Programming Languages – Preliminaries

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Why do we study PL?

- Increased ability to express ideas.
- Improved background for choosing appropriate languages.
- Increased ability to learn new languages.
- Better understanding of significance of implementation.
- Better use of languages that are already known.
- Overall advancement of computing.

Programming Domains

- Scientific applications
  - Large numbers of floating point computations; use of arrays

    Example: Fortran
- Business applications
  - Produce reports, use decimal numbers and characters

    Example: COBOL
- Artificial intelligence
  - Symbols rather than numbers manipulated; use of linked lists

    Example: LISP

Programming Domains

- Systems programming
  - Need efficiency because of continuous use, e.g. C
- Web Software
  - Eclectic collection of languages: markup (e.g. XHTML), scripting (e.g. PHP), general-purpose (e.g. Java)

Language Evaluation Criteria

- Readability:
  the ease with which programs can be read and understood.
- Writability:
  the ease with which a language can be used to create programs.
- Reliability: conformance to specifications.
- Cost: the ultimate total cost.

Language Evaluation Criteria

Table 1.1 Language evaluation criteria and the characteristics that affect them.

	CRITERIA		
Characteristic	READABILITY	WRITABILITY	RELIABILITY
Simplicity/orthogonality	•	•	•
Control structures	•	•	•
Data types and structures	•	•	•
Syntax design	•	•	•
Support for abstraction		•	•
Expressivity		•	•
Type checking			•
Exception handling			•
Restricted aliasing			•

Evaluation Criteria: Readability

- Trend: Machine → Human
  Coding → Maintenance
  Efficiency → Readability.

- Overall simplicity
  - A manageable set of features and constructs.
  - Minimal feature multiplicity.
    - Example: `a = a + 1, a += 1, ++a, a++`
  - Minimal operator overloading.
    - Example:
```
int a = 10 + 5;
double b = 1.0 + 0.5;
string s = string("abc") + "def";
```

Evaluation Criteria: Readability

- Orthogonality
  - A relatively small set of primitive constructs can be combined in a relatively small number of ways.
  - Every possible combination is legal.
  - Too much orthogonality can also cause problems.
  - IBM mainframes:

```
          A  Reg1, memory_cell
          AR Reg1, Reg2
VAX:      ADDL operand1, operand2
```

  - Lack of orthogonality example in C: `a + b`
    - The type of `a` affects the treatment of the value of `b`.

Evaluation Criteria: Readability

- Data types
  - Adequate predefined data types.
    - Example: `finished = 1; vs. finished = true;`

- Syntax considerations
  - Identifier forms: flexible composition.
  - Special words and methods of forming compound statements.
    - Example: { ↔ } v.s. `if` ↔ `end if`, `for` ↔ `end loop`.
  - Form and meaning: self-descriptive constructs, meaningful keywords.
    - Example: the meaning of `static` in C depends on the context.

Evaluation Criteria: Writability

- Simplicity and orthogonality
  - Fewer constructs, a small number of primitives, a small set of rules for combining them.
- Support for abstraction
  - The ability to define and use complex structures or operations in ways that allow details to be ignored.
  - Example: `sort` subprogram. STL classes in C++.
- Expressivity
  - A set of relatively convenient ways of specifying operations.
  - Strength and number of operators and predefined functions.

```
>>> m = re.search('(?<=-)\w+', 'spam-egg')
```

Evaluation Criteria: Reliability

- Type checking
  - Testing for type errors, at either compile time or run time.
  - Example: the subprogram parameters in the original C language.
- Exception handling
  - Intercept run-time errors and take corrective measures.
- Aliasing
  - Presence of two or more distinct referencing methods for the same memory location.
- Readability and writability
  - A language that does not support “natural” ways of expressing an algorithm will require the use of “unnatural” approaches, and hence reduced reliability.

Evaluation Criteria: Cost

- Training programmers to use the language.
- Writing programs (closeness to particular applications).
- Compiling programs.
- Executing programs.
- Language implementation system: availability of free compilers.
- Reliability: poor reliability leads to high costs.
- Maintaining programs.

Evaluation Criteria: Others

- Portability
  - The ease with which programs can be moved from one implementation to another.
- Generality
  - The applicability to a wide range of applications.
- Well-definedness
  - The completeness and precision of the language's official definition.

Language Design Trade-Offs

- Reliability vs. cost of execution
  - Example: Java demands all references to array elements be checked for proper indexing, which leads to increased execution costs.
- Readability vs. writability
  - Example: APL provides many powerful operators (and a large number of new symbols), allowing complex computations to be written in a compact program but at the cost of poor readability.
- Writability (flexibility) vs. reliability
  - Example: C++ pointers are powerful and very flexible but are unreliable.

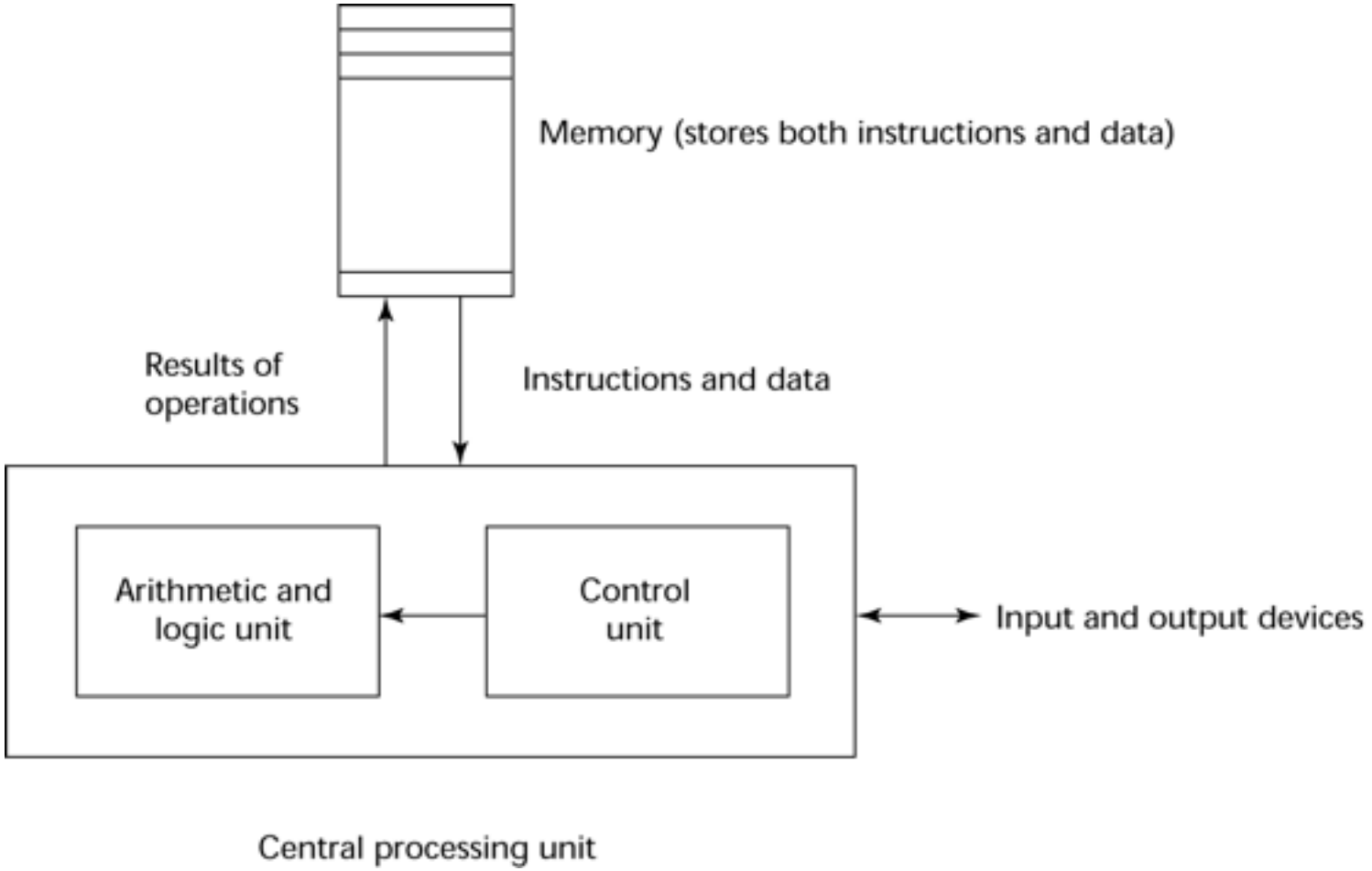
Influences on Language Design

- Computer Architecture
  - Languages are developed around the prevalent computer architecture, known as the von Neumann architecture.
- Programming Methodologies
  - New software development methodologies (e.g., object-oriented software development) led to new programming paradigms and by extension, new programming languages.

Computer Architecture Influence

- Well-known computer architecture: Von Neumann
- Imperative languages, most dominant, because of von Neumann computers
  - Data and programs stored in memory.
  - Memory is separate from CPU.
  - Instructions and data are piped from memory to CPU.
  - Basis for imperative languages.
    - Variables model memory cells.
    - Assignment statements model piping.
    - Iteration is efficient.

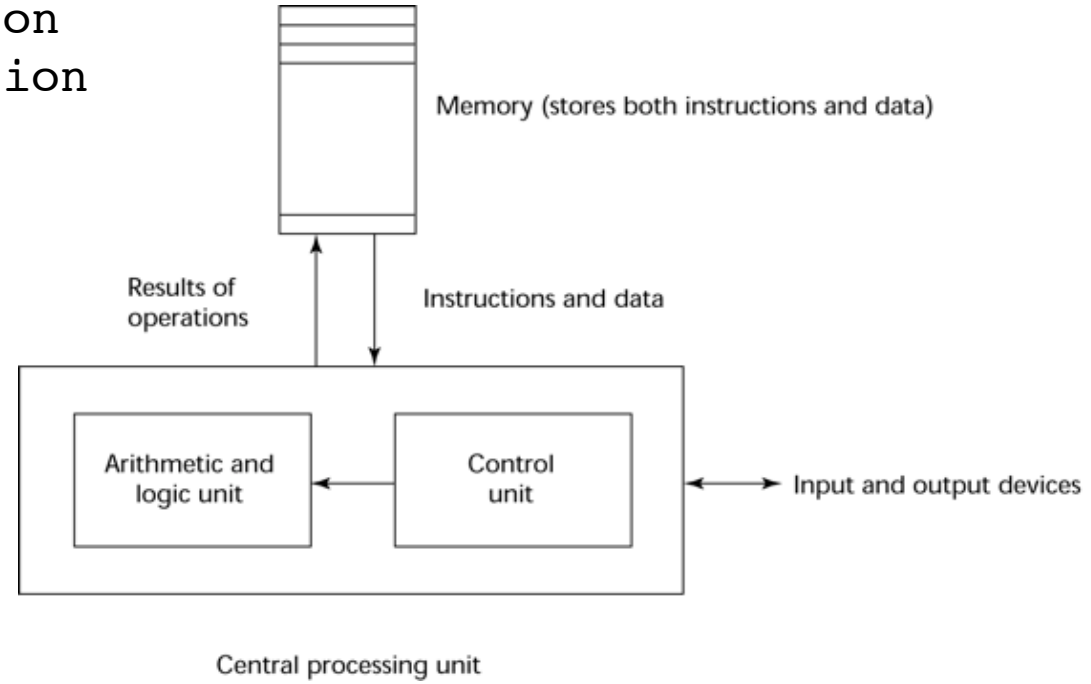
The von Neumann Architecture



The von Neumann Architecture

- Fetch-execute-cycle

```
initialize the program counter
repeat forever
  fetch the instruction pointed by the counter
  increment the counter
  decode the instruction
  execute the instruction
end repeat
```



Von Neumann Bottleneck

- Connection speed between a computer's memory and its processor determines the speed of a computer.
- Program instructions often can be executed much faster than the speed of the connection; the connection speed thus results in a bottleneck.
- Known as the von Neumann bottleneck; it is the primary limiting factor in the speed of computers.

Programming Methodologies Influences

- 1950s and early 1960s: Simple applications; worry about machine efficiency.
- Late 1960s: People efficiency became important; readability, better control structures.
  - structured programming
  - top-down design and step-wise refinement
- Late 1970s: Process-oriented to data-oriented.
  - data abstraction
- Middle 1980s: Object-oriented programming.
  - Data abstraction + inheritance + polymorphism

Language Categories

- Imperative
  - Central features are variables, assignment statements, and iteration
  - Include languages that support object-oriented programming, scripting languages, and the visual languages
  - Examples: C, Java, Perl, JavaScript, Visual BASIC .NET, C++
- Functional
  - Computations = applying functions to given parameters
  - Examples: LISP, Scheme

Language Categories

- Logic
  - Rule-based (rules are specified in no particular order)
  - Example: Prolog
- Markup/programming hybrid
  - Markup languages extended to support some programming
  - Examples: JSTL, XSLT

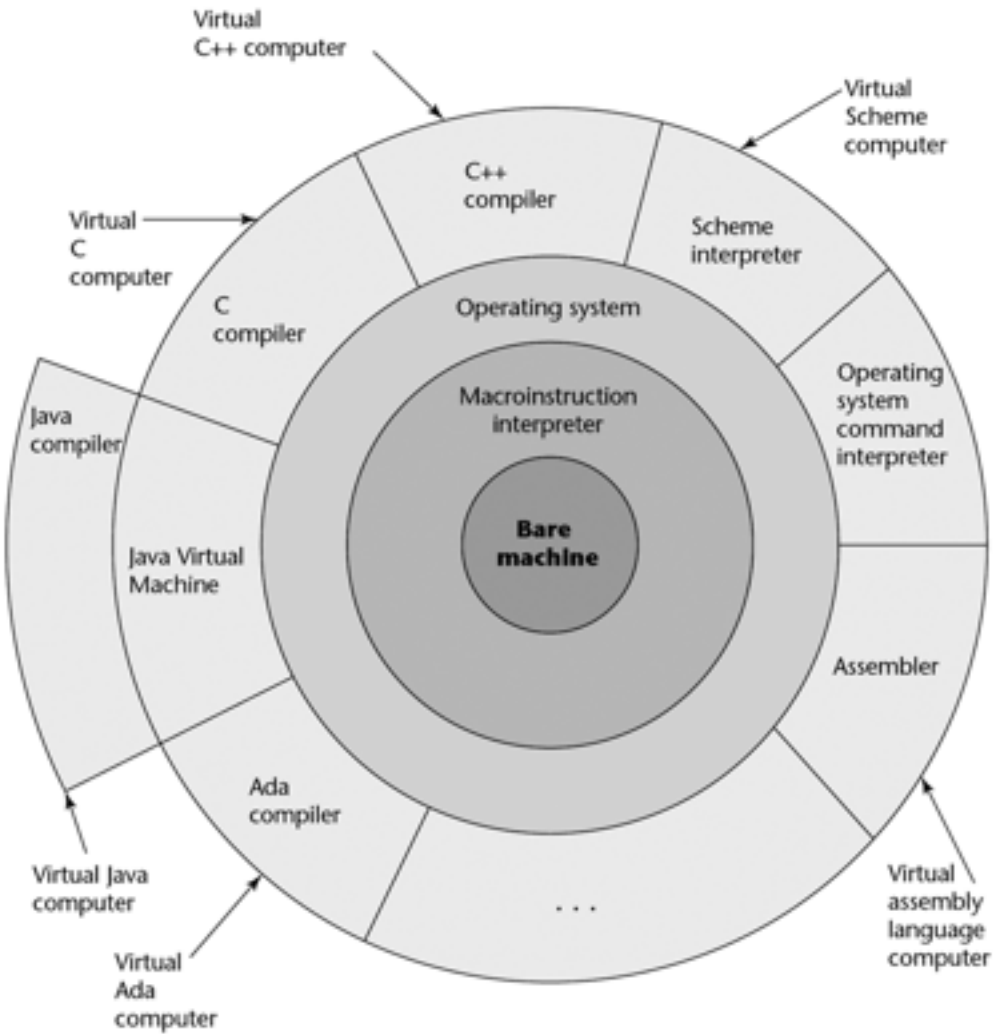
Implementation Methods

- Compilation
  - Programs are translated into machine language.
- Pure Interpretation
  - Programs are interpreted by another program known as an interpreter.
- Hybrid Implementation Systems
  - A compromise between compilers and pure interpreters.

Layered View of Computer

Figure 1.2

Layered interface of virtual computers, provided by a typical computer system

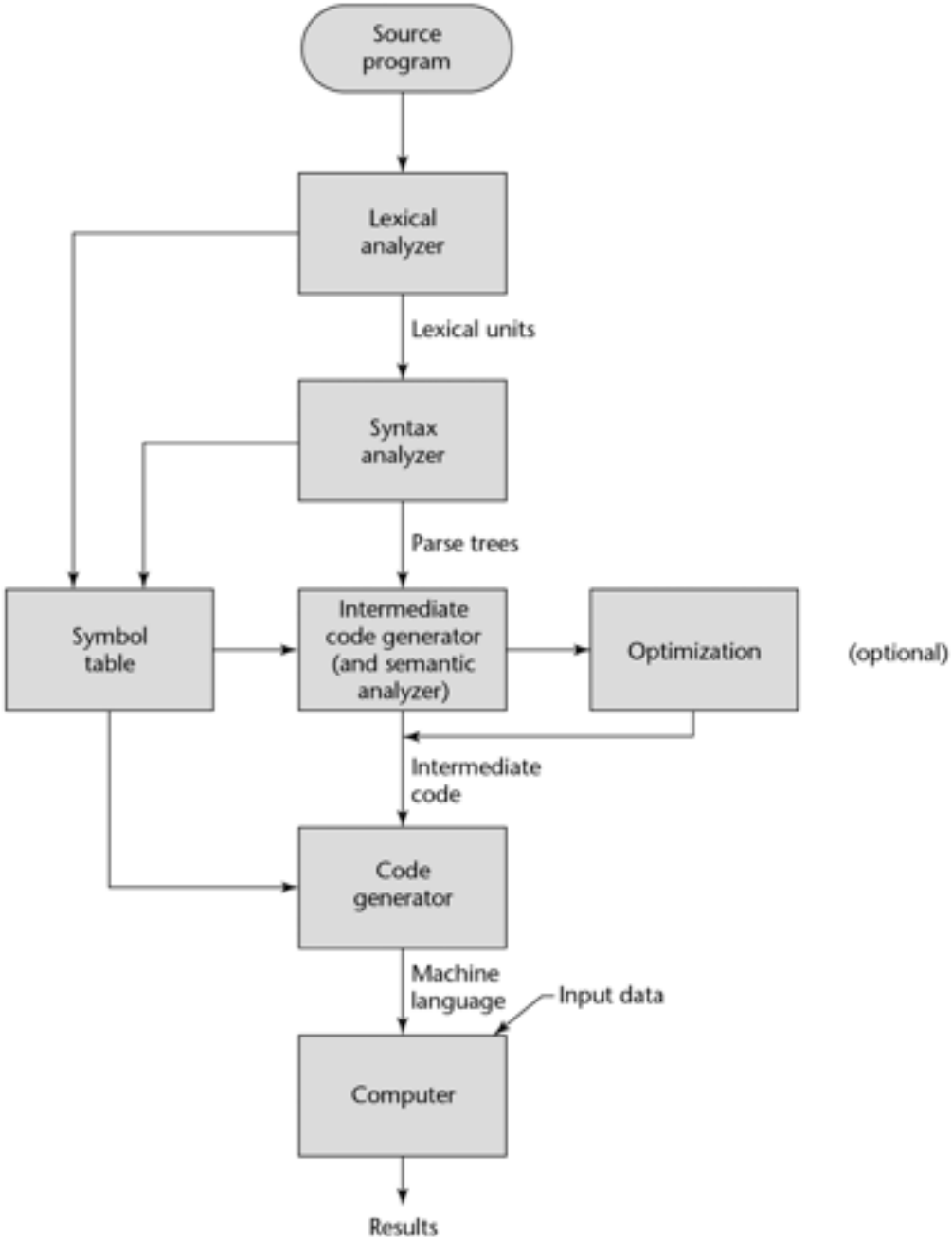


Compilation

- Translate high-level program (source language) into machine code (machine language).
- Slow translation, fast execution.
- Compilation process has several phases:
  - lexical analysis: converts characters in the source program into lexical units.
  - syntax analysis: transforms lexical units into parse trees which represent the syntactic structure of program.
  - Semantics analysis: generate intermediate code.
  - code generation: machine code is generated.

Figure 1.3

The compilation process

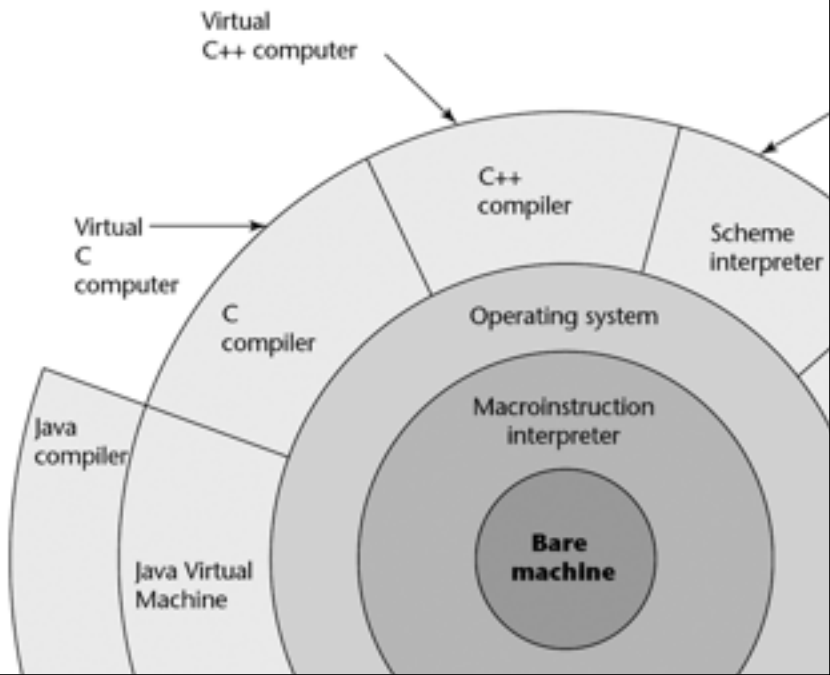


Additional Compilation Terminologies

- Load module (executable image): the user and system code together.
- Linking and loading: the process of collecting system program units and linking them to a user program.

```
hello_world.c
  #include <stdio.h>
  ...
  printf("hello world!\n");
  ...
```

```
std C library (dll)
  ...
  printf(const char*, ...);
  ...
```



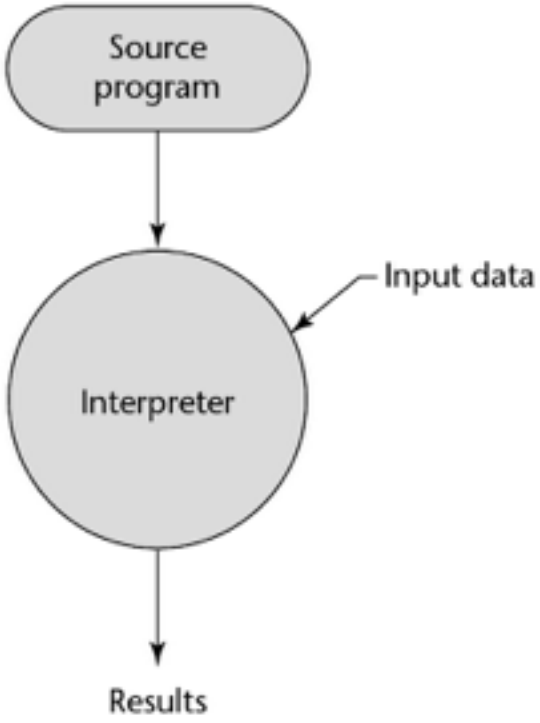
Pure Interpretation

- No translation.
- Easier implementation of programs
  (run-time errors can easily and immediately be displayed).
- Slower execution
  (10 to 100 times slower than compiled programs).
- Often requires more space.
- Now rare for traditional high-level languages.
- Significant comeback with some Web scripting languages
  (e.g., JavaScript, PHP).

Pure Interpretation Process

Figure 1.4

Pure interpretation

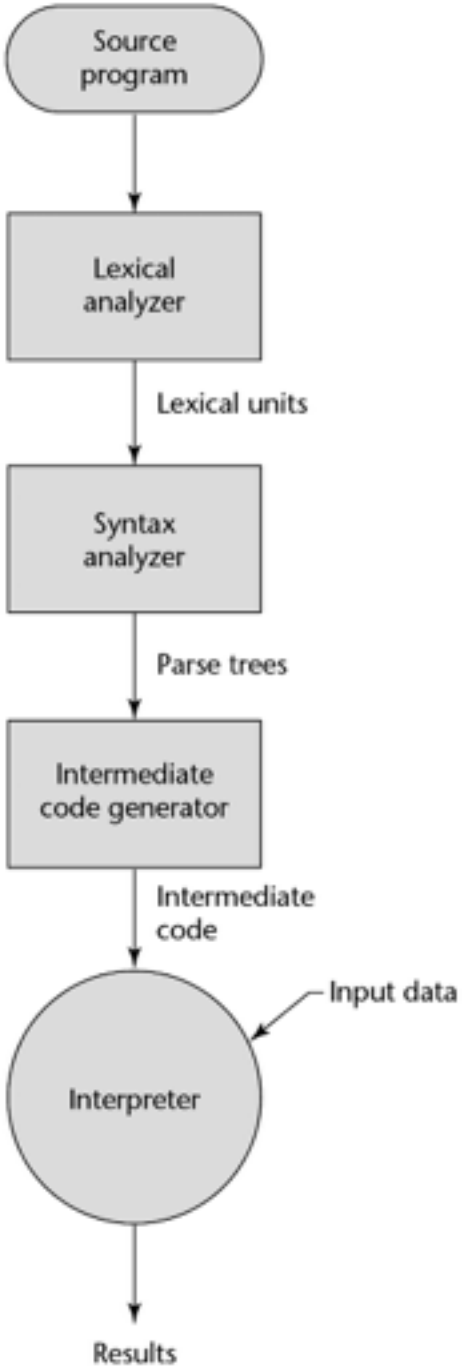


Hybrid Implementation Systems

- A compromise between compilers and pure interpreters.
- A high-level language program is translated to an intermediate language that allows easy interpretation.
- Faster than pure interpretation.
- Examples
  - Perl programs are partially compiled to detect errors before interpretation.
  - Initial implementations of Java were hybrid; the intermediate form, byte code, provides portability to any machine that has a byte code interpreter and a run-time system (together, these are called Java Virtual Machine).

Figure 1.5

Hybrid implementation system



Just-in-Time Implementation Systems

- Initially translate programs to an intermediate language.
- Then compile the intermediate language of the subprograms into machine code when they are called.
- Machine code version is kept for subsequent calls.
- JIT systems are widely used for Java programs.
- .NET languages are implemented with a JIT system.

Preprocessors

- Preprocessor macros (instructions) are commonly used to specify that code from another file is to be included.
- A preprocessor processes a program immediately before the program is compiled to expand embedded preprocessor macros.
- A well-known example: C preprocessor
  - expands #include, #define, and similar macros.
  - Macro functions can cause trouble if used with expression with side effects.
    - e.g.

```
#define max(A, B) ((A) > (B) ? (A) : (B))
max_distance = max(1.0, distance);
max_count = max(max_count, ++count);
```

Programming Environments

- A collection of tools used in software development.
- UNIX
  - An older operating system and tool collection.
  - Nowadays often used through a GUI (e.g., CDE, KDE, or GNOME) that runs on top of UNIX.
- Microsoft Visual Studio.NET
  - A large, complex visual environment.
  - Used to build Web applications and non-Web applications in any .NET language.
- NetBeans
  - Related to Visual Studio .NET, except for Web applications in Java.

Summary

- The study of programming languages is valuable for reasons:
  - Increase our capacity to use different constructs.
  - Enable us to choose languages more intelligently.
  - Makes learning new languages easier.
- Most important criteria for evaluating programming languages include: Readability, writability, reliability, cost.
- Major influences on language design have been machine architecture and software development methodologies.
- The major methods of implementing programming languages are: compilation, pure interpretation, and hybrid implementation.