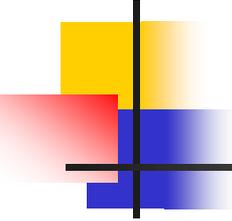


CSE 401 – Compilers

Code Shape I – Basic Constructs

Hal Perkins

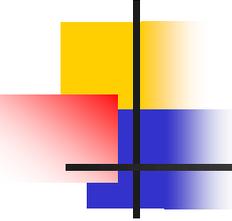
Autumn 2011



Agenda

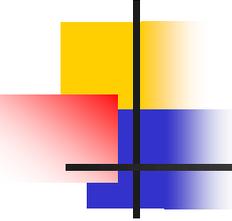
- Mapping source code to x86
 - Mapping for other common architectures follows same basic pattern
- Now: basic statements and expressions
 - We'll go quickly since this is review for many, fast orientation for others, and pretty straightforward
- Next: Object representation, method calls, and dynamic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

Footnote: These slides include more than is specifically needed for the project



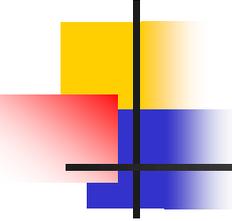
Review: Variables

- For us, all data will be in either:
 - A stack frame (method local variables)
 - An object (instance variables)
- Local variables accessed via ebp
 - `mov eax,[ebp+12]`
- Object instance variables accessed via an object address in a register
 - Details later



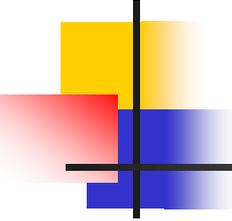
Conventions for Examples

- Examples show code snippets in isolation
 - Much the way we'll generate code for different parts of the AST in our compilers
- Register `eax` used below as a generic example
 - Rename as needed for more complex code using multiple registers
- A few peephole optimizations included below for a flavor of what's possible



What we're skipping for now

- Real code generator needs to deal with many things like:
 - Which registers are busy at which point in the program
 - Which registers to spill into memory when a new register is needed and no free ones are available
 - (x86: temporaries are often pushed on the stack, but can also be stored at preallocated locations in the stack frame)
 - Exploiting the full instruction set



Code Generation for Constants

- Source

17

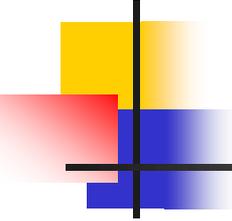
- x86

```
mov  eax,17
```

- Idea: realize constant value in a register

- Optimization: if constant is 0

```
xor  eax,eax
```



Assignment Statement

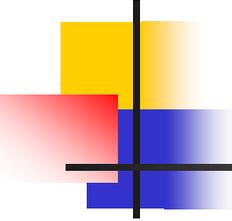
- Source

`var = exp;`

- x86

<code to evaluate exp into, say, eax>

`mov [ebp+offsetvar],eax`



Unary Minus

- Source

 - exp

- x86

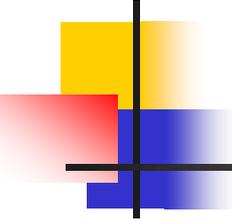
 - <code evaluating exp into eax>

 - neg eax

- Optimization

 - Collapse $-(-\text{exp})$ to exp

- Unary plus is a no-op



Binary +

- Source

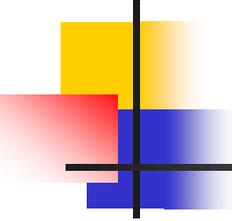
exp1 + exp2

- x86

<code evaluating exp1 into eax>

<code evaluating exp2 into edx>

add eax,edx



Binary +

- Optimizations

- If `exp2` is a simple variable or constant, don't need to load it into another register first.

Instead:

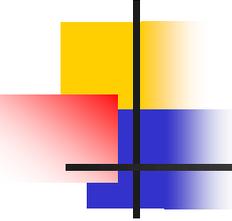
```
add eax,exp2
```

- Change `exp1 + (-exp2)` into `exp1-exp2`

- If `exp2` is 1

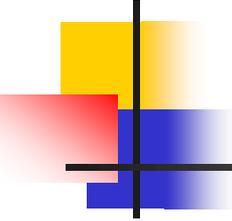
```
inc eax
```

- Somewhat surprising: whether this is better than `add eax,1` depends on processor implementation and has changed over time



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 slow or you've got free scalar units and multiplier is busy, you can do $10*x = (8*x) + (2*x)$
 - Use $x+x$ instead of $2*x$, etc. (often faster)
 - Can use `lea eax,[eax,eax*4]` to compute $5*x$, then add `eax,eax` to get $10*x$, etc. etc.
 - 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

exp1 / exp2

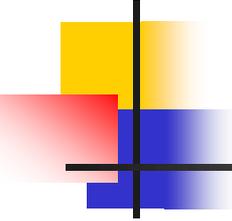
- x86

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

<code evaluating exp2 into ebx>

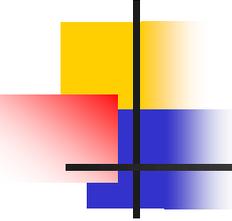
cdq ; extend to edx:eax, clobbers edx

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>
```

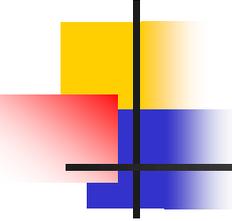
```
    jfalse done
```

```
    <code for stmt>
```

```
    jmp test
```

```
done:
```

- Note: In generated asm code we'll need to generate unique labels for each loop, conditional statement, etc.

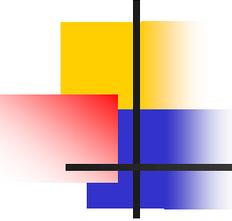


Optimization for While

- Put the test at the end

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

- Why bother?
 - Pulls one instruction (jmp) out of the loop
 - Avoids a pipeline stall on jmp on each iteration
 - Although modern processors will often predict control flow and avoid the stall – x86 does this particularly well
- Easy to do from AST or other IR; not so easy if generating code on the fly (e.g., recursive descent 1-pass compiler)



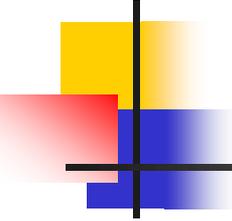
Do-While

- Source

```
do stmt while(cond);
```

- x86

```
loop: <code for stmt>  
      <code evaluating cond>  
      jtrue loop
```



If

- Source

if (cond) stmt

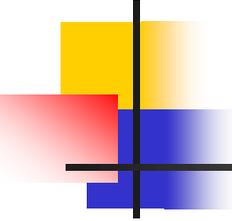
- x86

<code evaluating cond>

j_{false} skip

<code for stmt>

skip:



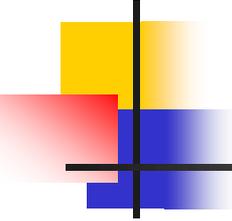
If-Else

- Source

```
if (cond) stmt1 else stmt2
```

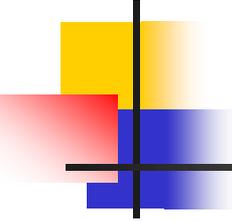
- x86

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



Jump Chaining

- Observation: naïve implementation can 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
 - Often done in peephole optimization pass after initial code generation

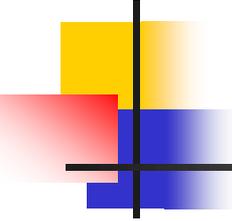


Boolean Expressions

- What do we do with this?

$x > y$

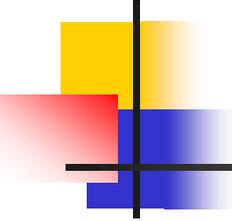
- It is an expression that evaluates to true or false
 - Could generate the value (0/1 or whatever the local convention is)
 - But normally we don't want/need the value; we're only trying to decide whether to jump



Code for $exp1 > exp2$

- Basic idea: Generated code depends on context:
 - What is the jump target?
 - Jump if the condition is true or if false?
- Example: evaluate $exp1 > exp2$, jump on false, target if jump taken is L123

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

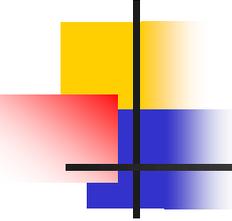


Boolean Operators: !

- Source

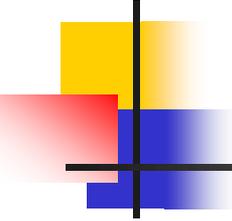
! exp

- 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)



Boolean Operators: && and ||

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



Example: Code for &&

- Source

```
if (exp1 && exp2) stmt
```

- x86

```
<code for exp1>
```

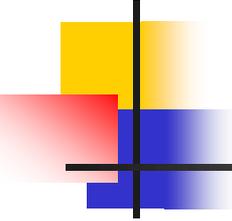
```
jfalse skip
```

```
<code for exp2>
```

```
jfalse skip
```

```
<code for stmt>
```

```
skip:
```



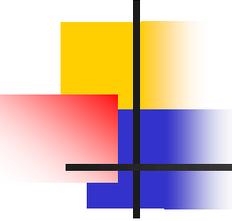
Example: Code for ||

- Source

```
if (exp1 || exp2) stmt
```

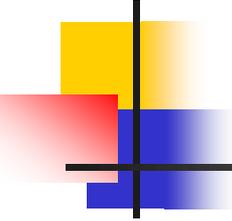
- x86

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



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; 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>
```

```
  jfalse genFalse
```

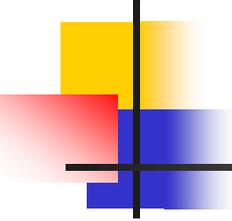
```
  mov  eax,1
```

```
  jmp  storeIt
```

```
genFalse:
```

```
  mov  eax,0
```

```
storeIt: mov  [ebp+offsetvar],eax  ; generated by asg stmt
```



Better, If Enough Registers

- Source

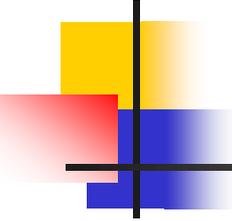
```
var = bexp ;
```

- x86

```
xor  eax,eax  
<code for bexp>  
jfalse storeIt  
inc  eax
```

```
storeIt: mov [ebp+offsetvar],eax ; generated by asg stmt
```

- Better: use `movcc` instruction to avoid conditional jump
- Can also use conditional move instruction for sequences like `x = y < z ? y : z`



Better yet: setcc

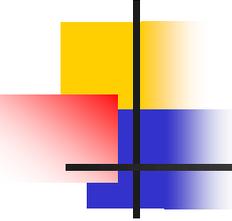
- Source

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

- x86

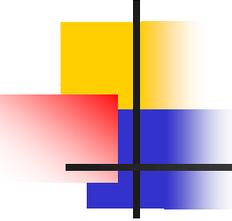
```
mov  eax,[ebp+offsetx] ; load x
cmp  eax,[ebp+offsety] ; compare to y
setl al                ; set low byte eax to 0/1
movzx eax,al           ; zero-extend to 32 bits
storeIt: mov [ebp+offsetvar],eax ; generated by asg stmt
```

- GNU asm mnemonic for movzx (byte->dbl word) is movzbl



Other Control Flow: switch

- Naïve: generate a chain of nested if-else if statements
- Better: switch is designed to allow an $O(1)$ selection in usual case, 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



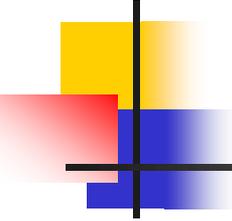
Switch

■ Source

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

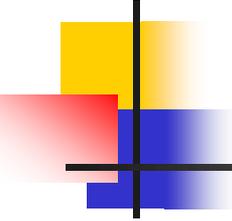
■ X86

```
<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 $a[0] \dots a[n-1]$
 - 1 or more 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

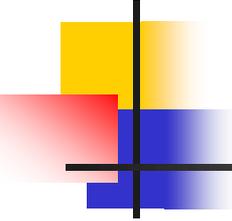
`exp1[exp2]`

- x86

<evaluate exp1 (array address) in eax>

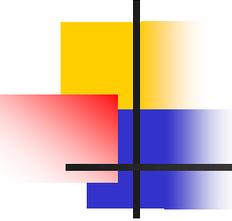
<evaluate exp2 in edx>

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



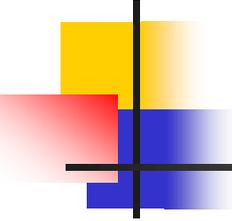
2-D Arrays

- 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



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 at load time – no recalculating at runtime



Coming Attractions

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