SynDEx v7 User Manual

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December 16, 2013

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Introduction

This manual uses some writing conventions:

- menus, buttons *etc.* are written in **bold**
  (*e.g.* **File** menu, **OK** button, **Definition list**, **Launch Adequation** option),
- SynDEx directories and files, examples *etc.* are written in `Computer Modern`
  (*e.g.* `libs` directory, `examples/tutorial/example7/example7_sdc.sdx` file, `!  int o` port definition),
- notions, windows, *etc.* are written in *italic*:
  (*e.g. AAA methodology*, *reference*, *definition mode*, *algorithm window*).

Chapter 1

Overview

1.1 The AAA methodology

SynDEx is based on the *AAA methodology* (*cf.* chapter 12).
A SynDEx application is made of:

- *algorithm graphs* (definitions of operations that the application may execute),
- *architecture graphs* (definitions of multicomponents: set of interconnected processors and specific integrated circuits).

Performing an *adequation* means to execute heuristics, seeking for an optimized *implementation* of a given algorithm onto a given architecture.

An implementation consists in:

- *distributing* the algorithm onto the architecture (allocate parts of algorithm onto components),
- *scheduling* the algorithm onto the architecture (give a total order for the operations *distributed* onto a component).

1.2 SynDEx distributions

SynDEx runs under Linux, Windows, and Mac OS X platforms. SynDEx is written in *Objective Caml*. The Graphical User Interface is written in *Tcl/Tk* with the OCaml library *CamlTk*. See chapter 12 for web links.

Chapter 2

Getting started

2.1 Application workspace

2.1.1 Launching SynDEx

SynDEx is launched by running the SynDEx executable, located in the directory `bin` of your installation directory. Some options can be specified on the command line, for example :

- `-libs` adds a directory where to find libraries to include (see chapter 3),
- `-html` specifies the path of the internet browser that displays the manual and tutorial html documentations from the **Help** menu. The url to open is appended at the end of the specified command. You can also try to use `%s` in the specifed command to make SynDEx replace this `%s` by the url in the command. In this case do not forget to put the command between " " .

The complete list of options can be obtained by running the SynDEx executable with the `--help` option.

For example write the command line:

> `/syndex-7.0.x/bin/syndex-7.0.x -libs /syndex-7.0.x/libs -html /usr/bin/firefox appli.sdx`

In this example the libraries directory and the web browser used to display the manuals are specified on the command line. In addition, the name of an application to open is also specified, otherwise only the principal window is opened.

2.1.2 SynDEx principal window

To create an application workspace, run the SynDEx executable without the name of an application. It opens the *principal window* of SynDEx (*cf.* figure 2.1).

2.1.3 Load a SynDEx application

To load an existing application in the workspace, from the **File** menu, choose the **Open** option and select a SynDEx file (*cf.* figure 2.2). For example load the `/syndex-7.0.x/examples/basic/basic.sdx` example.

2.1.4 Algorithm and architecture windows

Loading a SynDEx application will open:

- the *algorithm window* on the *main algorithm* if it have been defined (*cf.* figure 2.3),
- the *main architecture window* if the *main architecture* have been defined (*cf.* figure 2.4).

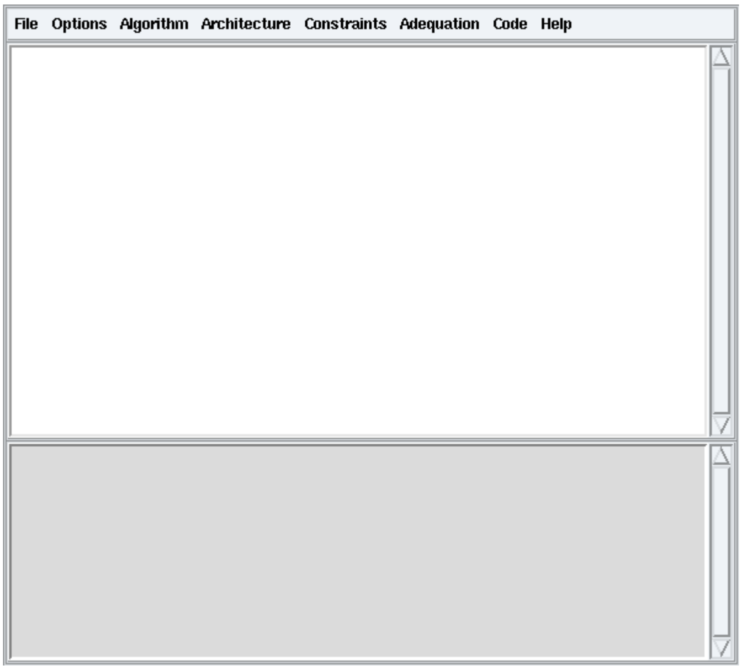

Figure 2.1: SynDEx *principal window*

Opening another application will replace the current one by the new one in the workspace.

Warning: some application may require libraries (cf. Chapter 3).

2.2 Modes

In the *algorithm window*, the *adress bar* displays `AlgorithmMain (main)` meaning that the *main algorithm* is viewed in the *main mode* (*cf.* section 5.1.2). **Double left** click on `AlgorithmMain` in the **Definition list**. The algorithm is now viewed in its *definition mode* and the adress bar displays `[Function] AlgorithmMain`. See section 5.1.2 for more information.

Note that you can create several algorithms and architectures but only one *main algorithm* and one *main architecture* on which the *adequation* will be applied.

2.3 Adequation and code generation

To launch the *adequation* of the *main algorithm* (*cf. Main mode* in section 5.1.2) onto the *main architecture* (*cf.* section 6.3.2), from the **Adequation** menu of the *principal window*, choose the **Launch Adequation** option. To save the result of the *adequation*, from the **Options** menu, check **Save Adequation with Application**. Then save your application. To view the computed *schedule*, from the **Adequation** menu, choose the **Display Schedule** option. See chapter 9 for more information.

To generate the code of the application, from the **Code** menu, choose the **Generate Executive(s)** option. The generated `.m4` files are saved in the example's directory. To view theses files from the SynDEx workspace, from the **Code** menu, choose the **Display Executive(s)** option. See chapter 10 for more information.

2.4 Save, Close, Quit

To save the current application, from the **File** menu, choose the **Save** option. To save it with a new name, choose the **Save as** option and type the new name in the *dialog window*. The file will be suffixed

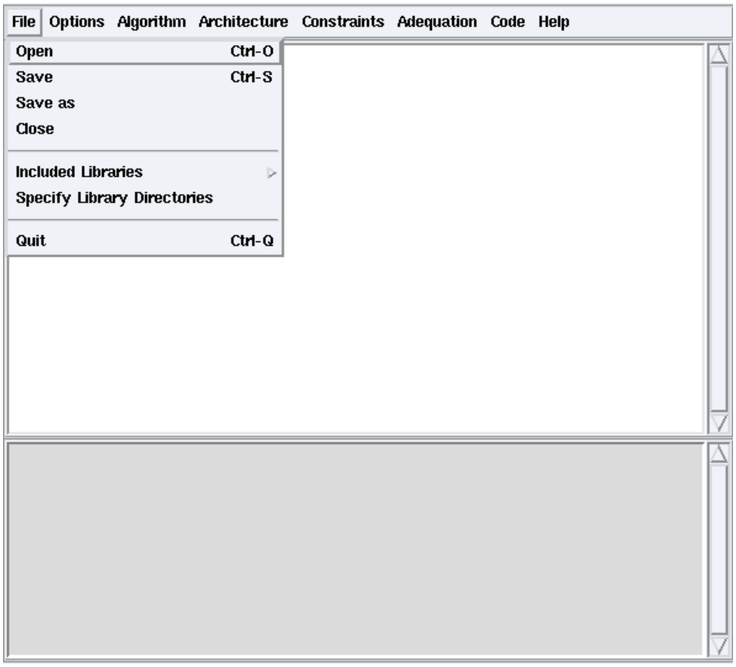

Figure 2.2: Open a file

by `.sdx`.

To close the current application, from the **File** menu, choose the **Close** option. It closes all the *application windows* and leaves the workspace empty.

To quit SynDEx from the **File** menu, choose the **Quit** option.

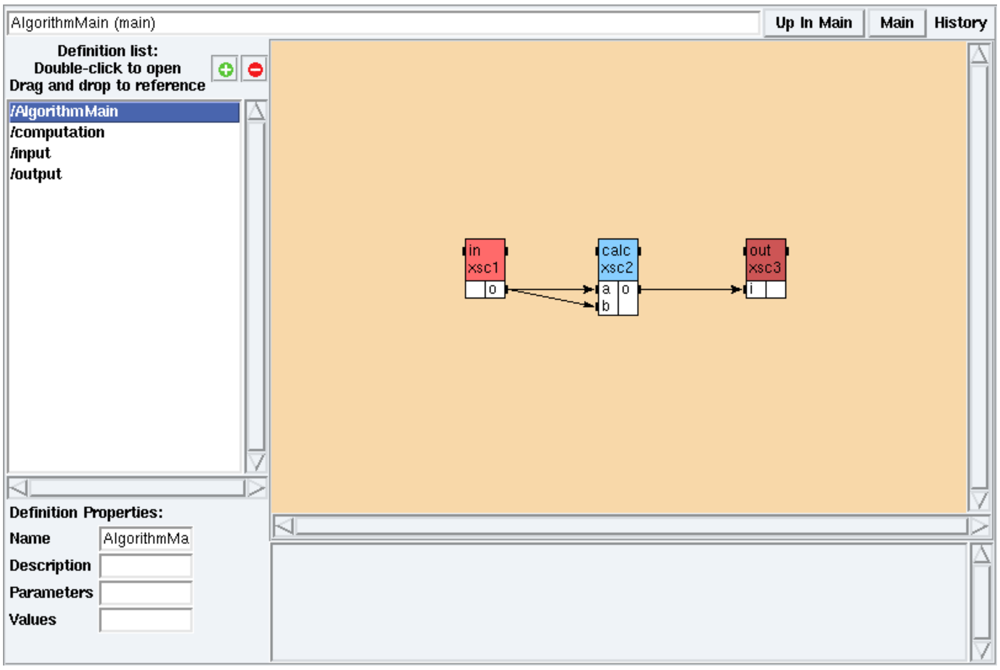

Figure 2.3: *Algorithm window* in `examples/basic/basic.sdx`

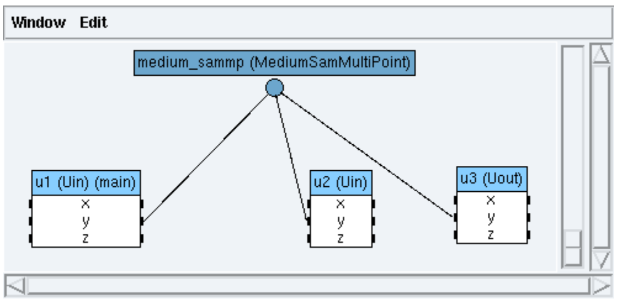

Figure 2.4: *Main architecture window* in `examples/basic/basic.sdx`

Chapter 3

Libraries

3.1 To use libraries

To create a new application you may want to use pre-defined algorithm or architecture *definitions* contained in libraries. These definitions are called *global definitions* (*vs. local definitions* from the current application).

From the **File** menu of the *principal window*, choose the **Specify Library Directories** option. Then **left** click on the **Add** button of the *dialog window* and select the target directory. For example, specify the SynDEx `libs` directory and the `examples/basic_with_library/basicLibraries` directory.

To include a library in an application in order to make *references* to the objects it contains, from the **File** menu of the *principal window*, choose the **Included Libraries** option. Then check the target library. Uncheck an already included library to un-include it, provided there are no *references* in your application on *definitions* from this library.

3.2 To create a library

To create a library of algorithm or architecture *definitions*, you must create a `.sdx` file containing the *definitions* you need. Libraries may be located in the `libs` directory, at the root of your installation directory. Or you will have to specify their location to the SynDEx application (*cf.* section 3.1).

Chapter 4

Using the interface

4.1 Selection

Selection may be applied to vertices or edges of both algorithm or architecture graphs.

Left click on a vertex (resp. an edge). Red squares appear on its borders, meaning that the vertex (resp. the edge) is selected. To select multiple vertices and/or edges, use the **shift** key. To select a set of vertices and/or edges, use the **left** button of the mouse while dragging it, in order to draw a square when the button is released. Vertices inside or intersecting the square are selected.

To move a selection, **left** click on a vertex of the selection. Then drag it until the target position and release the mouse. To cancel a selection **left** click outside the selection.

Contextuals menus are available on selections (*cf.* section 4.3).

4.2 Zoom

Zoom may be applied to *architecture* (*cf.* chapter 6) and *schedule windows* (*cf.* section 9.6) by moving the zoom cursor on the border of these windows.

4.3 Contextual menus

Some *contextual menus* are available in SynDEx. Contextual menus mainly include *edition commands* (**Copy, Cut, Paste, Delete**).

Algorithm window

In the *algorithm window*, **right** click on the background of an *algorithm definition window.* It opens a contextual menu on the target *definition.* **Left** click on a vertex (*function, delay, sensor, actuator, constant*) of an algorithm graph. Red squares appear. Then **right** click the mouse. It opens a contextual menu on the target *reference.*

The **Activate Info Bubbles** option displays additionnal information when pointing the cursor at a vertex of any algorithm graph.

Architecture window

In an *architecture window*, **right** click on the background or **left** click on the **Edit** menu. It opens a contextual menu on the target *definition.* **Left** click on a vertex (*operator, communication medium*) of an architecture graph. Red squares appear. Then **right** click the mouse. It opens a contextual menu on the target *reference.*

4.4 Contextual information

When the cursor points at an object of an *algorithm* (*cf.* chapter 5), an *architecture* (*cf.* chapter 6) or a *schedule window* (*cf.* section 9.6), information is displayed in the *principal window*.

By default information is not kept when switching between objects. The new information overwrites the older one. To change this behaviour and keep all the information, from the **Options** menu of the *principal window*, check **Keep Information in the Principal Window**. This is for instance useful when the information displayed does not fit in the window, which requires to scroll the *principal window*.

4.5 To find an object

Looking for a vertex, from which you now the name, in a complex graph can become rather tedious.

Architecture window

In the *architecture window* (*cf.* chapter 6), from the **Edit** menu, choose the **Find Operator Reference** or **Find Medium Reference** option to locate a vertex of your graph by its name. It opens a window listing all the vertices of your graph. **Double left** clicking on one of them will select it.

Schedule window

In the *schedule window* (*cf.* section 9.6), from the **Edit** menu, choose the **Find Operation** option to locate an operation of your graph by its name. It opens a window listing all the operations of your graph. **Double left** clicking on one of them will select it.

4.6 Refresh

To refresh an *architecture window*, from its **Window** menu, choose the **Refresh** option. If necessary, re-open the *algorithm window* (*cf. Algorithm window* in chapter 5) to refresh it.

Chapter 5

Algorithm

AAA methodology

In the *AAA methodology*, an algorithm is specified as a directed acyclic graph (*DAG*) infinitely repeated. *Directed* means that for each edge representing a relation between vertices, the vertices tuple is ordered, i.e. its first element is the source vertex and the other one(s) is(are) the destination vertex(vertices). A vertex is an *operation* corresponding to a sequence of instructions which starts after all its input data are available and produces all its output data at the end of the sequence. An edge is a *dependence* between two vertices corresponding to a data transfer and an execution precedence, or to an execution precedence only. Note that some vertices may be independent, i.e. may not be connected by dependences.

Definition *vs.* reference

In SynDEx there is a distinction between algorithm *definition* and algorithm *reference*. A *definition* preexists to a *reference* that corresponds to one an only one *definition*. On the contrary, to a given *definition* may correspond several *references*. That allows for referencing, with different names, a unique *definition*. Therefore, an algorithm is described by a *definition*, which is a DAG similar to those in *AAA*, where vertices are *references* or ports, and edges are dependences between references, or between references and ports.

Atomic or hierarchical definitions

To a given *reference* contained in a *definition* corresponds a *definition* which may contain itself several *references*, and so on. That corresponds to *hierarchy*. A *definition* is said *hierarchical* when it defines an algorithm which contains at least one dependence connecting an input port to an output port, and possibly one or several *references* connected by dependences, otherwise it is said *atomic*.

There are five types of *atomic definitions*: **functions** read data on *input* ports, execute instructions without any side-effect, write data on *output* ports, **sensors** are input vertices of the DAG producing data from a physical sensor, **actuators** are output vertices of the DAG consuming data for a physical actuator, **constants** are input vertices of the DAG, with null execution time, **delays** memorize data during one or several infinite repetition of the DAG, for use in next repetitions. These types are detailed in section 5.1.1.

A *definition* is said *explicitly hierarchical* when the algorithm contains at least one dependence (and possibly *references*). This includes *conditioning* (*cf.* section 5.2), *repetitions* (*cf.* section 5.3) of *hierarchical definitions*, and more generally *definitions* defined through several levels of *hierarchy*. Only a *function* may be defined through *explicit hierarchy*.

A *definition* is said *implicitly hierarchical* when the algorithm does not contain any dependence and yet will be transformed by SynDEx, for the *adequation*, into a graph which contains dependences. This happens only with *repetitions* (*cf.* section 5.3) of *atomic definitions*.

Warning: A *hierarchical definition* does not have to wait for all its input data to be available before starting some computations. Indeed, parts of the algorithm graph of a *hierarchical* algorithm *definition* may only require parts of the input data of the *definition* and therefore can start as soon as this part is available (and not all the data). In the same way, some data may be produced before the end of the complete sequence of computations.

Dependences

There are two types of dependences:

- *data dependence*: data transfer and execution precedence,
- *precedence dependence*: execution precedence only.

A *data dependence* imposes that the *reference* at the source of the *dependence*, produces data and is executed before the *reference* at the destination of the *dependence*, which consumes the data. A *precedence dependence* only imposes an execution order between *references*, no data is produced or consumed.

Algorithm window

Definitions and references are managed through an*algorithm window*. If necessary it is possible to open several *algorithm windows*.

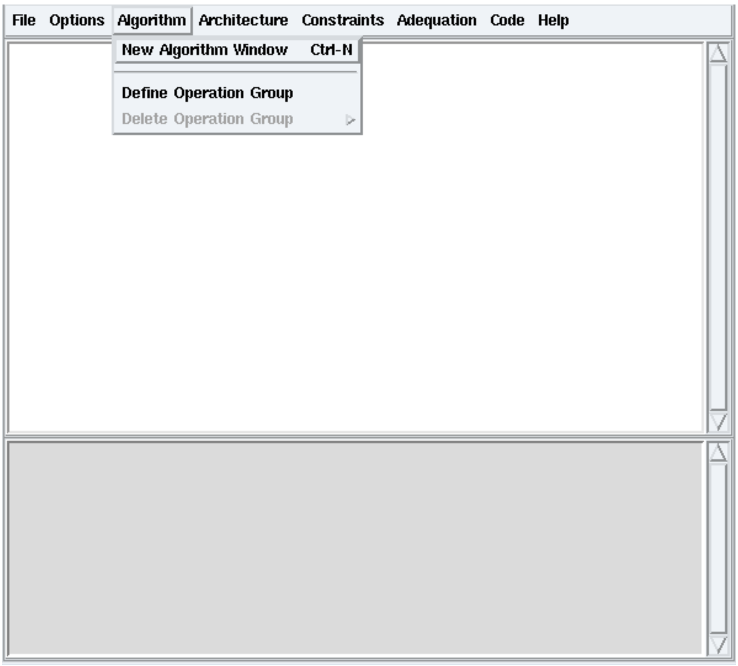

Figure 5.1: **Algorithm / New Algorithm Window**

From the **Algorithm** menu, choose the **New Algorithm Window** option (*cf.* figure 5.1). It opens an *algorithm window* for algorithm *definitions* (*cf.* figure 5.2). **Left** click on the background of a *definition window*: the *algorithm window* shows its **Definition Properties**. **Left** click on a *reference* in this *definition window*: the *algorithm window* shows its **Reference Properties**. These definition or reference properties appear in the left bottom part of the *algorithm window* (*cf.* figure 5.4 for definition properties and figure 5.5 for reference properties).

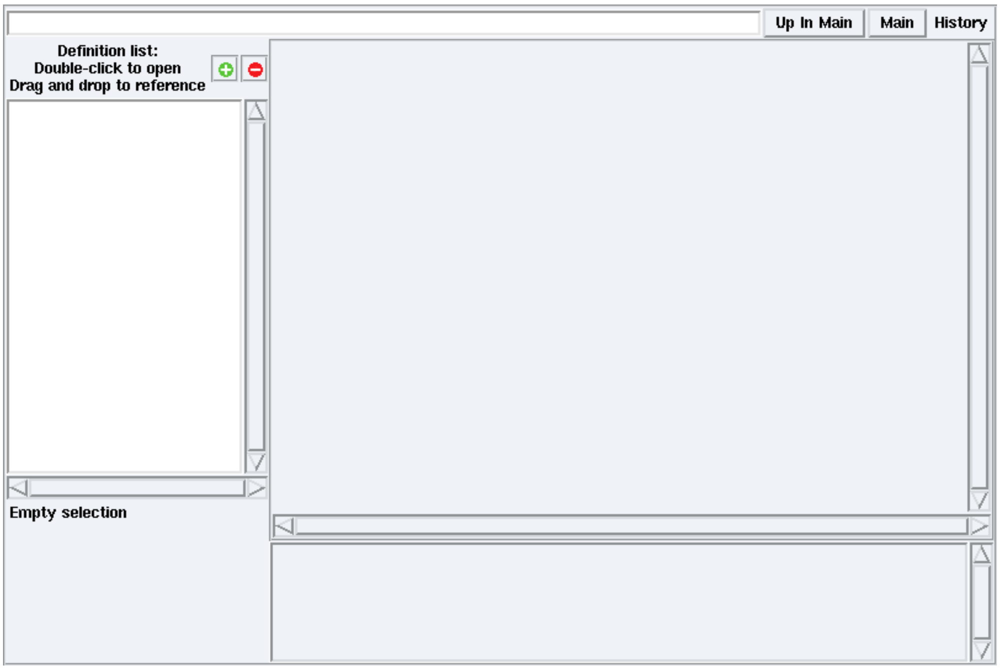

Figure 5.2: **Algorithm Window**

5.1 To create an algorithm definition

5.1.1 To create a definition

Types of definitions

SynDEx distinguishes five types of *definitions* with different edition rules:

- a *function* is a general abstraction with no edition restriction: it can contain *dependences*, *references* and ports;

- a *sensor* is an abstraction of a physical device producing data: it can only contain *output* ports;

- an *actuator* is an abstraction of a physical device consuming data: it can only contain *input* ports;

- a *constant* is a an abstraction of a typed value: it can only contain one *output* port producing that value. For convenience, the value hold by the *constant* can be given as a parameter to the *constant definition*. Note that this is only possible for values that are representable within the parameter language: `integer`, `float`, `string` and list of such values. SynDEx standard library uses this trick to define *constants* for the library base types (`int`, `float`, ...). For example, the `cst` *definition* of the `int` library has one parameter: `ListOfValues`;

- a *delay* is an abstraction of a memory region: it must contain one *input* port (the *write* port) and one *output* port (the *read* port) of the same type, but nothing more. *Delays* hold the state of a SynDEx application. Using *delays* is the only way to propagate data from one iteration of the application to the next. A *delay* must be initialized, either by using a parameter (as suggested above for *constant definitions*) or lately in the *real world* code (as for *constant definitions*, doing it in the code is the only alternative for *delays* holding values of complex types). SynDEx standard library defines *delays* for its base types as shift registers with two parameters: the first one is a list of initial values and the second one is the size (in number of elements) of the shift register. For example, the *delay definition* of the `int` library has two parameters: `listInit` and `nbDelay`.

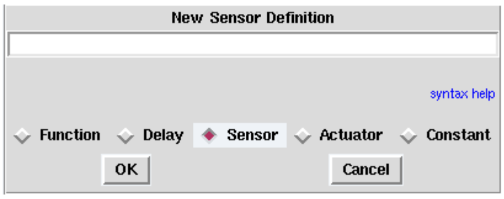

Figure 5.3: Definition of a *sensor*

New definition

To create a new *definition*, in the *algorithm window*, **left** click on the + green button. It opens a *dialog window* in which you can select the *definition*'s type. For example check **Sensor** (*cf.* figure 5.3). Type the name of the new *sensor* and optionally parameters. For example type `input`. Then **left** click **OK**. It creates a *definition* of *sensor* named `input`.

Definition with parameters

Parameters are local to the scope of a *definition*. Often, parameters are used to create more generic *definitions*. For example, the increment of an incrementer can be given as a parameter of the incrementer *definition*. Parameters of a *definition* are names (not values) separated by semi-colon between $<$ and $>$ following the name of the *definition*, according to the following **syntax**:

```
parameters ::= "<" { parameter ";" } parameter ">"
parameter ::= name
```

where curly brackets {...} represent zero, one or several repetitions of the enclosed element, and keywords are quoted.

You can also edit the parameters of a definition directly in its **Definition Properties** (*cf.* figure 5.8) using the same syntax. The parameters will be instanciated (values given to names) when the definition will be referenced (*cf.* section 5.1.4). The only *definition* whose parameters can be instanciated, is the *main algorithm* (*cf.* section 5.1.2) only through its field **Values** in its **Definition Properties** (*cf.* figure 5.8).

5.1.2 Definition mode and main mode

This section refers to section 2.2.

Definition mode

Double left click on a *definition* name in the **Definition list** (*e.g.* open the `examples/hierarchy/hierarchy.sdx` application and **double left** click on `C` in the **Definition list**). You are now in a *definition mode* (*cf.* figure 5.4). From a *definition mode*, to open the *definition* corresponding to a *reference* in order to inspect and possibly modify its content, **left** click on the target *reference* to select it. Red squares appear on its borders (*cf.* figure 5.5). Then **double left** click on it. It displays the *definition* of the target *reference* (*cf.* figure 5.6).

Note that as soon as you have included an algorithm library (*cf. section 3.1*), all its definitions appear in the definition list. The **Definition list** in figure 5.4 shows some *local definitions* (*e.g.* `A, B, C, Main`) and *global definitions* (*e.g.* `int/Arit_add, int/Arit_div`, etc.) since the integer library was included.

Main mode

To define an algorithm as *main*, **right** click on the background of the target *definition window*. Choose the **Set As Main Definition** option (*cf.* figure 5.7). The color of the background changes and the

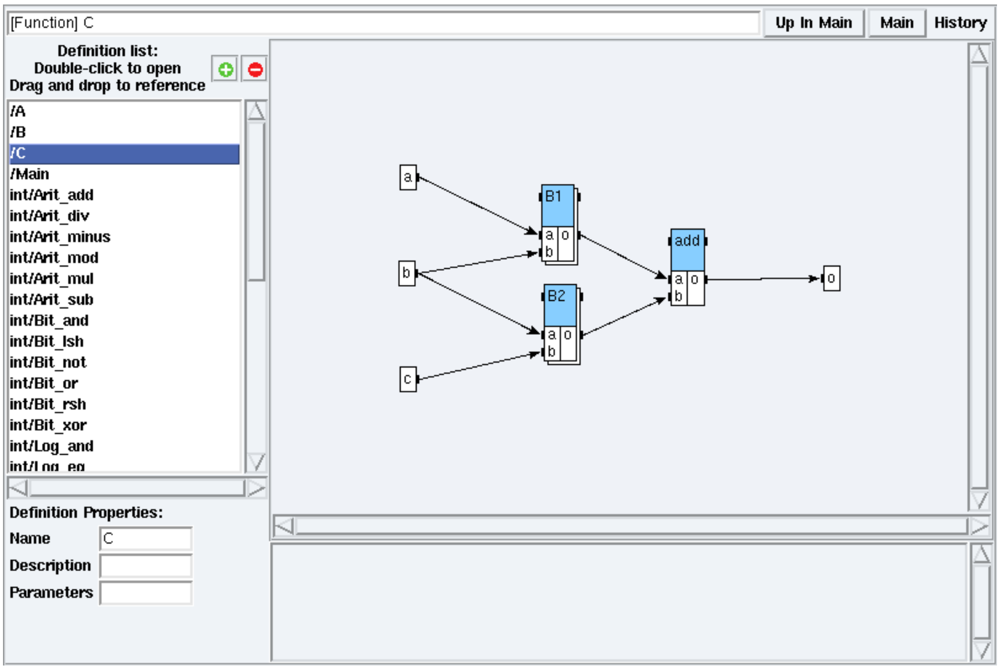

Figure 5.4: `C` *definition* in `examples/hierarchy/hierarchy.sdx`

adress is changed from a `[Function]` to a `(main)`, meaning that you are now in the *main mode* on the *main algorithm* (*cf.* figure 5.8). Note that the *main algorithm* must be at the root level of a *hierarchy*; it can not contain unconnected ports. Only the *main algorithm* can instanciate (give values to names) its parameters (*cf.* section 5.1.1) thanks to its field **Values** in its **Definition Properties** (*cf.* figure 5.8).

Left click on the **Main** button of the *algorithm window*. It displays the *main algorithm* in the *main mode*. **Left** click on a hierarchical *reference* to browse down the *main algorithm* (*e.g.* **left** click on the `C` *reference* of `Main` then **left** click on the `B2` *reference* of `C`). Then **left** click on **Up In Main** to browse up the *main algorithm*.

Hierarchy

Now you may construct a graph with *references* to *constants*, *sensors*, *actuators*, *delays* and *functions*. If this *definition* is intended to be referenced in an *explicit hierarchy*, i.e. this *reference* will belong to a certain level of *hierarchy* (possibly a leaf), you must use *input* and *output* ports. If this *definition* is intended to be referenced at the *root level* of the *hierarchy*, *input* ports are replaced by *sensors* and *output* ports are replaced by *actuators*.

References to an *explicitly hierarchical definition* are displayed with a *double-border* (in the figure 5.4 `B1` is a *reference* on an *explicitly hierarchical definition* contrary to `add`).

5.1.3 To create a port in a definition

Ports are communication interface of a *definition* with the outside world.

Direction of ports

SynDEx distinguishes three directions for ports:

- an *input* port represents a data that is provided *by* the outside world *to* the *definition*;
- an *output* port represents a data that is provided *by* the *definition* *to* the outside world;

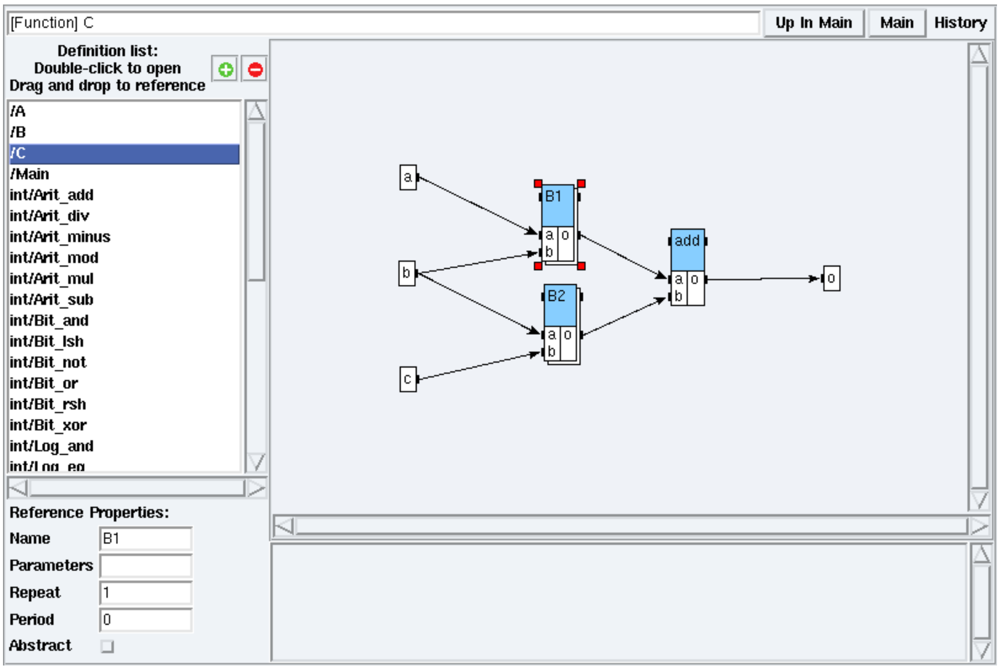

Figure 5.5: Opening `B1` *reference* in `examples/hierarchy/hierarchy.sdx`

- an *input/output* port can be seen as a *reference* (or pointer) to a data provided by the outside world that the *definition* can modify in place. This explains the name of *input/output* ports: we can read the value of the port and replace it by a new one.

New port

To create a port in an *atomic definition* (*cf.* chapter 5):

- in the *definition mode* (*cf.* section 5.1.2), **right** click on the background and choose the **Create port** option For example create a new *definition* named `input` and create a port in this *definition* (*cf.* figure 5.9);
- it opens a *dialog window* in which you can type the port direction, type, name and optionally its size. You can **left** click on the **syntax help** link for more information. For example type `! int o`, then **left** click **OK** (*cf.* figure 5.10);
- it creates the target port. In this example, the new port is an integer *output* port named `o` (*cf.* figure 5.11) in the *definition window*.

You can undo and redo this action, **right** click on the background and choose the **Undo, Redo** options.

A port *definition* has the following **syntax**:

```
port_definition ::= direction type [ "[" size "]" ] name
direction ::= "?" | "!" | "&"
```

where:

- `?` specifies an *input* port,
- `!` specifies an *output* port,
- `&` specifies an *input/output* port,

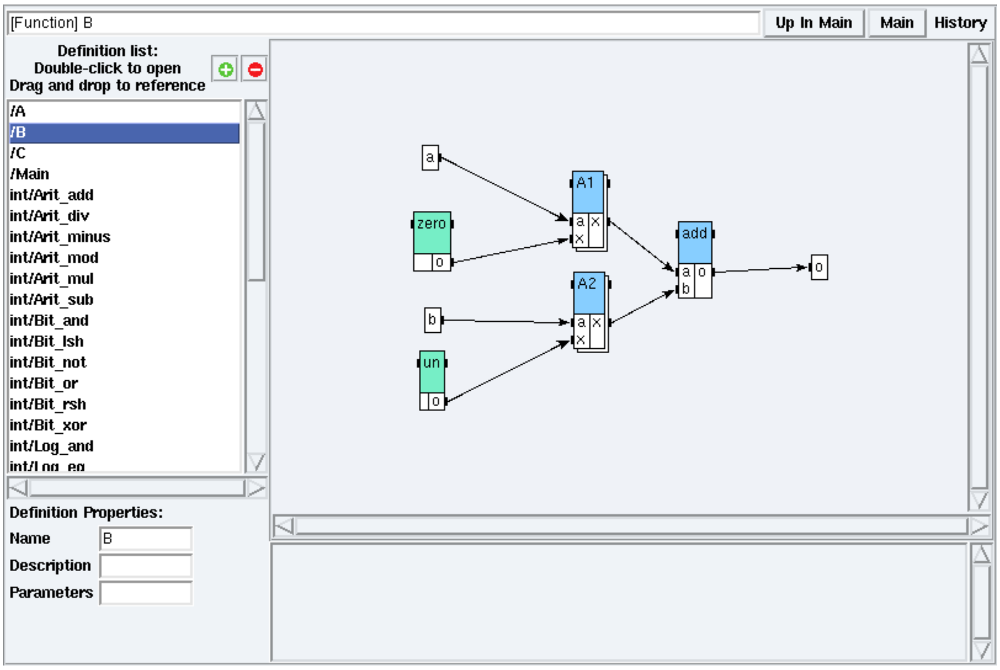

Figure 5.6: `B` *definition* in `examples/hierarchy/hierarchy.sdx`

square brackets [...] represent optional elements, pipes | represent alternatives, and keywords are quoted.

Hint: you can create several ports in one breath by simply putting several port *definitions* in a row in the *dialog window*, according to the following **syntax**:

```
port_definition ::= { port_definition }
```

where curly brackets {...} represent zero, one or several repetitions of the enclosed element.

Ports order

If you plan to generate code, it is necessary to specify an order for ports which is consistent with the declaration of the corresponding executable function. To specify the ports order, **right** click on the background and choose the **Ports Order** option.

Input/output ports

Input-output ports have a very specific behavior concerning data memory allocation in the executives generated by SynDEx. For any application, SynDEx makes data buffer allocations for (and only for) the *output* ports of the *atomic references* of your algorithm graph. Input-output ports do not cause an allocation but instead an alias on the *output* port of its predecessor. The operation containing this *input-output* port directly modifies the value of its predecessor port (side-effect). This is useful to avoid reallocation of big data buffers of the same type (for instances images) by making successive computations on the same data buffer.

However, as side-effects are not supposed to happen in data-flow graphs, this comes with some restrictions:

- Ports of *delay definitions* can not be *input/output* ports,
- Ports of *hierarchical definitions* can not be *input/output* ports,

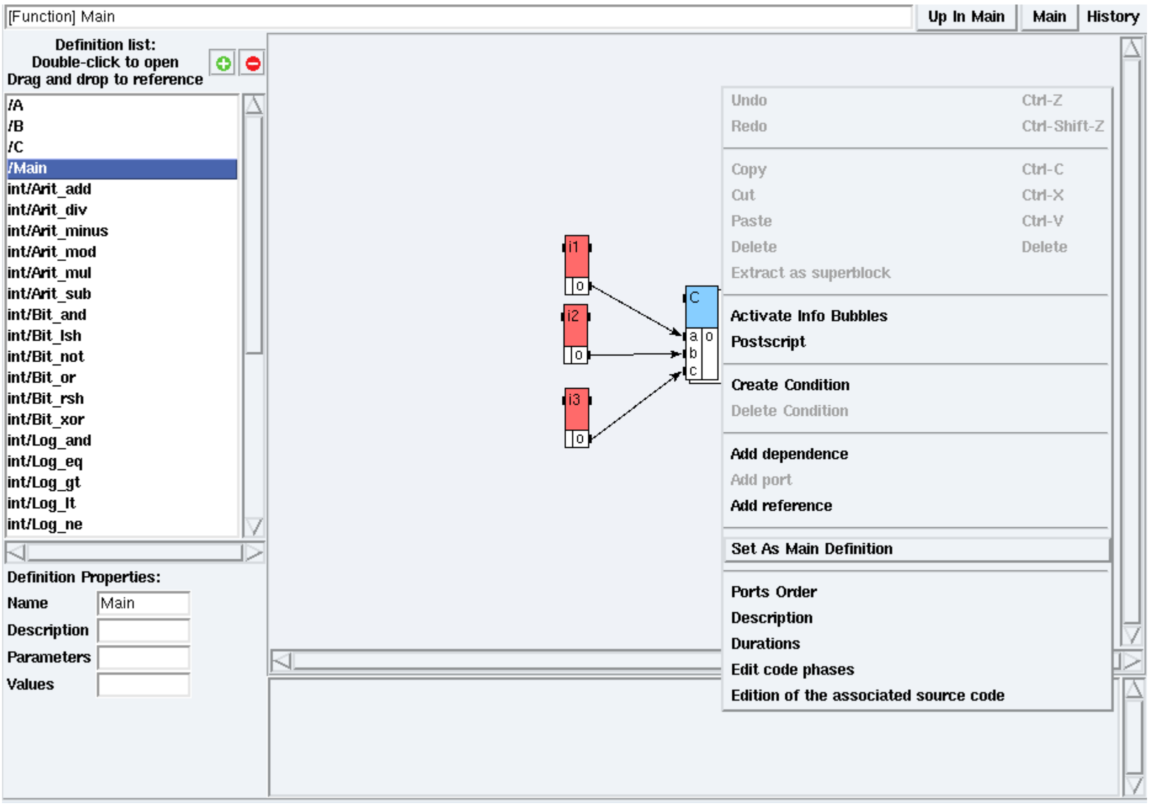

Figure 5.7: Set `Main` *definition* as *main algorithm* in `examples/hierarchy/hierarchy.sdx`

- The data of an *input/output* port can not be diffused: if there is a dependence `A.o --> B.io` (where `A.o` is an *output* port and `B.io` is an *input/output* port), neither `A.o` nor `B.io` can be diffused (*cf.* section 5.3.1).

5.1.4 To create a reference in a definition

A *reference* can be thought as a call to a function in a traditional programming language. Here the *called function* is an algorithm *definition*.

New reference

To reference a *definition* (*e.g.* `myReferencedDef`) into another one (*e.g.* `myDefinition`), set the *algorithm window* in *definition mode* on `myDefinition` (*cf.* section 5.1.2). Then drag and drop `myReferencedDef` from the **Definition list** to the *definition window* (or select `myReferencedDef` in the **Definition list**, **right** click on the background of the *definition window*, and choose the **Create reference** option). It opens a *dialog window*. Type the name of the *reference* (*e.g.* `myReference`). See figure 5.12 to see the result.

Reference with parameters

To reference a *definition* with parameters (*cf.* section 5.1.1), a *valued expression* is required for each parameter of the definition. Parameters of a reference are *valued expressions* separated by semi-colon between $<$ and $>$ following the name of the *reference*, according to the **syntax**:

```
expr_list ::= "<" { expr ";" } expr ">"
expr ::= name | value | "(" expr ")" | expr "+" expr |
         expr "-" expr | expr "*" expr | expr "/" expr |
```

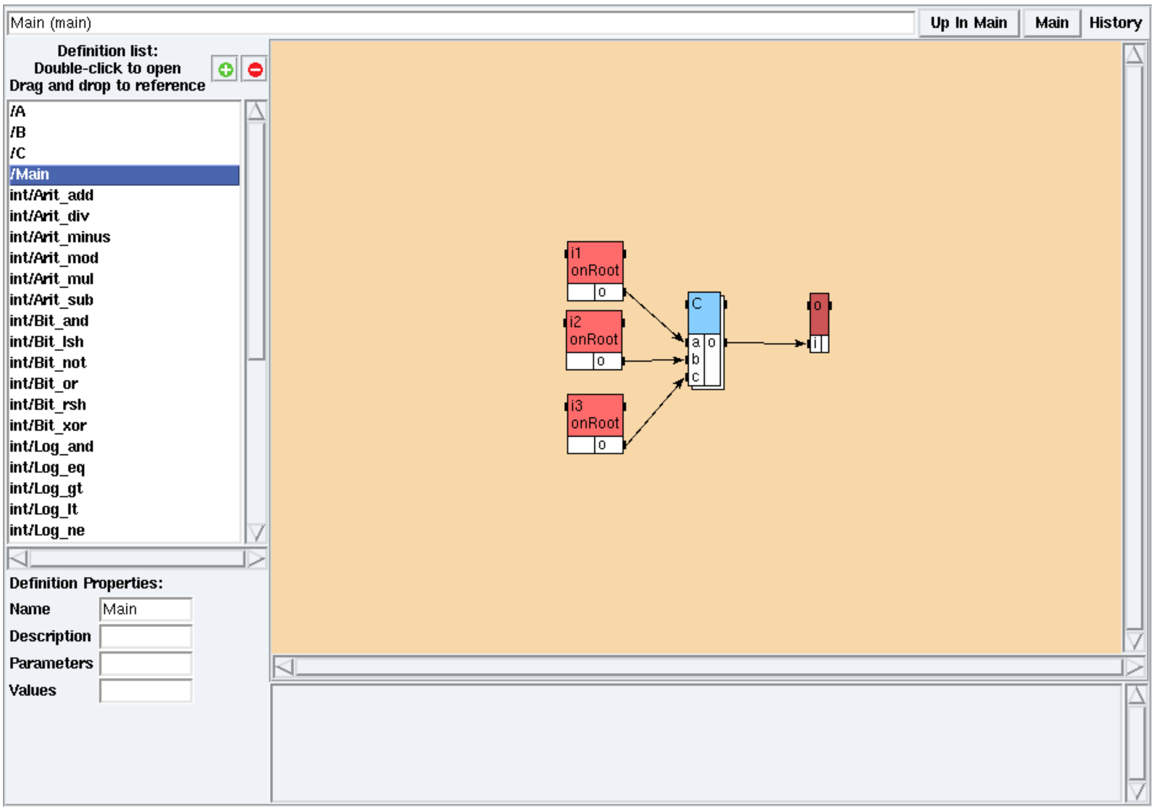

Figure 5.8: *Main mode* in `examples/hierarchy/hierarchy.sdx`

```
          "-" expr | "{" { expr "," } expr "}"
valued_expression ::= expr
```

where curly brackets {...} represent zero, one or several repetitions of the enclosed element, pipes | represent alternatives, and keywords are quoted. A parameter is instanciated when it has a value otherwise it is not.

You can also edit the parameters in the **Reference Properties** with the same syntax. Note that the number of valued expressions must match the number of parameters of the referenced *definition*, and that types must match.

5.1.5 To create a dependence in a definition

A *dependence* is a directed edge connecting a producer operation to one or several consumer operations. As such, it specifies an *execution order* relation between two *references* used in a definition.

SynDEx distinguishes two types of dependences: data dependences and precedence dependences (without data) (*cf.* introduction of chapter 5). SynDEx automatically creates the right type of dependence depending on the context:

- To create a *data dependence* in a definition between two *references*, point the cursor at an *output* port (little black rectangle) of the source, **middle** click (or **Ctrl left** click), then drag and drop on an *input* port (little black rectangle) of the destination (or **right** click on the background, and choose the **Add dependence** option). The source and destination of a data dependence can also be ports: this is used to read a data from (resp. write a data to) the outside world. Note that for a given *non-atomic definition*, all *output* ports must be in dependence with *input* ports: all outputs must be defined;
- To create a *precedence dependence* in a definition between two *references*, point the cursor at an *output* precedence port (little black rectangle) of the source, **middle** click (or **Ctrl left** click), then

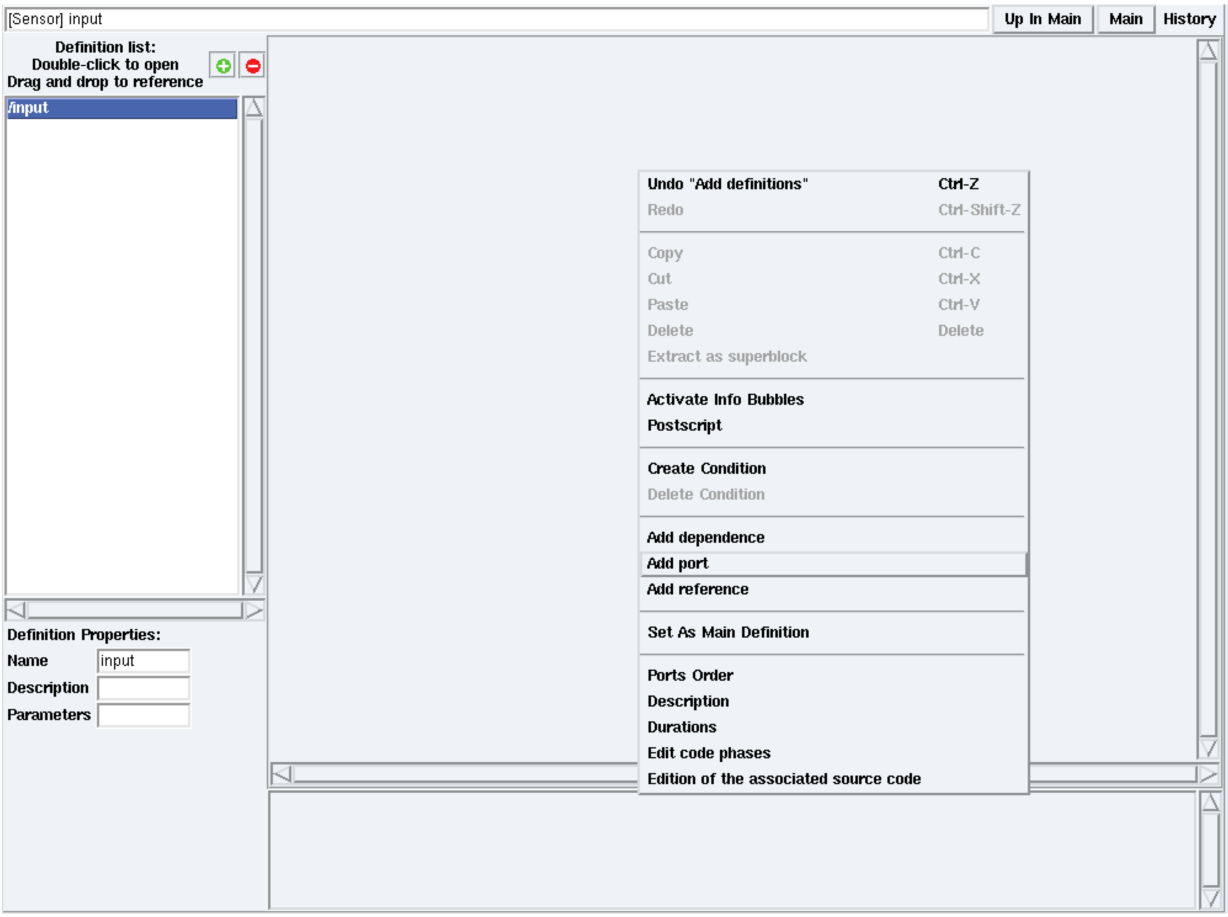

Figure 5.9: Contextual menu → **Create port**

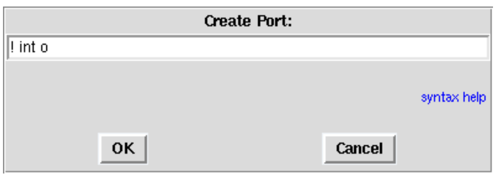

Figure 5.10: Name of the new port

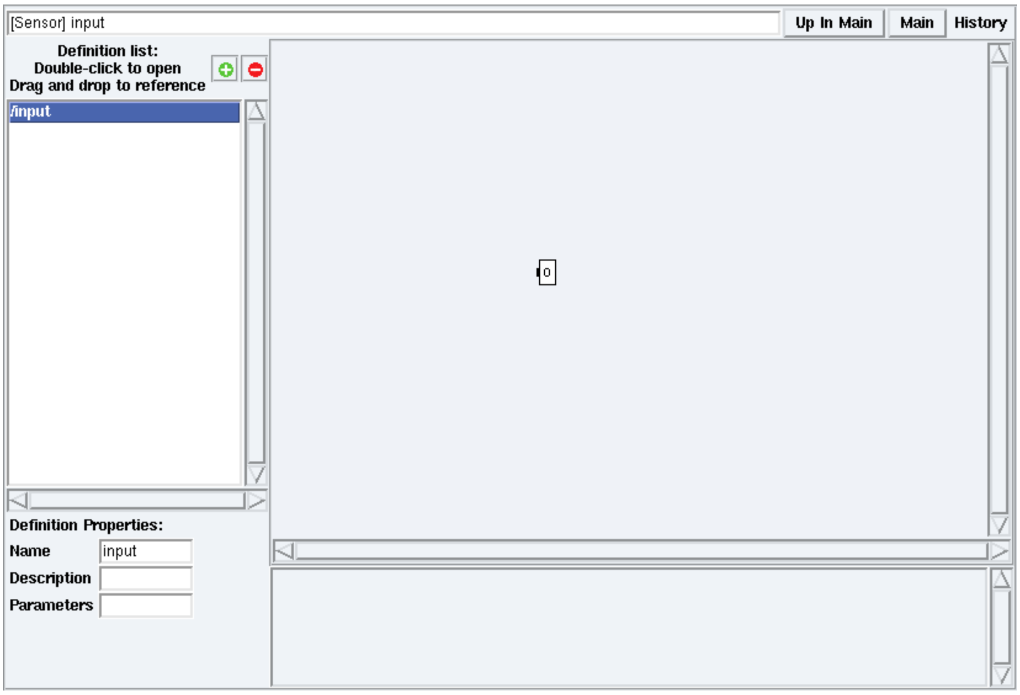

Figure 5.11: A *definition* after port creation

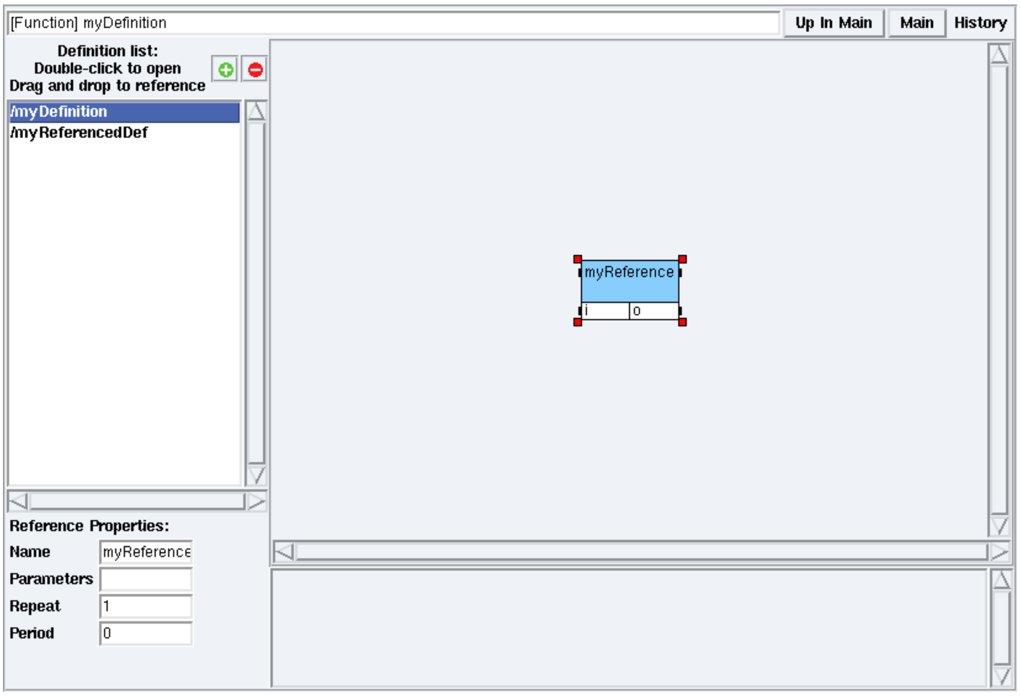

Figure 5.12: A *reference* to `myReferencedDef` into `myDefinition`

drag and drop on an *input* precedence port (little black rectangle) of the destination. *Input* (resp. *output*) precedence ports are represented by little black squares at the left (resp.right) of the boxes holding the *reference* names.

5.1.6 To create a superblock

A *superblock* is a set of operations, edges and ports extracted as a new *definition*.

To create a *definition* as a superblock, select the target set of operations, edges and ports you want to extract (*cf.* section 4.1). Then **right** click and choose the **Extract as superblock** option. A new *definition* is created and a *reference* to this *definition* replaces the selected set. The new *definition* is available in the **Definition list**, You can rename both the *definition* and the *reference*.

You can undo and redo this action.

5.1.7 To create an abstract reference

An *abstract reference* is a *reference* to a *hierarchical definition* in which the *hierarchy* is not taken into account, i.e. the *flattening* (*cf.* section 9.5) does not go into the *hierarchical* referenced *definition* that becomes therefore *abstract*. However, note that to perform the adequation this definition must have a duration.

To create an abstract reference, select the desired hierarchical reference then, check the option **Abstract** in the **Reference properties** of this reference.

You can undo and redo this action.

5.2 To condition an algorithm definition

First make sure that the target *definition* contains an *input* port of type **int** for the *conditioning* port. Note that the SynDEx **libs** directory already provides an **int** library for operations on integer values.

New condition

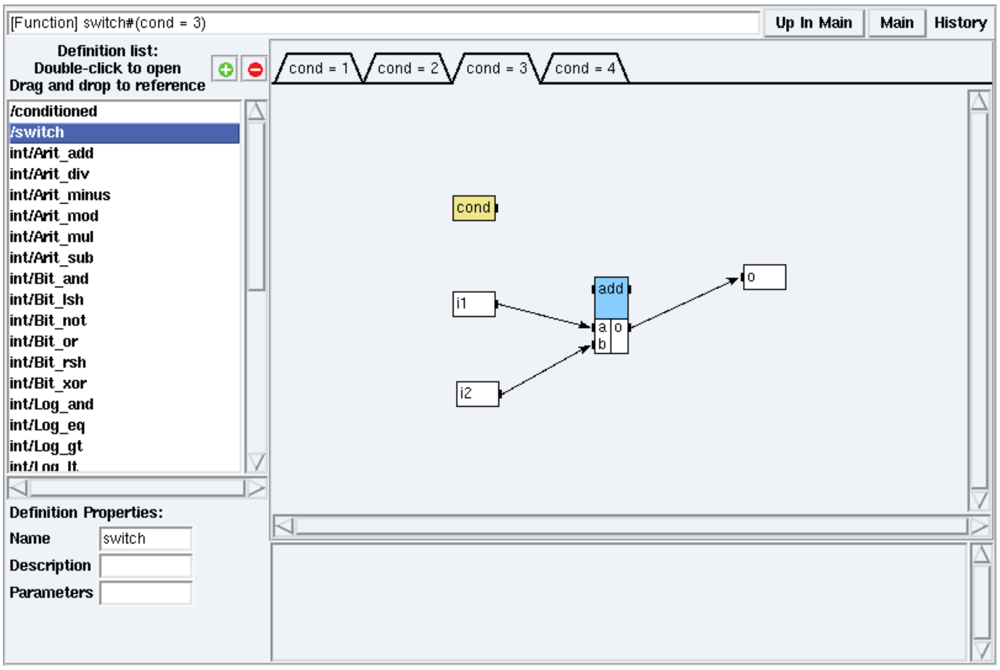

Figure 5.13: `switch` *definition mode* for `cond = 3` in `examples/condition/simpleCondition/simpleCondition.sdx`

Right click on the background of the *definition window* and choose the **Create Condition** option. It opens a *dialog window* for the new condition. A condition is a `port = value` expression where `port` is the name of the *conditioning* port and `value` is an integer. Note that the *conditioning* port must be of direction *input* (*cf.* 5.1.3). A new tab is created for the given condition. The *conditioning* port is now colored in yellow (*cf.* figure 5.13).

If necessary, refresh the *algorithm window* (*cf.* section 4.6).

Remarks

Note that there can be only one *conditioning* input port. You have to construct one sub-graph per value associated to a *conditioning* input port (*cf.* figure 5.13). For each other value of the *conditioning* input port, the result is unspecified and will be inconsistent.

CondI and CondO vertices

The *adequation* and the code generation will take into account the *expanded* graph (*cf.* section 9.5). SynDEx will introduce new vertices during the *expansion*: *CondI* and *CondO* vertices.

A *CondI* vertex consumes the *conditioning* data and connects the input ports of the *conditioned* operation according to its value.

A *CondO* vertex consumes the *conditioning* data and connects the output ports of the *conditioned* operation according to its value.

References

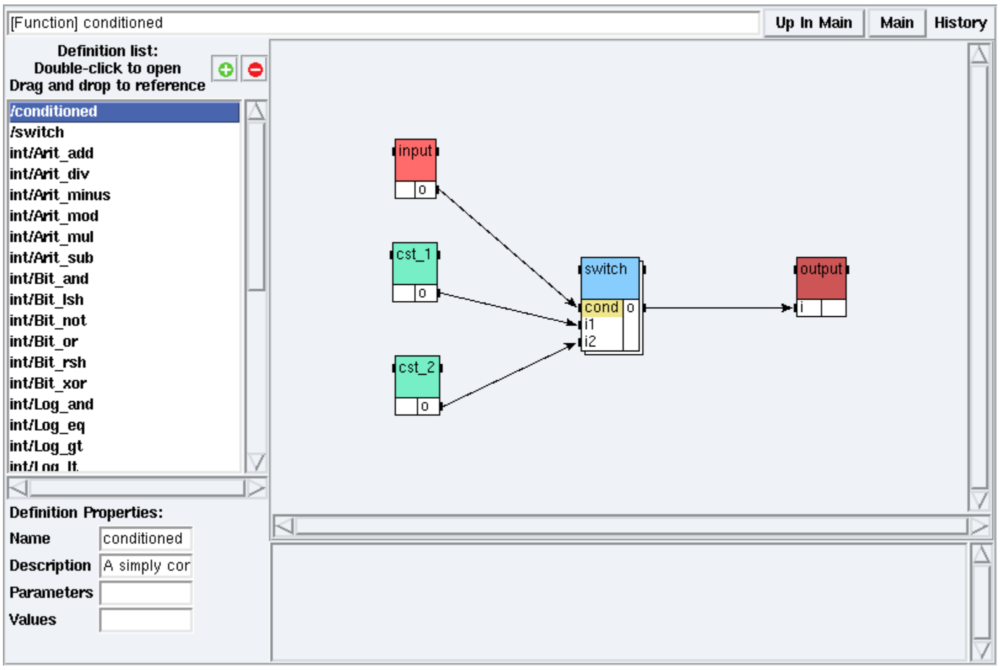

Figure 5.14: `conditioned` *definition mode* in `examples/condition/simpleCondition/simpleCondition.sdx`

In a *definition mode* (*cf.* section 5.1.2), references to *conditioned definitions* have their *conditioning* port yellow colored (*cf.* figure 5.14).

Delete a condition

Right click on the background of the *definition window* and choose the **Delete Condition** option.

5.3 To repeat an algorithm definition

5.3.1 Diffuse, Fork, and Join

You can create a *reference* to a *definition*, and connect to its *input* (resp. *output*) ports some *output* (resp. *input*) ports *with different sizes*. The pre-condition is to have *a unique common multiple* between each pair of ports of different sizes. This multiple is the *repetition factor* of the *reference*.

Multiplication of a vector by a scalar

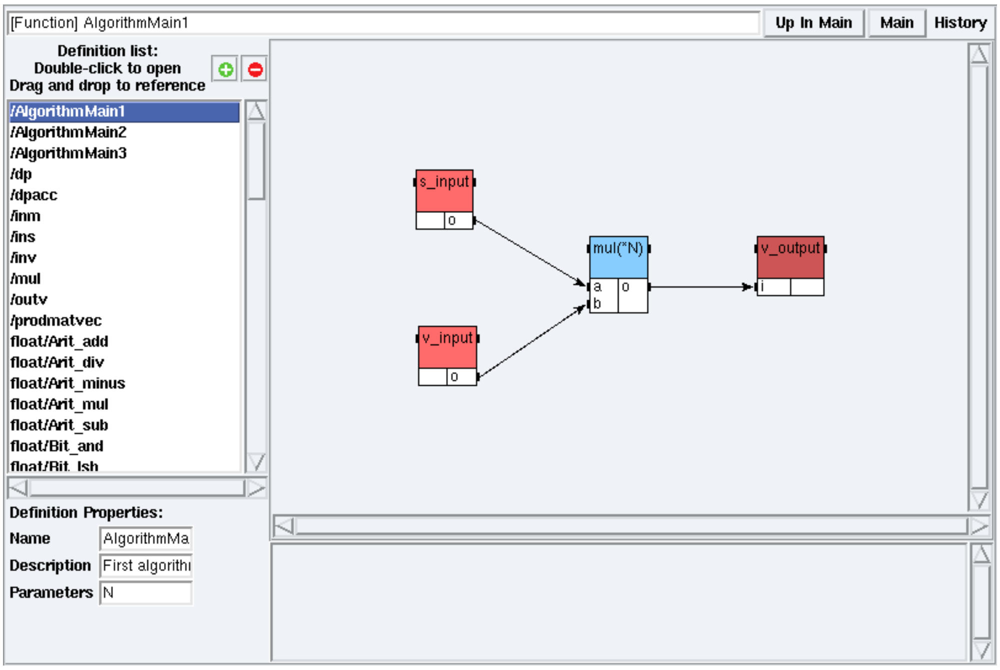

Figure 5.15: `AlgorithmMain1` *definition mode* in `examples/tutorial/example4/example4.sdx`

Suppose that you want to specify the multiplication of a vector by a scalar giving a vector as result (*cf.* `AlgorithmMain1` in `examples/tutorial/example4`). You can specify it by *repeating* the multiplication between two scalars instead of defining a new one. For example for `N` length vectors, you may specify the *repetition* by `N` multiplications between scalars giving a scalar as a result (*cf.* figure 5.15).

You have to:

- create a *definition* with the parameter `N`,
- reference the multiplication on scalars `mul`,
- connect the *output* port of a scalar (*e.g.* `s_input`) to one of its *input* ports (*e.g.* `mul.a`),
- connect the *output* port of a vector (*e.g.* `v_input`) to the other *input* port (*e.g.* `mul.b`),
- connect its *output* port (`mul.o`) to the *input* port of a vector (*e.g.* `v_output`),
- set the *repetition factor* of `mul` to `N`: **left** click on the `mul` *reference*, then type `N` in its **Reference Properties** (*cf.* *Algorithm window* in chapter 5).

Repetition factor

The common multiple between each pair of ports with different sizes is `N`. It is the *repetition factor* that you have to set explicitely by using a *symbolic numbered expression*.

Diffuse the scalar

Since the *output* port of `s_input` has the same size as its connected *input* port of the multiplication *function*, it is replicated `N` times in order to be multiplicated by each element of `v_input`. This is a *Diffuse* operation.

Fork the vector

Since the *function* operates on scalars and the `v_input` vector has `N` elements, each of its elements are provided separately in order to be multiplicated. This is a *Fork* operation.

Join the internal results

Since the *function* operates on scalars and the `v_output` vector has `N` elements, each *repetition* of the multiplication is taken in order to be provided as a `N` elements vector. This is a *Join* operation.

Representation

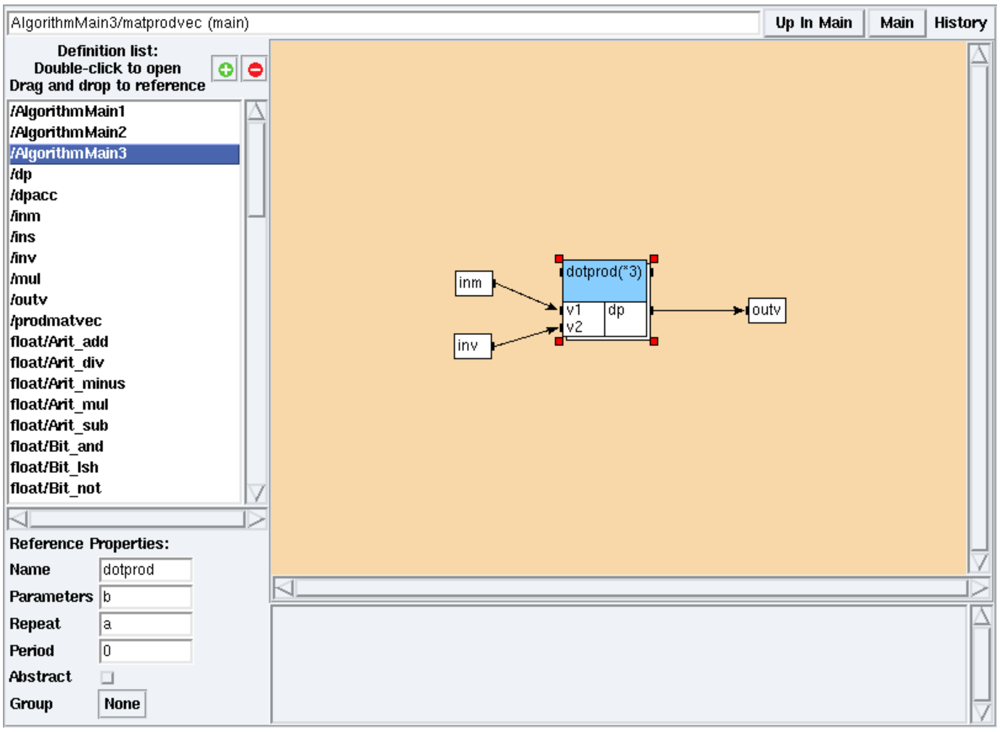

Figure 5.16: `matprodvec` *main mode* from `AlgorithmMain3` *main algorithm* in `examples/tutorial/example4/example4.sdx`

The *repetition factor* is displayed next to the name of the *reference* (*e.g.* in the figure 5.15 `mul` is *repeated* `N` times). The *main algorithm* (*e.g.* `AlgorithmMain3`) instanciates its parameters (*cf.* figure 5.8). From the *main mode* in `examples/tutorial/example4/example4.sdx` (*cf.* section 5.1.2), **double left** click on the `matprodvec` *reference*, the `dotprod` *reference* is *repeated* three times (*cf.* figure 5.16).

Explode and Implode vertices

The *adequation* and the code generation will take into account the *expanded* graph (*cf.* section 9.5). SynDEx *will* introduce new vertices during the expansion: *Explode* and *Implode* vertices.

An *Explode* vertex extracts for each *repetition* of a *definition* each element of the data it receives (*cf.* subsections *Diffuse* and *Fork*).

An *Implode* vertex builds the data it sends by concatenating each separated element produced by each *repetition* of the *definition* (*cf.* subsection *Join*).

5.3.2 Iterate

In some cases, you may want to *repeat* a *reference* but have no difference between port sizes.

Multiplication of two vectors

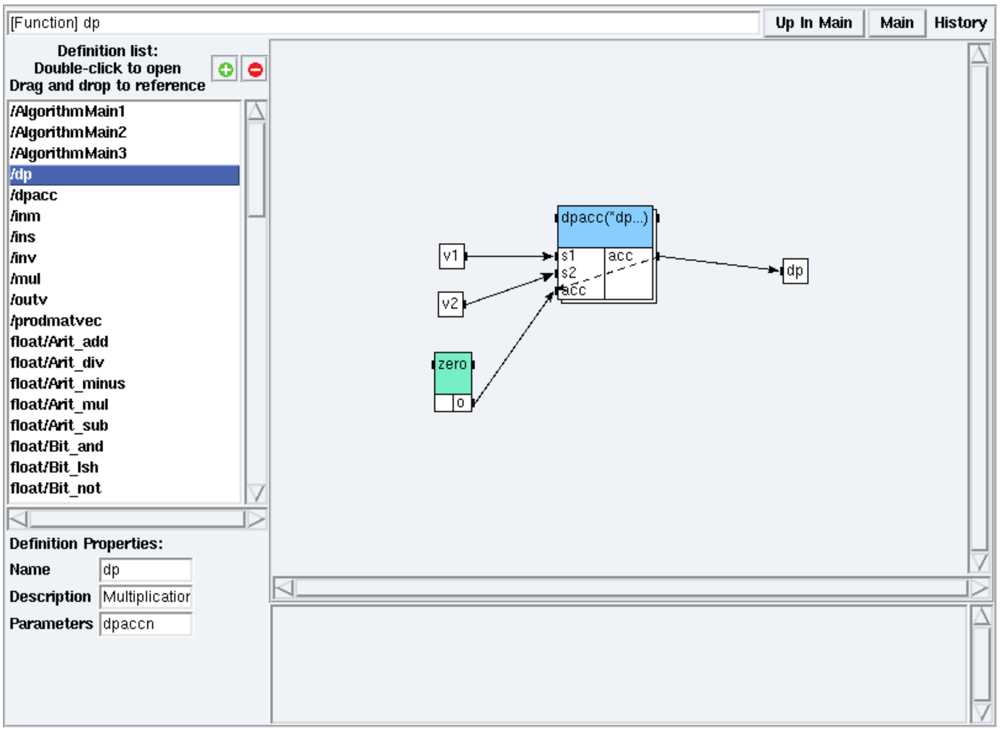

Figure 5.17: `dp` *definition mode* in `examples/tutorial/example4/example4.sdx`

Suppose that you want to specify the multiplication of two vectors giving a scalar as a result (*cf.* figure 5.17). You can specify it by *repeating* the multiplication between two scalars, that used an accumulator to store the partial sum. For example if for `dpaccn` length vectors, you may specify the *repetition* by `dpaccn` multiplications between three scalars (the `i` element of the first vector, the `i` element of the second one, and the accumulator, initialized to `0`).

You have to:

- reference the multiplication on scalars with accumulator (*e.g.* `dp`),
- connect two vectors (*e.g.* `v1` and `v2`) to the scalar *input* ports of the multiplication,
- connect a {`0`} *constant* to the `acc` *input* port of the multiplication,
- connect the *output* port of the multiplication to a scalar (*e.g.* `dp`),
- connect the `acc` *output* port of the multiplication to its `acc` *input* port choosing an *Iterate* edge,
- *repeat* `dpaccn` times the multiplication (in the **Reference Properties** of the `dpacc` *reference*).

The accumulator is initialized with {`0`}. Then the output of the *repetition* *i* becomes the accumulator of the *repetition* *i+1*. The output of the last *repetition* is the output of the *repeated definition*. This is an *Iterate* operation.

5.4 To modify an algorithm definition or a reference

5.4.1 Modify a definition

Double left click on the *definition* name in the **Definition List** or **double left** click on a *reference* from a *definition mode* (*cf.* section 5.1.2). It opens its *definition window*. **Right** click on the background of the *definition window*. Choose the **Create dependence** option (*cf.* section 5.1.5), **Create port** (*cf.* section 5.1.3), **Create reference** (*cf.* section 5.1.4), **Create Condition** or **Delete Condition** (*cf.* section 5.2) to modify the *definition*.

As soon as you have **Left** clicked on the background of a *definition window* (*cf. Algorithm window* in chapter 5) you can change its **Definition Properties** to modify its **Name, Description, Parameters** or **Values**. The latter property appears only in the case of a *main algorithm* definition.

Note that you can modify *local* and *global definitions* (*cf.* section 3.1). Modifications on a *global definition* impact only the current application and the library remains unchanged. To modify a *global definition* over-all, open the corresponding SynDEx library file (*e.g.* `libs/int.sdx`). Modifications on a *definition* in a library may have consequences on all the applications using this library.

5.4.2 Modify a reference

Left click on a *reference* in a *definition window* (*cf. Algorithm window* in chapter 5). Use its **Reference Properties** to modify its **Name, Parameters, Repeat** or **Period**. For the period see the section 5.7 “To build mutli-periodic applications”.

5.5 To delete an algorithm definition

To delete a *definition*, in the *algorithm window*, **left** click on the **-** red button.

Note that deleting a *global definition* (*cf.* section 3.1) impacts only the current application.

5.6 To associate code with an algorithm definition

5.6.1 The code editor window

Right click on the background of a *definition window*. Choose the **Edit code phases** option (*cf.* figure 5.18). Check **init** (resp. **end**) to generate code in the *initialization phase* (resp. *ending phase*).

Right click on the background of a *definition window*. Choose the **Edition of the associated source code** option (*cf.* figure 5.19). It opens the *code editor window* on the *initialization phase* for the selected *definition*. **Left** click on **loop phase** (resp. **end phase**) to edit the code associated in the *loop phase* (resp. *ending phase*) (*cf.* figure 5.20).

5.6.2 The code editor macro language

From the **Code** menu of the *principal window*, check **Generate m4x files**. At code generation time, the code written in the *code editor* will be wrapped into *M4 macro code*, and outputed into an *application_name*`_sdc.m4x` file. These files contain one *M4 macro* definition per algorithm *definition* (*cf.* figure 5.21). The *code editor* offers several *macros* to abstract away the *M4 nature* of the output file. These *macros* are of two kinds: port and parameter names *translation macros*, and *quoting macros* (*cf.* `macros` directory).

Names translation macros

Parameter and port names of an algorithm *definition* are encoded as parameters of the corresponding *M4 macro*. Because the *M4 language* uses positional parameters, when you want to refer to a parameter or port in the associated code he has to know its position in the *M4 macro* parameters list. More than being not very handy, this is fragile relatively to creation or deletion of ports and parameters in the *definition*: when you create a port or a parameter to a *definition*, he has to adjust (replace `$n` by `$n+1`

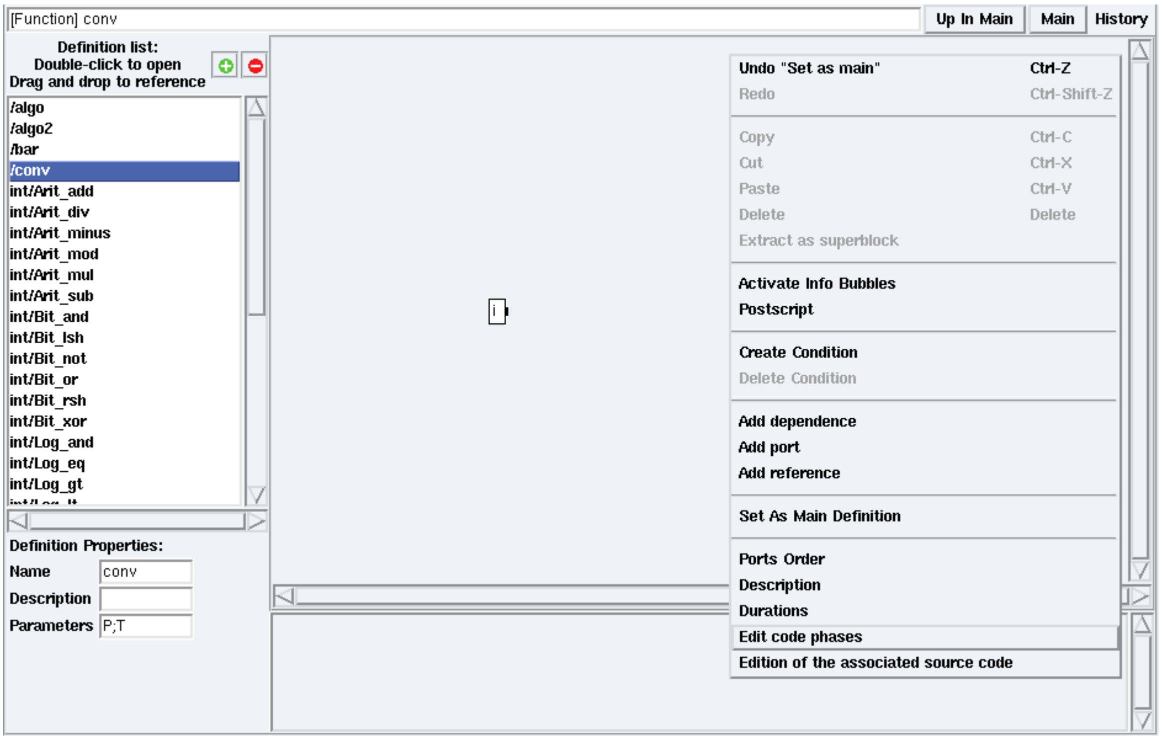

Figure 5.18: Edition of the `conv` code phases in `examples/tutorial/example7/example7.sdx`

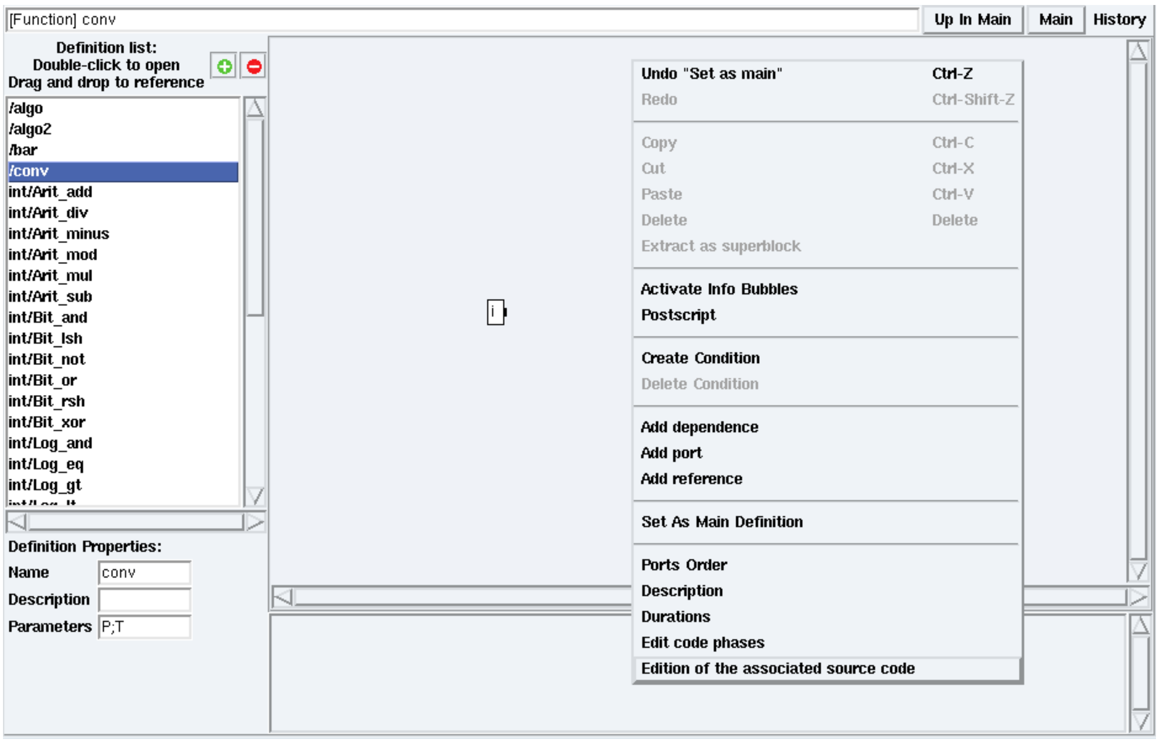

Figure 5.19: Edition of the code associated with `conv` in `examples/tutorial/example7/example7.sdx`

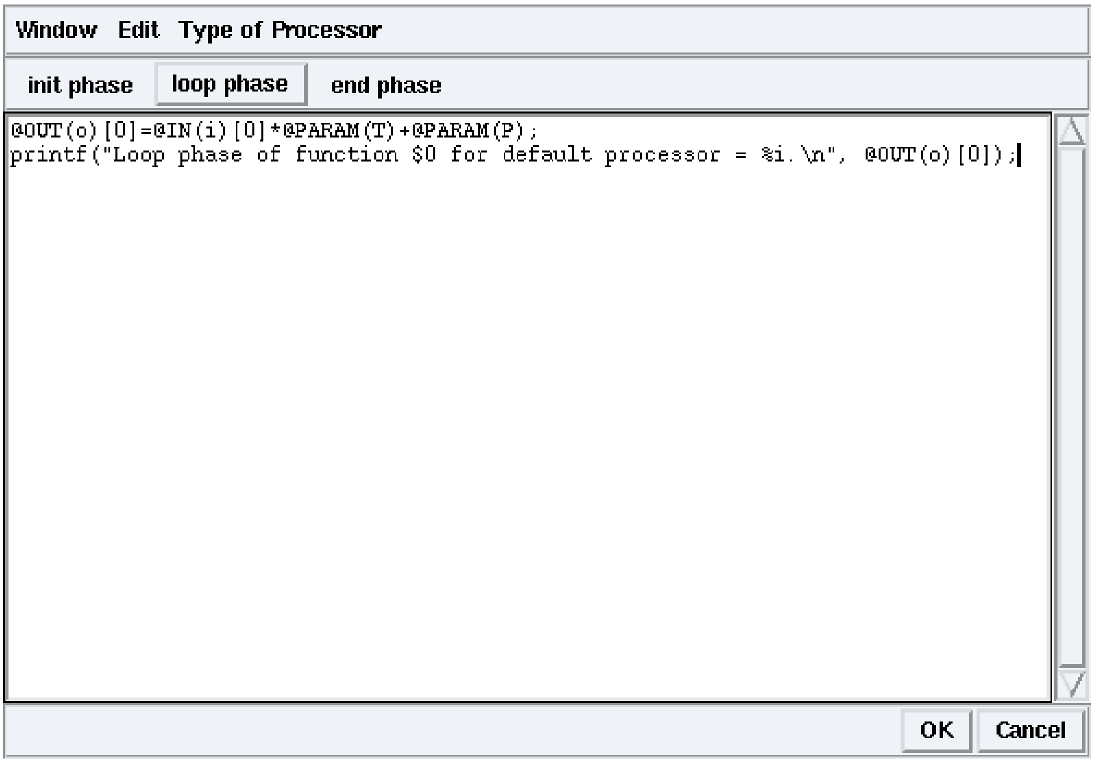

Figure 5.20: Code associated with `conv` in *loop phase* in `examples/tutorial/example7/example7.sdx`

```
define(`example7_conv',`conv')
define(`conv',`ifelse(
    processorType_,processorType_,`ifelse(
         MGC,`INIT',``printf("Init phase of function $0 for default processor.\n");}'',
         MGC,`LOOP',``$4[0]=$3[0]*$2+$1;
printf("Loop phase of function $0 for default processor = %i.\n", $4[0]);'',
         MGC,`END',``printf("End phase of function $0 for default processor.\n");}'')')')
```

Figure 5.21: *M4 macro code* for `conv` in `examples/tutorial/example7/example7_sdc.sdx`

in) all *references* to parameters or ports coming after the created one in the parameters list of the *M4 macro*. To overcome this difficulty, the *code editor* recognizes the following *macros* (*cf.* figure 5.20):

- `@IN(prt)` refers to the *input* port named `prt`,
- `@OUT(prt)` refers to the *output* port named `prt`,
- `@INOUT(prt)` refers to the *input/output* port named `prt`,
- `@PARAM(prm)` refers to the parameter named `prm`,
- `@NAME(pr)` refers to the port or parameter named `pr`. When using this *macro*, you should be careful that the port or parameter you want to refer to has a unique name in the *definition*.

Quoting macros

Quoting macros are used to wrap or unwrap code by *M4* quote. The *code editor* recognizes the following *quoting macros*:

- `@QUOTE(txt)` will be put as `‘txt’` in the output file,
- `@TEXT(‘txt’)` will be put as `txt` in the output file.

5.6.3 The code editor shortcuts

The *code editor* supports various keyboard shortcuts that could be handy when editing source code.

Ctr-Tab	Insert a tabulation.
Tab	Complete a port name. Type the beginning of a port name, then press **Tab** and as many times as necessary for the editor to find the wanted completion.
Ctr-I	Insert the `@IN` *macro* at cursor position.
Ctr-O	Insert the `@OUT` *macro* at cursor position.
Ctr-N	Insert the `@INOUT` *macro* at cursor position.
Ctr-P	Insert the `@PARAM` *macro* at cursor position.
Ctr-T	Insert the `@TEXT` *macro* at cursor position.
Ctr-Q	Insert the `@QUOTE` *macro* at cursor position.
Ctr-W	Cut the selected text into the clipboard.
Ctr-K	Cut text from cursor position to the end of the line.
Alt-W	Copy the selected text into the clipboard.
Ctr-Y	Paste the clipboard content at cursor position.
Ctr-A	Jump to the beginning of the line.
Ctr-E	Jump to the end of the line.
Ctr-up	Jump to the beginning of the buffer.
Ctr-down	Jump to the end of the buffer.

5.7 To build multi-periodic applications

Until version 6 of SynDEx a unique timing information (execution duration) is associated to each operation (resp. each data type of a dependence) relatively to the operators (resp. media) it may be distributed onto. This timing information, which depends on the hardware, is associated to the definition of every operation. Applications specified by the user with version 6 are implicitely mono-periodic, meaning that all the operations of the algorithm graph have the same period which is equal to the total execution time of all the operations executed on the different components of the architecture, taking into account the duration of data communications through the media. This total execution time is displayed as the value of the “Cycle time” in the schedule window resulting from the adequation.

Version 7 of SynDEx allows the user to specify, in addition to a duration, a period to each operation. The period is a timing information associated to the reference of an operation instead of its definition, which does not depend on the hardware. This feature allows the user to specify an operation definition with the same execution duration each time it is referenced, whereas this operation may be referenced with several periods. Note that for a given operation it is necessary that its **execution duration is smaller than its period** to be schedulable.

As soon as a period is associated to an operation reference, the application becomes multi-periodic, and a period must be associated to every operation reference. If it is not the case the application remains mono-periodic. For both mono-periodic and multi-periodic applications, execution durations must be associated to operation definitions and data type of dependences. A multi-periodic application has a hyper period equal to the LCM (Least Common Multiple) of all the periods associated to the operation references. This hyper period is displayed as the value of the "Cycle time" in the schedule window resulting from the adequation. Note that the "Cycle time" is different from the total execution time of all the operations executed on the different components of the architecture, taking into account the duration of data communications through the media.

Version 7 of SynDEx, using the period and the execution duration of every operation, performs a distributed real-time schedulability analysis. If the application is schedulable, SynDEx may generate the corresponding macro-code (or may not find any schedule).

Version 7 of SynDEx, using the period and the execution duration of every operation, performs a distributed real-time schedulability analysis to determine if the multi-periodic application is schedulable. If it is the case it will generate the corresponding macro-code.

Multiple or equal periods

Operations related by a dependence **must have multiple or equal periods**. While creating a dependence between operations which have inconsistent periods, an error message appears to help the user (*e.g.* `Can not create dependence input.o -> compute.in in definition basicAlgorithm Error #1 [Inconsistent periods]`).

While creating a dependence between operations which have multiple periods, there are two cases:

- the producer operation has a period p smaller than the period n of the consumer operation. In this case the producer operation executes n/p times more than the consumer operation and consequently, produces n/p data for the consumer operation involving that these data are memorized. SynDEx displays a warning message indicating that the destination port's size will be increased (*e.g.* `#1 Warning about dependence input.o -> compute.in in definition basicAlgorithm [The size of destination compute.in will increase to 2 times the original size]`). In addition, it creates a new operation called with the data type of the dependence prefixed by "Implode_" (e.g. Implode_int). This new operation is in charge of collecting the n/p data for the consumer operation. Note that the user must give a duration to this new operation. In case he forgot it a warning message will ask for during the adequation ;
- the producer operation has a period p greater than the period n of the consumer operation. In this case the consumer operation executes p/n times more than the producer operation and consequently, the consumer operation consumes p/n times the same data.

Hierarchical references

Verifications on periods are propagated to hierarchical references.

While setting the period to a hierarchical reference, SynDEx verifies that the new period is compatible with the periods of the references it contains. Actually, the period of a hierarchical reference must be equal (or multiple) to the Least Common Multiple (LCM) to the periods of the references it contains.

While setting the period to a reference contained in a hierarchical reference, SynDEx verifies that the new period is compatible with the period of the hierarchical reference. Actually, the period of a reference contained in a hierarchical reference must be equal (or must be a divisor) to the period of the hierarchical reference.

Edit the period of an operation

The user can edit the period of an operation only in its reference properties (cf. paragraph "*Algorithm window*" in section 5) unlike its name, its parameters and its repeat factor which can also be edited during the reference creation.

By default the period of an operation is equal to 0. Note that, as soon as an operation has a period equal to 0, the application is mono-periodic whatever the other periods are. In other words, to obtain a multi-periodic application the period of all the references must be edited.

Adequation

See the section 9.4 for details about the adequation process in case of mutli-periodic applications.

Chapter 6

Architecture

An architecture is specified as a *non directed graph* where vertices are of two types: *operator* or *communication medium*, and each edge is a connection between an *operator* and a *communication medium*.

6.1 Operator

6.1.1 To create an operator definition

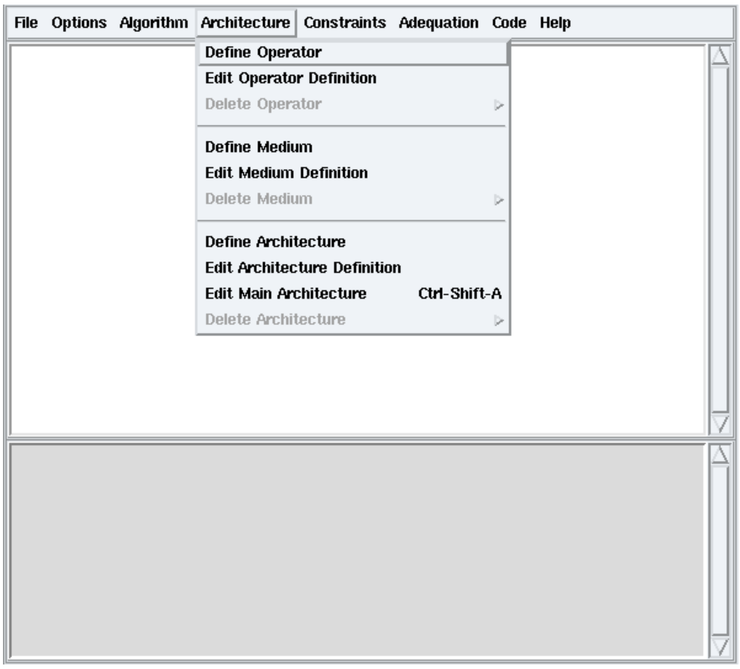

Figure 6.1: Definition of an *operator*

From the **Architecture** menu of the *principal window*, choose the **Define Operator** option (*cf.* figure 6.1). It opens a *dialog window*. Type the name of the new *operator* (*e.g.* `U`). Then **left** click **OK**. It opens the new *operator definition window* (*cf.* figure 6.2). By default the code will be generated only for the *loop phase* of the *operator*. See the section 6.1.2 to set its gates, durations and code phases.

6.1.2 To modify an operator definition

From the **Architecture** menu of the *principal window*, Choose the **Edit Operator Definition** option. It opens a *browse window*. Select the target *operator*. It opens its *definition window* with **Modify gates**,

Figure 6.2: New `U` *operator definition window*

Modify durations, and **Modify code generation phases** buttons.

Gates

Left click on the **Modify gates** button. It opens a *dialog window* in which you can set the gates, one per line. For example type

```
TCP x
TCP y
```

A gate has the following **syntax**:

```
gate_definition ::= medium_definition_name gate_name
```

where:

- `medium_definition_name` specifies a *communication medium* to connect with,
- `gate_name`. specifies the new gate.

Durations

Left click on the **Modify durations** button to specify durations by operation (*cf.* chapter 7).

Code generation phases

Left click on the **Modify code generation phases** button. Check **init** (resp. **end**) to generate code in the *initialization phase* (resp. *ending phase*).

Note that you can modify *local* and *global operators* (*cf.* section 3.1). Modifications on a *global operator* impact only the current application and the library remains unchanged. To modify a *global operator* over-all, open the corresponding SynDEx library file (*e.g.* `libs/u.sdx` to modify u/U). Modifications on a *definition* in a library may have consequences on all the applications using this library.

6.1.3 To delete an operator definition

From the **Architecture** menu of the *principal window*, choose the **Delete Operator** option. It lists the *local operator definitions* (*cf.* section 3.1). Select the target *operator*.

Note that deleting a *global operator* (*cf.* section 3.1) impacts only the current application.

6.2 Communication medium

6.2.1 To create a medium definition

From the **Architecture** menu of the *principal window*, choose the **Define Medium** option. It opens a *dialog window*. Type the name of the new *communication medium*. Then **left** click **OK**. It opens the new *communication medium definition window*. By default a new *communication medium* has type *SAM point-to-point*. See the section 6.2.2 to set its type and durations.

6.2.2 To modify a medium definition

From the **Architecture** menu of the *principal window*, Choose the **Edit Medium Definition** option. It opens a *browse window*. Select the target *communication medium*. It opens its *definition window* with **Modify type**, and **Modify durations** buttons.

Type

Left click on the **Modify type** button. It opens a *dialog window* in which you can change the type of the *communication medium*. For example, check **SAM MultiPoint** (resp. **RAM**).

Durations

Left click on the **Modify durations** button to specify durations by data type (*cf.* chapter 7).

Note that you can modify *local* and *global* media (*cf.* section 3.1). Modifications on a *global communication medium* impact only the current application and the library remains unchanged. To modify a *global communication medium* over-all, open the corresponding SynDEx library file (*e.g.* `libs/u.sdx` to modify u/TCP). Modifications on a *definition* in a library may have consequences on all the applications using this library.

6.2.3 To delete a medium definition

From the **Architecture** menu of the *principal window*, choose the **Delete Medium** option. It lists the *local communication medium definitions* (*cf.* section 3.1). Select the target *communication medium*.

Note that deleting a *global communication medium* (*cf.* section 3.1) impacts only the current application.

6.3 Architecture

6.3.1 To create an architecture definition

From the **Architecture** menu of the *principal window*, choose the **Define Architecture** option. It opens a *dialog window*. Type the name of the new architecture. Then **left** click **OK**. It opens the new architecture *definition window*. Now you may construct a graph with *references* to *operators* and *media*. Note that, as soon as you have more than one operator, a connection must be created between each operator and at least another operator through at least one medium.

New operator reference

To reference an *operator* into an architecture, from the **Edit** menu of the *architecture window* choose the **Reference Operator** option. It opens a *browse window*. Select the target *operator*. It opens a *dialog window*. Type the name of the *reference*. Then **left** click **OK**.

New medium reference

To reference a *communication medium* into an architecture, from the **Edit** menu of the *architecture window* choose the **Reference Medium** option. It opens a *browse window*. Select the target *operator*. It opens a *dialog window*. Type the name of the *reference*. Then **left** click **OK**. In case of a *SAM multipoint medium*, it opens a *dialog window*. Check **Broadcast** or **No Broadcast** for the mode of the *reference*. Then **left** click **OK**.

Note that for a *SAM multipoint medium* in *Broadcast* mode, all *operators* connected to this *communication medium* will receive *every* message sent on the *communication medium*. In case of *SAM multipoint medium* in *No Broadcast* mode, each message will be received by *only one operator*: the destination *operator* of the message. **Right** click on a *medium reference* and choose **Broadcast Mode** to change it.

New connection

To connect an *operator* and a *communication medium*, point the cursor at a gate of the *operator reference*, **middle** click (or **Ctrl left** click), then drag and drop on the *communication medium reference*.

Operator and medium reference deletion

To delete a reference to an operator definition or a reference to a medium definition, **left** click on the target operator or medium, **right** click, then choose the **Delete** option.

6.3.2 To set the main architecture

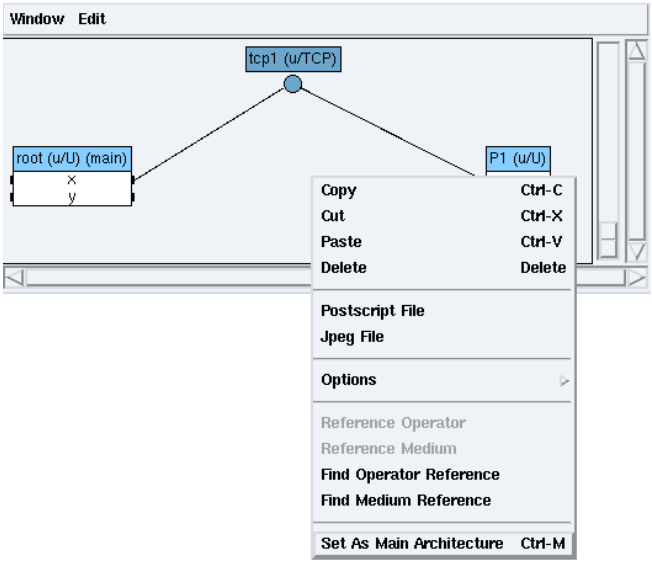

Figure 6.3: Set `u/biProc` as *main architecture* in `examples/tutorial/example7/example7.sdx`

Set the main operator

To define an *operator* of an architecture as *main*, **left** click on the target *operator*, **right** click, then choose the **Set As Main Operator** option.

Set the main architecture

To define an architecture as *main*, **right** click on the background of the target architecture. Choose the **Set As Main Architecture** option (*cf.* figure 6.3). The *architecture window* is now labelled with `(main)`.

Edit the main architecture

To open the *main architecture*, from the **Architecture** menu of the *principal window*, choose the **Edit Main Architecture** option.

6.3.3 To modify an architecture definition

From the **Architecture** menu of the *principal window*, Choose the **Edit Architecture Definition** option. It opens a *browse window*. Select the target architecture. It opens its *definition window*.

Note that you can modify *local* and *global* architectures (*cf.* section 3.1). Modifications on a *global* architecture impact only the current application and the library remains unchanged. To modify a *global* architecture over-all, open the corresponding SynDEx library file (*e.g.* `libs/u.sdx` to modify u/biProc). Modifications on a *definition* in a library may have consequences on all the applications using this library.

6.3.4 To delete an architecture definition

From the **Architecture** menu of the *principal window*, choose the **Delete Architecture** option. It lists the *local architecture definitions* (*cf.* section 3.1). Select the target architecture.

Note that deleting a *global* architecture (*cf.* section 3.1) impacts only the current application.

Chapter 7

Characteristics

The heuristics performed by the *adequation* use the characteristics of each operation and each data dependence relatively to the *operators* and *media* it may be *distributed* onto. Presently we are mainly interested in real-time performances. Therefore the operations of algorithm graphs must be characterized in terms of *duration* relatively to the *operators* and *media* of architecture graphs.

7.1 Execution durations

7.1.1 Operation durations

In the *algorithm window*, **right** click on the background of an *algorithm definition window*. Choose the **Durations** option. It opens a *dialog window* in which you can set the execution durations of the operation by *operator* (*e.g.* `u/U = 3` specifies the duration required to execute the target operation on an `u/U` *operator*).

An operation duration has the following **syntax**:

```
operation_duration ::= operator_definition_name "=" value
```

where:

- `operator_definition_name` specifies an *operator*,
- `value` specifies the duration as an *integer* time unit.

7.1.2 Operator durations

In an *operator definition window*, **left** click on the **Modify durations** button. It opens a *dialog window* in which you can set the execution durations on the *operator* by operation (*e.g.* `bool/AND = 2` specifies the duration required to execute a `bool/AND` operation on the target *operator*).

An *operator* duration has the following **syntax**:

```
operator_duration ::= operation_definition_name "=" value
```

where:

- `operation_definition_name` specifies an operation,
- `value` specifies the duration as an *integer* time unit.

7.2 Communication durations

In a *medium definition window*, **left** click on the **Modify durations** button. It opens a *dialog window* in which you can set the communication durations on the *communication medium* by data type (*e.g.* `u/bool = 1` specifies the duration required to transfer one element of type `u/bool` on the target *communication medium*).

A *medium* duration has the following **syntax**:

```
medium_duration ::= data_type "=" value
```

where:

- `data_type` specifies a basic data type,
- `value` specifies the duration as an *integer* time unit.

7.3 Libraries

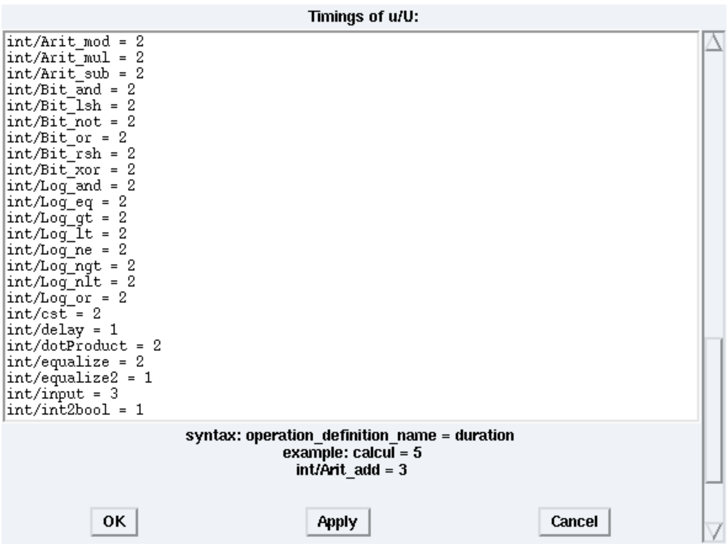

Figure 7.1: `u/U` *durations window* in `examples/basic_with_library/basicBiProc/basicBiProc.sdx`

In case of a duration already specified in a library, a `lib/operator_definition_name = value` or `lib/operation_definition_name = value` or `lib/data_type = value` line will appear in the corresponding *duration windows* (*cf.* figure 7.1).

You can modify durations of *local* and *global definitions*. Modifications on a duration of a *global definition* impact only the current application and will not be saved with the current application.

Chapter 8

Constraints

Some operations of the *main algorithm graph* may be constrained to be executed on specific *operators* of the architecture graphs. In this case the heuristics will not have the choice in *distributing* them. These constraints are specified through *operation groups*. All the operations of an *operation group* will be *distributed* onto the same *operator*.

8.1 To create an operation group

To create a new *operation group*, from the **Algorithm** menu of the *principal window*, choose the **Define Operation Group** option. It opens a *dialog window*. Type the name of the new *operation group*. Then **left** click **OK**.

8.2 To attach references to operation groups

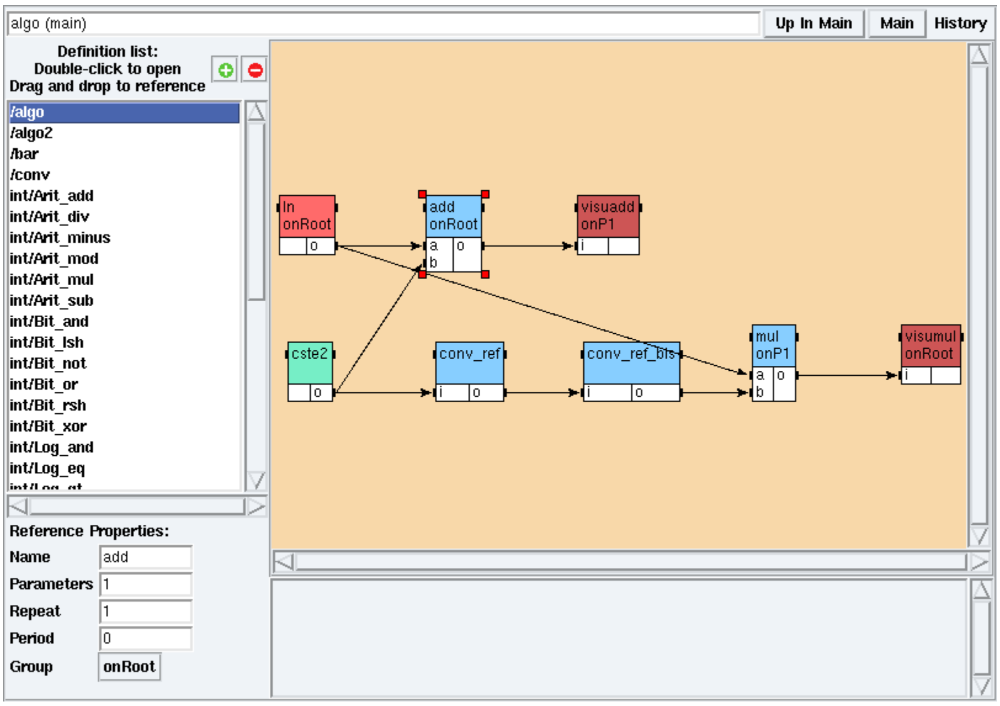

Figure 8.1: `algo` as *main algorithm* in `examples/tutorial/example7/example7.sdx`

From the *main mode* of the *algorithm window* (*cf.* section 5.1.2) **left** click on the target *reference*. In its **Reference Properties** (*cf. Algorithm window* in chapter 5) **left** click on the **Group** button and select the target *operation group* (*cf.* figure 8.1).

If it references a *hierarchical definition*, all the *references* of this *hierarchy* will be attached to this *operation group* (except *references* of this *hierarchy* that may be explicitly attached to another *operation group*).

In particular, in case of a *reference* to a *conditioned* (resp. *repeated*) *definition* its *CondI* and *CondO* (resp. *Explode* and *Implode*) vertices created by SynDEx when *flattening* the algorithm graph (*cf.* section 9.5). will be attached to the *operation group*.

8.3 To constraint operation groups on operators

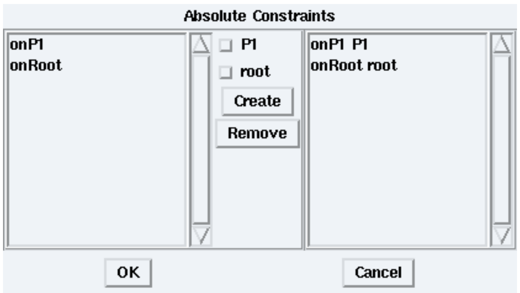

Figure 8.2: Constraints on the *main architecture* in `examples/tutorial/example7/example7.sdx`

To constraint the *references* attached to a given *operation group* to be *distributed* onto a specific *operator*, you will constraint the *operation groups* on *operators*. From the **Constraints** menu, choose the **Absolute Constraints** option. Then, select the target architecture that will open a *constraints window*.

The **Absolute Constraints on Main** option does not allow you to choose the target architecture which, of course, is the architecture defined as *main*.

In the *constraints window*, **left** click on the target group in the left list to constraint an *operation group* on an *operator*, then **left** click on the target *operator* in the middle of the *constraints window*, and finally **left** click on the **Create** button. It adds the new constraint in the right list (*cf.* figure 8.2). **Left** click on the **OK** button to confirm your new constraint list, otherwise **left** click on the **Cancel** button.

8.4 To delete an operation group

To delete an *operation group*, from the **Algorithm** menu of the *principal window*, choose the **Delete Operation Group** option. It lists all the *operation groups*. Select the target group.

Chapter 9

Adequation

Performing an *adequation* means to execute heuristics, seeking for an optimized *implementation* of a given algorithm onto a given architecture, both set as "Main".

9.1 Main algorithm and main architecture

There can be several algorithms and architectures but only one *main algorithm* (*cf. Main mode* in section 5.1.2) and one *main architecture* (*cf.* section 6.3.2) on which the *adequation* will be performed.

To define an algorithm as *main*, **right** click on the background of the target *definition window*. Choose the **Set As Main Definition** option. To define an architecture as *main*, **right** click on the background of the target architecture. Choose the **Set As Main Architecture** option

9.2 Characterization

To be able to perform an *adequation*, each operation and each data type of a dependence must be associated with a duration (*cf.* chapter 7).

You will also have to characterize additional operations generated by SynDEx in case of *conditioning* (*cf.* section 5.2) or *repetition* (*cf.* section 5.3).

9.3 To launch the adequation

To launch the *adequation* of the *main algorithm* onto the *main architecture*, from the **Adequation** menu of the *principal window*, choose the **Launch Adequation** option.

The adequation process is preceded by:

- a flattening process (cf. 9.5),
- a verification process on the flattened graph (*i.e.* non existence of dependence cycles).

9.4 Multi-periodic applications

In case of a multi-periodic application, the flattening process is preceded by:

- an unroll process: operations are repeated in accordance with their periods, dependences are added, *Implode* vertices are added to group data sent by several instances of a given producer operation to a consumer operation when the period of the producer is smaller than the period of the consumer. Note that this new operation created by SynDEx must have an execution duration. If the user omits to set this value SynDEx will ask for by displaying a warning window.

- an assignment process which performs a schedulability analysis on original operations: in case of a non-schedulable application, SynDEx displays an error message (*e.g.* `ABORTING: The system is not schedulable.`). SynDEx may not find any schedule for a schedulable application and then displays a message ((*e.g.* `SynDEx cannot find any schedule for this system.`)

9.5 Flattening

Hierarchy

The *main algorithm* graph is *transformed* for the *adequation* to obtain a graph with a unique level of *hierarchy*, where each vertex is an operation in the sense of *AAA* (which is the same as an *atomic definition* in SynDEx). This *transformation* consists in replacing *references* by corresponding *definitions*, and paths of *dependences* connected along the *hierarchy* through ports by direct *dependences* between corresponding ports of the transformed operations.

Abstract references

In case of *abstract references* (*cf.* section 5.1.7), the *hierarchy* is not taken into account, i.e. the *flattening* does not go into the *hierarchical* referenced *definitions.* All the *abstract references* are directly replaced by operations containing the same ports as their *definition. References* or *dependences* included in those *definitions* are ignored.

9.6 Schedule

The schedule is displayed as sets of ordered operations infinitely repeated.

In case of a multi-periodic application, the schedule may have one or two parts. In the first case it is a permanent part displayed as sets of ordered operations infinitely repeated and in the second case it is:

- a transient part displayed as sets of ordered operations executed only one time,
- then a permanent part displayed as sets of ordered operations infinitely repeated.

SynDEx adds some *Wait* vertices to force the operators to satisfy the start time dates of every operation computed by the adequation according to their period.

9.6.1 To display the schedule

To view the computed *distribution* and *schedule*, from the **Adequation** menu, choose the **Display Schedule** option. It opens a window for the diagram of the real-time simulation of the algorithm executed on the architecture.

9.6.2 The schedule window

In the *schedule window* you will find one *schedule* for each *operator* and for each *communication medium* of the architecture. Each operation or communication (send/receive) is represented by a box the length of which is proportional to its duration. The operations of the transient part have a red left edge whereas the operations of the permanent part have a green left edge.

Operator

Each *schedule* for an *operator* describes a scheduling of *constants*, *sensors*, *actuators*, *functions* and *delays.* By default *constants* are not displayed. From the **Window** menu, choose **Schedule Display Options**. Then check **Show Constants** to change this setting.

Medium

Each *schedule* for a *communication medium* describes a scheduling of inter-*operator* communications, sending (resp. receiving) data from (resp. to) an *operator*. Note that although a communication is called "Send proc1 proc2" it is represented by a unique operation which represents the duration of the communication (send/receive) on the medium.

Start and end dates

The start date (resp. the end date) is displayed on the left edge (resp. right) of each box.

Scale

In case of big duration differences, you can disable the scale. From the **Window** menu, choose **Schedule Display Options**. Then uncheck **Scale** to change this setting.

Colors

When the cursor points at an operation, its box is highlighted in orange. The predecessors of the pointed operation have their boxes highlighted in green and its successors in red. Operations highlighted in pink are successors in the next repetition, rather than in the same repetition, in case of multi-periodic application.

Schedule position

Position the pointer inside the small space between two schedules of *operators* or between the schedule of an *operator* and the schedule of a *communication medium* then, **left click and before releasing the button**, drag and drop that schedule to change its position.

Warning: This feature is operational only in Vertical Display mode.

Other options

From the **Window** menu, choose **Schedule Display Options**. Check **Horizontal Display** to change the orientation of the display. Check **Show Arrows** to draw arrows between boxes which are in relation of execution precedence Uncheck **Labels** to not draw the names of the operations.

Chapter 10

Code generation

When the *adequation* has been performed, code may be generated for the *main architecture*.

Warning: To generate code, it is mandatory to define a *processor* of the *main architecture* as the *main operator* (*cf.* section 6.3.2).

10.1 To generate the code

From the **Code** menu, choose the **Generate Executive(s)** option. The generated `.m4` files are saved in the application's directory, one file per *processor*.

10.2 To view generated files

From the **Code** menu, choose the **Display Executive(s)** option.

If the option **Generate m4x Files** of the **Code** menu is checked, SynDEx also produces *macro* files:

- an *application_name*`.m4x` file (if not already existing),
- an *application_name*`_sdc.m4x` file.

The `.m4x` file is the only user *macro* file which the *M4* machinery is aware of. Thus, it should include the `_sdc.m4x` file. The `_sdc.m4x` file contains *M4 macro* definitions corresponding to algorithm *definitions* that have been associated with a source code via the SynDEx *code editor*. This file should not be edited by hand because it is overwritten each time the user triggers code generation.

The user should put its *hand-written macro* definitions in the `.m4x` which is automatically created by SynDEx only if not already existing. If this file is created by hand, the user should be careful to include the `_sdc.m4x` at the beginning of the file.

10.3 Overview

In this section we give a brief summary of files you will require to generate and compile your executive files. Code generation principles will be detailed in next sections. Files required are:

- *application_name*`.m4x` which may be empty, and optionally some *processor_name*`.m4x`,
- *application_name*`.m4m`,
- `GNUmakefile`,
- *application_name*`.m4`, and one *processor_name*`.m4` file per *processor* from the *main architecture* These files are generated during the executive generation by SynDEx.

For the files which are not generated by SynDEx most of the time you can simply copy existing ones (for instance from the example directory) and make modifications explained in the comments of these files. Once you gathered all these files, type `make` `application_name.all` in your shell. It compiles the executive files. Then launch the executable file of the *main processor*. You can also clean your directory by typing *make clean*.

10.4 To compile an executive

Each *macro*-executive source file must be first translated by the *GNU M4* *macro*-processor, into a text file in the language preferred for the *processor* (usually assembler for efficiency, sometimes C or another high-level language for portability). This translation relies on several files included in the following order:

- the first *macro*-call of the *macro*-executive source (`include(syndex.m4x)`) includes the file `syndex.m4x` which defines all the SynDEx generic (*processor*-independent) *macros* which rely on low-level specific *macros* expected to be defined by the following included files;
- the second *macro*-call of the *macro*-executive source `processor_(processor_type, processor_name, application_name, version, date)` includes:
  - the file `processor_type.m4x` which defines low-level *macros* specific to the type of *processor*,
  - the file `application_name.m4x` which defines application-specific *macros*,
  - optionally the file `processor_name.m4x` which defines *macros* specific to the target *processor*;
- then, after the memory-allocation *macro*-calls, each communication sequence starts with a `thread_(medium_type, medium_name, connected_processor_names)` *macro*-call which includes the file `medium_type.m4x` which defines low-level communication *macros* specific to the type of the *communication medium*.

These indirected inclusions, through the names specified under SynDEx, provide a very flexible and powerful mechanism needed to support efficiently heterogeneous architectures, with heterogeneous languages and compilation chains. Then each *macro*-processed text file must be compiled with the adequate compiler, and linked with the adequate linker against separately compatibly-compiled application-specific files and/or *processor*-specific libraries, for those *macros* which cannot simply inline the desired code, but instead must call separately compiled codes.

10.5 To load the compiled executive

In an heterogeneous architecture, there are different compilation chains, with different executable formats which have to be transfered through different types of intermediate *media* and *processors* to be finally loaded by different boot loaders. For these reasons, a post-processor is required for each type of *processor*, in order to encapsulate this heterogeneity into a common download format. This is explained in more details in the *downloader specification* (*cf.* chapter 11).

10.6 To automate the compilation/load process

All *processor* types require the same compilation sequence, but with different compilation tools:

- *macro*-processing of the *macro*-executive generated by SynDEx,
- compilation into *processor*-specific object code,
- linking into *processor*-memory-map-specific executable code,
- post-processing into common downloadable format.

This compilation sequence may be automatically generated for each *processor* by *macro*-processing the *macro*-makefile generated by SynDEx which includes:

- a very first *macro*-call (`include(syndex.m4m)`) that includes the file `syndex.m4m` which generates a makefile header, and defines the *macros* *`architecture_`*, *`processor_`*, *`connect_`*, and *`endarchitecture_`* used in the *macro*-makefile;
- the second *macro*-call (*`architecture_(application_name, version, date)`* that includes the file *`application_name`*`.m4m` (if it exists) which defines application-specific make-*macros*;
- a *macro*-call *`processor_(processor_type, processor_name, connectors_type_and_name)`* per *processor* that includes the file *`processor_type`*`.m4m` which should have for side effect to generate the required compilation dependences for this *processor*;
- a *macro*-call `connect_(`*`medium_type, medium_name, connectors_opr_and_name`*`)` per *communication medium* that includes the file *`medium_type`*`.m4m` (if it exists) which should have for side effect to generate any loader-specific dependences (presently unused).

Although this indirect inclusion mechanism is able to generate most of the core makefile, an application-specific *top* makefile is still required to specify how to generate the core makefile, and to specify the compilation and linking dependencies with application-specific files (include files, separately compiled files and libraries).

Chapter 11

SynDEx downloader specification

11.1 Context

SynDEx allows the efficient programming of parallel, distributed, heterogeneous architectures, composed of several different types of *processors*, and of several different types of *communication medium.* From a user specification of an algorithm dataflow graph and of an architecture resources graph, and from algorithm and architecture characterized libraries, SynDEx automatically generates an application specific *executive* code for each *processor*, and provides a *makefile* to automate the compilation and linking of each executive, and its downloading into the program memory of the corresponding *processor*.

Separate programming of non-volatile program memories being unpractical, SynDEx considers that each *processor* has, for only non-volatile resident program, a boot-loader (which may be very small and simple, or may rely on a big and complex operating system) expecting an executive to be downloaded from a neighbour *processor* through a *communication medium*, except for a single *host processor*, designated by the name `root` in the specified architecture graph, which boot-loader expects all executives to be stored altogether in its local non-volatile memory.

Consequently, SynDEx computes, over the architecture graph, an oriented coverage tree rooted on the `root` *processor*, and generates in each *processor executive* the code needed to download the compiled executives through this tree, in a predetermined order which is also used to generate the makefile.

11.2 Boot and download process

This process is the same for all *processors*, except that the `root` *processor* gets executives from its local non-volatile memory, whereas all the other *processors* get executives from their neighbour *processor* which is their ascendant towards the root of the download tree. The *processors* which have the same ascendant *processor* are called the descendants of that *processor*.

When powered on, each *processor* boots by executing its resident boot-loader which gets the *processor*'s executive, loads it into the *processor*'s program memory, and executes it. During its *initialization phase*, the executive gets and forwards executives to all its descendants, before proceeding with application data processing.

The root *processor*, usually an embedded PC or other kind of workstation, bootloads from its disk an operating system which automatically loads and executes a startup program allowing the user to choose between different applications. During early developments, this program may be a simple shell (but this requires a keyboard to be available), and the user enters a `make` command to compile the executives if needed, and to execute the root executive, with the other executive files passed as arguments on the command line. In applications where it is unpractical to use a keyboard permanently connected, the startup program may use another input device (for example a switch or a touch screen) to let the user choose between different predefined shell commands, starting different applications through the corresponding `make` command, or simply launching a shell for interaction with a keyboard. In more deeply embedded applications, where the root *processor* has neither a disk nor an operating system, all the executives are stored in a FLASH memory, and the root *processor* boots by executing directly its own executive, and finds the other executives sequentially stored in its FLASH.

The first executive forwarded to a descendant is received, stored, and executed by that descendant's boot-loader. Then, while that descendant's executive asks for executives, the ascendant executive gets and forwards the next executives to the same descendant, until that descendant's executive signals that it has itself no more executives to forward. Then the ascendant may switch to its next descendant, until it has no more descendant to service, and hence no more executive to forward. This fully sequential download process boots *processors* in the order of a depth-first traversal of the download tree.

In the case of a *point-to-point medium*, the descendant executive may proceed to application data communications as soon as it has no more executive to forward, whereas in the case of a *multipoint medium*, the descendant executive must wait until the ascendant executive signals that it has no more executive to forward (to avoid communication interferences between descendant application data and ascendant download data).

11.3 Common download format

Each *processor* type may have a different compiler (linker) output format, and some *processor* types may have a ROM-ed embedded boot-loader (firmware), with its own requirements on the download format. The SynDEx common download format encapsulates the details and the differences of the compiler output formats, and of the boot-loaders download formats; it is composed as follows:

- four bytes prefix encoding the 32 bits big-endian total length of the following sequence of bytes,
- a sequence of bytes encoding one complete executive, structured as required by the destination boot-loader, and padded if needed with null bytes until the total length is a multiple of four.

The first executive forwarded to a descendant being received by that descendant's boot-loader, that executive must be sent *without* its four bytes prefix; the following executives sent to the same descendant being forwarded by that descendant's executive, they must be sent *with* their four bytes prefix.

The sequence of bytes itself must follow the format expected by the destination boot-loader. Therefore a linker post-processor must be developped for each *processor* type, to translate the linker output file into the SynDEx common dowload format described above. All the post-processors' outputs will be concatenated by the makefile into a unique contiguous image (file), that the root executive will use as source.

11.4 Downloader macros

The *downloader* code is generated by two *macros*:

- `loadFrom_` starts the *initialization phase* of the communication sequence of the *communication medium* connected to the ascendant *processor*; its first argument is the name of the ascendant *processor*, its next arguments, if any, are the names of the other *communication medium* connected to descendant *processors*, if any;
- `loadDnto_` starts the *initialization phase* of the communication sequence of each *communication medium* connected to a descendant *processor*; its first argument is the name of the *communication medium* connected to the ascendant *processor*, its next argument(s) is (are) the name(s) of the descendant *processor(s)*.

Processor names are usefull to address *processors* connected to *multipoint medium*: a *processor* name may be suffixed to give the name of a user defined *macro*, which substitution gives the *processor* address.

As executives data may be forwarded through several *communication medium* of different bandwidths, transfers must be synchronized such that data flow at the speed of the slowest *communication medium.*

Between *processors*, if flow control is not supported by the *communication medium* hardware, it must be implemented by *ready to receive* control messages sent by the `loadFrom_` code for each chunk of data to be sent by the `loadDnto_` code. Inside a *processor*, the `loadFrom_` and `loadDnto_` *macro* cooperation is based on the order in which the `spawn_thread_` *macros* (one for each communication sequence, i.e. for each communication media) are generated in the *initialization phase* of the `main_ ... endmain_` sequence: the `spawn_thread_` *macro* corresponding to the `thread_` *macro* of the communication sequence starting with the `loadFrom_` *macro* (i.e. of the media connected to the ascendant *processor*) is called first, followed by the other `spawn_thread_` *macros*, among which the ones, if any, corresponding to the communication sequences with a `loadDnto_` *macro* (i.e. of the media connected to the descendant *processors*).

If the *processor* is a leaf node of the download tree, its `loadFrom_` *macro* has only one argument; in this case, it directly generates the code sending to the ascendant *processor* a "null" message meaning that no more executive is requested, followed, in the case of a *multipoint medium*, by the code waiting for other executives to be downloaded to the other *processors* connected to the *communication medium*, until the ascendant *processor* sends an "empty" executive meaning that the download process is complete on this *communication medium.*

Otherwise, before generating the code described in the previous paragraph, the `loadFrom_` *macro* generates a `RETURN` instruction (which will return control after the `CALL` instruction generated by the `spawn_thread_` *macro*), followed by a `loadFrom_end_:` label, and the `loadFrom_` *macro* also defines three *macros* for use by the `loadDnto_` *macros*:

- the `loadFrom_req_` *macro* must generate the code that sends a *non-null* message requesting the ascendant *processor* to download another executive;
- the `loadFrom_get_` *macro* must generate the code that receives one *word* of executive data from the ascendant *processor*; *word* means the size of a *processor* register, usually 32 bits; if the *communication medium* transfers executive data by chunks of N words, then every N calls to the code generated by the `loadFrom_get_` *macro* receives a full chunk of data and returns its first word, and the next *N-1* calls each return a next word of the chunk;
- the `loadFrom_next_`*macro* which is called at the end of each `loadDnto_` *macro*, must generate a `CALL loadFrom_end_`, but only for the very last `loadDnto_` *macro.*

If the code generated by any of these three *macros* is limited to a few instructions, it may be generated inline, otherwise the `loadFrom_` *macro* generates this code as a subroutine (between the `RETURN` instruction and the `loadFrom_end_` label), and a call to that subroutine is generated instead of the inline code.

Chapter 12

Links

For more information:

SynDEx: `http://www.syndex.org`

AAA methodology: `http://www-rocq.inria.fr/syndex/pub/execv4/execv4.pdf`

Objective-Caml: `http://caml.inria.fr/`

Tcl/Tk: `http://www.tcl.tk/`

CamlTk: `http://pauillac.inria.fr/camltk/`