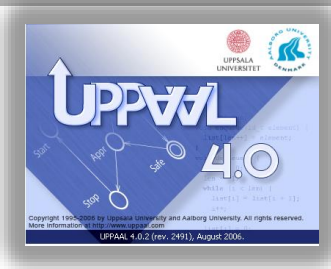
Validation and Performance Analysis of CPS in UPPAAL



Kim G. Larsen
Aalborg University, DENMARK

Cyber Physical Systems

OPTIMAL:
finding a **controller** for a given system such that a certain optimality criterion is achieved.

Discrete

Real Time

Resources

Stochasticity

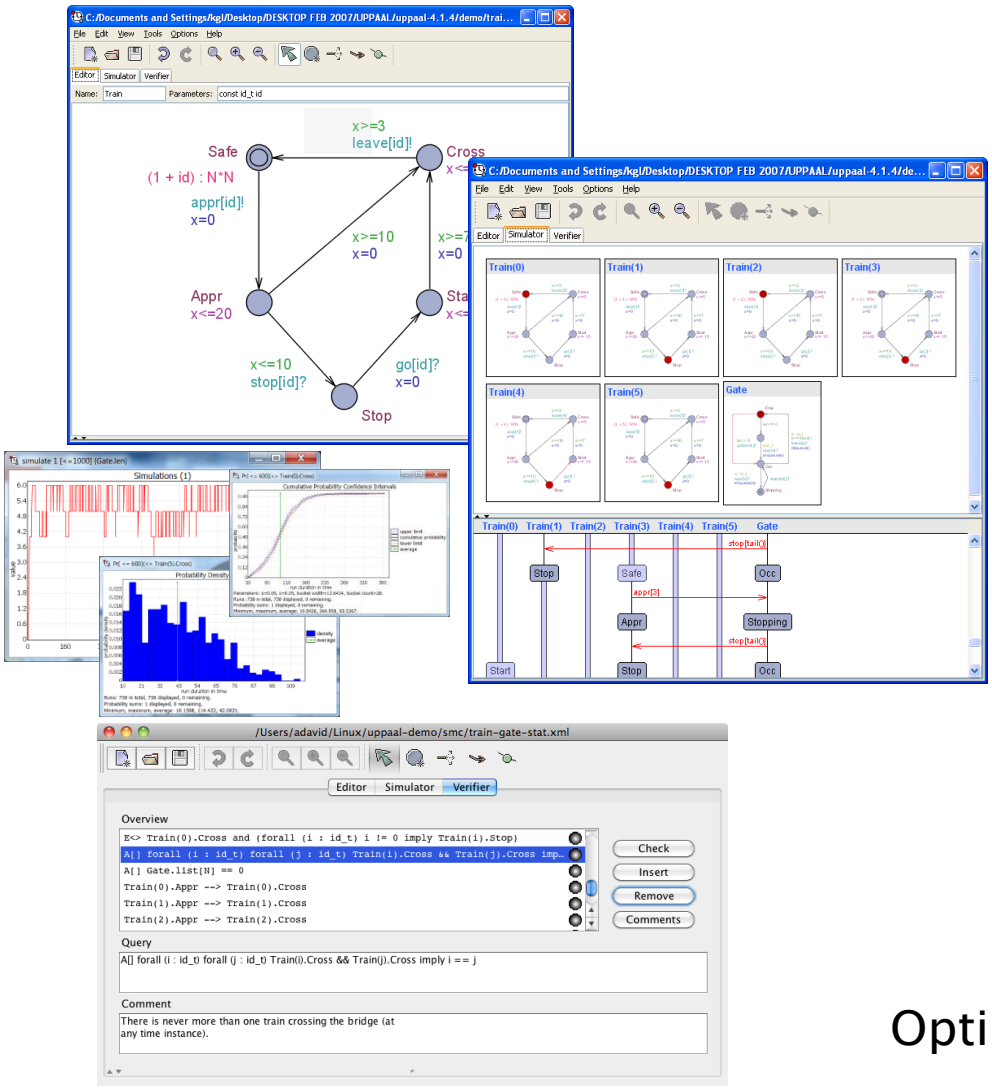
Hybrid

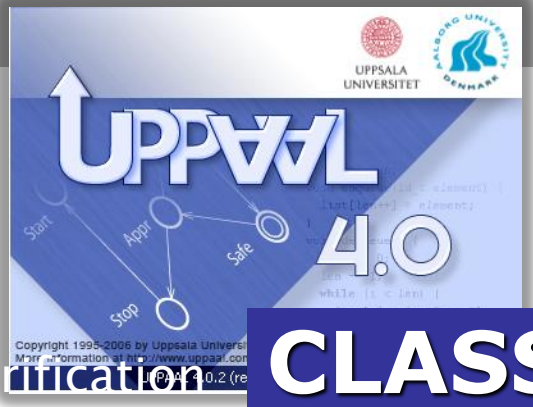
DEPENDABLE:
the ability of a **controller** to function (correct) under stated conditions for a specified period of time.

IoT

Cyber-Physical Systems

UPPAAL Tool Suite





1995

Verification **CLASSIC**

Optimization **CORA** 2001

Testing **TRON** 2004

Synthesis **TIGA** 2005

Component **ECDAR** 2010

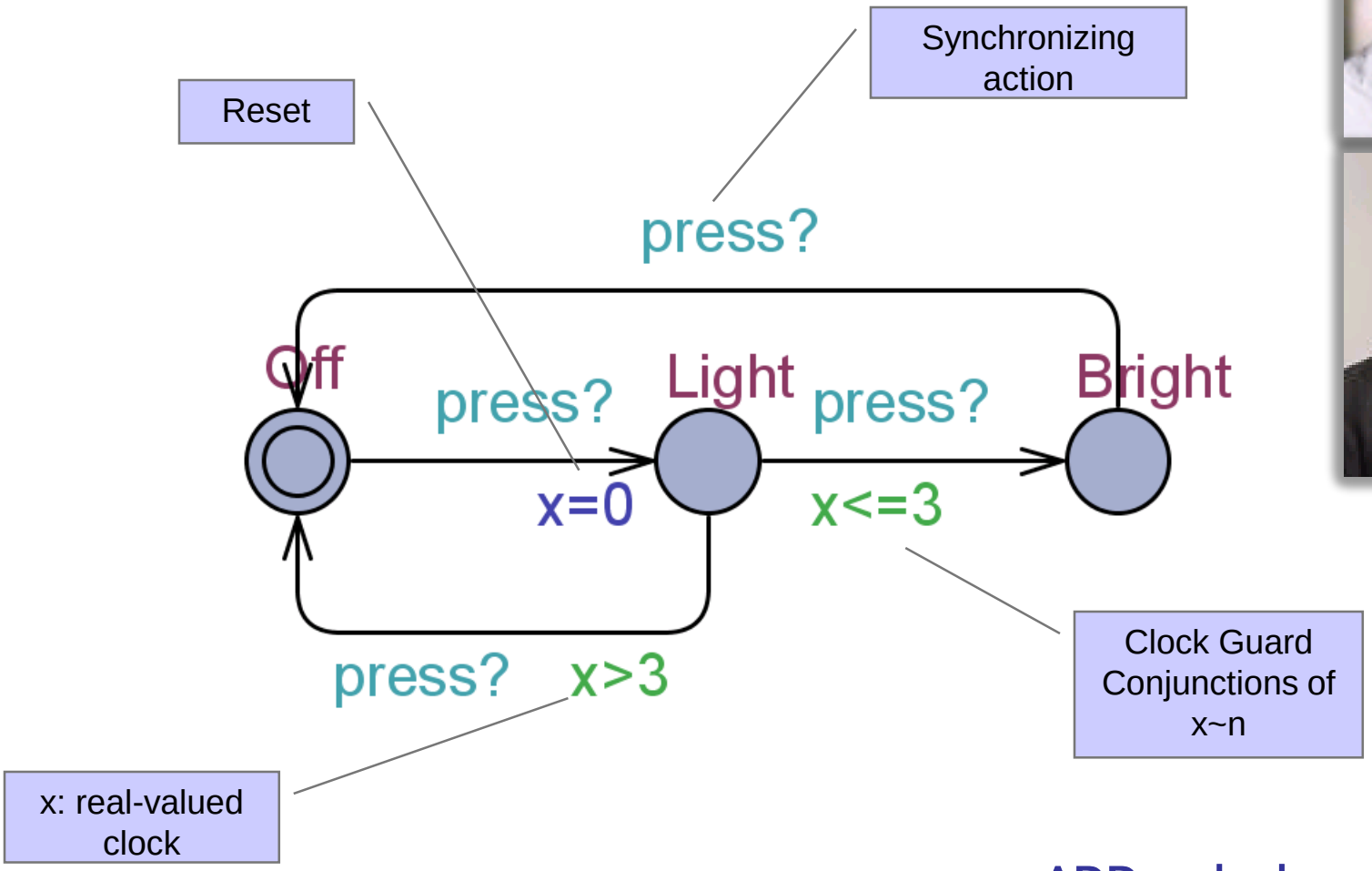
Performance Analysis **SMC** 2011

Optimal Synthesis **STRATEGO** 2014

Timed Automata

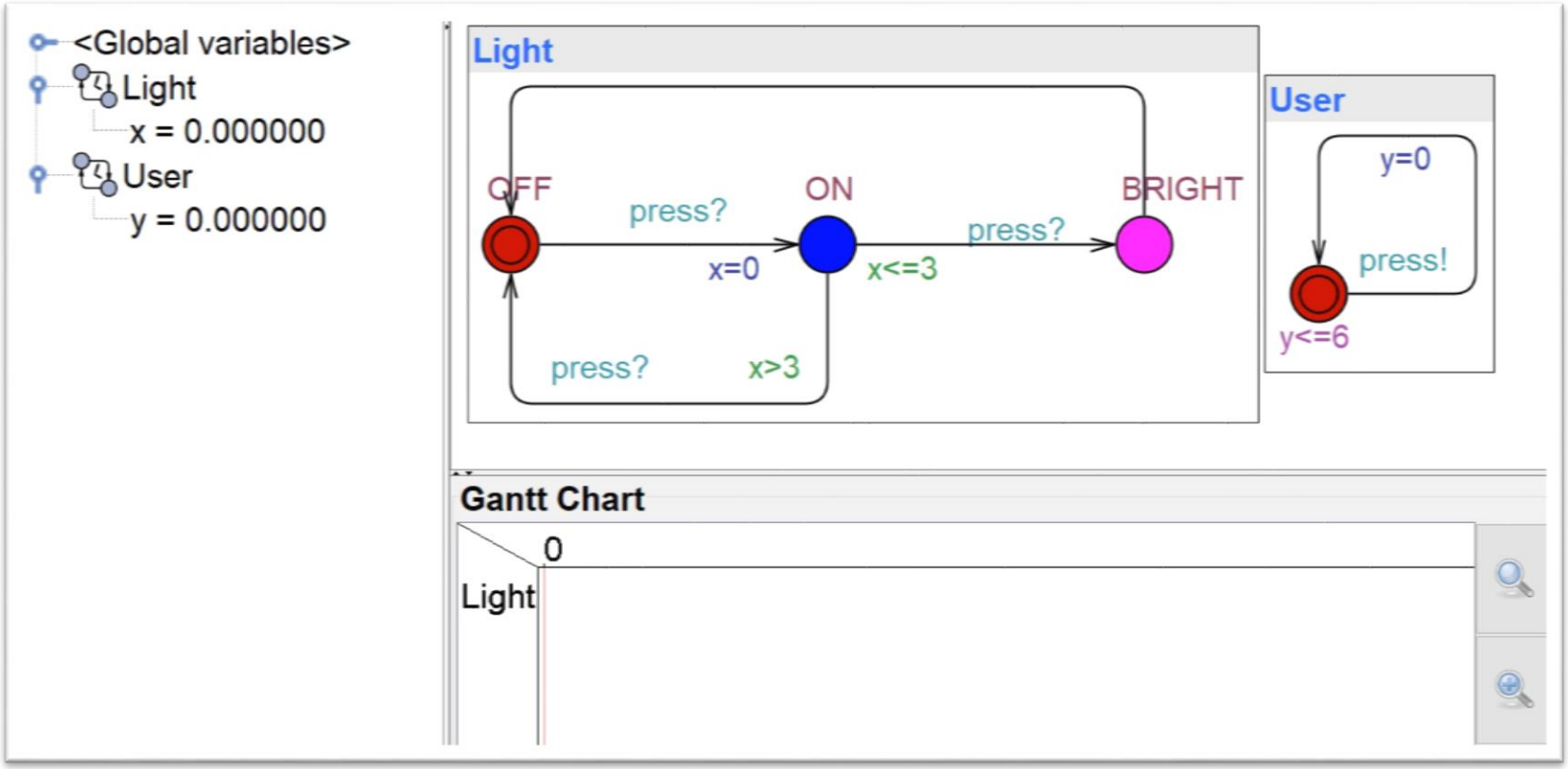
AALBORG UNIVERSITET

Timed Automata [Alur & Dill'89]

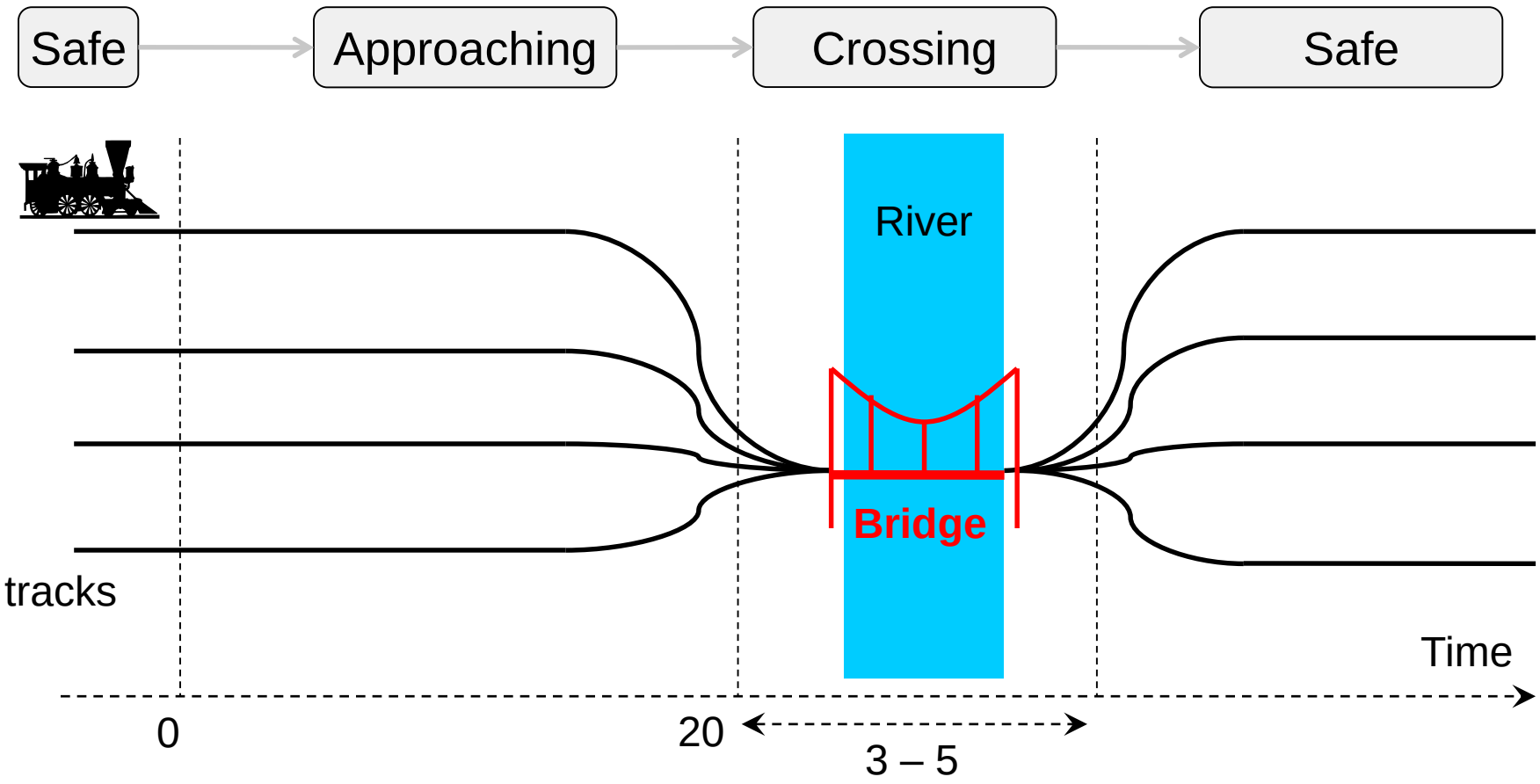


ADD a clock x

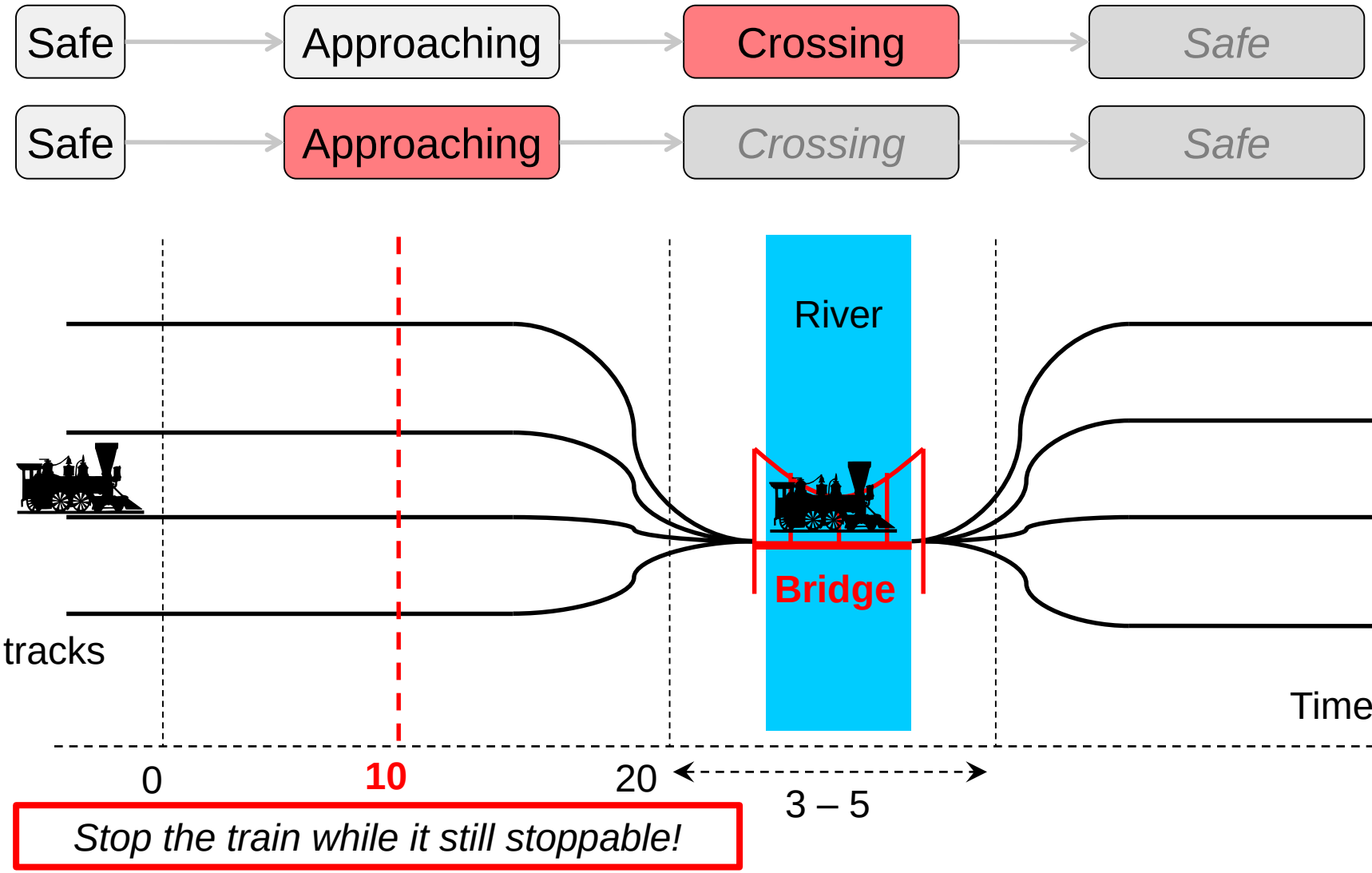
Semantics in UPPAAL



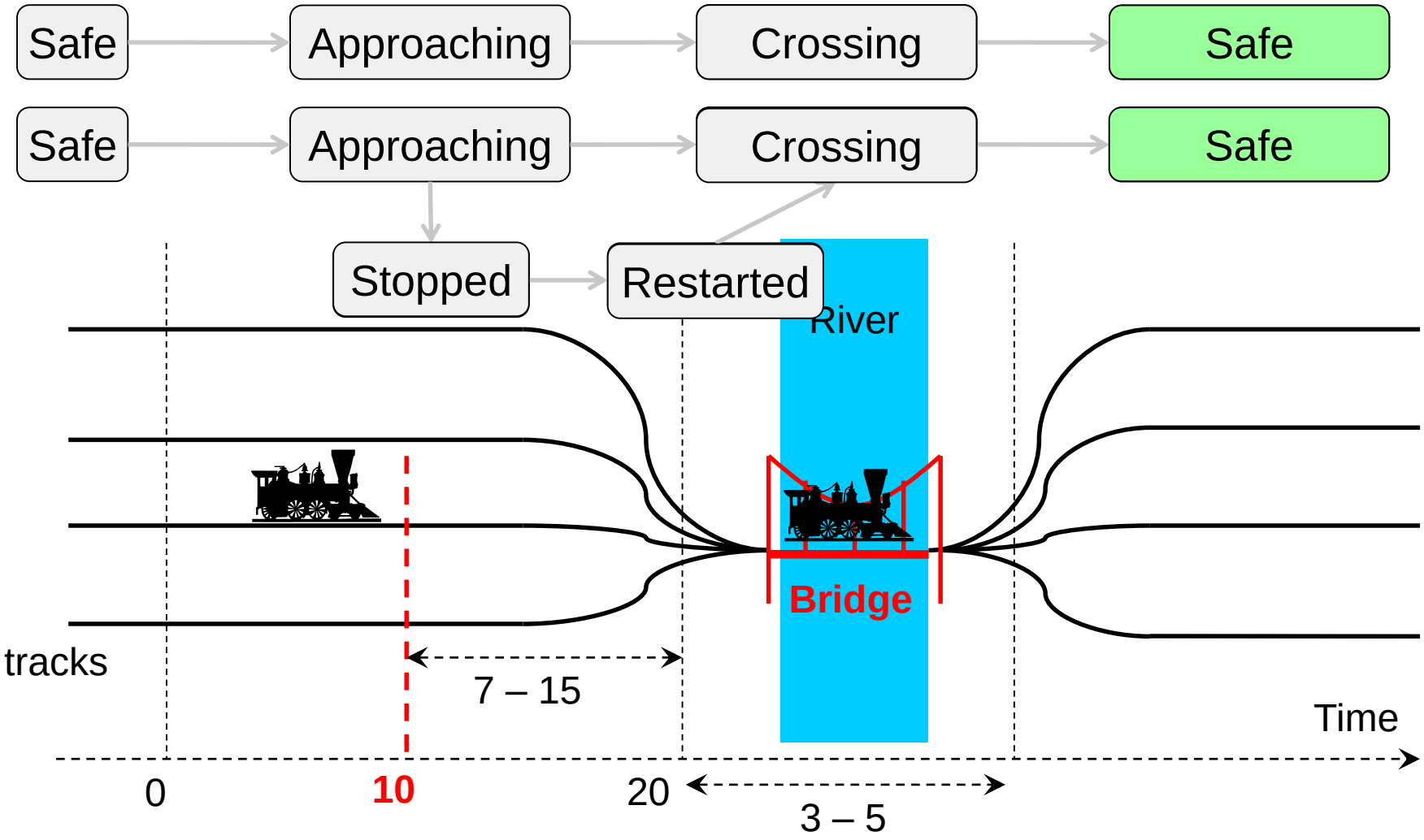
Train Crossing



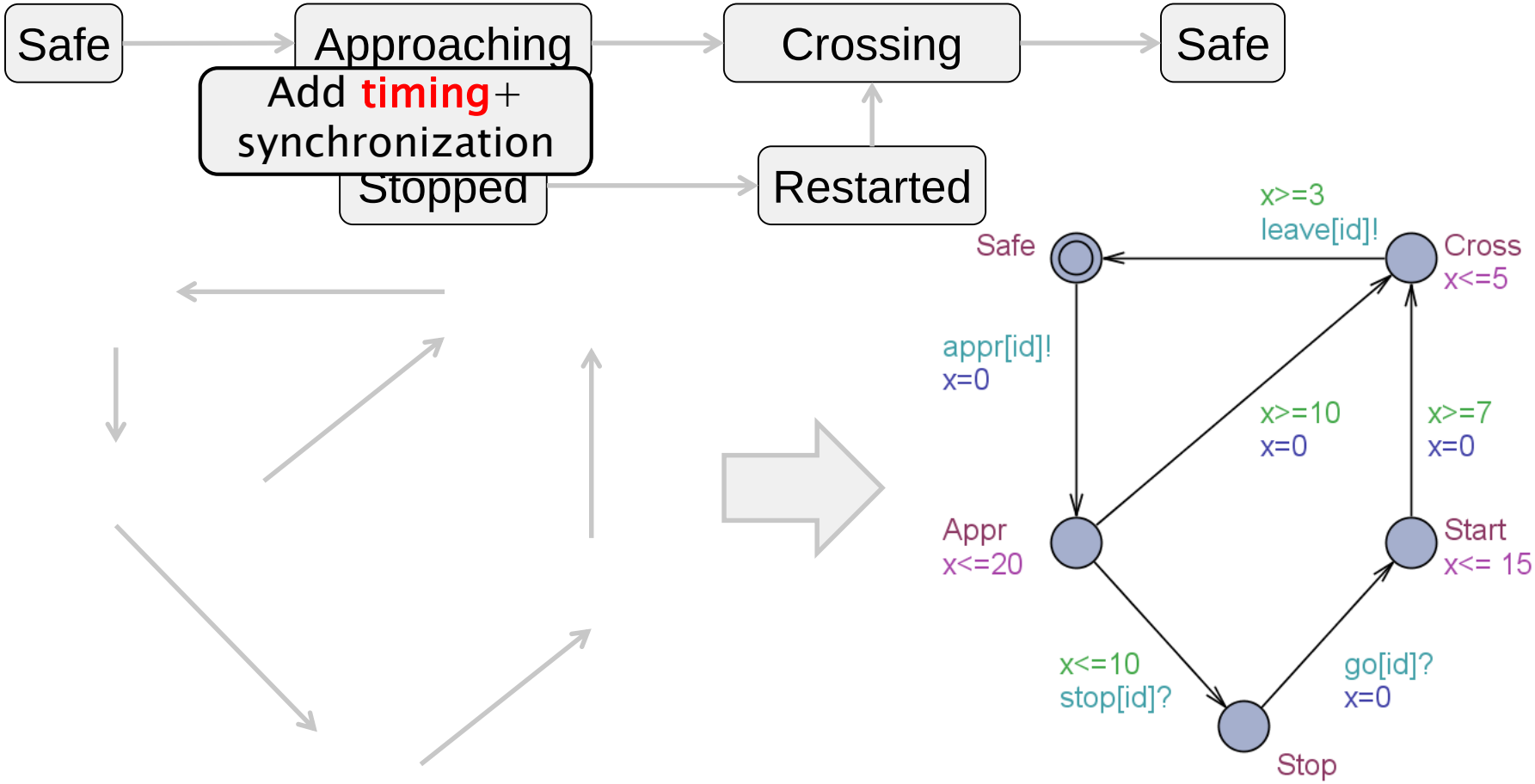
Train Crossing



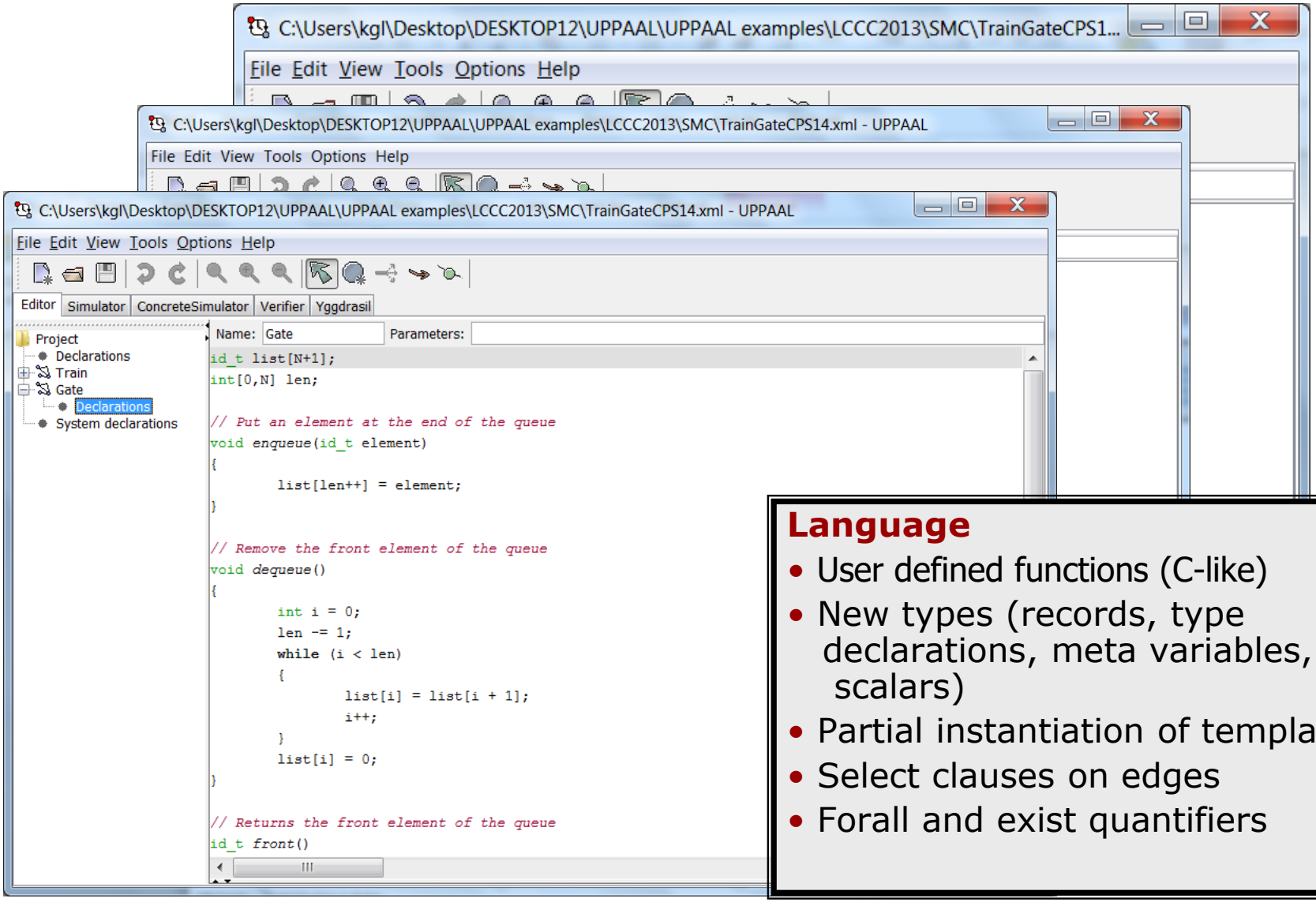
Train Crossing



Train Crossing



Editor



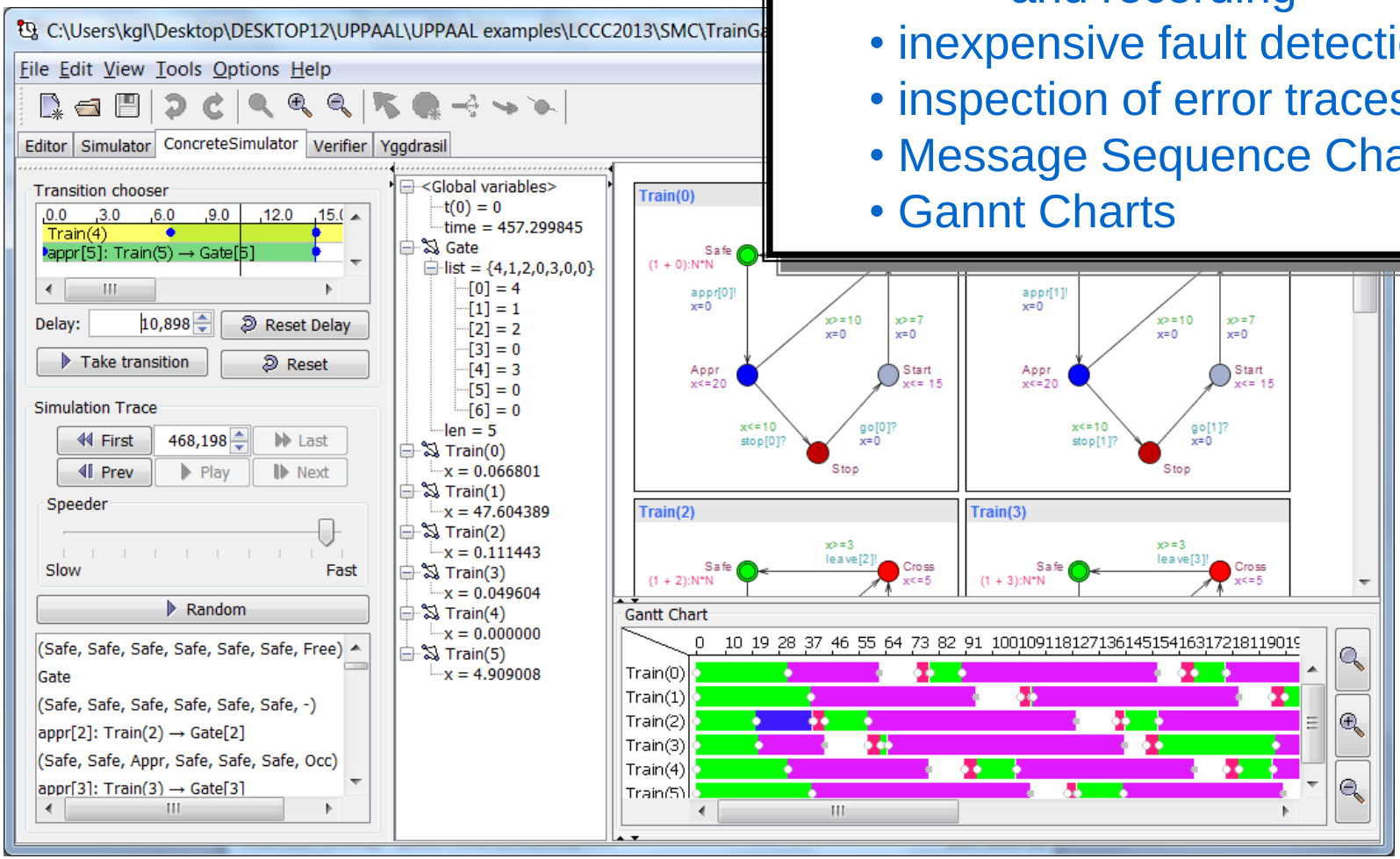
Language

- User defined functions (C-like)
- New types (records, type declarations, meta variables, scalars)
- Partial instantiation of templates
- Select clauses on edges
- Forall and exist quantifiers

Concrete Simulator

Graphical Simulator

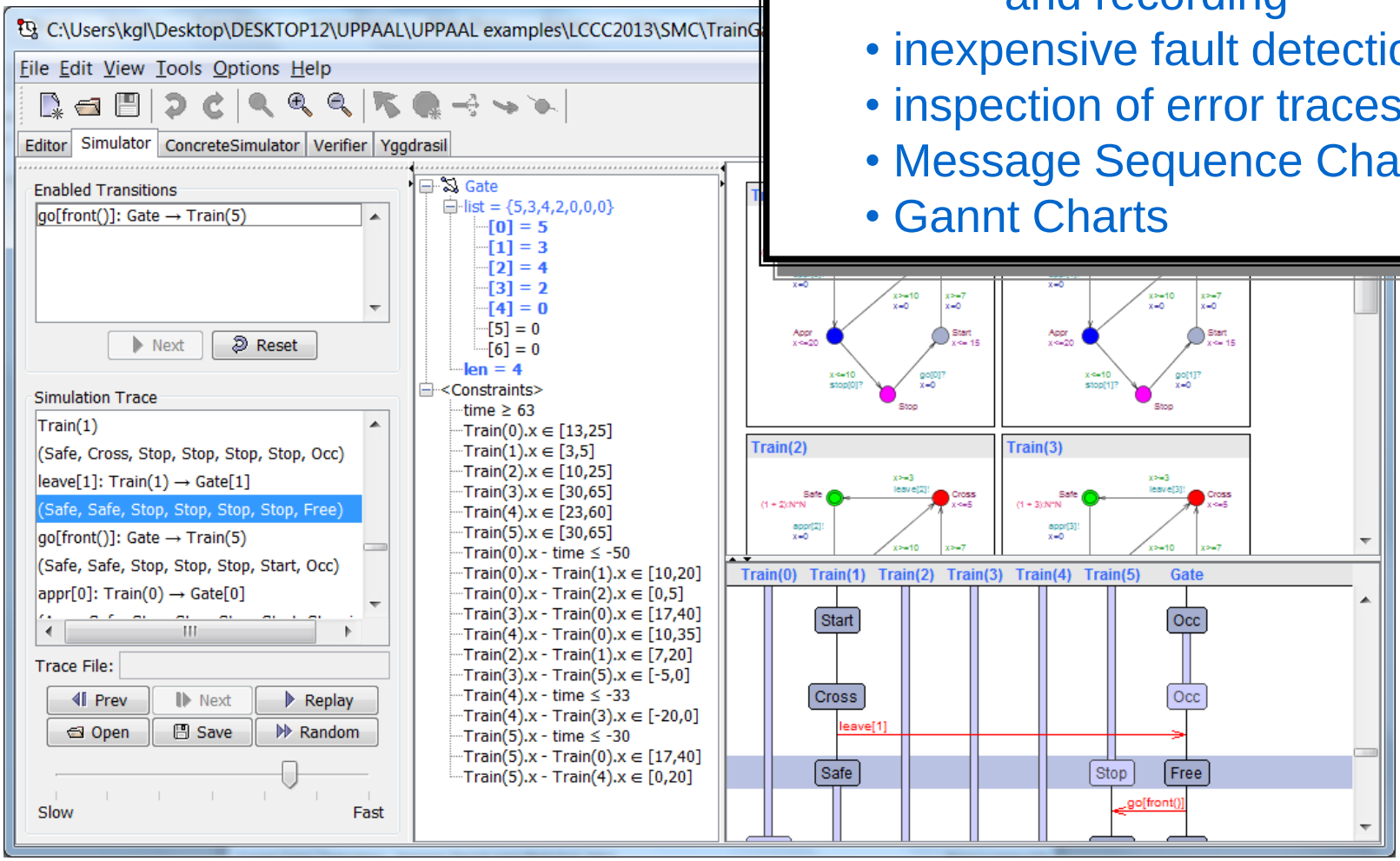
- visualization
  and recording
- inexpensive fault detection
- inspection of error traces
- Message Sequence Charts
- Gannt Charts

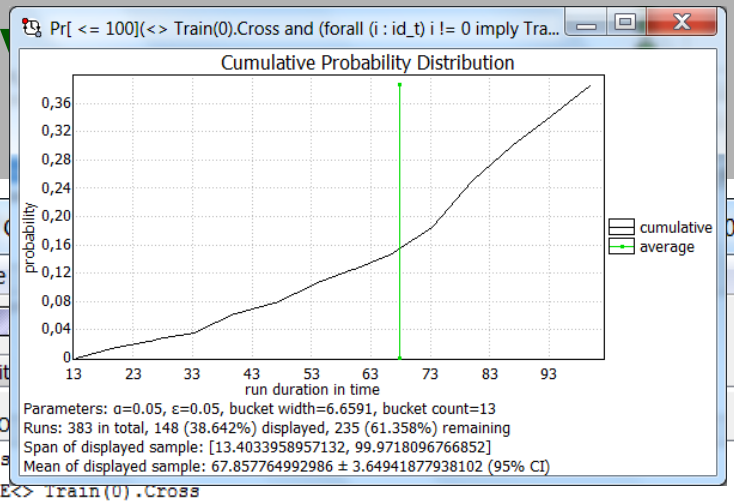


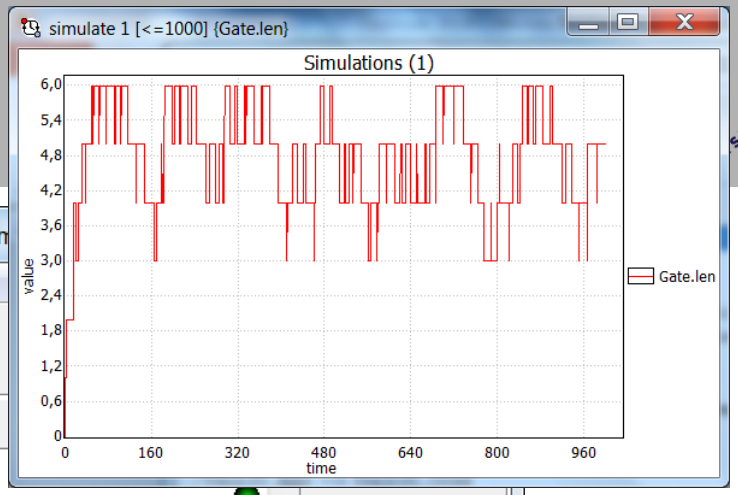
Symbolic Simulator

Graphical Simulator

- visualization
  and recording
- inexpensive fault detection
- inspection of error traces
- Message Sequence Charts
- Gannt Charts



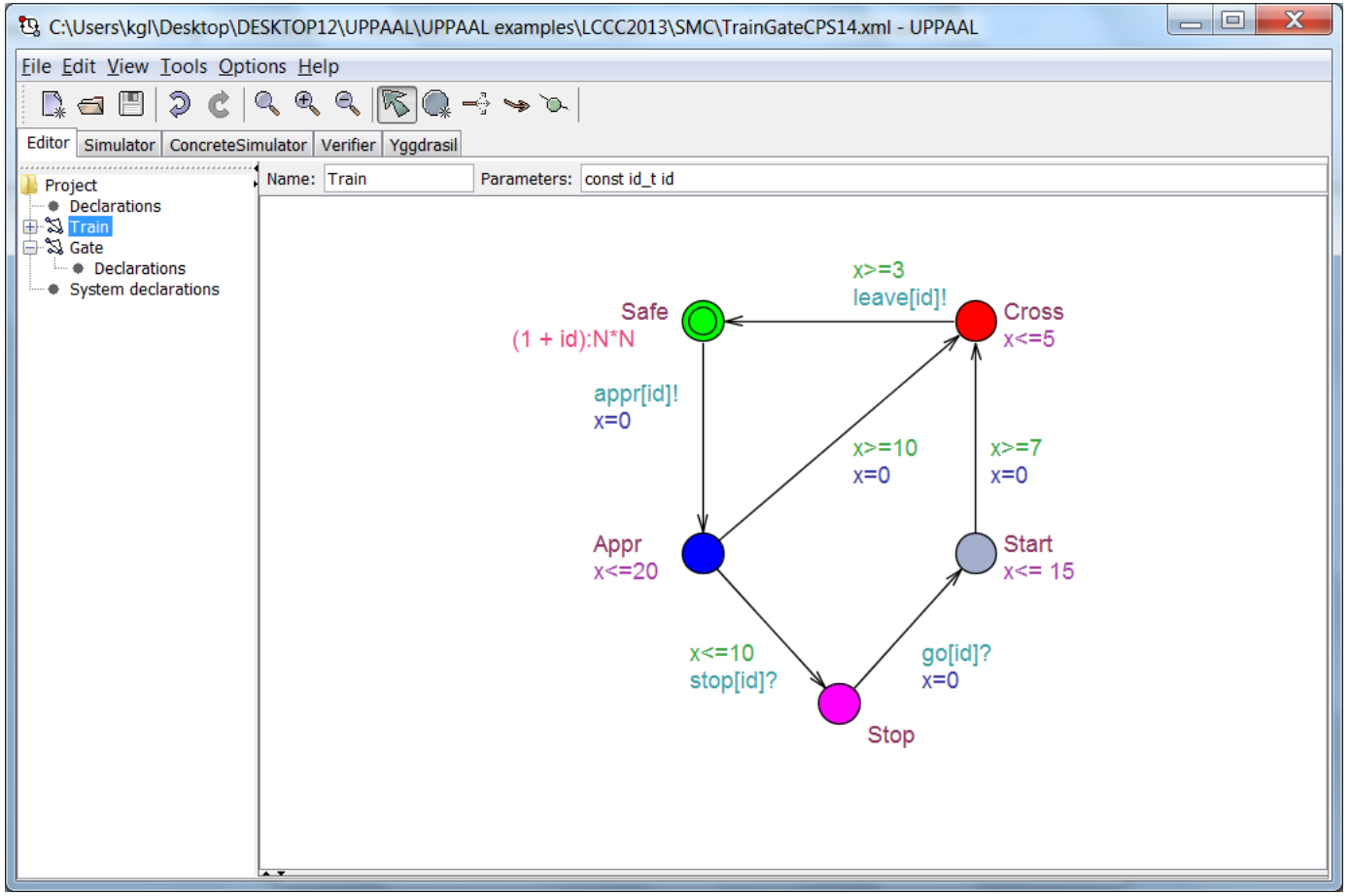




Verifier

- Exhaustive & automatic checking of requirements
- .. including validating, safety, liveness, bounded liveness and response properties
- .. performance properties, e.g probabilistic and expectation.
- .. generation of debugging information for visualisation in simulator.
- .. plot composer

Demo 1



UPPAAL Examples
SSFT15/UPPAAL SMC/

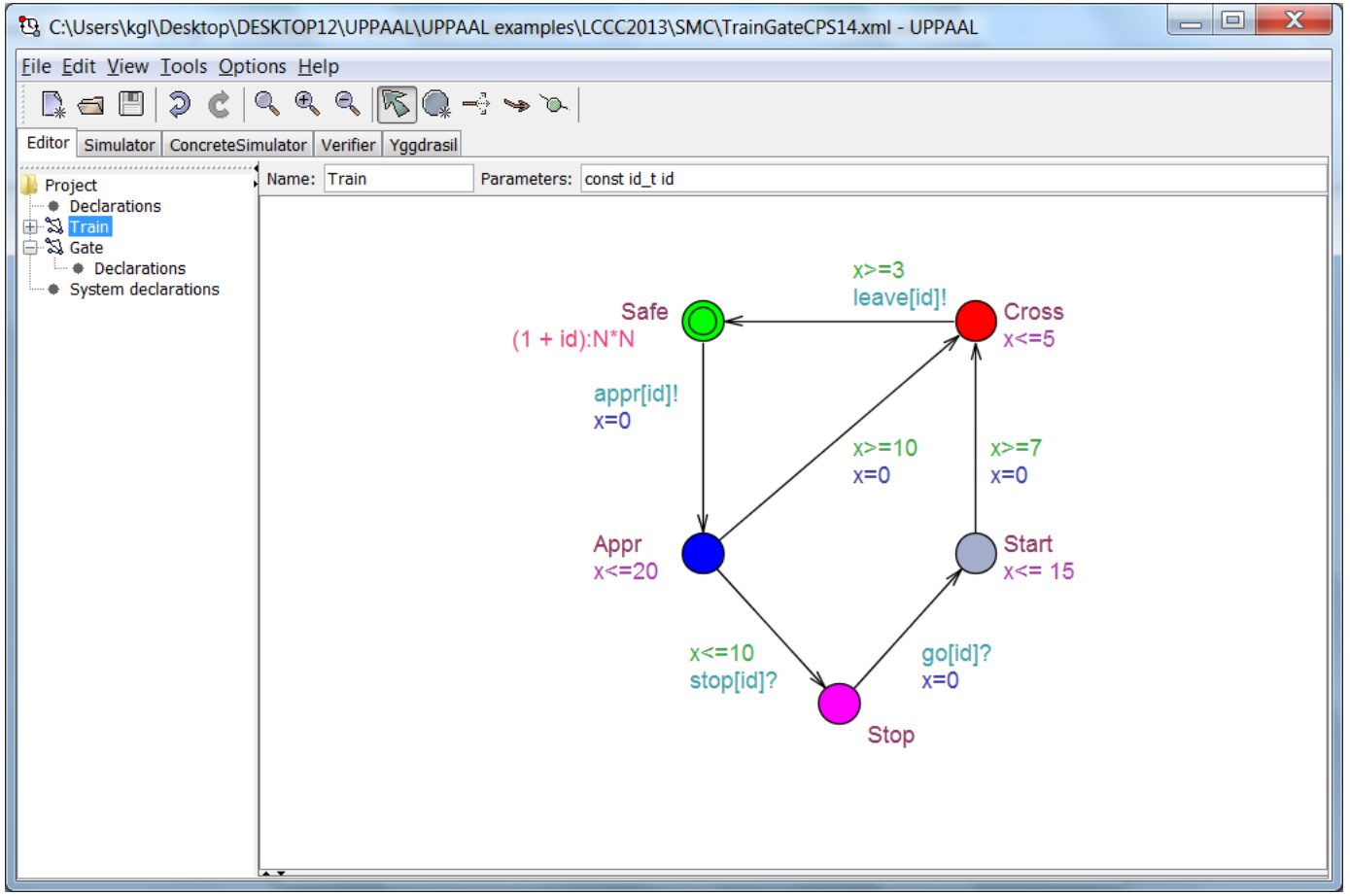
Verification Queries

- **Validation Properties**
  - Possibly: `E<> P`
- **Safety Properties**
  - Invariant: `A[] P`
  - Pos. Inv.: `E[] P`
- **Liveness Properties**
  - Eventually: `A<> P`
  - Leadsto: `P --> Q`
- **Bounded Liveness**
  - Leads to within: $P \dashrightarrow_{\leq t} Q$

The expressions *P* and *Q* must be type safe, side effect free, and evaluate to a boolean.

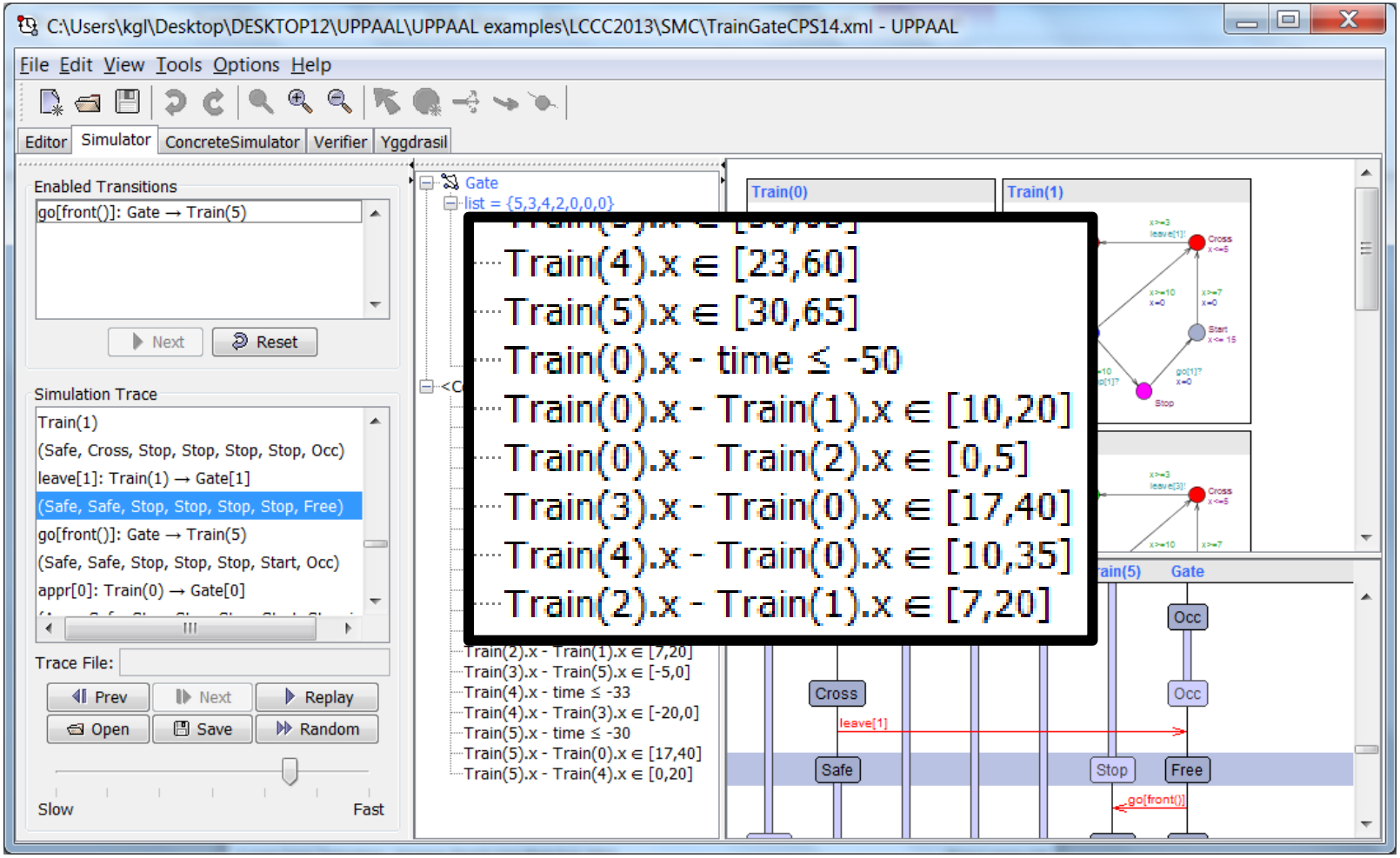
Only references to integer variables, constants, clocks, are allowed (and arrays of these).

Demo 2

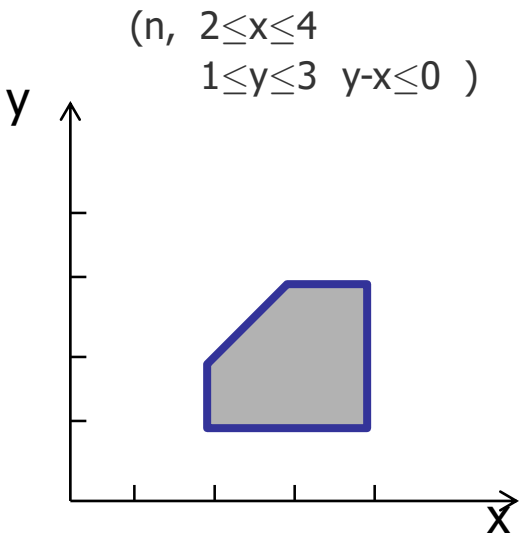


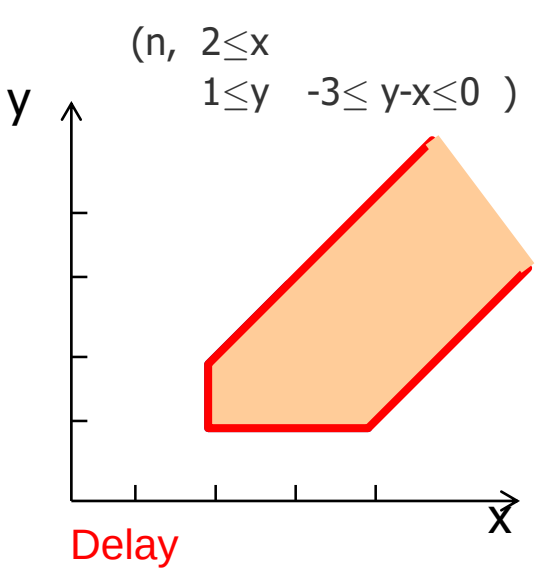
UPPAAL Examples
SSFT15/UPPAAL SMC/

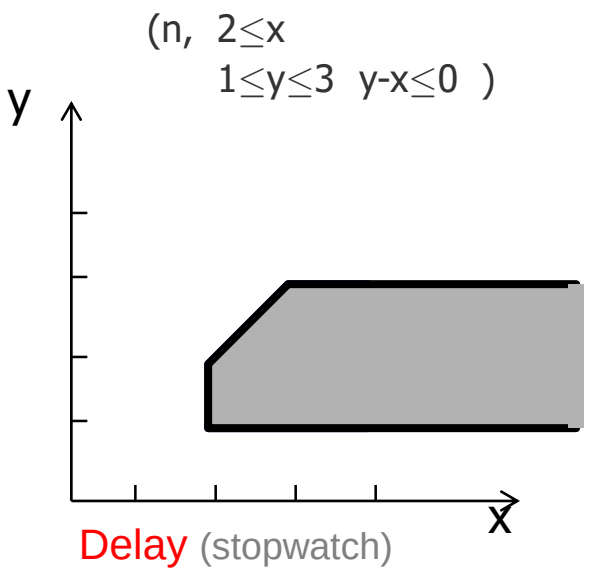
THE ”secret” of UPPAAL

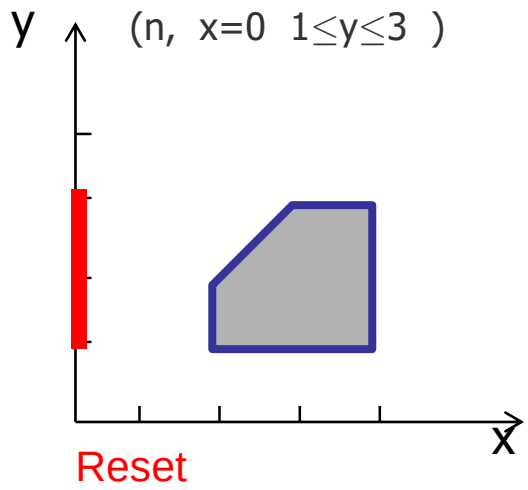


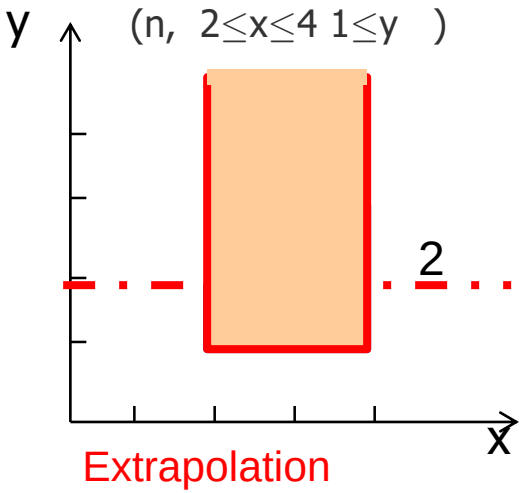
Zones – Operations

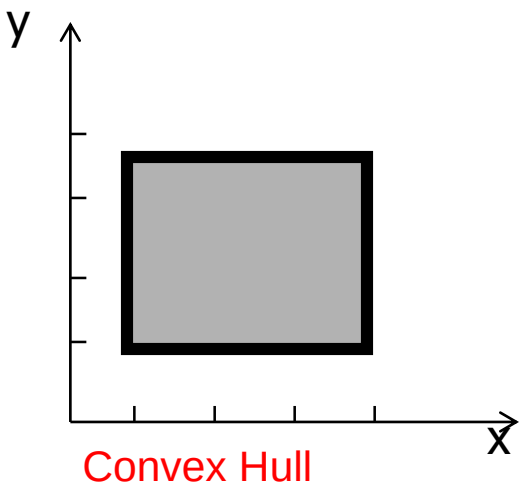




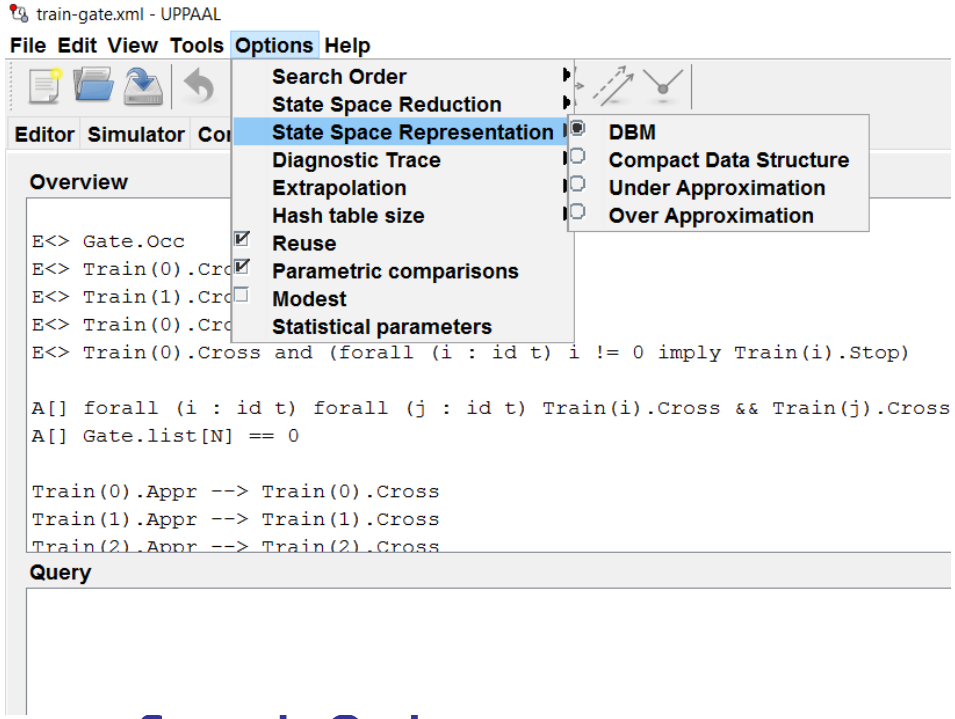








Verification Options



- Search Order
  - Depth First
  - Breadth Frist
  - Random Depth First

- State Space Reduction
  - None
  - Conservative
  - Aggressive
  - Extreme
- State Space Representation
  - DBM
  - Compact Form
  - Under Approximation
  - Over Approximation
- Diagnostic Trace
- Extrapolation
  - Automatic
  - None
  - Difference
  - Local
  - Lower/Upper

Stochastic Timed Automata

With

Peter Bulychev, Alexandre David,
Marius Mikucionis
Dehui Du, Axel Legay, Guangyuan Li,
Danny B. Poulsen, Amalie Stainer, Zheng Wang

FORMATS11+12, CAV11,
RV12, HSB12,QAPL12,
NaSA12+13,SCIENCE CH13, STTT15

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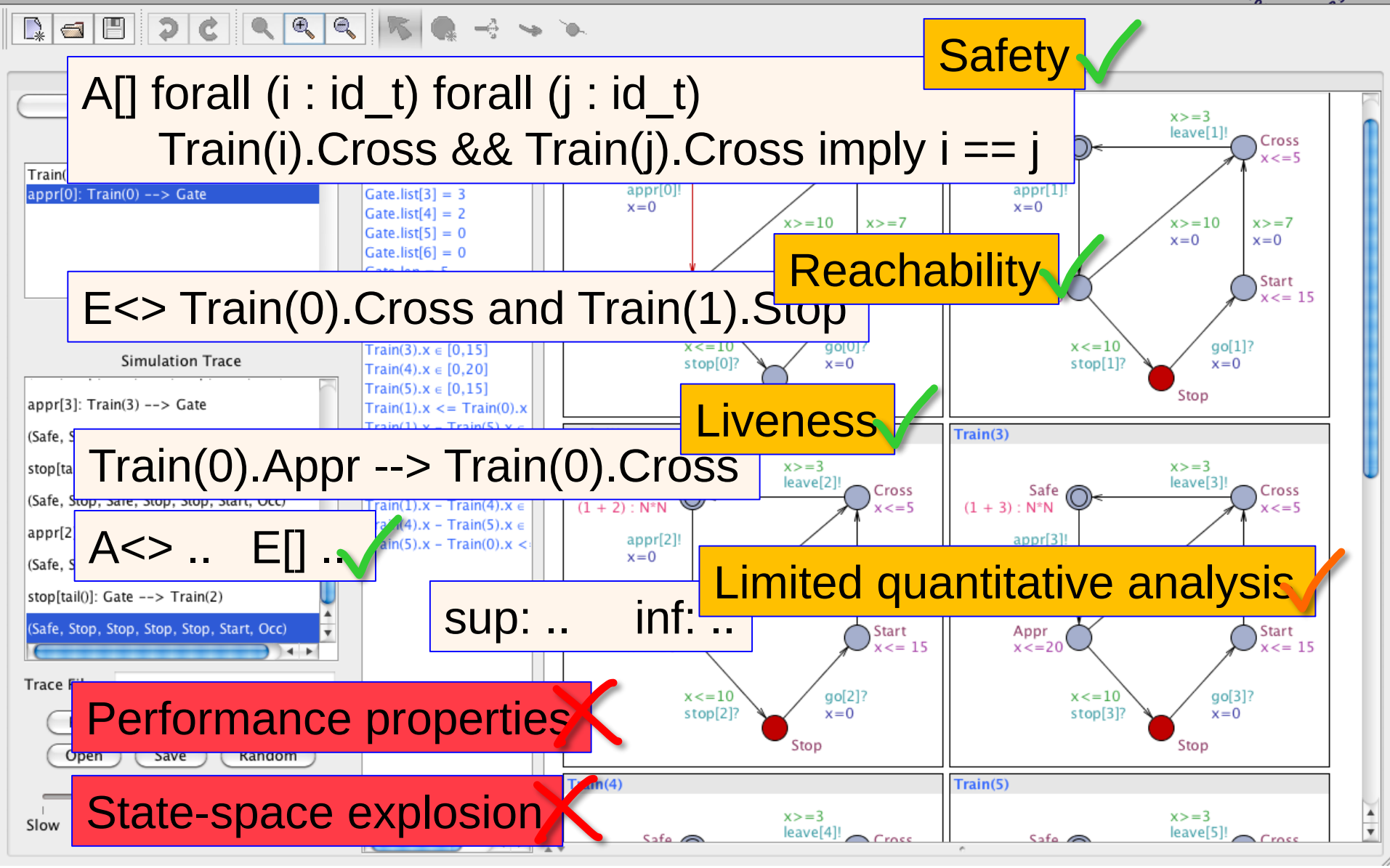
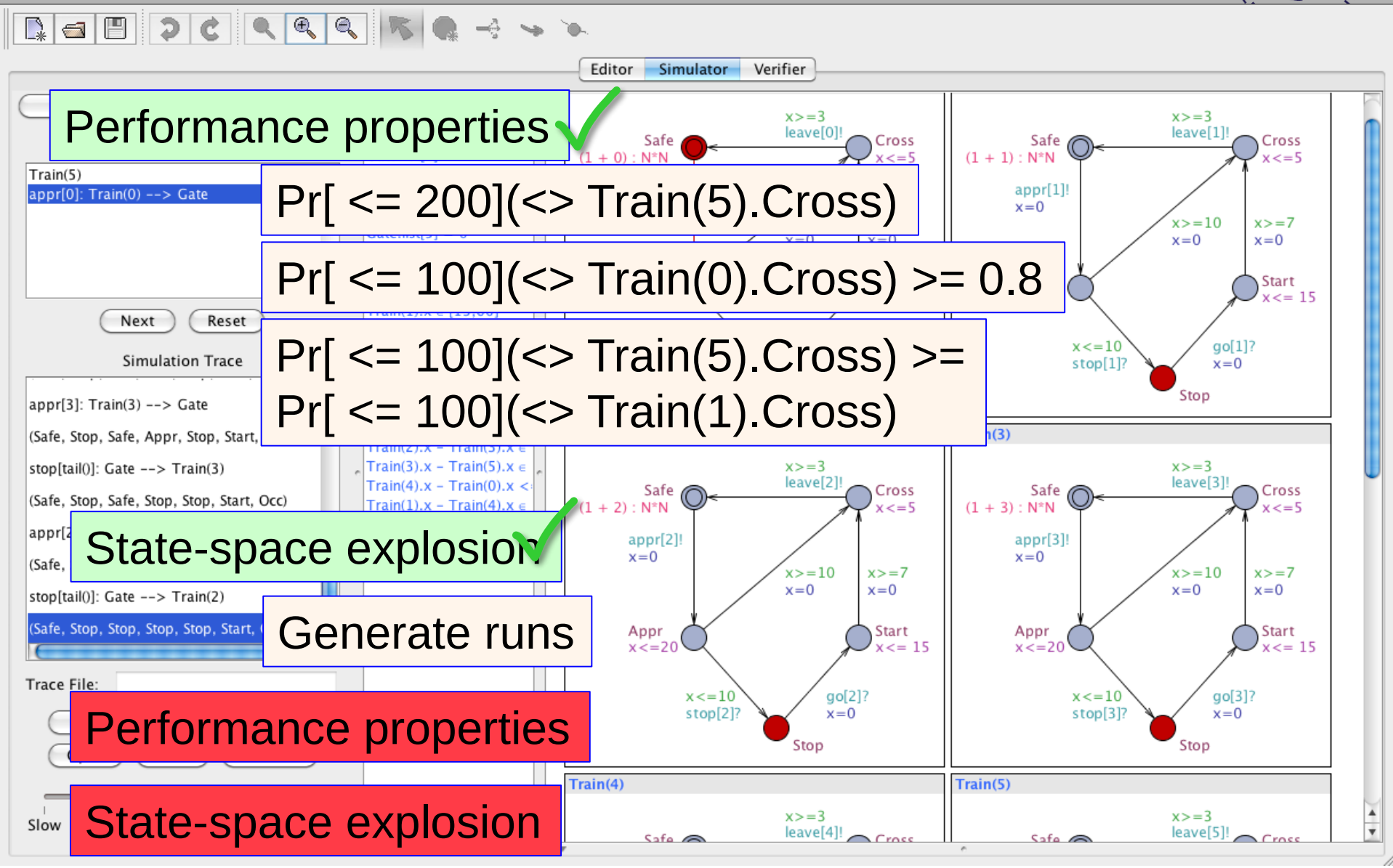
UPPAAL


A[] forall (i : id_t) forall (j : id_t)
Train(i).Cross && Train(j).Cross imply i == j
Safety
E<> Train(0).Cross and Train(1).Stop
Reachability
Train(0).Appr --> Train(0).Cross
Liveness
A<> .. E[] ..
sup: .. inf: ..
Limited quantitative analysis
Performance properties
State-space explosion
Simulation Trace
Train(3)
Train(4)
Train(5)
Cross
Start
Stop
Appr
Safe

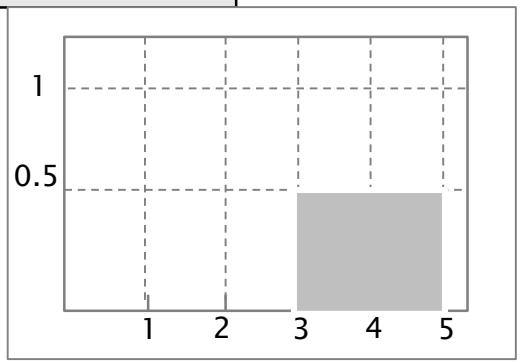
UPPAAL SMC

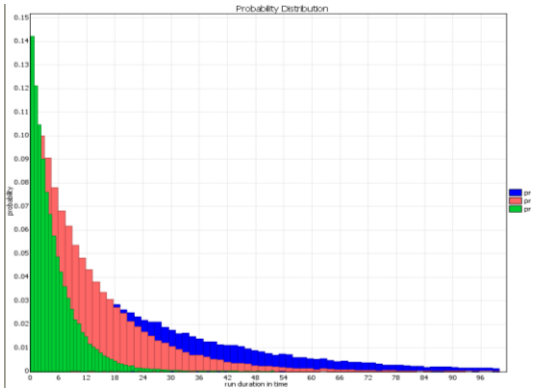

Editor
Simulator
Verifier
Performance properties
Train(5)
appr[0]: Train(0) --> Gate
Pr[<= 200](<> Train(5).Cross)
Pr[<= 100](<> Train(0).Cross) >= 0.8
Next
Reset
Simulation Trace
Pr[<= 100](<> Train(5).Cross) >=
Pr[<= 100](<> Train(1).Cross)
appr[3]: Train(3) --> Gate
(Safe, Stop, Safe, Appr, Stop, Start,
stop[tail()]: Gate --> Train(3)
(Safe, Stop, Safe, Stop, Stop, Start, Occ)
State-space explosion
stop[tail()]: Gate --> Train(2)
(Safe, Stop, Stop, Stop, Stop, Start,
Generate runs
Trace File:
Performance properties
Slow
State-space explosion
Safe
Cross
Appr
Start
Stop
Train(4)
Train(5)

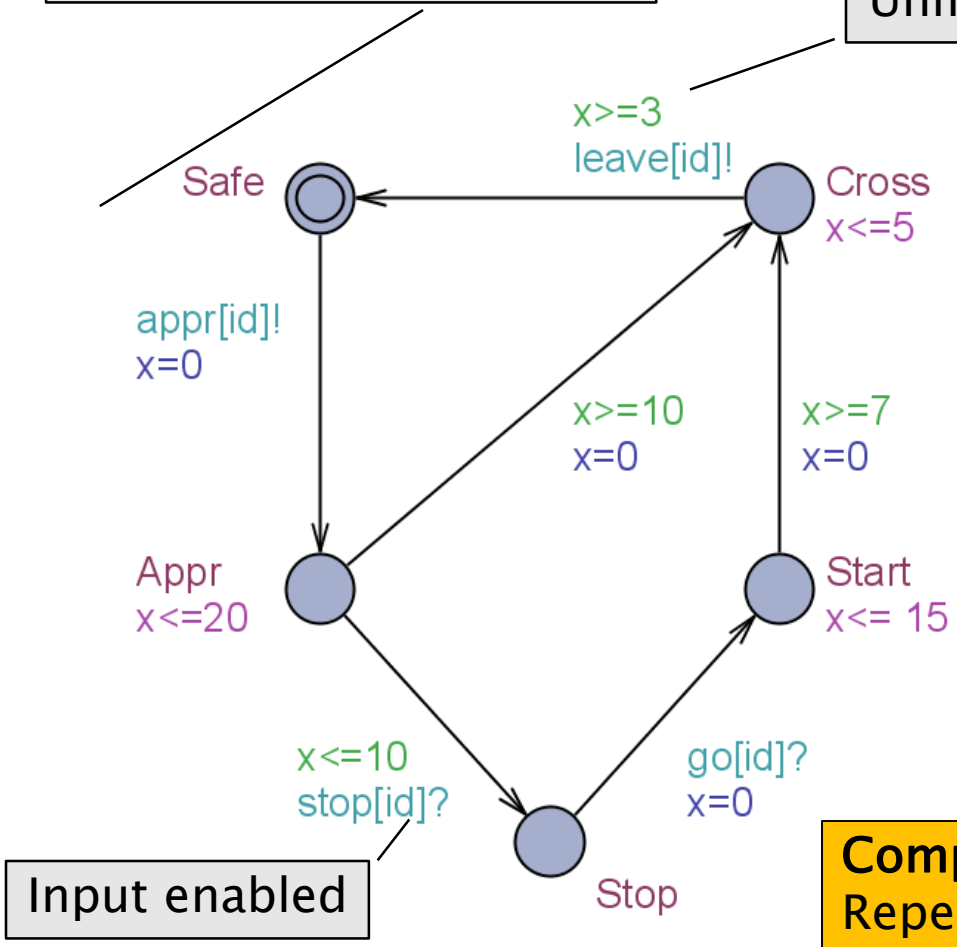
Stochastic Semantics of TA

Exponential Distribution

Uniform Distribution



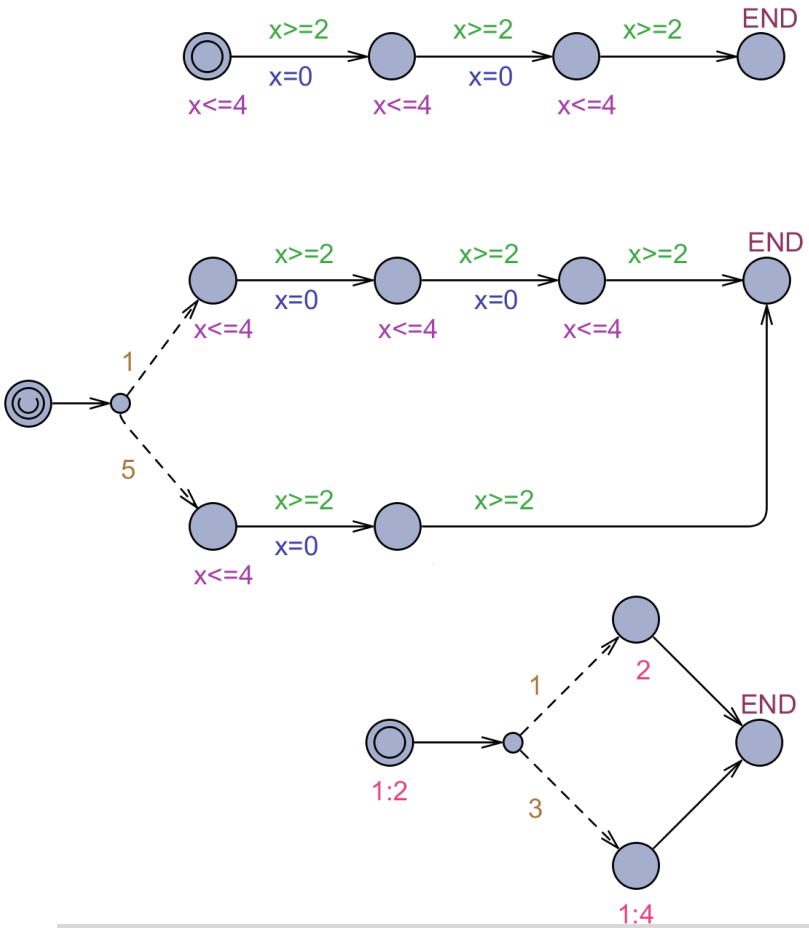


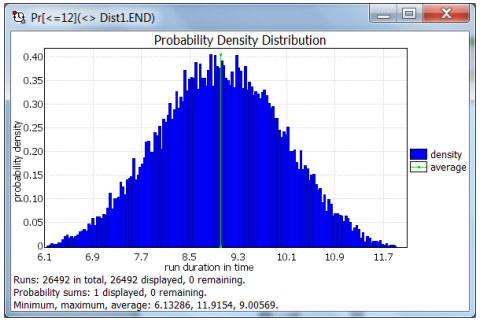


Input enabled

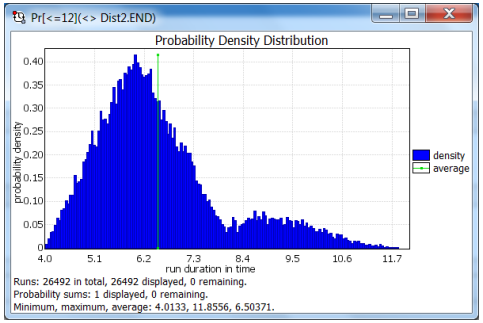
Composition =
Repeated races between components for **outputting**

Composed Distributions

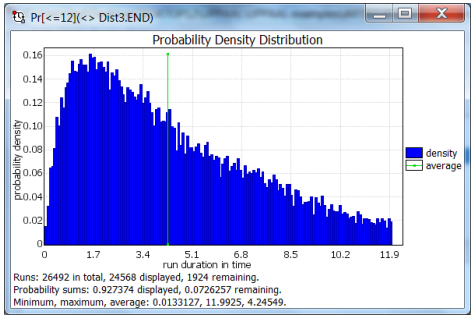




$\Pr(\langle\rangle_{\leq 9}\ \mathrm{END}) = ½$



$\Pr(\langle\rangle_{\leq 7}\ \mathrm{END}) \geq ½$

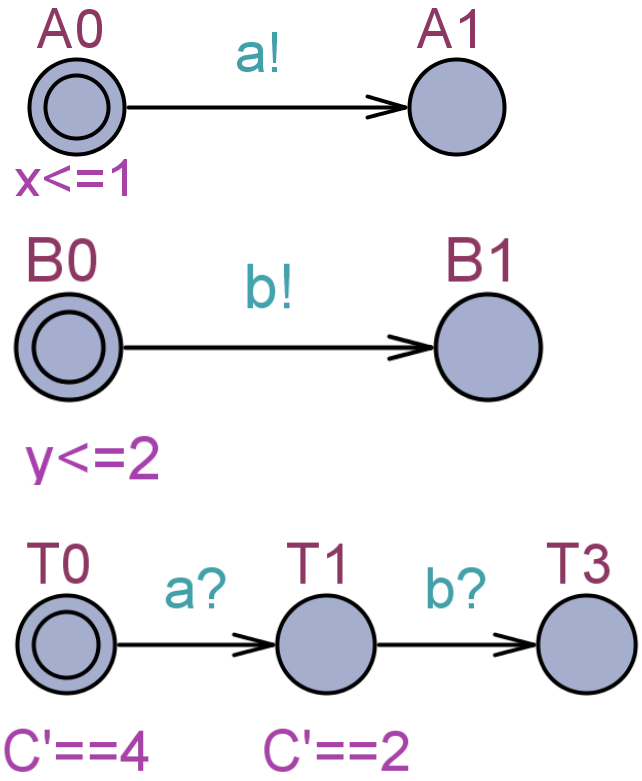


Includes all Phase-Type Distributions.

Can encode any distribution with arbitrary precision.

σ-algebra with prob. measure from cylinders $C(I_0\ \ell_0\ I_1\ \ell_1\ I_2 \ldots\ I_n\ \ell_{n+1})$

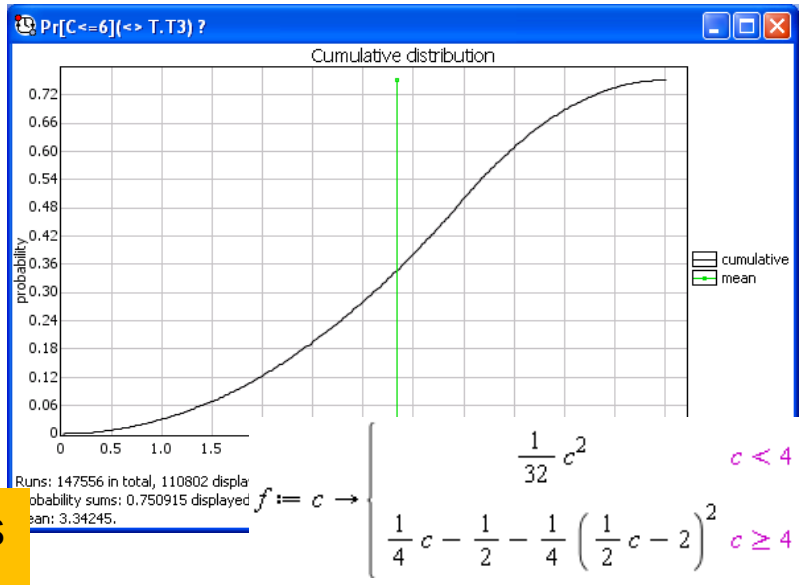
Composition of STA



Pr[time<=2](<> T.T3) ?

$$= \int_{t_a=0}^{1} 1 \cdot \int_{t_b=t_a}^{2} ½ \; dt_b \;\; dt_a = 3/4$$

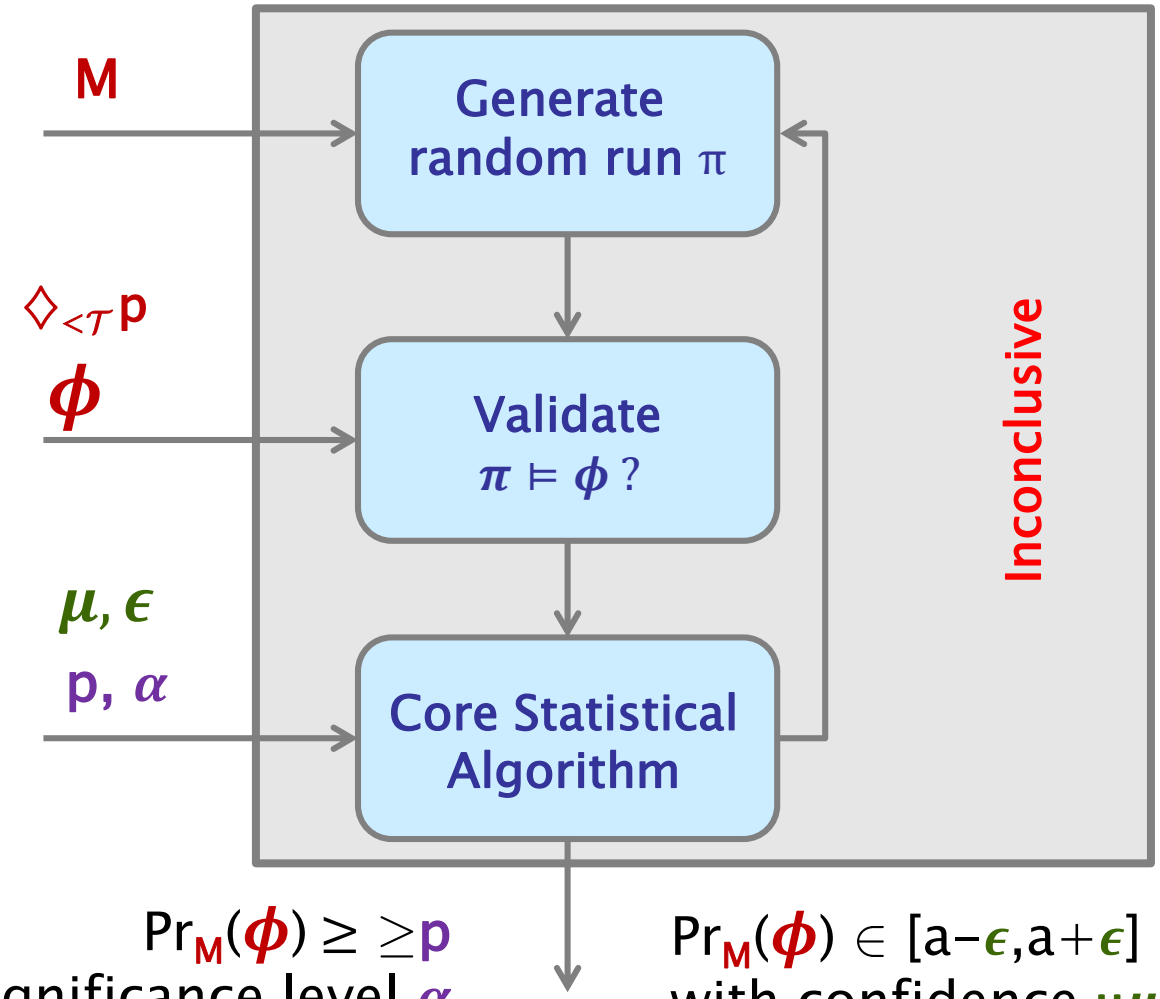
Pr[C<=6](<> T.T3) ?



Composition = Race between components for outputting

Statistical Model Checking

[FORMATS11, LPAR12, RV12]



Hypothesis testing

Confidence Interval

Performance Queries

- Evaluation

  `Pr[<=100](<> expr)` $\Pr(\Phi): \Phi \in MITL$

  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)`

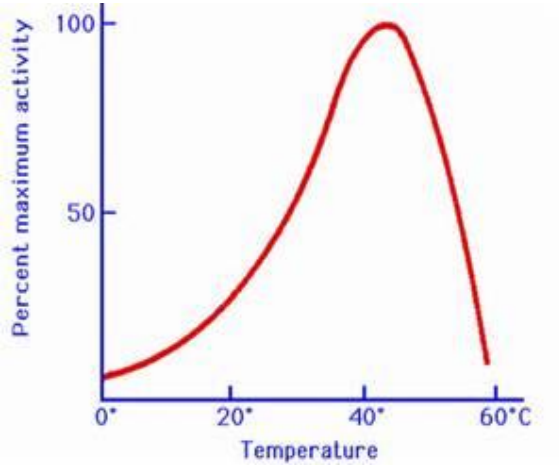
  Explicit number of runs. Min or max.

- Simulations

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

DEMO

Stochastic Hybrid Automata



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UP4ALL

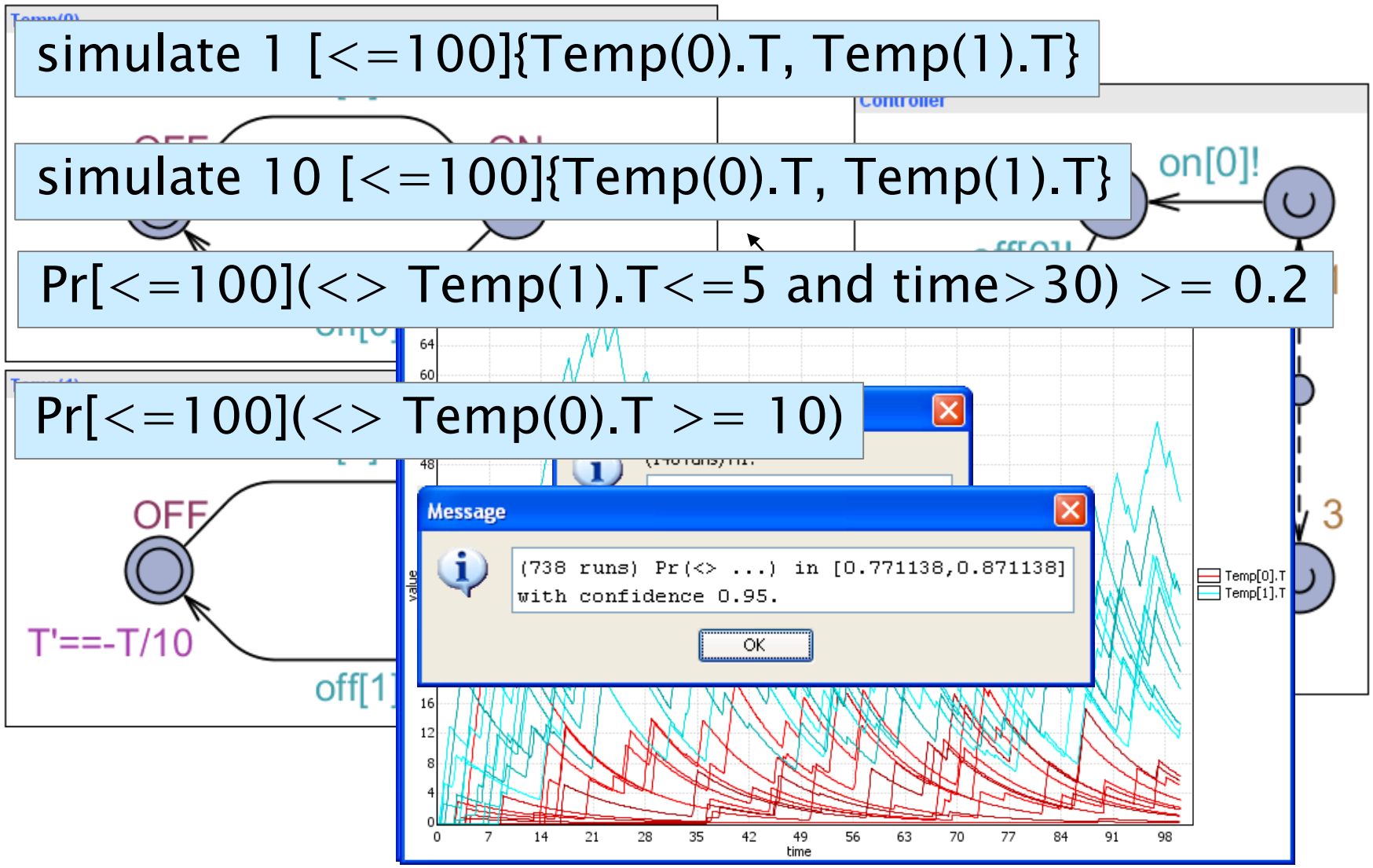
Stochastic Hybrid Systems

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

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

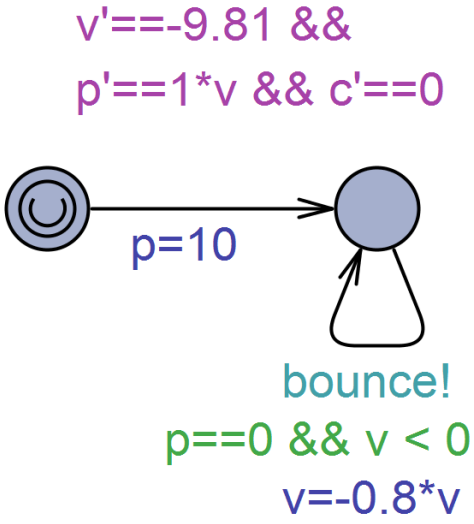
Pr[<=100](<> Temp(1).T<=5 and time>30) >= 0.2

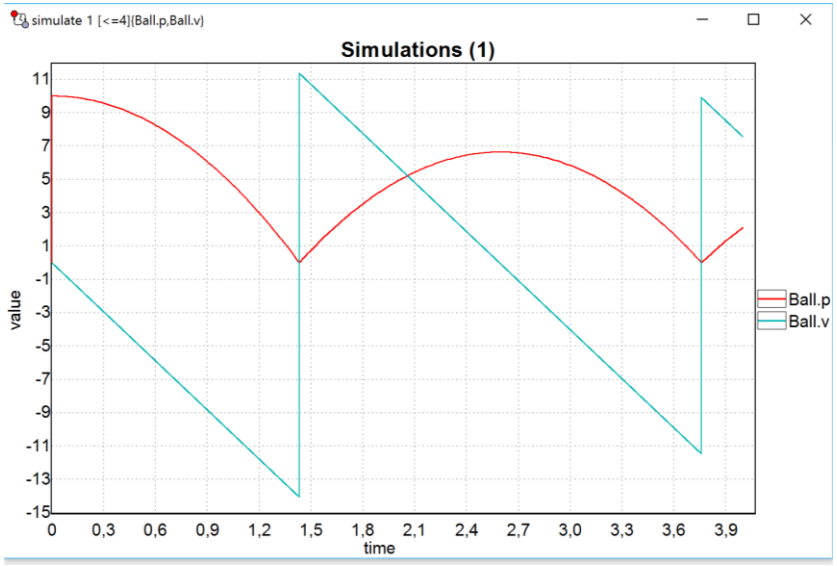
Pr[<=100](<> Temp(0).T >= 10)



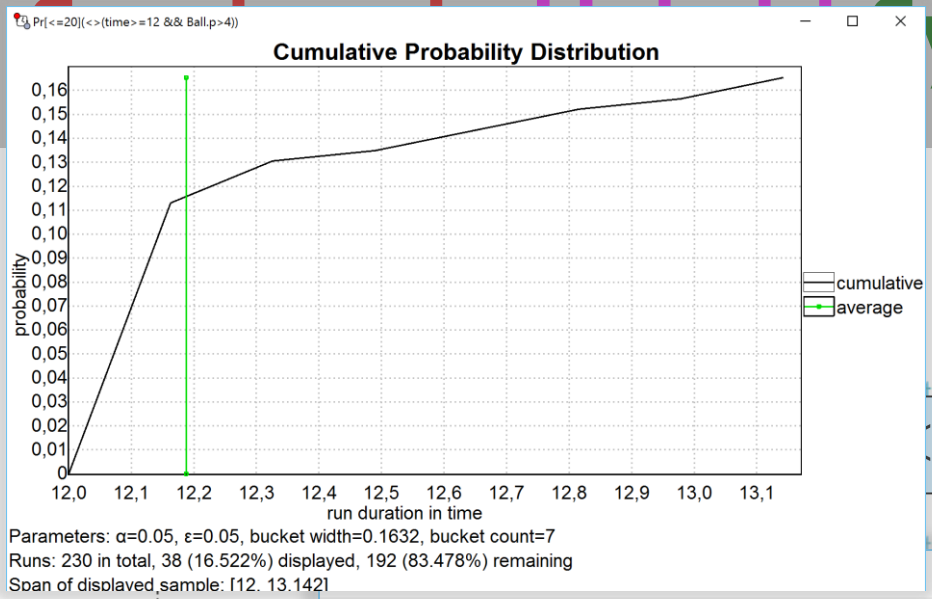
Stochastic Hybrid Systems

- A Bouncing Ball

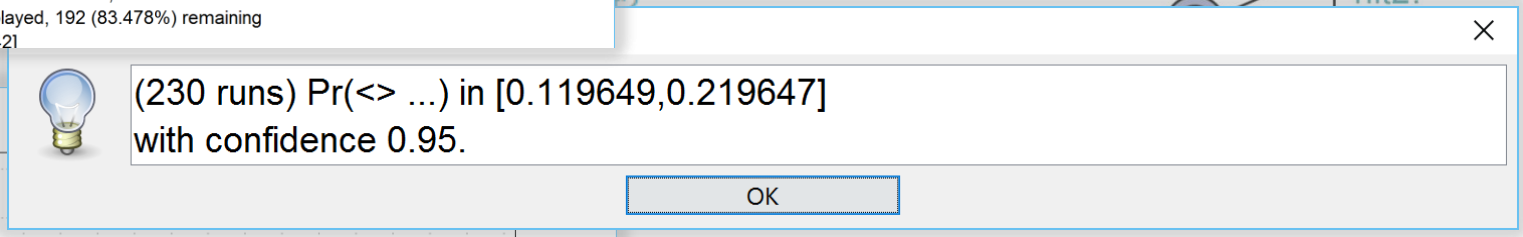


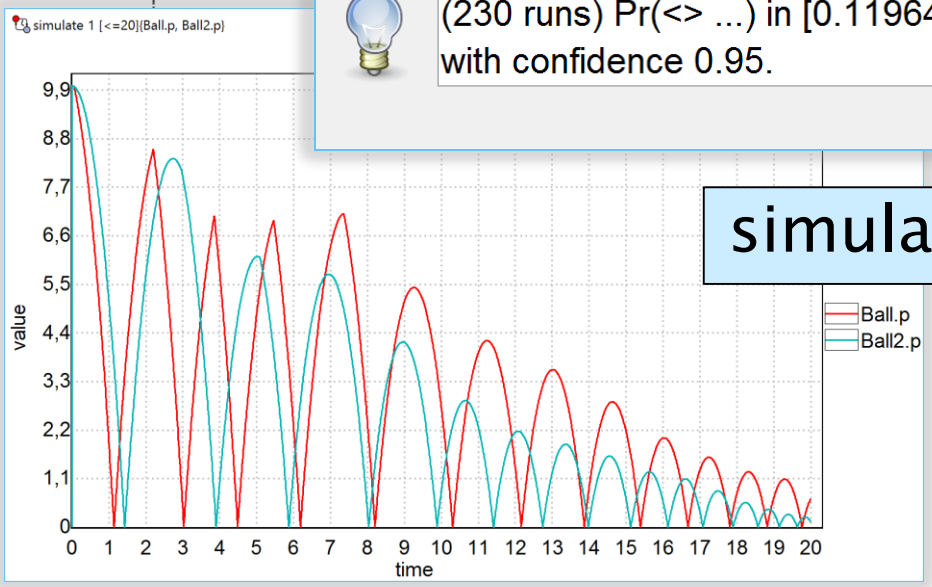


simulate 1 [<=4]{Ball.p, Ball.v}


Pr[<=20](<>(time>=12 && Ball.p>4))
Cumulative Probability Distribution
probability
run duration in time
cumulative
average
Parameters: α=0.05, ε=0.05, bucket width=0.1632, bucket count=7
Runs: 230 in total, 38 (16.522%) displayed, 192 (83.478%) remaining
Span of displayed sample: [12, 13.142]


Player 1
5:2
hit!


(230 runs) Pr(<> ...) in [0.119649,0.219647]
with confidence 0.95.
OK


simulate 1 [<=20]{Ball.p, Ball2.p}
value
time
Ball.p
Ball2.p

>(time>=12 && Ball1.p>4))

hit2!

simulate 1 [<=20]{Ball1.p, Ball2.p}

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

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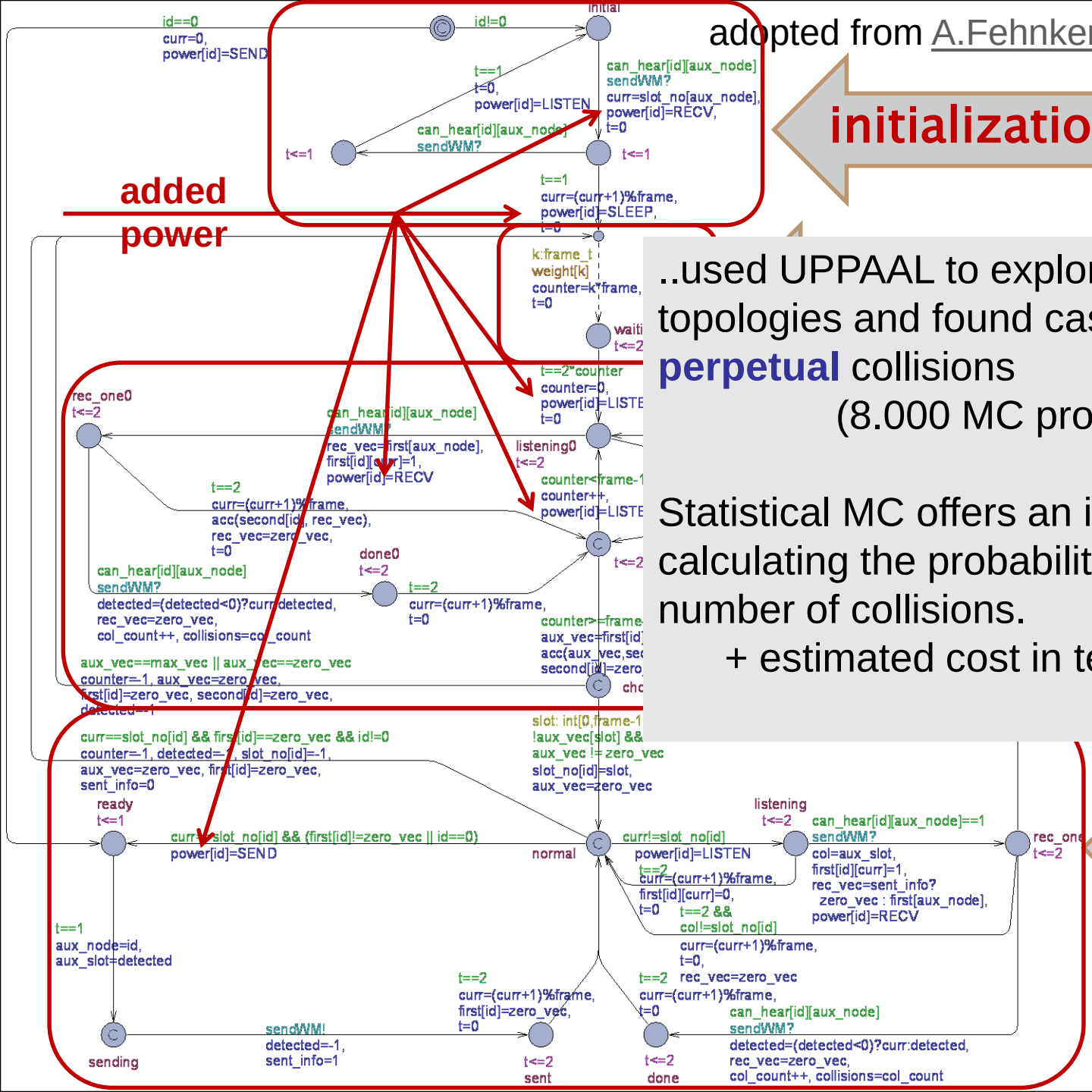
Lightweight Media Access Control

- 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

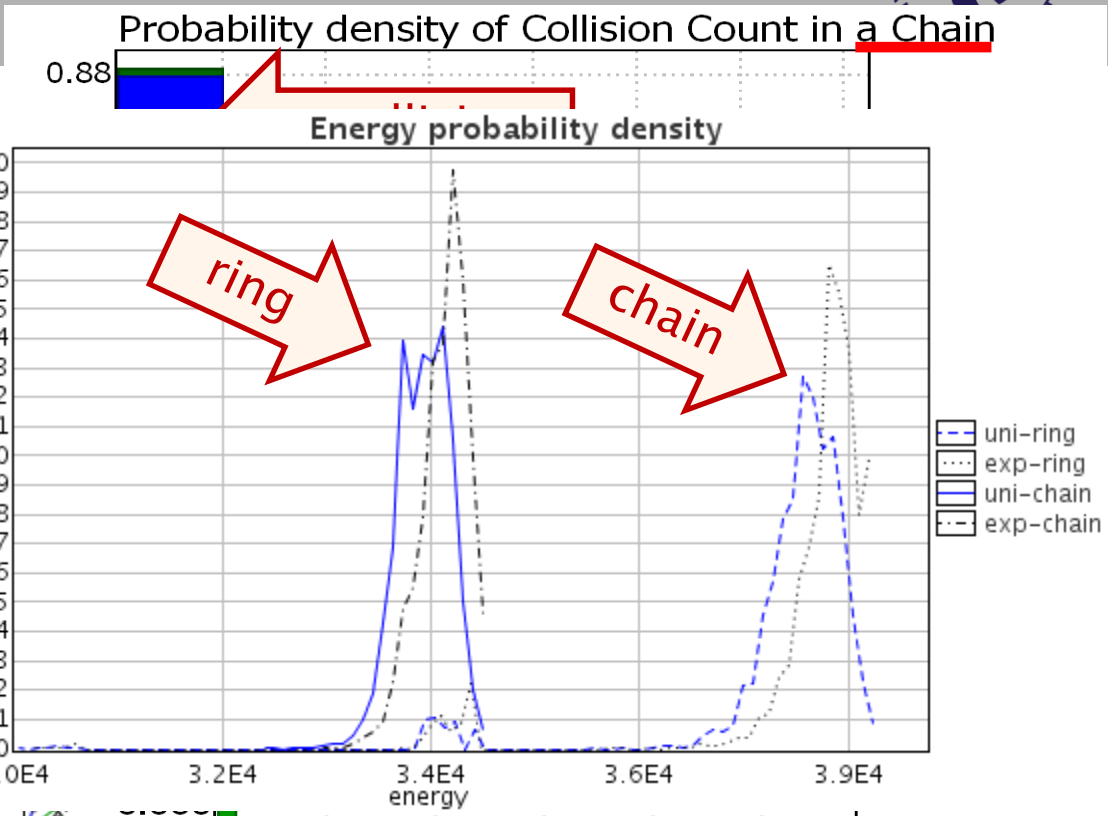
(8.000 MC problems)

Statistical MC offers an insight by calculating the probability over the number of collisions.

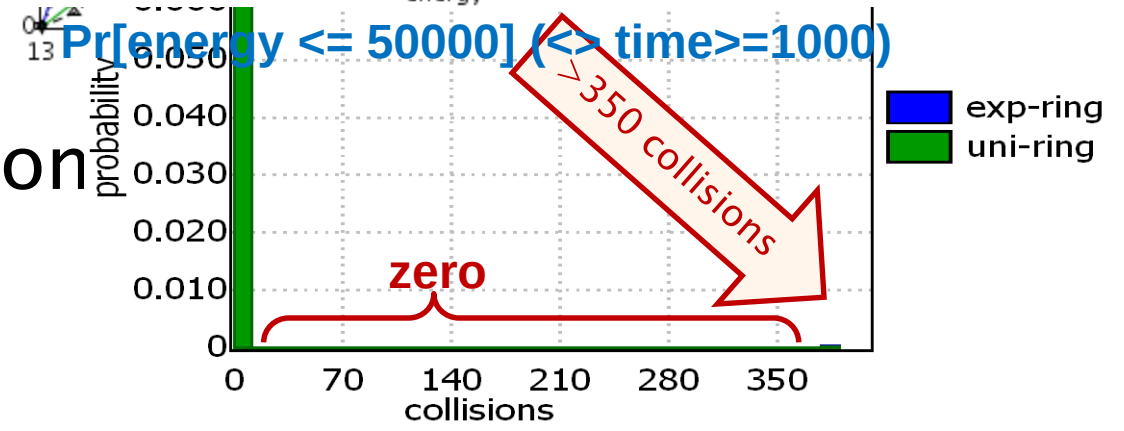
+ estimated cost in terms of energy.

SMC of LMAC with 4 Nodes

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

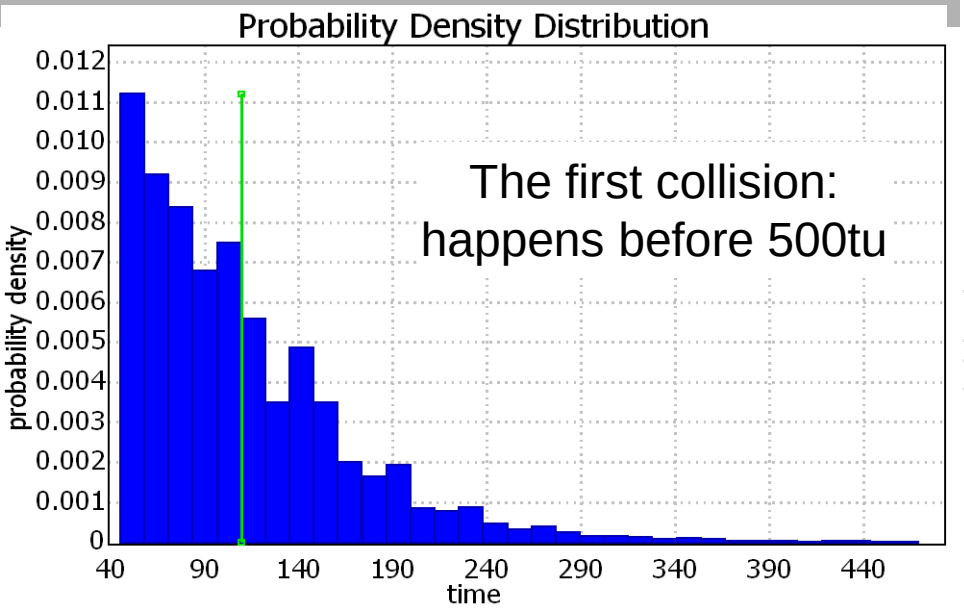


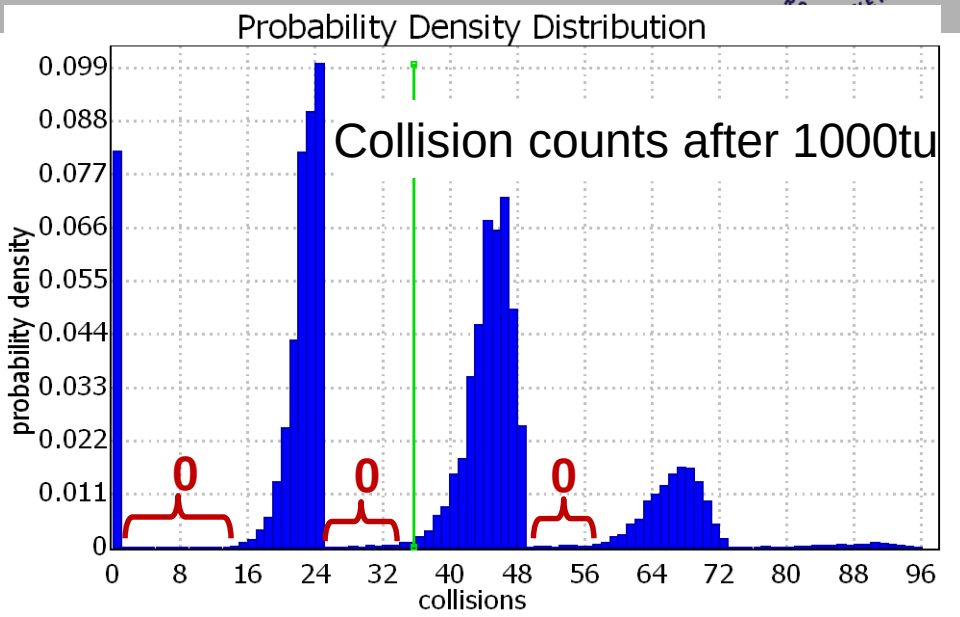
Pr[energy <= 50000] (<> time>=1000)

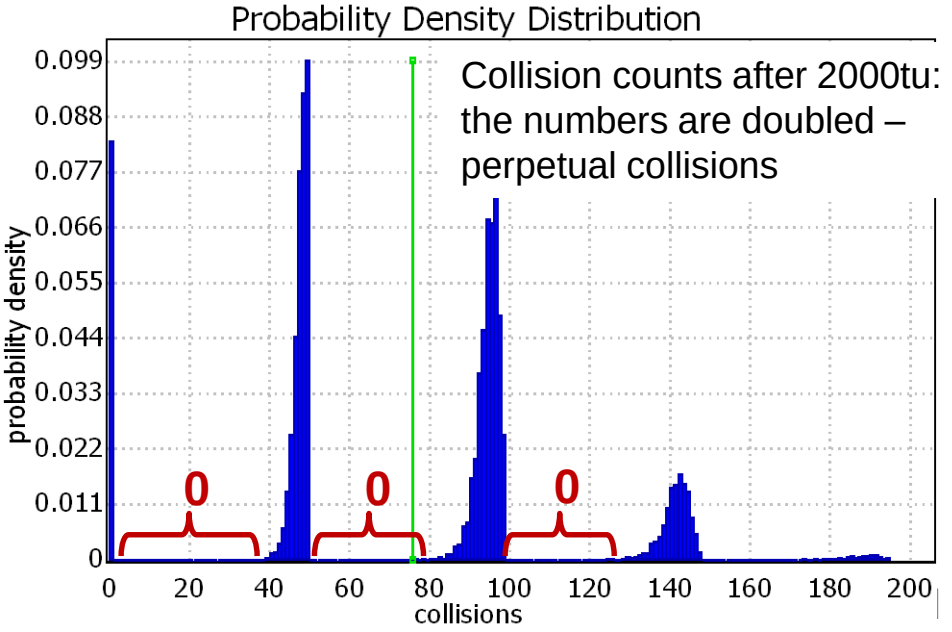


Pr[collisions<=50000] (<> time>=1000)

10-Node Star

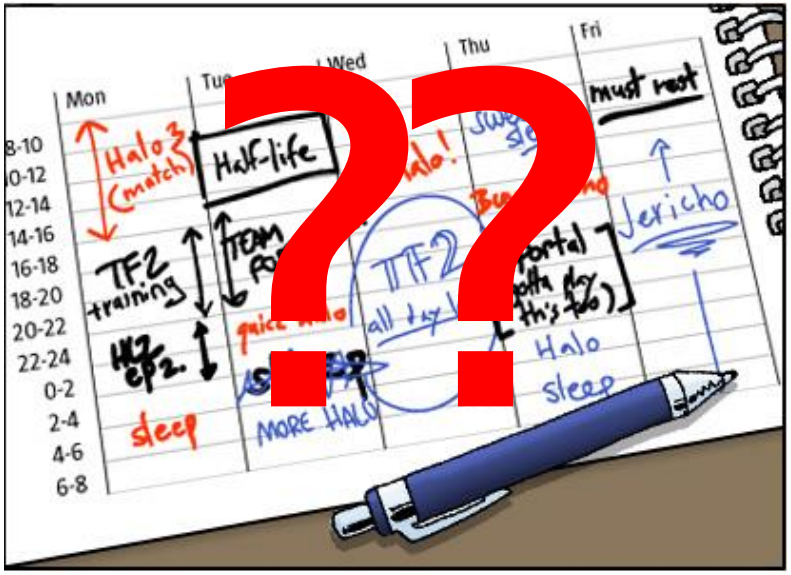






- The first collisions happen before **500**tu.
- It is unlikely (**8.2%**) that
  there will be **0** collisions.
- And if they happen, they are perpetual.

Schedulability & Performance Analysis



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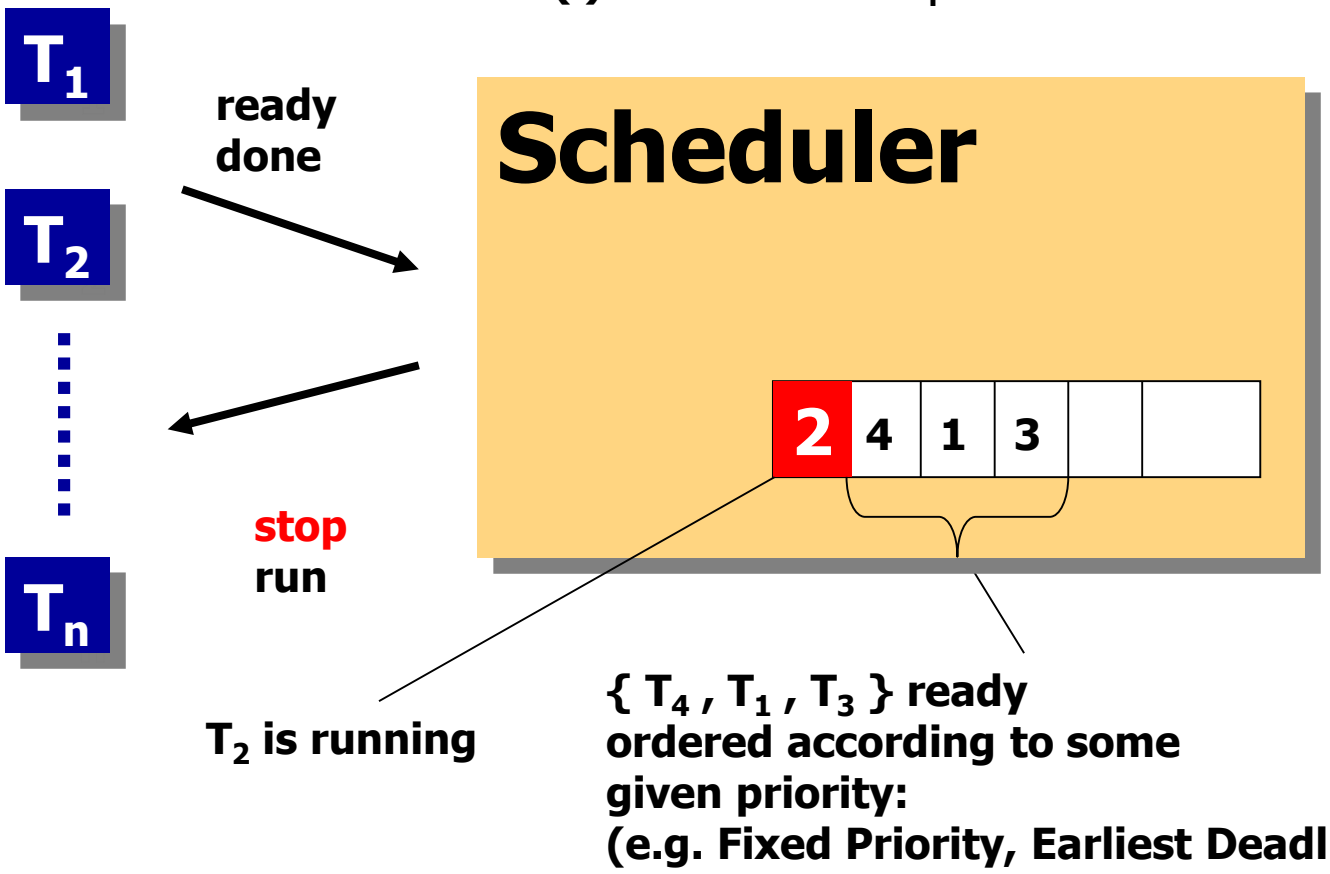
Task Scheduling

utilization of CPU

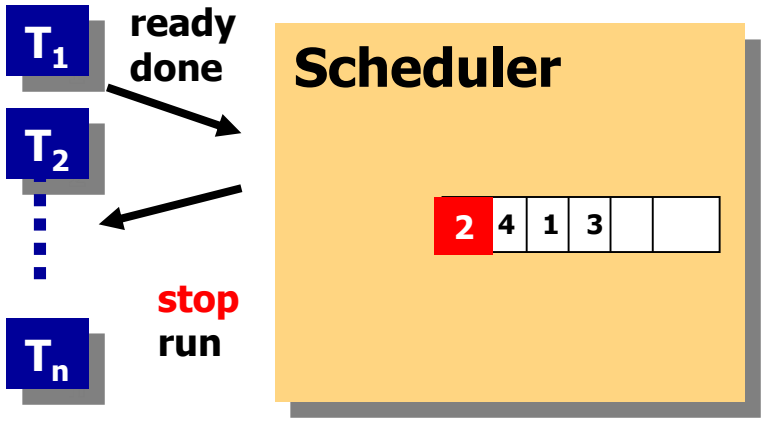
P(i), UNI[E(i), L(i)], .. : period or earliest/latest arrival or .. for T_i

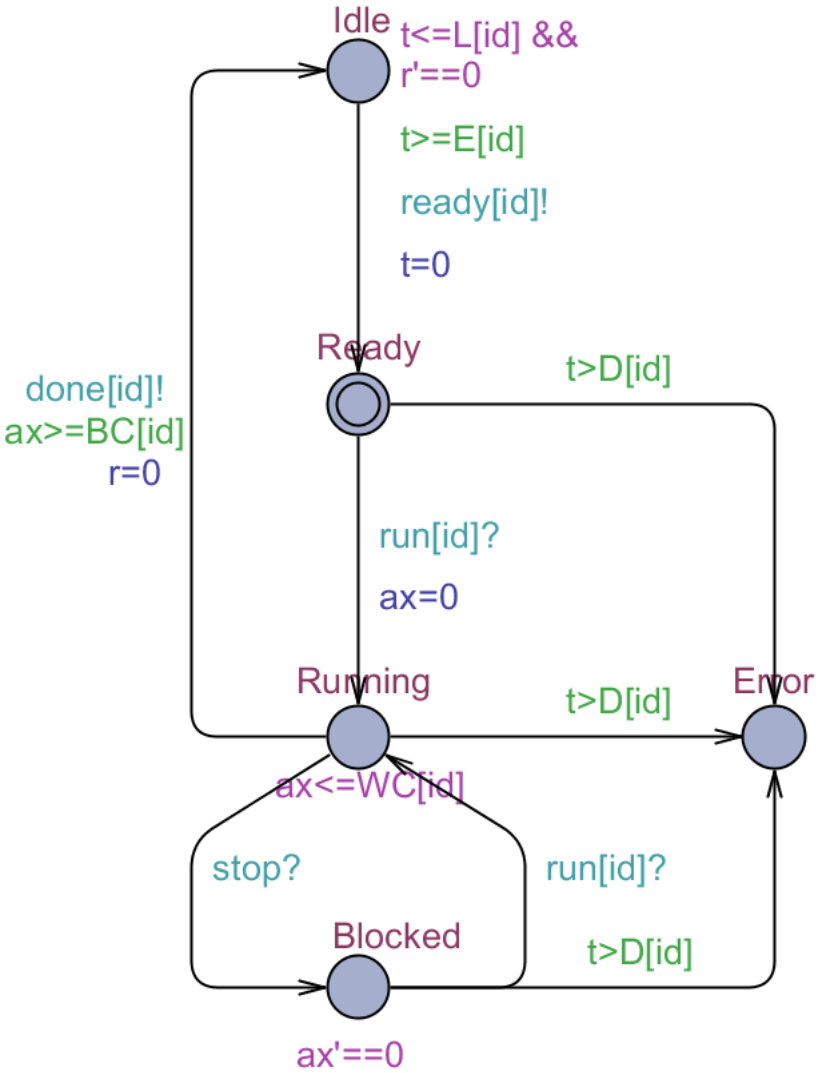
C(i), UNI[BC(i),WC(i)] : execution time for T_i

D(i): deadline for T_i

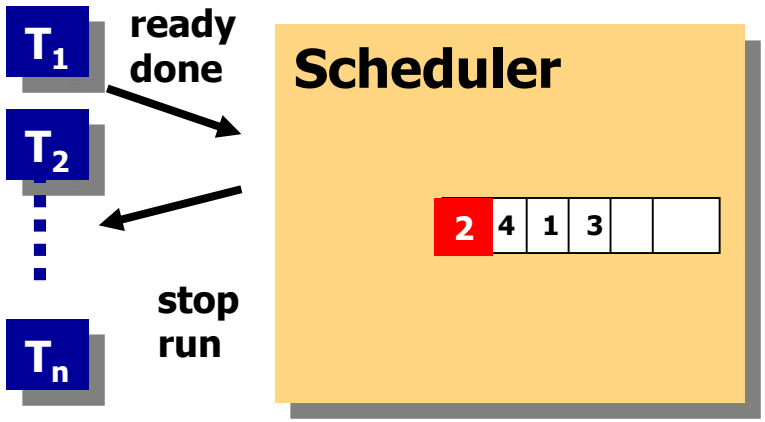


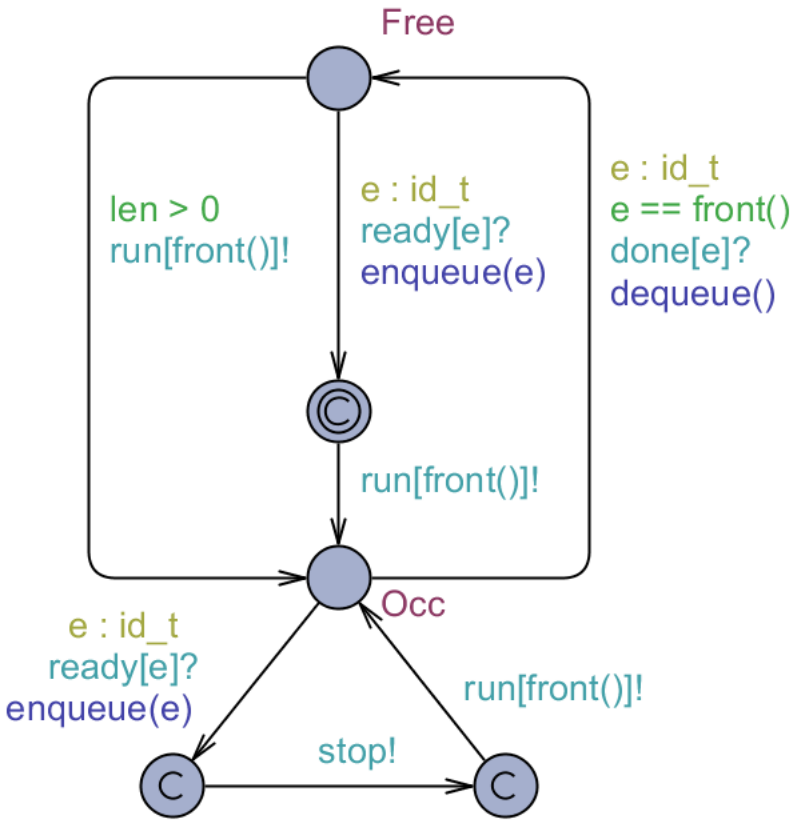
Modeling Task



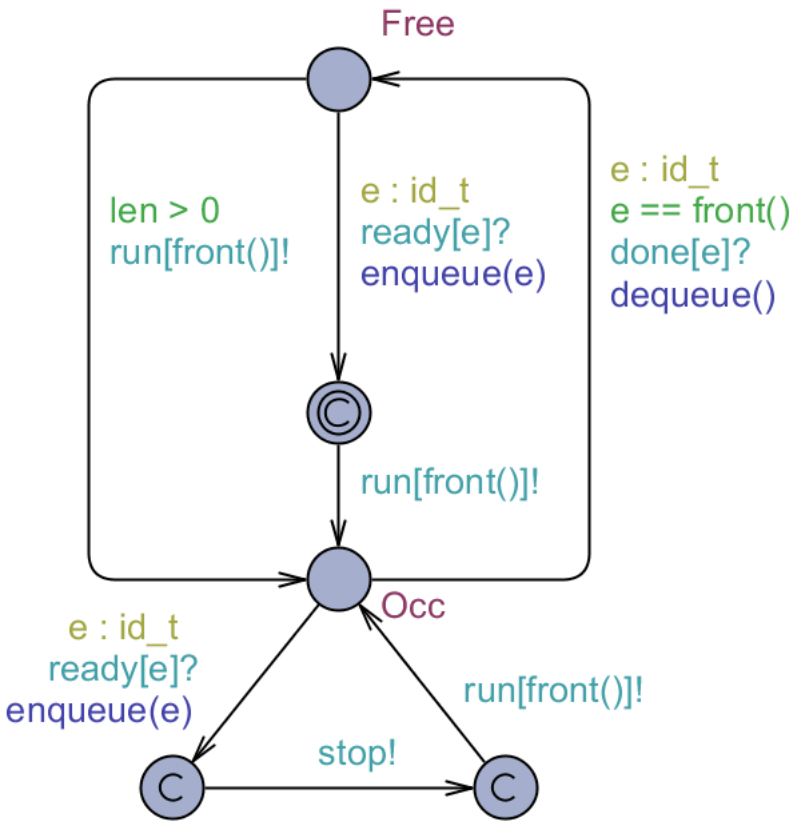


Modeling Scheduler





Modeling Queue



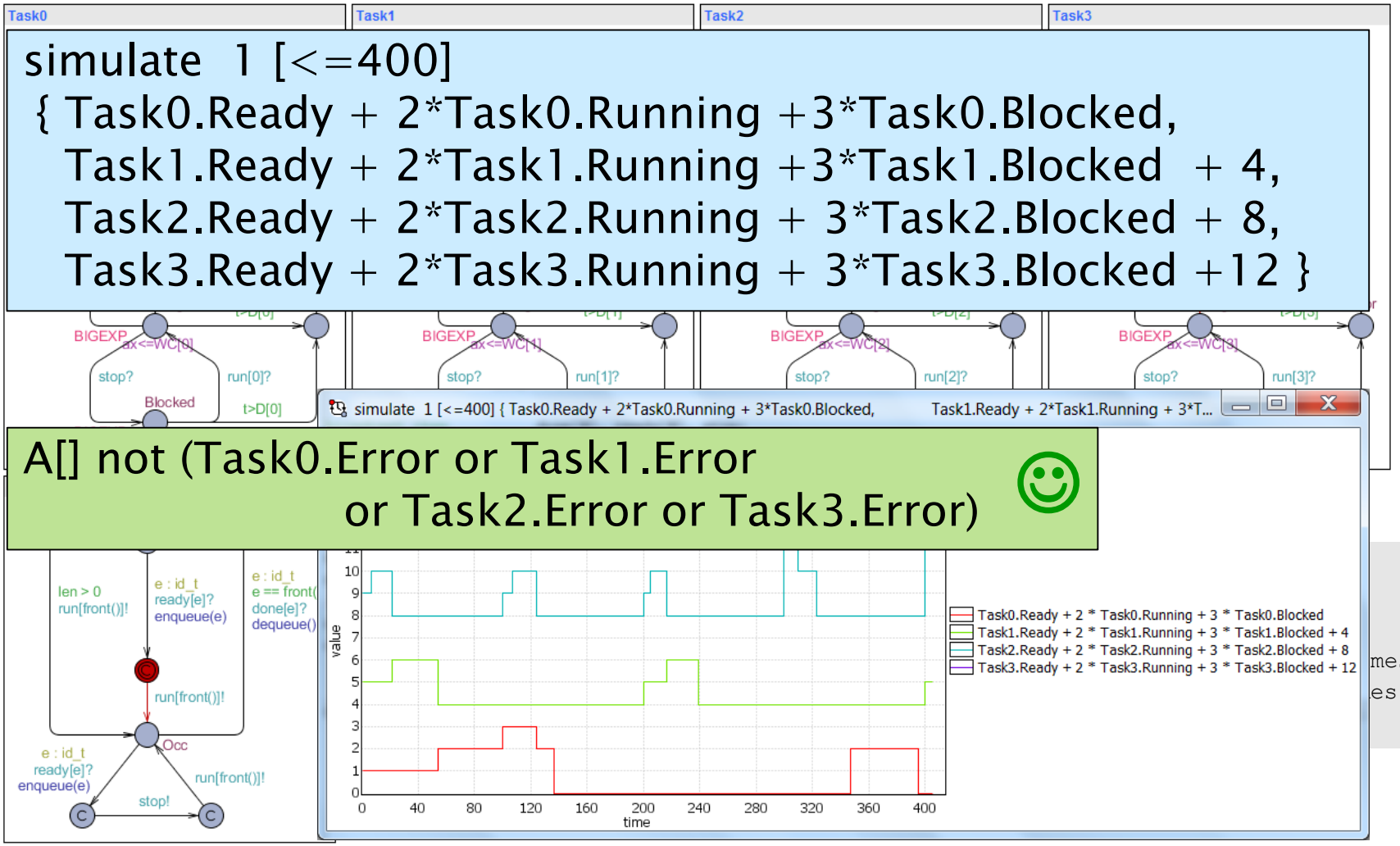

```
// Put an element at the end of the queue
void enqueue(id_t element)
{
int tmp=0;
list[len++] = element;
if (len>0)
{
        int i=len-1;
        while (i>1 && P[list[i]]>P[list[i-1]])
        {
                tmp = list[i-1];
                list[i-1] = list[i];
                list[i] = tmp;
                i--;
        }
}
}

// Remove the front element of the queue
void dequeue()
{
  ......
```

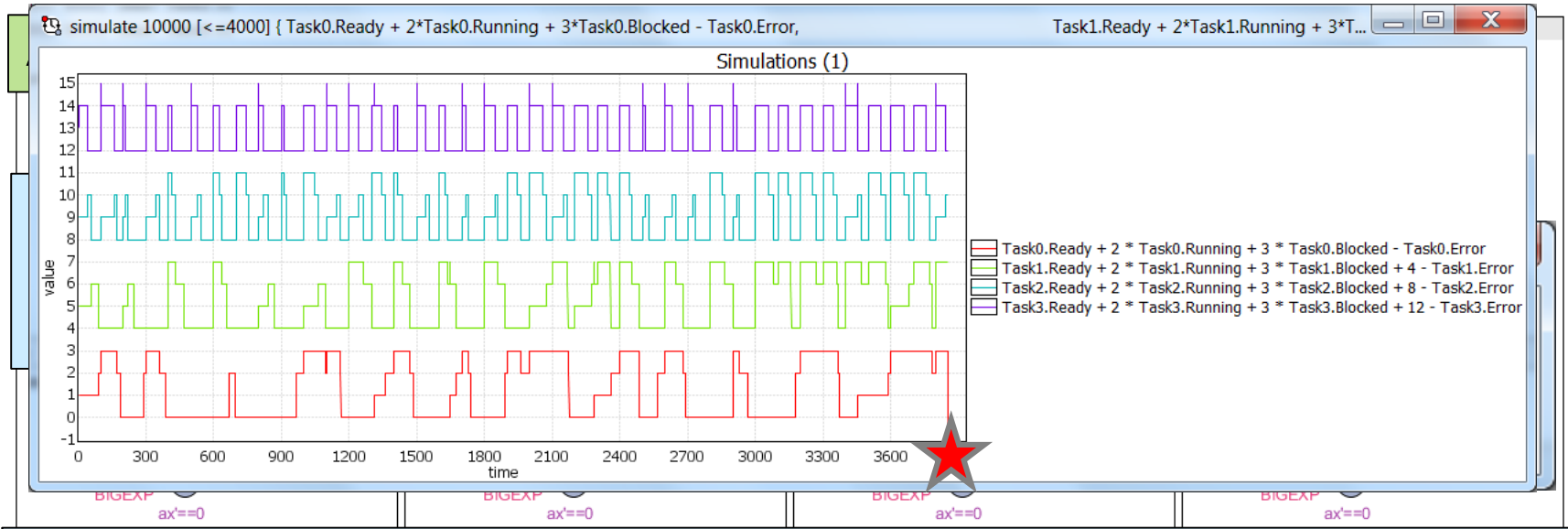
Schedulability Analysis

simulate 1 [<=400]
{ Task0.Ready + 2*Task0.Running +3*Task0.Blocked,
Task1.Ready + 2*Task1.Running +3*Task1.Blocked + 4,
Task2.Ready + 2*Task2.Running + 3*Task2.Blocked + 8,
Task3.Ready + 2*Task3.Running + 3*Task3.Blocked +12 }

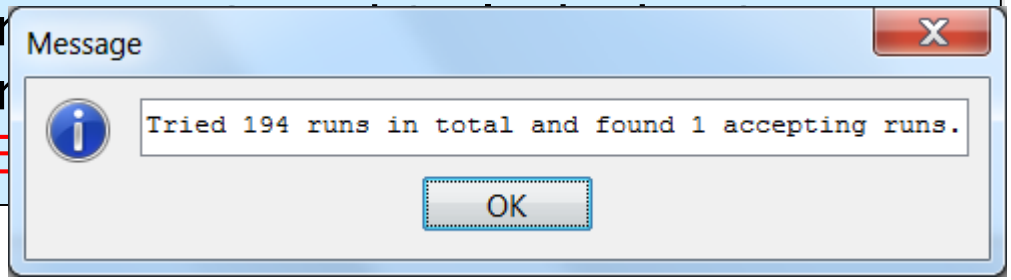
A[] not (Task0.Error or Task1.Error
or Task2.Error or Task3.Error)



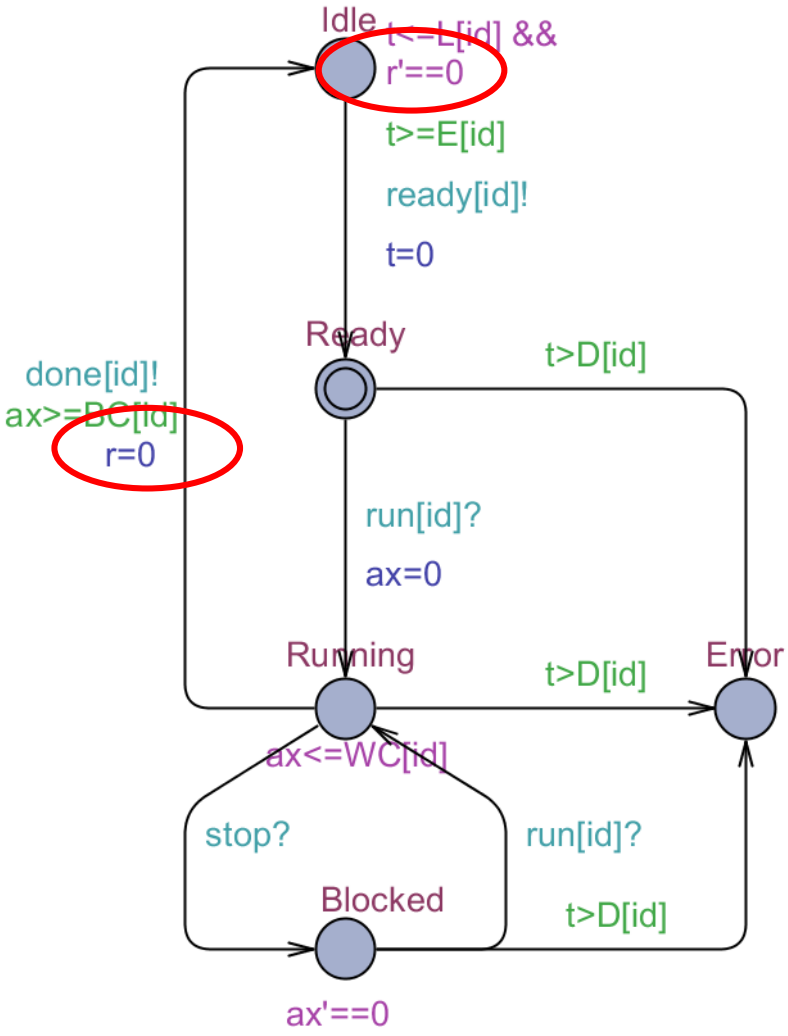
Schedulability Analysis



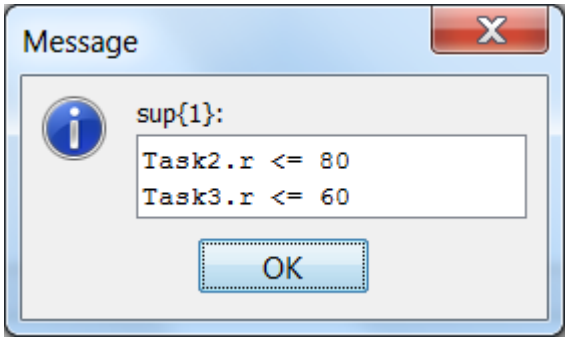

```
simulate  10000 [<=400]
 { Task0.Ready + 2*Task0.Running +3*Task0.Blocked,
   Task1.Ready + 2*Task1.Running +3*Task1.Blocked  + 4,
   Task2.Ready + 2*Task2.Rur
   Task3.Ready + 2*Task3.Rur
   : 1 : (Task0.Error or Task1.E
```



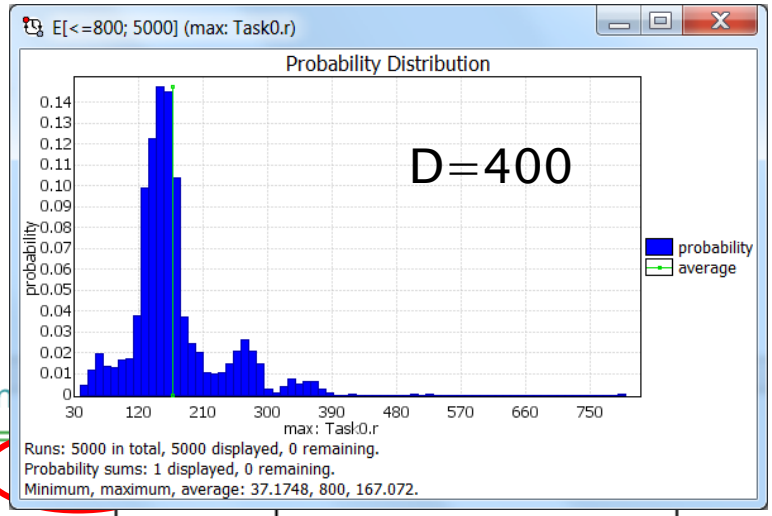
Performance Analysis

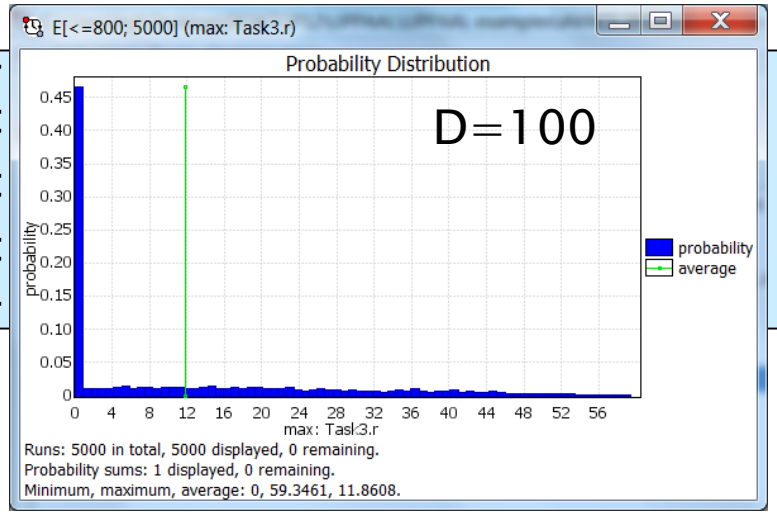


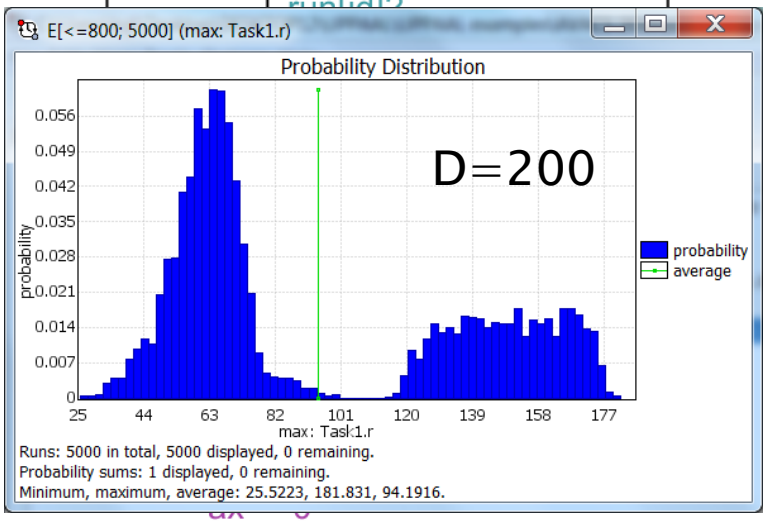
sup : Task2.r, Task3.r

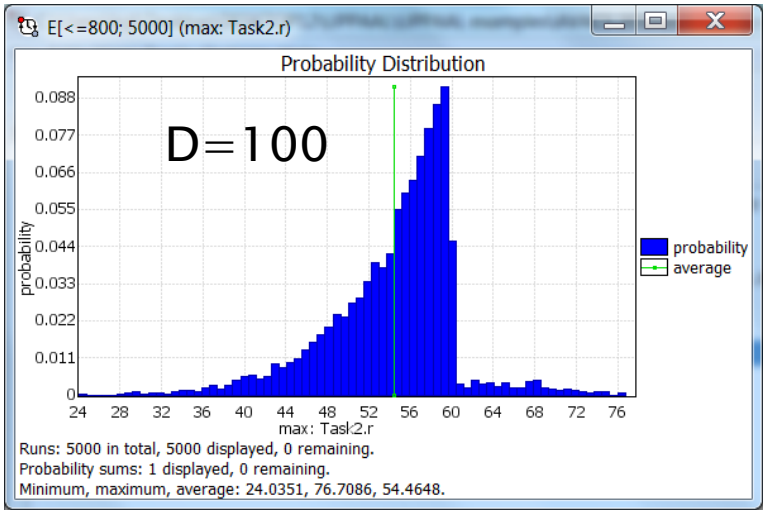


Performance Analysis







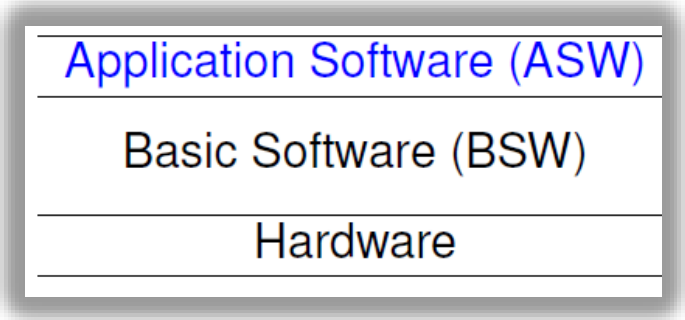


Herschel-Planck Scientific Mission at ESA

Attitude and Orbit Control Software
TERMA A/S Steen Ulrik Palm, Jan Storbank Pedersen, Poul Hougaard

Herschel & Planck Satelites

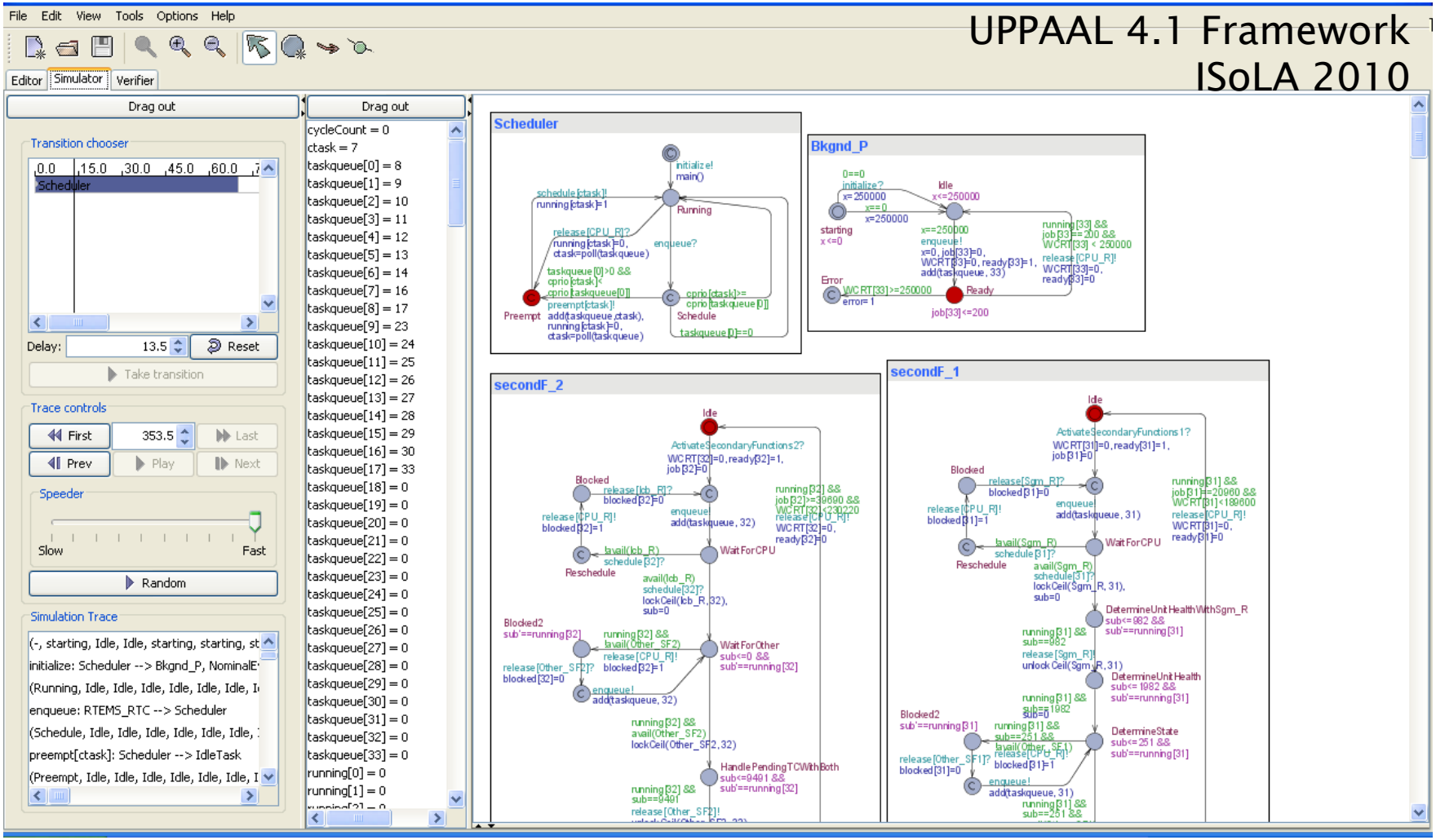
- **Application software (ASW)**
  - built and tested by Terma:
  - does attitude and orbit control, tele-commanding, fault detection isolation and recovery.
- Basic software (BSW)
  - low level communication and scheduling periodic events.
- Real-time operating system (RTEMS)
  - Priority Ceiling for ASW,
  - Priority Inheritance for BSW
- Hardware
  - single processor, a few buses, sensors and act



Requirements:

Software tasks should be schedulable.
CPU utilization should not exceed 50% load

Modeling in UPPAAL



Blocking & WCRT

ID	Task	Specification			Blocking times			WCRT		
		Period	WCET	Deadline	Terma	UPPAAL	Diff	Terma	UPPAAL	Diff
1	RTEMS_RTC	10.000	0.013	1.000	0.035	0	0.035	0.050	0.013	0.037
2	AswSync_SyncPulseIsr	250.000	0.070	1.000	0.035	0	0.035	0.120	0.083	0.037
3	Hk_SamplerIsr	125.000	0.070	1.000	0.035	0	0.035	0.120	0.070	0.050
4	SwCyc_CycStartIsr	250.000	0.200	1.000	0.035	0	0.035	0.320	0.103	0.217
5	SwCyc_CycEndIsr	250.000	0.100	1.000	0.035	0	0.035	0.220	0.113	0.107
6	Rt1553_Isr	15.625	0.070	1.000	0.035	0	0.035	0.290	0.173	0.117
7	Bc1553_Isr	20.000	0.070	1.000	0.035	0	0.035	0.360	0.243	0.117
8	Spw_Isr	39.000	0.070	2.000	0.035	0	0.035	0.430	0.313	0.117
9	Obdh_Isr	250.000	0.070	2.000	0.035	0	0.035	0.500	0.383	0.117
10	RtSdb_P_1	15.625	0.150	15.625	3.650	0	3.650	4.330	0.533	3.797
11	RtSdb_P_2	125.000	0.400	15.625	3.650	0	3.650	4.870	0.933	3.937
12	RtSdb_P_3	250.000	0.170	15.625	3.650	0	3.650	5.110	1.103	4.007
14	**FdirEvents**	250.000	5.000	230.220	0.720	0	0.720	7.180	5.153	2.027
15	**NominalEvents_1**	250.000	0.720	230.220	0.720	0	0.720	7.900	5.873	2.027
16	**MainCycle**	250.000	0.400	230.220	0.720	0	0.720	8.370	6.273	2.097
17	HkSampler_P_2	125.000	0.500	62.500	3.650	0	3.650	11.960	5.380	6.580
18	HkSampler_P_1	250.000	6.000	62.500	3.650	0	3.650	18.460	11.615	6.845
19	Acb_P	250.000	6.000	50.000	3.650	0	3.650	24.680	6.473	18.207
20	IoCyc_P	250.000	3.000	50.000	3.650	0	3.650	27.820	9.473	18.347
21	**PrimaryF**	250.000	34.050	59.600	5.770	0.966	4.804	65.470	54.115	11.355
22	**RCSControlF**	250.000	4.070	239.600	12.120	0	12.120	76.040	53.994	22.046
23	Obt_P	1000.000	1.100	100.000	9.630	0	9.630	74.720	2.503	72.217
24	Hk_P	250.000	2.750	250.000	1.035	0	1.035	6.800	4.953	1.847
25	StsMon_P	250.000	3.300	125.000	16.070	0.822	15.248	85.050	17.863	67.187
26	TmGen_P	250.000	4.860	250.000	4.260	0	4.260	77.650	9.813	67.837
27	Sgm_P	250.000	4.020	250.000	1.040	0	1.040	18.680	14.796	3.884
28	TcRouter_P	250.000	0.500	250.000	1.035	0	1.035	19.310	11.896	7.414
29	Cmd_P	250.000	14.000	250.000	26.110	1.262	24.848	114.920	94.346	20.574
30	**NominalEvents_2**	250.000	1.780	230.220	12.480	0	12.480	102.760	65.177	37.583
31	**SecondaryF_1**	250.000	20.960	189.600	27.650	0	27.650	141.550	110.666	30.884
32	**SecondaryF_2**	250.000	39.690	230.220	48.450	0	48.450	204.050	154.556	49.494
33	Bkgnd_P	250.000	0.200	250.000	0.000	0	0.000	154.090	15.046	139.044

Marius Micusionis

TERMA Case Follow-Up

[f*WCET, WCET]

limit	f=100%			f=95%		
	states	mem	time	states	mem	ti
1	1300	51.2	1.47	485077	83.0	90
2	2522	53.7	2.45	806914		
4	4981	54.5	4.62	1499700	2	280.8
8						
16						
∞	1					

f=90%			f=86%		
states	mem	time, s	states	mem	time
1481162	124.1	4962.8	3348246	186.9	23986.5
2414679	139.7	7755	5253778	198.7	33299.2
4421630	138.3	13720	9231399	274.6	51176.6
9093562	156.5	3112.3	18240030	364.6	102932.4
17798572	176.0	6014.5	35432003	520.4	158816.7
181869652	1682.2	530604.9	error may be reachable		

1 Day

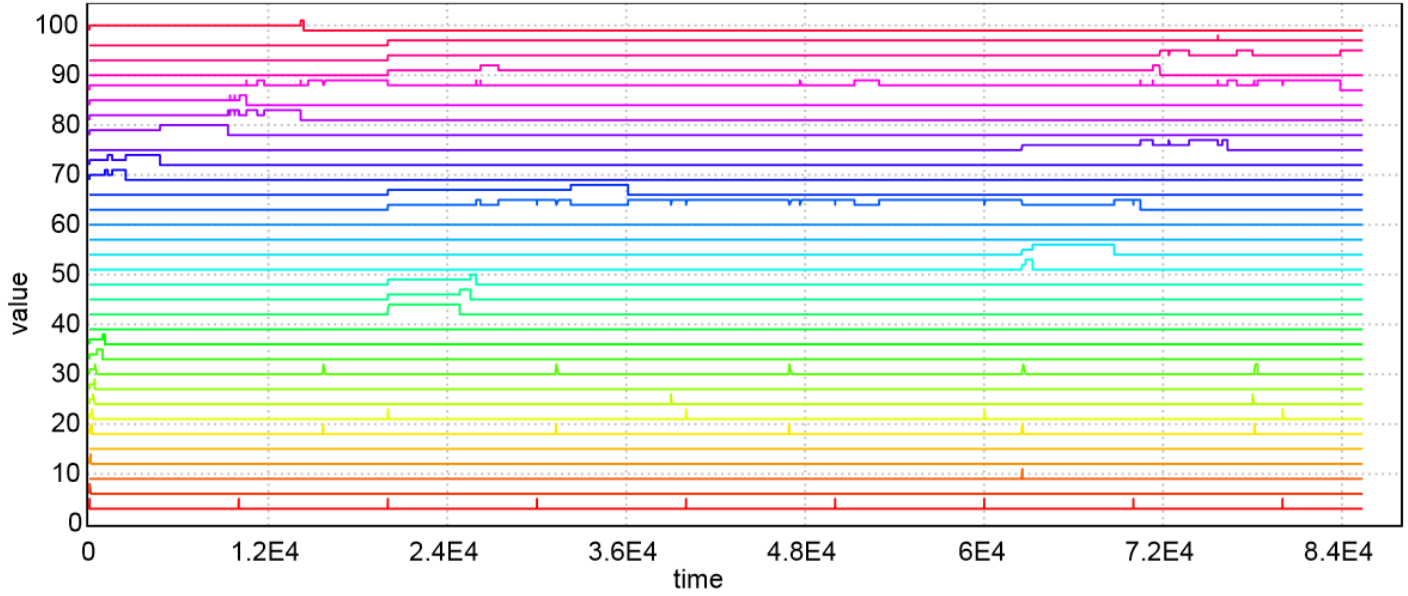
6 Days

TERMA Case – Statistical MC

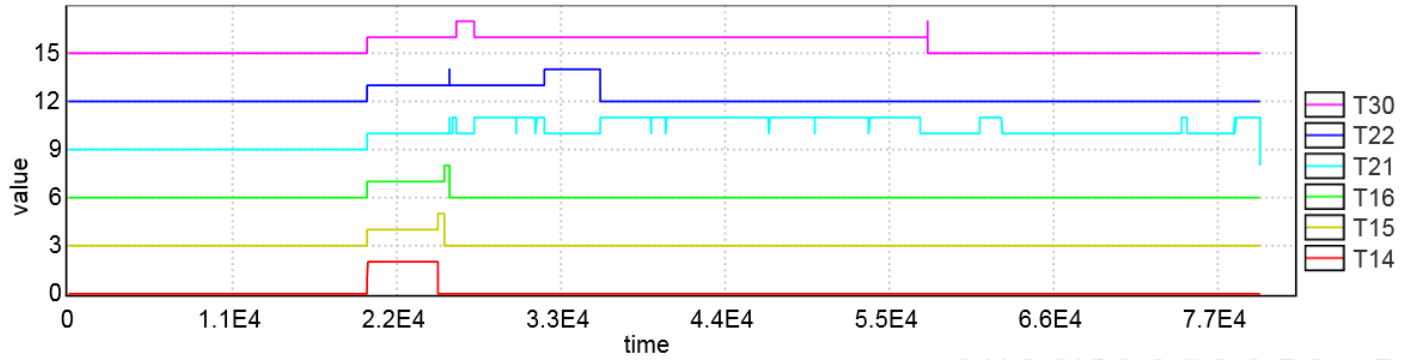
Limit cycles	f %	α	ε	Total traces, #	Error traces #	Probability	Earliest Error cycle	offset	Verification time
1	0	0.0100	0.005	105967	1928	0.018194	0	79600.0	1:58:06
1	50	0.0100	0.005	105967	753	0.007106	0	79600.0	2:00:52
1	60	0.0100	0.005	105967	13	0.000123	0	79778.3	2:01:18
1	62	0.0005	0.002	1036757	34	0.000033	0	79616.4	19:52:22
160	63	0.0100	0.05	1060	177	0.166981	0	81531.6	2:47:03
160	64	0.0100	0.05	1060	118	0.111321	1	79803.0	2:55:13
160	65	0.0500	0.05	738	57	0.077236	3	79648.0	2:06:55
160	66	0.0100	0.05	1060	60	0.056604	2	82504.0	2:62:44
160	67	0.0100	0.05	1060	26	0.024528	1	79789.0	2:64:20
160	68	0.0100	0.05	1060	3	0.002830	67	81000.0	2:67:08
640	69	0.0100	0.05	1060	8	0.007547	114	80000.0	12:23:00
640	70	0.0100	0.05	1060	3	0.002830	6	88070.0	12:30:49
1280	71	0.0100	0.05	1060	2	0.001887	458	80000.0	25:19:35

TERMA Case – Conclusion

Herschel simulation run with $f = 90\%$:



Herschel deadline violation with $f = 50\%$:



Reading

- Frits Vaandrager: A first introduction to UPPAAL
- Alexandre David, Kim G Larsen: More features in UPPAAL
- Alexandre David, Kim G. Larsen, Axel Legay, Marius Mikucionis, Zheng Wang: Time for Statistical Model Checking of Real-Time Systems. CAV 2011: 349-355.
- Alexandre David, Kim G. Larsen, Axel Legay, Marius Mikucionis, Danny Bøgsted Poulsen: Uppaal SMC tutorial. STTT 17(4): 397-415 (2015)
- Kim Guldstrand Larsen: Validation, Synthesis and Optimization for Cyber-Physical Systems. TACAS (1) 2017: 3-20

- Alexandre David, Peter Gjøl Jensen, Kim Guldstrand Larsen, Marius Mikucionis, Jakob Haahr Taankvist: Uppaal Stratego. TACAS 2015: 206-211

Applications
(some)

Bang & Olufsen IR-Link

- Bug known to exist for 10 years
- Ill-described:
  2.800 lines of assembler code + 3 flowchart + 1 B&O eng.
- 3 months for modeling.
- UPPAAL detects error with 1.998 transition steps (shortest)
- Error trace was confirmed in B&O laboratory.
- Error corrected and verified in UPPAAL.

Arne Skou, Klaus Havelund

Bang & Olufsen IR-Link

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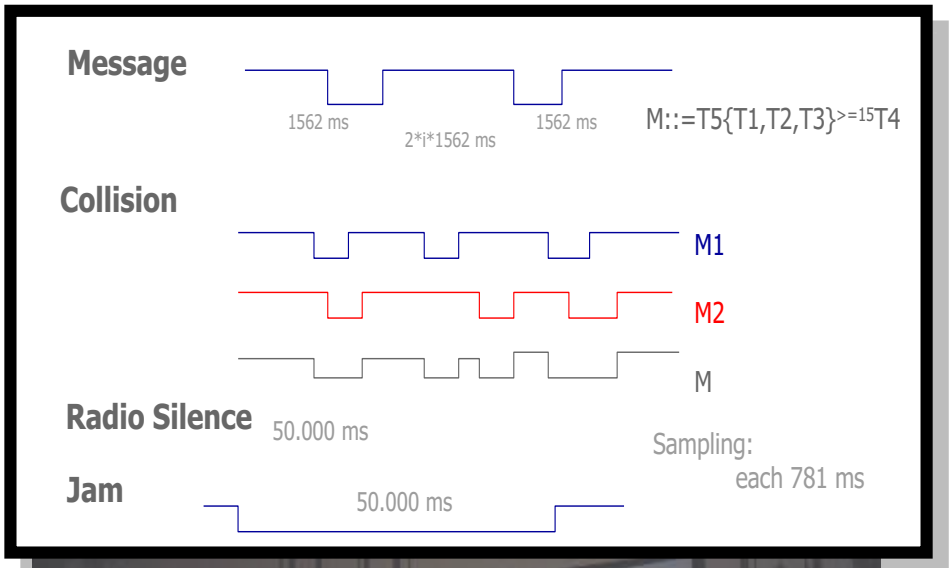


1st RTSS'97 talk, Klaus Havelund

Philips Bounded Retransmission Protocol

Pedro D'Argenio
Joost-Pieter Katoen
Theo Ruys
Jan Tretmans

Science):

> I should tell you that I am quite dissappointed with this new
> release of Uppaal ;). You take all the fun out of it!!. With this
> new releas I could verify everything in a couple of minutes,
> including a couple of properties that where impossible before!!!
> Moreover, I was playing with the simulator and I found a silly
> deadlock in the specification.
>
> ...
>
> I found this new Uppaal a quite huge leap from the previous version.
> As a user, I have had a really good first impression. I will
> compile a list of comments for tomorrow afternoon.

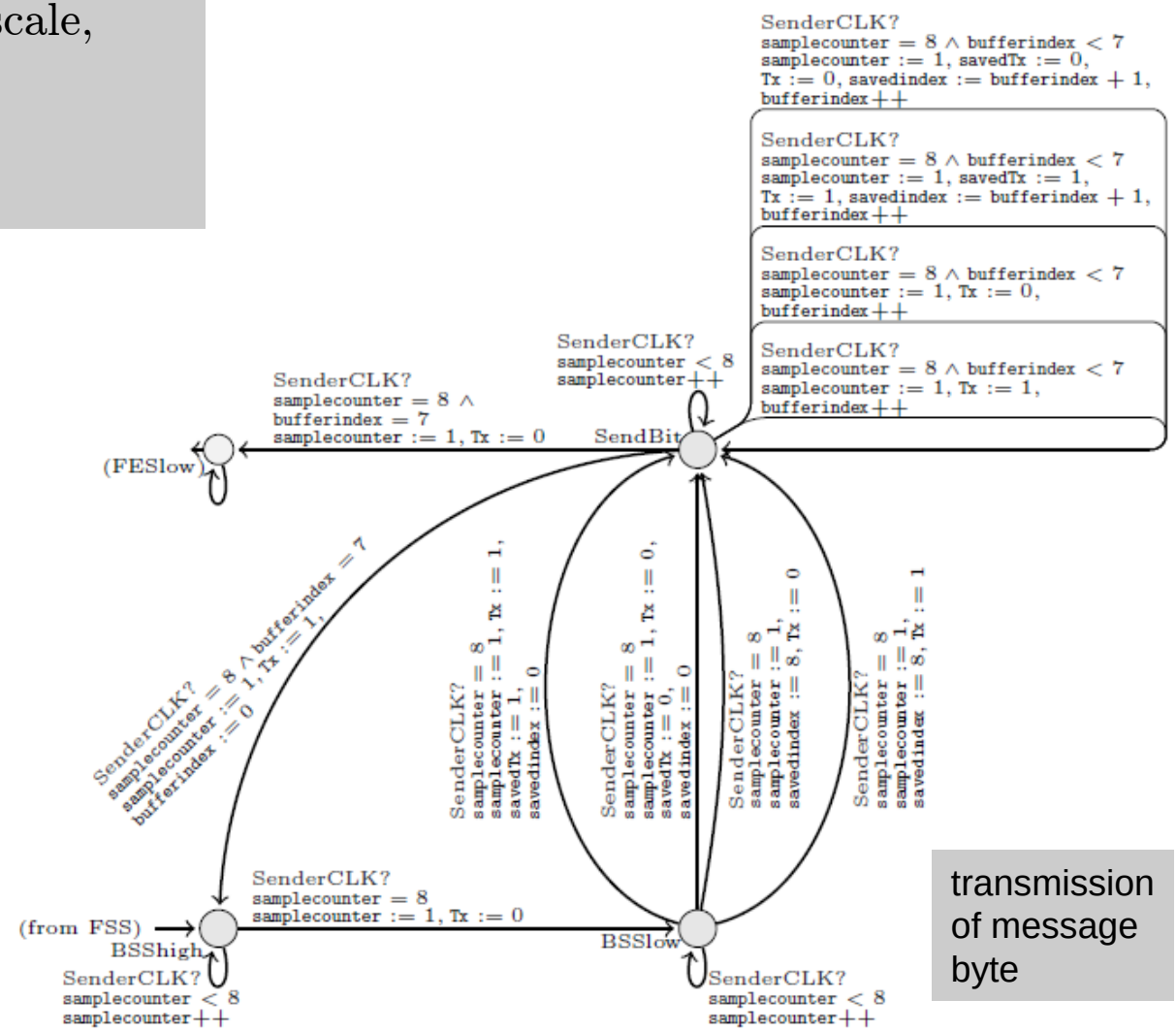
Regards,

FlexRay

[Gerke, Ehlers, Finkbeiner, Peters, 2010]

BMW, Bosch, Daimler, Freescale, General Motors, NXP Semiconductors, and Volkswagen

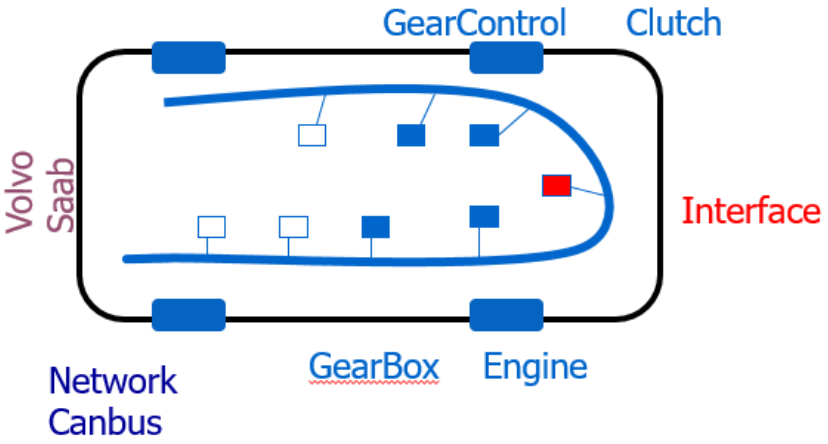
Fault-tolerance
Timed hardware model
Parameterized error models
(glitches, jitter)
Voting & bit-clock alignment

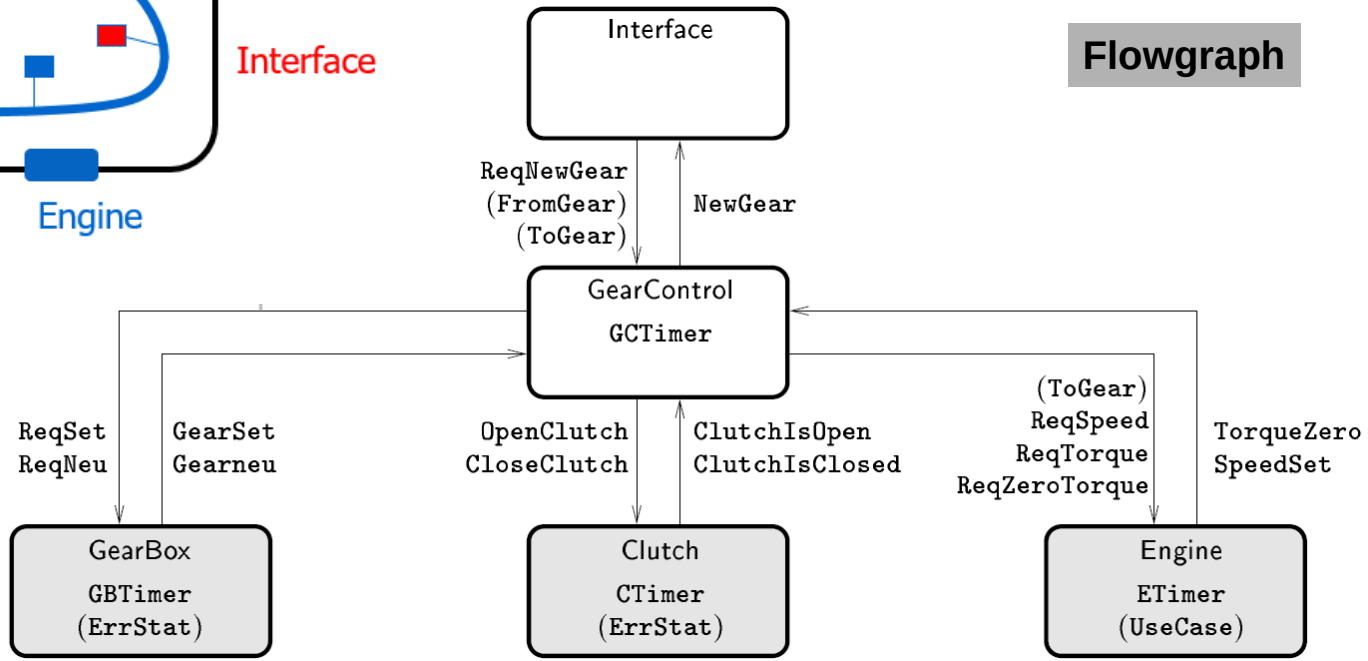


transmission of message byte

Gear Controller

with MECEL AB



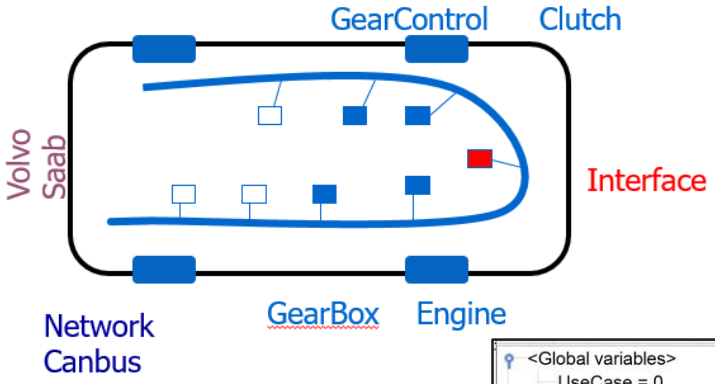


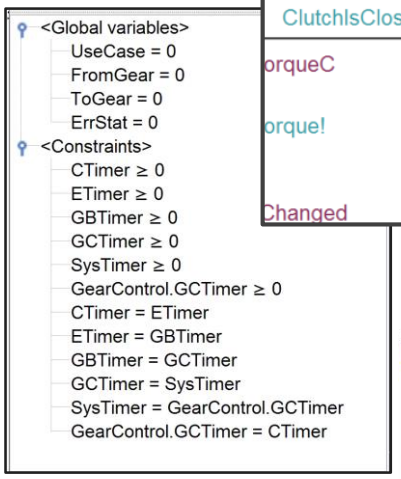
Flowgraph

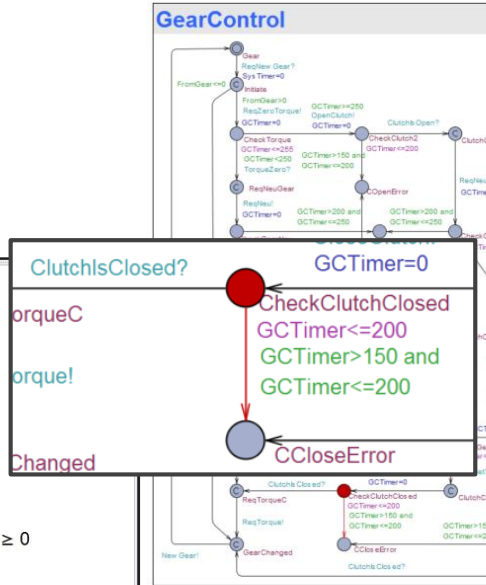
Magnus Lindahl
Paul Pettersson
Wang Yi
2001

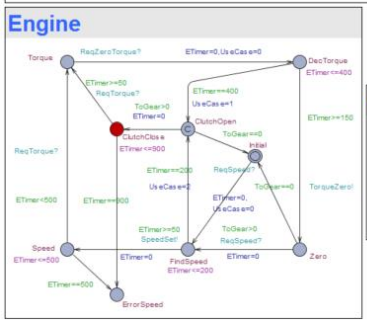
Gear Controller

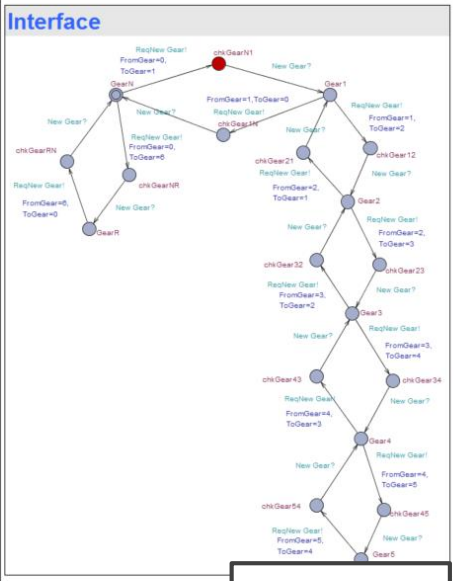
with MECEL AB

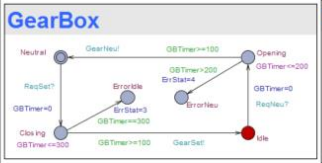


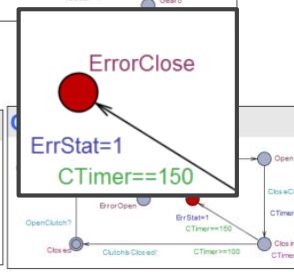










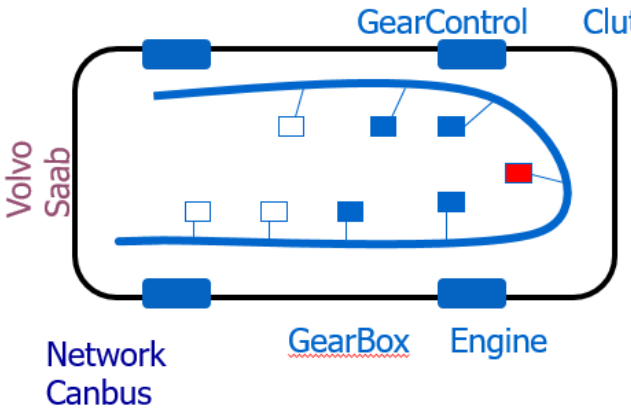


Magnus Lindahl
Paul Pettersson
Wang Yi
2001

Timed Automata Models

Gear Controller

with MECEL AB



Magnus Lindahl
Paul Pettersson
Wang Yi
2001

Requirements

$$\mathtt{GearControl@Initiate} \rightsquigarrow_{\leq 1500} (\mathtt{ErrStat} = 0) \Rightarrow \mathtt{GearControl@GearChanged}$$

$$\mathtt{GearControl@Initiate} \rightsquigarrow_{\leq 1000} (\mathtt{ErrStat} = 0 \wedge \mathtt{UseCase} = 0) \Rightarrow \mathtt{GearControl@GearChanged}$$

$$\mathtt{Clutch@ErrorClose} \rightsquigarrow_{\leq 200} \mathtt{GearControl@CCloseError}$$

$$\mathtt{Clutch@ErrorOpen} \rightsquigarrow_{\leq 200} \mathtt{GearControl@COpenError}$$

$$\mathtt{GearBox@ErrorIdle} \rightsquigarrow_{\leq 350} \mathtt{GearControl@GSetError}$$

$$\mathtt{GearBox@ErrorNeu} \rightsquigarrow_{\leq 200} \mathtt{GearControl@GNeuError}$$

$$Inv (\mathtt{GearControl@CCloseError} \Rightarrow \mathtt{Clutch@ErrorClose})$$

$$Inv (\mathtt{GearControl@COpenError} \Rightarrow \mathtt{Clutch@ErrorOpen})$$

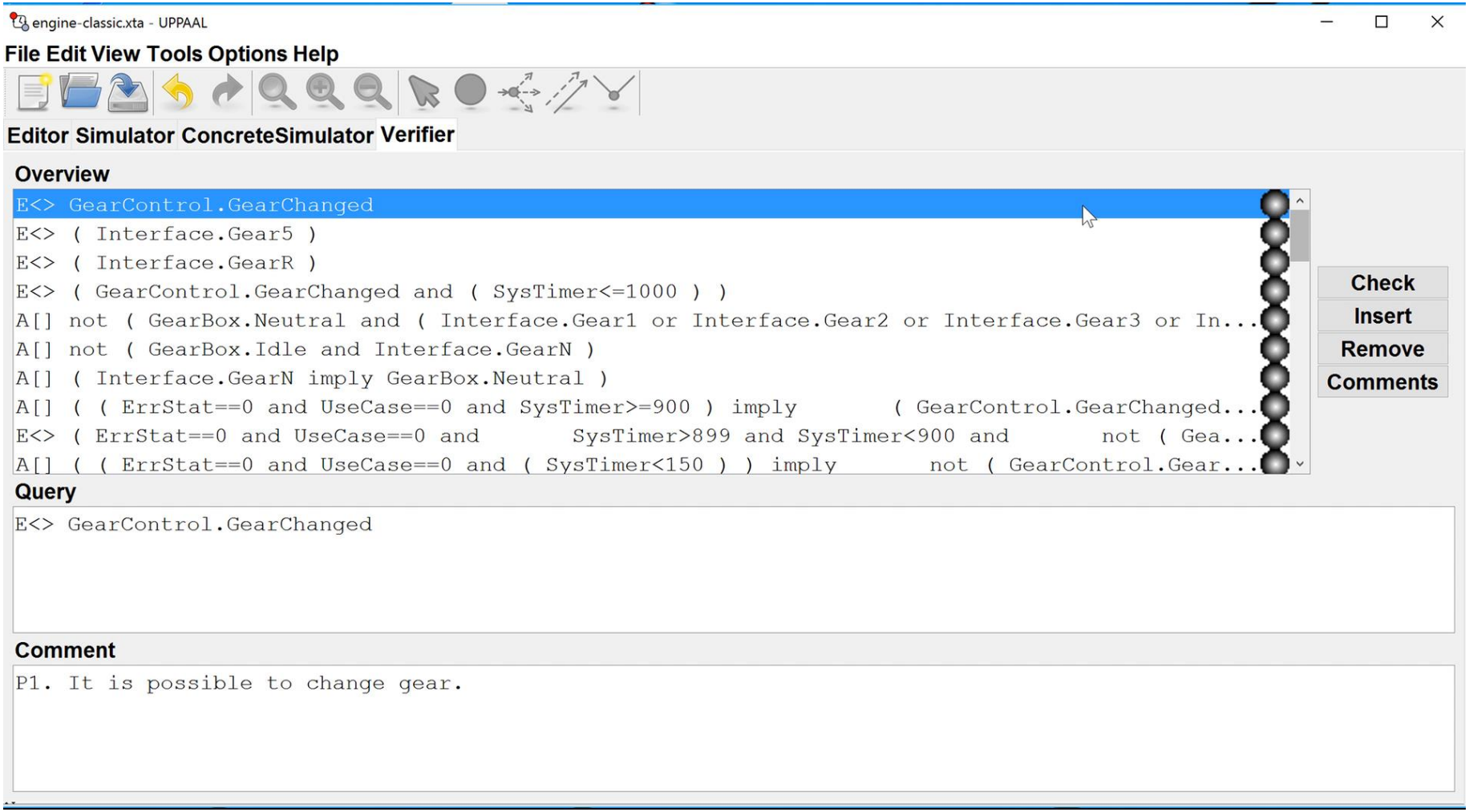
$$Inv (\mathtt{GearControl@GSetError} \Rightarrow \mathtt{GearBox@ErrorIdle})$$

$$Inv (\mathtt{GearControl@GNeuError} \Rightarrow \mathtt{GearBox@ErrorNeu})$$

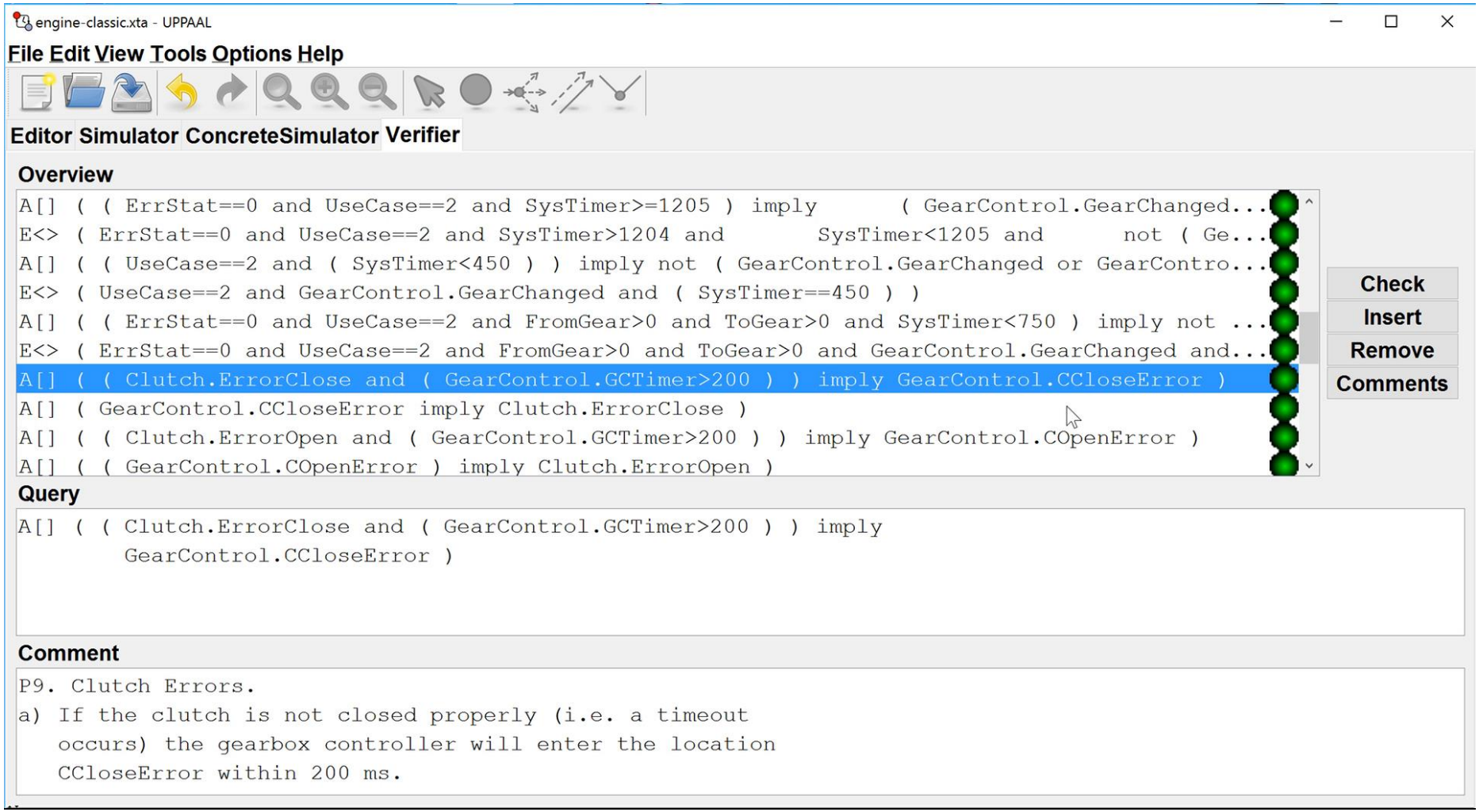
$$Inv (\mathtt{Engine@ErrorSpeed} \Rightarrow \mathtt{ErrStat} \neq 0)$$

$$Inv (\mathtt{Engine@Torque} \Rightarrow \mathtt{Clutch@Closed})$$

UPPAAL Model Checking – Demo

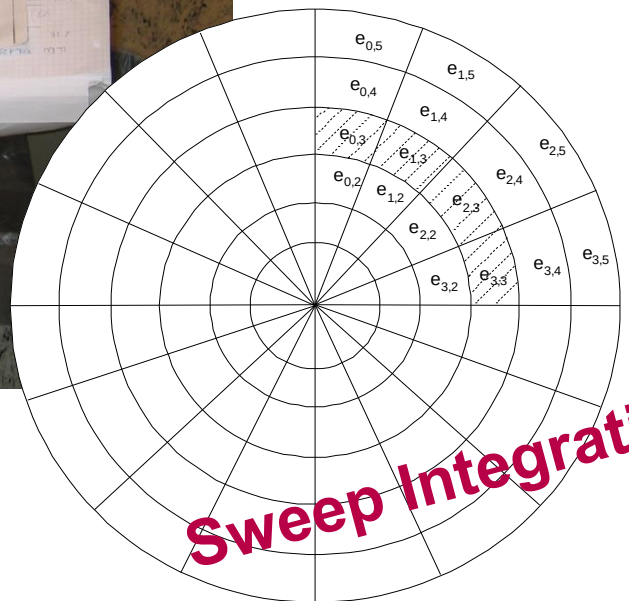


UPPAAL Model Checking – Demo

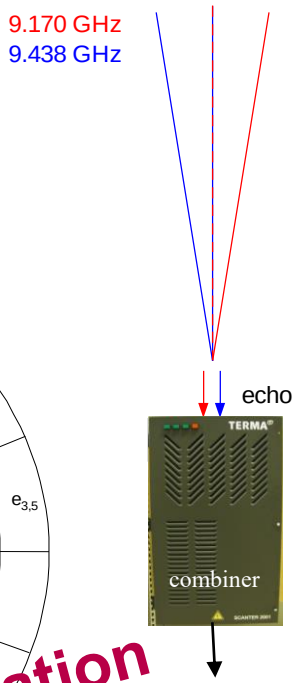


TERMA A/S (2004)

Memory Management for Radars



Sweep Integration



Frequency Diversity

AMETIST
advanced methods for timed systems

TERMA A/S (2011)

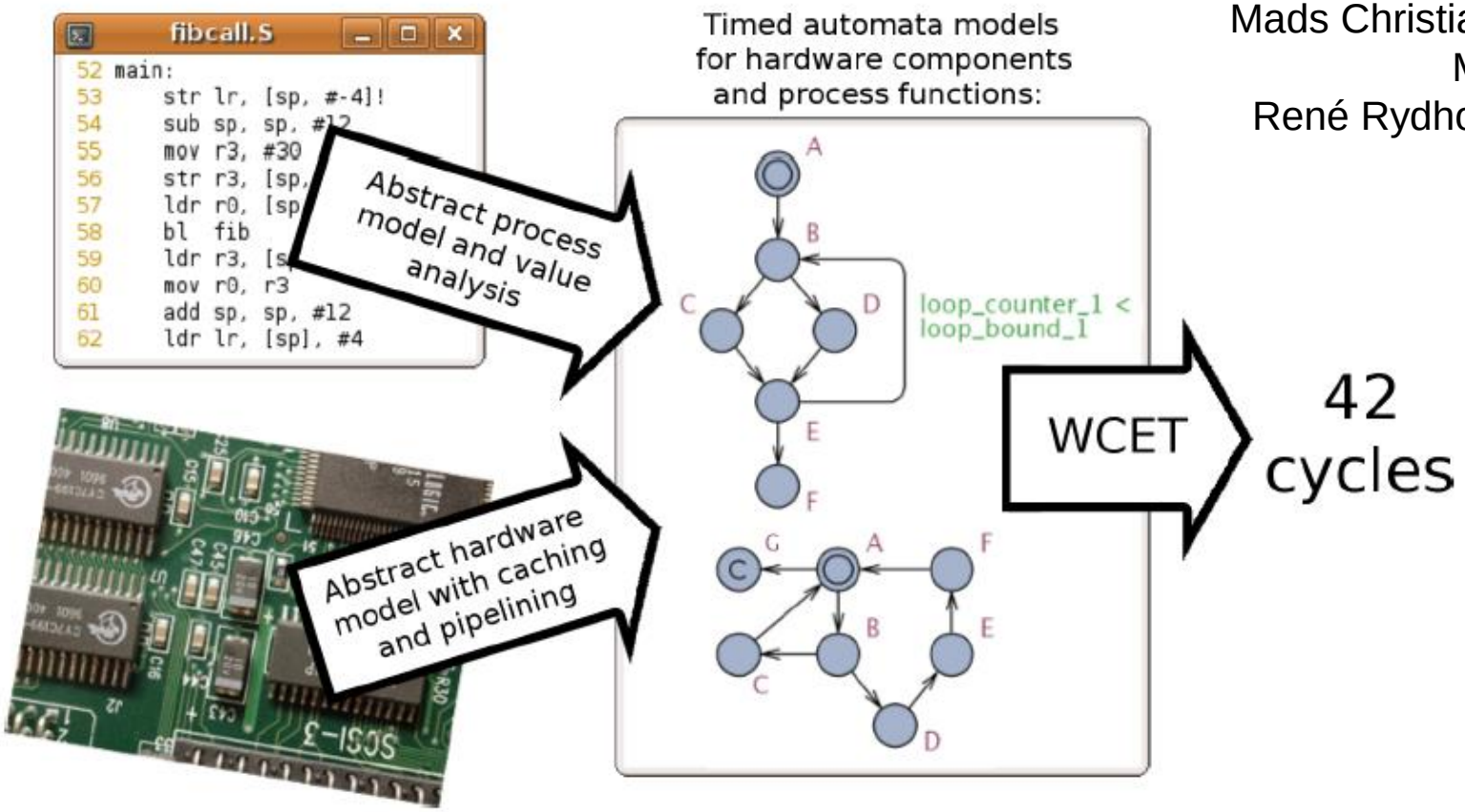
Herschel-Planck Scientific Mission at ESA

Attitude and Orbit Control Software
TERMA A/S Steen Ulrik Palm, Jan Storbank Pedersen, Poul Hougaard

METAMOC

Modular Execution Time Analysis using MOdel Checking

with
Andreas Dalsgaard
Mads Christian Olesen
Martin Toft
René Rydhof Hansen



Controllers in UPPAAL

- Gearbox Controller [TACAS'98]
- Bang & Olufsen Power Controller [RTPS'99,FTRTFT'2k]
- SIDMAR Steel Production Plant [RTCSA'99, DSVV'2k]
- Real-Time RCX Control-Programs [ECRTS'2k]
- Terma, Verification of Memory Management for Radar (2001)
- Scheduling Lacquer Production (2005)
- Memory Arbiter Synthesis and Verification for a Radar Memory Interface Card [NJC'05]
- Adapting the UPPAAL Model of a Distributed Lift System, 2007
- Analyzing a χ model of a turntable system using Spin, CADP and Uppaal, 2006
- Designing, Modelling and Verifying a Container Terminal System Using UPPAAL, 2008
- Model-based system analysis using Chi and Uppaal: An industrial case study, 2008
- Climate Controller for Pig Stables, 2008
- Optimal and Robust Controller for Hydralic Pump, 2009

(Wireless) Protocols in UPPAAL

- Bang & Olufsen IR Link
- Philips Audio Protocol
- Collision-Avoidance Protocol
- Bounded Retransmission Protocol
- TDMA Protocol
- Multimedia Streams
- ATM ABR Protocol
- Lamport's Leader Election Protocol
- ABB Fieldbus Protocol
- IEEE 1394 Firewire Root Contention
- Bluetooth Protocol
- Distributed Agreement Protocol
- FlexRay
- CHESS MAC Protocol
- Proprietary WSN, Other Big Danish Company
- MESH Protocol (MAC & Routing), NEOCORTEC

UPPAAL as a Back-End

- Vooduu: verification of object-oriented designs using Uppaal, 2004
- Moby/RT: A Tool for Specification and Verification of Real-Time Systems, 2000
- Formalising the ARTS MPSOC Model in UPPAAL, 2007

- Timed automata translator for Uppaal to PVS
- Component-Based Design and Analysis of Embedded Systems with UPPAAL PORT, 2008
- Verification of COMDES-II Systems Using UPPAAL with Model Transformation, 2008
- METAMOC: Modular WCET Analysis Using UPPAAL, 2010.

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RELATED TOOLS: TIMES | Stratego | CORA | TRON | TIGA | SMC | COVER | PORT | PRO

UPPAAL
Home

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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.

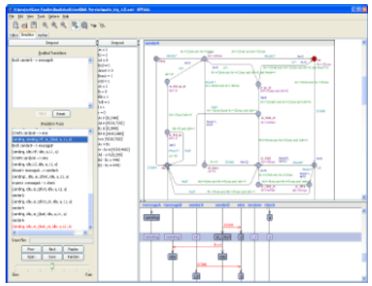


Figure 1: UPPAAL on screen.

Download

News: The current official release is UPPAAL 4.0.13 (Sep 27, 2010). Compared to version 3, the 4.0 release is the result of over 2.5 years of additional development, and many new features and improvements are introduced (see also this release note and the web help section new features). To support models created in previous versions of UPPAAL, version 4.0 can convert most old models directly from the GUI (alternatively it can be run in 3.4 compatibility mode by defining the environment variable UPPAAL_OLD_SYNTAX, see also item 2 of the FAQ).

Since Feb 26 2008, we also distribute development snapshots of the tool. The current version is

License

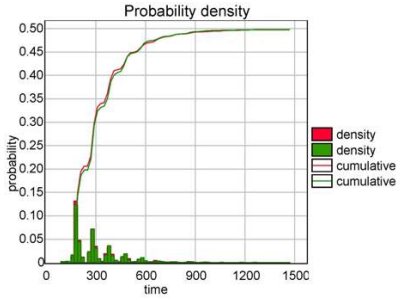
The UPPAAL tool is free for non-commercial applications in academia **only**. For commercial applications a commercial license is required. Please see the Download section or www.uppaal.com for more information.

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.

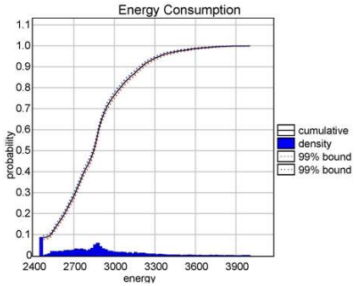
Mailing Lists

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

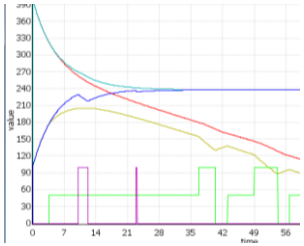
More Applications



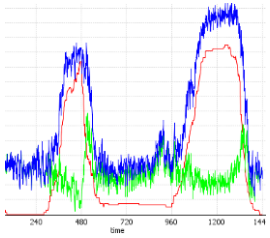
FIREWIRE



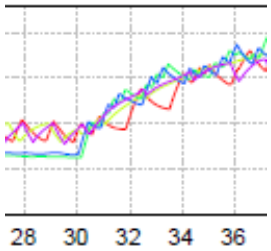
BLUETOOTH



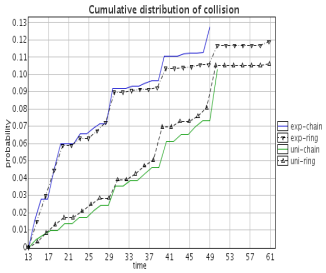
Battery Scheduling

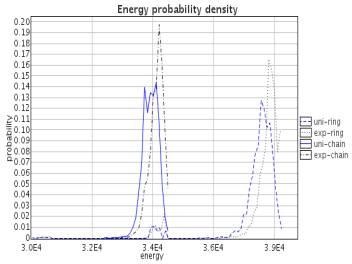


Smart Grid

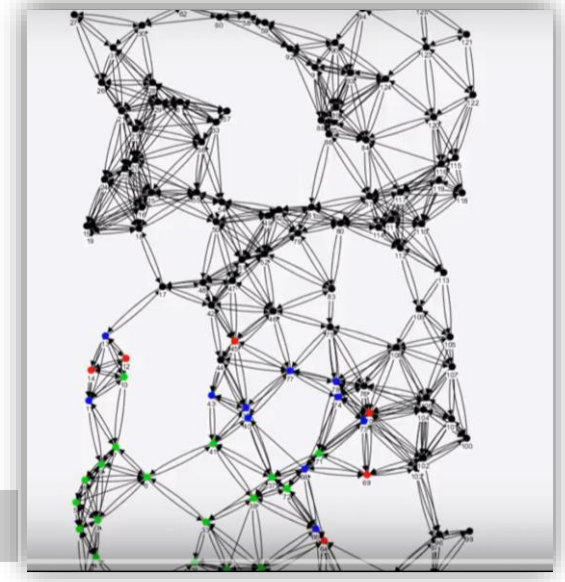


Energy Aware Buildings

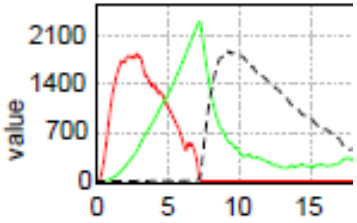




10 node LMAC



Mesh Network



Genetic Oscilator