CSE P 501 – Compilers

Code Shape I – Basic Constructs

Hal Perkins

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Agenda

- Mapping source code to x86
  - Mapping for other common architectures follows same basic pattern
- Now: basic statements and expressions
  - We'll go quickly since this is probably review for many and pretty straightforward
- Next: Object representation, method calls, and dynamic dispatch

Review: Variables

- For us, all data will be in either: offset ± ebp
  - A stack frame (method local variables)
  - An object (instance variables)

- Local variables accessed via ebp

```
mov  eax,[ebp+12]
```

- Instance variables accessed via an object address in a register
  - Details later

Conventions for Examples

- Examples show code snippets in isolation
- Real code generator needs to deal with things like:
  - Which registers are busy at which point in the program
  - Which registers to spill into memory (pushed onto stack or stored in stack frame) when a new register is needed and no free ones are available
- Register eax used below as a generic example
  - Rename as needed for more complex code
- Also includes a few peephole optimizations

Code Generation for Constants

- Source

```
17
```

- x86

```
mov  eax,17
```

  - Idea: realize constant value in a register

- Optimization: if constant is 0

```
xor  eax,eax
```

Assignment Statement

- Source

```
var = exp;
```

- x86

<code to evaluate exp into, say, eax>

mov [ebp+offset$_{var}$],eax

Unary Minus

- Source

```
-exp
```

- x86

```
<code evaluating exp into eax>
neg  eax
```

- Optimization
  - Collapse -(-exp) to exp
- Unary plus is a no-op

Binary +

- Source

    exp1 + exp2

- x86

    <code evaluating exp1 into eax>
    <code evaluating exp2 into edx>
    add eax,edx

Binary +

- Optimizations
  - If exp2 is a simple variable or constant

    ```
    add  eax,exp2
    ```
  - Change exp1 + (-exp2) into exp1-exp2
  - If exp2 is 1

    ```
    inc  eax
    ```
    - Surprisingly, the Intel optimization guide recommends against this on newer processors

Binary -, *

- Same as +
  - Use sub for – (but not commutative!)
  - Use imul for *
- Optimizations
  - Use left shift to multiply by powers of 2
    - If your multiplier is really slow or you've got free scalar units and multiplier is busy, 10*x = (8*x)+(2*x)
  - Use x+x instead of 2*x, etc. (faster)
  - Use dec for x-1

Integer Division

- Ghastly on x86
  - Only works on 64 bit int divided by 32-bit int
  - Requires use of specific registers
- Source

  edx:eax

  exp1 / exp2

  64
- x86

  <code evaluating exp1 into eax **ONLY**>

  <code evaluating exp2 into ebx>

  cdq ; extend to edx:eax, clobbers edx

  idiv ebx ; quotient in eax; remainder in edx

Control Flow

- Basic idea: decompose higher level operation into conditional and unconditional gotos
- In the following, j_{false} is used to mean jump when a condition is false
  - No such instruction on x86
  - Will have to realize with appropriate sequence of instructions to set condition codes followed by conditional jumps
  - Normally wouldn't actually generate the value "true" or "false" in a register

While

- Source

```
while (cond) stmt
```

- x86

```
test:   <code evaluating cond>
        j_false done
        <code for stmt>
        jmp  test
done:
```

- Note: In generated asm code we'll need to create a unique label name for each loop, conditional statement, etc.

Optimization for While

- Put the test at the end

```
        jmp  test
loop:   <code for stmt>
test:   <code evaluating cond>
        j_true  loop
```

- Why bother?
  - Pulls one instruction (jmp) out of the loop
  - Avoids a pipeline stall on jmp on each iteration
    - But modern processors can predict control flow and avoid stalls
- Easy to do from AST or other IR; not so easy if generating code on the fly (e.g., recursive descent 1-pass compiler)

Do-While

- Source

  do stmt while(cond);

- x86

  loop: <code for stmt>

  <code evaluating cond>

  j_{true} loop

If

- Source

    if (cond) stmt

- x86

```
      <code evaluating cond>
      jfalse skip
      <code for stmt>
skip:
```

If-Else

- Source

  if (cond) stmt1 else stmt2

- x86

```
       <code evaluating cond>
       jfalse else
       <code for stmt1>
       jmp  done
else:  <code for stmt2>
done:
```

Jump Chaining

- Observation: naïve code gen ~~can~~ will produce jumps to jumps
- Optimization: if a jump has as its target an unconditional jump, change the target of the first jump to the target of the second
  - Repeat until no further changes

Boolean Expressions

- What do we do with this?

  x > y
- Expression evaluates to true or false
  - Could generate the value in a register (0/1 or whatever the local convention is)
  - But normally we don't want/need the value; we're only trying to decide whether to jump

Code for exp1 > exp2

- Basic idea: designate jump target, and whether to jump if the condition is true or if false
- Example: exp1 > exp2, target L123, jump on false

```
<evaluate exp1 to eax>
<evaluate exp2 to edx>
cmp eax,edx
jng  L123
```

Boolean Operators: !

- Source

  ! exp

- Context: evaluate exp and jump to L123 if false (or true)
- To compile !, reverse the sense of the test: evaluate exp and jump to L123 if true (or false)

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Boolean Operators: && and ||

- In C/C++/Java/C#, these are *short-circuit* operators
  - Right operand is evaluated only if needed
- Basically, generate if statements that jump appropriately and only evaluate operands when needed

Example: Code for &&

- Source

  if (exp1 && exp2) stmt

- x86

```
    <code for exp1>
    j_false skip
    <code for exp2>
    j_false skip
    <code for stmt>
skip:
```

Example: Code for ||

- Source

    if (exp1 || exp2) stmt

- x86

```
        <code for exp1>
        j_true doit
        <code for exp2>
        j_false skip
doit:   <code for stmt>
skip:
```

$p = \underline{x<y}$
1 or 0

Realizing Boolean Values

- If a boolean value needs to be stored in a variable or method call parameter, generate code needed to actually produce it
- Typical representations: 0 for false, +1 or -1 for true
  - C specifies 0 and 1 if stored; we'll use that
  - Best choice can depend on machine instructions; normally some convention is established during the primeval history of the architecture

Boolean Values: Example

- Source

  var = bexp ;

- x86

```
        <code for bexp>
        j_false  genFalse
        mov  eax,1
        jmp  storeIt
genFalse:
        mov  eax,0
storeIt: mov  [ebp+offset_var],eax   ; generated by asg stmt
```

Better, If Enough Registers

- Source

    var = bexp ;

- x86

```
          xor   eax,eax
          <code for bexp>
          jfalse  storeIt
          inc   eax
storeIt:  mov   [ebp+offsetvar],eax    ; generated by asg stmt
```

  - Or use conditional move (movecc) instruction – avoids pipeline stalls due to conditional jumps

x<y

Better yet: setcc

- Source

```
var = x < y;
```

- x86

```
         mov   eax,[ebp+offset_x]     ; load x
         cmp   eax,[ebp+offset_y]     ; compare to y
         setl  al                     ; set low byte eax to 0/1
         movzx eax,al                 ; zero-extend to 32 bits
storeIt: mov   [ebp+offset_var],eax   ; generated by asg stmt
```

  - Gnu mnemonic for movzx (byte->dbl word) is movzbl
  - Or use conditional move (movecc) instruction for sequences like x = y<z ? y : z

Other Control Flow: switch

- Naïve: generate a chain of nested if-else's
- Better: switch is intended to allow an O(1) selection, provided the set of switch values is reasonably compact
- Idea: create a 1-D array of jumps or labels and use the switch expression to select the right one
  - Need to generate the equivalent of an if statement to ensure that expression value is within bounds

Switch

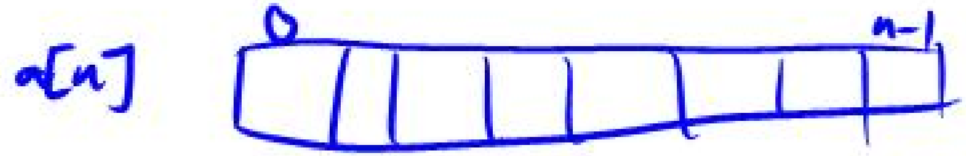
- Source

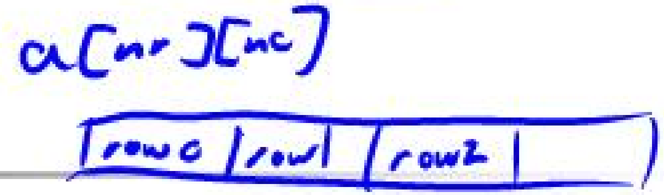
```
switch (exp) {
  case 0: stmts0;
  case 1: stmts1;
  case 2: stmts2;
}
```

- X86

```
<put exp in eax>
"if (eax < 0 || eax > 2)
    jmp defaultLabel"
mov eax,swtab[eax*4]
jmp eax
            .data
swtab:      dd L0
            dd L1
            dd L2
            .code
L0:         <stmts0>
L1:         <stmts1>
L2:         <stmts2>
```

Arrays





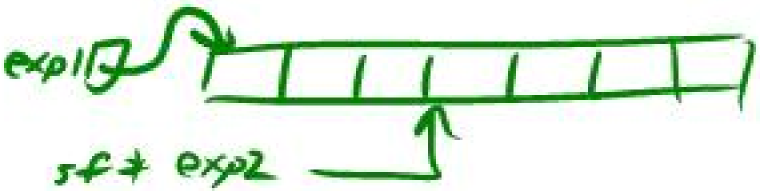
- Several variations

- C/C++/Java
  - 0-origin; an array with n elements contains variables a[0]…a[n-1]
  - Multiple dimensions; row major order
- Key step is to evaluate a subscript expression and calculate the location of the corresponding element

0-Origin 1-D Integer Arrays

- Source

  exp1[exp2]



- x86

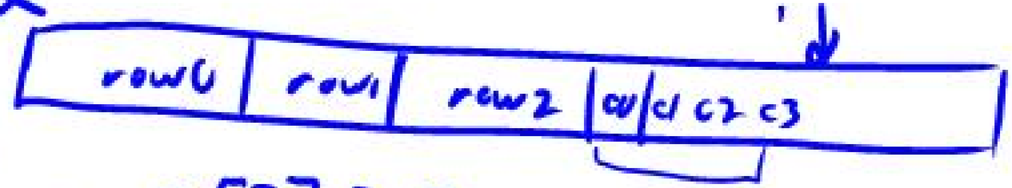
  <evaluate exp1 (array address) in eax>

  <evaluate exp2 in edx>

  address is [eax+4*edx]   ; 4 bytes per element

$\alpha + ((3 * ncols) + 4) * scale$ α

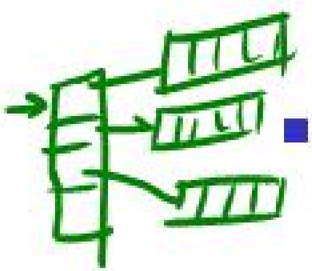
fixed + offset(3,4)



2-D Arrays

a[3][4]

- Subscripts start with 1 (default)
- C, etc. use row-major order
  - E.g., an array with 3 rows and 2 columns is stored in this sequence: a(1,1), a(1,2), a(2,1), a(2,2), a(3,1), a(3,2)
- Fortran uses column-major order
  - Exercises: What is the layout? How do you calculate location of a(i,j)? What happens when you pass array references between Fortran and C/etc. code?
- Java does not have "real" 2-D arrays. A Java 2-D array is a pointer to a list of pointers to the rows



in C: $a[i] \equiv *(a+i) = *(i+a) \equiv i[a]$

a(i,j) in C/C++/etc.

- To find a(i,j), we need to know
  - Values of i and j
  - How many *columns* the array has
- Location of a(i,j) is

  Location of a + (i-1)*(#of columns) + (j-1)
- Can factor to pull out load-time constant part and evaluate that once – no recalculating at runtime

Coming Attractions

- Code Generation for Objects
  - Representation
  - Method calls
  - Inheritance and overriding
- Strategies for implementing code generators
- Code improvement – optimization