The TIMES Tool

version 1.0 beta

User Manual

Introduction

TIMES is a modelling and schedulability analysis tool for embedded real-time systems, developed at Uppsala University. It is appropriate for systems that can be described as a set of preemptive or non-preemptive tasks which are triggered periodically or sporadically by time or external events. It provides a graphical interface for editing and simulation, and an engine for schedulability analysis.

The main features of TIMES are:

- A graphical editor for timed automata extended with tasks, which allows the user to model a system and the abstract behaviour of its environment In addition the user may specify a set of preemptive or non-preemtive tasks with parameters such as (relative) deadline, execution time, priority, etc.

- A simulator, in which the user can validate the dynamic behaviour of the system and see how the tasks execute according to the task parameters and a given scheduling policy. The simulator shows a graphical representation of the generated trace showing the time points when the tasks are released, invoked, suspended, resumed, and completed.

- A verifier for schedulability analysis, which is used to check if all reachable states of the complete system are schedulable that is, all task instances meet their deadlines. A symbolic algorithm has been developed based on the DBM techniques and implemented based on the verifier of the UPPAAL tool.

- A code generator for automatic synthesis of C-code on brickOS platform from the model. If the automata model is schedulable according to the schedulability analyser the execution of the generated code will meet all the timing constraints specified in the model and the tasks.

More information about TIMES can be found on the web site www.timestool.com.

Installation

Before installing TIMES tool uninstall any previously installed version first. In order to do that execute Uninstall_Timestool script from ~/Times Directory/UninstallerData directory on *NIX systems or perform the standard uninstallation procedure using the Control Panel on Windows.

System requirements

```
Hardware:
CPU Pentium 166 MHz or faster or
    Sparc processor
RAM 32 MB (128 MB recommended)
HDD 10 MB of available space
800x600 or higher-resolution monitor
Mouse or other pointing device
```

```
Operating system:
Linux (kernel >= 2.2.12)
Solaris 7/8/9
Microsoft Windows 95/98/NT/2000/XP
Software:
JDK 1.4.1 or higher version
PostScript Printer Driver
```

In order to run the Server part of the TIMES tool on a remote host you must also install and configure an applicable network. See Installing a remote server for further information.

Installation procedure

- **Installing TIMES tool on Linux and Solaris**

After downloading an appropriate for your OS **timestool-1.0b.bin.gz** file execute the following commands in the directory where you have saved it and follow the installation steps.

```
bash$ gunzip timestool-1.0b.bin.gz
bash$ sh ./timestool-1.0b.bin
```

The second screen of the wizard contains the License Agreement. Please, read it carefully and continue the installation only if you can accept it. Choose the directory where you would like to install the TIMES tool and the location where the links are to be put. After installation execute the following command from your links directory to run the TIMES tool:

```
bash$ ./runTimestool
```

- **Installing TIMES tool on Windows**

After downloading double-click on **timestool-1.0b.exe** and follow the steps of the standard installation wizard. The second screen of the installation wizard contains the License Agreement. Please, read it carefully and continue the installation only if you can accept it. Choose the folder where you would like to install the TIMES tool and the location where the icons are to be put. After installation click on the corresponding icon to run the TIMES tool.

- **Trooubleshooting**

If you are experiencing problems running the TIMES tool, try to execute the following command from the directory where you have installed it:

```
java -jar timestool.jar
```

and, please, e-mail the problem description to bugs@timestool.com. We will fix it in the next release if possible.

Installing a remote server

The TIMES tool consists of two parts: the Graphical User Interface (GUI) and the Server. Thus it can be used as either a standalone or distributed application. Since the server requires much more computational power that GUI, one might want to run it on a powerful remote host. Moreover running the server separately allows several users to use it simultaneously. Currently only Linux based systems can be used for hosting the TIMES tool server.

In order to use TIMES server remotely you have to configure it to run as a network service. Create a service configuration file in **/etc/xinetd.d/timesserver** with the following contents:

```
service timesserver
{
        disable = no
        socket_type         = stream
        protocol            = tcp
        wait                = no
        user                = root
        passenv             = PATH
        server              = /path/to/the/times/server/server
        flags               = NODELAY
}
```

Add the following two lines to your **/etc/services** file:

```
timesserver    2351/tcp
timesserver    2351/udp
```

This will setup the TIMES server run on the port number **2351**. You can specify the number of any available port here but ensure you have your clients configured appropriately.

Execute the following command in order to restart **xinet** daemon:

```
bash$ /etc/init.d/xinetd restart
```

You are ready to use your Linux box as a remote TIMES server! Don't forget to configure your TIMES clients to use the remote server (see Configuration for further information).

Tutorials

The tutorials show in a step-by-step manner how the different parts of the TIMES tool work allowing you to start quickly using the tool in your own projects.

- Editing tutorial
- Simulation tutorial
- Schedulability analysis tutorial
- Verification tutorial
- Code synthesis tutorial

Editing tutorial

This tutoral describes how to create a very simple system using the TIMES editor. It will help you understand the main concepts of the editor.

- **Creating an empty project**

Abstract: Create a new project, name it ***Simple***, and then save the project to the file named ***empty.xml***.

1. Start the TIMES tool or, if you have it already started, save and close the current project and create a new one using menu `File->New`.

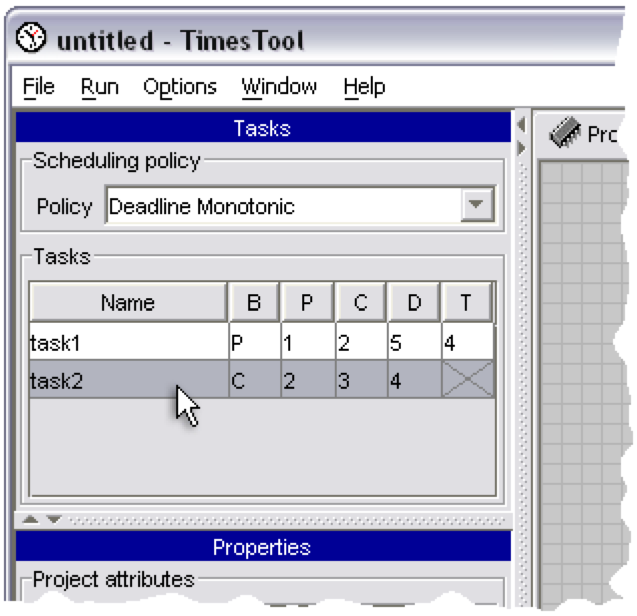
2. Double click the edit box of the project attribute `Name`. The current name ***Project*** will be highlighted. Type in the new project name ***Simple***.

3. Use the menu `File->Save As...` to save your project. A standard file dialog will appear. Type in the filename ***empty***, and click the `Save` button.

4. Use the menu `File->Exit` to close the tool.

- **Adding and configuring tasks**

Abstract: Create two tasks as shown in the figure below and then set the deadline monotonic scheduling policy. Set the maximum of ***2*** task instances for the ***task1*** and save the project as ***tasks.xml***.



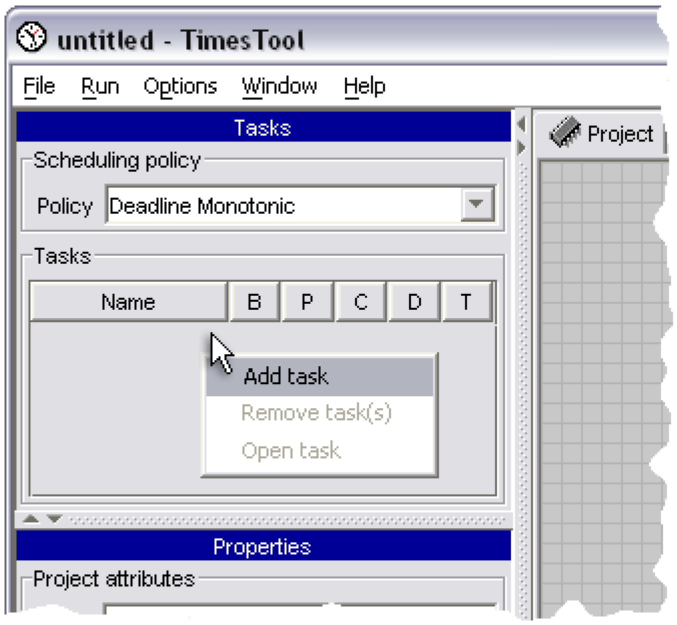
Policy: Deadline Monotonic

Name	B	P	C	D	T
task1	P	1	2	5	4
task2	C	2	3	4	

Task Configurations and Scheduling Policy

1. Use the menu `File->Open` to open the project file ***empty.xml***.

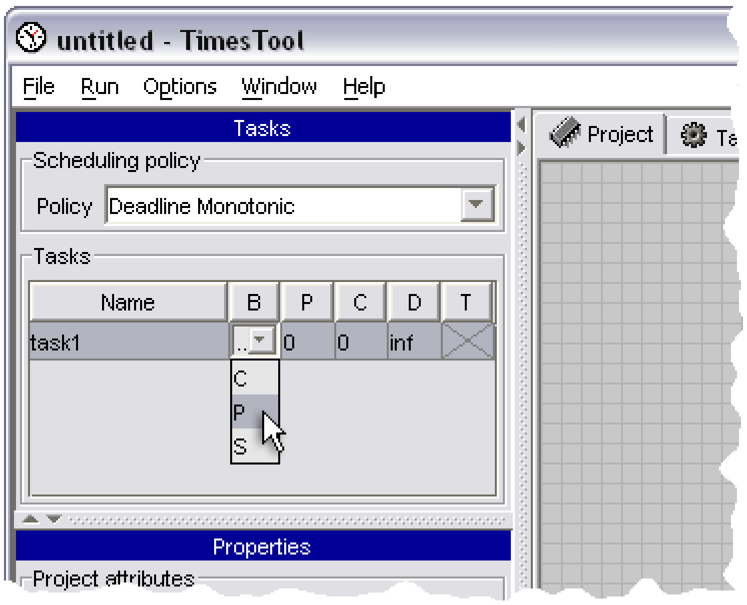
2. Right-click in the tasks table, below the table headings. A popup menu will appear, as in the figure below. Select the menu item `Add task`. A new task ***task1*** will be created with its behavior set to `controlled`. See Editor chapter for more information about the task table.



Policy: Deadline Monotonic

Adding a Task to The Task Table

3. Left-click in the `B` column of the row for ***task1***. This will bring up a drop-down menu with the task behaviors. Select `P`. This will set the behavior of the ***task1*** to `prediodic`.



Scheduling policy

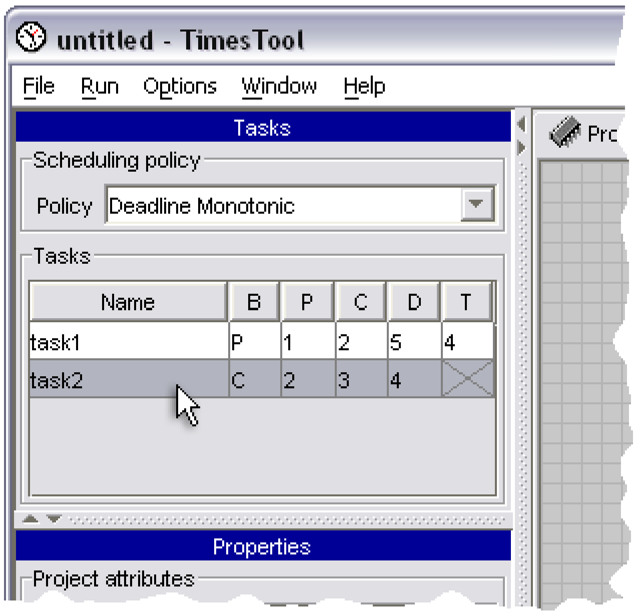
Policy: Deadline Monotonic

Tasks

Name	B	P	C	D	T
task1	..	0	0	inf	

Selecting Task Behavior

4. Add another task named ***task2*** to the task table. Set the task parameters as in the figure below.



Scheduling policy

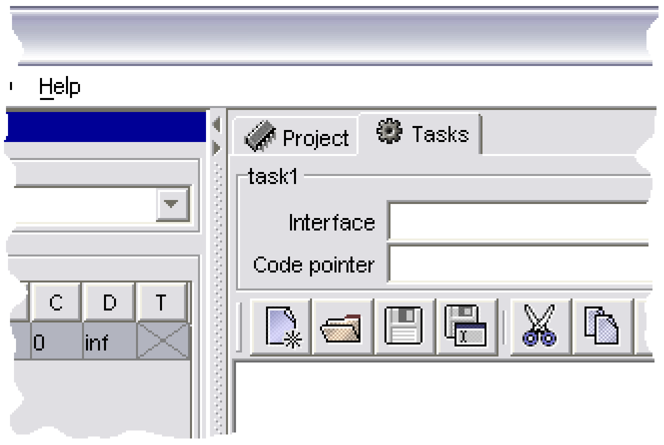
Policy: Deadline Monotonic

Tasks

Name	B	P	C	D	T
task1	P	1	2	5	4
task2	C	2	3	4	

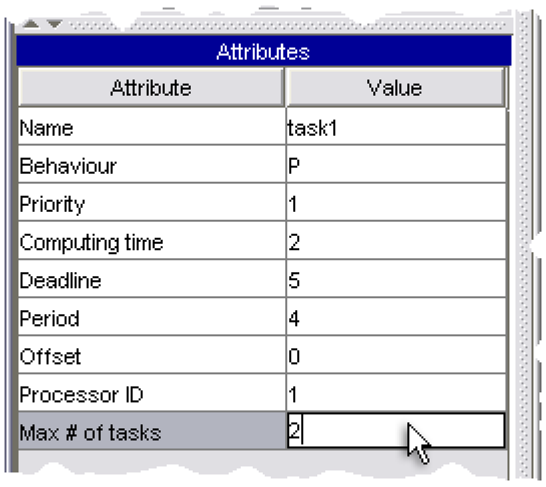
Task Configurations

5. Select `Deadline Monotonic` in the scheduling policy drop-down box. The task priorities will be automatically assigned.



The Tasks Tab

6. Select the `Tasks` tab and then select ***task1*** in the task table. The attributes of the selected task will appear in the panel below the task table. Double-click in the `value` column of the `Max # of tasks` row and type in ***2***. This will allow two instances of the ***task1*** to be active at any time as maximum.



Attribute	Value
Name	task1
Behaviour	P
Priority	1
Computing time	2
Deadline	5
Period	4
Offset	0
Processor ID	1
Max # of tasks	2

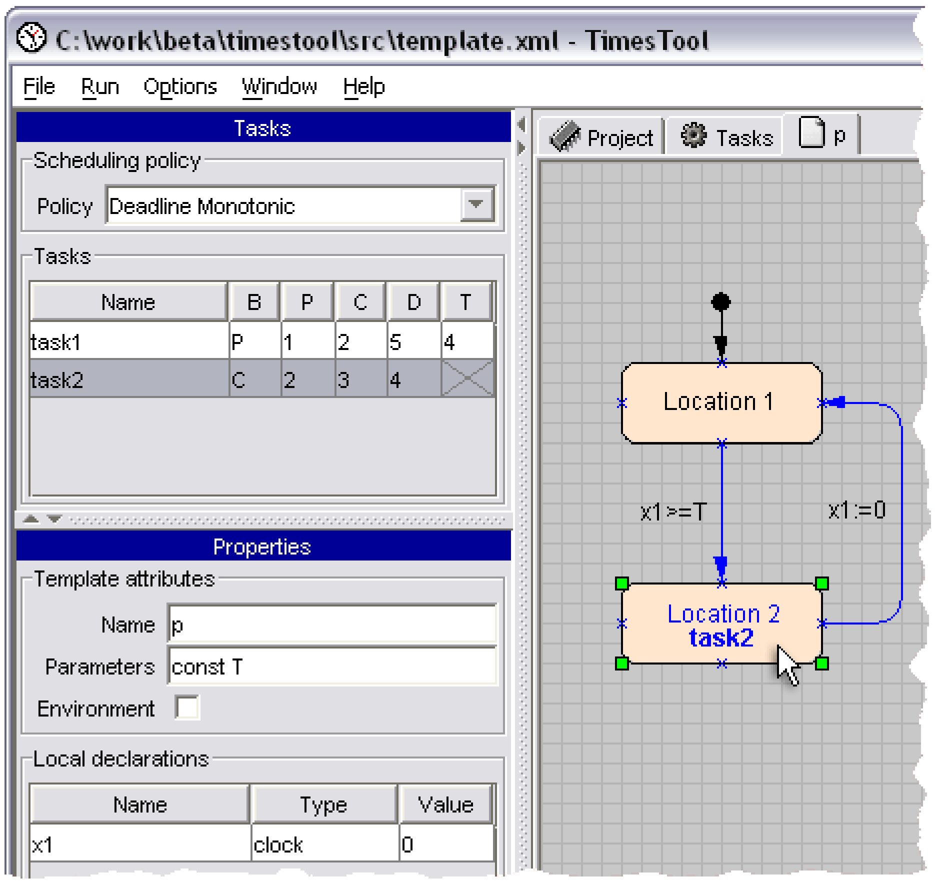
Setting Maximum Number of Task Instances

7. Use the menu `File->Save As...` to save the project to the file named ***tasks.xml***.

8. Use the menu `File->Exit` to close the tool.

- **Creating an automaton template**

Abstract: Create an automaton template ***p(const T)***, as in the figure below. Save the project as ***automaton.xml***.



Scheduling policy

Policy: Deadline Monotonic

Tasks

Name	B	P	C	D	T
task1	P	1	2	5	4
task2	C	2	3	4	

Template attributes

Name: p

Parameters: const T

Environment: ☐

Local declarations

Name	Type	Value
x1	clock	0

The automaton template 'p(const T)'

1. Use the menu `File->Open` to open the project file named ***tasks.xml***.

2. Right-click in the tabbed area. A popup menu will appear, select the menu item `Add template`. A new template, called ***Template1***, will be added to the project.

3. Go to the tab with the ***Template1***. The template properties will appear below the task table. Change the template name to ***p*** and type in ***const T*** in the `Parameters` field.

4. Below the template attributes there is an empty table of local declarations. Right-click below the table headings and select `Add declaration` in the popup menu. A clock named ***x1*** with the initial value 0 will be added to the local declarations table.

5. Right-click in the template drawing area, and select `Create->Location` in the popup menu. A new location named ***Location 1*** will be created. Double-click below ***Location 1*** to create ***Location 2***. You can move locations on the drawing are as well as adjust location label position dragging them.

6. Right-click on the ***Location 1*** and select `Location->Make initial` in the pop-up menu. ***Location 1*** will be marked as initial.

7. Right-click on the ***Location 2*** and select `Arguments->Edit` in the pop-up menu (or you can simply double click on the location instead). An inline editor will appear. Select ***task2*** in the `Task` drop-down menu. This will associate the location with the ***task2*** so that it will be released for execution every time an automaton reaches ***Location 2***. Click outside the inline editor to close it or simply press `Enter` key.

8. Right-click on the blue cross (port) on the lower border of the ***Location 1*** and select `Create transition` in the popup menu (or simply double-click the port). Drag the

transition end to the upper port of the ***Location2*** and left-click on it once. A transition between ***Location1*** and ***Location2*** will be created.

9. Right-click on the transition line and select `Arguments->Edit` in the popup menu. Type in ***x1 >= T*** in the `Guard` field.

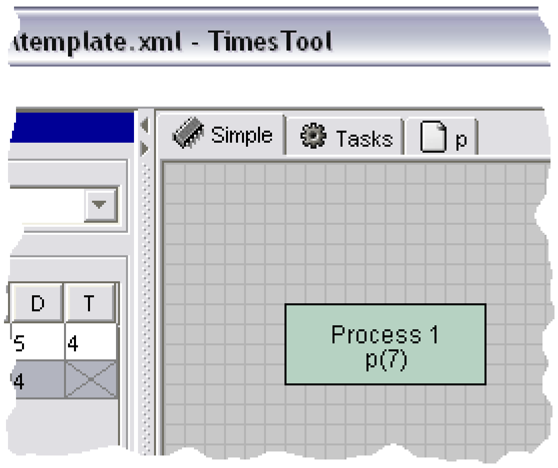
10. Create another transition, from ***Location 2*** to ***Location 1***. During dragging a transition end create two nails (turning points) in order to bend the transition line by left-clicking on the drawing area at their locations. Right-click on the newly created transition and select `Arguments->Edit`. Type in ***x1 := 0*** in the `Assign` field.

11. Use the menu `File->Save As...` to save the project in the file named ***automaton.xml***.

12. Use the menu `File->Exit` to close the tool.

- **Creating a process**

Abstract: Create a process named ***Process 1*** as in the figure below. Save the project as ***process.xml***.



Your First Process

1. Use the menu `File->Open` to open the project file ***automaton.xml***.

2. Click on the project tab ***Simple*** and double-click in its drawing area. A process ***Process1*** will be created.

3. Double-click on the ***Process 1*** to open an inline editor. Select template named ***p*** in the `Template` drop-down menu and type in ***7*** in the `Parameters` field.

4. Use the menu `Run->Syntax checking` to run system syntax checking procedure. A message should appear saying that the system is syntactically correct. If not, check whether you have performed all the steps as described in this tutorial. The error message dialog will describe the errors you have made and help you to locate them.

5. Use the menu `File->Save As...` to save the project to the file named ***process.xml***.

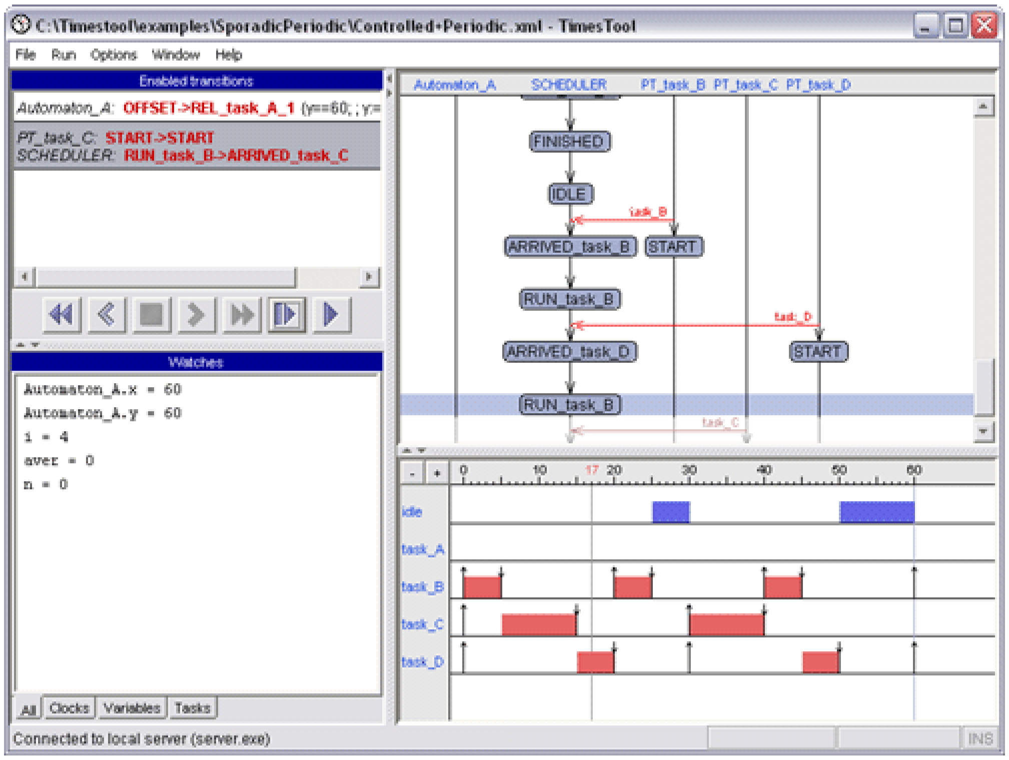
6. Use the menu `File->Exit` to close the tool.

Simulation tutorial

This tutorial describes how a system is simulated in the TIMES simulator.

1. Use the menu `File->Open` to open an example project named ***Controlled+Periodic.xml*** located in the subfolder ***Timestool/ examples/ SporadicPeriodic*** of the TIMES installation.

2. Start the TIMES simulator using the menu `Run->Simulator`.


C:\Timestool\examples\SporadicPeriodic\Controlled+Periodic.xml - TimesTool
File Run Options Window Help
Enabled transitions
Watches
All Clocks Variables Tasks
Automaton_A SCHEDULER PT_task_B PT_task_C PT_task_D
FINISHED
IDLE
task_B
ARRIVED_task_B
START
RUN_task_B
task_D
ARRIVED_task_D
START
RUN_task_B
task_C
0 10 17 20 30 40 50 60
idle
task_A
task_B
task_C
task_D
INS

```
Automaton_A: OFFSET->REL_task_A_1 (y==60; ; y=
PT_task_C: START->START
SCHEDULER: RUN_task_B->ARRIVED_task_C
```

```
Automaton_A.x = 60
Automaton_A.y = 60
i = 4
aver = 0
n = 0
```

Connected to local server (server.exe)

The TIMES Simulator

3. Simulation in **step-by-step** mode is performed manually. Select one of the enabled transitions and press the button to make one simulation step.
Note: When selecting an enabled transition you can see the next predicted system state at the bottom of the Message Sequence Chart below the violet bar drawn with lighter colors.

4. The **random run** simulation mode is activated by pressing the button. In this mode transitions are chosen randomly and the simulator continuously performs one simulation step after another. To stop simulation press the button.

5. You can reset the simulatior to its initial state pressing the button. When there is a trace in the Message Sequence Chart you can move along it back and forth, observing the system internal state and variable values in all simulator views, using and buttons. The button sets the simulator to the end of the trace from where you can continue current simulation.
Note: If you continue simulation somewhere from the middle of the existing trace, the tail

of this trace will be erased.

6. You can also navigate along the trace by clicking either on the Message Sequence Chart levels or on the Gantt Chart time points.

7. In the Message Sequence Chart process states are hidden (replaced by a thin vertical line) if they have the same names as the name of a state since the last state change. To view the state names of all processes at a certain level of the chart move over the pointer to this level.

8. You can switch back to the editor view preserving the state of the simulator by using the menu `Window->Editor`. In order to return to the simulation use menu `Window->Simulator`. *Note:* If you rerun the simulator from the editor via menu `Run->Simulation`, the state of previous simulation will be reset and the system being edited will be uploaded to the simulator again.

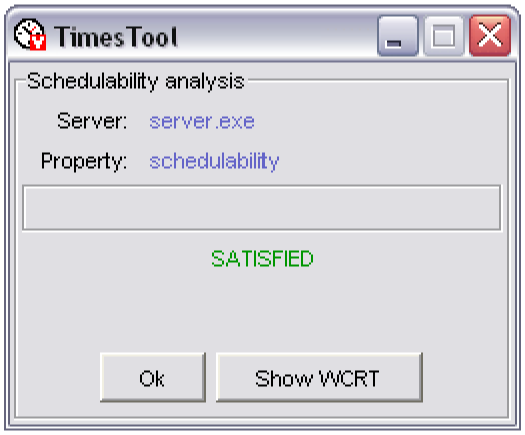
9. You can close the simulator using menu `File->Close Simulator`.

Schedulability analysis tutorial

This tutorial describes how the schedulability analysis is performed in TIMES.

1. Use the menu `File->Open` to open a project to be analysed named ***Controlled+Periodic.xml*** located in the subfolder ***Timestool/ examples/ SporadicPeriodic*** of the TIMES installation.

2. Start the schedulability analysis using menu `Run->Schedulability Analysis`. A new window will pop up showing location of the server being used and an activity indicator. An answer `SATISFIED` or `NOT SATISFIED` is returned by the time analysis has been performed.



Schedulability analysis

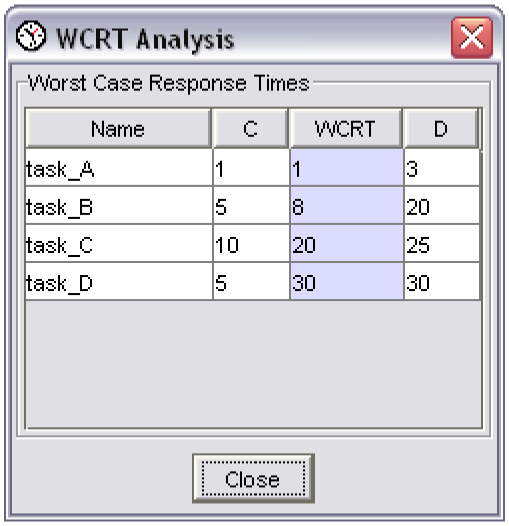
Server: server.exe

Property: schedulability

SATISFIED

Result of Schedulability Analysis

3. In our case the answer is `SATISFIED`, which means that all the tasks in the system managed to meet their deadlines in all possible execution traces. In this case one can observe worst-case response time of each task, i.e. the lowest integer value greater or equal to the longest response time of a task. Press `Show WCRT` button to open a window containing those values.



Name	C	WCRT	D
task_A	1	1	3
task_B	5	8	20
task_C	10	20	25
task_D	5	30	30

Worst Case Response Times

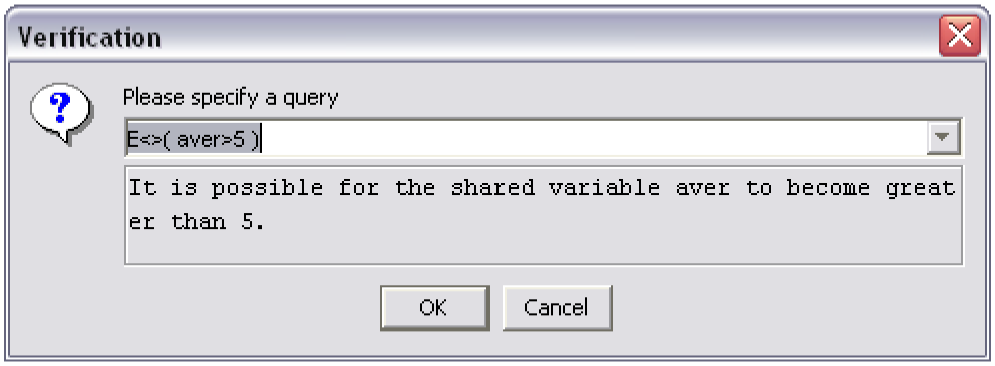
Clearly, the WCRT value should be greater or equal than the execution time and less or equal the the deadline of a task.

Verification tutorial

This tutorial describes how model properties are verified in TIMES.

1. Use the menu `File->Open` to open an example project named ***Controlled+Periodic.xml*** located in the subfolder ***Timestool/ examples/ SporadicPeriodic*** of the TIMES installation.

2. Open the verification dialog using menu `Run->Verification`. In the dialog specify the property `E<>(aver>5)` secting it from a drop-down menu and press the `OK` button to start verification. The query syntax is given in the Languages chapter.

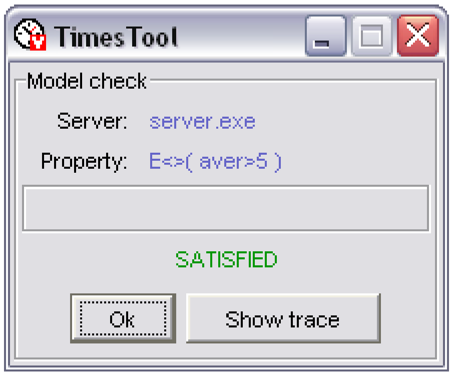


```
It is possible for the shared variable aver to become great
er than 5.
```

Specifying a Property to Verify

3. After verification is done you are provided with the result: `SATISFIED`, if the property holds, `NOT SATISFIED` if not and `MAYBE SATISFIED` if *Over Approximation* or *Under Approximation* is used (see Configuration chapter for information about configuring the verifier).

4. If the property has not been satisfied and there is a counterexample, you can load the trace containing it into the simulator by pressing the `Show trace` button. The same holds for the traces generated while verifying "***E<>***" and "***A[] not***" properties.



```
Server:   server.exe
Property: E<>( aver>5 )

SATISFIED
```

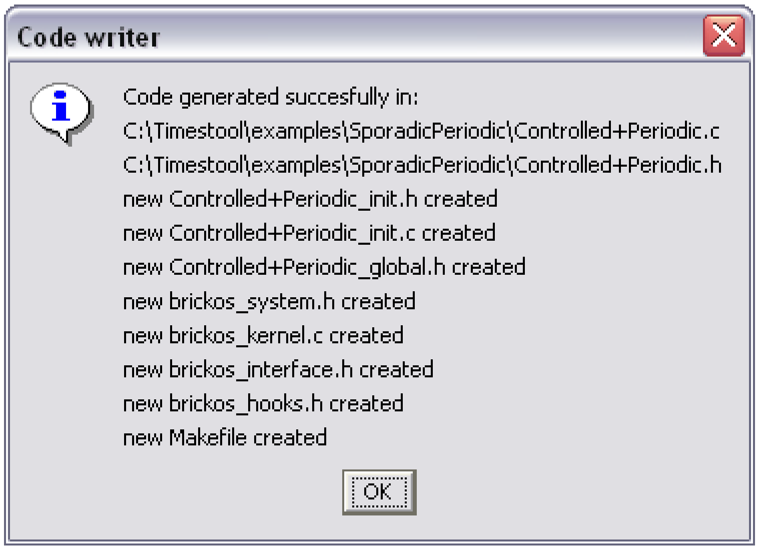
The Result of Property Checking

5. You can start several verification processes simultaneously. Every verification process uses a separate connection to the verifier.

Code synthesis tutorial

This tutorial shows how to synthesise executable code from your models in TIMES.

1. Use the menu `File->Open` to open an example project named ***Controlled+Periodic.xml*** located in the subfolder ***Timestool/ examples/ SporadicPeriodic*** of the TIMES installation.



```
Code generated succesfully in:
C:\Timestool\examples\SporadicPeriodic\Controlled+Periodic.c
C:\Timestool\examples\SporadicPeriodic\Controlled+Periodic.h
new Controlled+Periodic_init.h created
new Controlled+Periodic_init.c created
new Controlled+Periodic_global.h created
new brickos_system.h created
new brickos_kernel.c created
new brickos_interface.h created
new brickos_hooks.h created
new Makefile created
```

Generating Code from a Model

2. Start the code generation using menu `Run->Code synthesis`. In the newly opened window you can see the names of the files that have been generated.

3. See Configuration chapter for more information about setting up the code generator and Synthesis to learn how to compile and run the generated code.

Editor

Concepts

- **Task**

A *task* is a piece of code, as in general real-time scheduling theory. It has properties such as worst case execution time, deadline, and possibly others. The *task behavior* defines how a task is released: periodically with the fixed period, by entering a control automaton state or periodically with the given minimal inter-arrival time (sporadically).

- **Automaton Template**

An *automaton template* is an uninstantiated timed automaton with tasks and possibly some parameters. States can be associated with tasks and have invariants whereas transitions have guards, synchronization and assignments as arguments. More information about timed automata with tasks can be found in the paper "Timed Automata with Asynchronous Processes: Schedulability and Decidability" on the TIMES publications page.

- **Process**

A *process* is a building block of the system, an automaton template instantiated with the given arguments. When the process instance enters a state with a task assotiated, an instance of that task is released for execution.

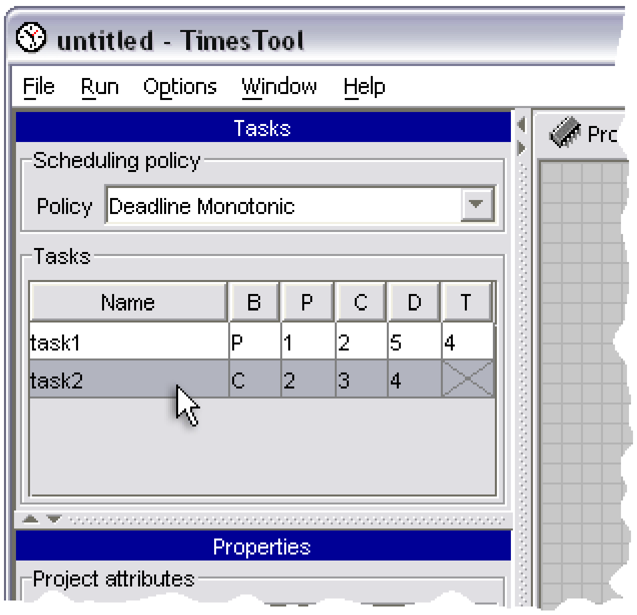
Overview of the TIMES editor

- **Tabbed Area**

We refer to the large area to the right as the *tabbed area*. At the top of the tabbed area there are *tabs*: the *project tab*, the *tasks tab* and the *template* tabs, one for each defined automaton template.

- **Task Table**

The task table contains information about tasks in the system being modelled. Tasks can be added or removed from the task table, and their parameters can be changed also. The scheduling policy is selected from a corresponding combobox on the top of the task table.



Scheduling policy

Policy: Deadline Monotonic

Tasks

Name	B	P	C	D	T
task1	P	1	2	5	4
task2	C	2	3	4	

The Task Table

There are three possible selections for the scheduling policy:

Deadline Monotonic
Task priorities are assigned according to deadlines, with the higher priority for the shorter deadline.

Rate Monotonic
Task priorities are assigned according to periods, with the higher priority for the shorter period.

User-defined Priorities
Task priorities are manually set.

You can add a task to the task table by right-clicking below the table heading. A popup menu appears, select `Add task` and a new task will be added. Remove a task by right-clicking on a line containing task, and select `Remove task(s)` in the menu.

The task parameters that can be edited directly in the task table are:

Name
The task name.

B (Behavior)
The behavior of a task, indicating how the task instances are released. The possible values are `C` for controlled, `P` for periodic, and `S` for sporadic. The release of a controlled task is specified by an automaton, periodic tasks are released periodically with the period specified in the column `T`, sporadic tasks are released quasi periodically with the minimum inter-arrival time specified in the column `T`.

P (Priority)
The priority of the task (bigger numbers correspond to higher priorities).

C (Execution time)
Time required for a task to complete its execution in a worst case.

D (Deadline)
Task execution deadline.

T (Period)
Period (time interval between releases of two sequential task instances) for periodic tasks and minimal inter-arrival time for sporadic tasks.

- **Properties or Attributes**

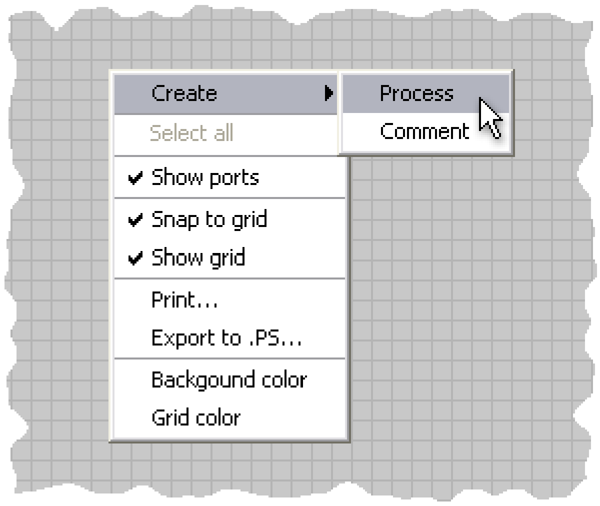
  In the lower left part of the main window there is a property panel. The contents of this panel is changed depending on the currently selected tab in the tab area. If the project tab is selected, there is an edit box for the project name, and a global declarations table. If the tasks tab is selected, and a task is selected in the task table, there is a table with all the task parameters. If a template tab is selected, there are edit boxes for the template name and parameters, a check-box showing whether the template represents environment, and a local declarations table.

Project tab

When the *project tab* is selected, you can create and edit system processes and add comments in the project *drawing area*.

- **Creating a process**

  To create a new process right-click on the drawing area where you want the process symbol to appear, and select `Create->Process` in the popup menu.

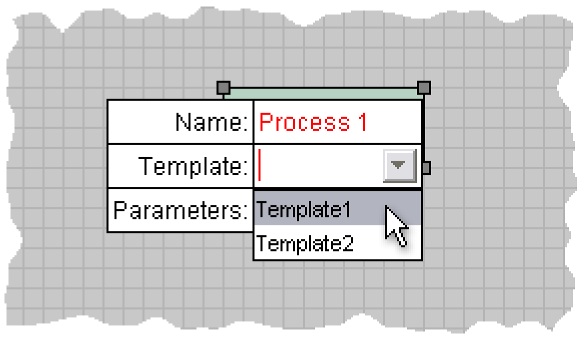


Creating a process

You can also create a process by double-clicking on the empty part of the drawing area.

- **Editing process arguments**

  To modify process arguments double-click on the process, or right-click on it and select `Arguments->Edit` in the popup menu. An inline editor will appear containing the following fields: `Name`, `Template`, and `Parameters`.



Editing process arguments

The `Name` field contains the name of an instantiated template automaton specified in the `Template` field. If you have already created templates before, simply choose the name of a template in a combobox. The `Parameters` field contains actual parameter list being passed to the template during process instantiation.

- **Creating a comment**

  Comments improve readability of your models. To create a comment right-click on the drawing area where you want the comment to appear, and in the popup menu select `Create->Comment`.

- **Editing a comment**

  Double-click on the comment, or right-click and select `Arguments->Edit` in the popup menu to start modifying comment text.

All the graphical elements that are created in the drawing area have additional formatting attributes such as colors, font styles etc. that can also be modified in order to make your model layout look nicer. This also applies to all the drawing areas described below.

Tasks tab

The major part of a tasks tab contains the task code editor. It supports customizable syntax highlightning for the C-style program text. The task code put in this editor is used by the code generator during creation of an executable program out of your model. The pointer to the file containing a piece of code representing a task is specified in the corresponding field above the editor.

There is also *task interface* field, where an expression should be entered showing how the task code influence internal model variables by the end of it's execution.

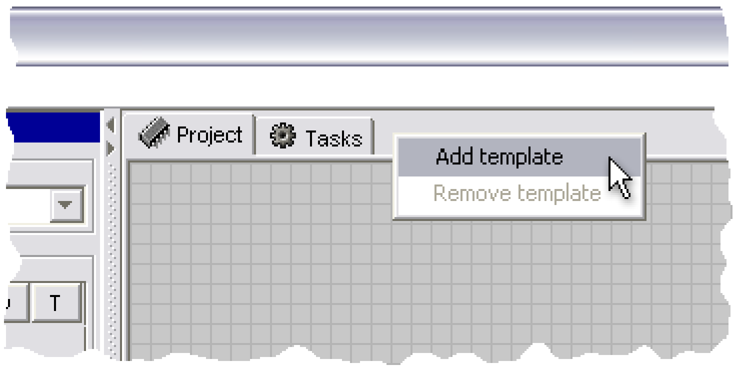
When the *tasks tab* is selected you can also view and edit task attributes in the *Attributes* panel, by selecting a task in the task table.

Template tab

Template tabs contain automata graphical editors similar to the project graphical editor. Use those to create and modify timed automata of particular templates. As any other state chart template automaton consists of locations (states) and transitions between them. For your convenience there is also possible to add connectors and comments.

- **Adding a template**

  To create a new automaton template, right-click on the tab area, and select `Add template` in the popup menu.



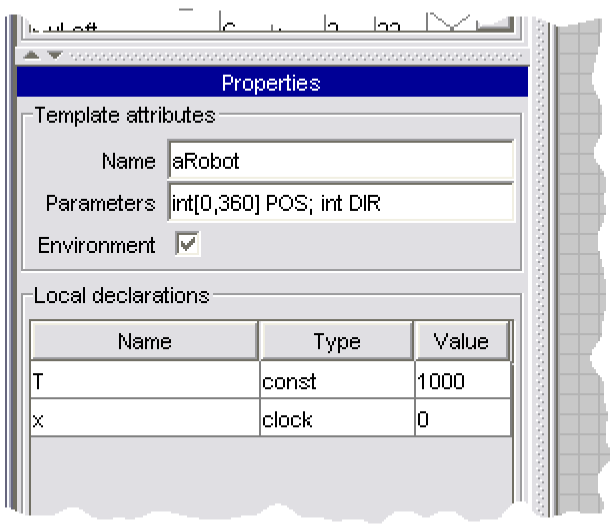
Adding a new template

- **Removing a template**

To remove a template, right-click on a template tab, and select `Remove template` in the popup menu. A confirmation dialog will appear. Choose "Yes" to remove a template.

- **Template properties**

Below the task table the properties of the automaton template appear when a tab with that template is active.



Name: aRobot
Parameters: int[0,360] POS; int DIR
Environment: ✓

Name	Type	Value
T	const	1000
x	clock	0

Template properties

Use the properties panel to modify the name of a template, define its formal parameters, specify whether the template is a part of an environment and declare local variables.

- **Creating a location**

To create a new location right-click on the drawing area where you want the location to appear, and select `Create->Location` in the popup menu. Another way to do this is to simply double-click on a drawing area where you want the location to be created.

- **Deleting a location**

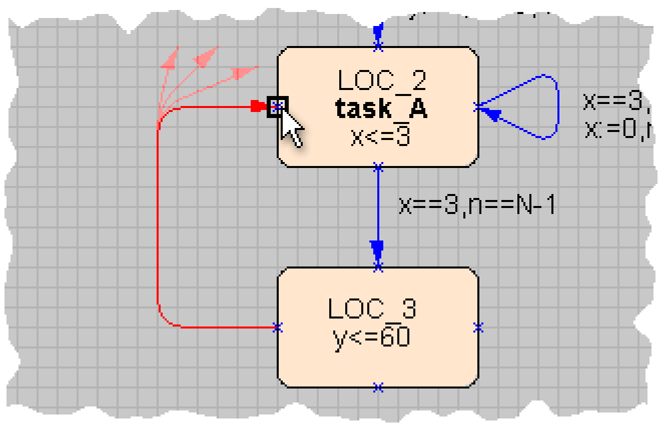
Select the location you want to delete, right-click on it, and select `Delete` in the popup menu. Another way to do this is to select the location and press the `DEL` key. You can also select and delete a group of locations at a time. To select a group drag a frame with your pointing device or left-click on locations while holding the `CTRL` key.

- **Editing location arguments**

To edit location arguments right-click on the location, and select `Arguments->Edit` in the popup menu. An inline editor will appear containing the following fields: `Name`, `Task`, and `Invariant`. The `Name` field contains location name, in the `Task` field a name of the task associated with this location is specified (if any), and the `Invariant` field conatins an invariant expression.

- **Creating a transition**

To create a transition between locations right-click on one of the ports (blue cross on the location border) of the source location, and select `Create transition` in the popup menu. Another way to do that is by simply double-clicking on a source location port.



Creating a new transition

Move the pointer to the destination location port left-clicking at the positions where you want to put nails (turning points) and finally left-click on a destination port. The transition creation process will be automatically terminated. Every transition should begin and end at a location port. To create a self-loop use the same or different ports of the same location. You can also reconnect transitions to different locations after creating them by selecting and dragging edge nails. Note that a disconnected transition is drawn with the red color.

- **Deleting a transition**

To delete a transition select it first, right-click on it, and select `Delete` in the popup menu. Another way to do this is to select the transition and press the `DEL` key.

- **Editing transition arguments**

To edit transition arguments right-click on the transition, and in the popup menu select `Arguments->Edit`. An inline editor will appear containing the following fields: `Name`, `Guard`, `Sync`, and `Assign`. The `Name` field contains transition name. `Guard` is an expression that has to be satisfied in order to take this transition. `Sync` is the name and direction of a synchronization channel. Use a combobox to choose between one of the declared channels. The `Assign` field is used to specify assignments that are performed if the transition is taken.

- **Creating a connector**

To create a connector right-click on the drawing area where you want the connector to appear, and select `Create->Connector` in the popup menu. Connector is a piece of syntactical sugar since semantically connector it is a committed location that should be passed in zero time only if both incoming and one of outgoing transitions are enabled.

- **Deleting a connector**

Select the connector you want to delete, right-click on it, and select `Delete` in the popup menu. Another way to do this is to select the connector and press the `DEL` key.

- **Comments**

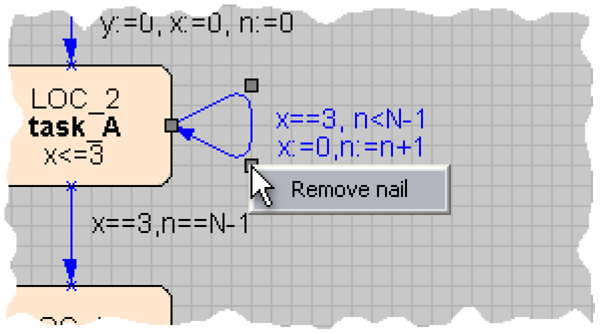
Comment operations are the same as in the project editor.

- **Adding a nail**

Right-click on a transition in a place where you want to add a new nail, and select `Add nail` in the popup menu.

- **Removing a nail**

Select a nail, right-click on it, and select `Remove nail` in the popup menu.



Removing transition nail

TIMES menus

- **File**
  - **New**

    Create a new project.
  - **Open...**

    Open a project file.
  - **Save**

    Save the active project file.
  - **Save As...**

    Save the active project to a file specified using a standard file dialog box.
  - **Export to...**

    Export the model to either Uppaal .ta file or printable postscript document.
  - **Print...**

    Print the grahical parts of the projects.
  - **Close**

    Close the active project windows.
  - **previously opened files**

    Opens a previously opened project.
  - **Exit**

    Exit from the TIMES tool.

- **Run**
  - **Syntax checking**

    Perform a syntax check of a project.
  - **Simulation**

    Start the simulator, as described in the simulator chapter.
  - **Schedulability analysis**

    Start the schedulability analysis.
  - **Verification**

    Verify a property of a model as described in the analysis chapter.
  - **Code synthesis**

    Generate the source code for the active project, as described in the code synthesis chapter.
  - **Compile**

    Compile the source code generated by a code generator.
- **Options**
  - **Configuration...**

    Modify the global settings of the TIMES tool as described in configuration chapter.
- **Window**
  - **Editor**

    Show the editor window.
  - **Simulator**

    Show the simulator window (if the simulator has been started).
  - **Response times**

    Show the window with the worst case response times of tasks evaluated during schedulability analysis.
- **Help**
  - **About...**

    Display a dialog box with the program version, build and copyright notice.

Simulator

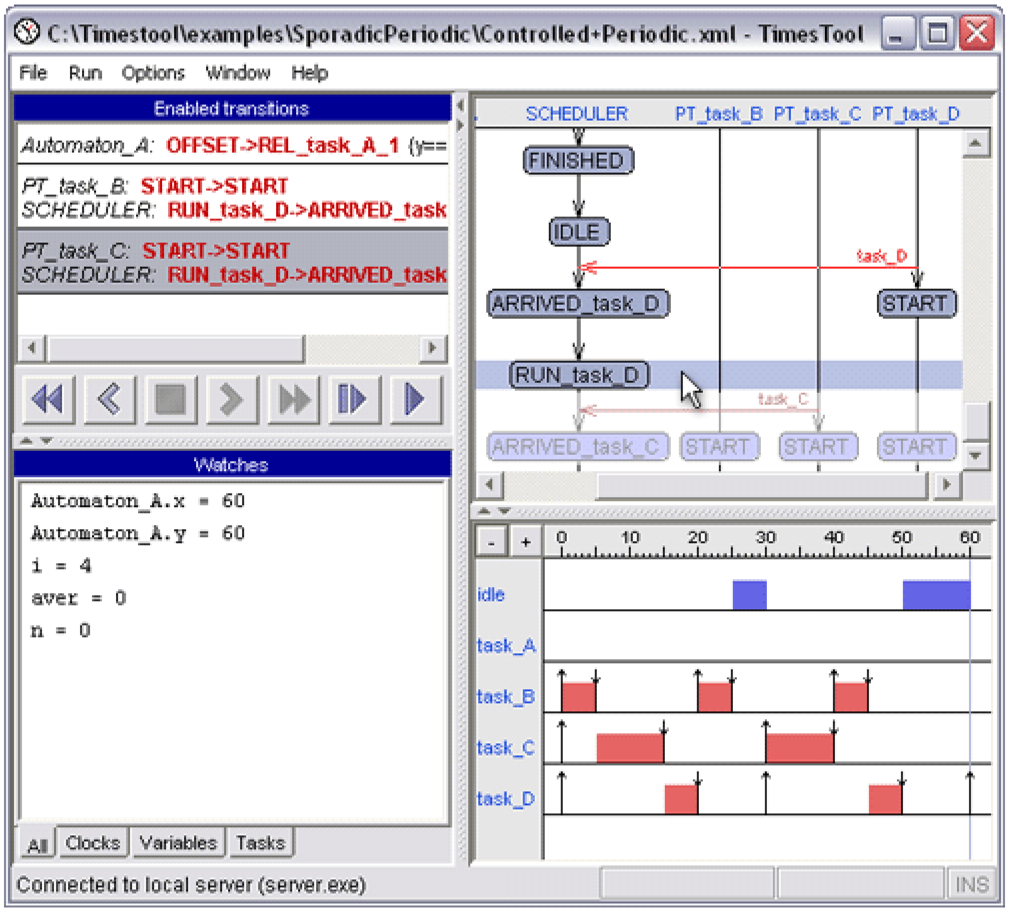
The simulator window is divided into four sections:

- Enabled transitions part is in the upper left corner showing the transitions that the system can take from the given state. You can choose the transition to be taken in the step-by-step manual simulation mode. In the random run simulation mode the transitions are randomly chosen.

- Watches part is right below **Enabled transitions** part. Here you can observe the values of clocks, variables as well as task and processor utilization factors at any time during simulation.

- The upper right part is displaying the Message Sequence Chart. Vertical lines correspond to the system process control flows showing their current states in rounded rectangles. Horizontal arrows are interprocess synchronizations performed via named channels.

- The lower right part is a Gantt Chart showing the timeline where you can see the tasks being executed and a processor idle time.



```
Automaton_A:  OFFSET->REL_task_A_1  (y==
PT_task_B:  START->START
SCHEDULER:  RUN_task_D->ARRIVED_task
PT_task_C:  START->START
SCHEDULER:  RUN_task_D->ARRIVED_task
```

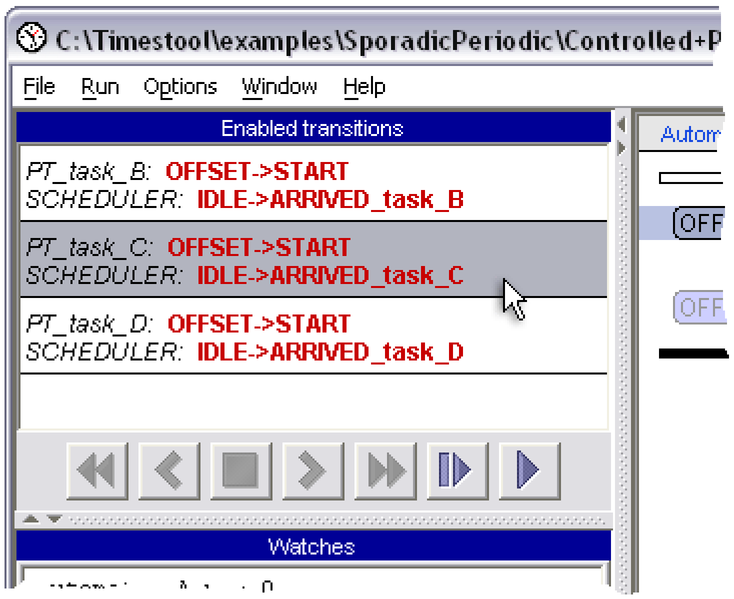
```
Automaton_A.x = 60
Automaton_A.y = 60
i = 4
aver = 0
n = 0
```

```
Connected to local server (server.exe)
```

Times Simulator

Enabled transitions

When simulating only one execution trace within the tree is explored. On every step of simulation there can be several enabled transitions, different ways to go, due to non-determinism. These possibilities are shown in the Enabled Transitions view.



PT_task_B: OFFSET->START
SCHEDULER: IDLE->ARRIVED_task_B
PT_task_C: OFFSET->START
SCHEDULER: IDLE->ARRIVED_task_C
PT_task_D: OFFSET->START
SCHEDULER: IDLE->ARRIVED_task_D

Enabled transitions

The buttons below the list of enabled transitions are used to control the simulation process and navigate through the trace being explored. There are two modes of simulation: **step-by-step** simulation and **random run** initiated by means of control buttons and correspondingly.

Simulation in **step-by-step** mode is performed manually by selecting one of the enabled transitions and pressing the button to make the next simulation step.
Note: When selecting an enabled transition you can see the next predicted state of the system at the bottom of the Message Sequence Chart below the violet bar drawn with brighter colors.

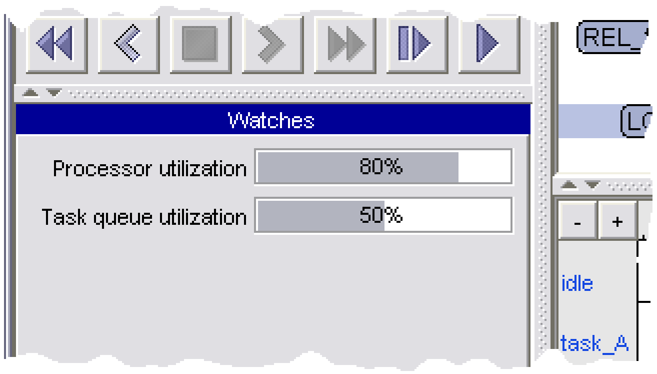
In the **random run** mode transitions are chosen randomly and the simulator continuously performs one simulation step after another. You can stop the simulation at any time by pressing the button.

When you have got a trace you can move along it back and forth in the Message Sequence Chart using and buttons. Being at any point of the trace you can observe the state of the system together with the variable values. The button moves the simulator to the end of the trace that is exlored so far. It is possible to continue simulation from any point withing the explored trace. In this case the tail of this trace will be erased.

If you press the button the simulator will reset its state to initial as if you have just started it.

Watches

In this section you can observe values of variables and clocks as simulation goes. You can choose the view to see either only clocks, only variables or both together. There is also a fourth view with two progress bars in it. The first progress bar is showing the processor utilization, i.e. how busy is the processor executing your model tasks. This is an average value taken from the beginning of the current execution trace. The second bar is showing momentary task queue utilization, i.e. how many task instances are currently in the queue relative to the queue capacity (sum of `Max # of tasks` parameter for all tasks).



Processor and task queue utilization

Message Sequence Chart

Traces in TIMES are represented by Message Sequence Chart (MSC), a UML-like sequence diagram showing concurrent execution of processes and their intercommunication. The MSC view is quite interactive: you can observe the whole execution trace, move to particular states in it, hide/show different processes etc.

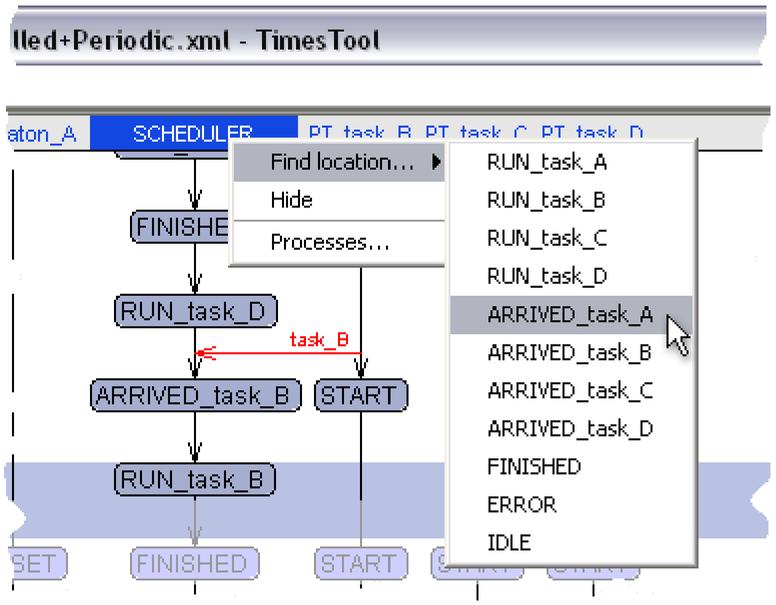
In the Message Sequence Chart process states are hidden (replaced by a thin vertical line) if they have the same names as the name of a state since the last state change. To view the state names of all processes at a certain level of the chart move over the pointer to this level.

- **Menus**

  If you move the pointer over a process name in MSC header, it will become high-lighted. Right-click on it and a menu containing the following items will appear.

  - **Find location...**

    Allows you to find the next occurrence of the location name of the selected process in the whole trace. If location is found the MSC cursor (violer bar) jumps to it. Otherwise if the end of the trace is reached you will be asked to continue search from its beginning.



Finding location in MSC trace

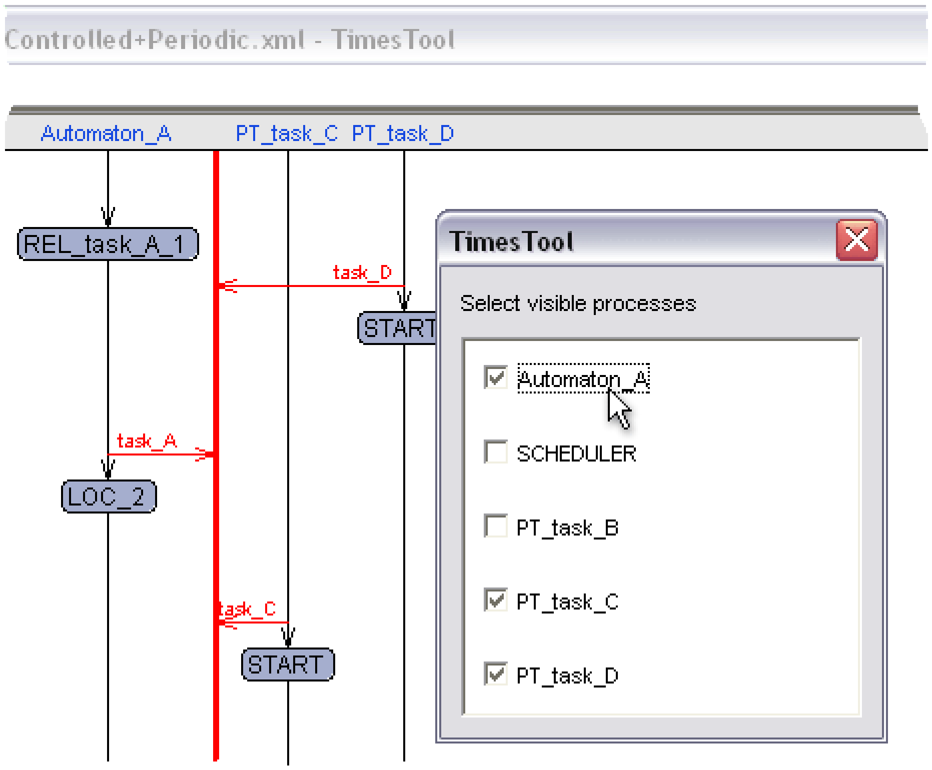
If one occurrence of the location name was found, you can easily search for the next/previous one using menues `Next 'location'` and `Previous 'location'`.

- **Hide**

  Hides the whole process substituting it with the thick red line in the MSC view. All communications between visible and hidden processes are still shown as outgoing and incoming into the red vertical line horizontal arrows. It is also possible to hide several going one after another processes into one line. Hidden processes can be shown again using menu `Processes...`.

- **Processes...**

  Opens a window where you can select which processes to show in the MSC view. Simply check the boxes of the processes you want to make visible.



[✓] Automaton_A
[ ] SCHEDULER
[ ] PT_task_B
[✓] PT_task_C
[✓] PT_task_D

Selecting processes visible in MSC

You can also access this menu item right-clicking at any point of the MSC header, which is useful if all the processes have been accidentially hidden.

Gantt Chart

This section has a form of Gantt Chart visualizing executed tasks, where the horizontal axis represents time. The top line is associated with the processor idling, i.e. blue rectanges appearing on it denote periods when the processor doesn't execute any task. On the lines below the execution of tasks is drawn. Tasks sorted on a Gantt Chart according to their priorities with the higher priority task depicted on the top line. The black up-arrow denotes a task release time, red rectangle corresponds to the task execution and the down-arrow shows that the task has finished its execution.

Similarly to the MSC view Gantt Chart is also interactive in the sense that you can move the pointer over the timepoint you are interested in and jump to it by left-clicking. The scale of the timeline is adjustable. Use [+] and [-] buttons in the upper left corner to change the scale.

Simulator menus

- **File**
  - **Close simulator**

    This closes the simulator. If you just want to switch view to the editor, you should use menu `Window->Editor`.

- **Run**
  - **Syntax checking**

    Performs a check of system syntax.

  - **Simulation**

    Starts the simulator, as described in the simulator section.

  - **Schedulability analysis**

    Determines whether the system is schedulable.

  - **Verification**

    Displays a dialog box where you can enter the system property to be verified, as described in the analysis section.

  - **Code synthesis**

    Generates source code, as described in the code synthesis section.

  - **Compile**

    Compiles generated code, as described in the code synthesis section.

- **Options**
  - **Configuration...**

    Shows the configuration dialog box, as desribed in the configuration section.

- **Window**
  - **Editor**

    Shows the editor window.

  - **Simulator**

    This option is not available in the simulator view.

  - **Response times**

Shows the window with the response times resulting from the schedulability analysis.

- **Help**
  - **About...**

    Displays the dialog box with the version, copyright notice, and a web address of the tool home Page.

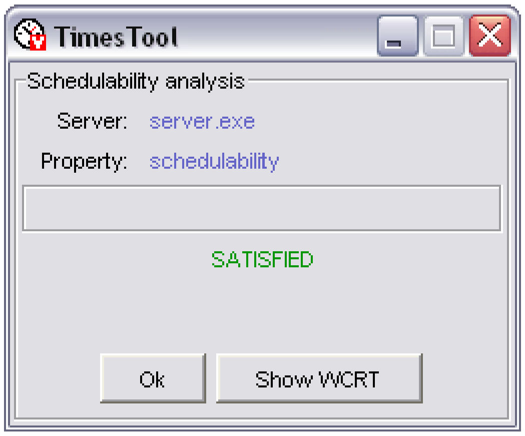
Analysis

The TIMES tool supports two kinds of analysis: schedulability analysis and verification of properties specified by temporal formulas.

Schedulability analysis

The schedulability analysis in TIMES tool is based on the reachability analysis of the scheduler automaton that is constructed according to the chosen scheduling policy. An automaton is schedulable if there exists a (preemptive or non-preemptive) scheduling strategy such that all possible sequences of events accepted by the automaton are schedulable in the sense that all associated tasks can be computed within their deadlines.

To run the Schedulability analysis select the menu item `Run->Schedulability analysis`. When the computation is finished the property `schedulability` is shown to be `SATISFIED` or `NOT SATISFIED`.



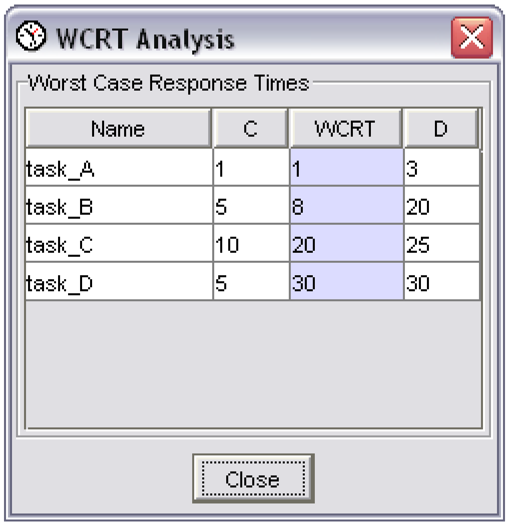
Server: server.exe

Property: schedulability

SATISFIED

Schedulability Property is `SATISFIED`

Once schedulability analysis has been performed and the result is positive you can observe the Worst Case Response Times (WCRT) of the tasks in the system. Click on the `Show WCRT` button or use menu `Window->Response times` to open a window showing worst case response times.

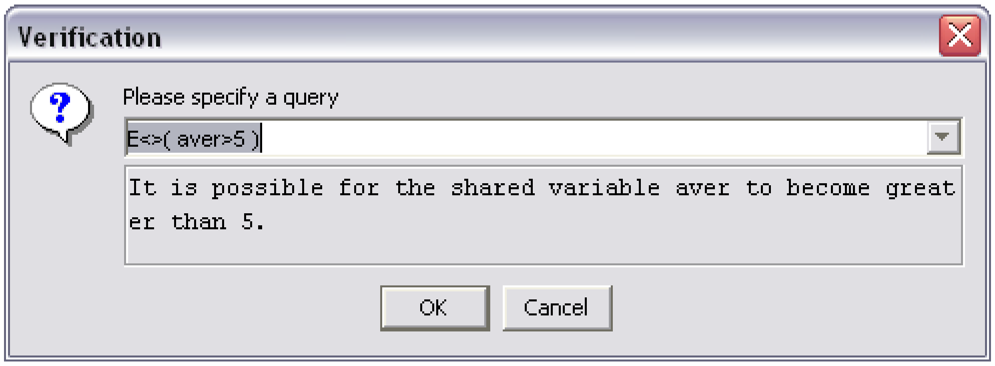


Name	C	WCRT	D
task_A	1	1	3
task_B	5	8	20
task_C	10	20	25
task_D	5	30	30

Worst Case Response Times

Verification

Using the verification you can check properties of your system specified by temporal formulas. The complete syntax of the formulas is given in the Languages chapter. To run verification select the menu item `Run->Verification`. In the dialog that appears you can select a predefined property (read from the .q file, which has the same name as the name of the .xml file), or write your own property.

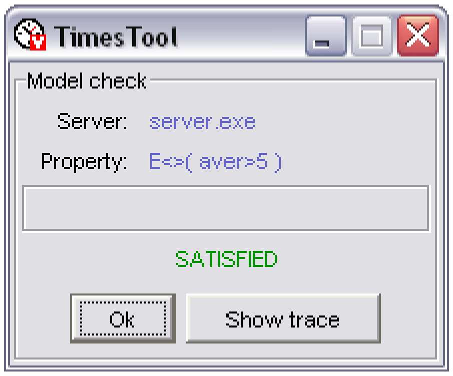


E<>(aver>5)

```
It is possible for the shared variable aver to become great
er than 5.
```

Entering a Property

Click `OK` to check the specified property. A result dialog appears, with a progress bar. When the progress completes, the result is displayed as *SATISFIED*, *NOT SATISFIED* or `MAYBE SATISFIED` if *Over Approximation* or *Under Approximation* was used (see Configuration chapter for information about configuring the verifier).



Server: server.exe

Property: E<>(aver>5)

SATISFIED

The Result of Property Checking

If the property has not been satisfied and there is a counterexample, you can load the trace containing it into the simulator by pressing the `Show trace` button. The same holds for the traces generated while verifying "***E<>***" and "***A[] not***" properties.

Code Synthesis

TIMES provides automatic generation of the executable code from the system description. Currently the only supported target is `Hitachi H8` processor of a LEGO Mindstorms RCX brick running brickOS 0.2.6. (Note that brickOS was formerly known as legOS and that the version supported by TIMES was released under the old name. The pre-releases of brickOS, version 0.2.6.9 etc. are not supported).

Installing brickOS

To use the code generation for a RCX brick you need to have the brickOS operating system installed on the brick. You will find instructions on how to get and install operating system from the brickOS website.

Here we only provide a brief summary of the installation process.

- **On Linux/Solaris :**
  - Install a cross compiler for Hitachi H8 (see the brickOS site for further instructions).
  - Download brickOS from legos.sourceforge.net.
- **On Windows:**
  - Install the Cygwin environment from www.cygwin.com.
  - Download and install a pre-built cross compiler from Hitachi (the H8 GNU Tool). Note that brickOS 0.2.6 does not work with GCC from the 3.x series.
  - Download brickOS from legos.sourceforge.net.

Configuring brickOS:

Open the file Makefile.common in the brickOS root directory. About line 116 there is a line:

```
CFLAGS=$(COPT) $(CWARN) $(CINC)
```

change it to:

```
CFLAGS=$(COPT) $(CWARN) $(CINC) $(CMACROS)
```

Configuring TIMES:

- Make note of the directory where you have installed brickOS.
- Open the Configuration window via menu `Options->Configuration...`
- In the tab `Code generator` enter the name of the directory where brickOS is installed into the field `brickOS directory`.

See the Configuration chapter to learn more about available options.

Generating Code

To generate code from a system description use the menu command `Run->Code synthesis`. This will generate several files in the directory specified in the base name. The code generation does not require brickOS to be installed.

What are the files generated?

- **Makefile**
- **brickos_kernel.c**
  The kernel code interpreting an automata structure.
- **brickos_system.h**
  Type and macros definitions.
- **brickos_interface.h**
  Kernel API definition.
- **brickos_hooks.h**
  Definition of hooks executed at events in the kernel (used by the logging module).
- ***basename*_init.c**
  A stub for user hardware initialization code.
- ***basename*_init.h**
  API definition of the initialization code.
- ***basename*_global.h**
  An empty file where the shared global variables are be defined, if they are not defined in the model.
- ***basename*.h**
  Generated definitions of the constants used in the code (e.g. number of transitions).
- ***basename*.c**
  The main code generated including the tasks and the automata structure.

Compiling Generated Code

To compile the generated code you can either use the GUI or a separate shell. The compilation requires legOS and the cross compiler to be installed. To compile from the GUI use the menu option `Run->Compile`. To compile, using a separate shell, go to the output directory and enter execute the following command:

```
bash$ make
```

Uploading and Executing Compiled Binaries

To upload the generated and compiled code to the RCX-brick you must connect and switch on the IR-tower. Place the brick in front of the tower and turn it on. To upload binaries to the RCX brick execute the following command:

```
bash$ make upload
```

To execute an uploaded program simply press the `Run` button on a brick.

Logging

If the code is generated with the logging option a module that sends LNP messages at events in the kernel is included. The logged events are:

- Discrete transition.
- Task release.
- Task start.
- Task end.

Languages

This chapter contains BNF grammars of languages used in the TIMES tool. Note that words made of capital letters represent non-terminals.

Modeling Language

The input language of the TIMES tool is a network of timed automata extended with real-time tasks. Each timed automata is represented as a process instantiated from a template with the set of arguments. In addition there is a task table describing various task parameters.

- **Declarations**

Declarations can be either local or global. Local declarations relate to the different templates while global ones belong to the whole system. Every declaration must have an identifier, type and optionally an initial value. An identifier must satisfy the following regular expression:

```
                 ID:   [a-zA-Z]([a-zA-Z0-9_])*
```

In this document non-terminals `CLOCK, INTEGER, CHANNEL, URGENT_CHANNEL, EXTERNAL_CHANNEL and CONSTANT` denote identifiers of the respective declaration types. The valid declaration types are:

```
   DECLARATION_TYPE:   clock
                     | int
                     | int[CONST_EXPR,CONST_EXPR]
                     | chan
                     | urgent chan
                     | extern chan
                     | const
```

where **int[...,...]** is a bounded integer with lower and upper bounds defined as constant expressions. Constant expressions have the following syntax:

```
         CONST_EXPR:   CONST_TERM{+|-}CONST_TERM
         CONST_TERM:   CONST_UNAR{*|/}CONST_UNAR
         CONST_UNAR:   CONST_ELEM
                     | -CONST_ELEM
         CONST_ELEM:   NATURAL
                     | CONSTANT
                     | (CONSTANT_EXPR)
            NATURAL:   ([0-9])+
```

Declaration identifiers of types **`clock`**, **`int`** and **`int[,]`** defined:

```
        CLOCK_ARRAY:   ID[CONST_EXPR]
      INTEGER_ARRAY:   ID[CONST_EXPR]
```

represent arrays of clocks and integers respectively. The size of array is set equal to the value of the constant expression given in square brackets. Declaration initial value is specified as a constant expression. In case of arrays the same value is assigned to all the elements in the array.

- **Processes and Templates**

Processes are templates instantiated with the set of arguments. Process has the following attributes:

```
       PROCESS_NAME:   ID_WITH_SPACES
   PROCESS_TEMPLATE:   ID
  PROCESS_ARGUMENTS:   [ID(,ID)*]
```

where ID_WITH_SPACES is an identifier with spaces allowed:

```
     ID_WITH_SPACES:   [a-zA-Z]([a-zA-Z0-9_ ])*
```

Note that during process instantiation spaces in the process name are replaced with underscores. Be sure that you use underscores instead of spaces specifying properties in verifier.

Attributes of a template include the template name and the list of formal parameters, defined as following:

```
      TEMPLATE_NAME:   ID
TEMPLATE_PARAMETERS:   [TEMPLATE_PARAMETER(;TEMPLATE_PARAMETER)*]
 TEMPLATE_PARAMETER:   DECLARATION_TYPE ID
```

- **Locations**

The location attributes are:

```
      LOCATION_NAME:   [ID_WITH_SPACES]
      LOCATION_TASK:   [TASK_NAME]
 LOCATION_INVARIANT:   INVARIANT_LIST
```

where:

```
     INVARIANT_LIST:   [INVARIANT(,INVARIANT)*]
          INVARIANT:   CLOCK{<|<=}INTEGER_EXPR
```

and the syntax of the integer expression is:

```
       INTEGER_EXPR:   INTEGER_TERM{+|-}INTEGER_TERM
       INTEGER_TERM:   INTEGER_UNAR{*|/}INTEGER_UNAR
       INTEGER_UNAR:   INTEGER_ELEM
                     | -INTEGER_ELEM
       INTEGER_ELEM:   INTEGER
                     | CONSTANT
                     | (INTEGER_EXPR)
                     | (INTEGER_GUARD?INTEGER_EXPR:INTEGER_EXPR)
```

```
      INTEGER_GUARD:   INTEGER_EXPR RELATION INTEGER_EXPR
           RELATION:   !=
                     | <
                     | <=
                     | ==
                     | >=
                     | >
```

The name of the location is an optional attribute; if not given, assigned automatically in the form Sx, where 'x' is a zero-based index. The name of the task associated with the location is also optional; if not specified, no task is released for execution when the automaton reaches given location.

- **Transitions**

The transition attributes are:

```
    TRANSITION_NAME:   [ID_WITH_SPACES]
   TRANSITION_GUARD:   GUARD_LIST
    TRANSITION_SYNC:   {CHANNEL|URGENT_CHANNEL|EXTERNAL_CHANNEL}{?|!}
  TRANSITION_ASSIGN:   ASSIGNMENT_LIST
```

where the syntax of the guard is:

```
         GUARD_LIST:   [GUARD(,GUARD)*]
              GUARD:   INTEGER_GUARD
                     | CLOCK_GUARD
        CLOCK_GUARD:   CLOCK RELATION CLOCK_EXPR_WITH_INT
CLOCK_EXPR_WITH_INT:   CLOCK ({+|-} CONST_TERM)*
                     | INTEGER_EXPR
```

and the syntax of the assignment is:

```
    ASSIGNMENT_LIST:   [ASSIGNMENT(,ASSIGNMENT)*]
         ASSIGNMENT:   INTEGER := INTEGER_EXPR
                     | CLOCK := CLOCK_EXPR
                     | (INTEGER_GUARD?CLOCK_RESET)
         CLOCK_EXPR:   CLOCK ({+|-} CONST_TERM)*
                     | CONST_EXPR (should be equal to zero)
        CLOCK_RESET:   CLOCK := CONST_TERM (should be equal to zero)
```

- **Tasks**

Tasks and their parameters are defined in the task table. The name of the task should satisfy the identifier's regular expression and should be different from the channel names declared in the system.

- **Reserved Words**

The following words are reserved and cannot be used as identifiers, names of locations, transitions or tasks:

```
assign, commit, externalDecl, globalDecl, graphinfo, guard, hide, imports
init, invariant, localDecl, location, locationName, paramList, procAssign,
process, rate, state, sync, system, systemDef, templateName, trans, int,
clock, chan, urgent, extern, const
```

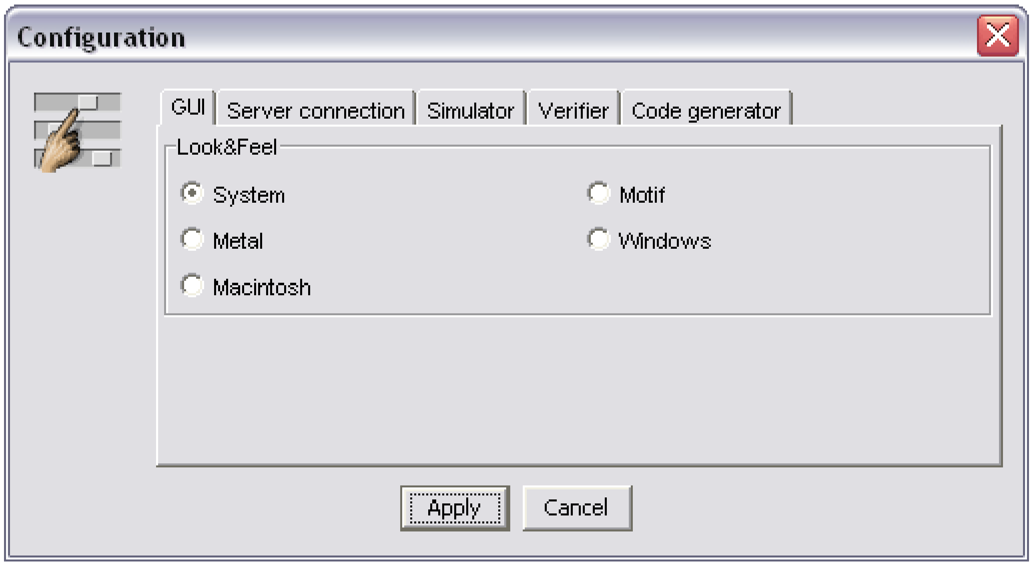
Query Language

The syntax of the query string is as follows:

```
     QUERY:   A[] PROP_EXPR
            | A<> PROP_EXPR
            | E[] PROP_EXPR
            | E<> PROP_EXPR
            | PROP_EXPR -> PROP_EXPR
 PROP_EXPR:   PROPERTY
            | not PROP_EXPR
            | (PROPERTY)
            | PROP_EXPR or PROP_EXPR
            | PROP_EXPR and PROP_EXPR
            | PROP_EXPR imply PROP_EXPR
  PROPERTY:   ID.ID
            | CLOCK RELATION CLOCK_EXPR
            | INTEGER_GUARD
            | deadlock
```

Configuration

There is a global tool configuration that can be saved once set. You can access it through the TIMES configuration dialog shown on the picture below. Settings are saved in the **.timestoolrc** file in your home directory.

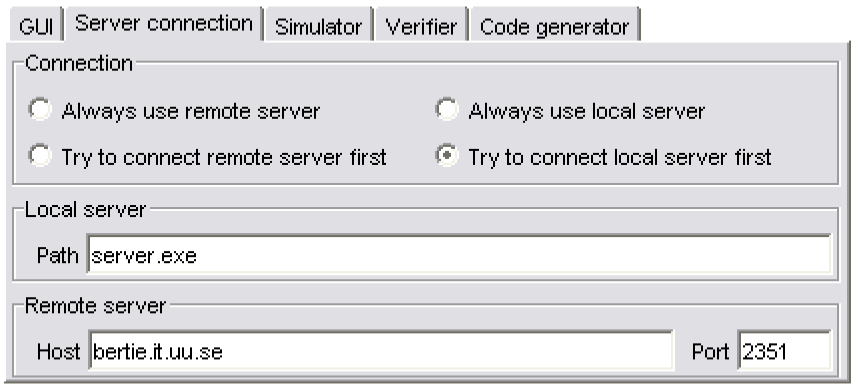


Look&Feel

[✓ System] Motif
Metal Windows
Macintosh

Look&Feel Configuration

The *GUI* tab allows you to choose look and feel of TIMES graphical user interface. Note "Macintosh" and "Windows" styles are supported only on MacOS and Windows operating systems. The default and recommended setting is "System" meaning that the look and feel will be chosen automatically according to your operating system.



Connection

Always use remote server | Always use local server
Try to connect remote server first | [✓ Try to connect local server first]

Local server

Path: server.exe

Remote server

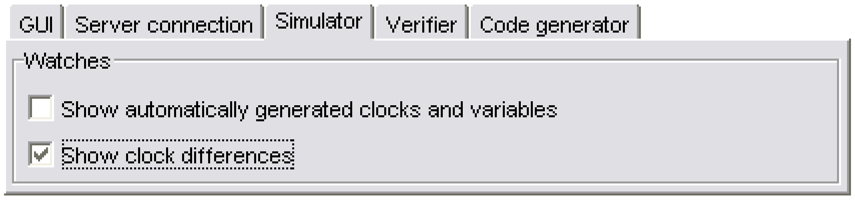
Host: bertie.it.uu.se Port: 2351

Server Connection Configuration

The second tab contains server connection options. TIMES can perform simulation and analysis using either local or remote server. The full path and file name of the local server should be specified in *Path* field. If no path specified (only the file name) then TIMES will look for the server executable in the directory where **timestool.jar** file is located.

The host name (or IP address) and the port number of a remote server are to be set in the *Host* and *Port* fields respectively. Find more information about setting up a remote server in the Installation chapter.

Using the *Connection* group of radio buttons specify which server you want to use. When *Try to...* option is selected TIMES will try to connect remote (or local) server first, and in case of failure - the local (or remote) one.

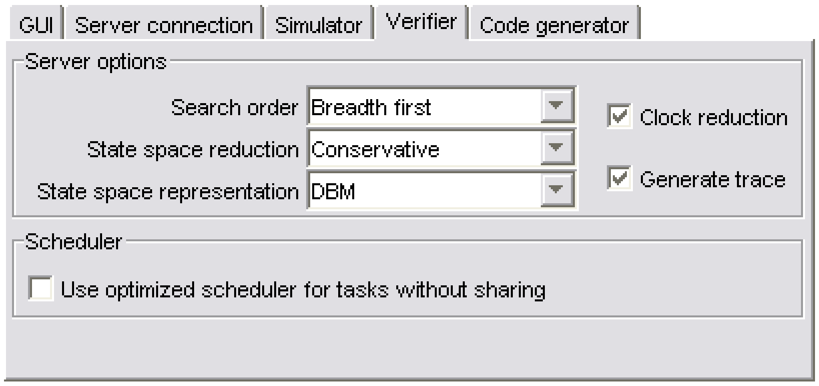


[ ] Show automatically generated clocks and variables
[✓] Show clock differences

Simulator Configuration

In the *Simulator* tab you can configure the watches window of the simulator. Enable the first checkbox if you want to observe internal variables of the automatically generated scheduler automaton in the simulator. This option also enables showing scheduler transition arguments in the *Enabled transitions* view.

If the second checkbox is enabled, the differences between clocks will be shown in the *Clock* tab of the watches view in addition to the clock intervals.



Search order: Breadth first
State space reduction: Conservative
State space representation: DBM
[✓] Clock reduction
[✓] Generate trace
[ ] Use optimized scheduler for tasks without sharing

Verifier Configuration

The server options are set in the *Verifier* tab. These settings affect schedulability analysis and verification processes.

- **Search order** option tells if the symbolic state-space exploration should be performed in breadth-first or depth-first order.

- **State Space Reduction** option determines if control-structure analysis should be performed to reduce the space requirements during verification. Possible values are none, conservative (control-structure reduction saving all non-comitted states and all loop-entry points), and aggressive (control-structure reduction saving only loop-entry points). Note that there is normally a tradeoff between space requirement and speed.

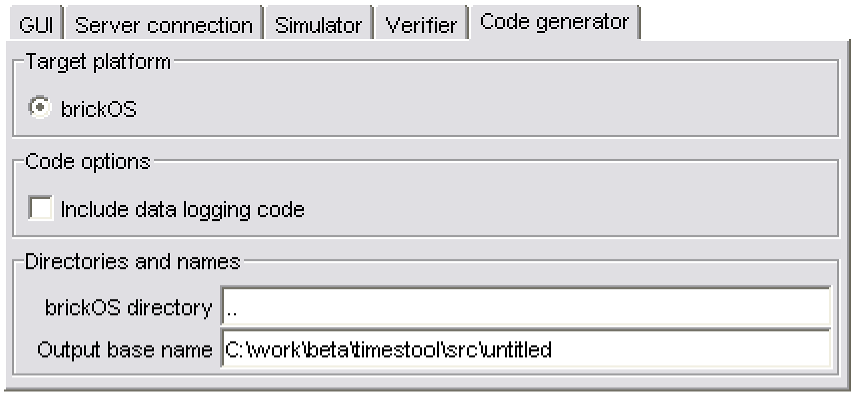
- **State Space Representation** option determines how the state-space should be represented in the model checker. Possible values are DBM (Difference Bound Matrices), the Compact Data Structure, Under Approximation (by bit-state hashing), and Over Approximation (by convex-hull approximation).

- **Clock Reduction** flag activates (in-)active clock reduction.

- **Diagnostic Trace** flag enables generating of a trace (if there is one) that shows how the checked property is (or is not) satisfied. The trace is automatically loaded into the simulator.

Note that this flag is automatically disabled when the State Space Representation option is set to Over Approximation.

- **Use optimized scheduler for tasks without sharing** flag tells the TIMES tool to generate (whenever possible) an optimized scheduler with two clocks. You can learn more about two clocks scheduler encoding in our paper "Schedulability Analysis Using Two Clocks".



Target platform

(●) brickOS

Code options

[ ] Include data logging code

Directories and names

brickOS directory ..

Output base name C:\work\beta\timestool\src\untitled

Code Generator Configuration

In the fifth tab you can configure TIMES code generator. In **TIMES 1.0 beta** only brickOS is supported as a target platform. brickOS is an open source embedded operating system, which provides a C and C++ programming environment for the Lego Mindstorms Robotics Kits. You can find more about brickOS installation and configuration here.

- **brickOS** is the only currently supported target platform.

- **Include data logging code** tells the TIMES tool to include code that will create a log of the brick events when running over the LNP protocol.

- **brickOS directory** is a path to the brickOS (legOS) installation directory.

- **Output base name** is a path and name that is used as a base for names of the generated files. When a project is loaded into TIMES the output base name is set to the path and name of the project minus the ".xml" suffix. This means that the Times tool will generate files in the same dirctory as the project file. Modify this to generate files in another directory and/or with another name.

Contacts

You can get the latest version of the TIMES tool and other info on www.timestool.com.

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```

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