Model Checking Applied to Mobile Agent System

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LACL, Team Systems Specification and Verification

SAFA Workshop - October 6, 2010

Outline

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Mobile Agent

Definition

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A mobile agent is a program that can migrate from machine to machine in a heterogeneous network. This migration is a part ot its execution.

- Some advantages over the traditional client/server model
  - Efficiency
  - Fault tolerance
  - Customization

High Order π-calculus

To model a mobile agent system, we use a process algebra as the language π-calculus which this is the syntax :

$$\text{Definition } A, \ldots \; ::= \; A(x_1, \ldots, x_n) \; = \; P$$
$$\text{Process } P, \; Q, \ldots \; ::= \; 0 \mid \alpha.\, P \mid P \mid Q \mid P + Q \mid [a = b]\, P \mid [a = b]\, P \mid (\nu\, n)\; P \mid A(\, v_1, \ldots, v_n\,)$$
$$\text{Prefix } \alpha, \ldots \; ::= \tau \mid \overline{c}\,\langle\, a \,\rangle \mid c(\, x\,)$$

Expression of mobile agent needs use of languages which allow higher order term, that's why we use the High Order π-calculus.

$$\text{Prefix } \alpha, \ldots \; ::= \tau \mid \overline{c}\,\langle\, Q \,\rangle \mid c(\, P\,)$$

Definition of a mobile agent

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- Q sends M to P along the x channel : M is a mobile agent.

$$(\nu x)\left(\left(x(A) \,.\, A \,.\, P'\right) \mid \left(\overline{x}\langle M\rangle \,.\, Q'\right)\right)$$

π-calcul, sources of infinity

- Despite its simple syntax, the language has a rich semantic.
- Modeling in this process algebra leads to the definition of infinite systems
- Numerous sources of infinity :
  - Recursion and parallelism : Dynamic creation of processes, Dynamic evolution of systems
  - Parameterized systems : System sizing, Open Systems

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Question

How to verify these systems ?

Context

Computer-aided proof adapted to π-calculus are very few.

- Mobility Workbench (Victor and Moller, 1994) : Open bisimulation equivalent and state space generation "on-the-fly"
- HAL (Ferrari et al., 2003) : historical substitutions of names with HD-Automa (HAL)

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Scope of our work

We want to translate these systems into networks of timed automata to use UPPAAL toolkit (a more friendly tool !).

Outline

UPPAAL toolkit

- Integrated tool environment for modeling, validation and verification of real-time systems
- Systems modeled as networks of timed automata
- The Uppaal modeling language extends timed automata with the following additional features :
  - automata are defined with a set of parameters
  - committed locations
  - arrays (clocks, channels, constants, integers)
  - broadcast channels
  - ...

A Short Example

- We consider 2 terms written in π-calculus

$$P(x) \stackrel{def}{=} (\nu\, u)\ \left(\overline{x}\langle u \rangle \,.\, u(a) \,.\, 0\right) \text{ and } Q(z) \stackrel{def}{=} z(b) \,.\, (\nu\, c)\ \overline{b}\langle c \rangle \,.\, 0$$

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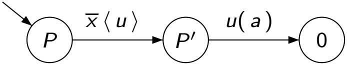
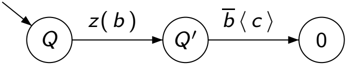
- A translation into 2 automata might be





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$$P(\,x\,) \overset{def}{=} (\,\nu\, u\,)\ \left(\overline{x}\,\langle\, u\,\rangle\ .\ u(\,a\,)\ .\ 0\right) \text{ and } Q(\,z\,) \overset{def}{=} z(\,b\,)\ .\ (\,\nu\, c\,)\ \overline{b}\,\langle\, c\,\rangle\ .\ 0$$

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⚠ We must define a execution context ⚠

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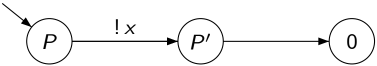

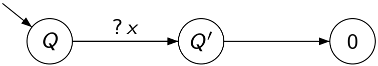

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$$System \xrightarrow{\tau} (\nu\, u) \Big(u(a) \,.\, 0 \;\Big|\; (\nu\, c)\, \overline{u}\langle c \rangle \,.\, 0 \Big)$$

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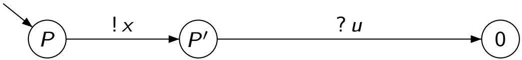
2. Reduction
3. Scope extrusion
4. Communication on u

$$System \xrightarrow{\tau} (\nu u)\left(u(a) . 0 \mid (\nu c)\,\overline{u}\langle c\rangle . 0\right)$$

Operational Semantics

Formally, a automaton $\mathcal{P}(id_P)$, translation of a π-calculus term P, is a automaton such as :

- id_P is a unique identifier



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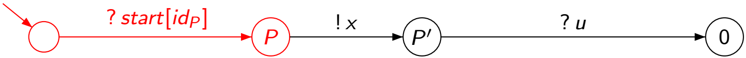

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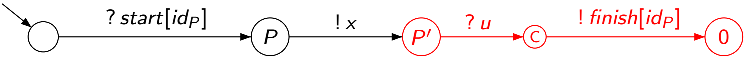
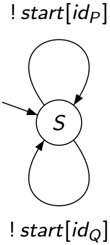
- if q_0 is the initial state then $\langle q_0, ?\,start[id_P], P \rangle$ is the first transition
- if a term Q waits the end of P execution and $P' \xrightarrow{\alpha} 0$ then the double transition $\langle P', \alpha, !\,finish[id_P], 0 \rangle$ is the last of $\mathcal{P}$ and $\mathcal{Q}$, translation of Q, have a transition $\langle Q', ?\,finish[id_P], Q'' \rangle$.



Operational Semantics

A special case : $\mathcal{S}$, automaton representing the term *System*, has neither ID nor the labeled transition $?\,start[\ldots]$.

$\mathcal{S}$, translation of $System \stackrel{def}{=} (\ P \mid Q\ )$



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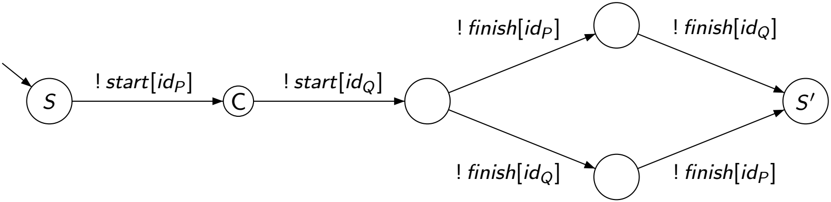
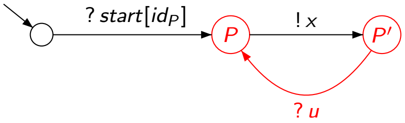


Operational Semantics

Translations of some π-calculus operators

- Recursion : $P(x) \stackrel{def}{=} (\nu\, u)\left(\overline{x}\langle u\rangle \,.\, u(a) \,.\, P(x)\right)$



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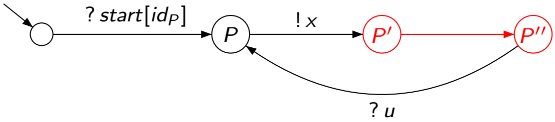

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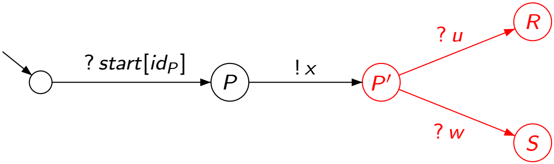
- Sum : $P(x) \stackrel{def}{=} (\nu\, u,w) \left(\overline{x}\langle u,w \rangle \,.\, \left(u(a) \,.\, R + w(a) \,.\, T \right) \right)$



Mobility

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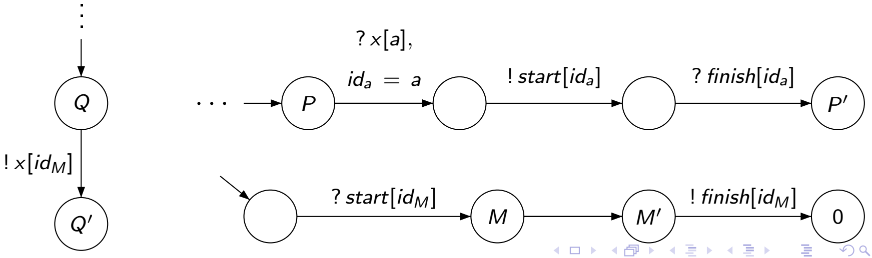
- This system is translated into a network of automata such as



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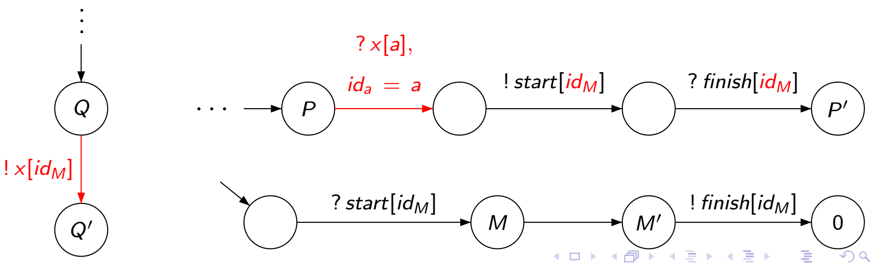

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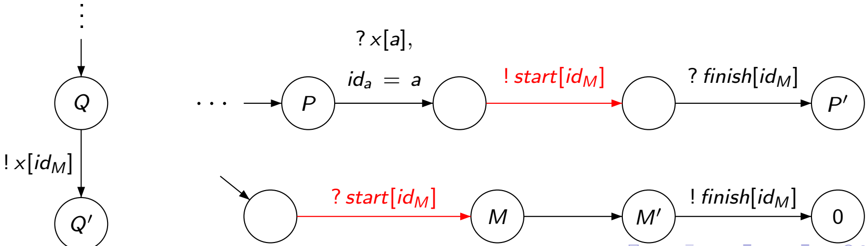

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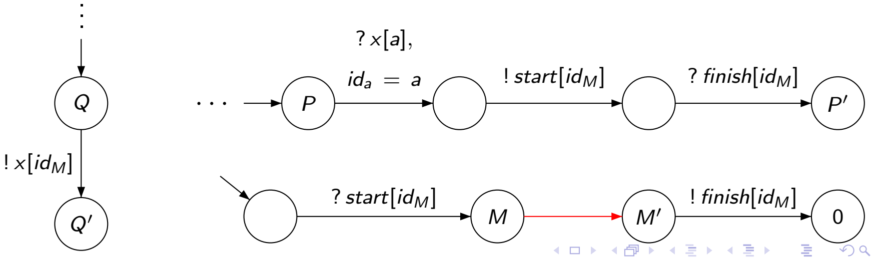

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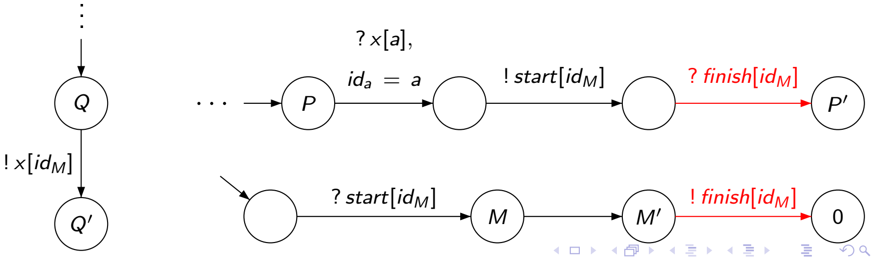


Time for fault tolerance

- In Mobile Agent System, like any distributed system, errors or accidents are inevitable.
    - Design errors, programming errors, ...
    - Environmental accidents (network, hardware, ...)
    - ...
- A Mobile Agent System must be a fault-tolerant system.
- To model a fault-tolerant system, we add a notion of time to our automata with Timed Automata.

Outline

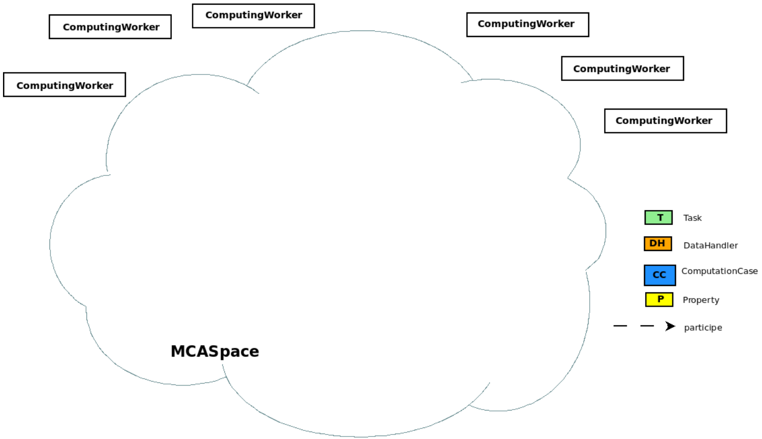
MCA Architecture

MCA (Mobile Computing Architecture) is :

- A platform for the resolution of cases of numerical computation
- Capable to execute algorithms implemented in Java or in native language thanks to LLVM [1] (Low Level Virtual Machine)
- Implemented in Java
- Based on a JavaSpace (provided by Jini API)

1. http ://llvm.org/

MCA Architecture
Key components



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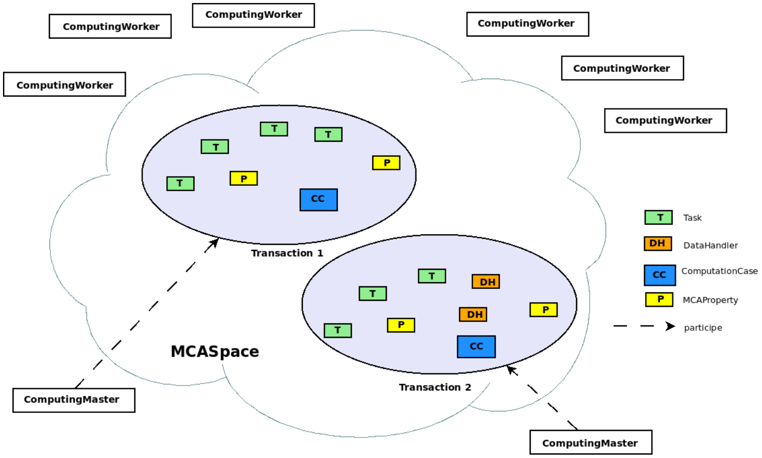

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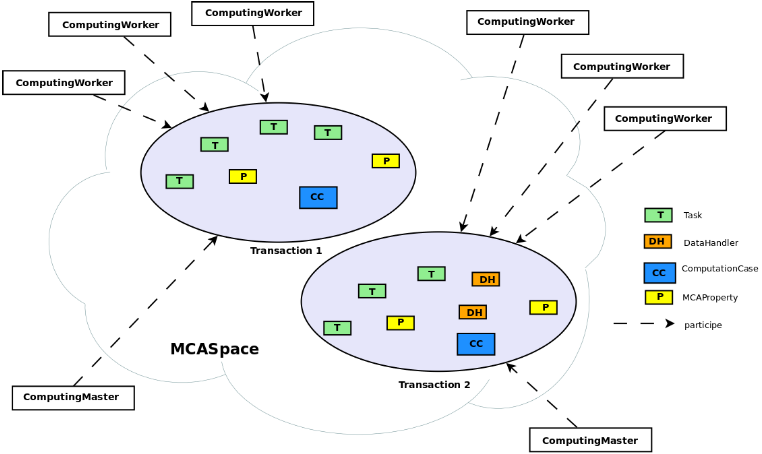

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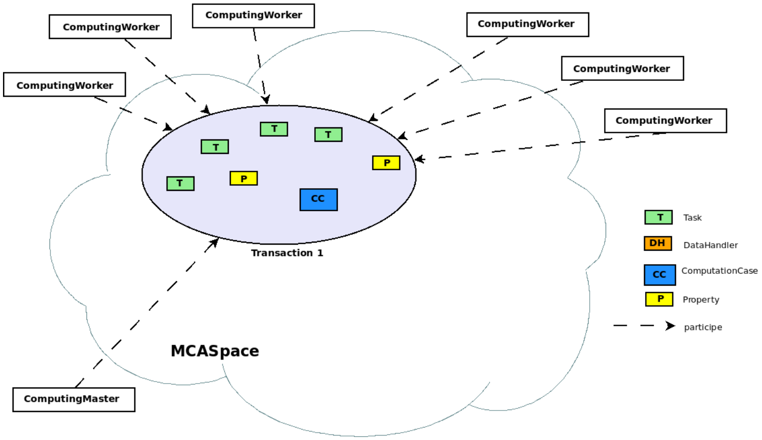
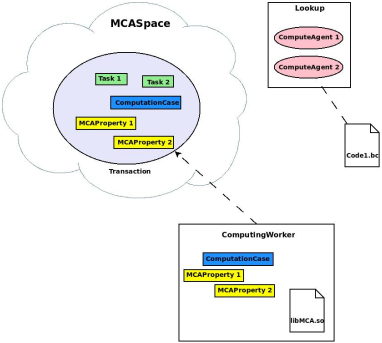


MCA Architecture
Task execution



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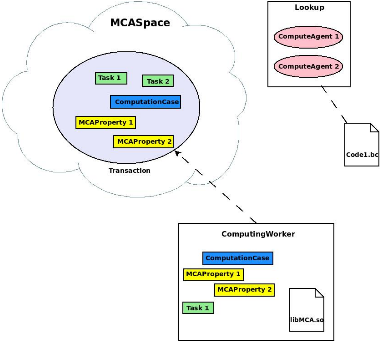
1. *CW* takes a *Task* object which contains the *ComputeAgent* name to execute



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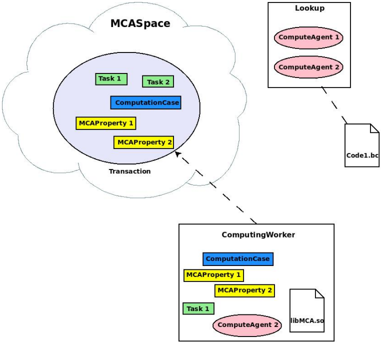

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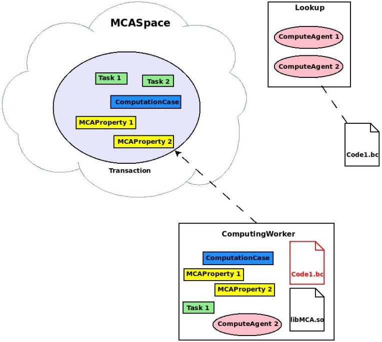

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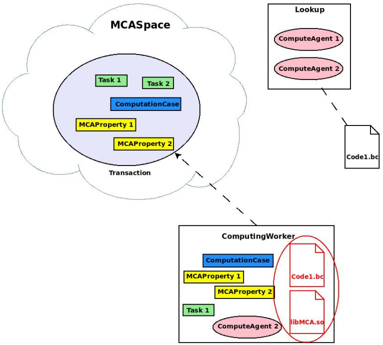

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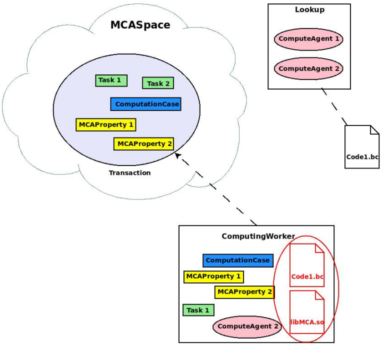
5. *CW* updates the *Task* state on *MCASpace*



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A system to solve a computation case consists of

- 1 workspace

which translates into a network of timed automata such as

$$\mathcal{M}_{space}(id_s) \parallel \mathcal{T}_{dir}(id_{td})$$

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- 1 computation case
- n tasks and their respective mobile agents
- m Worker agents

which translates into a network of timed automata such as

$$\mathcal{M}_{space}(id_s) \parallel \mathcal{T}_{dir}(id_{td}) \parallel \mathcal{M}(id_m) \parallel \mathcal{C}c(id_{cc}) \\ \parallel \mathcal{T}(id_{t_1}) \parallel \cdots \parallel \mathcal{T}(id_{t_n}) \parallel \mathcal{C}a(id_{c_1}) \parallel \cdots \parallel \mathcal{C}a(id_{c_n}) \\ \parallel \mathcal{W}(id_{w_1}) \parallel \cdots \parallel \mathcal{W}(id_{w_m})$$

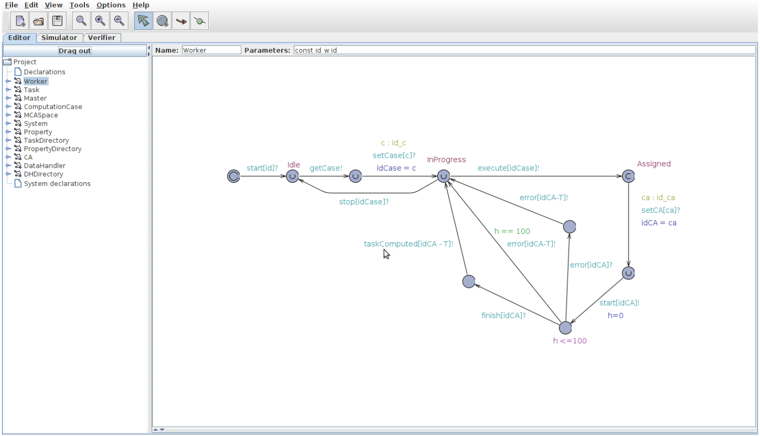
MCA Properties

Using our network of timed automata, we can verify properties specific to our architecture based on a system of mobile agents. We expressed the following properties :

- To ensure that a task put on the *MCASpace* is necessarily executed if a *Worker* agent is available
- To assert that a task are never accessed by two *Worker* agents at same time
- To assert that each *Worker* agent is given a chance to execute a task.
- To assert that the system will never get itself into deadlock
- ...

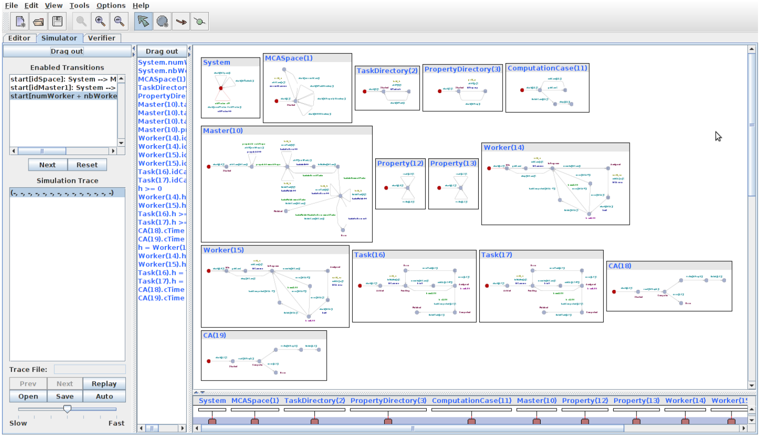
Modeling with UPPAAL

Modeling



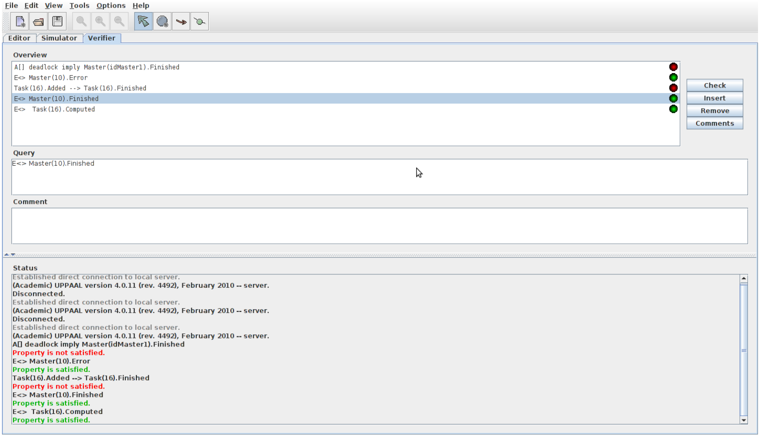
Modeling with UPPAAL

Simulation



Modeling with UPPAAL

Verification



Outline

Conclusion

Conclusion

- Modeling of a Mobile Agent System into HOπ-calculus terms
- Translation of HOπ-calculus terms into timed automata
- Model-Checking of our MCA Architecure with UPPAAL toolkit

Future works

- Manage code generation with the use of formal specification
  - Define new operator to get a skeleton of mobile code
  - Keep initial assertions into programming definition

Questions ?