Optimizing Control Strategy Using SMC

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What This Work is About

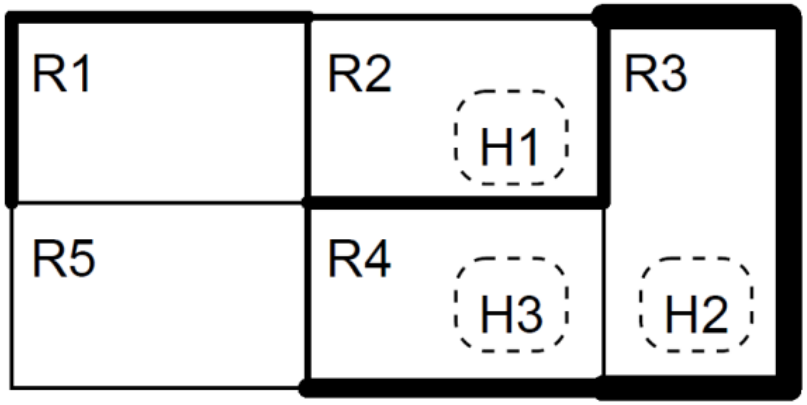
- Find optimal parameters for, e.g., a controller.
  - Applied to stochastic hybrid systems.
  - Suitable for different domains: biology, avionics…
- Technique: statistical model-checking.
  - This work: Apply ANOVA to reduce the number of needed simulations.

Overview

- Energy aware buildings
  - The case-study in a nutshell
- Choosing the parameters
  - Naïve approach
- Efficiently choosing the (best) parameters
  - ANOVA

Energy Aware Buildings

- The case:
  - Building with **rooms** separated by doors or walls.
  - Contact with the **environment** by windows or walls.
  - Few transportable **heat sources** between the rooms.
  - Objective: **maintain the temperature** within range.



(a) Rooms R_i with heaters H_k.

Energy Aware Buildings

- Model:
  - Matrix of coefficients for heat transfer between *rooms*.

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

  - Environment temperature → *weather* model.
  - Different controllers → *user* profiles.
- Goal:
  - ***Optimize the controller.***

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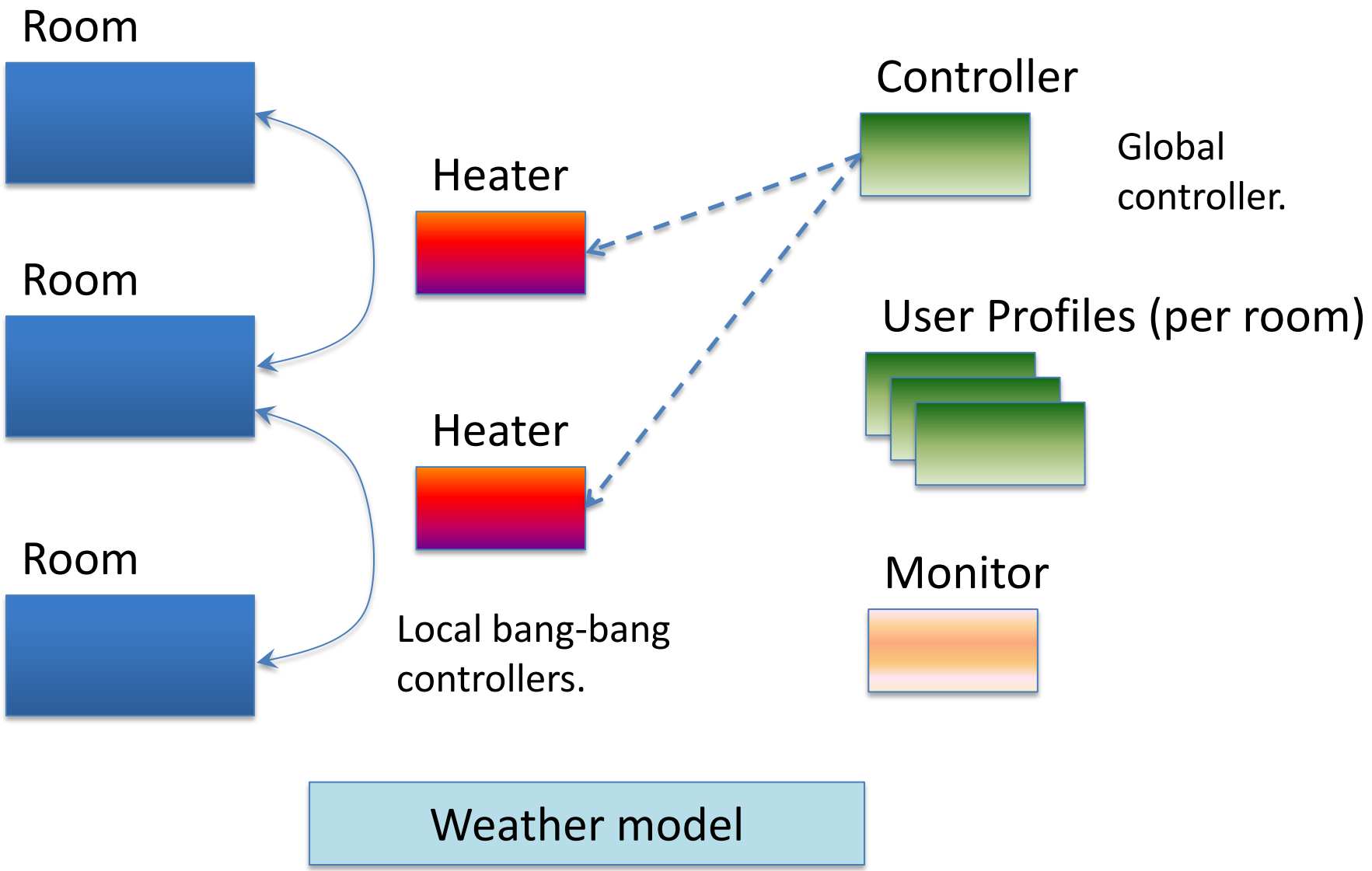
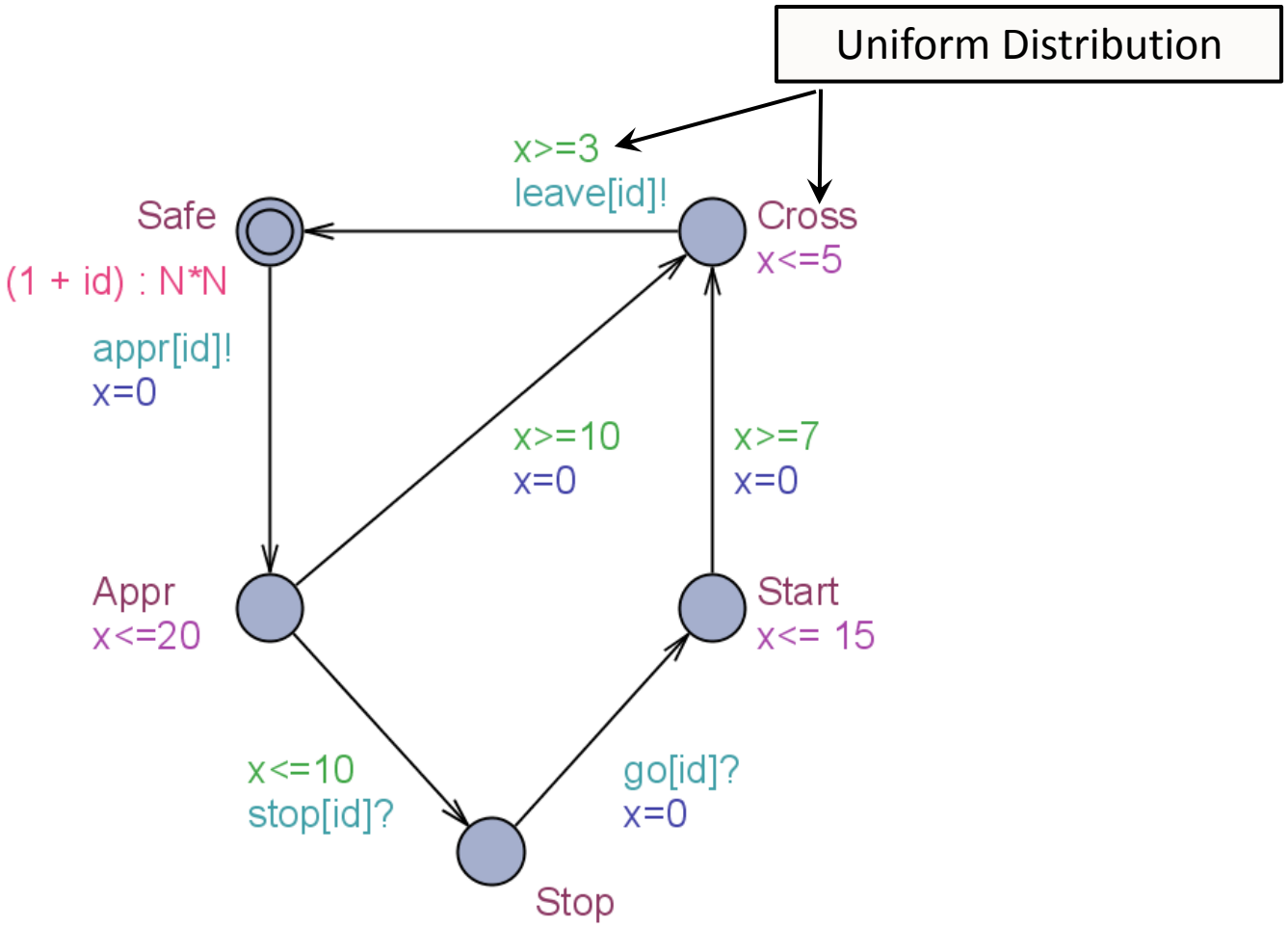
Science China 2012

Model Overview



Stochastic Timed Automata



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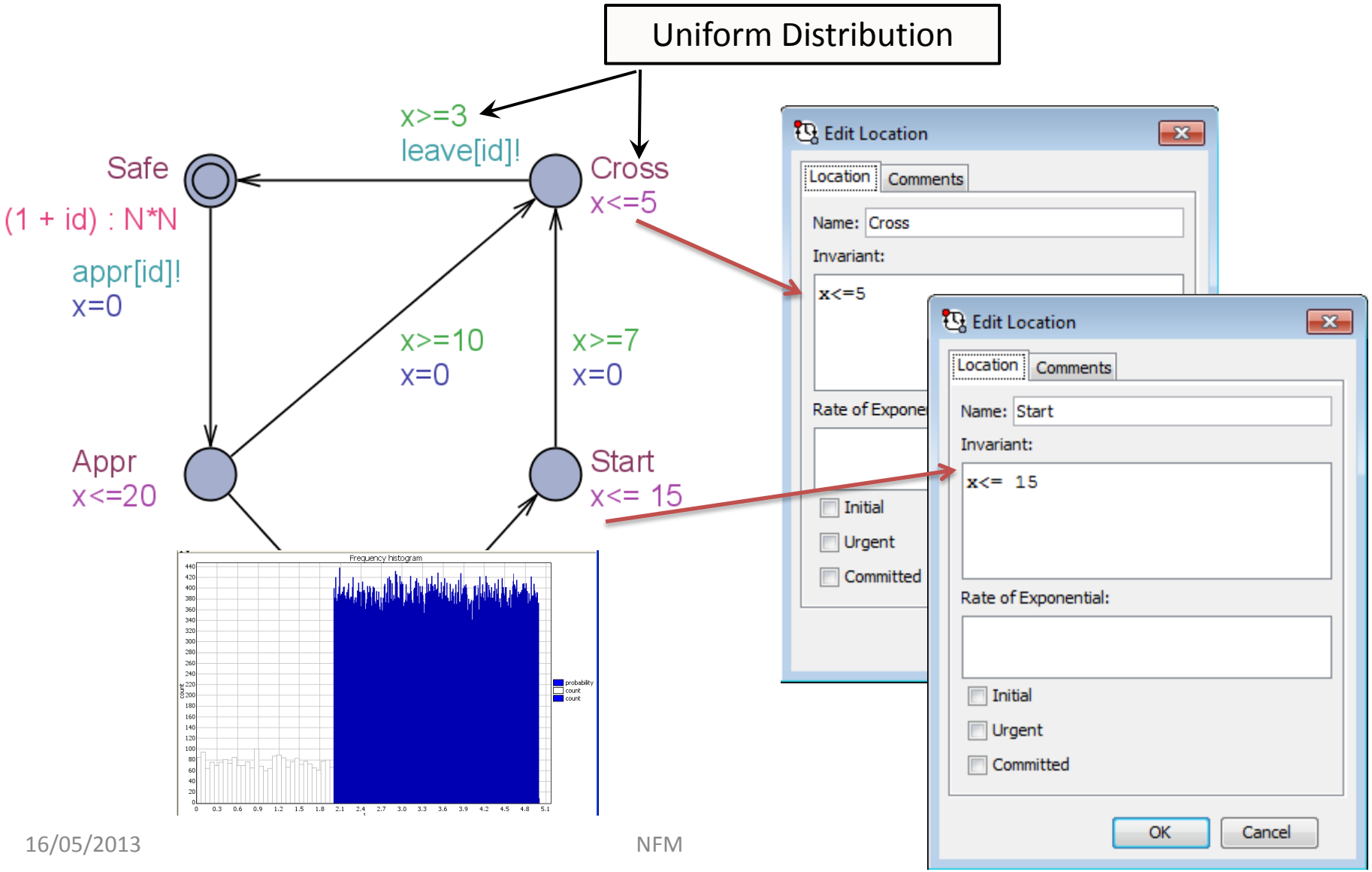

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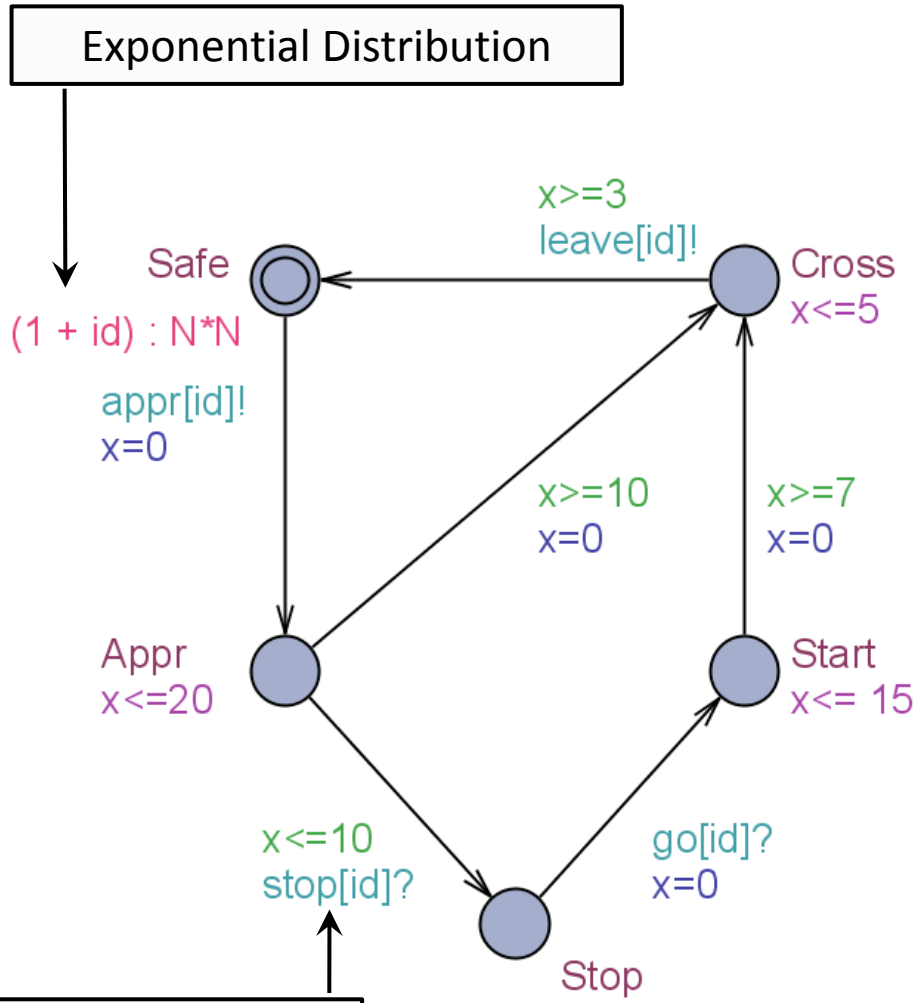
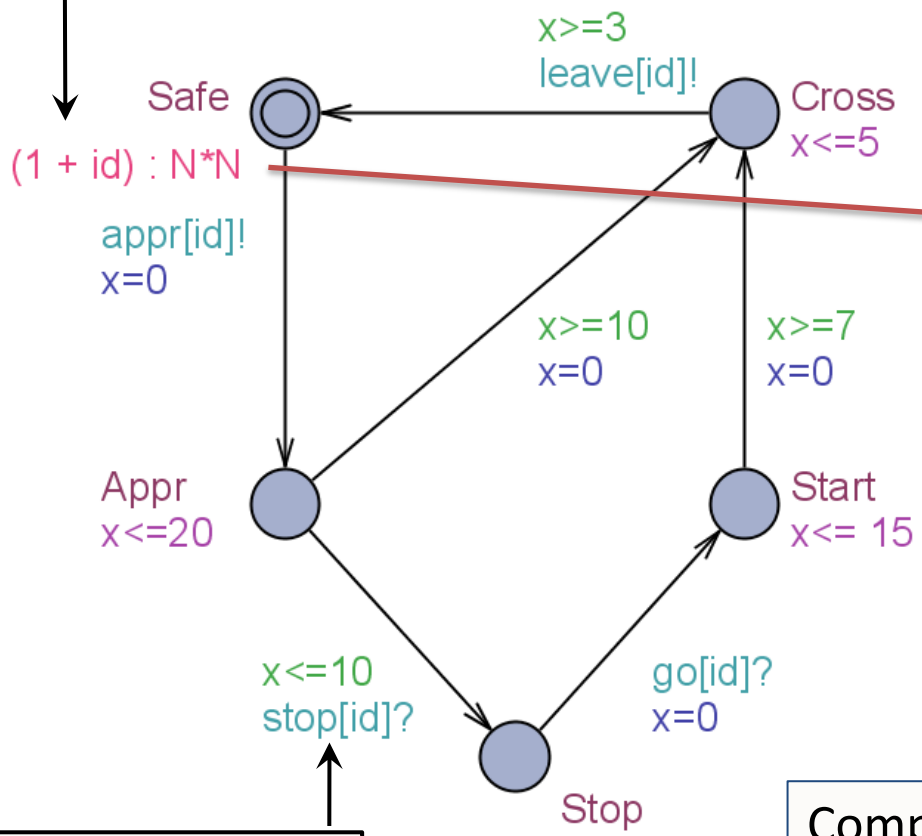
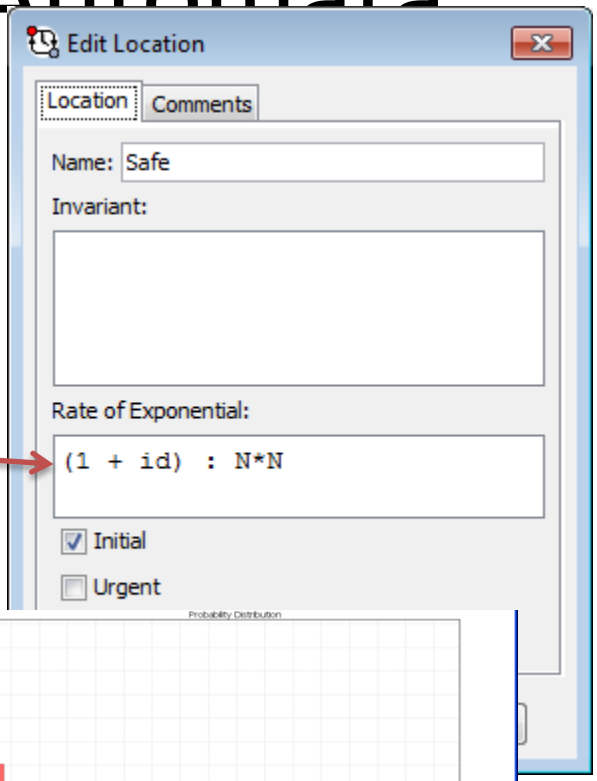
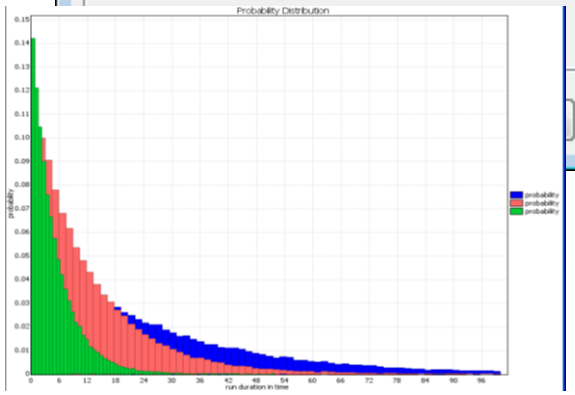


Stochastic Timed Automata

Exponential Distribution



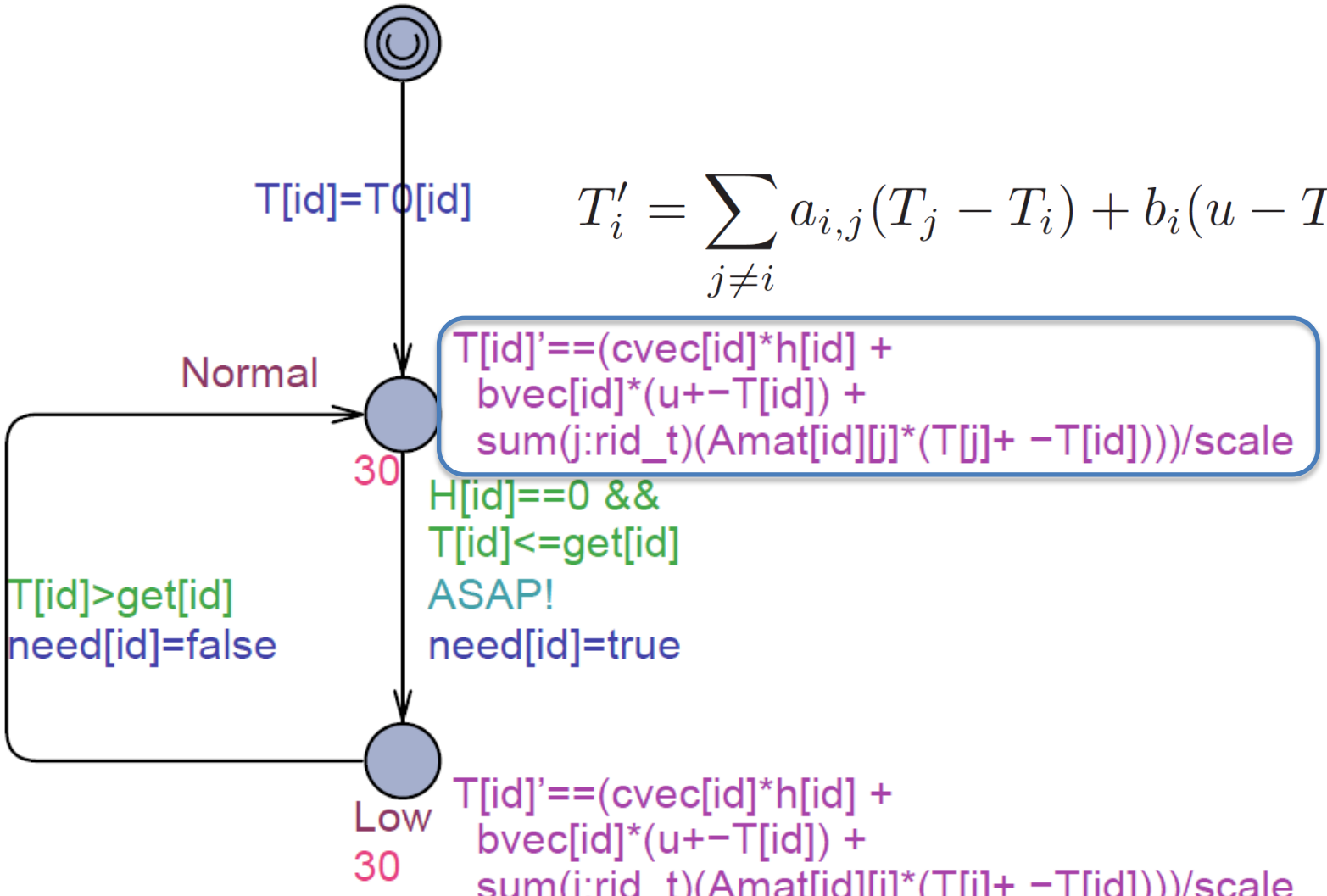




Input enabled
broadcast channels

Composition =
Repeated races between components

Stochastic **Hybrid** Model of the Room



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(a) Template for Room temperature.

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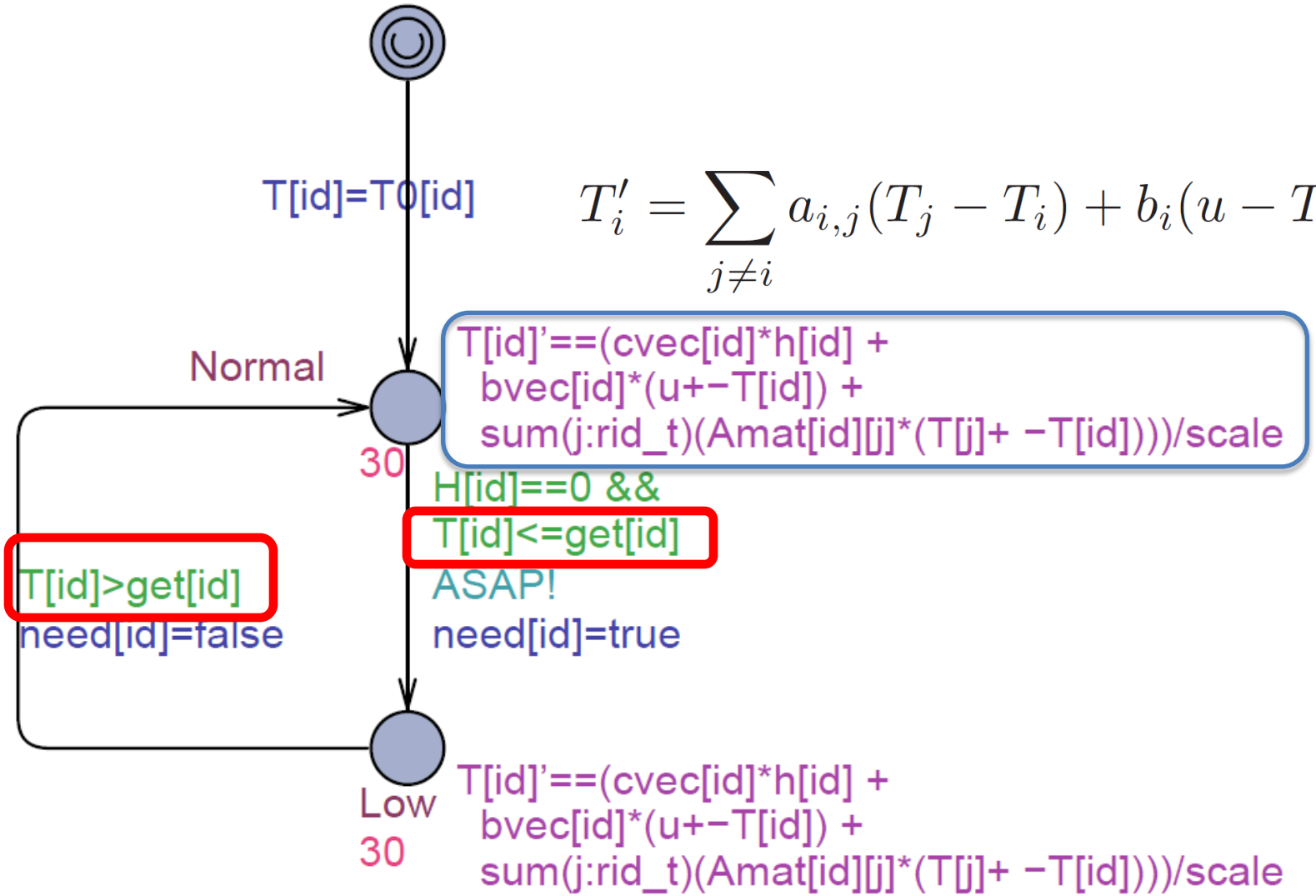

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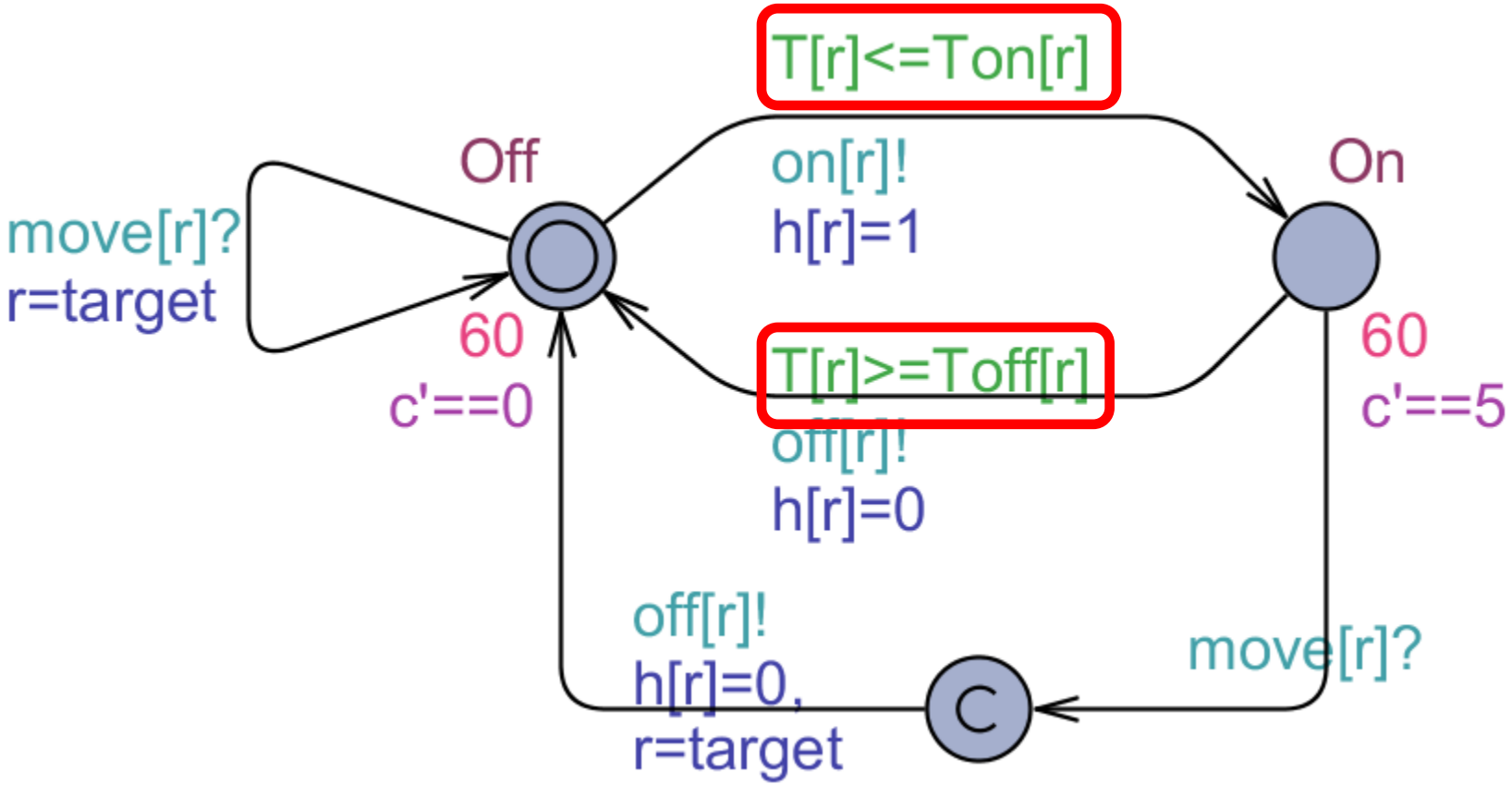
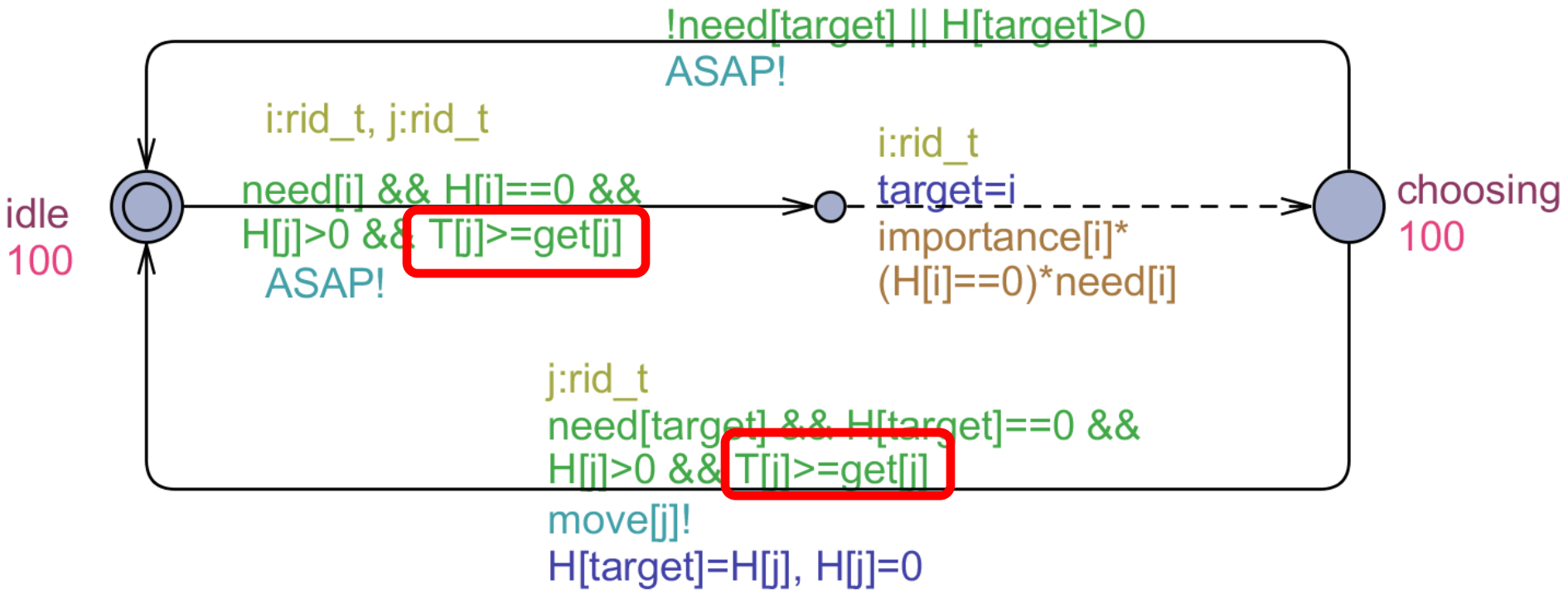
Model of the Heater

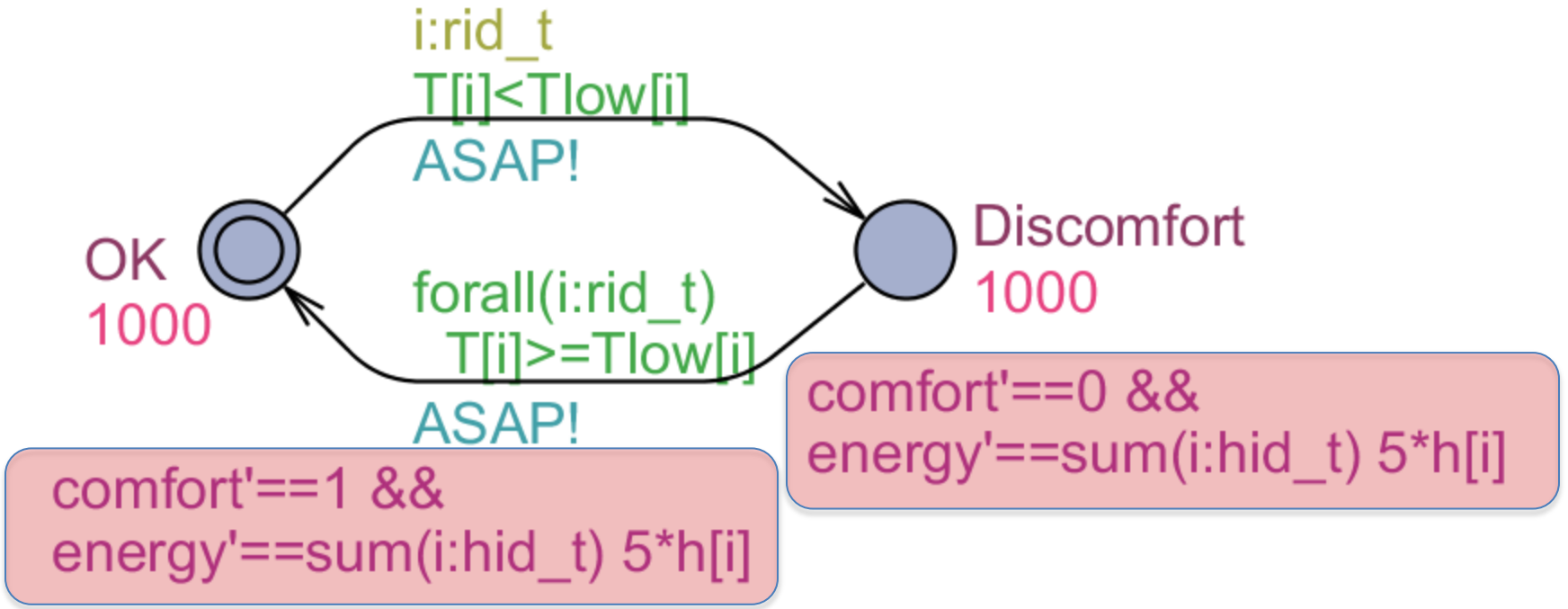


Local “bang-bang” controller.

Main Controller



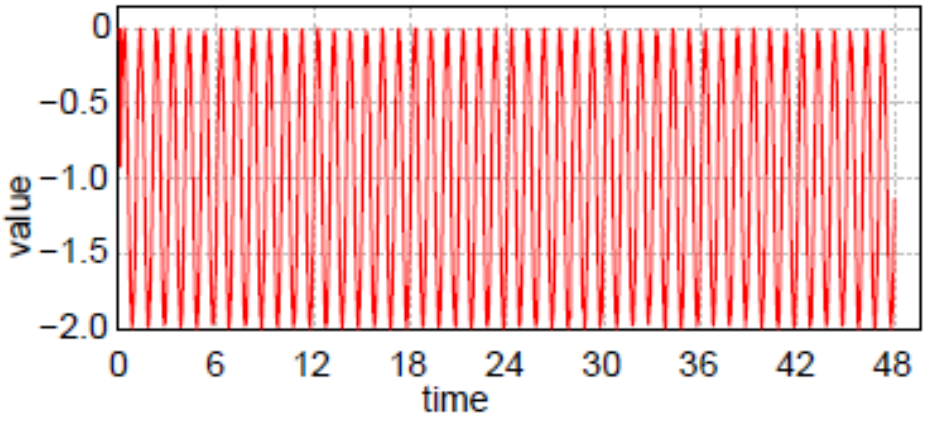
Global Monitoring



+ Maximize comfort.
- Minimize energy.
? Play with Ton and Tget.

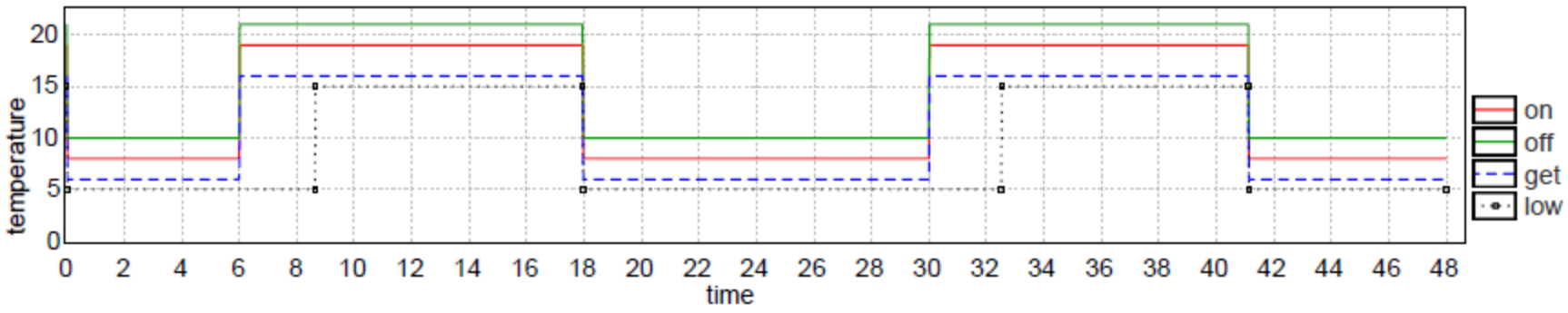
(Possible with Toff but not here).

Simulations



Weather Model

User Profile



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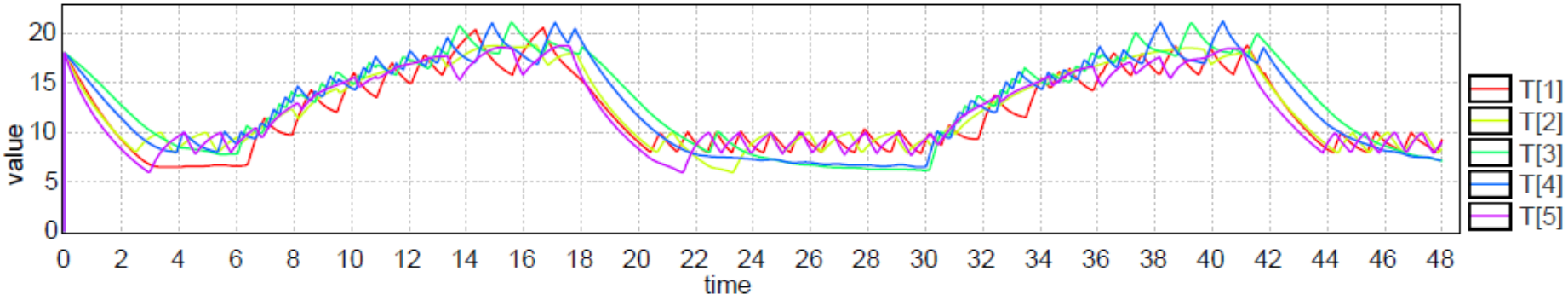
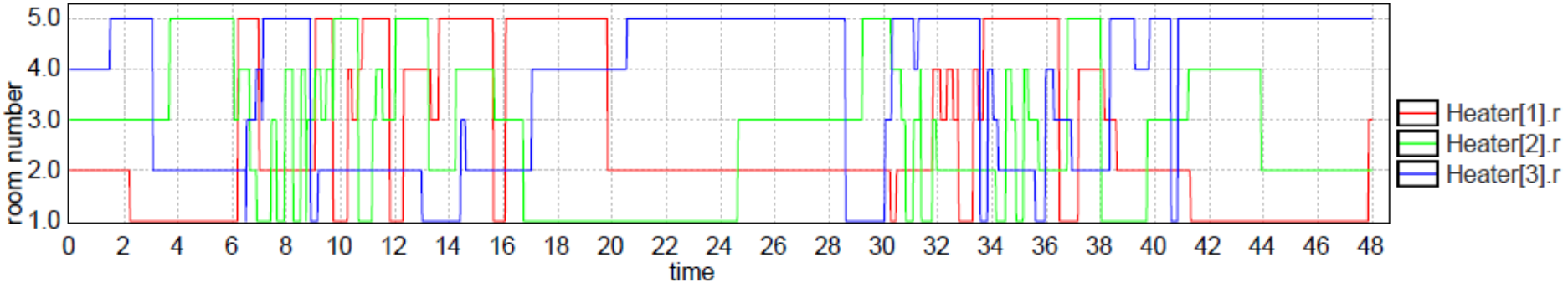



```
simulate 1 [<=2*day]{ T[1], T[2], T[3], T[4], T[5] }
```

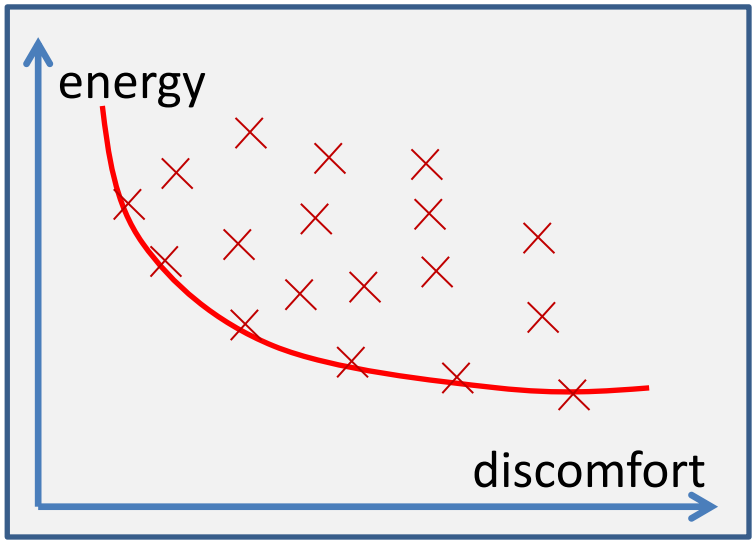



```
simulate 1 [<=2*day]{ Heater(1).r,Heater(2).r,Heater(3).r }
```

How to Pick the Parameter Values?

- $T_{on}, T_{get} \in [16,22] \rightarrow 49\ discrete\ choices.$
  More if considering other parameters.
- Stochastic simulations.
  - Weather not deterministic.
  - User not deterministic (present, absent…)
- How to decide that one combination is better?
  - Probabilistic comparisons?
    49*48 comparisons * number of runs.
  - To optimize what? Discomfort or energy?

How to Pick the Parameter Values?



- Remark:
  - Stochastic hybrid system $\Rightarrow$ SMC
- Idea:
  - Generate runs.
  - Plot the result energy/comfort.
  - Pick the Pareto frontier of the means.
- *How many runs do you need?*
  - *What's the significance of the results?*

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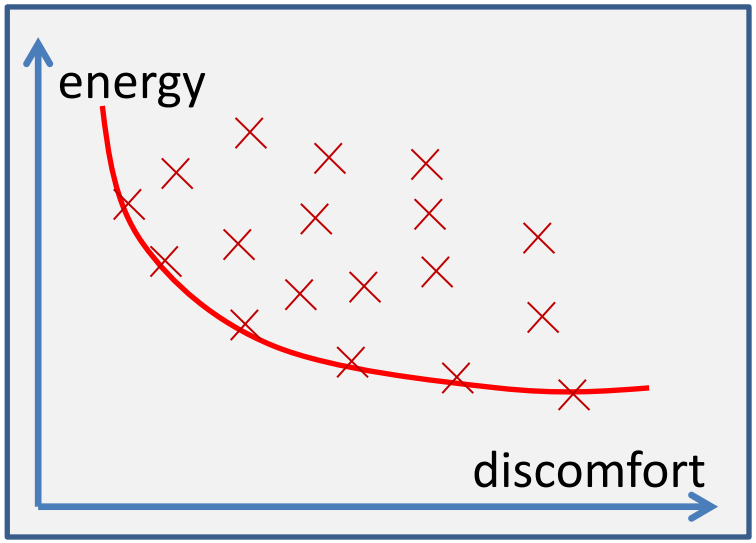

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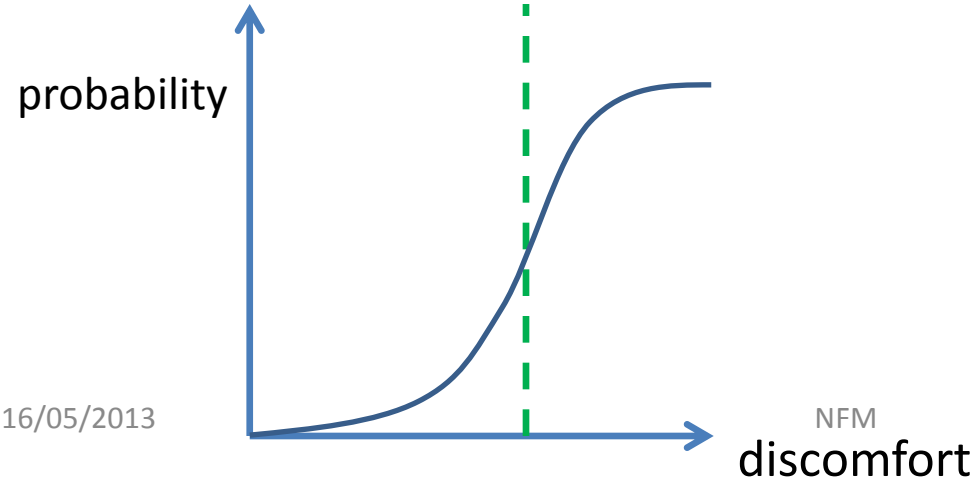
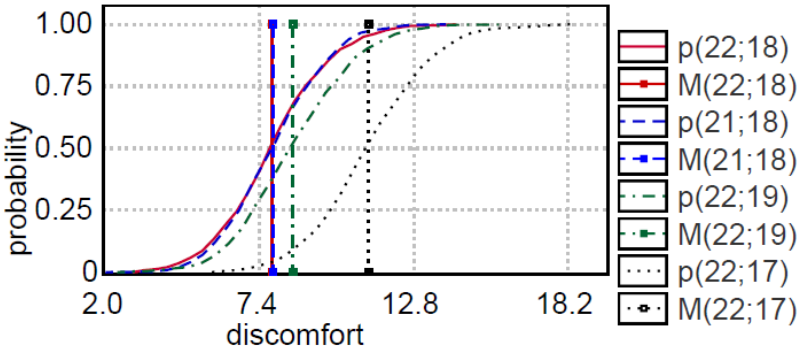
“Naïve” Solution

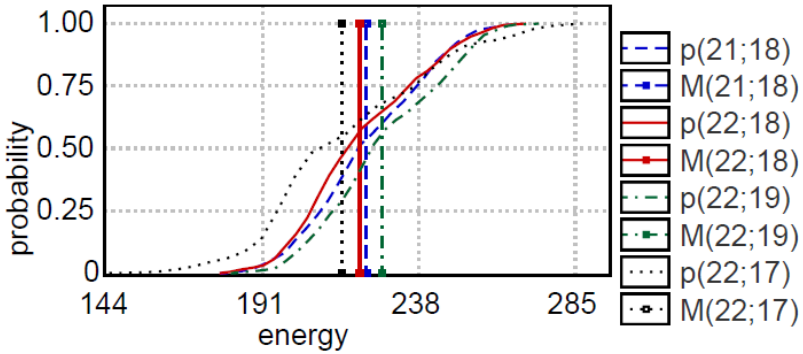
- Estimate the probabilities
  *Pr[discomfort<=100](<> time >= 2*day)*
  *Pr[energy<=1000](<> time >= 2*day)*
- From the obtained distributions (confidence known), compute the means.
- Pick the Pareto frontier of the means.



“Naïve” Approach

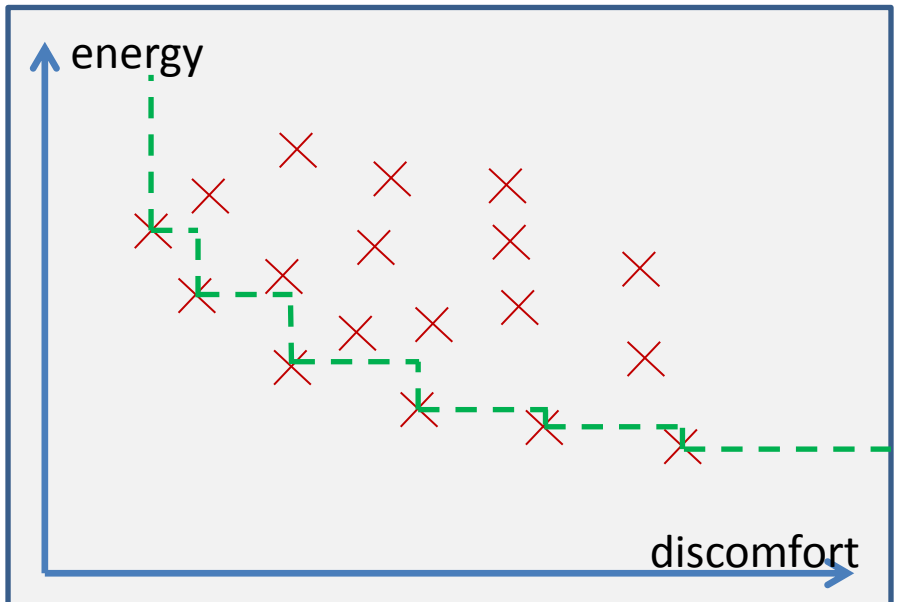


(a) Over discomfort.



(b) Over energy.

For each (Ton,Tget)



ANOVA Method

- Compare several distributions.
  - *Evaluate influence of each factor on the outcome.*
- Generalization of Student's t-test.
  - Compare 2 distributions using the mean of their difference.
  - If confidence interval does not include zero, distributions are significantly different.
  - Cheaper than evaluating 2 means + on-the-fly possible.

ANOVA Method

- 2-factor factorial experiment design
  - Ton, Tget are our 2 factors.
  - Each combination gives a distribution to compare.
  - Measure cost outcome (discomfort or energy).
- ANOVA estimates *a linear model* and computes the influence of each factor.
  - The measure of the influence is the F-statistic.
  - This is translated into P-value, the factor significance.
  - *Assume balanced experiments.*

ANOVA Method

1. Generate balanced measurements for each configuration to compare.
2. Apply ANOVA on the data (used the tool R).
3. If the factors are not significant, goto 1.
4. Reuse the data and compute the confidence intervals of the means for each comparison.
5. Compute the Pareto frontier.

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ANOVA Method

Fewer runs, more efficient than before.

1. Generate balanced measurements for each configuration to compare.
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3. If the factors are not significant, goto 1.
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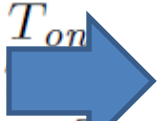
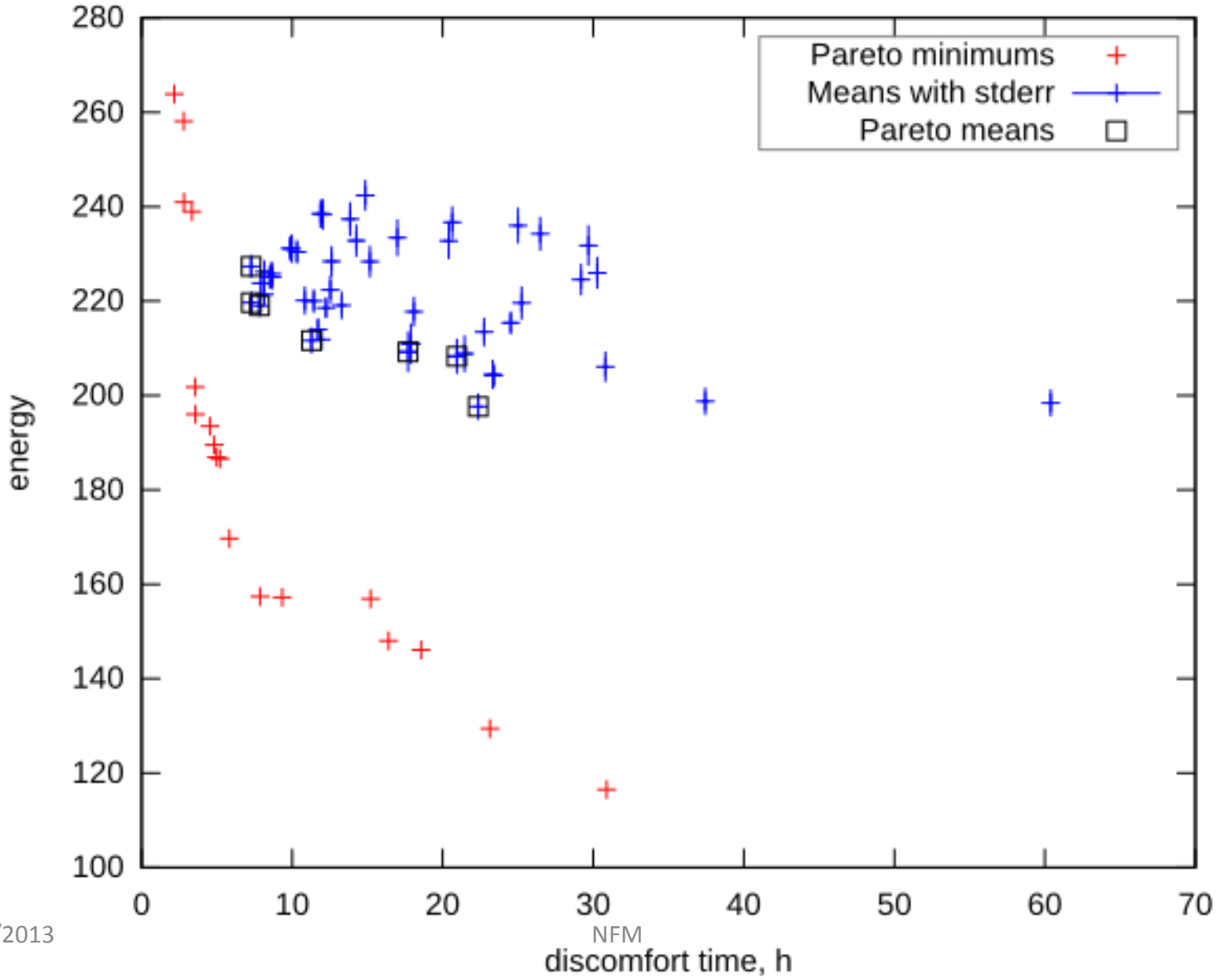
P<0.05⇒significant

ANOVA Results

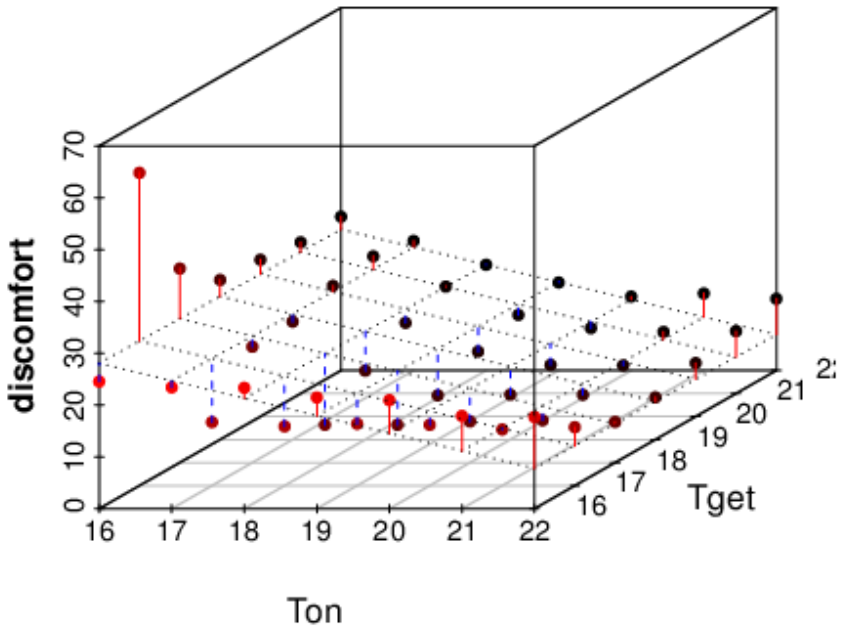
Number of runs	Factor	Discomfort time F value	Discomfort time P-value	Energy consumption F value	Energy consumption P-value
$2 \cdot 49$	T_{on}	63.8874	**3.30e-12**	0.7147	0.4000
	T_{get}	0.0063	0.9369	17.5777	**6.24e-05**
	$T_{on} : T_{get}$	0.0629	0.8026	0.7181	0.3989
$4 \cdot 49$	T_{on}	136.1676	**<2e-16**	1.1647	0.2818
	T_{get}	0.1537	0.6955	17.9283	**3.55e-05**
	$T_{on} : T_{get}$	0.0003	0.9869	0.0582	0.8096
$8 \cdot 49$	T_{on}	315.7978	**<2e-16**	2.4425	0.1189
	T_{get}	0.1202	0.7290	35.8938	**4.76e-09**
	$T_{on} : T_{get}$	0.0096	0.9218	0.8253	0.3642
$16 \cdot 49$	T_{on}	629.1384	**<2e-16**	6.5909	0.01044
	T_{get}	0.5895	0.4429	90.9612	**<2e-16**
	$T_{on} : T_{get}$	0.2852	0.5935	5.3053	0.02152
$32 \cdot 49$	T_{on}	1263.5390	**<2e-16**	27.9527	**1.42e-07**
	T_{get}	1.0840	0.2980	172.3296	**<2.2e-16**
	$T_{on} : T_{get}$	0.5401	0.4625	3.2632	0.07104
$64 \cdot 49$	T_{on}	2575.3208	**<2e-16**	65.6245	**7.74e-16**
	T_{get}	4.6682	0.0308	405.4892	**<2.2e-16**
	$T_{on} : T_{get}$	0.5949	0.4406	0.1926	0.6608

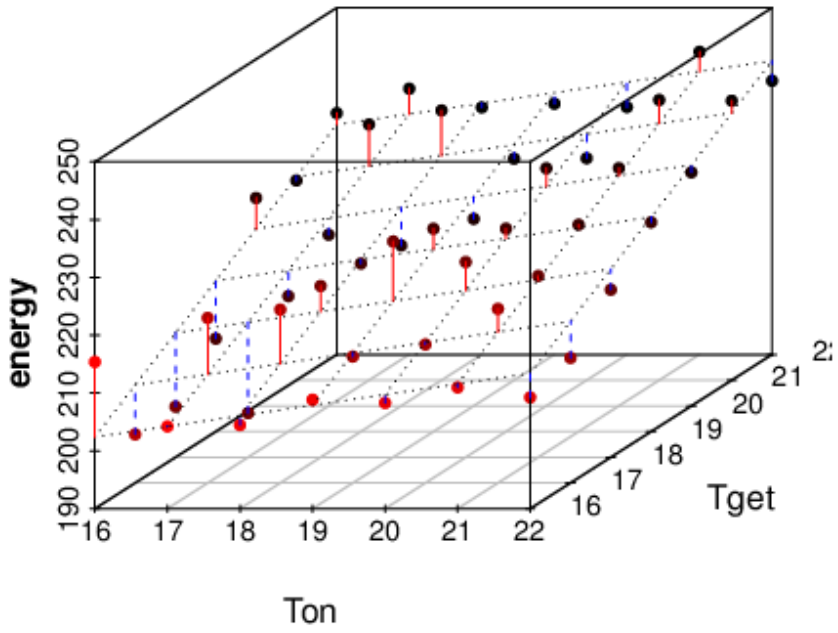


Results


Pareto minimums
Means with stderr
Pareto means
energy
discomfort time, h
280
260
240
220
200
180
160
140
120
100
0
10
20
30
40
50
60
70

Visualization of the Cost Model





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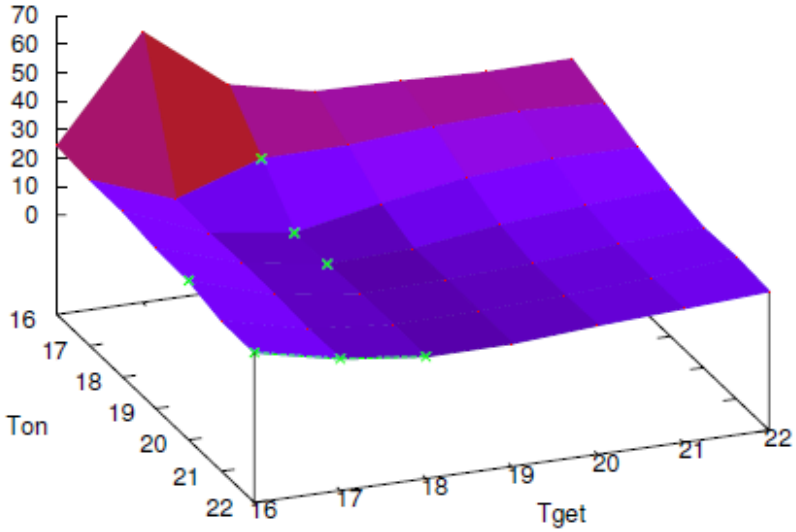
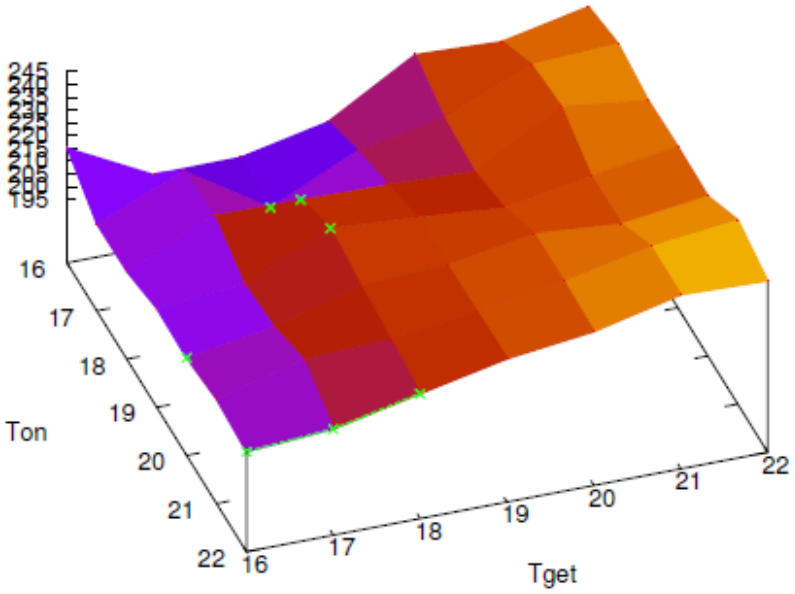


(a) Discomfort.



(b) Energy.

Comparison

- Naïve approach:
  738 runs per evaluation per cost
  *2 (energy & discomfort) *49 (configurations).
  $\Rightarrow$ 1h 5min
- ANOVA:
  3136 runs $\Rightarrow$ 6min 6s.
- *Core i7 2600*

Conclusion

- Analysis of variance used sequentially to decide when there is enough data to distinguish the effect of 2 factors.
  - Efficient use of SMC.
- What if the factor has no influence?
  - Need an alternative test.
- Possible to distribute.
- Future work: Integrate ANOVA in UPPAAL

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