RoboChart and RoboTool

Modelling, Verification and Simulation for Robotics



Alvaro Miyazawa Pedro Ribeiro Ana Cavalcanti

WWW.CS.YORK.AC.UK/CIRCUS/ROBOCALC

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Contents

	Tutorial	
1	RoboTool Instalation	7
1.1	Requirements	7
1.2	Download and Update Site	7
1.3	Installation	8
1.4	Creating a new RoboChart Project	11
1.5	Creating a new RoboChart diagram	13
1.6	Exercises	15
2	RoboChart Modelling	17
2.1	Creating Interfaces	17
2.2	Creating Robotic Platforms	19
2.3	Creating Controllers	22
2.4	Creating State Machines	23
2.5	Creating Modules	30
2.6	Exercises	33
3	Analysing RoboChart Models	35
3.1	Checking core assertions	35
3.2	Using RoboTool's Assertion DSL	41
3.3	Exercises	44

11	Appendices	
Α	RoboChart Project Management	47
A.1	Exporting a RoboChart project	47
A.2	Importing a RoboChart project	49
A.3	Deleting a RoboChart package	51
A.4	Editing a RoboChart diagram	51
A.5	Deleting element from diagrams	52
A.6	Exporting diagrams as figures	52
A.7	Adapting the generated semantics	53
B	RoboChart Syntax	55
B.1	Transition labels	55
B.2	Types	56
B.3	Expressions	56
B.4	Actions and statements	60
С	Assertion DSL Syntax	61
	Credits	63
	Bibliography	65

Tutorial

1RoboTool Instalation7

- 1.1 Requirements
- 1.2 Download and Update Site
- 1.3 Installation
- 1.4 Creating a new RoboChart Project
- 1.5 Creating a new RoboChart diagram
- 1.6 Exercises

2 RoboChart Modelling 17

- 2.1 Creating Interfaces
- 2.2 Creating Robotic Platforms
- 2.3 Creating Controllers
- 2.4 Creating State Machines
- 2.5 Creating Modules
- 2.6 Exercises

3 Analysing RoboChart Models 35

- 3.1 Checking core assertions
- 3.2 Using RoboTool's Assertion DSL
- 3.3 Exercises



This section contain the instruction to download and install RoboTool.

1.1 Requirements

RoboTool (v.2.0.0) is a collection of Eclipse plugins. Its requirements for installations are:

- 1. Operating System: Linux, Windows or macOS¹;
- 2. Java 11 or above;
- 3. Eclipse 2021-06 IDE; and
- 4. FDR4 refinement checker (Optional).

1.2 Download and Update Site

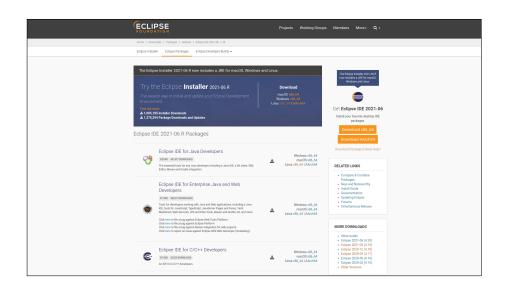
If you are already an Eclipse user, you can install RoboTool from its update site located in https://www.cs.york.ac.uk/robostar/robotool/update/. Detailed instructions for installation from the update site are given in the next section.

¹While the RoboTool works on all these operating systems, it is only actively developed for Linux. Furthermore, models created in one operating system may lose formatting when open on different operating systems.

1.3 Installation

If you wish to install RoboTool from the update site, follow the steps below.

1. In order to install RoboTool, first download and install eclipse. We recommend starting with the package *Eclipse IDE for Java Developers*.



2. Start eclipse, and select the menu item [Help > Install New Software...].

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- 3. Enter the RoboTool update site https://www.cs.york.ac.uk/robostar/robotool/ update/ in the field Work with, wait for the available features to load, select the feature you require, and click Next. For the purposes of this tutorial, we recommend the following features:
 - (a) RoboChart Assertions
 - (b) RoboChart Graphical Editor
 - (c) RoboChart Metamodel
 - (d) RoboChart Textual Editor
 - $(e) \ {\tt RoboChart} \ {\tt CSP} \ {\tt Generator}$

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4. Eclipse will present the list of dependencies that will also be installed. Click Next.

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🖗 RoboChart CSP Generator	3.0.0.202107271958	circus.robocalc.robochart.generator.csp.feat		
🕶 🖗 RoboChart Graphical Editor	2.0.0.202107272159	circus.robocalc.robochart.graphical.feature.		
🚯 RoboChart Metamodel	2.0.0.202105071032	circus.robocalc.robochart.feature.feature.gr		
🖗 RoboChart Textual Editor	3.0.0.202107262205	circus.robocalc.robochart.textual.feature.fea		
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🕨 🖗 Sirius Runtime IDE	6.5.0.202105071935	org.eclipse.sirius.runtime.ide.ui.feature.grou		
🖗 Sirius Runtime Support for AQL	6.5.0.202105071935	org.eclipse.sirius.runtime.aql.feature.group		
🕨 🖗 Sirius Specifier Environment	6.5.0.202105071935	org.eclipse.sirius.specifier.feature.group		
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5. Accept all licenses, and click Finish.

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Licenses must be reviewed and accepted before the software can be installed.			
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6. Wait for Eclipse to finish downloading all plugins.

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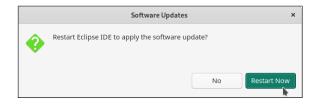
7. Eclipse will show a security warning indicating that the software is unsigned. Click Install anyway.



8. If prompted, select all certificates as trusted, and click OK.

Selection Needed		×
Do you trust these certificates?		
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9. Finally, restart Eclipse.



1.4 Creating a new RoboChart Project

1. Click on the menu item [File > New > Other...].

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Open File		📑 Project		 🏂 Outline 😫			
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2. Select the wizard New RoboChart Project, and click Next.

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Select a wizard	Ď
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Example EMF Model Creation Wizards	
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3. Give the project a name, optionally change the default location, and click Finish.

New RoboChart Project		×
Aodeling project		ĝ
oject name		
me: MyRoboChartModel		
afault location		
/tmp/eclipse/workspace/MyRoboChartModel	Browse	
< Back Next > Cancel	Finish	
	Aodeling project oject name me: MyRoboChartModel efault location /tmp/eclipse/workspace/MyRoboChartModel	Aodeling project oject name me: MyRoboChartMode efault location /tmp/eclipse/workspace/MyRoboChartModel Browse

The first time a project is created, Eclipse will switch to the RoboChart perspective indicated by the RoboTool icon on the top-right corner of the window. This perspective is based on the modelling perspective and organises the Eclipse window to include the properties tab at the bottom, the project explorer at the top-left and the outline at the bottom-left corner. Additionally, it adds shortcuts to new RoboChart project and RoboChart package directly on the File > New menu item.

1.5 Creating a new RoboChart diagram

1. Right click on the project, and click on the item [New > Other...].

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2. Select the wizard New RoboChart Package, and click Next.

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Example EMF Model Creation	Wizards		
? < Back	Next >	Cancel	Finish

3. Select a file name and make sure a container (e.g. your project) is selected. Click Finish.

	• ×
Multi-page Editor File	
This wizard creates a new file with *.robochart extension that can be opened by a multi-page editor.	
Container: //MyRoboChartModel	Browse
Eile name: mymodel.rct	ך
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? < Back Next > Cancel	Finish N

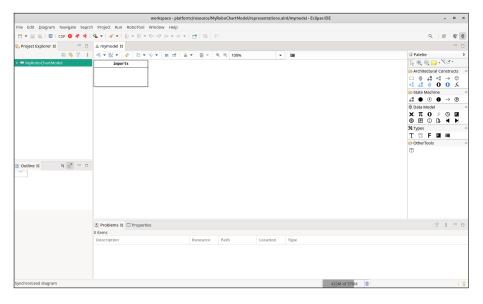
4. The editor will open the newly created diagram.

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5. (Optional) The palette at the right does not show all diagram edition tools, and you must expand and contract the sections as necessary. It is possible to configure the palette to show only icons. Right click on the palette, and select [Layout > Icons Only].

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6. (Optional) With the icons Only layout selected, the palette can show all the edition tools. To find out the name of the tool, you can hover you mouse over the icons for a few seconds.

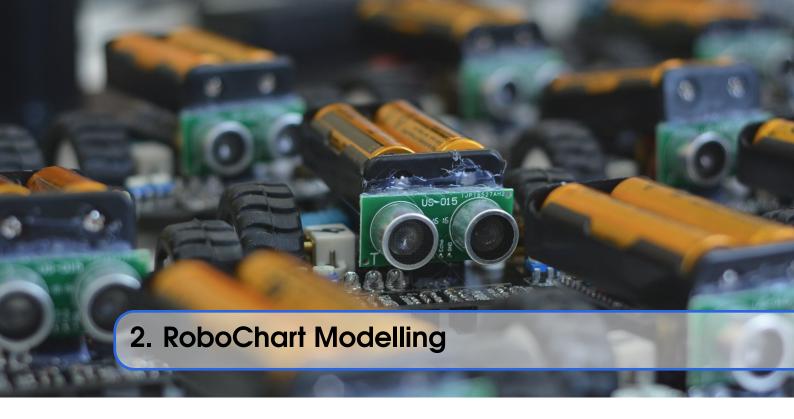


1.6 Exercises

Exercise 1.1 Download Eclipse and install RoboTool.

Exercise 1.2 Switch to the modelling perspective.

Exercise 1.3 Create a new RoboChart project and an empty RoboChart package.



This chapter includes step-by-step instruction to build a simple RoboChart model.

2.1 Creating Interfaces

Interfaces in RoboChart can contain events, variables and operations. Below are the steps used to create two interfaces, the first containing an operation move, and the second containing an event.

1. Select the interface tool \Box in the Architectural Constructs section of the palette, and click on the editor to position the interface.

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2. With the interface selected, press F2 to rename the interface.

	workspace - platform:/resource/MyRoboChartModel/representations.aird/mymodel - Eclipse IDE	_ = ×
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3. Add an operation by selecting the operation signature tool **O** in the Data Model section, and clicking on the interface.

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4. RoboTool will open a dialog window to input the operation signature. Type the operation signature¹ and click OK to add the operation to the interface.

	×
Define an operation as [Name]([Parameter]*)	
move(lv:real,av:real)	
Cancel OK	

¹Syntax errors are listed in the dialog box.

5. Add another interface called SensorsI and add an event to it by selecting the event tool % in the Data Model section, and clicking on the interface. A similar dialog as in Step 4 will open. Input the event definition and click OK.

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6. The final model with two interfaces MovementI and SensorsI should be as follows.

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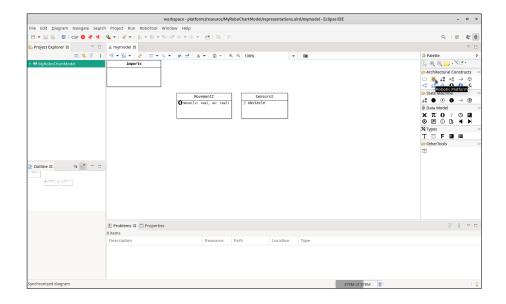
2.2 Creating Robotic Platforms

A robotic platform represents an abstraction of the robot in terms of the variables, events and operations available to the software. These elements can either be added directly to the robotic platform, or they can be indirectly added by providing **P**, requiring **O** or defining **O** interfaces.

Required and provided interfaces represent dependencies between platforms, controllers and state machines, and can contain only variables and operations, which can be shared between components. Events are locally defined and are connected explicitly. Defined interfaces simply define its variables and events on platforms (controllers and state machines) as if they were declared individually. Defined interfaces cannot contain operations.

The steps to create a robotic platform using the interfaces defined in the previous section are shown next.

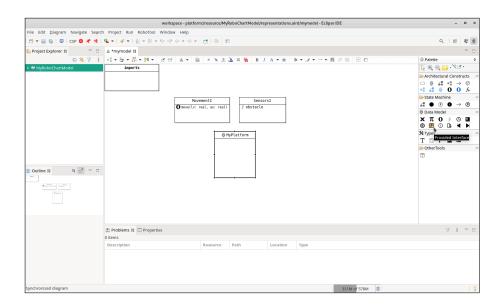
1. Select the robotic platform tool 4 in the Architectural Constructs section of the palette, and click on the editor to position the platform.



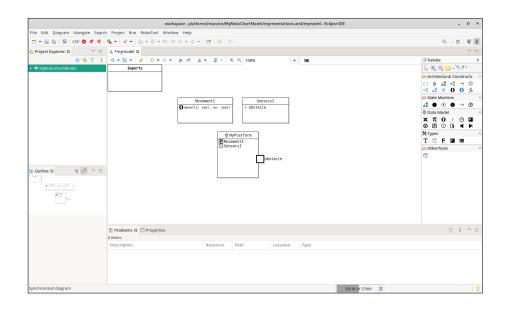
2. With the platform selected, press F2 to rename the robotic platform.

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3. Select the provided interface tool 🖻 (required 🕲 or defined ①) in the Data Model section of the palette, and click on the platform. Input the name of an interface and click OK.



4. The result of providing the MovementI interface, and defining the SensorsI interface is shown below.

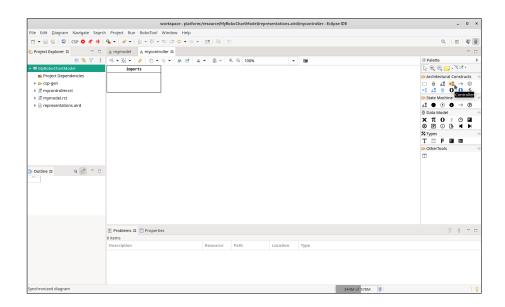


Additionally, events, variables and operations can be added to platforms in an identical fashion as for interfaces.

2.3 Creating Controllers

A controller describes possibly parallel behaviours, containing one or more state machines.

1. Select the controller tool \propto in the Architectural Constructs section of the palette, and click on the editor to position the controller.



2. After clicking, you can drag the mouse pointer to size the controller box. The resulting diagram is shown below.

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3. Use the required and defined interface tool to provide MovementI and define SensorsI.

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2.4 Creating State Machines

In this section, we will create a simple state machine with two states Moving and Turning inside the controller created in the previous section.

1. Select the state machine tool 43 in the Architectural Constructs section of the palette, and click inside the controller to position the state machine.

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2. Rename it and add the required and defined interfaces as in the previous section.

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3. In order to connect the events of the controller and state machine, select the connection tool → in the Architectural Constructs section.

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4. Start the connection by first clicking on the event of the controller.

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5. Complete the connection by clicking on the event of the state machine.

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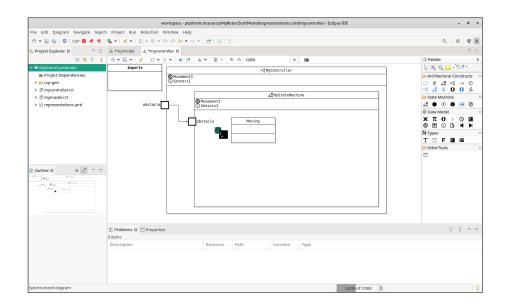
6. Next, add an initial junction to the state machine using the initial junction tool **①** in the State Machine section of the palette. Click inside the state machine to position the initial junction.

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7. Select the state tool \Box in the State Machine section of the palette, and click inside the state machine to position state. Press F2 to rename the state.

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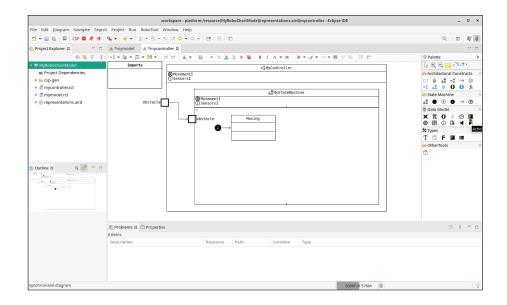
8. Use the transition tool → in the State Machine section of the palette, and click on the initial junction to start connecting the transition.



9. Next, click on the state to complete the transition.

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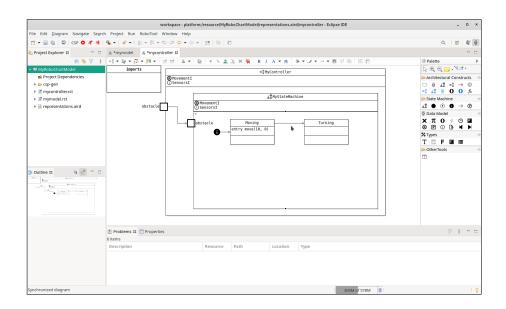
10. Add an entry action to the state Moving using the action tool in the State Machine section of the palette.



11. RoboTool will open a dialog window to input the action. A syntax hint is provided on the title of the dialog window, and syntax errors are shown below the text field. Add the entry action entry move(10,0) and click OK.

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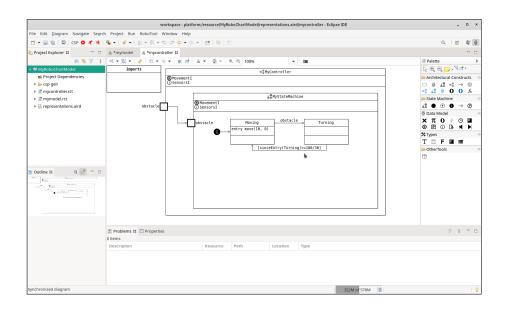
12. Add a second state Turning and a transition from Moving to Turning. Double click the transition to open a dialog windows to edit the transition label.



13. The dialog box provides a description of the syntax of labels and also any syntax errors. Define the trigger of the transition as the event obstacle and click OK.

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Enter a transition label in the format (Trigger p{Probability})? (#Clock)* (<{deadline}) ([guard])? / action?	
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14. Finally, add a transition from Turning to Moving. Add a label to the transition specifying its condition as [sinceEntry(Turning)>=180/30], which enables the transition as soon as 6 time units have elapsed since entering the state Turning.



2.5 Creating Modules

Modules are the top level constructs of RoboChart, and they associate one or more controllers with exactly one robotic platform. Below are the steps to create a module.

1. Select the module tool \otimes in the Architectural Constructs section of the palette.

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2. Click on a new created diagram, and press F2 to rename the module².

3. Select the robotic platform reference tool \$\frac{1}{9}\$ (blue icon) in the Architectural Constructs section of the palette, and click on the module.

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4. RoboTool will open a dialog window to input the name of a robotic platform. Input the name of the platform created in Section 2.2 and click OK.

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	Cancel	ок

²The errors shown in the problems tab at the bottom of the window occur because a module must have one robotic platform and at least one controller. These errors are resolved in the remaining steps.

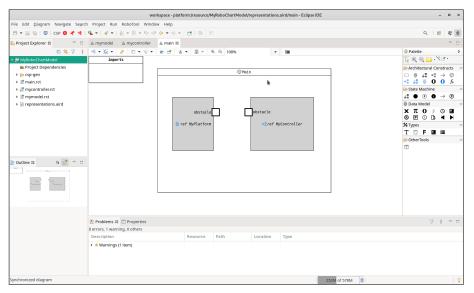
5. The resulting module shows the reference with a gray background and blue icon.

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6. Select the controller reference tool \ll in the Architectural Constructs section of the palette.

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7. Click on the module, input the name of the controller created in Section 2.3 in the dialog box, and click OK.



8. Finally, use the connection tool \rightarrow in the Architectural Constructs section of the palette to connect the obstacle event of the robotic platform to the obstacle event of the controller.

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2.6 Exercises

Exercise 2.1 The alpha algorithm is a simple aggregation algorithm in swarm robotics [2].

A simulation of this algorithm can be found in www.youtube.com/watch?v=8A7454VVhys.

The basic algorithm is very simple:

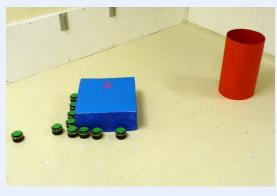
- The default behaviour of a robot is forward motion.
- While moving each robot periodically sends an "Are you there?" message. It will receive "Yes, I am here" messages only from those robots that are in range, namely its neighbours.
- If the number of a robot's neighbours should fall below the threshold α then it assumes it is moving out of the swarm and will execute a 180° turn.

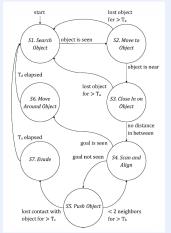
• When the number of neighbours rises above α (when the swarm is regained) the robot then executes a random turn. This is to avoid the swarm simply collapsing in on itself.

Complete the following tasks to model a robot that implements the alpha algorithm:

- a) Define the robotic platform. *Suggestion: the fewer requirements on the platform, the more actual platforms can be used to implement the system.*
- b) Define the module: controller(s) and connections to platform. *Suggestion: create separate controllers for separate requirements.*
- c) Define a state machine to model movement control.
- d) Define a state machine to model neighbour detection.

Exercise 2.2 In this exercise, you will model the control software of a simple robot that by itself cannot push an object, but when combined in a swarm can achieve the desired goal of transporting a larger object.



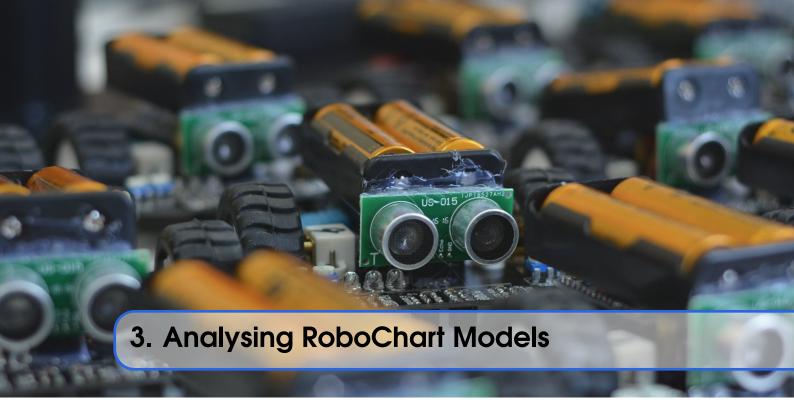


A group of robots transporting an object (blue box) towards a goal (red cylinder) [4].

An informal state machine account of the solution [4].

Construct a RoboChart model that implements the transporter robot:

- a) Define the robotic platform based on the events, variables, clocks and operations used in the state machine.
- b) Rewrite the state machine above in RoboChart.
- c) Define the module: controller(s) and connections to platform.



The semantics of RoboChart is formalised in CSP, and RoboTool generates the semantics of wellformed model in the csp-gen folder. You can use the refinement checker FDR[7] to analyse your RoboChart models.

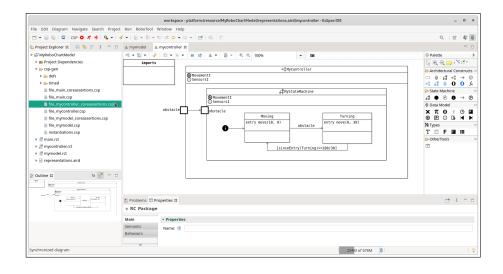
Section 3.1 illustrates the use of automatically generated assertions to check standard properties such as deadlock freedom and determinism, and Section 3.2 illustrates the use of a simple assertions DSL to specify custom properties.

3.1 Checking core assertions

Along with the CSP semantics of a model, RoboTool automatically generates assertions to check standard properties such as deadlock freedom and determinism. These properties are specified in a file with the suffix _coreassertions.csp, and can be checked by FDR.¹

¹We recommend cleaning the project at least once using the menu item Project > Clean... This is to avoid potentially outdated generated components.

1. The core assertions for the controller created in the previous chapter are contained in the file file_mycontroller_coreassertions.csp in the csp-gen folder.



2. (Optional) In order to open the file in FDR directly from eclipse, select FDR as the default editor. Right-click the file, and select [Open With > Other...].

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3. In the Editor Selection dialog, select External programs.

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6. Find the FDR4 executable, and click OK.

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7. Make sure FDR4 is selected in the Editor Selection dialog, and click OK.

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8. The last step opens the FDR4 windows with all assertions loaded and displayed on the right-hand side panel.

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9. Click the Run All button at the top-right corner, and wait for the checks to finish. Alternatively, click each Check button to run each assertion separately.

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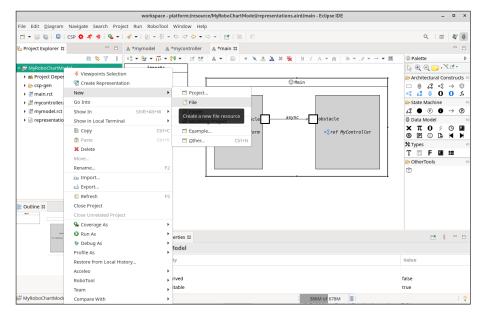
10. If any of the (positive) assertions fail, a counter example is produced. It can be viewed by clicking the Debug button of the assertion.



3.2 Using RoboTool's Assertion DSL

RoboTool also provides a simple text editor for an assertion DSL, which includes syntax highlighting, auto-completion, and error feedback. The DSL helps you write simple assertions such as deadlock freedom and refinement without requiring knowledge of the naming conventions of our semantics. More complex properties can be specified in CSP within special environments, but this requires an understanding of the structure and naming conventions of the RoboChart semantics.

1. Create a new file by right-clicking the project, and selecting [New > File].



2. Name the file with the .assertions extension, and click OK.

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3. (Optional) If RoboTool has not yet been configure to find the FDR executable, select the menu item [Window > Preferences].

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4. (Optional) Select the RoboChart > Analysis item, and click Browse... to select the path to the installation directory of FDR.

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5. (Optional) Click Apply and Close to apply the configuration.

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 Oomph RoboChart 	
Analysis	
Compiler Errors/Warnings Refactoring Syntax Coloring	Restore Defaults Apply
7emplates	Cancel Apply and Close

6. In the .assertions file, right your custom assertions. Notice that it may be necessary to use the qualified name of RoboChart elements, such as, MyController::MyStateMachine.

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🎟 R4									
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7. In order to verify the assertions, right-click the .assertions file, and select the [RoboTool > CSP > Run...] item.

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8. Provided there are no errors in the assertions or models, FDR checks the assertions in the background, and RoboTool summarises the result in the form of a report, which is automatically opened upon completion of the checks.

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3.3 Exercises

Exercise 3.1 Check the core assertions for the model created in exercise 2.1.

Exercise 3.2 Write custom assertions for the model created in exercise 2.1, and check them using RoboTool and FDR.

Exercise 3.3 Check the core assertions for the model created in exercise 2.2.

Exercise 3.4 Write custom assertions for the model created in exercise 2.2, and check them using RoboTool and FDR.

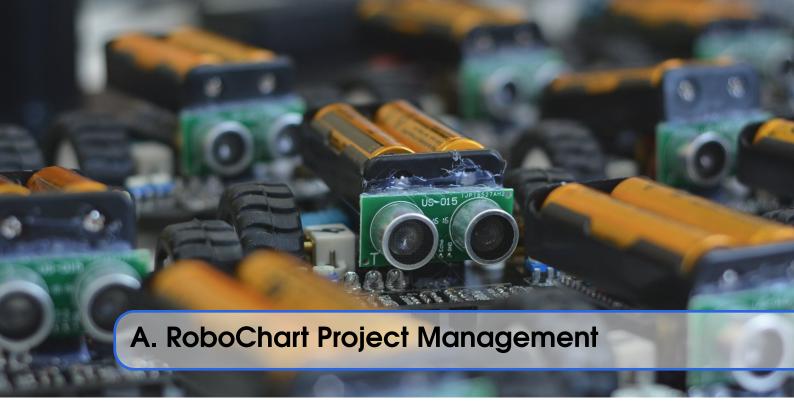


A RoboChart Project Management 47

- A.1 Exporting a RoboChart project
- A.2 Importing a RoboChart project
- A.3 Deleting a RoboChart package
- A.4 Editing a RoboChart diagram
- A.5 Deleting element from diagrams
- A.6 Exporting diagrams as figures
- A.7 Adapting the generated semantics

B RoboChart Syntax 55

- B.1 Transition labels
- B.2 Types
- B.3 Expressions
- B.4 Actions and statements
- C Assertion DSL Syntax 61



This appendix describes common tasks in managing RoboChart projects.

A.1 Exporting a RoboChart project

1. Right click on the project and select Export... item.

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3. Select the path to the archive file, and click Finish.

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A.2 Importing a RoboChart project

1. Right click on the Model Explorer, and select Import... item.

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2. Select wizards General > Existing Project into Workspace, and click Next.

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🔻 🗁 General				
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🕨 🗁 Git				
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3. Check Select archive file, and click Browse to select the archive.

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W <u>o</u> rking sets:			v	S <u>e</u> lect
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4. Select the project to import, ad click Finish.

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• Select <u>a</u> rchive file:	/tmp/MyM	lodel.zip	~	B <u>r</u> owse
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W <u>o</u> rking sets:			~	S <u>e</u> lect
(?)	< Back	Next >	Cancel	Finish
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A.3 Deleting a RoboChart package

Since a RoboChart package is associated with an rct file and a diagram (in the aird file), we need to delete both the rct file and the diagram¹.

- 1. In order to delete a RoboChart package, that is, the rct file and the associated diagrams:
 - (a) Select the file, press Delete (or select delete on the context menu) and click OK;
 - (b) Click the left arrows on the file *representation.aird*, the subitem *RoboChart* and the subitem RCPackage. The names of the diagrams associated with the deleted file will be in a lighter font. Select them, press delete (or right-click and click Delete) and confirm the deletion by clicking OK.

A.4 Editing a RoboChart diagram

- Use the palette to the right to select objects to add to the diagram. For most objects (except connection) you can either drag and drop the object to the diagram, or select and click (if you keep Ctrl pressed, it is possible to click multiple times on the diagram to create multiple instances of the object). After creating a new component (e.g., type), make sure to save the diagram (press Ctrl+S or click File > Save) to guarantee the newly created element can be used.
 - The palette may not show all tools depending on the size of the screen. It is divided into category boxes that group similar tools. In order to explore the available tools you can click click a category box to close it, and click once more to fully expand it. It is also possible to use the arrows at the bottom and top of the category box (or the scroll wheel on your mouse) to scroll through the available tools. If you are familiar with the icons, it is possible to reduce the space taken by the tools by removing the text and showing only the icons. To do this, right click the palette and select Layout > Icons Only
- 2. To use connections, select the appropriate connection tool (e.g., transition), click the source node and then the target node²;
- 3. To change labels (e.g., interface names, transition labels) there are a few options:
 - (a) Select the item and start typing. This option will delete the original text; to avoid this use one of the next two options; or
 - (b) Press F2 and the text will become editable; or
 - (c) Click once over the text and it will become editable.
 - **R** Label editing has some limitations that are worth mentioning:
 - (a) Not all labels editors are implemented yet (if you think label editing for a specific feature is missing, create an issue in the bitbucket issue tracker);
 - (b) If you type a label with syntax errors, the edit will fail and the previous text will show (potentially empty text).
- 4. Most textual elements (variable declarations, operations, actions etc) are input through a pop-up window that provides a hint of the syntax and parses the input before creating the element. For example, when creating a new action in a state:
 - (a) a pop-up windows will appear requesting the text of the action in the format [(entry|exit|during) Action], that is, one of the keyword entry, exit or during followed by an action³

¹We must delete the diagram associated with the RoboChart package, not the whole aird file.

²While you can use Ctrl+Z to undo changes to the diagram, it can create inconsistencies, so use it carefully.

³See the language reference manual for the concrete syntax of actions and other elements.

- i. if you only type entry, for instance, the box will show Cannot parse below the text box and keep the button OK disabled
- ii. if, on the other hand, you type entry skip, the tool parses the action correctly and enables the OK button. If you click OK the action will be added to the state.
- 5. To save a diagram, press Ctrl+S or click File > Save.

A.5 Deleting element from diagrams

To delete an object from the diagram, select it and press delete; avoid using the option Right-click > Edit > Delete from Model as it can make the diagram inconsistent.

Be careful when deleting elements:

- 1. In general, make sure they are not used elsewhere. For example, when deleting an event used as the trigger of a transition, the transition will point to a non-existent event; make sure to remove the reference first;
- 2. We have implemented controlled deletions for Interfaces and Types, but not for other elements⁴.
 - (a) When deleting an interface, the tool will delete all required and provided references and try to replace call to the operations in the interface by other operations of the same name in scope; if this is not possible, operation calls are converted into skip
 - (b) When deleting a type, the tool will look for uses of that type, if none are found, the type is deleted. Otherwise, a list of types is offered to the user to replace the deleted type.

A.6 Exporting diagrams as figures

It is possible to export the diagrams as figure⁵.

To export all the diagrams at the same time:

- 1. Click the arrow to the left of the file representations.aird to expand it.
- 2. Expand the items RoboChart and Package.
- 3. Use ctrl+left click to select multiple diagrams
- 4. Right click the selection and click Export representations as images
- 5. A popup window will appear allowing you to select the target directory and the image format; after selecting the directory and the format, click OK.

To export a specific diagram, follow these steps:

- 1. Open the diagram (if it not already open)
- 2. If any diagram elements are selected, deselect them by pressing Esc or clicking in the background of the diagram
- 3. The toolbar at the top of the diagram contains a camera icon 💷 ; click it
- 4. A popup window will appear allowing you to select the target file and the image format; after selecting the file and the format, click OK.

If you right click representation.aird, an option Export representations as images is available. While this option works and generates images for all diagrams, it may have a side effect of closing all open diagrams, and making the project tree inconsistent. In this case, collapse the project by clicking the arrow to the left of the project name, and expand it again. This should refresh the project and offer to reopen the diagrams.

⁴If and when I implement more cases, I'll add them to this manual.

⁵The available formats are JPG, PNG, SVG, BMP and GIF.

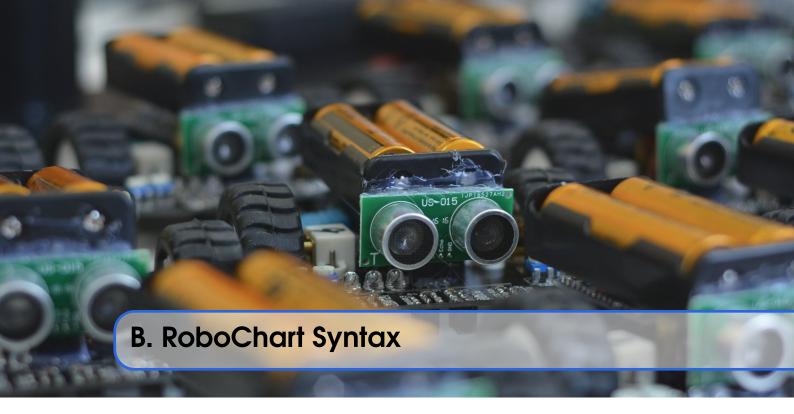
A.7 Adapting the generated semantics

RoboTool automatically generate the semantics of each construct of a model, provided there are no warnings concerning that construct. Additionally, it generates a instantiations.csp file and _assertions.csp files for each construct and rct file.

These files use a special annotation to indicate which parts of the file can be re-generated. They have annotations of the form — generate ID, where ID is any identifier, followed by excerpts of CSP. The specification under the comment will be regenerated every time the model is saved. If you do not want the specification under the comment to be re-generated, add a not after the identifier (- generate ID not). This will cause the generator to ignore that part of the specification.

The instantiations file provides default values for constants, functions and bounds, and the assertions file provide default assertion checks where relevant. Use these files and the annotations above to add your own assertions and values without losing them on re-generation.

If you delete these files, they will be regenerated but the changes will be lost.



B.1 Transition labels

The syntax of transition labels is described below.

```
Transition Label
Label ::= Trigger ('<{'Expression'}')? ('['Expression']')? ('/'Statement)?
```

The first expression after the trigger is the end deadline, the second expression is the transition condition and the statement is the transition action. The syntax of triggers is as follows.

Trigger

```
Trigger ::= (Input|Output|Sync|Simple)? ClockReset*
Input ::= Event '?' Variable
Output ::= Event '!' Expression
Sync ::= Event '.' Expression
Simple ::= Event
```

The last component of a trigger consists of zero or more ClockResets (e.g., #T, where T is a clock), which are executed when the transition is taken.

Trigger Type	Meaning
Input Trigger (I)	Receives any value from the event and stores it on the variable.
Output Trigger (O)	Sends the value of the expression through the event.
Sync Trigger (Sync)	Synchronises on the event with the value of the expression.
Simple Trigger (S)	Synchronises on the event.

The table above summarises the meaning of the different types of triggers.

B.2 Types

RoboChart has type system similar to that of Z. The syntax of types is described below.

```
Type
```

```
Type ::= '(' Type ')'
                                                                  - parenthesised type
          Ν
                                                                  - type reference
          Т
             'Set' '(' Type ')'
                                                                  – set type
          'Seq' '(' Type ')'
                                                                  - sequence type
          | Type '*' Type
                                                                  - product type
          1
            Type '->' Type
                                                                  - function type
          Type '<->' Type
                                                                  - relation type
```

The table below summarises the interpretation of the type constructors.

Element	Concrete Syntax	Meaning
Type Reference	N	N is the name of a declared type.
Set Type	Set(T)	Type of sets of elements of T.
Sequence Type Seq(T)		Type of sequences of elements of T1 to T2.
Product Type	T1 * T2	Type of pairs whose first element has type T1 and
		second element has type T2.
Function Type	T1 -> T2	Type of functions from T1 to T2.
Relation Type	T1 <-> T2	Type of relations between T1 and T2.

B.3 Expressions

The syntax of expressions is summarised below.

```
Expressions
Expr
        : :=
              ('0'..'9')+
                                                                   - integer
              ('0'...'9')+.('0'...'9')+
                                                                   -float
              ,",[~,",]+,",
                                                                   - string
              'true' | 'false'
                                                                   – boolean
              Ν
                                                                   - reference
              '<'(Expr (',' Expr)*)?'>'
                                                                   - sequence
              '{'(Expr (',' Expr)*)?'}'
                                                                   – set
              '{' N ':' Type '|' Expr '@' Expr '}'
                                                                   - set comprehension
              '['Expr ',' Expr ']'
                                                                   – closed interval
              '(' Expr ',' Expr ')'
                                                                   - open interval
              N '::' N
                                                                   - enumeration constant
              '(|' (Expr (',' Expr)*)? '|)'
                                                                   – tuple
              Expr '[' Expr ']'
                                                                   - array access
              Expr '(' (Expr (',' Expr)*)? ')'
                                                                   - function application
              Expr '.' N
                                                                   - field access
              •••
                                                                   - continues on next page
```

Expres	ssions	(cont.)	
Expr	::=		
1	1	'-' Expr	– negation
	1	Expr '+' Expr	– sum
	1	Expr '-' Expr	– subtraction
	Ι	Expr '*' Expr	- multiplication
	I	Expr '/' Expr	- division
	I	Expr '%' Expr	– remainder
	1	Expr '==' Expr	– equality
	1	Expr '=' Expr!	– difference
	1	Expr '>' Expr	– greater
	I	Expr '>=' Expr	– greater or equal
	1	Expr '<' Expr	– less
	I	Expr '<=' Expr	– less or equal
	I	'not' Expr	– not
	I	Expr '/\' Expr	– and
	I	Expr '\/' Expr	- <i>or</i>
	I	Expr '=> Expr	– implies
	I	Expr 'iff' Expr	– if and only if
	I	'forall' N ':' Type ' ' Expr '@' Expr	– universal quantification
	I	'exists' N ':' Type ' ' Expr '@' Expr	- existential quantification
	Ι	'exists1' N ':' Type ' ' Expr '@' Expr	- uniqueness quantification
	Ι	Expr '^' Expr	- concatenation
	I	'if' Expr 'then' Expr 'else' Expr 'end'	- conditional
	1	'let' N '==' Expr '@' Expr	– local definition
	1	'the' N ':' Type ' ' Expr '@' Expr	– definite description
	1	'lambda' N ':' Type ' ' Expr '@' Expr	– lambda expression
	1	'since' '(' N ')'	– clock expression
		'sinceEntry' '(' N ')'	– state clock expression

The tables below summarise and explain expressions used to construct values, arithmetic expressions, comparison expressions, logic expressions, and advanced expressions.

Basic Expressions	Concrete Syntax	Comment
Integer	(09)+	
Float	(09)+.(09)+	
String	""	Quoted values
Boolean	true false	
Reference	N	N is the name of a variable or constant.
Sequence	<e1,e2,></e1,e2,>	Sequence with values ei.
Set	{e1,e2,}	Set with values ei.
Set Comprehension	{x:T P @ e}	Set containing values e, calculated from el-
		ements of type T, for which the predicate P
		holds.
Interval	[e1,e2] or (e3,e4)	Closed interval between e1 and e2, and open
		interval between e3 and e4, or a combination
		of both.
Enumeration	E::c	Constant c of enuneration E.
Tuple	(e1,e2,)	Tuple containing elements ei.
Array	e[i]	The i-th element of array e.
Function application	f(e1,e2,)	Apply function f to parameters ei.
Selection	e.n	The n field of record e.

Arithmetic Expressions	Concrete Syntax	Comment
Negation	-e	Arithmetical negation of expression e.
Sum	e1 + e2	Sum of e1 and e2.
Subtraction	e1 - e2	Subtraction of e1 and e2.
Multiplication	e1 * e2	Multiplication of e1 by e2.
Division	e1 / e2	Division of e1 by e2.
Modulo	e1 % e2	Remainder of dividing e1 by e2.

Comparison Expressions	Concrete Syntax	Comment
Equality	e1 == e2	True if both expressions are equal.
Different	e1 != e2	True if both expressions are different.
Greater than	e1 > e2	True if e1 is greater than e2.
Greater than or equal to	e1 >= e2	True if e1 is greater than or equal to e2.
Less than	e1 < e2	True if e1 is less than e2.
Less than or equal to	e1 <= e2	True if e1 is less than or equal to e2.

B.3 Expressions

Logical Expressions	Concrete Syntax	Comment
Logical not	not e	True if and only if e is false.
Logical and	e1 /\ e2	True if and only if e1 and e2 are
		true.
Logical or	e1 \/ e2	True if and only if at least one of
		the expressions is true.
Logical implies	e1 => e2	Equivalent to not e1 $//$ e2.
Logical iff	e1 iff e2	Equivalent to e1=>e2 /\ e2=>e1
Universal quantification	forall x: T P @ Q	True if and only if for all elements
		of T, if P is true, then Q is true.
Existential quantification	exists x: T P @ Q	True if and only if there is an ele-
		ment of T, for which P is true and Q
		is true.
Uniqueness quantification	exists1 x: T P @ Q	True if and only if there is a unique
_		element of T, for which P and Q are
		true.

Advanced Expressions	Concrete Syntax	Comment
Concatenation	e1^e2	Concatenate sequences e1 and e2.
Conditional	if c then e else f end	If condition c is true, e1 else e2.
Local definition	let n == e @ f	Define locally n and use it to cal-
		culate f.
Definite description	the x: T P @ e	The value e calculated based on
		the unique x for which P holds.
Lambda expression	lambda x: T P @ e	The anonymous function that takes
		values of type T for which P holds,
		to values e calculated based on x.
Clock Expression	since(C)	Expression counting elapsed time
		since the last reset of clock C.
State Clock Expression	sinceEntry(S)	Expression counting elapsed time
		since entry of state S.

B.4 Actions and statements

The syntax of actions is described below.

```
Action ::= ('entry' | 'during' | 'exit') Statement
```

The syntax of statements is as follows.

```
Statements
Statement
            ::= 'skip'
                | N '(' (Expr (', ' Expr)*)? ')'
                                                                         - operation call
                | 'if' Expr
                                                                         - conditional
                    'then' Statement
                    'else' Statement 'end'
                  N '=' Expr
                - assignment
                   N '!' Expr
                                                                         - output event
                   N '?' N

    input event

                L
                   Ν
                                                                         - simple synchronisation
                   N '.' Expr
                - synchronisation
                   Statement ';' Statement
                - sequential composition
                    Statement '<{ Expr '}'</pre>
                I
                                                                         - timed statement
                    'wait' '(' Expr ')'
                                                                         - wait statement
                I
                    'wait' '(' '[' Expr ',' Expr ']' ')'
                                                                         - nondeterministic wait
                    '#' N
                                                                         - clock reset
```

Statement	Concrete Syntax	Comment
Skip	skip	Statement that terminates immediately.
Call	o(e1,e2,)	Calls operation o with parameters ei.
Conditional	if cthen S1 else S2 end	If c is true, execute S1, otherwise execute S2.
Assignment	x = e	Assign expression e to variable x.
Output event	ev!e	Output value e through channel ev.
Input event	ev?x	Receive value through channel ev and store it
		in variable x.
Synchronisation	ev.e	Synchronise on value e through event ev.
Synchronisation	ev	Synchronise on event ev.
Sequential composition	S1;S2	Execute S1, and then S2.
Timed Statement	S<{e}	Statement S is required to terminate within e
		time units.
Wait Statement	wait(e)	Waits for e units of time.
Nondeterministic Wait	<pre>wait([a,b])</pre>	Waits nondeterminstically for d units of time
		where $a \le d \le b$.
Clock Reset	#C	Resets clock C.

60

Actions



Assertions

Specification

CSP Models

Constant Definitions

CONSTANTS ::= (DEF (',' DEFs)*)? DEF ::= N ('assigned' | 'set' 'to' | 'with' 'value') Expr



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