Uppaal. The Model Checker.

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Uppaal. What is it?

Uppaal is a model checker for real-time systems (in mind of embedded systems). What we can do with it?

1. Modeling
2. Simulation
3. Verification

Internal representation of model consists of:

- Network of timed automata
- Extended with data types

Where to use?

"Any system can be analysed using a model checker, as long as it has *states* and *transitions* between states" (from Chapter 1: A First Introduction to Uppaal by Frits Vaandrager)

Reactive systems such as:

- Hardware components
- Embedded controllers
- Network protocols
- Others...

Whenever there is need to handle real-time issues (the timing of transitions).

Brief history

Uppaal was started by Uppsala University, Sweden and Aalborg University, Denmark.

Time-line of development:

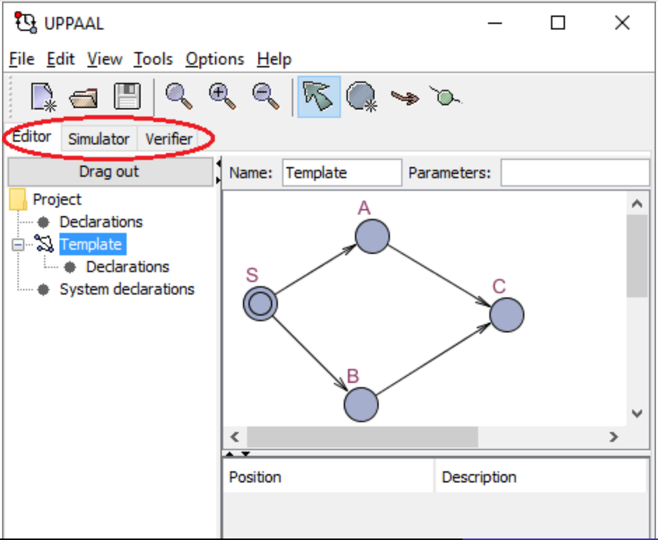
- 1995 - project started
- 1999 - first beta
- 1999/2000 - first stable release (v 3.0.X)
- September 27, 2010 - latest stable release (v 4.0.13)
- July 1, 2014 - preview release (v 4.1.19)

Uppaal variations

Versions: Windows, Mac, Linux, 32/64 bits
Available licenses:

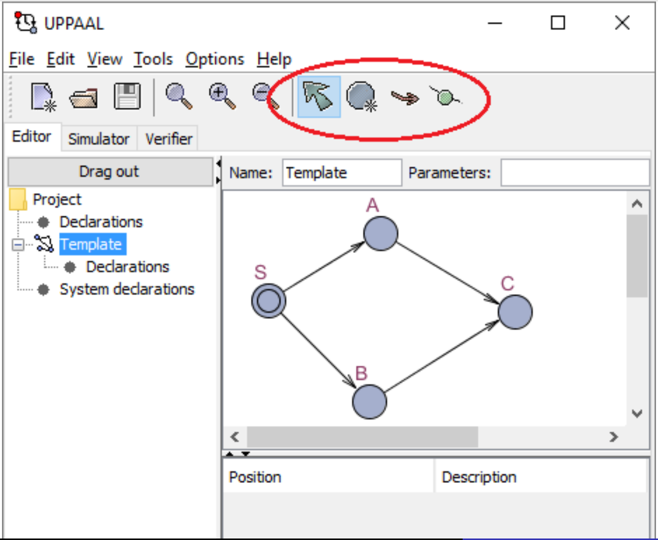
- Academic use (more info: http://www.uppaal.org/)
- Commercial use (more info: http://www.uppaal.com/)

Uppaal GUI - Main parts



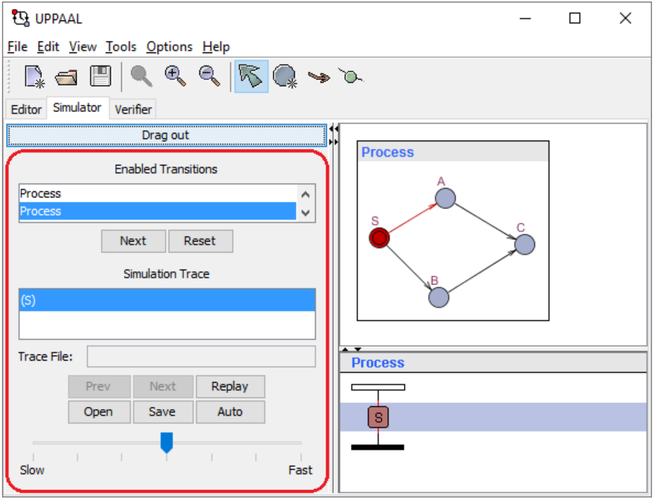
- System editor
- Simulator
- Verifier

Uppaal GUI - System editor



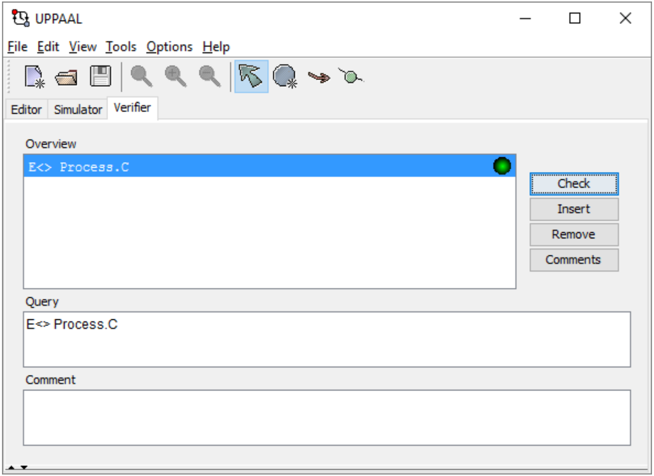
- Name: Template (default)
- Select
- Add location
- Add edge
- Add nail
- Syntax check (for global, local, system declarations)

Uppaal GUI - Simulator



- Select transition
- Track simulation
- Control (Prev/Next/Auto)
- Visualization

Uppaal GUI - Verifier

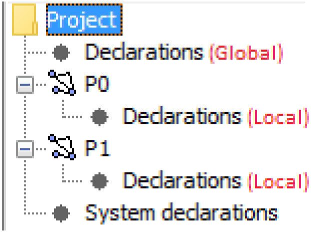


- Query editor
- Check query
- Overview
- Save/load

System/model/project

Description of system consist of:

- Concurrent process templates modelled using timed-automata (here *P0* and *P1*);
- Local declarations for each process;
- Global declarations for whole system;
- System definition.



Process/automata

Process is a timed-automata represent as diagram with states (called locations) and transitions between states (called edges). Timed-automata is finite state machine with time (clocks).

Each process has only one **initial location**.

Processes execute concurrently and they can be synchronized using channels.

Time/clocks

Time is continuous and the clocks measure time progress. Time progress globally and clocks values increase at the same rate for the whole system.

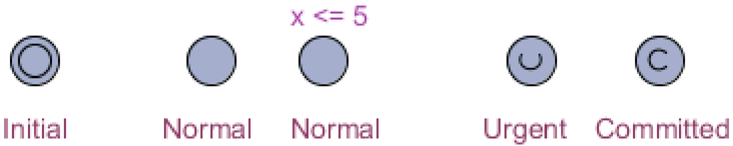
A clock is a special type of variable with domain being a set of non-negative real numbers. At system start, all clocks have value 0.

Using clocks we can specify:

- **Invariants** - upper bounds on timing, describes how long we can stay in given *location*;
- **Guard** - lower bound on timing, describes after what amount of time a *transition* can be executed.

We can test the value of clock using standard expressions or we can reset clock.

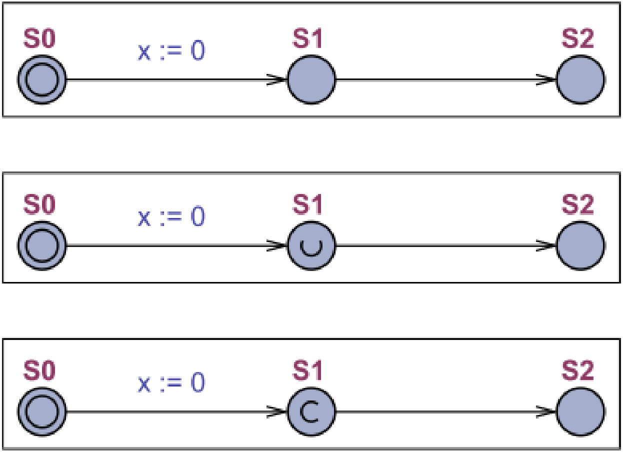
Location/state (part I)



Location represents state of the system. There are four types of locations:

- Initial (one for each process);
- Normal (with or without **invariants**);
- Urgent (time cannot elapse in this location, so transition to another location must occur **immediately**);
- Committed.

Location/state (part II)



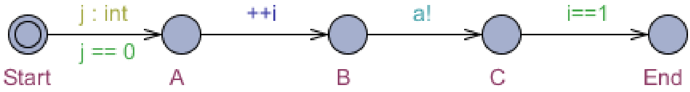
Edge/transition (part I)

An edge/transition connects two locations. Edges can have four types of annotations:

- **Selection** - binds a given identifier to a value in a scope of current transition; allowed types: *boundend integers*, *scalar sets*; defined here identifiers will shadow local/global variables.
- **Guard** - transition is enabled only if guard's expression evaluates to **true** and consists of:
  - Conjunction of simple conditions on clocks;
  - Differences between clocks;
  - Boolean expressions not involving clocks.
- **Synchronization** - transition labelled with complementary actions (e.g. *a!* and *a?*) will synchronize over a common channel (here channel *a*)

Edge/transition (part II)

- **Update** - evaluate given expression when transition occur.



Example of transitions with annotations:

- Selection: $j : int$;
- Update: $++i$;
- Synchronization: $a!$;
- Guard: $j{=}{=}0$, $i{=}{=}1$.

Edge/transition (part III)

Without prior specification, all transitions occur instantaneously and do not take time.

When no further transition is possible we reach so called **deadlock state**.

Unspecified choice is called non-deterministic:

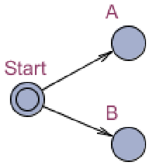


Figure: Non-deterministic choice.

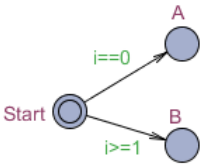


Figure: Deterministic choice.

Parameters

Template of process can have parameters with different call semantics (C++ syntax):

- call-by-value (using local copy, e.g. *int a*)
- call-by-reference (using original value, e.g. *int& a*)

Clocks and channels must always be call-by-reference parameters. Uppaal does not allow data parameters for synchronization channels (?).
In template parameters field: urgent chan &get, chan &put. When creating templates: Hammer = Tool(get_hammer, put_hammer); Mallet = Tool(get_mallet, put_mallet);

System declaration

Channels

(!) Uppaal offers urgent channels (defined using urgent chan) that are synchronization that must be taken when the transition is enabled, without delay. Clock conditions on these transitions are not allowed.

(!) There is no value passing through the channels

(!)The synchronization mechanism in Uppaal is a hand-shaking synchronization: two processes take a transition at the same time, one will have an a! and the other an a?, with a being the synchronization channel. When taking a transition, two actions are possible: assignment of variables or reset of clocks.

Uppaal does not allow data parameters for synchronization channels.

When a synchronization channel is urgent, this means that whenever a synchronization with this channel is enabled, time can not advance and a transition has to be taken immediately.

Variables

Global/local variables

Examples:

const int $J = 10$;
$int[0, J]$ jobs; // integer with min. value 0 and max. value J

The domain of integer is always bounded. By default *int* has range $[-32768, 32768]$.

Variable assigned with a value outside of its domain generates "run-time error".

Transition can have guards: expressions which use variables. Every transition have guard, by default they return **true**.

Expressions with variables

All are C-like:

- jobs++
- jobs = jobs + 1
- jobs := jobs + 1

Verification

Whereas the Verifier has an option to compute the fastest execution leading to a certain state, there is no corresponding option to compute the slowest execution.

Queries (part I)

Query is a property expressed as temporal logic formula, that may or may not hold for a given model. The Verifier can establish whether a Query is **satisfied** or **not**.

Basic queries:

- *A[] p* : for all paths *p* **always holds**;
- *E[] p* : there exists a path where *p* **always holds**;
- *A<> p* : for all paths *p* will **eventually hold**;
- *E<> p* : there exists a path where *p* **eventually holds**;
- *p --> q* : whenever p holds q will eventually hold.

Simple queries are in form of e.g *A[] p* where *p* is an expression build from **boolean combination** of **atomic propositions**.

Queries (part II)

The simplest atomic proposition can be of the form *P0.C*, where *P0* is an automaton and *C* is a location. Such a proposition is **true** if process *P0* is in location *C*.

Expression	Name	True when...
e && f	and	e and f evaluate to **true**
e || f	or	e or f evaluate to **true**
e == f	equality	e and f evaluate to the same value
e imply f	implication	e evaluate to **false** or f evaluate to **true**
e not f	negation	e evaluates to **false**

Queries (part III)

- $A[]$ not deadlock
- $E <>$ Process_1.C
- $E <>$ (Process_1.C && Process_2.C)
- $A[]$ now $>=$ 200 imply (Belt.end && Jobber1.begin &&Jobber2.begin)
- $A[]$ Obs.taken imply ($x >= 2$ and $x <= 3$)
- $E <>$ Obs.idle and $x > 2$
- $A[]$ Obs.idle imply $x <= 3$

Reasoning

(!)The tool just uses brute force to explore all the reachable global states of the model and to check for each of these states whether both jobbers are working on a hard job.
(!)Model checker engine. It can run in server mode on a more powerful, dedicated machine.
(!) More precisely, the engine uses on-the-fly verification combined with a symbolic technique reducing the verification problem to that of solving simple constraint systems [YPD94, LPY95]. The verifier checks for simple invariants and reachability properties for efficiency reasons. Other properties may be checked by using testing automata [JLS96] or the decorated system with debugging information [LPY97].
(!)Then we can ask the verifier to check reachability properties, i.e., if a certain state is reachable or not. This is called model checking and it is basically an exhaustive search that covers

Diagnostic traces

(!)Uppaal can also provide a concrete example that illustrates why the property holds (for $E <>$ properties) or not (for $A[]$ properties, so called: *counterexample*).

(!)In the case of $E <>$ properties that do not hold, or $A[]$ properties that hold, Uppaal can only report that it exhaustively checked all the reachable states of the model and didnt find anything.

(!)We choose under *Options* the entry *Diagnostic Trace* and then select the option *Shortest*. Simulator will then show found diagnostic trace.

Saving data

We can save various types of data:

- Model/system - **.xml* file;
- Queries - **.q* file;
- Traces (binary) - **.xtr* file.

Keeping models manageable

- Committed locations - reduce significantly the state space, but on the other hand they can take away relevant states;
- Variables and its ranges - use small amount of variables with the shortest value ranges;
- Clocks - has an important impact on the complexity of the model.

Examples

1. First automata, deterministic and non-deterministic choices.
2. Location types.
3. Simple synchronization.
4. Guards and invariants.
5. BIG! Production line.

- F.W. Vaandrager. *"A First Introduction to Uppaal"* In J. Tretmans, editor. Quasimodo Handbook. To appear.
- *Uppaal 4.0: Small Tutorial. A short description of the tool as well as some examples.*
- *Uppaal Help/Documentation*. Built-in. Uppaal 4.0.14, May 2014.