Compiling Techniques

Lecture 2: The view from 35000 feet

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19 September 2017

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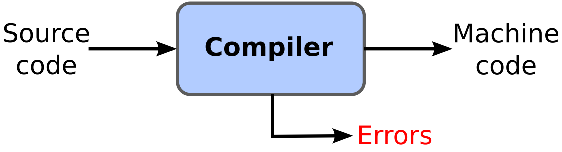
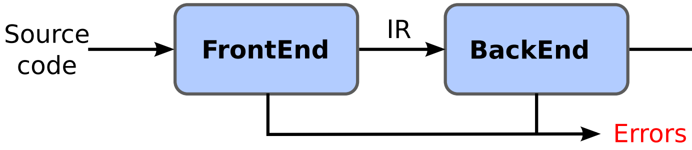
High-level view of a compiler



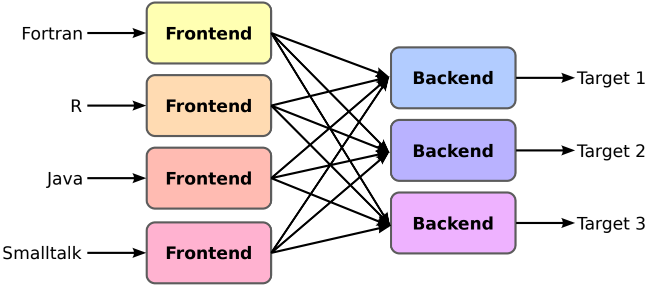
- Must recognise legal (and illegal) programs
- Must generate correct code
- Must manage storage of all variables (and code)
- Must agree with OS & linker on format for object code
- Big step up from assembly language; use higher level notations

Traditional two-pass compiler



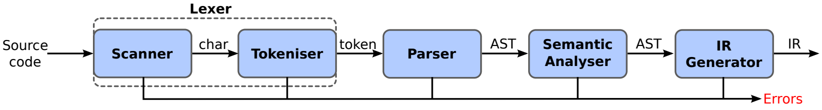
- Use an intermediate representation (IR)
- Front end maps legal source code into IR
- Back end maps IR into target machine code
- Admits multiple front ends & multiple passes
- Typically, front end is O(n) or O(n log n), while back end is NPC (NP-complete)

A common fallacy two-pass compiler



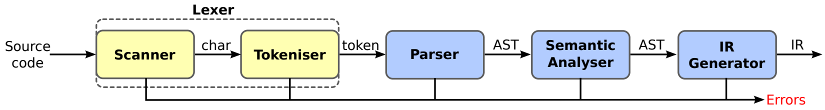
- Can we build n x m compilers with n+m components?
- Must encode all language specific knowledge in each front end
- Must encode all features in a single IR
- Must encode all target specific knowledge in each back end
- Limited success in systems with very low-level IRs (e.g. LLVM)
- Active research area (e.g. Graal, Truffle)

The Frontend



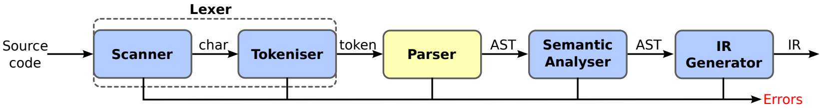
- Recognise legal (& illegal) programs
- Report errors in a useful way
- Produce IR & preliminary storage map
- Shape the code for the back end
- Much of front end construction can be automated

The Lexer



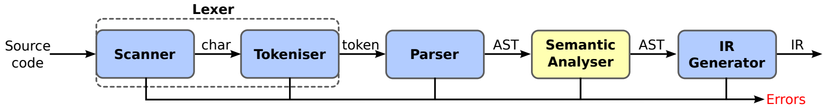
- Lexical analysis
- Recognises words in a character stream
- Produces tokens (words) from lexeme
- Collect identifier information
- Typical tokens include number, identifier, $+$, $-$, new, while, if
- Example: x$=$y$+$2; becomes
  IDENTIFIER(x) EQUAL IDENTIFIER(y) PLUS CST(2)
- Lexer eliminates white space (including comments)

The Parser



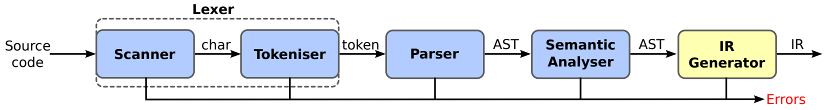
- Recognises context-free syntax & reports errors
- Hand-coded parsers are fairly easy to build
- Most books advocate using automatic parser generators

Semantic Analyser



- Guides context-sensitive (“semantic”) analysis
- Checks variable and function declared before use
- Type checking

IR Generator



- Generates the IR used by the rest of the compiler.
- Sometimes the AST is the IR.

Simple Expression Grammar

1	$goal$	$\rightarrow$	$expr$
2	$expr$	$\rightarrow$	$expr \ op \ term$
3		$\mid$	$term$
4	$term$	$\rightarrow$	$number$
5		$\mid$	id
6	op	$\rightarrow$	$+$
7		$\mid$	$-$

$$
\begin{aligned}
S &= goal \\
T &= \{number, id, +, -\} \\
N &= \{goal, expr, term, op\} \\
P &= \{1, 2, 3, 4, 5, 6, 7\}
\end{aligned}
$$

- This grammar defines simple expressions with addition & subtraction over "number" and "id"
- This grammar, like many, falls in a class called "context-free grammars", abbreviated CFG

Derivations

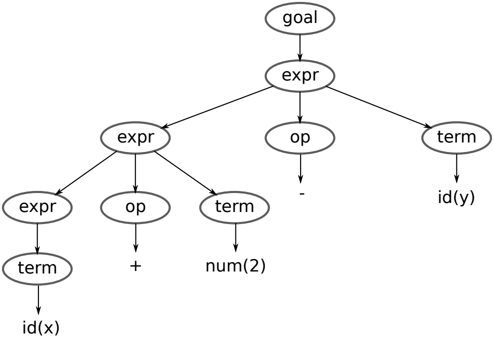
Given a CFG, we can derive sentences by repeated substitution

Production	Result
	goal
1	expr
2	expr op term
5	expr op y
7	expr - y
2	expr op term - y
4	expr op 2 - y
6	expr + 2 - y
3	term + 2 - y
5	x + 2 - y

To recognise a valid sentence in a CFG, we reverse this process and build up a parse tree

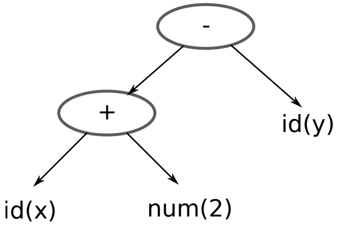
Parse tree

x + 2 -y



This contains a lot of unnecessary information.

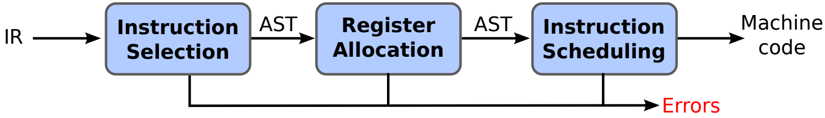
Abstract Syntax Tree (AST)



The AST summarises grammatical structure, without including detail about the derivation.

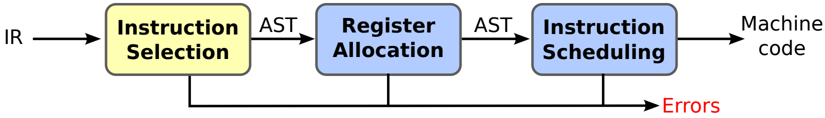
- Compilers often use an abstract syntax tree
- This is much more concise
- ASTs are one kind of intermediate representation (IR)

The Back end



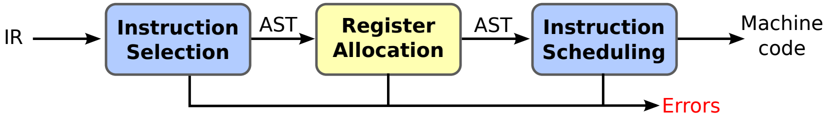
- Translate IR into target machine code
- Choose instructions to implement each IR operation
- Decide which value to keep in registers
- Ensure conformance with system interfaces
- Automation has been less successful in the back end

Instruction Selection



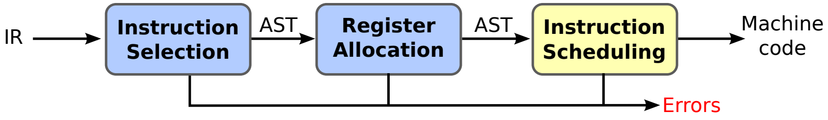
- Produce fast, compact code
- Take advantage of target features such as addressing modes
- Usually viewed as a pattern matching problem
- ad hoc methods, pattern matching, dynamic programming
- Example: madd instruction

Register Allocation



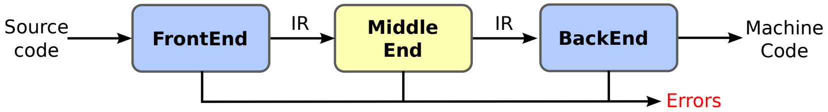
- Have each value in a register when it is used
- Manage a limited set of resources
- Can change instruction choices & insert LOADs & STOREs (spilling)
- Optimal allocation is NP-Complete (1 or k registers)
- Graph colouring problem
- Compilers approximate solutions to NP-Complete problems

Instruction Scheduling



- Avoid hardware stalls and interlocks
- Use all functional units productively
- Can increase lifetime of variables (changing the allocation)
- Optimal scheduling is NP-Complete in nearly all cases
- Heuristic techniques are well developed

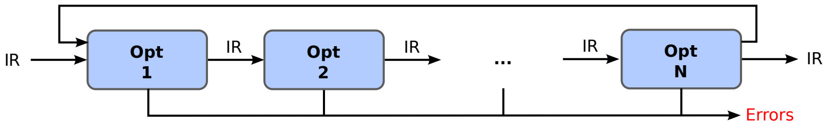
Three Pass Compiler



- Code Improvement (or Optimisation)
- Analyses IR and rewrites (or transforms) IR
- Primary goal is to reduce running time of the compiled code
  - May also improve space, power consumption, . . .
- Must preserve meaning of the code
  - Measured by values of named variables
- Subject of UG4 Compiler Optimisation

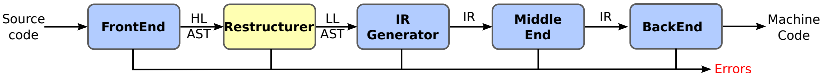
The Optimiser

Modern optimisers are structured as a series of passes
e.g. LLVM



- Discover & propagate some constant value
- Move a computation to a less frequently executed place
- Specialise some computation based on context
- Discover a redundant computation & remove it
- Remove useless or unreachable code
- Encode an idiom in some particularly efficient form

Modern Restructuring Compiler



- Translate from high-level (HL) IR to low-level (LL) IR
- Blocking for memory hierarchy and register reuse
- Vectorisation
- Parallelisation
- All based on dependence
- Also full and partial inlining
- Not covered in this course

Role of the runtime system

- Memory management services
  - Allocate, in the heap or in an activation record (stack frame)
  - Deallocate
  - Collect garbage
- Run-time type checking
- Error processing
- Interface to the operating system (input and output)
- Support for parallelism (communication and synchronization)

Programs related to compilers

- Pre-processor:
  - Produces input to the compiler
  - Processes Macro/Directives (*e.g.* `#define`, `#include`)
- Assembler:
  - Translate assembly language to actual machine code (binary)
  - Performs actual allocation of variables
- Linker:
  - Links together various compiled files and/or libraries
  - Generate a full program that can be loaded and executed
- Debugger:
  - Tight integration with compiler
  - Uses meta-information from compiler (*e.g.* variable names)
- Virtual Machines:
  - Executes virtual assembly
  - typically embedded a just-in-time (jit) compiler

Next lecture

- Introduction to Lexical Analysis
- Decomposition of the input into a stream of tokens
- Construction of scanners from regular expressions