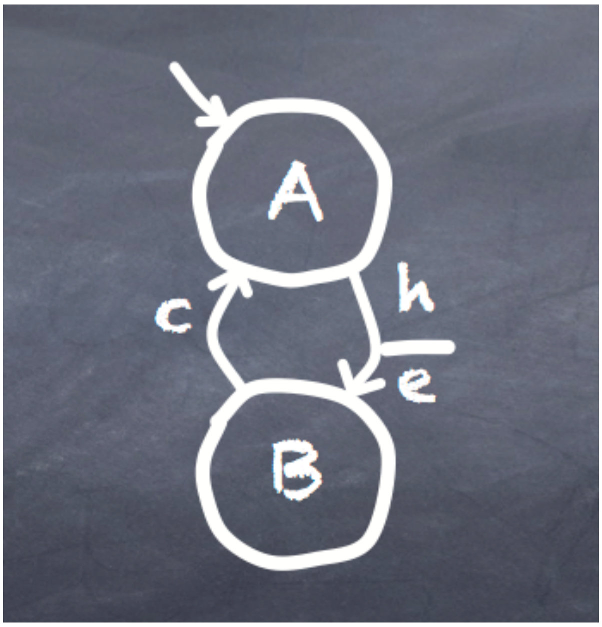
RFSM Reference Manual - 2.0

J. Sérot



Chapter 1

Formal syntax of RFSM programs

This appendix gives a BNF definition of the concrete syntax RFSM programs. As stated in the introduction, this syntax is that of the so-called *standard* RFSM language. Variant languages will essentially differ in the definition of the ⟨type_decl⟩, ⟨type_expr⟩, ⟨expr⟩, ⟨constant⟩, and ⟨const⟩ syntactical categories.

The meta-syntax is conventional. Keywords are written in **boldface**. Non-terminals are enclosed in angle brackets (`<` ... `>`). Vertical bars (`|`) indicate alternatives. Constructs enclosed in non-bold brackets (`[` ... `]`) are optional. The notation E^* (resp E^+) means zero (resp one) or more repetitions of E, separated by spaces. The notation E^*_x (resp E^+_x) means zero (resp one) or more repetitions of E, separated by symbol x. Terminals `lid` and `uid` respectively designate identifiers starting with a lowercase and uppercase letter.

⟨program⟩	::=	⟨type_decl⟩*
		⟨cst_decl⟩*
		⟨fn_decl⟩*
		⟨fsm_model⟩*
		⟨fsm_model⟩*
		⟨global⟩*
		⟨fsm_inst⟩*
⟨type_decl⟩	::=	**type** lid = ⟨type_expr⟩
	|	**type** lid = **enum** { uid$^*_,$ }
	|	**type** lid = **record** { ⟨record_field⟩$^+_,$ }
⟨record_field⟩	::=	lid : ⟨type_expr⟩
⟨cst_decl⟩	::=	**constant** lid : ⟨type_expr⟩ = ⟨const⟩
⟨fn_decl⟩	::=	**function** lid (⟨farg⟩$^*_,$) : ⟨type_expr⟩ { **return** ⟨expr⟩ }
⟨farg⟩	::=	lid : ⟨type_expr⟩
⟨fsm_model⟩	::=	**fsm model** ⟨id⟩ [⟨params⟩] (⟨io⟩$^*_,$) {
		states : ⟨state⟩$^*_,$;
		[⟨vars⟩]
		trans : ⟨transition⟩$^*_,$;
		itrans : ⟨itransition⟩ ;
		}
⟨state⟩	::=	uid [**where**⟨outp_val⟩$^+_{\mathbf{and}}$]
⟨outp_val⟩	::=	lid = ⟨scalar_const⟩
⟨params⟩	::=	< ⟨param⟩$^*_,$ >
⟨param⟩	::=	lid : ⟨type_expr⟩
⟨io⟩	::=	**in** ⟨io_desc⟩
	|	**out** ⟨io_desc⟩
	|	**inout** ⟨io_desc⟩
⟨io_desc⟩	::=	lid : ⟨type_expr⟩
⟨vars⟩	::=	**vars** : ⟨var⟩$^*_,$;
⟨var⟩	::=	lid$^+_,$: ⟨type_expr⟩
⟨transition⟩	::=	⟨rule_prefix⟩ uid -> uid ⟨condition⟩ [⟨actions⟩]

⟨rule_prefix⟩ ::= `|` | `!`

⟨condition⟩ ::= **on** lid [⟨guards⟩]

⟨guards⟩ ::= **when** $\langle\text{expr}\rangle^{+}_{.}$

⟨actions⟩ ::= **with** $\langle\text{action}\rangle^{+}_{;}$

⟨action⟩ ::= lid
| ⟨lhs⟩ `:=` ⟨expr⟩

⟨lhs⟩ ::= lid
| lid `[` ⟨expr⟩ `]`
| lid `[` ⟨expr⟩ `:` ⟨expr⟩ `]`
| lid `.` lid

⟨itransition⟩ ::= `| ->` uid [⟨actions⟩]

⟨global⟩ ::= **input** ⟨id⟩ `:` ⟨type_expr⟩ `=` ⟨stimuli⟩
| **output** $\langle\text{id}\rangle^{+}_{,}$ `:` ⟨type_expr⟩
| **shared** $\langle\text{id}\rangle^{+}_{,}$ `:` ⟨type_expr⟩

⟨stimuli⟩ ::= **periodic** `(` **int** `,` **int** `,` **int** `)`
| **sporadic** `(` $\textbf{int}^{*}_{,}$ `)`
| **value_changes** `(` $\langle\text{value\_change}\rangle^{*}_{,}$ `)`

⟨value_change⟩ ::= **int** `:` ⟨stim_const⟩

⟨fsm_inst⟩ ::= **fsm** ⟨id⟩ `=` ⟨id⟩ [`<` $\langle\text{param\_value}\rangle^{+}_{,}$ `>`] `(` $\langle\text{id}\rangle^{*}_{,}$ `)`

⟨param_value⟩ ::= ⟨scalar_const⟩
| lid

⟨type_expr⟩ ::= **event**
| **int** ⟨int_annot⟩
| **float**
| **char**
| **bool**
| lid
| ⟨type_expr⟩ **array** `[` ⟨array_size⟩ `]`

⟨int_annot⟩ ::= ϵ
| `<` ⟨type_size⟩ `>`
| `<` ⟨type_size⟩ `:` ⟨type_size⟩ `>`

⟨array_size⟩ ::= ⟨type_size⟩

```
⟨type_size⟩    ::= int
                |  lid

⟨expr⟩         ::= ⟨simple_expr⟩
                |  ⟨expr⟩ + ⟨expr⟩
                |  ⟨expr⟩ - ⟨expr⟩
                |  ⟨expr⟩ * ⟨expr⟩
                |  ⟨expr⟩ / ⟨expr⟩
                |  ⟨expr⟩ % ⟨expr⟩
                |  ⟨expr⟩ == ⟨expr⟩
                |  ⟨expr⟩ != ⟨expr⟩
                |  ⟨expr⟩ > ⟨expr⟩
                |  ⟨expr⟩ < ⟨expr⟩
                |  ⟨expr⟩ >= ⟨expr⟩
                |  ⟨expr⟩ <= ⟨expr⟩
                |  ⟨expr⟩ & ⟨expr⟩
                |  ⟨expr⟩ || ⟨expr⟩
                |  ⟨expr⟩ ^ ⟨expr⟩
                |  ⟨expr⟩ >> ⟨expr⟩
                |  ⟨expr⟩ << ⟨expr⟩
                |  ⟨expr⟩ +. ⟨expr⟩
                |  ⟨expr⟩ -. ⟨expr⟩
                |  ⟨expr⟩ *. ⟨expr⟩
                |  ⟨expr⟩ /. ⟨expr⟩
                |  ⟨subtractive⟩ ⟨expr⟩
                |  lid [ ⟨expr⟩ ]
                |  lid [ ⟨expr⟩ : ⟨expr⟩ ]
                |  lid ( ⟨expr⟩*, )
                |  lid . lid
                |  ⟨expr⟩ ? ⟨expr⟩ : ⟨expr⟩
                |  ⟨expr⟩ :: ⟨type_expr⟩

⟨simple_expr⟩  ::= lid
                |  uid
                |  ⟨scalar_const⟩
                |  ( ⟨expr⟩ )

⟨subtractive⟩  ::= -
                |  -.

⟨scalar_const⟩ ::= int
                |  bool
                |  float
                |  char

⟨const⟩        ::= ⟨scalar_const⟩
                |  ⟨array_const⟩
```

$$
\begin{array}{rcl}
\langle \text{array\_const} \rangle & ::= & \texttt{[}\ \langle \text{const} \rangle^{+}_{,}\ \texttt{]} \\
\\
\langle \text{stim\_const} \rangle & ::= & \langle \text{scalar\_const} \rangle \\
 & | & \langle \text{scalar\_const} \rangle\ \texttt{::}\ \langle \text{type\_expr} \rangle \\
 & | & \text{uid} \\
 & | & \langle \text{record\_const} \rangle \\
\\
\langle \text{record\_const} \rangle & ::= & \{\ \langle \text{record\_field\_const} \rangle^{+}_{,}\ \} \\
\\
\langle \text{record\_field\_const} \rangle & ::= & \text{lid} = \langle \text{stim\_const} \rangle \\
\\
\langle \text{id} \rangle & ::= & \text{lid} \\
 & | & \text{uid}
\end{array}
$$

Chapter 2

Formal semantics

We here give the formal *static* and *dynamic* semantics for a simplified version of the RFSM language, called CORE RFSM. Compared to the "standard" RFSM language[1], it lacks type, constant and function declarations, state valuation and has only basic types. Its abstract syntax is described below. We note X^* (resp. X^+) the repetition of 0 (resp. 1) or more X. The syntax of expressions is deliberately not explicited here.

program ::=	`program` *fsm_model*$^+$ *io_decl*$^+$ *fsm_inst*$^+$	
fsm_model ::=	`fsm model` id *inp** *outp** *state*$^+$ *var** *trans*$^+$ *itrans*	
state ::=	id	
inp, *outp*, *var* ::=	id : *typ*	
trans ::=	$\langle$id, *cond*, *action**, id$\rangle$	$\langle$*src state*, *cond*, *actions*, *dst state*$\rangle$
cond ::=	$\langle$id, *guard**$\rangle$	$\langle$*triggering even*, *guards*$\rangle$
guard ::=	*expr*	*boolean expression*
action ::=	| id	*emit event*
	| id := *expr*	*update local, shared or output variable*
io_decl ::=	*io_cat* `id` : *typ*	
io_cat ::=	`input` | `input` | `shared`	
fsm_inst ::=	`fsm` id i^* o^*	*model, IO bindings*
typ ::=	`event` | `int` | `bool`	

2.1 Common definitions

Both the static and static semantics will use *environments*. An **environment** is a (partial) map from *names* to *values*. If Γ is an environment and x a name, we will, classically, note

- $x \in \Gamma$ if $x \in \mathrm{dom}(\Gamma)$,
- $\Gamma(x)$ the value mapped to x in Γ ($\Gamma(x) = \bot$ if $x \notin \Gamma$),

[1] Described in the User Manual.

- $\Gamma[x \mapsto v]$ the environment that maps x to v and behaves like Γ otherwise (possibly overriding an existing mapping of x),
- $\emptyset$ the empty environment,

2.2 Static semantics

The static interpretation of a Core Rfsm program is a pair

$$\mathcal{H} = \langle M, C \rangle$$

where

- M is a set of **automata**,
- C is a **context**.

▶ A **context** is a 6-tuple $\langle I_e, I_v, O_e, O_v, H_e, H_v \rangle$ where

- I_e (resp. O_e, H_e) is the set of global inputs (resp. outputs, shared values) with an *event* type,
- I_v (resp. O_v, H_v) is the set of global inputs (resp. outputs, shared values) with a *non-event* type.

▶ An **automaton** $\mu \in M$ is a 3-tuple

$$\mu = \langle \mathcal{M}, q, \mathcal{V} \rangle$$

where

- $\mathcal{M}$ is the associated (static) model,
- q its current state,
- $\mathcal{V}$ an environment giving the current value of its local variables.

▶ A **model** $\mathcal{M}$ is a 6-tuple

$$\mathcal{M} = \langle Q, I, O, V, T, \tau_0 \rangle$$

where

- Q is a (finite) set of *states*,
- I and O are environments respectively mapping input and output names to types,
- V is an environment mapping local variable names to types,
- $I_e = \{x \in I \mid I(x) = \texttt{event}\}$ and $I_v = \{x \in I \mid I(x) \neq \texttt{event}\}$,
- $O_e = \{x \in O \mid O(x) = \texttt{event}\}$ and $O_v = \{x \in O \mid O(x) \neq \texttt{event}\}$,
- $T \subset Q \times C \times \mathcal{S}(A) \times Q$ is a set of **transitions**, where
  - $C = I_e \times 2^{\mathcal{B}(I_v \cup V)}$,

– $\mathcal{B}(E)$ is the set of *boolean expressions* built from a set of variables E and the classical boolean operators[2],
– $\mathcal{S}(A)$ is the set of *sequences* built from elements of the set A, where a *sequence* $\vec{a}$ is an ordered collection $\langle a_1; \ldots ; a_n\rangle$[3],
– $A = \mathcal{U}(O_v \cup V, I_v \cup V) \cup O_e$,
– $\mathcal{U}(E, E')$ is the set of *assignations* of variables taken in a set E by *expressions* built from a set of variable E' and the classical boolean and arithmetic operators and constants[4].

- $\tau_0 \in Q \times \mathcal{S}(\mathcal{U}(O_v \cup V, \emptyset))$ is the **initial transition**.

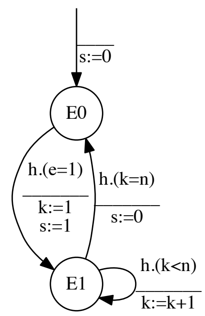
Having $\tau = (q, c, \vec{a}, q')$ in T means that there's a transition from state q to state q' enabled by the condition c and triggering a (possibly empty) sequence $\vec{a}$, where

- the condition $c \in C$ is made of
  – a trigerring event $e \in I_e$,
  – a (possibly empty) set of boolean expressions (guards), involving inputs having a non-event type or local variables,
- the actions in $\vec{a}$ consist either in the emission of an event or the modification of an output or local variable.

The initial transition τ_0 consists in a state (the initial state) and a (possibly empty) sequence of initial actions. Contrary to actions associated to "regular" transitions, initial actions cannot not emit events and the assigned values cannot depend on inputs or local variables.

Example. The model of the automaton depicted below[5] can be formally described as $\mathcal{M} = \langle Q, I, O, V, T, \tau_0\rangle$ where :

- $Q = \{E0, E1\}$
- $I = \{h \mapsto \mathsf{event}, e \mapsto \mathsf{bool}\}$
- $O = \{s \mapsto \mathsf{bool}\}$
- $V = \{k \mapsto \mathsf{bool}\}$
- $T = \{$
  $\langle E0, \langle H, \{e = 0\}\rangle, \langle\rangle, E0\rangle$,
  $\langle E0, \langle H, \{e = 1\}\rangle, \langle s \leftarrow 1; k \leftarrow 1\rangle, E1\rangle$,
  $\langle E1, \langle H, \{k < 3\}\rangle, \langle k \leftarrow k + 1\rangle, E1\rangle$,
  $\langle E1, \langle H, \{k = 3\}\rangle, \langle s \leftarrow 0\rangle, E0\rangle\}$
- $\tau_0 = \langle E0, \langle s \leftarrow 0\rangle\rangle$



[2]This set can be formally derived from the abstract syntax.
[3]For example, if $A = \{1, 2\}$, then $\mathcal{S}(A) = \{\langle\rangle, \langle 1\rangle, \langle 2\rangle, \langle 1; 1\rangle, \langle 1; 2\rangle, \langle 2; 1\rangle, \langle 2; 2\rangle, \langle 1; 2; 1\rangle, \ldots\}$, where $\langle\rangle$ denotes the empty sequence.
[4]Again, this can be formally derived from the abstract syntax.
[5]This model, a calibrated pulse generator has been introduced in the *Overview* chapter of the user manual.

Rules

▶ Rule Program gives the static interpretation of a program. The static environment Γ_{M} (resp. Γ_{I}) records the (typed) declarations of models (resp. IOs).

$$\frac{\begin{array}{c} \mathit{fsm\_model}^{+} \rightarrow \Gamma_{\mathsf{M}} \\ \mathit{io\_decl}^{+} \rightarrow \Gamma_{\mathsf{I}} \\ \Gamma_{\mathsf{M}}, \Gamma_{\mathsf{I}} \vdash \ \mathit{fsm\_inst}^{+} \rightarrow M \\ C = \mathcal{L}(\Gamma_{\mathsf{I}}) \end{array}}{\texttt{program}\ \mathit{fsm\_model}^{+}\ \mathit{io\_decl}^{+}\ \mathit{fsm\_inst}^{+} \rightarrow M, C} \qquad (\textsc{Program})$$

The $\mathcal{L}$ function builds a static context C from the IO environment Γ_{I} :

$$\mathcal{L}(\Gamma_{\mathsf{I}}) = \langle I_e, I_v, O_e, O_v, H_e, H_v \rangle$$

where

$$\begin{array}{rlrl} I_e = & \{x \in \mathrm{dom}(\Gamma_{\mathsf{I}}) \mid \Gamma_{\mathsf{I}}(x) = \langle \mathrm{input}, \texttt{event} \rangle\} & I_v = & \{x \in \mathrm{dom}(\Gamma_{\mathsf{I}}) \mid \Gamma_{\mathsf{I}}(x) = \langle \mathrm{input}, \tau \rangle,\ \tau \neq \texttt{event}\} \\ O_e = & \{x \in \mathrm{dom}(\Gamma_{\mathsf{I}}) \mid \Gamma_{\mathsf{I}}(x) = \langle \mathrm{output}, \texttt{event} \rangle\} & O_v = & \{x \in \mathrm{dom}(\Gamma_{\mathsf{I}}) \mid \Gamma_{\mathsf{I}}(x) = \langle \mathrm{output}, \tau \rangle,\ \tau \neq \texttt{event}\} \\ H_e = & \{x \in \mathrm{dom}(\Gamma_{\mathsf{I}}) \mid \Gamma_{\mathsf{I}}(x) = \langle \mathrm{shared}, \texttt{event} \rangle\} & H_v = & \{x \in \mathrm{dom}(\Gamma_{\mathsf{I}}) \mid \Gamma_{\mathsf{I}}(x) = \langle \mathrm{shared}, \tau \rangle,\ \tau \neq \texttt{event}\} \end{array}$$

▶ Rule Models gives the interpretation of model declarations, giving an environment Γ_{M}.

$$\frac{\begin{array}{c} \forall i \in \{1, \ldots, n\} \qquad \Gamma_{\mathsf{M}}^{i-1},\ \mathit{fsm\_model}_i \rightarrow \Gamma_{\mathsf{M}}^{i} \\ \Gamma_{\mathsf{M}}^{0} = \emptyset \quad \Gamma_{\mathsf{M}} = \Gamma_{\mathsf{M}}^{n} \end{array}}{\mathit{fsm\_model}_1, \ldots, \mathit{fsm\_model}_n \rightarrow \Gamma_{\mathsf{M}}} \qquad (\textsc{Models})$$

▶ Rule Model gives the interpretation of a single model declaration. It just records the corresponding description in the environment Γ_{M}, after performing some sanity checks, using the $\mathsf{valid\_model}$ function, not detailed here. This function checks that :

- all variable names occuring in guards are listed as input or local variable,
- all expressions occuring in the guards of a transition have type bool,
- ...

TODO: TBC

$$\frac{\mathcal{M} = \langle Q, I, O, V, T, \tau_0 \rangle \quad \mathsf{valid\_model}(\mathcal{M})}{\texttt{fsm model id}\ I\ O\ Q\ V\ T\ \tau_0 \rightarrow \Gamma_{\mathsf{M}}[\mathrm{id} \mapsto \mathcal{M}]} \qquad (\textsc{Model})$$

▶ Rules IOs and IO give the interpretation of IO declarations, producing an environment Γ_{I} binding names to a pair $\langle \mathit{io\_cat}, \mathit{typ} \rangle$.

$$\frac{\begin{array}{c} \forall i \in \{1, \ldots, n\} \qquad \Gamma_{\mathsf{I}}^{i-1},\ \mathit{io\_decl}_i \rightarrow \Gamma_{\mathsf{I}}^{i} \\ \Gamma_{\mathsf{I}}^{0} = \emptyset \quad \Gamma_{\mathsf{I}} = \Gamma_{\mathsf{I}}^{n} \end{array}}{\mathit{io\_decl}_1, \ldots, \mathit{io\_decl}_n \rightarrow \Gamma_{\mathsf{I}}} \qquad (\textsc{IOs})$$

$$\frac{}{\Gamma_{\mathsf{I}},\ \mathit{cat}\ \texttt{id} : \mathit{typ} \rightarrow \Gamma_{\mathsf{I}}[\texttt{id} \mapsto \langle \mathit{cat}, \mathit{typ} \rangle]} \qquad (\textsc{IO})$$

▶ Rules INSTS gives the interpretation of FSM instance declarations.

$$\frac{\forall i \in \{1,\dots,n\} \qquad \Gamma_{\mathsf{M}}, \Gamma_{\mathsf{I}} \vdash \ \mathit{fsm\_inst}_i \rightarrow \mu_i \qquad M = \langle \mu_1; \dots; \mu_n \rangle}{\mathit{fsm\_inst}_1, \dots, \mathit{fsm\_inst}_n \rightarrow \mathcal{H} = \langle M, C \rangle} \quad (\textsc{Insts})$$

▶ Rule INST gives the interpretation of a single FSM instance as an automaton.

$$\frac{\begin{array}{c}\Gamma_{\mathsf{M}}(\mathrm{id}) = \langle \langle i_1'{:}\tau_1', \dots; i_m'{:}\tau_m' \rangle, \langle o_1'{:}\tau_1'', \dots; o_n'{:}\tau_n'' \rangle, Q, V, T, \langle q_0, \vec{a_0} \rangle \rangle \\ \Phi = \{ i_1' \mapsto i_1, \dots, i_m' \mapsto i_m, o_1' \mapsto o_1, \dots, \o_n' \mapsto o_n \} \\ \forall i \in \{1,\dots,m\} \quad \Gamma_{\mathsf{I}}(i_i) = \langle \mathrm{cat}_i, \tau_i \rangle, \ \mathrm{cat}_i \in \{\mathtt{input}, \mathtt{shared}\} \wedge \tau_i = \tau_i' \\ \forall i \in \{1,\dots,n\} \quad \Gamma_{\mathsf{I}}(o_i) = \langle \mathrm{cat}_i, \tau_i \rangle, \ \mathrm{cat}_i \in \{\mathtt{output}, \mathtt{shared}\} \wedge \tau_i = \tau_i'' \\ \mathcal{M}' = \langle \langle i_1{:}\tau_1', \dots; i_m{:}\tau_m' \rangle, \langle o_1{:}\tau_1'', \dots; o_n{:}\tau_n'' \rangle, Q, V, \Phi_T(T), \langle q_0, \Phi_A(\vec{a_0}) \rangle \rangle \\ \mu = \langle \mathcal{M}', q_0, \mathcal{I}(V) \rangle \end{array}}{\Gamma_{\mathsf{M}}, \Gamma_{\mathsf{I}} \vdash \ \mathtt{fsm}\ \mathrm{id}\ \langle i_1; \dots; i_m \rangle \ \langle o_1; \dots; o_n \rangle \rightarrow \mu} \quad (\textsc{Inst})$$

Rule INST checks the arity and the type conformance of the inputs and outputs supplied to the instanciated model. The rule builds a *substitution* Φ for binding *local* input and output names to *global* ones. This substitution is applied to each transition (including the initial one) of the resulting automaton using the derived functions Φ_T and Φ_A (not detailed here). The $\mathcal{I}$ function builds an environment from a set of names, initializing each binding with the $\perp$ ("undefined") value :

$$\mathcal{I}(\{x_1, \dots, x_n\}) = \{x_1 \mapsto \perp, \dots, x_n \mapsto \perp\}$$

2.3 Dynamic semantic

The dynamic semantics of a CORE RFSM program will be given in terms of (instantaneous) **reactions**.

$$\mathcal{C} \vdash \ M, \ \Gamma \ \xrightarrow[\rho]{\sigma} M', \ \Gamma'$$

meaning

"in the static context $\mathcal{C}$ and given a (dynamic) environment Γ, a set of automata M reacts to a *stimulus* σ leading to an updated set of automata M', an updated environment Γ' and producing a *response* ρ"

Definitions

▶ Given an expression e and an environment Γ, $\mathcal{E}_\Gamma[\![\mathsf{e}]\!]$ denotes the value obtained by **evaluating** expression e within environment Γ. For example

$$\mathcal{E}_{\{x \mapsto 1, y \mapsto 2\}}[\![x + y]\!] = 3$$

▶ An **event** e is either the occurrence of a *pure event* ϵ or the assignation of a **value** v to a **name** (input, output or local variable) :

$$e = \begin{cases} \epsilon \\ x \leftarrow v \end{cases}$$

► An **event set** E is a dated set of events

$$E = \langle t, \{e_1, \ldots, e_n\} \rangle$$

where t gives the occurrence **time** (logical instant).

For example $E = \langle 10, \{h, e \leftarrow 0\} \rangle$ means

"At time t=10, event `h` occurs and (input) e is set to 0" .

The union of *event sets* is defined as

$$\langle t, e \rangle \cup \langle t', e' \rangle = \begin{cases} \langle t, e \cup e' \rangle & \text{if } t = t' \\ \perp & \text{otherwise} \end{cases}$$

► A **stimulus** σ (resp. **response** ρ) is just an event set involving inputs (resp. outputs).

TODO: Input et output par rapport à quoi : automate ou contexte ?

Rules

► Given a static description $\mathcal{H} = \langle M, C \rangle$ of a program, the **execution** of this program submitted to a sequence of stimuli $\vec{\sigma} = \sigma_1, \ldots, \sigma_n$ is formalized by rule Exec

$$\frac{\begin{array}{c} C \vdash\ M \rightarrow M_0,\ \Gamma_0 \\ \forall i \in \{1, \ldots, n\} \qquad C \vdash\ M_{i-1},\ \Gamma_{i-1} \xrightarrow[\rho_i]{\sigma_i} M_i,\ \Gamma_i \end{array}}{\mathcal{H} = \langle M, C \rangle \xrightarrow[\vec{\rho}=\langle \rho_1; \ldots; \rho_n \rangle]{\vec{\sigma}=\langle \sigma_1; \ldots; \sigma_n \rangle} M_n,\ \Gamma_n} \quad (\text{Exec})$$

In other words, the execution of the program is described as as a sequence of **instantaneous reactions**, which can be denoted as[6] :

$$M_0,\ \Gamma_0 \xrightarrow[\rho_1]{\sigma_1} M_1,\ \Gamma_1 \rightarrow \ldots \xrightarrow[\rho_n]{\sigma_n} M_n,\ \Gamma_n$$

where

- the *global environment* Γ here records the value of inputs and shared variables[7],
- $\rho_1, \ldots, \rho_n$ is the sequence of responses,
- M_n and Γ_n respectively give the final state of the automata and global environment.

► Rule Init describes how the initial set of automata M_0 and global environment Γ_0 are initialized by executing the initial transition of each automaton (producing a set of initial responses ρ_0.

[6] Omitting context C, which is constant during an execution.

[7] This environment is required to handle events describing modifications of these values, as described below (see rule ReactUpd).

$$\frac{\forall i \in \{1,\ldots,n\} \quad \mu_i = \langle \mathcal{M}_i, q_i, \mathcal{V}_i\rangle \quad \mathcal{M}_i = \langle ., ., ., ., ., \langle ., \vec{a_i}\rangle\rangle \quad C \vdash\ \mathcal{V}_i,\ \gamma_{i-1} \xrightarrow[\langle 0,\emptyset\rangle]{\vec{a_i},0} \mathcal{V}'_i,\ \gamma_i \quad \mu'_i = \langle \mathcal{M}_i, q_i, \mathcal{V}'_i\rangle \qquad C = \langle ., I_v, ., O_v, ., H_v\rangle \quad \gamma_0 = \mathcal{I}(I_v \cup O_v \cup H_v)}{C \vdash\ M = \{\mu_1,\ldots,\mu_n\} \rightarrow M_0 = \{\mu'_1,\ldots,\mu'_n\},\ \Gamma_0 = \gamma_n} \quad (\textsc{Init})$$

where the I_v, O_v and H_v sets, taken from the static context C, respectively give the name of inputs, outputs and shared variables.

Note. Rule Init does *not* produce any response ρ. This is because the initial actions of an automaton cannot emit events hence can only update the its local environment or the global one.

▶ Rule Acts describes how a sequence of actions $\vec{a}$ (at time t) updates the local and global environments, possibly emitting a set of responses[8].

$$\frac{\forall i \in \{1,\ldots,n\} \qquad C \vdash\ \mathcal{V}_{i-1},\ \Gamma_{i-1} \xrightarrow[\rho_i]{a_i,\ t} \mathcal{V}_i,\ \Gamma_i \qquad \mathcal{V}_0 = \mathcal{V} \quad \Gamma_0 = \Gamma \quad \rho_e = \bigcup_{i=1}^{n} \rho_i}{C \vdash\ \mathcal{V},\ \Gamma \xrightarrow[\rho_e]{\langle a_1;\ldots;a_n\rangle,\ t} \mathcal{V}_n,\ \Gamma_n} \quad (\textsc{Acts})$$

Note. The definition of rule Acts given above enforces a *sequential interpretation* of actions. For example

$$\{x \mapsto 1,\ s \mapsto \bot\},\ \Gamma \xrightarrow{\langle x\leftarrow x+1; s\leftarrow x\rangle, t} \{x \mapsto 2,\ s \mapsto 2\}, \Gamma$$

Rule Acts could easily be reformulated to describe other interpretations, such as a *synchronous* one, in which all RHS values are first evaluated and then assigned to LHS in parallel[9].

▶ Rules ActUpdL and ActUpdG respectively describe the effect of an action updating a local or global variable (shared variable or output)[10].

$$\frac{x \in \mathrm{dom}(\mathcal{V}) \quad v = \mathcal{E}_{\mathcal{V}\cup\Gamma}[\![\mathsf{e}]\!]}{C \vdash\ \mathcal{V},\ \Gamma \xrightarrow[\langle t,\emptyset\rangle]{x\leftarrow \mathsf{e},\ t} \mathcal{V}[x \mapsto v],\ \Gamma} \ (\textsc{ActUpdL}) \qquad \frac{x \in \mathrm{dom}(\Gamma) \quad v = \mathcal{E}_{\mathcal{V}\cup\Gamma}[\![\mathsf{e}]\!]}{C \vdash\ \mathcal{V},\ \Gamma \xrightarrow[\langle t,\emptyset\rangle]{x\leftarrow \mathsf{e},\ t} \mathcal{V},\ \Gamma[x \mapsto v]} \ (\textsc{ActUpdG})$$

▶ Rule React describes how a program M within a global environment Γ (instantaneously) reacts to a stimulus (event set) σ, producing a response (event set) ρ, an updated program M' and an updated environment Γ'.

$$\frac{\sigma_e, \sigma_v = \Sigma(\sigma) \qquad C \vdash\ M,\ \Gamma \xrightarrow{\sigma_v} M,\ \Gamma_v \qquad C \vdash\ M,\ \Gamma_v \xrightarrow[\rho_e]{\sigma_e} M',\ \Gamma'}{C \vdash\ M,\ \Gamma \xrightarrow[\rho_e]{\sigma} M',\ \Gamma'} \quad (\textsc{React})$$

where the function Σ partitions a *event set* into one containing the stimuli corresponding to *pure* events (ϵ) and another containing those corresponding to updates to global inputs :

[8] This set of responses is always empty when rule Acts is invoked in the context of Init.
[9] As happens in hardware synchronous implementations for example.
[10] The effect of an action emitting an event will be described by rules ActEmitS and ActEmitG, given latter.

$$\Sigma(\langle t, \{e_1, \ldots, e_n\}\rangle) = \langle t, \{e_i \mid e_i = \epsilon_i\}\rangle, \quad \langle t, \{e_i \mid e_i = x_i \leftarrow v_i\}\rangle$$

▶ Rule ReactUpd describes how a program M within a global environment Γ reacts to set of events describing updates to global inputs. These updates are just recorded in the environment and do not produce responses, nor trigger any reaction of the automata :

$$\frac{}{C \vdash\ M,\ \Gamma \xrightarrow{\sigma_v = \langle t, \{x_1 \leftarrow v_1, \ldots, x_m \leftarrow v_m\}\rangle} M,\ \Gamma[x_1 \mapsto v_1] \ldots [x_m \mapsto v_m]} \quad (\text{ReactUpd})$$

▶ Rule ReactEv describes how a program reacts to a set of pure events.

$$\frac{\begin{array}{c}\forall i \in \{1, \ldots, n\} \quad C \vdash\ \mu_{\pi(i)},\ \Gamma_{i-1} \xrightarrow[\rho_i]{\sigma_i} \mu'_{\pi(i)},\ \Gamma_i \qquad \sigma_i = \sigma_{i-1} \cup \rho_i \\ \Gamma_0 = \Gamma \qquad \sigma_0 = \sigma_e \qquad \rho_e = \bigcup_{i=1}^{n} \rho_i \qquad \Gamma' = \Gamma_n\end{array}}{C \vdash\ M = \{\mu_1, \ldots, \mu_n\}, \Gamma \xrightarrow[\rho]{\sigma_e = \langle t, \{\epsilon_1, \ldots, \epsilon_m\}\rangle}{}_e\ M' = \{\mu'_1, \ldots, \mu'_n\},\ \Gamma'} \quad (\text{ReactEv})$$

Each automaton reacts separately but *in a specific order*. This order is derived from the dependencies between automata. We say that an automaton μ' *depends on* another automaton μ at a given instant t, and note

$$\mu \leq \mu'$$

if the reaction of μ at this instant can trigger or modify the reaction of μ' at the same instant. Concretely, this happens when μ and μ' are respectively in states q and q' and there's (at least) one pair of transitions (τ, τ') starting respectively from q and q' so that

- τ' is triggered by an event emitted by τ, or
- a variable occuring in the guards associated to τ' is written by the actions associated to τ.

The function π used in ReactEv is a permutation of $\{1, \ldots, n\}$ defined so that

$$\mu_{\pi(1)} \leq \mu_{\pi(2)} \leq \cdots \leq \mu_{\pi(n)}$$

Having the automata of M react in the order $\pi(1), \ldots, \pi(n)$ ensures that any event emitted or local variable update performed by an automaton during a given reaction is effectively perceived by any other automaton *at the same reaction*, a principle called *instantaneous broadcats*.

The permutation π can easily be computed by a *topological sort* of the dependency graph derived from the conditions expressed above. In practice, this will be carried out by a static analysis of the program.

▶ Rules React1, React0 and ReactN describe how a single automaton reacts to a set of pure events, updating both its internal and global states and producing another set of (pure) events in response.

$$\frac{\begin{array}{c}\Delta_{\Gamma \cup \mathcal{V}}(\mathcal{M}, q, e) = \{\tau\} \\ C \vdash\ \mu,\ \Gamma \xrightarrow[\rho_e]{\tau,\ t} \mu', \Gamma'\end{array}}{C \vdash\ \mu = \langle \mathcal{M}, q, \mathcal{V}\rangle,\ \Gamma \xrightarrow[\rho_e]{\sigma_e = \langle t, e\rangle} \mu',\ \Gamma'} \quad (\text{React1}) \qquad \frac{\Delta_{\Gamma \cup \mathcal{V}}(\mathcal{M}, q, e) = \emptyset}{C \vdash\ \mu = \langle \mathcal{M}, q, \mathcal{V}\rangle,\ \Gamma \xrightarrow[\langle t, \emptyset\rangle]{\sigma_e = \langle t, e\rangle} \mu,\ \Gamma} \quad (\text{React0})$$

$$\frac{\begin{array}{c}\Delta_{\Gamma\cup\mathcal{V}}(\mathcal{M},q,e)=\{\tau_1,\ldots,\tau_n\}\\ \tau=\mathsf{choice}(\{\tau_1,\ldots,\tau_n\})\\ C\vdash\ \mu,\ \Gamma\xrightarrow[\rho_e]{\tau,\ t}\mu',\Gamma'\end{array}}{C\vdash\ \mu=\langle\mathcal{M},q,\mathcal{V}\rangle,\ \Gamma\xrightarrow[\rho_e]{\sigma_e=\langle t,e\rangle}\mu',\ \Gamma'}\qquad(\textsc{ReactN})$$

Given a automaton modelised by $\mathcal{M}$ and currently in state q, $\Delta_\Gamma(\mathcal{M},q,e)$, where $e=\{\epsilon_1,\ldots,\epsilon_n\}$, returns the set of *fireable* transitions, *i.e.* all the transitions triggered by the event set e starting from q and for which the all the associated boolean guards evaluate, in environment Γ, to true.

$$\Delta_\Gamma(\mathcal{M},q,\{\epsilon_1,\ldots,\epsilon_n\})=\bigcup_{i=1}^{n}\Delta_\Gamma(\mathcal{M},q,\epsilon_i)$$

where

$$\Delta_\Gamma(\langle.,.,.,.,T,.\rangle,q,\epsilon)=\{(q_s,c,a,q_d)\in T\mid q=q_s\wedge c=\langle\epsilon,\{e_1,\ldots,e_n\}\rangle\wedge\forall i\in\{1,\ldots,n\}\quad\mathcal{E}_\Gamma[\![e_i]\!]=\mathsf{true}\}$$

Rule React1 describes the case when the set of events triggers exactly *one* transition of the automaton. Its state and local variables are updated according to the actions listed in the transition and the remaining actions are used to generated the set of responses.

Rule React0 describes the case when the set of events does not trigger any transition. The automaton and the global environment are left unchanged.

Rule ReactN describes the case when the set of events triggers more than one transition. This situation corresponds to a non-deterministic behavior of the automaton. The function choice is here used to choose one transition[11].

► Rule Trans describes the effect of performing a transition, updating the automaton local and global states and returning a set of (pure) events as responses.

$$\frac{\begin{array}{c}\mu=\langle\mathcal{M},q,\mathcal{V}\rangle\qquad\tau=\langle q,c,\vec{a},q'\rangle\\ C\vdash\ \mathcal{V},\ \Gamma\xrightarrow[\rho_e]{\vec{a},t}\ \mathcal{V}',\ \Gamma'\\ \mu'=\langle\mathcal{M},q',\mathcal{V}'\rangle\end{array}}{C\vdash\ \mu,\ \Gamma\xrightarrow[\rho_e]{\tau,\ t}\mu',\ \Gamma'}\qquad(\textsc{Trans})$$

► Rules ActEmitS and ActEmitG complement the rules ActUpdL and ActUpdG given previously by describing the effect of an action emitting a shared or output event. The H_e set, taken from context C, is here used to distinguish between to to. The formers can trigger the reaction of other(s) automaton(s), the latters are just ignored here (see note below).

$$\frac{C=\langle.,.,.,.,H_e,.\rangle\quad\epsilon\in H_e}{C\vdash\ \mathcal{V},\ \Gamma\xrightarrow[\langle t,\{\epsilon\}\rangle]{\epsilon,\ t}\mathcal{V},\ \Gamma}\ (\textsc{ActEmitS})\qquad\frac{C=\langle.,.,.,.,H_e,.\rangle\quad\epsilon\notin H_e}{C\vdash\ \mathcal{V},\ \Gamma\xrightarrow[\langle t,\emptyset\rangle]{\epsilon,\ t}\mathcal{V},\ \Gamma}\ (\textsc{ActEmitG})$$

Note. The semantics described here only defines how a program execution progresses, from the initial program to the final program state M. In practice, an interpreter will also build a *trace* of such an execution, recording all significant events (stimuli, responses, state moves, *etc.*). Building such a trace is easily performed by modifying the semantic rules given above. It has not been done here for the sake of simplicity.

[11]This can done, for example, by adding a *priority* to each transition.

Chapter 3

Compiler options

Compiler usage : `rfsmc [options...] files`

-main	set prefix for the generated main files
-dump_typed	dump typed representation of model(s)/program to stdout
-dump_static	dump static representation of model(s)/program to stdout
-target_dir	set target directory (default: .)
-lib	set location of the support library (default: ¡opam_prefix¿/share/rfsm)
-dot	generate .dot representation of model(s)/program
-sim	run simulation (generating .vcd file)
-ctask	generate CTask code
-systemc	generate SystemC code
-vhdl	generate VHDL code
-version	print version of the compiler and quit
-show_models	generate separate representations for uninstanciated FSM models
-dot_qual_ids	print qualified identifiers in DOT representations
-gui	generate report and error messages for interacting with rfsm-light
-dot_no_captions	Remove captions in .dot representation(s)
-dot_short_trans	Print single-line transition labels (default is multi-lines)
-dot_abbrev_types	Print abbreviated types (default is to print definitions)
-dot_boxed	Draw FSM instances in boxes
-sim_trace	set trace level for simulation (default: 0)
-vcd_int_size	set default int size for VCD traces (default: 8)
-synchronous_actions	interpret actions synchronously
-sc_time_unit	set time unit for the SystemC test-bench (default: SC_NS)
-sc_trace	set trace mode for SystemC backend (default: false)
-stop_time	set stop time for the SystemC and VHDL test-bench (default: 100)
-sc_double_float	implement float type as C++ double instead of float (default: false)
-vhdl_trace	set trace mode for VHDL backend (default: false)
-vhdl_time_unit	set time unit for the VHDL test-bench
-vhdl_ev_duration	set duration of event signals (default: 1 ns)
-vhdl_rst_duration	set duration of reset signals (default: 1 ns)
-vhdl_numeric_std	translate integers as numeric_std [un]signed (default: false)
-vhdl_bool_as_bool	translate all booleans as boolean (default: false)
-vhdl_dump_ghw	make GHDL generate trace files in .ghw format instead of .vcd

Chapter 4

Building language variants

Following the approach described in [1] for example, the RFSM compiler is implemented in a *modular* way. The language is split into a *host* language, describing the general structure and behavior of FSMs (states, transitions, ...) and a *guest* language[1] describing the syntax and semantics of *expressions* used in transition guards and semantics. Technically, this "separation of concern" is realized by providing the host language in the form of a *functor* taking as argument the module implementing the guest language.

This approach makes it fairly easy to produce variants of the "standard" RFSM language – with dedicated type systems and expression languages typically – by simply defining the module defining the guest language and applying the aforementioned functor. Actually, the "standard", RFSM language was designed using this approach, starting from a very simple "core" guest language gradually enriched with new features at the expression level[2].

The directory `src/guests/templ` in the distribution provides the basic structure for deploying this approach. In practice, to implement a language variant, one has to

- write the implementation of the guest language in the form of a collection of modules in the `lib` subdirectory[3],
- write the lexer and the parser for this guest language (expressions, type expressions, ...),
- build the compiler by simply invoking *make*

To illustrate this process, we describe in the sequel the implementation of a very simple language language for which the guest language has only two types, 'event' and 'bool', and expressions are limited to boolean constants and variables[4]. We focus here on the most salient features. The `Readme` file in the `templ` directory describes the procedure in details. Other examples, given in `src/guests/core` and `src/guests/others`[5], can also be used as guidelines.

4.1 Implementing the `Guest` module

The module implementing the guest language must match the following signature :

[1] "Base" in the terminology of [1].

[2] Traces of the incremental design process can be found in the `srs/guests/core`, `src/guests/others/szdints` and `src/guests/others/szvars` directories for example.

[3] These modules will be encapsulated in a single module and the latter will be passed to the host functor to build the target language.

[4] This language is essentially that provided in `src/guests/others/mini`.

[5] And, of course, in `src/guests/std`.

```
module type T = sig
  module Info : INFO
  module Types : TYPES
  module Syntax : SYNTAX with module Types = Types
  module Typing : TYPING with module Syntax = Syntax and module Types = Types
  module Value : VALUE with type typ = Types.typ
  module Static : STATIC with type expr = Syntax.expr and type value = Value.t
  module Eval : EVAL with module Syntax = Syntax and module Value = Value
  module Ctask: CTASK with module Syntax = Syntax
  module Systemc: SYSTEMC with module Syntax = Syntax and module Static = Static
      and type value = Value.t
  module Vhdl: VHDL with module Syntax = Syntax and module Static = Static and
     type value = Value.t
  module Error : ERROR
  module Options : OPTIONS
end
```

where

- module `Info` gives the name and version of the guest language,
- module `Syntax` describes the (abstract) syntax of the guest language,
- modules `Types` and `Typing` respectively describe the types and the typing rules of the guest language,
- module `Static` describes the static semantics of the guest language (basically, the interpretation of model parameters),
- modules `Value` and `Eval` respectively describe the values and the dynamic semantics manipulating these values,
- modules `CTask`, `Systemc` and `Vhdl` respectively describe the guest-level part of the C, SystemC and VHDL backends,
- module `Error` describes how guest-specific errors are handled,
- module `Options` describes guest-specific compiler options.

Listings 4.1, 4.2,4.4 and 4.6 respectively show the contents of of the `Types`, `Syntax`, `Value` and `Eval` modules for the `mini` language. The definition of non essential fonctions has been omitted[6].

Listing 4.1: Module `Guest.Types` (excerpt)

```
type typ =
  | TyEvent
  | TyBool
  | TyUnknown

let no_type = TyUnknown

let is_event_type (t: typ) = match t with TyEvent -> true | _ -> false
let is_bool_type (t: typ) = match t with TyBool -> true | _ -> false

let pp_typ ?(abbrev=false) fmt (t: typ) = ...
```

[6]See the corresponding source files in `src/guests/others/mini/lib` for a complete listing.

In module `Types`, the key definition is that of type `typ`, which describes the guest-level types, *i.e.* the types which can be attributed to guest-level expressions and variables. The type `TyUnknown` is used to define the value `no_type` which is attributed by the host language to (yet) untyped syntax elements.

Listing 4.2: Module `Guest.Syntax` (excerpt)

```
module Types = Types

module Location = Rfsm.Location
module Annot = Rfsm.Annot
module Ident = Rfsm.Ident

let mk ~loc x = Annot.mk ~loc ~typ:Types.no_type x

(* Type expressions *)

type type_expr = (type_expr_desc,Types.typ) Annot.t
and type_expr_desc = TeConstr of string (* name, no args here *)

let is_bool_type (te: type_expr) = ...
let is_event_type (te: type_expr) = ...

let pp_type_expr fmt (te: type_expr) =  ...

(* Expressions *)

type expr = (expr_desc,Types.typ) Annot.t
and expr_desc =
  | EVar of Ident.t
  | EBool of bool

let vars_of_expr (e: expr) = ...
and pp_expr fmt (e: expr) = ...

(* LHSs *)

type lhs = (lhs_desc,Types.typ) Annot.t
and lhs_desc = Ident.t

let lhs_var (l: lhs) = ...
let vars_of_lhs (l: lhs) = ...
let is_simple_lhs (l: lhs) = true

let mk_simple_lhs (v: Ident.t) =
  Annot.{ desc=v; typ=Types.no_type; loc=Location.no_location }

let pp_lhs fmt l =  ...
```

The module `Syntax` use the modules `Location`, `Annot` and `Ident` provided by the `Rfsm` host library. These modules provide types and functions to handle source code locations, syntax annotations and identifiers respectively. The type `('a,Types.typ) Annot.t` is associated to syntax nodes of type `'a`. The types `type_expr`, `expr` and `lhs` respectively describe guest-level type expressions, expressions and left-hand-sides (LHS). LHS are used in the definition of actions. In this language they are limited to simple identifiers (ex: `x:=<expr>`) but the guest language can use other forms (like in the RFSM "standard" language which support arrays and records in LHS).

Listing 4.3: Module `Guest.Values` (excerpt)

```
type typ =
  | TyEvent
  | TyBool
  | TyUnknown

let no_type = TyUnknown

let is_event_type t = match t with TyEvent -> true | _ -> false
let is_bool_type t = match t with TyBool -> true | _ -> false
let mk_type_fun ty_args ty_res = ...

let pp_typ ?(abbrev=false) fmt t = ...
```

Listing 4.4: Module `Guest.Value` (excerpt)

```
type t =
  | Val_bool of bool
  | Val_unknown

let default_value ty = match ty with
  | _ -> Val_unknown

exception Unsupported_vcd of t

let vcd_type (v: t) = match v with
  | Val_bool _ -> Rfsm.Vcd_types.TyBool
  | _ -> raise (Unsupported_vcd v)

let vcd_value (v: t) = match v with
  | Val_bool v -> Rfsm.Vcd_types.Val_bool v
  | _ -> raise (Unsupported_vcd v)

let pp fmt (v: t) = ...
```

The module `Guest.Value` define the values, associated to guest-level expressions by the dynamic semantics. The value `Val_unknown` is used to represent undefined or unitialized value. The functions `vcd_type` and `vcd_value` provide the interface to the VCD backend, generating simulation traces : they should return a VCD compatible representation (defined in the host library `Vcd_types` module) of a value.

Listing 4.5: Module `Guest.Eval` (excerpt)

```
module Syntax = Syntax
module Value = Value
module Env = Rfsm.Env
module Annot = Rfsm.Annot

type env = Value.t Env.t

exception Illegal_expr of Syntax.expr
exception Uninitialized of Rfsm.Location.t

let mk_env () = Env.init []
```

```
let upd_env lhs v env = Env.upd lhs.Annot.desc v env

let lookup ~loc v env =
 match Rfsm.Env.find v env with
   | Value.Val_unknown -> raise (Uninitialized loc)
   | v -> v

let eval_expr env e = match e.Annot.desc with
   | Syntax.EVar v -> lookup ~loc:e.Annot.loc v env
   | Syntax.EBool i -> Val_bool i

let eval_bool env e =
  match eval_expr env e with
   | Val_bool b -> b
   | _ -> raise (Illegal_expr e)

let pp_env fmt env = ...
```

The module `Guest.Eval` defines the guest-level dynamic semantics, *i.e.* the definition of the dynamic environment `env`, used to bind identifiers to values and of the functions `eval_expr` and `exal_bool` used to evaluate guest-level expressions. The presence of a distinct, `eval_bool` function is required because the boolean type and expressions are not part of the host-level syntax. The definition of the `env` type here uses that provided by the host library but any definition matching the corresponding signature would do.

4.2 Implementing the `Guest` parser

The parser for the guest language defines the concrete syntax for guest-level type expressions, expressions and LHS. It is written in a separate `.mly` file which will be combined with the parser for the host language[7]. There are only two guest specific tokens here, denoting the boolean constants `true` and `false`. The `open` directive in the prologue section gives access to the abstract syntax definitions given in `Guest.Syntax` module. The function `mk`, defined in this module, builds annotated syntax nodes, inserting the source code location.

Listing 4.6: File guest_parser.mly

```
%token TRUE
%token FALSE

%{
open Mini.Top.Syntax
%}

%%
%public type_expr:
   | tc = LID { mk ~loc:$sloc (TeConstr tc) }

%public lhs:
   | v = LID { mk ~loc:$sloc (mk_ident v) }

%public expr:
```

[7]Using `menhir` facility to split parser specifications into multiple files.

```
  | v = LID { mk ~loc:$sloc (EVar (mk_ident v)) }
  | c = scalar_const { c }

%public scalar_const:
  | TRUE { mk ~loc:$sloc (EBool true) }
  | FALSE { mk ~loc:$sloc (EBool false) }

%public const:
  | c = scalar_const { c }

%public stim_const:
  | c = scalar_const { c }
```

4.3 Implementing the Guest lexer

The `ocamllex` tool, used for defining the lexer, does not support multi-file definitions. The lexer for the guest-specific part of the target language is therefore supplied in the form of code fragments to be inserted in the host lexer definition file[8]. These fragments are listed in two separate files, present in the `bin` subdirectory of the guest directory :

- the file `guest_km` contains the lexer definition of the guest-specific keywords,
- the file `guest_rules` contains the guest-specific rules.

In the case of the `mini` language defined here, the latter is empty and the former only contains the two following lines.

```
"true", TRUE;
"false", FALSE;
```

4.4 Building the compiler

Defining the target language implementation and building the associated compiler is then simply obtained by the two following functor applications[9] :

```
module L = Rfsm.Host.Make(Mini.Top)

module Compiler =
  Rfsm.Compiler.Make
    (L)
    (Lexer)
    (struct include Parser type program = L.Syntax.program end)
```

Invoking the compiler now boils down to executing

```
let _ = Printexc.print Compiler.main ()
```

[8]Technically, this insertion is performed using the `cppo` tool.
[9]For technical reasons, these two statements are placed in distinct files, `binlang.ml` and `binrfsmc.ml`.

Bibliography

[1] X. Leroy. *A Modular Module System*. J. Functional Programming, 10(3):269-303, 2000.