The Esterel language

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MOSIG - Embedded Systems

Introduction

- The first synchronous language (early 80's)
- Gérard Berry and his team
  (École des Mines de Paris / INRIA Sophia-Antipolis)
- Imperative, sequential style (i.e. structure reflects control flow)
- Communication by synchronous broadcasting of *signal*

Communication by signal broadcasting

- Elementary information: either present or absent
- A signal can be pure (just here or not),
  or valued (either absent, or present with a value)

Elementary behaviours

- Related to signal: emit, wait, test a signal

Composition statements

- run several behaviours in sequence,
- run several behaviours concurrently,
- repeat a behaviour,
- interrupt a behavior etc.

Example: a speedometer

Specification

- receives signals *second* and *centimeter*
- each *second*, emit a signal *speed* carrying the number of *centimeters* received since the last *second*

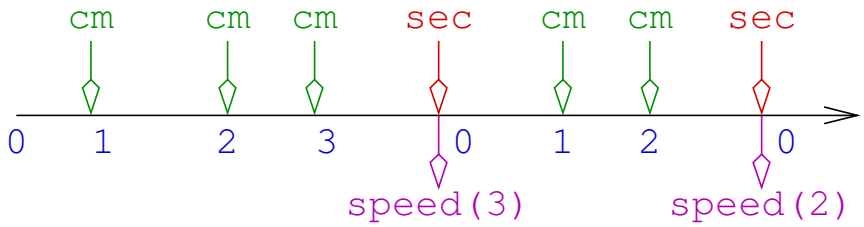
Hints on the implementation

- Use a *classical* variable `cpt` to count the occurences of *centimeter*

The code ...

```
module SPEEDOMETER:
input sec, cm;          % pure signals
output speed : integer; % valued signal
loop % infinite behaviour
  var cpt := 0 : integer in % internal variable
    abort      % terminate the folowing behavior:
      loop                  % normal behaviour:
        await cm ;          % each cm,
        cpt := cpt + 1 % increment cpt
      end loop
    when sec do          % ... when sec arrives,
      emit speed(cpt)     % emit the value of cpt on signal speed
    end abort
  end var
end loop.
```


Temporal behaviour



Why is it synchronous?

- Almost all statements are instantaneous:
  - ↪ sequence, assignment, emission ...
- Exceptions are:
  - ↪ **`await cm`**: waits for a strictly future occurence of `cm`
  - ↪ **`abort ... when sec`**: terminates on the strictly future occurence of `sec`

Conclusion of the example

- Imperative language “relativelly” classical ...
- but with a synchronous semantics
- Lots of constructs (variables, signals, interrupts ...)
- Semantics a little bit complex (at least unusual)

⇒ Let’s study in detail a sub-language (pure Esterel):

- only pure signals,
- no variable and assignments,
- only a few statements

Statements related to signals

Await

- **`await S`**
- halts as soon as it takes control, will terminate (and pass the control in sequence) on the next occurrence of `S`

Emission

- **`emit S`**
- emits `S` and terminates immediately

Test

- **`present S then c1 else c2 end`**
- if `S` is present, behaves as `c1`, otherwise behaves as `c2`
- Degenerated forms:
  - ↪ **`present S then c1 end`**
  - ↪ **`present S else c2 end`**

Composition of behaviours

Sequence

- **`c1 ; c2`**
- passes immediately the control to `c1`,
- if and when `c1` terminates, passes immediately the control to `c2`,
- terminates if and when `c2` terminates

Unbounded loop

- **`loop c end`**
- recursively equivalent to "`c ;` **`loop c end`**"
- never terminates

Parallelism

- `[ c1 || c2 ]`
- passes immediately the control to both `c1` and `c2`,
- terminates if and when the last of them terminates

Remark:

- Several concurrent behaviours may emit the same signal
- For a pure signal:
  - ↪ no problem, the signal is present if emited at least once
- For a valued signal:
  - ↪ values are combined by an associative, commutative operator
  - ↪ Typically: **`or`** for Booleans, **`+`** for integers ...
  - ↪ quite dangerous feature!

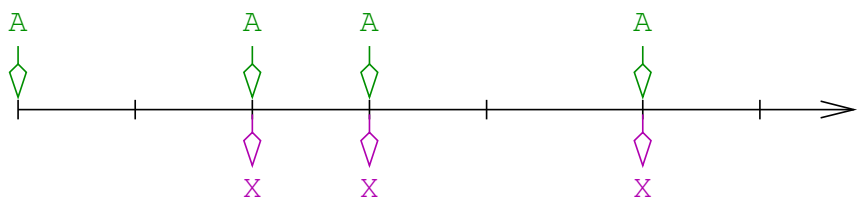
Synchronous semantics

How to give events a date?

- There exists an implicit basic discrete clock
- Any event takes place at some instant of this clock
- In particular, input signals are occurring on the basic clock

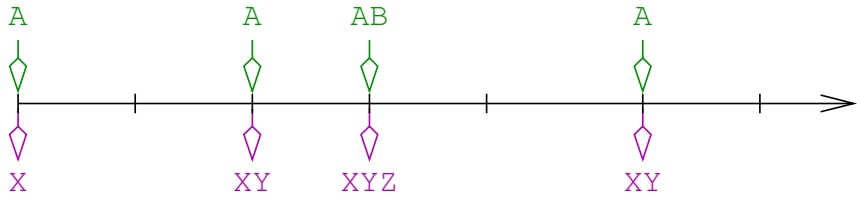
A simple example

- **`loop await A ; emit X end`**



Another example

```
module Foo:
input A,B;
output X,Y,Z;
loop
  emit X;
  await A;
  emit Y;
  present B then emit Z end
end loop.
```



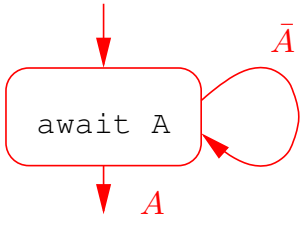
Esterel and Mealy machines

Principle

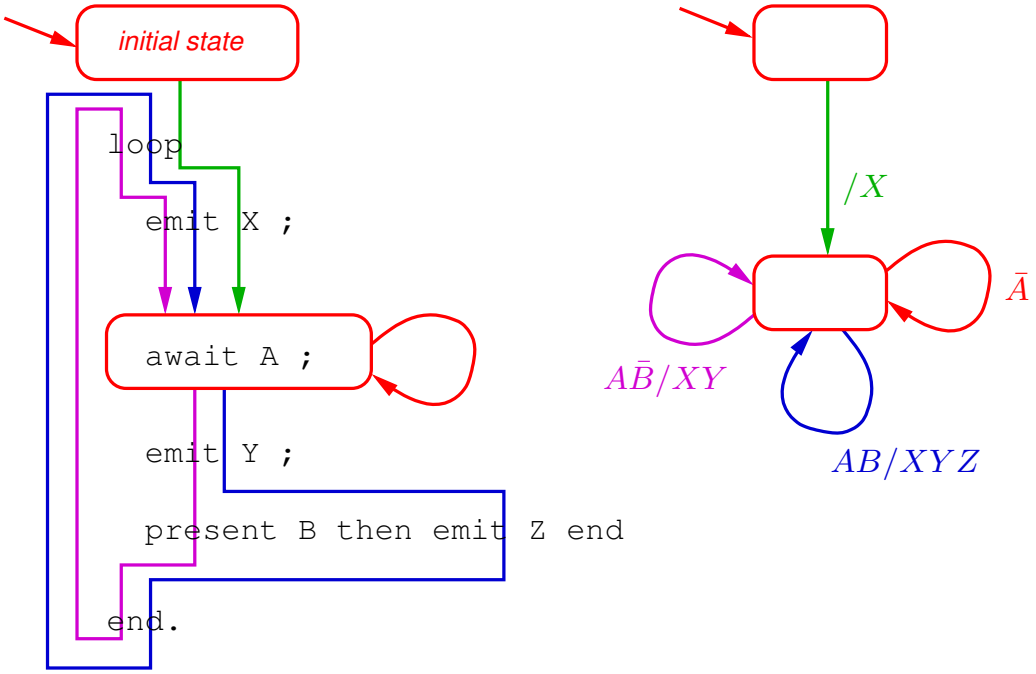
- An Esterel program is a finite automaton
- More precisely, a Mealy machine (events are occuring on transitions)

Control points (states)

- At the very beginning (initial state)
- On each statement that *takes time*
- Transition: condition/emission for going from one state to another



Example

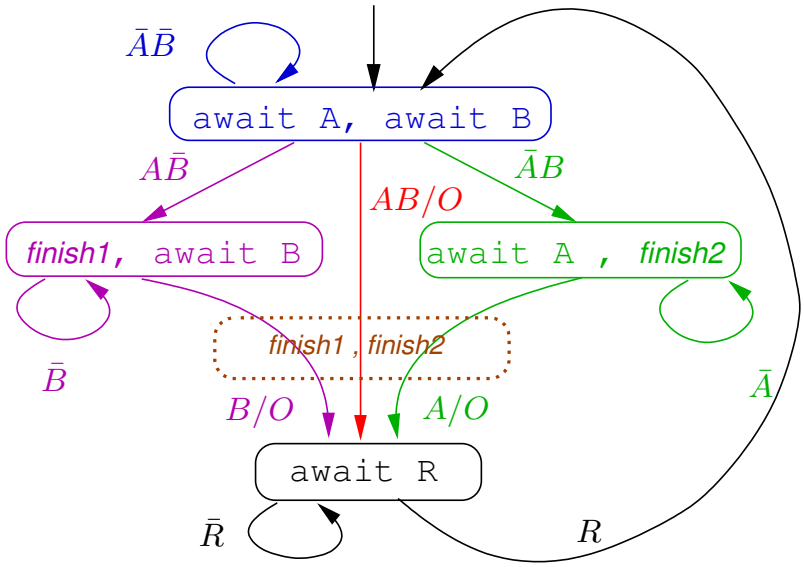


Parallel composition

- Synchronous product, with synchronization at the end
- Add a special state `finish1` to the states of `c1`
- Add a special state `finish2` to the states of `c2`
- Control points in `[ c1 || c2 ]`:
  - ↪ are couples *(`c1` state, `c2` state)*,
  - ↪ except `(finish1, finish2)` which is *transient*
- Transitions:
  - ↪ Conjunction of conditions
  - ↪ Union of emissions

Example

```
loop
  [
    await A
  ||
    await B
  ] ;
  emit O ;
  await R
end
```



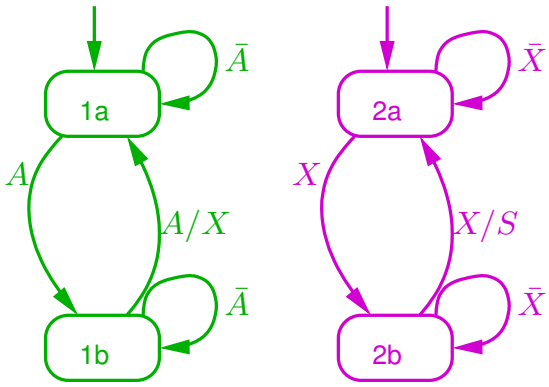
Local signals

Declaration

- **`signal X in c end`**
- Main use: communication between concurrent behaviours
- `X` can't come from outside
- `X` can't be received outside

```
signal X in [
  loop
    await A; % state 1a
    await A; % state 1b
    emit X
  end
  ||
  loop
    await X; % state 2a
    await X; % state 2b
    emit S
  end
]
```

Automata product

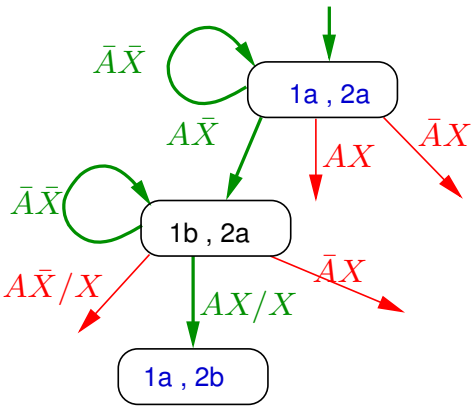


N.B. transient states finish1 et finish2 are useless

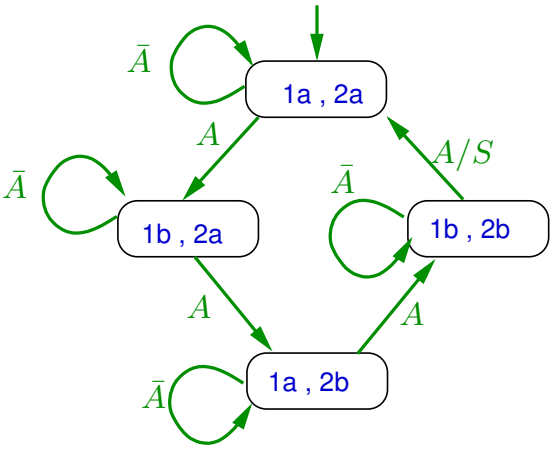
Local signal in product

- $\bar{X}/X$ → impossible (logic)
- $X/$ → impossible (local)
- X/X → ok (logic)
- $\bar{X}/$ → ok (local)

Automaton



ETC ...



Interrupt structures

Strong preemption

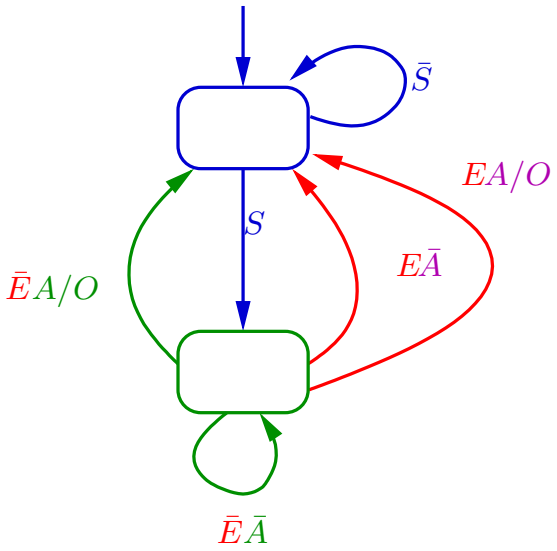
- **`abort c when X`**
- The next occurrence of X is a limit for the execution of C
- If X occurs C is immediately *killed*

Weak preemption

- **`weak abort c when X`**
- Similar, but if and when X occurs, C terminates its current reaction (last wishes)

Strong vs weak preemption

```
loop
  await S ;
weakabort
    await A ;
    emit O
  when E
end
```

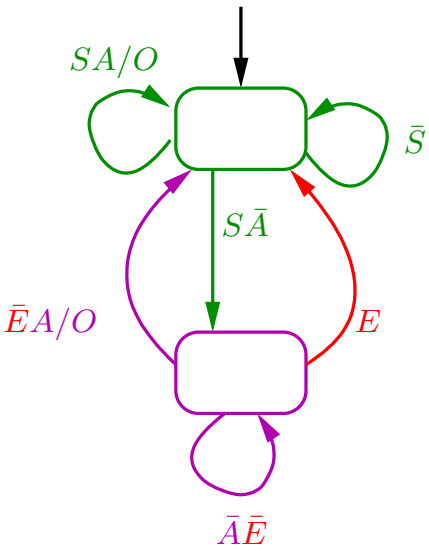


strong abort: no last wishes

weak abort: last wishes

Example (exo)

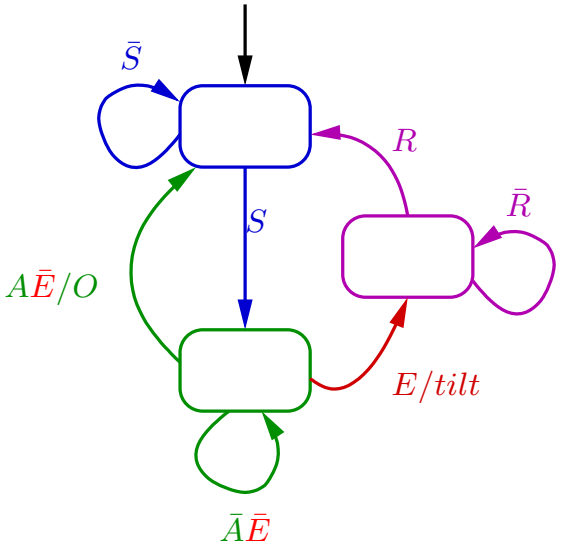
```
loop
  await S ;
  abort
    present A else
      await A
    end ;
    emit O
  when E
end
```



Catching and handling exceptions

- **`abort c1 when X do c2 end`**
- In case of interruption, control is passed to `c2`

```
loop
  await S ;
  abort
    await A ;
    emit O
  when E do
    emit tilt ;
    await R
  end
end
```



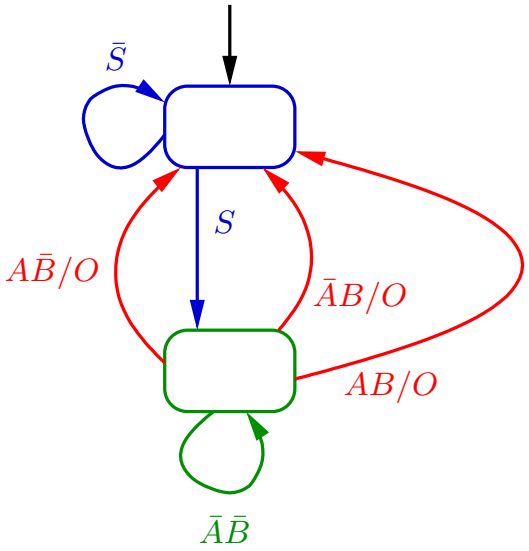
Trap/exit

- Termination from the “inside”
- Definition : **`trap X in c end`**
- Termination : `c` contains **`exit X`** statements
- When executed, **`exit X`** immediately passes the control to the end of the trap
- Ressembles both “goto” and “break” (in safer)

Example

Wait for next A or for next B

```
loop
   await S ;
   trap X in [
      await A ;
      exit X
   ||
      await B ;
      exit X
   ] end ;
   emit O
end
```



Trap/exit and parallel composition

- An `exit` statement in one branch of a parallel composition enforces all the branches to terminate
- The emiting branch stops immediately
- The other branches terminate their current reaction
- Example :

```
trap X in [
  emit A; exit X; emit B
|| emit C; await S; emit D
] end
```

is equivalent to:

```
emit A || emit C
```

Concurrent trap/exit

General form:

```
trap X1, X2, X3 in
  c
handle X1 do c1
handle X2 do c2
handle X3 do c3
end
```

In case of simultaneous exit, all the corresponding handler are executed *in parallel*

More statements

Example

- `present X else await X end`
- Common and useful,

  leads to a new statement:

  `await immediate X`

Similarly for `abort`

- `present X else abort ... when X end`
- becomes:

  `abort s when immediate X`

Notes on statements

- More and more statements where introduced
- They shorten the writing, but do not increase the expression power
- Need for a (small) kernel

Esterel kernel

- **emit**, **loop**, **present**, **;**, **||**
- **signal/in**, **trap/exit**, **abort**
- **pause** (stops for a single instant), **halt** (stops forever)

Example: **await X** is **abort halt when X**

Some derived statements

- **sustain X** :

```
loop
  emit X ; pause
end
```

- **do c upto X** :

```
abort
  c ; halt
when X
```

- **loop c each X** :

```
loop
  do c upto X
end
```

- **every X do c end** :

```
await X ; loop c each X
```

Conclusion

Dedicated language

- Esterel (like Lustre) is dedicated to *reactive kernel*
- Structured data types, complex functions, side effects are imported from the host language (tipycally C)

Esterel and SynchCharts

- SynchChart is a graphical language “à la StateCharts”, but with a clear synchronous semantics
- It can be viewed as a “graphical Esterel”
  (automata are (just) more general than nested statements)