Planning
via
Model Checking

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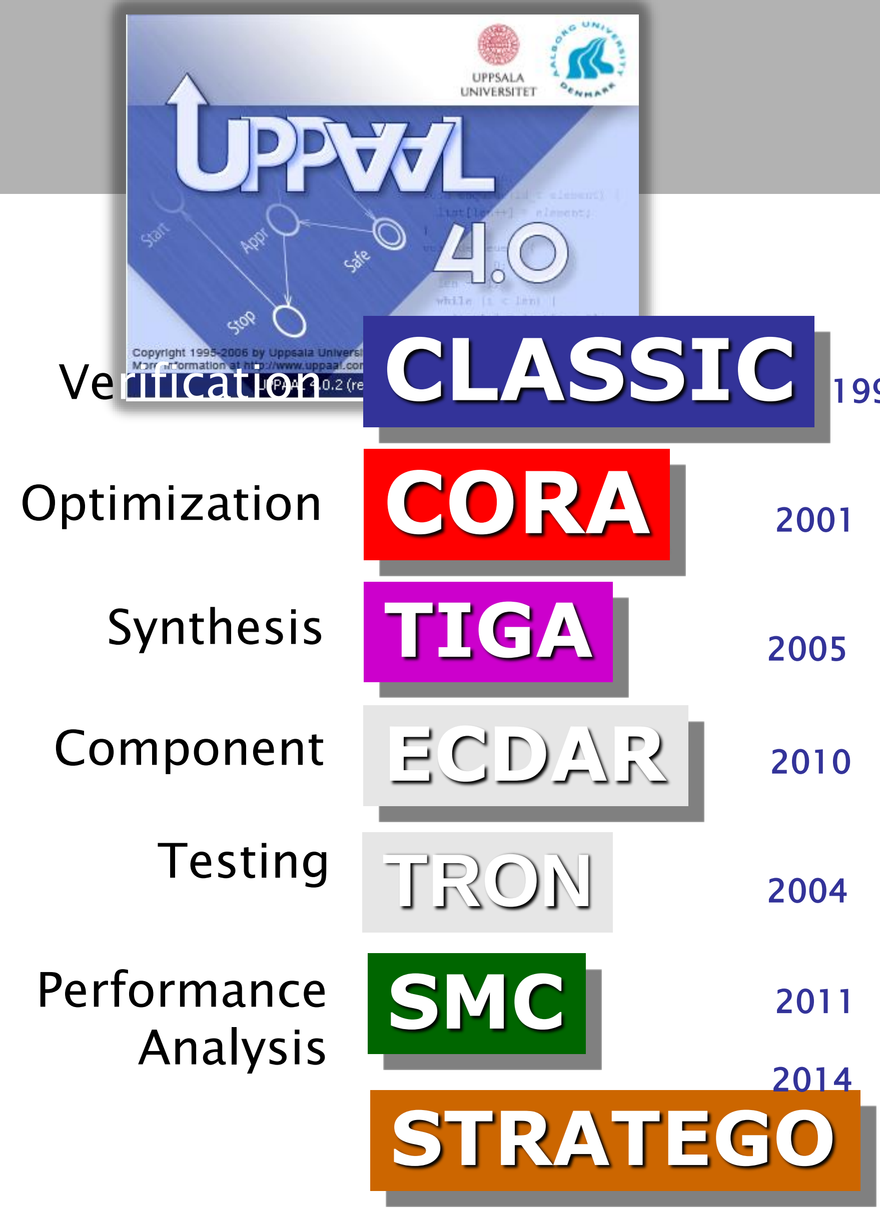
“Plan”

- Timed Automata
  - Model Checking
  - Time-optimal Planning
  - Zones
- Priced Timed Automata
  - Cost-optimal Planning
  - Priced Zones A*
- Timed Games
  - Dynamic Planning
  - Strategies, Zones
- Stochastic Timed Automata
  - Performance Analysis
  - Statistical Model Checking
- Stochastic Priced Timed Games
  - Expected Cost Optimal Adaptive Planning
  - Strategies
  - Reinforcement Learning
- Applications



Applications

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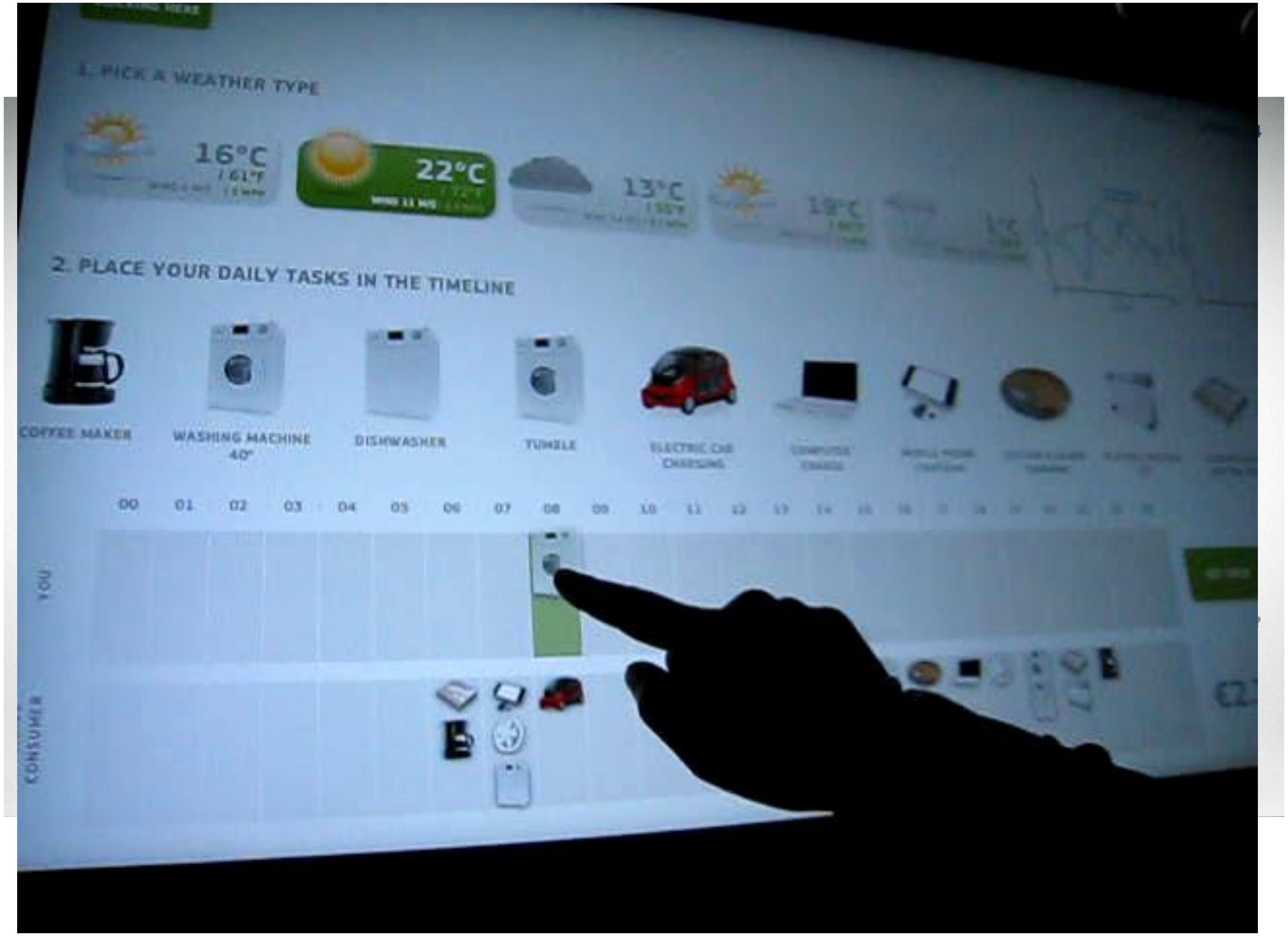
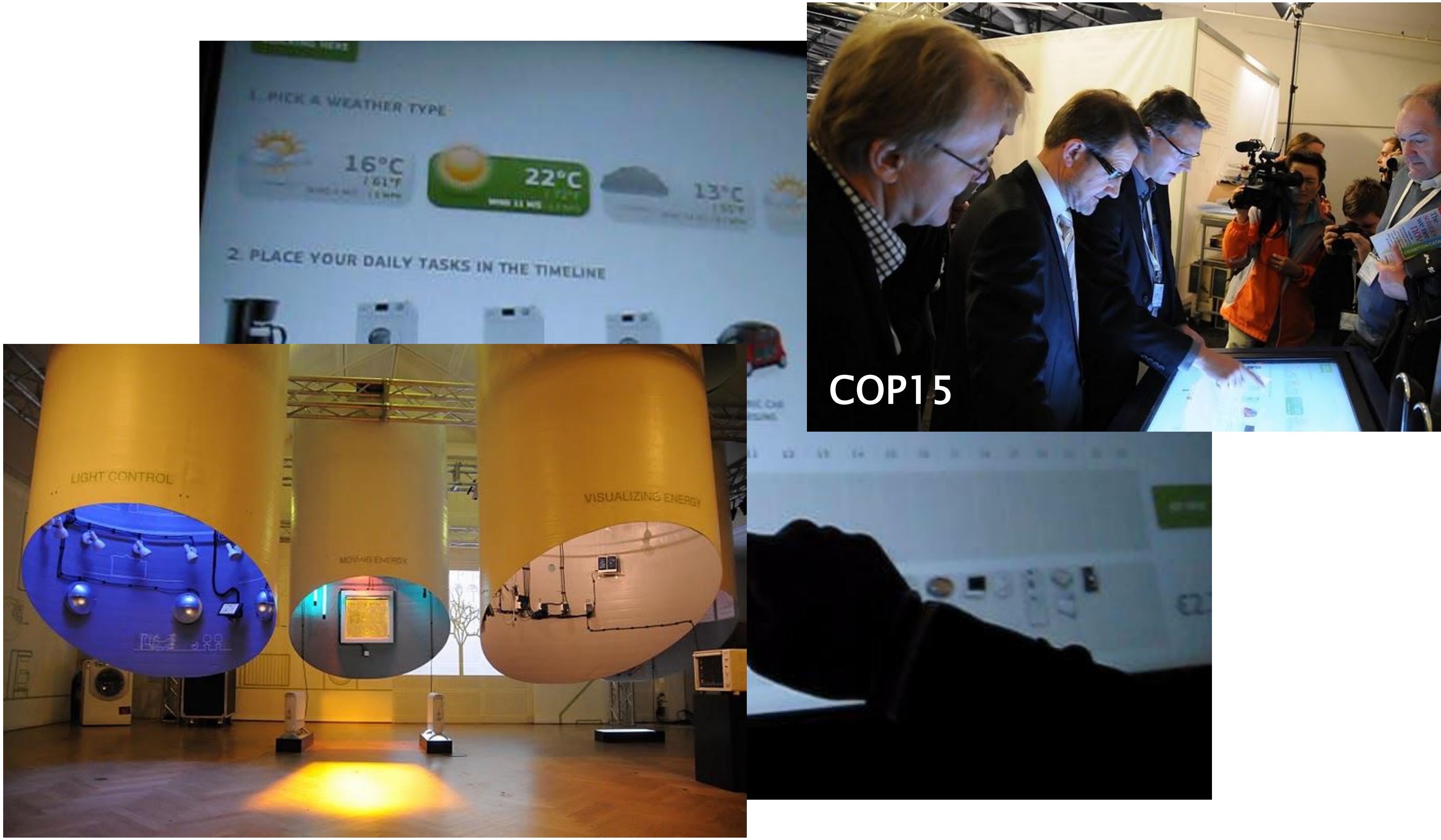
"Experimental" Results



"Experimental" Results

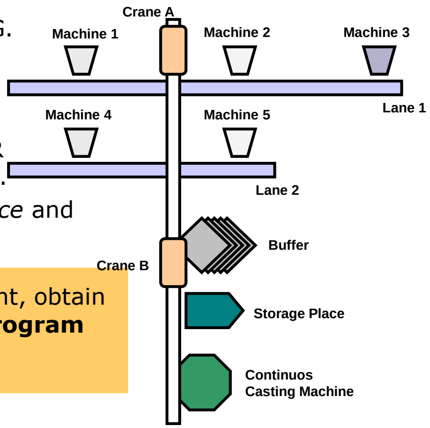


SIDMAR Production (2002) VHS

Steel Production Plant

- A. Fehnker, T. Hune, K. G. Larsen, P. Pettersson
- Case study of Esprit-LTR project 26270 VHS
- Physical plant of SIDMAR located in Gent, Belgium.
- Part between *blast furnace* and *hot rolling mill*.

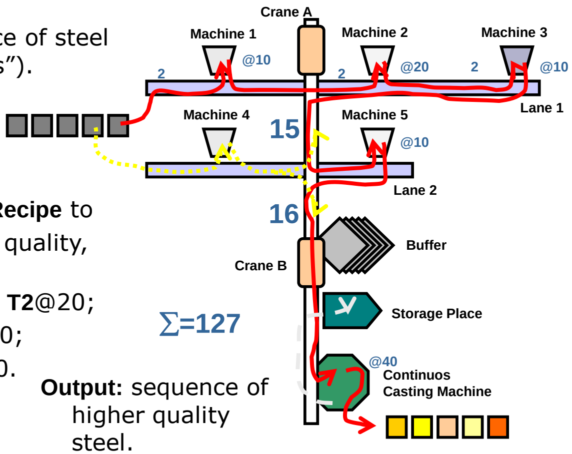
Objective: model the plant, obtain **schedule** and control **program** for plant.



Steel Production Plant

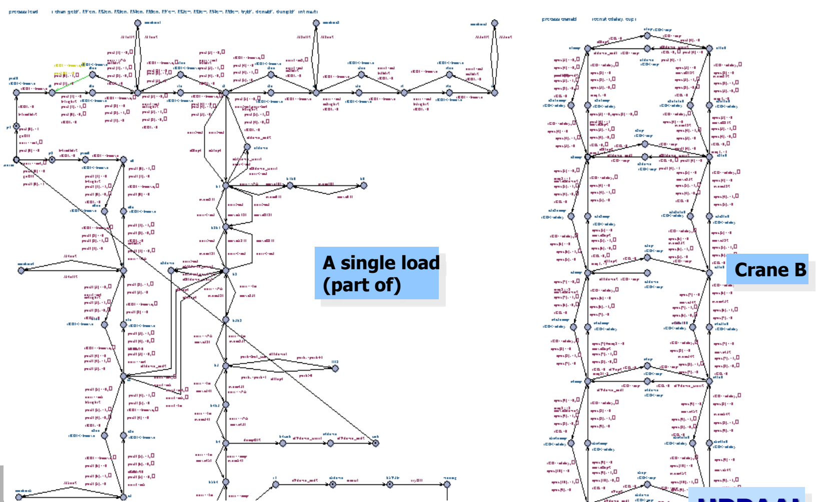
Input: sequence of steel loads ("pigs").

Load follows **Recipe** to obtain certain quality, e.g:
start; **T1**@10; **T2**@20; **T3**@10; **T2**@10; end within 120.



$\sum$=127

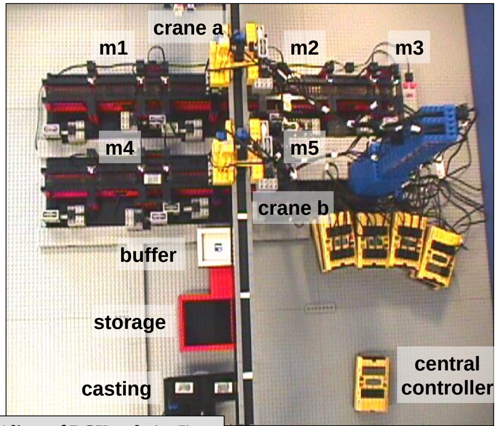
Output: sequence of higher quality steel.



UCb

Controller Synthesis for LEGO Model

- LEGO RCX Mindstorms.
- Local controllers with control programs.
- IR protocol for remote invocation of programs.
- Central controller.



1971 lines of RCX code (n=5),
24860 - " - (n=60).

Synthesis

UCb

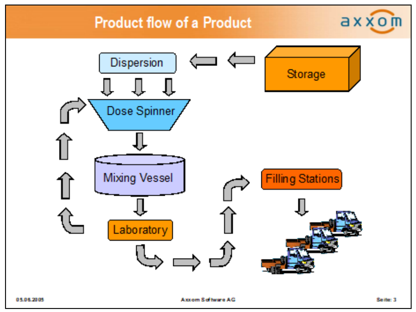
AXXOM Case Study (2005)

ARTEMIS

AXXOM Case study

Laquer Production Scheduling

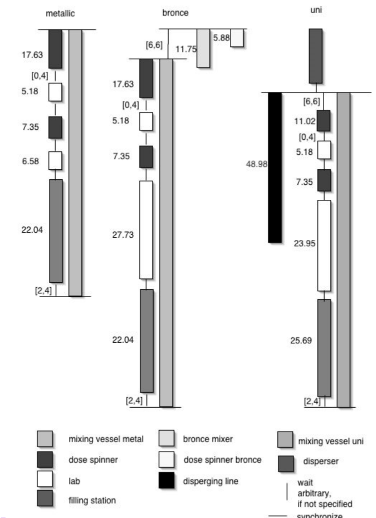
- 3 types of recipes
  - for uni/metallic/bronce
  - use of resources, processing times, timing
- 29 (73, 219) orders:
  - start time, due date, recipe
- extensions:
  - delay cost, storage cost, setup cost
  - weekend, nights



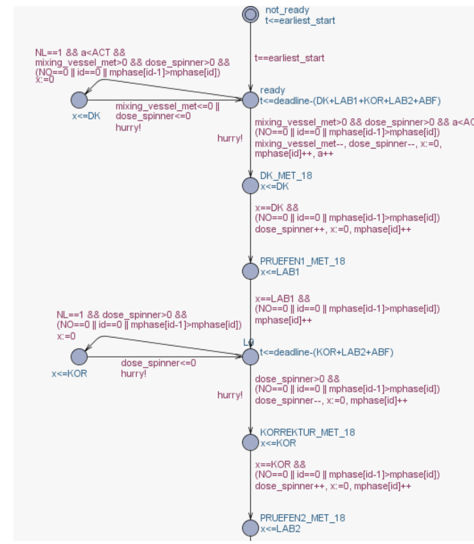
Behrmann, Brinksma, Hendriks, Mader
16th IFAC World Congress

UCb

Recipes



UPPAAL template for metal



UCb

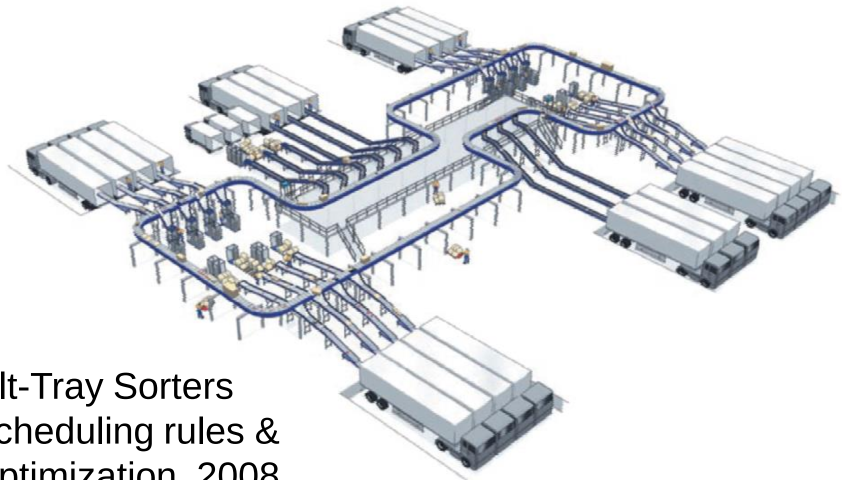
Results Extended Case

#jobs	work hrs	[illegible]	[illegible]istic	max orde[illegible]	cost
29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
29	[illegible]	[illegible]	[illegible]	-	[illegible]4,8[illegible]
[illegible]	[illegible]	[illegible]	6,[illegible]	-	2,263,496
[illegible]	[illegible]	[illegible]	no	4	192,881,129

Competitive with Orion-pi results

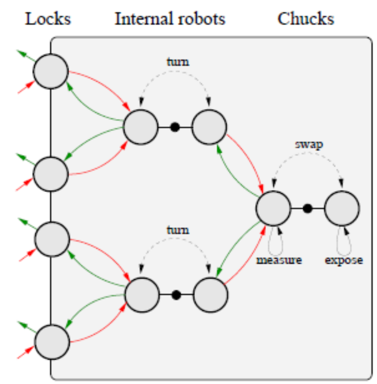
Orders of magnitude faster than MILP, GAMS/CPLEX

UCb



Tilt-Tray Sorters
Scheduling rules &
Optimization, 2008

Océ Datapath, 2012

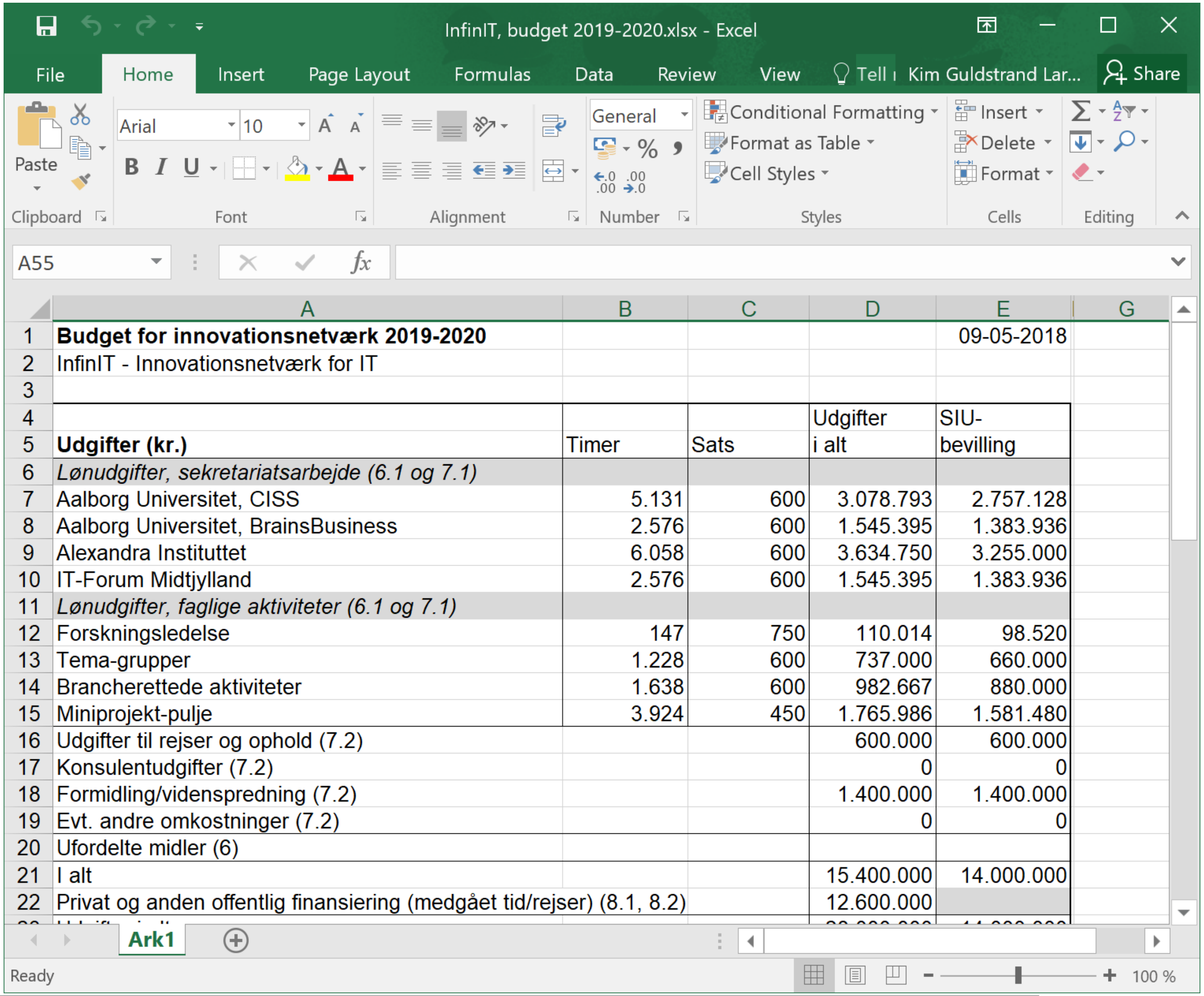


ASML, 2004:
Wafer Scanners
Optimization of
Throughput

Philips: Indoor Lighting systems, 2014

Within the Prisma project of TNO-ESI and Philips Lighting, research is done into the robustness and reliability of large-scale indoor lighting systems. The focus is on the robustness of the lighting control system. To analyse control system robustness, model checking is used. Timed automata models of lighting control systems have been created and checked with the model checker Uppaal. To validate

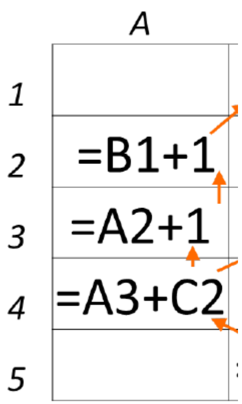
P3: Popular Parallel Programming



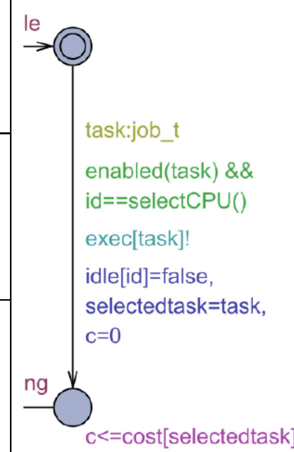
	A	B	C	D	E
1	**Budget for innovationsnetværk 2019-2020**				09-05-2018
2	InfinIT - Innovationsnetværk for IT				
3					
4				Udgifter	SIU-
5	**Udgifter (kr.)**	Timer	Sats	i alt	bevilling
6	*Lønudgifter, sekretariatsarbejde (6.1 og 7.1)*				
7	Aalborg Universitet, CISS	5.131	600	3.078.793	2.757.128
8	Aalborg Universitet, BrainsBusiness	2.576	600	1.545.395	1.383.936
9	Alexandra Instituttet	6.058	600	3.634.750	3.255.000
10	IT-Forum Midtjylland	2.576	600	1.545.395	1.383.936
11	*Lønudgifter, faglige aktiviteter (6.1 og 7.1)*				
12	Forskningsledelse	147	750	110.014	98.520
13	Tema-grupper	1.228	600	737.000	660.000
14	Brancherettede aktiviteter	1.638	600	982.667	880.000
15	Miniprojekt-pulje	3.924	450	1.765.986	1.581.480
16	Udgifter til rejser og ophold (7.2)			600.000	600.000
17	Konsulentudgifter (7.2)			0	0
18	Formidling/videnspredning (7.2)			1.400.000	1.400.000
19	Evt. andre omkostninger (7.2)			0	0
20	Ufordelte midler (6)				
21	I alt			15.400.000	14.000.000
22	Privat og anden offentlig finansiering (medgået tid/rejser) (8.1, 8.2)			12.600.000	

P3: Popular Parallel Programming

DANMARKS FRIE FORSKNINGSFOND



Model	CPUs	Cost	Greedy	Time Sec.	Speedup %
Supportgraph 31 cells, 119 dependencies	2	7.047	6.959	42	-1.20
	4	4.884	4.981	45	1.95
	8	4.611	4.611	62	0.00
	16	4.611	4.611	59	0.00
Example 115 cells, 65 dependencies	2	24.890	25.411	1.627	2.05
	4	12.581	13.375	1.373	5.94
	8	6.484	6.993	2.202	7.28
	16	3.450	4.035	199	14.50
Formulacopies 73 cells, 255 dependencies	2	16.051	16.087	253	0,09
	4	8.522	8.181	10	-4,17
	8	4.650	4.307	216	-7,96
	16	3.900	3.982	683	2,06

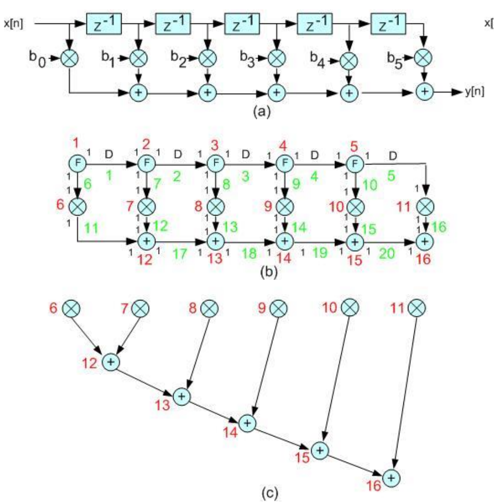


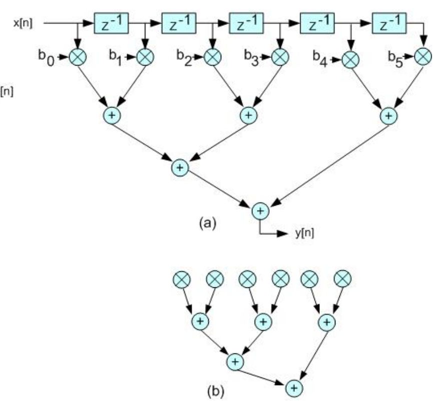
Analyzing spreadsheets for parallel execution via model checking.
Thomas Bgholm, Kim G. Larsen, Marco Muniz, Bent Thomsen, Lone Leth Thomsen
2018

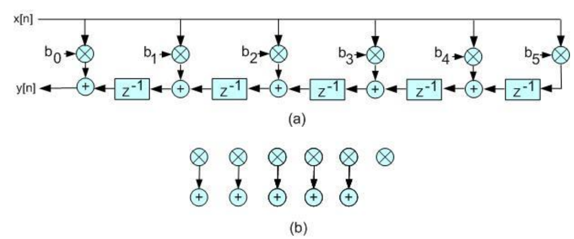
FIR Filter Structures

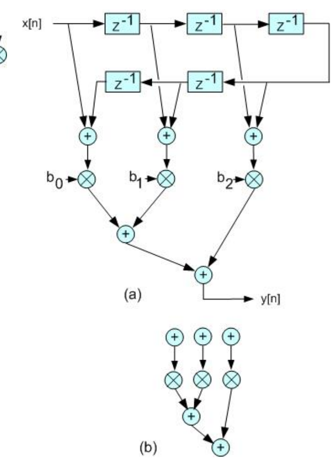
- Transversal w/Adder Chain
- Transversal w/Adder Tree
- Transposed
- Symmetric

Peter Koch
Erik Wognsen



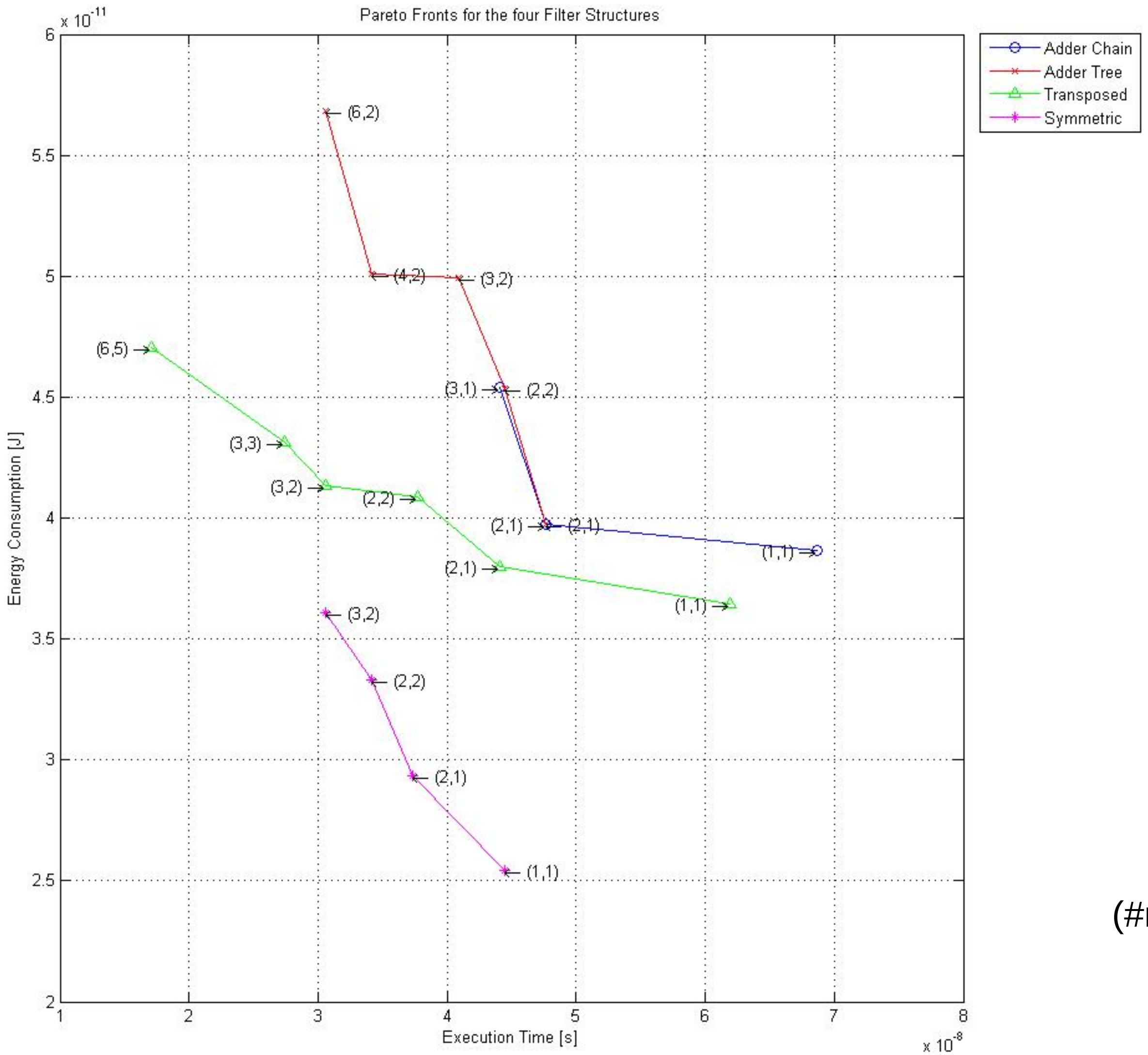






Design Space Exploration

Peter Koch
Erik Wognsen

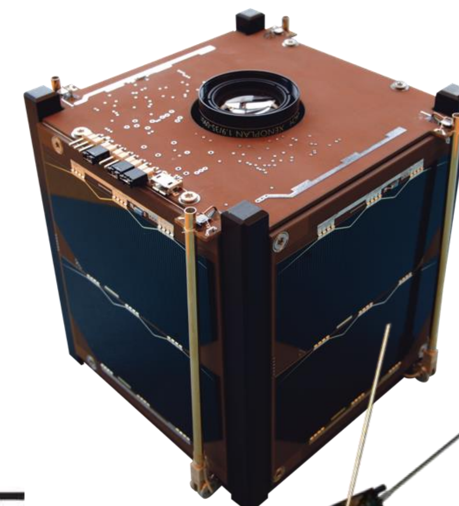


(#multipliers, #adders)

Nano Satellites

SENSATION

- **First wave:**
  Launch something into space
  - AAU Student Satelites
- **Second wave:**
  Exploit new opportunities
  - Small, non-critical, science missions
- **Third wave:**
  Mission critical services
  - Monitoring & com for national security needs
  - Commercial applications
  - Ambitious science missions

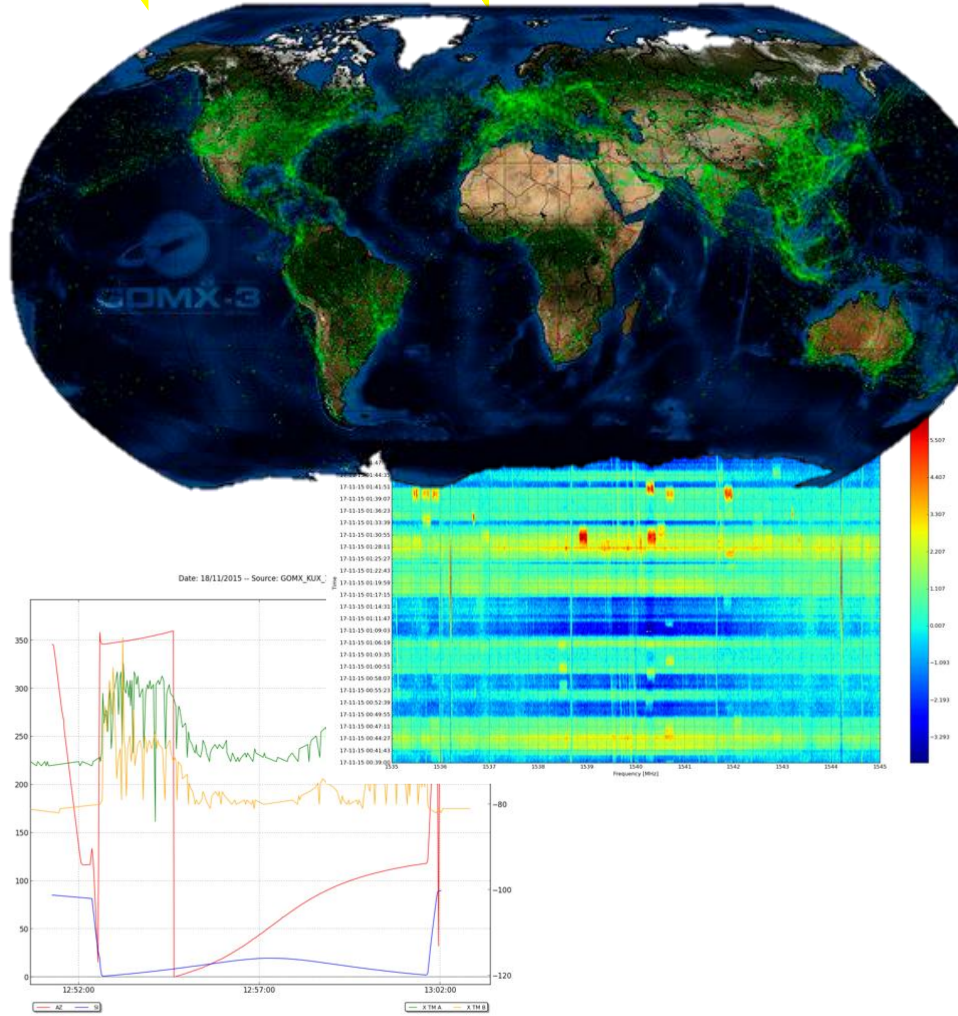


GOMSPACE

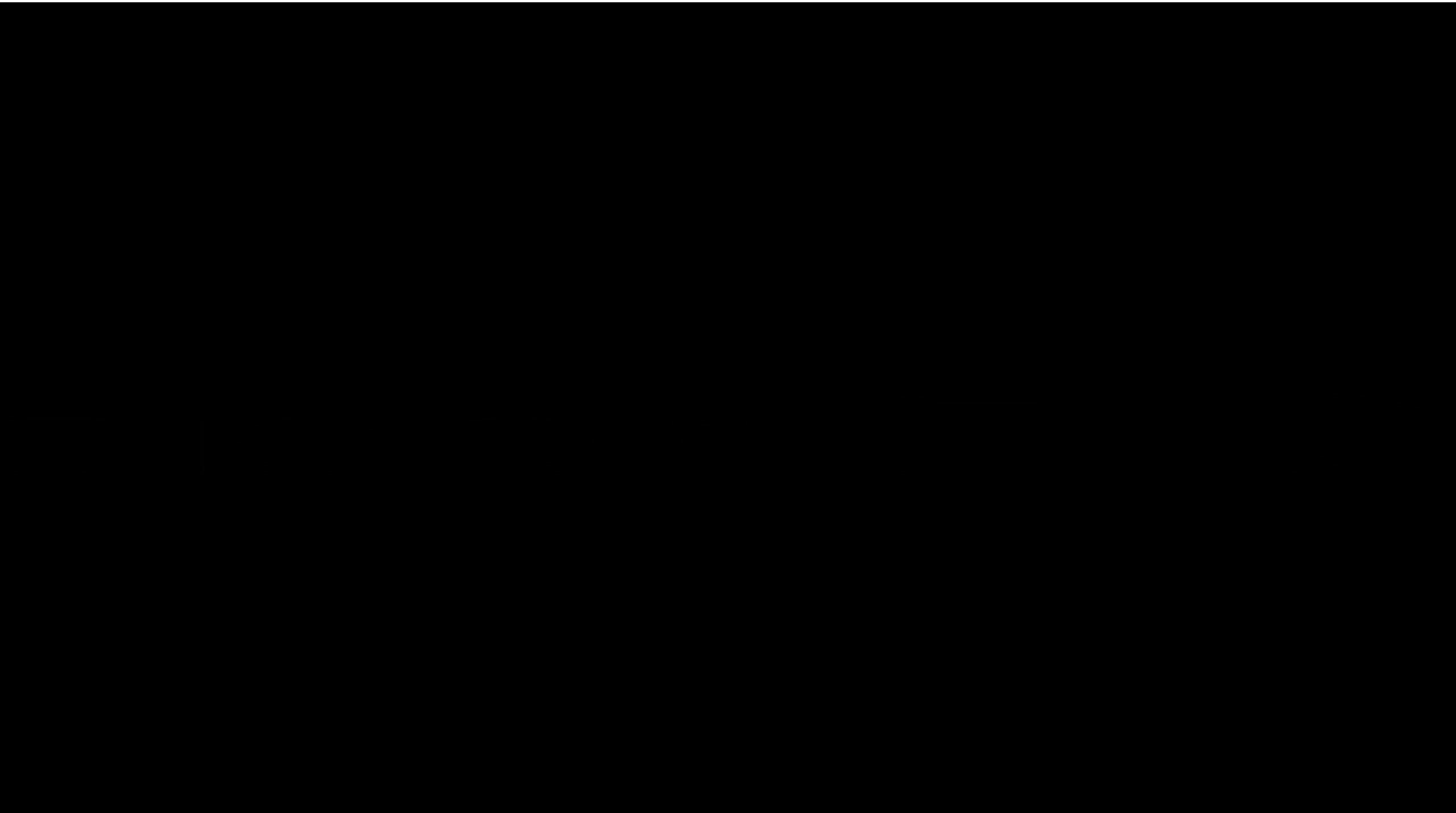
GOMX-3

SENSATION

- ADS-B receiver
  - Airplane tracking
- UHF transceiver
  - Groundstation up/down link
- SOFT Lband receiver
  - Geostationary satellite tracking
- Xband Downlink for ESA
  - Test to Kourou and Toulouse
- Tight power budget



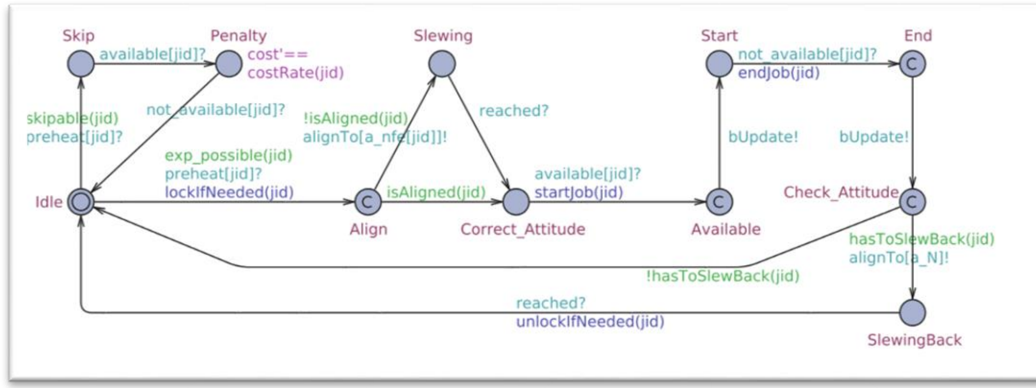
GOMX-3 Deployment



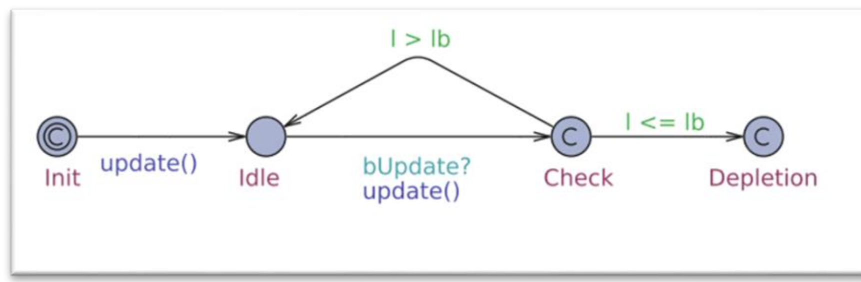
Planning GOMX-3

SENSATION

- Orbit can be accurately predicted (and modelled)
- Priced TA for
  - Experiments
    - Positioning, preheating, powering actual device
  - Battery
  - Environment
- Generate optimal schedule for 1 week using **UPPAAL CORA**



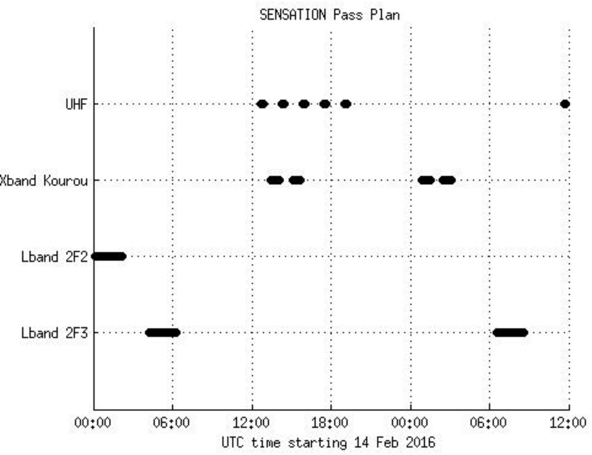
Job Instance

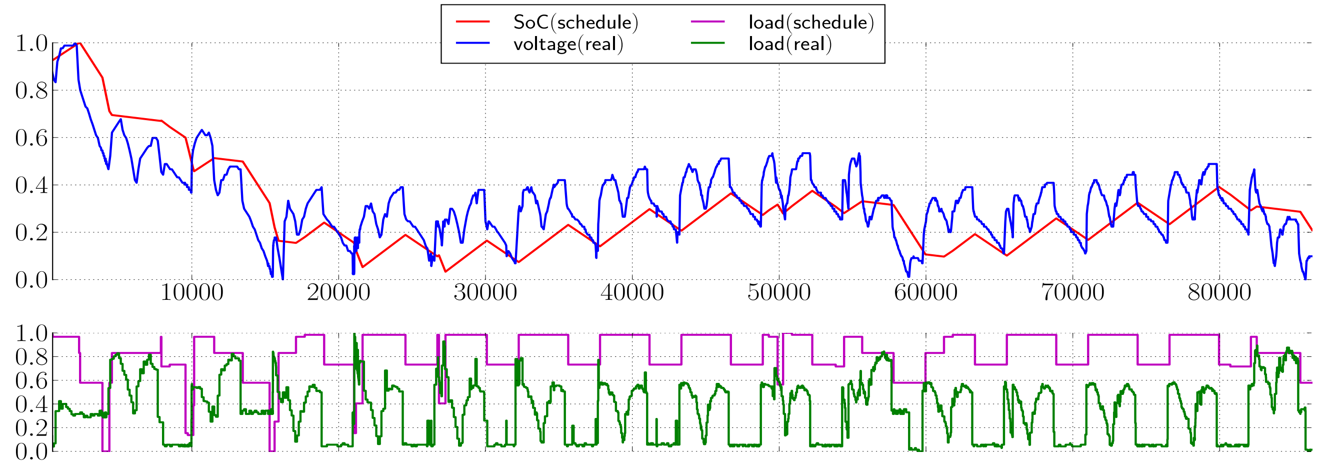


Battery

[Bisgaard, Gerhardt, Hermanns, Krcál, Nies, Stenger FM16]

[... Havercort, Jongerden, Larsen, Wognsen, International Astronautical Federation 16]


SENSATION Pass Plan
UHF
Xband Kourou
Lband 2F2
Lband 2F3
00:00
06:00
12:00
18:00
00:00
06:00
12:00
UTC time starting 14 Feb 2016


SoC(schedule)
voltage(real)
load(schedule)
load(real)
1.0
0.8
0.6
0.4
0.2
0.0
10000
20000
30000
40000
50000
60000
70000
80000

Timed Games
Optimal Dynamic Planning

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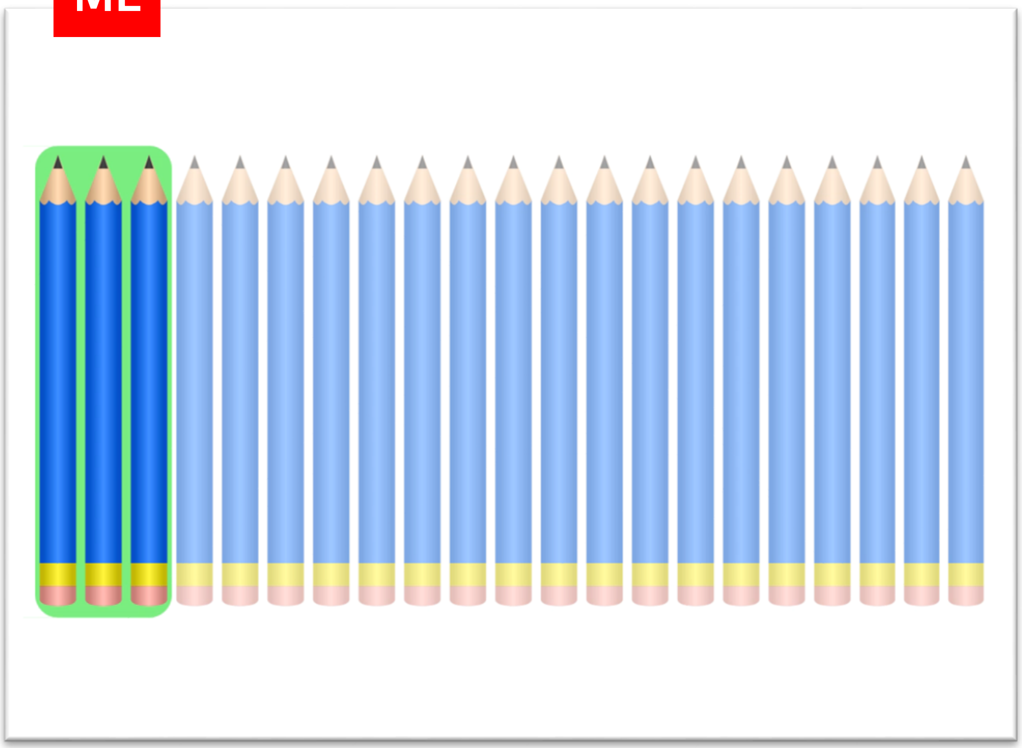
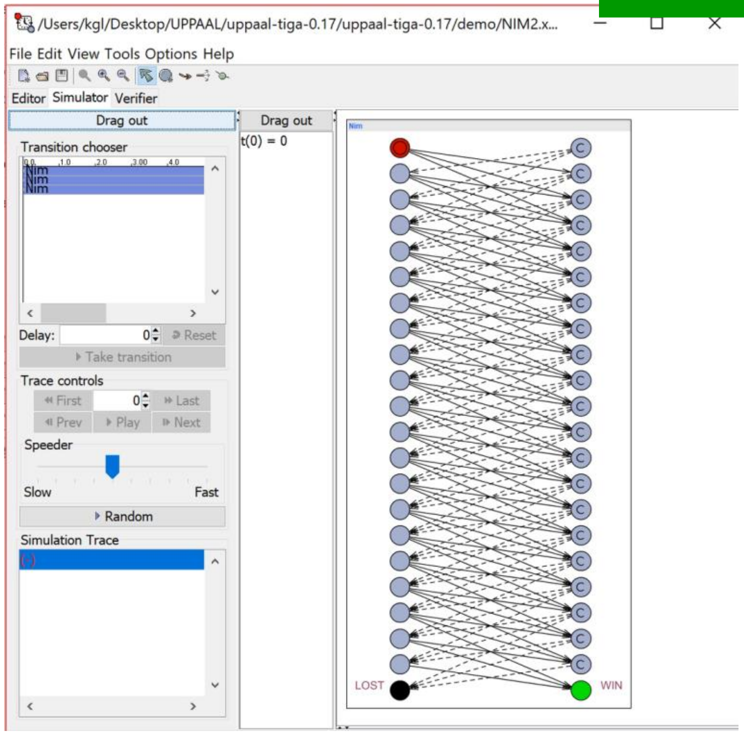
Playing Games – Nim

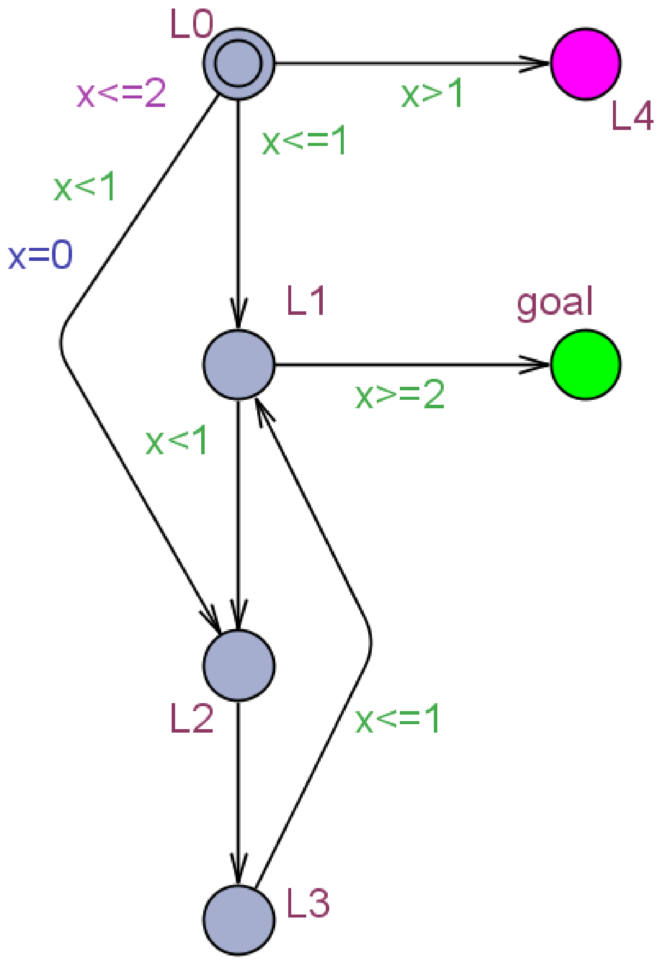
ME



UPPAAL



Timed Automata & Model Checking



State (L1, x=0.81)

Transitions

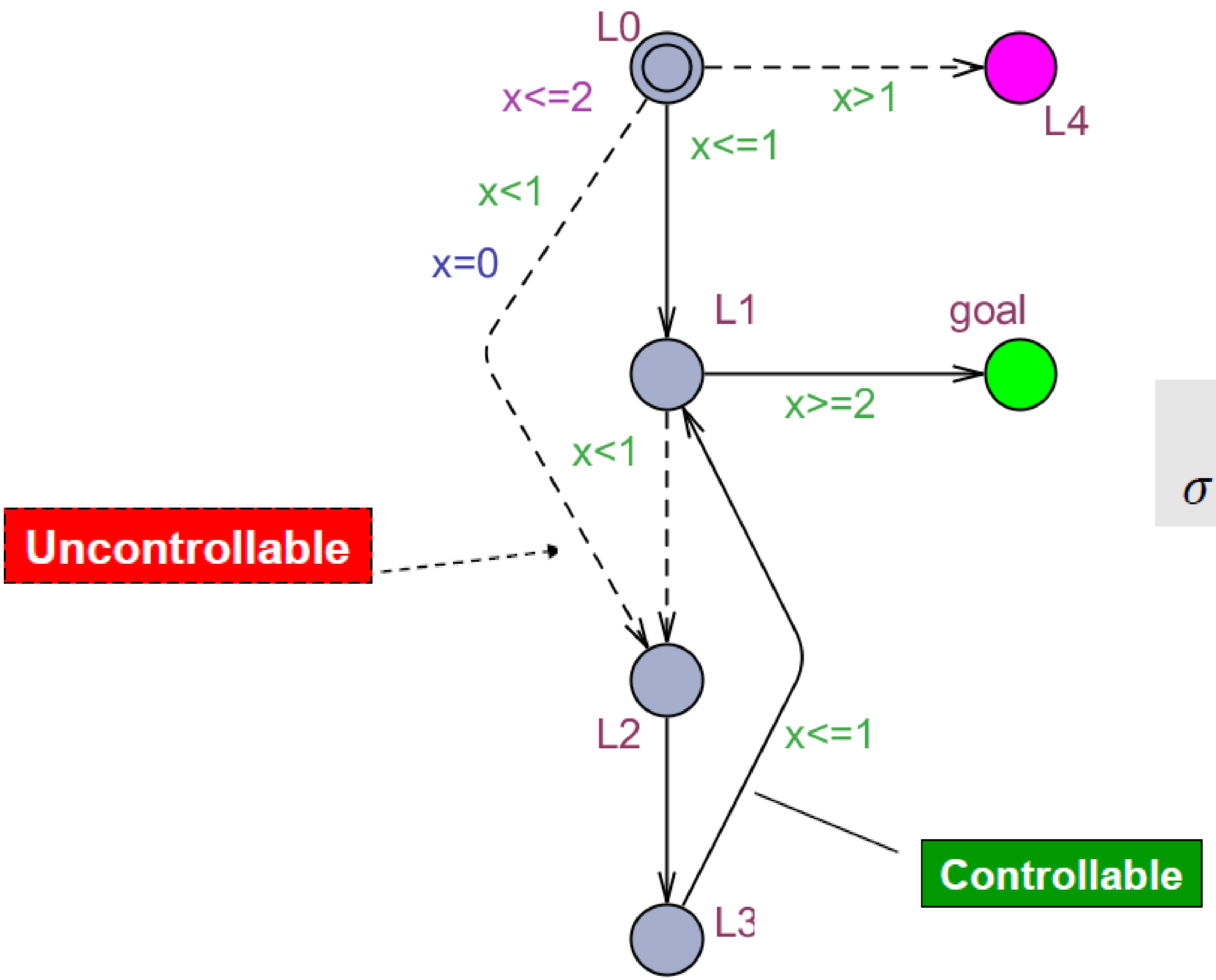
(L1 , x=0.81)
 – 2.1 ->
(L1 , x=2.91)
 ->
(goal , x=2.91)

E⟨⟩ goal ?

A⟨⟩ goal ?

A[ ] ¬ L4 ?

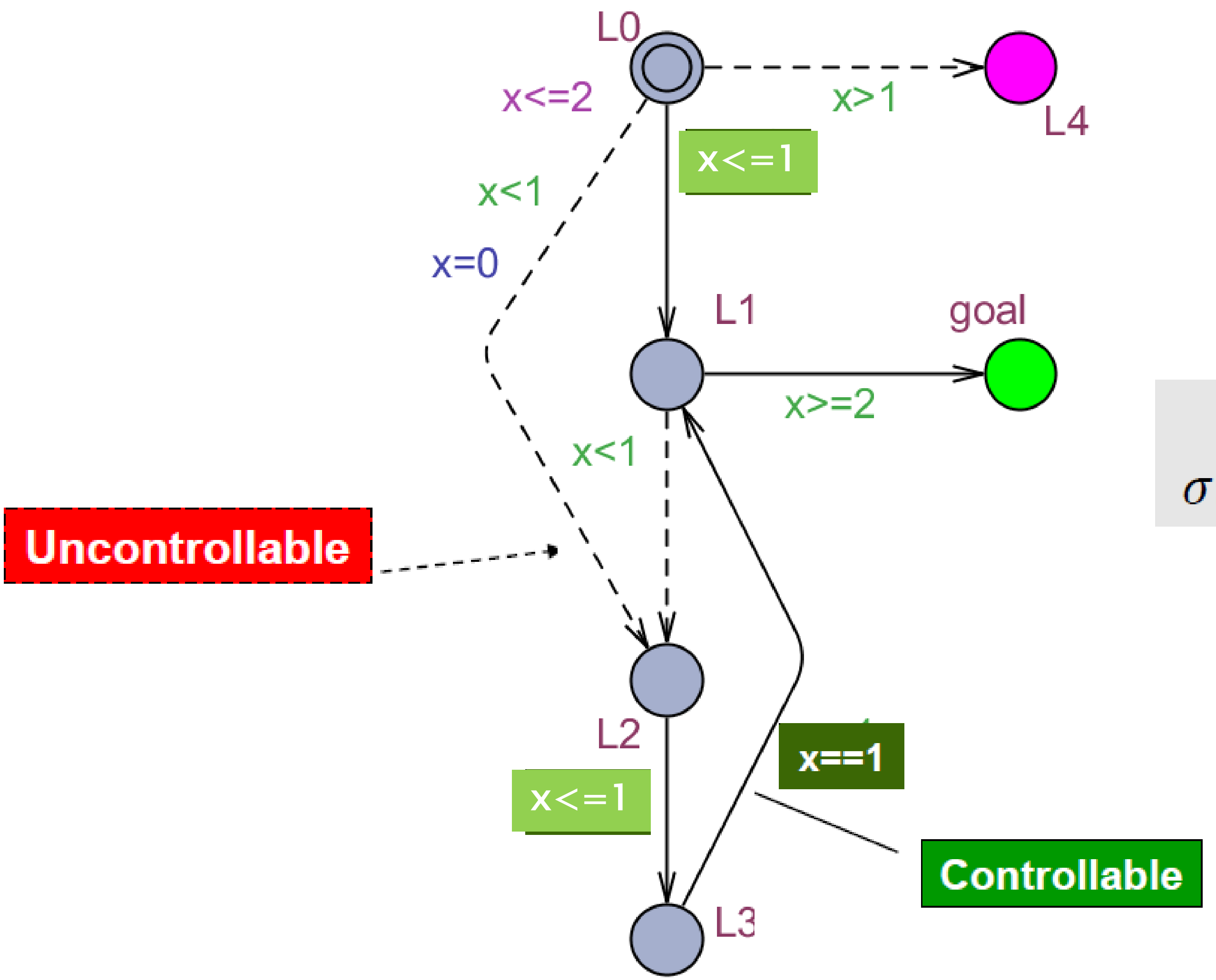
Timed Game



Question
Does their exist a **strategy** that guarantees
A<> Goal ?

Strategy:
$\sigma: (\ell, v) \mapsto \{\lambda, c_{act}\}$

Timed Game & Synthesis



Question
Does their exist a **strategy** that guarantees
A<> Goal ?

Strategy:
$\sigma: (\ell, v) \mapsto \{\lambda, c_{act}\}$

Decidability of Timed Games

Theorem [AMPS98,HK99]

Reachability and safety timed games are decidable and EXPTIME-complete. Furthermore memoryless and "region-based" strategies are sufficient.

$\rightsquigarrow$ classical regions are sufficient for solving such problems

Theorem [AM99,BHPR07,JT07]

Optimal-time reachability timed games are decidable and EXPTIME-complete.

[AM99] Asarin, Maler. As soon as possible: time optimal control for timed automata *(HSCC'99)*.
[BHPR07] Brihaye, Henzinger, Prabhu, Raskin. Minimum-time reachability in timed games *(ICALP'07)*.
[JT07] Jurdziński, Trivedi. Reachability-time games on timed automata *(ICALP'07)*.

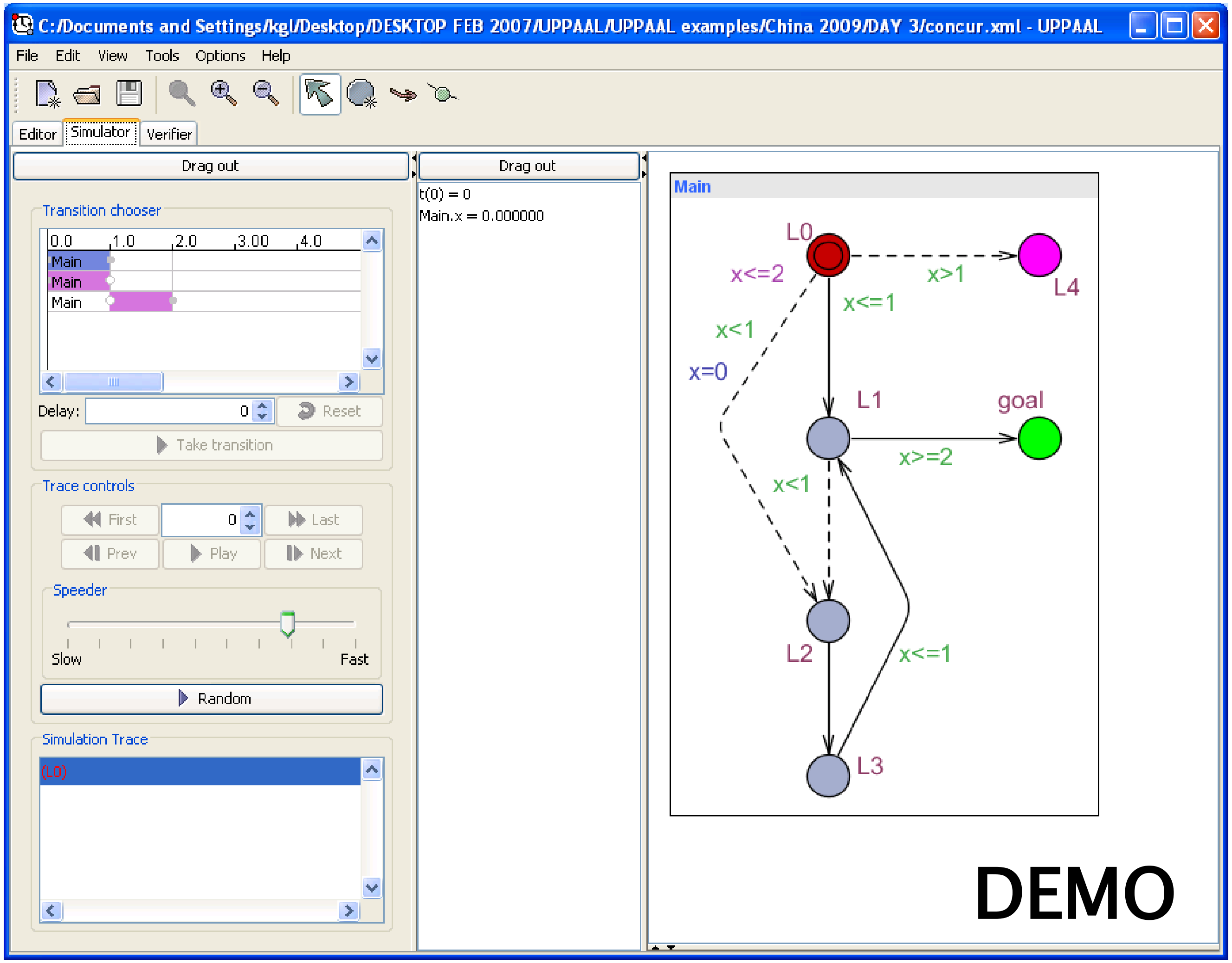
UPPAAL Tiga [CDF+05, BCD+07]

- Reachability properties:
  - control: A[p U q] *until*
  - control: A⟨⟩ q ⇔ control: A[true U q]
- Safety properties:
  - control: A[p W q] *weak until*
  - control: A[] p ⇔ control: A[p W false]
- Time-optimality :
  - control_t*(u,g): A[p U q]
    - u is an upper-bound to prune the search
    - g is the time to the goal from the current state

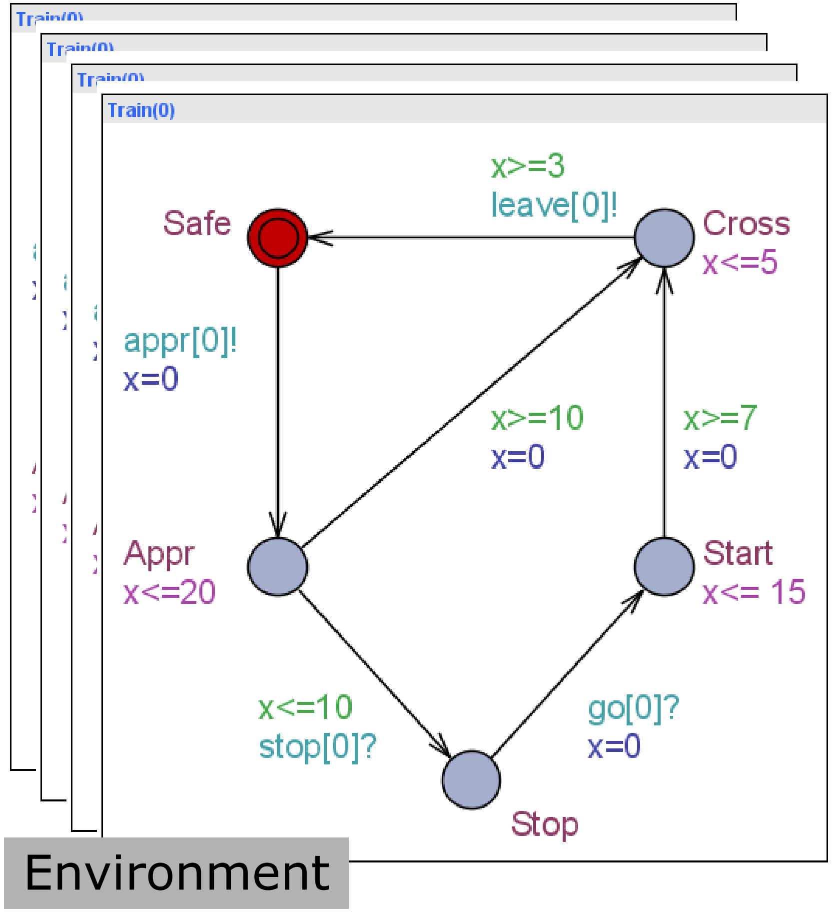
[CDF+05] Cassez, David, Fleury, Larsen, Lime. Efficient on-the-fly algorithms for the analysis of timed games *(CONCUR'05)*.
[BCD+07] Berhmann, Cougnard, David, Fleury, Larsen, Lime. Uppaal-Tiga: Time for playing games! *(CAV'07)*.

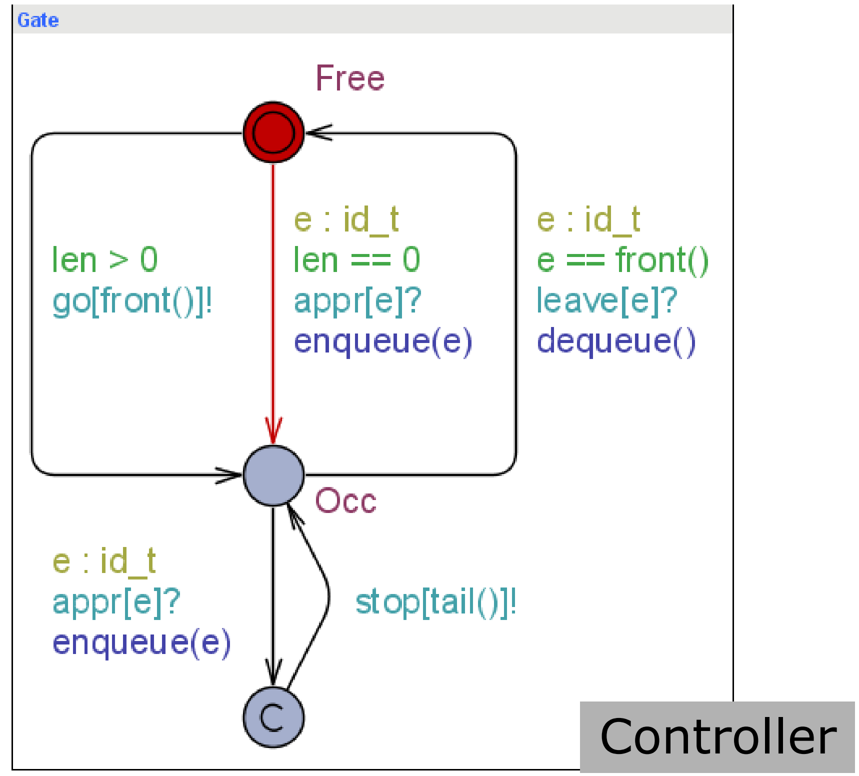
UPPAAL Tiga

Uppaal-tiga-0.17/concur015



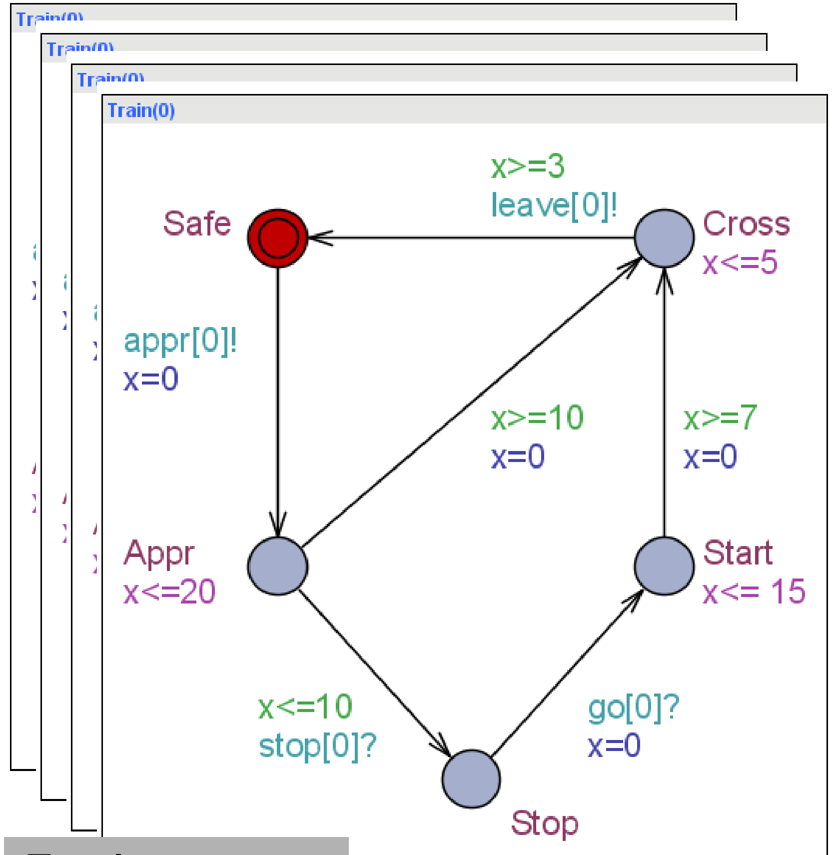
Model Checking (ex Train Gate)



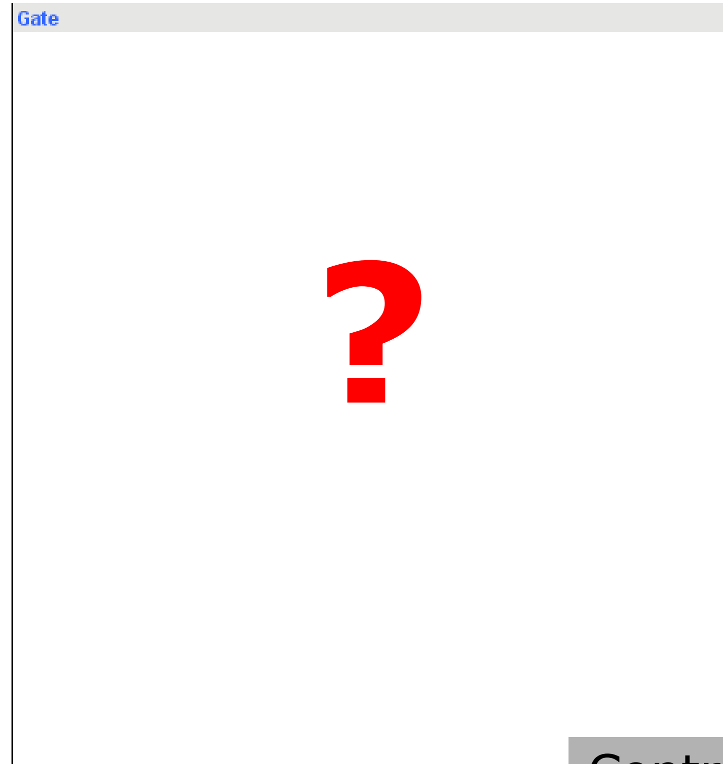


ϕ: Never two trains at the crossing at the same time

Synthesis (ex Train Gate)



Environment



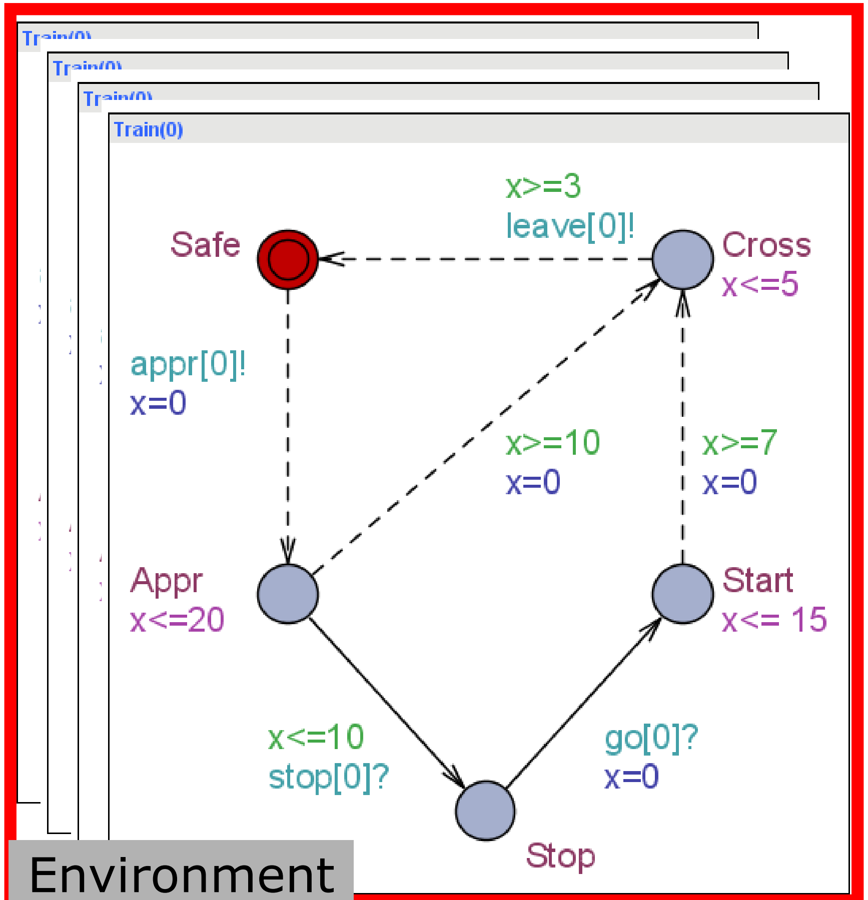
Controller

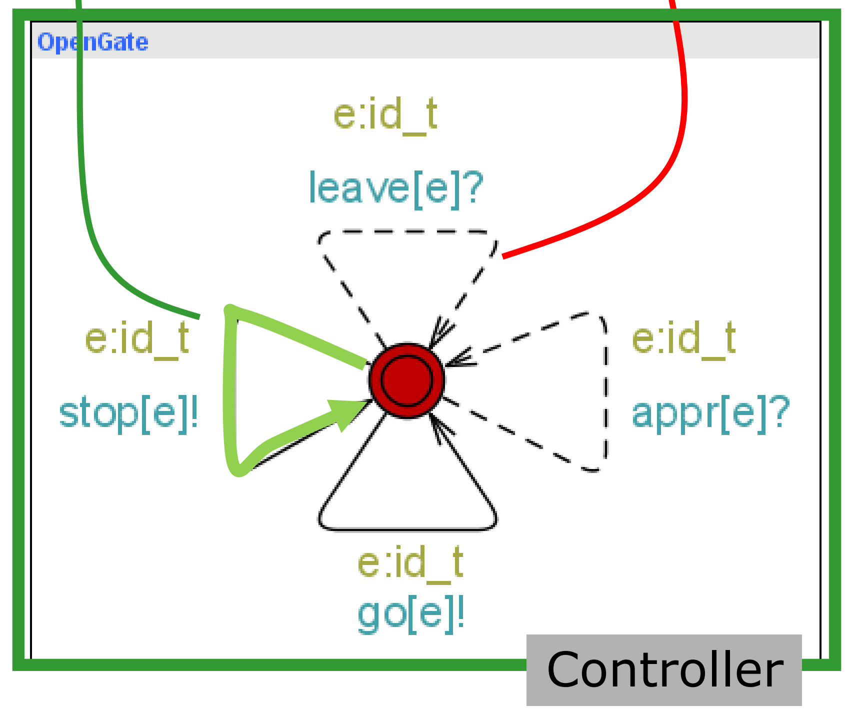
ϕ: Never two trains at the crossing at the same time

Timed Games

Uppaal examples/marktoberdorf08/lecture 5

Controllable Uncontrollable

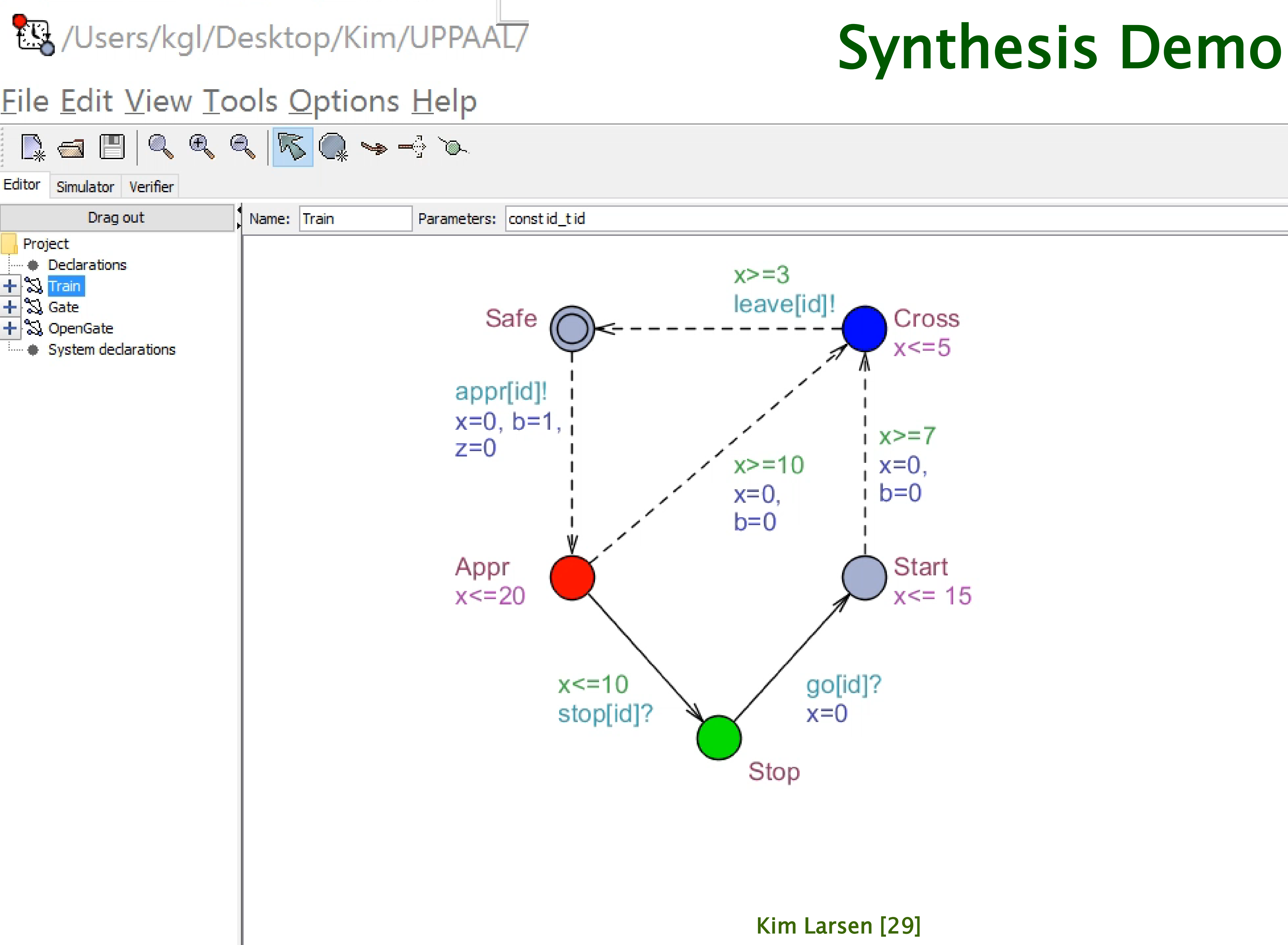




Find strategy for controllable actions st behaviour satisfies ϕ

ϕ: Never two trains at the crossing at the same time

Synthesis Demo

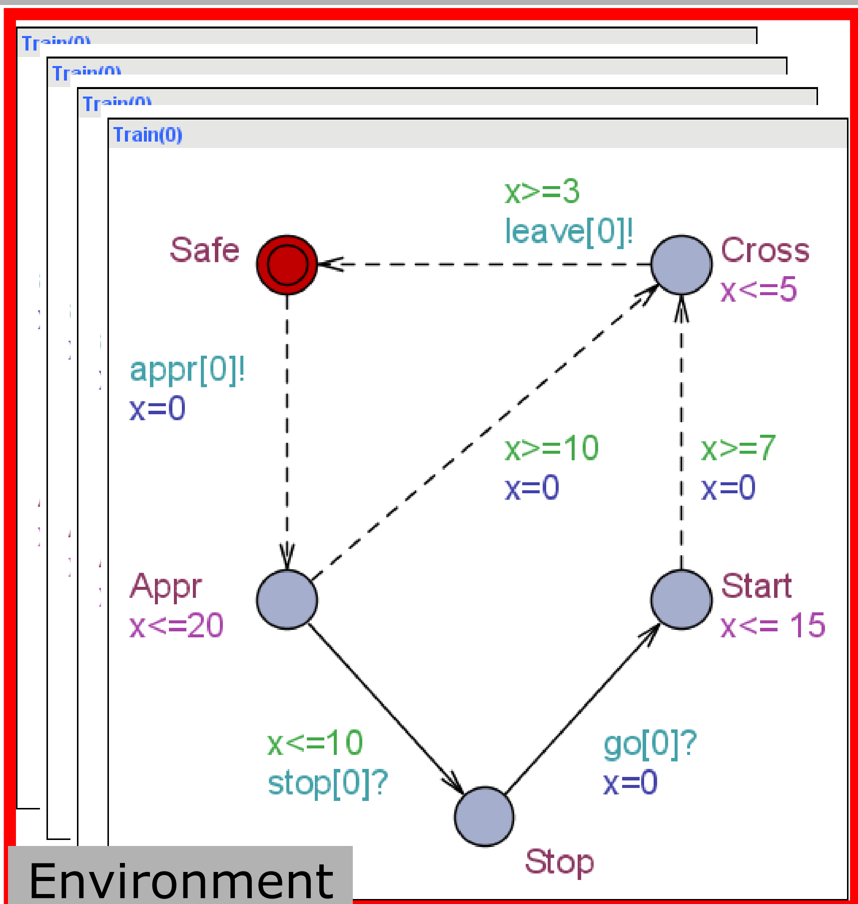


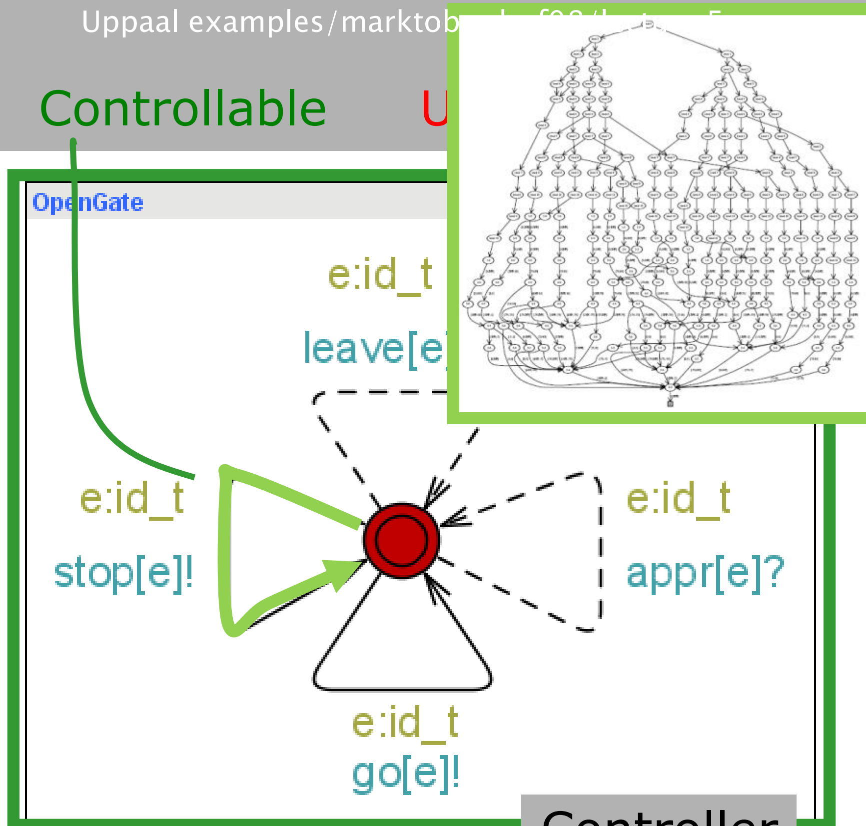
Kim Larsen [29]

Timed Games

Uppaal examples/marktob

Controllable U





Find strategy for controllable actions st behaviour satisfies ϕ

ϕ: Never two trains at the crossing at the same time

Exercises

Model Checking (optional)

- Exercise 2 (Coffee Machine)
- Excercise 19 (Train Crossing)

Planning (mandatory)

- Exercise 28 (Jobshop Scheduling)
- Exercise 22 (Crossing River) OR
  Exercise 21 (Rush Hour) -- homework for Lecture 2.