Code Generation for Control Flow

Mooly Sagiv

html://www.cs.tau.ac.il/~msagiv/courses/wcc12-13.html

Chapter 6.4

Outline

- Local flow of control
- Conditionals
- Switch
- Loops

Machine Code Assumptions

Instruction	Meaning
GOTO Label	Jump to Label
GOTO label register	Indirect jump
IF condition register then GOTO Label	Conditional Jump
IF not condition register then GOTO Label	

Boolean Expressions

- In principle behave like arithmetic expressions
- But are treated specially
  - Different machine instructions
  - Used in control flow instructions
  - Shortcut computations
  - Negations can be performed at compile-time

if (a < b) goto l

Code for a < b yielding a condition value

Conversion condition value into Boolean

Conversion from Boolean in condition value

Jump to l on condition value

Shortcut computations

- Languages such as C define shortcut computation rules for Boolean
- Incorrect translation of e1 && e2

Code to compute e1 in loc1
Code to compute e2 in loc2
Code for && operator on loc1 and loc2

Location Computation

- The result of a Boolean expression is pair of locations in the generated code
  - The true location corresponds to the target instruction when the condition holds
  - The false location corresponds to the target instruction when the condition does not hold

Code for e1 && e2

Code for e1

```
if e1 then goto L11
goto L12
```

Code for &&

```
L11:
```

Code for e2

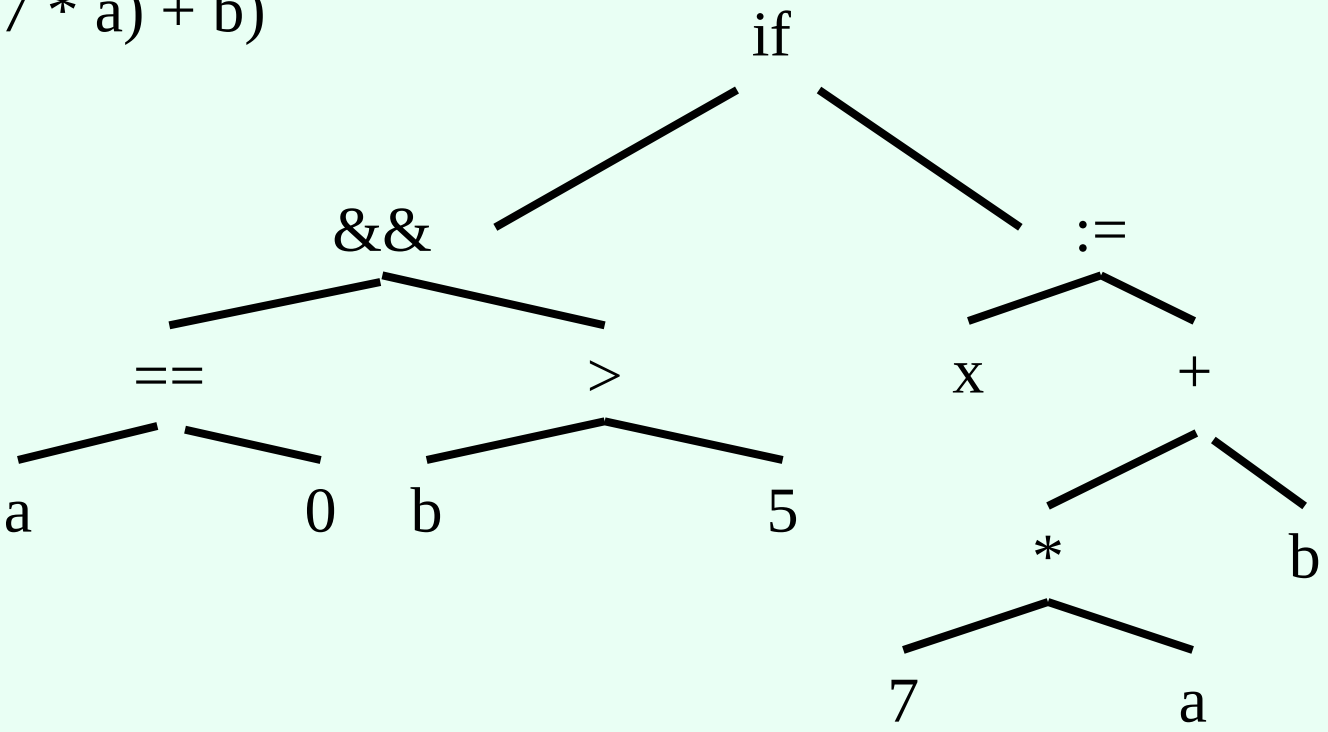
```
if e2 then goto L21
goto L22
```

Code for Booleans (Location Computation)

- Top-Down tree traversal
- Generate code sequences instructions
- Jump to a designated ‘true’ label when the Boolean expression evaluates to 1
- Jump to a designated ‘false’ label when the Boolean expression evaluates to 0
- The true and the false labels are passed as parameters

Example

```
if ((a==0) && (b > 5))
    x = ((7 * a) + b)
```



if

&&

:=

==

>

x

+

a

0

b

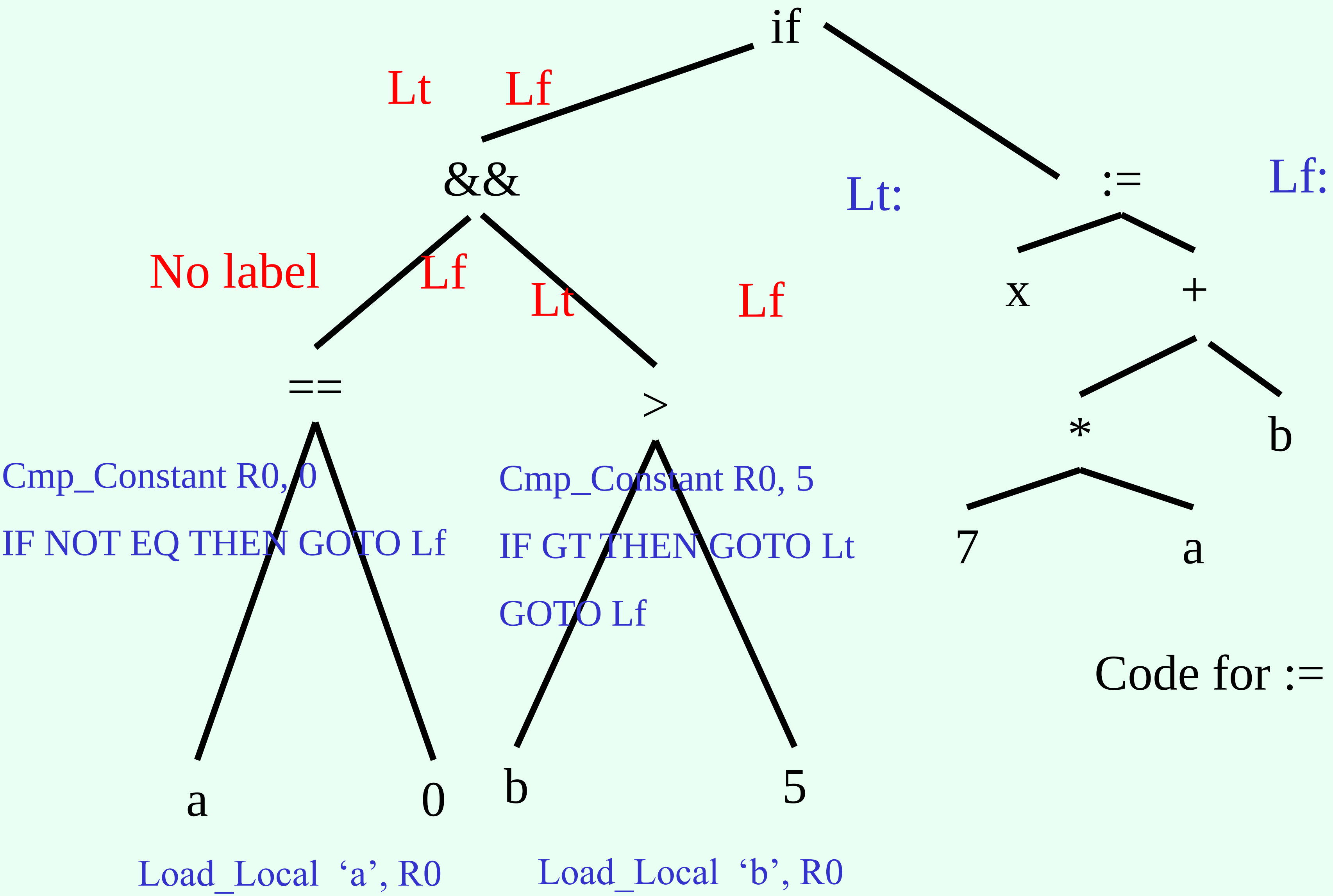
5

*

b

7

a



if

Lt Lf

&&

Lt:

:=

Lf:

No label

Lf

Lt

Lf

x

+

==

>

*

b

Cmp_Constant R0, 0

IF NOT EQ THEN GOTO Lf

Cmp_Constant R0, 5

IF GT THEN GOTO Lt

GOTO Lf

7

a

Code for :=

a

0

b

5

Load_Local ‘a’, R0

Load_Local ‘b’, R0

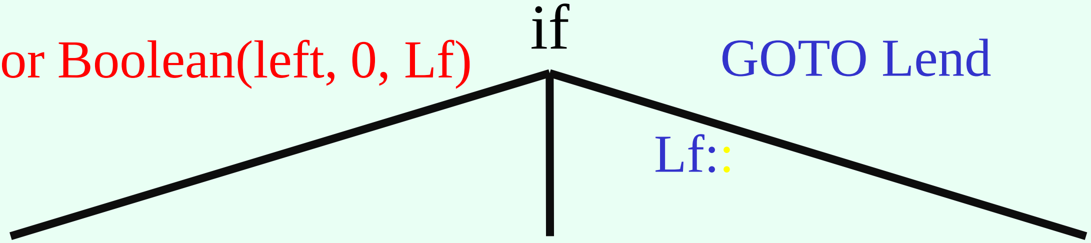
Location Computation for Booleans

```
Procedure  Generate Code for Boolean control expression (
    Node, True label, False label) :
      SELECT Node .type:
           CASE Comparison type:                          // <, >, ==, etc. in C
                 Generate code for comparison expression (Node .expr);
                 // The comparison result is now in condition register
                    IF True label =/ No label:
                        Emit(“If condition register THEN GOTO True label);
                        IF False label /= No label:
                             Emit(“GOTO” False label);
                    ELSE True label == No label:
                          IF False label /= No label:
                             Emit(“IF NOT” condition register THEN GOTO”,
                                                       False label);
          CASE Lazy and type:                                              // && in C
                Generate code for Boolean control expression
                     Node  .left, No Label, False label);
                 Generate code for Boolean control expression
                     Node  .right, True  label, False label);
         CASE Negation type:                                               //  !  in C
              Generate code for Boolean control expression
                     Node  .arg, False  label, True label);
        …
```

Code generation for IF

Allocate two new labels Lf, Lend

Generate code for Boolean(left, 0, Lf)



if

GOTO Lend

Lend:

Lf::

Boolean expression

true sequence

false sequence

Code for Boolean with jumps to Lf

Code for

true sequence

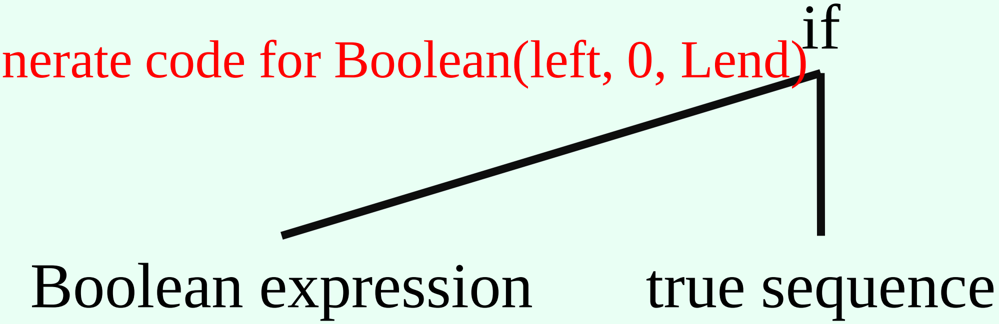
Code for

false sequence

Code generation for IF (no-else)

Allocate new label Lend

Generate code for Boolean(left, 0, Lend)



if

Boolean expression

true sequence

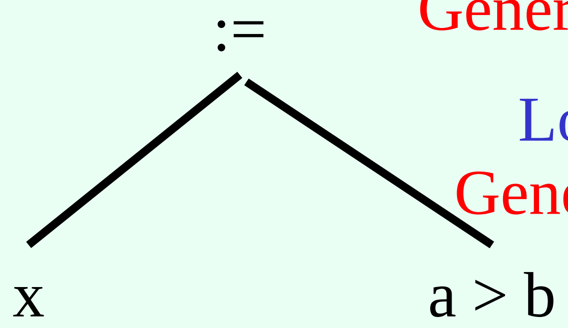
Code for Boolean with jumps
to Lend

Code for

true sequence

Lend:

Coercions into value computations



```
Generate new label Lf
    Load_Constant R0, 0;
 Generate code for Boolean(right, 0, Lf)

   Load_Local 'a', R1;
   CMP R1,  'b' ;

   IF <= GOTO Lf;


      Load_Constant R0, 1
  Lf: Store_Local R0, 'x'
```

Effects on performance

- Number of executed instructions
- Unconditional vs. conditional branches
- Instruction cache
- Branch prediction
- Target look-ahead

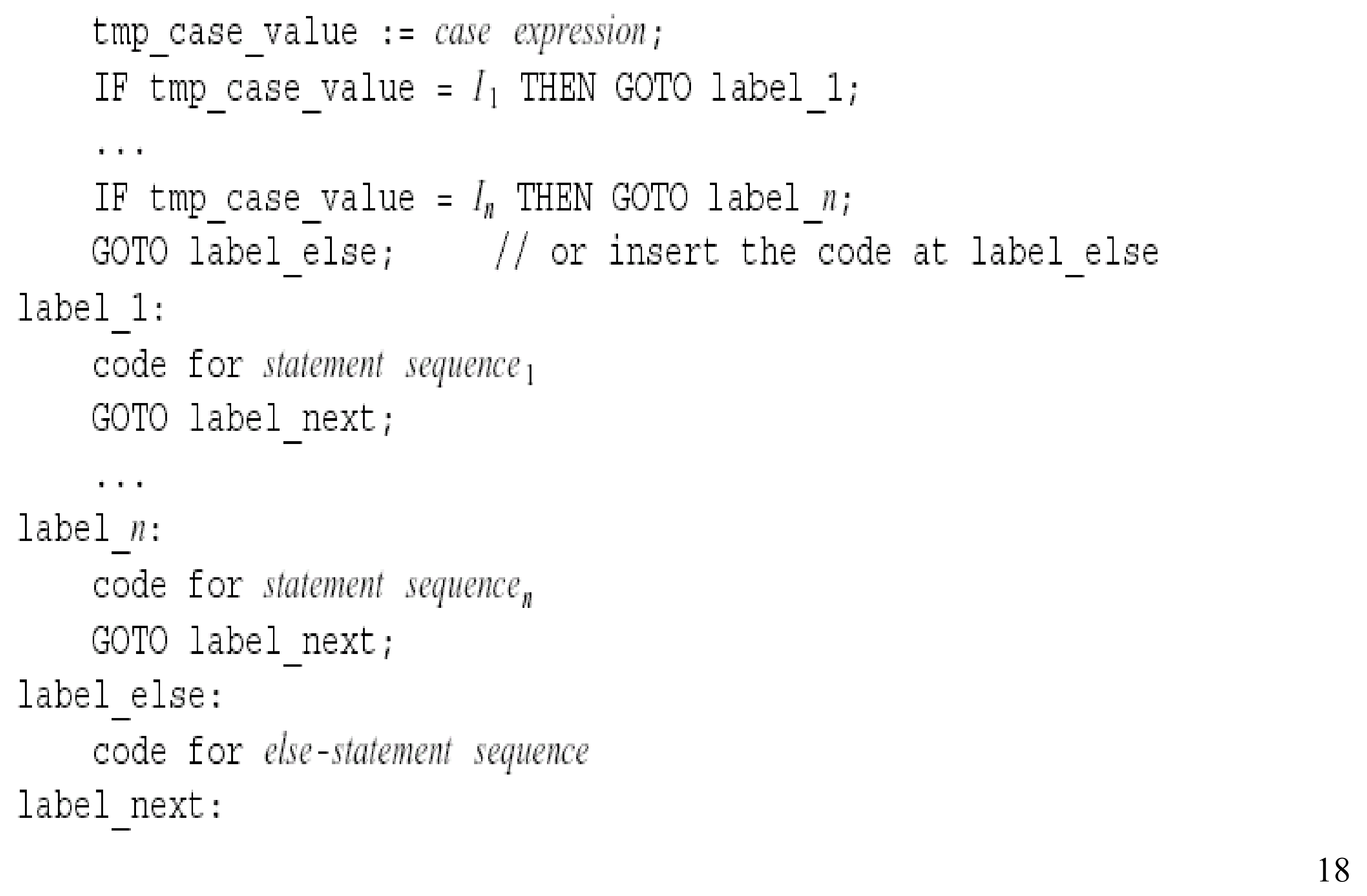
Code for case statements

- Three possibilities
  - Sequence of IFs
    - O(n) comparisons
  - Jump table
    - O(1) comparisons
  - Balanced binary tree
    - O(log n) comparisons
- Performance depends on n
- Need to handle runtime errors

Simple Translation

```
    tmp_case_value := case expression;
    IF tmp_case_value = $l_1$ THEN GOTO label_1;
    IF tmp_case_value = $l_2$ THEN GOTO label_2;
    …
    IF tmp_case_value = $l_n$ THEN GOTO label_n;
    GOTO label_else;  // or insert the code at label else
label 1:
  Code for statement $\text{sequence}_1$
  GOTO label_next;
label 2:
  Code for statement $\text{sequence}_2$
  GOTO label_next;
  …
label n:
  Code for statement $\text{sequence}_n$
  GOTO label_next;
label else:
  Code for else-statement sequence
```

Simple Translation



```
    tmp_case_value := case expression;
    IF tmp_case_value = $I_1$ THEN GOTO label_1;
    ...
    IF tmp_case_value = $I_n$ THEN GOTO label_$n$;
    GOTO label_else;     // or insert the code at label_else
label_1:
    code for statement sequence$_1$
    GOTO label_next;
    ...
label_$n$:
    code for statement sequence$_n$
    GOTO label_next;
label_else:
    code for else-statement sequence
label_next:
```

Jump Table

- Generate a table of L_{high}-L_{low}+1 entries
  - Filled at ?time
- Each entry contains the start location of the corresponding case or a special label
- Generated code

```
tmp_case_value:= case expression;
if tmp_case_value <$L_{low}$ GOTO label_else;
if tmp_case_value>$L_{high}$ GOTO label_else;
GOTO table[tmp_case_value –$L_{low}$];
```

Balanced trees

- The jump table may be inefficient
  - Space consumption
  - Cache performance
- Organize the case labels in a balanced tree
  - Left subtrees smaller labels
  - Right subtrees larger labels
- Code generated for node_k

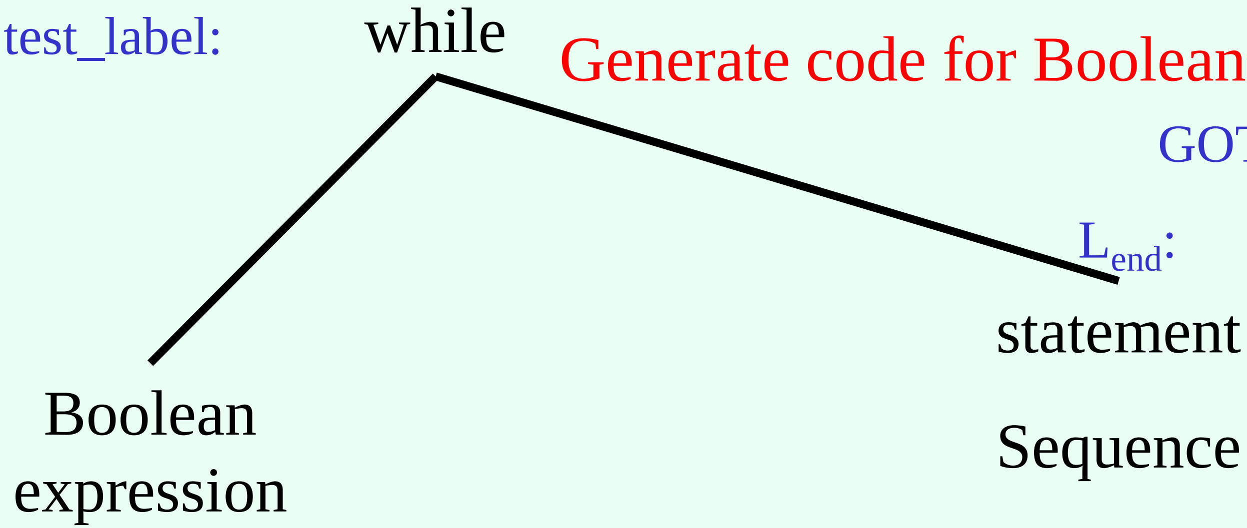
```
label_k: IF tmp_case_value < $l_k$ THEN
             GOTO label of left branch ;
         IF tmp_case_value >$l_k$ THEN
             GOTO label of right branch;
         code for statement sequence;
         GOTO label_next;
```

Repetition Statements (loops)

- Similar to IFs
- Preserve language semantics
- Performance can be affected by different instruction orderings
- Some work can be shifted to compile-time
  - Loop invariant
  - Strength reduction
  - Loop unrolling

while statements

Generate new labels test_label, L_{end}



test_label:

while

Generate code for Boolean(left, 0, L_{end})

GOTO test_label;

L_{end}:

Boolean expression

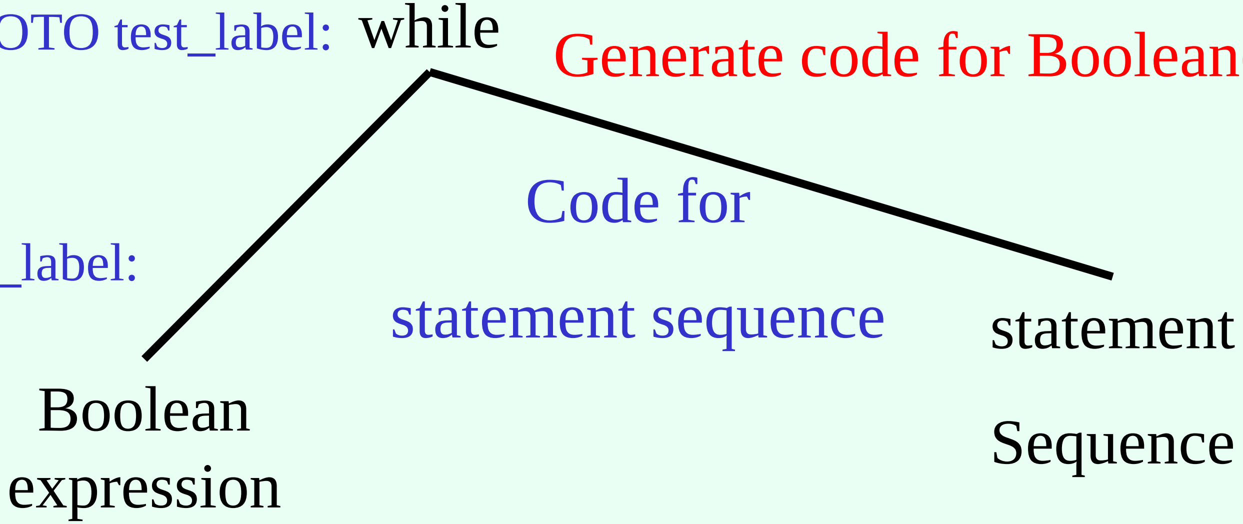
statement Sequence

Code for Boolean with jumps to L_{end}

Code for statement sequence

while statements(2)

Generate labels test_label, Ls



GOTO test_label: while

Generate code for Boolean(left, Ls, 0)

Ls:

Code for

statement sequence

test_label:

statement

Sequence

Boolean

expression

Code for Boolean with
jumps to L_S

For-Statements

- Special case of while
- Tricky semantics
  - Number of executions
  - Effect on induction variables
  - Overflow

Simple-minded translation

```
FOR i in lower bound .. upper bound DO
    statement sequence

END for
```

⇓

```
i := lower_bound;

tmp_ub := upper_bound;

WHILE i <= tmp_ub DO
    code for statement sequence

    i := i + 1;
END WHILE
```

Correct Translation

```
FOR i in lower bound .. upper bound DO
    statement sequence

END for
```

⇓

```
        i := lower_bound;

        tmp_ub := upper_bound;
        IF i >tmp_ub THEN GOTO end_label;

loop_label:
    code for statement sequence
    if (i==tmp_ub) GOTO end_label;

    i := i + 1;


   GOTO loop_label;

end_label:
```

Tricky question

```
for (exp1; exp2; exp3) {
    body;
   }
```

```
exp1;
while (exp2) {
    body;
    exp3;
   }
```

Summary

- Handling control flow statements is usually simple
- Complicated aspects
  - Routine invocation
  - Non local gotos
- Runtime profiling can help