Lecture 15: SCEst

Sequentially Constructive Esterel

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Thanks for discussions with Michael Mendler, Gérard Berry, Joaquin Aguado, Insa Fuhrmann, Christian Motika, Steven Smyth, Alain Girault, Marc Pouzet, Partha Roop ...

A work in progress report …

zest *noun* \'zest\

: lively excitement : a feeling of enjoyment and enthusiasm

: small pieces of the skin of a lemon, orange, or lime that are used to flavor food

[http://www.merriam-webster.com/dictionary/zest]

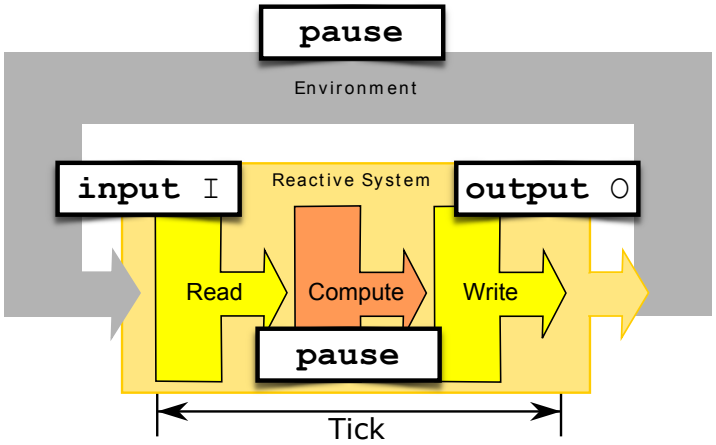
A work in progress report …

scest *noun* \'zest\

: lively excitement : a feeling of enjoyment and enthusiasm

: small pieces of a model of computation that are used to flavor programming languages

R1: inputs determine outputs
R2: **`pause`** separates reactions



R1: inputs determine outputs
R2: **`pause`** separates reactions

On R1:
Unique values throughout tick (Esterel) not needed

On R2:
Avoid **`pause`** statements that split reaction

Sequential Constructiveness:
Permit sequential evolution of values **within** reaction
⟹ Programmer freedom
⟹ Avoid timing issues within reaction

R1: inputs determine outputs
R2: **`pause`** separates reactions

	Esterel	SCEst
`O = 1 || O = 2`	Rejected	Rejected
`present Done else … emit Done end`	Rejected	Accepted
`emit O(1); emit O(?O + 1)`	Rejected	Accepted
`emit O(1); pause; emit O(pre(?O)+1)`	Accepted	Accepted

SCEst – MoC

- Based on Sequentially Constructive MoC
- A **conservative** extension of Esterel
- Valid Esterel programs are valid SCEst programs, with same semantics
- Transformation rules for Esterel also hold for SCEst

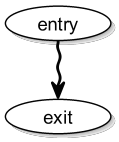
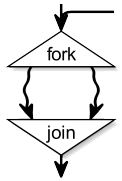
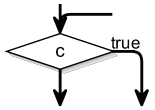
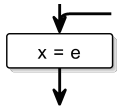
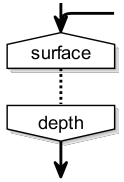
Aguado, Mendler, von Hanxleden, Fuhrmann
Grounding Synchronous Deterministic Concurrency in Sequential Programming
ESOP '14

SCEst – Language

- Esterel + SCL
- So far, consider Esterel v5 as base
- Might also adopt Esterel v7

Rathlev, Smyth, Motika, von Hanxleden, Mendler
SCEst: Sequentially Constructive Esterel
MEMOCODE '15

Sequentially **C**onstructive **L**anguage/**G**raph

	Thread	Concurrency	Conditional	Assignment	Delay
SCL	t	fork t_1 par t_2 join	if (c) s_1 else s_2	$x = e$	pause
SCG					

In addtion, SCL contains sequence **;** and **`goto`**

von Hanxleden, Mendler, Aguado, et al.
Sequentially Constructive Concurrency –
A Conservative Extension of the Synchronous Model of Computation
ACM TECS '14

SCEst – Definition

- Defined (here) by mapping to SCL
- Can be viewed as syntactic sugar on top of SCL
- Can view SCL as (SC)Est kernel statements

✓ **Simple definition of semantics**

✓ **Simple, incremental, certifiable (?) compiler**

	Variables			Pure Signals		Signal Values	
	C	**Esterel**	**SCEst**	**Esterel**	**SCEst**	**Esterel**	**SCEst**
Syntax	`x = y if (x)`	`x := y if x`	`x = y if (x)`	`emit x present x`	`emit x unemit x present x if (x)`	`emit x(v) ?x`	`emit x(v) ?x set x(v) unemit x`
Type	arbitrary	arbitrary	arbitrary	present/ absent	present/ absent	arbitrary	arbitrary
Initialized each tick	no	no	no	yes (absent)	yes (absent)	no	no
Persistence across ticks	yes	yes	yes	no	no	yes	yes
Allow multiple values / tick	yes	yes	yes	no	yes	no	yes
Sequential scheduling constraints	**none**	**none**	**none**	first `emit` ➛ reads	**none**	emits ➛ reads	**none**
Concurrent scheduling constraints	none	**read only**	inits ➛ updates ➛ reads	first emit ➛ reads	unemits ➛ first emit ➛ reads	emits ➛ reads	unemits ➛ sets ➛ emits ➛ reads
I/O determinacy guaranteed	**no**	**yes**	**yes**	**yes**	**yes**	**yes**	**yes**

First Example

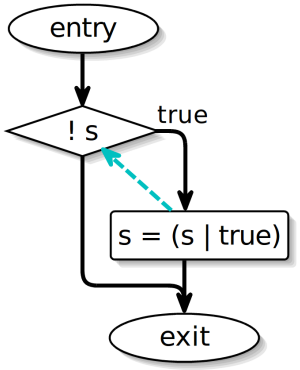
SCEst

```
present (not s) then
  emit s
end
```

SCL

```
if (!s) {
  s = s | true
}
```

SCG



First Rules

p, q: statement(s)
s: pure signal
l: fresh label
c: boolean exp.

SCEst	SCL
`[ p || q ]`	`fork p par q join`
`loop p end`	`l: p; goto l`
`do p while (c)`	`l: p; if (c) goto l`
`while (c) { p }`	`l: if (c) { p; goto l }`

Esterel Rules Still Hold

SCEst	SCEst
`halt`	`loop pause end`
`loop p each s`	`loop abort p; halt when s end`

Pure Signals

f: fresh flag
pnt: non-terminating statement(s)

Recall: SC MoC orders
`s = false` (init)
before concurrent
`s = s | true` (update)

Rule for output similar

SCEst	SCL
`signal s in p end`	`{ bool s; bool _f = false; fork p; _f = true par l: s = false; if (!_f) { pause; goto l } join }`
`signal s in pnt end`	`{ bool s; fork pnt par l: s = false; pause; goto l join }`
`emit s`	`s = s | true`
`present s …`	`if (s) …`

Pure Signals, avoiding schizophrenia

To be applied if
1. downstream-synthesis requires acyclic SCG, and
2. signal scopes are possibly instantaneously re-entered

f: fresh flag
pni: non-instantaneous statement(s)

SCEst	SCL
`signal s in pni end`	`{ bool f = false; // surface init bool s = false; fork p; f = true par do pause; // depth init s = false; while (!f) join }`

Schizophrenic Signal Example

```
loop
  signal S in
    present S then
      emit O
    end;
    pause;
    emit S
  end
end
```

signal

```
loop
  bool f = false;
  bool S = false;
  fork
    if (S)
      O |= true;
    pause;
    S |= true;
    f = true;
  par
    do
      pause;
      S = false;
    while (!f);
  join
end
```

To avoid cycle in dataflow SCG, also need „depth join“

Trap Example

```
trap T in
  fork
    pause;
    A |= true;
    pause;
    exit T
  par
    l: pause;
    if (!B) goto l;
    C |= true
  join
end trap;
D |= true
```

trap

```
  {
    bool T = false;
    fork
      if (T) goto l1;
      pause;
      A |= true;
      if (T) goto l1;
      pause;
      T |= true;
      goto l1;
l1:
    par
l:    if (T) goto l2;
      pause;
      if (!B) goto l;
      C |= true;
l2:
    join;
    if (T) goto l0
  };
l0:D |= true
```


Trap / Exit

SCEst	SCL

`trap t in`
`  p`
`end`
	`{ bool _t = false;`
	`  p [ exit t ->`
	`  {_t = true; gotoj _l}`
	`  | pause ->`
	`  if (_t) gotoj _l; pause`
	`  | join ->`
	`  join; if (_t) gotoj _l];`
	`_l: }`

p: statement(s) without **trap**

gotoj _l: **goto _l**, if **goto** in same thread as _l
goto _exit, otherwise

_exit: label at end of thread

Nested Trap Example

```
trap T1 in
  trap T2 in
    fork
      exit T1
    par
      exit T2
    join
  end;
  A |= true
end;
B |= true
```

trap

```
  {
    bool T1 = false;
    {
      bool T2 = false;
      fork
        T1 |= true;
        goto l1
l1:
      par
        T2 |= true;
        goto l2
l2:
      join;
      if (T1) goto l4;
      if (T2) goto l3;
    };
l3:  A |= true
  }
l4:B |= true
```

Deduction of Await Rule 1

```
await s
```

definition of await

```
pause;
trap t in
 loop
  present s
   then exit t
   else pause
  end present
 end loop
end trap
```


Deduction of Await Rule 2

```
pause;
trap t in
 loop
  present s
   then exit t
   else pause
  end present
 end loop
end trap
```

to SCL

```
pause;
{bool _t = false;
 _l: if (s) {
  _t |= true;
  goto _l1 }
 else {
  if (_t)
   goto _l1;
  pause };
 goto _l;
 _l1:
}
```


Deduction of Await Rule 3

```
pause;
{bool _t = false;
 _l: if (s) {
  _t |= true;
  goto _l1 }
 else {
  if (_t)
   goto _l1;
  pause };
 goto _l;
 _l1:
}
```

eliminate _t

```
pause;
_l: if (s)
  goto _l1
else
  pause;
goto _l;
_l1:
```


Deduction of Await Rule 4

```
pause;
_l: if (s)
  goto _l1
else
  pause;
goto _l;
_l1:
```

opt

```
_l: pause;
if (!s)
  goto _l
```

Resulting Await Rule

```
await S
```

await

```
_l: pause;
if (!s)
  goto _l
```

Esterel definitions of derived statements
\+ SCEst-SCL translation rules for kernel statements
\+ Reasoning at SCL-level
= Optimized rules for derived statements

No ad-hoc rules for derived statements!

Abort

SCEst	SCL

abort p **when** s	{ **bool** _t = **false**;
	  p [**pause** -> **pause**; **if** (s) {_t = **true**; **gotoj** _l}
	  | **join** -> **join**; **if** (_t) **gotoj** _l];
	_l: }

Further rules for weak and/or immediate abort, also WTO

Abort – Optimized

SCEst	SCL
abort pni **when** s	p [**pause** -> **pause**; **if** (s) **gotoj** _l | **join** -> **join**; **if** (s) **gotoj** _l]; _l:

pni: statements without instantaneously reachable join

ABRO

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

ABRO

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

parallel

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```
loop
  abort
    fork
      await A
    par
      await B
    join;
    emit O;
    halt
  when R
end
```

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```
loop
  abort
    fork
      await A
    par
      await B
    join;
    emit O;
    halt
  when R
end
```

await

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```
loop
  abort
    fork
l1:   pause;
      if (!A)
        goto l1
    par
l2:   pause;
      if (!B)
        goto l2
    join;
    emit O;
    halt
  when R
end
```

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```
loop
  abort
    fork
l1:   pause;
      if (!A)
        goto l1
    par
l2:   pause;
      if (!B)
        goto l2
    join;
    emit O;
    halt
  when R
end
```

```
loop
  abort
    fork
l1:   pause;
      if (!A)
        goto l1
    par
l2:   pause;
      if (!B)
        goto l2
    join;
    emit O;
    halt
  when R
end
```

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halt

```
loop
  abort
    fork
l1:   pause;
      if (!A)
        goto l1
    par
l2:   pause;
      if (!B)
        goto l2
    join;
    emit O;
l3: pause;
    goto l3;
  when R
end
```

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```
loop
  abort
    fork
l1:   pause;
      if (!A)
        goto l1
    par
l2:   pause;
      if (!B)
        goto l2
    join;
    emit O;
l3: pause;
    goto l3;
  when R
end
```

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abort

```
  loop
    fork
l1:   pause;
      if (R) goto l4;
      if (!A) goto l1;
l4:
    par
l2:   pause;
      if (R) goto l5;
      if (!B) goto l2;
l5:
    join;
    if (R) goto l6;
    emit O;
l3: pause;
    if (R) goto l6;
    goto l3;
l6:end
```

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```
  loop
    fork
l1:   pause;
      if (R) goto l4;
      if (!A) goto l1;
l4:
    par
l2:   pause;
      if (R) goto l5;
      if (!B) goto l2;
l5:
    join;
    if (R) goto l6;
    emit O;
l3: pause;
    if (R) goto l6;
    goto l3;
l6:end
```

```
   loop
     fork
l1:    pause;
       if (R) goto l4;
       if (!A) goto l1;
l4:
     par
l2:    pause;
       if (R) goto l5;
       if (!B) goto l2;
l5:
     join;
     if (R) goto l6;
     emit O;
l3:  pause;
     if (R) goto l6;
     goto l3;
l6:end
```

loop

```
l7:fork
l1:  pause;
     if (R) goto l4;
     if (!A) goto l1;
l4:
   par
l2:  pause;
     if (R) goto l5;
     if (!B) goto l2;
l5:
   join;
   if (R) goto l6;
   emit O;
l3:pause;
   if (R) goto l6;
   goto l3;
l6:goto l7
```



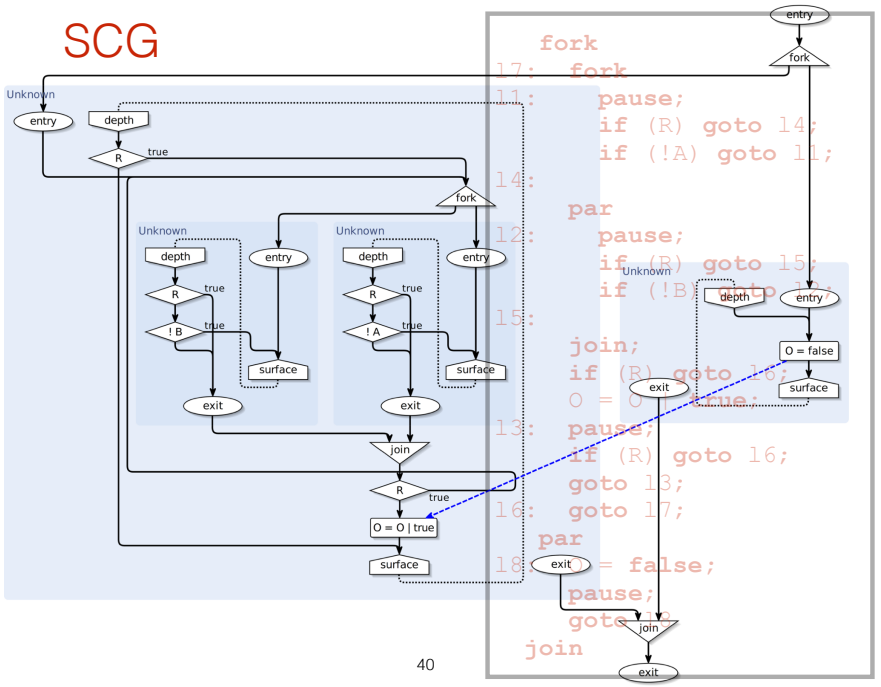
```
l7:fork
l1:  pause;
     if (R) goto l4;
     if (!A) goto l1;
l4:
   par
l2:  pause;
     if (R) goto l5;
     if (!B) goto l2;
l5:
   join;
   if (R) goto l6;
   emit O;
l3:pause;
   if (R) goto l6;
   goto l3;
l6:goto l7
```


emit, out-put

```
   fork
l7:  fork
l1:    pause;
       if (R) goto l4;
       if (!A) goto l1;
l4:
     par
l2:    pause;
       if (R) goto l5;
       if (!B) goto l2;
l5:
     join;
     if (R) goto l6;
     O = O | true;
l3:  pause;
     if (R) goto l6;
     goto l3;
l6:  goto l7;
   par
l8:  O = false;
     pause;
     goto l8
  join
```

init → update

SCG



Downstream Compilation

So far, two alternative compilation strategies from SCL/SCG to C/VHDL

	Dataflow	Priority
Accepts instantaneous loops	–	+
Can synthesize hardware	+	–
Can synthesize software	+	+
Size scales well (linear in size of SCChart)	+	+
Speed scales well (execute only active parts)	–	+
Instruction-cache friendly (good locality)	+	–
Pipeline friendly (little/no branching)	+	–
WCRT predictable (simple control flow)	+	+/–
Low execution time jitter (simple/fixed flow)	+	–

von Hanxleden, Duderstadt, Motika, et al.
SCCharts: Sequentially Constructive Statecharts for Safety-Critical Applications
PLDI'14

Wrap-Up

- SCEst conservatively extends Esterel
- SC MoC reduces likelihood of causality cycles
- Easy to adapt (hopefully) for C/Java programmers
- Defined by simple mapping to SCL
- Experience from SCCharts promising