Compiler Overview

ICS312
Machine-Level and Systems Programming

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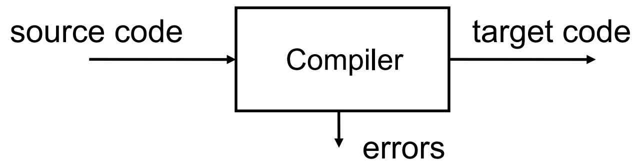
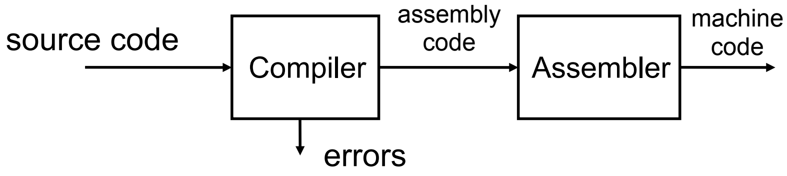
What's a compiler

- A Compiler is a translator
- It translate from a source language into a target language



- The target code is typically assembly

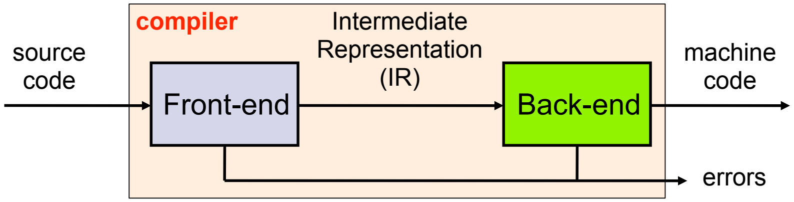


What Should a Compiler Do?

- It should translate legal code and reject illegal code with (hopefully helpful) error messages
- It should generate correct code
  - Correct text segments
- It should manage storage for all variables
  - Correct data segments

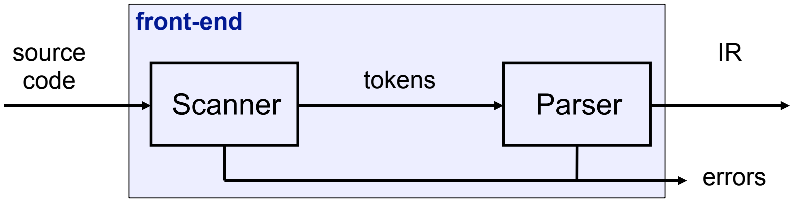
- Although these seem obvious, it wasn't always easy and the first compilers were known to have bugs and limitations

Traditional 2-Pass Compiler



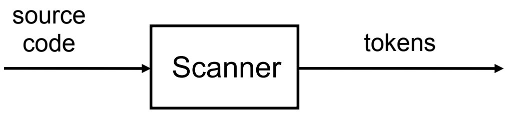
- Compilers use an Intermediate Representation (IR) for the program being compiled
- Makes it possible to have multiple front-end versions
  - You could have a front-end that takes in C++, and a front-end that takes in Python, and have 2 compilers for the price of 1.5
  - Limited to how general the IR is
  - Doesn't generalize to us having a single back-end in the world!
- Makes it possible to have multiple back-end passes to try to generate better and better code

What does the Front-End do?



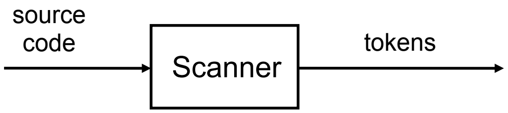
- The front-end is the “easy” part of the compiler
- It’s where all the error messages are generated
- Much of the front-end can be automated, and we have well-known tools to generate it
- In practice, some compilers use “implemented by-hand” Scanners or (more rarely) Parsers, for speed

What does the Scanner Do?



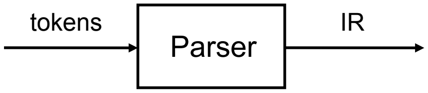
- The Scanner maps a stream of characters (ASCII codes of the characters in the text file that contains your program) into words
- A “words” is called a token, which is really a pair of two things
  - A lexeme: the actual string in the source code
  - A type: what does this mean in the programming language?
    - Different from the types in the language like “int”, “char”, etc.

What does the Scanner Do?



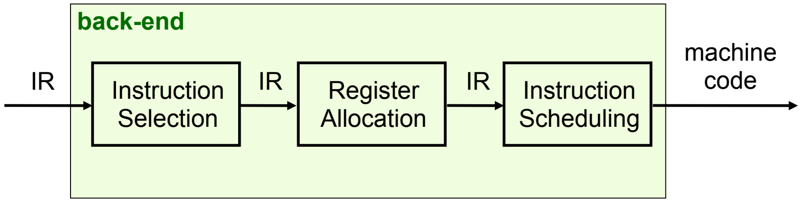
- Example:
- Source code: “x = x + y - 2”
- Will generate 7 tokens, which could look like this
  - (“x”, IDENTIFIER)
  - (“=“, ASSIGNMENT_OP)
  - (“x”, IDENTIFIER)
  - (“+”, ADD_OP)
  - (“y”, IDENTIFIER)
  - (“-”, SUB_OP)
  - (“2”, NUMBER)

What does the Parser do?



- Recognizes whether the stream of tokens matches the grammar of the language
- In the end, builds an annotated hierarchical view of the programs called an abstract syntax tree
  - We’ll look at this in another lecture

What does the Back-End do?

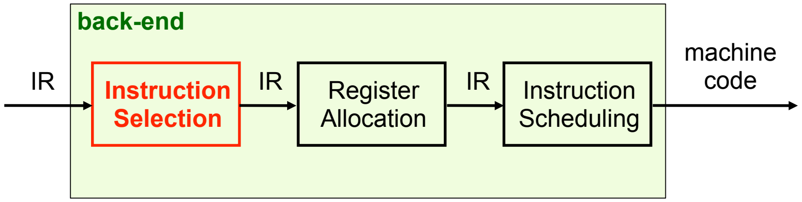


back-end

IR → Instruction Selection → IR → Register Allocation → IR → Instruction Scheduling → machine code

- The back-end translates the IR into machine code
  - It chooses which machine instructions to use to translate the IR
  - It chooses which values should be kept in registers
  - It decides of the order in which instructions should be executed in which order
- Back-end automation has been much less successful than for the front-end

Instruction Selection

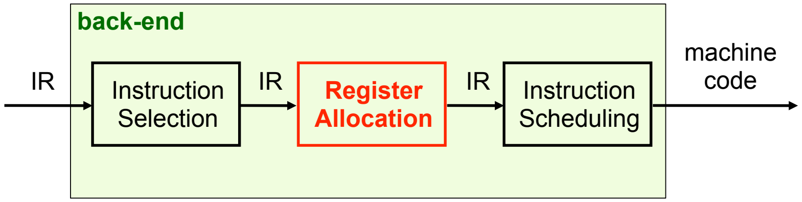


back-end

IR → **Instruction Selection** → IR → Register Allocation → IR → Instruction Scheduling → machine code

- The goal is to produce fast, compact code
  - E.g., use an “xor eax, eax” rather than “mov eax, 0”
- This used to be a huge issue when ISAs were very complicated with many, many options
  - E.g., VAX

Register Allocation

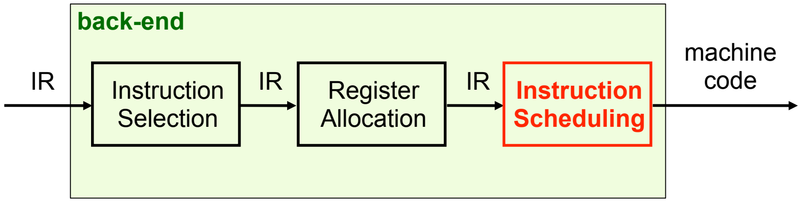


back-end

IR → Instruction Selection → IR → **Register Allocation** → IR → Instruction Scheduling → machine code

- Registers allow for fast variable access
- But there is a limited number of them
- Optimal allocation is known to be a difficult problem
  - NP-hard
- Compilers use approximation algorithms to try to get close to the optimal

Instruction Scheduling



back-end

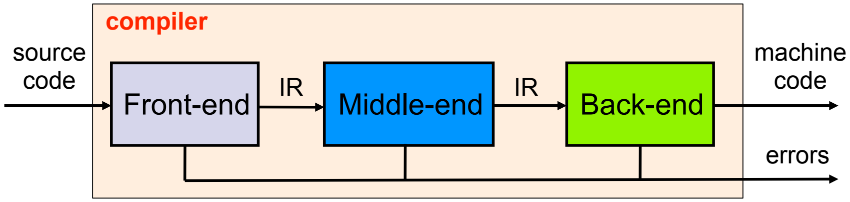
IR → Instruction Selection → IR → Register Allocation → IR → **Instruction Scheduling** → machine code

- Avoid hardware stalls and interlock
  - See ICS 431
- Use all functional units productively
  - Parallelism of ALUs
- Optimal scheduling is NP-hard
- Compilers use heuristics
  - Some scheduling happens in hardware!

Code Optimization

- What we've talked about so far has been known for decades
  - Some parts can be automated/generated using standard tools
  - Some parts have to be done by hand by many well-known techniques and algorithms can be used
- Most people who "work in compilers" today do not really work on these components
- More interesting is code optimization
- What people sometimes call the "middle-end"

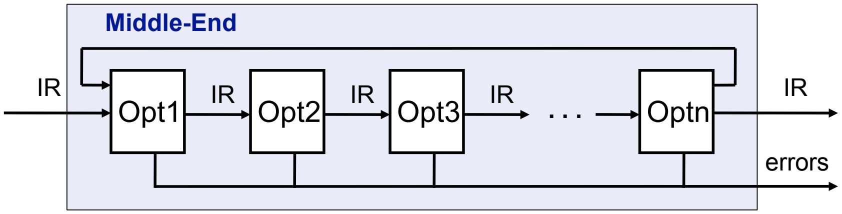
Traditional 3-Pass Compiler



- The Middle-end is all about improving the code
- Iteratively transforms/rewrites the Intermediate Representation
- The goal: reduce the running time of the produced code
- The constraint: must preserve the meaning of the code

- There are entire graduate courses on just the Middle-end component

Typical Middle-End



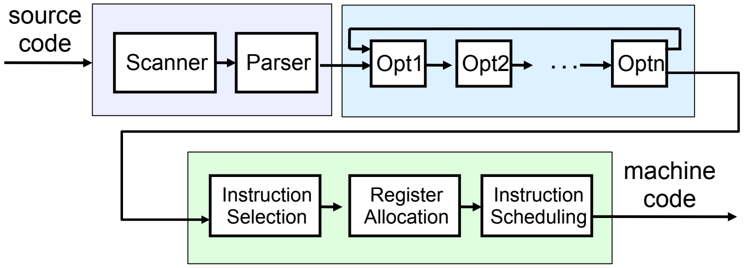
- The Middle-end is a series of optimizations
- Typical transformations
  - Discover a redundant computation and remove it

```
      ~~mov      eax, 12~~
      mov      eax, 8
```

  - Discover "dead code" and remove it

```
      ~~jmp      foo~~
      ~~mov      eax, 12~~
foo:  . . .
```

Conclusion



- Compilers are very complex (and interesting!) pieces of software, which we all typically take for granted