Proposal for a Dynamic Synchronous Language*

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Abstract

We propose a new scripting language called DSL based on the synchronous/reactive model. In DSL, systems are composed of several sites executed asynchronously, and each site is running scripts in a synchronous parallel way. Scripts may call functions that are considered in an abstract way: their effect on the memory is not considered, but only their “orchestration” i.e. the organisation of their calls in time and in place (the site where they are called). The mapping of sites onto cores allows one to benefit from multicore architectures. Two properties are assumed by DSL: reactivity of sites and absence of interferences between scripts run by distinct sites. We consider several variants of DSL. In the first variant, functions are defined in FunLoft. In the second variant of DSL, functions are defined in ReactiveML and the JoCaml system is used for asynchronous inter-sites communications. The third variant is based on SugarCubes which is a Java based framework for reactive programming. Finally, in the fourth variant, functions are defined in Scheme/Bigloo.

1 Introduction

Synchronous programming [6] simplifies concurrency, compared to standard approaches based on the exclusive use of the classic model of threads (pthreads or Java threads). The simplification basically results from a cleaner and simpler semantics, which reduces the number of possible interleavings in parallel computations. However, standard synchronous languages introduce specific issues (namely, non-termination of instants) and have major difficulties to cope with dynamic creation (of threads, components, or signals); moreover they are generally not able to fully benefit from real parallelism, as that provided by multicore machines. We propose a new synchronous language, called DSL (for Dynamic Synchronous Language), which addresses the above issues in the following way:

- We use the reactive variant [4] of the synchronous approach, which is able to express dynamic creation; basically, in this variant “causality cycles” are eliminated “by construction”, by forbidding immediate reaction to absence. Several related proposals are based on this variant (e.g. Reactive-C [9], SugarCubes [14], ReactiveML [17]).

- We introduce the notion of site, for combining synchronous and asynchronous aspects of system decompositions into a unique framework. This combination is inspired by the FairThreads model [10] which mixes cooperative and preemptive threads. Sites can be run by dedicated cores, thus giving a way to fully exploit multicore architectures.

DSL is designed with a simple formal semantics, describing without ambiguity how the system evolves.
Our approach is an alternative to the use of locks for memory protection in a classic threading context. We claim that our proposal makes both semantics and programming easier.

1.1 Orchestration Model

The computing model we consider is the following: there are $N$ sites, each of them being composed of two levels, the orchestration level and the host level. The sites are completely autonomous and are run asynchronously (possibly on different processing resources).

At the orchestration level, each site runs a script which is fundamentally parallel. At that level, inputs are:

- new scripts dropped by the other sites, by the external world, or by the host level of the site; these new scripts are put in parallel with the one currently executed by the site; events are input as simple scripts generating them;

- boolean values coming from the host level and used by if instructions;

- integer values coming from the host level and used by repeat statement.

The outputs of the orchestration level are:

- new scripts sent to other sites;

- calls of functions belonging to the host level of the site. Functions are treated in an abstract way: we do not consider their effect on the memory but only their “orchestration” i.e. the organisation of their calls in time and in place (the site where they are called).

Scripts run by the same site synchronise by means of local events which are broadcast in the whole site. Two properties are assumed in DSL: reactivity of sites, and absence of interferences between sites (i.e. sites do not share instants, nor memory, nor events). These two properties of sites allow them to be mapped on distinct cores while preserving the semantics, and to therefore benefit from multicore architectures.

Sites bear an analogy with a musical orchestra: the orchestration level corresponds to the orchestra conductor who leads the host level corresponding to the music players. The conductor follows a music partition (script) and communicates with the musicians by sending them orders and signals (modelled by events) and by listening to the music they play (also modelled by events; imagine events corresponding to sound waves produced by the instruments or by the voices). The conductor must be able to do several things in parallel: she must direct and listen to all instruments at the same time. Of course, as needed by any orchestra, a common clock is defined by the conductor; in our model, this clock which should be shared by the whole orchestra is given by instants. One can see the presence of several orchestras (sites) playing asynchronously as what happens sometimes in music festivals, when several stages are used independently, possibly simultaneously (of course in this case, the absence of interferences between distinct stages is mandatory: nothing should be shared by distinct sites).

1.2 Variants of DSL

We consider several variants of DSL, depending on the language (which we call the host language) in which functions are expressed.

- In the first variant, the host language is FunLoft [11, 12]. The basic properties of reactivity and of absence of data-races are checked by the FunLoft compiler. In order to insure these properties, the use of functions is restricted (for example functions cannot be stored in memory). As FunLoft does not currently provide any means for code distribution, this feature is not presently available.

- In the second variant of DSL, functions are defined in ReactiveML [17] which is an extension of ML to reactive programming. Higher-order functions can be defined without restriction in this variant of DSL. The JoCaml system [3] is used for asynchronous inter-site communications. Moreover, the ReactiveML variant provides users with the scripting top-level of ReactiveML. The ReactiveML variant does not check the reactivity and interference freeness properties which are thus left to the programmer’s responsibility.

- The third variant is based on SugarCubes [14] which is a Java based framework for reactive programming. Like with the ReactiveML variant, the basic reactivity and data-race freeness properties are not checked. The SugarCubes variant allows one to use the object approach of Java to program functions. Communication
The fourth variant is based on Scheme/Bigloo.

- The fourth variant is based on Scheme/Bigloo [1]. It directly implements the semantic rules. In the current implementation, distribution aspects are not covered but we plan to address them using the Hop [2] system implemented in Scheme/Bigloo.

1.3 Implementations

At the implementation level, each variant of DSL has its own particularities. The most interesting aspect of comparison is how the notion of instant in DSL is reflected in the various host languages.

With ReactiveML and SugarCubes, instants of DSL and instants of the host language are in a direct one-to-one correspondence. Actually, there is no need to introduce any supplementary mechanism to run DSL scripts, which are just directly translated in the host language to be executed. This is possible because the expressivity of these host languages is comparable to that of DSL: actually, each DSL primitive (except drop) has a direct counterpart in them.

Structure of the text

The language is first described informally in Section 2. Then, its formal semantics is given in Section 3. The FunLoft variant of DSL is described in Section 4; the SugarCubes variant is described in Section 5; the ReactiveML variant is described in Section 6; finally, the Scheme/Bigloo variant is described in Section 7. Section 8 contains some experiments with a multicore machine. Related work is considered in Section 9 and a conclusion is given in Section 10. Annex A contains the grammar of DSL. Annex B describes the evaluation of DSL scripts in FunLoft. Annex C describes the evaluation of DSL scripts in ReactiveML.

2 Language Description

A program is composed of several independent sites, each of them executing a script made of parallel components. To add a new script into a site, one puts the script in parallel with the already existing parallel components.

In the current version, DSL does not provide any means to define functions. However, scripts may call functions defined in a “host” language (different variants of DSL correspond to different host languages).

These functions have parameters of basic types only (integer, boolean, string).

Tasks are special functions whose execution is not immediate; actually, execution of a task does not start immediately, but at the next instant; moreover, the execution of a task can last several instants or even never terminate. Tasks are called using a specific keyword (launch). Scripts “orchestrate” the execution of functions and tasks on the various sites that compose a program.

We first present scripts in 2.1, then introduce sites in 2.2 and events in 2.3. The basic properties of DSL are presented in 2.4. Finally, an example which will be used to benchmark implementations is described in 2.5.

2.1 Scripts

Scripts are made of basic instructions whose informal semantics is as follows:

- nothing does nothing
- cooperate terminates the execution for the current instant. Execution resumes at the next instant.
- \( f(v_1, \ldots, v_n) \) calls the function \( f \) with the parameters \( v_1, \ldots, v_n \). Execution starts immediately and is instantaneous. To call a non-existing function is considered as an empty statement.
- launch \( t(v_1, \ldots, v_n) \) launches the task \( t \) with the parameters \( v_1, \ldots, v_n \). Execution takes several (at least, one) instants to terminate, or may even never terminate. To call a non-existing task is considered as an empty statement.
- \( s_1; s_2 \) runs the two scripts \( s_1 \) and \( s_2 \) in sequence.
- \( s_1 || s_2 \) runs the two scripts \( s_1 \) and \( s_2 \) in parallel. The parallel script terminates as soon as both \( s_1 \) and \( s_2 \) are terminated.
- if \( e \) then \( s_1 \) else \( s_2 \) end runs the script corresponding to the result of the evaluation of the boolean expression \( e \).
- loop \( s \) end cyclically runs the script \( s \). Execution of \( s \) is restarted as soon as it terminates, except if it terminates instantly (i.e. in the same instant it is started); in this last case, the loop waits for the next instant to restart \( s \). There is
thus no possibility to get an instantaneous loop
which would cycle for ever during the same instan-
t.

- repeat e do s end runs n times the script s, where
- generate e generates the event e.
- await e blocks execution while the event e is
  not generated. Execution resumes as soon as e
  is generated.
- do s watching e executes the script s while the
  event e is not generated. The execution of s
  is aborted when e is generated. The watching
  instruction terminates normally when s termin-
ates.
- drop s in site adds the script s in the remote
  site site. Execution continues immediately with-
out waiting for the completion of s.

The BNF syntax of scripts is given in Annex A.

2.2 Sites
Sites are asynchronous (i.e., each site is possibly run
by a distinct native thread). On the contrary, scripts
are executed synchronously on a site: they share the
same instants and thus proceed at the same pace.

The drop instruction is the means by which a
script can influence remote sites. Note that, if noth-
ing remains to be done after a drop instruction, one
can see it as a migration to the remote site.

The creation of sites is not specified in the lan-
guage; we suppose that for each script of the form
drop s in site, site always exists and is accessible.

2.3 Events
Events are boolean values that are present or absent
during instants. Events are not shared among sites.
Once an event is generated during an instant, it re-
mains present up to the end of the instant. Events
are automatically reset to absent at the beginning of
each instant. Events considered by the three instruc-
tions generate, await, and watching are created if
they are not already existing on the site of execution.

2.4 Basic Properties
DSL demands that the two following fundamental
properties are valid:
- No site can be prevented from passing to the
  next instant (reactivity property). This means
  that functions and tasks run by a site should
  not use all of the computing power of the site.
- No data-race can occur between scripts, func-
tions and tasks (interference freeness property).

Basically, tasks can be executed in two ways: in
the first way, the task is executed by the site in which
it is launched (the task is said to be linked to the site);
in the second way, a dedicated processing thread is
devoted to the task execution (the task is unlinked).

In all the considered variants of DSL, except the
Scheme/Bigloo variant, linked tasks are executed co-
operatively by sites where instants exist. In these
variants, data-races should only occur between tasks
that are unlinked, or that belong to distinct sites.
In the Scheme/Bigloo variant, tasks are always un-
linked.

In the FunLoft variant, the fundamental proper-
ties are checked by the compiler which verifies that:
- Functions always terminate instantaneously.
- Linked tasks always cooperate.
- Memory can only be shared by functions or
tasks linked to the same site.

In the other variants, the validity of the two fun-
damental properties is left to the programmer.

2.5 Example
We consider a system composed of 3 sites site1,
site2, and site3, and a script supposed to be run
by site1; the script is made of two sub-parts ex-
cuted on site2 and site3. Each sub-part calls the
consume function (which heavily uses the CPU, ac-
cording to the value of its parameter) and then drops
back a script on site1 to signal its termination. The
two events generated upon termination are awaited
in parallel. The code is:

repeat 1000 do
  drop
  print ("0");
  consume (10000000);
drop generate done0 in site1
in site2
||
drop
print ("1");
consume (10000000);
drop generate done1 in site1
in site3
||
await done0
||
await done1
);
cooperate
end

Note that there are similar parts in the code (for example, the two calls to consume). Actually, the DSL language does not give any means to share or parametrize scripts. In this respect, scripts are not very friendly and should thus be produced from some higher-level language; the definition of such a language is not in the scope of the present paper.

The two calls of consume can be executed in real parallelism (for example, on a dual-core machine). It is assumed that no interferences appear between them (for example, resulting from the sharing of a global counter). This assumption is statically verified in the FunLoft variant of DSL, while it is the responsibility of the programmer in the other variants. We shall return on this example later, when implementation is considered.

Remark: the body of a repeat statement is not demanded to be non-instantaneous, unlike the body of a loop statement. Indeed, a repeat script always terminates (provided its body terminates), and thus cannot prevent the other scripts to get the control. In the previous code, the justification for the cooperate is to prevent an instantaneous termination of the repeat if both done0 and done1 are received in the same instant; this is actually possible because of the asynchronous execution of sites.

3 Semantics

We give DSL a semantics expressed with rewriting rules. The semantics is “big step”: one rewriting of a term represents the global execution of the term during one instant (as opposite, a “small step” semantics would describe the various execution steps occurring during the instant).

Evaluation of expressions is considered in 3.1. The (big-step) rewriting of scripts is first described in 3.2; then, fix-points are considered in 3.3; site execution is described in 3.4; three examples are considered in 3.5; finally, three variants of the semantics are analysed in 3.6.

3.1 Expressions

Expressions are either basic values (of type integer, boolean, or string), or calls of functions of the form $f(v_1, \ldots, v_n)$ where $v_i$ are basic values. We adopt the following notation: we write $f(v_1, \ldots, v_n)\uparrow$ if there is no function named $f$ which is defined, or if the call is not well typed; in this case we say that we have a wrong call; we write $f(v_1, \ldots, v_n)\downarrow$ otherwise.

The evaluation of a basic value returns itself. There are two cases for the evaluation of $f(v_1, \ldots, v_n)$:

- if $f(v_1, \ldots, v_n)\uparrow$, the evaluation of the call returns the value of $f$ applied to the list of values $v_i$, where $f$ is the function associated to $f$;
- if $f(v_1, \ldots, v_n)\downarrow$, then the value returned is the default value of the expected (basic) type (0 for integers, false for booleans, and the empty string "" for strings).

The evaluation of the expression $\exp$ returning a value $v$ is noted $\exp \rightarrow v$.

As with functions, we write $t(v_1, \ldots, v_n)\uparrow$ if the task $t$ does not exist or if the call is not well typed, and we write $t(v_1, \ldots, v_n)\downarrow$ otherwise.

3.2 Scripts

The general format of the script semantics is:

$$P \vdash s \rightarrow s', G, D$$

- $P$ is the set of present events; events not belonging to $P$ are absent;
- $s$ is the script which is rewritten;
- $s'$ is the residual script (“what remains to do at the next instant”);
- $G$ is the set of events generated by the rewriting of $s$;
- $D$ is the multiset of dropped scripts of the form site↓u, where site is a site name and u is a script; the union of multiset is noted $\omega$;
- $b$ is a boolean which is true (tt) if $s'$ is terminated and false (ff) otherwise; the boolean conjunction is noted $\land$.

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The semantics of scripts is given by the following rules:

**Nothing**

\[
P \vdash \text{nothing} \xrightarrow{tt} \text{nothing}, \emptyset, \emptyset \tag{1}
\]

**Cooperate**

\[
P \vdash \text{cooperate} \xrightarrow{ff} \text{nothing}, \emptyset, \emptyset \tag{2}
\]

**Drop**

\[
P \vdash \text{drop } s \text{ in site} \xrightarrow{tt} \text{nothing}, \emptyset, \{\text{site} \downarrow s\} \tag{3}
\]

**Sequence**

\[
P \vdash s_1 \xrightarrow{ff} s'_1, G, D \quad P \vdash s_2 \xrightarrow{b} s'_2, G, D
\]

\[
P \vdash s_1; s_2 \xrightarrow{b} s'_2, G_1 \cup G_2, D_1 \uplus D_2 \tag{4}
\]

**Parallel**

\[
P \vdash s_1 \xrightarrow{b} s'_1, G_1, D_1 \quad P \vdash s_2 \xrightarrow{b} s'_2, G_2, D_2
\]

\[
P \vdash s_1 \parallel s_2 \xrightarrow{b \land b_2} s'_1 \parallel s'_2, G_1 \cup G_2, D_1 \uplus D_2 \tag{5}
\]

**Loop**

\[
P \vdash s \parallel \text{cooperate} \xrightarrow{ff} s', G, D
\]

\[
P \vdash \text{loop } s \text{ end} \xrightarrow{ff} s'; \text{loop } s \text{ end}, G, D \tag{7}
\]

**Generate**

\[
P \vdash \text{generate } e \xrightarrow{tt} \text{nothing}, \{e\}, \emptyset \tag{8}
\]

**Await**

\[
e \in P \quad P \vdash \text{await } e \xrightarrow{tt} \text{nothing}, \emptyset, \emptyset \tag{9}
\]

\[
e \notin P \quad P \vdash \text{await } e \xrightarrow{ff} \text{await } e, \emptyset, \emptyset \tag{10}
\]

**Watching**

\[
P \vdash s \xrightarrow{tt} s', G, D
\]

\[
P \vdash \text{do } s \text{ watching } e \xrightarrow{tt} \text{nothing}, G, D
\]

\[
e \in P \quad P \vdash s \xrightarrow{ff} s', G, D \tag{11}
\]

\[
e \notin P \quad P \vdash s \xrightarrow{ff} s', G, D \tag{12}
\]

**Function**

\[
f(v_1, \ldots, v_n) \rightsquigarrow v
\]

\[
P \vdash f(v_1, \ldots, v_n) \xrightarrow{tt} \text{nothing}, \emptyset, \emptyset \tag{14}
\]

\[
\text{Execution of a function call is equivalent to its evaluation; the returned value is of no use, and the call is actually only evaluated for its side-effects (a wrong call does nothing and has no side-effect).}
\]

**Task**

\[
t(v_1, \ldots, v_n) \uparrow
\]

\[
P \vdash \text{launch } t(v_1, \ldots, v_n) \xrightarrow{tt} \text{nothing}, \emptyset, \emptyset \tag{15}
\]

\[
t(v_1, \ldots, v_n) \downarrow
\]

\[
P \vdash \text{launch } t(v_1, \ldots, v_n) \xrightarrow{ff} \text{await } e, \emptyset, \emptyset \tag{16}
\]

Three points should be noted:
• Rule 15 states that a wrong call of a task is equivalent to a nothing statement.

• In rule 16, e is a new event\(^1\) which signals the termination of the launched task; it is automatically generated by the system when the call of \(t\) turns to be completely terminated.

• In case of real preemption, i.e. when rule 12 applies, the waiting for termination is abandoned and the task is not actually started.

Repeat
\[
\begin{align*}
\text{Repeat} & \quad \text{Repeat} \\
\text{exp} & \Rightarrow n \quad P \vdash s_1; \ldots ; s_n \xrightarrow{b} s', G, D \\
\text{P} & \vdash \text{repeat exp do s end} \xrightarrow{b} s', G, D
\end{align*}
\]

Two points should be noted:

• Evaluation of \(\text{exp}\) is performed when the rule is applied, that is at execution time (not at compile time).

• In case \(\text{exp}\) is a wrong function call, \(n\) is equal to 0, and the sequence is equal to nothing\(^2\). The repeat statement is thus in this case equivalent to nothing.

If
\[
\begin{align*}
\text{If} & \quad \text{If} \\
\text{exp} & \Rightarrow \text{tt} \quad P \vdash s_1 \xrightarrow{b} s'_1, G, D \\
\text{P} & \vdash \text{if exp then s1 else s2 end} \xrightarrow{b} s'_1, G, D
\end{align*}
\]

\[
\begin{align*}
\text{exp} & \Rightarrow \text{ff} \quad P \vdash s_2 \xrightarrow{b} s'_2, G, D \\
\text{P} & \vdash \text{if exp then s1 else s2 end} \xrightarrow{b} s'_2, G, D
\end{align*}
\]

Note that if \(\text{exp}\) is a wrong function call, its evaluation returns \(\text{ff}\), and thus \(s_2\) is chosen.

3.3 Least Fix-Point

The execution of scripts is deterministic:

If \(P \vdash s \xrightarrow{b} s_1, G, D_1\) and \(P \vdash s \xrightarrow{b} s_2, G_2, D_2\), then \(s_1 = s_2, G_1 = G_2, D_1 = D_2\), and \(b_1 = b_2\).

Let \(s\) be a script; the determinism property allows one to define the function \(f_s\) which, given a set \(P\) of present events, returns the set \(G\) of events generated by \(s\):

\[
f_s(P) = G\text{ where } P \vdash t \xrightarrow{b} s', G, D
\]

The function \(f_s\) has two main characteristics: it is total and it is increasing. It is total because, for each script and each set of present events, there exists a (unique) rewriting:

\[
\forall s, P, \exists s', G, D, b\quad P \vdash s \xrightarrow{b} s', G, D
\]

The function \(f_s\) is increasing (for the set inclusion order):

\[
\text{if } P_1 \subseteq P_2 \text{ then } f_s(P_1) \subseteq f_s(P_2)
\]

The function \(f_s\) thus has a least fix-point \(\mu f_s\) (Kleene theorem) verifying:

\[
f_s(\mu f_s) = \mu f_s
\]

that is:

\[
\mu f_s \vdash s \xrightarrow{b} s', \mu f_s, D
\]

and:

\[
f_s(Q) = Q\text{ implies } \mu f_s \subseteq Q
\]

We know that the least fix-point \(\mu f_s\) is the limit of the sequence of approximations \(X_0, X_1, \ldots \) defined by:

\[
X_0 = \emptyset \text{ and } X_{n+1} = f_s(X_n)
\]

which is noted:

\[
\mu f_s = \bigcup f_s^n(\emptyset)
\]

Finally, when the value of the least fix-point is not required, we write:

\[
s \Rightarrow s', D
\]

instead of:

\[
\mu f_s \vdash s \xrightarrow{b} s', \mu f_s, D
\]

3.4 Sites

A site is a couple \((\text{site}, s)\) made of a site name \(\text{site}\) and a script \(s\); it is noted \(\text{site: } s\).

A program is a (finite) multiset of sites and of dropped scripts waiting to be incorporated into sites. A program is thus a multiset \(S\) where each element is either a site \(\text{site}_{i: } s_i\) or a dropped script \(\text{site}_{i: } \downarrow s_i\). One supposes that there is at least one site and that all sites have distinct names:

\[
\forall \text{site}_{i: } s_i, \text{site}_{j: } s_j \in S, i \neq j \Rightarrow \text{site}_{i: } \neq \text{site}_{j: }
\]
Note that the same dropped element can appear several times in a program (it is a multiset), as for example in:

\[ \{ \text{site} : \text{nothing}, \text{site} \downarrow f(), \text{site} \downarrow f() \} \]

The execution of a program \( S_0 \) is a sequence of rewritings of the form:

\[ S_0 \mapsto S_1 \mapsto S_2 \mapsto \ldots \]

where the arrow \( \mapsto \) is defined by rules 20, 21, and 22 defined below.

**Site execution**

\[ s \Rightarrow s', D \]

\[ \{ \ldots, \text{site}: s, \ldots \} \mapsto \{ \ldots, \text{site}: s', \ldots \} \cup D \quad (20) \]

The dropped scripts resulting from a site execution are added in the program by rule 20; they are waiting to be absorbed by rule 21 below. In the definition of \( \Rightarrow \), note that the least fix-point is not explicitly built: the semantics is not effective in this respect as it does not indicate how to compute it.

**Absorbtion of dropped scripts**

\[ \{ \ldots, \text{site}: s, \text{site} \downarrow u, \ldots \} \mapsto \{ \ldots, \text{site}: s \parallel u, \ldots \} \quad (21) \]

Rule 21 represents the absorbtion of a dropped script \( u \) by the appropriate site \( \text{site} \): the dropped script is simply put in parallel with the script \( s \) already present in \( \text{site} \).

**Inputs** The dynamic adding of a script \( s \) in the site \( \text{site} \) of a program \( S \) is modelised by:

\[ S \mapsto S \cup \{ \text{site} \downarrow s \} \quad (22) \]

Program inputs are dropped events: the input of the event \( e \) in the site \( \text{site} \) is simply modelised by the rewriting:

\[ S \mapsto S \cup \{ \text{site} \downarrow \text{generate} e \} \]

### 3.5 Examples

We give several examples: the first shows the computation of the semantics by successive approximations; the second illustrates the links between the fix-point semantics and the notion of causality; the third example considers the drop primitive; the fourth considers the relation between the watching and launch instructions; finally, the last example shows the global execution of a program.

#### 3.5.1 Approximations

Let us consider the following script \( s \):

\[ \text{generate} e; \text{await} f \parallel \text{await} c; \text{generate} f \]

Actually, one can prove that:

\[ \{ e, f \} \vdash s \Rightarrow \text{nothing} \parallel \text{nothing}, \{ e, f \}, \emptyset \]

Let us show that this corresponds to the least fix-point \( \mu f_s \) of \( f_s \) (using the previous notations). Let \( X_0 = \emptyset \). One has:

\[ X_0 \vdash s \Rightarrow \text{await} f \parallel \text{await} c; \text{generate} f, \{ e \}, \emptyset \]

Let \( X_1 = \{ e \} \). We have:

\[ X_1 \vdash s \Rightarrow \text{await} f \parallel \text{nothing}, \{ e, f \}, \emptyset \]

Let \( X_2 = \{ e, f \} \). Since:

\[ X_2 \vdash s \Rightarrow \text{nothing} \parallel \text{nothing} \]

we get the result:

\[ \mu f_s = \bigcup f_s^n(\emptyset) = X_2 = \{ e, f \} \]

#### 3.5.2 Minimality

Minimality of fix-points is mandatory to reject “violations of causality”. Indeed, consider the following script \( s = \text{await} e; \text{generate} e \). Two fix-points, \( \{ e \} \) and \( \emptyset \), exist:

1. \( \{ e \} \vdash s \Rightarrow \text{nothing}, \{ e \}, \emptyset \)
2. \( \emptyset \vdash s \Rightarrow s, \emptyset, \emptyset \).

The least fix-point is thus \( \emptyset \). Note that in the first rewriting, the generation of \( e \) “results” from the test of presence of \( e \), and thus does not correspond to any “causal” execution. In a sense, the minimality of fix-points is a way to rule out non-causal executions.
3.5.3 Asynchrony
Let us consider the script:

drop
generate e || await e; print ("ok")
in site1

The message will always be printed, because the dropped script is incorporated in site1 as a whole. This would not be the case with:

drop
generate e
in site1;
drop
await e; print ("ok")
in site1

Indeed, site1 may incorporate the first script and may react before the incorporation of the second script; in this case, the message is not printed because the generation of e is lost.

3.5.4 Task Abortion
Let us consider the immediate preemption of a task launched by the body of a watching statement:

generate e;
do
launch t ()
watching e

If task t does not exist or is incorrectly called, then the global instruction terminates immediately (rules 15 and 11). Otherwise (t exists and is correctly called), the task is not launched by the executive system (last remark, rule 16), and the instruction will terminate at the next instant (rule 12).

3.5.5 Program Input
Let us consider the following program made of a unique site:

\[ S = \{ \text{site}: \text{await} e; \text{print}(msg) \} \]

The only rewriting that can be made is:

\[ S \mapsto S \]

Suppose a new input is given to the program, which becomes \( S' \):

\[ S \mapsto S' = S \cup \{ \text{site} | \text{generate } e \} \]

There are two possible rewritings for \( S' \):

\[ S' \mapsto S' \]

and (rule 21):

\[ S' \mapsto S'' = \{ \text{site}: \text{await } e; \text{print}(msg) \| \text{generate } e \} \]

Now, one can prove that the only possible rewriting of \( S'' \) is:

\[ S'' \mapsto \{ \text{site}: \text{nothing} \} \]

During this rewriting, the function print is called and a message is printed as a side-effect of the call.

3.6 Variants of the semantics
In this section, we discuss 3 aspects of the semantics: instantaneous loops are first considered; then, a variant of the drop instruction is analysed; finally, the watching instruction is discussed.

3.6.1 Instantaneous Loops
The fact that the function \( f_s \) is total basically results from the rule 7 that “fixes” instantaneous loops. Note that without the fix, some loops could have no rewriting at all; this would be for instance the case with the rule:

\[ P \vdash s; \text{loop } s \text{ end} \xrightarrow{b} s', G, D \]

in which the execution of a loop basically means to unfold it. The reactivity property of DSL would thus be lost by using this rule instead of rule 7.

3.6.2 Packed Drop
Let us consider a possible variant of the semantics in which the dropped scripts are grouped by destination. The idea is that, instead of dropping one after the other several scripts destined to the same site, one drops the parallel composition of these scripts, in one unique drop action. This reduces the asynchrony of sites execution and thus makes the reasoning about programs easier. To model this variant, we first define the pack function which takes a multiset of dropped scripts and returns the set which is the compact version of it:

\[ \text{pack}(D) = D \text{ if } \forall d_1 = (\text{site}_1, s_1) \in D, \forall d_2 = (\text{site}_2, s_2) \in D, d_1 \neq d_2 \text{ implies } \text{site}_1 \neq \text{site}_2 \]

### hal-00590420, version 1 - 3 May 2011
• \( \text{pack}(D \cup \{(\text{site}, s_1), (\text{site}, s_2)\}) = \text{pack}(D \cup \{(\text{site}, s_1 \parallel s_2)\}) \)

The site execution rule (20) becomes:

\[
\begin{align*}
\text{s} \Rightarrow s', D & \quad \text{for } s \Rightarrow s', D
\end{align*}
\]

\[
\begin{align*}
\{\ldots, \text{site}: s, \ldots\} & \rightarrow \{\ldots, \text{site}: s', \ldots\} \cup \text{pack}(D)
\end{align*}
\]

Note that the two drop scripts of 3.5.3 become equivalent in this variant of the semantics. To implement the variant, dropped scripts have to be stored, up to the end of the current instant, before being compacted and actually sent to remote sites.

### 3.6.3 Preemption Operator

The basic assumption of the model resides in the couple of rules 12 and 13 which state that the body of a watching instruction is executed in both cases of presence and of absence of \( e \). The alternative proposed by Esterel, called “strong preemption”, corresponds to the two following rules:

\[
\begin{align*}
& e \in P \\
& P \vdash \text{do } s \text{ watching } e \xrightarrow{\text{tt}} \text{nothing, } D, G
\end{align*}
\]

\[
\begin{align*}
& e \notin P \\
& P \vdash s \xrightarrow{\text{b}} s', G, D
\end{align*}
\]

With these rules, the body is immediately executed in absence of \( e \) (rule 13'), and it is not executed at all when \( e \) is present (rule 12'). One thus has an immediate reaction to the absence of \( e \), which introduces “causality cycles” (e.g. do generate \( e \) watching \( e \)). Causality cycles are a major obstacle to the introduction of dynamic creation in Esterel. It is thus clear that strong preemption cannot be, in a way or another, introduced coherently in DSL.

We could have replaced rule 11 by the following:

\[
\begin{align*}
& P \vdash s \xrightarrow{\text{tt}} s', G, D \\
& P \vdash \text{do } s \text{ watching } e \xrightarrow{\text{tt}} \text{nothing, } G, D
\end{align*}
\]

This alternative rule gives a more uniform treatment of the preemption operator that actually would never terminate instantaneously. However, we prefer to keep on rule 11 because it entails the following intuitive invariant: do \( s \) watching \( e \) is strictly equivalent to \( t \) if \( e \) is never present. This invariant would be violated with the alternative rule 11'.

### 4 FunLoft Variant

In the FunLoft variant of DSL, a script is first translated into an instruction of the type \text{instruction}_t defined in FunLoft, before being compiled by the FunLoft compiler. The definition of FunLoft insures the reactivity and memory protection properties of the compiled code (actually, the static checks for bounded resource consumption are switched-off in the FunLoft compiler, but the remaining checks are sufficient to insure reactivity and memory protection).

The translation has the following characteristics:

- The notion of an instant is re-built: an instant of a script is made of several micro-steps of the target FunLoft program, each micro-step corresponding actually to one instant of the translated FunLoft program.
- Events are designed by strings. A hashtable (of the type \text{aa}_t) associating strings to events is available on each site.
- The generation of a DSL event is sustained during the following micro-steps, up to the end of instant.
- A valued event is used to deal with the dynamic adding of new scripts in a site (it has type (\text{instruction}_t, \text{event}_t)).

The basic data structures defining the three recursive types \text{instruction}_t, \text{site}_t, and \text{engine}_t, the API for instructions, and the evaluation of scripts are defined in Annex B.

#### 4.1 Dynamic Adding of Instructions

A special event is associated to each site, used to add the scripts dropped in the site. The module \text{dynamic} awaits this event and collects its associated values using the \text{get_all_values} instruction of FunLoft; the collected instructions are processed by calling the function \text{incorporate}, defined below. The code of \text{dynamic} is:

```coffeescript
let module dynamic (eng) =
  let inst_list = ref Nil_list in
  loop
    let add = Engine.add (eng) in
    begin
      await add;
      get_all_values add in inst_list;
      incorporate (eng,!inst_list);
    end
```
The `continue_instant` function just sets the flag `move` of the engine:

```ocaml
generate Engine.wakeup (eng);
continue_instant (eng);
end
```

The function `incorporate` is recursively defined and the FunLoft compiler checks that it always terminates:

```ocaml
let incorporate (eng,inst_list) =
  match inst_list with
    Nil_list do ()
  | Cons_list (head,tail) do
    begin
      thread evaluate (eng,head,event);
      incorporate (eng,tail);
    end
  end
```

To drop an instruction in a site, basically means to generate the special event of the site engine with the instruction as value:

```ocaml
let module send_to (site,inst) =
  link Site.sched (site) do
    let engine = !Site.rengine (site) in
    generate Engine.add (engine) with inst
```

### 4.2 Reactive Engine

The reactive engine of a site basically sustains the generated events and decides when instants are terminated. Each time an event is generated, it is stored in the list `sustain` of the engine, in order to be re-generated at each micro-step, up to the end of instant. Moreover, the `move` flag of the engine is set (by calling `continue_instant`) to resume execution of scripts awaiting the event, if there are such scripts:

```ocaml
let dsl_generate (eng,evt) =
  let e = event_lookup (eng,evt) in
  begin
    generate e;
    let s = Engine.sustain (eng) in
    s := Cons_list (e,s);
    continue_instant (eng);
    generate Engine.wakeup (eng);
  end
```

The algorithm of the engine is the following: micro-steps are executed cyclically while the `move` flag is set; when the `move` flag has not been set by the last micro-step, the `pre_eoi` flag is set to let `watching` statements proceed, in case of preemption. Indeed, in this case, a `watching` has to let its body react, in order to choose safely between rules 11 and 12. Cyclic execution is then resumed as previously, while there are new moves. The end of the current DSL instant is decided when the setting of `pre_eoi` does not produce any new move; in this case the `eoi` flag is set, to indicate the end of the current instant. This algorithm corresponds to the following code:

```ocaml
let module react (eng) =
  let move = Engine.move (eng) in
  loop
    begin
      move := false;
      sustain_all (eng);
      cooperate;
      if not !move then
        begin
          generate Engine.pre_eoi (eng);
          cooperate;
          if not !move then
            begin
              close_instant (eng);
              return;
            end
        end
    end
end
```

The `sustain_all` function maintains the generated events during the next micro-steps, up to the end of instant. The `close_instant` function generates `eoi`, stops the sustainment of generated events, and increments the instant counter:

```ocaml
let close_instant (eng,trace) =
  let instant = Engine.instant (eng) in
  begin
    generate Engine.eoi (eng);
    Engine.sustain (eng) := Nil_list;
    instant++;
  end
```

Note that the flag `pre_eoi` becomes useless if we replace the rule 11 by the alternative rule 11’. The alternative rule would thus simplify the implementation in FunLoft (however, this would not be the case for the other variants of DSL).
4.3 Functions and Tasks

Functions are called using the Call instruction. Functions and parameters are represented as character strings. The function call\_dispatch analyses the first string passed to Call and calls the correct function. Functions that are used in a program must always be called through the call dispatcher. Here is an example of definition of it:

```plaintext
let call\_dispatch (eng,fun,params) =
  if fun = "print\_string" then
    let p1 = get\_param (params,0) in
    print\_string (p1)
  else if fun = "print\_int" then
    let p1 = string2int(get\_param(params,0)) in
    print\_int (p1)
  else if fun = "quit" then
    quit (0)
  else
    warning ("unknown call")
```

Tasks are launched in sites with the Launch instruction. As with functions, tasks and parameters are represented as character strings. The module task\_dispatch analyses the first string and launches the appropriate thread. An event given as parameter is generated at the end of the task execution. Here is an example of a task dispatcher:

```plaintext
let module task\_dispatch (eng,task,params,evt) =
begin
  if task = "print\_getchar" then
    run print\_getchar ()
  else if task = "getchar" then
    run getchar ()
    ...
    generate evt;
end
```

Note that the compiler checks that non-cooperative FunLoft functions are always called while unlinked. Here is an example of use of the non-cooperative FunLoft function fl\_getchar (which basically corresponds to the getchar function of C):

```plaintext
let getchar\_result = ref ' '

let module getchar () =
  let loc = local ref ' ' in
  begin
    unlink loc := fl\_getchar ();
    link main\_scheduler do
      getchar\_result := !loc;
  end
```

The compiler complains if the unlink statement is omitted. Note the use of a local reference to store the character read; an intermediate local reference is mandatory because it is not possible to access the global reference getchar\_result while unlinked (otherwise, data-races while accessing it could occur).

Note that the executing engine is given as parameter to call\_dispatch and task\_dispatch; this allows the function dsl\_generate to be called by functions and tasks. Communication through events can occur by this means from the host level, to the orchestration level.

4.4 Instantaneous Loops

The FunLoft compiler statically checks for the absence of instantaneous loops; more precisely, it rejects a program in which a loop body has the possibility to terminate instantly. In the present context, this means that there is no possibility for an instruction to cycle during the same micro-step. According to the semantics of DSL, loops that would cycle during the same (DSL) instant are dynamically detected and “corrected”; this is for example the case with:

```
Loop (Nothing)
```

The implementation proceeds as follows: the DSL instant is stored when the body of a loop starts to execute and the system checks that the instant when the body terminates is different from the stored instant. When the two instants are the same (the body thus terminates instantly), the system forces the body to wait for the next DSL instant (it is like if a cooperate statement is dynamically inserted at the end of the body when it terminates instantly).

4.5 Static Checks

The static checks performed by the compiler are the ones of FunLoft, excepted those insuring that the consumption of resources is bounded (actually, the execution engine defined does not run in bounded memory, basically because new scripts can always be dropped dynamically in sites).

4.5.1 Reactivity

Basically, the reactivity property comes from the fact that there is no way for a script to prevent the execution of the other scripts by exhausting the CPU. More precisely:

```
```
• It is not possible to define recursive scripts in DSL. A script can only launch an already defined task.

• Recursive tasks (recursive FunLoft modules) are allowed because they are needed by the implementation in FunLoft; however, execution of a launched task does not begin immediately, but at the next DSL instant; thus, there is no possibility for a recursively defined task to cycle forever during the same micro-step. Hence, no task could cycle forever during the same DSL instant.

• Functions are proved to always terminate. An example of correct function is:

\[
\text{let length(l) =}
\begin{align*}
\text{match l with} & \\
\text{Nil_list} & \rightarrow 0 \\
\text{Cons_list (h,t)} & \rightarrow 1 + \text{length(t)}
\end{align*}
\]

On the contrary, the following function is rejected:

\[
\text{let f(l) =}
\begin{align*}
\text{match l with} & \\
\text{Nil_list} & \rightarrow 0 \\
\text{default} & \rightarrow f (l)
\end{align*}
\]

4.5.2 Memory Protection

Each site (scheduler) has its own memory, which is protected from accesses by instructions run by the other sites. As a consequence, no data-race can occur from the parallel execution of two scripts run on two distinct sites (thus, run by two distinct native threads).

Moreover, tasks may have a local private memory and the system verifies that this memory cannot be accessed by the other tasks. Basically, a task is forbidden to store one of its private reference into a public reference accessible by the other tasks.

To illustrate the memory protection technique, let us consider the following task dispatcher:

\[
\text{let r = ref 0}
\]

\[
\text{let module task_dispatch (eng,task,params,evt) =}
\begin{align*}
\text{if task = "tst1" then} & \\
\text{thread tst1 (r)} & \\
\text{else if task = "tst2" then} & \\
\text{thread tst2 (r)} & \\
\text{...}
\end{align*}
\]

An error is detected if both tasks \texttt{tst1} and \texttt{tst2} access the reference \texttt{r} while on different sites; indeed, in this case, there could be a data-race while accessing \texttt{r}. A way to fix the bug is to force the two tasks to be in the same site:

\[
\text{let module task_dispatch (eng,task,params,evt) =}
\begin{align*}
\text{if task = "tst1" then} & \\
\text{link site1.sched do thread tst1 (r)} & \\
\text{else if task = "tst2" then} & \\
\text{link site1.sched do thread tst2 (r)} & \\
\text{else}
\end{align*}
\]

4.6 Execution of Instructions

Let us return to the script of Section 2.5. An equivalent FunLoft program is:

\[
\text{#include "dsl3.fl"}
\]

\[
\text{let turns = 1000}
\]

\[
\text{let consume_value =}
\begin{align*}
\text{Cons_list ("1000000",Nil_list)}
\end{align*}
\]

\[
\text{let remote (from,target,msg,done) =}
\begin{align*}
\text{Drop (target,}
\text{Seq (Print (msg),}
\text{Seq (Call ("consume",consume_value),}
\text{Drop (from,Generate (done)))})}
\end{align*}
\]

\[
\text{let parallel =}
\begin{align*}
\text{Repeat (IntConst (turns),}
\text{Seq (}
\text{Par (remote (site1,site2,"0","done0"),}
\text{Par (remote (site1,site3,"1","done1"),}
\text{Par (Await ("done0"),Await ("done1")))},}
\text{Cooperate))}
\end{align*}
\]

\[
\text{let module dsl_main () =}
\begin{align*}
\text{drop_in_site1 (parallel)}
\end{align*}
\]

The include directive of the file \texttt{dsl3.fl} defines the types and the constructors used for instructions, and three sites \texttt{site1}, \texttt{site2}, and \texttt{site3}. The function \texttt{remote} is called twice by the instruction \texttt{parallel}. Finally, the module \texttt{dsl_main} is defined; it is actually the program entry point. The body of \texttt{dsl_main} simply drops the instruction \texttt{parallel} in \texttt{site1}.

4.7 Translation in FunLoft

A translator of DSL in FunLoft is implemented; it translates the script of Section 2.5 into the following instruction:
Repeat (IntConst (1000), Seq (Par (Par (Par (Drop (site2, Seq (Seq (Print ("0"), Call ("consume", Cons_list ("10000000", Nil_list))), Drop (site1, Generate ("done0")))), Drop (site3, Seq (Seq (Print ("1"), Call ("consume", Cons_list ("10000000", Nil_list))), Drop (site1, Generate ("done1")))), Await ("done0")), Await ("done1")), Cooperate))

To execute it, one just replaces the definition of parallel by this instruction, in the FunLoft program of section 4.6.

5 SugarCubes Variant

The main points of the implementation of DSL in SugarCubes are:

- Sites are coded as reactive machines of the class machine, and the drop instruction is implemented as the addProgram method of machine.
- Scripts, except drop and loop are directly coded by their counterpart in SugarCubes; there is no need to make a distinction between DSL instances and SugarCubes instances.
- The loop instruction of DSL is implemented as a parallel instruction of the loop body with the stop instruction of SugarCubes.

5.1 Dispatcher

Dispatchers for calls, tasks and wrappers are coded in Java as a unique JavaAction. Here is an example of dispatcher:

class CallDispatcher implements JavaAction {
    final String fun;
    final Vector args = new Vector();

    public CallDispatcher (final String fun, final String arg) {
        this.fun = fun;
        this.args.add(arg);
    }
    public void execute (ReactiveEngine env) {
        if (fun.equals("quit")) {
            System.exit(0);
        }
    }
}

5.2 Drop

The drop instruction calls the addProgram method of the class Machine of SugarCubes:

class Drop implements JavaAction {
    final Machine target;
    final Program p;
    public Drop (final Machine target, final Program p) {
        this.target = target;
        this.p = p;
    }
    public void execute (ReactiveEngine env) {
        target.addProgram (p);
    }
}

5.3 Translation in SugarCubes

A translator of DSL into SugarCubes has been implemented which translates scripts into SugarCubes programs. The following class Parseq uses the translation of the script of Section 2.5 and defines three sites as instances of the class machine of SugarCubes. The three sites are started and the program obtained with the translator is added in the first site. The code is the following:

class Parseq {
    public static void main (final String[] args) {
        final Machine site1 = SC.machine ();
        final Machine site2 = SC.machine ();
        final Machine site3 = SC.machine ();

        final Program p = SC.seq (SC.seq (SC.repeat (1000, SC.seq (SC.merge (SC.merge (SC.seq (SC.action(new Drop(site2,SC.seq (SC.seq (SC.print("0"),SC.action(new CallDispatcher("consume","10000000")))))), SC.action(new Drop(site1, Integer.parseInt((String)args.elementAt(0));
        for (int k = 0; k < n; k++) x++;
    }
})

}
new Thread (site2).start ();
new Thread (site3).start ();
site1.addProgram (p);
site1.run ();
}

It is important to remind that the interference free property, automatically checked by the compiler in the FunLoft variant, is now of the programmer's responsibility.

6 ReactiveML Variant

The main points of the implementation of DSL in ReactiveML are:

- Sites are coded in JoCaml. It provides high level constructs to implement the asynchronous communication between sites.
- Each site is executed in a process and the communication between sites is done over sockets. It allows to distribute the sites on different computers.
- Similarly to the FunLoft implementation, scripts are translated into a ReactiveML values of type script (that corresponds to the type instruction_t in FunLoft). Scripts are not directly translated to ReactiveML constructs as it is done in the SugarCubes implementation because it would require code mobility to implement the drop action.
- Scripts, except drop and loop have a direct counterpart in ReactiveML; there is no need to make a distinction between DSL instants and ReactiveML instants. The identification of the two notions of instants is analogous as in the SugarCubes variant of Section 5.
- The loop instruction of DSL is implemented as a parallel instruction of the loop body with the pause instruction of ReactiveML.

6.1 Evaluator in ReactiveML

In ReactiveML, a DSL script is represented as a value of type script which is similar to the type instruction_t in the FunLoft implementation. For example, the script of the Section 2.5 is translated by the compiler into the following value:

```
S_repeat (E_const (C_int 1000),
S_seq
(S_par (S_par (S_par
(S_drop ("site2",
S_seq (S_seq
(S_print "0",
S_call ("consume", [C_int 10000000]),
S_drop ("main", S_generate "done0"))),
S_drop ("site3",
S_seq (S_seq
(S_print "1",
S_call ("consume", [C_int 10000000]),
S_drop ("main", S_generate "done1"))),
S_await "done0",
S_await "done1"),
S_cooperate))
```

The evaluation of a script represented by a value of type script is defined by a ReactiveML process eval_script. Since the semantics of ReactiveML is very close to the semantics of DSL, the implementation of this process is straightforward. We define here the beginning of the process (the complete implementation and the definition of the type script is given in annex C).

```
let rec process eval_script script =
  match script with
  | S_nothing -> ()
  | S_cooperate -> pause
  | S_seq (s1, s2) ->
    run (eval_script s1);
    run (eval_script s2)
  | S_par (s1, s2) ->
    run (eval_script s1) ||
    run (eval_script s2)
  | ...
```

6.2 Dispatcher

Like in the other implementations, function calls are made through a dispatcher that dynamically links the function name with its definition. In the eval_script process, function calls are implemented as follows:

```
| S_call (f_id, vl) ->
  let f = fun_of_fun_id f_id in
  f vl
```
where the function `fun_of_fun_id` is defined with the function `record_fun` as follows:

```ocaml
let fun_of_fun_id, record_fun =
  let tbl = Hashtbl.create 7 in
  let fun_of_fun_id f_id =
    try Hashtbl.find tbl f_id
    with Not_found ->
      prerr_endline ("unbound function "^f_id);
      (fun x -> C_unit)
  and record_fun f_id f =
    Hashtbl.add tbl f_id f
  in
  fun_of_fun_id, record_fun
```

The two functions `fun_of_fun_id` and `record_fun` share a common hash table (`tbl`). `fun_of_fun_id` returns the function associated in `tbl` to the string given in argument and `record_fun` allows to fill the hash table.

To do dynamic typing, DSL values are encapsulated in a type `const`:

```ocaml
type const =
  | C_unit
  | C_int of int
  | C_bool of bool
  | C_string of string
```

So if we want to register a function that take as input two integers and return a Boolean, we will use the following function:

```ocaml
let int_x_int_to_bool f_id f =
  record_fun f_id
  begin function
    | [ C_int n1 ; C_int n2 ] ->
      let b = f n1 n2 in C_bool b
    | _ ->
      prerr_endline "type error";
      C_bool false
  end
```

### 6.3 Drop

The `drop` instruction is implemented in the process `eval_script` as follows:

```ocaml
| S_drop (site_id, script) ->
  Dsl_drop.put (site_id, script)
```

The `Dsl_drop.put` function is implemented with a join pattern of the JoCaml language:

```ocaml
let put, get =
  def put(site_id_x_script) & state(to_drop) =
    reply () to put &
    state(site_id_x_script :: to_drop)
```

The functions `put` and `get` share a common list. `put` adds an element to the list and `get` removes all the elements. The two functions can safely modify the list concurrently thanks to their join definition and their communication through the channel `state`.

### 6.4 Sites

In the ReactiveML implementation of DSL, a site is basically a JoCaml program that repeatedly executes the following three steps:

1. get the scripts dropped by the other sites
2. execute one instant of the DSL program with the new scripts in parallel
3. send the dropped scripts to the other sites.

The first step is implemented with a JoCaml function similar to the function `Dsl_drop.get`. The second step executes one instant of the `eval_script` process. The third step calls `Dsl_drop.get` and dispatches the dropped scripts to the corresponding sites.

### 7 Bigloo/Scheme Variant of DSL

The main points of the implementation of DSL in Scheme/Bigloo are:

- Sites are coded in Scheme/Bigloo and executed by a native thread.
- Script execution basically follows the semantics rules described in previous section.
- As there is no notion of instant in Scheme/Bigloo, we introduce the notion of reactive machine to implement them.
- In Scheme/Bigloo there is no difference between functions and tasks.
7.1 Site

In our implementation a reactive machine (site) is made of four lists:

- The first one contains the executing scripts.
- The second one contains the waiting scripts.
- The third one contains scripts whose execution is finished for the current instant.
- The last list is the event environment.

We also need a boolean to indicate if it the fix point is reached \((eoi)\). A site is thus coded as:

\[
\text{(define site (list (list) (list) (list) (list) eoi))}
\]

The behaviour of the reactive machine is extremely simple: it executes the function \(\text{one\_step}\) which defines one instant of DSL, up to the least fixed point. This function returns the new state of the reactive machine. The code of \(\text{one\_step}\) is:

\[
\text{(define (one\_step site)}
\text{\hspace{1em} (when (event\_generated site))}
\text{\hspace{1em} (set! site (wakeup\_waiting\_script site)))}
\]

\[
\text{(if (eoi site)}
\text{\hspace{1em} site)}
\text{\hspace{1em} (let ((res (sem\_action}
\text{\hspace{2em} (first\_script site)}
\text{\hspace{2em} (get\_env site)}
\text{\hspace{2em} (get\_eoi site))))))}
\]

\[
\text{(if (execution\_finished res)}
\text{\hspace{1em} (one\_step}
\text{\hspace{2em} (list (next\_script site)}
\text{\hspace{2em} (get\_waiting\_script site)}
\text{\hspace{2em} (cons (get\_script\_res res)}
\text{\hspace{3em} (get\_finished\_script site)}
\text{\hspace{3em} (get\_env\_res res)}
\text{\hspace{3em} (get\_eoi res))))}
\]

\[
\text{(one\_step}
\text{\hspace{1em} (list (next\_script site)}
\text{\hspace{1em} (cons (get\_script\_res res)}
\text{\hspace{2em} (get\_finished\_script site)}
\text{\hspace{2em} (get\_env\_res res)}
\text{\hspace{2em} (get\_eoi\_res res))))))})
\]

First, we check if there are generated events \((event\_generated)\). If it is the case, we wake-up all the waiting scripts \((\text{wakeup\_waiting\_script})\). Then, we should verify if the fixed point \((eoi)\) is already reached. In that case, there is no need to continue; otherwise, we try to execute a new script \((\text{sem\_action})\). If \(\text{execution\_finished}\) returns true, the current script is terminated for the current instant. Otherwise, the script is waiting for an event. In both cases, we pass to the next script after storing the script in the appropriated list (waiting script lists or finished scripts list).

7.2 Functions and Tasks

In Scheme/Bigloo there is no different between function and tasks. In DSL, we require that functions are instantaneous, but tasks can take several instants. In the current implementation, the only way for the user to implement a task is to define a Scheme/Bigloo function executed as a native thread.

7.3 Translation in Bigloo

There are two possibilities in Scheme/Bigloo to execute a script: either it is translated in Scheme/Bigloo, then compiled, and executed as a standard Scheme/Bigloo program; or it is given as input to a top-level interpreter that analyses the script, translates it in an abstract tree, and run it using a native Scheme/Bigloo thread.

From the script of Section 2.5, the DSL to Bigloo translator produces a code which is exactly the same as the one produced by the FunLoft variant:

\[
\text{Repeat (IntConstWrapper (1000),Seq (Par (Par (}
\text{Par (Drop (site2,Seq (Seq (Print ("0"),
\text{Call ("consume",Cons_list ("10000000",}
\text{Nil_list)))),Drop (site1,Generate ("done0"))),)
\text{Drop (site3, Seq (Seq (Print ("1"),
\text{Call ("consume",Cons_list ("10000000",}
\text{Nil_list)), Drop (site1,Generate ("done1"))),
\text{Await ("done0")), Await ("done1")),Cooperate))}
\]

To execute the script, we drop it into the appropriated reactive machine. This execution is descripted in annex D.

8 Experiments

In this section, we execute the script defined in section 2.5 with the four variants of DSL and compare the results.
FunLoft

In FunLoft, the function consume called by the script to consume the computing resource can be defined by:

```ocaml
let consume_intern (n) =
  let x = local ref 0 in
  repeat n do x++
```

Alternatively, one could define consume as an extern C function, introduced in FunLoft by:

```ocaml
extern "C" consume : int -> unit
```

The definition of consume in C is then:

```
#include "val.h"

value consume (value vn)
{
  long n = val2int (vn);
  long k, x = 0;
  for ( k = 0; k < n; k++ ) x++;
  return val_unit;
}
```

The extern function is much more efficient than the function defined in FunLoft (see below). However, with the extern function, the compiler looses the possibility to detect an error in the C implementation (this is recalled to the user by a message issued at compile time).

The execution machine we use is a dual-core machine\(^3\). The execution time is obtained with the Unix command `time`.

Results with the FunLoft variant are shown in Figure 1: on the left, the (intern) FunLoft definition of consume is used, while on the right it is defined in C (extern).

<table>
<thead>
<tr>
<th>FL</th>
<th>intern</th>
<th>extern</th>
</tr>
</thead>
<tbody>
<tr>
<td>real</td>
<td>2m58.616s</td>
<td>0m32.922s</td>
</tr>
<tr>
<td>user</td>
<td>5m47.278s</td>
<td>1m4.562s</td>
</tr>
<tr>
<td>sys</td>
<td>0m2.516s</td>
<td>0m0.208s</td>
</tr>
</tbody>
</table>

![Figure 1: FunLoft variant](image)

SugarCubes

Figure 2 shows the results with the SugarCubes variant (the consume method is directly implemented in Java). The counter used by consume is both implemented as an integer of type `int` and as a long integer of type `long`. The implementation with `int` is:

```
class FUN_consume implements Fun
{
  public void exec(final String arg){
    int len = Integer.valueOf(arg);
    int x = 0;
    for(int i = 0 ; i < len ;i++) x++;
  }
}
```

![Table 1: SugarCubes variant with JIT](image)

```
<table>
<thead>
<tr>
<th>SC + JIT</th>
<th>long</th>
<th>int</th>
</tr>
</thead>
<tbody>
<tr>
<td>real</td>
<td>0m30.658</td>
<td>0m1.899s</td>
</tr>
<tr>
<td>user</td>
<td>1m7.288s</td>
<td>0m3.692s</td>
</tr>
<tr>
<td>sys</td>
<td>0m0.160s</td>
<td>0m0.028s</td>
</tr>
</tbody>
</table>
```

In Figure 3 is shown the execution time when the JIT of Java is switched off (option `-Xint`).

```
<table>
<thead>
<tr>
<th>SC - JIT</th>
<th>long</th>
<th>int</th>
</tr>
</thead>
<tbody>
<tr>
<td>real</td>
<td>6m32.884s</td>
<td>3m34.355s</td>
</tr>
<tr>
<td>user</td>
<td>19m5.076s</td>
<td>10m25.387s</td>
</tr>
<tr>
<td>sys</td>
<td>0m13.617s</td>
<td>0m5.044s</td>
</tr>
</tbody>
</table>
```

![Figure 3: SugarCubes variant without JIT](image)

ReactiveML

Figure 4 shows the results with the ReactiveML variant (the consume method is directly implemented in ReactiveML). The code of consume is:

```
let consume n =
  let x = ref 0 in
  for i = 1 to n do
    x := !x + 1
  done
```

```
<table>
<thead>
<tr>
<th>RML</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>real</td>
<td>1m27.292s</td>
</tr>
<tr>
<td>user</td>
<td>0m39.946s</td>
</tr>
<tr>
<td>sys</td>
<td>0m0.584s</td>
</tr>
</tbody>
</table>
```

![Figure 4: ReactiveML variant](image)

\(^3\)machine characteristics: Dell Latitude, Linux 2.6.35 processor Intel Core i5, 2.4 GHz, 4GB of memory
Scheme/Bigloo

The results for the Scheme/Bigloo variant are shown on figure 5. We have considered the two cases, where the counter is implemented as an integer and as a long.

<table>
<thead>
<tr>
<th>Scheme</th>
<th>long</th>
<th>int</th>
</tr>
</thead>
<tbody>
<tr>
<td>real</td>
<td>47m34.820s</td>
<td>4m40.714s</td>
</tr>
<tr>
<td>user</td>
<td>76m53.744s</td>
<td>8m0.614s</td>
</tr>
<tr>
<td>sys</td>
<td>4m9.536s</td>
<td>0m4.572s</td>
</tr>
</tbody>
</table>

Figure 5: Scheme/Bigloo variant

Interpretation

With the FunLoft, SugarCubes and Scheme/Bigloo variants, we see that the user time is (more or less) twice the real time, which shows that the two cores are running simultaneously at full speed. The two instances of consume are indeed executed in real parallelism by the two cores. The ReactiveML variant does not use the two cores in an optimal way; it seems to be slow down by the presence of JoCaml which introduces a communication overhead.

The efficiency of the SugarCubes variant heavily depends on the JIT of Java. We see also that it depends on the use of integers instead of longs. Note that in the FunLoft variant, integers are coded as long long integers of C.

The dependence on the choice between integers and longs is also clear in the Scheme/Bigloo variant. Note that in this variant, no optimization is performed in the reactive engine; optimization were not the focus and the efficiency of this variant could be clearly improved in that matter.

9 Related Work

9.1 Esterel

DSL differs from Esterel [7] in two main aspects: first, it allows dynamicity. The main idea which makes this possible is to forbid the immediate reaction to absence of signals (called events, in DSL); this is the basis of reactive programming [4]. Second, DSL introduces asynchrony through the notion of site. Asynchrony is not present in Esterel\(^4\), thus the issue of memory protection against asynchronous concurrent accesses is not addressed.

9.2 Reactive Scripts

A proposal very close to the one presented here, called Reactive Scripts, has been made in [13]. Reactive Scripts define migration means based on RPC. Reactive Scripts is defined independently of the precise definition of atomic actions (function calls). Thus, the main issues considered in DSL were not considered with Reactive Scripts: termination of instants and absence of interferences. Reactive Scripts however proposes the notion of an object, which could be interesting to introduce in DSL (this notion basically relies on a control primitive that is currently not present in DSL).

9.3 FunLoft

DSL is of course strongly linked to FunLoft [12], which is based on the work of [15]. FunLoft adopts a thread-based approach, while DSL uses a parallel operator. Actually, the implementation of DSL in FunLoft shows how a parallel primitive can be implemented with threads. Moreover, resources consumption is checked for boundness by the FunLoft compiler; this feature is switched-off for the DSL compiler. Resource control is actually totally absent from DSL.

9.4 SugarCubes

A correct program in DSL should be proved to be reactive (i.e. the flow of instants is infinite) and free from data-races. These properties should be valid in SugarCubes [14] (and in the related framework Junior [16]), but they are not checked by the implementations. In SugarCubes, instantaneous loops are dealt with, but non-terminating atomic functions are not. However, SugarCubes offers a much more rich set of instructions, in particular for distributed programming; it is also object-based unlike DSL.

9.5 ReactiveML

The language ReactiveML [17] gives a possibility to execute scripts which are standard ReactiveML programs, compiled “on-the-fly”. This feature introduces high flexibility in programming. Based on ML, ReactiveML is safe (no crash can occur at run-time). However, the termination of instants is not checked by the compiler. Moreover, ReactiveML, as ML, is

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\(^4\)except in the first versions of the language, in which the notion of an exec task was defined.
not presently able to benefit from the real parallelism offered by multiprocessor architectures.

9.6 S-π Calculus

The theoretical approach of the S-π Calculus [5] is related to DSL, as it is based on the same synchronous model. The focus in S-π Calculus is resource control: it provides a way to checks that resources are polynomially bounded. This is not the case in DSL which does not consider resource control at all.

9.7 Cooperative Multithreading

The use of static analysis techniques in the context of cooperative multithreading is considered in several recent papers [8], [19]. The case of synchronous parallelism is not however covered in these works.

9.8 ORC

ORC [18] is an orchestration language dedicated to the Web. The objectives of ORC are close to the ones of DSL. We plan to compare ORC and DSL and to implement ORC in DSL.

10 Conclusion

We have presented a dynamic approach to parallel programming, based on the synchronous - reactive model. Synchronous programming is simpler than the traditional asynchronous approaches, based on the exclusive use of preemptive threads. However, three major issues are raised by synchronous programming: how to be sure that the program is indeed reactive? how to execute it efficiently on a multicore architecture? how to be sure that there is no harmful interference between parallel computations (e.g. data-races)? Our proposal gives answers to these questions. In the FunLoft variant of DSL, the basic properties of DSL (reactivity and data-race freeness) are statically checked. However, sites cannot be run by different machines (they are confined to the cores of the same machine). In the ReactiveML, SugarCubes, or Scheme/Bigloo variants, the basic properties of DSL are not automatically checked but are of the programmer’s responsibility. The ReactiveML and SugarCubes variants give access to distribution of sites across the network (using JoCaml for ReactiveML, and Java RMI for SugarCubes). Note that in all the variants of DSL, sites can be run in full parallelism (either cores or processors).

We envision the following tracks for future work:

- Introduction of means for distribution of sites in the FunLoft version.
- Implementation of a communication protocol, based on Hop, allowing the different variants of DSL to run as a unique distributed program.
- Design and implementation of a top-level for DSL adapted to each version.
- Extension of DSL to allow the dynamic mapping of programs onto cores, in order to maximise the use of cores at execution time.

References

A DSL Grammar

This appendix describes the grammar of DSL expressed in a YACC format.

```
script:                  basic.script
    | script ';'    script
    | script '||'   script
    | '(' script ')'  

basic.script:           NOTHING
    | COOPERATE
    | if
    | loop
    | repeat
    | generate
    | await
    | watching
    | call
    | launch
    | drop

if:                     IF bool.test THEN script ELSE script END
    | IF bool.test THEN script END

loop:                   LOOP script END
    | WHILE bool.test DO script END

repeat:                 REPEAT int.val DO script END

generate:               GENERATE event

await:                  AWAIT event

watching:               WATCHING event DO script END

call:                   IDENTIFIER '(' 'value.list' ')'  

launch:                 LAUNCH IDENTIFIER '(' 'value.list' ')'  

drop:                   DROP script IN site  

site:                   IDENTIFIER

bool.test:              BOOLEAN | call

int.val:                NUMBER | call

event:                  IDENTIFIER

value:                  NUMBER | BOOLEAN | STRING

value.list:             /* empty */
    | value
    | value ',' value.list
```

B Evaluation in FunLoft

The basic data structures define the three recursive types `instruction_t`, `site_t`, and `engine_t`:

```
type
  instruction_t =
    _Nothing
    | _Print of string
    | _Call of string * string list
    | _Launch of string * string list
    | _Cooperate
    | _Seq of instruction_t * instruction_t
        * ref bool
        * ref thread_t
    | _If of bool_wrapper_t * instruction_t
        * instruction_t
        * ref bool
```
The API for scripts is:

```ocaml
let rn () = ref null_thread
let Nothing = _Nothing
let Print (s) = _Print (s)
let Cooperate = _Cooperate
let Par (i1,i2) = _Par (i1,i2,rn(),rn())
let If (w,i1,i2) = _If (w,i1,i2,ref true,rn())
let Seq (i1,i2) = _Seq (i1,i2,ref true,rn())
let Loop (i) = _Loop (i,rn())
let Repeat (w,body) = _Repeat (w,body,ref true,rn())
let Generate (e) = _Generate (e)
let Await (e) = _Await (e)
let Calling (fun,params) = _Calling (fun,params)
let Launch (task,params) = _Launch (task,params)
let Drop (site,i) = _Drop (site,i)
```

The evaluation of atomic scripts is defined by the following function:

```ocaml
let eval_atomically (eng,inst) =
match inst with
  _Nothing do ()
| _Print (s) do begin
  print_string (s); flush (); end
| _Call (fun,params) do
  call_dispatch (eng,fun,params)
| _Generate (evt) do
  dsl_generate (eng,evt)
| _Seq (i1,i2,_,_) do
  begin
  eval_atomically (eng,i1);
  eval_atomically (eng,i2);
  end
| _If (w,i1,i2,_,_) do
  if bool_wrapper (w) then
    eval_atomically (eng,i1)
  else
    eval_atomically (eng,i2)
| _Par (i1,i2,_,_) do
  begin
  eval_atomically (eng,i1);
  eval_atomically (eng,i2);
  end
| _Repeat (w,body,_) do
  repeat int_wrapper (w) do
    eval_atomically (eng,body)
| default do warning ("internal error")
```

For the non-atomic scripts, one first defines a synchronisation barrier module, needed by the parallel operator:

```ocaml
let module barrier (engine,reach,go) =
  let threshold = 2 in
  let count = local ref 0 in
  let b = local ref true in
  while !b do
    begin
    await reach;
    continue_instant (engine);
    for_all_values reach with _ do count++;
    if !count = threshold then
      begin
      continue_instant (engine);
      generate go;
      b := false;
      end
    end;
  end;
```

The following macro is used to shorten the code:

```ocaml
#define EVAL(r,inst,term)\begin\r := thread evaluate (eng,inst,term);\end
```

The evaluation of scripts is defined by the following module:
let module evaluate (eng, inst, term) =
let eoi = Engine.eoi (eng) in
begin
  Engine.next (eng) := true;
  if is_atom (inst) then
    begin
      eval_atomically (eng, inst);
      generate term;
    end
  else
    match inst with
    | _Launch (t, p) do
      if not known_task (t) then
        begin
          generate term
        end
      else
        begin
          let e = event in
          begin
            await eoi;
            continue_instant (eng);
            thread task_dispatch (eng, t, p, e);
            await e;
            generate Engine.wakeup (eng);
            generate term;
          end
        end
    | _Cooperate do
      begin
        await eoi;
        generate term;
      end
    | _Seq (i1, i2, b, r) do
      let e = event in
      begin
        b := true;
        EVAL (r, i1, e);
        await e;
        b := false;
        EVAL (r, i2, term);
      end
    | _If (w, i1, i2, b, r) do
      begin
        b := bool_wrapper (w);
        if !b then
          EVAL (r, i1, term)
        else
          EVAL (r, i2, term);
      end
    | _Par (i1, i2, r1, r2) do
      let e = event in
      begin
        thread barrier (eng, e, term);
        EVAL (r1, i1, e);
        EVAL (r2, i2, e);
        end
    | _Loop (body, r) do
      begin
        let e = event in
        let k = Engine.instant (eng) in
        loop
          begin
            let initial = !k in
            EVAL (r, body, e);
            await e;
            continue_instant (eng);
            cooperate;
            if initial = !k then
              await eoi
            end
        end
    | _Repeat (w, body, r) do
      begin
        let e = event in
        repeat int_wrapper (w) do
          begin
            EVAL (r, body, e);
            await e;
            continue_instant (eng);
            cooperate;
            end;
        generate term;
      end
    | _Await (evt) do
      begin
        let e = get_event (eng, evt) in
        await e;
        generate term;
      end
    | _Watching (evt, body, b_th, w_th) do
      begin
        let b_evt = event in
        let e = event in
        let r = ref false in
        loop
          begin
            thread await_mod (b_evt, e, r);
            EVAL (b_th, body, b_evt);
            EVAL (w_th, Await (evt), e);
            await e;
            await Engine.pre_eoi (eng);
            killing (eng, inst);
            if !r then
              begin
                generate term;
                continue_instant (eng);
              end
            else
              begin
                await eoi;
              end
          end
        end
      end
    end
end
C Evaluation in ReactiveML

The DSL programs are represented with the following abstract syntax tree in ReactiveML:

```plaintext
type fun_id = string
| C_unit
| C_int of int
| C_bool of bool
| C_string of string

| E_const of const
| E_call of fun_id * expr list

type script =
| S_nothing
| S_cooperate
| S_seq of script * script
| S_par of script * script
| S_if of expr * script * script
| S_loop of script
| S_repeat of expr * script
| S_generate of event_id
| S_await of event_id
| S_watching of event_id * script
| S_call of fun_id * const list
| S_launch of module_id * const list
| S_drop of site_id * script

Script are interpreted as follows:

let rec eval_expr expr =
match expr with
| E_const c -> c
| E_call (f_id, vl) ->
    let f = fun_of_fun_id f_id in
    f vl

let rec process eval_script script =
match script with
| S_nothing -> ()
| S_cooperate -> pause
| S_seq (s1, s2) ->
    run (eval_script s1);
    run (eval_script s2)
| S_par (s1, s2) ->
    run (eval_script s1) ||
    run (eval_script s2)
| S_if (e, s1 ,s2) ->
    if eval_expr_bool e then
        run (eval_script s1)
    else run (eval_script s2)
| S_loop s ->
    loop
    pause ||
    run (eval_script s)
end
| S_repeat (e, s) ->
    let n = eval_expr_int e in
    for i = 1 to n do
        run (eval_script s)
    done
| S_generate ev_id ->
    let ev = event_of_event_id ev_id in
    emit ev
| S_await ev_id ->
    let ev = event_of_event_id ev_id in
    await immediate ev
| S_watching (ev_id, s) ->
    let ev = event_of_event_id ev_id in
    do
        run (eval_script s)
        until ev done
| S_call (f_id, vl) ->
    let f = fun_of_fun_id f_id in
    ignore (f vl)
| S_launch (m_id, vl) ->
    let m = module_of_module_id m_id in
```

---

5 a while instruction is added to DSL.
D Evaluation in Scheme/Bigloo

The basic data structure in Scheme/Bigloo is the lists. A site principally is a set of list as we explained it before (section 7). Each script is identified by an integer and its arguments by a list, if there is no arguments it will be an empty list. The evaluation of scripts is defined by the following function, where `sem_action` is a function which evaluate a script in exact semantics rules; all the function start with `get_` try to acquire an object, for example: `get_env_res` get the current environment for the result that we obtained before.

```scheme
(define (sem_action s env eoi)
  (case (car s)
    ;; b = true(0) | falase(1) | Bot (2)
    ((13) ;; PRINT
      (print (first_elm s))
      (list (list NOTHING) env '(' #f 0))
    ((0) ;; NOTHING
      (list (list NOTHING) env (list) #f 0))
    ((1) ;; COOP
      (list (list NOTHING) env (list) #f 1))
    ((2) ;; IF
      (if (string=? (first_elm s) "true")
        (sem_action (get_true s) env eoi)
        (sem_action (get_false s) env eoi))
    ((3) ;; SEQ
      (let ((res (sem_action (first_elm s) env eoi)))
        (if (execution_succed res)
          (let ((res2
            (sem_action (get_second s)
            (get_env_res res) env eoi)))
            (list (car res2)
              (get_env_res res2)
              (get_drop_res res2)
              (get_move_res res2)
              (get_state_res res2)))
            (list (list SEQ (get_script_res res)
              (car (cddr s)))
              (get_env_res res)
              (get_drop_res res)
              (get_move_res res)
              (get_state_res res)))))
    ((4) ;; PARA
      (let* ((s1 (sem_action (first_elm s) env eoi))
        (s2 (sem_action (get_second s)
          (get_env_res s1)
          (get_state_res s1)))
        (list (if (equal? (car s1) (car s2))
          (list NOTHING)
          (list NOTHING))
        (car s1)
        (list PARA
          (car s1)
          (car s2)))
        (get_env_res s2)
        (get_drop_res s2)
        (or (get_move_res s1)
          (get_move_res s2)))
        (set_state (get_state_res s2)
          (get_state_res s1)))))
    ((5) ;; LOOP
      (let ((s1 (sem_action (first_elm s) env eoi)))
        (list (list SEQ (car s) s)
          (get_env_res s1)
          (get_drop_res s1)
          (get_move_res s1)
          (get_state_res s1))))
    ((6) ;; REPEAT
      (let ((count (first_elm s)))
        (if (string? count)
          (let ((proc (funcall-resolve count)))
            (if proc
              (set! count (proc))
              (set! count
                (string->number count))))
          (sem_action
            list SEQ
            (create_repeat (get_second s) count)
            (get_second s)
            env eoi)))
    ((7) ;; GENERATE
      (if (member (string->symbol (get_evt s)) env)
        (list (list NOTHING) env (list) #t 0)
        (list (list NOTHING)
          (cons (string->symbol (get_evt s)) env)
          (list) #t 0)))
    ((8) ;; AWAIT
      (if (member (string->symbol (get_evt s)) env)
        (list (list NOTHING) env (list) #f 0)
        (list s env (list) #f 2)))
    ((9) ;; WATCHING
      (let ((s1 (sem_action (first_elm s) env eoi)))
        (if (execution_succed s1)
          (list (list NOTHING) (get_env_res s1)
            (get_state_res s1)))
          (get_drop_res s1)
          (get_move_res s1)
          (get_state_res s1))))
```

25
(if (member (get_evt_watching s) env)
  (list (list NOTHING)
        (get_env_res s1)
        (get_drop_res s1)
        (get_move_res s1)
        (get_state_res s1))
  (list (list WATCHING
          (car s1)
          (get_evt s))
        (get_env_res s1)
        (get_drop_res s1)
        (get_move_res s1)
        (get_state_res s1))))

((10);;CALL
 (let ((proc (firstelm s))
       (args (get_second s)))
  (when (procedure? proc) (apply proc args))
  (list (list NOTHING) env (list) #f 0)))

((11);;LAUNCH
 (let ((proc (firstelm s))
       (args (get_second s)))
  (when (procedure? proc) (apply proc args))
  (list (list NOTHING) env (list) #f 1)))

((12);;DROP
 (let ((script (get_dropped_script s))
       (site (site-resolve (get_dropped_site s))))
  (when site
    (if (site-is-remote? site)
        (cond-expand
         (hop-server
          (let ((host (site-remote-host site))
            (port (site-remote-port site))
            (remote (site-remote-site site)))
          (with-hop
           (DSL/drop :script script
                      :site remote)
           :host host
           :port port
           :sync #f
           :user "admin"
           :password "admin"
           (lambda (r) #t)))
        )
        (bigloo
         (list (list NOTHING) env script #f 0)))))

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