CSCI 742 - Compiler Construction

Lecture 30

Control Structures: Efficient Translation

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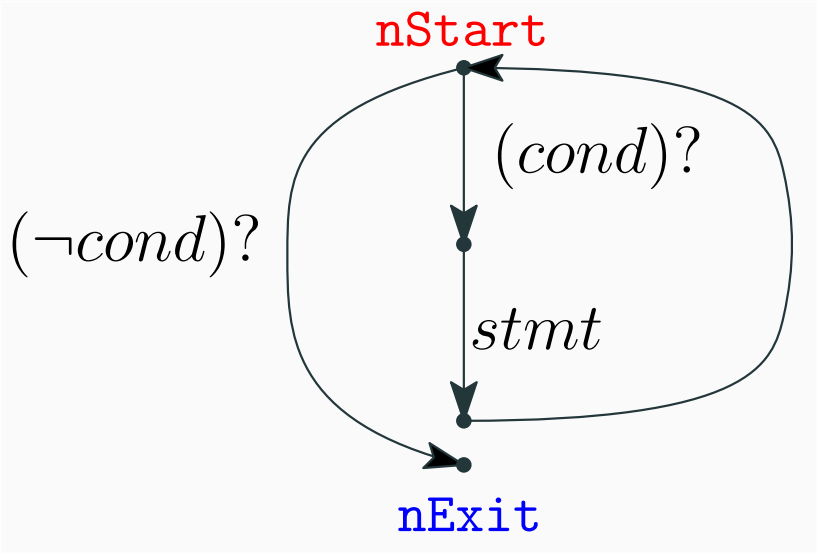
Recap: Code Generation for `while`

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

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



Code Generation for Relational Expressions

$[\![e_1 < e_2]\!] =$

```
        [[e1]]
        [[e2]]
        if_icmplt(nTrue)
        iconst_0
        goto(nExit)
nTrue:  iconst_1
nExit:
```

Compare Two Translations

```
while (counter < to) {
  counter = counter + step;
}
```

Translation 1:

```
nBegin: iload #counter
        iload #to
        if_icmplt nTrue
        iconst_0
        goto nAfter
nTrue:  iconst_1
nAfter: ifeq nExit
        iload #counter
        iload #step
        iadd
        istore #counter
        goto nBegin
nExit:
```

Translation 2:

```
nBegin: iload #counter
        iload #to
        if_icmplt nBody
        goto nExit
nBody:  iload #counter
        iload #step
        iadd
        istore #counter
        goto nBegin
nExit:
```

Compare Two Translations

```
while (counter < to) {
  counter = counter + step;
}
```

Translation 1:

```
nBegin: iload #counter
        iload #to
        if_icmplt nTrue
        iconst_0
        goto nAfter
nTrue:  iconst_1
nAfter: ifeq nExit
        iload #counter
        iload #step
        iadd
        istore #counter
        goto nBegin
nExit:
```

Translation 2:

```
nBegin: iload #counter
        iload #to
        if_icmplt nBody
        goto nExit
nBody:  iload #counter
        iload #step
        iadd
        istore #counter
        goto nBegin
nExit:
```

Translation 2 immediately jumps to body, no intermediate result for `while` condition

Macro `branch` Instruction

- Introduce an imaginary big instruction

  `branch``(c,nTrue,nFalse)`

- `c` is a potentially complex Java boolean expression
  - Main reason why branch is not a real instruction
- `nTrue` is label to jump to when `c` evaluates to true
- `nFalse` is label to jump to when `c` evaluates to false
- No "fall through" - always jumps (symmetrical)

We show how to:

- Use branch to compile `if`, `while`, etc.
- Expand branch recursively into concrete bytecodes

Using `branch` in Compilation

$[\![\texttt{if } (c)\ t\ \texttt{else}\ e]\!] =$

```
        branch(c,nTrue,nFalse)
nTrue:  [[ t ]]
        goto(nAfter)
nFalse: [[ e ]]
nAfter:
```

$[\![\texttt{while } (c)\ s]\!] =$

```
nTest:  branch(c,nBody,nExit)
nBody:  [[ s ]]
        goto(nTest)
nExit:
```

Decomposing `branch`

```
branch(!c,nThen,nElse) = branch(c,nElse,nThen)
```

```
branch(c1 && c2,nThen,nElse) =
              branch(c1,nNext,nElse)
    nNext:    branch(c2,nThen,nElse)
```

```
branch(c1 || c2,nThen,nElse) =
              branch(c1,nThen,nNext)
    nNext:    branch(c2,nThen,nElse)
```

```
branch(true,nThen,nElse) = goto nThen
```

```
branch(false,nThen,nElse) = goto nElse
```

---

boolean variable `b` with slot `N`

```
branch(b,nThen,nElse) =
    iload_N
    ifeq nElse
    goto nThen
```

Compiling Relations

$$\texttt{branch}(e_1\ \mathbf{R}\ e_2, \texttt{nThen}, \texttt{nElse}) =$$

$$[\![e_1]\!]$$

$$[\![e_2]\!]$$

$$\texttt{if\_icmp}\mathbf{R}\texttt{(nThen)}$$

$$\texttt{goto(nElse)}$$

R can be < , > , == , != , <= , >=,...

Put Boolean Variable on Stack

- Consider storing `x = c` where `x` , c are boolean and c has `&&`, `||`
- How to put result of branch on stack to allow `istore`?

$[\![\texttt{x} = c]\!] =$

```
        branch(c,nThen,nElse)
nThen:  iconst_1
        goto(nAfter)
nElse:  iconst_0
nAfter: istore #x
```

Complex Boolean Expression: Example

Fewer push/pop of boolean constants compared to previous translation

```
if ((x < y) && !((y < z) && cond))
  return
else
  y = y + 1
```

```
        branch(x<y,n1,else)
n1:     branch(y<z,n2,then)
n2:     branch(cond,else,then)
then:   return
        goto after
else:   iload #y
        iconst_1
        iadd
        istore #y
after:
```

Implementing `branch`

- Option 1: emit code using `branch`, then rewrite
- Option 2: `branch` is a just a function in the compiler that expands into instructions

```
branch(c,nTrue,nFalse)
```

⇓

```
public List<Bytecode> compileBranch(Expression c,
    Label nTrue, Label nFalse) {
  ...
}
```

- The function takes two destination labels

`break` Statement

- A common way to exit from a loop is to use a `break` statement

```
while (true) {
  code1
  if (cond) break;
  cond2
}
```

- Consider a language that has expressions, assignments, blocks {...}, `if`, `while`, and a `break` statement
- `break` statement exits the innermost loop and can appear inside arbitrarily complex blocks and `if` conditions
- How would translation scheme for such construct look like?
- We need a generalization of compilation functions $[\![\cdots]\!]$

Destination Parameters in Compilation

- Pass a **label** to compilation functions $[\![\cdot\cdot\cdot]\!]$ indicating to which instructions to jump after they finish
  - No fall-through

```
[[x = e]] after =     // new parameter 'after'
  [[e]]
  istore #x
  goto(after)     // at the end jump to it
```

```
[[s1; s2]] after =
    [[s1]] freshL
freshL:  [[s2]] after
```

we could have any junk in here because ([[s1]] freshL) ends in a jump

Translation of `if`, `while`, `return`

$$[\![\texttt{if}\ (c)\ t\ \texttt{else}\ e]\!]\ \texttt{after} =$$

$$\texttt{branch}(c, \texttt{nTrue}, \texttt{nFalse})$$

$$\texttt{nTrue:}\quad [\![t]\!]\ \texttt{after}$$

$$\texttt{nFalse:}\quad [\![e]\!]\ \texttt{after}$$

$$[\![\texttt{while}\ (c)\ s]\!]\ \texttt{after} =$$

$$\texttt{nTest:}\quad \texttt{branch}(c, \texttt{nBody}, \texttt{after})$$

$$\texttt{nBody:}\quad [\![s]\!]\ \texttt{nTest}$$

$$[\![\texttt{return}\ e]\!]\ \texttt{after} =$$

$$[\![e]\!]$$

$$\texttt{ireturn}$$

Generated Code for Example

$[\![$`if (x < y) return; else y = 2;`$]\!]$ `after` $=$

```
        iload #x
        iload #y
        if_icmplt nTrue
        goto nFalse
nTrue:  return
nFalse: iconst_2
        istore #y
        goto after
```

Note: no `goto` after `return` because

- translation of `if` does not generate `goto` as it did before, since it passes it to the translation of the body
- translation of `return` knows it can ignore the `after` parameter

Two Destination Parameters

$[\![s1; s2]\!]$ `after brk =`

`  `$[\![s1]\!]$ `freshL brk`

`freshL:` $[\![s_2]\!]$ `after brk`

$[\![x = e]\!]$ `after brk =`

`  `$[\![e]\!]$

`  istore #x`

`  goto after`

$[\![$`return` $e]\!]$ `after brk =`

`  `$[\![e]\!]$

`  ireturn`

$[\![$`break`$]\!]$ `after brk =`

`  goto brk`

$[\![$`while` $(c)\ s]\!]$ **`after`** `brk =`

`  test:  branch(c,body,after)`

`  body:  `$[\![s]\!]$ `test` **`after`**

this is where the second parameter gets bound to the exit of the loop

`if` with two parameters

$$[\![\texttt{if}\ (c)\ t\ \texttt{else}\ e]\!]\ \texttt{after brk} =$$

$$\texttt{branch}(c, \texttt{nTrue}, \texttt{nFalse})$$

$$\texttt{nTrue:} \quad [\![t]\!]\ \texttt{after brk}$$

$$\texttt{nFalse:} \quad [\![e]\!]\ \texttt{after brk}$$

break and continue

$[\![\texttt{break}]\!]\ \texttt{after brk}\ \textbf{cont} =$

```
goto brk
```

$[\![\texttt{continue}]\!]\ \texttt{after brk}\ \textbf{cont} =$

```
goto cont
```

$[\![\texttt{while}\ (c)\ s]\!]\ \texttt{after brk}\ \textbf{cont} =$

```
nTest:  branch(c,nBody,after)
nBody:  [[s]] nTest after nTest
```