

Compiling Esterel

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Outline

Introduction to Esterel and Existing Compilers
My Earlier Compiler [DAC 2000, TransCAD 2002]
New Compiler: ESUIF (work in progress [SLAP 2002])

The Esterel Language

Developed by Gérard Berry starting 1983
Originally for robotics applications
Imperative, textual language
Synchronous model of time like that in digital circuits
Concurrent

An Example

```
emit B;
present C then
  emit D end;
```

Force signal present in this cycle
Make D present if C is

An Example

```
await A;
emit B;
present C then
  emit D end;
pause
```

Wait for next cycle where A is present
Wait for next cycle

An Example

```
loop
  await A;
  emit B;
  present C then
    emit D end;
  pause
end
```

Infinite Loop

An Example

```
every R do
  loop
    await A;
    emit B;
    present C then
      emit D end;
    pause
  end
end
||
loop
  present B then
    emit C end;
  pause
end
end
```

Run Concurrently

An Example

```
every R do
  loop
    await A;
    emit B;
    present C then
      emit D end;
    pause
  end
end
||
loop
  present B then
    emit C end;
  pause
end
end
```

Restart on R

An Example

```
every R do
  loop
    await A;
    emit B;
    present C then
      emit D end;
    pause
  end
end
||
loop
  present B then
    emit C end;
  pause
end
end
```

Same-cycle bidirectional communication

An Example

```

every R do
  loop
    await A;
    emit B;
    present C then
      emit D end;
    pause
  end
||
  loop
    present B then
      emit C end;
    pause
  end
end
    
```

Good for hierarchical FSMs

Bad at manipulating data

Hardware Esterel variant
proposed to address this

Automata Compilers

Esterel is a finite-state language, so build an automata:

```

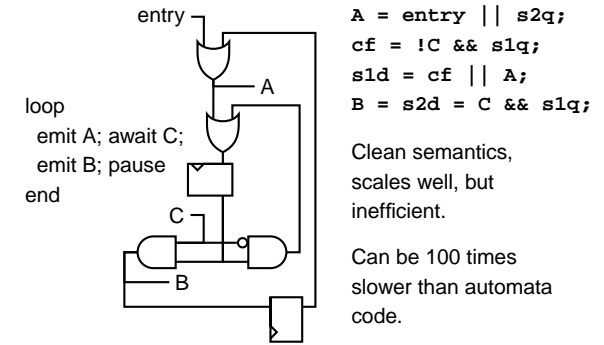
loop
  emit A; await C;
  emit B; pause
end
switch (s) {
  case 0: A = 1; s = 1; break;
  case 1: if (C) B = 1; s = 0; break;
}
    
```

V1, V2, V3 (INRIA/CMA) [Berry, Gonthier 1992]

Fastest known code; great for programs with few states.

Does not scale; concurrency causes state explosion.

Netlist-based Compilers



Other Esterel Compilers

Control-flow-graph based

My work: EC [DAC 2000, TransCAD 2002]

Produces very efficient code for acyclic programs only

Discrete-event based

SAXO-RT [Weil et al. 2000]

Produces very efficient code for acyclic programs only

Being improved at Esterel Technologies?

Both proprietary; unlikely to be released.

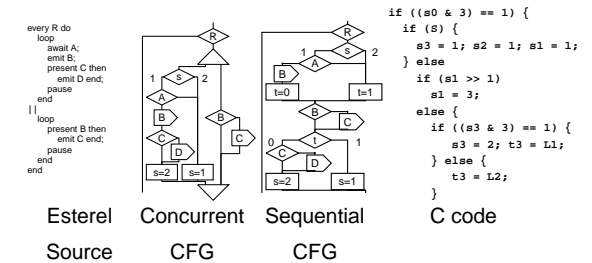
Neither currently copes with statically cyclic programs.

My Earlier Esterel Compiler

Presented at DAC 2000 (also TransCAD 2002)

Used inside Synopsys' CoCentric System Studio to generate control code

Outline



Translate every

```

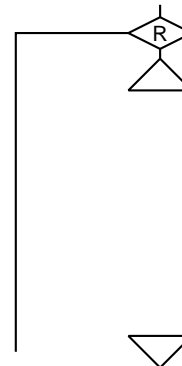
every R do
  loop
    await A;
    emit B;
    present C then
      emit D end;
    pause
  end
||
  loop
    present B then
      emit C end;
    pause
  end
end
    
```



Add Threads

```

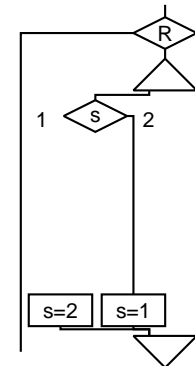
every R do
  loop
    await A;
    emit B;
    present C then
      emit D end;
    pause
  end
||
  loop
    present B then
      emit C end;
    pause
  end
end
    
```



Split at Pauses

```

every R do
  loop
    await A;
    emit B;
    present C then
      emit D end;
    pause
  end
||
  loop
    present B then
      emit C end;
    pause
  end
end
    
```

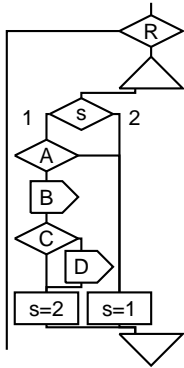


Add Code Between Pauses

```

every R do
  loop
    await A;
    emit B;
    present C then
      emit D end;
    pause
  end
||
  loop
    present B then
      emit C end;
    pause
  end
end
end

```

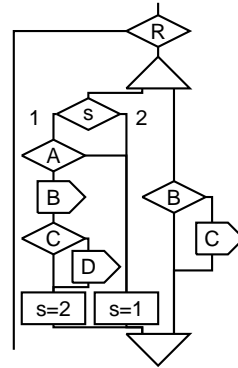


Translate Second Thread

```

every R do
  loop
    await A;
    emit B;
    present C then
      emit D end;
    pause
  end
||
  loop
    present B then
      emit C end;
    pause
  end
end
end

```

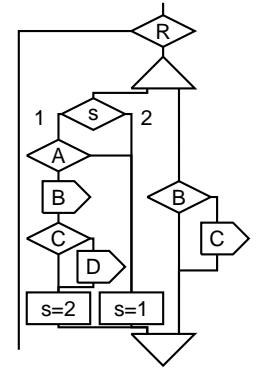


Finished Translating

```

every R do
  loop
    await A;
    emit B;
    present C then
      emit D end;
    pause
  end
||
  loop
    present B then
      emit C end;
    pause
  end
end
end

```

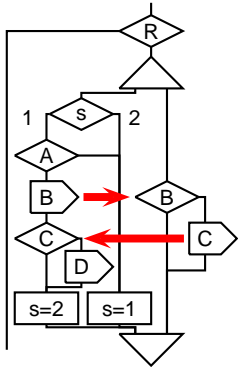


Add Dependencies and Schedule

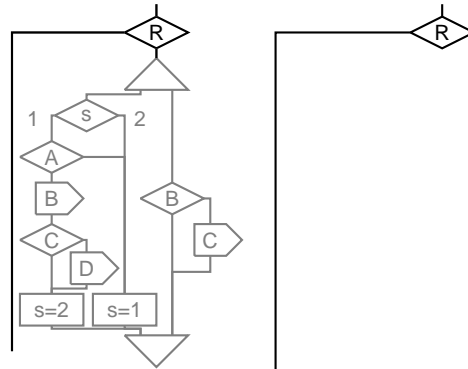
```

every R do
  loop
    await A;
    emit B;
    present C then
      emit D end;
    pause
  end
||
  loop
    present B then
      emit C end;
    pause
  end
end
end

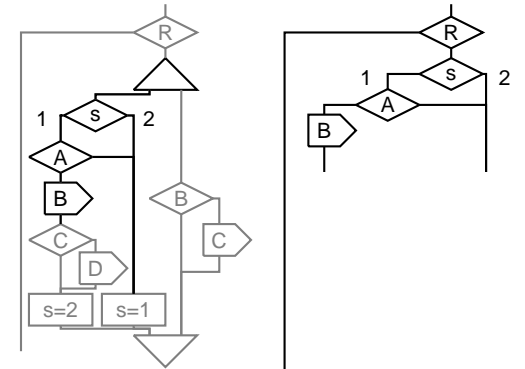
```



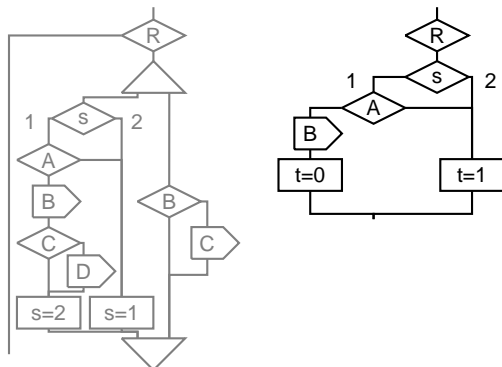
Run First Node



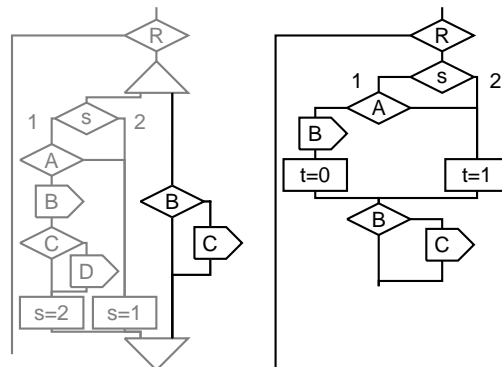
Run First Part of Left Thread



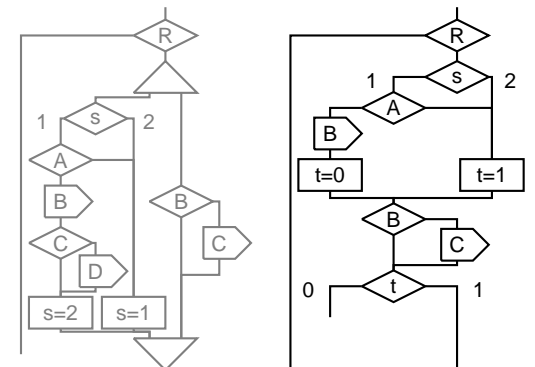
Context Switch



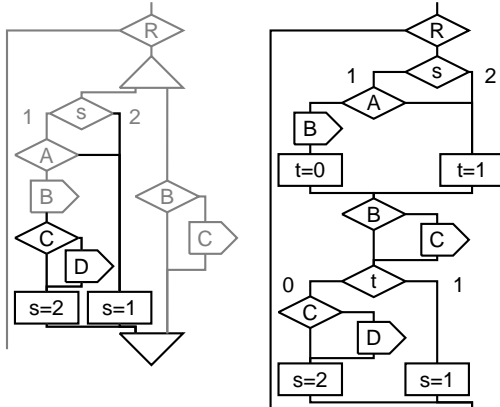
Run Right Thread



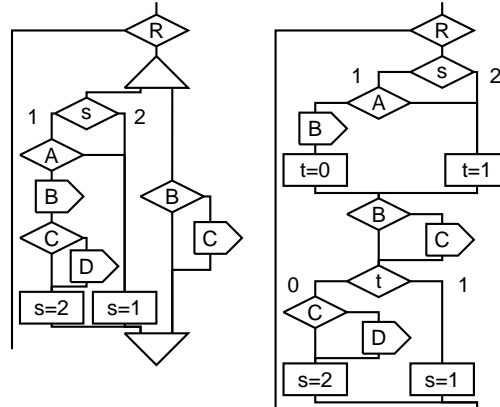
Context Switch



Finish Left Thread



Completed Example



ESUIF

New, open-source compiler being developed at Columbia
Based on SUIF 2 system from Stanford University
Much more modular: implemented as many little passes
Common database represents program throughout

SUIF 2 Database

Main component of the SUIF 2 system
User-customizable object-oriented database
Written in C++
Not highly efficient, but very flexible

ESUIF: An Esterel Compiler for Research

My goal is to improve Esterel compilation technology
We still don't have a technique that builds fast code for large programs
No decent Esterel compiler available in source form
Being presented at SLAP 2002 (Grenoble, April)

SUIF 2 Database

Database schema written in their own "hoof" format
C++ implementation automatically generated

```
class MyClass : public Suifoject
{
public:
    int get_x();
    void set_x(int the_value);
    ~MyClass();
    void print(...);
    static const Lstring
        get_class_name();
};

concrete MyClass {
    int x;
} ⇒
```

Three Intermediate Representations

AST-like representation from front end

Primitives: abort, emit, present, suspend, etc.

Lower-level "C-like" representation

Primitives: if-then-else, try, resume, parallel, etc.

C code

Primitives: if, goto, expressions

SUIF 2 includes a complete C schema

My New Intermediate Representation

Intermediate Representation Goals

Linear, textual, imperative style fits the SUIF 2 philosophy

Gonthier's IC format used in V3-V5 is graph-based and difficult to visualize. Analysis requires depth-first search.

Straightforward translation into C code; simple semantics

IC format requires complicated depth-first search to linearize. Handling of "completion codes" is subtle.

Compound statements express traps, preemption, and concurrency

Tree structure present in IC, but must be rediscovered.

Intermediate Representation

```

var := expr
if (expr) { stmts } else { stmts }
Label:
goto Label

break n
continue
try { stmts } catch 2 { stmts } ...
resume { stmts } catch 1 { stmts } ...
parallel { resumes } catch 1 { stmts } ...

fork Label1, Label2, ...
join
    
```

Implementing Exceptions

```

trap T1 in
  exit T1
  try {
    break 2
    goto Catch2;
    goto Catch0;
  } catch 2 {
    Catch2:
    c = 1;
  }
end
handle T1 do
  c := 1
end
    
```

try becomes a few labels.

break becomes a goto.

Parallel and Exit

```

trap T1 in
  trap T2 in
    exit T1
    ||
    exit T2
  handle T2 do emit B end
  handle T1 do emit A end
  try {
    parallel {
      resume {
        break 3 }
      resume {
        break 2 }
    } catch 1 {
      break 1; continue }
    } catch 2 { B := 1 }
    } catch 3 { A := 1 }
    
```

Intermediate Representation

```

var := expr
if (expr) { stmts } else { stmts }
Label:
goto Label
    
```

Self-explanatory

Signals represented as variables.

Restrictions on where a goto may branch.

Resume/Continue

```

abort      resume {
  goto E
  C: switch (s) {
    case 0: goto St0;
    case 1: goto St1;
  }
  E: s = 0; goto Cal; St0:
    s = 1; goto Cal; St1:
    goto Ca0;
  Cal:
    so = 0; goto Calo; St0o:
    if (!A) goto C;
  Ca0:
}

pause      break 1
pause      break 1

} catch 1 {
  break 1
  if (!A) continue
}

when A
    
```

resume becomes a multi-way branch plus some labels.

continue sends control to the multi-way branch.

Parallel

```

parallel {
  resume {
    break 1
  }
  resume {
    break 1
  }
} catch 1 {
  break 1
  continue
}
    
```

Intermediate Representation

```

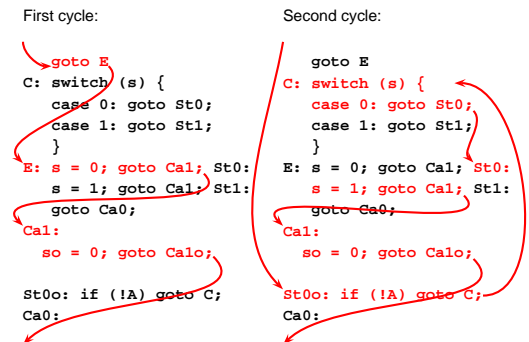
break n
continue
try { stmts } catch 2 { stmts } ...
resume { stmts } catch 1 { stmts } ...
parallel { resumes } catch 1 { stmts } ...
    
```

Numerically-encoded "exceptions"

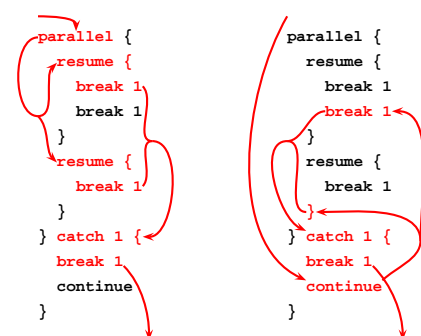
Based on Esterel's completion codes

0=terminate 1=pause 2,3,...=exit

Resume/Continue



Parallel Behavior



A Minor Point on Completion Codes

Berry's encoding reduces the exit code if it is not handled.

```
try {  
    break 5  
} catch 2 { ... }
```

generates `break 4` in Berry's encoding. I treat it as `break 5`.

I assign each trap its own completion code; they pass unchanged.

Simpler semantics vs. the danger of larger codes.

Irrelevant in HW, probably not a problem for SW.

Future Work on HW & SW Synthesis

- HW/SW synthesis from control dependence
Clever concurrent representation produces efficient hardware and facilitates "sequentializing" SW.
- SW synthesis by static unrolling of cyclic programs
Unrolling SW à la Bourdoncle coupled with constant propagation should quickly execute cyclic programs.
- SW synthesis with dynamic event-based scheduling
Unrolling is expensive if done statically; a scheduler can do it dynamically with little overhead.

Summary

Introduction to Esterel and Existing Compilers

Synchronous, Concurrent, Textual Language

Automata, Netlist, and Control-based compilers

My Earlier Compiler [DAC 2000, TransCAD 2002]

Translate to Concurrent CFG, schedule, then synthesize Sequential CFG

New Compiler: ESUIF (work in progress [SLAP 2002])

Based on SUIF 2 infrastructure

Open-source, under development

Intermediate Representation

Future Work