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, Karsten Rathlev, Partha Roop, Frank Steffahn
…

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

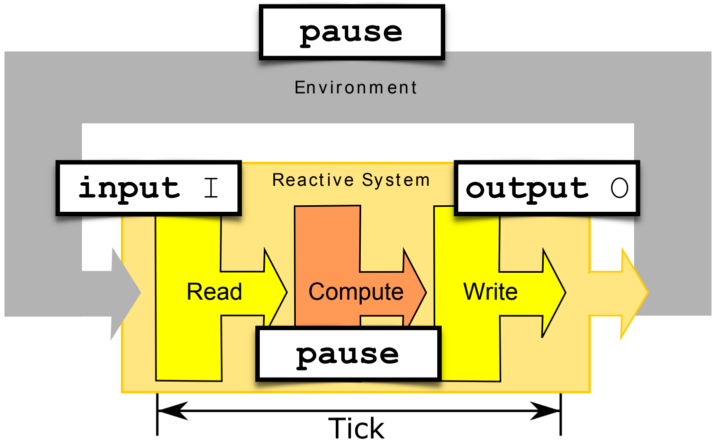
[http://www.merriam-webster.com/dictionary/zest]

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 <u>determine</u> outputs
R2: **`pause`** separates <u>reactions</u>



R1: inputs <u>determine</u> outputs
R2: **`pause`** separates <u>reactions</u>

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 <u>determine</u> outputs
R2: **`pause`** separates <u>reactions</u>

	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

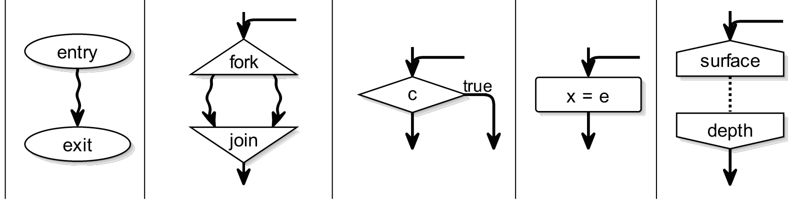
SCEst – Language

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

Smyth, Motika, Rathlev, von Hanxleden, Mendler
SCEst: Sequentially Constructive Esterel
ACM TECS '17

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

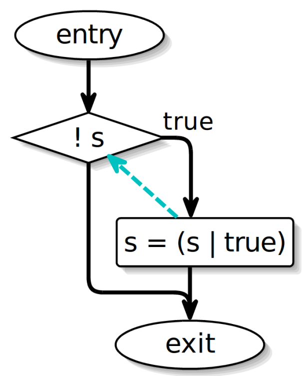
SCEst

```
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.

<table>
<tr><th>SCEst</th><th>SCL</th></tr>
<tr><td>[
  p || q
]</td><td>fork
  p par q
join</td></tr>
<tr><td>loop
  p
end</td><td>l: p;
   goto l</td></tr>
<tr><td>do
  p
while (c)</td><td>l: p;
   if (c) goto l</td></tr>
<tr><td>while (c) {
  p }</td><td>l: if (c) {
   p; goto l }</td></tr>
</table>

Esterel Rules Still Hold

<table>
<tr><th>SCEst</th><th>SCEst</th></tr>
<tr><td>halt</td><td>loop
  pause
end</td></tr>
<tr><td>loop
  p
each s</td><td>loop
  abort
    p;
    halt
  when s
end</td></tr>
</table>

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

<table>
<tr><th>SCEst</th><th>SCL</th></tr>
<tr><td>signal s in
  p
end</td><td>{ bool s;
  bool _f = false;
  fork
    p; _f = true
  par
l: s = false;
    if (!_f) {
      pause;
      goto l }
  join }</td></tr>
<tr><td>signal s in
  pnt
end</td><td>{ bool s;
  fork
    pnt
  par
l: s = false;
    pause; goto l
 join }</td></tr>
<tr><td>emit s</td><td>s = s | true</td></tr>
<tr><td>present s …</td><td>if (s) …</td></tr>
</table>

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)

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

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) goto _exit; 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

Note: the jump at pause can only be triggered by a concurrent exit; the corresponding fork/join then must be nested within trap scope; thus, if we have to jump at pause, we must jump to _exit, never to _l

```
  {
   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
```

opt. →

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

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

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

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

Abort – Optimized

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

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



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



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

await

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

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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```
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
```

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
```

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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

```
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
```

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```
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
```

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```
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, output

```
  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

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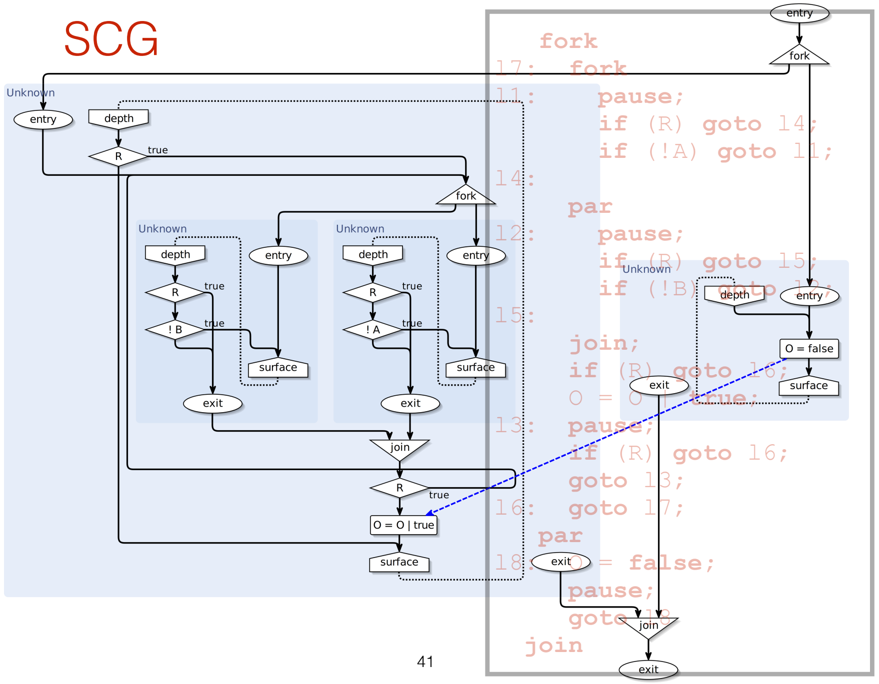
SCG



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