Programming Languages

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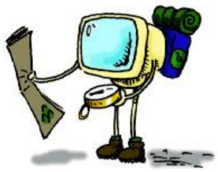
Lecture - II

January 19th, 2006

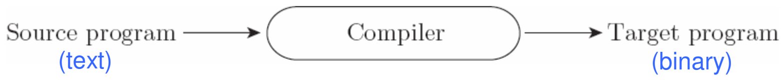
Roadmap

- Compilation
- Interpretation
- Preprocessing
- Linking
- Assembling
- Phases of Compilation
    - Scanning
    - Parsing
    - Semantic Analysis



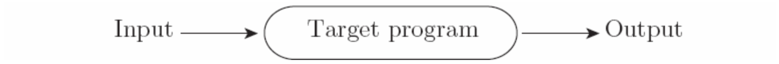
Compiler

- Translates high-level program source code (in text) into a target code (generally binary executable)



Source program (text) → Compiler → Target program (binary)

- Generated target program is standalone
  - After compilation the compiler goes away

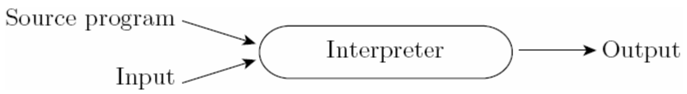


Input → Target program → Output

- Generated target program can be platform-dependant

Interpreter

- Reads and executes the source code line by line
- Stays around during execution
- Does not generate standalone executables

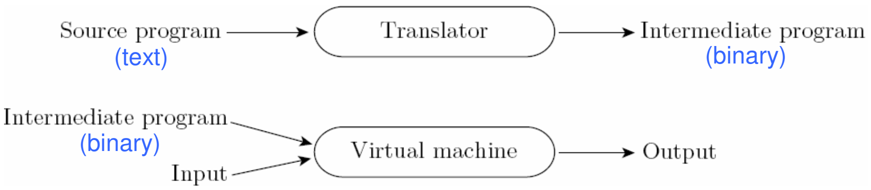


Source program → Interpreter
Input → Interpreter
Interpreter → Output

Compilation vs Interpretation

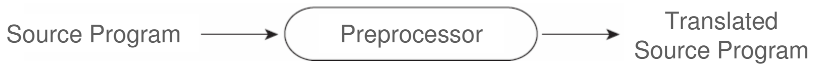
- Compilation
  - Better performance
    - Most decisions are done at compile time (eg. memory references)
    - Compile once, execute may times
- Interpretation
  - More flexible
  - Enables better diagnostics (error messages)
    - After compilation some information is lost
  - Can have source-level debugger

Hybrid Systems



- Example: Java
  - Intermediate binaries are called: “byte codes”

Preprocessors


Source Program

Preprocessor

Translated Source Program

- Preprocessor : initial translator
  - Removes comments & white space
  - Groups characters into tokens (keywords, identifiers, numbers)
  - Expends macros and abbreviations
  - Produced source can be compiled/interpreted more efficiently
    - In early versions of Basic, you had to remove comments to improve performance (reread everytime a certain part was executed)

Compilation, Interpretation & Preprocessing

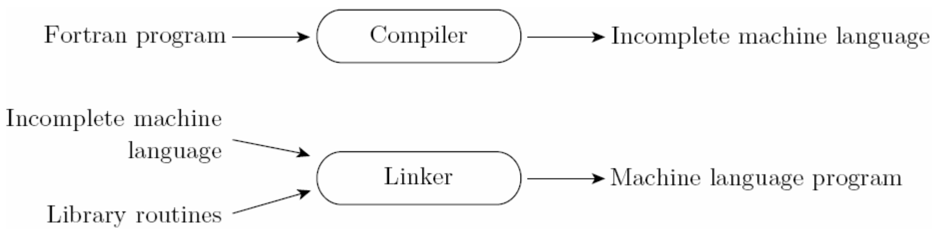
- Compilation generally produces a binary; but does NOT have to produce machine language for some sort of hardware
- Compilation is *translation* from one language into another, with full analysis of the meaning of the input
- Compilation & Interpretation entail semantic *understanding* of what is being processed; pre-processing does not
- A pre-processor will often let errors through. Compilers and Interpreters will not.

Examples

- Interpreted Languages:
  - Java
  - Scheme
  - Prolog
  - Python
  - Most Scripting Languages
- Compiled Languages
  - C / C++
  - Pascal
  - Fortran
  - Ada

Linking

- Compiler uses a *linker* program to merge the appropriate *library* of subroutines (e.g., math functions such as sin, cos, log, etc.) into the final program:
  - eg. Fortran Compiler



Fortran program → Compiler → Incomplete machine language

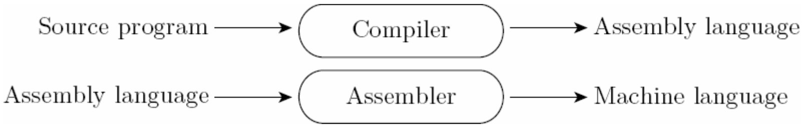
Incomplete machine language → Linker

Library routines → Linker

Linker → Machine language program

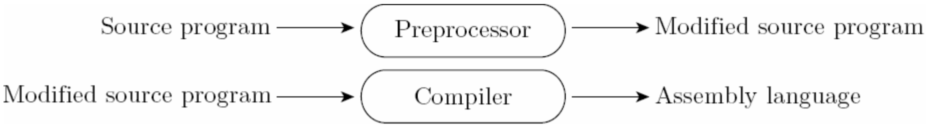
Assembling

- Many compilers generate assembly language instead of a machine language



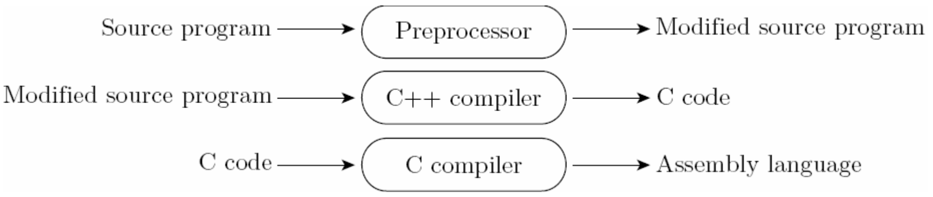
- Facilitates debugging
  - Assembly is easier to read
- Isolates compiler from changes in the format of machine language files
  - only assembler need to be changed, and it is shared by many compilers

C Compiler



- C preprocessor
  - Removes comments & extends macros
  - It can also delete portions of code, which allows several versions of a program to be built from the same source
    - eg. Adding & removing debugging information

Early C++ Compiler



- Early C++ compilers were generating C code
- Complete error check was performed
- If no errors, C compiler was invoked by the C++ compiler
  - Programmers were unaware of this fact

Roadmap

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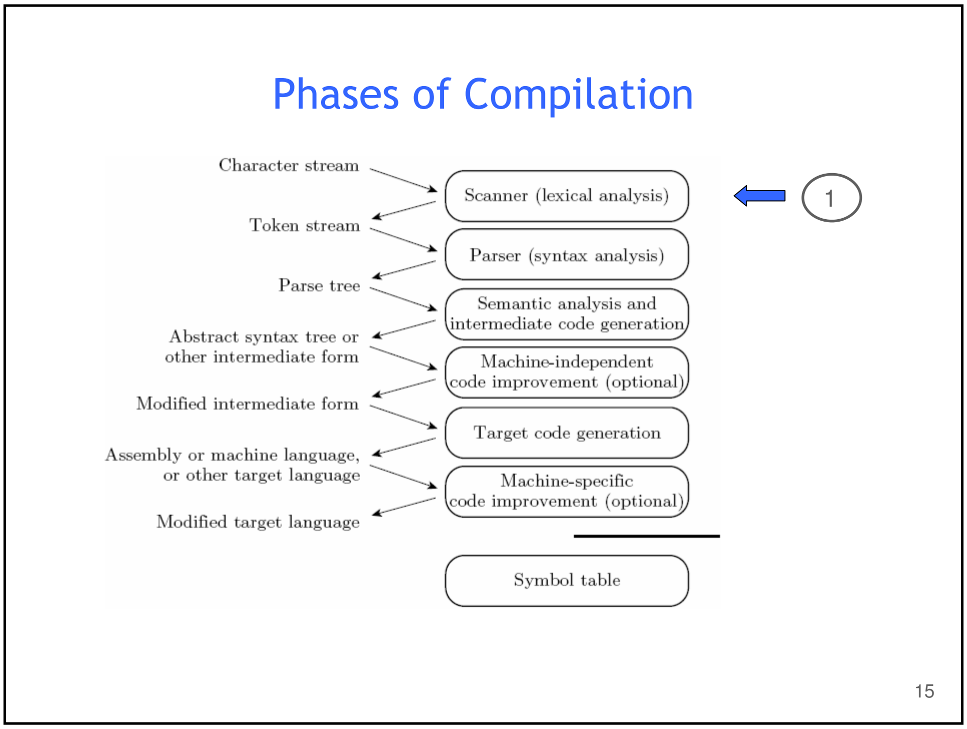
- Interpretation
- Preprocessing
- Linking
- Assembling
- Phases of Compilation
  - Scanning
  - Parsing
  - Semantic Analysis



Phases of Compilation

Character stream

Scanner (lexical analysis)

1

Token stream

Parser (syntax analysis)

Parse tree

Semantic analysis and intermediate code generation

Abstract syntax tree or other intermediate form

Machine-independent code improvement (optional)

Modified intermediate form

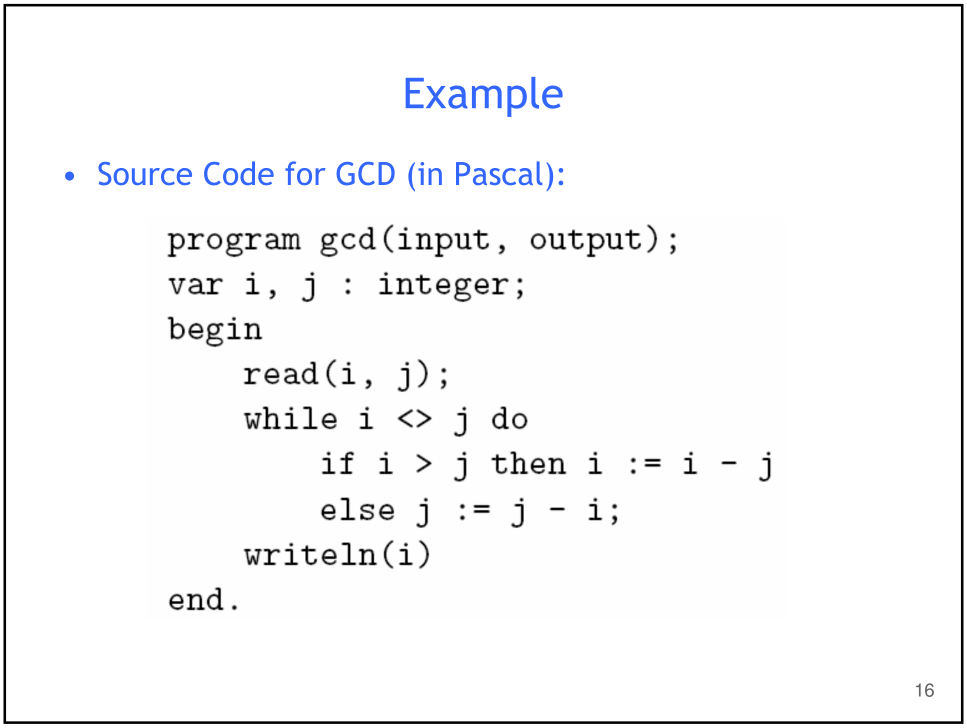
Target code generation

Assembly or machine language, or other target language

Machine-specific code improvement (optional)

Modified target language

Symbol table



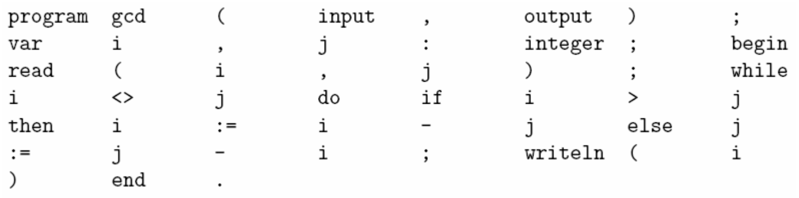
Example

- Source Code for GCD (in Pascal):

```
program gcd(input, output);
var i, j : integer;
begin
    read(i, j);
    while i <> j do
        if i > j then i := i - j
        else j := j - i;
    writeln(i)
end.
```

Example

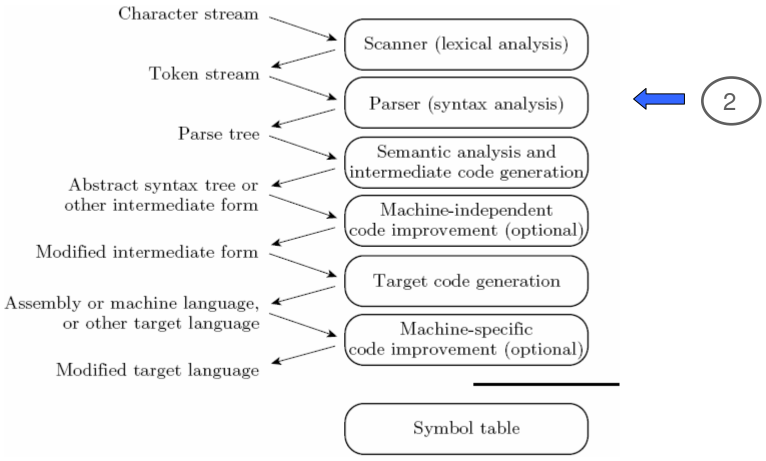
- After Scanning (Lexical Analysis):
  - Characters are grouped in to tokens (smallest meaningful units of the program)
    - Eg. identifiers, variables, punctuation, operators ..



```
program  gcd      (        input    ,        output   )        ;
var      i        ,        j        :        integer  ;        begin
read     (        i        ,        j        )        ;        while
i        <>       j        do       if       i        >        j
then     i        :=       i        -        j        else     j
:=       j        -        i        ;        writeln  (        i
)        end      .
```

- Purpose of Scanning (Lexical Analysis):
  - Simplify the task for parser by reducing the input size

Phases of Compilation


Character stream
Scanner (lexical analysis)
Token stream
Parser (syntax analysis)
2
Parse tree
Semantic analysis and intermediate code generation
Abstract syntax tree or other intermediate form
Machine-independent code improvement (optional)
Modified intermediate form
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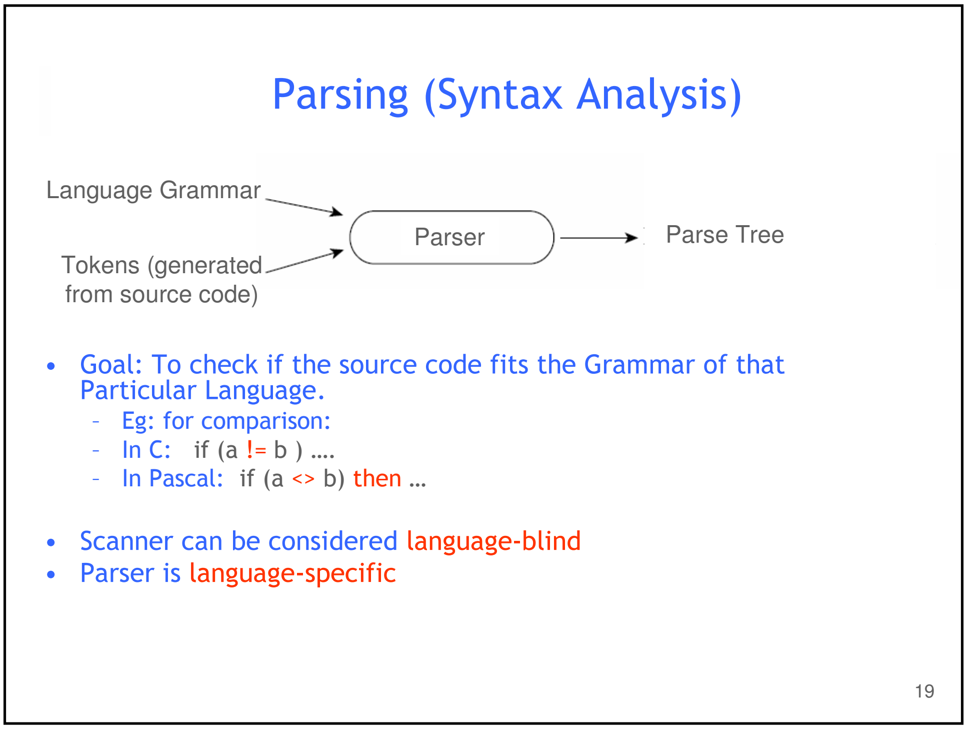
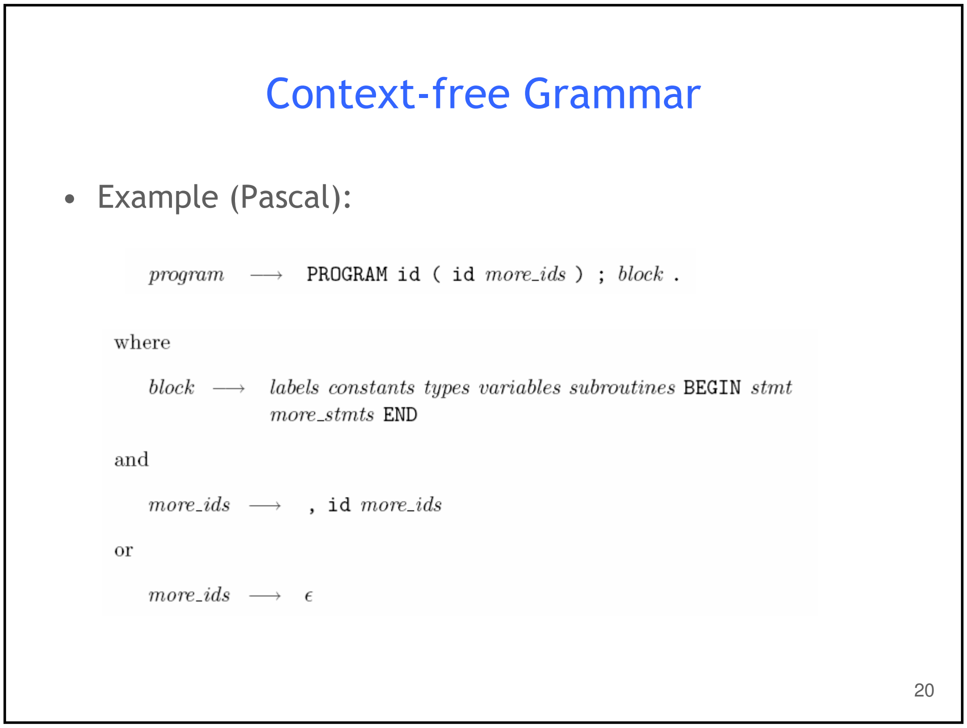


Parsing (Syntax Analysis)

Language Grammar → Parser → Parse Tree

Tokens (generated from source code) → Parser

- Goal: To check if the source code fits the Grammar of that Particular Language.
  - Eg: for comparison:
  - In C: if (a != b) ….
  - In Pascal: if (a <> b) then …
- Scanner can be considered language-blind
- Parser is language-specific



Context-free Grammar

- Example (Pascal):

$$\textit{program} \longrightarrow \texttt{PROGRAM id (id } \textit{more\_ids} \texttt{) ; } \textit{block} \texttt{ .}$$

where

$$\textit{block} \longrightarrow \textit{labels constants types variables subroutines } \texttt{BEGIN } \textit{stmt more\_stmts } \texttt{END}$$

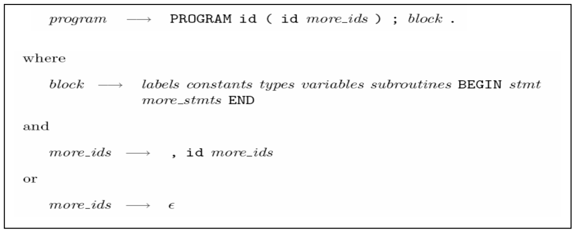
and

$$\textit{more\_ids} \longrightarrow \texttt{, id } \textit{more\_ids}$$

or

$$\textit{more\_ids} \longrightarrow \epsilon$$

Parsing Example



program ⟶ PROGRAM id (id *more_ids*) ; *block* .

where

block ⟶ *labels constants types variables subroutines* BEGIN *stmt* *more_stmts* END

and

more_ids ⟶ , id *more_ids*

or

more_ids ⟶ ϵ

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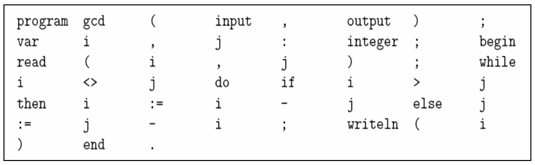
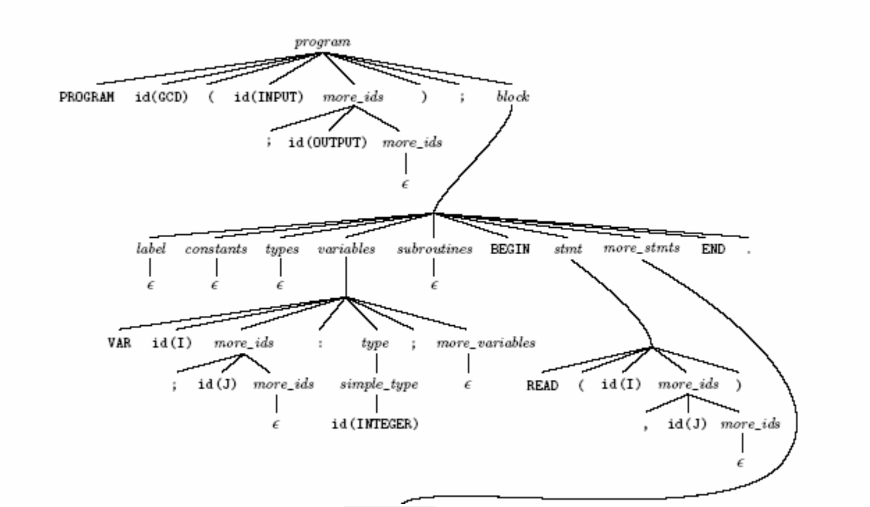


program	gcd	(	input	,	output	)	;
var	i	,	j	:	integer	;	begin
read	(	i	,	j	)	;	while
i	<>	j	do	if	i	>	j
then	i	:=	i	-	j	else	j
:=	j	-	i	;	writeln	(	i
)	end	.					

Parse Tree



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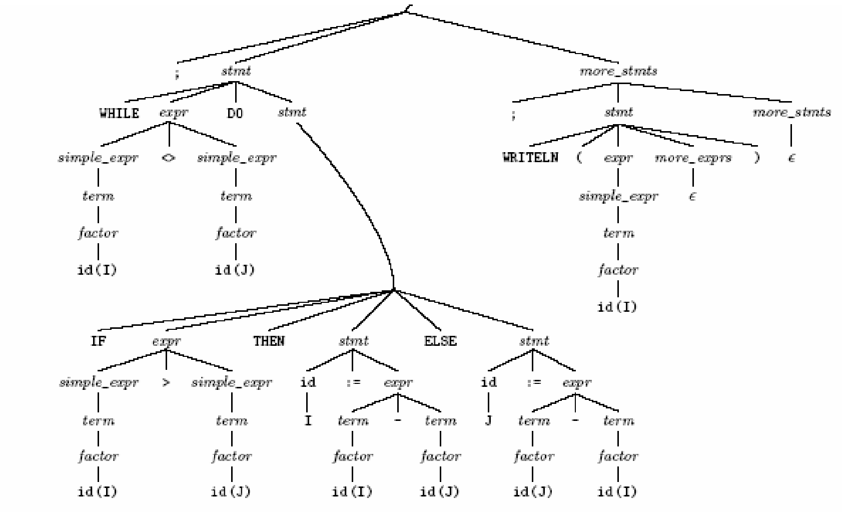
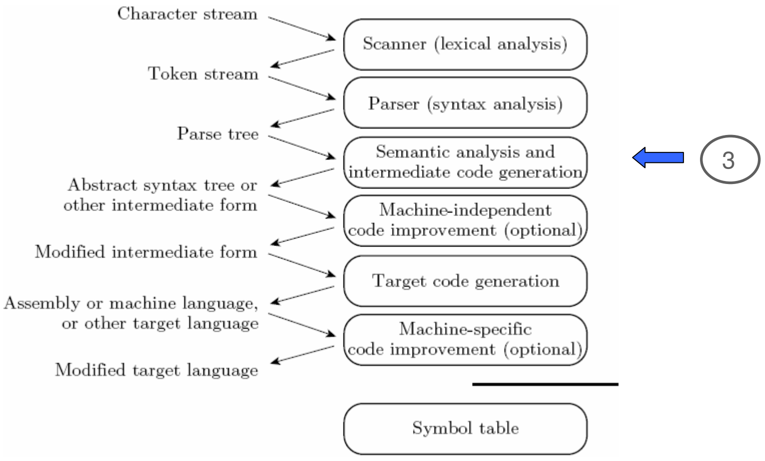
Parse Tree (cont.)



Phases of Compilation



Character stream

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Token stream

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Parse tree

Semantic analysis and intermediate code generation

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Abstract syntax tree or other intermediate form

Machine-independent code improvement (optional)

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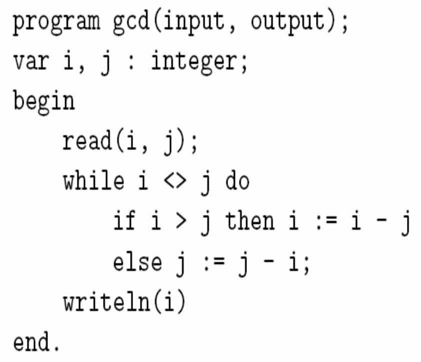
Symbol table

Semantic Analysis

- Discovery of the meaning of the program
- Creates a symbol table which maps each identifier to the information known about it
  - eg. type, scope (the portion of the program it is valid)
- Semantic Analyzer checks to make sure that:
  - Every identifier is declared before it is used
  - No identifier is used in an inappropriate context
    - Assigning incompatible types to each other.
  - Subroutine calls have the correct number and types of arguments

Example

- Source Code



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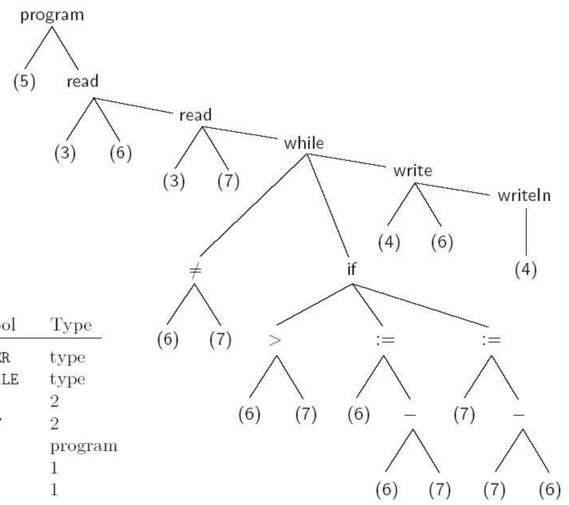
    writeln(i)
end.
```

- Symbol Table

Index	Symbol	Type
1	INTEGER	type
2	TEXTFILE	type
3	INPUT	2
4	OUTPUT	2
5	GCD	program
6	I	1
7	J	1

Syntax Tree



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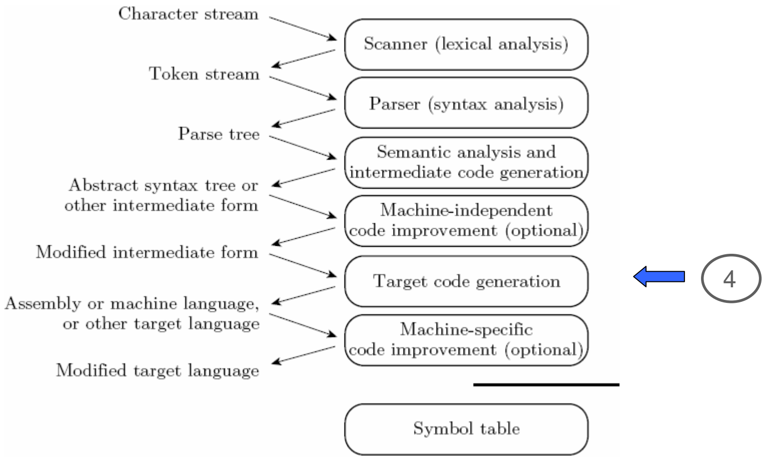
Syntax tree and symbol table for the GCD program.

Phases of Compilation



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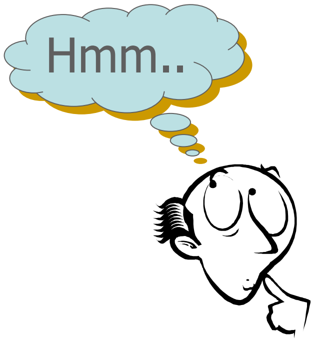
Any Questions?



Announcements

- Reading Assignment: Sections 2.1 & 2.2
- HW 1 will be out next Tuesday and will be due 1 week
- Please send your course schedules to me
- Make sure you are in the mailing list