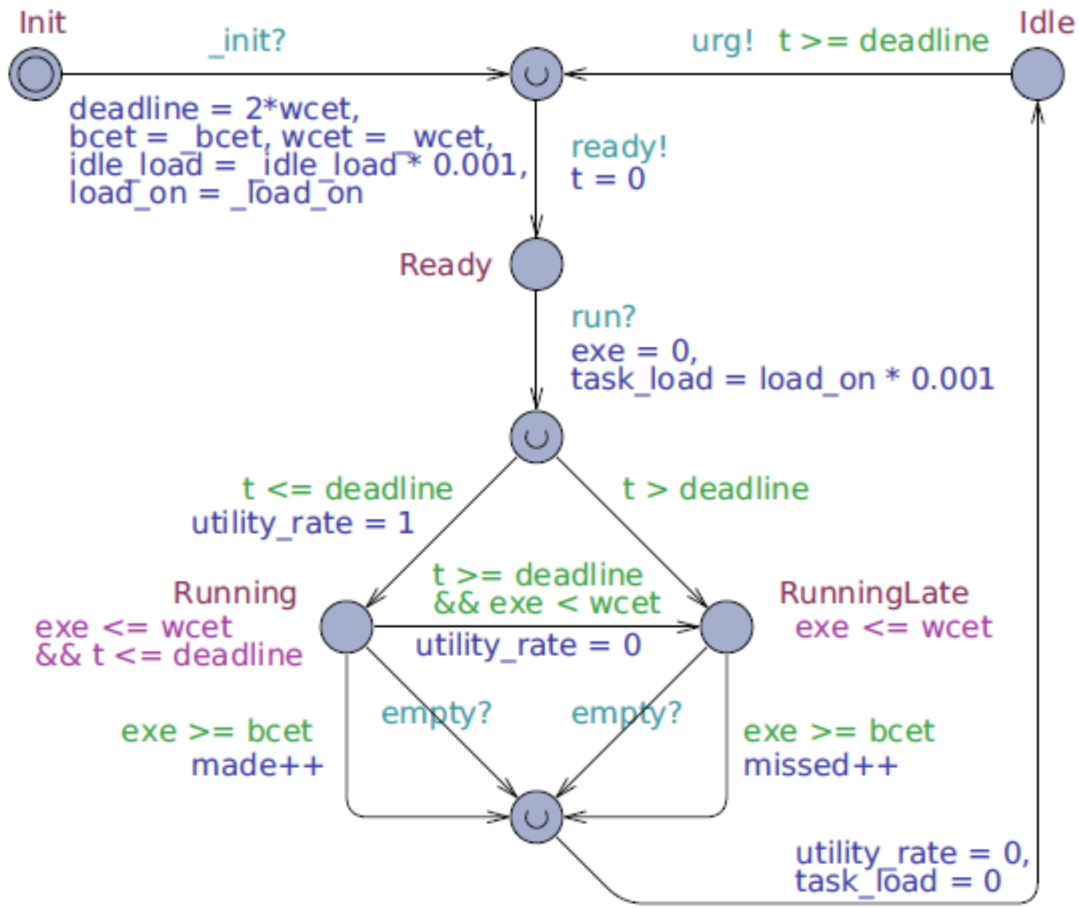


Random Load Simulation

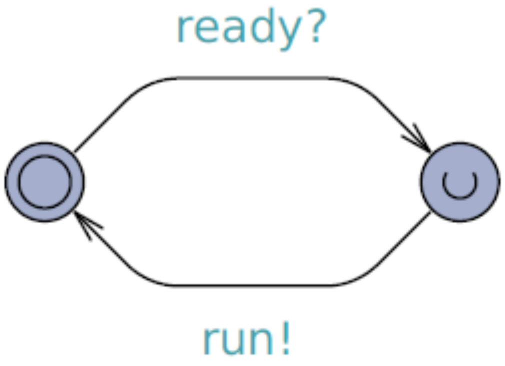


load total charge available charge bound charge bound charge height empty

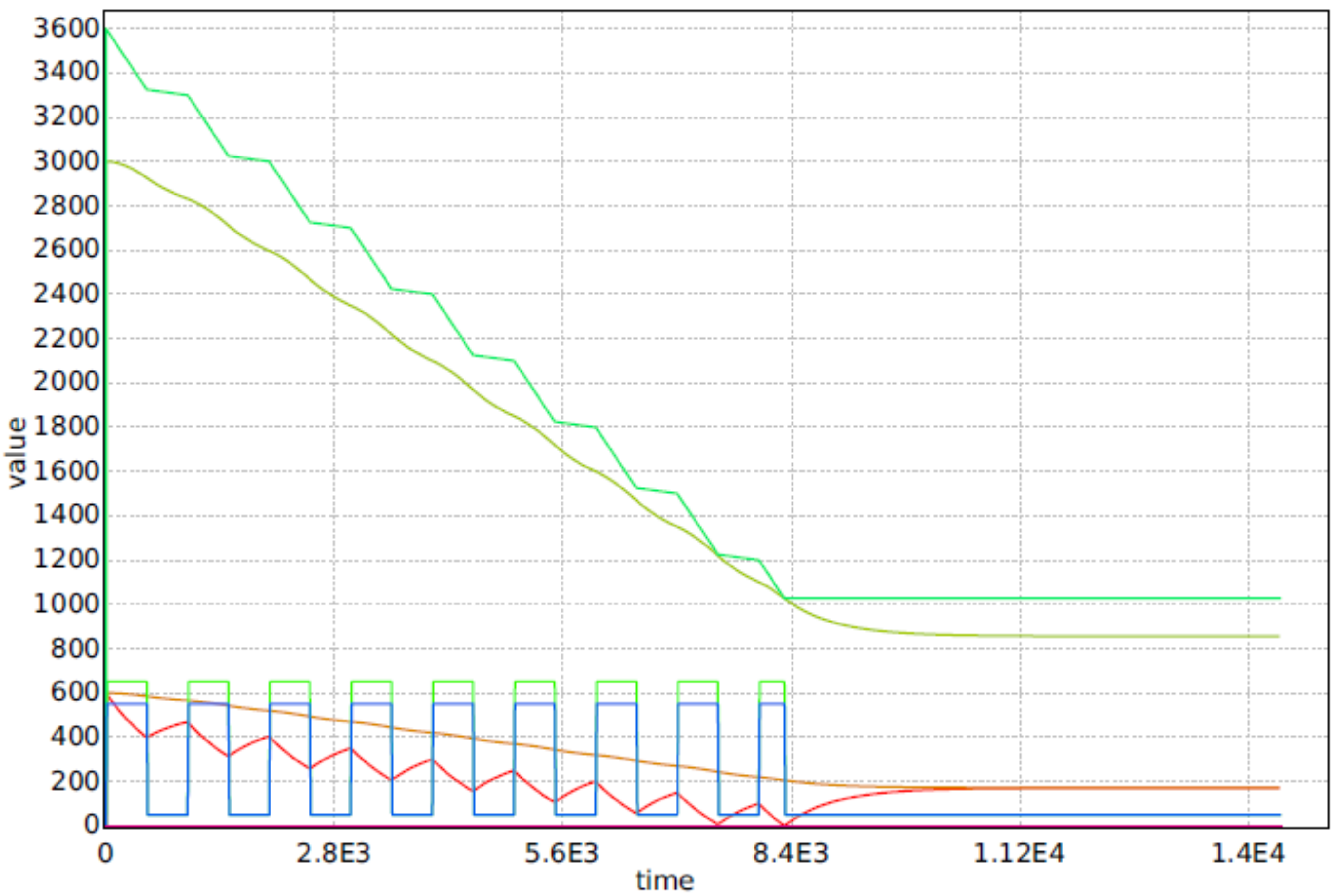
Soft Real Time Task Model



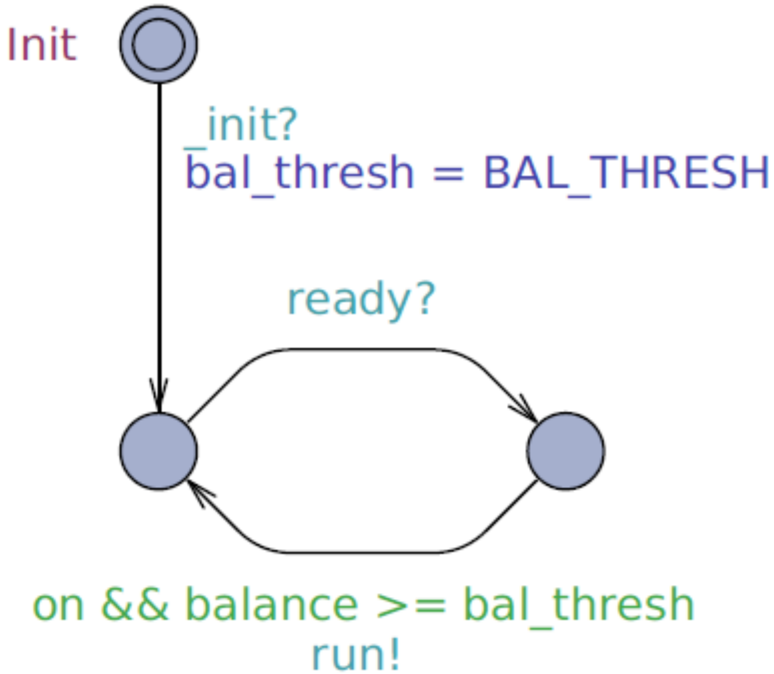
Immediate Scheduler



Immediate Scheduler Simulation

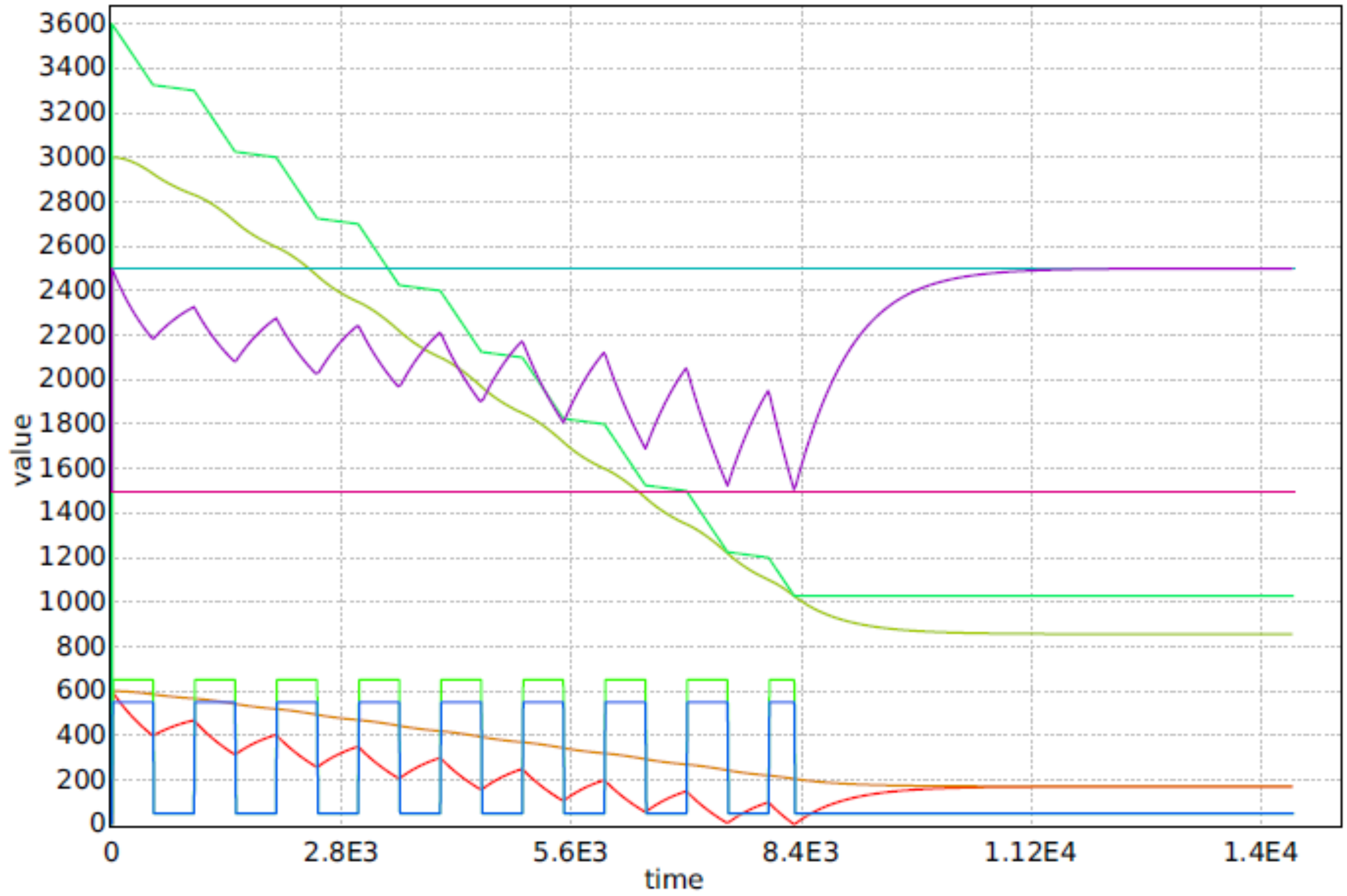


Balance Scheduler Model

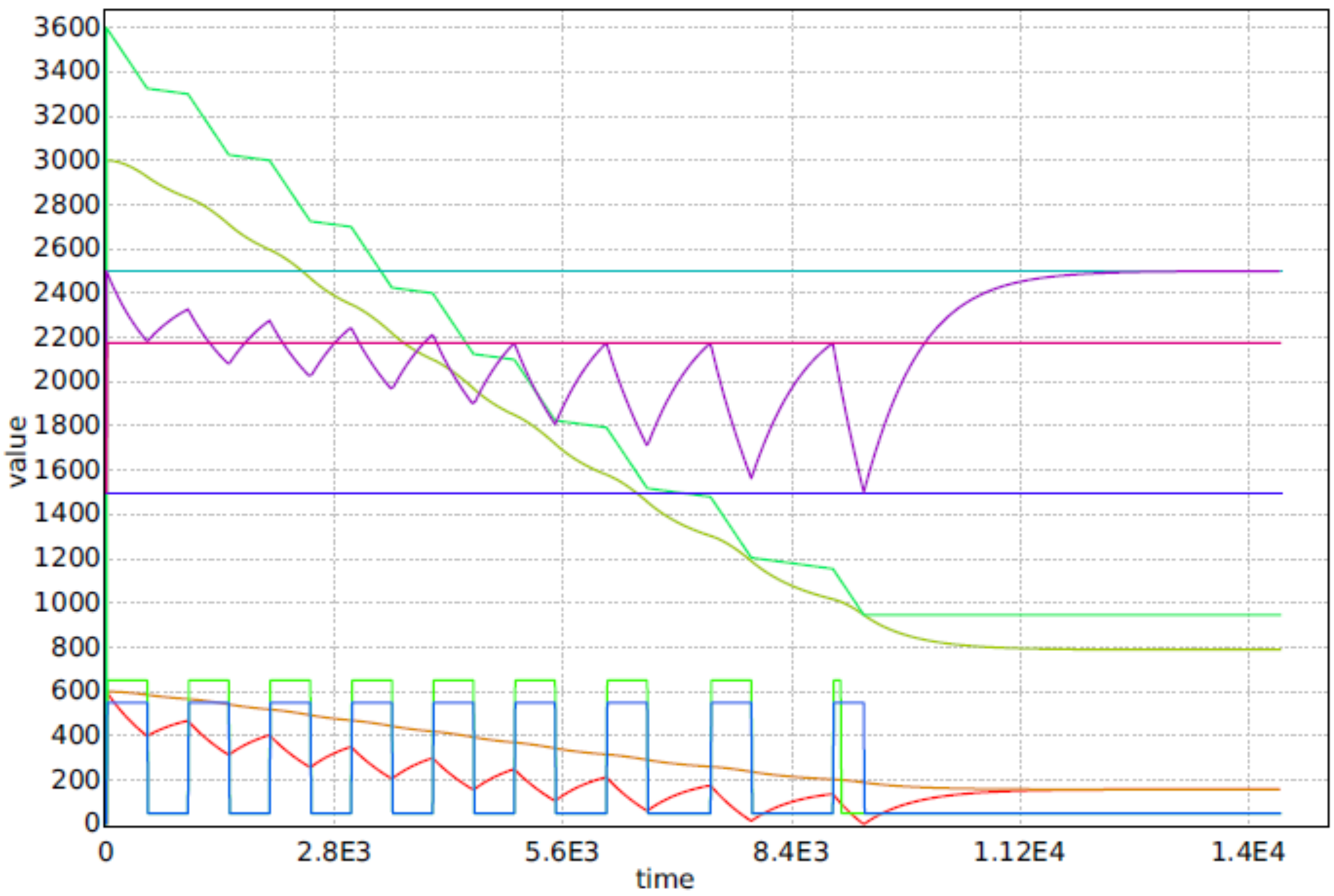


$$\text{Balance} = \frac{h_1}{h_2}$$

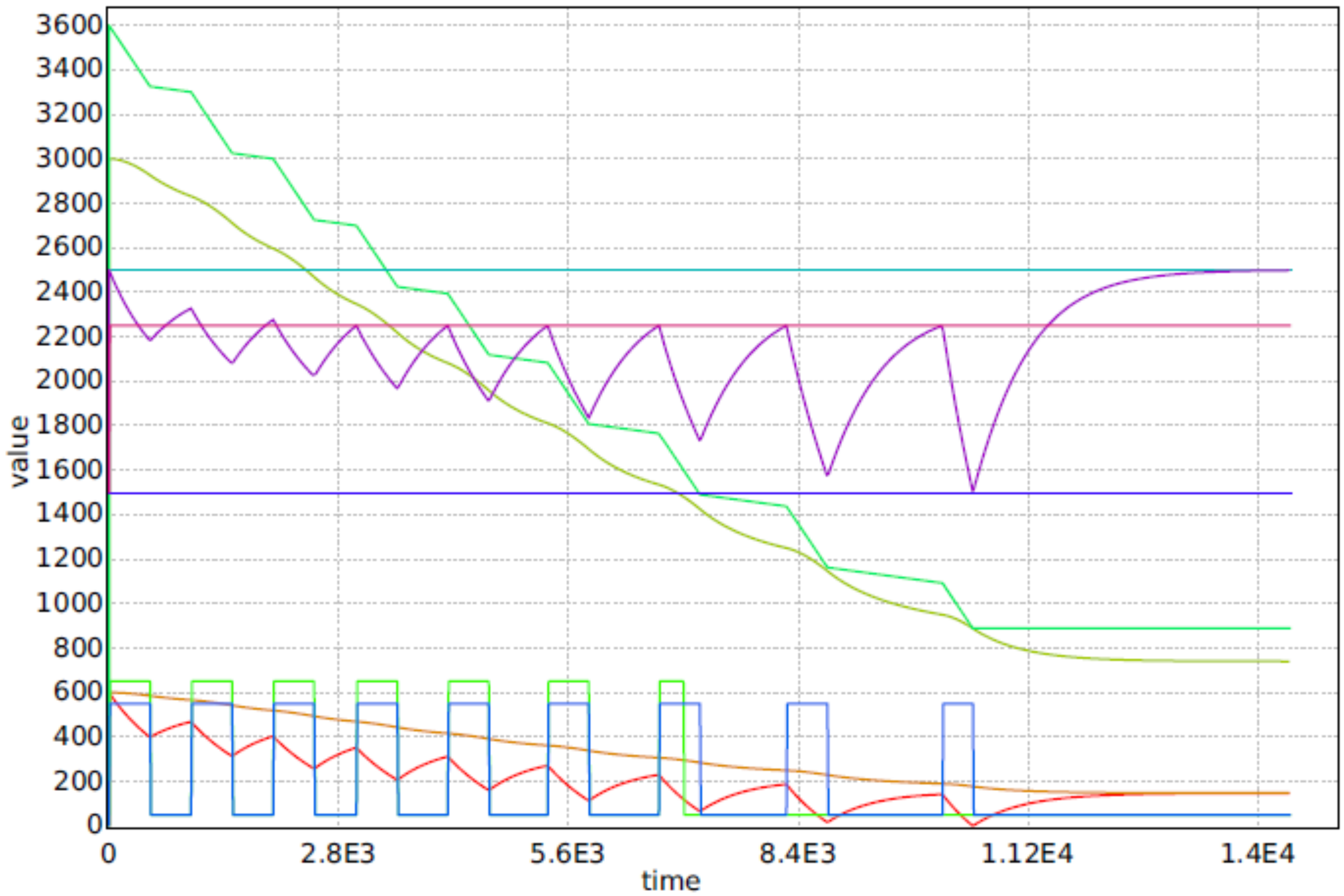
Balance Scheduler Simulation (>=0%)



Balance Scheduler Simulation (>=67.5%)



Balance Scheduler Simulation (>=75%)

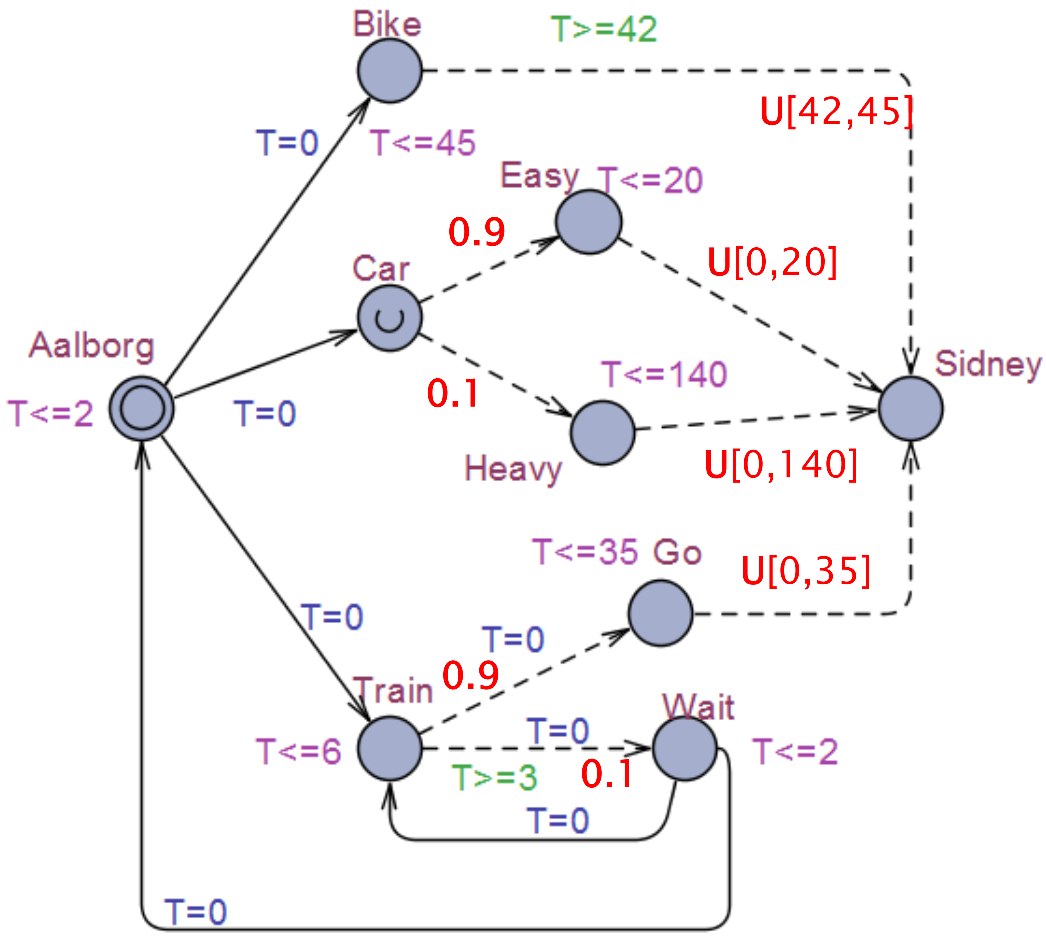


Overview

- Timed Automata / UPPAAL
  - Verification
- Priced Timed Automata / UPPAAL CORA
  - Optimal Scheduling (multicore applications)
  - Optimal Infinite Scheduling
  - Multi objective optimization
- Schedulability Analysis & Scheduling
  - Single Core, Multi Core
  - Dynamic voltage Scheduling
  - Energy Automata
- Stochastic Priced Timed Automata / UPPAAL SMC
  - Statistical Model Checking
  - Low Power Medium Access Protocol
  - Stochastic Hybrid Automata
  - Energy-Aware Buildings
  - Battery-Aware Scheduling
- **Stochastic Priced Timed Games / UPPAAL STRATEGO**
  - Optimal & Safe Synteses
  - Energy-Aware and Optimal Satelitte Scheduling
- Conclusion

Stochastic Priced Timed Games

Going to Sydney – in 1 hour



Can I get to Sidney?
(1–player)

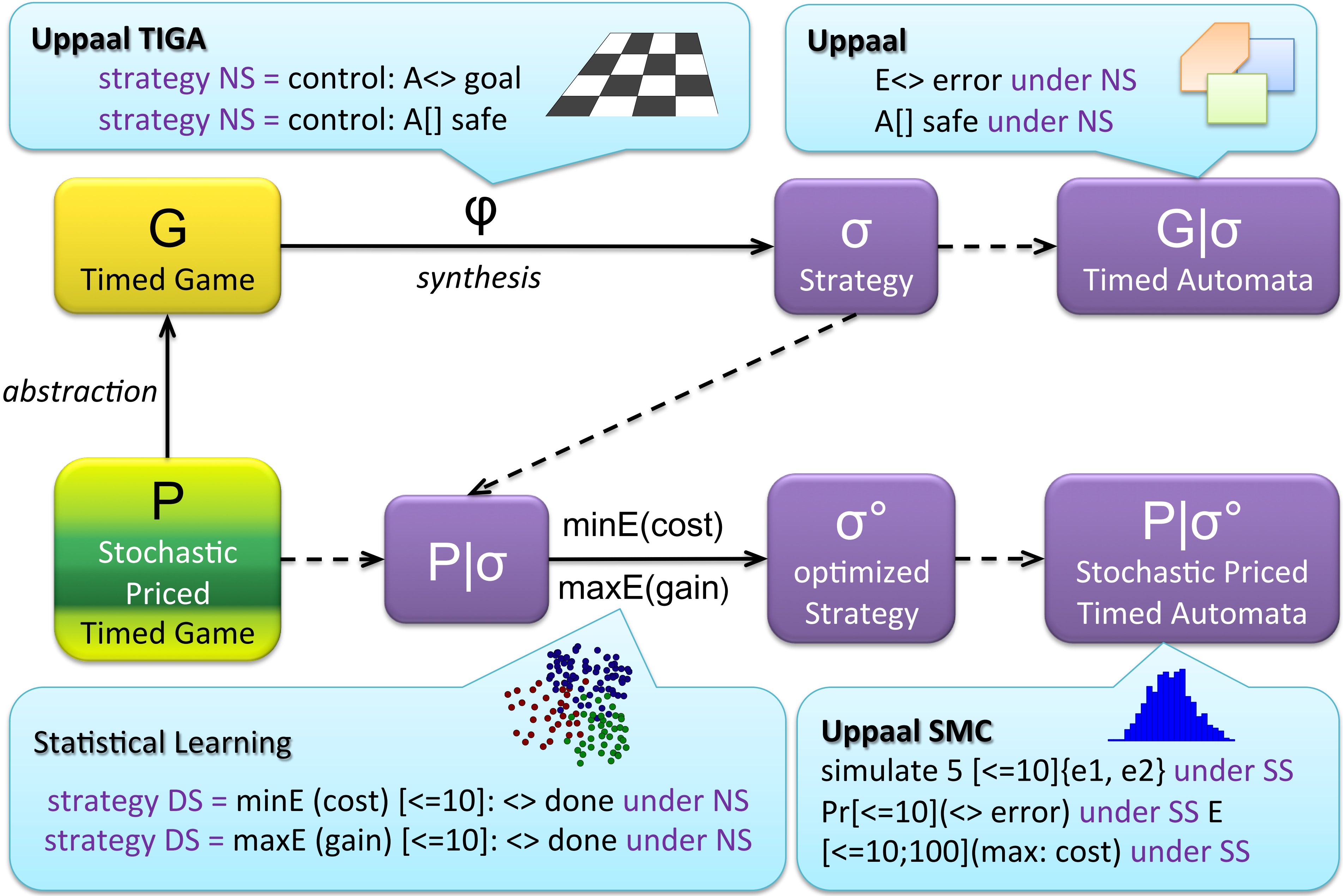
Will I always come to Sidney?
(1–player)

What is the optimal WC strategy?
(2–player)

Is there a strategy guaranteeing WC <= 60?
(2–player)

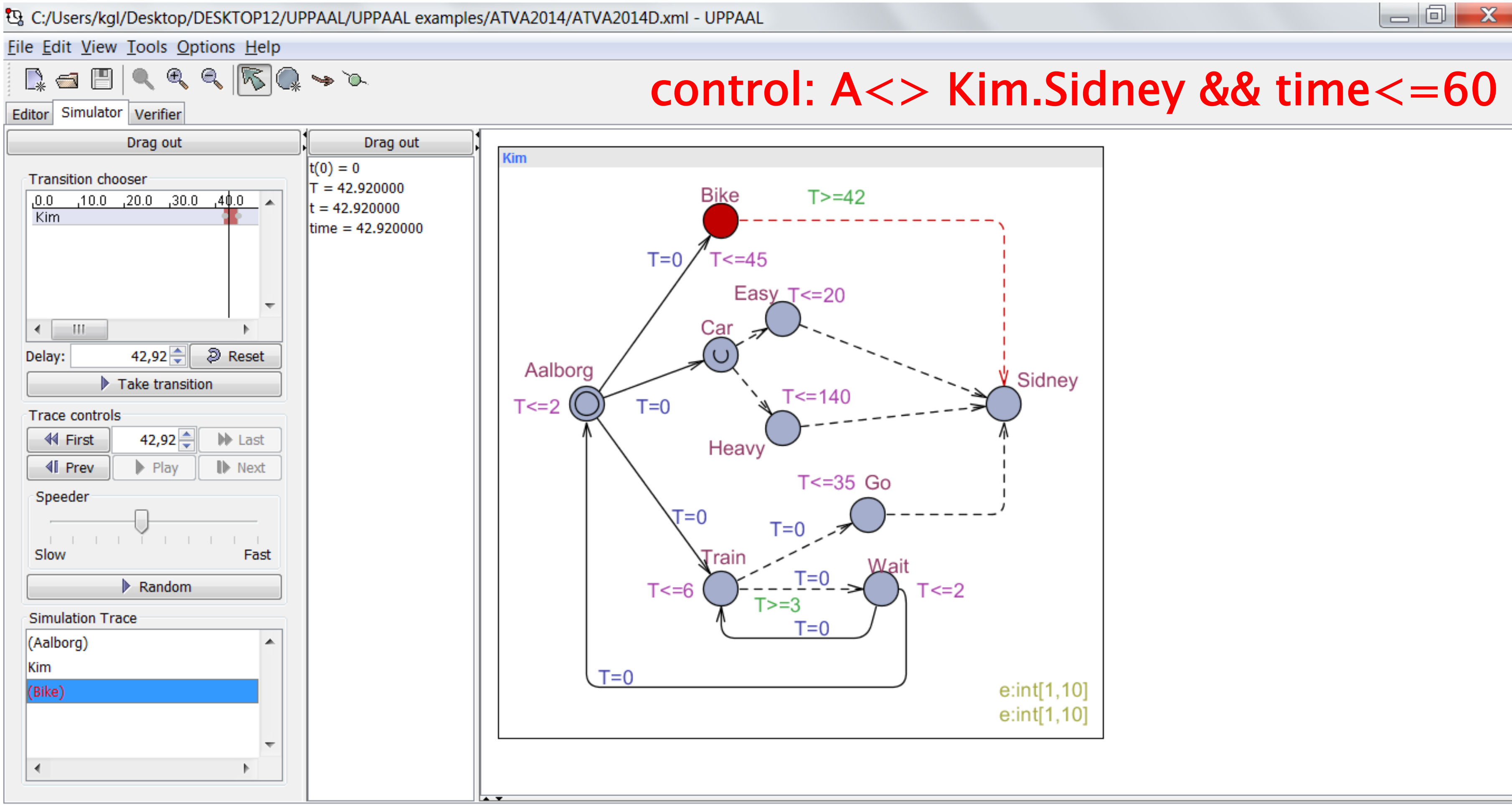
What is the optimal strategy?
(1½–player)

What is the optimal strategy Guarenteeing WC <= 60?
(1½–player)

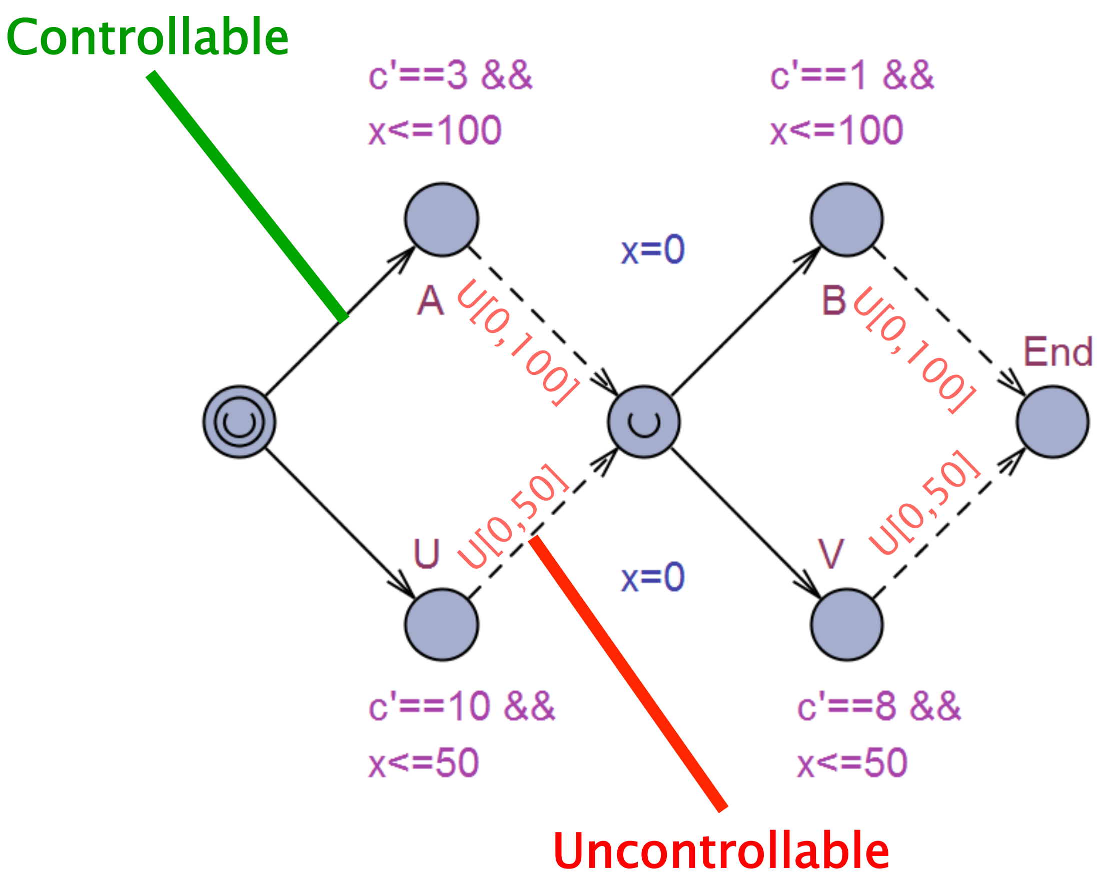

Uppaal TIGA
strategy NS = control: A<> goal
strategy NS = control: A[] safe
Uppaal
E<> error under NS
A[] safe under NS
G
Timed Game
φ
synthesis
σ
Strategy
G|σ
Timed Automata
abstraction
P
Stochastic
Priced
Timed Game
P|σ
minE(cost)
maxE(gain)
σ°
optimized
Strategy
P|σ°
Stochastic Priced
Timed Automata
Statistical Learning
strategy DS = minE (cost) [<=10]: <> done under NS
strategy DS = maxE (gain) [<=10]: <> done under NS
Uppaal SMC
simulate 5 [<=10]{e1, e2} under SS
Pr[<=10](<> error) under SS E
[<=10;100](max: cost) under SS

Stratego – DEMO

control: A<> Kim.Sidney && time<=60

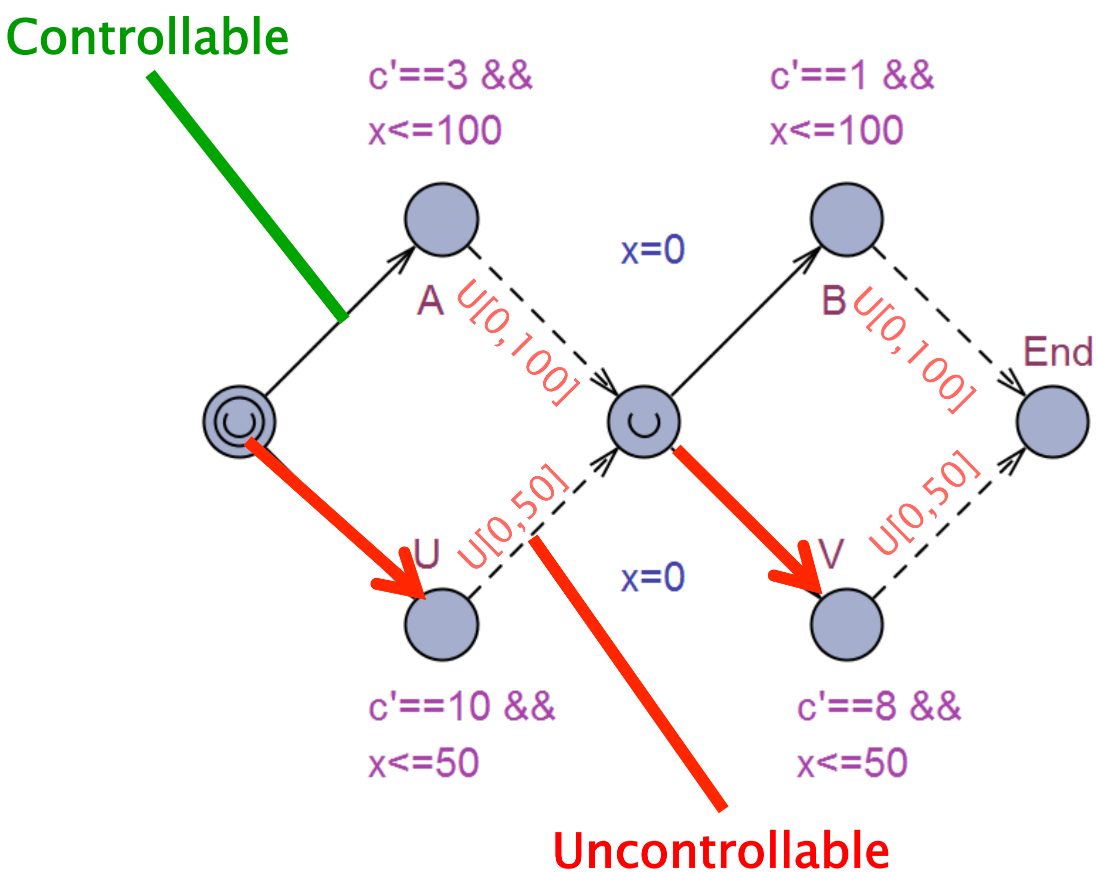


Timed Game for Two Phase Task



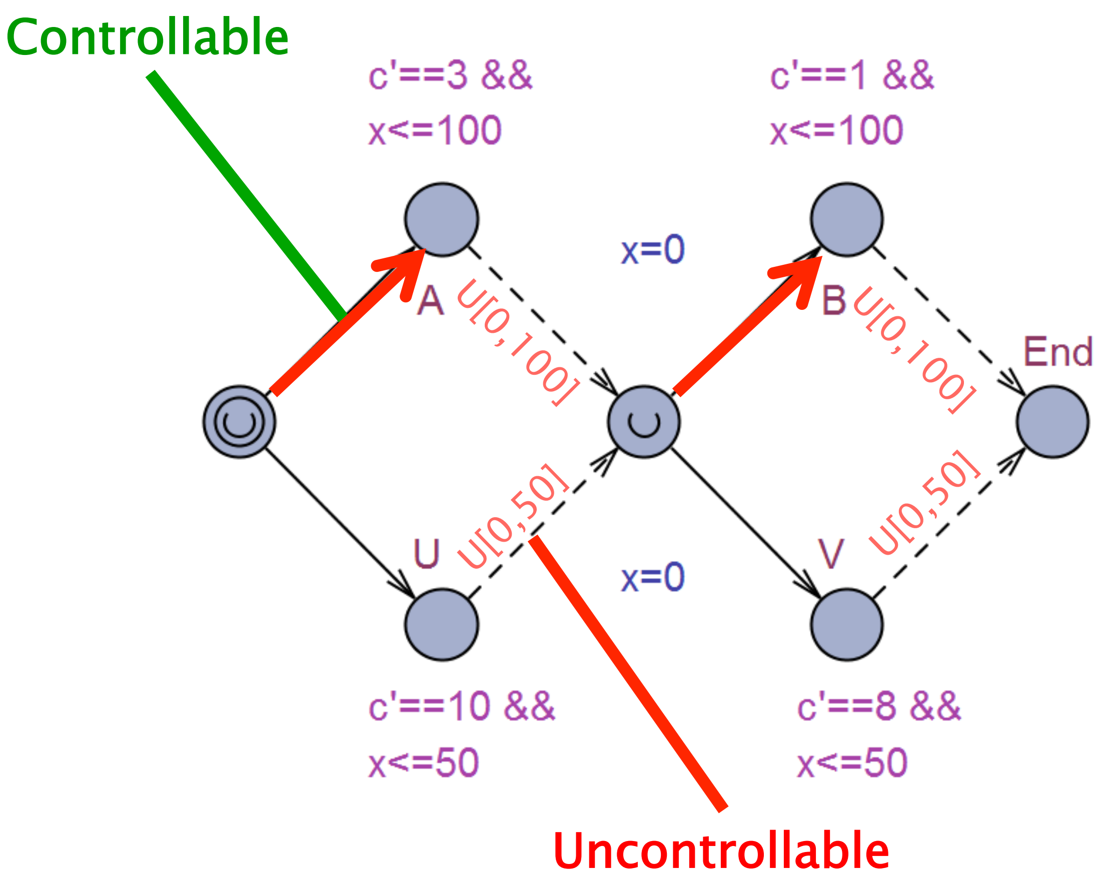
- What is the best WC time ?
- What is the best WC cost?
- What is the best expected time?
- What is the best expected cost?
- What is the best expected cost if task **must** be done before 150 ?

Timed Game for Two Phase Task



- What is the best WC time ?
- What is the best WC cost?
- What is the best expected time?
- What is the best expected cost?
- What is the best expected cost if task **must** be done before 150 ?

Timed Game for Two Phase Task



- What is the best WC time ?
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- What is the best expected cost?
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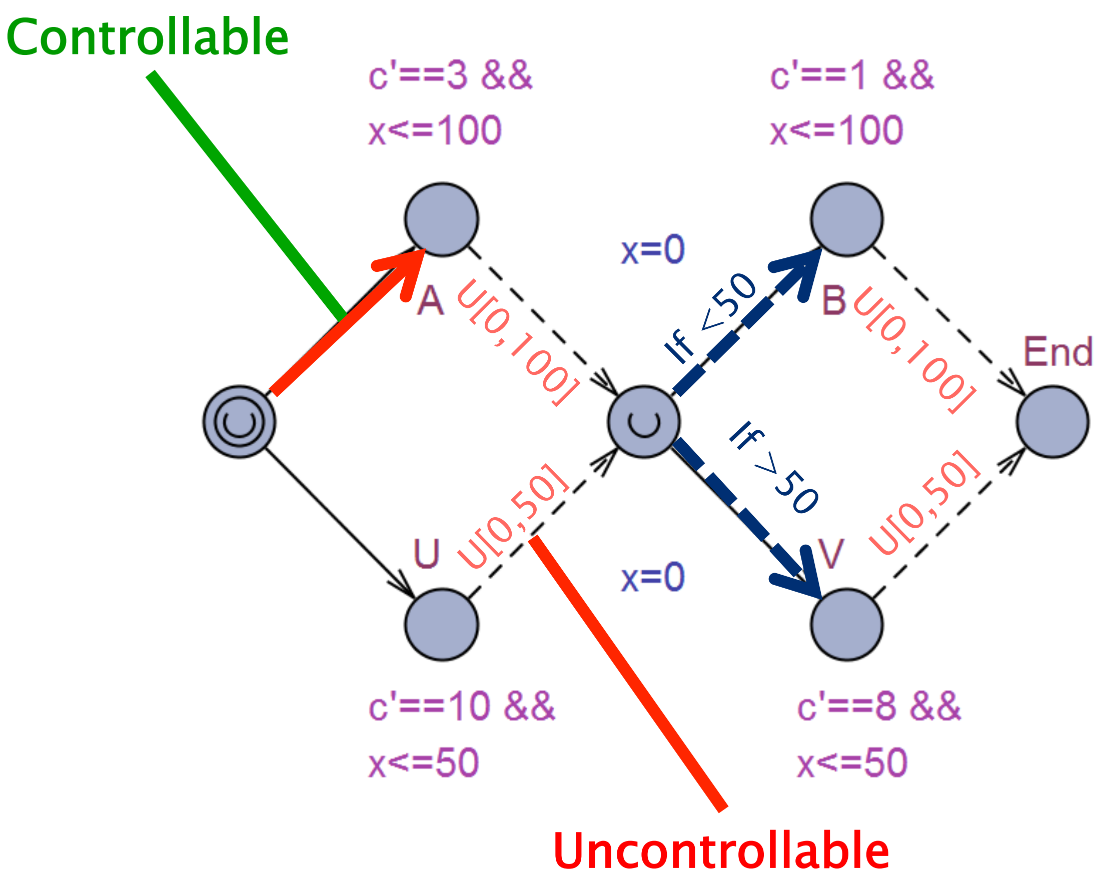
Timed Game for Two Phase Task



- What is the best WC time ?
- What is the best WC cost?
- What is the best expected time?
- What is the best expected cost?
- What is the best expected cost if task must be done before 150 ?

GOMSPACE

Energy-Aware and Optimal Scheduling of Satellites

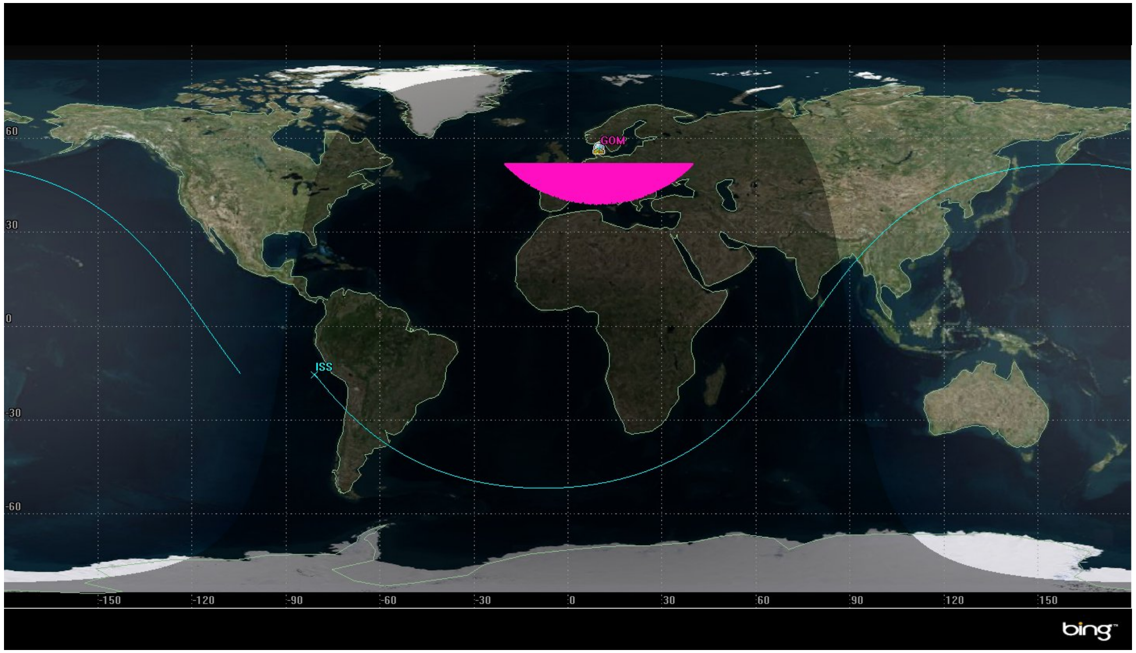
Satellite as a Service

GOMX3

AALBORG UNIVERSITY DENMARK

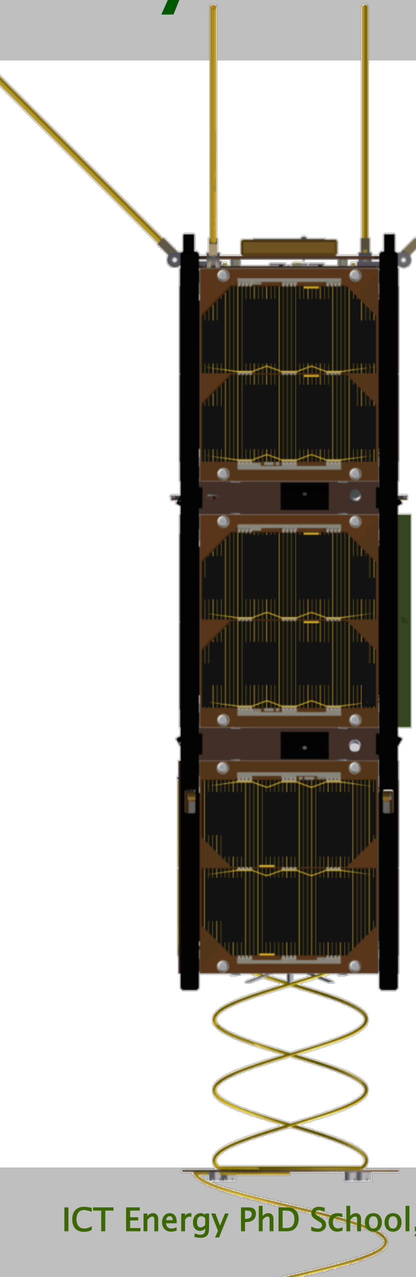
Mission Analysis

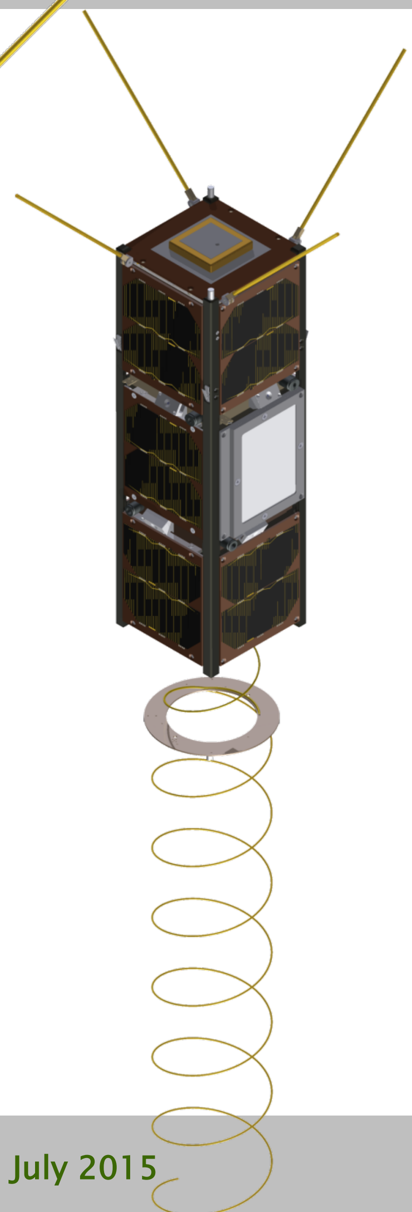
- Aalborg ground station can supply 37 min link time per day
- Max of 18 hours between passes

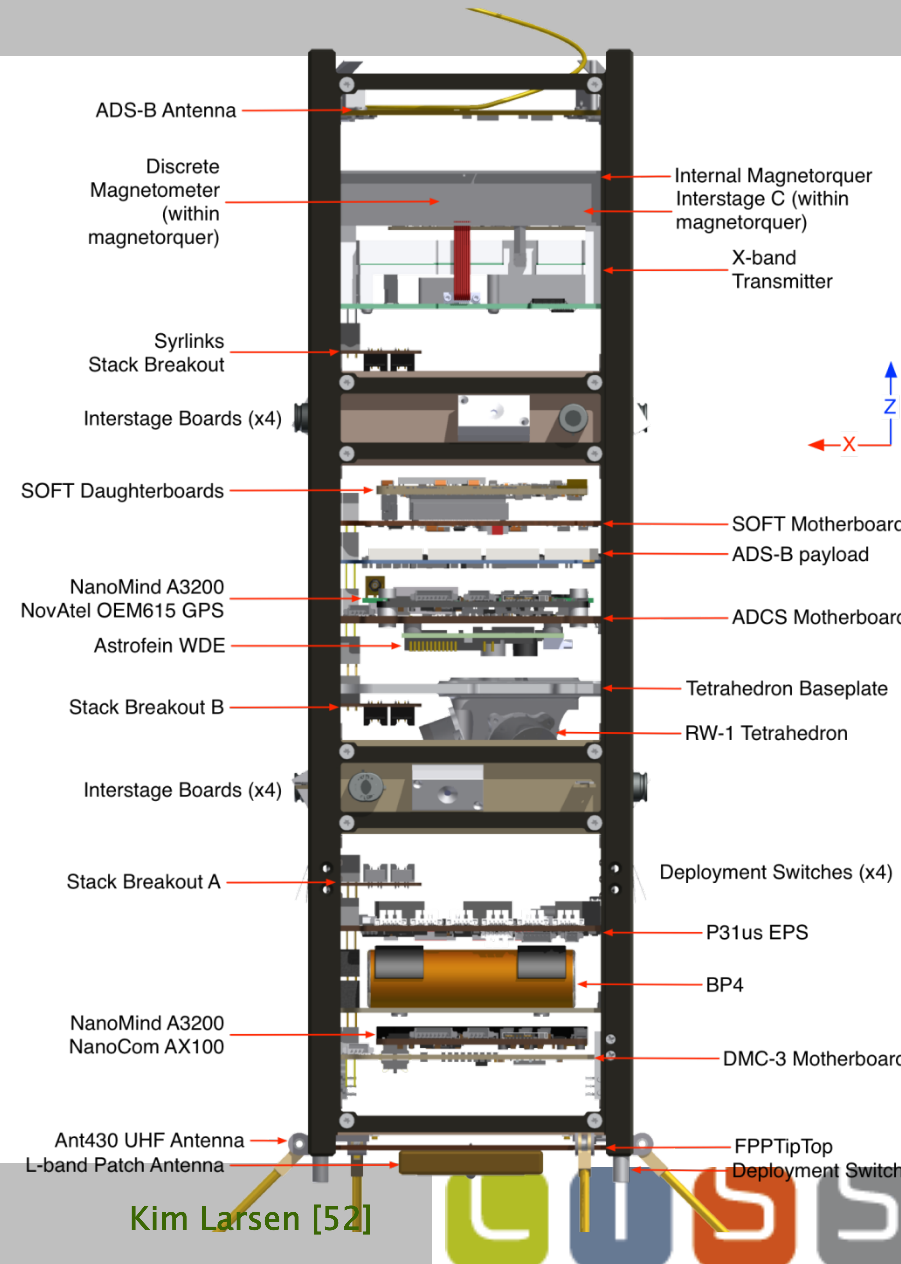


Elevation Mask (deg)	**Mean Daily Passes**	**Average Pass Length** (min)	**Mean Daily Access** (min)	**Max Time Between Passes** (hr)
0	5.41	8.31	44.9	18.1
2	5.01	7.40	37.1	18.2
5	4.45	6.20	27.6	19.7

System Design: Layout



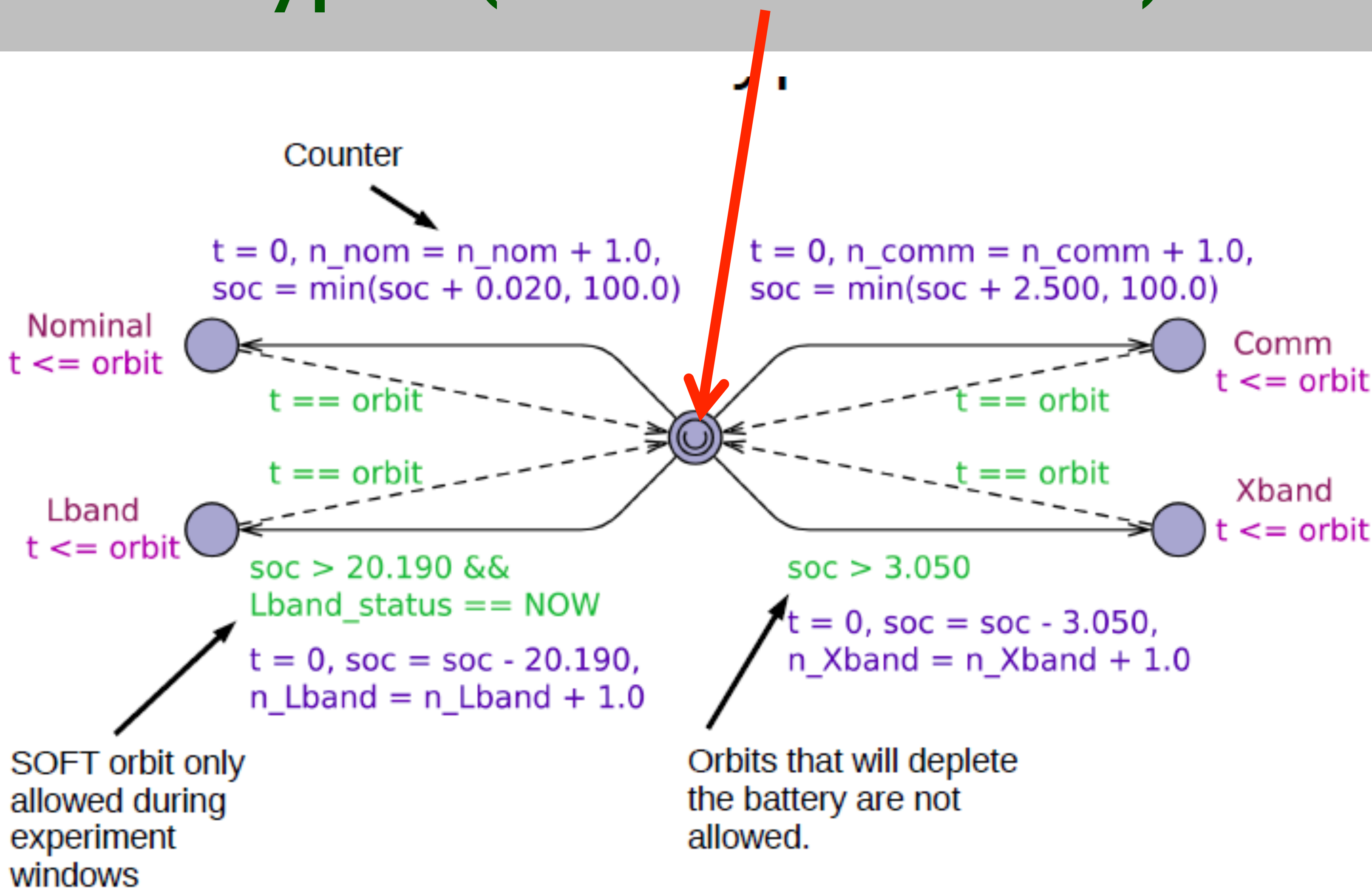




GOMX3 Power Budget

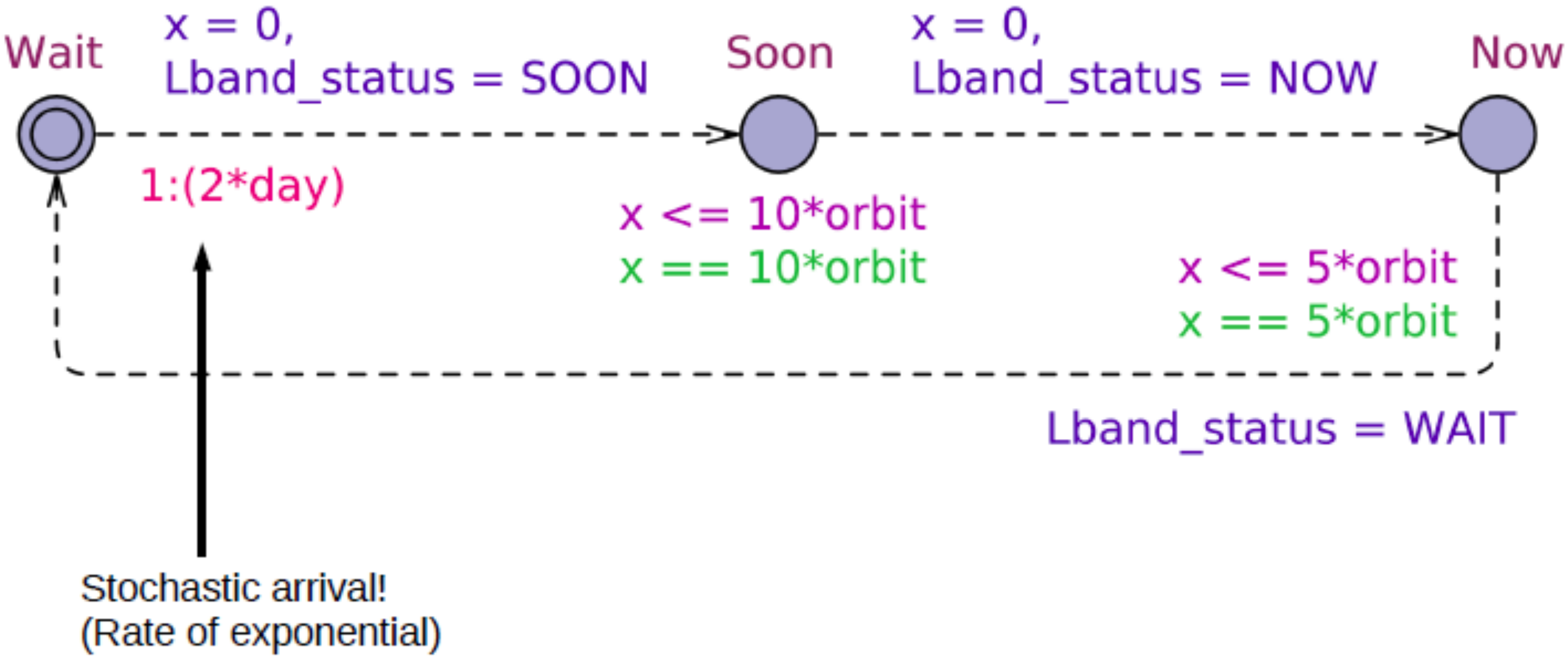
705.162	Comm Orbit		Nominal Orbit		X-band Orbit		SOFT Orbit	
Energy Consumption	**Energy**		**Energy**		**Energy**		**Energy**	
NanoMind A3200 OBC	1538	Joules	1538	Joules	1538	Joules	1538	Joules
NanoPower P31US	705	Joules	705	Joules	705	Joules	705	Joules
NanoPower BP4 Heaters	0	Joules	0	Joules	0	Joules	0	Joules
NanoCom AX100 Rx	1538	Joules	1538	Joules	1538	Joules	1538	Joules
NanoCom Ax100 Tx	2051	Joules	1073	Joules	1073	Joules	708	Joules
NanoMind A3200 ADCS	1538	Joules	1538	Joules	1538	Joules	1538	Joules
ADCS Sensors	1668	Joules	1668	Joules	1668	Joules	1668	Joules
Magnetorquers	1309	Joules	1309	Joules	1309	Joules	1309	Joules
Reaction Wheels + 4WDE	7026	Joules	7026	Joules	7026	Joules	7026	Joules
GPS	431	Joules	431	Joules	431	Joules	431	Joules
ADS-B Payload	0	Joules	3836	Joules	3836	Joules	3836	Joules
SOFT RF Receive	0	Joules	677	Joules	0	Joules	31483	Joules
SOFT Data Transmit	0	Joules	49	Joules	2296	Joules	0	Joules
X-band Transmitter	0	Joules	127	Joules	5928	Joules	0	Joules
UHF Antenna Release	0	Joules	0	Joules	0	Joules	0	Joules
Helix Antenna Release	0	Joules	0	Joules	0	Joules	0	Joules
Orbit energy consumed	17805 J		21517 J		28887 J		51780 J	
Orbit energy generated	21548 J		21548 J		24324 J		21548 J	
Net energy	3743 J		31 J		-4563 J		-30232 J	
Battery Net Energy Change	0.025	2.5%	0.00021	0.0%	-0.0305	-3.0%	-0.2019	-20.0%
Net Energy Difference	0.17372		0.00146		-0.1876		-1.403	

Orbit Types (which to choose)



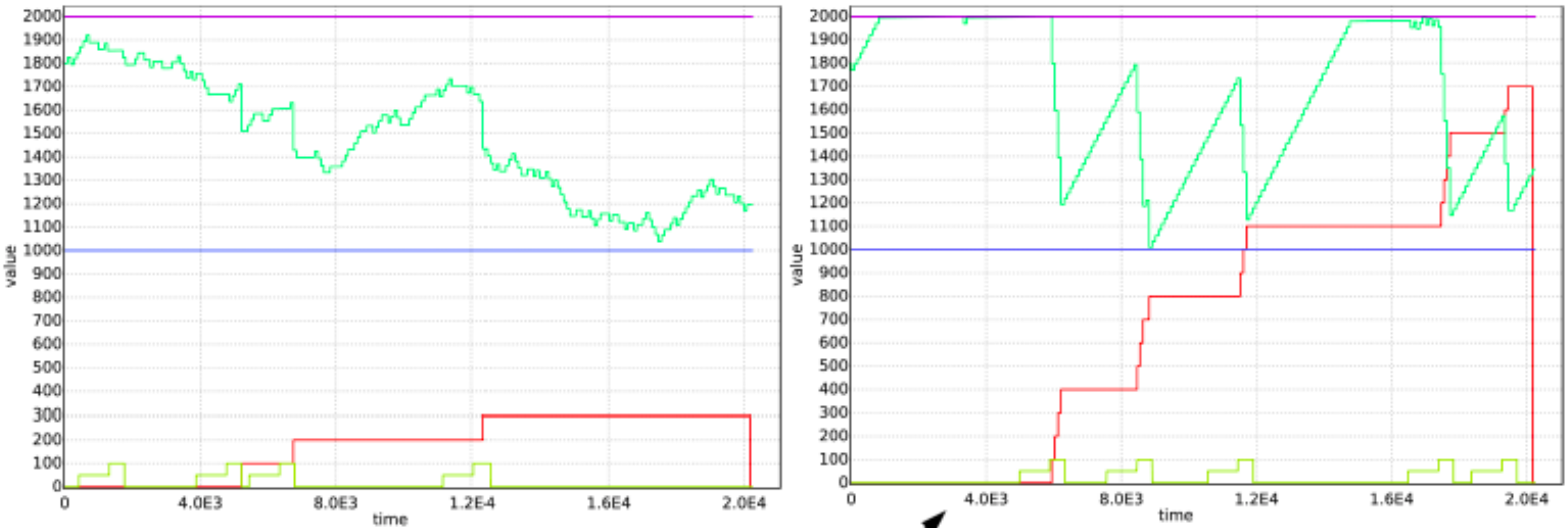
`double soc = 80.0;` // Battery is a floating point value between 0 and 100

Experiment Window



GOMX3 Orbits Optimized

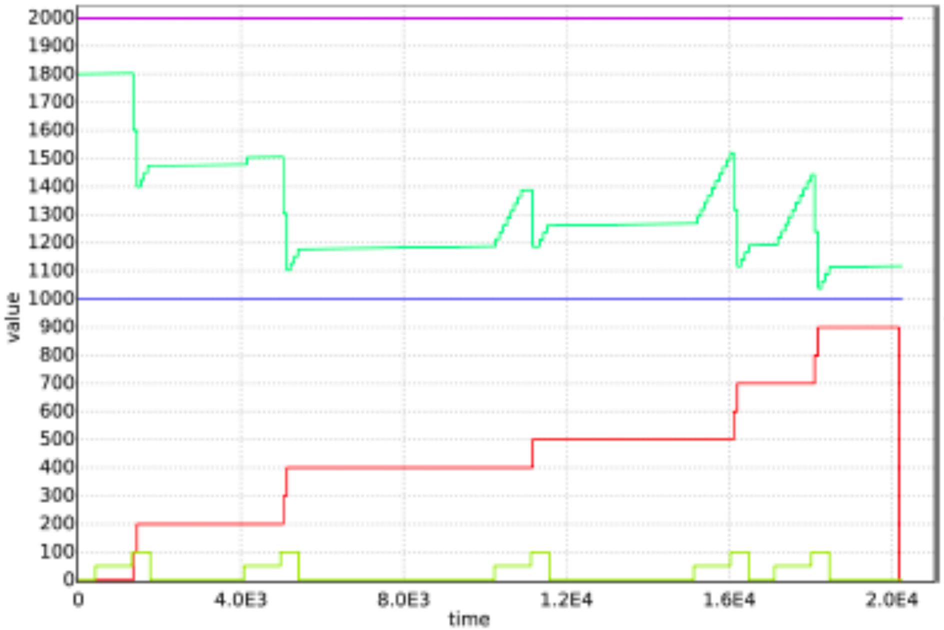
```
simulate 1 [<=2*week] {n_soft*100, (Mission.Soon + Mission.Now*2)
*50, 1000+soc*10, 1000, 2000}
```



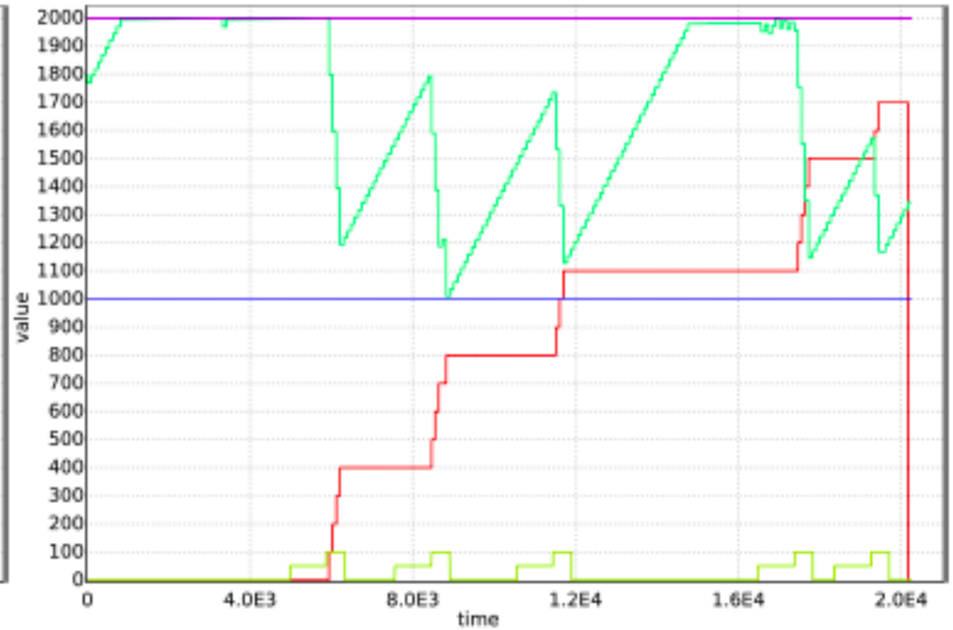
- `strategy s = maxE(n_soft) [<=2*week]: <> time==2*week`
- `simulate 1 [<=2*week] {...}` **`under s`**

GOMX3 Orbits Optimized

maxE(n_soft + 0.08 * n_nom)

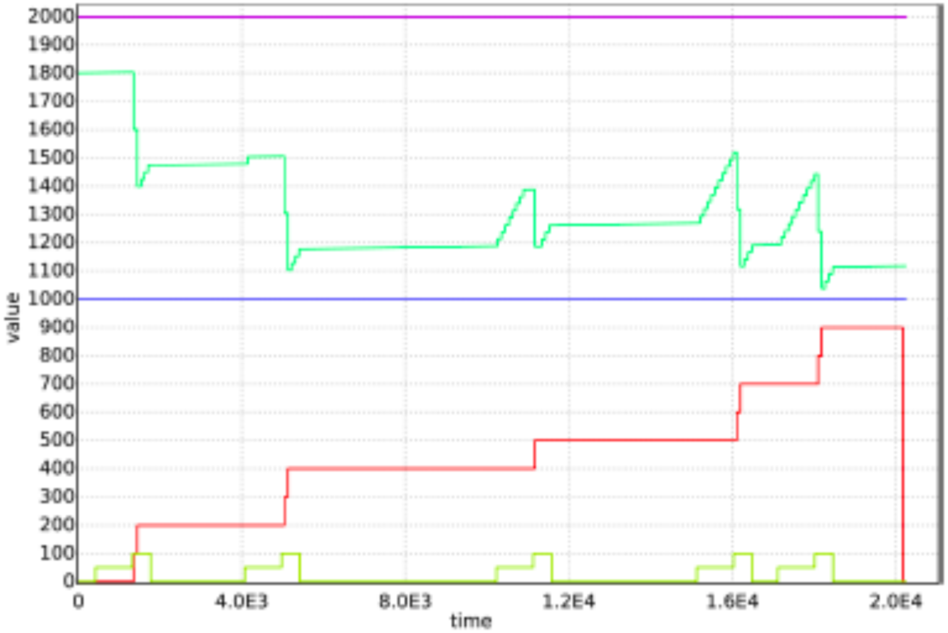


maxE(n_soft)

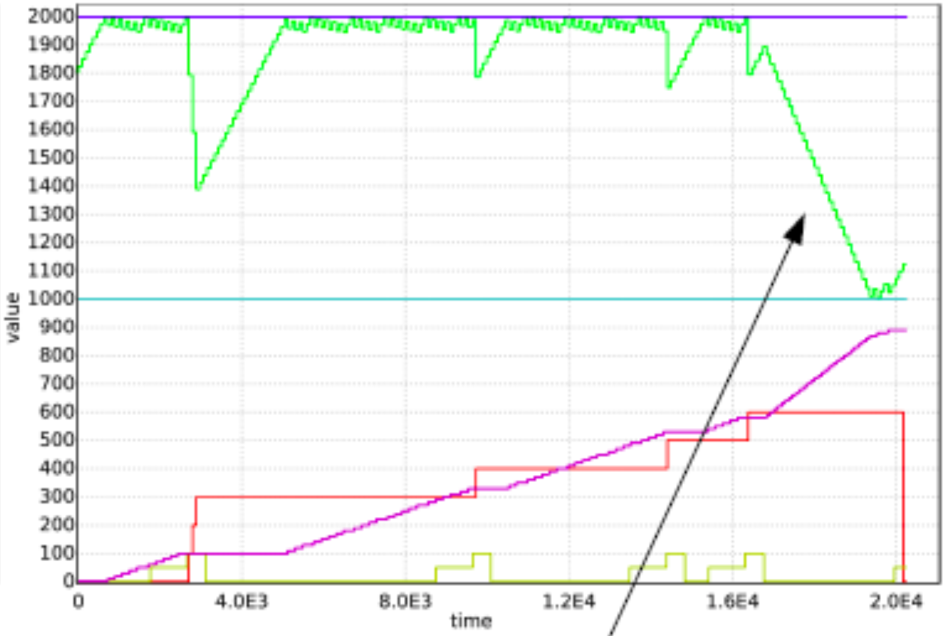


GOMX3 Orbits Optimzed

`maxE(n_soft + 0.08 * n_nom)`

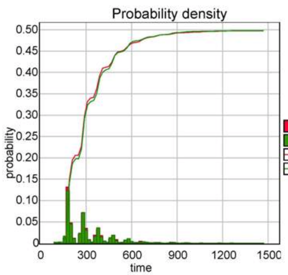


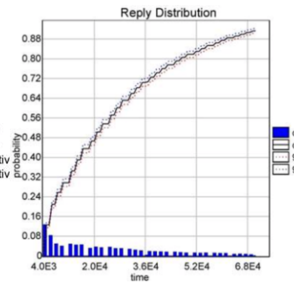
`maxE(n_soft + 0.2*n_xband)[<=2*week]`

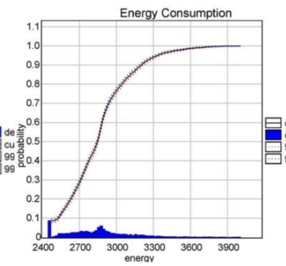


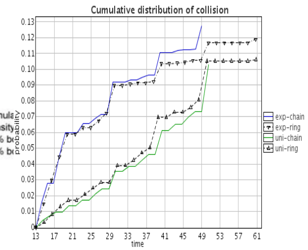
Be careful what you wish for!

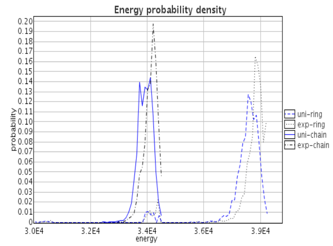
Other Case Studies

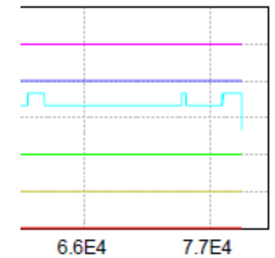










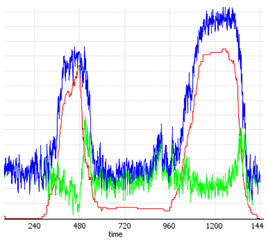


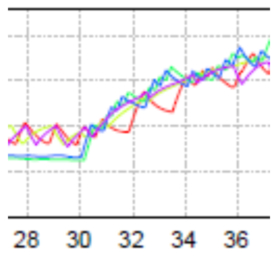
FIREWIRE

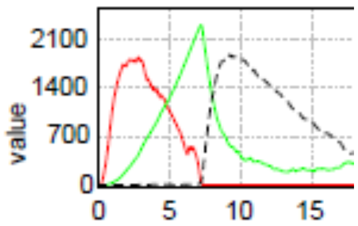
BLUETOOTH

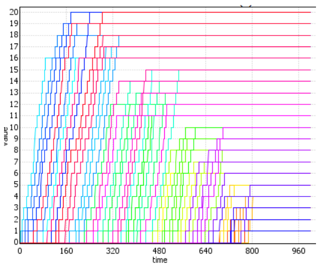
10 node LMAC

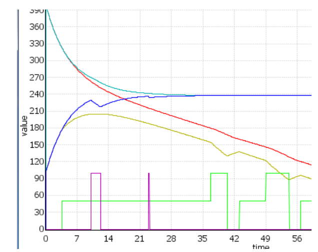
Schedulability Analysis for Mix Cr Sys











Smart Grid Demand / Response

Energy Aware Buildings

Genetic Oscilator (HBS)

Passenger Seating in Aircraft

Battery Scheduling

www.uppaal.org

RELATED SITES: TIMES | UPPAAL CORA | UPPAAL TRON

UPPAAL

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UPPAAL is an integrated tool environment for modeling, validation and verification of real-time systems modeled as networks of timed automata, extended with data types (bounded integers, arrays, etc.).

The tool is developed in collaboration between the Department of Information Technology at Uppsala University, Sweden and the Department of Computer Science at Aalborg University in Denmark.

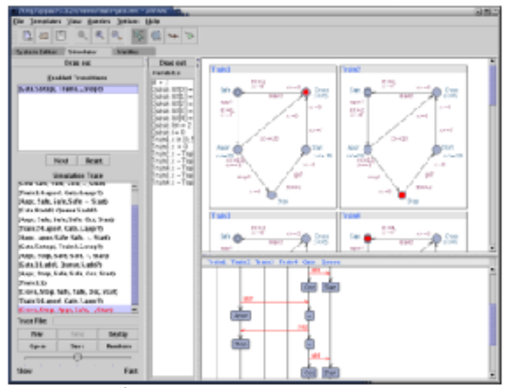

Figure 1: UPPAAL on screen.

Download

The current official release is UPPAAL 3.4.11 (Jun 23, 2005). A release of UPPAAL **3.6 alpha 3** (dec 20, 2005) is also available. For more information about UPPAAL version 3.4, we refer to this press release.

UPPSALA UNIVERSITET

AALBORG UNIVERSITY

License

The UPPAAL tool is **free** for non-profit applications. For information about commercial licenses, please email sales(at)uppaal(dot)com.

To find out more about UPPAAL, read this short introduction. Further information may be found at this web site in the pages About, Documentation, Download, and Examples.

Mailing Lists

UPPAAL has an open discussion forum group at Yahoo!Groups intended for users of the tool. To join or post to the forum, please refer to the information at the discussion forum page. Bugs should be reported using the bug tracking system. To email the development team directly, please use uppaal(at)list(dot)it(dot)uu(dot)se.

www.uppaal.{org,com}