# CSE P 501 – Compilers

Running MiniJava
Basic Code Generation and Bootstrapping

Hal Perkins

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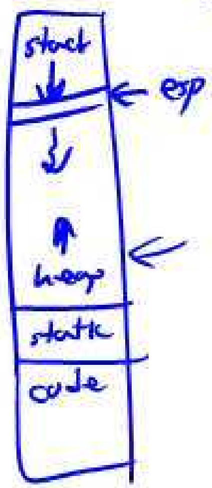
# Agenda

- Enough to get a working project
  - Assembler source file format
  - A very basic code generation strategy
  - Interfacing with the bootstrap program
  - Implementing the system interface

# What We Need

- To run a MiniJava program
  - Space needs to be allocated for a stack and a heap
  - ESP and other registers need to have sensible initial values
  - We need some way to allocate storage (new) and communicate with the outside world



# Bootstraping from C

- Idea: take advantage of the existing C runtime library
- Use a small C main program to call the MiniJava main method as if it were a C function
- C's standard library provides the execution environment and we can call C functions from compiled code for I/O, malloc, etc.

# Assembler File Format

- Here is a skeleton for the .asm file to be produced by MiniJava compilers (MASM syntax)

```
.386                                    ; use 386 extensions
.model  flat,c                          ; use 32-bit flat address space with
                                        ;    C linkage conventions for
                                        ;    external labels
public asm_main                         ; start of compiled static main
extern put:near,get:near,mjmalloc:near  ; external C routines
.code                                   ]
;; generated code                       ]  repeat .code/.data as needed
.data                                   ]
;; generated method tables              ]
...
end
```

# GNU Assembler File Format

- GNU syntax is roughly the same

```
.text                          # code segment
.globl asm_main   # start of compiled static main
;; generated code               repeat .code/.data as needed
.data
;; generated method tables  # repeat .text/.data as needed
...
end
```

# External Names

- In a unix enviornment, an external symbol is used as-is
- In Windows, the convention is that an external symbol xyzzy appears in the asm code as _xyzzy (leading underscore)
  - True in both VS masm and gnu assembler under cygwin
  - Also true on Intel OS X systems?
- **You should adapt to whatever environment you're using**

# Intel vs. GNU Syntax

- The GNU assembler uses AT&T syntax for historical reasons. Main differences:

| | Intel/Microsoft | AT&T/GNU as |
|---|---|---|
| Operand order: op a,b | a = a op b (dst first) | b = a op b (dst last) |
| Memory address | [baseregister+offset] | offset(baseregister) |
| Instruction mnemonics | mov, add, push, ... | movl, addl, pushl [operand size is added to end] |
| Register names | eax, ebx, ebp, esp, ... | %eax, %ebx, %ebp, %esp, ... |
| Constants | 17, 42 | $17, $42 |
| Comments | ; to end of line | # to end of line or /* ... */ |

# Generating .asm Code

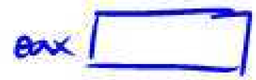
- Suggestion: isolate the actual compiler output operations in a handful of routines
  - Modularity & saves some typing
  - Possibilities

```
// write code string s to .asm output
void gen(String s) { … }
// write "op  src,dst" to .asm output
void genbin(String op, String src, String dst) { … }
// write label L to .asm output as "L:"
void genLabel(String L) { … }
```

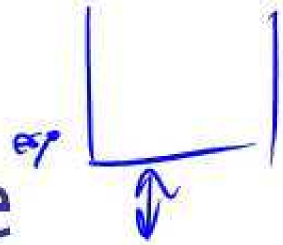
  - A handful of these methods should do it

# A Simple Code Generation Strategy

- Goal: quick 'n dirty correct code, optimize later if time
- Traverse AST primarily in execution order and emit code during the traversal
  - May need to control the traversal from inside the visitor methods, or have both bottom-up and top-down visitors
- Treat the x86 as a 1-register stack machine at first
- Alternative strategy: produce lower-level linear IR and generate from that (after possible optimizations)
  - Usually more ambitious than is reasonable for 10 weeks




# x86 as a Stack Machine




- Idea: Use x86 stack for expression evaluation with eax as the "top" of the stack
- Invariant: Whenever an expression (or part of one) is evaluated at runtime, the result is in eax
- If a value needs to be preserved while another expression is evaluated, push eax, evaluate, then pop when needed
  - Remember: always pop what you push
  - Will produce lots of redundant, but correct, code
- Examples below follow code shape examples, but with some details about where code generation fits

# Example: Generate Code for Constants and Identifiers

- Integer constants, say 17

  gen(mov eax,17)

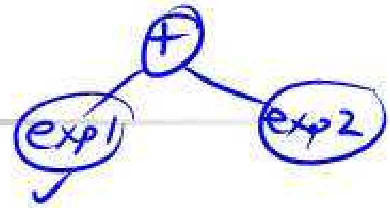
  - leaves value in eax

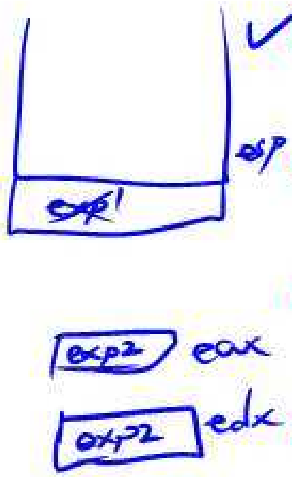
- Variables (whether int, boolean, or reference type)

  gen(mov eax,[appropriate base register+ appropriate offset])

  - also leaves value in eax

# Example: Generate Code for exp1 + exp1




- Visit exp1
  - generates code to evaluate exp1 and put result in eax
- gen(push eax)
  - generate a push instruction
- Visit exp2
  - generates code for exp2; result in eax
- gen(pop edx)
  - pop left argument into edx; cleans up stack
- gen(add eax,edx)
  - perform the addition; result in eax

# Example: var = exp; (1)

- Assuming that var is a local variable
  - visit node for exp
    - Generates code that leaves the result of evaluating exp in eax
  - gen(mov [ebp+offset of variable],eax)

# Example: var = exp; (2)

- If var is a more complex expression (object or array reference, for example)
  - visit var
  - gen(push eax)
    - push reference to variable or object containing variable onto stack
  - visit exp
  - gen(pop edx)
  - gen(mov [edx+appropriate_offset],eax)

obj.f = exp

# Example: Generate Code for obj.f(e1,e2,...en)

x qq y
f(x,y)

- Visit en
  - leaves argument in eax
- gen(push eax)
- ... Repeat until all arguments pushed
- Visit obj
  - leaves reference to object in eax
  - Note: this isn't quite right if evaluating obj has side effects – ignore for simplicity for now
- gen(mov ecx,eax)
  - copy "this" pointer to ecx
- generate code to load method table pointer
- generate call instruction with indirect jump
- gen(add esp,numberOfBytesOfArguments)
  - Pop arguments

# Method Definitions

- Generate label for method
- Generate method prologue
- Visit statements in order
  - Method epilogue will be generated as part of each return statement (next)

# Example: return exp;

- Visit exp; leaves result in eax where it should be
- Generate method epilogue to unwind the stack frame; end with ret instruction

# Control Flow: Unique Labels

- Needed: a String-valued method that returns a different label each time it is called (e.g., L1, L2, L3, …)
  - Variation: a set of methods that generate different kinds of labels for different constructs (can really help readability of the generated code)
    - (while1, while2, while3, …; if1, if2, …; else1, else2, …; fi1, fi2, … .)

# Control Flow: Tests


- Recall that the context for compiling a boolean expression is
  - Jump target
  - Whether to jump if true or false
- So visitor for a boolean expression needs this information from parent node

p = x<y

# Example: while(exp) body

- Assuming we want the test at the bottom of the generated loop…
  - gen(jmp testLabel)
  - gen(bodyLabel:)
  - visit body
  - gen(testLabel:)
  - visit exp (condition) with target=bodyLabel and sense="jump if true"

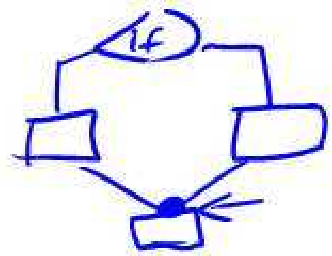
# Example exp1 < exp2

- Similar to other binary operators
- Difference: context is a target label and whether to jump if true or false
- Code
  - visit exp1
  - gen(push eax)
  - visit exp2
  - gen(pop edx)
  - gen(cmp eax,edx)
  - gen(condjump targetLabel)
    - appropriate conditional jump depending on sense of test

# Boolean Operators

- && and ||
  - Create label needed to skip around second operand when appropriate
  - Generate subexpressions with appropriate target labels and conditions
- !exp
  - Generate exp with same target label, but reverse the sense of the condition

# Join Points




- Loops and conditional statements have join points where execution paths merge
- Generated code must ensure that machine state will be consistent regardless of which path is taken to reach a join point
  - i.e., the paths through an if-else statement must not leave a different number of bytes pushed onto the stack
  - If we want a particular value in a particular register at a join point, both paths must put it there, or we need to generate additional code to get value in the right register
- With a simple 1-accumulator model of code generation, this should generally be true without needing extra work; with better use of registers this becomes an issue

# Bootstrap Program

- The bootstrap will be a tiny C program that calls your compiled code as if it were an ordinary C function
- It also contains some functions that compiled code can call as needed
  - Mini "runtime library"
  - You can add to this if you like
    - Sometimes simpler to generate a call to a newly written library routine instead of generating in-line code – implementor tradeoff

# Example Bootstrap Program

```
#include <stdio.h>
extern void asm_main();  /* compiled code */
/* execute compiled program */
void main() { asm_main(); }
/* return next integer from standard input */
int get() { ... }
/* write x to standard output */
void put(int x) { ... }
/* return a pointer to a block of memory at least nBytes
   large (or null if insufficient memory available) */
void * runtimealloc(int nBytes) { return malloc(nBytes); }
```

# Interfacing to External Code

- Recall that the .asm file includes these declarations at the top

```
public asm_main    ; start of compiled static main
extern put:near,get:near,mjmalloc:near
                   ; external C routines
```

- "public" means that the label is defined in the .asm file and can be linked from external files
  - Jargon: also known as an entry point
- "extern" declares labels used in the .asm file that must be found in another file at link time
  - "near" means in same segment (as opposed to multi-segment MS-DOS programs of ancient times)

# Main Program Label

- Compiler needs special handling for the static main method
  - Label must be the same as the one declared extern in the C bootstrap program and declared public in the .asm file
  - asm_main used above
    - Can be changed if you wish
    - Why not "main"? (Hint: what is / where is the *real* main function?)

# Interfacing to "Library" code

- To call "behind the scenes" library routines:
  - Must be declared extern in generated code
  - Call using normal C language conventions

# System.out.println(exp)

- Can handle in an ad-hoc way
  - (particularly since this is a "reserved word" in MiniJava)

```
<compile exp; result in eax>
push    eax        ; push parameter
call    put        ; call external put routine
add     esp,4      ; pop parameter
```

- A more general solution if System.out were a real class:
  - Hand-code (in asm) classes to act as a bridge between compiled code and the C runtime
  - Put information about these classes in the symbol table at compiler initialization
  - Calls to these routines compile normally – no other special case code needed in the compiler(!)

# And That's It…

- We've now got enough on the table to complete the compiler project
- Coming Attractions
  - Lower-level IR
  - Back end (instruction selection and scheduling, register allocation)
  - Middle (optimizations)