Interactive Programming of Reactive Systems

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Abstract

ReactiveML is a synchronous reactive extension of the general purpose programming language OCaml. It allows to program reactive systems such as video games or simulators.
This paper presents `rmltop`, the ReactiveML counterpart of the OCaml toplevel. This toplevel allows a programmer to interactively write ReactiveML programs which are type-checked, compiled and loaded on the fly. The user can then progressively run concurrent processes and observe the interactions between them.
The main strength of `rmltop` is that all valid ReactiveML expressions are accepted in the toplevel with the same semantics as in the compiler. This allows to use the ReactiveML toplevel as a debugger. Furthermore, the interpreted code is as efficient as if it was compiled.
Moreover, a toplevel interpreter being itself a reactive system, another originality of `rmltop` is its own implementation in ReactiveML which makes it relatively light.

Keywords: Reactive Programming, Prototyping, Debugging, Reactive Scripts.

1 Introduction

ReactiveML is a programming language dedicated to the implementation of interactive systems as found in graphical user interfaces, video games or simulation problems. ReactiveML is based on the synchronous reactive model of Frédéric Boussinot [3] embedded in an ML language (here Objective Caml [14]). The synchronous reactive model provides synchronous parallel composition and dynamic features like dynamic creation of processes. ReactiveML is compiled into a purely sequential OCaml code. Native-code or bytecode executables are then generated by the OCaml compiler.

We propose here an interactive mode for ReactiveML in a way similar to the interaction loop (or toplevel) of OCaml. In this mode, ReactiveML programs can be defined and executed in an interactive manner. The toplevel (`rmltop`) reads ReactiveML phrases on the standard input, compiles them and executes them. Moreover it provides control directives to run a process, suspend the execution of

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the running processes, execute only the next n reactions or resume the execution. Those directives are directly launched in the toplevel. Additionally, the suspension directive can be launched by processes. It allows to program an *observer* that decides to suspend the execution when a certain condition is verified.

All these features make this execution mode a convenient tool for prototyping reactive behaviors. Contrary to sequential programs, reactive programs continuously interact with their environment. Modifying and programming the environment during the execution of the system is thus useful for testing and debugging. It can also help for teaching purposes: the interaction with the processes behaviors improves the understanding of the reactive model.

The ReactiveML toplevel is also useful to study dynamic reconfiguration of reactive programs. The addition of new processes during the execution can be used as a basic element to build a framework for programming reconfigurable applications. Icobjs [5,10], a graphical programming language based on the reactive model, is an example of such a framework.

`rmltop` is included in the distribution of ReactiveML which is available at: `http://rml.inria.fr`.

Any ReactiveML program accepted by the compiler can be executed in the toplevel. Moreover, the execution is as efficient as the compiled version of the program. The ReactiveML toplevel does not interpret programs. It compiles them into bytecode and executes the bytecode.

The implementation of `rmltop` reuses the ReactiveML compiler. It has two consequences: (1) the implementation is small (about 500 source lines of code) and (2) the semantics of the two execution modes (the compiled mode and the interactive mode) are the same by construction. Moreover, a toplevel interpreter being itself a reactive system, one originality of `rmltop` is to be itself implemented in ReactiveML, making its implementation relatively elegant.

The ReactiveML toplevel is based on the original idea of Reactive Scripts [8] by Frédéric Boussinot and Laurent Hazard. Reactive Scripts is a scripting language first built on ReactiveC [6] and Tcl-Tk. Then Jean-Ferdy Susini proposed a new implementation [18] of this language based on Sugar-Cubes [9] and Java. We will discuss the differences between our approach and Reactive Scripts in Section 4.1.

In the following, we first present the use of `rmltop` in Section 2 through a collection of examples. Section 3 describes its implementation. Section 4 is devoted to a discussion and we conclude in Section 5.

2 Interactive Programming in ReactiveML

ReactiveML is an extension of OCaml[3] such that we can define data types and functions like in OCaml. Moreover, it provides synchronous reactive processes as functions that can be executed through several instants.

The body of a process mixes OCaml code with reactive constructs *à la* Esterel. Programs can be composed in parallel (`||` operator) and communication is based

[3] The current implementation of ReactiveML does not support objects, labels, polymorphic variants and functors.

```
louis@machiavel> rmltop
       ReactiveML version 1.06.07
       Objective Caml version 3.10.1

# signal s;;
val s : ('_a, '_a list) event
val s : ('_a, '_a list) Implem.Lco_ctrl_tree_record.event = <abstr>
# let process p =
    await s;
    print_endline "Present";;
val p : unit process
val p : unit Implem.Lco_ctrl_tree_record.process = <fun>
# #run p;;
# emit s ();;
- : unit = ()
Present
```

Fig. 1. An `rmltop` session.

on broadcast with associated construct to emit signals (`emit`), test their presence (`present`, `await`), etc.

Notice that contrary to Esterel, ReactiveML follows the Boussinot semantics: the reaction to absence of signals is delayed. This restriction ensures that programs are causal by construction (a signal cannot be present and absent during an instant). In the following, we assume that the reader has some notions of the OCaml language [14] and of synchronous programming [1]. We will not present the ReactiveML language in details here, but only what is necessary for the following. For more details on ReactiveML the reader can refer to [15,16].

2.1 First ReactiveML *Session*

An `rmltop` session is a succession of definitions (types, values, processes ...), executions of directives and ReactiveML instantaneous expressions. An example of session is given Fig. 1. It is launched by the `rmltop` command. The session begins with the following line:

```
# signal s;;
```

that declares a global signal `s` (the character `#` is the prompt). This declaration is followed by two pieces of information given by the toplevel: (1) the type inferred by the ReactiveML compiler for this declaration and (2) the type of the corresponding OCaml code.

Next, we define a process `p` (introduced by the keyword `process`) that prints `Present` when the signal `s` is emitted:

```
# let process p =
    await s;
    print_endline "Present";;
```

Then an instance of `p` is executed by means of the `#run` directive (directives begin with a `#` character):

```
# #run p;;
```

The instance of `p` now runs in background and the control is returned to the user.

Finally the signal `s` is emitted in the reactive machine:

```
# emit s ();;
```

Hence, the instance of the `p` process that is awaiting `s` reacts and the message `Present` is printed.

The main directive of `rmltop` is `#run`. This directive executes the process given as parameter. The directive `#exec` is derived from `#run`. It executes a reactive expression. It is implemented as follows: `#exec e;;` ≡ `#run (process e);;`

2.2 A Complete Example

We illustrate the use of `rmltop` on the so-called n-body problem. The n-body problem is the simulation of planets that obey the gravity laws of Newton. The entire code and a video presentation are available at http://rml.inria.fr/slap08.

We first define the data type of planets.

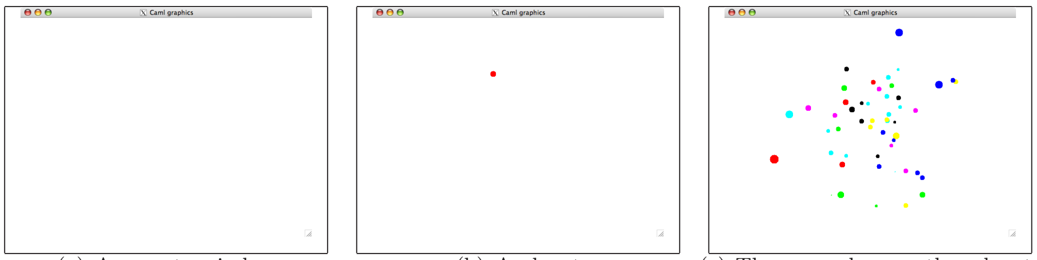
```
# type planet =
    { id : int;
      mass : float;
      pos : float * float * float;
      speed : float * float * float; } ;;
```

We can notice here that we benefit from the expressiveness of OCaml data types.

We now declare some useful constants and functions like the gravitational constant, the integration step and a function that creates a random speed value. The `random_speed` function uses the `Random` module of the OCaml standard library.

```
# let g = 6.67;;
val g : float
val g : float = 6.67
# let dt = 0.1;;
val dt : float
val dt : float = 0.1
#let random_speed () =
    ((Random.float 100.0) -. 50.0,
     (Random.float 100.0) -. 50.0,
     (Random.float 100.0) -. 50.0)
;;
val random_speed : unit -> float * float * float
val random_speed : unit -> float * float * float = <fun>
```

Other pure OCaml functions are then defined but not detailed here. A global signal `env` is declared. This signal will gather the positions of all the planets in a list.



(a) An empty window (b) A planet (c) The sun and some other planets

Fig. 2. Screenshots of the `window` process.

```
# signal env;;
val env : ('_a, '_a list) event
val env : ('_a, '_a list) Implem.Lco_ctrl_tree_record.event = <abstr>
```

The `env` signal has type `('_a, '_a list) event` where `'_a` will be instantiated with the type `planet`. It means that the values emitted on this signal must be of type `planet` and the value associated to the signal has type `planet list`.

The signal `env` is then used for display by process `window`.

```
# let process window =
    Graphics.open_graph "";
    Graphics.auto_synchronize false;
    loop
      await env (all) in update_display all
    end ;;
val window : unit process
val window : unit Implem.Lco_ctrl_tree_record.process = <fun>
```

This process first initializes the graphical window and then enters into an infinite loop. The behavior of the loop is the following. The expression "`await env (all) in ...`" waits for the emission of the `env` signal, and binds `all` to the value associated to `env`. Then, at the instant following the emission of the signal, the body of `await/in` construct is executed. The `update_display` function uses the `all` value to draw all planets. Notice that there is no instantaneous loop since the `await/in` expression takes at least one instant.

This process is then executed by writing:

```
# #run window;;
```

Its effect is to open an empty OCaml graphics window (Fig 2(a)). Since the `env` signal is not emitted, the `window` process is stuck on its `await` expression.

Now the behavior of a planet is given by:

```
# let random_planet () = ... ;;
val random_planet : unit -> planet
val random_planet : unit -> planet = <fun>
# let compute_pos p all = ... ;;
val compute_pos : planet -> planet list -> planet
val compute_pos : planet -> planet list -> planet = <fun>
```

```
# let process planet =
    let me = ref (random_planet()) in
    loop
      emit env !me;
      await env (all) in
      me := compute_pos !me all
    end ;;
val planet : unit process
val planet : unit Implem.Lco_ctrl_tree_record.process = <fun>
```

The process `planet` uses two previously defined functions: (1) `random_planet` that creates a new planet at a random position with a random speed and (2) `compute_pos` that given a planet `p` and a list of planets `all` computes the new position of the planet `p` submitted to the attraction of all other planets.

The process `planet` creates a new random planet and enters in an infinite repetition of three parts. First it emits the position of the planet on the signal `env` to communicate it to other planets. Then it waits for the value of this signal (the list of all planets) which is available at the next instant. Finally, it uses this information to compute the new position of the planet. To summarize, all the planets emit their position on the signal `env`. It is used by the `window` process for display and by each planet to compute its position at the next instant. We now run the process `planet`.

```
# #run planet;;
```

It launches the `planet` process in background, in parallel with already running processes (here `window`). It creates a new planet that appears on the graphical window (Fig. 2(b)). As it is the unique body of the system, its trajectory is not modified and it goes out of the window. We can run several times the `planet` process to create other planets.

```
# #run planet;;
# #run planet;;
```

As the planets are of non null weights their trajectories are modified by the interaction with the other ones, but they still go out of the window. Nevertheless, as the value of the signal `env` is the list of the planets, we can verify that all created planets are still running by observing the value of `env`. To observe the value of the signal `env` in a stable state, we first use the `#suspend` directive. It asks for the suspension of the simulation at the beginning of the next instant.

```
# #suspend;;
```

Planets stop their movement. We can now observe the environment using the ReactiveML `pre` operator.

```
# pre env;;
 - : bool = true
```

The evaluation of expression `pre env` returns the status (emitted or not) of signal `env` at the preceding instant. `pre` can also be used to ask for the value of the signal:

```
# pre ?env;;
  - : planet list =
[{id = 1; mass = 1.;
  pos = (25486.668, -30490.001, -3332.7650);
  speed = (27.458270, -32.814312, -3.5462074)};
 {id = 2; mass = 1.;
  pos = (-17667.938, 18421.838, -12995.214);
  speed = (-34.721283, 35.976223, -25.585873)};
 {id = 3; mass = 1.;
  pos = (-5691.3338, 8876.0819, 6907.2694);
  speed = (-17.164963, 26.688011, 20.773542)}]
```

We can observe that it is indeed a list of three planets, and we can consult the values of the different fields. Note that it is not possible to ask for the status or the value of a signal at the current instant: it's an intrinsic feature of the reactive model.

When the execution is suspended, we can call another useful directive: the `#step` directive. It executes one instant of the system.

```
# #run planet;;
# #step;;
# pre ?env;;
 - : planet list =
[{id = 1; mass = 1.;
  pos = (25492.159, -30496.564, -3333.4747);
  speed = (27.458270, -32.814312, -3.5462149)};
 {id = 2; mass = 1.;
  pos = (-17674.882, 18429.033, -13000.331);
  speed = (-34.721283, 35.976220, -25.585873)};
 {id = 3; mass = 1.;
  pos = (-5694.7668, 8881.4195, 6911.4241);
  speed = (-17.164961, 26.688011, 20.773546)};
 {id = 4; mass = 1.;
  pos = (-44.769087, -83.553279, -76.555396);
  speed = (12.309124, -15.532798, 12.909834)}]
```

Here we run a new planet, then we execute one step of the system and we ask for the `env` value. We can notice that a fourth planet has indeed been added to the list, and the other ones have moved.

The directives `#suspend` and `#step` are helpful for debugging and understanding reactive systems. Notice that the directive `#step` n is also available. It allows to execute n instants of the system.

The directive `#resume` goes back to the sampled mode.

```
# #resume;;
```

We now define a new process `sun` that creates a planet much heavier than the other ones and which does not move:

```
# let process sun =
    let me =
      { id = 0;
        mass = 30000.0;
        pos = (0.0, 0.0, 0.0);
        speed = (0.0, 0.0, 0.0) }
    in
    loop
      emit env me;
      pause
    end ;;
val sun : unit process
val sun : unit Implem.Lco_ctrl_tree_record.process = <fun>
```

Its behavior is to make its position available to the planets by emitting it at each instant on the `env` signal and to wait for the following instant.

If we run the `sun` process, a sun appears on the graphical window.

```
# #run sun;;
# #exec (for i = 1 to 50 dopar run planet done);;
```

To add several planets at the same time, we use the primitive `#exec` that allows to launch a non-instantaneous ReactiveML expression. The expression we execute here is a loop that runs 50 planets in parallel (`for/dopar` construct). We can observe that each newly added planet is attracted by the sun and turns around it (Fig. 2(c)).

We now want to observe eclipses.

```
# let eclipse { pos = (x, y, z) } =
    abs_float x < 10. && abs_float y < 10. && z > 0.;;
val eclipse : planet -> bool
val eclipse : planet -> bool = <fun>
```

The boolean function `eclipse` takes a planet as argument and tests if it is in front of the sun. We can test if at least a planet was at an eclipse position at the preceding instant by evaluating the following expression:

```
# List.exists eclipse (pre ?env);;
- : bool = false
```

It applies the `exist` function of the `List` module of OCaml to the planets environment. The returned value is false, so there was no eclipse when the phrase has been evaluated.

It would be very difficult to suspend by hand the simulation exactly when a planet is in front of the sun, and tedious to execute the system step by step until an eclipse occurs. Fortunately, the `#suspend` directive can be launched by processes. We can thus define a process `eclipse_observer` that suspends the simulation if a planet is at an eclipse position.

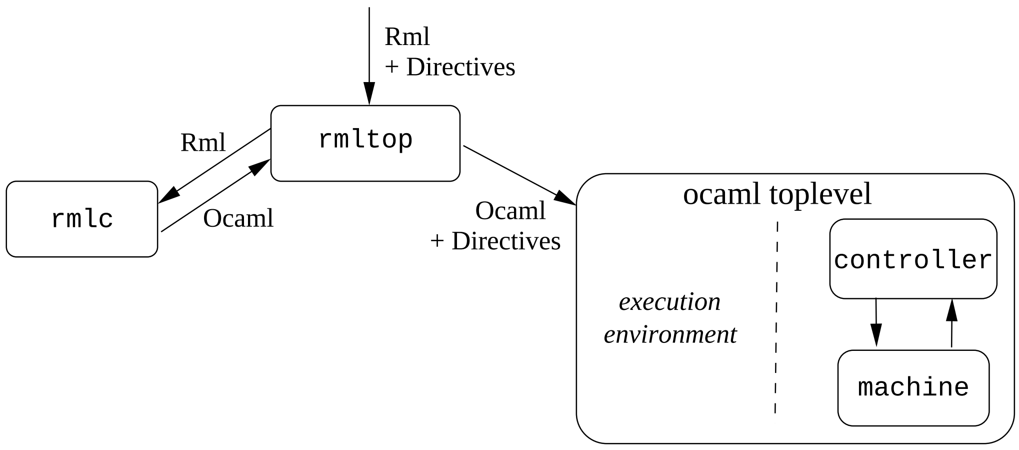


Fig. 3. Structure of the implementation of the ReactiveML interactive mode.

```
# let process eclipse_observer =
    loop
      await env (all) in
      if List.exists eclipse all then #suspend
    end;;
val eclipse_observer : unit process
val eclipse_observer : unit Implem.Lco_ctrl_tree_record.process = <fun>
# #run eclipse_observer;;
```

As soon as we run the eclipse observer, each time an eclipse occurs, the simulation is suspended.

The process `eclipse_observer` is a synchronous observer. It can observe dynamic properties without modifying the behavior of the system. The combination of this feature with the possibility to suspend the simulation allows to set semantic breakpoints. These breakpoints are defined by arbitrarily complex conditions expressed in the language itself. This is an original and powerful way to suspend the execution of a program.

We have shown through this example of the n-body problem that the ReactiveML toplevel is not only useful to understand a reactive system, but also to test and debug it. We are now going to describe its implementation.

3 Implementation

The ReactiveML interactive mode consists of three parts: (1) a toplevel that reads the source code to build the execution environment and record the directives, (2) a reactive machine that evaluates processes launched by the `#run` directive and (3) a controller that supervises the execution of the reactive machine with respect to the other directives (`#suspend`, `#resume` and `#step`).

3.1 The Toplevel

As the ReactiveML language is compiled into OCaml, it is natural that the ReactiveML toplevel uses the OCaml toplevel to execute compiled ReactiveML phrases and dynamically builds an execution environment.

The structure of the implementation is presented Fig. 3. A Unix process `rmltop` coordinates the parallel execution of a ReactiveML compiler `rmlc` and an OCaml toplevel `ocaml`.

- The ReactiveML compiler runs in an interactive mode. ReactiveML phrases are given as input to the `rmlc` compiler. The compiler returns the corresponding OCaml code.
- The compiled code is then sent to the OCaml toplevel that executes it. This execution builds an environment that contains the definition of the functions and processes.

The reactive machine and its controller run in a separate thread of the OCaml toplevel. This software architecture allows the reactive machine to share the environment of the OCaml toplevel. The communication between the two threads is made through shared memory. So we use a lock `Rmltop_global.mutex` to prevent data races. This lock is taken during the execution of ReactiveML phrases (compiled into OCaml).

The execution of a directive sets a global reference in the execution environment. The controller can then access the reference to treat the directive. There is one reference by directive, defined in the module `Rmltop_global`. Let us now present the reactive machine.

3.2 The Reactive Machine

The reactive machine executes the processes launched by the `#run` directive. It is implemented by the function `Rmltop_reactive_machine.rml_react` that computes the reaction of one instant of the machine.

```
val rml_react: unit Rmltop_global.rml_process list -> unit
```

It takes as argument a list of processes to execute in parallel with the processes that are already running in the machine. This function is the interface between the reactive machine and the controller.

The body of `rml_react` takes the lock `Rmltop_global.mutex` during its execution. It ensures that it is not executed in parallel with a ReactiveML phrase in the toplevel.

3.3 The Reactive Machine Controller

The controller makes the reactive machine react: it controls when the machine must compute a new instant. In particular, the controller interprets the following directives: `#suspend`, `#resume` and `#step`.

As shown in [12], the control of the execution of a reactive program is itself a reactive program. Thus, the control of the reactive machine can be programmed

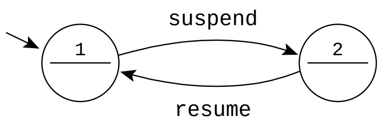


Fig. 4. `machine_controller` automaton.

by a process written in ReactiveML. The core of the controller is a process `machine_controller`. It determines when the reactive machine must compute a new instant. It is composed of two modes : (1) the sampled mode and (2) the step by step mode. It must switch from the first one to the second one when the signal `suspend` is emitted, and from the second one to the first one when `resume` is emitted. When the machine is in the second mode, if the signal `step` is emitted, then a fix number of instants (given by the value associated to `step`) is computed. This computation can be interrupted if the signal `suspend` is emitted.

```
let process sampled =
  loop Rmltop_reactive_machine.rml_react(get_to_run()); pause end

let process step_by_step =
  loop
    await step(n) in
    do
      for i = 1 to n do
        Rmltop_reactive_machine.rml_react(get_to_run()); pause
      done
    until suspend done
  end

let process machine_controller =
  loop
    do run sampled until suspend done;
    do run step_by_step until resume done
  end
```

The process `machine_controller` implements the two states Moore automaton of Fig. 4. The expression `do` e `until` s `done` executes its body (e) until signal s is present. The first `do/until` is the first state, and the second `do/until` is the second one. The condition to go from the first state to the second one is the presence of signal `suspend`. Respectively, the condition to go from the second state to the first one is the presence of signal `resume`. Let's now detail the code of each state.

In the sampled mode, an infinite loop periodically calls the reaction function of the machine.[4] In the step by step mode, each time the signal `step` is emitted with the value `n`, `n` instants of the reactive machine are executed. The `do/until` interrupts this sequence of reactions if the signal `suspend` is emitted.

The controller is also in charge of the translation of directives into ReactiveML signals. We have seen in Section 3.1 that the reactive machine and the controller

[4] The function `get_to_run` returns the list of processes to add to the machine and resets the list.

communicate through shared variables (`suspend`, `resume` and `step`) defined in the `Rml_global` module. The controller monitors these global variables and emits the corresponding signal when the status of a variable changes. This behavior is implemented by the following `generate_signals` process.

```
let ref_to_sig ref s =
  match !ref with
  | None -> ()
  | Some v -> ref := None; emit s v

let process generate_signals =
  loop
    Mutex.lock Rmltop_global.global_mutex;
    ref_to_sig Rmltop_global.suspend suspend;
    ref_to_sig Rmltop_global.resume resume;
    ref_to_sig Rmltop_global.step step;
    Mutex.unlock Rmltop_global.global_mutex;
    pause;
  end
```

Finally, the behavior of the controller is to execute the two processes `machine_controller` and `generate_signals` in parallel.

```
let process controller = run machine_controller || run generate_signals
```

3.4 Conclusion

Due to the software architecture of `rmltop`, any valid ReactiveML expression is accepted in the toplevel and has the same semantics and efficiency as the compiled version. Indeed, the same ReactiveML compiler is used for the two versions of the language and the OCaml toplevel is as efficient as the bytecode compiler. Moreover this software architecture results in a light implementation.

4 Discussions

4.1 Related Works

First, we can remark that it is not possible to implement a reactive toplevel based on the semantics of Esterel. In this model, processes cannot be dynamically added to a running program because causality loops may appear when two expressions are composed in parallel. For example, in the following expression, even if each `present` expression is causal, the parallel composition of the two is not causal.

```
signal s1, s2 in
present s1 then emit s2 else ()
|| present s2 then () else emit s1
```

Here, with Esterel semantics, if we suppose that `s1` is absent we can deduce that it is emitted in the *same* instant. If we suppose that it is present, we can deduce that it is not emitted. Hence, this program is absurd.

With ReactiveML semantics, if we suppose that `s1` is absent then we can deduce that it will be emitted at the *next* instant: there is no causality loop. With the reactive model of Boussinot, all programs are causal by construction. So, contrary to Esterel, it is always possible to add a process to a running machine.

Reactive Scripts [8,18] is a scripting language based on the reactive model and mixed with the Reactive Object Model [4]. It provides some powerful features like freezing an object such that it can be serialized and migrate to another reactive machine.

Reactive Scripts is implemented as "macros" that are expanded into another reactive language (ReactiveC or SugarCubes) which is then interpreted. Conversely, ReactiveML has a language approach in which programs are typed and compiled. It allows to define specific type systems and optimisations and provides a more efficient implementation.

Another advantage of the ReactiveML toplevel is that it accepts as input the whole ReactiveML language, whereas Reactive Scripts is less expressive than ReactiveC and SugarCubes. It imposes some limitations on the host language.

4.2 Dynamic Reconfiguration

The combination of the reactive model with the ability to dynamically define and add new processes provides good basic elements to study dynamic reconfiguration of reactive systems. For example, it is easy to extend the ReactiveML toplevel such that each process *p* launched by the `#run (killable` *p*`)` command can be killed by the emission of its identifier on a `kill` signal.

```
# let process killable p =
    let id = gen_id () in print_endline ("["^(string_of_int id)^"]");
    signal kill_me in
    do
      run p; emit kill_me
      || loop await kill(ids) in if List.mem id ids then emit kill_me end
    until kill_me done;;
val killable : 'a process -> unit process
val killable :
  'a Implem.Lco_ctrl_tree_record.process ->
  unit Implem.Lco_ctrl_tree_record.process = <fun>
```

The `killable` process is a higher order process. It associates a fresh identifier to `p` using the `gen_id` function and prints it such that the user can know it. Then the body of the process executes `p` under the supervision of a `kill_me` signal: the presence of this signal interrupts the execution. `kill_me` is emitted when the identifier of the process belongs to the list of processes to kill (the value associated to `kill`) or when the execution of `p` is terminated.

In a same way, it is for example possible to define a kind of `icobj` combinator that automatically provides the possibility to suspend and resume a process (and only this one), to add a process inside a running `icobj`, etc. A strength of ReactiveML is polymorphism and higher order that allow to easily program such combinators.

Note that dynamic reconfiguration of reactive systems does not only consist in modifying the behavior but also in modifying data types. For this aspect of reconfiguration, ReactiveML does not provides any facilities. In particular, it is not possible to change during the execution the type of a signal but this feature ensures the type safety of the system.

4.3 Language Extension

The implementation of `rmltop` has highlighted an extension of the ReactiveML language that should be interesting to consider.

To implement the communication between the OCaml toplevel and the controller we had to use shared memory and a mutex. Moreover, the process `generate_signals` had to do active waiting. Thus it would be interesting to have asynchronous tasks.

We are currently working on an extension of ReactiveML with asynchronous concurrent constructs based on the join-calculus [11] similar to the ones of JoCaml [13]. With this extension, a function `new_cell` that creates a one place buffer could be written as follows:

```
let new_cell () =
  def state (_) & set(x) = state(Some x) & reply () to set
   or state (Some x) & get() = state(None) & reply x to get in
  spawn (state None);
  (set, get)
val new_cell : ('a -> unit process, unit -> 'a process)
```

The body of the function contains a join-definition (`def/in`) that introduces three channels (`state`, `set` and `get`). This join-definition is made of two reaction rules. The first one defines the behavior of `set`: it updates the state of the buffer. The second one defines the behavior of `get`: it returns the value contained in the buffer. Notice that a call to `get` is blocked until the value on the `state` channel matches the pattern `Some x`. The expression `spawn (state None)` initializes the state of the buffer.

For example, this buffer can be used to communicate the value of `#step` directive as follows:

```
let set_step, get_step = new_cell()
let process generate_step =
  loop let n = run (get_step ()) in emit step n ; pause end
```

The work on this extension is related with some other language like Loft [7], Fair Threads [17] or ULM [2].

5 Conclusion

We have presented `rmltop`, an interactive mode for the ReactiveML language. It can be helpful to design and debug reactive systems and for teaching purposes.

It provides a way to execute a program in a sampled mode or step by step and to dynamically modify the behavior of a system. An originality of this toplevel lies in the fact that it is itself coded in ReactiveML. It results in a light and elegant code, that could be even better if ReactiveML would provide asynchronous tasks. This gives a good motivation to add such a feature to the ReactiveML language.

Acknowledgements

We would like to thank Jean-Ferdy Susini for motivating us in taking advantage of the OCaml toplevel to implement `rmltop`, and Marc Pouzet for his conclusive ideas of improvement. We also thank the referees for their useful comments.

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