Compilers Crash Course

Prof. Michael Clarkson

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Slides Acknowledgment:
Prof. Andrew Myers (Cornell)

What are Compilers?

- Translators from one representation of program code to another
- Typically: high-level source code to machine language (object code)
- Not always:
  - Java compiler: Java to interpretable bytecodes
  - Java JIT: bytecode to executable image

Source Code

- Source code: optimized for human readability
  - expressive: matches human notions of grammar
  - redundant to help avoid programming errors
  - computation possibly not fully determined by code

```
int expr(int n)
{
    int d;
    d = 4 * n * n * (n + 1) * (n + 1);
    return d;
}
```


Machine Code

- Optimized for hardware
  - Redundancy, ambiguity reduced
  - Information about intent and reasoning lost
  - Assembly code ≈ machine code

```
expr:
        pushl   %ebp                    55
        movl    %esp, %ebp              89 e5
        subl    $4, %esp                83 ec 04
        movl    8(%ebp), %eax           8b 45 08
        movl    %eax, %edx              89 c2
        imull   8(%ebp), %edx           0f af 55 08
        movl    8(%ebp), %eax           8b 45 08
        incl    %eax                    40
        imull   %eax, %edx              0f af d0
        movl    8(%ebp), %eax           8b 45 08
        incl    %eax                    40
        imull   %edx, %eax              0f af c2
        sall    $2, %eax                c1 e0 02
        movl    %eax, -4(%ebp)          89 45 fc
        movl    -4(%ebp), %eax          8b 45 fc
        leave                           c9
        ret                             c3
```

Example (Output assembly code)

Unoptimized Code

```
expr:
        pushl   %ebp
        movl    %esp, %ebp
        subl    $4, %esp
        movl    8(%ebp), %eax
        movl    %eax, %edx
        imull   8(%ebp), %edx
        movl    8(%ebp), %eax
        incl    %eax
        imull   %eax, %edx
        movl    8(%ebp), %eax
        incl    %eax
        imull   %edx, %eax
        sall    $2, %eax
        movl    %eax, -4(%ebp)
        movl    -4(%ebp), %eax
        leave
        ret
```

Optimized Code

```
expr:
        pushl   %ebp
        movl    %esp, %ebp
        movl    8(%ebp), %edx
        movl    %edx, %eax
        imull   %edx, %eax
        incl    %edx
        imull   %edx, %eax
        imull   %edx, %eax
        sall    $2, %eax
        leave
        ret
```

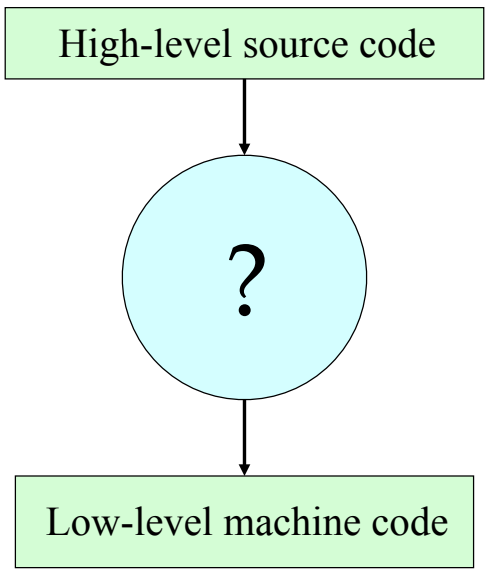

How to translate?

- Source code and machine code mismatch
- Goals:
  - source-level expressiveness for task
  - best performance for concrete computation
  - reasonable translation efficiency (< $O(n^3)$)
  - maintainable compiler code

How to translate correctly?

- Programming languages describe computation precisely
- Therefore: translation can be precisely described (a compiler can be correct)
- Correctness is very important!
  - hard to debug programs with broken compiler…
  - non-trivial: programming languages are expressive
  - implications for development cost, security
  - some compilers have been **proven** correct!
    [X. Leroy, *Formal Verification of a Realistic Compiler*, CACM 52(7), 2009]

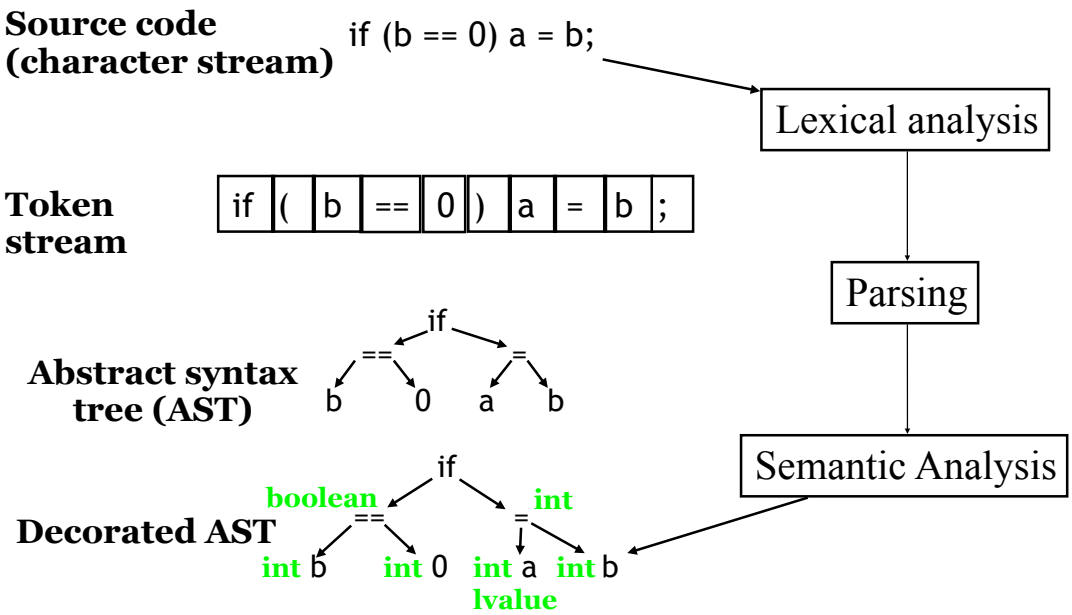
How to translate effectively?



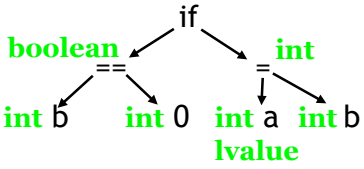
Idea: translate in steps

- Compiler uses a series of different **intermediate representations (IRs)** of programs.
- Different IRs are good for different phases of compilation

Compilation in a Nutshell 1

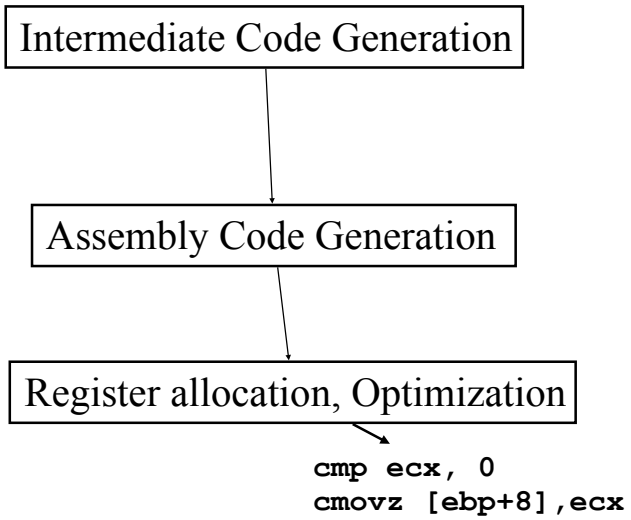


Compilation in a Nutshell 2

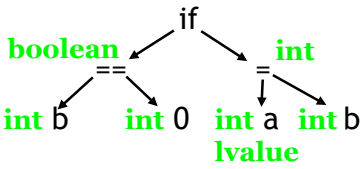


if b == 0 goto L1 else L2
L1: a = b
L2:

```
cmp r_b, 0
jnz L2
L1: mov r_a, r_b
L2:
```



Compilation in a Nutshell 2



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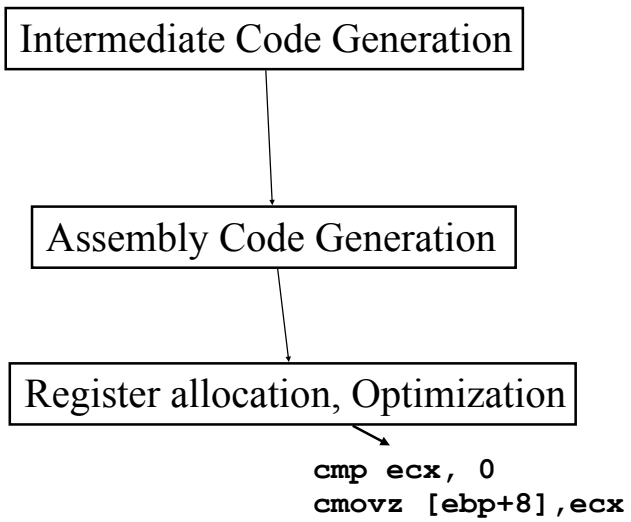
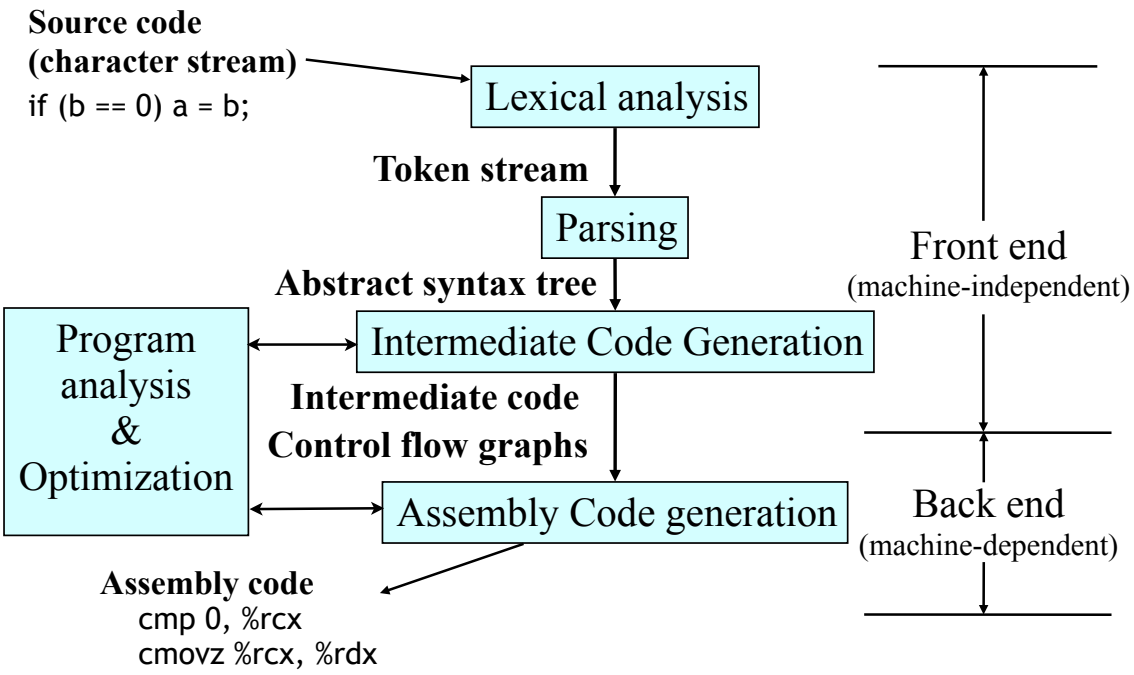
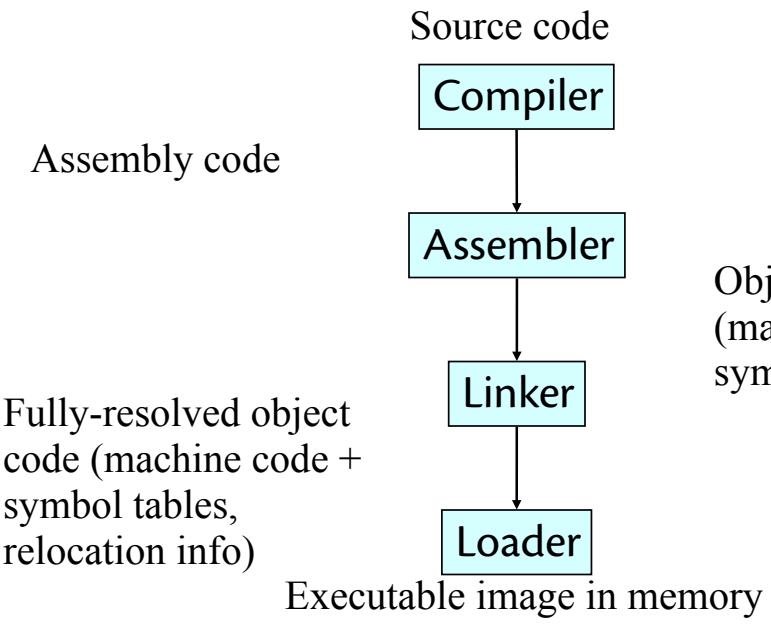


Simplified Compiler Structure



Even Bigger Picture



Where to Learn More

- **Compilers—Principles, Techniques and Tools.** Aho, Lam, Sethi and Ullman (The Dragon Book)
  (strength: parsing)
- **Modern Compiler Implementation in Java.** Andrew Appel.
  (strength: translation)
- **Advanced Compiler Design and Implementation.** Steve Muchnick.
  (strength: optimization)