Plan for Today

Bridging the semantic gap
- MiniJava to MIPS assembly

Intermediate Representations
- why?
- characteristics

3-address code

Tiger book expression Trees

Tiger book Assem representation

Bridging the semantic gap

```
class WhileUsage {
    public static void main(String[] a){
        System.out.println(new Foo().testing(5)); }}
class Foo {
    public int testing(int p) {
        while (p<10) {
            System.out.println(p);
            p = p+1;
        }
        return 0; } }
```

```
        .text
main:
main_framesize32
        sw $fp, -4($sp)
        move $fp, $sp
        subu $sp, $sp, main_framesize
        ...
       # push parameter onto stack.
        subu $sp, $sp, 4
        # ExpCONST
        li $t1, 4
        sw $t1, 0($sp)
        jal _halloc
        addu $sp, $sp, 4
        ...
                                        L0:
# push parameter onto stack.
subu $sp, $sp, 4
# ExpCONST
li $t0, 5
sw $t0, 0($sp)
# push parameter onto stack.
subu $sp, $sp, 4
sw $t2, 0($sp)
jal Foo_testing
addu $sp, $sp, 8
...

# sink.statement
addu $sp, $sp, main_framesize
lw $fp, -4($sp)
j $ra
...
```


Intermediate Program Representations

AST
- usually language dependent

Intermediate Representation (IR)
- Usually a language independent and target independent representation
- Examples
  - 3-address code
  - RTL used in GCC (like 3-address code)
  - LLVM used in the LLVM compiler (like 3-address code but typed)
  - Microsoft's Common Intermediate Language (CIL)
  - Java byte code
  - Tree data structure in the MiniJava Compiler (a little different)

AST ==> IR ==> target code

A Low-Level IR: 3-address code

3-address code
- Linear representation
- Typically language-independent
- Nearly corresponds to machine instructions

Example operations
- Assignment `x = y`
- Unary op `x = op y`
- Binary op `x = y op z`
- Address of `p = & y`
- Load `x = *p`
- Store `p = y`
- Pass param `param x_1`
- Call `y = call p, 1`
- Branch `goto L1`
- Cbranch `if (x==3) goto L1`

IR Code Generation

Goal

- Transforms AST into low-level *intermediate representation* (IR)

Simplifies the IR

- Removes high-level control structures: `for`, `while`, `do`, `switch`
- Removes high-level data structures: arrays, structs, unions, enums

Results in assembly-like code

- Semantic lowering
- Control-flow expressed in terms of "gotos"
- Each expression is very simple (three-address code)

e.g., `x = a * b * c` ➡

```
t = a * b
x = t * c
```


Example

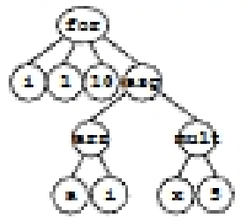
Source code (FORTRAN)

```
for i = 1 to 10 do
  a(i) = x * 5;
```

Low-level IR (3-address code)

```
      i := 1
loop1:
      if i > 10 goto loopexit
      t1 = x * 5
      t2 = &a
      t3 = sizeof(int)
      t4 = t3 * i
      t5 = t2 + t4
      *t5 = t1
      i = i + 1
      goto loop1
loopexit:
```

High-level IR (AST)



Compiling Control Flow

Switch statements

- Convert `switch` into low-level IR

e.g.,

```
switch (c) {
    case 0: f();
            break;
    case 1: g();
            break;
    case 2: h();
            break;
}
```

➡

```
      if (c!=0) goto next1
      call f,0
      goto done
next1: if (c!=1) goto next2
      call g,0
      goto done
next2: if (c!=3) goto done
      call h,0
done:
```

- Optimizations (depending on size and density of cases)
  - Create a jump table (store branch targets in table)
  - Use binary search

Compiling Arrays

Array declaration

- Store name, size, and type in symbol table

Array allocation

- Call `malloc()` or create space on the runtime stack

Array referencing (C is source code)

- e.g., `A[i]` ➡ `*(A + i * sizeof(A_elem))`

```
t2 = sizeof(A_elem)
t3 = i * t2
t4 = A + t3
*t4
```

Missed Opportunities

3-address code is low level

- many architectures have CISC-like instructions
- the low-level IR might preclude using certain instructions in the ISA
- 6800 example

Desired characteristics of Irs

- should be easy to translate to
- should be easy to translate from to all target machines
- each piece should have simple semantics
- should be able to efficiently and effectively apply program optimizations

MiniJava Compiler Tree Language (Array Example)

x[2] = 42;