The Columbia Esterel Compiler

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Yet Another Esterel Compiler?

Not quite.

First complete open-source Esterel compiler.

Designed for research; modular like the CMA compilers.

What happened to ESUIF?

- Collapsed under its own weight.
- Less and less of SUIF became useful as development progressed.
- SUIF does not compile under gcc 3.0 (standard library problems).
- Requiring people to install SUIF to use ESUIF prohibitive.

Automata Compilers

Esterel is finite-state; build an automata:

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

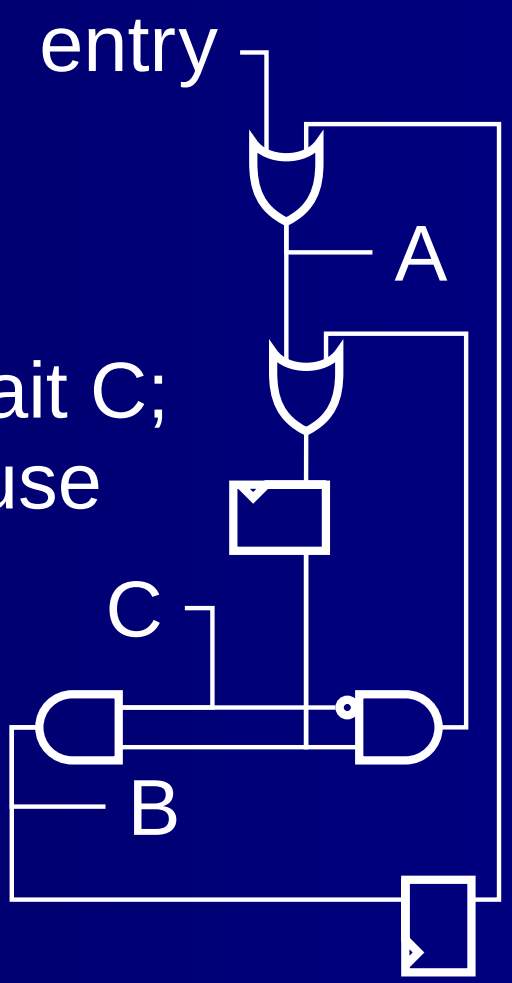
V1, V2, V3 (INRIA/CMA)

Very fast code for programs with few states.

Exponential number of states.

Netlist-based Compilers

```
loop
  emit A; await C;
  emit B; pause
end
```




```
A = entry || s2q;
cf = !C && s1q;
s1d = cf || A;
B = s2d = C && s1q;
```

Clean semantics, scales well, but inefficient.

Can be 100 times slower than automata code.

Discrete-Event Based Compilers

SAXO-RT [Weil et al. 2000] Divides program into event functions dispatched by fixed scheduler

```
loop
  emit A; await C;
  emit B; pause
end
```

```
unsigned curr = 0x1;
unsigned next = 0;
static void f1() {
  A = 1;
  curr &= ~0x1; next |= 0x2;
}
static void f2() {
  if (!C) return;
  B = 1;
  curr &= ~0x2; next |= 0x1;
}
void tick() {
  if (curr & 0x1) f1();
  if (curr & 0x2) f2();
  curr |= next;
  next = 0;
}
```

The Columbia Esterel Compiler

Uses a variant of Potop-Butucaru's GRC format.

Both hardware and software back ends.

Supports most of Esterel V5.

Open-source, BSD license.

http://www.cs.columbia.edu/~sedwards

Back Ends

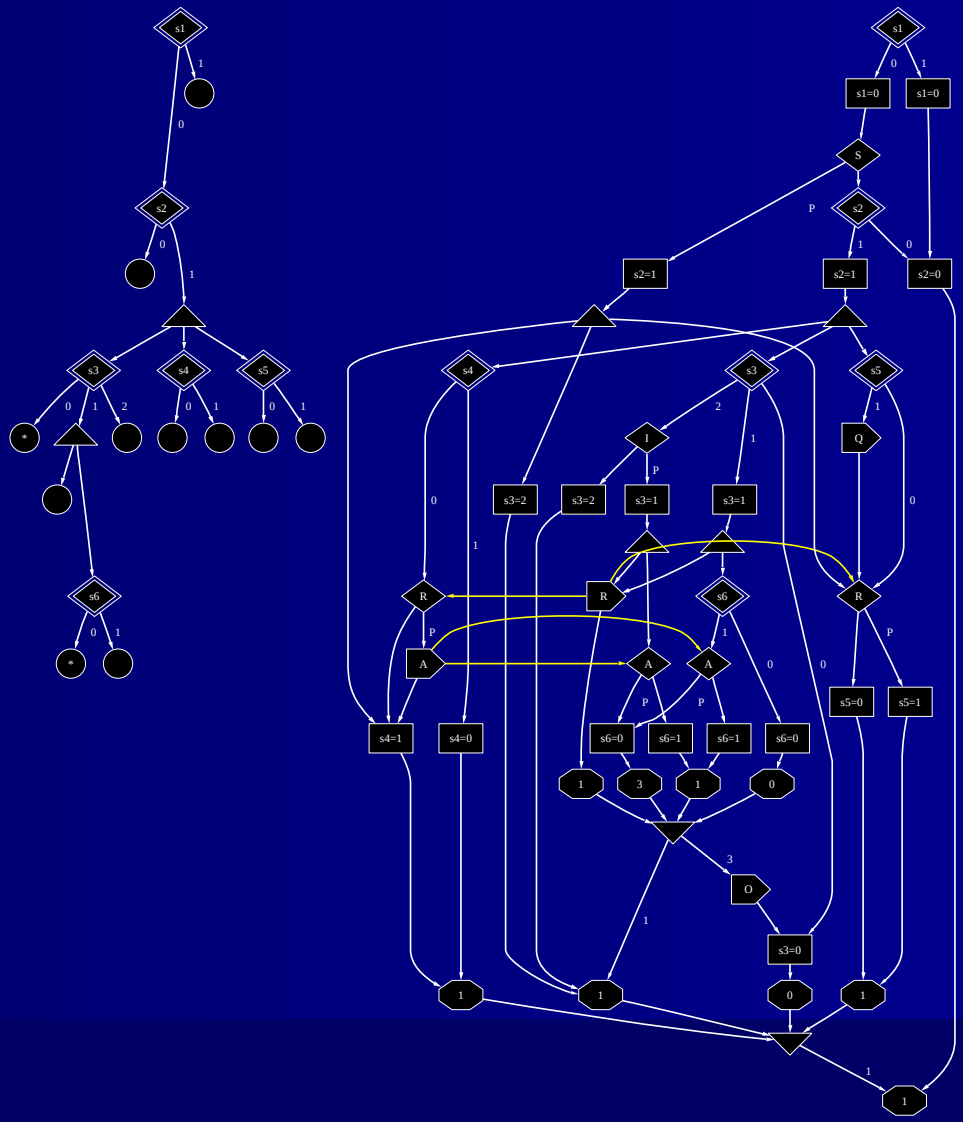
Hardware (BLIF/Verilog). Cristian Soviani.

Software (Event-driven C). Stephen Edwards, Vimal Kapadia, Michael Halas.

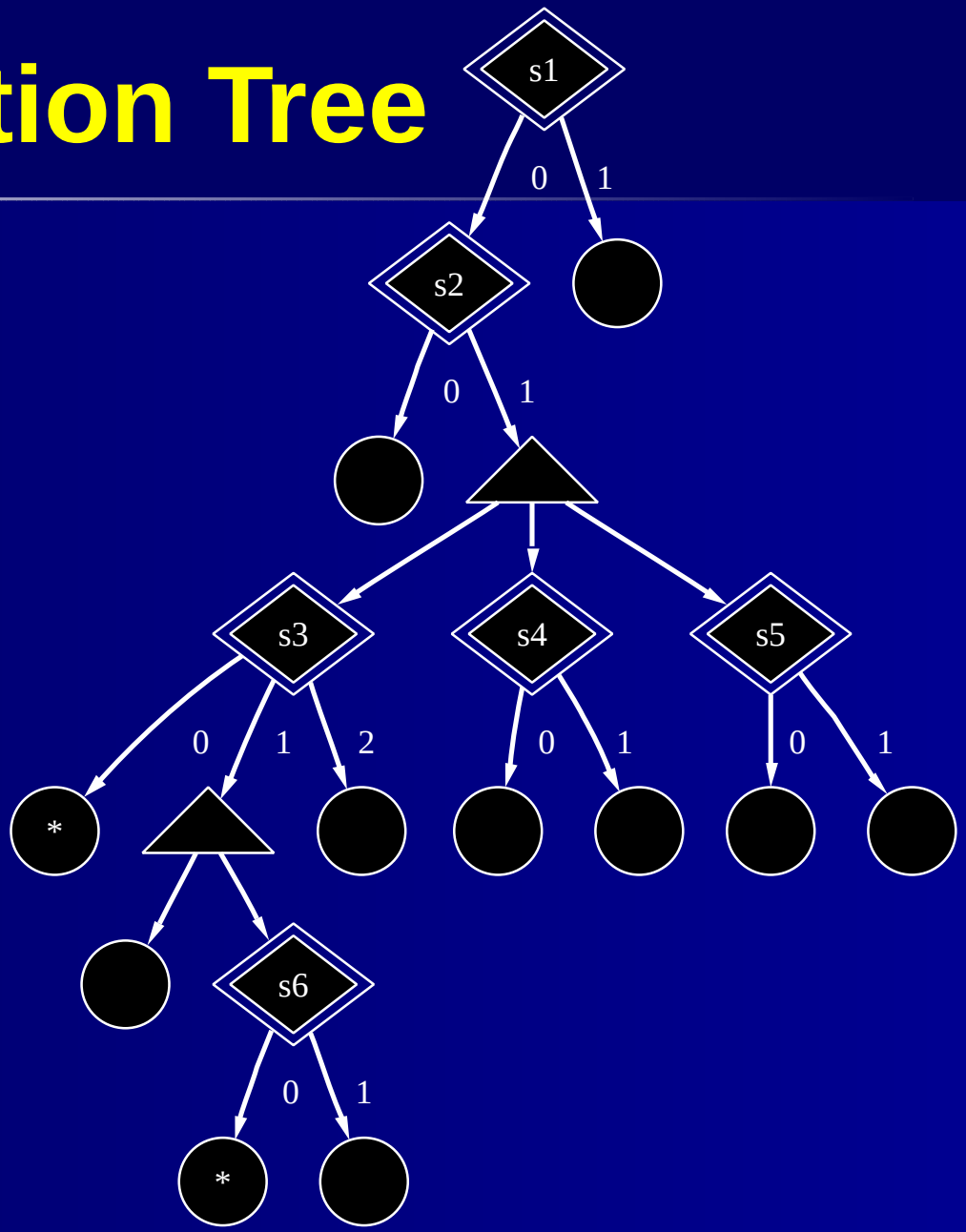
Software (PDG-based Static C). Jia Zeng.

Event-driven C back end

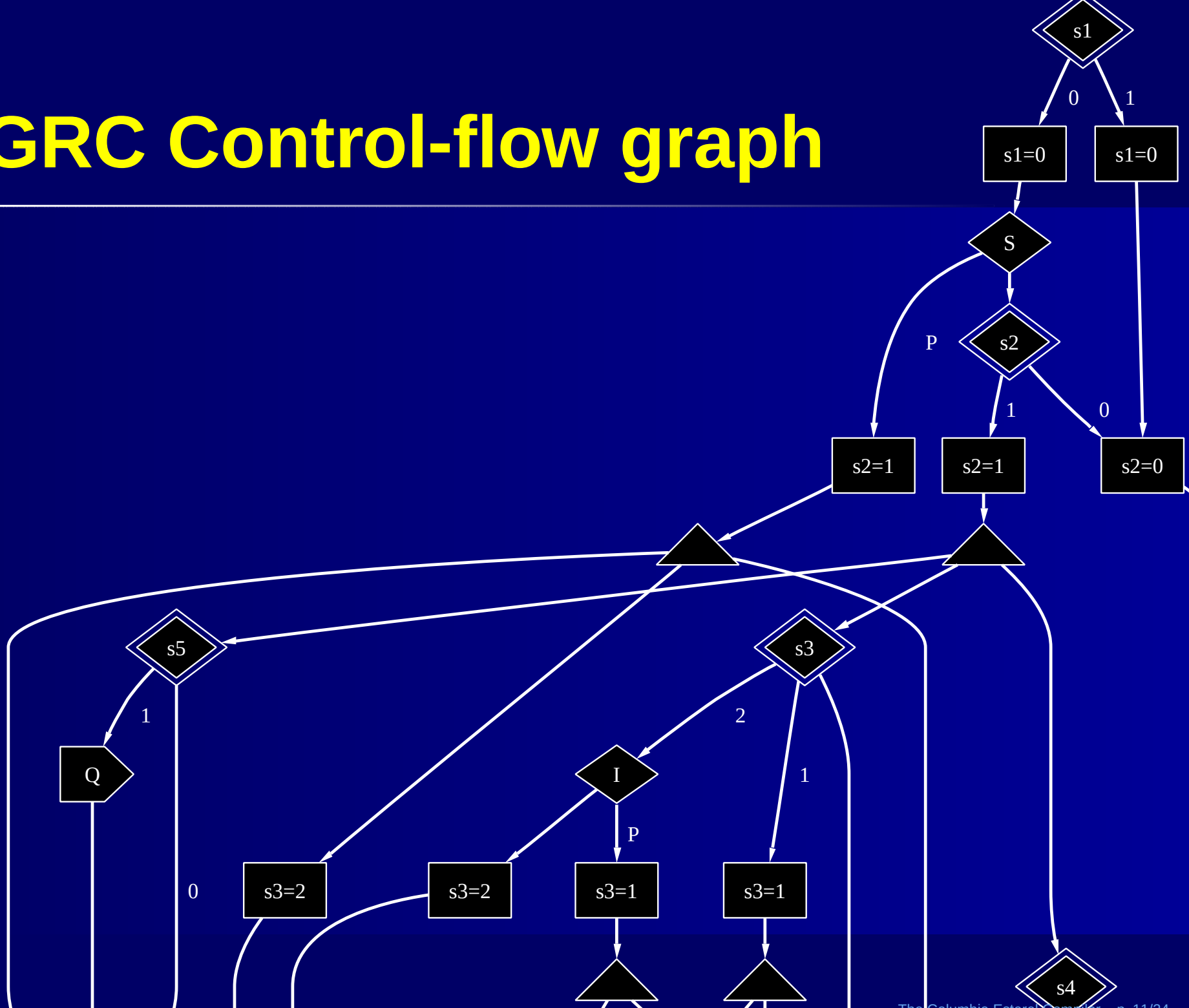
```
module Example:
input I, S;
output O, Q;
signal R, A in
  every S do
      await I;
      weak abort
        sustain R
      when immediate A;
      emit O
    ||
      loop
        pause; pause;
        present R then
          emit A
        end present
      end loop
    ||
      loop
        present R then
          pause; emit Q
        else
          pause
        end present
      end loop
  end every
end signal
end module
```

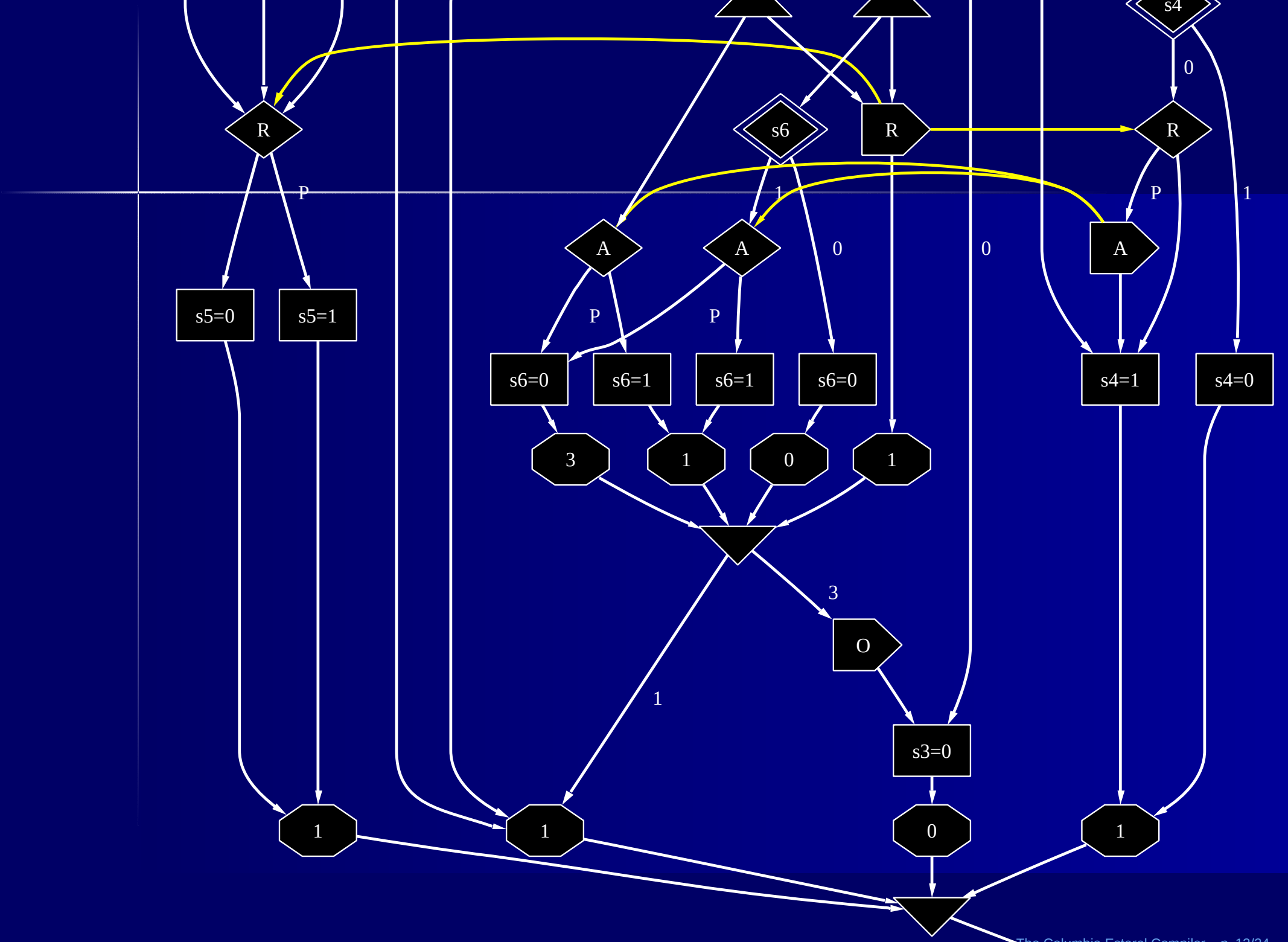


GRC Selection Tree



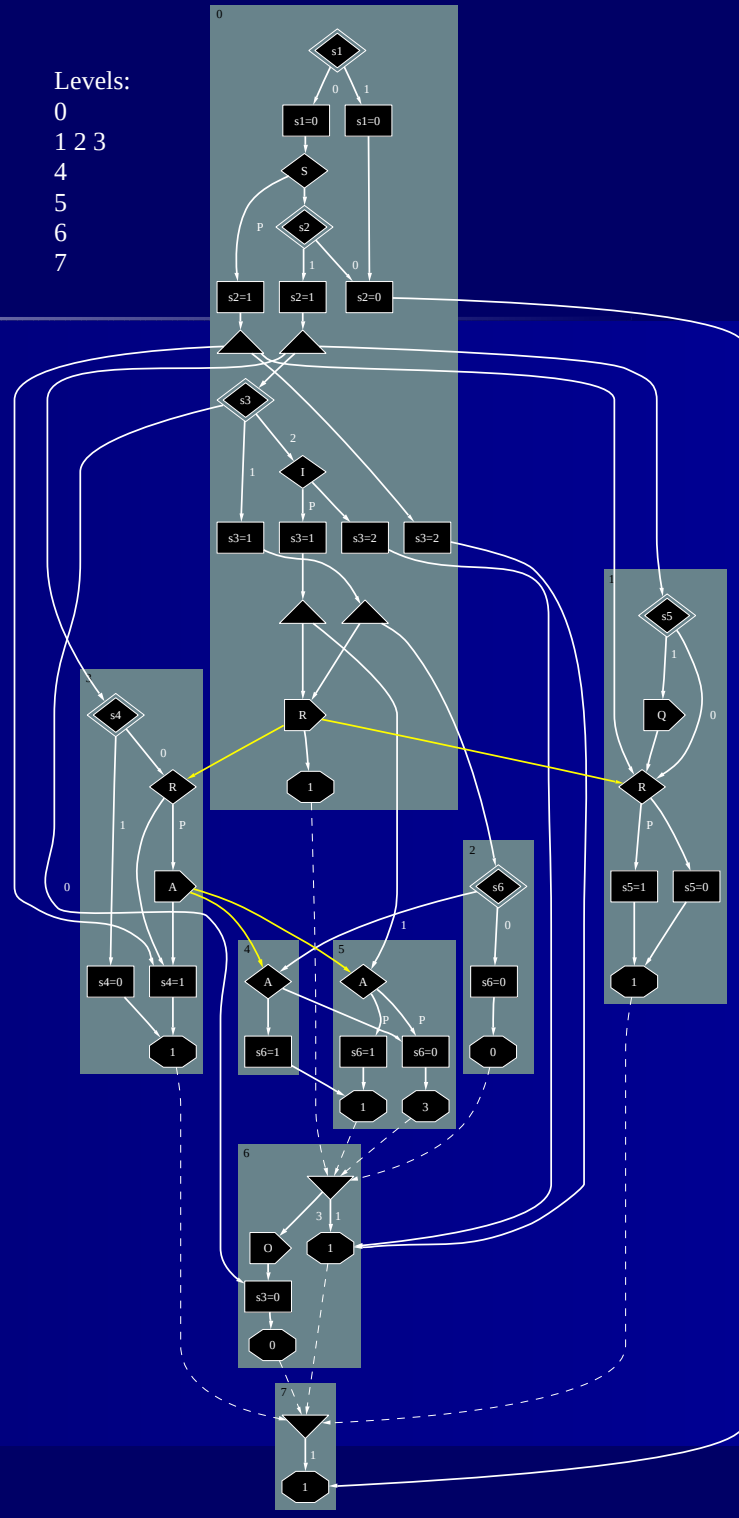
GRC Control-flow graph



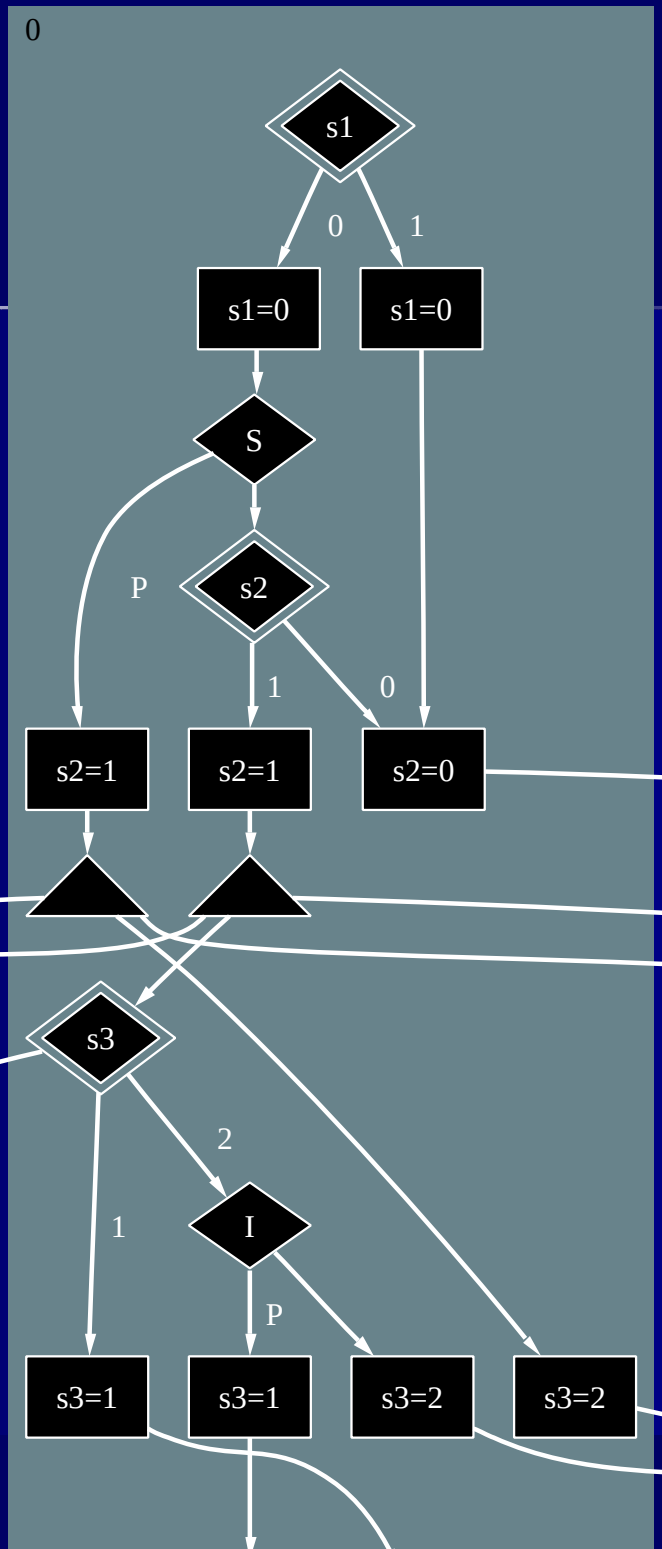

s4
0
R
s6
R
R
P
1
P
1
A
A
0
0
A
s5=0
s5=1
P
P
s6=0
s6=1
s6=1
s6=0
s4=1
s4=0
3
1
0
1
3
O
1
s3=0
1
1
0
1

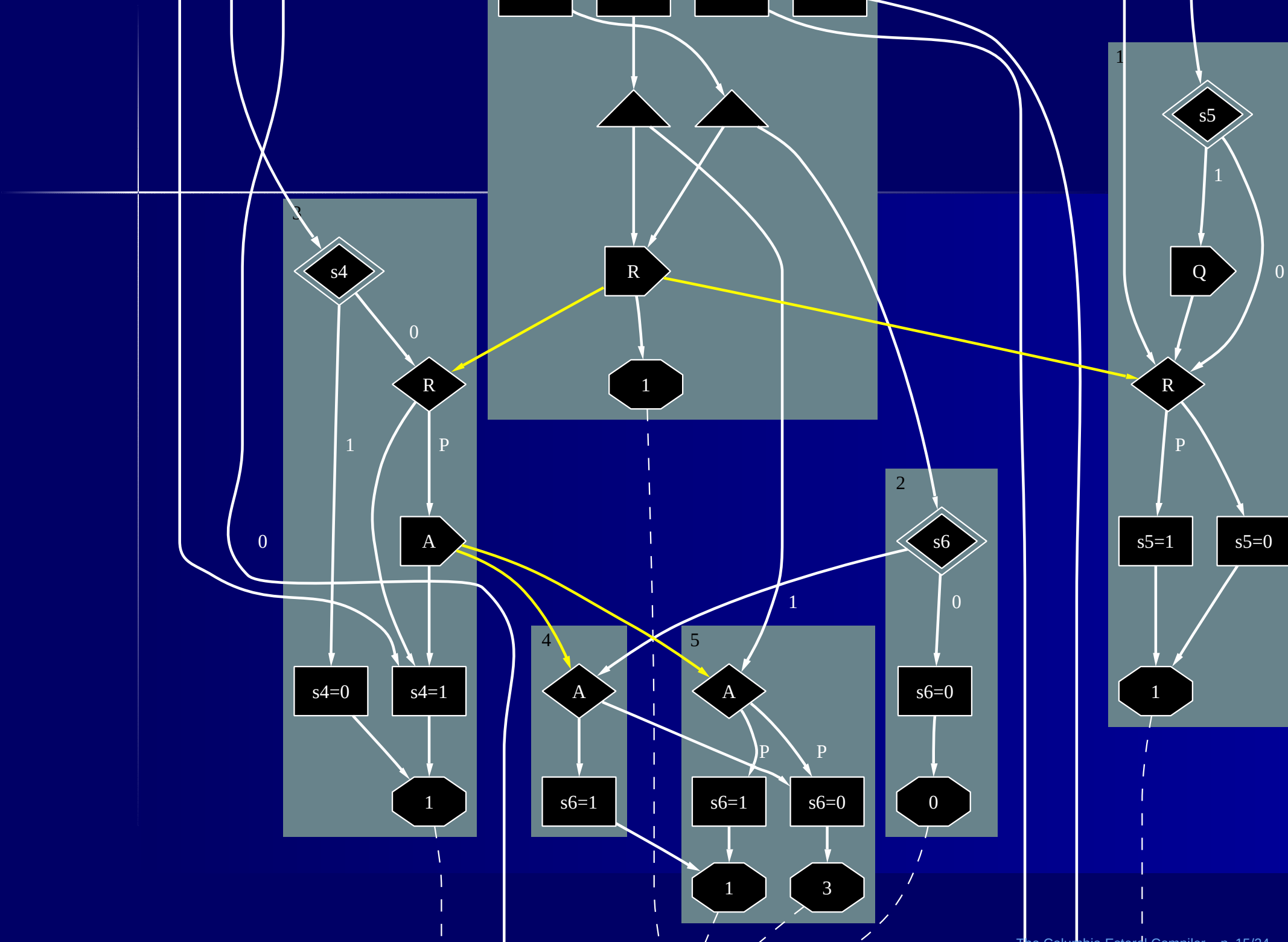
After Clustering

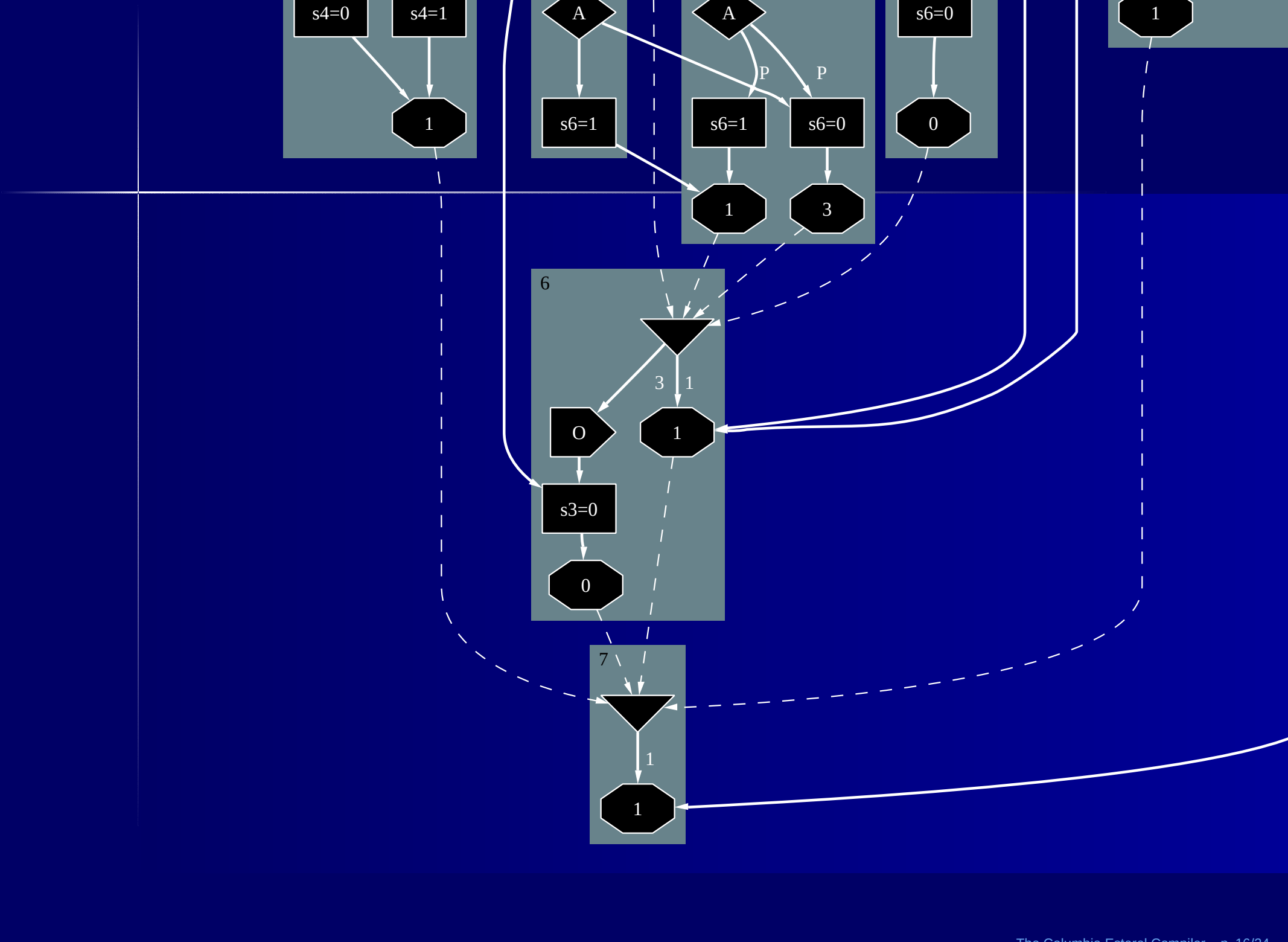
Levels:
0
1 2 3
4
5
6
7



Levels:
0
1 2 3
4
5
6
7




3
s4
0
R
1
P
A
0
s4=0
s4=1
1
4
A
s6=1
5
A
P
P
s6=1
s6=0
1
3
1
R
1
2
s6
0
1
s6=0
0
1
s5
1
Q
0
R
P
s5=1
s5=0
1


s4=0
s4=1
1
A
s6=1
A
P
P
s6=1
s6=0
s6=0
0
1
3
1
6
3
1
O
1
s3=0
0
7
1
1

Generated code (1)

```
#define sched1a next1 = head1, head1 = &&C1a
#define sched1b next1 = head1, head1 = &&C1b
#define sched2  next2 = head1, head1 = &&C2
#define sched3a next3 = head1, head1 = &&C3a
#define sched3b next3 = head1, head1 = &&C3b
#define sched4  next4 = head2, head2 = &&C4
#define sched5a next5 = head3, head3 = &&C5a
#define sched5b next5 = head3, head3 = &&C5b
#define sched5c next5 = head3, head3 = &&C5c
#define sched6a next6 = head4, head4 = &&C6a
#define sched6b next6 = head4, head4 = &&C6b
#define sched6c next6 = head4, head4 = &&C6c
#define sched7a next7 = head5, head5 = &&C7a
#define sched7b next7 = head5, head5 = &&C7b
```

Generated code (2)

```
int cycle() {
  void *next1;
  void *next2;
  void *next3;
  /* other next pointers */

  void *head1 = &&END_LEVEL_1;
  void *head2 = &&END_LEVEL_2;
  /* other level pointers */

  if (s1) {s1 = 0; goto N26; }
  else {
    s1 = 0;
    if (S) {
      s2 = 1; code0 = -1;
      sched7a; sched1b; sched3b;
      s3 = 2; sched6b;
    }else {
```

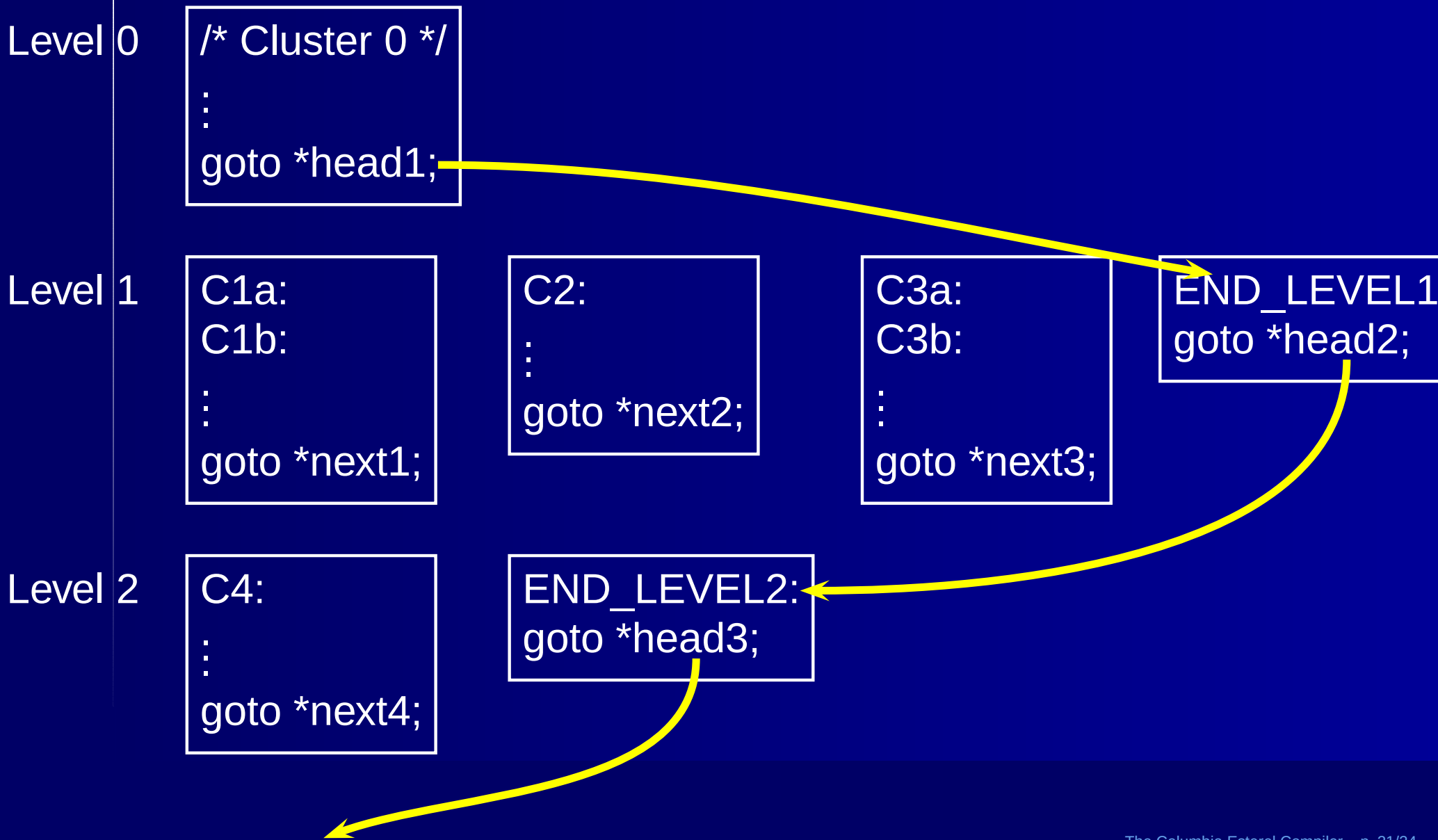
Generated code (3)

```
    if (s2) {
      s2 = 1;
      code0 = -1;
      sched7a; sched1a; sched3a;
      switch (s3) {
      case 0:  sched6c; break;
      case 1:
        s3 = 1; code1 = -1;
        sched6a; sched2; goto N38;
      case 2:
        if (I) {
          s3 = 1; code1 = -1;
          sched6a; sched5a;
     N38:  R = 1; code1 &= -(1 << 1);
        }else {s3 = 2; sched6b; }
        break;
    }}else {
 N26:  s2 = 0; sched7b;
}}}
goto *head1;
```

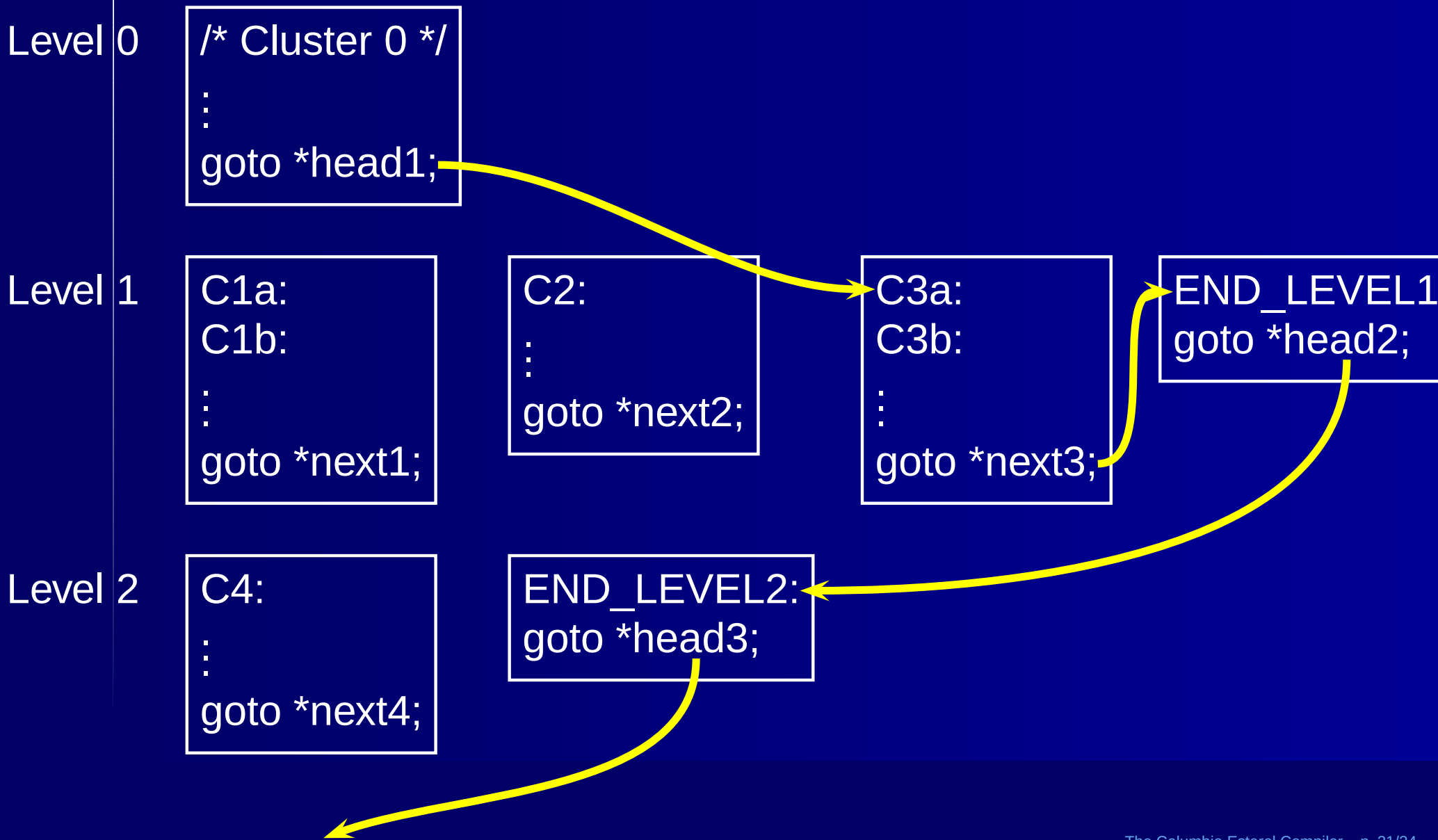
Generated code (4)

```
C1a:  if (s5) Q = 1;
C1b:  if (R) s5 = 1;
      else s5 = 0;
      code0 &= -(1 << 1);
      goto *next1;

C2:     if (s6) sched4;
      else s6 = 0;
      goto *next2;

C3a:  if (s4) s4 = 0;
      else {
        if (R) A = 1;
C3b:       s4 = 1;
      }
      code0 &= -(1 << 1);
      goto *next3;

END_LEVEL1:  goto *head2;
```

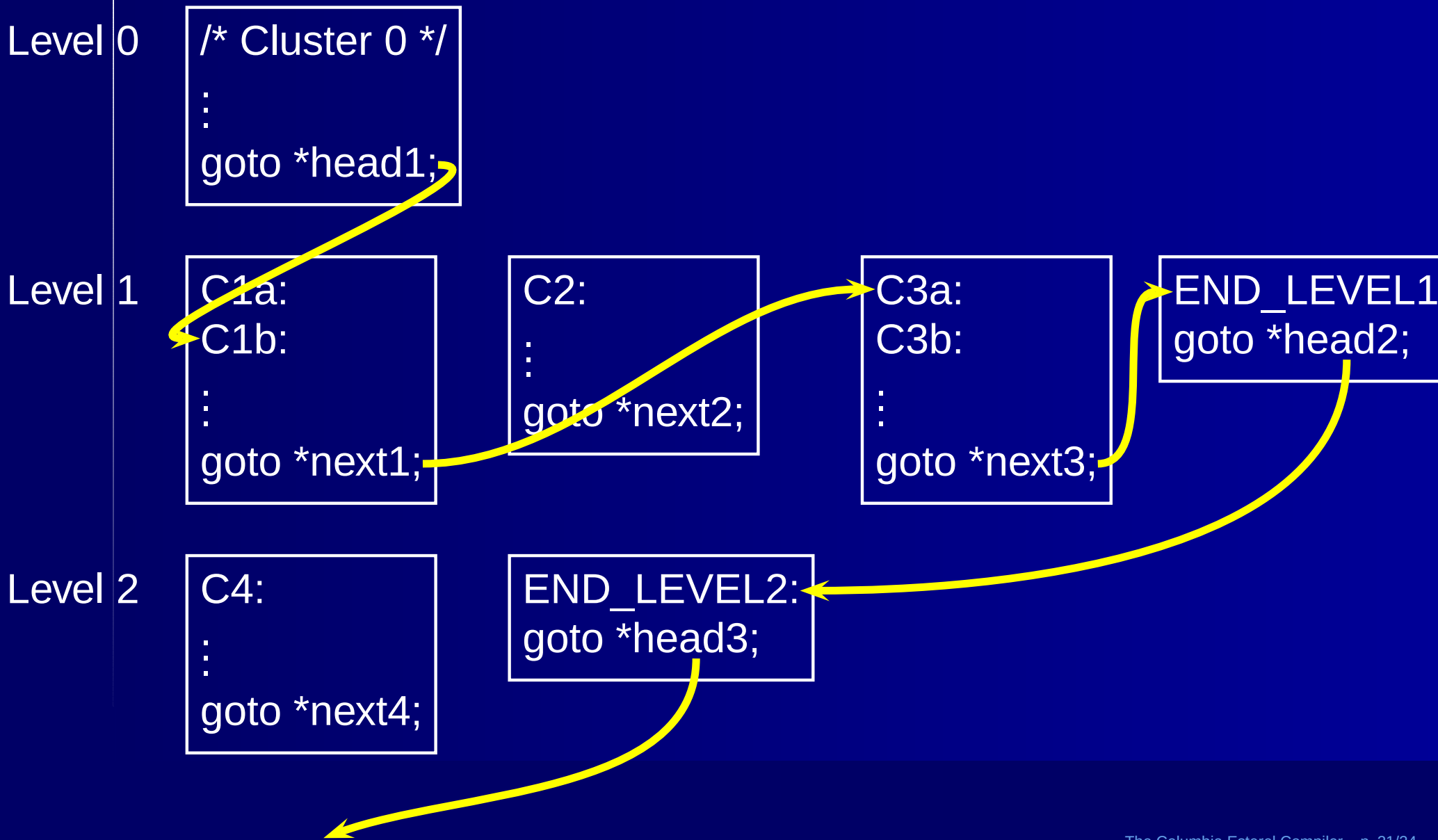
Linked Lists — initial state



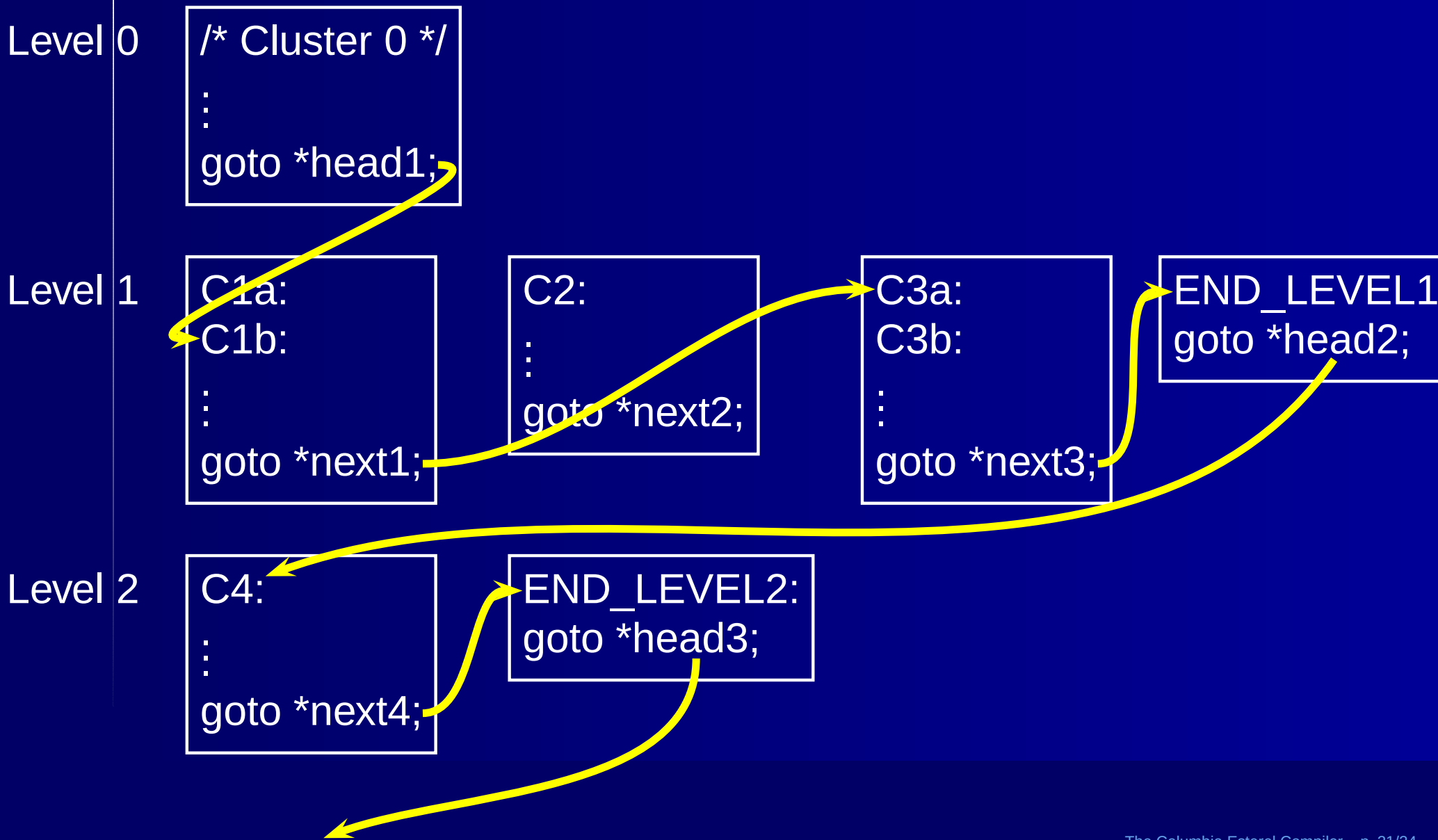
Linked Lists — schedule C3a



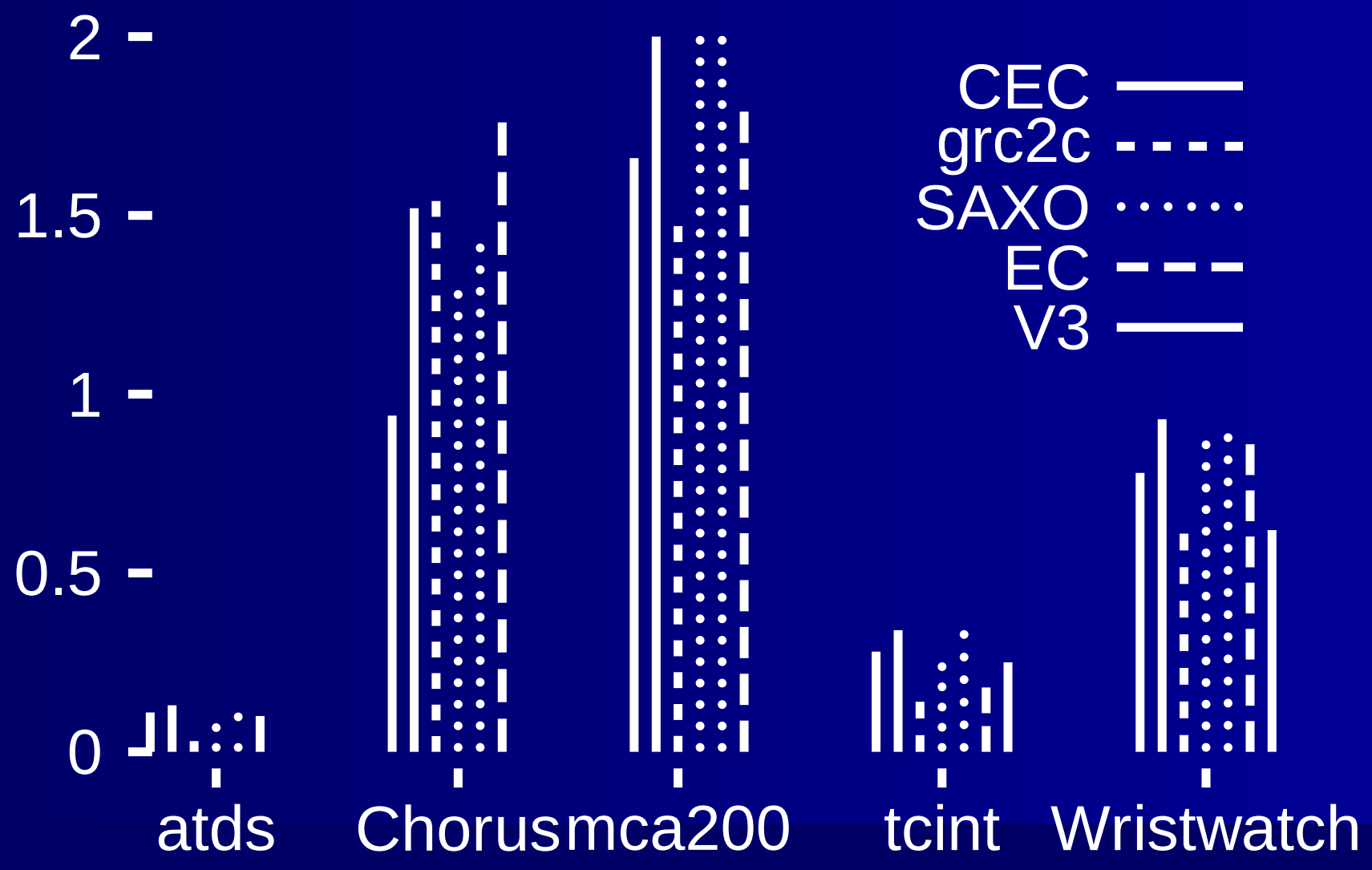
Linked Lists — schedule C1b



Linked Lists — schedule C4



Results (seconds/1 000 000 cycles)



Statistics

Example	Size	Clusters	Levels	C/L	Threads
atds	622	156	16	9.8	138
Chorus	3893	662	22	30.1	563
mca200	5354	148	15	9.9	135
tcint	357	101	19	5.3	85
Wristwatch	360	87	13	6.7	87

Conclusions

CEC: First open-source Esterel compiler

Hardware and software back ends

Event-driven back end like SAXO-RT

Contribution: clustering, levelizing, and linked lists

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