CSE 3341 Introduction

Scott, Chapter 1

Objectives

- 3341: Principles of Programming Languages
- Master important concepts for PLs
- Master several different language paradigms
  - Imperative, object-oriented, functional
- Master some implementation issues
  - You will have some idea how to implement compilers and interpreters for PLs
- Other related courses
  - 6341: Foundations of Programming Languages
  - 5343: Compiler Design and Implementation

Programming in Machine Code

- Too labor-intensive and error-prone
- Euclid's GCD algorithm in MIPS machine code

```
27bdffd0 afbf0014 0c1002a8 00000000 0c1002a8 afa2001c 8fa4001c
00401825 10820008 0064082a 10200003 00000000 10000002 00832023
00641823 1483fffa 0064082a 0c1002b2 00000000 8fbf0014 27bd0020
03e00008 00001025
```

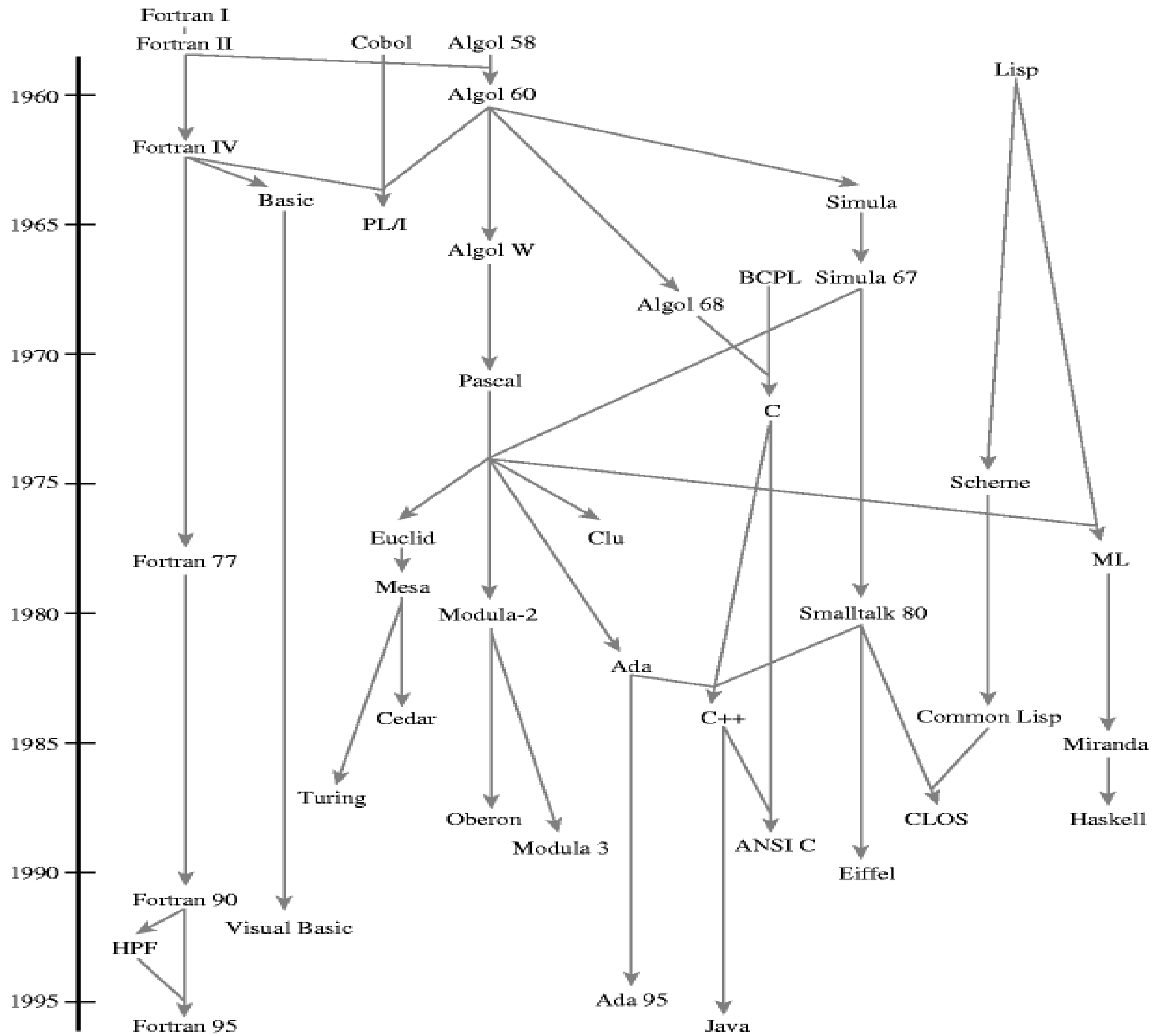
- Assembly lang
  - Mnemonics
  - Translated by an assembler

```
        addiu   sp,sp,-32
        sw      ra,20(sp)                b       C
        jal     getint                   subu    a0,a0,v1
        nop                          B:  subu    v1,v1,a0
        jal     getint               C:  bne     a0,v1,A
        sw      v0,28(sp)                slt     at,v1,a0
        lw      a0,28(sp)            D:  jal     putint
        move    v1,v0                    nop
        beq     a0,v0,D                  lw      ra,20(sp)
        slt     at,v1,a0                 addiu   sp,sp,32
    A:  beq     at,zero,B                jr      ra
        nop                              move    v0,zero
```

Evolution of Programming Languages

- Hardware
- Machine code
- Assembly language
- Macro assembly language
- FORTRAN, 1954: first machine-independent, high-level programming language
  - The IBM Mathematical **For**mula **Tran**slating System
- LISP, 1958 (LISt Processing)
- ALGOL, 1958 (**ALGO**rithmic **L**anguage)
- Many hundreds of languages since then

Incomplete History



Why So Many Programming Languages?

- Evolution of language features and user needs
  - Control flow: **goto** vs. **if-then**, **switch-case**, **while-do**
  - Procedures (Fortran, C) vs. classes/objects (C++, Java)
  - Weak types (C) vs. strong types (Java)
  - Error conditions: error codes (C) vs. exceptions and exception handling (C++, Java)
  - Memory management: programmer (C, C++) vs. language (Java through garbage collection)

Why So Many Programming Languages?

- Different application domains require different specialized languages
  - Scientific computing (Fortran, C, Matlab)
  - Business applications (Cobol)
  - Artificial intelligence (Lisp)
  - Systems programming (C, C++)
  - Enterprise computing (Java, C#)
  - Web programming (PHP, JavaScript)
  - String processing (AWK, Perl)

Programming Languages Spectrum

- Imperative languages
  - What are the steps the computer should follow in order to achieve the programmer's goals?
  - "Prescriptive" attitude
  - Traditional imperative; object-oriented
- Declarative languages
  - What are the properties of the desired?
  - "Descriptive" attitude – higher level of abstraction
  - Often, lower performance than imperative languages
  - Functional; logic
- The lines are blurred – e.g., CLOS

Example: Euclid's GCD Algorithm

```
int gcd(int a, int b) {
   while (a != b) {
      if (a > b) a = a – b;
      else b = b – a;
   }
   return a;
}  /* C procedure */
```

C: First, compare **a** and **b**. If they are equal, stop. Otherwise, … assign to **a** … assign to **b** …

Scheme: same as a math definition

$$\gcd(a,b) = \begin{cases} a & \text{if } a=b \\ \gcd(b,a-b) & \text{if } a>b \\ \gcd(a,b-a) & \text{otherwise} \end{cases}$$

```
(define gcd (a b)
   (cond ( (= a b)  a )
            ( (> a b) (gcd  (–  a b)  b) )
            ( else (gcd  (– b a)  a) )
    )) ; Scheme function
```

Programming Languages Paradigms

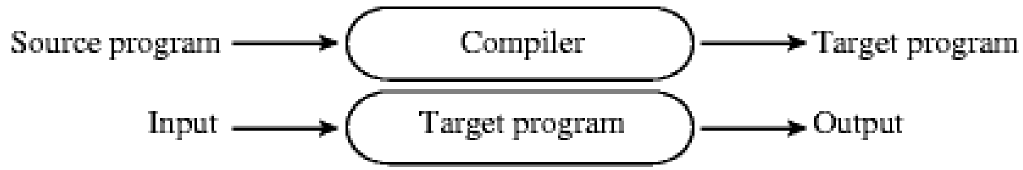
- Imperative (Fortran, C, Pascal, Ada)
  – Underlying model: von Neumann machine
  – Primary abstraction: procedure
- Object-oriented (Smalltalk, C++, Java, C#, CLOS)
  – Underlying model: object calculus
  – Primary abstraction: class or object
- Functional (Lisp, Scheme, ML, Haskell)
  – Underlying model: lambda calculus
  – Primary abstraction: mathematical function
- Logic (Prolog)
  – Underlying model: first-order logic

Why Study Programming Languages?

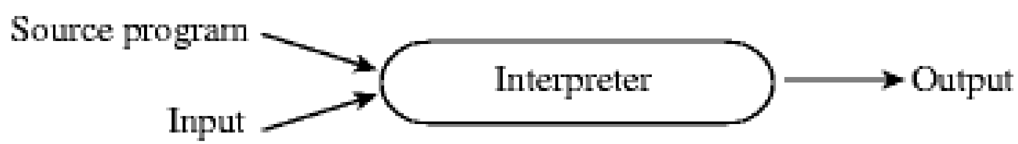
- Choose the right language for the job
  - They all have strengths and weaknesses
- Learn new languages faster
  - This is a course on common principles of PL
- Understand your tools better
  - Compilers, debuggers, assemblers, linkers
- Write your own languages
  - Happens more often than you'd think!
- PLs are important in computing; it is embarrassing if you do not know the basic concepts

Implementation Methods

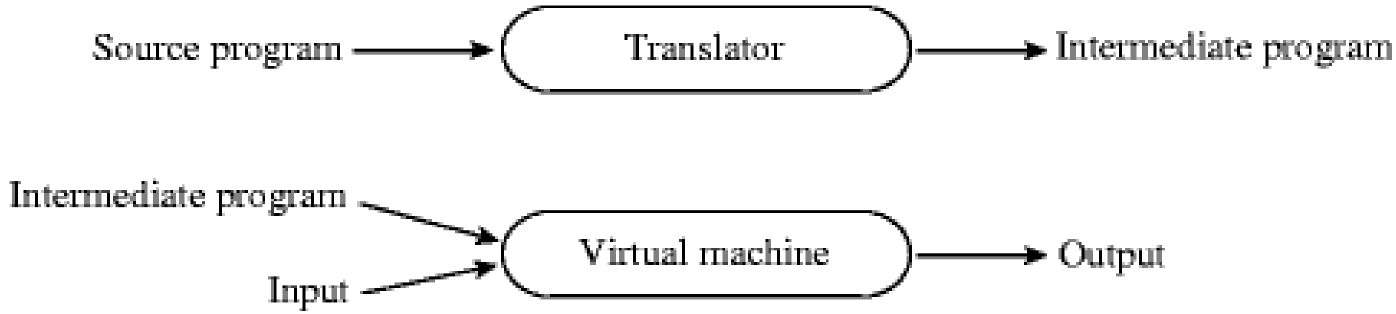
- Compilation (C, C++, ML)



- Interpretation (Lisp)



- Hybrid systems (Java)



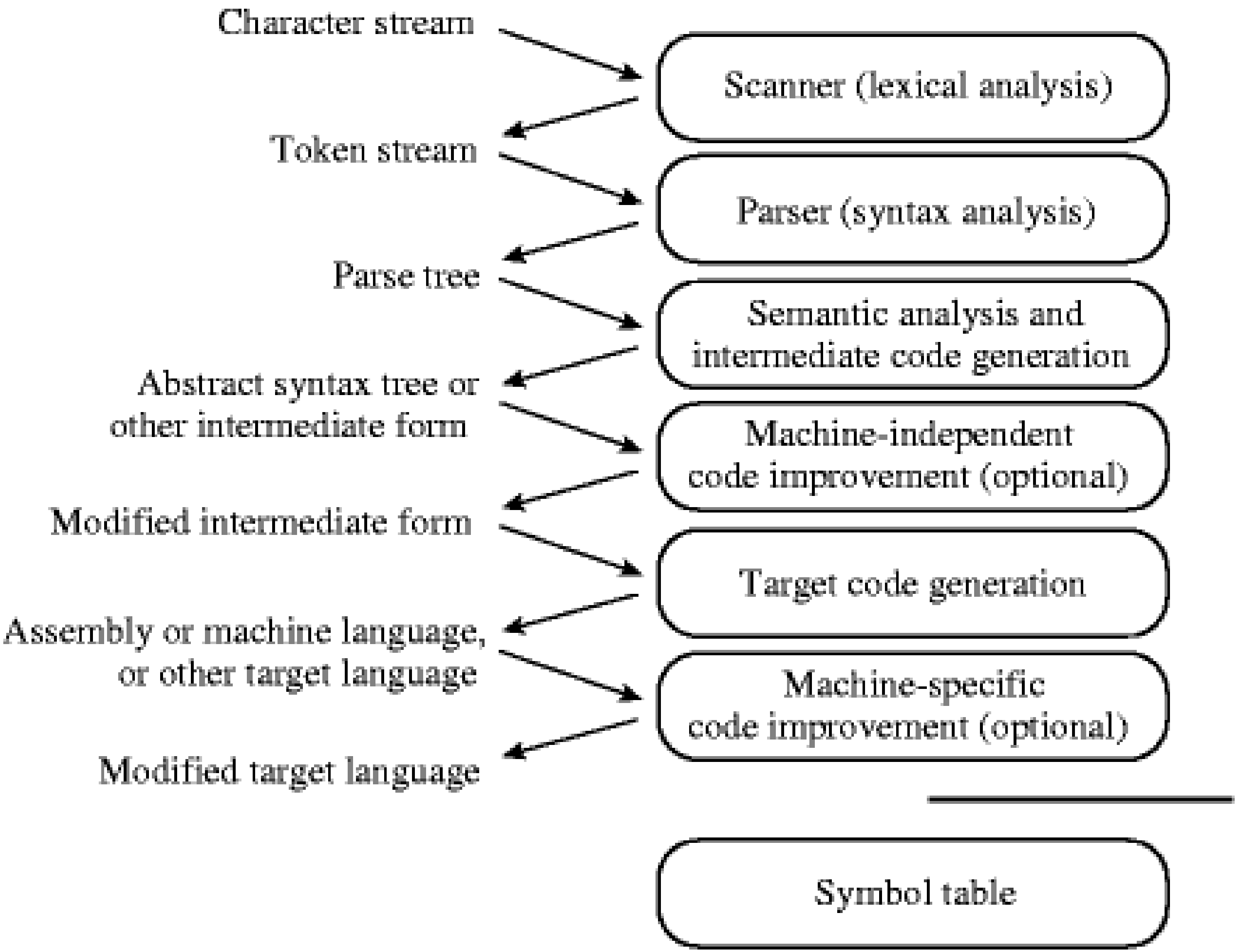
The Entire Compiler Toolchain (1/2)

- Preprocessor: source to source translation
  - E.g., GNU C/C++ macro preprocessor **cpp**
    - Inlines **#include**, evaluates **#ifdef**, expands **#define**
    - Produces valid C or C++ source code
- Compiler: source to assembly code
  - E.g., GNU C/C++/… compiler **gcc**
  - Produces assembly language for the target processor
- Assembler: assembly to object code
  - E.g., GNU assembler **as**
  - Translates mnemonics (e.g., ADD) to opcodes; resolves symbolic names for memory locations

The Entire Compiler Toolchain (2/2)

- Linker: object code from several modules (including libraries) to single executable program
  - E.g. GNU linker **ld**
  - Resolves inter-module symbol references; relocates the code (recomputes addresses)
- Example: **gcc** from Unix command line is a driver program that invokes the entire toolchain
  - **gcc -E test.c**: preprocessor (output: C code)
  - **gcc -S test.c**: preprocessor+compiler (output: assembly)
  - **gcc -c test.c**: preprocessor+compiler+assembler (output: object code for this compilation unit)
  - **gcc test.c**: preprocessor+compiler+assembler+linker

Overview of Compilation



Source Code for Euclid's GCD Algorithm

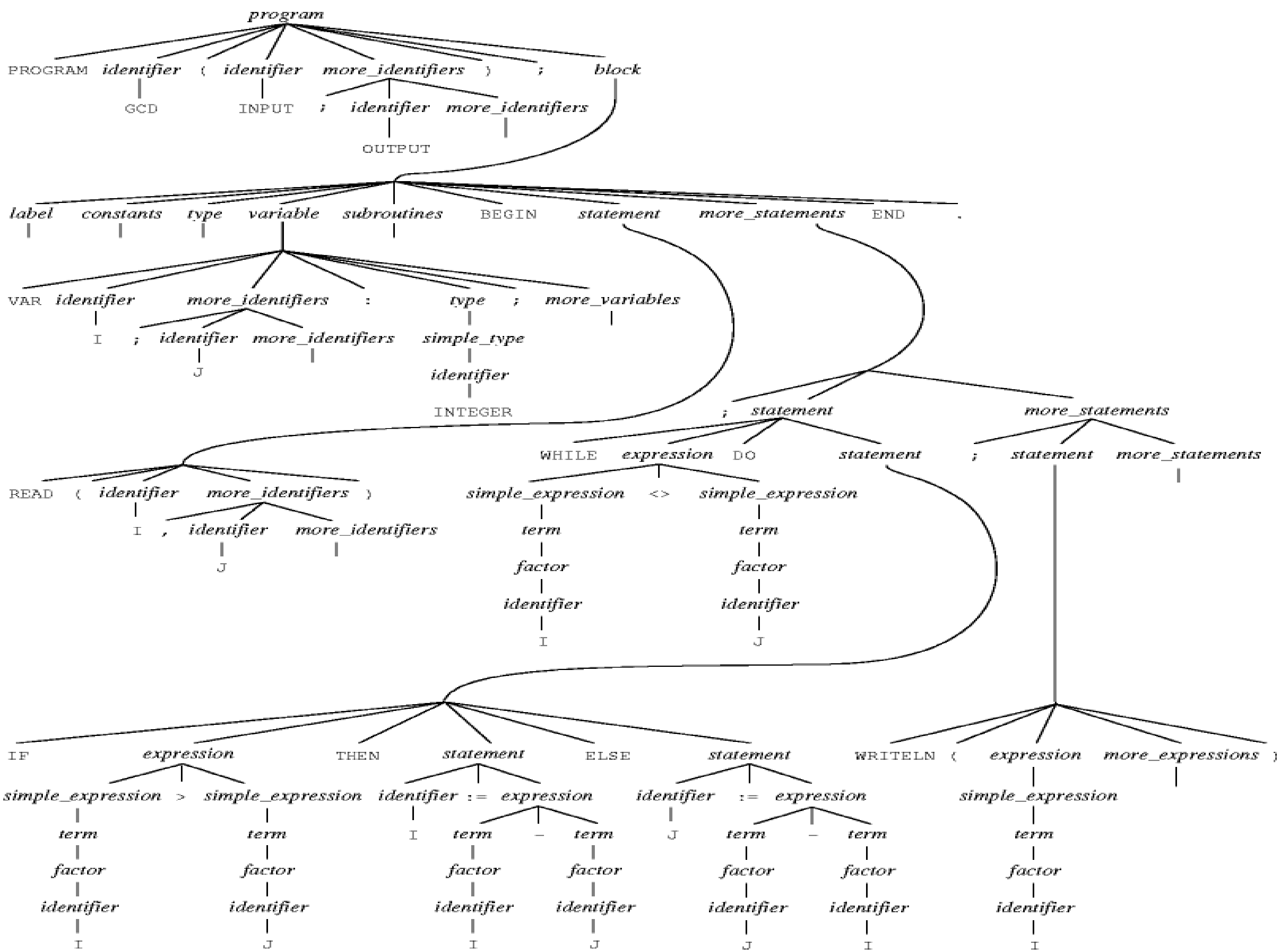
- This is code in Pascal, but you should have no problem reading it

```
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(j);
end.
```

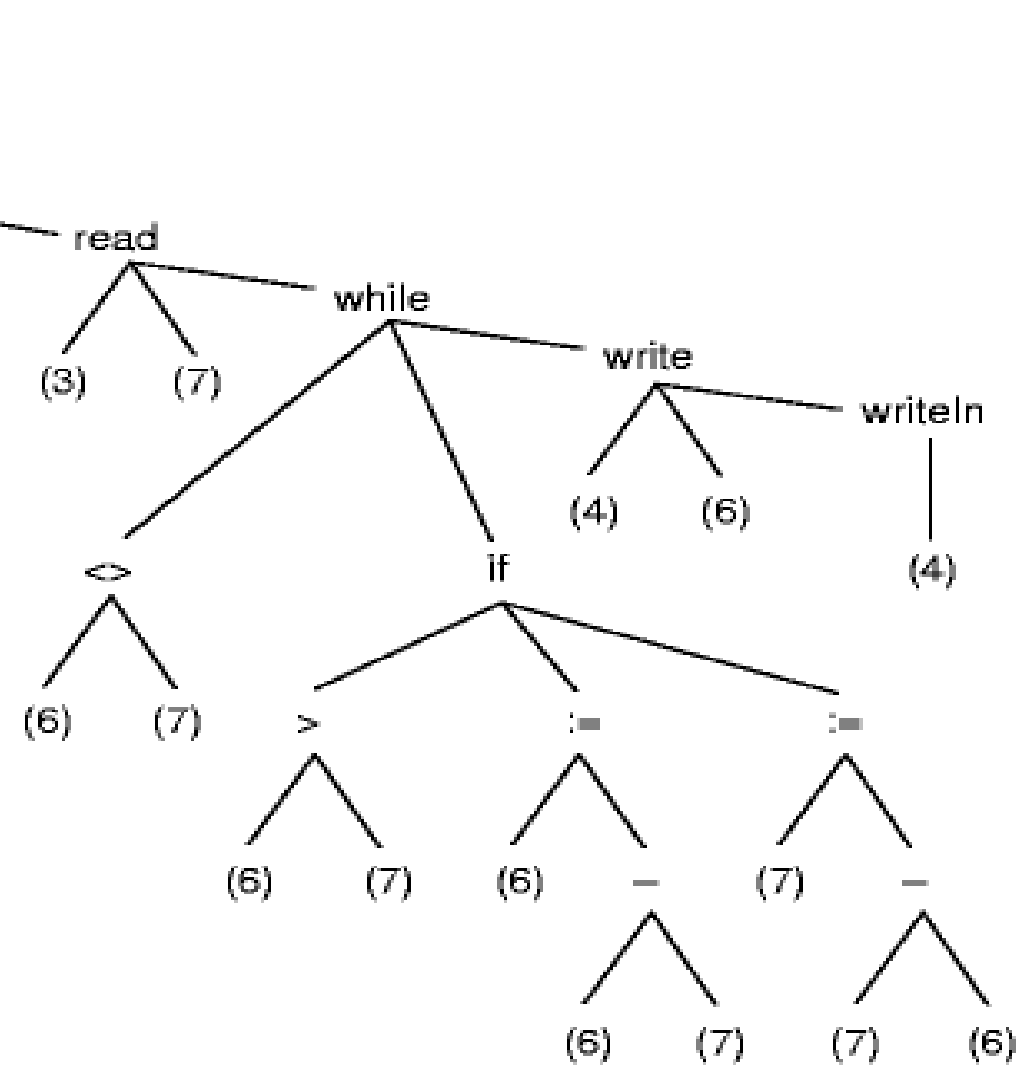
Tokens (After Lexical Analysis)

```
PROGRAM, (IDENT, “gcd”), LPAREN,
(IDENT, “input”), COMMA,
(IDENT, “output”), SEM, VAR,
(IDENT, “i”), COMMA, (IDENT, “j”),
COLON, INTEGER, SEM, BEGIN, ...
```

Parse Tree (After Syntax Analysis)



Abstract Syntax Tree and Symbol Table



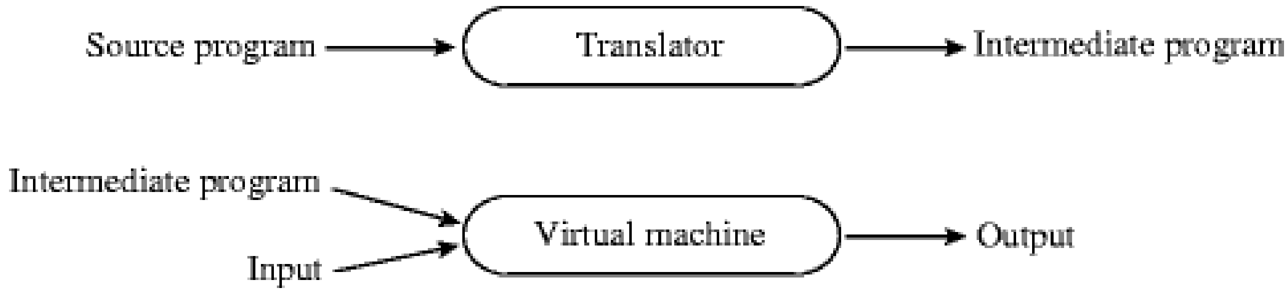
Index	Symbol	Type
1	INTEGER	type
2	TEXTFILE	type
3	INPUT	2
4	OUTPUT	2
5	GCD	program
6	I	1
7	J	1

Assembly (Target Language)

```
    addiu   sp,sp,-32       # reserve room for local variables
    sw      ra,20(sp)       # save return address
    jal     getint          # read
    nop
    sw      v0,28(sp)       # store i
    jal     getint          # read
    nop
    sw      v0,24(sp)       # store j
    lw      t6,28(sp)       # load i
    lw      t7,24(sp)       # load j
    nop
    beq     t6,t7,D         # branch if i = j
    nop
A:  lw      t8,28(sp)       # load i
    lw      t9,24(sp)       # load j
    nop
    slt     at,t9,t8        # determine whether j < i
    beq     at,zero,B       # branch if not
    nop
    lw      t0,28(sp)       # load i
    lw      t1,24(sp)       # load j
    nop
    subu    t2,t0,t1        # t2 := i - j
    sw      t2,28(sp)       # store i
    b       C
    nop
B:  lw      t3,24(sp)       # load j
    lw      t4,28(sp)       # load i
    nop
    subu    t5,t3,t4        # t5 := j - i
    sw      t5,24(sp)       # store j
C:  lw      t6,28(sp)       # load i
    lw      t7,24(sp)       # load j
    nop
    bne     t6,t7,A         # branch if i <> j
    nop
D:  lw      a0,28(sp)       # load i
    jal     putint          # writeln
    nop
    move    v0,zero         # exit status for program
    b       E               # branch to E
    nop
    b       E               # branch to E
    nop
E:  lw      ra,20(sp)       # retrieve return address
    addiu   sp,sp,32        # deallocate space for local variables
    jr      ra              # return to operating system
    nop
```

Intermediate Languages for Portability

- Java: the translator produces Java bytecode
  - Executed on the Java Virtual Machine (JVM)



  - Inside the JVM, there is a bytecode interpreter and a just-in-time (JIT) compiler (triggered for “hot” code)
  - Android: Java bytecode → Dalvik bytecode, for execution on the Dalvik Virtual Machine
- C can be used as an intermediate language: a C compiler is available on pretty much any machine