Embedded Systems Specification and Design
Model-based Design and Verification

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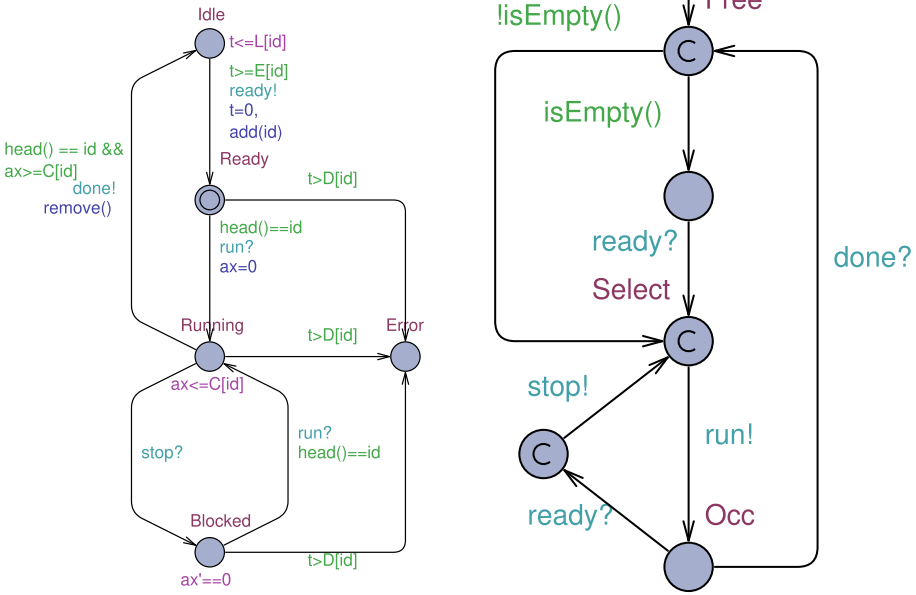
Going further

- Stopwatch automata
- Costs (Priced Timed Automata)
- Statistical model checking
- Hybrid and stochastic systems

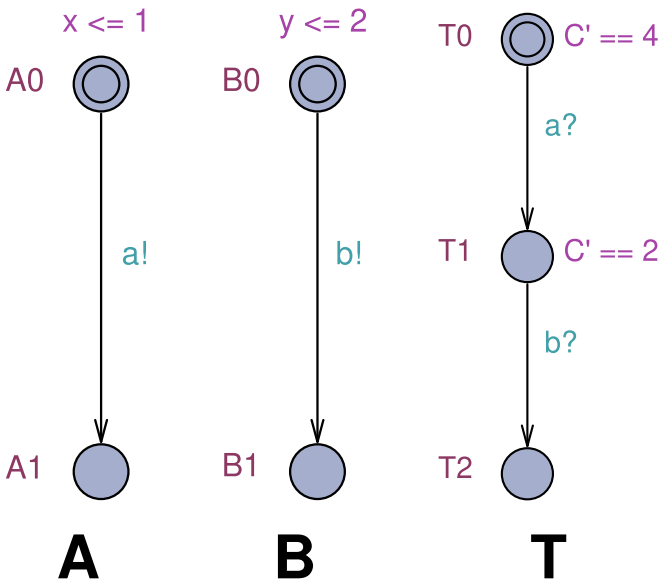
Stopwatch automata



Task **Scheduler**

- Can use clocks with a rate of 0 in one or more locations
- Clock `ax` in `Task` has a rate of 0 in location `Blocked`
- The rate is specified using the notation for the derivative, e.g. `ax' == 0`
- Reachability is undecidable for stopwatch automata but . . .
- UPPAAL uses an over-approximation algorithm to allow a 'classical' model-checking approach
- See demo (also Gantt chart in concrete simulator)

Costs – Priced Timed Automata



- A more general expression can be used to determine the rate of a clock, e.g. $C' == 4$
- The rate need not be a constant expression and may depend on the values of discrete state variables
- Clocks with this kind of rate are often used to measure the costs associated with the use of resources
- 'Classical' model-checking is not available for clocks with this kind of rate but ...
- *Statistical model-checking* can be used to simulate behaviour and to estimate the probability that properties will be satisfied

Statistical model checking

Monitor simulations of a system model and use statistical techniques to determine, with some degree of confidence, whether or not properties are satisfied

Queries supported by UPPAAL-SMC

- *Simulation* — `simulate N [<= bound] {E1, ..., Ek}`
  e.g. `simulate 1 [A.x <= 2] {A.x, C}`
- *Probability estimation* — `Pr[ bound ] ( psi )`
- *Hypothesis testing* — `Pr[ bound ] ( psi ) >= p`
- *Probability comparison* —
  `Pr[ bound1 ] ( psi1 ) >= Pr[ bound 2 ] (psi2 )`

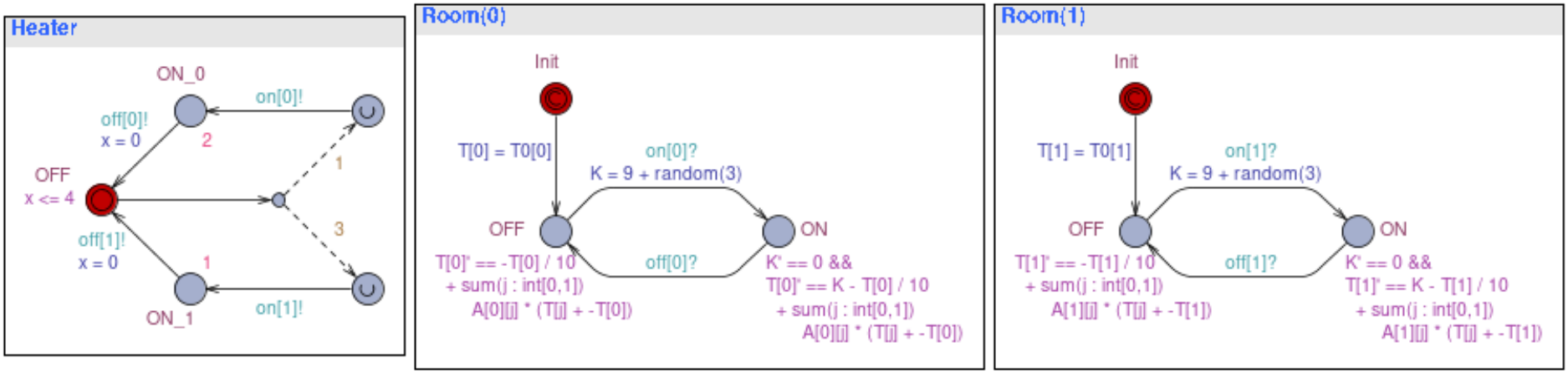
Bounds can be given

- Implictly by time, e.g. `[<=600]`
- Explicitly by cost, e.g. `[C <= 6]`
- By number of discrete steps, e.g. `[# <= 1000]`

Hybrid and Stochastic Systems

Hybrid — mixed continuous and discrete dynamics

Stochastic — having a random probability distribution



- Clock rates can depend not only on the values of discrete variables but also on other clocks (effectively supports representation of ODE's)
- Time elapsed chosen from uniform distribution over bounded time delays and exponential distribution (with given rate) over unbounded time delays
- Probabilistic choices represented by *branch points*
  - Each branch has a probability of being chosen of its weight over the sum of the weights of all branches at the branch point

Summary

- UPPAAL-SMC conducts simulations of hybrid, stochastic systems, monitors them, and uses statistical methods to decide, with some degree of confidence, whether or not properties are satisfied
- SMC is a compromise between testing and classical model-checking
- Requires much less memory and time than classical model checking to produce a result
- Becoming more widely used in industrial applications of
  - software engineering
  - embedded systems
  - systems biology
- See David, A., Larsen, K., Legay, A., Mikucionis, M., and Poulsen, D., *UPPAAL SMC Tutorial*, International Journal on Software Tools for Technology Transfer, 17(4), pp. 397-415, Springer Verlag, August 2015 [local copy (updated 2018)]