A Conservative Extension of Synchronous Data-flow with State Machines

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A Bit of History

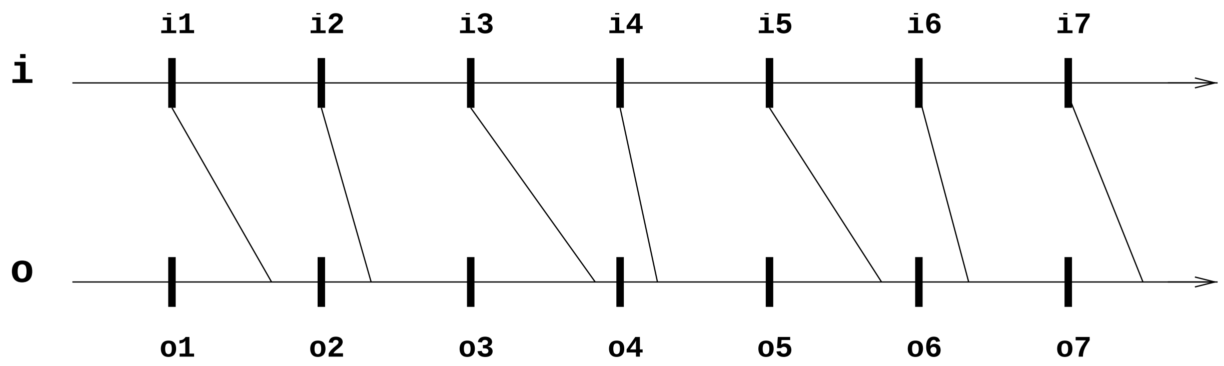
Arround 1984, several groups introduced domain-specific languages to program/design control embedded systems.

- **Lustre** (Caspi & Halbwachs, Grenoble): data-flow (block diagram) formalisms with functional (deterministic) semantics;
- **Signal** (Benveniste & Le Guernic, Rennes): data-flow formalisms with relational (non-deterministic) semantics to model also under-specified systems;
- **Esterel** (Berry & Gonthier, Sophia): hierarchical automata and process algebra (and SCCS flavor)

All these languages were recognised to belong to the same family, sharing the same *synchronous model of time*.

The Synchronous Model of Time

- a global **logical** time scale shared by all the processes;
- every event can be tagged according to this global time scale;
- parallel processes all agree on the presence/absence of events during those instants;
- parallel process do not fight for resources (as opposed to time-sharing concurrency): $P||Q$ means that P and Q (virtually) run in parallel;
- this reconcile parallelism and determinism



maximal reaction time $max_{n \in IN}(t_n - t_{n-1}) \leq bound$

Extension Needs for Synchronous Tools

Arround 1995, with Paul Caspi, we identified several “language” needs in synchronous tools

- modularity (libraries), abstraction mechanisms
- how to mix dataflow (e.g., Lustre) and control-flow (e.g., Esterel) in a unified way?
- language-based approach (vs verification) in order to statically guaranty some properties at compile time: type and clock inference (mandatory in a graphical tool), absence of deadlocks, etc.
- links with classical techniques from type theory (e.g., mathematical proof of programs, certification of a compiler)

The origins of Lucid Synchrone

What are the relationships between:

- Kahn Process Networks
- Synchronous Data-flow Programming (e.g., Lustre)
- (Lazy) Functional Programming (e.g., Haskell)
- Types and Clocks
- State machines and stream functions

What can we learn from the relationships between synchronous and functional programming?

Lucid Synchrone

Build a laboratory language to investigate those questions

- study extensions for SCADE/Lustre
- experiment things and write programs!
- Version 1 (1995), Version 2 (2001), V3 (2006)

Milestones

- Synchronous Kahn Networks [ICFP'96]
- Clocks as types [ICFP'96]
- Compilation (co-induction *vs* co-iteration) [CMCS'98]
- Clock calculus à la ML [Emsoft'03]
- Causality analysis [ESOP'01]
- Initialization analysis [SLAP'03, STTT'04]
- Higher-order and typing [Emsoft'04]
- Mixing data-flow and state machines [EMSOFT'05, EMSOFT'06]]
- N-Synchronous Kahn Networks [EMSOFT'05, POPL'06]

Some examples (V3)

- `int` denotes the type of integer streams,
- `1` denotes the (infinite) constant stream of 1,
- usual primitives apply point-wise

`c`	t	f	t	$\ldots$
`x`	x_0	x_1	x_2	$\ldots$
`y`	y_0	y_1	y_2	$\ldots$
`if c then x else y`	x_0	y_1	x_2	$\ldots$

Combinatorial functions

Example: 1-bit adder

```
let xor x y = (x & not (y)) or (not x & y)

let full_add(a, b, c) = (s, co)
  where
      s = (a xor b) xor c
  and co = (a & b) or (b & c) or (a & c)
```

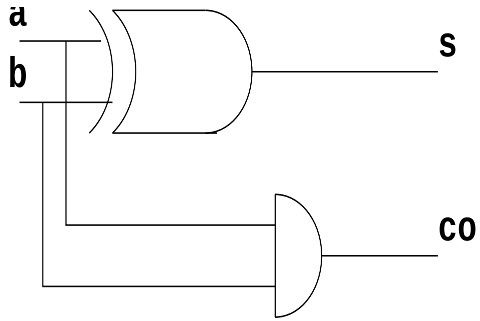
The compiler automatically infer the type and clock signature.

```
val full_add :  bool * bool * bool -> bool * bool
val full_add :: 'a * 'a * 'a -> 'a * 'a
```

Full Adder (hierarchical)

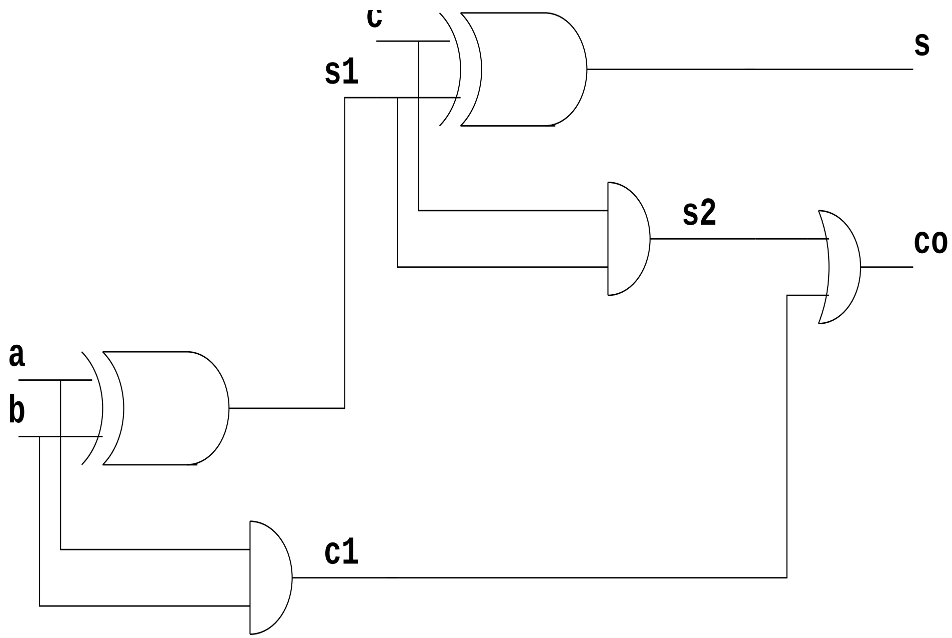
Compose two “half adder”

```
let half_add(a,b) = (s, co)
    where
        s = a xor b
    and co = a & b
```



Instantiate it twice

```
let full_add(a,b,c) = (s, co)
  where
      (s1, c1) = half_add(a,b)
  and (s, c2) = half_add(c, s1)
  and co = c1 or c2
```



Temporal operators

Operators `fby`, `->`, `pre`

- `fby`: unit initialized delay
- `->`: stream initialization operator
- `pre`: non initialized delay (register)

`x`	x_0	x_1	x_2	$\ldots$
`y`	y_0	y_1	y_2	$\ldots$
`x fby y`	x_0	y_0	y_1	$\ldots$
`pre x`	nil	x_0	x_1	$\ldots$
`x -> y`	x_0	y_1	y_2	$\ldots$

Sequential functions

- Functions may depend on the past (the system has a state)
- Example: edge front detector

```
let node edge x = x -> not (pre x) & x

val edge :  bool => bool
val edge :: 'a -> 'a
```

x	t	f	t	t	t	f	$\ldots$
edge x	t	f	t	f	f	f	$\ldots$

In the V3, we distinguish combinatorial functions (`->`) from sequential ones (`=>`)

Polymorphism (code reuse)

```
let node delay x = x -> pre x

val delay :  'a => 'a
val delay :: 'a -> 'a

let node edge x = false -> x <> pre x

val edge :  'a => 'a
val edge :: 'a -> 'a
```

In Lustre, polymorphism is limited to a set of predefined operators (e.g, `if/then/else`, `when`) and do not pass abstraction barriers.

Other features: higher-order, data-types, etc.

Question: How to mix data-flow and control-flow in an arbitrary way?

Designing Mixed Systems

Data dominated Systems: continuous and sampled systems, block-diagram formalisms

↪ Simulation tools: Simulink, etc.

↪ Programming languages: SCADE/Lustre, Signal, etc.

Control dominated systems: transition systems, event-driven systems, Finite State Machine formalisms

↪ StateFlow, StateCharts

↪ SyncCharts, Argos, Esterel, etc.

What about mixed systems?

- most system are a mix of the two kinds: systems have **"modes"**
- each mode is a big control law, naturally described as data-flow equations
- a control part switching these modes and naturally described by a FSM

Extending SCADE/Lustre with State Machines

SCADE/Lustre:

- data-flow style with synchronous semantics
- certified code generator

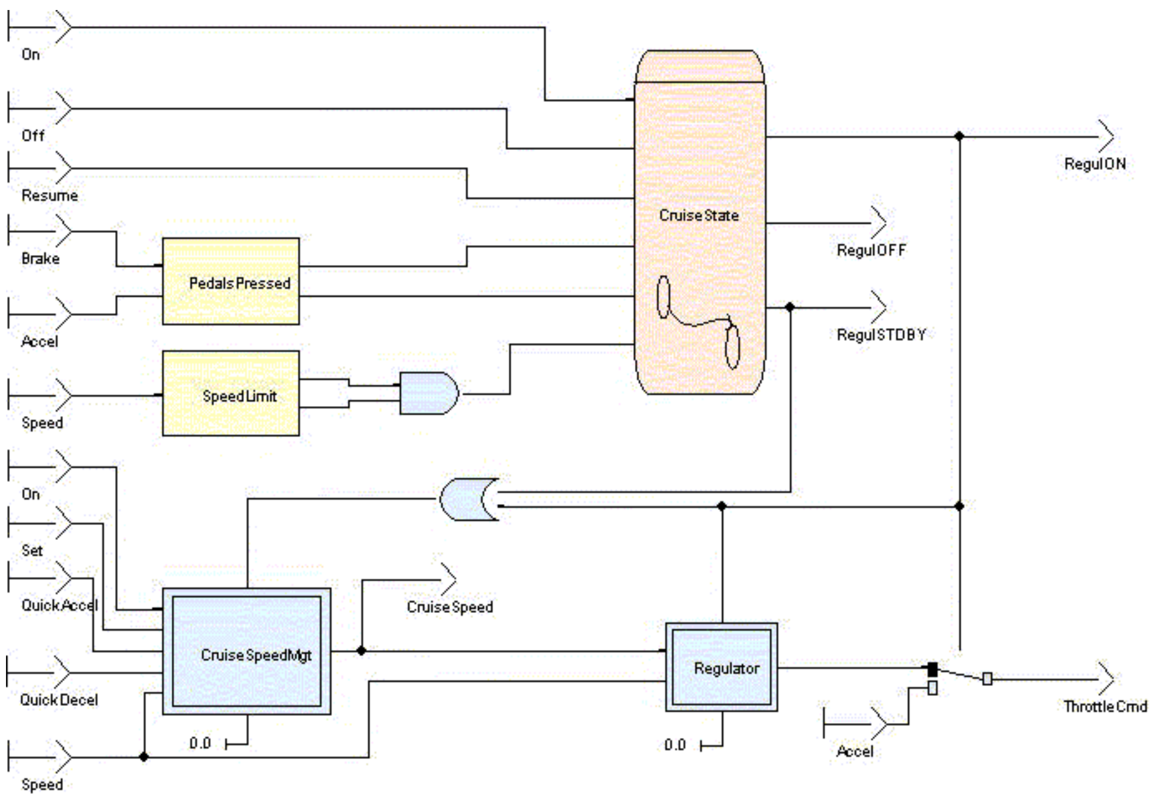
Motivations

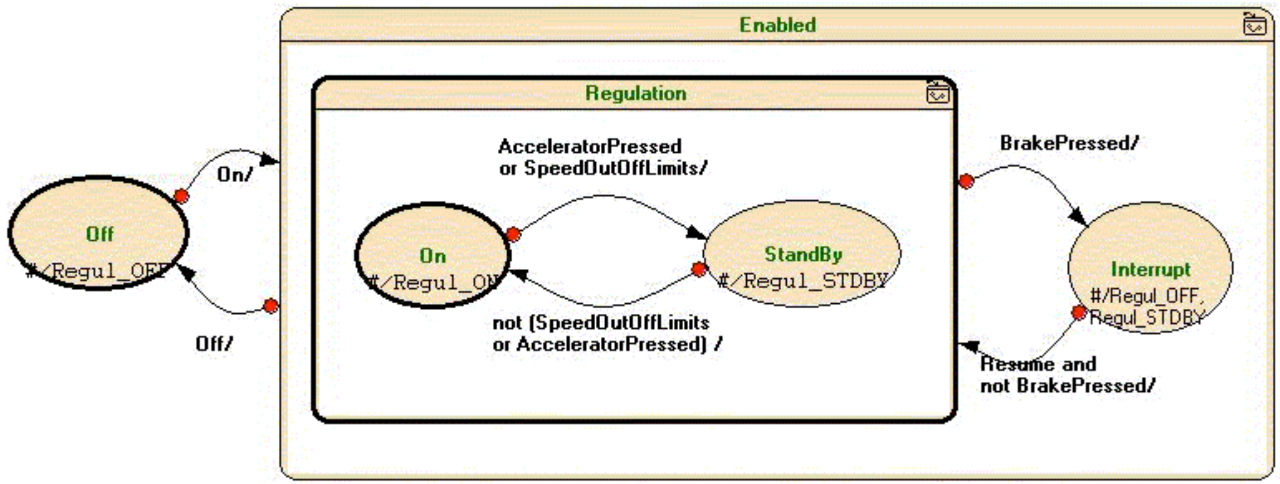
- activation conditions between several "modes"
- arbitrary nesting of automata and equations
- well integrated, inside the same language (tool)
- in a **uniform formalism** (code certification, code quality, readability)
- be **conservative**: accept all Scade/Lustre and keep the semantics of the kernel
- which can be formely **certified** (to meet avionic constraints)
- efficient code, keep (if possible) the existing certified code generator

First approach: linking mechanisms

- two (or more) specific languages: one for data-flow and one for control-flow
- "linking" mechanism. A sequential system is more or less represented as a pair:
  - a transition function $f : S \times I \rightarrow O \times S$
  - an initial memory $M_0 : S$
- agree on a common representation and add some glue code
- this is provided in most academic and industrial tools
- PtolemyII, Simulink + StateFlow, Lustre + Esterel Studio SSM, etc.

An example: the Cruise Control (SCADE V5.1)





Observations

- automata can only appear at the leaves of the data-flow model: we need a finer integration
- forces the programmer to make decisions at the very beginning of the design (what is the good methodology?)
- the control structure is not explicit and hidden in boolean values: nothing indicate that modes are exclusive
- code certification?
- efficiency/simplicity of the code?
- how to exploit this information for program analysis and verification tools?

Can we provide a finer integration of both styles inside a unique language?

Extending Synchronous Data-flow with Automata [EMSOFT05]

Basis

- *Mode-Automata* by Maraninchi & Rémond [ESOP98, SCP03]
- *SignalGTI* (Rutten [EuroMicro95] and *Lucid Synchrone V2* (Hamon & Pouzet [PPDP00])

Proposal

- extend a basic clocked calculus with automata constructions
- base it on a *translation semantics* into well clocked programs; gives both the semantics and the compilation method

Two implementations

- *Lucid Synchrone* language and compiler
- *ReLuC* compiler of SCADE at Esterel-Technologies; the basis of SCADE V6 (released in summer 2007)

Semantic principles

- only one set of equations is executed during a reaction
- two kinds of transitions: Weak delayed ("until") or Strong ("unless")

- both can be "by history" (H* in UML) or not (if not, both the SSM and the data-flow in the target state are reseted
- at most one strong transition followed by a weak transition can be fired during a reaction
- at every instant:
  - what is the current active state?
  - execute the corresponding set of equations
  - what is the next state?
- forbids arbitrary long state traversal, simplifies program analysis, better generated code

Translation semantics into well-clocked programs

- use clocks to give a precise semantics: we know how to compile clocked data-flow programs efficiently
- give a translation semantics into the basic clocked data-flow language;
- clocks are fundamental here: classical one-hot (clock-less) coding (as done for circuits) does not allow to generate good sequential code afterwards
- type and clock preserving source-to-source transformation
  - $T : ClockedBasicCalculus + Automata \rightarrow ClockedBasicCalculus$
  - $H \vdash e : ty$ iff $H \vdash T(e) : ty$
  - $H \vdash e : cl$ iff $H \vdash T(e) : cl$

A clocked data-flow basic calculus

Expressions:

$$
\begin{array}{lll}
e & ::= & C \mid x \mid e \;\texttt{fby}\; e \mid (e, e) \mid x(e) \\
 & & \mid x(e) \;\texttt{every}\; e \\
 & & \mid e \;\texttt{when}\; C(e) \\
 & & \mid \texttt{merge}\; e\; (C \rightarrow e) \ldots (C \rightarrow e)
\end{array}
$$

Equations:

$$D \quad ::= \quad D \;\texttt{and}\; D \mid x = e$$

Enumerated types:

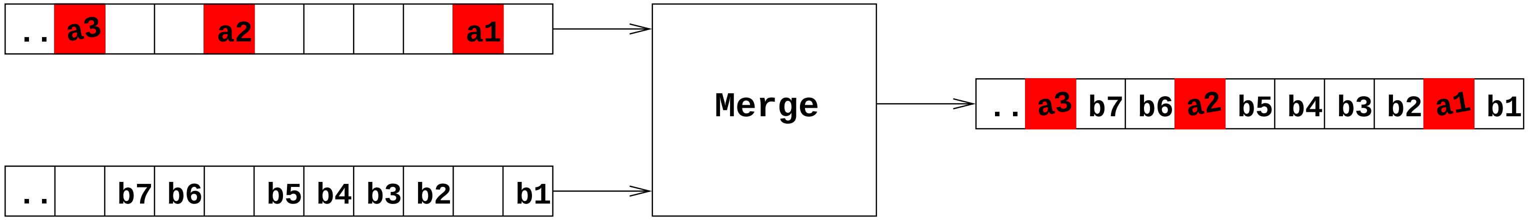
$$td \quad ::= \quad \texttt{type}\; t \mid \texttt{type}\; t = C_1 + \ldots + C_n \mid td; td$$

Basics:

- synchronous data-flow semantics, type system, clock calculus, etc.
- efficient compilation into sequential imperative code

N-ary Merge

`merge` combines two complementary flows (flows on complementary clocks) to produce a faster one:



introduced in Lucid Synchrone V1 (1996), input language of ReLuC

Example: `merge c (a when c) (b whenot c)`

Generalization:

- can be generalized to n inputs with a specific extension of clocks with enumerated types
- the sampling e `when` c is now written e `when` `True`(c)
- the semantics extends naturally and we know how to compile it efficiently
- thus, **a good basic for compilation**

Reseting a behavior

- in Scade/Lustre, the "reset" behavior of an operator must be explicitly designed with a specific reset input

```
let node count  () = s where
  rec s = 0 -> pre s + 1


let node resetable_counter r = s where
  rec s = if r then 0 else 0 -> pre s + 1
```

- painful to apply on large model
- propose a primitive that applies on node instance and allow to reset any node (no specific design condition)

Modularity and reset

Specific notation in the basic calculus: $x(e)$ `every` c

- all the node instances used in the definition of node x are reseted when the boolean c is true
- the reset is "asynchronous": no clock constraint between the condition c and the clock of the node instance

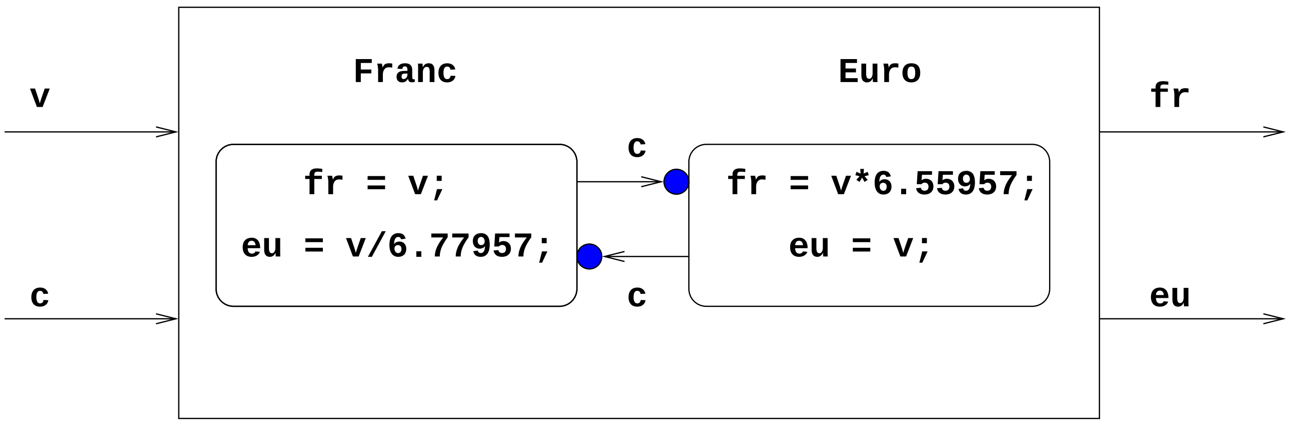
is-it a primitive construct? yes and no

- modular translation of the basic language with reset into the basic language without reset [PPDP00]
- essentially a translation of the initialization operator `->`
- e_1 `->` e_2 becomes `if true ->` c `then` e_1 `else` e_2
- very demanding to the code generator whereas it is trivial to compile!
- useful translation for verification tools, basic for compilation
- thus, **a good basic for compilation**

Automata extension

- Scade/Lustre implicit parallelism of data-flow diagrams
- automata can be composed in parallel with these diagrams
- hierarchy: a state can contain a parallel composition of automata and data-flow
- each hierarchy level introduces a new lexical scope for variables

An example: the Franc/Euro converter



in concrete (Lucid Synchrone) syntax:

```
let node converter v c = (euro, fr) where
  automaton
    Franc -> do fr = v and eur = v / 6.55957
             until c then Euro
  | Euro -> do fr = v * 6.55957 and eu = v
            until c then Franc
  end
```

Remark: `fr` and `eur` are *shared flow* but with only one definition at a time

Strong vs Weak pre-emption

Two types of transitions can be considered

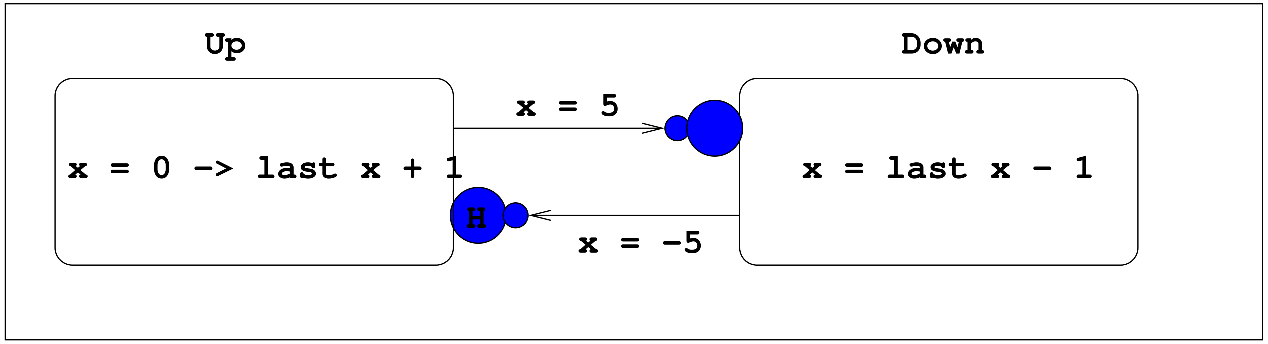
```
let node converter v c = (euro, fr) where
  automaton
    Franc -> do fr = v and eur = v / 6.55957
             unless c then Euro
  | Euro -> do fr = v * 6.55957 and eu = v
            unless c then Franc
  end
```

- `until` means that the escape condition is executed after the body has been executed
- `unless` means that the escape condition is executed before and determines the active state of the reaction

Equations and Expressions in States

- every state defines the current value of a *shared flow*
- a flow must be defined only once per cycle
- the Lustre "pre" is local to its upper state (`pre e` gives the previous value of `e`, the last time `e` was alive)
- the substitution principle of Lustre is still true at a given hierarchy $\Rightarrow$ data-flow diagrams make sense!
- the notation `last x` gives access to the latest value of `x` in its scope (Mode Automata in the Maraninchi & Rémond sense)
- an absent definition for a shared flow `x` is implicitly complemented (i.e., `x = last x`)

Mode Automata, a simple example

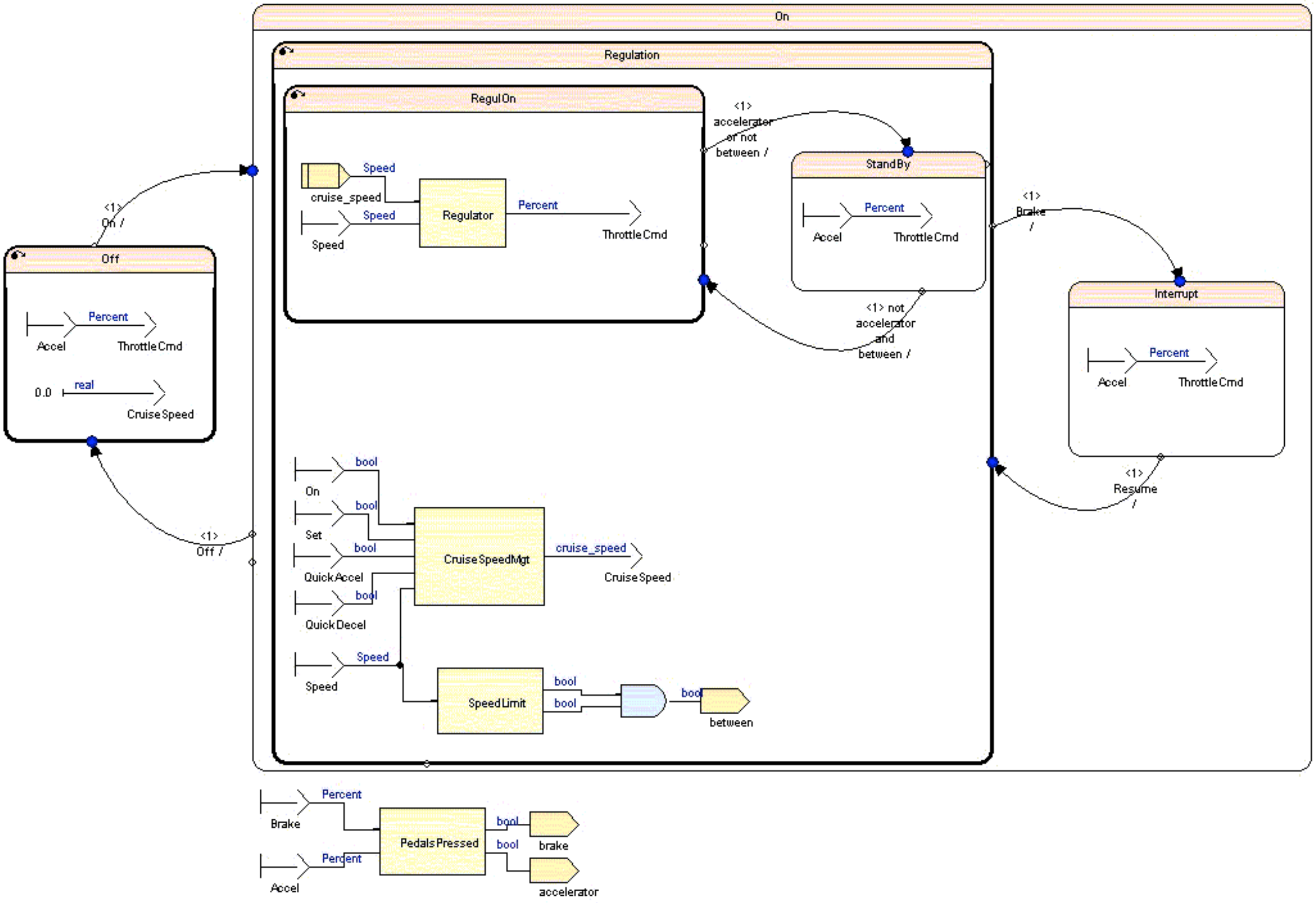



```
x = 0 1 2 3 4 5 4 3 2 1 0 -1 -2 -3 -4 -5 -4 -3 -2 -1 0 ...
```

```
let node two_modes () = x where
  rec automaton
        Up -> do x = 0 -> last x + 1
              until x = 5 continue Down
      | Down -> do x = last x - 1
                until x = -5 continue Up
      end
```

Remark: replacing `until` by `unless` would lead to a causality error!

The Cruise Control with Scade 6



The extended language

$$
\begin{array}{lcl}
e & ::= & \cdots \mid \texttt{last}\ x \\
D & ::= & D\ \mathsf{and}\ D \mid x = e \\
 & & \mid \texttt{match}\ e\ \texttt{with}\ C \rightarrow D \ldots C \rightarrow D \\
 & & \mid \texttt{reset}\ D\ \texttt{every}\ e \\
 & & \mid \texttt{automaton}\ S \rightarrow u\ s \ldots S \rightarrow u\ s \\
u & ::= & \texttt{let}\ D\ \texttt{in}\ u \mid \texttt{do}\ D\ w \\
s & ::= & \texttt{unless}\ e\ \ \texttt{then}\ S\ s \mid \texttt{unless}\ e\ \ \texttt{continue}\ S\ s \mid \epsilon \\
w & ::= & \texttt{until}\ e\ \ \texttt{then}\ S\ w \mid \texttt{until}\ e\ \ \texttt{continue}\ S\ w \mid \epsilon
\end{array}
$$

Translation semantics

- several steps in the compiler, each of them eliminating one new construction
- must be preserve type (in the general sense)

Several steps

- compilation of the automaton construction into the control structures (`match/with`)
- compilation of the `reset` construction between equations into the basic reset
- elimination of shared memory `last x`

Translation

$$T(\texttt{reset}\ D\ \texttt{every}\ e) = \texttt{let}\ x = T(e)\ \texttt{in}\ CReset_x\ T(D)$$

$$\text{where } x \notin fv(D) \cup fv(e)$$

$$T(\texttt{match}\ e\ \texttt{with}\ C_1 \rightarrow D_1\ \ldots\ C_n \rightarrow D_n) = CMatch\ (T(e))$$

$$(C_1 \rightarrow (T(D_1), Def(D_1)))$$

$$\ldots$$

$$(C_n \rightarrow (T(D_n), Def(D_n)))$$

$$T(\texttt{automaton}\ S_1 \rightarrow u_1\ s_1\ \ldots\ S_n \rightarrow u_n\ s_n) = CAutomaton$$

$$(S_1 \rightarrow (T_{S_1}(u_1), T_{S_1}(s_1)))$$

$$\ldots$$

$$(S_n \rightarrow (T_{S_n}(u_n), T_{S_n}(s_n)))$$

Static analysis

- they should mimic what the translation does
- well typed source programs must be translated into well typed basic programs

Typing: easy

- check unicity of definition (SSA form)
- can we write `last x` for any variable?
- No (in Lucid Synchrone): only shared variables can be accessed through a `last`
- otherwise, possible confusion with the regular `pre`

Clock calculus: easy under the following conditions

- free variables inside a state are all on the same clock
- the same for shared variables
- corresponds exactly to the translation semantics into `merge`

Initialization analysis

More subtle: must take into account the semantics of automata

```
let node two x = o where
  automaton
    S1 -> do o = 0 -> last o + 1
          until x continue S2
  | S2 -> do o = last o - 1 until x continue S1
  end
```

o is clearly well defined. This information is hidden in the translated program.

```
let node two x = o where
   o = merge s (S1 -> 0 -> (pre o) when S1(s) + 1)
               (S2 -> (pre o) when S2(s) - 1)
  and
   ns = merge s (S1 -> if x when S1(s) then S2 else S1)
                (S2 -> if x when S2(s) then S1 else S2)
  and
   clock s = S1 -> pre ns
```

This program is not well initialized:

```
let node two x = o where
  automaton
    S1 -> do o = 0 -> last o + 1
          unless x continue S2
  | S2 -> do o = last o - 1
          until x continue S1 end
```

- we can make a local reasoning
- because at most two transitions are fired during a reaction (strong to weak)
- compute shared variables which are necessarily defined during the initial reaction
- intersection of variables defined in the initial state and variables defined in the successors by a *strong* transition
- implemented in Lucid Synchrone (soon in ReLuC)

New questions and extensions

A more direct semantics

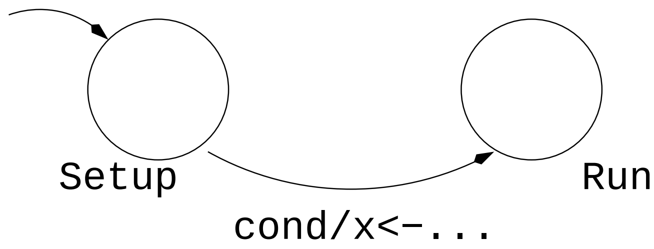
- the translation semantics is good for compilation but...
- can we define a more "direct" semantics which expresses how the program reacts?
- we introduce a ***logical reaction semantics***

Further extensions

- can we go further in closing the gap between synchronous data-flow and imperative formalisms?
- **Parameterized State Machines:** this provides a way to pass local information between two states without interfering with the rest of the code
- **Valued Signals:** these are events tagged with values as found in Esterel and provide an alternative to regular flows when programming control-dominated systems

Parameterized State Machines

- it is often necessary to communicate values between two states upon taking a transition
- e.g., a *setup* state communicate initialization values to a *run* state



- can we provide a safe mechanism to communicate values between two states?
- without interfering with the rest of the automaton, i.e.,
- without relying on global shared variables (and imperative modifications) in states nor transitions?

Parameterized states:

- states can be Parameterized by initial values which can be used in turn in the target automaton
- preserves all the properties of the basic automata

A typical example

several modes of normal execution and a failure mode which needs some contextual information

```
let node controller in1 in2 = out where
  automaton
  | State1 ->
     do out = f (in1, in2)
     until (out > 10) then State2
     until (in2 = 0) then Fail_safe(1, 0)
  | State2 ->
     let rec x = 0 -> (pre x) + 1 in
     do out = g (in1,x)
     until (out > 1000) then Fail_safe(2, x)
  | Fail_safe(error_code, resume_after) ->
     let rec
       resume = resume_after -> (pre resume) - 1 in
     do out = if (error_code = 1) then 0
              else 1000
     until (resume <= 0) then State2
  end
```

Parameterized states vs global modifications on transitions

Is all that useful?

- expressiveness? every parameterized state machine can be programmed with regular state machines using global shared flows
- efficiency? depends on the program and code-generator (though parameters only need local memory and are not all alive at the same time)

But this is bad!

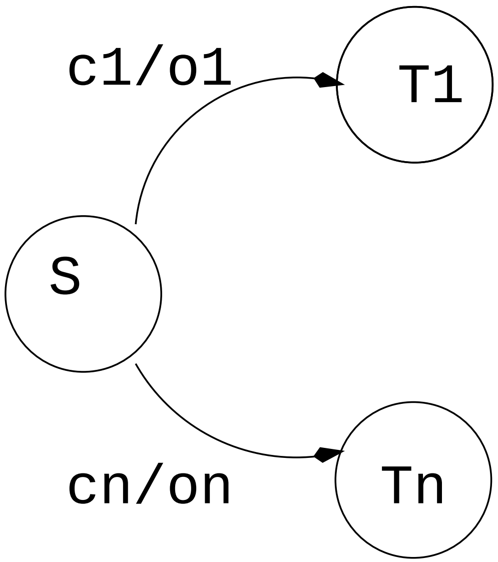
- who is still using global shared variables to pass parameters to a function in a general-purpose language?
- passing this information through shared memory would mean having global shared variables to hold it
- they would receive meaningless values during normal execution and be set on the transition itself
- this breaks locality, modularity principles and is error-prone
- making sure that all such variables are set correctly before being use is not trivial

Parameterized states

- we want the language to provides a safer way to pass local information
- complementary to global shared variables and do not replace them
- keep the communication between two states local without interfering with the rest of the automaton
- do not raise initialization problems
- reminiscent to continuation passing style (in functional programming)
- yet, we provide the same compilation techniques (and properties) as in the case of unparameterized state machines (initialization analysis, causality, type and clocks)

Example (encoding Mealy machines)

- reduces the need to have equations on transitions
- adding equations on transitions is feasible but make the model awfully complicated




```
automaton
   ...
| S(v) -> do o = v unless c1 then T1(o1)
                ...
                unless cn then Tn(on)
   ...
end
```

Valued Signals and Signal Pattern Matching

- in a control structure (e.g., automaton), every shared flow must have a value at every instant
- if an equation for `x` is missing, it keeps implicitly its last value (i.e., `x = last x` is added)
- how to talk about absent value? If `x` is not produced, we want it to be absent
- in imperative formalisms (e.g., Esterel), an event is present if it is explicitly emitted and considered absent otherwise
- can we provide a simple way to achieve the same in the context of data-flow programming?

An example

```
let node vend drink cost v = (o1, o2) where
  match v >= cost with
      true ->
        do emit o1 = drink
        and o2 = v - cost
        done
    | false ->
        do o2 = v done
  end
```

- `o2` is a regular flow which has a value in every branch
- `o1` is only emitted when (`v >= cost`) and is supposed to be absent otherwise

Accessing the value of a valued signal

- the value of a signal is the one which is emitted during the reaction
- what is the value in case where no value is emitted?
- **Esterel:** keeps the last computed value (i.e., implicitly complement the value with a register)

  ```
  emit S( ?A + 1)
  ```

  this is **unsafe** and raises **initialization problems**: what is the value if it has never been emitted?
- need extra methodology development rules to guard every access by a test for presence

  ```
  present A then ... emit S(?A + 1) ...
  ```

provide a programming construct which forbid the access to a signal which is not emitted

Signal pattern matching

- a pattern-matching construct testing the presence of valued signals and accessing their content
- a block structure and only present value can be accessed

```
let node sum x y = o where
  present
  | x(v) & y(w) -> do emit o = v + w done
  | x(v1) -> do emit o = v1 done
  | y(v2) -> do emit o = v2 done
  | _ -> do done
  end
```

Signals as existential clock types

```
let node sum x y = o where
  present
  | x(v) & y(w) -> do emit o = v + w done
  | x(v1) -> do emit o = v1 done
  | y(v2) -> do emit o = v2 done
  | _ -> do done
  end
```

- `o` is partially defined and should have clock ck `on` $(?x \wedge ?y) \vee ?x \vee ?y$ if x and y are themselves on clock ck
- giving it the existential type $\Sigma(c : ck).ck$ `on` c, that is, "exists c on clock ck such that the result is on clock ck `on` c is a correct abstraction

Clock type of a signal: a dependent pair $ck\ \texttt{sig} = \Sigma(c : ck).ck\ \texttt{on}\ c$ made of:

- a boolean sequence c which is itself on clock type ck
- a sequence sampled on c, that is, with clock type $ck\ \texttt{on}\ c$

The flow is boxed with its presence information

- this is a restriction compared to what can provide a synchronous data-flow language equipped with a powerful clock calculus
- but this is the way **Esterel** valued signal are implemented
- reminiscent to the constraints in **Lustre** to return the clock of a sampled stream

Clock verification (and inference) only need modest techniques

- box/unbox mechanisms of a Milner type system + extension by Laufer & Odersky for abstract data-types

$$\frac{H \vdash e : ck\ \texttt{on}\ c}{H \vdash \texttt{emit}\ x = e : [x : ck\ \texttt{sig}]}$$

Translation Semantics

- parameterized state machines and signals can be combined in an arbitrary way
- a translation semantics of the extension into a basic language

Example

```
let node sum (a, b, r) = o where
    automaton
    | Await -> do unless a(x)&b(y) then Emit (x + y)
    | Emit (v) -> do emit o = v unless r then Await
```

- a signal of type t is represented by a pair of type $\texttt{bool} \times t$
- nil stands for any value with the right type (think of a local stack allocated variable

```
let node sum (a,b,r) = o where
    match pnextstate with
    | Await -> match (a,b) with
                | ((True,x), (True,x)) -> state = Emit(x+y)
                | _ -> state = Await
    | Emit(v) -> match r with
                 | true -> state = Await
                 | false -> state = Emit(v)
    and
    match state with
    | Await -> o = (False,nil) and nextstate = Await
    | Emit(v) -> o = (True,nil) and nextstate = Emit(v)
    and
    pnextstate = Await -> pre nextstate
```

Conclusion

- An extension of a data-flow language with automata constructs
- various kinds of transitions, yet quite simple
- translation semantics relying on the clock mechanism which give a good discipline
- the existing code generator has not been modified and the code is (at least as) efficient than direct ad-hoc techniques
- fully implemented in Lucid Synchrone; integration in Scade 6 is under way
- distribution and documentation: `www.lri.fr/~pouzet/lucid-synchrone`

References

[1] Jean-Louis Colaço, Grégoire Hamon, and Marc Pouzet. Mixing Signals and Modes in Synchronous Data-flow Systems. In *ACM International Conference on Embedded Software (EMSOFT'06)*, Seoul, South Korea, October 2006.

[2] Jean-Louis Colaço, Bruno Pagano, and Marc Pouzet. A Conservative Extension of Synchronous Data-flow with State Machines. In *ACM International Conference on Embedded Software (EMSOFT'05)*, Jersey city, New Jersey, USA, September 2005.

[3] Grégoire Hamon and Marc Pouzet. Modular Resetting of Synchronous Data-flow Programs. In *ACM International conference on Principles of Declarative Programming (PPDP'00)*, Montreal, Canada, September 2000.