Al Aho

aho@cs.columbia.edu

Unnatural Language Processing

COMPUTER SCIENCE AT
COLUMBIA UNIVERSITY

Keynote Presentation SSST-3
NAACL HLT 2009 - Boulder, CO
June 5, 2009

Natural Languages

A *natural language* is a form of communication peculiar to humankind. [Wikipedia]

Popular spoken natural languages:

Chinese	1,205m	Portuguese	178m
Spanish	322m	Bengali	171m
English	309m	Russian	145m
Arabic	206m	Japanese	122m
Hindi	108m	German	95m

[Wikipedia]

Ethnologue catalogs 6,912 known living languages.

Conlangs: Made-Up Languages

Okrent lists 500 invented languages including:

- **Lingua Ignota** [Hildegaard of Bingen, c. 1150]
- **Esperanto** [L. Zamenhof, 1887]
- **Klingon** [M. Okrand, 1984]

  Huq Us'pty G'm (I love you)
- **Proto-Central Mountain** [J. Burke, 2007]
- **Dritok** [D. Boozer, 2007]

  Language of the Drushek, long-tailed beings with large ears and no vocal cords

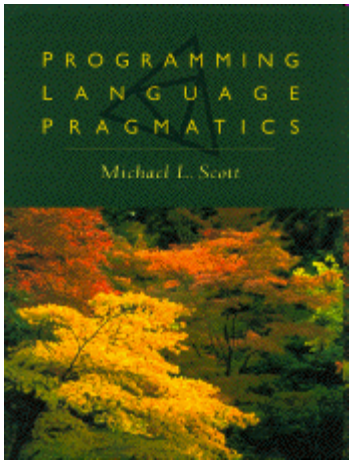
[Arika Okrent, *In the Land of Invented Languages*, 2009]
[http://www.inthelandofinventedlanguages.com]

Programming Languages

Programming languages are notations for describing computations to people and to machines.

Underlying every programming language is a model of computation:

- **Procedural: C, C++, C#, Java**
- **Declarative: SQL**
- **Logic: Prolog**
- **Functional: Haskell**
- **Scripting: AWK, Perl, Python, Ruby**



Programming Languages

There are many thousands of programming languages.

Tiobe's ten most popular languages for May 2009:

1. Java
2. C
3. C++
4. PHP
5. Visual Basic
6. Python
7. C#
8. JavaScript
9. Perl
10. Ruby

[http://www.tiobe.com]

http://www.99-bottles-of-beer.net has programs in 1,271 different programming languages to print out the lyrics to "99 Bottles of Beer."

“99 Bottles of Beer”

99 bottles of beer on the wall, 99 bottles of beer.
Take one down and pass it around, 98 bottles of beer on the wall.

98 bottles of beer on the wall, 98 bottles of beer.
Take one down and pass it around, 97 bottles of beer on the wall.

.
.
.

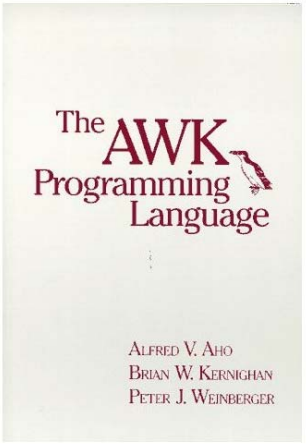
2 bottles of beer on the wall, 2 bottles of beer.
Take one down and pass it around, 1 bottle of beer on the wall.

1 bottle of beer on the wall, 1 bottle of beer.
Take one down and pass it around, no more bottles of beer on the wall.

No more bottles of beer on the wall, no more bottles of beer.
Go to the store and buy some more, 99 bottles of beer on the wall.

[Traditional]

“99 Bottles of Beer” in AWK




```
BEGIN {
 for(i = 99; i >= 0; i--) {
  print ubottle(i), "on the wall,", lbottle(i) "."
  print action(i), lbottle(inext(i)), "on the wall."
  print
 }
}
function ubottle(n) {
 return sprintf("%s bottle%s of beer", n ? n : "No more", n - 1 ? "s" : "")
}
function lbottle(n) {
 return sprintf("%s bottle%s of beer", n ? n : "no more", n - 1 ? "s" : "")
}
function action(n) {
 return sprintf("%s", n ? "Take one down and pass it around," : \
                          "Go to the store and buy some more,")
}
function inext(n) {
 return n ? n - 1 : 99
}
```

[Osamu Aoki, http://people.debian.org/~osamu]

“99 Bottles of Beer” in Perl

```
  ''=~(          '(?{'          .('`'          |'%')          .('['          ^'-')
  .('`'          |'!')          .('`'          |',')          .'"'.          '\\$'
  .'=='          .('['          ^'+')          .('`'          |'/')          .('['
  ^'+')          .'||'          .(';'          &'=')          .(';'          &'=')
  .';-'          .'-'.          '\\$'          .'=;'          .('['          ^'(')
  .('['          ^'.')          .('`'          |'"')          .('!'          ^'+')
 .'_\\{'        .'(\\$'       .';=('.       '\\$=|'       ."\|".(       '`'^'.'
).((`')|      '/').').'     .'\\"'.+(     '{'^'['').     (`'|'"')     .(`'|'/'
).('['^'/')   .('['^'/').   (`'|',').(   `'|('%')).   '\\".\\"'.(   '['^('(')).
'\\"'.('['^   '#').'!!--'   .'\\$=.\\"'   .('{'^'[').   (`'|'/').(   `'|"\&").(
'{'^"\[").(   `'|"\"").(   `'|"\%").(   `'|"\%").(   '['^(')')).   '\\").\\"'.
('{'^'[').(   `'|"\/").(   `'|"\.").(   '{'^"\[").(   '['^"\/").(   `'|"\(").(
`'|"\%").(    '{'^"\[").(   '['^"\,").(   `'|"\!").(   `'|"\,").(   `'|(',')).
'\\"\\}'.+(   '['^"\+").(   '['^"\)").(   `'|"\)").(   `'|"\.").(   '['^('/')).
'+_,\\",'.(   '{'^('[')).   (\\$;!').(   '!'^"\+").(   '{'^"\/").(   `'|"\!").(
`'|"\+").(    `'|"\%").(   '{'^"\[").(   `'|"\/").(   `'|"\.").(   `'|"\%").(
'{'^"\[").(   `'|"\$").(   `'|"\/").(   '['^"\,").(   `'|('.')).   ,'.(('{')^
'[').("\["^   '+').("\`"|   '!').("\["^   '(').("\["^   '(').("\{"^   '[').("\`"|
')').("\["^   '/').("\{"^   '[').("\`"|   '!').("\["^   ')').("\`"|   '/').("\["^
'.').("\`"|   '.').("\`"|   '$')."\,".(   '!'^('+')).   '\\",_,\\"'   .'!'.("\!"^
'+').("\!"^   '+').'\\"'.   ('['^',').(   `'|"\(").(   `'|"\)").(   `'|"\,").(
`'|('%')).    '++\\$="})'   );$:=('.')^   '~';$~='@'|   '(';$^=')'^   '[';$/='`';
```

[Andrew Savage, http://search.cpan.org/dist/Acme-EyeDrops/lib/Acme/EyeDrops.pm]

“99 Bottles of Beer” in the Whitespace Language

[Edwin Brady and Chris Morris, U. Durham]

A Little Bit of Formal Language Theory

An *alphabet* is a finite set of symbols.

{0, 1}, ASCII, UNICODE

A *string* is a finite sequence of symbols.

ε (the empty string), 0101, dog, cat

A *language* is a countably infinite set of strings called *sentences*.

{ $a^n b^n$ | n ≥ 0 }, { *s* | *s* is a Java program }, { *s* | *s* is an English sentence }

A language has properties such as a *syntax* and *semantics*.

Language Translation

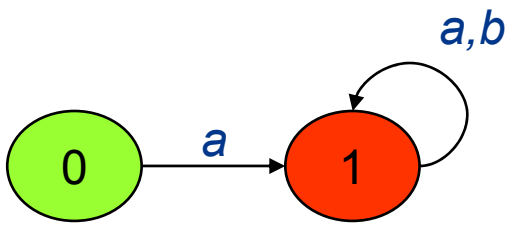
Given a source language *S*, a target language *T*, and a sentence *s* in *S*, map *s into* a sentence *t* in T that has the same meaning as *s*.

Specifying Syntax: Regular Sets

Regular expressions generate the regular sets

a(*a*|*b*)* generates all strings of *a*'s and *b*'s beginning with an *a*

Finite automata recognize the regular sets



Some Regular Sets

All words with the vowels in order

```
facetiously
```

All words with the letters in increasing lexicographic order

```
aegilops
```

All words with no letter occurring more than once

```
dermatoglyphics
```

Comments in the programming language C

```
/* any string without a star followed by a slash */
```

Some Regular Expression Pattern-Matching Tools

egrep

```
egrep 'a.*e.*i.*o.*u.*y' /usr/dict/words
```

AWK

C

Java

JavaScript

Lex

Perl

Python

Ruby

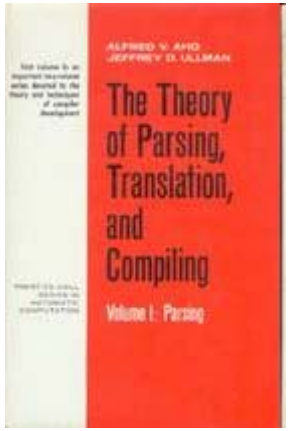
Context-Free Languages

Context-free grammars generate the CFLs

- Let *G* be the grammar with productions $S \rightarrow aSbS \mid bSaS \mid \varepsilon$.
- The language denoted by *G* is all strings of *a*'s and *b*'s with the same number of *a*'s as *b*'s.

Parsing algorithms for recognizing the CFLs

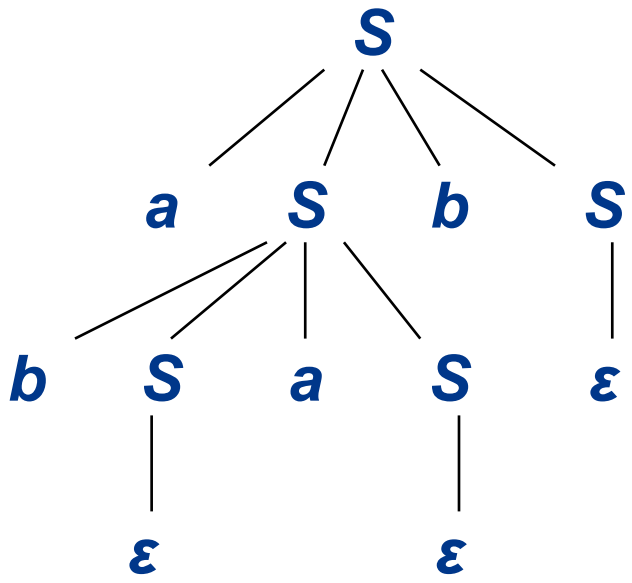
- Earley's algorithm
- Cocke-Younger-Kasami algorithm
- Top-down LL(k) parsers
- Bottom-up LR(k) parsers

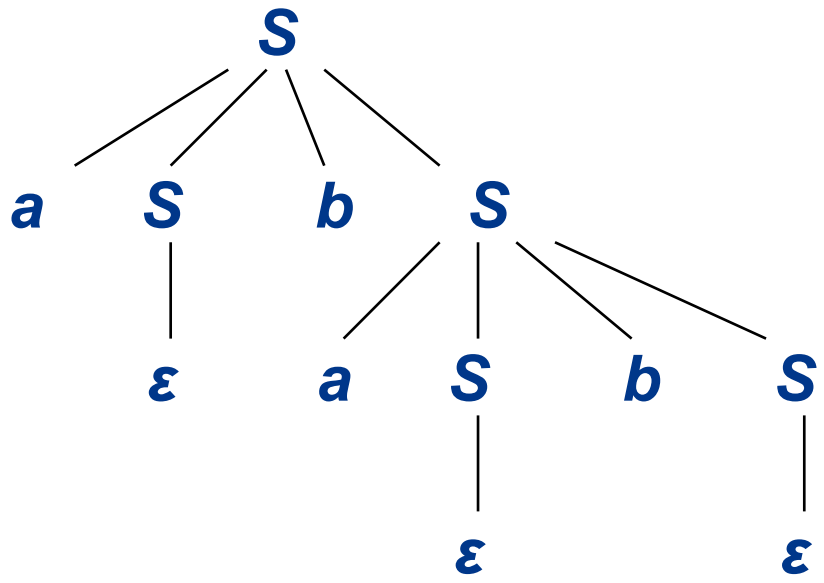


Ambiguity in Grammars

Grammar $S \rightarrow aSbS \mid bSaS \mid \varepsilon$ generates all strings of *a*'s and *b*'s with the same number of *a*'s as *b*'s.

This grammar is ambiguous: abab has two parse trees.





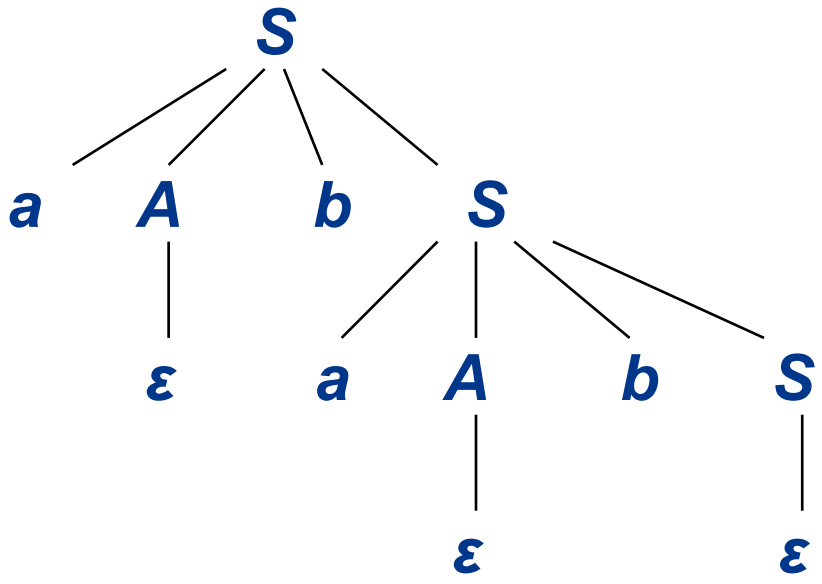
$(ab)^n$ has $\frac{1}{n+1}\binom{2n}{n}$ parse trees

Programming Languages are not Inherently Ambiguous

The grammar *G* generates the same language

$$S \rightarrow aAbS \mid bBaS \mid \varepsilon$$
$$A \rightarrow aAbA \mid \varepsilon$$
$$B \rightarrow bBaB \mid \varepsilon$$

***G* is unambiguous and has only one parse tree for every sentence in *L*(*G*).**



Natural Languages are Inherently Ambiguous

I made her duck.

[5 meanings: D. Jurafsky and J. Martin, 2000]

One morning I shot an elephant in my pajamas. How he got into my pajamas I don't know.

[Groucho Marx, *Animal Crackers*, 1930]

List the sales of the products produced in 1973 with the products produced in 1972.

[455 parses: W. Martin, K. Church, R. Patil, 1987]

Methods for Specifying the Semantics of Programming Languages

Operational semantics

- translation of program constructs to an understood language

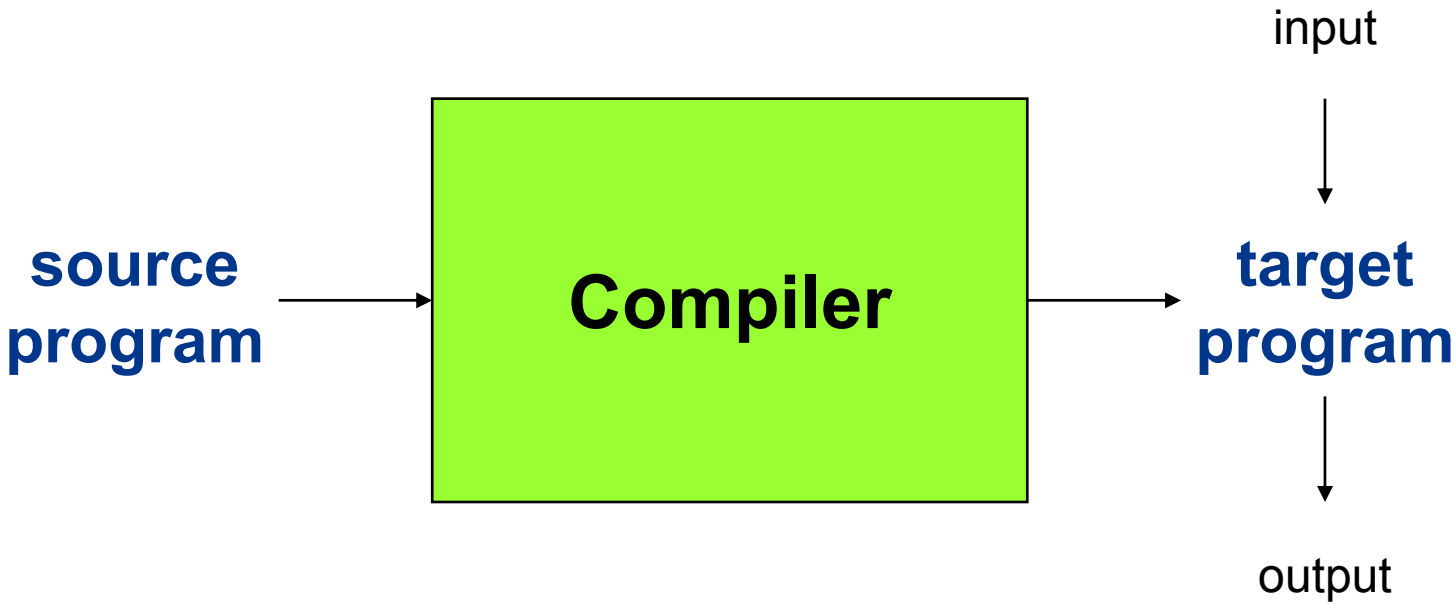
Axiomatic semantics

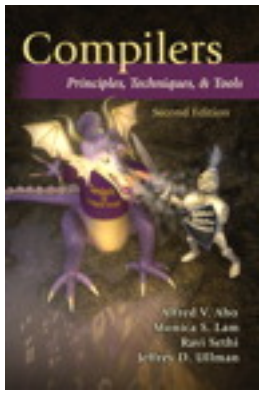
- assertions called preconditions and postconditions specify the properties of statements

Denotational semantics

- semantic functions map syntactic objects to semantic values

Translation of Programming Languages





Target Languages

Another programming language

CISCs

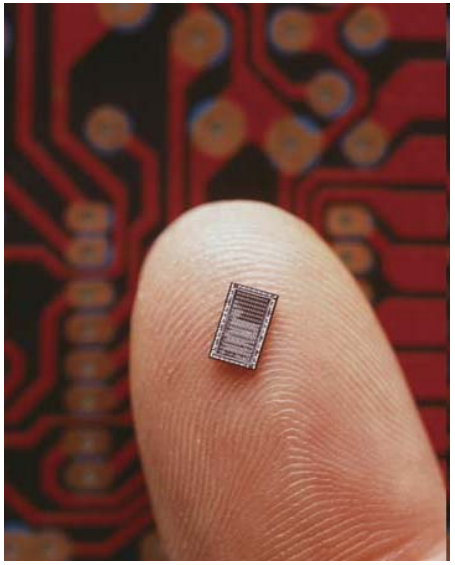
RISCs

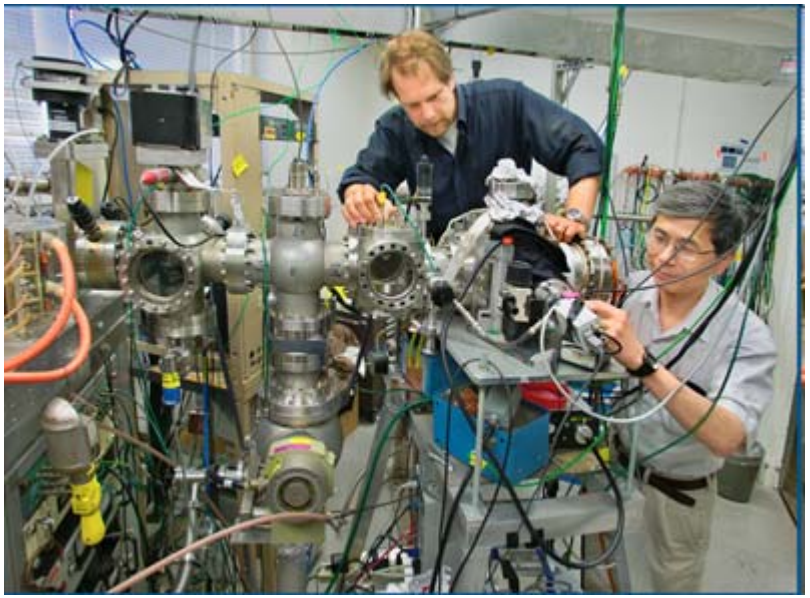
Vector machines

Multicores

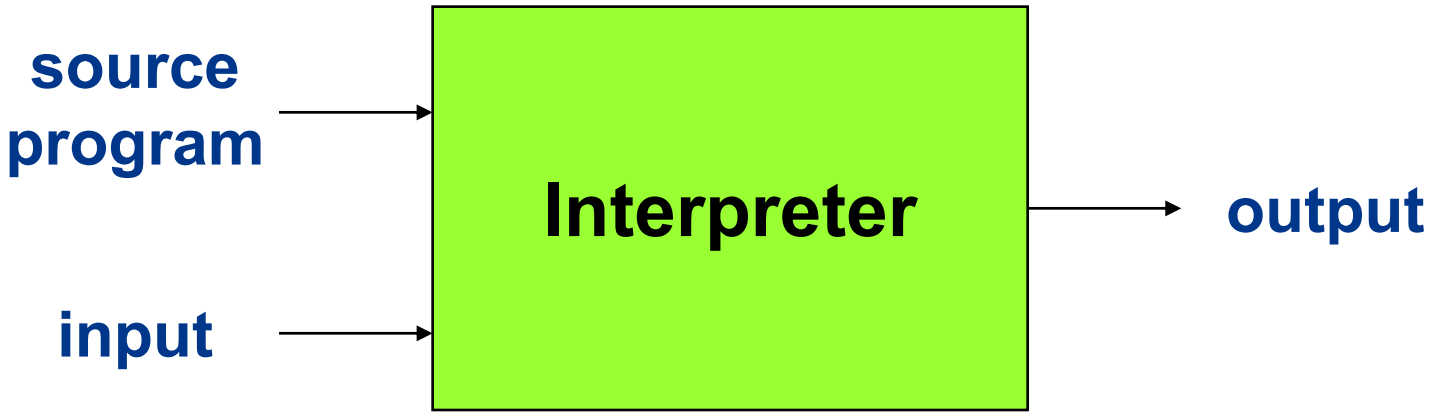
GPUs

Quantum computers

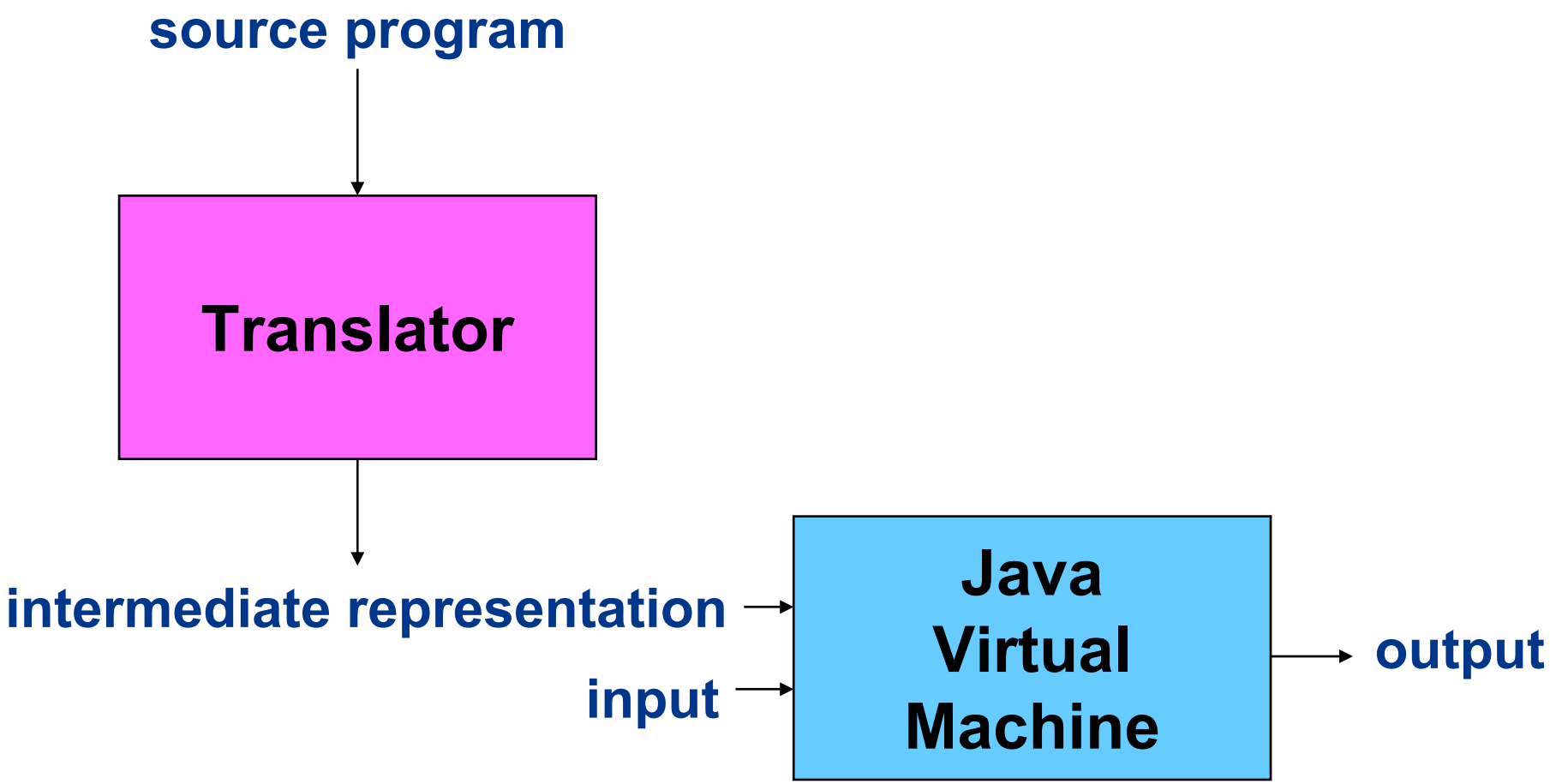




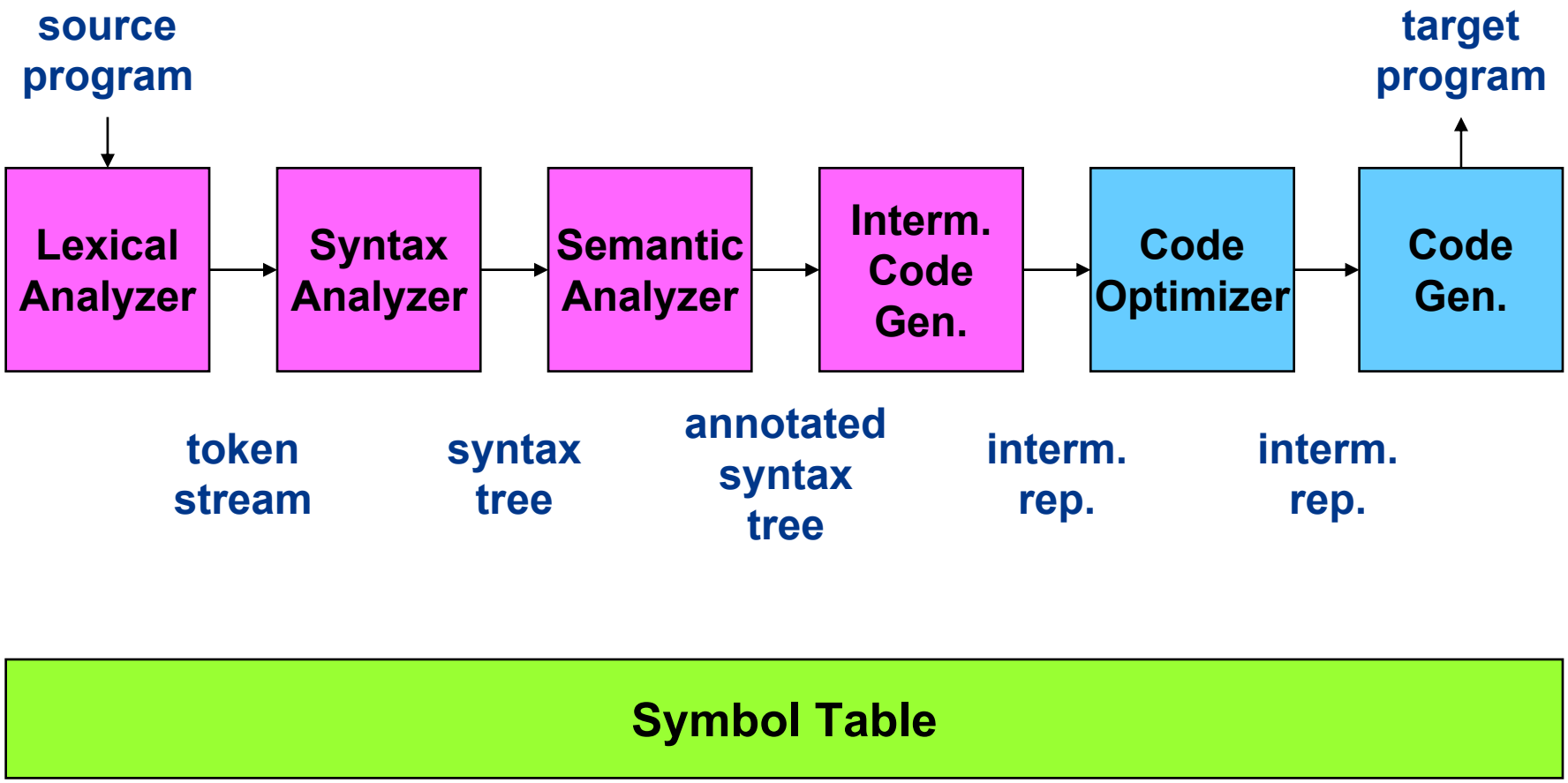
An Interpreter Directly Executes a Source Program on its Input



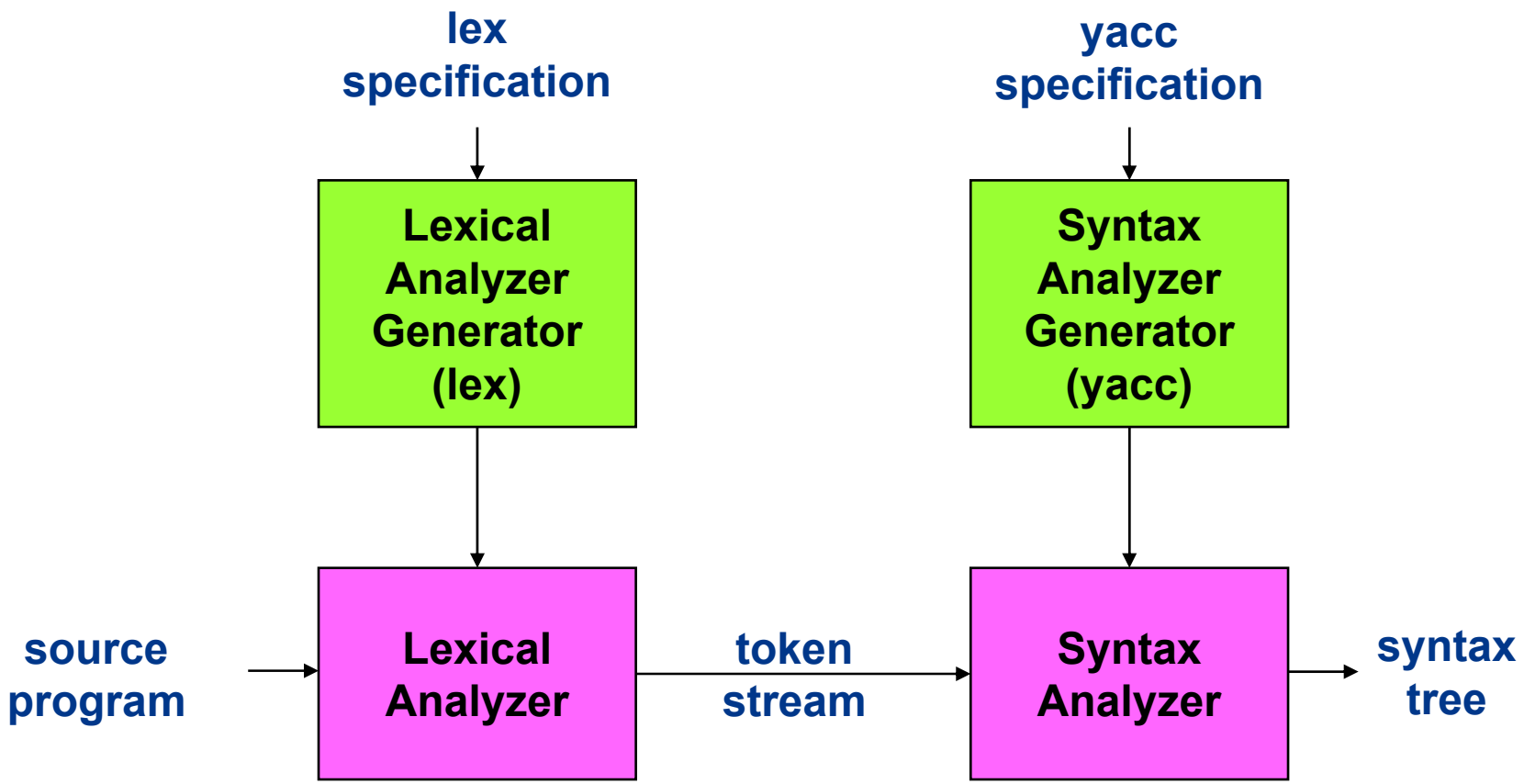
Java Compiler



Phases of a Classical Compiler



Compiler Component Generators



Lex Specification for a Desk Calculator

```
number          [0-9]+\.?|[0-9]*\.[0-9]+
%%
[ ]             { /* skip blanks */ }
{number}        { sscanf(yytext, "%lf", &yylval);
                  return NUMBER; }
\n|.            { return yytext[0]; }
```

Yacc Specification for a Desk Calculator

```
%token NUMBER
%left '+'
%left '*'
%%
lines : lines expr '\n' { printf("%g\n", $2); }
      | /* empty */
      ;
expr  : expr '+' expr   { $$ = $1 + $3; }
      | expr '*' expr   { $$ = $1 * $3; }
      | '(' expr ')'    { $$ = $2; }
      | NUMBER
      ;
%%
#include "lex.yy.c"
```

Creating the Desk Calculator

Invoke the commands

```
lex desk.l
yacc desk.y
cc y.tab.c -ly -ll
```

Result