SynDEx v7 Tutorial

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Introduction

This tutorial respects some writing conventions:

- menus, buttons *etc.* are written in **bold**
  (*eg.* **Algorithm / New Algorithm Window**, **OK**, **Definition list**);

- command lines, SynDEx files, examples *etc.* are written in `Computer Modern`
  (*eg.* `-libs libs`, `examples/tutorial`, `! int o`);

To create an application workspace, run the SynDEx executable, located at the root of your installation directory, with option `-libs libs`. See the **SynDEx v7 User Manual** for more information.

The examples presented in this tutorial are located in the sub-directory `examples/tutorial`. Each example is located in its sub-directory.

Example 1

Algorithm, architecture, and adequation:

- we create a sensor definition, an actuator definition, and a function definition. Then, we create an algorithm and define it as main. Finally, we create in the main algorithm two references to the sensor definition, three references to the actuator definition, and one reference to the function definition, and we create data dependences between these references by connecting their ports;

- we create four different architectures:

  - an architecture with one operator,
  - an architecture with two operators and a SAM point-to-point communication medium,
  - an architecture with three operators and a SAM multipoint communication medium,
  - an architecture with three operators and a RAM communication medium;

- we create constraints on the third architecture;

- we perform the adequation of the main algorithm onto the third architecture defined as main, without constraint and then with constraints.

Example 2

Hierarchy in algorithm:

- we create a function definition and a constant. Inside the function we create a reference to another function; in that way this definition is defined by hierarchy. Then, we create a third function that references both previous ones. Finally, we create an algorithm that references the third function and define it as main. In that way, the main algorithm references a hierarchical function;

- we create parameters names for an operation, and assign values to these parameters.

Example 3

Delay in algorithm:

- we create a delay definition;
- we create a main algorithm by referencing a delay, a sensor, an actuator, and a function and by connecting them.

Example 4

Repetition and library in algorithm:

- we create a multiplication function of a vector by a scalar by repeating a multiplication function on scalars:
  - firstly without any library,
  - secondly with a library;
- we create a multiplication function of a matrix by a vector by repeating a multiplication function on vectors.

Example 5

Condition and nested condition in algorithm:

- we create an algorithm conditioned by a data dependence, the value of which indicates the operation to be executed;
- we create an algorithm conditioned by a data dependence, one operation of which is in turn conditioned (nested condition) by the same data dependence.

Example 6

Algorithm, architecture, adequation, and code generation:

- we create a main algorithm by referencing a sensor, two actuators, three functions, and a constant and by connecting them;
- we create an architecture with two operators of type `U` and a communication medium of type `u/TCP`;
- we perform the adequation;
- we perform the code generation, then we create manualy the `example6.m4x` file (for operations not defined in libraries);
- we create manualy the `example6.m4m` file (to define the hostname) and the `root.m4x` file (for the main operator);
- we create manualy the `GNUmakefile`, then we execute the executives created after compilation.

Example 7

Edition of the source code associated with an operation:

- we add parameters to the `conv` function of **Example 6**;
- we modify the code associated with this function first in case of a generic processor then in case of an architecture with heterogenous processors;
- we create manualy the `example7.m4m` file (to define the hostname) and the `root.m4x` file (for the main operator);
- we create manualy the `GNUmakefile`;
- we perform the adequation, then we perform compilation, finally we compile the executives and launch the executables.

Example 8

A complete realistic application from adequation to execution:

- we build the model of a complete application for two cars;
- we perform the adequation;
- we generate the code for each processor;
- we compile and execute the code associated with each processor.

Example 9

A multiperiodic application:

-
-
-
-

Chapter 1

Example 1: algorithm, architecture, and adequation

1.1 The main algorithm

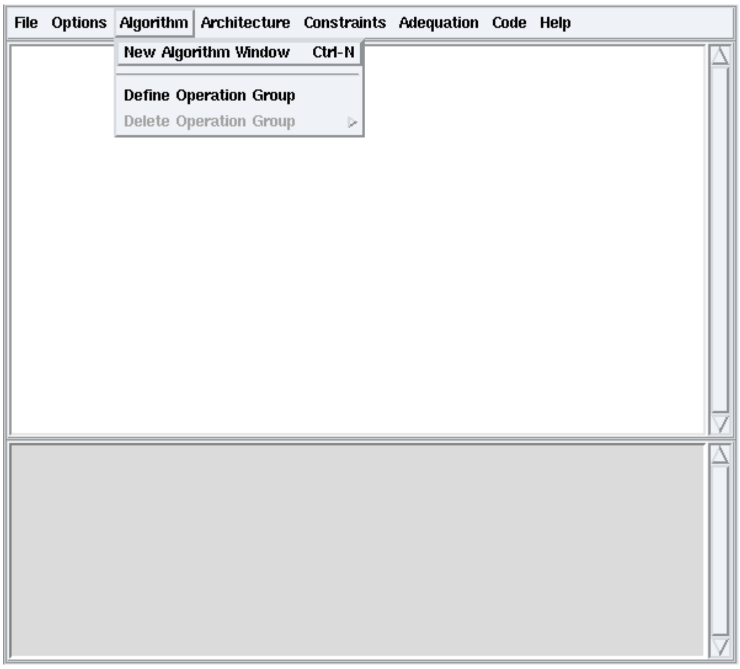

Figure 1.1: **Algorithm / New Algorithm Window**

From the main window, choose the **File / Save as** option and save your first application under a new folder (*eg.* `my_tutorial`) with the name `example1`.

Choose **Algorithm / New Algorithm Window** (*cf.* figure 1.1). It opens the edition window for algorithm definitions.

1.1.1 Definition of a sensor

To create an `input` sensor definition:

- from the algorithm window, click on the + green button. It opens a dialog window, check **Sensor** (*cf.* figure 1.2). Type the sensor name and optionally a list of parameters for the sensor. For example type `input`, then

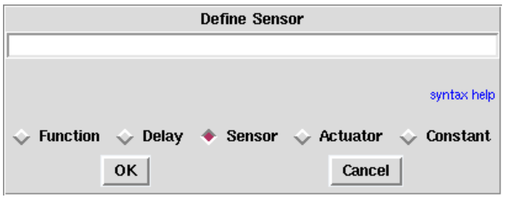

Figure 1.2: **Define Sensor**

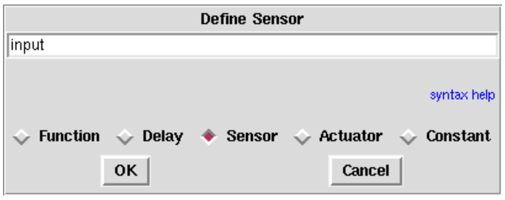

Figure 1.3: Name of the new sensor

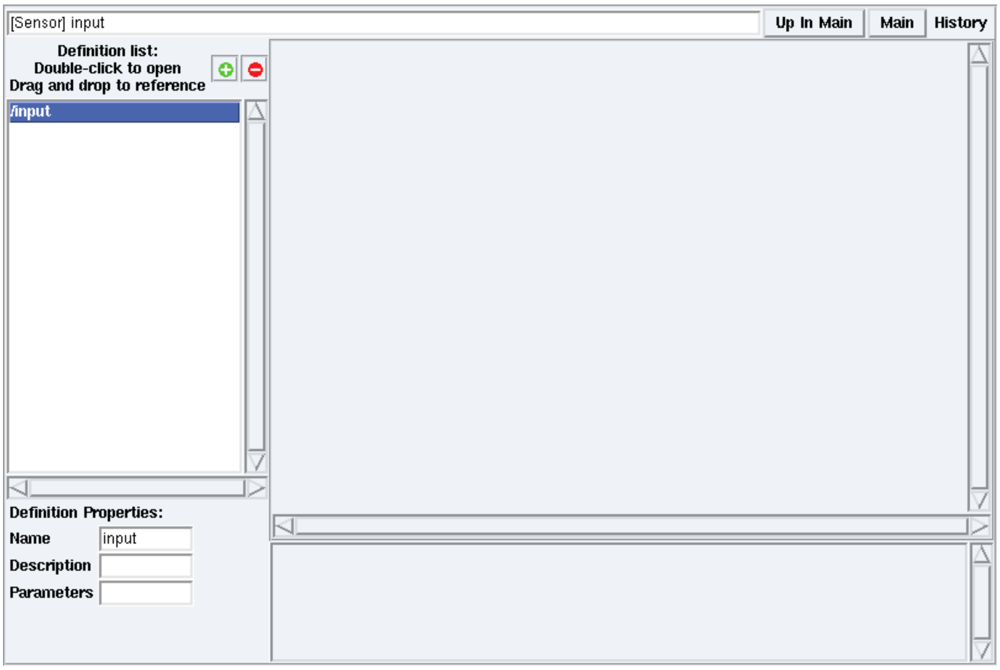

Figure 1.4: Sensor definition window

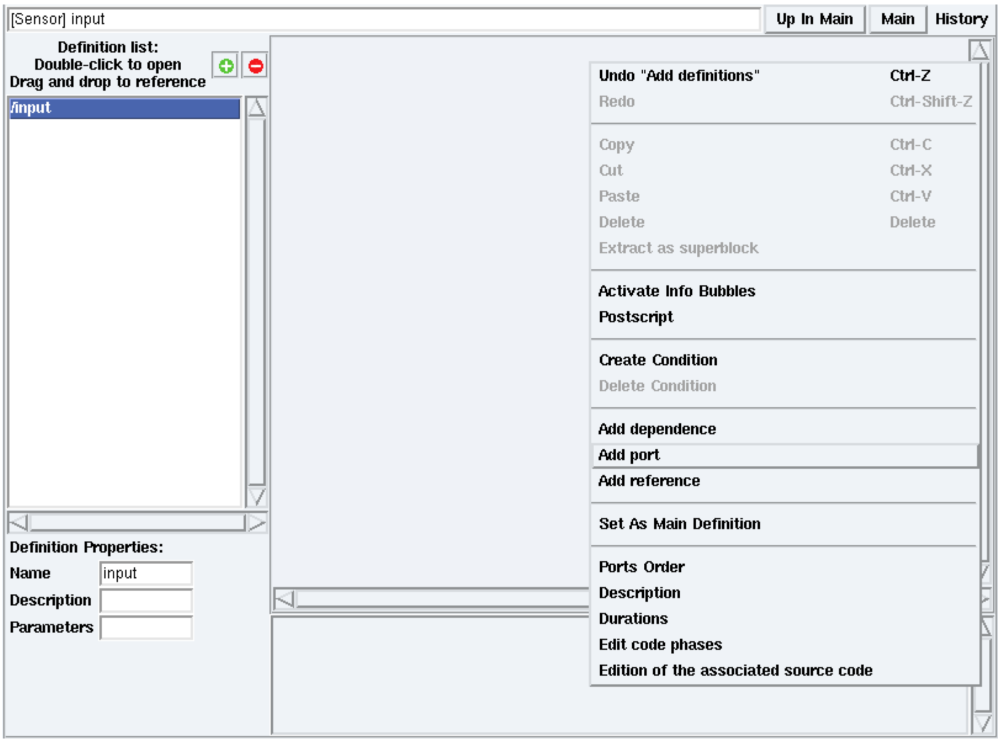

Figure 1.5: Contextual menu → **Add port**

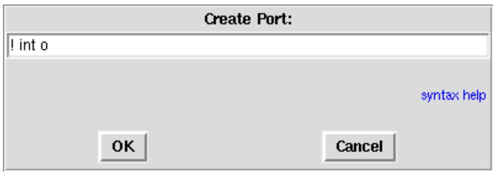

Figure 1.6: **Create Port**

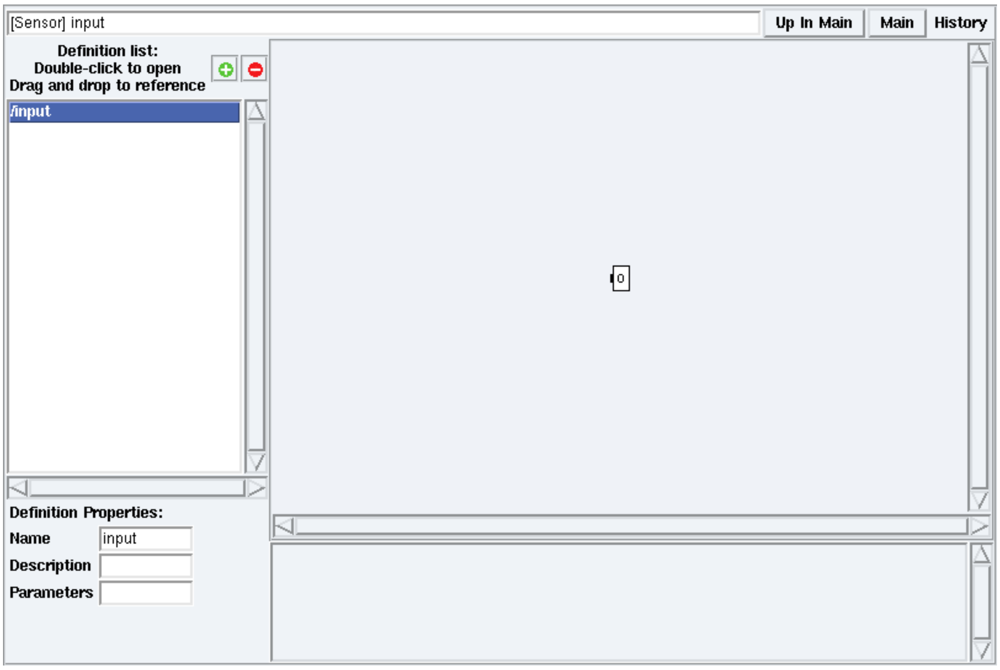

Figure 1.7: Sensor definition window after output port created

click **OK** (*cf.* figure 1.3). It creates the definition of the `input` sensor. To open it in definition mode, double click on `input` in the **Definition list** (*cf.* figure 1.4);

- in `input` definition mode, right click on the background and select **Add port** (*cf.* figure 1.5). It opens a dialog window for the port's direction, type, name and optionally its size. For example type `! int o`, then click **OK** (*cf.* figure 1.6). It creates the integer output port `o` (*cf.* figure 1.7) in the sensor definition window.

1.1.2 Definition of an actuator

To create an `output` actuator definition:

- from the algorithm window, click on the **+** green button → dialog window: check **Actuator** then type `output` and click **OK**;
- double click on `output` in the **Definition list**. Then right click on its background and select **Add port** → dialog window: `? int i`. Click **OK**. It creates the integer input port `i` in the sensor definition window.

1.1.3 Definition of a function

To create a `computation` function definition:

- from the algorithm window, click on the **+** green button → dialog window: check **Function** then type `computation` and click **OK**;
- double click on `computation` in the **Definition list**. Thenright click on its background and select **Add port** → dialog window: `? int a ? int b ! int o`. Click **OK**. It creates the integer ports `a`, `b`, and `o` in the function definition window.

1.1.4 Definition of the main algorithm

To create an `AlgorithmMain` function definition:

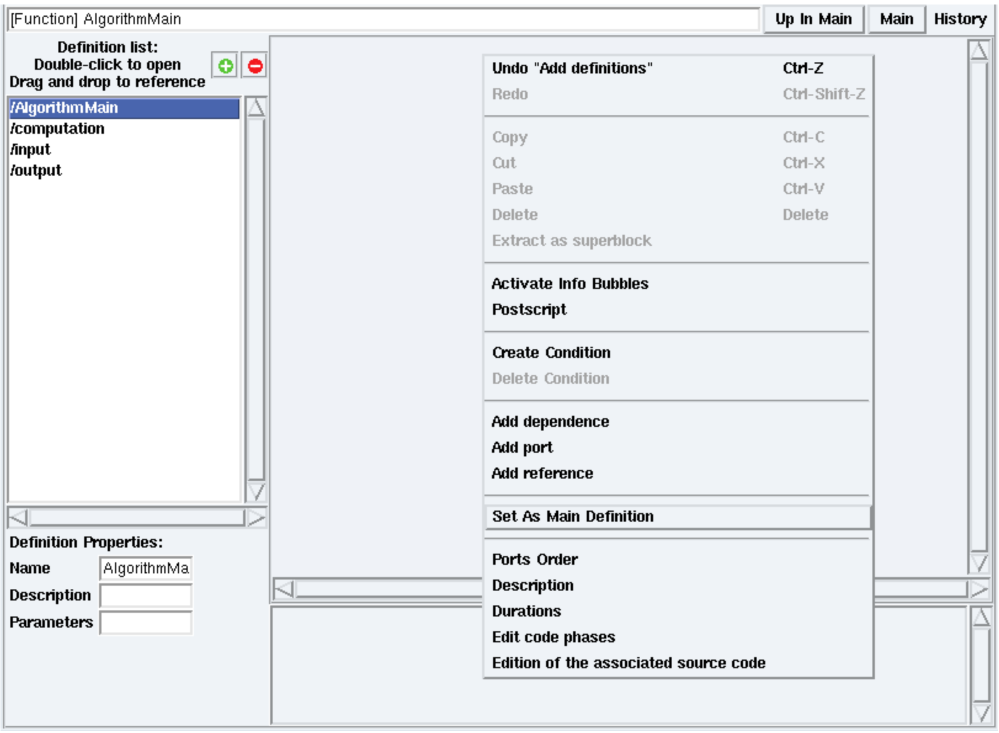

Figure 1.8: Contextual menu → **Set As Main Definition**

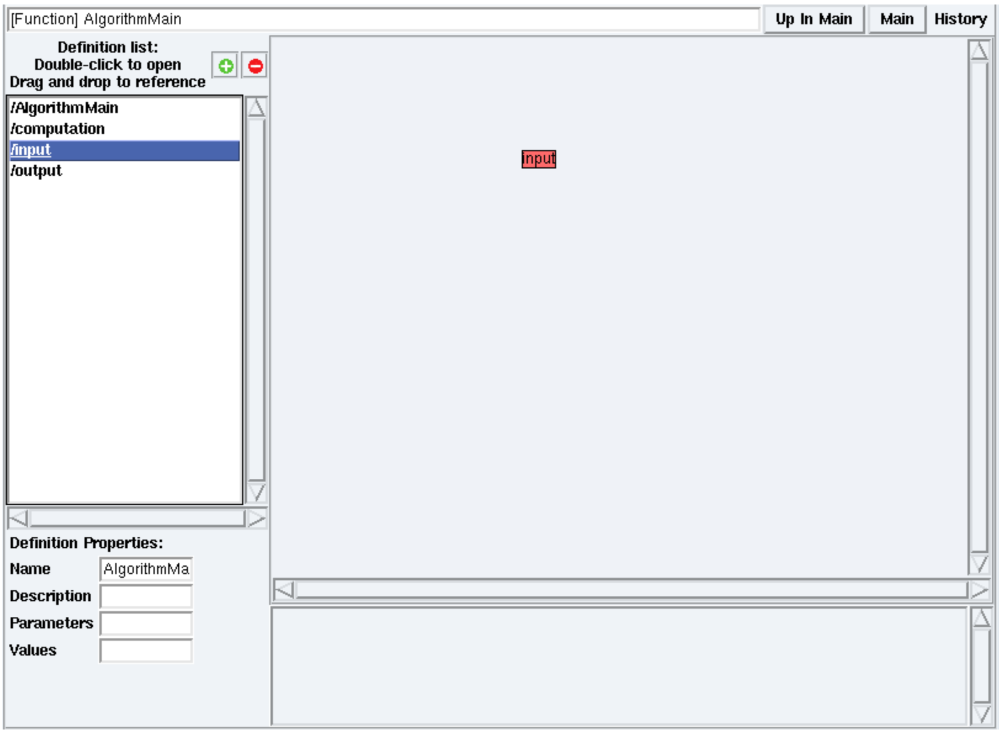

Figure 1.9: Drag and drop `input` definition

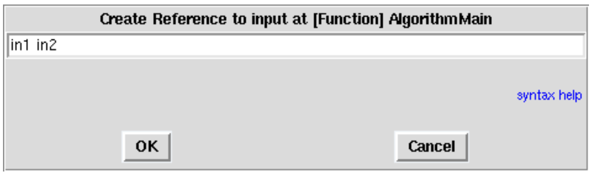

Figure 1.10: **Create References to** `input`

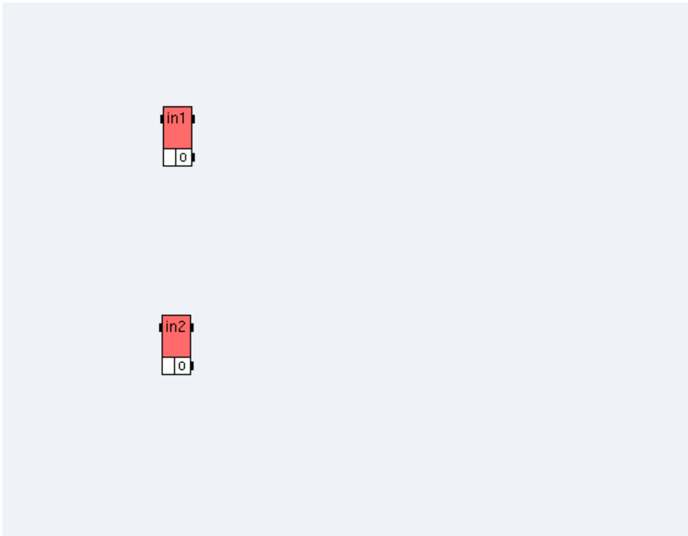

Figure 1.11: Main algorithm after references to sensor created

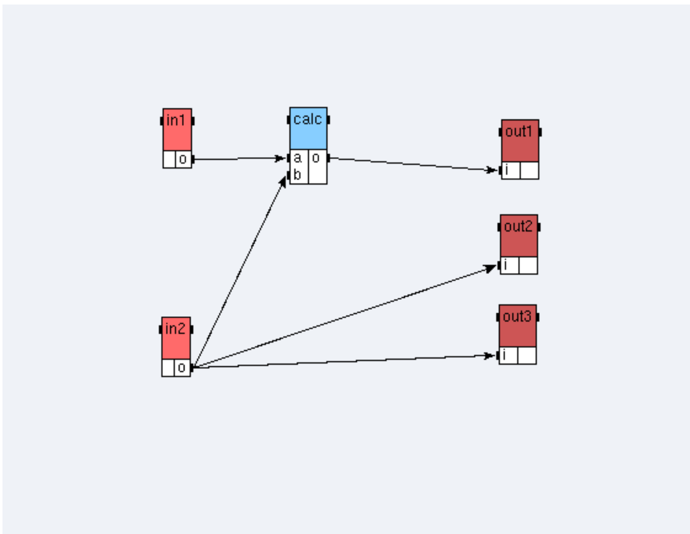

Figure 1.12: Main algorithm of the **Example 1**

- from the algorithm window, click on the `+` green button → dialog window: check **Function** then type `AlgorithmMain` and click **OK**;

- double click on `AlgorithmMain` in the **Definition list**. Thenright click on its background and select **Set As Main Definition** (*cf.* figure 1.8);

- in its definition mode,

  - to create references to the sensor `input`, drag and drop the sensor definition from the **Definition list** to the `AlgorithmMain` definition window (*cf.* figure 1.9) → dialog window: `in1 in2` (*cf.* figure 1.10). The main algorithm looks like the figure 1.11,
  - to create references to the actuator `output`, drag and drop the actuator definition from the **Definition list** to the `AlgorithmMain` definition window → dialog window: `out1 out2 out3`,
  - to create a reference to the function `computation`, drag and drop its definition → dialog window: `calc`,
  - from the `AlgorithmMain` definition window, to create a data dependence between `in1` and `calc`, point the cursor on the output port `o` of the `in1` operation, middle click, and drag to the input port `a` of the `calc` operation. It draws an arrow between these target ports. After creating the other data dependences, the main algorithm looks like the figure 1.12.

1.2 An architecture with one operator

1.2.1 Definition of an operator

Figure 1.13: Operator definition window

To create an `Uinout` operator definition:

- from the main window, choose **Architecture / Define Operator**. It opens a dialog window, type `Uinout` and click **OK**. It opens the operator definition window (*cf.* figure 1.13);

- from the `Uinout` definition window:

  - to add a gate: click **Modify gates** → dialog window: `gate_type_1 x`,
  - to set the operator execution durations: click **Modify durations** → dialog window:

```
computation = 2
input = 1
output = 3
```

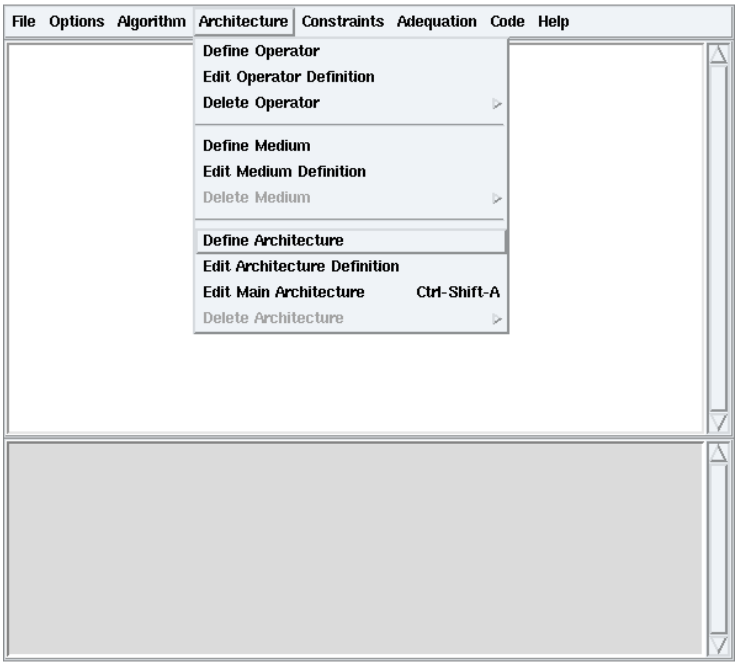

Figure 1.14: **Architecture / Define Architecture**

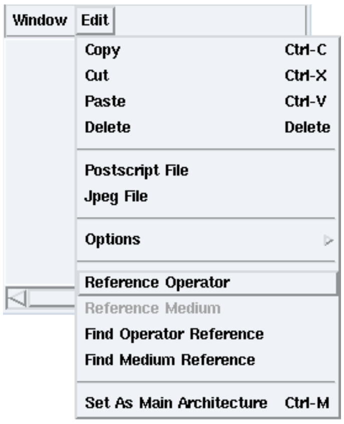

Figure 1.15: **Edit / Reference Operator**

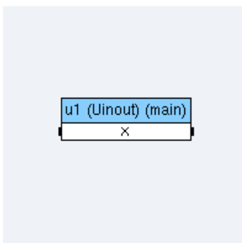

Figure 1.16: Architecture with one operator

1.2.2 Definition of the main architecture

To create an `ArchiOneOperator` architecture definition:

- from the main window: **Architecture / Define Architecture** (*cf.* figure 1.14) → dialog window: type `ArchiOneOperator` then click **OK** → definition window;
- from the `ArchiOneOperator` definition window, to define it as main: **Edit / Set As Main Architecture**;
- from the `ArchiOneOperator` definition window:
  - to create a reference to the operator `Uinout`, **Edit / Reference Operator** (*cf.* figure 1.15) → dialog window: click **user**, double click **Uinout** → dialog window: `u1`,
  - to define the operator as main, right click on its reference and select **Set As Main Operator**.

The architecture looks like the figure 1.16.

1.3 An architecture with a SAM point-to-point comunication medium

1.3.1 Definition of operators

To create `Uin` and `Uout` definitions:

- from the main window: **Architecture / Define Operator** → dialog window: `Uin`, click **OK** → definition window;
- from the `Uin` definition window:
  - click **Modify gates** → dialog window:

```
MediumSamPointToPoint x
MediumSamMultiPoint y
MediumRam z
```

  - click **Modify durations** → dialog window:

```
computation = 2
input = 2
output = 5
```

- from the main window: **Architecture / Define Operator** → dialog window: `Uout`, click **OK** → definition window;
- from the `Uout` definition window:
  - click **Modify gates** → dialog window:

```
MediumSamPointToPoint x
MediumSamMultiPoint y
MediumRam z
```

  - click **Modify durations** → dialog window:

```
computation = 2
input = 5
output = 3
```

1.3.2 Definition of a medium

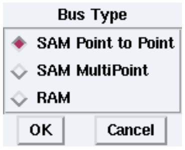

Figure 1.17: Type of a communication medium

To create a `MediumSamPointToPoint` medium definition:

- from the main window: **Architecture / Define Medium** → dialog window: `MediumSamPointToPoint`, click **OK** → definition window;
- from the `MediumSamPointToPoint` definition window:
  - click **Modify type** → dialog window: **SAM Point to Point** (*cf.* figure 1.17),
  - click **Modify durations** → dialog window:

```
float = 2
int = 2
uchar = 1
ushort = 1
```

1.3.3 Definition of the main architecture

To create an `ArchiSamPointToPoint` architecture definition:

- from the main window: **Architecture / Define Architecture** (*cf.* figure 1.14) → dialog window `ArchiSamPointToPoint` → definition window;
- define it as main;
- from the `ArchiSamPointToPoint` definition window, create references `u1` and `u2` to the operators `Uin` and `Uout`;
- from the `ArchiSamPointToPoint` definition window: **Edit / Reference Medium** → dialog window: click **user**, select **MediumSamPointToPoint** → dialog window: type `medium_sampp`;
- define the operator `u1` as main.

1.3.4 Connections between the operators and the medium

In the main architecture window, to create a connection between the `u1` operator and the `medium_sampp` medium, point the cursor on the port `x` of the operator, middle click, and drag it to the communication medium. It draws an edge between the operator and the communication medium. After creating the other connection, the main architecture looks like the figure 1.18.

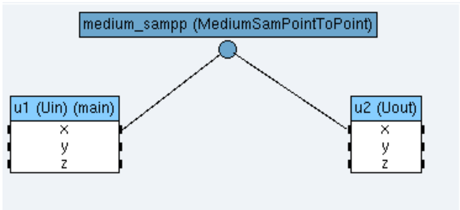

Figure 1.18: Architecture with two operators and a SAM point-to-point communication medium

1.4 An architecture with a SAM multipoint medium

To create an `ArchiSamMultiPoint` architecture definition:

- from the main window: **Architecture / Define Architecture** (*cf.* figure 1.14) → dialog window: `ArchiSamMultiPoint` → `ArchiSamMultiPoint` definition window;
- define it as main;
- create references `u1` and `u2` to the operator `Uin` and a reference `u3` to the operator `Uout`, like in the previous example;
- create a medium definition `MediumSamMultiPoint` of type **SAM MultiPoint** with durations:

```
float=2
int=2
uchar=1
ushort=1
```

- create a reference `medium_sammp` to this medium in the main architecture window → dialog window: check **No Broadcast**;
- define the operator `u1` as main;
- connect the operators ports `y` to the medium.

The architecture looks like the figure 1.19

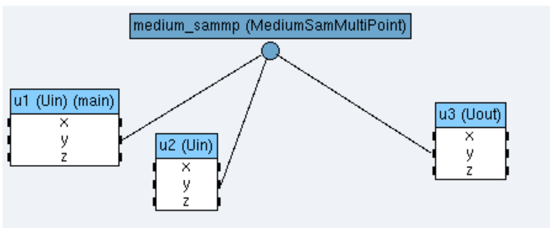

Figure 1.19: Architecture with three operators and a SAM multipoint communication medium

1.5 An architecture with a RAM medium

To create the `ArchiRam` architecture definition:

- from the main window: **Architecture / Define Architecture** (*cf.* figure 1.14) → dialog window `ArchiRam` → `ArchiRam` definition window;
- define it as main;
- create a reference `u1` to the operator `Uin` and references `u2` and `u3` to the operator `Uout`;
- create a medium definition `MediumRam` of type **RAM** with durations

```
float=2
int=2
uchar=1
ushort=1
```

  and create a reference `medium_ram` in the main architecture;
- define the operator `u1` as main;
- connect the operators ports `z` to the medium.

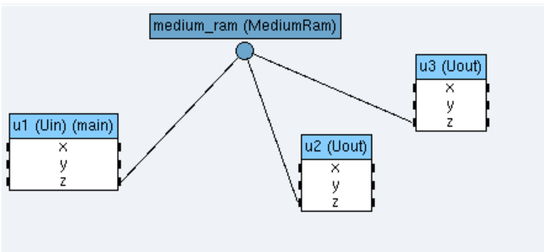

Figure 1.20: Architecture with three operators and a RAM comunication medium

The architecture looks like the figure 1.20.

1.6 The adequation

1.6.1 Without constraint

Define the architecture with three operators and a medium of type **SAM MultiPoint** (*cf.* 1.4) as main architecture (**Edit / Set As Main Architecture**).

From the main window, choose **Adequation / Launch Adequation**, then choose **Adequation / Display schedule**.

It opens the schedule window (*cf.* figure 1.21) in which you can see the schedule of the algorithm on the architecture and the schedule of the different inter-operator communications on the medium.

1.6.2 With constraints

To contraint the `ArchiSamMultiPoint` architecture:

- from the main window, to create the constraints:
  - **Algorithm / Define Operation Group** (*cf.* figure 1.22) → dialog window: `og1 og2 og3`,
  - **Constraints / Absolute Constraints** → dialog window: select **ArchiSamMultiPoint** It opens a dialog window in which you can create constraints on the different operators of the architecture selected:

    * first click on **og1**, then **u1**, and the **Create** button, to constrain the operation group `og1` on the operator `u1`,
    * constrain the operation group `og2` on the operator `u2`,
    * constrain the operation group `og3` on the operator `u3`,
    * click on **OK** button (*cf.* figure 1.23),

- in the main mode (`Main` button):

  - select the operation `in1`, click on the **Group** button of its **Reference Properties** then select **og1** (*cf.* figure 1.24),
  - attach the operation `in2` to the operation group `og2`,
  - attach the operation `out1` to the operation group `og1`,
  - attach the operation `out2` to the operation group `og2`,
  - attach the operation `out3` to the operation group `og3`,
  - attach the operation `calc` to the operation group `og3`;

  The algorithm with constraints looks like the figure 1.25.

- from the main window, to perform the adequation with constraints: **Adequation / Launch Adequation**, then **Adequation / Display Schedule** → schedule window. The schedule looks like the figure 1.26.

From the main window, choose **File / Close**. In the dialog window, click on the **Save** button.

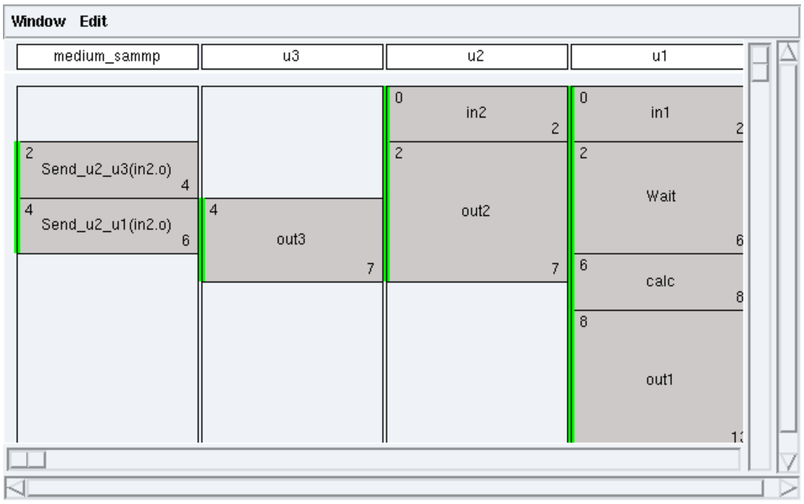

Figure 1.21: Schedule

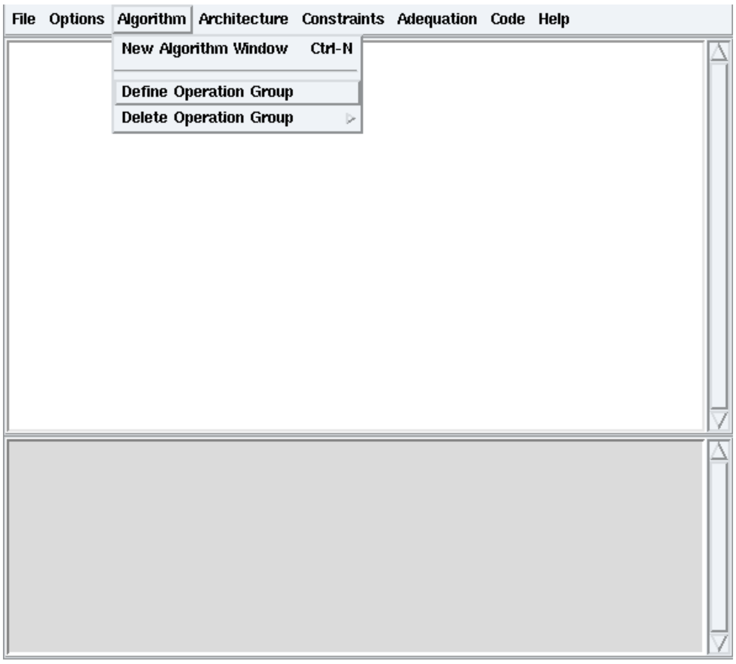

Figure 1.22: **Define Operation Group**

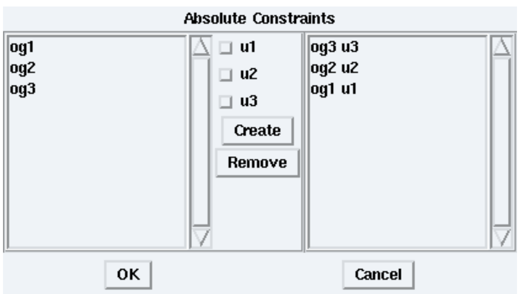

Figure 1.23: Constrain operation groups on operators of the architecture selected

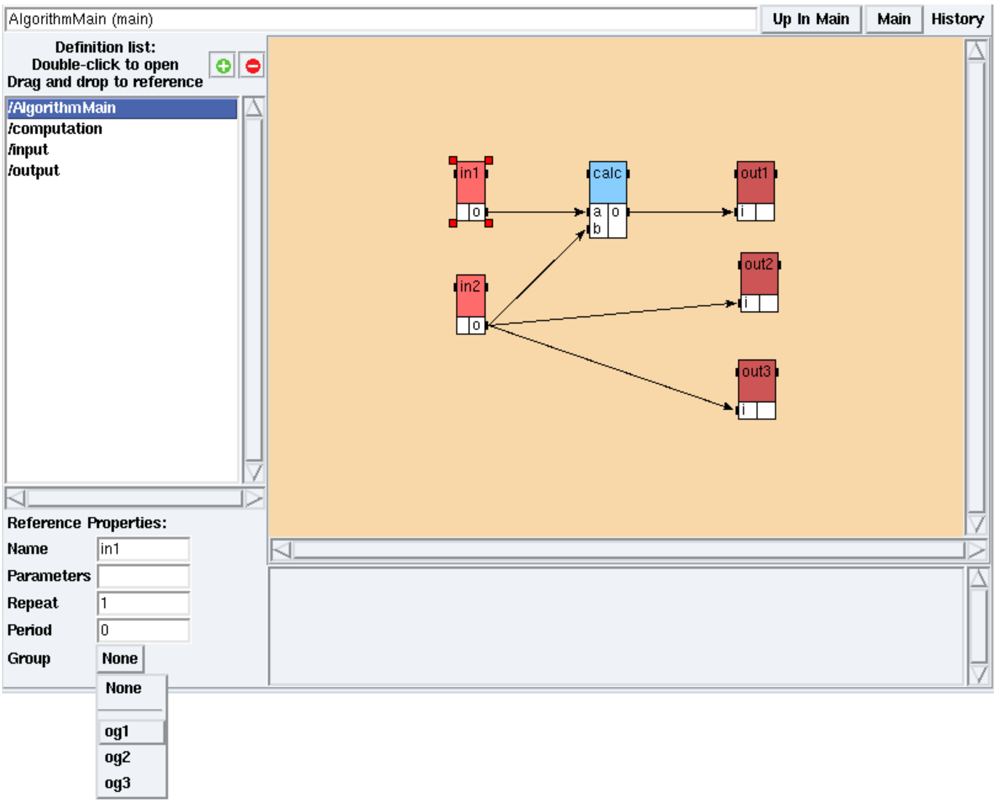

Figure 1.24: Attach a reference to an operation group

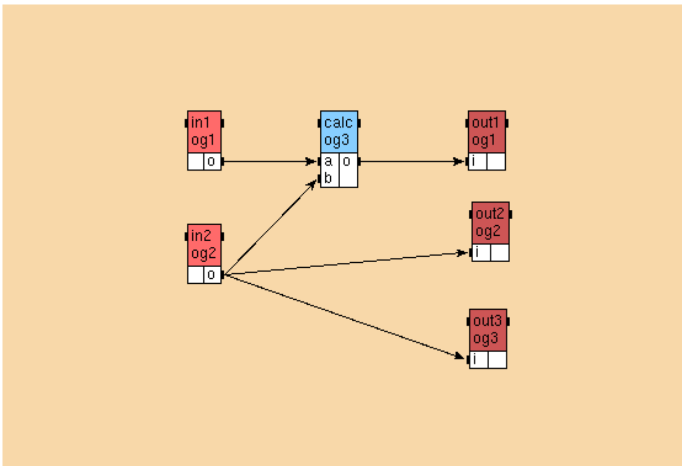

Figure 1.25: Algorithm with constraints

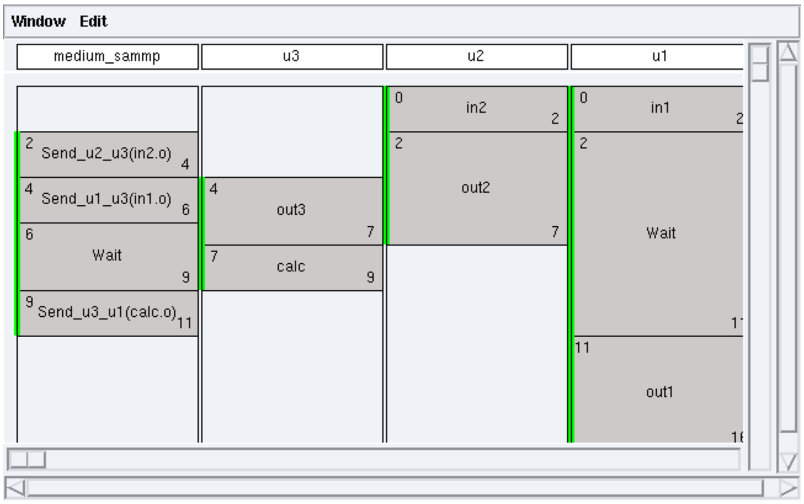

Figure 1.26: Schedule with constraints

Chapter 2

Example 2: hierarchy in algorithm

From the main window, choose **File / Save as** and save your second application under your tutorial folder with the name example2.

2.1 Definition of the function A

To create the A function definition:

- from the algorithm window:
  - click on the **+** green button → dialog window: check **Function** then type A and click **OK**,
  - click on the **+** green button → dialog window: check **Constant** then type constante<X> and click **OK**. Create an integer output port o inside;
- in the A definition window:
  - create a reference cst<T> to the definition constante,
  - create an integer input port a, an integer output port o (Contextual menu → **Add port** *cf.* 1.1.3);
- from the algorithm window,
  create a function definition calcul1, with two integer input ports a and b and an integer output port o;
- in the A definition window:
  - create a reference calc1 to the definition calcul1,
  - add a parameter name (*cf.* figure 2.1): Field **Parameters** → T.

The function A looks like the figure 2.2.

2.2 Definition of the function B

To create the B function definition:

- from the algorithm window: **+** green button → dialog window: B<X;Y>;
- in the B definition window:
  - create references A1 and A2 to the definition A (A1<X> A2<Y>),
  - create two integer input ports a and b, one integer output port o, and the function calc1 of the definition calcul1,
  - add the parameters names X and Y (field **Parameters**).

The function B looks like the figure 2.3.

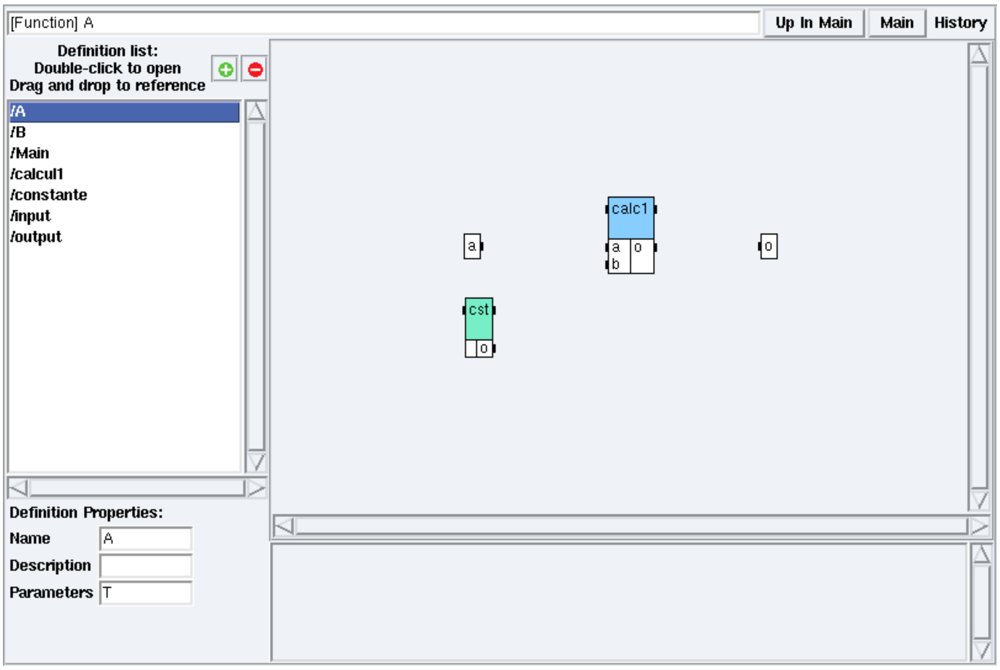

Figure 2.1: **Parameters**

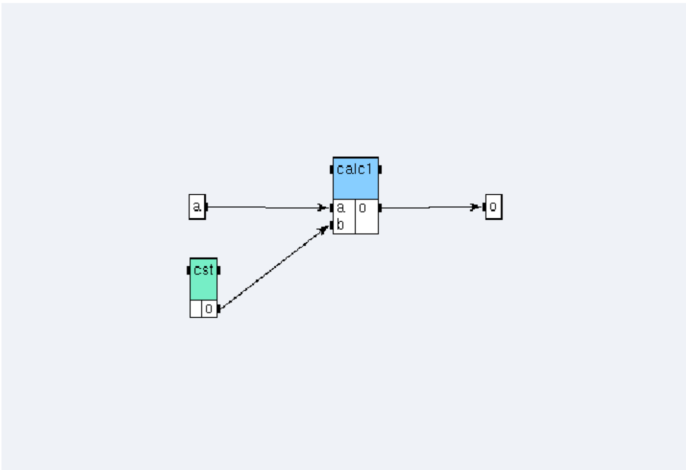

Figure 2.2: Function `A`

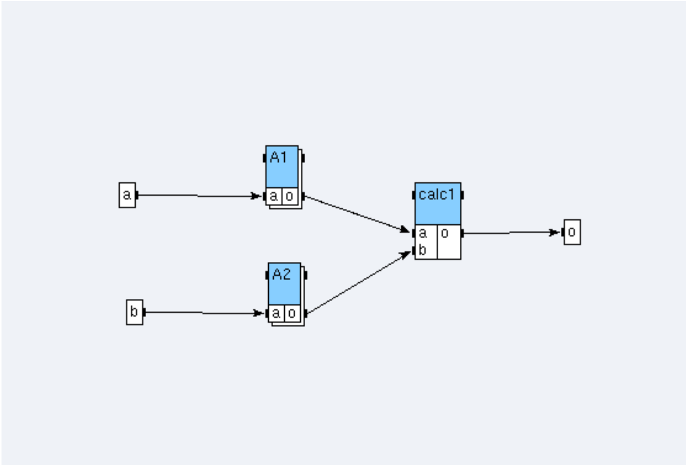

Figure 2.3: Function `B`

2.3 Definition of the algorithm with hierarchy

To create the `Main` algorithm:

- from the algorithm window: `+` green button $\longrightarrow$ dialog window: `Main`;
- from the definition window, define it as main;
- create a sensor `input` with an integer output port `o` and an actuator `output` with an integer input port `i`;
- in the `Main` algorithm window, create a reference `B<1;2>` to the definition `B`, a reference `i1 i2` to the definition `input`, and a reference `out` to the definition `output`;
- create dependences between the references.

The algorithm looks like the figure 2.4.

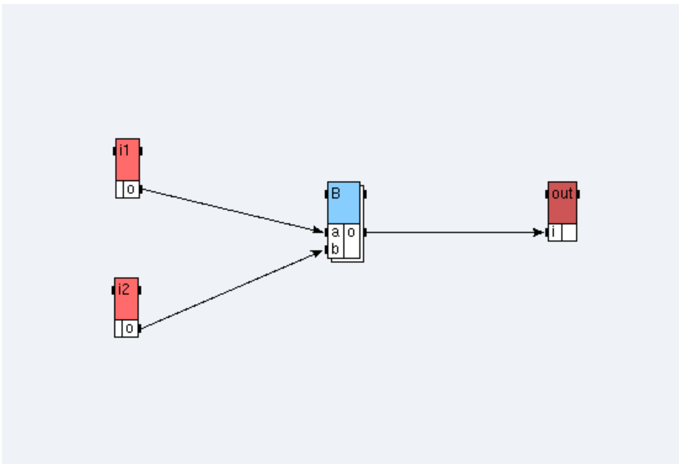

Figure 2.4: Algorithm of the **Example 2**

From the main window, choose **File / Close**. In the dialog window, click on the **Save** button.

Chapter 3

Example 3: delay in algorithm

From the main window, choose **File / Save as** and save your third application under your tutorial folder with the name `example3`.

3.1 Definition of the operations `input`, `output`, and `calc`

Create a sensor `input`, an actuator `output`, and the function `calc`, like in the **Examples 1** and **2**. (*cf.* 1.1.3 and `calcul1` in 2.1)

3.2 Definition of the delay

To create the `calcPrec` delay:

- from the main window: **Algorithm / New Local Definition / Delay** → dialog window: `calcPrec<init;size>` → definition window. The parameter `init` will be use to specify the initial value, and `size` the number of delays to repeat;
- in the definition window, create one input port and one output port. Enter: `? int x ! int x`. Notice that input and output names are the same.

3.3 Definition of the algorithm with delay

Create an algorithm `algorithmMain`. Create a reference `in1` to the definition `input`, a reference `calc` to the definition `calc`, a reference `out1` to the definition `output`, and a reference `calcPrec<0;1>` to the definition `calcPrec`. Create dependences between the references.

The algorithm looks like the figure 3.1.

From the main window, choose **File / Close**. In the dialog window, click on the **Save** button.

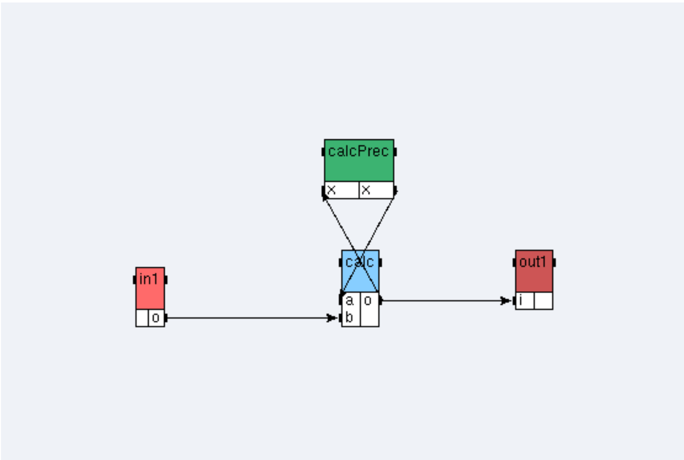

Figure 3.1: Algorithm of the **Example 3**

Chapter 4

Example 4: repetition and library in algorithm

From the main window, choose **File / Save as** and save your fourth application under your tutorial folder with the name `example4`.

4.1 An algorithm with repetition without any library

In this section, we create a multiplication function of a N elements vector by a scalar by repeating N times a multiplication function on scalars.

4.1.1 Definition of the scalar `ins` and the function `mul` on scalars

In a new algorithm window:

- create a new sensor definition named `ins` with an integer output port `o`;
- create a new function definition named `mul` with two integer input ports `a` and `b` and an integer ouput port `o`).

4.1.2 Definition of the vectors `inv` and `outv`

To create the vectors:

- to create the definition `inv`:
  - from the algorithm window, create a new sensor definition named `inv`,
  - from the `inv` definition window, type `N` in the **Parameters** textfield of its **Definition Properties** (it has N elements),
  - create its integer output port named `o` with length `N`: `! int[N] o`;
- to create the definition `outv`:
  - from the algorithm window, create a new actuator definition `outv`,
  - in `outv` definition window, type `N` in the **Parameters** textfield of its **Definition Properties** (it has N elements),
  - create its integer input port named `i` with length `N`: `? int[N] i`.

4.1.3 Definition of the algorithm `AlgorithmMain1`

To create the `AlgorithmMain1` algorithm:

- from the algorithm window, create a new function definition named `AlgorithmMain1` and from its definition window, define it as main;
- in the `AlgorithmMain1` definition mode:
  - create a reference `s_input` to the scalar `ins`,
  - create a reference `v_input<N>` to the vector `inv`,
  - create a reference `mul` to the function `mul` and type `N` in the **Repeat** textfield of its **Reference Properties** (it is repeated *N* times),
  - create a reference `v_output<N>` to the vector `outv`;
- create dependences between the references, in order to obtain the main algorithm (*cf.* figure 4.2);
- type `N` in the **Parameters** textfield of the **Definition Properties** of the main algorithm and `3` in the **Values** textfield (*cf.* figure 4.1). Notice that this value is keeped as long as the algorithm remains the main one.

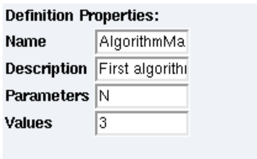

Figure 4.1: **Parameters Values**

The repetition consists in multiplying each of the *3* elements of the `v_input` vector with the `s_input` scalar and placing the result in the *3* elements `v_output` vector.

The parameter `N` is here the repetition factor of the `mul` function.

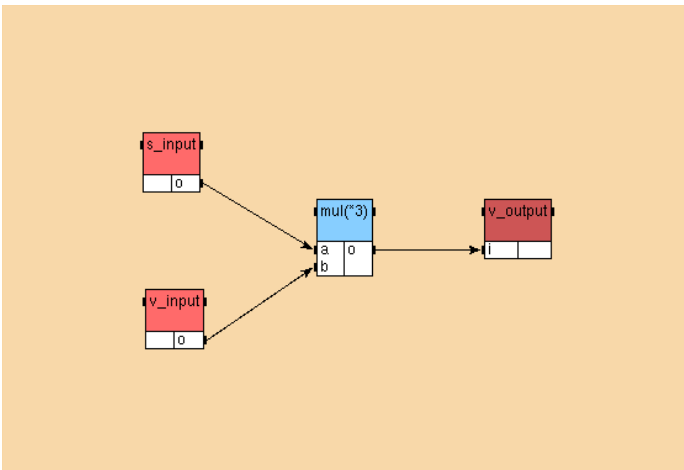

Figure 4.2: `AlgorithmMain1` of the **Example 4**

4.2 An algorithm with repetition with the `int` library

In this section, we create a multiplication function of a vector by a scalar by using the `int` library.

4.2.1 Inclusion of the library `int`

From the main window, choose **File / Included Libraries / int** (*cf.* figure 4.3).

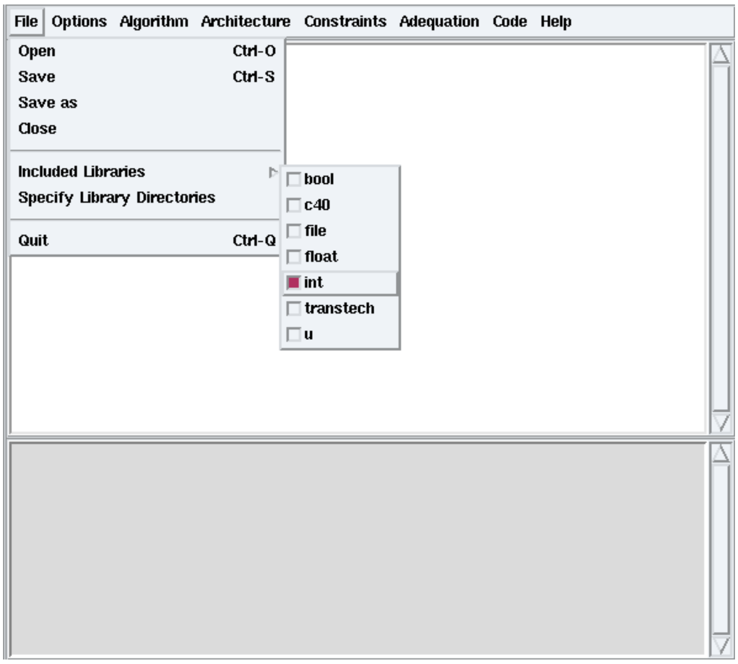

Figure 4.3: **File / Included Libraries / int**

4.2.2 Definition of the algorithm `AlgorithmMain2`

Notice that this library contains `input`, `mul`, and `output` definitions parameterized with `length`.

We will need to set it to `1` for the scalar and the multiplication function, and to `N` for the vectors:

- from the algorithm window, create the function definition `AlgorithmMain2` and define it as main;
- in `AlgorithmMain2` definition mode:
  - drag and drop the sensor definition **int/input** from the **Definition list** to the `AlgorithmMain2` window → dialog window: `s_input<1>` (*cf.* figure 4.4) (it is a scalar),

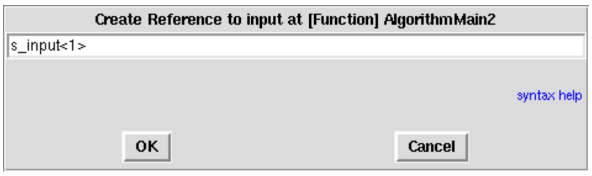

Figure 4.4: **Create Reference to** `int/input`

  - drag and drop the sensor definition **int/input** → dialog window: `v_input<N>` (it has N elements),
  - drag and drop the function definition **int/Arit_mul** → dialog window: `mul<1>` then type `N` in the **Repeat** textfield of its **Reference Properties**, (it is a multiplication on scalars, repeated N times),
  - drag and drop the actuator definition **int/output** → dialog window: `v_output<N>` (it has N elements);
- create dependences between the references in order to obtain the main algorithm (*cf.* figure 4.5);

- type `N` in the **Parameters** textfield of the **Definition Properties**, and `3` in the **Values** textfield.

Notice the difference of the `mul` reference when it is seen from the `AlgorithmMain2` definition mode or from the main mode (**Main** button).

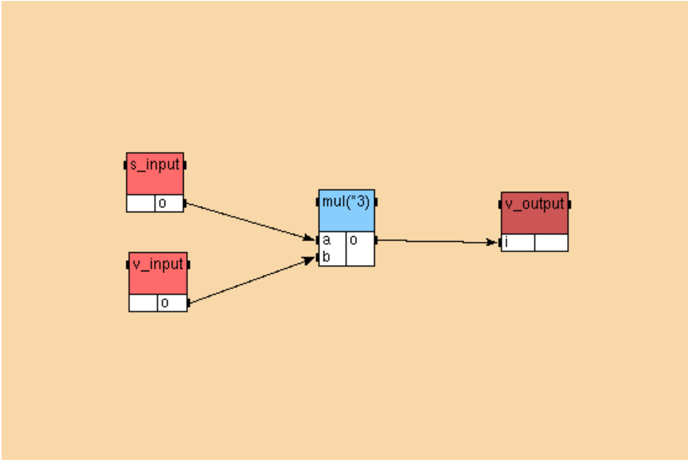

Figure 4.5: `AlgorithmMain2` of the **Example 4**

4.3 An algorithm with repetition with the `float` library

In this section, we create a multiplication function of a *N*M* matrix by a *M* elements vector by repeating *N* times a multiplication function on vectors.

4.3.1 Inclusion of the library `float`

Include the library `float` (**File / Included Libraries / Float**).

4.3.2 Definition of the function `dpacc`

This function is a multiplication function on scalars with an accumulator:

- create a new function definition named `dpacc`;
- create a reference `mul<1>` to the function **float/Arit_mul** (the reference works on scalars);
- create a reference `add<1>` to the function **float/Arit_add** (the reference works on scalars);
- add it three input ports and one output port: `? float s1 ? float s2 ? float acc ! float acc`;
- then create dependences to obtain an algorithm (*cf.* figure 4.6).

Notice that `acc` is an input port and an output port of the function. It will be used as an accumulator to store the partial sum.

4.3.3 Definition of the function `dp`

This function is a multiplication function on vectors with an accumulator:

- create a new function definition named `dp`;
- add it a parameter `dpaccn`;

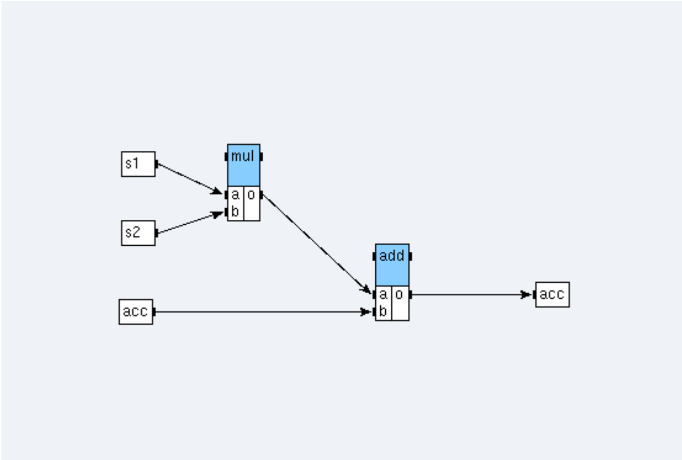

Figure 4.6: Algorithm of the function `dpacc`

- create a reference `zero<{0}>` to the constant **float/cst** (it is the `{0}` scalar);
- create a reference `dpacc` to the function `dpacc` then type `dpaccn` in the **Repeat** textfield of its **Reference Properties** (it is repeated `dpaccn` times);
- add it two input ports: `? float[dpaccn] v1 ? float[dpaccn] v2` and one output port: `! float dp` (vectors have `dpaccn` elements);
- create dependences to obtain an algorithm (*cf.* figure 4.7). To build the dependence between the output port `acc` of `dpacc` and its input port `acc`, choose **Iterate** on the dialog window (it is the connection between two successive calls of the function).

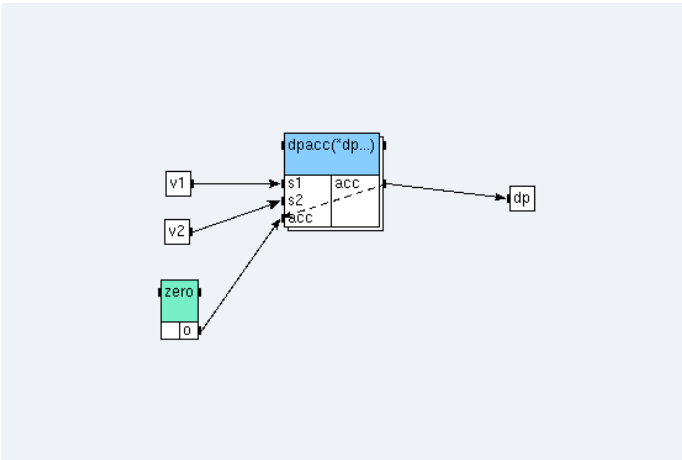

Figure 4.7: Algorithm of the function `dp`

The repetition consists in multiplying two *dpaccn* elements vectors by calling *dpaccn* times the `dpacc` multiplication function on scalars with accumulator. The initial value of its accumulator is given by the `zero` constant and the following are given by the accumulator itself.

4.3.4 Definition of the function `prodmatvec`

This function is a multiplication function of a matrix by a vector:

- create a new function definition named `prodmatvec`;
- type `a;b` in the **Parameters** textfield of its **Definition Properties**;
- create a reference `dotprod<b>` to the function `dp` (input vectors have `b` elements) and type `a` in the **Repeat** textfield of its **Reference Properties** (it is repeated `a` times);
- add it two input ports: `? float[a*b] inm ? float[b] inv` and one output port: `! float[a] outv`;
- then create dependences to obtain an algorithm (*cf.* figure 4.8).

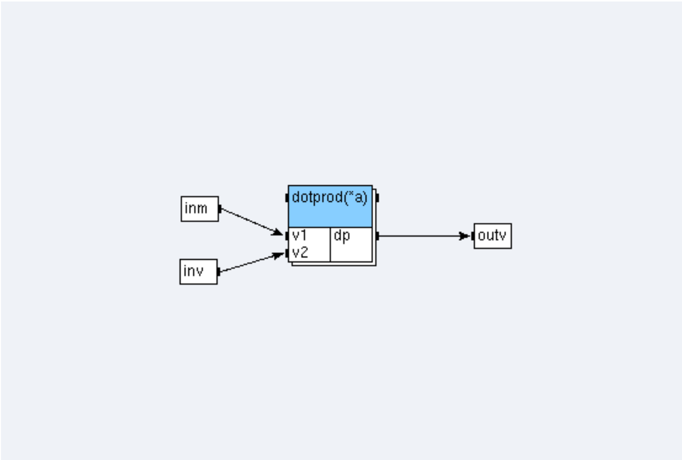

Figure 4.8: Algorithm of the function `prodmatvec`

The repetition consists in multiplying a *a*b* matrix by a *b* elements vector by calling *a* times the `dp` multiplication function on vectors.

4.3.5 Definition of the algorithm `AlgorithmMain3`

To create the `AlgorithmMain3` algorithm:

- create the definition of the sensor `inm`, with two parameters names `N` and `M`, and with an output port: `! float [N*M] o`;
- create a new function definition named `AlgorithmMain3` and define it as main;
- add it two parameters:`N;M` with values `3;4`;
- create a reference `m1<N;M>` to the matrix **inm**;
- create a reference `inv<N>` to the vector **float/input**;
- create a reference `matprodvec<N;M>` to the function **prodmatvec**;
- create a reference `outv<M>` to the vector **float/output**;
- then create dependences to obtain an algorithm (*cf.* figure 4.9).

From the main window, choose **File / Close**. In the dialog window, click on the **Save** button.

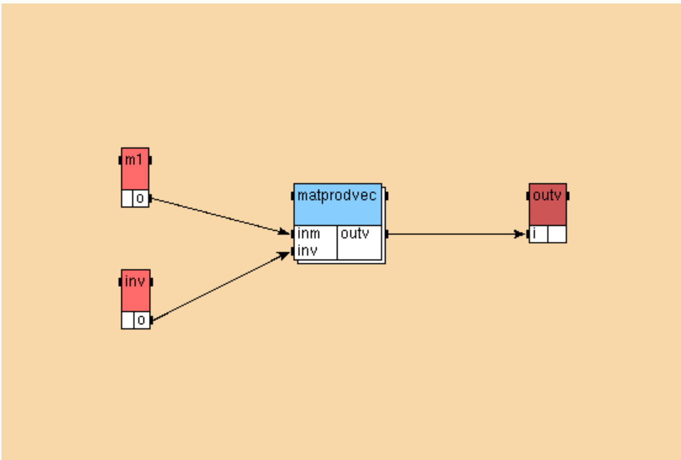

Figure 4.9: `AlgorithmMain3` of the **Example 4**

Chapter 5

Example 5: condition and nested condition in algorithm

From the main window, choose **File / Save as** and save your fifth application under your tutorial folder with the name `example5`.

5.1 An algorithm with condition

5.1.1 Sensors `x` and `i`, actuator `o`

To create the sensors and the actuator:

- from the algorithm window: **+** green button → dialog window: **Sensor** `x`;
- from the algorithm window: **+** green button → dialog window: **Sensor** `i`;
- from the algorithm window: **+** green button → dialog window: **Actuator** `o`.

5.1.2 Function `switch1`

To create the `switch1` function:

- from the algorithm window: **+** green button → dialog window: `switch1`;
- in the `switch1` definition window:
  - contextual menu → **Add port** → dialog window: `? int x ? int i ! int o`,
  - contextual menu → **Create Condition** → dialog window: `x=1 x=2 x=3 x=4` (*cf.* figure 5.1):
    * click on the condition **x=1** (*cf.* figure 5.2) and create a reference `div1<1>` to the definition `int/Arit_div`,
    * click on the condition **x=2** (*cf.* figure 5.3) and create a reference `div2<1>` to the definition `int/Arit_div`,
    * click on the condition **x=3** (*cf.* figure 5.4) and connect the port `i` to the port `o`,
    * click on the condition **x=4** (*cf.* figure 5.5) and create a reference `mul4<1>` to the definition `int/Arit_mul`;
  - create dependences between the references.

5.1.3 Algorithm `AlgorithmMain1`

The algorithm looks like the figure 5.6.

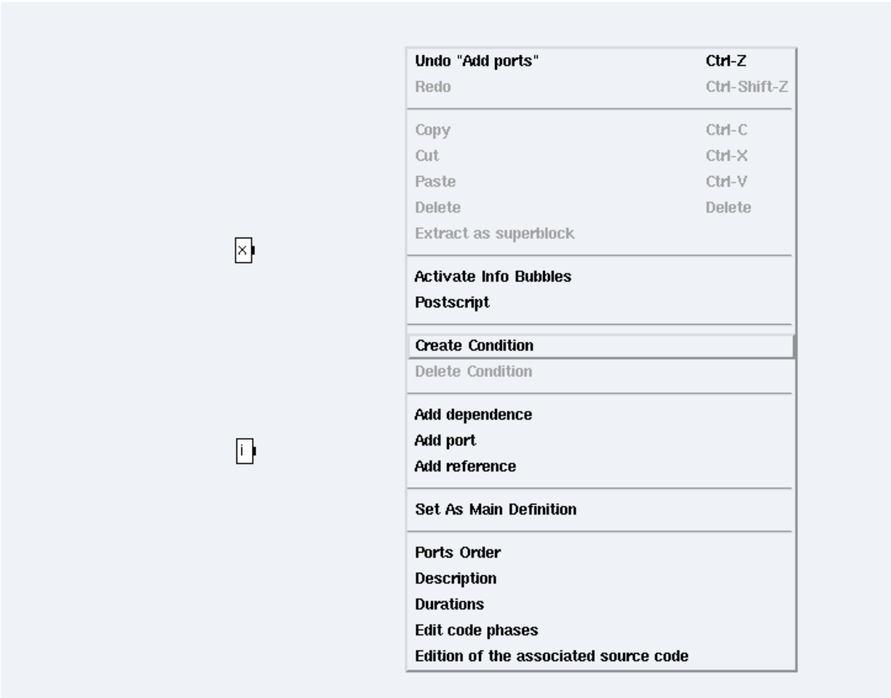

Figure 5.1: **Create Condition**

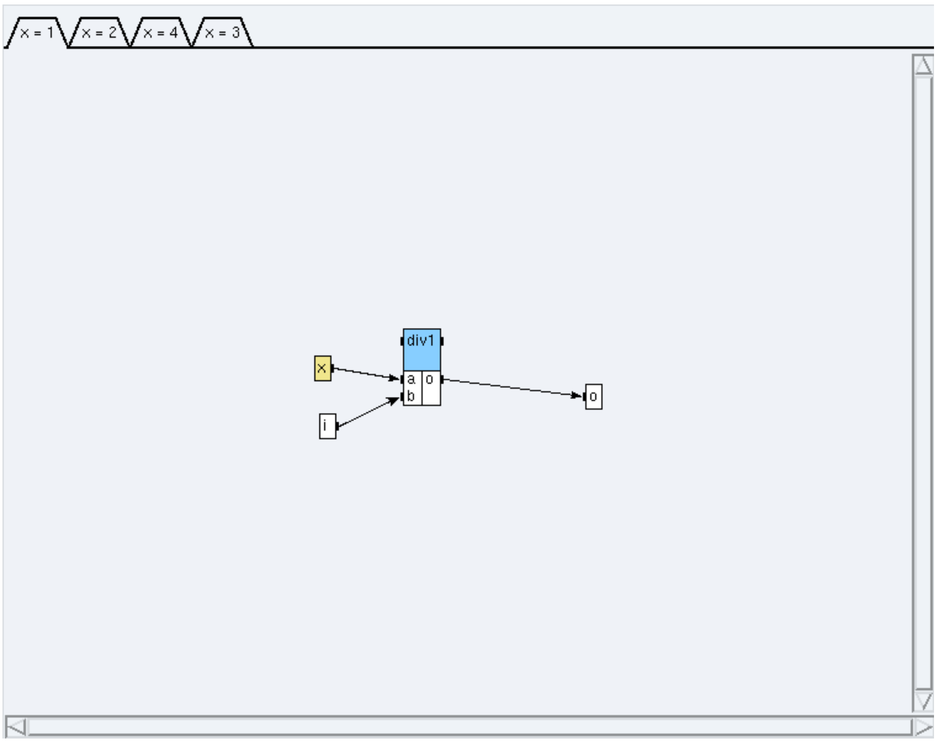

Figure 5.2: Condition x=1

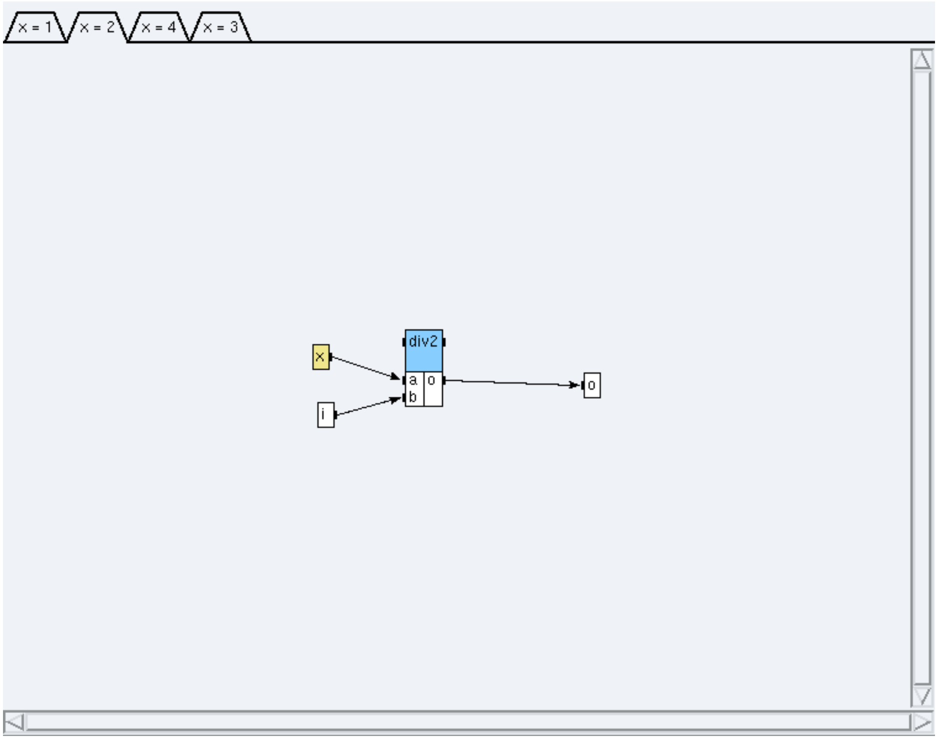

Figure 5.3: Condition x=2

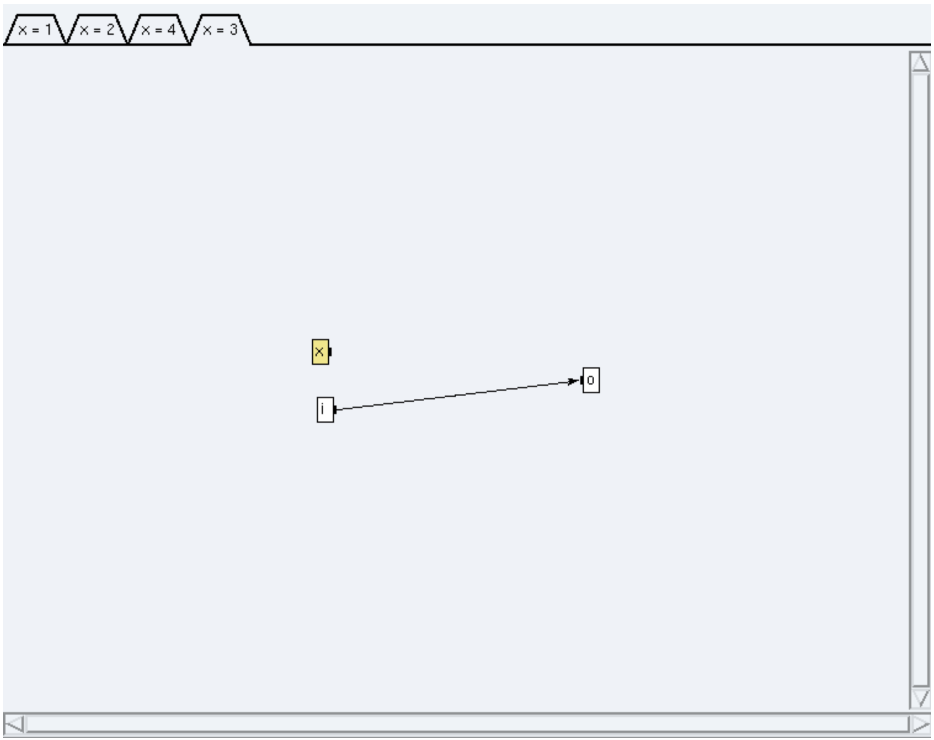

Figure 5.4: Condition x=3

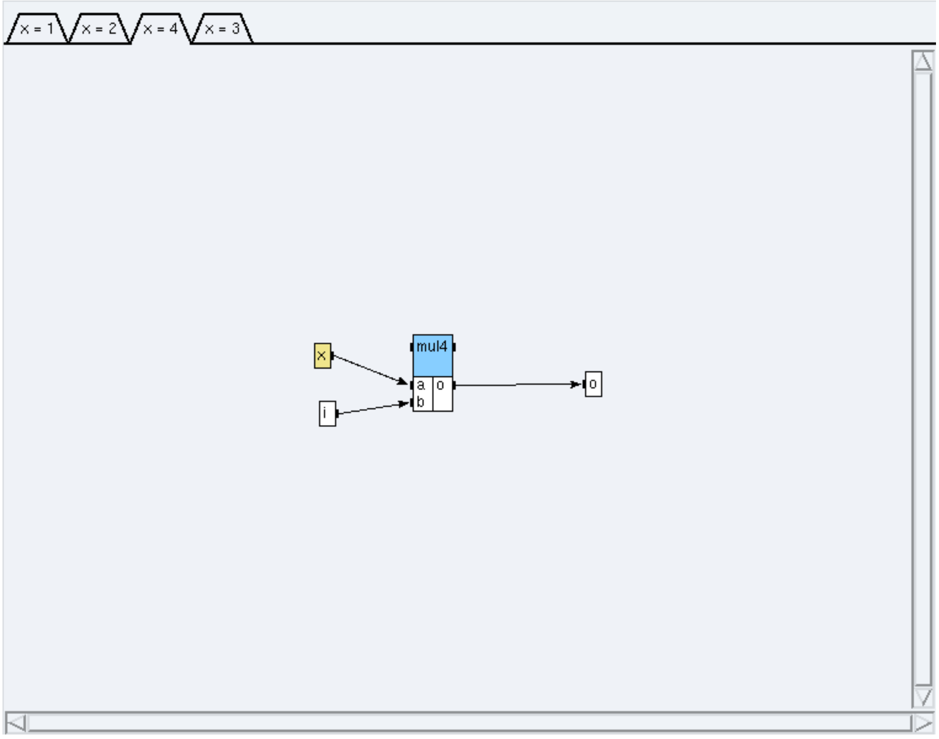

Figure 5.5: Condition x=4

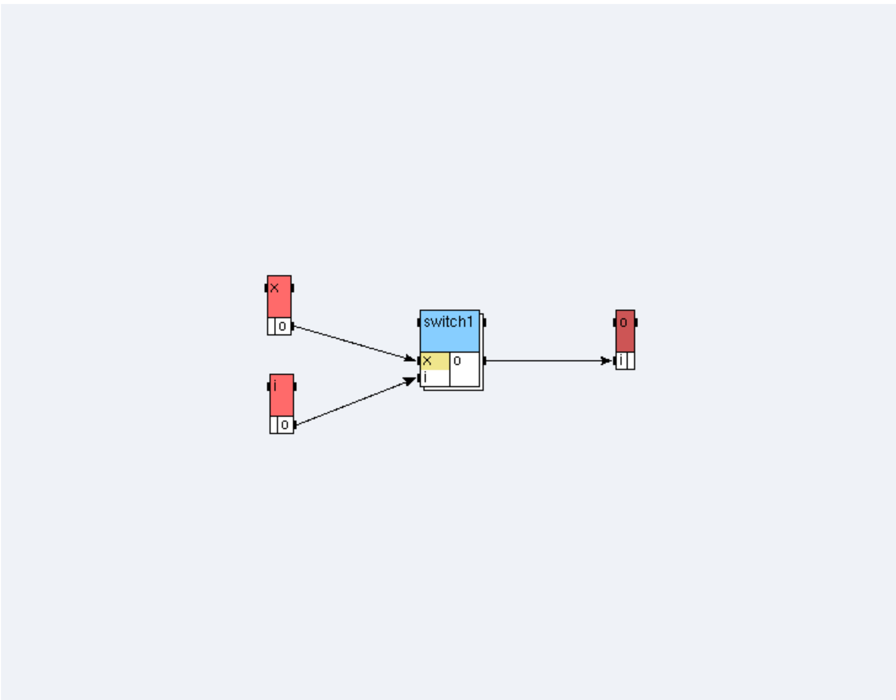

Figure 5.6: AlgorithmMain1 of the **Example 5**

5.2 An algorithm with nested condition

5.2.1 Sensors `x` and `i`, actuator `o`

Use previous definitions (*cf.* 5.1.1).

5.2.2 Function `switch2`

To create the `switch2` function:

- from the algorithm window: + green button → dialog window: `switch2`;
- in its definition window:
  - contextual menu → **Add port** → dialog window: `? int x ? int y ! int o`,
  - contextual menu → **Create Condition** → dialog window: `y=1 y=2`,
  - click on the condition **y=1** (*cf.* figure 5.7) and create the function `mul1` of the definition **Arit_mul** from `int` library,

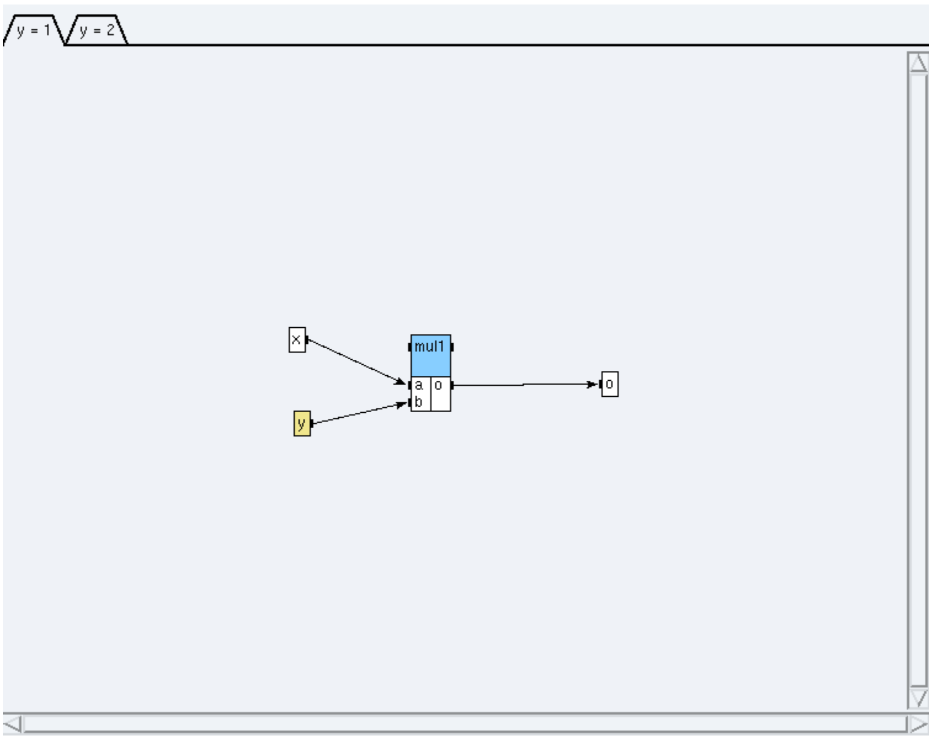

Figure 5.7: Condition y=1

  - click on the condition **y=2** (*cf.* figure 5.8) and create a reference `switch1` to the definition **switch1**;
- create dependences between the references.

5.2.3 Algorithm `AlgorithmMain2`

The algorithm looks like the figure 5.9.

From the main window, choose **File / Close**. In the dialog window, click on the **Save** button.

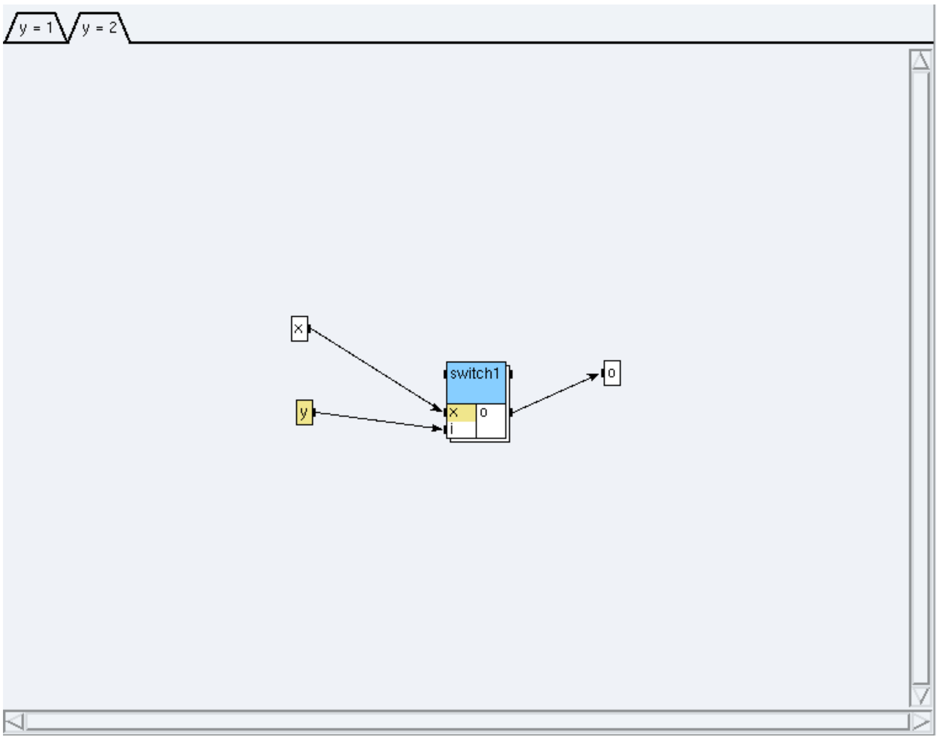

Figure 5.8: Condition y=2

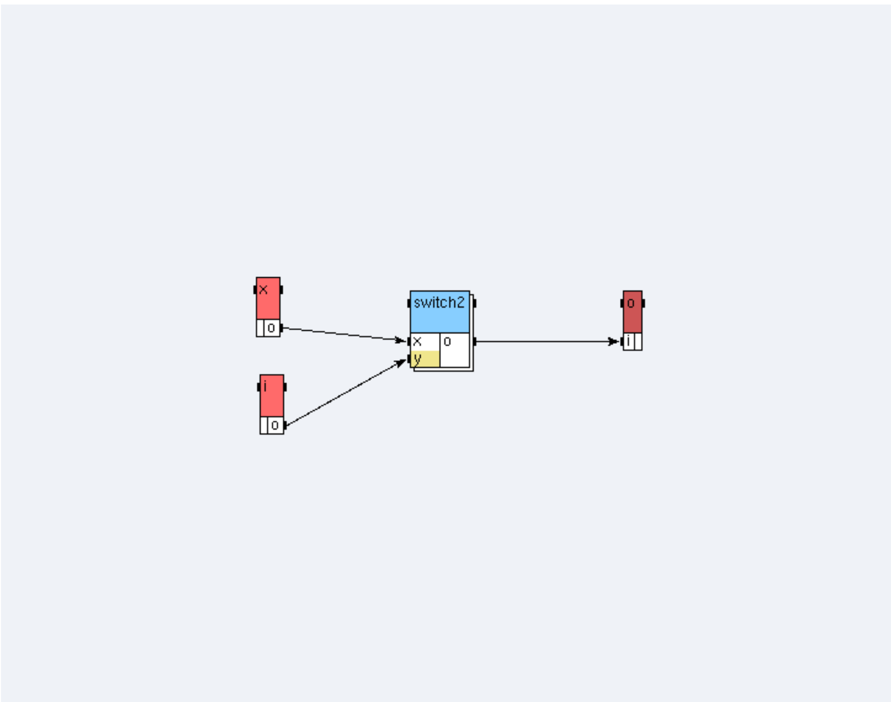

Figure 5.9: AlgorithmMain2 of the **Example 5**

Chapter 6

Example 6: algorithm, architecture, adequation, and code generation

From the main window, choose **File / Save as** and save your sixth application under a new folder of your tutorial folder (*eg.* `my_example6`) with the name `example6`.

6.1 The main algorithm

Create the main algorithm `algo` (*cf.* figure 6.1) using the library **int** for the operations `In<1>` (**input**), `cste2<{2}>` (**cst**), `add<1>` (**Arit_add**), `mul<1>` (**Arit_mul**), `visuadd<1>`, and `visumul<1>` (**output**). For the operation `conv`, create a function definition `conv` and create a reference to this definition. Create the dependences between the references. Set it as main.

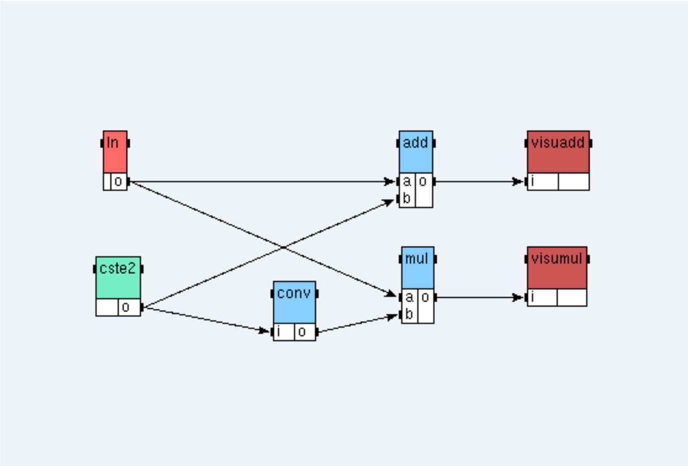

Figure 6.1: Main algorithm of the **Example 6**

6.2 The main architecture

To define and constraint the *main arhcitecure*:

- open the architecture `biProc` from the library `u`;
- define it as main;

- create the operation groups `og1` and `og2` then create the absolute constraints on the operators: `og1` on `root`, `og2` on `P1`. Attach references to operation groups: `In`, `add`, and `visumul` → `og1`, `mul`, and `visuadd` → `og2`.

6.3 The adequation and the code generation

To perform the adequation and to generate the code:

- before performing the code generation, you have to perform the adequation. Set the eventually missing durations, then from the main window: **Adequation / Launch Adequation**;

- from the main window: **Code / Generate Executive(s)**. It generates for each operator of the main architecture the code in a file (files `root.m4` and `P1.m4`) and an architecture description (file `example6.m4`). These files are generated in the same directory as the application. The files generated for each processor may be viewed: **Code / Display Executive(s)**;

- the macros corresponding to the operations, included in the libraries of SynDEx, are already defined under the folder `macros` (files `int.m4x`, `U.m4x`, and `TCP.m4x`);

- in the same folder as the SynDEx application of the **Example 6**, create a new file `example6.m4x` in which you define the macro corresponding to the operation `conv` which is the only one not defined in the library, and the number of iterations. The file looks like:

```
dnl (c)INRIA 2001-2009
dnl SynDEx v7 executive macros specific to application tutorial/example6/example6
divert(-1)

define('NOTRACEDEF')
define('NBITERATIONS',3)
define('BINPWD', 'pwd')
define('RSHELL', 'ssh')

define('conv','ifelse(
MGC,'INIT','dnl',
MGC,'LOOP','$2[0] = $1[0] + 1;',
MGC,'END','dnl')')

divert
divert(-1)
divert''dnl---------------- end of file ------------------
```

- create a new file `example6.m4m`, in which you set for each operator, except the main operator, the name of a workstation corresponding to this operator. The file looks like:

```
dnl (c)INRIA 2001-2009
define('P1_hostname_', HOSTNAME)dnl
```

  where `HOSTNAME` is substituted with the name of your remote station, as indicated in the `Readme` file under `syndex-6.8.5/examples/tutorial/example6`;

- create a new file `root.m4x` for the main operator including the file `example6.m4m`:

```
dnl (c)INRIA 2001-2009
include(example6.m4m)
```

- create a new file `GNUmakefile` which allows the compilation and the substitution of the macros from the code generation by the executable code. The file looks like:

```
# (c)INRIA 2001-2009
A  = example6
M4 = gm4

export Algo_Macros_Path = ../../../macros/algo_libraries
export Archi_Macros_Path = ../../../macros/archi_libraries
export M4PATH = $(Algo_Macros_Path):$(Archi_Macros_Path)

CFLAGS = -DDEBUG
VPATH = $(M4PATH)

.PHONY: all clean
all : $(A).mk $(A).run
clean ::
 $(RM) $(A).mk

$(A).mk : $(A).m4 syndex.m4m U.m4m $(A).m4m
 $(M4) $< >$@

root.libs =
p.libs =

include $(A).mk
```

The folder of the **Example 6** must contain the following files:

- `example6.m4`
- `example6.m4m`
- `example6.m4x`
- `example6.sdc`
- `example6.sdx`
- `GNUmakefile`
- `pc1.m4`
- `root.m4`
- `root.m4x`

To launch the execution, type the command `gmake` in the folder of the **Example 6**. To delete the file created during the compilation, type the command `gmake clean`.

From the main window, choose **File / Close**. In the dialog window, click on the **Save** button.

Chapter 7

Example 7: edition of the source code associated with an operation

In the previous **Example 6**, we have learnt that a **m4** file, called with the name of the application plus the **m4x** extension, must be manually written. It contains all the source code associated with all operations present in a SynDEx application. For example, in the `example6` application, the `conv` function increments of one the value of the input and stores the result in the output. Thus `example6.m4x` file contains:

```
define('conv','ifelse(
MGC,'INIT','dnl',
MGC,'LOOP','$2[0] = $1[0] + 1;',
MGC,'END','dnl')')
```

where `$1` and `$2` correspond respectively to the input port named `i` and the output port named `o` of the `conv` function.

Handwriting this kind of code is not very easy, for several reasons:

- the port number may change by inserting or removing a port or parameter, following the SynDEx's rule of port numeration. For example, after inserting a parameter `P` in the function `conv`, `$1` will not refer to the input port `i` but it will refer to the new added parameter `P`. All numbers are now brought, thus we must modify the code and replace the arguments `$1` by `$2` and `$2` by `$3`;
- this task is quite repetitive when an application contains many operations;
- it is easy to make a mistake in the **m4** syntax. Great knowledges in **m4** syntax (two different kind of quotes, `ifelse` ...) and SynDEx **m4** macros (`MGC`) are required.

It should be more convenient to write `@OUT(o)[0] = @IN(i)[0] + @PARAM(P)` and let SynDEx interpret it and generate the associated **m4x** file than to write the specification with the **m4** syntax. SynDEx (version $\geq$ 7.0.0) is able to do that thanks the *code editor* which is a tool integrated in the graphical user interface (GUI). In the following example, we will show how to use this tool.

7.1 To add parameters to an already defined operation

In this example, we show how to modify some functions by adding parameters in order to expand parameters into **m4** arguments.

Open the `example6.sdx` application

:

- from the main window; choose **File / Open** → Open the `example6.sdx` file;
- save it as `example7.sdx` under a new folder of your tutorial folder (*eg.* `my_example7`).

Add parameters to the conv function:

- from the algorithm window on the main algorithm: right click on the `conv` blue box → Popup menu: **Modify** → Write `conv_ref <2;3>` instead of `conv` → **OK**. [1];
- add parameters `P;T` to the `conv` definition.

Verify that the parameters have been stored in the function

We have three solutions:

- from the algorithm window on the main algorithm: put the mouse on the `conv_ref` box → In the SynDEx main window: read the printed informations;
- or, from the algorithm window on the main algorithm: double left click on the `conv_ref` blue box → **Algorithm Function conv**: **Edit / Ports Order**;
- or from the algorithm window on the main algorithm: **Edit / Options / Show Info Bubbles** → point the mouse cursor on the `conv_ref` operation box.

7.2 To edit the code associated with an operation

7.2.1 In the case of a generic processor

Open the code editor

We need to launch the code editor of the selected operation. Let us consider the case of the `conv_ref` function. We have to do the following operations:

- in the main algorithm: double left click on the `conv_ref` blue box. It opens the `conv` definition window. In its contextual menu, select **Edition of the associated source code**. It opens the code editor. It looks like a window with three push-buttons and an editable text area. Each push-button corresponds to one specific phase of three (**init**, **loop**, and **end** phases). When one of the three buttons is pressed, the text area shows the associated source code;
- in the `conv` definition window, right click on the background and select **Edit code phases** → Select **init** and **end** → **OK**;
- in the code editor window: **init phase** → write in the text area (which is empty) the following `C` language code. This code is understood as a generic code:

```
printf("Init phase of function $0 for default processor.\n");
```

- do the same thing for the **loop phase** [2]:

```
@OUT(o)[0]=@IN(i)[0]*@PARAM(T)+@PARAM(P);
printf("Loop phase of function $0 for default processor = %i.\n", @OUT(o)[0]);
```

- and for the **end phase**:

[1] Notice that you will have only to ignore the error messages printed from the main window if you have inverted this step with the following.
[2] Macros of the code editor as @IN, @OUT, @PARAM, ... are explained in the User Manual.

```
printf("End phase of function $0 for default processor.\n");
```

- in the code editor window: **Edit / Apply changes to all phases**. It saves all buffers of all edited phases;
- in the code editor window: **OK** (it also saves all buffers).

Notice the following points:

- you can not launch the code editor from a main algorithm or a read-only operation (definition coming from libraries);
- you can write a code associated with a super-operation meanwhile it will not be present in the `applicationName_sdc.m4x` file (the background color of the text area of the code editor is grey);
- it is important to recall that the code is common to all the references of the same operator. Only the values of parameters are specific of each instance.

Verify that code is common to all references

We create a new reference to the `conv` function:

- in the main algorithm: create a reference `conv_ref_bis<8;9>` to the definition `conv`;
- in the main algorithm: first remove the link between the `conv_ref` and `mul` boxes. Second, link the `conv_ref` output to the `conv_ref_bis` input. Third, link the `conv_ref_bis` output to the `mul b` input;
- in the main algorithm: **Window** → **Auto position** → **Space between vertices** window: in the two entry texts, write 120 → **OK**;
- open the code editor of this new box: the code is the same. To show that values of parameters are specific to the reference (and not to the definition), we must generate the **m4** code like shown in the previous example (Menu **Adequation / Launch Adequation** then **Code / Generate Executive(s)**) and look in `pc1.m4` (Menu **Code / Display Executive(s)**). The file contains

```
conv(2,3,_algo_cste2_P1_o,_algo_conv_ref_o)
conv(8,9,_algo_conv_ref_o,_algo_conv_ref_bis_o)
```

7.2.2 In the case of an architecture with heterogeneous processors

Sometimes it is interesting for an operation to have different source codes depending on the type of processor. For example, a given processor type `X` may only offer assembly language as a programming interface. In such case, we must be able to provide (for example) `C` code for processors that support it, and assembly language for the `X` processor type. To support heterogeneous architecture, the code editor associates code to a triplet (phase, processor, operation). A special processor type **Default** is provided for processors that have not been associated with dedicated code. Its use allows to share a code between different processor types.

Include a new processor type

From the main window, choose **File / Included Libraries** → Select **c40**

Define an new architecture:

- from the main window, choose **Architecture / Define Architecture** (*cf.* figure 1.14) → In the entry text, write `archi2`. → **OK**;
- in the `archi2` window: create a reference `root` to the operator `C40` and define it as the main operator.

Replace the `conv_ref_bis` box by a reference to `bar_ref`:

- create a new function definition named `bar` with one input port called `in` and one output port called `out`;
- from the main window, choose **Algorithm / Edit Main Definition**: select all the references using the mouse and copy it (Menu **Edit** → **Copy**);
- create a new main algorithm named `algo2`;
- paste `algo` in `algo2` definition window;
- in the `algo2` definition window: first delete the `conv_ref_bis` reference, then create a reference `bar_ref` box to the definition `bar`, finally create the missing dependences. The main algorithm should look like the figure 7.1.

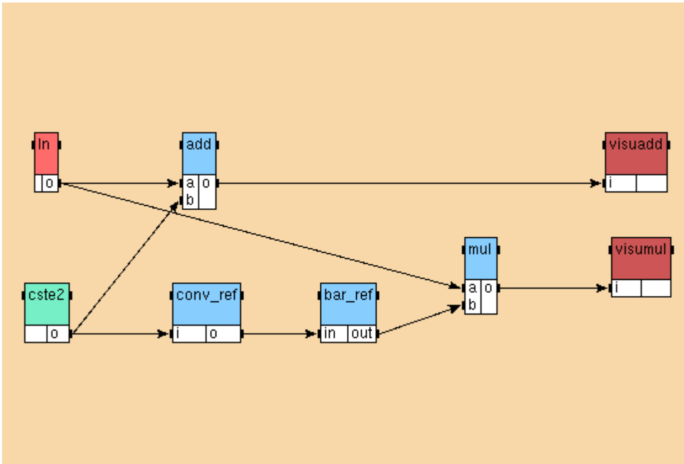

Figure 7.1: Main algorithm after adding 'bar_ref'

Insert code for `C40` processor type to the `bar` function:

- in the `algo2` definition window: double left click on the `bar_ref` blue box. It opens the **bar** definition window. In its contextual menu, select **Edition of the associated source code**. It opens the code editor;
- in the `bar` definition window, right click on the background and select **Edit code phases** → Select **init** and **end** → **OK**;
- in the code editor window: **Type of Processor**: Select **C40**;
- in the code editor window: click on the **init phase** button and write in the text area the following code:

```
/* Hi, I am $0 function, in init phase for C40 processor */
```

- in the code editor window: click on the **loop phase** button and write in the text area the following code:

```
@OUT(out)[0] = @IN(in)[0];
/* Hi, I am $0 function, in loop phase for C40 processor */
```

- in the code editor window: click on the **end phase** button and write in the text area the following code:

```
/* Bye, I am $0 function, in end phase for C40 processor */
```

Insert code for `U` processor type to the `bar` function:

- in the code editor window: **Type of Processor**: Select **U**;
- in the code editor window: click on the **init phase** button and write in the text area the following code:

```
/* Hi, I am $0 function, in init phase for U processor */
```

- in the code editor window: click on the **loop phase** button and write in the text area the following code:

```
@OUT(out)[0] = @IN(in)[0] * 42;
/* Hi, I am $0 function, in loop phase for U processor */
```

- in the code editor window: click on the **end phase** button and write in the text area the following code:

```
/* Bye, I am $0 function, in end phase for U processor */
```

Modify the durations

Add `c40/C40 = 1` at the end of the **Durations** text area for each definition referenced in `algo2`

7.2.3 Learn the macros of the code editor

The code editor comes with a set of predefined macros that alleviate the user from knowing the black magic of **m4** processing.

The more useful ones are names translation macros. These macros translate port and parameter names to their internal representation as **m4** parameters. We have already encountered such macros in what we have just done: `@IN`, `@OUT` and `@INOUT` are port name translation macros, and `@PARAM` is the parameter name translation macro. As a rule of thumb, you should use `@PARAM(x)` when you want to refer to a parameter `x` and `@IN(i)` (resp. `@OUT(o)` / `@INOUT(io)`) when you refer to an input port `i` (resp. output port `o` / input-output port `io`).

The code editor recognizes three more macros: `@NAME`, `@QUOTE` and `@TEXT`. These advanced macros are not used in this tutorial and the reader is refered to SynDEx user manual to learn more about it.

7.3 To generate m4x files

Before performing the code generation we have to perform the adequation:

- from the main window, choose **Adequation / Launch Adequation**;
- from the main window, choose **Code**: Select **Generate m4x Files**;
- from the main window, choose **Code / Generate Executive(s)**;

- from the main window, choose **Code / Display Executive(s)**.

Two cases are possible:

- the check box `Generate m4x Files` has not been checked. For each operator of the main architecture a *processor_name*.m4 file containing **m4** macro-code is produced. As previously explained an architecture description file (named `example7.m4`) is also produced;
- the check box `Generate m4x Files` has been checked. Then, two new files (`example7.m4x` and `example7_sdc.m4x`) are generated in the same directory as the application.

These two files constitute the *Applicative kernel*:

- the `MyApplication_sdc.m4x` file contains all **m4** macro code associated with operations used in the SynDEx application. Each time code generation is triggered, this file is overwritten;
- the `MyApplication.m4x` file is an user editable file whose goal is to allow the user to complete the applicative kernel if needed. At code generation time, if this file does not exist then SynDEx creates a generic file (including the `MyApplication_sdc.m4x` file plus some other features), otherwise the existing file is kept.

The `example7_sdc.m4x` file contains the following code:

```
divert(-1)
# (c)INRIA 2001-2009
divert(0)

define('example7_bar','bar')
define('bar','ifelse(
 processorType_,'C40','ifelse(
  MGC,'INIT', ''/* Hi, I am $0 function, in init phase for C40 processor */'',
  MGC,'LOOP',''$2[0] = $1[0]; /* Hi, I am $0 function, in loop phase for C40 processor */'',
  MGC,'END', ''/* Bye, I am $0 function, in end phase for C40 processor */'')')')
 processorType_,'U','ifelse(
  MGC,'INIT',''/* Hi, I am $0 function, in init phase for U processor */'',
  MGC,'LOOP',''$2[0] = $1[0] * 42; /* Hi, I am $0 function, in loop phase for U processor */'',
  MGC,'END', ''/* Bye, I am $0 function, in end phase for U processor */'')',

define('example7_conv','conv')
define('conv','ifelse(
 processorType_,processorType_,'ifelse(
  MGC,'INIT',''printf("Init phase of function $0 for default processor.\n");'',
  MGC,'LOOP',''$5[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");'')')')
```

If the `example7.m4x` file did not exist at code generation time then it will contain the following code:

```
divert(-1)
# (c)INRIA 2001-2009
divert(0)

define('dnldnl',''// '')
define('NOTRACEDEF')
define('NBITERATIONS',''5'')

include('example7_sdc.m4x')

divert
#include <stdio.h> /* for printf */
```

```
divert(-1)
divert`'dnl
```

Deeper insights about the **m4** macro language can be found in SynDEx user manual and GNU M4 manual.

See the difference between executable codes:

- create the `example7.m4m` file (*cf.* 6.3);
- create the `root.m4x` file (*cf.* 6.3);
- create the `GNUmakefile` (*cf.* 6.3), containing:

```
$(A).mk : $(A).m4 syndex.m4m U.m4m C40.m4m $(A).m4m
 $(M4) $< >$@
```

- define `algo2` as main algorithm;
- define `archi` as main architecture, perform the adequation, generate the code, and run the `GNUmakefile` compilation You obtain a `root.c` file containing `U` code only (no `C40` code);
- define `archi2` as main architecture, perform the adequation, generate the code, and compile again. This time, only `C40` code is present in the `root.c` file.

Notice that:

- adequation modifies original files `example7.sdx` and `example7.sdc`;
- code generation produces these files: `example7.m4`, `root.m4`, `pc1.m4` (if `archi` is defined as main), `example7_sdc.m4x` (if **Generate m4x files** is set) and `example7.m4x` (if **Generate m4x files** is set and the file did not exist before);
- compilation produces these files: `example7.mk`, `root`, `root.c`, and `root.root.o`, and (if `archi` is defined as main) `pc1`, `pc1.c`, and `pc1.pc1.o`.

From the main window, choose **File / Close**. In the dialog window, click on the **Save** button.

Chapter 8

Example 8: a complete realistic application from adequation to execution

From the main window, choose **File / Save as** and save your eighth application under a new folder of yout tutorial folder (*eg.* `my_example8`) with the name `example8`.

8.1 The aim of the example

In the seven previous examples we have learnt how to use SynDEx's GUI to create architectures, algorithms, launch adequation, obtain executive files... Now, we have sufficient knowledge to perform a simple automatic control application that will be executed on a multiprocessor architecture.

First the application is described and the system is defined in Scicos (the block diagram editor of the Scilab software[1]). Second the corresponding SynDEx application is created (using the **Example 1** to **3** of the tutorial). This needs the generation of some `C` code following the method discussed in **Example 7**. Finally, we compile the application to obtain executable for several processors as it has been shown in **Examples 6** and **7**. SynDEx generates the code necessary to the communication between the processors.

8.2 The model

We consider a system of two cars. The second car $\mathcal{C}_2$ follows the car $\mathcal{C}_1$ trying to maintain the distance l while the acceleration and the deceleration of $\mathcal{C}_1$. We call: $x_1(t)$ the position of the first car; $x_2(t)$ the position of the second car plus l; $\dot{x_1}(t)$ and $\dot{x_2}(t)$ the speeds of two cars. We denote k_1 and k_2 the inverse of the car masses. We call $r(t)$ the reference speed chosen by the first driver. We suppose that we are able to observe the speed of the first car and the distance between the cars.

We have the following fourth order (four degrees of liberty) system:

$$\begin{aligned} \ddot{x_1} &= k_1 u_1 \\ \ddot{x_2} &= k_2 u_2 \\ y_1 &= \dot{x_1} \\ y_2 &= x_1 - x_2 \end{aligned} \tag{8.1}$$

We will decompose the system into mono-input mono-output system $S_1(u_1, y_1)$ and $S_2(u2, y2)$. Denoting by uppercase letter the Laplace transform of the variables, we have $Y_1 = k_1 U_1/s$ and $Y_2 = (k_1 U_1 - k_2 U_2)/s^2$ where U_1 is seen as a perturbation that we want reject in the second system.

A first proportional feedback $U_1 = \rho_1(R - Y_1)$ will insure the first car to follow the reference speed. The second controller will be proportional derivative $U_2 = \rho_2 Y_2 + \rho_3 s Y_2$ (in fact we will suppose in the following diagram that the derivative of y_2 is also observed). The coefficient ρ_1 is obtained by placing the pole of the first loop:

$$Y_1 = \rho_1 k_1 R/(s + \rho_1 k_1).$$

[1] `http://www.scilab.org`

The coefficient ρ_2 and ρ_3 are obtained by placing the pole of the transfer from U_1 to Y_2 in the closed loop system which is given by:

$$Y_2 = U_1 k_1/(s^2 + k_2\rho_3 s + k_2\rho_2).$$

8.3 The controllers

The purpose of the controller of the C_1 car is to follow the reference in speed given the first driver. It stabilizes the C_1 speed around its reference speed by using pole placement. For example, gains are respectively: `(0, -5, 0, 0, -5)`. The controller of second car stabilizes the distance between the two cars. It stabilizes y_2 around 0 by pole placement. For example, gains are respectively: `(4, 4,-4,-4)`.

The controler of C_2 knows these informations and sends them electronically to C_1. This remark is available for C_1.

8.3.1 Block diagrams of controllers

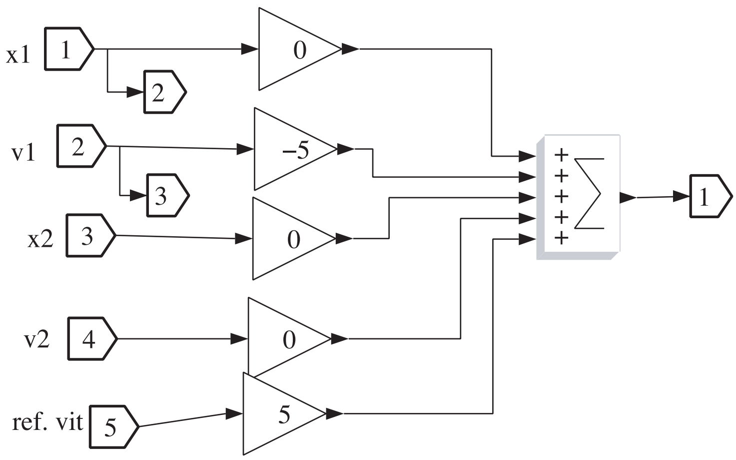

Figure 8.1: Scicos controller of the first car

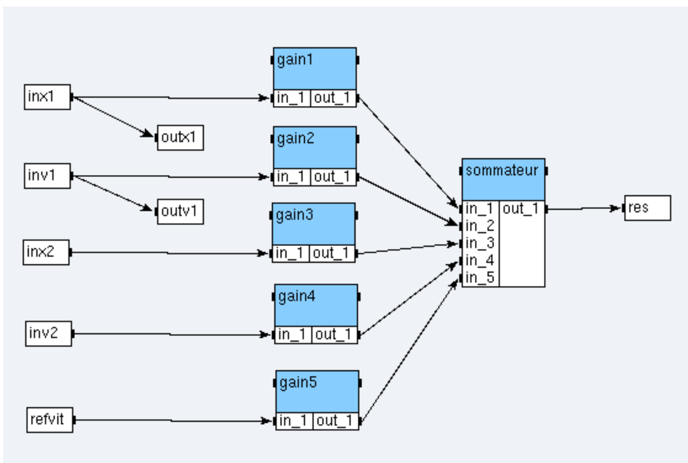

Figure 8.2: SynDEx controller of the first car

Our controllers are simple. They are represented in figures 8.1 and 8.3 in Scicos and figures 8.2 and 8.4 in SynDEx:

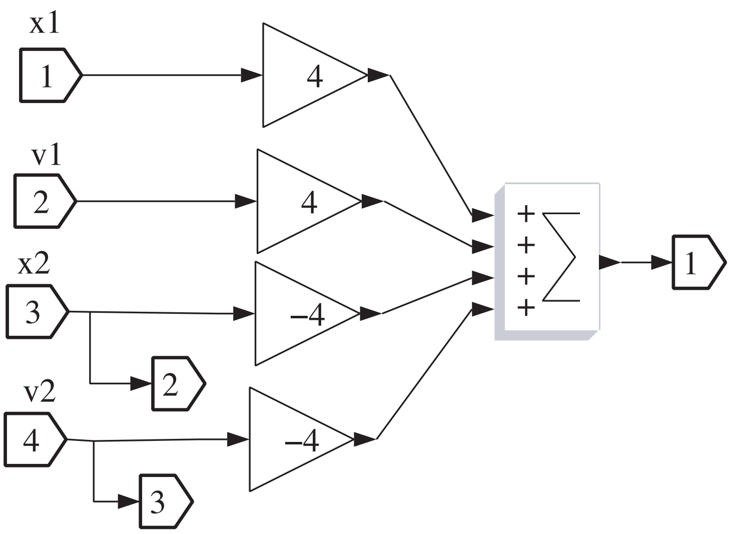

Figure 8.3: Scicos controller of the second car

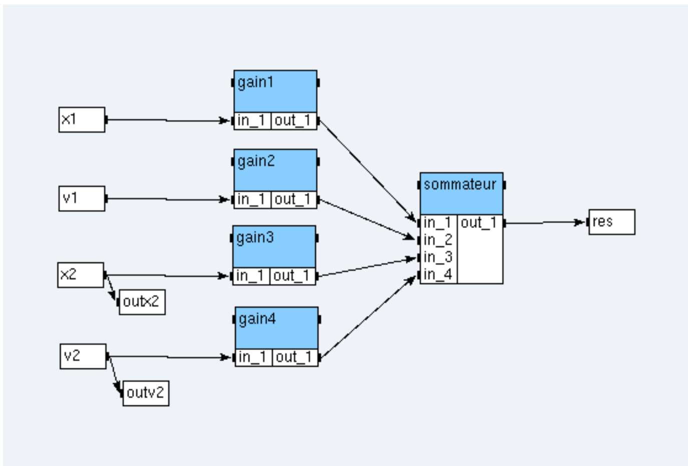

Figure 8.4: SynDEx controller of the second car

- create a `gain_def` function with one input port `in_1` and one output port `out_1`. Notice that all ports will be of type `float`;
- then create `sommateur2_def`, `sommateur4_def`, and `sommateur5_def` functions, respectively with two input ports (`in_1` and `in_2`), four input ports (from `in_1` to `in_4`), and five input ports (from `in_1` to `in_5`). Each of these three functions is created with only one output port `out_1`;
- finally create both algorithms `controleur1_sup` and `controleur2_sup` (*cf.* figures 8.2 and 8.4), setting their gain parameters respectively to `0, -5, 0, 0, 5` and `4, 4 ,-4 , -4`.

8.3.2 Source code associated with the functions

We associate `C` source code to each function definition: gain and nary-sums. The code is inserted for the default processor.

Gain

A gain is a function that multiplies its input by a coefficient given as a parameter, named `GAIN`. After adding this parameter, open the code editor of the gain definition and write the following code in the loop phase of the default processor:

```
@OUT(out_1)[0] = @IN(in_1)[0] * @PARAM(GAIN);
```

Sum

We have three different forms of sum depending of its arity: two, four or five input ports:

- open the code editor of the sum function with two input ports and write the following code in the loop phase of the default processor:

  ```
  @OUT(out_1)[0] = @IN(in_1)[0] + @IN(in_2)[0];
  ```

- open the code editor of the sum function with the four input ports and write the following code in the loop phase of the default processor:

  ```
  @OUT(out_1)[0] = @IN(in_1)[0] + @IN(in_2)[0] +
  @IN(in_3)[0] + @IN(in_4)[0];
  ```

- open the code editor of the sum function with the five input ports and write the following code in the loop phase of the default processor:

  ```
  @OUT(out_1)[0] = @IN(in_1)[0] + @IN(in_2)[0] +
  @IN(in_3)[0] + @IN(in_4)[0] + @IN(in_5)[0];
  ```

8.4 The complete model

In a real application, our job stops with the SynDEx's adequation of the two controllers on their associated architectures. Nevertheless, for pedagogic reasons, we will simulate the whole system (with the dynamics of the cars) in the aim to verify that our application does the same job that Scicos.

8.4.1 The car dynamics

SynDEx is only used in discrete time model (not continuous time) and is not able to manage implicit algebraic loop. That is, in SynDEx, any loop contains at least a delay $1/z$. Therefore, our application which is a continuous time dynamic system described in Scicos, must be discretized in time to be used in SynDEx.

The differential equation $\dot{x} = u$ is discretized using the simplest way: the Euler scheme. Let us denote by h the step of the discretization and x_0 an arbitrary initial value, the discretized system can be written as:

$$x_{n+1} - x_n = uh \tag{8.2}$$

Finally, the system is given in Scicos in the figure 8.5 and 8.2 is given in SynDEx in the figure 8.6. Notice that the variable h is stored in the Scicos context, and used in the input of the gain and the clock definition. In SynDEx, h is defined as parameter in the definition of a gain and the clock definition is directly used in the source code associated with operations.

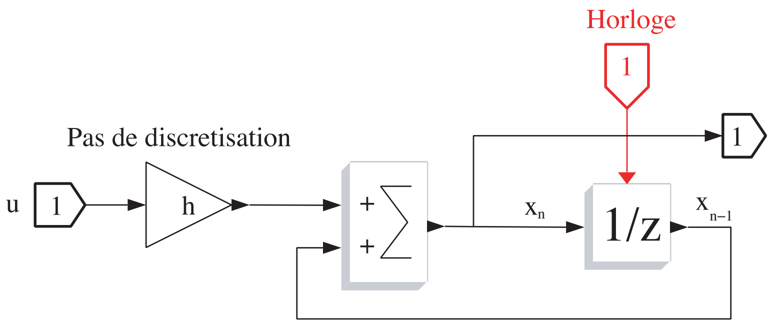

Figure 8.5: An integral discretized in Scicos

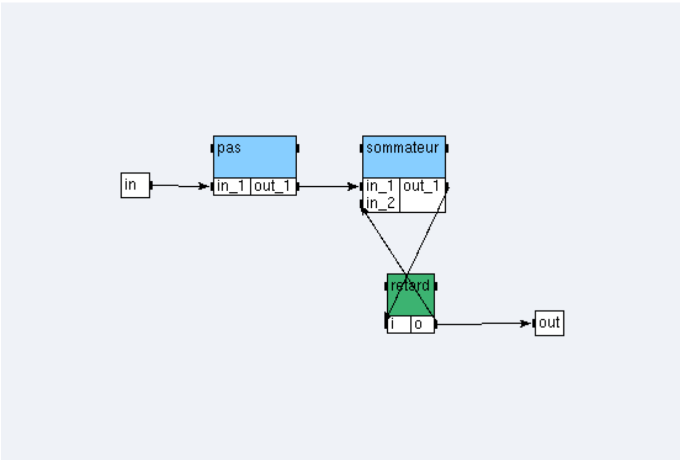

Figure 8.6: An integral discretized in SynDEx

Create the `integrale_discrete_sup` algorithm (*cf.* figure 8.6). Notice that `pas` is of type `gain_def` with parameter `GAIN` equal to `0.001`, `sommateur` is of type `sommateur2_def`, and `retard` is of type `float/delay` with parameters equal to `{0}` and `1`.

The car dynamics are given with Scicos block diagrams in the figure 8.7 and with SynDEx operations in the figure 8.8, where the input `1` (`ref`) is the acceleration of the car. The first integral gives the speed of the car and the second its position.

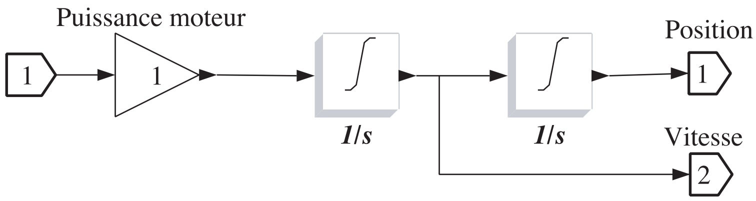

Figure 8.7: Car dynamics with Scicos block diagrams (continous time)

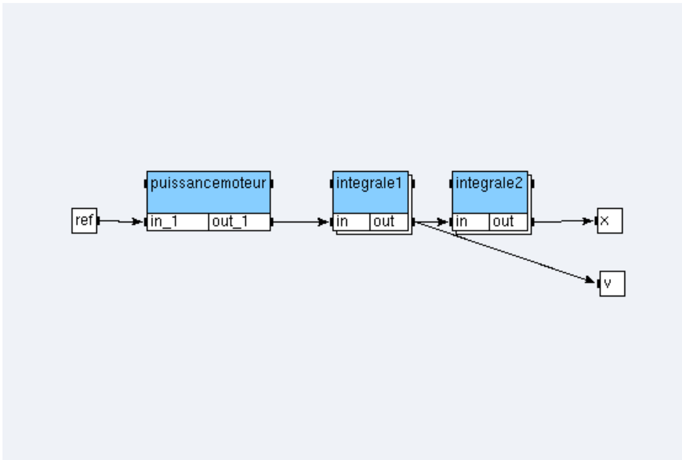

Figure 8.8: Car dynamics with SynDEx operations

Create the `mecanique_sup` algorithm (*cf.* figure 8.8). Notice that `puissancemoteur` is of type `gain_def` with parameter `GAIN` equal to `1` whereas `integrale1` and `integrale2` are of type `integrale_discrete_sup`.

8.4.2 The cars and their controllers

In the following diagrams (from 8.9 to 8.12), the blocks (operations) denoted by `meca` are the car dynamics. Let us get the controllers of the two cars.

Create the `voiture1_sup` and `voiture2_sup` algorithms (*cf.* figures 8.10 and 8.12). Notice that `meca1` and `meca2` are references to `mecanique_sup` wherease `control1` (resp. `control2`) is a refrence to `controleur1_sup` (resp. `controleur2_sup`).

8.4.3 The main algorithm

Create the `senseur_def` sensor, the `vitesse_def` actuator and `scope_def` actuator (this one with two input ports `in_1` and `in_2`. Then create `algomain`. After inserting the reference speed `ref_vit` (of type `senseur_def`, with `POSI_ARRAY` parameter equal to `0`) and two kinds of output: `vitesse` ($\dot{x_1}$, of type `vitesse_def` with `POSI_ARRAY` parameter equal to `1`) and `distance` between the two cars (of type `scope_def` with `POSI_ARRAY` parameter equal to `2`), the applications looks like the figure 8.13 in SynDEx.

8.4.4 Source code associated with the sensor and the actuator

We associate `C` source code to each function definition: input and two kinds of output.

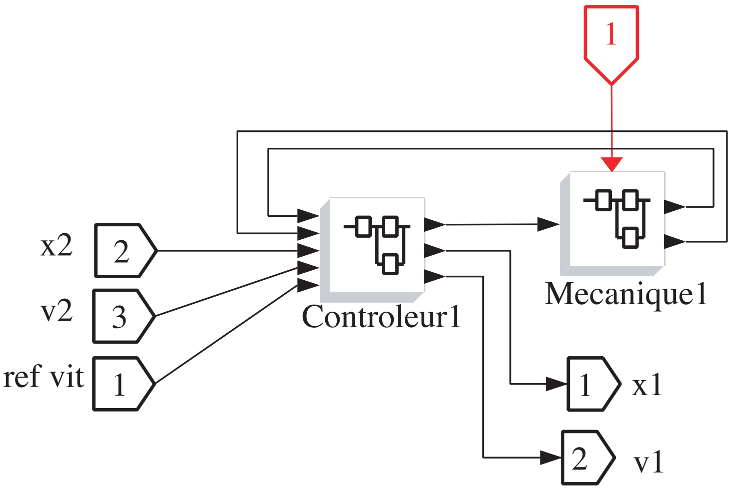

Figure 8.9: Scicos C_1 car dynamics and its controller

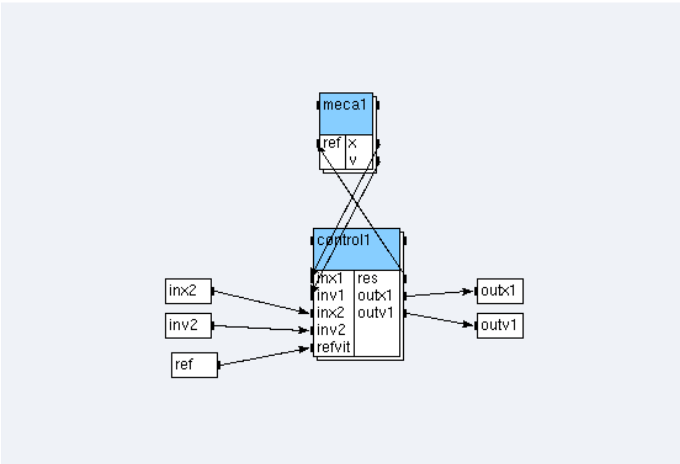

Figure 8.10: SynDEx C_1 car dynamics and its controller

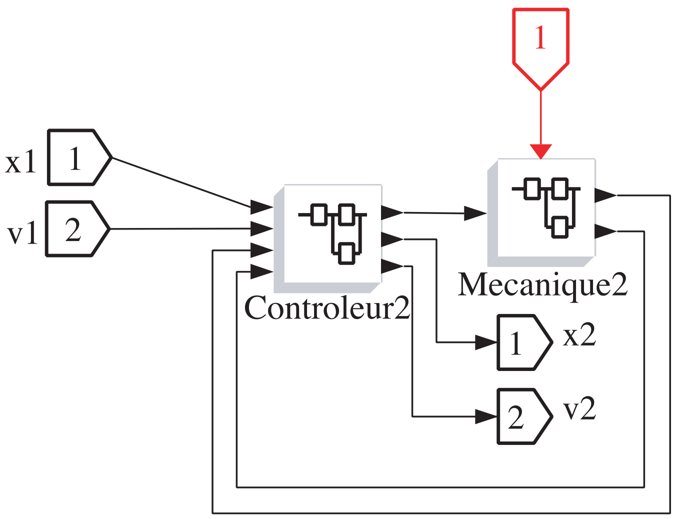

Figure 8.11: Scicos C_2 car dynamics and its controller

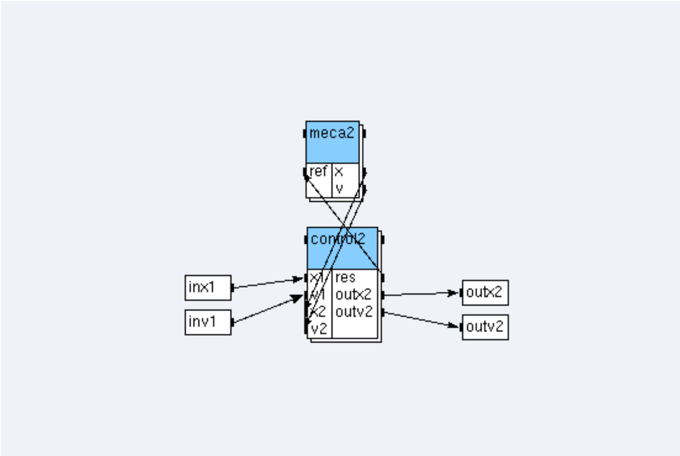

Figure 8.12: SynDEx C_2 car dynamics and its controller

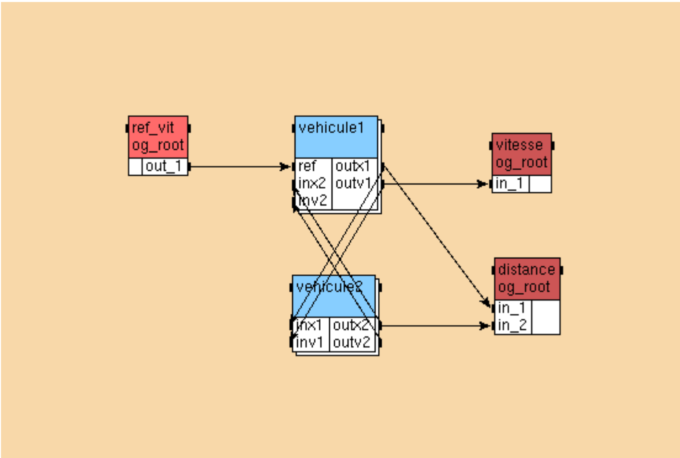

Figure 8.13: SynDEx's main algorithm

Input

In our Scicos application an input is a square wave generator. As a rule, we will simulate a square wave generator by reading values in a text file (named `ref_vitesse.txt`). We will use the `fopen`, the `fclose` and the `fscanf` functions (`stdio.h` library). We will also use assertions (`assert.h` library) to ensure that the opening of a file has been successful.

For the moment, let suppose that it exists an array of `FILE*` (the structure returned by the `fopen` function) called `fd_array` and a variable called `timer` to simulate a pseudo-timer. Our sensor has a parameter called `POSI_ARRAY` to remember the position of the `FILE*` structure in the array.

Now, open the code editor of the `senseur_def` sensor and write the following code in the init phase of the default processor:

```
timer = 0;
fd_array[@PARAM(POSI_ARRAY)] = fopen("ref_vitesse.txt", "r");
assert(fd_array[@PARAM(POSI_ARRAY)] != NULL);
```

In the Scicos application, we have defined the clock period of the square wave generator to the value 5 and the step of discretization *h* to the value 0.001. Thus we need, in the SynDEx application, to send 5000 times the same value. To count, we use the variable `timer`. All the 5000-th times, we read a new value in the file.

Write the following code in the loop phase of the default processor:

```
timer = (timer + 1) % 5000;
if (timer == 1)
fscanf(fd_array[@PARAM(POSI_ARRAY)], "%f\n", &data);
@OUT(out_1)[0] = data;
```

We need to free memory by closing the file. Write the following code in the end phase of the default processor:

```
fclose(fd_array[@PARAM(POSI_ARRAY)]);
```

Speed output

An output saves in a file the values of the system states. Thus, an output has a parameter called `POSI_ARRAY` to remember the position of the array where the stream has been saved. Open the code editor of the `vitesse_def` actuator and write the following code in the init phase of the default processor:

```
fd_array[@PARAM(POSI_ARRAY)] = fopen("actuator_@TEXT(@PARAM(POSI_ARRAY))", "w");
assert(fd_array[@PARAM(POSI_ARRAY)] != NULL);
```

The loop phase, allows to save the values:

```
fprintf(fd_array[@PARAM(POSI_ARRAY)], "%E\n", @IN(in_1)[0]);
```

We need to free the memory by closing the file. Write the following code in the end phase:

```
fclose(fd_array[@PARAM(POSI_ARRAY)]);
```

Distance output

Contrary to the first type of output, this output has two input ports but the `init` and `end` source codes are identical. The loop phase differs. Open the code editor of the `scope_def` actuator and write the following code in the init phase of the default processor:

```
fprintf(fd_array[@PARAM(POSI_ARRAY)], "%E\n", (@IN(in_1)[0] - @IN(in_2)[0]));
```

8.4.5 The `example8_sdc.m4x`

SynDEx's code generation will create the `example8_sdc.m4x` file (as explained in **Example 7**):

```
define('example8_algomain','algomain')
define('algomain','ifelse(
processorType_,processorType_,'ifelse(
 MGC,'INIT','''',
 MGC,'LOOP',''WARNING: empty code for macro $0 in loop phase'',
 MGC,'END','''')')')

define('example8_controleur1_sup','controleur1_sup')
define('controleur1_sup','ifelse(
processorType_,processorType_,'ifelse(
 MGC,'INIT','''',
 MGC,'LOOP',''WARNING: empty code for macro $0 in loop phase'',
 MGC,'END','''')')')

define('example8_controleur2_sup','controleur2_sup')
define('controleur2_sup','ifelse(
processorType_,processorType_,'ifelse(
 MGC,'INIT','''',
 MGC,'LOOP',''WARNING: empty code for macro $0 in loop phase'',
 MGC,'END','''')')')

define('example8_gain_def','gain_def')
define('gain_def','ifelse(
processorType_,processorType_,'ifelse(
 MGC,'INIT','''',
 MGC,'LOOP',''WARNING: empty code for macro $0 in loop phase'',
 MGC,'END','''')')')

define('example8_integrale_discrete_sup','integrale_discrete_sup')
define('integrale_discrete_sup','ifelse(
processorType_,processorType_,'ifelse(
 MGC,'INIT','''',
 MGC,'LOOP',''WARNING: empty code for macro $0 in loop phase'',
 MGC,'END','''')')')

define('example8_scope_def','scope_def')
define('scope_def','ifelse(
processorType_,processorType_,'ifelse(
 MGC,'INIT','''',
 MGC,'LOOP',''WARNING: empty code for macro $0 in loop phase'',
 MGC,'END','''')')')

define('example8_senseur_def','senseur_def')
define('senseur_def','ifelse(
processorType_,processorType_,'ifelse(
 MGC,'INIT','''',
```

```
 MGC,‘LOOP’,‘‘WARNING: empty code for macro $0 in loop phase’’,
 MGC,‘END’,‘’’’)’)’)

define(‘example8_sommateur2_def’,‘sommateur2_def’)
define(‘sommateur2_def’,‘ifelse(
processorType_,processorType_,‘ifelse(
 MGC,‘INIT’,‘’’’,
 MGC,‘LOOP’,‘‘WARNING: empty code for macro $0 in loop phase’’,
 MGC,‘END’,‘’’’)’)’)

define(‘example8_sommateur4_def’,‘sommateur4_def’)
define(‘sommateur4_def’,‘ifelse(
processorType_,processorType_,‘ifelse(
 MGC,‘INIT’,‘’’’,
 MGC,‘LOOP’,‘‘WARNING: empty code for macro $0 in loop phase’’,
 MGC,‘END’,‘’’’)’)’)

define(‘example8_sommateur5_def’,‘sommateur5_def’)
define(‘sommateur5_def’,‘ifelse(
processorType_,processorType_,‘ifelse(
 MGC,‘INIT’,‘’’’,
 MGC,‘LOOP’,‘‘WARNING: empty code for macro $0 in loop phase’’,
 MGC,‘END’,‘’’’)’)’)

define(‘example8_vitesse_def’,‘vitesse_def’)
define(‘vitesse_def’,‘ifelse(
processorType_,processorType_,‘ifelse(
 MGC,‘INIT’,‘’’’,
 MGC,‘LOOP’,‘‘WARNING: empty code for macro $0 in loop phase’’,
 MGC,‘END’,‘’’’)’)’)

define(‘example8_voiture1_sup’,‘voiture1_sup’)
define(‘voiture1_sup’,‘ifelse(
processorType_,processorType_,‘ifelse(
 MGC,‘INIT’,‘’’’,
 MGC,‘LOOP’,‘‘WARNING: empty code for macro $0 in loop phase’’,
 MGC,‘END’,‘’’’)’)’)

define(‘example8_voiture2_sup’,‘voiture2_sup’)
define(‘voiture2_sup’,‘ifelse(
processorType_,processorType_,‘ifelse(
 MGC,‘INIT’,‘’’’,
 MGC,‘LOOP’,‘‘WARNING: empty code for macro $0 in loop phase’’,
 MGC,‘END’,‘’’’)’)’)
```

8.4.6 To handwrite the `example8.m4x` file

You will not can use directly the SynDEx’s generated `example8.m4x` generic file because both the creation of local variable and the call of libraries is missing. After the code generation, you will must handwrite it to obtain the following code:

```
define(‘dnldnl’,‘‘// ’’)
define(‘NOTRACEDEF’)
define(‘NBITERATIONS’,‘‘20000’’)

define(‘BINPWD’, ‘pwd’)
define(‘RSHELL’, ‘ssh’)

define(‘proc_init_’,‘
```

```
 FILE *fd_array[10];
 float data;
 int timer;')

include('example8_sdc.m4x')

divert
divert(-1)
divert''dnl
```

Where the macro proc_init_ allows the local variable declaration to be declared because it inserts its source code between the main function and the operations initialization. Notice that the main loop of the program is defined generically with a loop of NBITERATIONS where NBITERATIONS is initialized with the size of the input file (ref_vitesse.txt). Finally, the call of libraries is inserted after the include of the example8_sdc.m4x file.

8.5 Scicos simulation

Scicos software allows to simulate models in a window (*cf.* figure 8.14), where the values of three states are plotted (ordinate axle) according to the time (abscissa axle). We have:

- the square wave generator drawn at the bottom (red);
- the speed of the first car at the top (black);
- the distance between the two cars seen in the middle of the figure (green).

Thanks the diagram, the system is stable (plots do not grow exponentially) and so it works. We do not continue to ameliorate the controllers job.

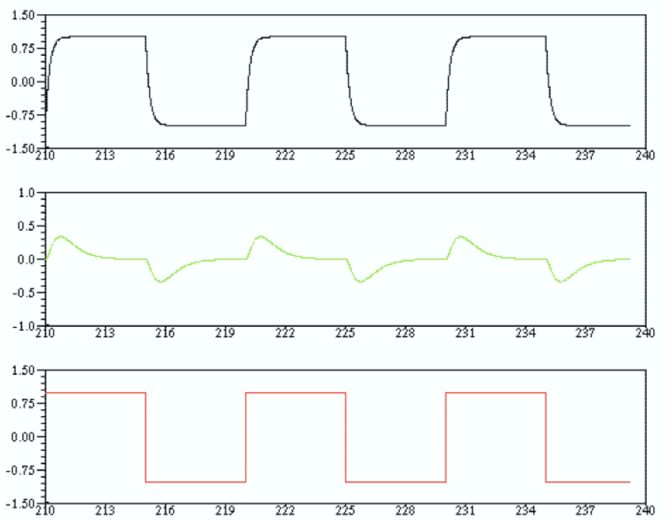

Figure 8.14: Scope window obtained with the values 0; -5; 0; 0; -5 for gains of the C_1 controller and 4; 4; -4; -4 for the C_2 controller.

8.6 SynDEx simulation

8.6.1 In the case of a mono-processor architecture

The architecture

In this subsection, we suppose that the architecture is constituted of an only operator named root:

- create the `U` operator:
  - set the durations with

    ```
    float/delay = 1
    gain_def = 1
    scope_def = 1
    senseur_def = 2
    sommateur2_def = 2
    sommateur4_def = 1
    sommateur5_def = 2
    vitesse_def = 1
    ```

  - choose **init** as code generation phase in which to generate code;
- create the `mono` architecture:
  - add one `U` operator named `root` and define it as main operator,
  - define the `mono` architecture as main.

The adequation and the code generation

First, launch the adequation. It modifies `example8.sdc` and `example8.sdx` files.

Then, generate the executive and applicative files (setting **Code / Generate m4x Files**). It creates `example8.m4`, `example8.m4x`, `example8_sdc.m4x`, and `root.m4` files.

Finally, handwrite the `example8.m4x` file as explained in 8.4.6.

The compilation

First, generate manually a `GNUmakefile` containing:

```
A  = example8
M4 = gm4

export ArchiMacros_Path = ../../../macros/archi_libraries
export AlgoMacros_Path = ../../../macros/algo_libraries
export M4PATH = $(ArchiMacros_Path):$(AlgoMacros_Path)

CFLAGS = -DDEBUG
VPATH = $(M4PATH)

.PHONY: all clean
all : $(A).mk $(A).run
clean ::
 $(RM) $(A).mk *~ *.o *.a *.c actuator_*

$(A).mk : $(A).m4 syndex.m4m U.m4m
 $(M4) $< >$@

root.libs =
p.libs =

include $(A).mk
```

Where:

- `A` is set with the name of your application (here `example8`);
- the path about the generic *.m4? macro-files are stored in the exported shell variables `ArchiMacros_Path` and `AlgoMacros_Path` then grouped into a new exported shell variable named `M4PATH`. The separator `:` means that a *m4* macro-file will be search first in `ArchiMacros_Path` and then in `AlgoMacros_Path` if is not found;
- a mix of this makefile and the informations stored in file named `example8.m4m` will create another makefile called `example8.mk` during the compilation.

Then, copy-paste the `ref_vitesse.txt` file from the **Example 8** folder to yours.
Then, type the command `gmake` in a shell commands interpreter. It creates `actuator_1`, `actuator_2`, `example8.mk`, `root`, `root.c`, and `root.root.o` files:

- the `actuator_1` file contains the speed of the first car;
- the `actuator_2` file contains the distance between the cars.

8.6.2 In the case of a bi-processor architecture

The architecture

In this subsection, we suppose that the architecture is constituted of two operators named `root` and `pc1`, of type `U` and linked with a medium `tcp1` of type `TCP`:

- create the `TCP` medium:
  - set the type with **SAM MultiPoint**,
  - set the durations with `float = 1`;
- modify the `U` operator: set the gates with `TCP x` and `TCP y`;
- create the `biProc` architecture:
  - add one `U` operator named `root` and define it as main operator,
  - add one `U` operator named `pc1`,
  - add one `TCP` medium named `tcp1`,
  - links the medium to the `x` gates of the operators,
  - define the `biProc` architecture as main.

The adequation and the code generation

First, launch the adequation. It modifies `example8.sdc` and `example8.sdx` files.
Then, generate the executive and applicative files (setting **Code / Generate m4x Files**). It creates `example8.m4`, `example8.m4x`, `example8_sdc.m4x`, `root.m4`, and `pc1.m4` files.
Finally, handwrite the `example8.m4x` file as explained in 8.4.6.

The compilation

First, generate manually the `GNUmakefile`, the `example8.m4m`, and the `root.m4x` files:

- the `GNUmakefile` has to be created as explained in 8.6.1. Upgrade it so that the line:

```
$(A).mk : $(A).m4 syndex.m4m U.m4m
```

  is changed by:

```
$(A).mk : $(A).m4 syndex.m4m U.m4m $(A).m4m
```

- create the `example8.m4m` file with this line: `define('pc1_hostname_', HOSTNAME)dnl` where `HOSTNAME` is substituted with the name of your remote station;
- create the `root.m4x` file with this line: `include(example8.m4m)`.

Then, copy-paste the `ref_vitesse.txt` file from the **Example 8** folder to yours.

Then, type the command `gmake` in a shell commands interpreter. It creates `actuator_1`, `actuator_2`, `example8.mk`, `root`, `root.c`, `root.root.o`, `pc1`, `pc1.c`, and `pc1.pc1.o` files:

- the `actuator_1` file contains the speed of the first car;
- the `actuator_2` file contains the distance between the cars.

8.6.3 In the case of a multi-processor architecture

The architecture

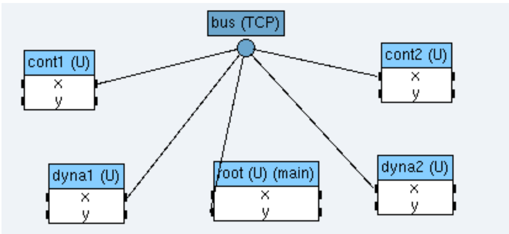

Figure 8.15: L'architecture avec cinq opérateurs.

In this subsection, we suppose that the architecture is constituted of five operators named `root`,`cont1`, `cont2`, `dyna1`, and `dyna2`, of type `U` and linked with a medium `bus` of type `TCP`:

- create the `multi` architecture (*cf.* figure 8.15):
  - add one `U` operator named `root` and define it as main operator,
  - add one `U` operator named `cont1`,
  - add one `U` operator named `cont2`,
  - add one `U` operator named `dyna1`,
  - add one `U` operator named `dyna2`,
  - add one `TCP` medium named `bus`,
  - links the medium to the `x` gates of the operators, except for the `root` one, linked with its `y` gate to the medium,
  - define the `multi` architecture as main;
- create operation groups:
  - create the `og_root` operation group, attach `ref_vit`, `vitesse`, and `distance` to it,
  - create the `og_dyna1` operation group, from the main mode, in the `vehicule1` reference attach `meca1` to it,
  - create the `og_cont1` operation group, from the main mode, in the `vehicule1` reference attach `control1` to it,

- create the `og_dyna2` operation group, from the main mode in the `vehicule2` reference attach `meca2` to it,
- create the `og_cont2` operation group, from the main mode, in the `vehicule2` reference attach `control2` to it;

- create absolute constraints:
  - constrain `og_root` on `root`,
  - constrain `og_cont1` on `cont1`,
  - constrain `og_cont2` on `cont2`,
  - constrain `og_dyna1` on `dyna1`,
  - constrain `og_dyna2` on `dyna2`.

The adequation and the code generation

First, launch the adequation. It modifies `example8.sdc` and `example8.sdx` files.

Then, generate the executive and applicative files (setting **Code / Generate m4x Files**). It creates `example8.m4`, `example8.m4x`, `example8_sdc.m4x`, `root.m4`, `cont1.m4`, `cont2.m4`, `dyna1.m4`, and `dyna2.m4` files.

Finally, handwrite the `example8.m4x` file as explained in 8.4.6.

The compilation

First, generate manually the `Makefile.ocaml`, the `example8.m4m`, the `root.m4x`, the `cont1.m4x`, the `cont2.m4x`, the `dyna1.m4x`, and the `dyna2.m4x` files:

- copy-paste the `Makefile.ocaml` from the **Example 8** folder to yours;
- create the `example8.m4m` file with these lines:

```
define('cont1_hostname_', HOSTNAME)dnl
define('cont2_hostname_', HOSTNAME)dnl
define('dyna1_hostname_', HOSTNAME)dnl
define('dyna2_hostname_', HOSTNAME)dnl
```

  where `HOSTNAME` is substituted with the name of your remote station;

- create the `root.m4x`, `cont1.m4x`, `cont2.m4x`, `dyna1.m4x`, and `dyna2.m4x` files with this line: `include(example8.m4m)`.

Then, copy-paste some files from the **Example 8** folder to yours:

- copy-paste the `example8.ml` file.
- copy-paste the `pa_example8.ml` file.
- copy-paste the `root.sh`, `cont1.sh`, `cont2.sh`, `dyna1.sh`, and `dyna2.sh` files;
- copy-paste the `ref_vitesse.txt` file.

You will probably need to install camlp5 (see at `http://pauillac.inria.fr/~ddr/camlp5/`).

Then, type the command `make -f Makefile.ocaml` in a shell commands interpreter. It creates `example8.cmi`, `example8.o`, `pa_example8.cmi`, and `<processor>.cmi`, `<processor>.cmx`, `<processor>.o`, `<processor>.opt` for each processor.

Finally, launch separatly the five script files. At the end of their execution, the `actuator_1` and `actuator_2` files are created:

- the `actuator_1` file contains the speed of the first car;
- the `actuator_2` file contains the distance between the cars.

From the main window, choose **File / Close**. In the dialog window, click on the **Save** button.

Chapter 9

Example 9: a multiperiodic application

From the main window, choose **File / Save as** and save your ninth application under a new folder of yout tutorial folder (*eg.* `my_example9`) with the name `example9`.

9.1 The main algorithm

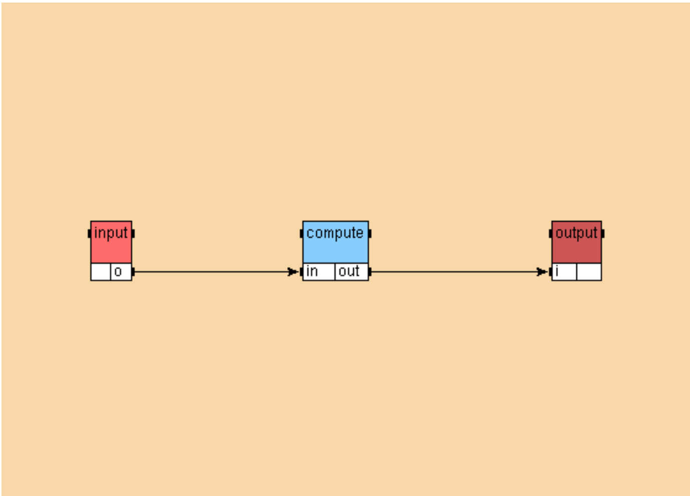

Figure 9.1: Main algorithm of the **Example 9**

Create the main algorithm `basicAlgorithm` (*cf.* figure 9.1) using the library `int` for the operations `input<1>` (`int/input`) and `output<1>` (`int/output`). For the operation `compute`, create a function definition `compute` and create a reference to this definition. Create the dependences between the references. Set the periods to 4 for `input`, 8 for `compute`, and 8 for `output`.

9.2 The main architecture

Open the architecture `monoProc` from the library `u`. Define it as main. The durations for the `U` operator are by default:

```
int/input = 3
Implode_int = 1
compute = 1
int/output = 3
```

In this case, the system is not schedulable.

9.3 A mono-phase schedule

9.3.1 Durations

Modify the durations for the `U` operator:

```
int/input = 1
Implode_int = 1
compute = 1
int/output = 1
```

9.3.2 Adequation

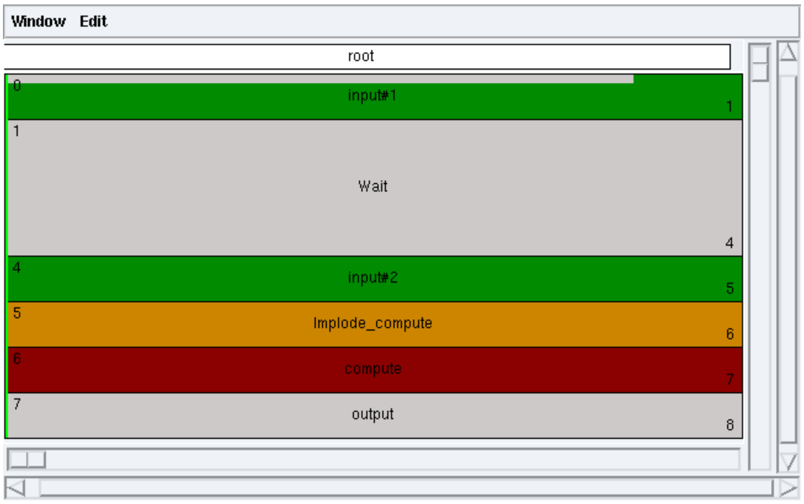

Figure 9.2: A mono-phase schedule

Launch the adequation (**Adequation / Launch Adequation**). Display the schedule (**Adequation / Display Schedule**) (*cf.* figure 9.2).

Wait operation

Notice the new operation added by SynDEx (`Wait`) to respect the period of the `input` operations.

Multiple occurrences

Notice that because of the periods, during a cycle two `input` operations are executed (`input#1` and `input#2`) whereas only one `compute` and one `output` operations are executed.

Implode operation

Notice the new operation added by SynDEx (`Implode_compute`) to provide the data from the `input` operations to the `compute` one.

9.4 A multi-phase schedule

9.4.1 Durations

Modify the durations for the `U` operator:

```
int/input = 1
Implode_int = 1
compute = 2
int/output = 1
```

9.4.2 Adequation

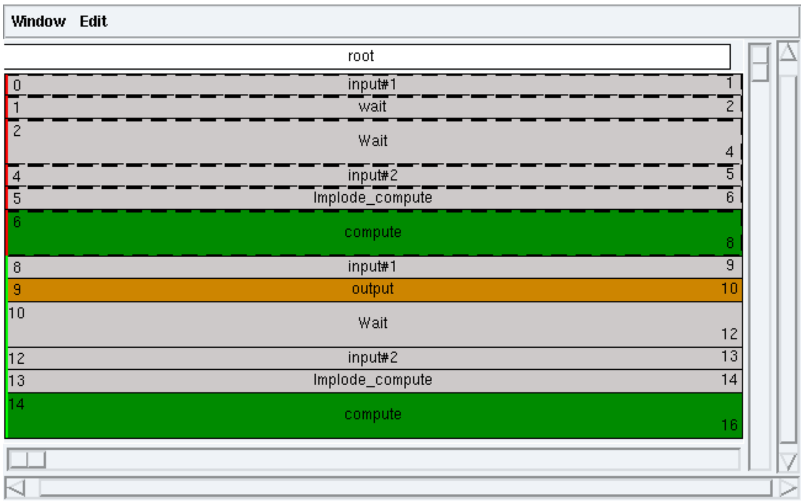

Figure 9.3: A multi-phase schedule

Launch the adequation (**Adequation / Launch Adequation**). Display the schedule (**Adequation / Display Schedule**). The computed schedule has two phases: a transitory phase (red) and a permanent phase (green) (*cf.* figure 9.3).

Transitory phase

The transitory phase is executed only once. It contains the first occurrence of the `input#1` operation, the first occurrence of the `input#2` operation, the first occurrence of the `Implode_compute` operation, and the fist occurrence of the `compute` operation. The `compute` operation provide data consumed by the `output` operation schedule at time 9 in the permanent phase.

Permanent phase

The permanent phase is the one that is executed infinitely. It contains the second occurrence of the `input#1` operation (and its following occurrences). It contains the first occurrence of the `output` operation (and its following occurrences).