Programming Language Translators

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Credits

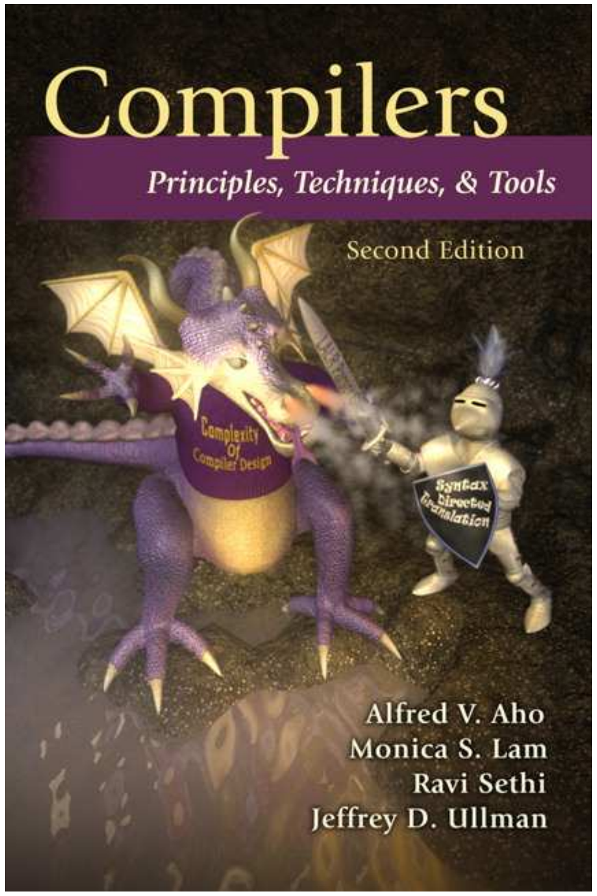
Most of the material in these slides has been extracted from the one elaborated by Prof. Stephen A. Edwards (University of Columbia) for the course COMS W4115 (Programming Languages and Translators)

Objectives

- Different languages and paradigms
- Overall structure of a compiler
- Automated tools and their use
- Lexical analysis to assembly generation

Bibliography

Alfred V. Aho, Monica S. Lam, Ravi Sethi, and Jeffrey D. Ullman. *Compilers: Principles, Techniques, and Tools*. Addison-Wesley, 2007. Second Edition.


Compilers
Principles, Techniques, & Tools
Second Edition
Complexity of Compiler Design
Syntax Directed Translation
Alfred V. Aho
Monica S. Lam
Ravi Sethi
Jeffrey D. Ullman

What’s in a Language?

Components of a language: Syntax

How characters combine to form words, sentences, paragraphs.

```
The quick brown fox jumps over the lazy dog.
```

is syntactically correct English, but isn’t a Java program.

```
class Foo {
  public int j;
  public int foo(int k) { return j + k; }
}
```

Is syntactically correct Java, but isn’t C.

Specifying Syntax

Usually done with a context-free grammar.

Typical syntax for algebraic expressions:

$$
\begin{array}{rcl}
\mathit{expr} & \rightarrow & \mathit{expr} + \mathit{expr} \\
 & | & \mathit{expr} - \mathit{expr} \\
 & | & \mathit{expr} * \mathit{expr} \\
 & | & \mathit{expr} / \mathit{expr} \\
 & | & \mathbf{digit} \\
 & | & (\mathit{expr})
\end{array}
$$

Components of a language: Semantics

What a well-formed program "means."

The semantics of C says this computes the nth Fibonacci number.

```
int fib(int n)
{
  int a = 0, b = 1;
  int i;
  for (i = 1 ; i < n ; i++) {
    int c = a + b;
    a = b; b = c;
  }
  return b;
}
```

Semantics

Something may be syntactically correct but semantically nonsensical.

> The rock jumped through the hairy planet.

Or ambiguous

> The chickens are ready for eating.

Semantics

Nonsensical in Java:

```
class Foo {
  int bar(int x) { return Foo; }
}
```

Ambiguous in Java:

```
class Bar {
  public float foo() { return 0; }
  public int foo() { return 0; }
}
```

Specifying Semantics

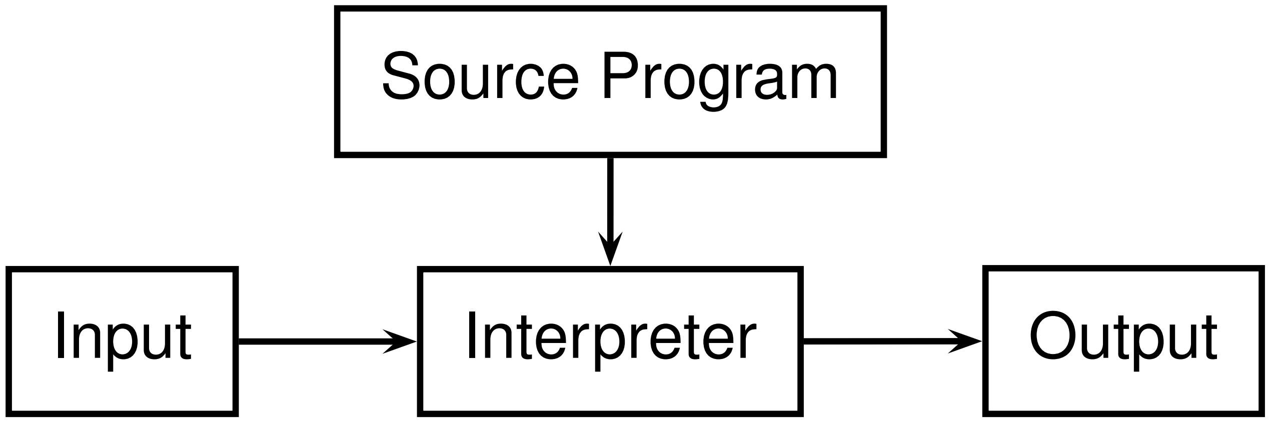
Doing it formally beyond the scope of this class, but basically two ways:

- Operational semantics: Define a virtual machine and how executing the program evolves the state of the virtual machine
- Denotational semantics: Shows how to build the function representing the behavior of the program (i.e., a transformation of inputs to outputs) from statements in the language.

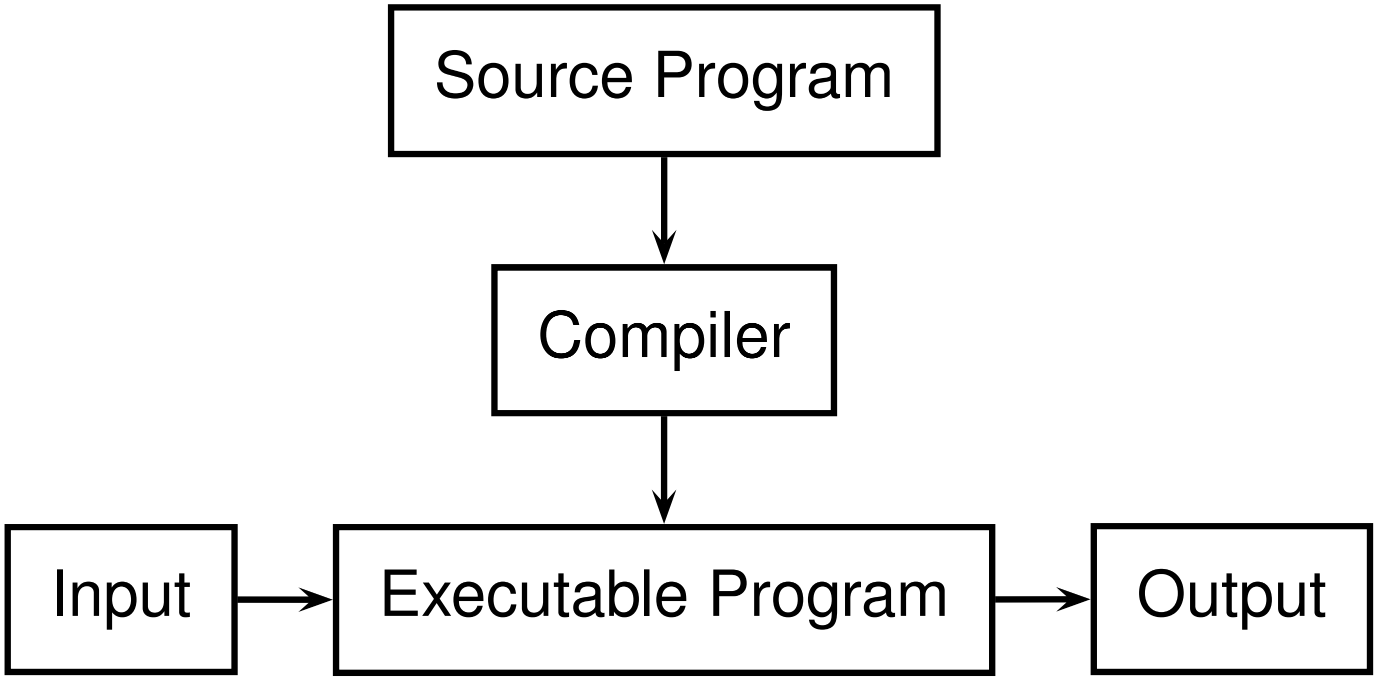
Most language definitions use an informal operational semantics written in English.

Language Processors

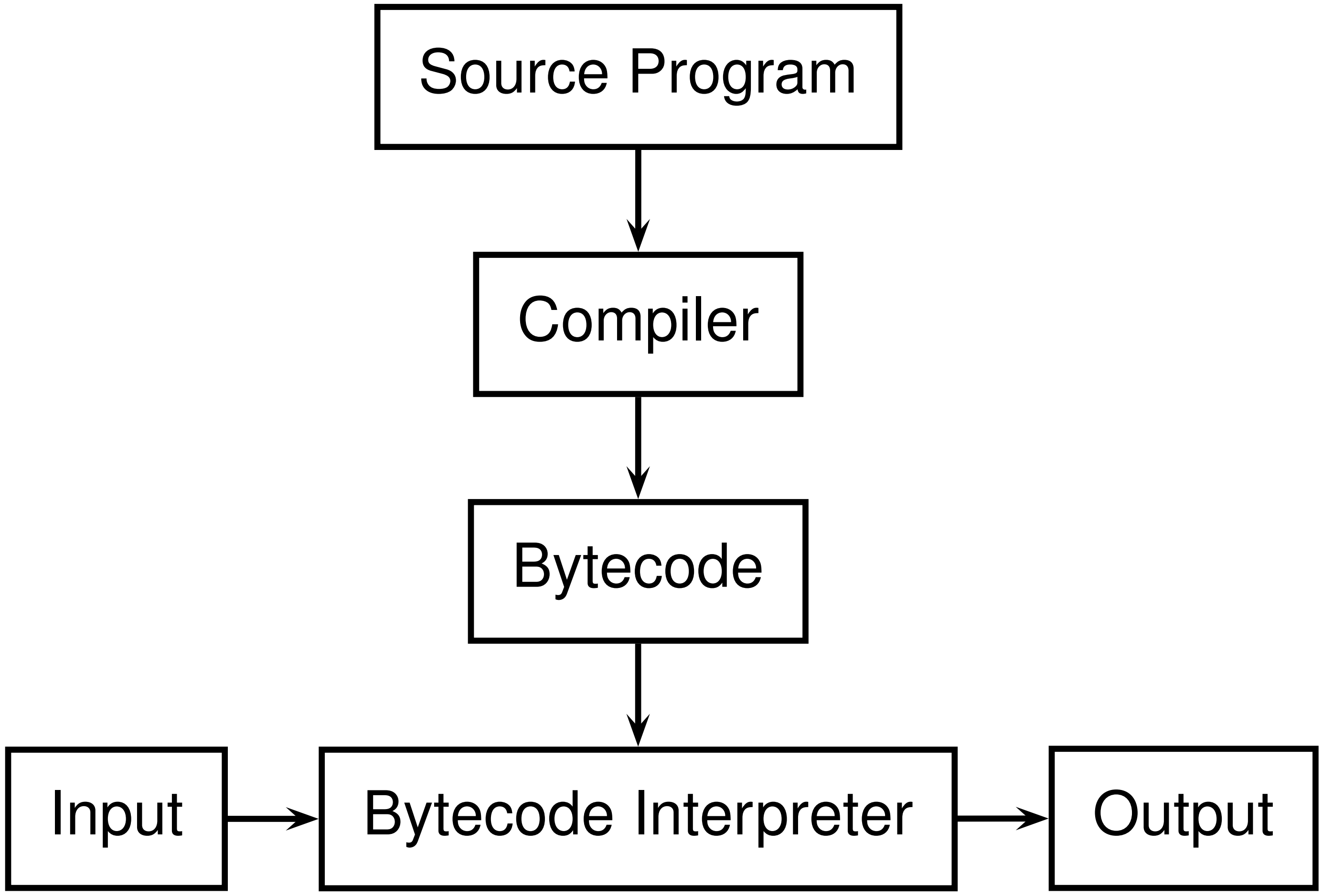
Interpreter



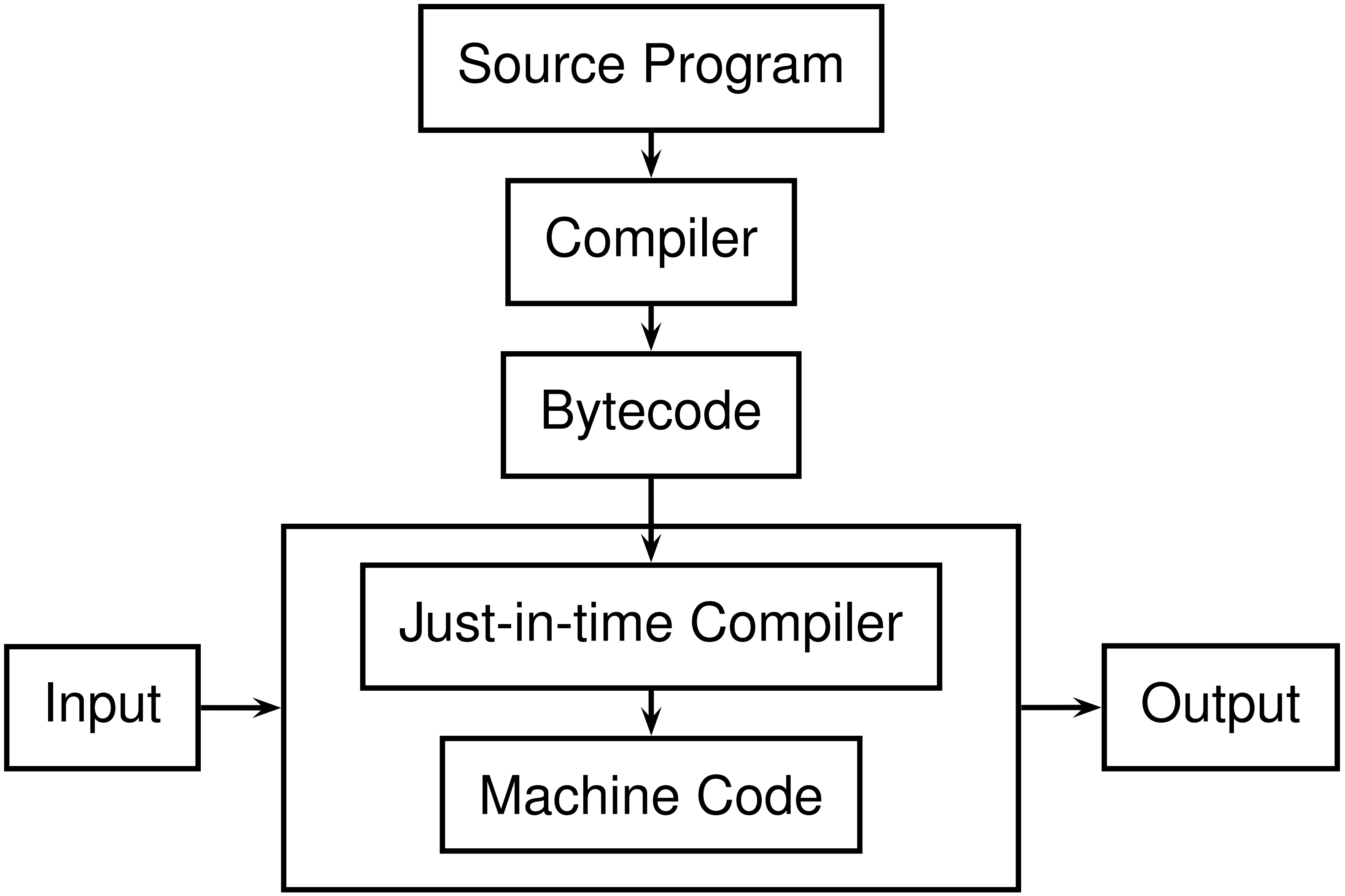
Compiler



Bytecode Interpreter

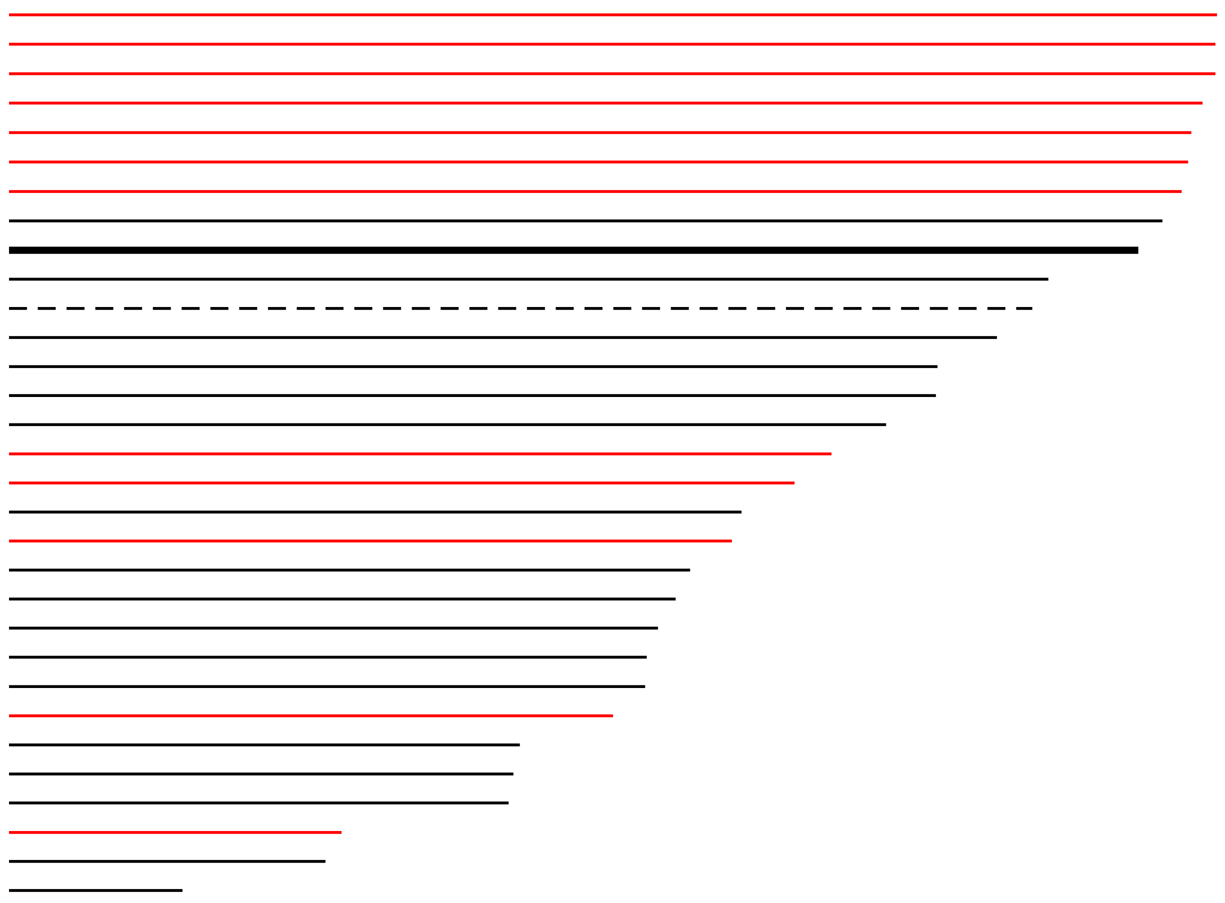


Just-in-time Compiler



Language Speeds Compared

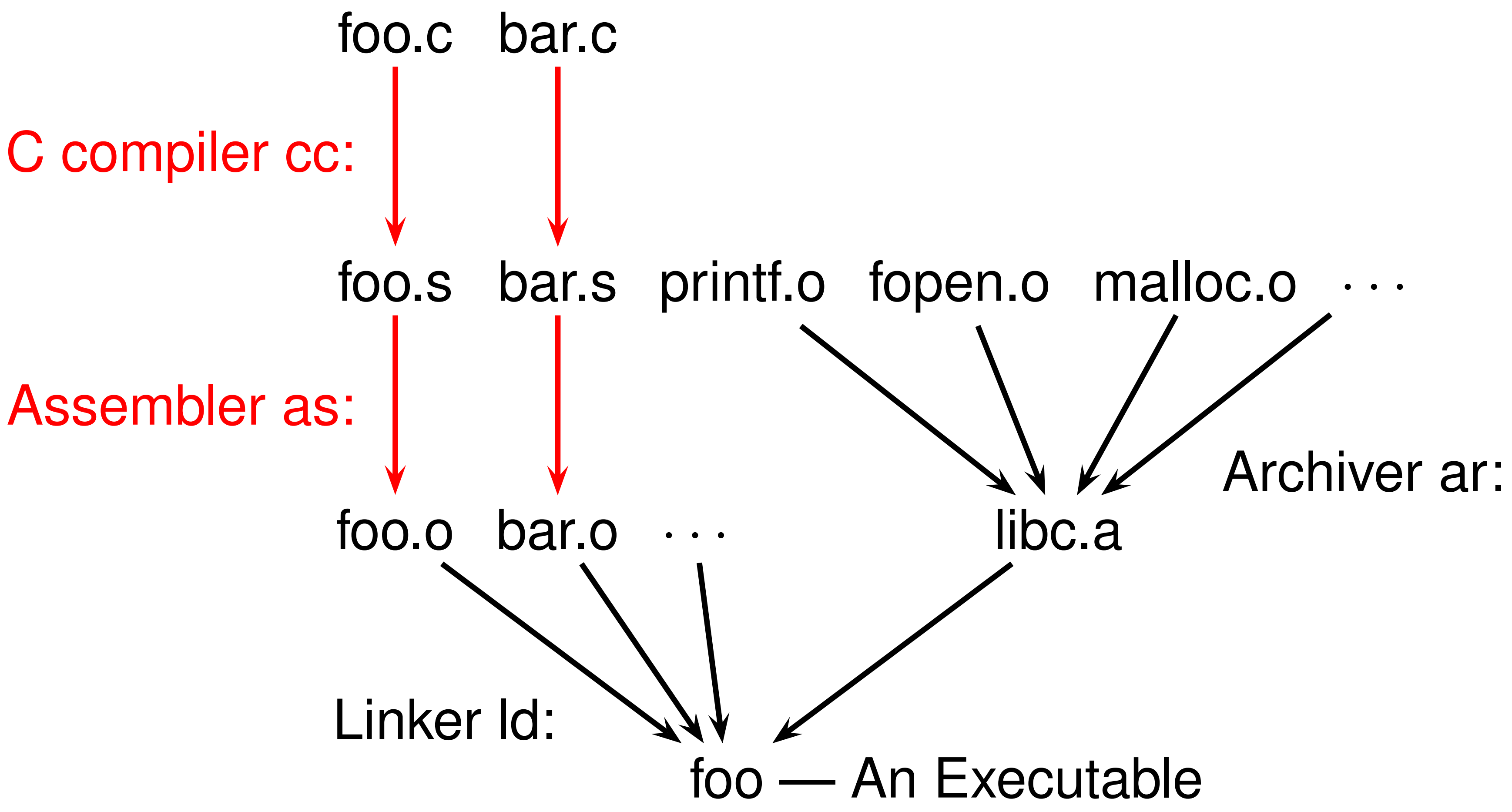
Language	**Impl.**
C	**gcc**
Ocaml	**ocaml**
SML	**mlton**
C++	**g++**
SML	**smlnj**
Common Lisp	**cmucl**
Scheme	**bigloo**
Ocaml	ocamlb
Java	**java**
Pike	pike
Forth	*gforth*
Lua	lua
Python	python
Perl	perl
Ruby	ruby
Eiffel	**se**
Mercury	**mercury**
Awk	mawk
Haskell	**ghc**
Lisp	rep
Icon	icon
Tcl	tcl
Javascript	njs
Scheme	guile
Forth	**bigforth**
Erlang	erlang
Awk	gawk
Emacs Lisp	xemacs
Scheme	**stalin**
PHP	php
Bash	bash



bytecodes **native code** **JIT** *Threaded code*

http://www.bagley.org/~doug/shootout/

Separate Compilation



Preprocessor

“Massages” the input before the compiler sees it.

- Macro expansion
- File inclusion
- Conditional compilation

The C Preprocessor

```
#include <stdio.h>
#define min(x, y) \
  ((x)<(y))?(x):(y)
#ifdef DEFINE_BAZ
int baz();
#endif
void foo()
{
  int a = 1;
  int b = 2;
  int c;
  c = min(a,b);
}
```

`cc -E example.c` gives

```
extern int
printf(char*,...);
```

... many more declarations from stdio.h

```
void foo()
{
  int a = 1;
  int b = 2;
  int c;
  c = ((a)<(b))?(a):(b);
}
```

Compiling a Simple Program

```
int gcd(int a, int b)
{
  while (a != b) {
    if (a > b) a -= b;
    else b -= a;
  }
  return a;
}
```

What the Compiler Sees

```
int gcd(int a, int b)
{
  while (a != b) {
    if (a > b) a -= b;
    else b -= a;
  }
  return a;
}
```

```
i  n  t  sp g  c  d  (  i  n  t  sp a  ,  sp i
n  t  sp b  )  nl {  nl sp sp w  h  i  l  e  sp
(  a  sp !  =  sp b  )  sp {  nl sp sp sp sp i
f  sp (  a  sp >  sp b  )  sp a  sp -  =  sp b
;  nl sp sp sp sp e  l  s  e  sp b  sp -  =  sp
a  ;  nl sp sp }  nl sp sp r  e  t  u  r  n  sp
a  ;  nl }  nl
```

Text file is a sequence of characters

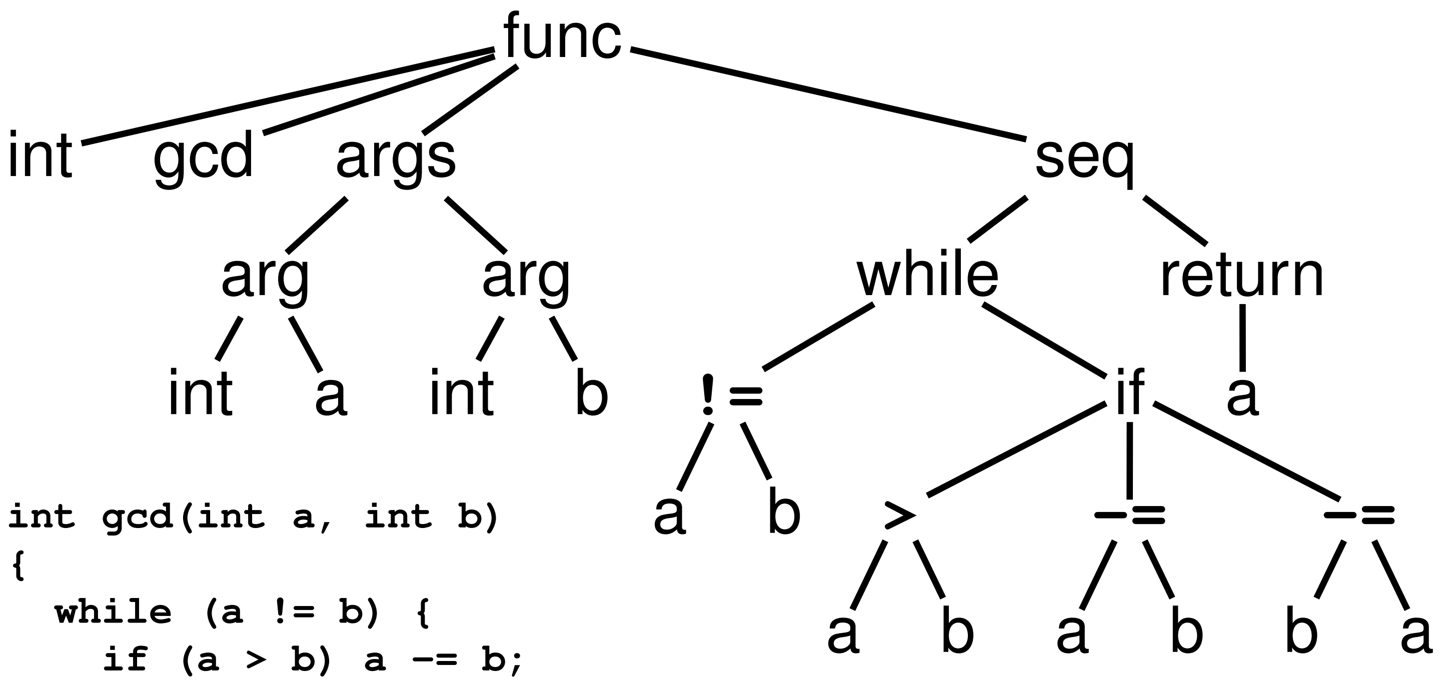
Lexical Analysis Gives Tokens

```
int gcd(int a, int b)
{
  while (a != b) {
    if (a > b) a -= b;
    else b -= a;
  }
  return a;
}
```

$$\boxed{\texttt{int}}\ \boxed{\texttt{gcd}}\ \boxed{\texttt{(}}\ \boxed{\texttt{int}}\ \boxed{\texttt{a}}\ \boxed{\texttt{,}}\ \boxed{\texttt{int}}\ \boxed{\texttt{b}}\ \boxed{\texttt{)}}\ \boxed{\{}$$
$$\boxed{\texttt{while}}\ \boxed{\texttt{(}}\ \boxed{\texttt{a}}\ \boxed{\texttt{!=}}\ \boxed{\texttt{b}}\ \boxed{\texttt{)}}\ \boxed{\{}\ \boxed{\texttt{if}}\ \boxed{\texttt{(}}\ \boxed{\texttt{a}}\ \boxed{>}$$
$$\boxed{\texttt{b}}\ \boxed{\texttt{)}}\ \boxed{\texttt{a}}\ \boxed{\texttt{-=}}\ \boxed{\texttt{b}}\ \boxed{\texttt{;}}\ \boxed{\texttt{else}}\ \boxed{\texttt{b}}\ \boxed{\texttt{-=}}\ \boxed{\texttt{a}}\ \boxed{\texttt{;}}$$
$$\boxed{\}}\ \boxed{\texttt{return}}\ \boxed{\texttt{a}}\ \boxed{\texttt{;}}\ \boxed{\}}$$

A stream of tokens. Whitespace, comments removed.

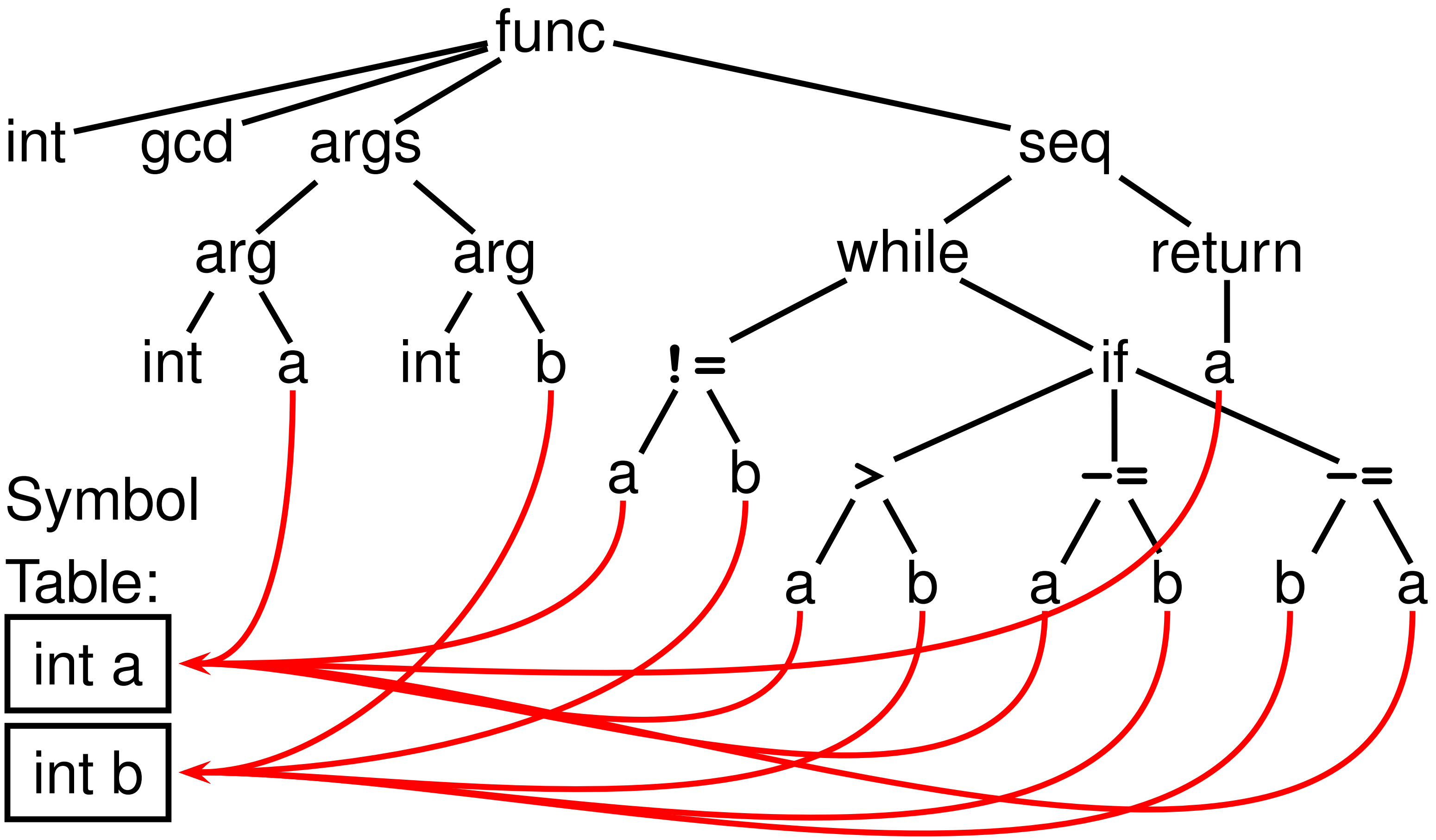
Parsing Gives an AST



```
int gcd(int a, int b)
{
  while (a != b) {
    if (a > b) a -= b;
    else b -= a;
  }
  return a;
}
```

Abstract syntax tree built from parsing rules.

Semantic Analysis Resolves Symbols



Types checked; references to symbols resolved

Translation into 3-Address Code

```
L0: sne    $1,  a, b
    seq    $0, $1, 0
    btrue  $0, L1     % while (a != b)
    sl     $3,  b, a
    seq    $2, $3, 0
    btrue  $2, L4     % if (a < b)
    sub    a,   a, b  % a -= b
    jmp    L5
L4: sub    b,   b, a  % b -= a
L5: jmp    L0
L1: ret     a
```

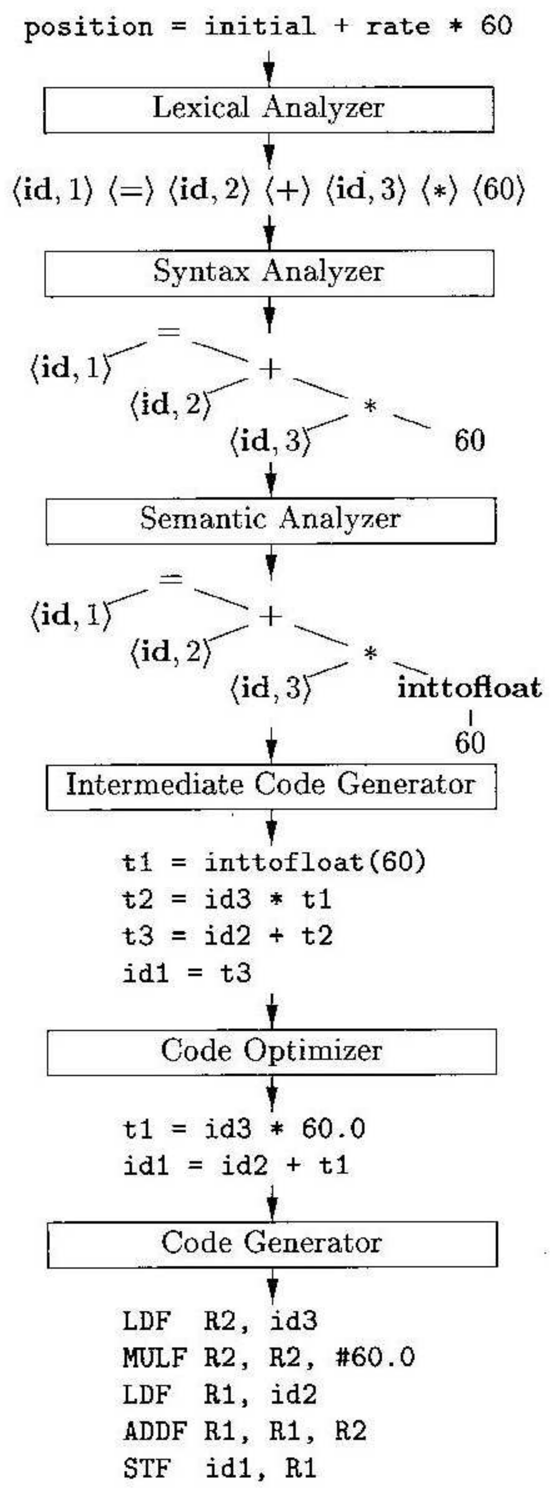
```
int gcd(int a, int b)
{
  while (a != b) {
    if (a > b) a -= b;
    else b -= a;
  }
  return a;
}
```

Idealized assembly language w/ infinite registers

Generation of 80386 Assembly

```
gcd:   pushl  %ebp               % Save FP
       movl   %esp,%ebp
       movl   8(%ebp),%eax       % Load a from stack
       movl   12(%ebp),%edx      % Load b from stack
.L8:   cmpl   %edx,%eax
       je     .L3                % while (a != b)
       jle    .L5                % if (a < b)
       subl   %edx,%eax          % a -= b
       jmp    .L8
.L5:   subl   %eax,%edx          % b -= a
       jmp    .L8
.L3:   leave                     % Restore SP, BP
       ret
```

Compiler overview


position = initial + rate * 60
Lexical Analyzer
⟨id, 1⟩ ⟨=⟩ ⟨id, 2⟩ ⟨+⟩ ⟨id, 3⟩ ⟨*⟩ ⟨60⟩
Syntax Analyzer
Semantic Analyzer
inttofloat
Intermediate Code Generator
Code Optimizer
Code Generator

```
t1 = inttofloat(60)
t2 = id3 * t1
t3 = id2 + t2
id1 = t3
```

```
t1 = id3 * 60.0
id1 = id2 + t1
```

```
LDF  R2, id3
MULF R2, R2, #60.0
LDF  R1, id2
ADDF R1, R1, R2
STF  id1, R1
```

1	position	···
2	initial	···
3	rate	···

SYMBOL TABLE