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

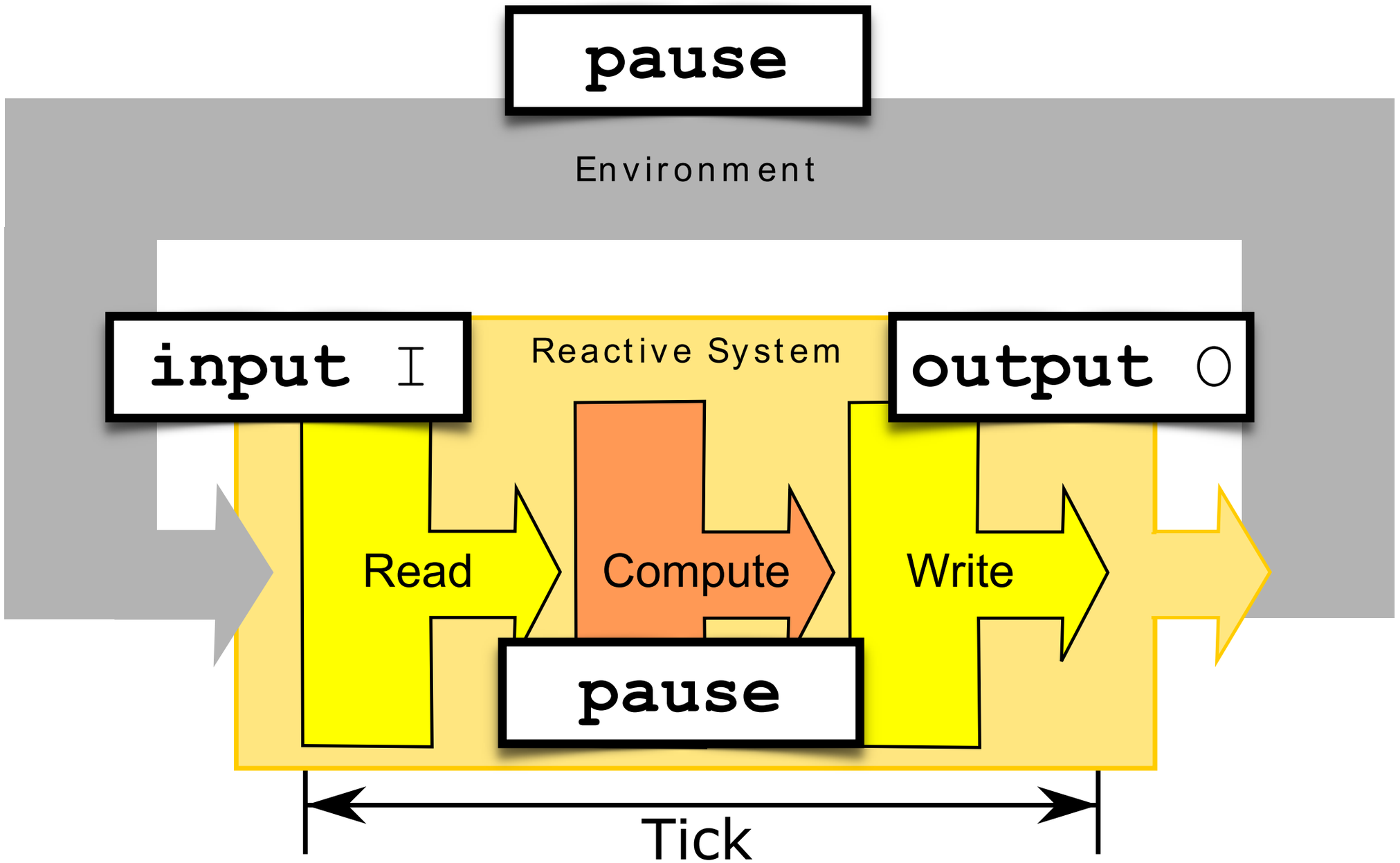
[http://www.merriam-webster.com/dictionary/zest]

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 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

$\Longrightarrow$ Programmer freedom

$\Longrightarrow$ 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

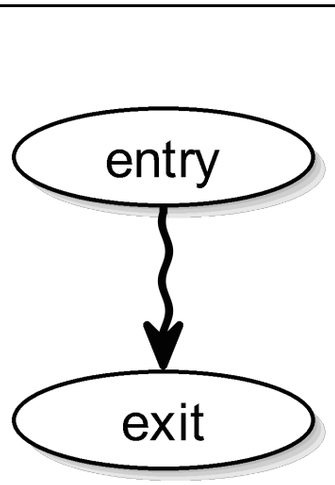
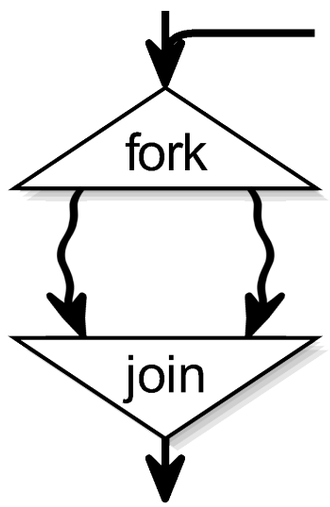
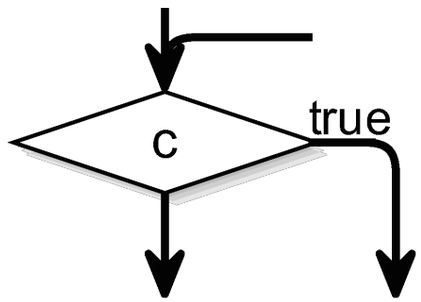
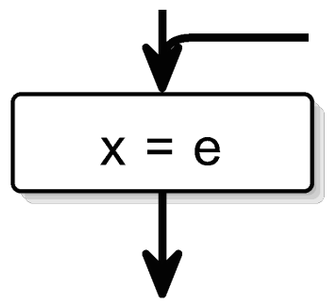
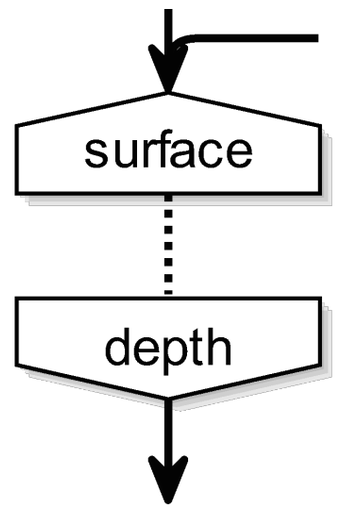
Aguado, Mendler, von Hanxleden, Fuhrmann
Grounding Synchronous Deterministic Concurrency in Sequential Programming
ESOP '14

SCEst – Language

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

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`

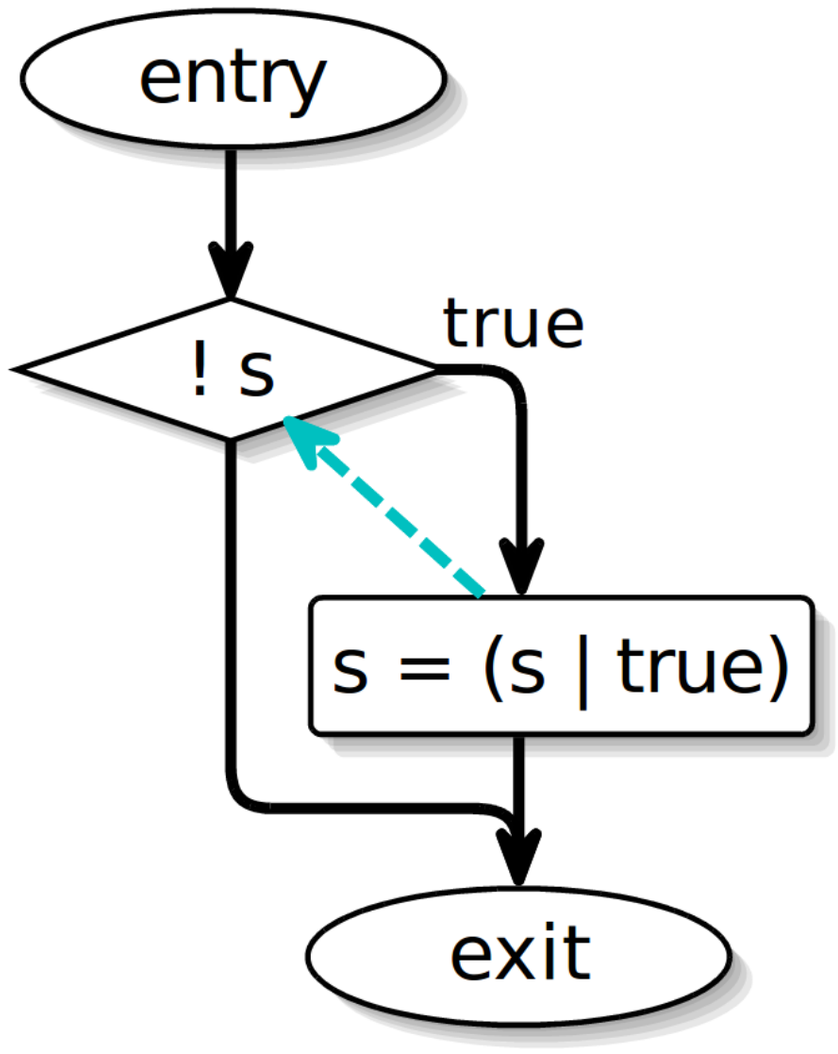
Type	arbitrary	arbitrary	arbitrary	present/ absent	present/ absent	arbitrary	arbitrary
Initialized each tick	no	no	no	yes (absent)	yes (absent)	no	no
Persistence across ticks	yes	yes	yes	no	no	yes	yes
Allow multiple values / tick	yes	yes	yes	no	yes	no	yes
Sequential scheduling constraints	**none**	**none**	**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
```

SCG



SCL

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

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

```
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	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

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
```

```
{
   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

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

```
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
11:       pause;
          if (!A)
             goto 11
       par
12:       pause;
          if (!B)
             goto 12
       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
11:       pause;
          if (!A)
             goto 11
       par
12:       pause;
          if (!B)
             goto 12
       join;
       emit O;
       halt
    when R
 end
```

halt

```
 loop
    abort
       fork
11:       pause;
          if (!A)
             goto 11
       par
12:       pause;
          if (!B)
             goto 12
       join;
       emit O;
13:    pause;
       goto 13;
    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
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;
        emit O;
13:     pause;
        if (R) goto 16;
        goto 13;
16:end
```

loop

```
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;
      emit O;
13:pause;
      if (R) goto 16;
      goto 13;
16:goto 17
```

```
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;
   emit O;
13:pause;
   if (R) goto 16;
   goto 13;
16:goto 17
```

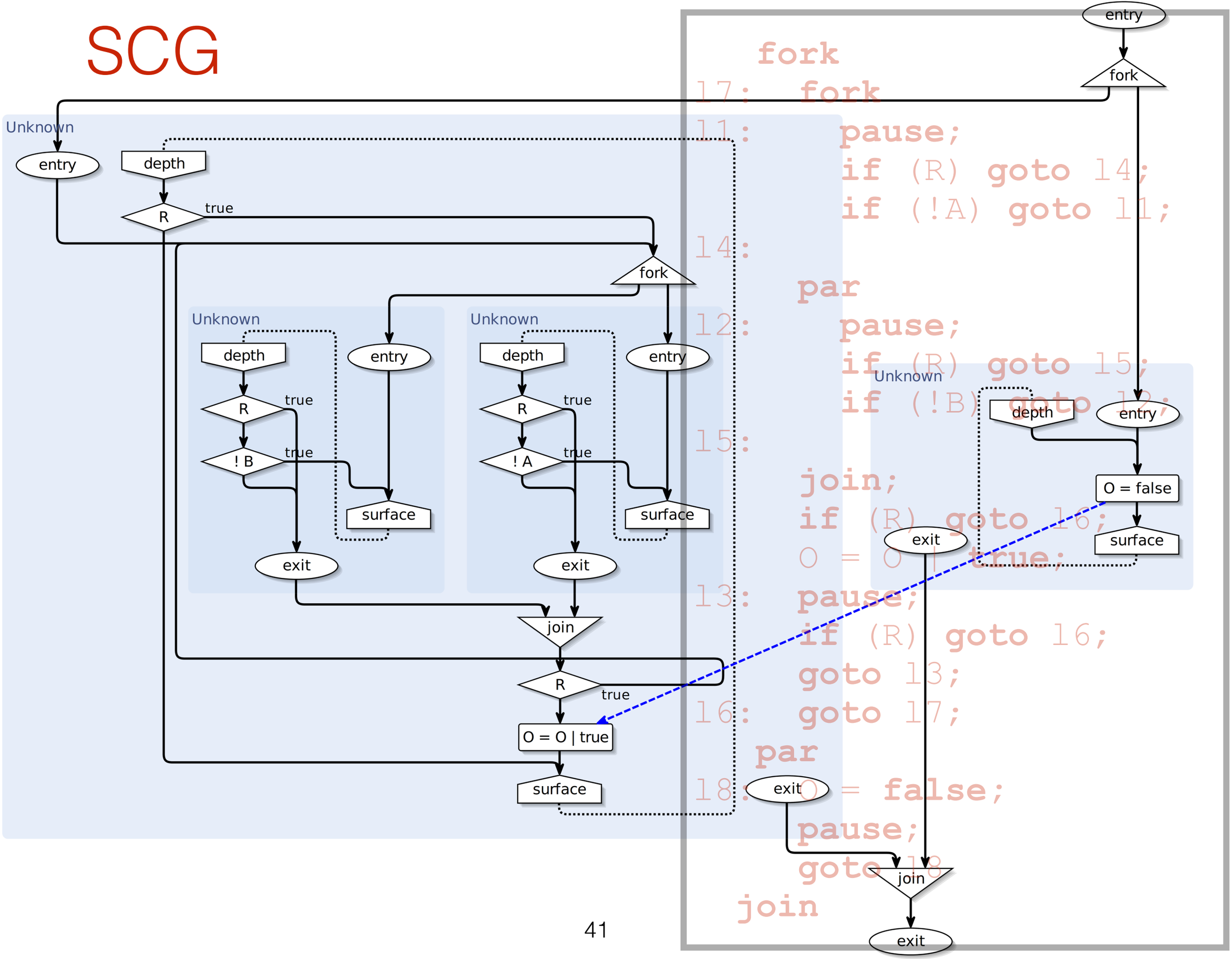
```
17:fork
11:   pause;
      if (R) goto 14;
      if (!A) goto 11;
14:
    par
12:   pause;
      if (R) goto 15;
      if (!B) goto 12;
15:
    join;
    if (R) goto 16;
    emit O;
13:pause;
    if (R) goto 16;
    goto 13;
16:goto 17;
```

emit, out-put

```
    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
```

init → update

SCG


Unknown
entry
depth
R
true
fork
Unknown
depth
R
true
! B
true
surface
exit
entry
Unknown
depth
R
true
! A
true
surface
exit
entry
join
R
true
O = O | true
surface
entry
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
Unknown
depth
entry
O = false
surface
exit
join
exit

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