Verified Compilation of the Modular Reset, Finally

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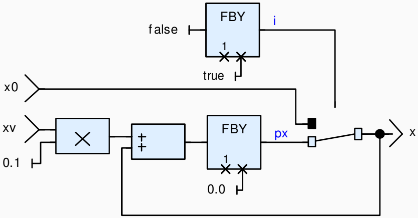
Adding the modular reset to Vélus

- Compilation and optimization
- Semantic model
- Proof of correctness

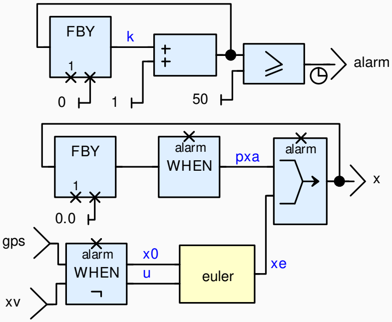
A Normalized Lustre Example




```
node euler(x0, u: double)
  returns (x: double);
  var i: bool, px: double;
let
  i = true fby false;
  x = if i then x0 else px;
  px = 0.0 fby (x + 0.1 * u);
tel
```

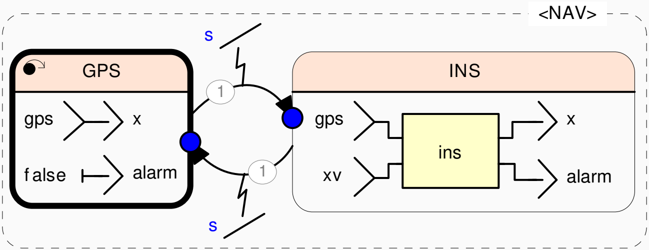
A Normalized Lustre Example

[Cas+87; CPP17]

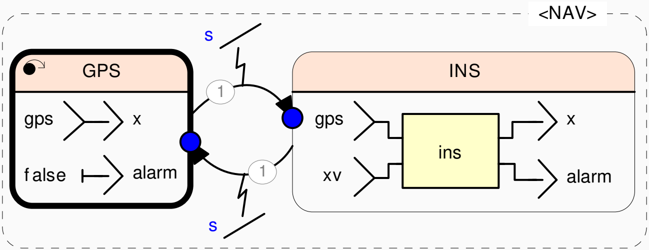



```
node ins(gps, xv: double)
  returns (x: double, alarm: bool)
  var k: int, px: double,
      xe: double whenot alarm;
let
  k = 0 fby k + 1;
  alarm = (k ≥ 50);
  xe = euler(gps whenot alarm,
             xv whenot alarm);
  x = merge alarm (px when alarm) xe;
  px = 0. fby x;
tel
```

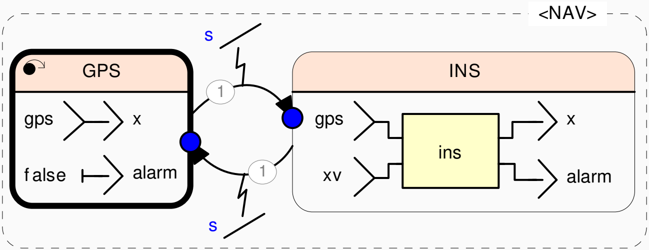
SCADE-like State Machines and Reset Primitive



SCADE-like State Machines and Reset Primitive



Can be compiled into Lustre



Can be compiled into Lustre

Reset:

- Reset the state of a node, ie. reinitialize the `fby`s
- Useful primitive, not only for state machines
- How?

A Simpler Example

```
node nat(i: int) returns (n: int)
let
  n = i fby (n + 1);
tel
```

A Simpler Example

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node nat(i: int) returns (n: int)
let
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tel
```

r	F
i	0
$nat(i)$	0
$(\texttt{restart}\ nat\ \texttt{every}\ r)(i)$	0

A Simpler Example

```
node nat(i: int) returns (n: int)
let
  n = i fby (n + 1);
tel
```

r	F	F
i	0	5
$nat(i)$	0	1
$(\texttt{restart}\ nat\ \texttt{every}\ r)(i)$	0	1

A Simpler Example

```
node nat(i: int) returns (n: int)
let
  n = i fby (n + 1);
tel
```

r	F	F	T
i	0	5	10
$nat(i)$	0	1	2
(**restart** nat **every** r)(i)	0	1	10

A Simpler Example

```
node nat(i: int) returns (n: int)
let
  n = i fby (n + 1);
tel
```

r	F	F	T	F
i	0	5	10	15
$nat(i)$	0	1	2	3
$(\texttt{restart}\ nat\ \texttt{every}\ r)(i)$	0	1	10	11

A Simpler Example

```
node nat(i: int) returns (n: int)
let
  n = i fby (n + 1);
tel
```

r	F	F	T	F	F
i	0	5	10	15	20
$nat(i)$	0	1	2	3	4
(**restart** nat **every** r)(i)	0	1	10	11	12

A Simpler Example

```
node nat(i: int) returns (n: int)
let
  n = i fby (n + 1);
tel
```

r	F	F	T	F	F	T
i	0	5	10	15	20	25
$nat(i)$	0	1	2	3	4	5
(**restart** *nat* **every** r)(i)	0	1	10	11	12	25

A Simpler Example

```
node nat(i: int) returns (n: int)
let
  n = i fby (n + 1);
tel
```

r	F	F	T	F	F	T	F
i	0	5	10	15	20	25	30
$nat(i)$	0	1	2	3	4	5	6
(**restart** *nat* **every** r)(i)	0	1	10	11	12	25	26

A Simpler Example

```
node nat(i: int) returns (n: int)
let
  n = i fby (n + 1);
tel
```

r	F	F	T	F	F	T	F	$\cdots$
i	0	5	10	15	20	25	30	$\cdots$
$nat(i)$	0	1	2	3	4	5	6	$\cdots$
$(\texttt{restart}\ nat\ \texttt{every}\ r)(i)$	0	1	10	11	12	25	26	$\cdots$

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r	F	F	T	F	F	T	F	···
i	0	5	10	15	20	25	30	···
$nat(i)$	0	1	2	3	4	5	6	···
($\texttt{restart}$ nat $\texttt{every}$ r)(i)	0	1	10	11	12	25	26	···

A Simpler Example

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node nat(i: int) returns (n: int)
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tel
```

r	F	F	T	F	F	T	F	$\cdots$
i	0	5	10	15	20	25	30	$\cdots$
$nat(i)$	0	1	2	3	4	5	6	$\cdots$
(**restart** *nat* **every** r)(i)	0	1	10	11	12	25	26	$\cdots$

A Simpler Example

```
node nat(i: int) returns (n: int)
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```

r	F	F	T	F	F	T	F	...
i	0	5	10	15	20	25	30	...
$nat(i)$	0	1	2	3	4	5	6	...
$(\texttt{restart}\ nat\ \texttt{every}\ r)(i)$	0	1	10	11	12	25	26	...

A Recursive Intuition

[Cas94; CP97; HP00]

```
node whilenot(r: bool) returns (c: bool)
let
  c = true → if r then false else (pre c);
tel

node reset_nat(i: int, r: bool) returns (y: int)
  var c: bool;
let
  c = whilenot(r);
  y = merge c (nat(i when c))
              (reset_nat((i, r) whenot c));
tel
```

r	F	F	T	F	F	T	F	⋯
c	T	T	F	F	F	F	F	⋯

Infinitely Unrolling the Recursion

r	F	F	T	F	F	T	F	$\cdots$
i	0	5	10	15	20	25	30	$\cdots$
(`restart` *nat* `every` r)(i)	0	1	10	11	12	25	26	$\cdots$

Infinitely Unrolling the Recursion

r	F	F	T	F	F	T	F	$\cdots$
count r	0	0	1	1	1	2	2	$\cdots$
i	0	5	10	15	20	25	30	$\cdots$

(`restart` *nat* `every` r)(i)	0	1	10	11	12	25	26	$\cdots$

Infinitely Unrolling the Recursion

r	F	F	T	F	F	T	F	$\cdots$
count r	0	0	1	1	1	2	2	$\cdots$
i	0	5	10	15	20	25	30	$\cdots$
$\text{mask}_r^0\ i$	0	5						$\cdots$
(`restart` *nat* `every` r)(i)	0	1	10	11	12	25	26	$\cdots$

Infinitely Unrolling the Recursion

r	F	F	T	F	F	T	F	$\cdots$
count r	0	0	1	1	1	2	2	$\cdots$
i	0	5	10	15	20	25	30	$\cdots$
$\text{mask}_r^0\ i$	0	5						$\cdots$
$nat(\text{mask}_r^0\ i)$	0	1						$\cdots$
(`restart` *nat* `every` r)(i)	0	1	10	11	12	25	26	$\cdots$

Infinitely Unrolling the Recursion

r	F	F	T	F	F	T	F	$\cdots$
count r	0	0	1	1	1	2	2	$\cdots$
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$\text{mask}_r^0\ i$	0	5						$\cdots$
$nat(\text{ mask}_r^0\ i)$	0	1						$\cdots$
$\text{mask}_r^1\ i$			10	15	20			$\cdots$
(`restart` nat `every` r)(i)	0	1	10	11	12	25	26	$\cdots$

r	F	F	T	F	F	T	F	$\cdots$
count r	0	0	1	1	1	2	2	$\cdots$
i	0	5	10	15	20	25	30	$\cdots$
$\text{mask}_r^0\ i$	0	5						$\cdots$
$nat(\text{ mask}_r^0\ i)$	0	1						$\cdots$
$\text{mask}_r^1\ i$			10	15	20			$\cdots$
$nat(\text{ mask}_r^1\ i)$			10	11	12			$\cdots$

(`restart` *nat* `every` r)(i)	0	1	10	11	12	25	26	$\cdots$

r	F	F	T	F	F	T	F	$\cdots$
count r	0	0	1	1	1	2	2	$\cdots$
i	0	5	10	15	20	25	30	$\cdots$
$\text{mask}_r^0\ i$	0	5						$\cdots$
$nat(\text{mask}_r^0\ i)$	0	1						$\cdots$
$\text{mask}_r^1\ i$			10	15	20			$\cdots$
$nat(\text{mask}_r^1\ i)$			10	11	12			$\cdots$
$\text{mask}_r^2\ i$						25	30	$\cdots$
(`restart` nat `every` r)(i)	0	1	10	11	12	25	26	$\cdots$

Infinitely Unrolling the Recursion

r	F	F	T	F	F	T	F	$\cdots$
count r	0	0	1	1	1	2	2	$\cdots$
i	0	5	10	15	20	25	30	$\cdots$
$\text{mask}_r^0\ i$	0	5						$\cdots$
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(`restart` *nat* `every` r)(i)	0	1	10	11	12	25	26	$\cdots$

r	F	F	T	F	F	T	F	$\cdots$
count r	0	0	1	1	1	2	2	$\cdots$
i	0	5	10	15	20	25	30	$\cdots$
$\text{mask}_r^0\ i$	0	5						$\cdots$
$nat(\text{mask}_r^0\ i)$	0	1						$\cdots$
$\text{mask}_r^1\ i$			10	15	20			$\cdots$
$nat(\text{mask}_r^1\ i)$			10	11	12			$\cdots$
$\text{mask}_r^2\ i$						25	30	$\cdots$
$nat(\text{mask}_r^2\ i)$						25	26	$\cdots$
$\vdots$								
(`restart` *nat* `every` *r*)(*i*)	0	1	10	11	12	25	26	$\cdots$

Node application

$$\frac{}{\vdash_{\text{eqn}} x = f(e)}$$

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$$\frac{\vdash_{\text{exp}} e \Downarrow es}{\vdash_{\text{eqn}} x = f(e)}$$

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Modular reset

$$\frac{}{\vdash_{\text{eqn}} x = (\texttt{restart}\ f\ \texttt{every}\ y)(e)}$$

Node application

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Modular reset

$$\frac{\vdash_{\text{exp}} e \Downarrow es \qquad \begin{array}{c}\vdash_{\text{var}} y \Downarrow rs\\ \end{array} \qquad \vdash_{\text{var}} x \Downarrow xs}{\vdash_{\text{eqn}} x = (\texttt{restart}\ f\ \texttt{every}\ y)(e)}$$

Node application

$$\frac{\vdash_{\text{exp}} \boldsymbol{e} \Downarrow \boldsymbol{es} \quad \vdash_{\text{node}} f(\boldsymbol{es}) \Downarrow \boldsymbol{xs} \quad \vdash_{\text{var}} \boldsymbol{x} \Downarrow \boldsymbol{xs}}{\vdash_{\text{eqn}} \boldsymbol{x} = f(\boldsymbol{e})}$$

Modular reset

$$\frac{\begin{array}{c} \vdash_{\text{var}} y \Downarrow rs \quad r = \text{bools-of } rs \\ \vdash_{\text{exp}} \boldsymbol{e} \Downarrow \boldsymbol{es} \qquad\qquad \vdash_{\text{var}} \boldsymbol{x} \Downarrow \boldsymbol{xs} \end{array}}{\vdash_{\text{eqn}} \boldsymbol{x} = (\texttt{restart}\ f\ \texttt{every}\ y)(\boldsymbol{e})}$$

Node application

$$\frac{\vdash_{\text{exp}} \boldsymbol{e} \Downarrow \boldsymbol{es} \quad \vdash_{\text{node}} f(\boldsymbol{es}) \Downarrow \boldsymbol{xs} \quad \vdash_{\text{var}} \boldsymbol{x} \Downarrow \boldsymbol{xs}}{\vdash_{\text{eqn}} \boldsymbol{x} = f(\boldsymbol{e})}$$

Modular reset

$$\frac{\begin{array}{c}\vdash_{\text{var}} y \Downarrow rs \quad r = \text{bools-of } rs \\ \vdash_{\text{exp}} \boldsymbol{e} \Downarrow \boldsymbol{es} \quad r \vdash_{\text{reset}} f(\boldsymbol{es}) \Downarrow \boldsymbol{xs} \quad \vdash_{\text{var}} \boldsymbol{x} \Downarrow \boldsymbol{xs}\end{array}}{\vdash_{\text{eqn}} \boldsymbol{x} = (\texttt{restart}\ f\ \texttt{every}\ y)(\boldsymbol{e})}$$

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$$\frac{}{r \vdash_{\text{reset}} f(\boldsymbol{xs}) \Downarrow \boldsymbol{ys}}$$

Node application

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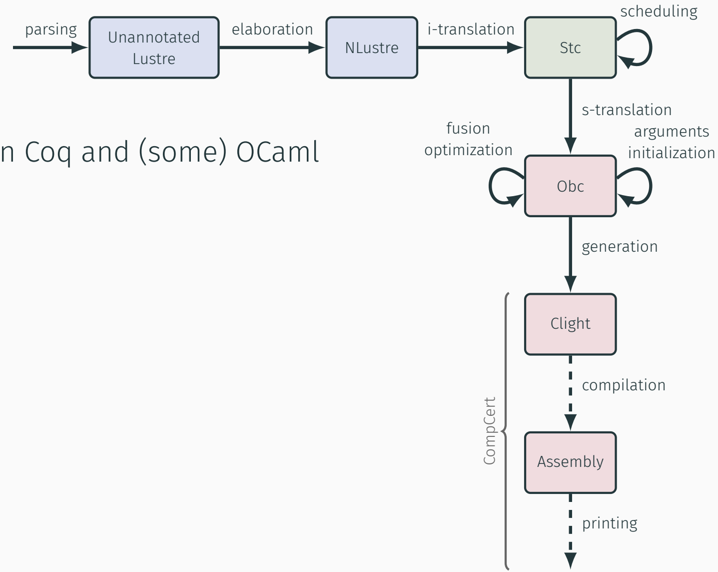
Use of an universally quantified relation as a constraint:

$$\frac{\forall k,\ \vdash_{\text{node}} f(\text{mask}_r^k\, \boldsymbol{xs}) \Downarrow \text{mask}_r^k\, \boldsymbol{ys}}{r \vdash_{\text{reset}} f(\boldsymbol{xs}) \Downarrow \boldsymbol{ys}}$$

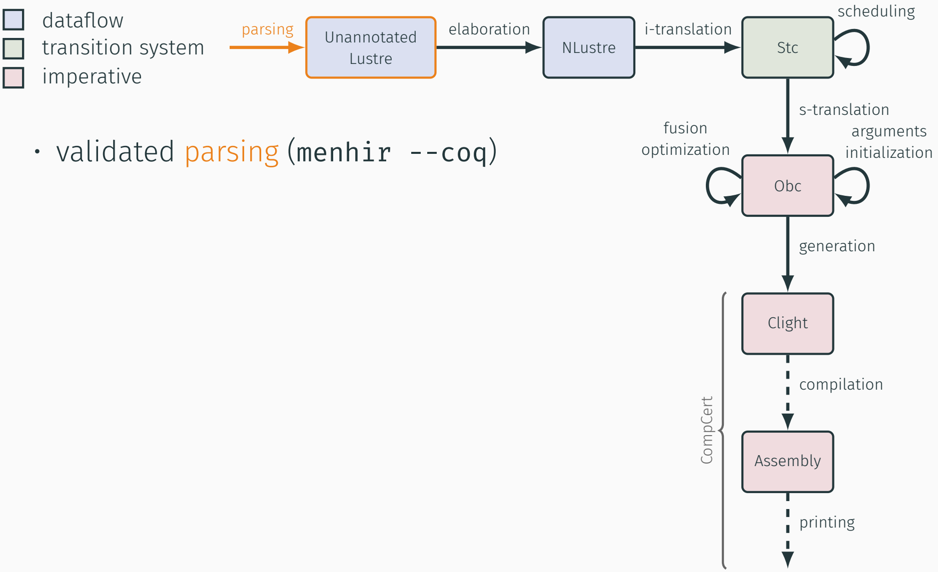
Vélus: a Verified Lustre Compiler

- dataflow
- transition system
- imperative



Implemented in Coq and (some) OCaml

VÉLUS: A VERIFIED LUSTRE COMPILER



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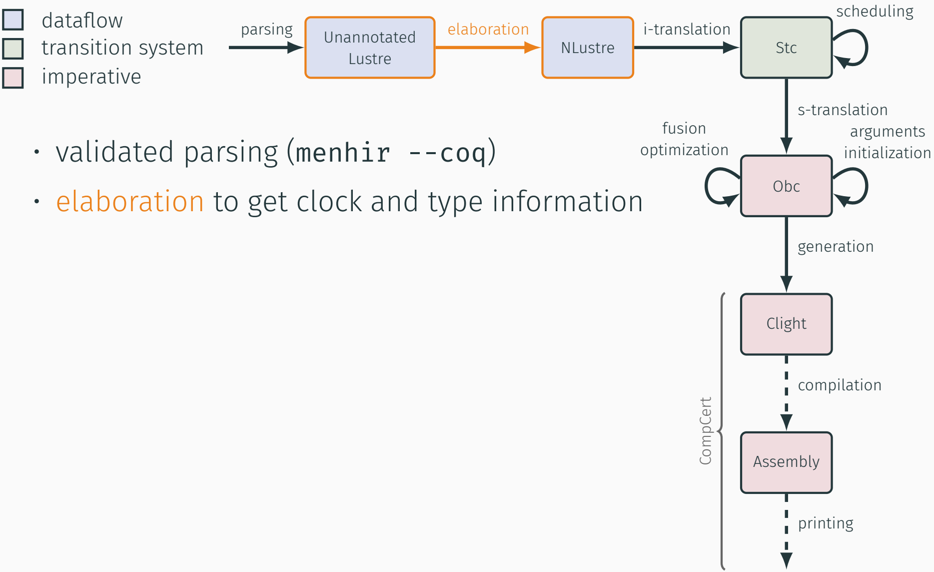

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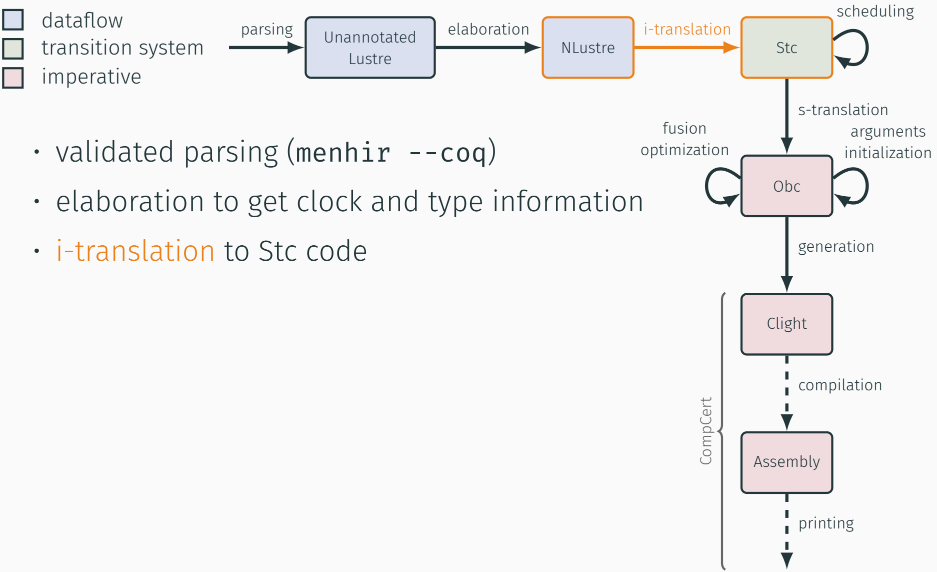

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- i-translation to Stc code

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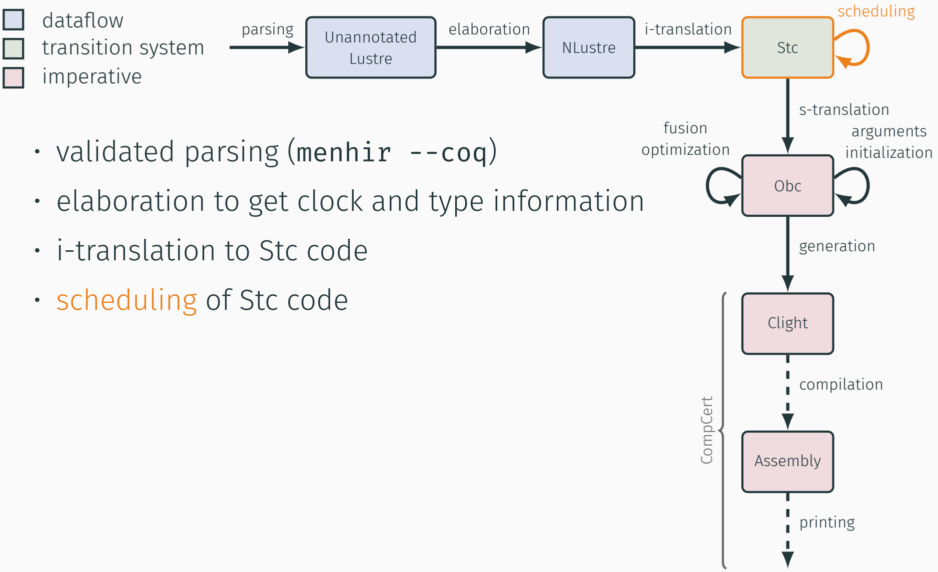

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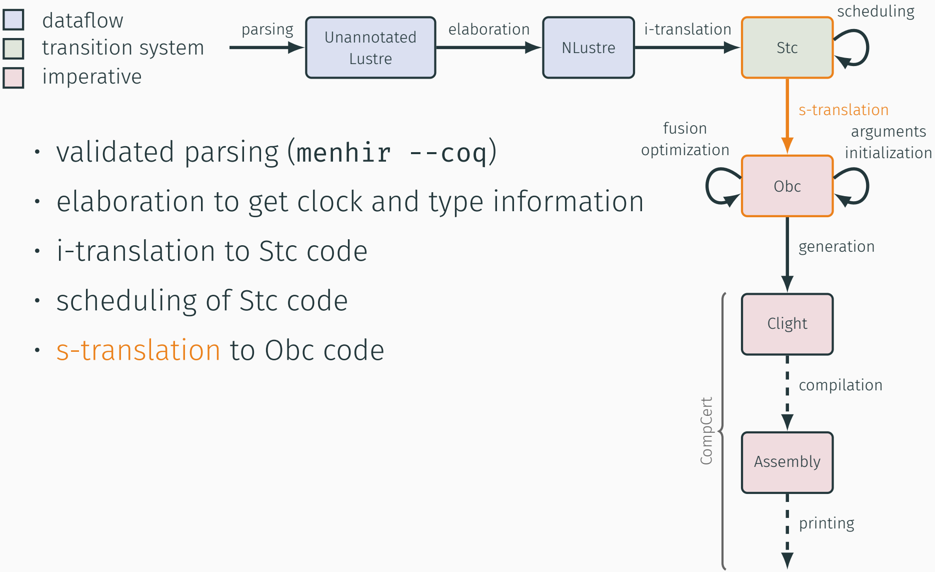

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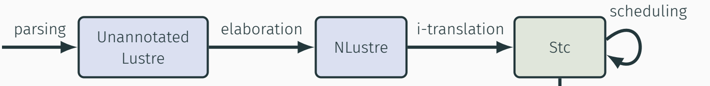

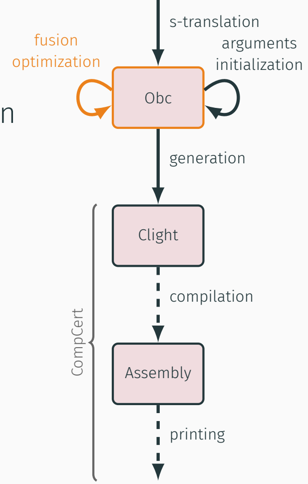

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- s-translation to Obc code
- fusion optimization of conditionals

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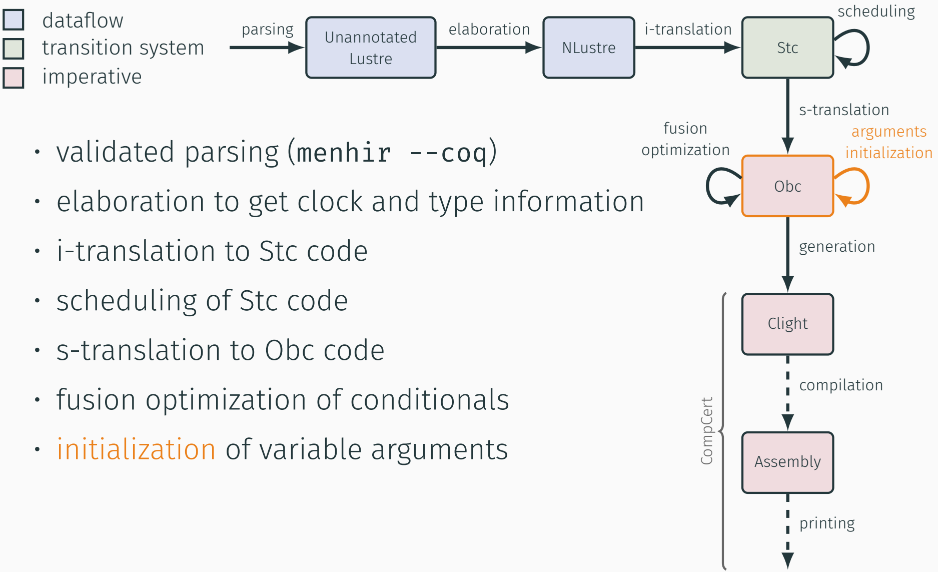

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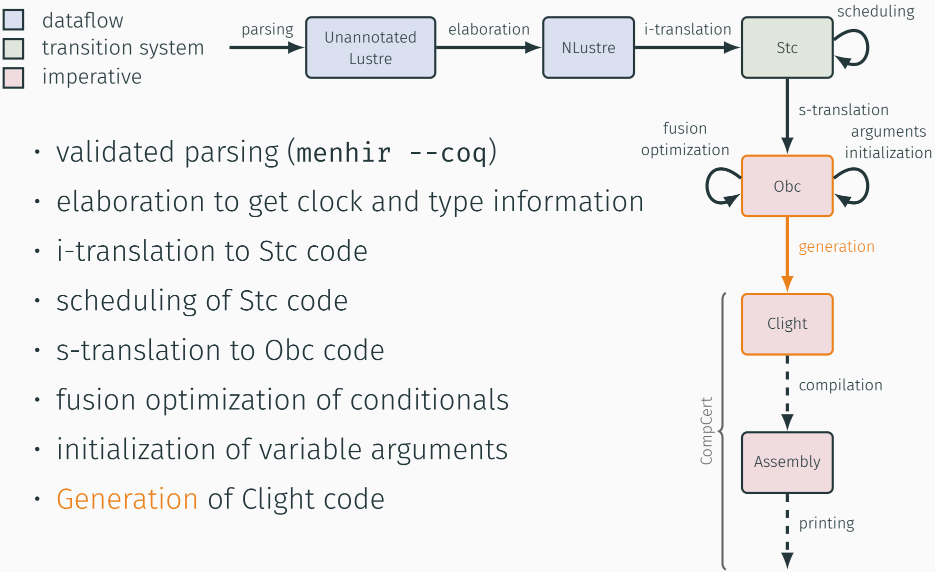
- initialization of variable arguments

Vélus: a Verified Lustre Compiler

[BL09]



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- s-translation to Obc code
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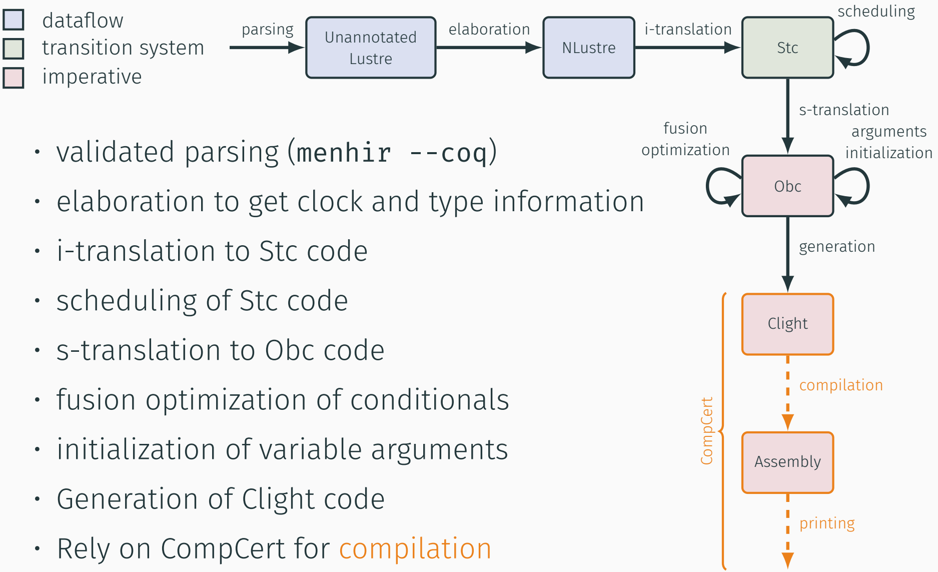
- Generation of Clight code

Vélus: a Verified Lustre Compiler



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- elaboration to get clock and type information
- i-translation to Stc code
- scheduling of Stc code
- s-translation to Obc code
- fusion optimization of conditionals
- initialization of variable arguments
- Generation of Clight code
- Rely on CompCert for compilation

Why Stc?

Two issues:

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Syntactic granularity

reset: *schedulable* separate construct

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Syntactic granularity

reset: *schedulable* separate construct

Semantic granularity

transient states

First Issue: Naive Compilation

NLustre

```
x, a = (restart ins every r)(x0, u);
```

Obc

```
if ck_r {
  if r { ins(i).reset() }
};
x, a := ins(i).step(x0, u)
```

First Issue: Naive Compilation

NLustre

```
x, a = (restart ins every r)(x0, u);
```

Obc

```
if ck_r {
  if r { ins(i).reset() }
};
x, a := ins(i).step(x0, u)
```

Problem with fusion optimization:

```
x, ax = (restart ins every r)(x0, u);
y, ay = (restart ins every r)(y0, v);
```

```
if ck_r {
  if r { ins(i).reset() }
};
x, ax := ins(i).step(x0, u);
if ck_r {
  if r { ins(j).reset() }
};
y, ay := ins(j).step(y0, v)
```

NLustre

```
x, a = (restart ins every r)(x0, u);
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Obc

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Problem with fusion optimization:

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```

```
if ck_r {
  if r {
    ins(i).reset();
    ins(j).reset()
  }
};
x, ax := ins(i).step(x0, u);
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NLustre

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```
if ck_r {
  if r { ins(i).reset() }
};
x, a := ins(i).step(x0, u)
```

Problem with fusion optimization:

```
x, ax = (restart ins every r)(x0, u);
y, ay = (restart ins every r)(y0, v);
```

```
if ck_r {
  if r {
    ins(i).reset();
    ins(j).reset()
  }
};
x, ax := ins(i).step(x0, u);
y, ay := ins(j).step(y0, v)
```

→ Schedule node applications and resets separately

Second Issue: Proof of Correctness

NLustre

$V^\omega \times V^\omega$

Obc

$S \times \mathbf{V} \rightarrow S \times \mathbf{V}$

Second Issue: Proof of Correctness

NLustre

$V^\omega \times V^\omega$

too weak for induction

Obc

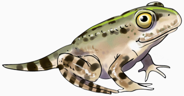
$S \times V \rightarrow S \times V$

Second Issue: Proof of Correctness

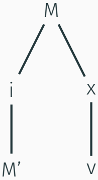
NLustre

$V^\omega \times V^\omega$

"easy": $\exists M$



$V^\omega \times M^\omega \times V^\omega$



Obc

$S \times V \rightarrow S \times V$

Second Issue: Proof of Correctness

NLustre

$V^{\omega} \times V^{\omega}$

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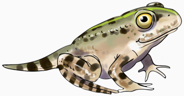

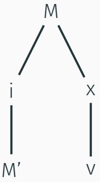

$V^{\omega} \times M^{\omega} \times V^{\omega}$

"hard"

Obc

$S \times V \to S \times V$

Second Issue: Proof of Correctness

What about the reset?

- Similar semantics in the memory model

What about the reset?

- Similar semantics in the memory model
- The “easy” proof can be done

Second Issue: Proof of Correctness

What about the reset?

- Similar semantics in the memory model
- The “easy” proof can be done
- The “hard” one failed

Stc: Synchronous Transition Code

Propose a new intermediate language

- Declarative, like NLustre

Stc: Synchronous Transition Code

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- Declarative, like NLustre
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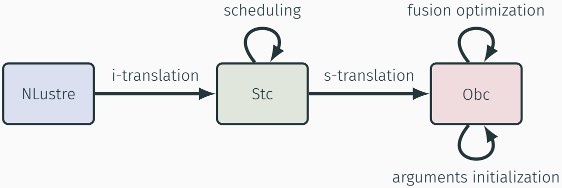

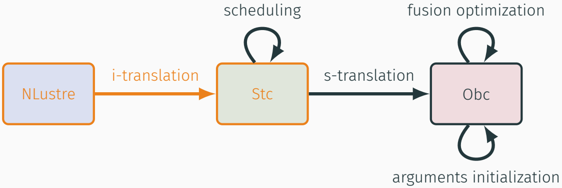
scheduling
fusion optimization
NLustre
i-translation
Stc
s-translation
Obc
arguments initialization

NLustre

```
node euler(x0, u: double)
  returns (x: double);
  var i: bool, px: double;
let
  i = true fby false;
  x = if i then x0 else px;
  px = 0.0 fby (x + 0.1 * u);
tel
```

Stc

```
system euler {
  init i = true, px = 0.;

  transition(x0, u: double)
    returns (x: double)
  {
    next i = false;
    x = if i then x0 else px;
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```
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  var k: int, px: double,
      xe: double whenot alarm;
let
  k = 0 fby k + 1;
  alarm = (k ≥ 50);
  xe = euler(gps whenot alarm,
             xv whenot alarm);
  x = merge alarm (px when alarm) xe;
  px = 0. fby x;
tel
```

```
system ins {
  init k = 0, px = 0.;
  sub xe: euler;

  transition(gps, xv: double)
    returns (x: double, alarm: bool)
    var xe: double whenot alarm;
  {
    next k = k + 1;
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    x = merge alarm (px when alarm) xe;
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  }
}
```

```
node driver(x0, y0, u, v: double,
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  var ax, ay: bool;
let
  x, ax = (restart ins every r)(x0, u);
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```

```
system driver {
  sub x: ins, y: ins;

  transition(x0, y0, u, v: double,
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    returns (x, y: double)
    var ax, ay: bool;
  {
    x, ax = ins<x,1>(x0, u);
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NLustre

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Stc

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}
```
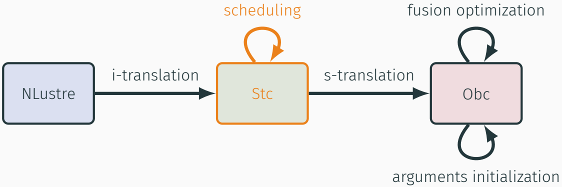

Scheduling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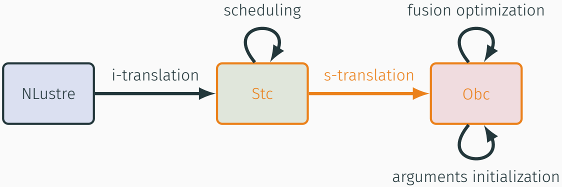
  }
}
```

Stc → Obc


scheduling
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Stc

```
system euler {
  init i = true, px = 0.;

  transition(x0, u: double)
    returns (x: double)
  {
    x = if i then x0 else px;
    next i = false;
    next px = x + 0.1 * u;
  }
}
```

Obc

```
class euler {
  state i: bool, px: double;

  step(x0, u: double)
    returns (x: double)
  {
    if state(i) { x := x0 }
    else { x := state(px) };
    state(i) := false;
    state(px) := x + 0.1 * u
  }

  reset() { state(i) := true;
            state(px) := 0. }
}
```

Stc

Obc

```
system euler {
  init i = true, px = 0.;

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}
```

Stc

```
system ins {
  init k = 0, px = 0.;
  sub xe: euler;

  transition(gps, xv: double)
    returns (x: double, alarm: bool)
    var xe: double whenot alarm;
  {
    alarm = (k ≥ 50);
    next k = k + 1;
    xe = euler<xe,0>(gps whenot alarm,
                     xv whenot alarm);
    x = merge alarm (px when alarm) xe;
    next px = x;
  }
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```

Obc

```
class ins {
  state k: int, px: double;
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    returns (x: double, alarm: bool)
    var xe: double
  {
    alarm := state(k) ≥ 50;
    state(k) := state(k) + 1;
    if alarm { }
    else { xe := euler(xe).step(gps, xv) };
    if alarm { x := state(px) }
    else { x := xe };
    state(px) := x
  }

  reset() { state(k) := 0;
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            euler(xe).reset() }
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Stc

```
system driver {
  sub x: ins, y: ins;

  transition(x0, y0, u, v: double,
             r: bool)
    returns (x, y: double)
    var ax, ay: bool;
  {
    reset ins<x> every (. on r);
    reset ins<y> every (. on r);
    x, ax = ins<x,1>(x0, u);
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  }
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class driver {
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    var ax, ay: bool
  {
    if r { ins(x).reset() };
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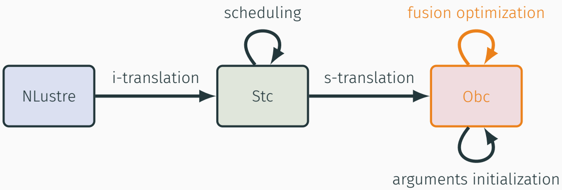
Fusion Optimization



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```
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Fusion Optimization

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class driver {
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    returns (x, y: double)
    var ax, ay: bool
  {
    if r { ins(x).reset() };
    if r { ins(y).reset() };
    x, ax := ins(x).step(x0, u);
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            ins(y).reset() }
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```

Stc Formal Semantics: Intuition

```
system f {
  sub i: g;
  transition (x: int, r: bool)
    returns (y: int)
  {
    reset g<i> every (. on r);
    y = g<i,1>(x);
  }
}
```

Transition system

- Three states S, I and S'
- Transition constraints

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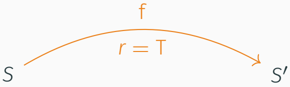

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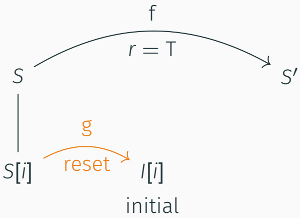

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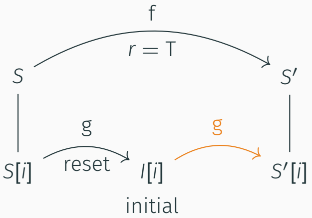

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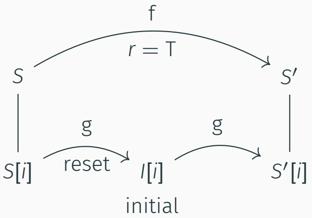
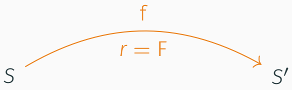
- Transition constraints



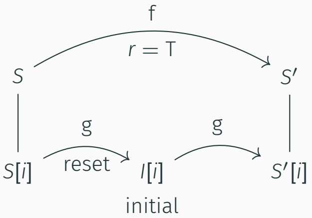


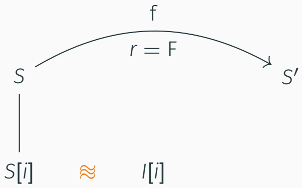
Stc Formal Semantics: Intuition

```
system f {
  sub i: g;
  transition (x: int, r: bool)
    returns (y: int)
  {
    reset g<i> every (. on r);
    y = g<i,1>(x);
  }
}
```

Transition system

- Three states S, I and S'
- Transition constraints





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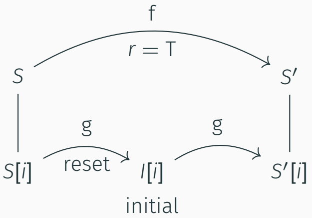

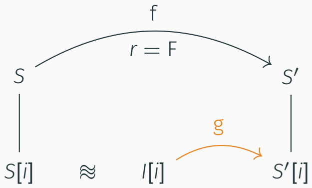

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system f {
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  }
}
```
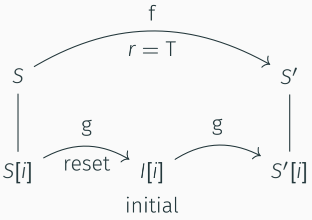
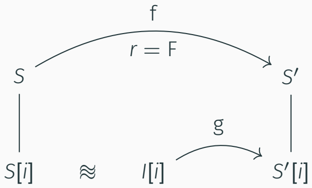

Transition system

- Three states S, I and S'
- Transition constraints
- Declarative





Stc Formal Semantics: Simplified Rules

Basic transition constraint

$$\frac{R, b \vdash e \downarrow R(x)}{P, R, b, S, I, S' \vdash x = e}$$

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Next transition constraint

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Default transition

$$\frac{R, b \vdash \boldsymbol{e} \downarrow \boldsymbol{v} \quad P, I[i]\,, S'[i] \vdash f\,(\boldsymbol{v}) \Downarrow R(\boldsymbol{x}) \qquad \text{if } \ (k = 0) \ \text{ then } I[i] \approx S[i]}{P, R, b, S, I, S' \vdash \boldsymbol{x} \texttt{ = } f\texttt{<}i, k\texttt{>(}\,\boldsymbol{e}\,\texttt{)}}$$

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Reset transition

$$\frac{R, b \vdash ck \downarrow \text{true} \quad \text{initial-state}\, P\; f\; I[i]}{P, R, b, S, I, S' \vdash \texttt{reset}\ f\texttt{<}i\texttt{>}\ \texttt{every}\ ck}$$

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$$\frac{R, b \vdash ck \downarrow \text{false} \quad I[i] \approx S[i]}{P, R, b, S, I, S' \vdash \texttt{reset}\ f\texttt{<}i\texttt{>}\ \texttt{every}\ ck}$$

System

$$\frac{\text{system}(P, f) = s \quad R(s.\mathsf{in}) = \boldsymbol{xs} \quad R(s.\mathsf{out}) = \boldsymbol{ys} \qquad \forall tc \in s.\mathsf{tcs},\ P, R, \text{base-of}\ \boldsymbol{xs}, S, I, S' \vdash tc}{P, S, S' \vdash f\,(\boldsymbol{xs}) \Downarrow \boldsymbol{ys}}$$

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Loop

$$\frac{P, S, S' \vdash f(xs_n) \downdownarrows ys_n \quad P, S' \vdash f(xs) \overset{n+1}{\circlearrowleft} ys}{P, S \vdash f(xs) \overset{n}{\circlearrowleft} ys}$$

Theorem (i-translation correctness)
Given a program G, a name f, streams of lists of values xs and ys, and a memory stream M such that $G, M \vdash f(xs) \Downarrow ys$*, then*

$$\text{initial-state}\,(\text{i-tr}\,G)\;\; f\, M_0 \quad \textit{and} \quad \text{i-tr}\,G, M_0 \vdash f\,(xs) \overset{0}{\circlearrowleft} ys$$

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Proof.

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2. **node/system:** induction on the equations, then on G
3. **loop:** coinduction

□

Theorem (s-translation correctness)
Given a program P, a name f, streams of lists of values xs and ys, a state S such that initial-state $P\ f\ S$ *and* $P, S \vdash f(xs) \overset{0}{\circlearrowleft} ys$*, then there exists a memory tree* $me \approx S$ *such that:*

$$\textsf{s-tr}\, P, \{\varnothing\} \vdash f.reset\,() \Downarrow me \quad \textit{and} \quad \textsf{s-tr}\, P, me \vdash f.step\,(xs) \overset{0}{\circlearrowleft} ys$$

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Given a program P, a name f, streams of lists of values xs and ys, a state S such that initial-state $P\ f\ S$ *and* $P, S \vdash f(xs) \overset{0}{\circlearrowleft} ys$, *then there exists a memory tree* $me \approx S$ *such that:*

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Proof.

1. **expressions:** by induction
2. **transition constraint/statement:** by cases, using correspondence relations

□

From Stc to Obc

Theorem (s-translation correctness)
Given a program P, a name f, streams of lists of values xs and ys, a state S such that $\text{initial-state}\, P\, f\, S$ *and* $P, S \vdash f\,(xs) \overset{0}{\circlearrowleft} ys$*, then there exists a memory tree* $me \approx S$ *such that:*

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Proof.

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3. **system/step method:** induction on the transition constraints, then on P

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Proof.

1. **expressions:** by induction
2. **transition constraint/statement:** by cases, using correspondence relations
3. **system/step method:** induction on the transition constraints, then on *P*
4. **loop:** coinduction

□

Theorem (Vélus correctness)
Given a list of declarations D, a name f, lists of streams of values $\mathbf{xs}$ and $\mathbf{ys}$, an NLustre program G and an assembly program P such that $\mathsf{compile}\, D\, f = \mathsf{OK}\,(G, P)$ *and* $G \vdash f\,(\langle \mathbf{xs} \rangle) \Downarrow \langle \mathbf{ys} \rangle$*, then there exists an infinite trace of events T such that*

$$P \Downarrow_{ASM} \mathsf{Reacts}(T) \quad \textit{and} \quad \mathsf{bisim\text{-}IO}^{G}\, f\, \mathbf{xs}\, \mathbf{ys}\, T$$

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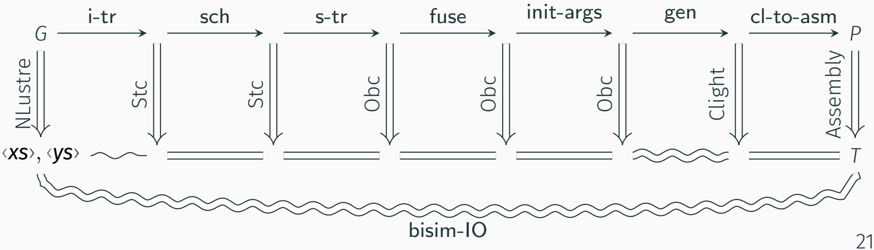

Summary

- A verified compiler for normalized Lustre with reset
- A single additional semantic rule for the reset
- An intermediate transition system language: Stc

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Future Work

- Normalization
- Extend Stc
- State machines

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