CSCI 742 - Compiler Construction

Lecture 31

Code Generation for Control Structures

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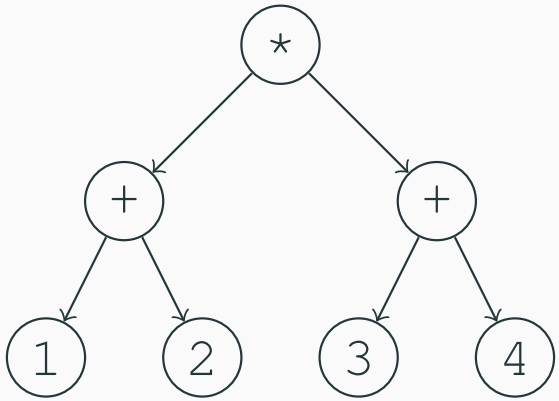
Recap: Code Generation for Expressions

$$[\![e_1 + e_2]\!] =$$
$$[\![e_1]\!]$$
$$[\![e_2]\!]$$
$$\texttt{iadd}$$

$$[\![e_1 * e_2]\!] =$$
$$[\![e_1]\!]$$
$$[\![e_2]\!]$$
$$\texttt{imul}$$

Recap: Code Generation for Expressions



Code generation visits AST nodes in post-order

```
iconst_1
iconst_2
iadd
iconst_3
iconst_4
iadd
imul
```

JVM Boolean Type

- Although JVM defines a `boolean` type, it only provides very limited support for it
- There are no JVM instructions solely dedicated to operations on `boolean` values
- Instead, expressions in Java that operate on `boolean` values are compiled to use values of `int`

Java Virtual Machine Specification
Java SE 8 Edition

- We represent Java boolean `false` in JVM by the integer 0
- We represent Java boolean `true` in JVM by the integer 1

`true`, `false`, variables

- $[\![\texttt{true}]\!] = \texttt{iconst\_1}$
- $[\![\texttt{false}]\!] = \texttt{iconst\_0}$
- for boolean variable $\texttt{b}$, for which $\texttt{n}$ = slotOf($\texttt{b}$)
- $[\![\texttt{b}]\!] = \texttt{iload\_n}$
- $[\![\texttt{b = } e]\!] =$

  $[\![e]\!]$

  $\texttt{istore\_n}$

Compiling `if` Statement

- Recap: `if<cond>` branches if int comparison with zero succeeds

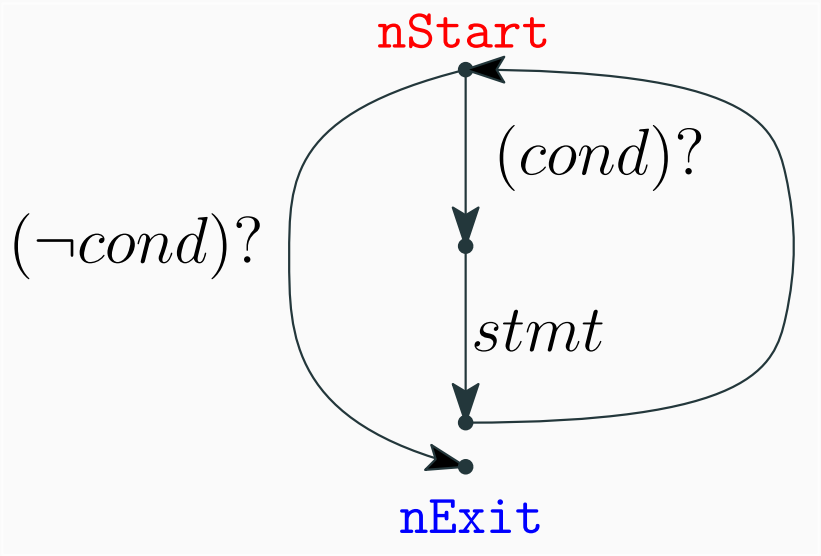
$[\![$`if (`$cond$`)` $tStmt$ `else` $eStmt$$]\!] =$

$[\![cond]\!]$
`ifeq(nElse)`
$[\![tStmt]\!]$
`goto(nAfter)`
`nElse:` $[\![eStmt]\!]$
`nAfter:`

$[\![$`if (`$cond$`)` $tStmt$ `else` $eStmt$$]\!] =$

$[\![cond]\!]$
`ifneq(nThen)`
$[\![eStmt]\!]$
`goto(nAfter)`
`nThen:` $[\![tStmt]\!]$
`nAfter:`

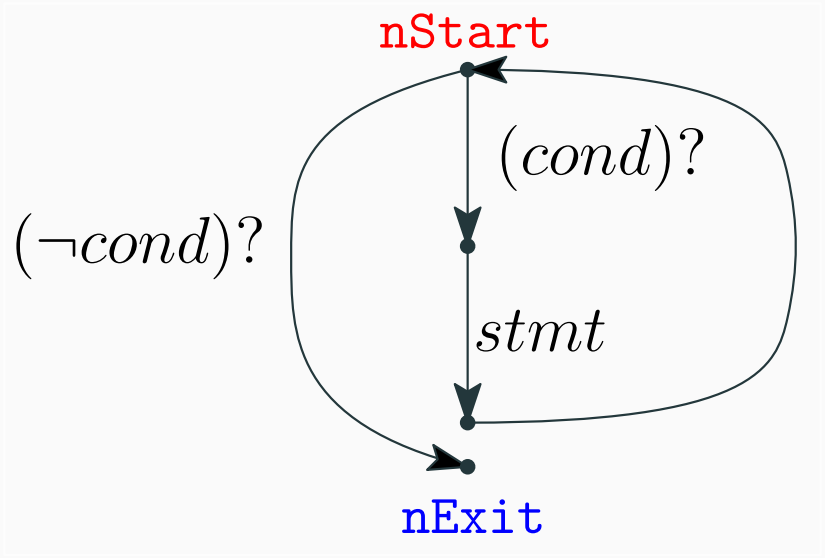
Compiling `while` Statement



$[\![$`while` $(cond)$ $stmt]\!] =$

```
    nStart:   [[cond]]
              ifeq(nExit)
              [[stmt]]
              goto(nStart)
     nExit:
```

Compiling `while` Statement

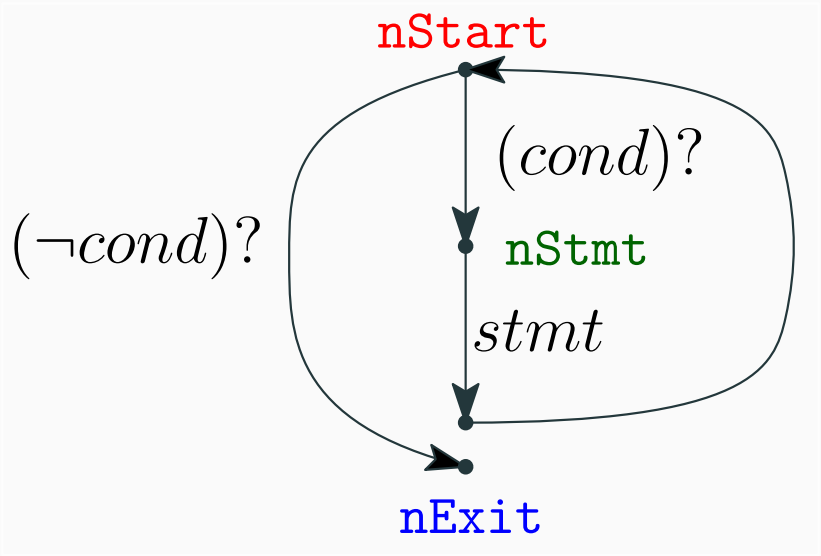


$[\![$`while` $(cond)$ $stmt]\!] =$

```
    nStart:   [[cond]]
              ifeq(nExit)
              [[stmt]]
              goto(nStart)
     nExit:
```

Exercise: Give a translation with only one jump during loop

Compiling `while` Statement



$[\![\texttt{while } (cond)\ stmt]\!] =$

```
    nStart:  [[cond]]
             ifeq(nExit)
             [[stmt]]
             goto(nStart)
     nExit:
```

$[\![\texttt{while } (cond)\ stmt]\!] =$

```
             goto(nStart)
      nStmt: [[stmt]]
    nStart:  [[cond]]
             ifneq(nStmt)
```

Exercise: Give a translation with only one jump during loop

Example: Code Generation for `while` Loop

```
static boolean cond(int n)
  { /* ...*/ }
static int work(int n)
  { /* ...*/ }
static void func(int n) {
  while(cond(n)) {
    n = work(n);
}}
```

```
 0:  iload_0
 1:  invokestatic #2 // cond:(I)Z
 4:  ifeq 15
 7:  iload_0
 8:  invokestatic #3 // work:(I)I
11: istore_0
12: goto          0
15: return
```

Exercise

- Oberon-2 has a `LOOP` statement that expresses repetitions with exit condition in the middle of the loop
- This generalizes `while` and `do ... while`
- Give a translation scheme for the `LOOP` construct

```
LOOP
   code1
   EXIT IF cond
   code2
END
```

Exercise

- Oberon-2 has a `LOOP` statement that expresses repetitions with exit condition in the middle of the loop
- This generalizes `while` and `do ... while`
- Give a translation scheme for the `LOOP` construct

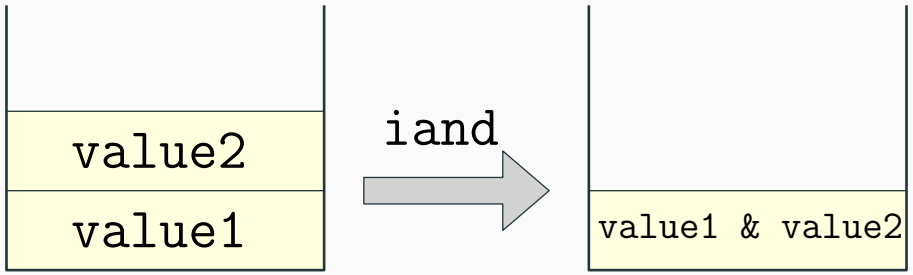
```
LOOP
   code1
   EXIT IF cond
   code2
END
```

```
nStart:  ⟦code1⟧
         ⟦cond⟧
         ifneq(nExit)
         ⟦code2⟧
         goto(nStart)
nExit:
```

Bitwise Operations

```
01001000  &          01001000  |
10101110  =          10101110  =
--------             --------
00001000             11101110
```

- `iand` computes the bitwise and of `value1` and `value2`
  - (which must be ints)
- The int result replaces `value1` and `value2` on stack



- `ior`: dual of `iand`

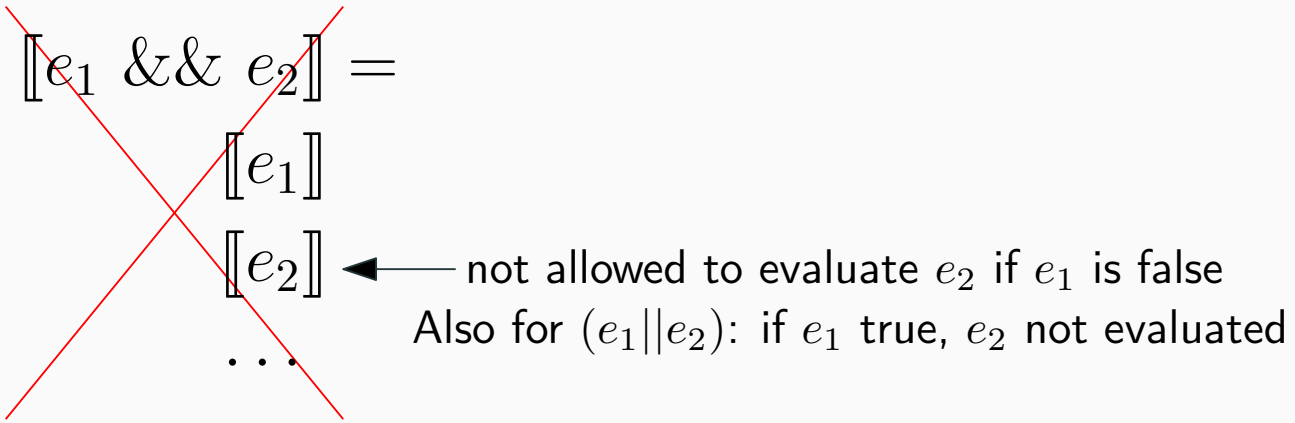
Compiling Bitwise Operations

$$[\![e_1 \mathbin{\&} e_2]\!] =$$
$$[\![e_1]\!]$$
$$[\![e_2]\!]$$
$$\texttt{iand}$$

$$[\![e_1 \mid e_2]\!] =$$
$$[\![e_1]\!]$$
$$[\![e_2]\!]$$
$$\texttt{ior}$$

Short-circuit Evaluation

- Non-bitwise operators && and || are short-circuit operators in Java
- They only evaluate their second operand if necessary
- Must compile short-circuit operators correctly
- It is not acceptable to emit code that always evaluates both operands of $\&\&$,||



Example

- What does this program do?

```
static boolean bigFraction(int x, int y) {
  return ((y==0) | (x/y > 100));
}
public static void main(String[] args) {
  bigFraction(10,0);
}
```

Example

- What does this program do?

```
static boolean bigFraction(int x, int y) {
  return ((y==0) | (x/y > 100));
}
public static void main(String[] args) {
  bigFraction(10,0);
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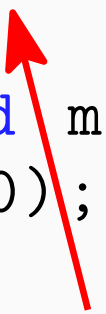


- Exception in thread "main" java.lang.ArithmeticException: / by zero

Example

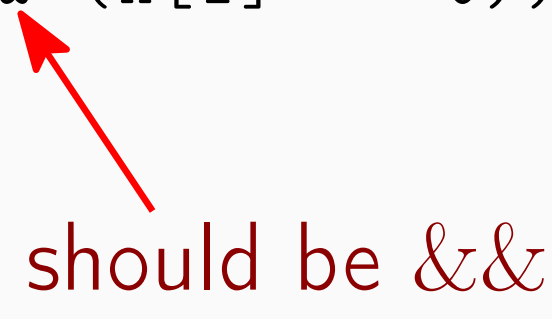
- What does this program do?

```
static int iterate() {
  int[] x = new int[10];
  int i = 0;
  int res = 0;
  while ((i < x.length) & (x[i] >= 0)) {
    i = i + 1;
    res = res + 1;
  }
  return res;
}
```

Example

- What does this program do?

```
static int iterate() {
  int[] x = new int[10];
  int i = 0;
  int res = 0;
  while ((i < x.length) & (x[i] >= 0)) {
    i = i + 1;
    res = res + 1;
  }
  return res;
}
```



- Exception in thread "main"
  java.lang.ArrayIndexOutOfBoundsException: 10

Conditional Expression

`c ? t : e` means:

1. evaluate `c`
2. if `c` is true, then evaluate `t` and return
3. if `c` is false, then evaluate `e` and return

- To compile $||$, $\&\&$ transform them into conditional expression

$$(p \;\&\&\; q) == (p) \;?\; q \;\texttt{ : false}$$
$$(p \;||\; q) == (p) \;?\; \texttt{true : } q$$

Compiling Conditional Expression

- Same as for if statement, even though code for branches will leave values on the stack

$$
\begin{aligned}
[\![(cond)\ ?\ t\ :e]\!] = \\
&[\![cond]\!] \\
&\texttt{ifeq(nElse)} \\
&[\![t]\!] \\
&\texttt{goto(nAfter)} \\
\texttt{nElse:}\quad &[\![e]\!] \\
\texttt{nAfter:}\quad &
\end{aligned}
$$

Java Example for Conditional

```
int f(boolean c, int x, int y) {
  return (c ? x : y);
}
```

```
0: iload_1
1: ifeq 8
4: iload_2
5: goto 9
8: iload_3
9: ireturn
```

Compiling &&

$[\![(cond)\ ?\ t\ :e]\!] =$

$[\![cond]\!]$

`ifeq(nElse)`

$[\![t]\!]$

`goto(nAfter)`

`nElse:` $[\![e]\!]$

`nAfter:`

$[\![p\ \&\&\ q]\!] =$

$[\![(p)\ ?\ q\ :\texttt{false}]\!] =$

$[\![p]\!]$

`ifeq(nElse)`

$[\![q]\!]$

`goto(nAfter)`

`nElse:` `iconst_0`

`nAfter:`

Compiling ||

$$[\![(cond)\ ?\ t\ :e]\!] =$$

```
        [[cond]]
        ifeq(nElse)
        [[t]]
        goto(nAfter)
nElse:  [[e]]
nAfter:
```

$$[\![p \mid\mid q]\!] =$$

$$[\![(p)\ ?\ \texttt{true}\ :\ q]\!] =$$

```
        [[p]]
        ifeq(nElse)
        iconst_1
        goto(nAfter)
nElse:  [[q]]
nAfter:
```