CSC 488S/CSC 2107S Lecture Notes

These lecture notes are provided for the personal use of students taking CSC488H1S or CSC2107HS in the
Winter 2013/2014 term at the University of Toronto

CSC488S/CSC2107S - Compilers and Interpreters

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Office	Bahen Centre, Room 5222
Office Hours	immediately after lecture and by appointment
Lectures	Tuesday 14:00 BA 1210
	Thursday 14:00 BA 1210
Tutorial	Thursday 13:00 BA 1210
Text	Charles Fischer, Ron Cytron and Richard LeBlanc Jr. , Crafting a Compiler , Addison-Wesley 2009
Marking	Mid term test, Final Exam, Course Project
Web Page	`http://cdf.toronto.edu/~csc488h/winter/`
Bulletin Board	**Read Often!!** `https://csc.cdf.toronto.edu/csc488h1s`
Slides	on the Bulletin Board
Handouts	on the Bulletin Board

Course Project

- Design and Implementation of a small compiler system for a toy language.
- Work in teams of 5 (- 1 , + 0)
- Five Phase Project
  - Phase 1 Write programs in project language
  - Phase 2 Revise grammar and build parser
  - Phase 3 Implement symbol table and semantic checking.
  - Phase 4 Design code generation
  - Phase 5 Implement code generator
- Language specification and project details will be announced soon

Course Outline

Topic	Chapters
Compiler structure	Ch. 1, 2
Lexical Analysis	Ch. 3
Syntax Analysis	Ch. 4, 5, 6
Tables & Dictionaries	Ch. 8
Semantic Analysis	Ch. 7, 9
Run-time Environments	Ch. 12
Code generation	Ch. 11, 13
Optimization	Ch. 14

Reading Assignment

Fischer, Cytron, LeBlanc

Chapter 1

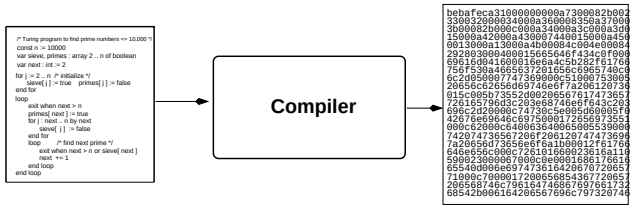
Section 10.1

What Do Compilers Do?

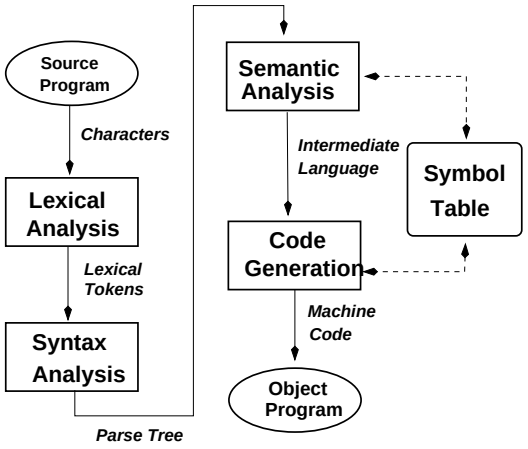
Check source program for correctness

- Well formed lexically i.e. spell check
- Well formed syntactically. i.e. grammar check
- Passes static semantic checks sensibility check
  - Type correctness
  - Usage correctness

Transform *source program* into an executable *object program*



Simple Generic Compiler



Source statement

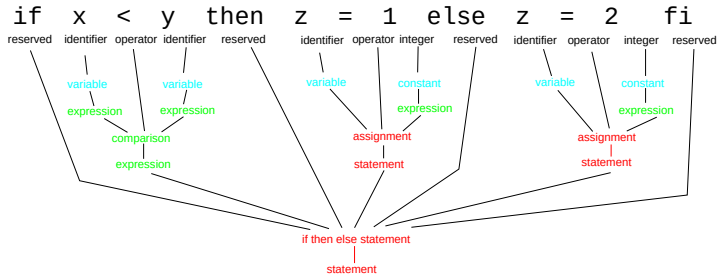
```
if x < y then z = 1 else z = 2 fi
```

Lexical analysis

```
if   x   <   y   then   z   =   1   else   z   =   2   fi
```

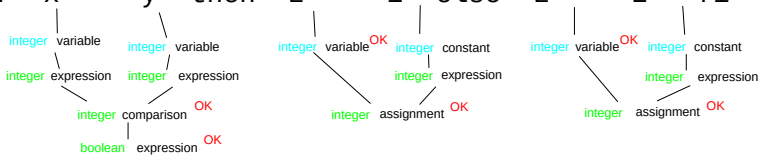
reserved identifier operator identifier reserved identifier operator integer reserved identifier operator integer reserved

Syntax analysis



Semantic analysis

```
if  x  <  y  then  z  =  1  else  z  =  2  fi
```



Code Generation

```
if  x  <  y  then  z  =  1  else  z  =  2  fi
```

```
load     r1,x
load     r2,y
less     r1,r2
brfalse  L23
```

```
load      r1,=1
loadaddr  r2,z
store     r2,r1
branch    L24
```

```
L23:  load      r1,=2
      loadaddr  r2,z
      store     r2,r1
L24:
```


Useful Background for Compiler Implementors

- Computer organization (CSC 258H)
- Software engineering (CSC 207H, CSC 301H, CSC 302H, CSC 410H)
- Software Tools (CSC 209H)
- File and Data structures (CSC 263H/CSC 265H)
- Communication Skills (CSC 290H)
- A large *variety* of programming languages (CSC 324H)
- Some operating systems (CSC 369H)
- Compiler implementation techniques (CSC 488H, ECE 489H).

Compiler Writing Requires Analytic Skills

- The compiler implementor(s) design the mapping from the source language to the target machine.
- Must be able to analyze a programming language for potential problems. Determine if language can be processed during lexical analysis, syntax analysis, semantic analysis and code generation.
- Must be able to analyze target machine and determine best way to implement each construct in the programming language.

Programming Language Designers are (usually) the Enemy

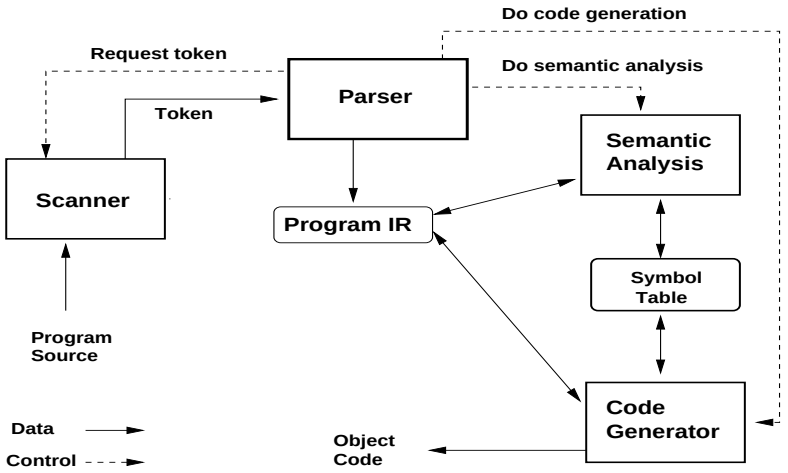
- Most programming language definitions are incomplete, imprecise and sometimes inconsistent. Real programs are written in language dialects.[a]
- Language designers often don't think deeply about the details of the implementation of a language, leaving lots of problems for the compiler writer.
- Typical problems
  - Poor lexical structure. May require extensive buffering or lookahead during lexical analysis
  - Difficulty syntax. Ambiguous, not suitable for normal parsing methods. May require hand written parser, backtracking or lookahead.
  - Incompletely defined or inconsistent semantics.
    User friendly options that are hard to implement.
  - Constructs that are difficult to generate good code for, make optimization difficult, require large run time support

[a] For a discussion of the difficulties of scanning and parsing real programs see
`http://cacm.acm.org/magazines/2010/2/69354-a-few-billion-lines-of-code-later/fulltext`

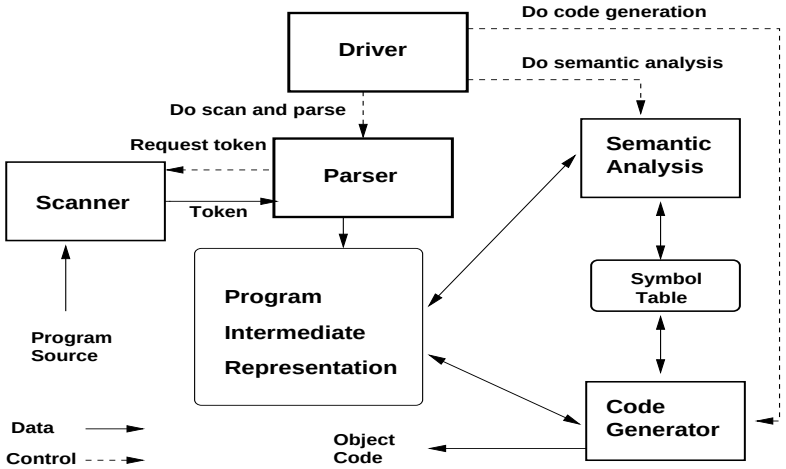
Characteristics of an Ideal Compiler

- User Interface
  - Precise and clear diagnostic messages
  - Easy to use processing options.
- Correctly implements the entire language
- Detects all *statically* detectable errors.
- Generates highly optimal code.
- Compiles quickly using modest system resources.
- Compiler software Engineering
  - Well modularized. Low coupling between modules.
  - Well documented and maintainable.
  - High level of internal consistency checking.
  - Thoroughly tested.

Single Pass Compiler Architecture



Multi Pass Compiler Architecture



Internal Compiler Data Structures

- Information flows between compiler passes
  - Representation(s) of the program
  - Tables
  - Error messages
  - Compiler flags
  - Source program coordinates.
- Form of communication may change as program is processed.
  A compiler may use multiple representations of a program.
- Use disk resident information for very large programs.
  Use memory resident information for better compiler speed.
- **Backward information flow should be avoided if possible.**

Intermediate Representations

- Represent the structure of the program being compiled
  - Declaration structure.
  - Scope structure.
  - Control flow structure.
  - Source code structure.
- Used to pass information between compiler passes
  - Compact representation desirable.
  - Should be efficient to read and write.
  - Provide utility to print intermediate language for compiler debugging.

Intermediate Representation Examples

Condensed Source

A * B + C / D - E

Polish Postfix Notation

A B * C D / + E -

Triples

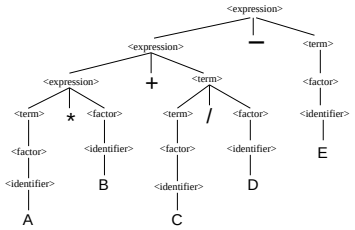
1 (* , A , B)
2 (/ , C , D)
3 (+ , (1) , (2))
4 (- , (3) , E)

Quadruples

(* , A , B , T1)
(/ , C , D , T2)
(+ , T1 , T2 , T3)
(- , T3 , E , T4)

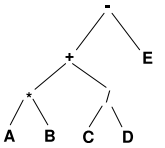
Parse Tree

Complete representation of the syntactic structure of the program according to some grammar.



Abstract Syntax Tree

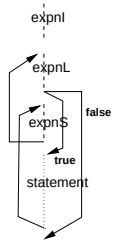
Similar to parse tree but only describes essential program structure.



Directed Acyclic Graphs

Used to represent control structure

for (expnI ; expnL ; expnS **)** statement



Interpretive Systems

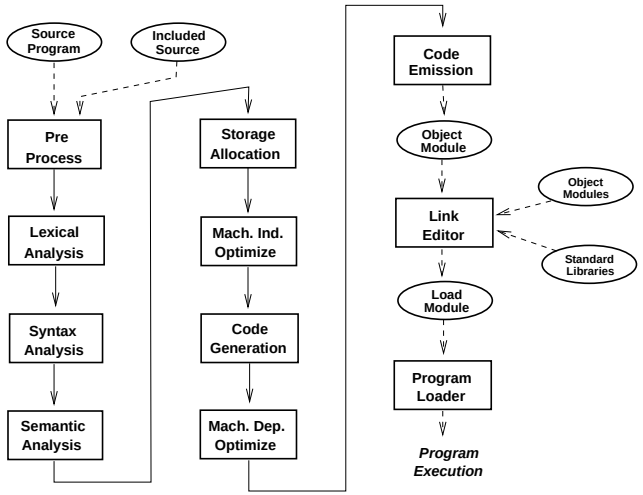
- Compiler generates a pseudo machine code that is a simple encoding of the program.
- The pseudo machine code is executed by another program (an *interpreter*)
- Interpreters are used for
  - Debugging newly written programs.
  - Student compilers that require good run-time error messages.
  - Languages that allow dynamic program modification.
  - Typeless languages that can't be semantically analyzed statically.
  - Cases where run-time size must be minimized.
  - Implementing ugly language features.
  - Quick and dirty compilers.
  - As a way to port programs between environments.
- Interpreters lose on
  - Execution speed, usually significantly slower than machine code.
  - May limit user data space or size of programs.
  - May require recompilation for each run.

Examples of Interpreters

- Pascal P Machine
  - First compiler for Pascal compiled to a pseudo code (P-code) for a language-oriented stack machine.
  - Compiler for Pascal was provided in P-code and source.
  - Porting Pascal to new hardware only required writing a P-code interpreter for the new machine. 1..2 months work.
  - P-code influenced many later pseudo codes including U-code (optimization intermediate language) and Turing internal T-code.
- Java Virtual Machine[a]
  - Java programs are compiled to a *byte-code* for the *Java Virtual Machine* (JVM).
  - JVM designed to make Java portable to many platforms.
  - JVM slow execution speed has lead to the development of *Just In Time* (JIT) native code compilers for Java.

[a] See *Fischer, Cytron, LeBlanc* Section 10.2

The Complete Compilation Process



Project Preview