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* \ˈzest\

: 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 …

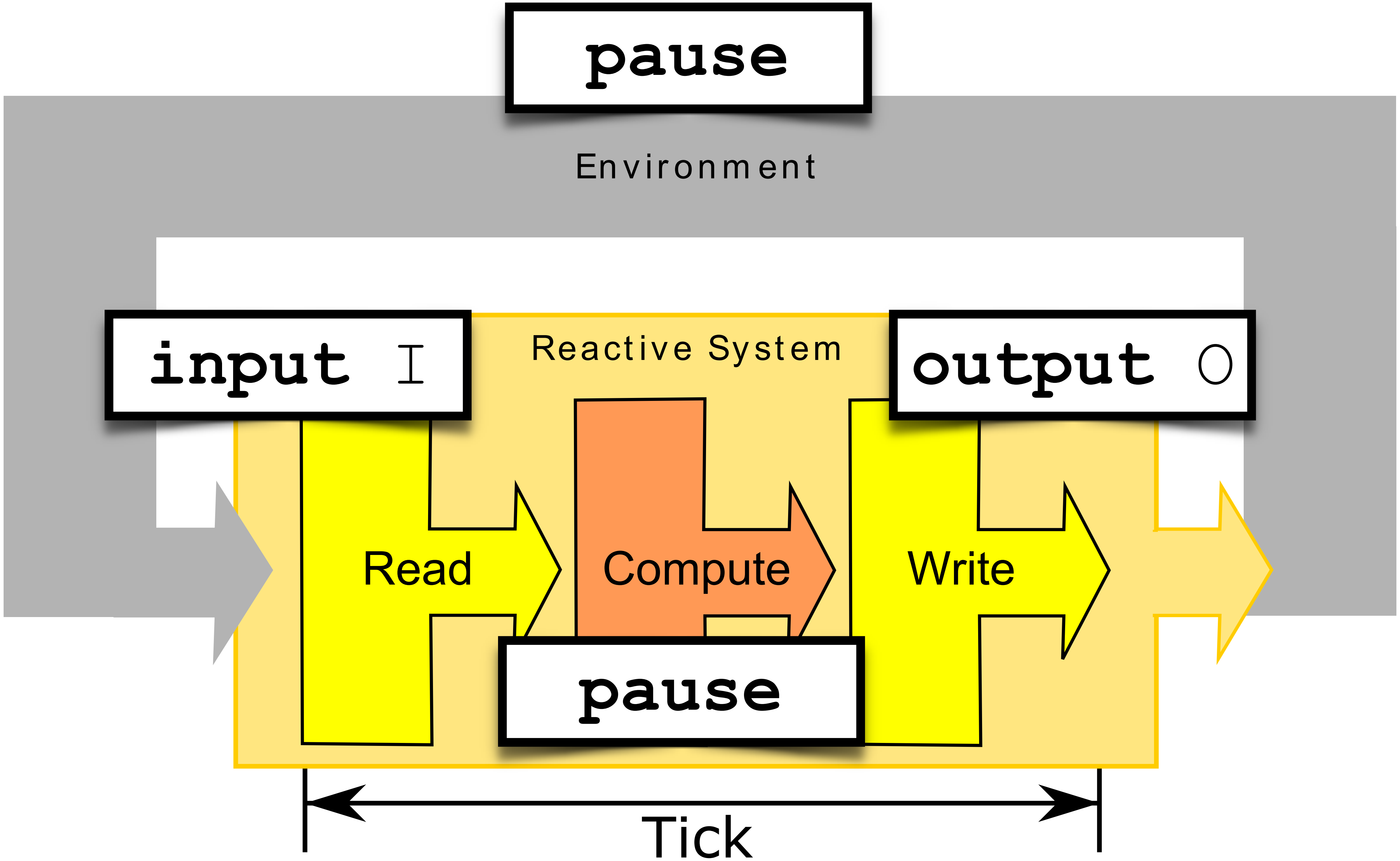
scest *noun* \'zest\

: lively excitement : a feeling of enjoyment and enthusiasm

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

R1: inputs <u>determine</u> outputs

R2: `pause` separates <u>reactions</u>



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

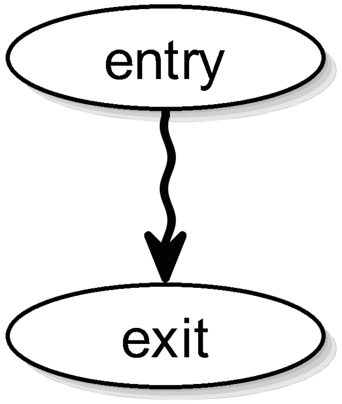
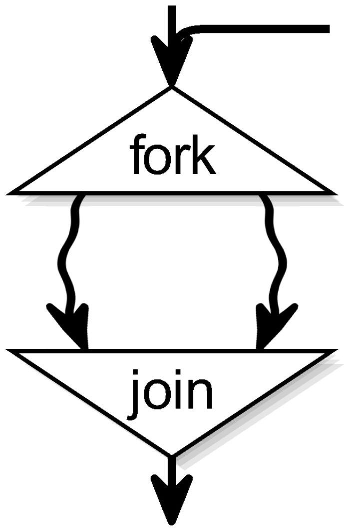
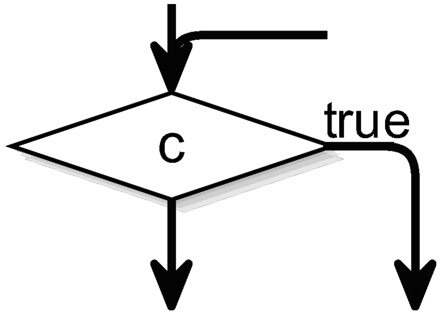
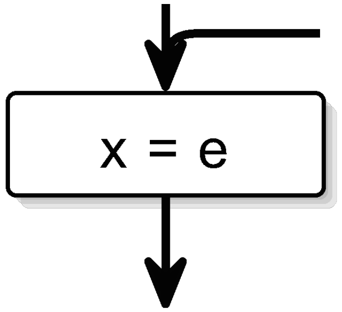
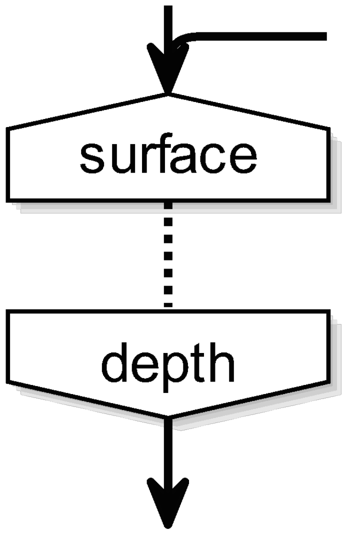
Aguado, Mendler, von Hanxleden, Fuhrmann
Grounding Synchronous Deterministic Concurrency in Sequential Programming
ESOP '14

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

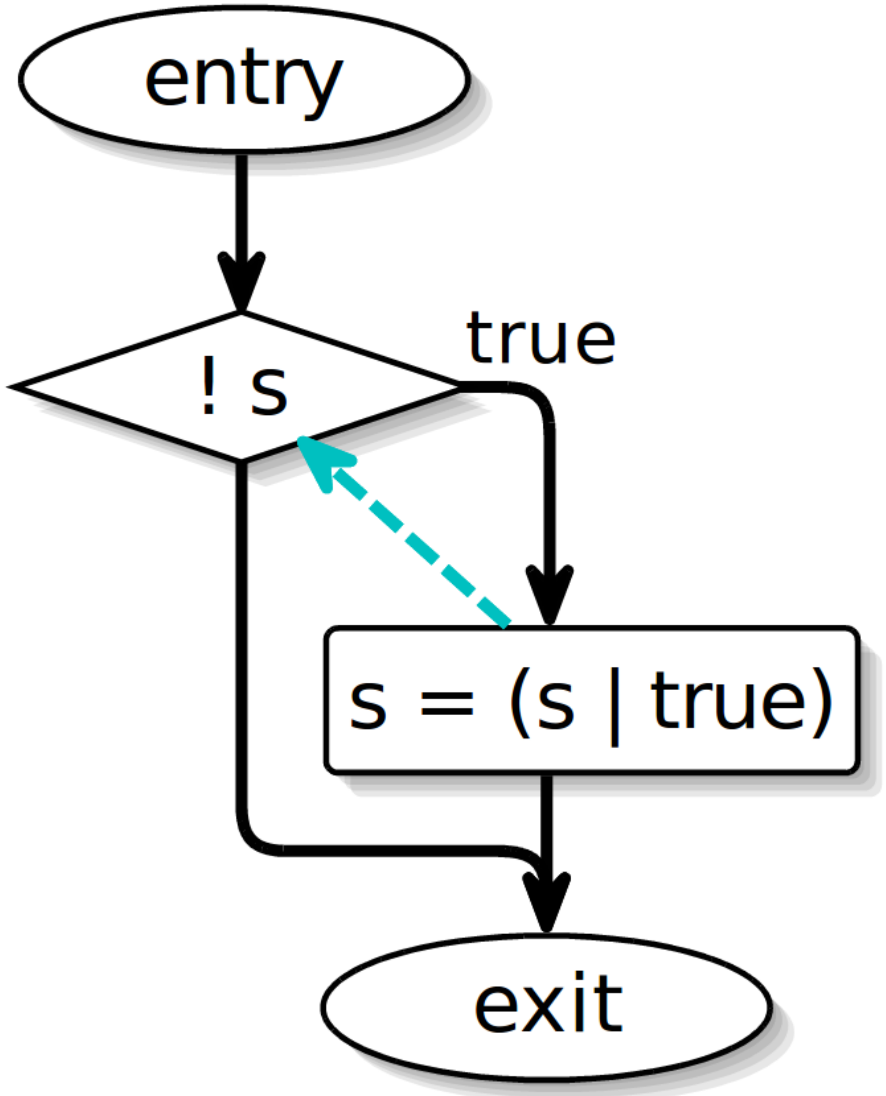
SCEst

```
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.

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

Esterel Rules Still Hold

SCEst | **SCEst**

```
                loop
halt              pause
                end
--------------------------------
                loop
                  abort
loop                p;
  p                 halt
each s            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

```
signal s in
  pni
end
```

SCL

```
{
  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 / Exit

SCEst

```
trap t in
  p
end
```

SCL

```
{ 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

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
```

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

```
abort
  p
when s
```

SCL

```
{ 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      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
```

```
 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
```

```
 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
```

```
 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
```

```
   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
```

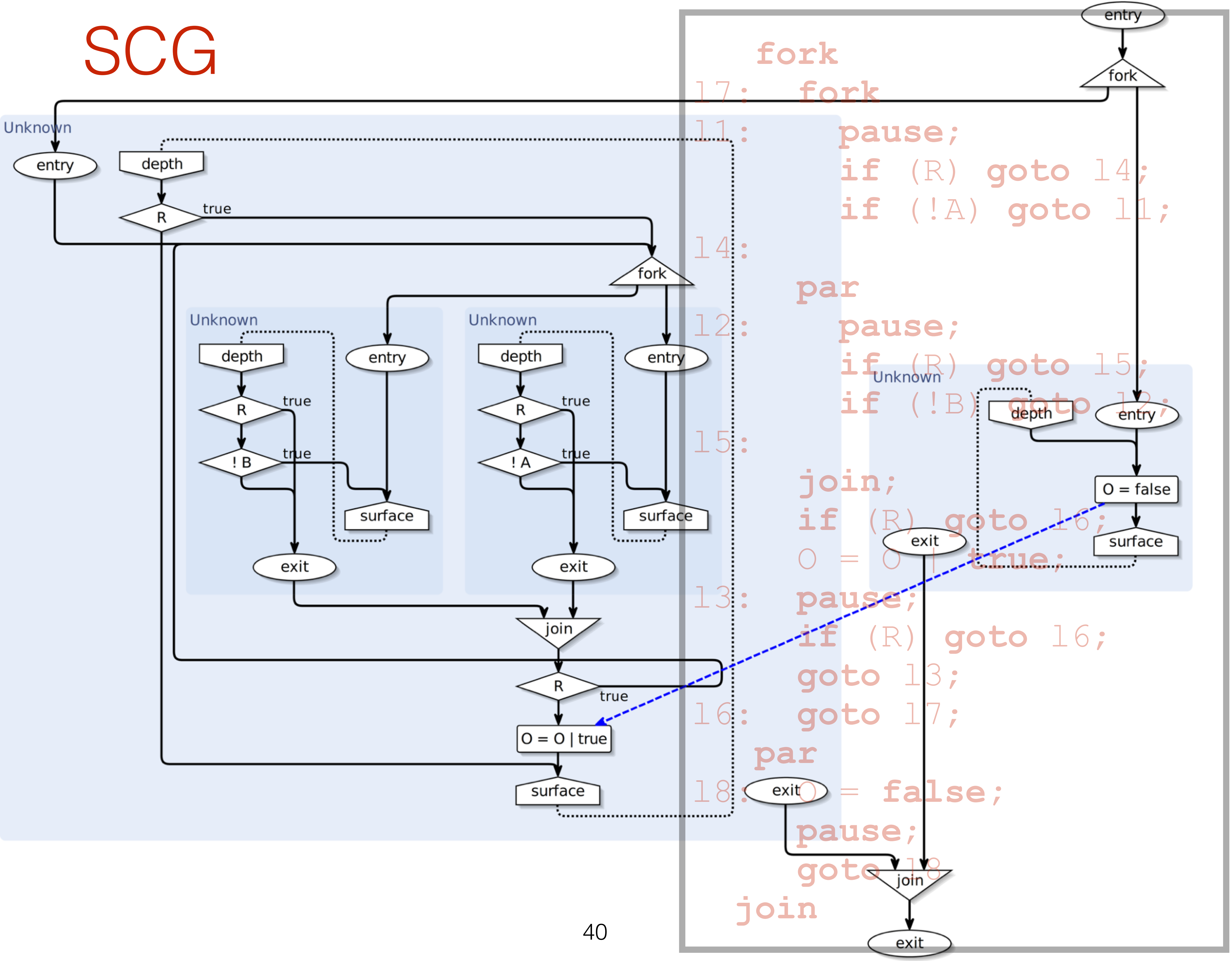
```
l7:fork
l1:  pause;
     if (R) goto l4;
     if (!A) goto l1;
l4:
   par
l2:  pause;
     if (R) goto l5;
     if (!B) goto l2;
l5:
   join;
   if (R) goto l6;
   emit O;
l3:pause;
   if (R) goto l6;
   goto l3;
l6:goto l7;
```

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

SCG



```
fork
17: fork
11:     pause;
        if (R) goto 14;
        if (!A) goto 11;
14:
    par
12:     pause;
        if (R) goto 15;
        if (!B) goto 12;
15:
    join;
    if (R) goto 16;
    O = O | true;
13: pause;
    if (R) goto 16;
    goto 13;
16: goto 17;
par
18: O = false;
    pause;
    goto 18
join
```

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