CS322 Languages and Compiler Design II

Spring 2012

Lecture 1

Languages and Compiler Design Part II

Topics

- Semantics
- Interpreters
- Runtime Organization
- Intermediate Code Generation
- Machine Code Generation
- Optimization

Project

- Build **fab** Interpreter
- Complete **fab** Compiler for X86-64

Themes

- Mapping from high-level to low-level
- Implementing resource management
- Integration with OS and hardware environment
- Syntax-directed techniques

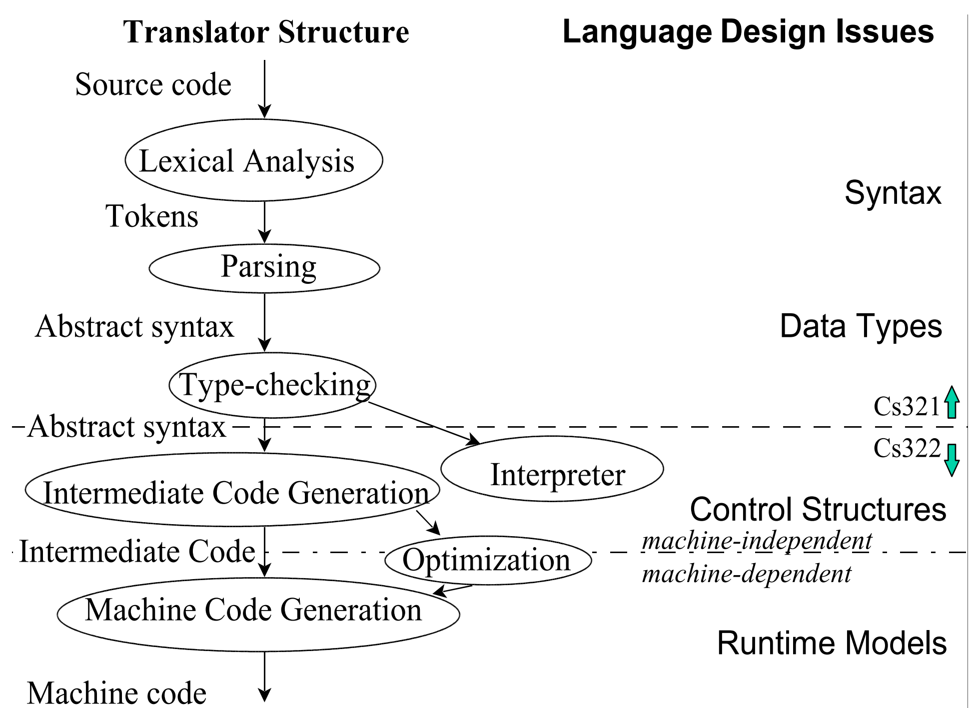
Compiler Back-end Tasks

Starting from type-checked abstract syntax for source language...

- Simplify expressions and statements into flat goto/label form
- Fix location of variables & temps in memory & registers
- Generate machine instructions
- Manage machine resources
- Interact with O/S, runtime system

...generate machine code for specific target architecture.

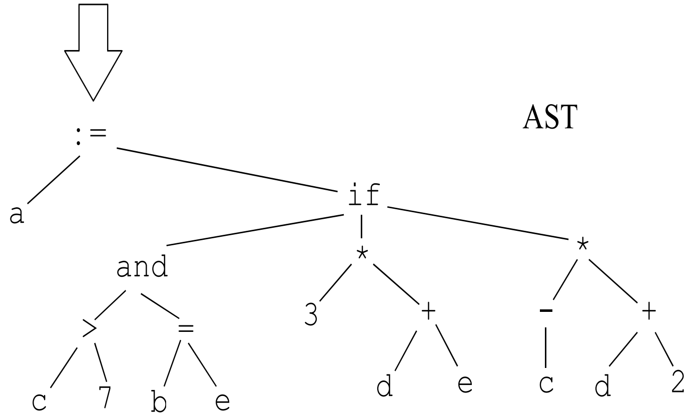
Or, build interpreter for higher-level language features.



TRANSLATION TO ABSTRACT SYNTAX TREES

```
a := if c > 7 and b = e
     then 3 * (d + e)
     else -c * (d + 2)
```

Source code



AST

INTERMEDIATE CODE GENERATION

Emit intermediate code/represenation ("IR") from abstract syntax or directly from parser .

Advantages:

- Keeps more of compiler machine-independent
- Facilitates some optimizations

Typical examples:

- Postfix stack code
- Trees or directed acyclic graphs (DAGs)
- Three-address code (quadruples, triples, etc.)

Abstracts key features of machine architectures

- e.g., sequential execution, explicit jumps
- but hides details
- e.g., # of registers, style of conditionals, etc.

Many possible levels of IR; some compilers use several

"THREE-ADDRESS CODE" - A TYPICAL LINEAR IR

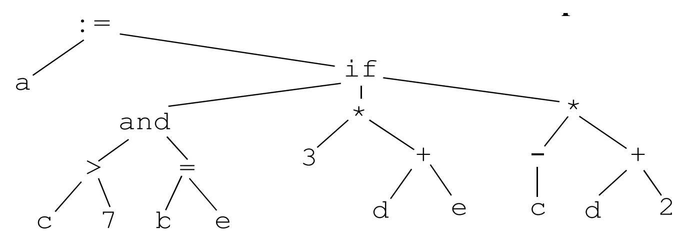
Generate list of "instructions"

- Each has an operator, up to 2 args, and up to 1 result
- Instructions can be labeled
- Operands are names for locations in some abstract memory (e.g., symbol table entries)

Examples of instructions:

A := B	copy
A = B op C	binary ops
A = op B	unary ops
goto L	jumps
if A relop B goto L	conditional jumps
param A	procedure call setup
call P,N	procedure call
return N	procedure return
A[I]	array dereference

3-ADDRESS CODE EXAMPLE



- Linearized
- Nested conditionals expanded (badly)
- Temporaries for all intermediate results

```
    if c > 7 goto L1
    goto L2
L1: if b = e goto L3
L2: t1 := d + 2
    t2 := -c
    t3 := t1 * t2
    goto L4
L3: t1 := d + e
    t3 := 3 * t1
L4: a := t3
```

Machine-code Generation

"Read" IR and generate assembly language (symbol or binary).

Must cooperate with IR to define and "enforce" runtime environment.

Must deal with idiosyncrasies of target machine,

- e.g., instruction selection

and perform resource management,

- e.g., register assignment.

Lots of case analysis, especially for complex target architectures.

Can do by hand, but hard.

Tools limited but sometimes useful; mainly based on pattern matching

Sample machine code

Assumes `a` global; `b,c` args; `d,e` locals.

Illustrates register conventions, condition code use, arithmetic tricks, ...

```
    movl  %edi, %ebx
    movl  %esi, %r12d
    cmpl  $7, %r12d
    setg  %dl
    cmpl  %ebx, %ecx
    sete  %al
    testb %al, %dl
    je    L2
    leal  (%r13,%rcx), %eax
    leal  (%rax,%rax,2), %edx
    jmp   L4
L2:
    movl  $-2, %eax
    movl  %r12d, %edx
    subl  %r13d, %eax
    imull %eax, %edx
L4:
    movq  _a@GOTPCREL(%rip), %rax
    movl  %edx, (%rax)
```

(initially `b:%edi c:%esi d:%r13 e:%ecx`)

"Optimization"

Improve (don't perfect) code by removing inefficiencies:

- in original program
- introduced by compiler itself

Can operate on source, IR, object code.

Local Improvements

- Example: changing

```
    if c > 7 goto L1
    goto L2
L1: ...
L2: ...
```

to

```
    if c <= 7 goto L2
L1: ...
L2: ...
```


Optimization (continued)

"Global" Improvements

- Example: changing

```
for (i := 0; i < 1000; i++)
   a[i] := b*c + i;
```

to

```
t1 := b * c;
for (i = 0; i < 1000; i++)
   a[i] = t1 + i;
```

Interprocedural improvements

- Example: Inlining a function

Most of a modern compiler is devoted to optimization.

INTERPRETATION

Simulate execution of program (source, AST, or other IR) on an abstract machine.

Implement abstract machine on a real machine.

Inputs to interpreter are

- Program to be interpreted
- Input to that program

Simpler than compiling and takes no time up front, but interpreted code runs (~10X) more slowly than compiled code.

Much more portable than real machine code (as for Java).

Helps with semantic definition.

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