CSCI 742 - Compiler Construction

Lecture 27

Code Generation for Expressions

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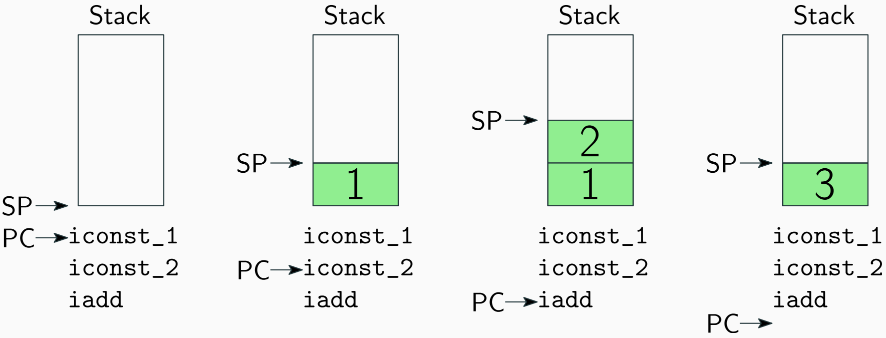
Recap: Java Virtual Machine (JVM)

- JVM is a stack machine: evaluation of expressions uses a stack (operand stack)
- Instructions fetch their arguments from the top of the operand stack
- Instructions store their results at the top of the operand stack



Prefix, Infix, Postfix

- Bytecodes are executed in a **postfix** manner
- Postfix: notation for writing arithmetic expressions in which the operands appear before their operators

Example.

- Postfix expression:

$$1 \;\; 2 \;\; +$$

- Bytecode instructions:

```
iconst_1
iconst_2
iadd
```

Prefix, Infix, Postfix

- Let f be a binary operation, e_1 and e_2 two expressions
- We can denote application $f(e_1, e_2)$ as follows
    - in prefix notation $f \; e_1 \; e_2$
    - in infix notation $e_1 \; f \; e_2$
    - in postfix notation $e_1 \; e_2 \; f$
- Suppose that each operator (like f) has a known number of arguments. For nested expressions:
    - infix requires parentheses in general
    - prefix and postfix do not require any parentheses

Expressions in Different Notation

- For infix, assume $*$ binds stronger than $+$
- There is no need for priorities or parentheses in the other notations

prefix	$+\ x\ y$	$+\ *\ x\ y\ z$	$+\ x\ *\ y\ z$	$*\ x\ +\ y\ z$
infix	$x\ +\ y$	$x\ *\ y\ +\ z$	$x\ +\ y\ *\ z$	$x\ *\ (y\ +\ z)$
postfix	$x\ y\ +$	$x\ y\ *\ z\ +$	$x\ y\ z\ *\ +$	$x\ y\ z\ +\ *$

- Infix is the only problematic notation and leads to ambiguity
- Why is it used in math? Ambiguity reminds us of algebraic laws:
- $x + y$ looks same from left and from right (commutative)
- $x + y + z$ parse trees mathematically equivalent (associative)

Exercise

- Convert the following expressions into prefix and postfix

infix	$(x + y) * (z - y)$	$(((x + y) + z) + t)$

Exercise

- Convert the following expressions into prefix and postfix

prefix	$* \; + \; x \; y \; - \; zy$	$+ + + \, x \; y \; z \; t$
infix	$(x + y) * (z - y)$	$(((x + y) + z) + t)$
postfix	$x \; y \; + \; z \; y \; - \; *$	$x \; y \; + \; z \; + \; t \, +$

Postfix Notation

Advantage of postfix expressions:

- we can evaluate postfix expressions easier by using a stack

```
public int evaluate(Expression expression) {
  Scanner scanner = new Scanner(expression);
  Stack<Integer> operands = new Stack<Integer>();
  while (scanner.hasNext()) {
    if (scanner.hasNextInt()) {
      operands.push(scanner.nextInt());
    } else {
      Integer operand2 = operands.pop();
      Integer operand1 = operands.pop();
      String operator = scanner.next();
      switch (operator) {
        case "+" : operands.push(operand1 + operand2); break;
        case "-" : operands.push(operand1 - operand2); break;
        case "*" : operands.push(operand1 * operand2); break;
        case "/" : operands.push(operand1 / operand2); break;
      }
    }
  }
  return operands.pop();}
```

Infix Notation

- Evaluating Infix Needs Recursion

```
public int evaluate(Expression e) {
  if (e.isInt())
    return e.intValue();
  else {
    switch (e.toString()) {
      case "+" : return evaluate(e.left) + evaluate(e.right);
      case "-" : return evaluate(e.left) - evaluate(e.right);
      case "*" : return evaluate(e.left) * evaluate(e.right);
      case "/" : return evaluate(e.left) / evaluate(e.right);
    }
  }
}
```

- Maximal stack depth in interpreter = expression height

Compiling Expressions

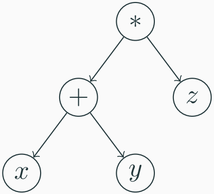
- Evaluating postfix expressions is like running a stack-based virtual machine on compiled code
- Compiling expressions for stack machine is like translating expressions into postfix form

infix: $(x + y) * z$

postfix: $x\ y +\ z *$

bytecode:

```
iload_1   x
iload_2   y
iadd      +
iload_3   z
imul      *
```



Compiling Trees into Bytecodes

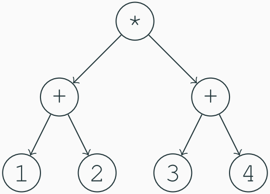
To evaluate $e_1 \;*\; e_2$ interpreter

- evaluates e_1
- evaluates e_2
- combines the result using $*$

Compiler for $e_1 \;*\; e_2$ emits:

- code for e_1 that leaves result on the stack, followed by
- code for e_2 that leaves result on the stack, followed by
- arithmetic instruction that takes values from the stack and leaves the result on the stack

Code Generation for Expressions



Code generation visits AST nodes in post-order

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

Local Variables

- For integers use instructions `iload` and `istore`
- Assigning indices (called slots) to local variables using function

$$\texttt{slotOf}: \ \texttt{VarSymbol} \to \{0, 1, 2, 3, \cdots\}$$

- How to compute the indices?
- Assign them in the order in which they appear in the tree

```
class Compiler implements Visitor<Tree> {
...
  public List<Bytecode> visit(Var n) {
    return List(ILoad(slotOf(n.name)));
  }
...
  public List<Bytecode> visit(Assign stat) {
    return
        visit(stat.rhs).addAll(IStore(slotOf(stat.lhs)));
  }
...
}
```

Global Variables and Fields

- `getfield`
  Get the value of an instance field
- `putfield`
  Write the value of an instance field
- `getstatic`
  Get the value of a static field
- `putstatic`
  Write the value of a static field

Global Variables and Fields

- `.class` file includes a data structure called the "constant pool"
- Constant pool is a table of symbolic names
  - e.g. class names, field names, methods names
- When a bytecode instruction refers to a field the reference is a number: it represents an index into the constant pool

```
getfield #20
```

- Instruction indicates the 20th symbolic name in the constant pool

Factorial Example

```
class Factorial {
 int num_aux = 0;
  public int fact(int num) {
   if (num < 1)
    num_aux = 1 ;
   else
    num_aux =
      num*(this.fact(num-1));
  return num_aux;
 }
}
```

```
public int fact(int);
Code:
0: iload_1
1: iconst_1
2: if_icmpge   13
5: aload_0
6: iconst_1
7: putfield    #2   // Field num_aux:I
10: goto        26
13: aload_0
14: iload_1
15: aload_0
16: iload_1
17: iconst_1
18: isub
19: invokevirtual #3 // Method fact:(I)I
22: imul
23: putfield    #2   // Field num_aux:I
26: aload_0
27: getfield    #2   // Field num_aux:I
30: ireturn
```

`aload_0` refers to receiver object (0th argument), since `fact` is not static

Shorthand Notation for Translation

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

$[\![e_1]\!]$

$[\![e_2]\!]$

`iadd`

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

$[\![e_1]\!]$

$[\![e_2]\!]$

`imul`

Compiling If Statement

- Assume we use 0/1 for translating conditions
- Recap: `if<cond>` branches if int comparison with zero succeeds

$$\llbracket \texttt{if }(cond)\ tStmt\ \texttt{else}\ eStmt \rrbracket =$$

$$\begin{array}{rl}
 & \llbracket cond \rrbracket \\
 & \texttt{Ifeq(nElse)} \\
 & \llbracket tStmt \rrbracket \\
 & \texttt{goto(nAfter)} \\
\texttt{nElse:} & \llbracket eStmt \rrbracket \\
\texttt{nAfter:} &
\end{array}$$

- We will discuss control structures (`if`, `while`, ...) in Lecture 29 (Code Generation for Control Structures)

Array Manipulation

`a` = reference - “address” arrays

`i` = int arrays (and some other int-like value types)

Selected array manipulation operations:

- `newarray`, `anewarray`, `multianewarray` - allocate an array object from the heap and put a reference to it on the stack
- `aaload`, `iaload` - take: a reference to array and index from stack, load the value from array and push it onto the stack
- `aastore`,`iastore` - take: a reference to array, an index, a value from stack, store the value into the array index
- `arraylength` - retrieve length of the array

Java arrays store the size of the array and its type, which enables run-time checking of array bounds and object types

Example

```
class ArrayExpr {
  public static void test(int x) {
    int a[] = new int[5];
    a[a.length] = x; // run-time error  }}
```

```
> javac -g ArrayExpr.java; javap -c -l ArrayExpr
```

```
public static void test(int);
  Code:
     0: iconst_5
     1: newarray       int
     3: astore_1
     4: aload_1
     5: aload_1
     6: arraylength
     7: iload_0
     8: iastore
     9: return
```