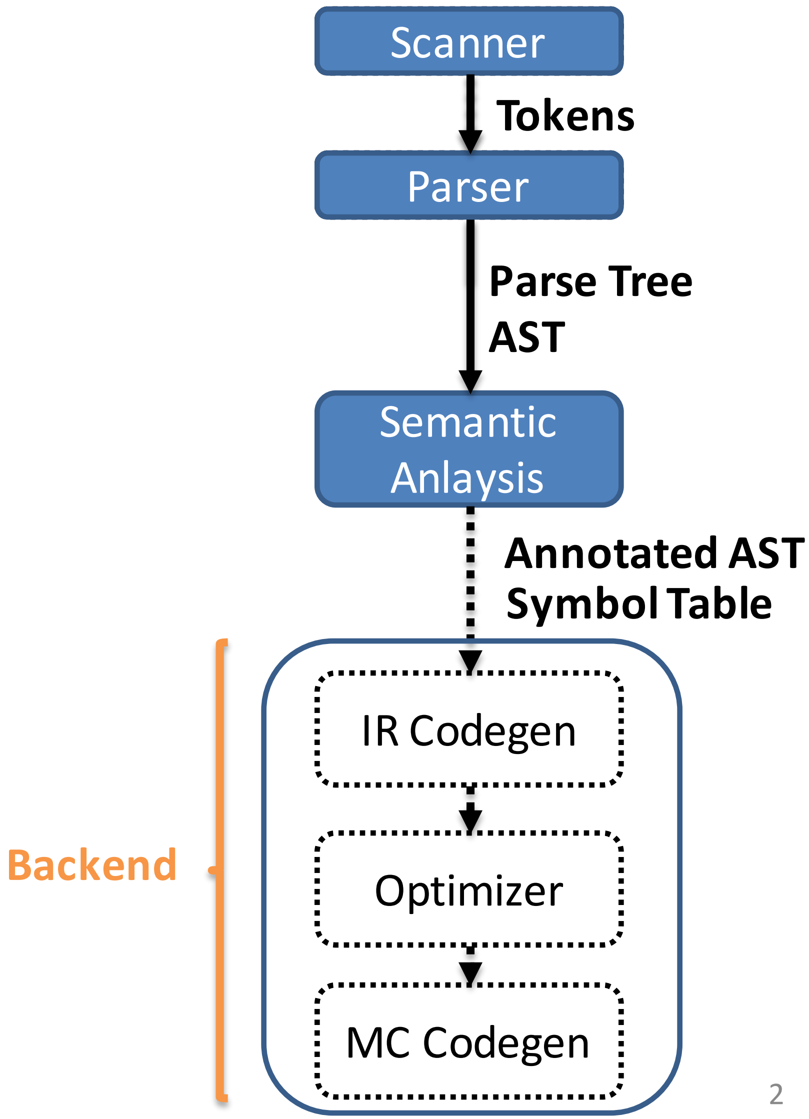
CS 536

Code Generation

Roadmap

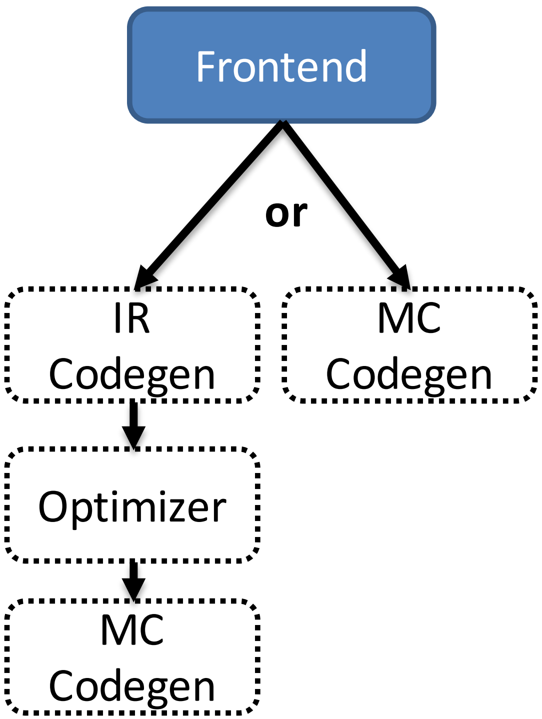

Scanner
Tokens
Parser
Parse Tree
AST
Semantic Anlaysis
Annotated AST
Symbol Table
Backend
IR Codegen
Optimizer
MC Codegen

The Compiler Back-end

- Unlike front-end, we can skip phases without sacrificing correctness
- Actually have a couple of options
  - What phases do we do
  - How do we order our phases

Outline

- Possible compiler designs
  - Generate IR code or MC code directly?
  - Generate during SDT or as another phase?



How many passes do we want?

- Fewer passes
  - Faster compiling
  - Less storage requirements
  - May increase burden on programmer
- More passes
  - Heavyweight
  - Can lead to better modularity
  - We’ll go with this approach for YES

To Generate IR Code or Not?

- If we do generate an Intermediate Representation:
  - More amenable to optimization
  - More flexible output options
  - Can reduce the complexity of code generation
- If we go straight to machine code:
  - Much faster to generate code (skip 1 pass, at least)
  - Less engineering in the compiler

What Might the IR Do?

- Infinite-register operations
- “Flatten out” expressions
  - Does not allow build-up of complex expressions
- 3AC (Three-Address Code)
  - Pseudocode-machine style instruction set
  - Every operator has at most 3 operands

3AC Example

```
if  (x + y * z > x * y + z)
    a = 0;
b = 2;
```

```
   tmp1 = y * z
   tmp2 = x+tmp1
   tmp3 = x*y
   tmp4 = tmp3+z
   if (tmp2 <= tmp4) goto L
      a = 0
L: b = 2
```

3AC Instruction Set

- **Assignment**
  - x = y op z
  - x = op y
  - x = y
- **Jumps**
  - if (x op y) goto *L*
- **Indirection**
  - x = y[z]
  - y[z] = x
  - x = &y
  - x = *y
  - *y = x
- **Call/Return**
  - param x,k
  - retval x
  - call p
  - enter p
  - leave p
  - return
  - retrieve x
- **Type Conversion**
  - x = AtoB y
- **Labeling**
  - label L
- **Basic Math**
  - times, plus, etc.

3AC Representation

- Each instruction represented using a structure called a “quad”
  - Space for the operator
  - Space for each operand
  - Pointer to auxilary info
    - Label, succesor quad, etc.
- Chain of quads sent to an architecture specific MC codegen phase

3AC LLVM Example

Direct machine code generation

- Option 1
  - Have a chain of quad-like structures where each element is a machine-code instruction
  - Pass the chain to a phase that writes to file
- Option 2
  - Write code directly to the file
    - Greatly aided by assembly conventions here
      - Assembler allows us to use function names, labels in output

YES: Skip the IR

- Traverse AST
  - add codeGen methods to the AST nodes
  - Directly spit corresponding code into file

Correctness/Efficiency Tradeoffs

- Two high-level goals
    1. Generate correct code
    2. Generate *efficient* code
- It can be difficult to achieve both of the these at the same time
    - Why?

Simplifying assumptions

- Make sure we don't have to worry about running out of registers
  - We'll put all function arguments on the stack
  - We'll make liberal use of the stack for computation
    - Only use $t1 and $t0 for computation

The CodeGen Pass

- We’ll now go through a high-level idea of how the topmost nodes in the program are generated

The Effect of Different Nodes

- Many nodes simply structure their results
  - ProgramNode.codeGen
    - call codeGen on the child
  - List node types
    - call codeGen on each element in turn
  - DeclNode
    - StructDeclNode – no code to generate!
    - FnDeclNode – generate function body
    - VarDeclNode – varies on context! Globals v locals

Generating Global Variable Declaration

- **Source code:**

```
int name;
struct MyStruct instance;
```

- **In varDeclNode**

  Generate:

```
       .data
       .align 2  #Align on word boundaries
_name: .space N  #(N is the size of variable)
```

Generating Global Variable Declaration

```
        .data
        .align 2  #Align on word boundaries
_name: .space N  #(N is the size of variable)
```

- How do we know the size?
  - For scalars, well defined: int,bool (4 bytes)
  - structs, 4 * size of the struct
- We can calculate this during name analysis

Generating Function Definitions

- Need to generate
  - Preamble
    - Sort of like the function signature
  - Prologue
    - Set up the function
  - Body
    - Do the thing
  - Epilogue
    - Tear down the function

MIPS crash course

- Registers

Register	Purpose
$sp	stack pointer
$fp	frame pointer
$ra	return address
$v0	used for system calls and to return int values from function calls, including the syscall that reads an int
$f0	used to return double values from function calls, including the syscall that reads a double
$a0	used for output of int and string values
$f12	used for output of double values
$t0 - $t7	temporaries for ints
$f0 - $f30	registers for doubles (used in pairs; i.e., use $f0 for the pair $f0, $f1)

Program structure

- Data
  - Label: .data
  - Variable names & size; heap storage
- Code
  - Label: .text
  - Program instructions
  - Starting location: **main**
  - Ending location

Data

- name: type value(s)
  - E.g.
    - `v1: .word 10`
    - `a1: .byte ‘a’ , ’b’`
    - `a2: .space 40`
      - 40 here is allocated space – no value is initialized

Mem Instructions

- `lw register_destination, RAM_source`
  - copy word (4 bytes) at source RAM location to destination register.
- `lb register_destination, RAM_source`
  - copy byte at source RAM location to low-order byte of destination register
- `li register_destination, value`
  - load immediate value into destination register

Mem instructions

- `sw register_source, RAM_dest`
  - store word in source register into RAM destination

- `sb register_source, RAM_dest`
  - store byte in source register into RAM destination

Arithmetic instructions

```
add     $t0,$t1,$t2
sub     $t2,$t3,$t4
addi    $t2,$t3, 5
addu    $t1,$t6,$t7
subu    $t1,$t6,$t7

mult    $t3,$t4

div     $t5,$t6

mfhi    $t0
mflo    $t1
```

Control instructions

```
b       target
beq     $t0,$t1,target
blt     $t0,$t1,target
ble     $t0,$t1,target
bgt     $t0,$t1,target
bge     $t0,$t1,target
bne     $t0,$t1,target
```

```
j       target
jr      $t3
```

```
jal     sub_label        #  "jump and link"
```

TODO

- Watch ***ALL*** MIPS and SPIM tutorials online
  - http://pages.cs.wisc.edu/~aws/courses/cs536-f15/resources.html

- MIPS tutorial
  - http://logos.cs.uic.edu/366/notes/mips%20quick%20tutorial.htm