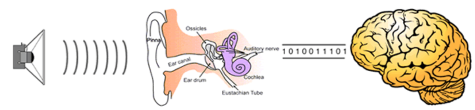
CSCI: 4500/6500 Programming Languages

Motivation & Big Picture

Why learn new [programming] languages?

- **Communicate ideas better**
  - » **Become a better communicator (programming skills)**
    - – **Translate ideas to words**
  - » **Become a better listener ('*compiler*' efficiency)**
    - – **Translate words to ideas**
- **Comprehension:**
  - » **Speakers ability to translate ideas into language**
  - » **Listeners ability to translate work into ideas**



Why study programming language concepts?

- **One School of thought of Linguists:**
  - » Language "**shapes the way we think**" and determines "***what we can think about***" [Whorf-Sapir Hypothesis 1956]
  - » **Programmers only skilled in one language may not have a deep understanding of concepts of other languages, whereas those who are multi-lingual can solve problems in many different ways.**
- **Help you choose appropriate languages for different application domains**
- **Increased ability to learn new languages**
  - » ***Concepts*** **have more similarities**
- **Easier to express ideas**
- **Helps you make better use of whatever language you do use**

What is programming language?

- **Translator between you (ideas), the programmer and the computer's native language**
- **Computer's native language:**
  - » **A computer is composed of on/off switches that tells the computer what to do.**
    - – `01111011 01111011 01111011`
- **How?**
  - » **Read by assemblers, compilers and interpreters and converted into machine code that the computer understands**

What are components of a programming language?

- **Like English -- each programming language has its own grammar, syntax (more details on this next week) and semantics.**

Programming Language Definition

- **Syntax**
  - » **Similar to the grammar of a natural language**
  - » **Most languages defined uses a context free grammar (Chomsky's type 2 grammar which can be described by non-deterministic PDA):**
    - – **Production rules: $A \rightarrow \Upsilon$, where A is a *single* non terminal and Υ is string of terminals and non terminals (regular languages are more restrictive $\Upsilon \in \{ \lambda, aA, a \}$)**
    - – **Example: the language of properly matched parenthesis is generated by the grammar: S → | SS | (S) | λ**
    - – **<if-statement> ::= if (<expression>) <statement> [else <statement>]**
- **Semantics**
  - » **What does the program "mean"?**
  - » **Description of an if-statement [K&R 1988]:**
    - – *An if-statement is executed by first evaluating its expression, which must have arithmetic or pointer type, including all side-effects, and if it compares unequal to 0, the statement following the expression is executed. If there is an else part, and the expression is 0, the statement following the else is executed.*

Why are there *so many* programming languages?

- **Evolution:** We *learn 'better' ways* of doing things over time
- **Application Domains:** Different languages are good for different application domains with different needs that often conflict (next slide)
  - » **Special purpose:** Hardware and/or Software
- **Socio-Economical:** Proprietary interests, commercial advantage
- **Personal Preferences:** For example, some prefers recursive thinking and other prefers iterative thinking

Some Application Domains

- **Scientific computing:** Large number of floating point computations (e.g. Fortran)
- **Business applications:** Produce reports, use decimal numbers and characters (e.g. COBOL)
- **Artificial intelligence:** Symbols rather than numbers manipulated (e. g. LISP)
- **Systems programming:** Need efficiency because of continuous use, low-level access (e.g., C)
- **Web Software:** Eclectic collection of languages: markup (e.g., XHTML-- not a programming language), scripting (e.g., PHP), general-purpose (e.g., Java)
- **Academic:** Pascal, BASIC

What makes a language successful?

- **Expressiveness:** Easy to express things, easy use once fluent, "powerful" (C, Common Lisp, APL, Algol-68, Perl)
- **Learning curve:** Easy to learn (BASIC, Pascal, LOGO, Scheme)
- **Implementation:** Easy to implement (BASIC, Forth)
- **Efficient:** Possible to compile to very good (fast/small) code (Fortran)
- **Sponsorship:** Backing of a powerful sponsor (COBOL, PL/1, Ada, Visual Basic)
- **Cost:** Wide dissemination at minimal cost (Pascal, Turing, Java)

What makes a *good* language?

No universal accepted metric for design.

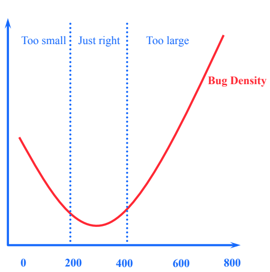
The "*Art* " of designing programming languages

Lets look at some characteristics and see how they affect the criteria below [Sebesta]:

- **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 (i.e., performs to its specifications)
- **Cost:** the ultimate total cost (includes efficiency)

Characteristics

- **Simplicity:**
  - » Modularity, Compactness (encapsulation, abstraction)
  - » Orthogonality (mutually independent; well separated)
- **Expressivity**
- **Syntax**
- **Control Structures**
- **Data types & Structures**
- **Type checking**
- **Exception handling**



sets of library or system calls runs up against human cognitive constraints producing Hatton's U-Curve]Raymond's The Art of Unix Programming]

Compactness (Raymond)

- ***Compact*:** Fits inside a human head
  - » Test: Does an experienced user normally need a manual?
  - » Not the same as *weak* (can be powerful and flexible)
  - » Not the same as easily learned
    - – Example: Lisp has a tricky model to learn then it becomes simple
  - » Not the same as small either (may be predictable and obvious to an experienced user with many pieces)
- **Semi-compact:** Need a reference or cheat sheet card

Compactness

- *The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information [Miller 1956]*
  - » Does a programmer have to remember more than seven entry points? Anything larger than this is unlikely to be strictly compact.
- C & Python are semi-compact
- Perl, Java and shells are not (especially since serious shell programming requires you to know half-a-dozen other tools like sed(1) and awk(1)).
- C++ is anti-compact -- the language's designer has admitted that he doesn't expect any one programmer to ever understand it all.

Orthogonality

- Mathematically means: "Involving right angles"
- Computing: Operations/Instructions *do not have side effects;* each action changes just one thing without affecting others.
- Small set of primitive constructs can be combined in a relatively small number of ways (every possible combination is legal)
  - » Example monitor controls:
    - – Brightness changed independently of the contrast level, color balance independently of both.
- Don't repeat yourself rule: Every piece of knowledge must have a *single*, unambiguous, authoritative representation within a system, or as Kernighan calls this: the Single Point Of Truth or SPOT rule.
- Easier to re-use

mutually independent and well separated

Affects Readability

- Overall simplicity
  - » Compactness
  - » Few "feature multiplicity" (c+=1, c++)
    - – (means of doing the same operation)
  - » Minimal operator overloading
- Orthogonality
- Syntax considerations
  - » Special words for compounds (e.g., `end if.`)
  - » Identifier forms (short forms of Fortran examp
- Control statements
  - » Data structures facilities (true/1)
  - » Control structures (*while* vs *goto example next…*

Simplicity	x
Control Structures	x
Data types & Structures	x
Syntax Design	x
Support Abstraction	
Expressivity	
Type Checking	
Exception Handling	
Restrictive Aliasing	

`while` vs `goto`

```
while( incr < 20 )
 {
 while( sum <= 100 )
     {
     sum += incr;
     }
 incr++;
 }
```

```
loop 1:
  if( incr >= 20 )
       goto out;
loop 2:
  if( sum > 100 )
       goto next;
  sum += incr;
  goto loop 2;
next:
  incr++;
  goto loop 1;
out:
```

- Comparison of a nested loop versus doing the same task in a language without adequate control statements.
- Which is more readable?

Affect Writability

- Simplicity and orthogonality
  - » Few 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
- Expressivity
  - » A set of relatively convenient ways of specifying operations
  - » Example: the inclusion of `for` statement in many modern languages

Simplicity Orthogonality	x
Control Structures	x
Data types & Structures	x
Syntax Design	x
Support Abstraction	x
Expressivity	x
Type Checking	
Exception Handling	
Restrictive Aliasing	

Affects Reliability

- Type checking
  - » Testing for type errors
- 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 necessarily use "unnatural" approaches, and hence reduced reliability

Simplicity Orthogonality	x
Control Structures	x
Data types & Structures	x
Syntax Design	x
Support Abstraction	x
Expressivity	x
Type Checking	x
Exception Handling	x
Restrictive Aliasing	x

Summary

	Criteria		
	Readability	Writability	Reliability
Simplicity: Modular, Compact & Orthogonal	x	x	x
Control Structures	x	x	x
Data types & Structures	x	x	x
Syntax Design	x	x	x
Support Abstraction		x	x
Expressivity		x	x
Type Checking			x
Exception Handling			x
Restrictive Aliasing			x

Affects Cost

- Training programmers to use 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

Others

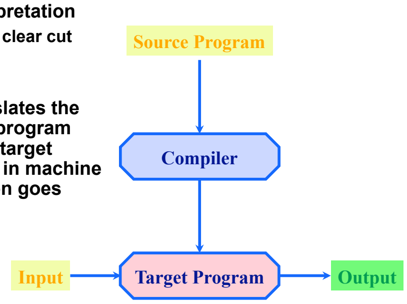
- Portability
  - » The ease with which programs can be moved from one implementation to another
- Generality
  - » The applicability to a wide range of applications
- Well-definedness
  - » The completeness and precision of the language's official definition

Design Trade-offs

- Reliability vs. cost of execution
  - » Example: Java demands all references to array elements be checked for proper indexing but that 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 not reliably uses

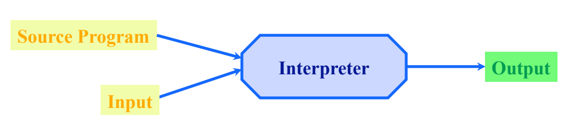
Language Implementation Methods

- Compilation vs. Interpretation
  - » Not opposites, not a clear cut distinction
- Pure Compilation
  - » The compiler translates the high-level source program into an equivalent target program (typically in machine language), and then goes away:



Compilation vs. Interpretation

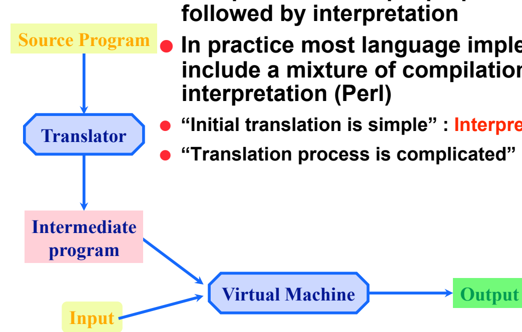
- Pure Interpretation
  - » Interpreter stays around for the execution of the program
  - » Interpreter is the locus of control during execution



Compilation vs. Interpretation

- **Interpretation:**
  - » **Greater flexibility**
  - » **Better diagnostics (error messages, related to the text of source)**
  - » **Platform independence**
  - » **Example: Java, Perl, Ruby, Python, Lisp, Smalltalk**
- **Compilation:**
  - » **Better performance**
  - » **C, Fortran, Ada, Algol**

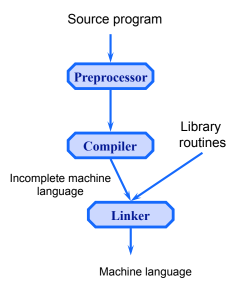
Hybrid: Compilation and Interpretation



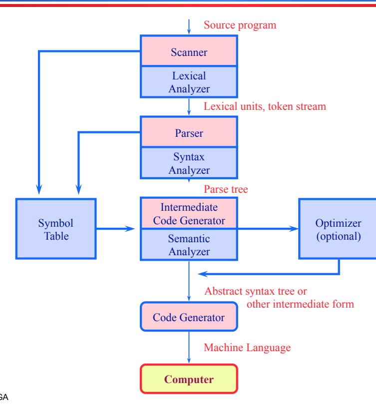
- **Compilation or simple preprocessing followed by interpretation**
- **In practice most language implementations include a mixture of compilation and interpretation (Perl)**
- **"Initial translation is simple" : Interpreted**
- **"Translation process is complicated" : Compiled**

Other implementation strategies

- **Preprocessor - removes comments and white space, expand macros.**
- **Library routines and linking - math routines, system programs (e.g., I/O)**
- **Post-compilation assembly - compiler compiles to assembly. Facilitates debugging & isolate debugger from changes in machine language (only assembler need to be changed)**
- **Just-In-Time Compilation - delay compilation until last possible moment**
  - » **Lisp, Prolog - compiles on fly**
  - » **Java's JIT - byte code → machine code**
  - » **C# → .NET Common Intermediate Language (CIL) → machine code**

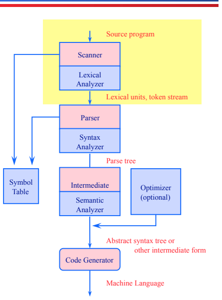


Overview Compilation Process



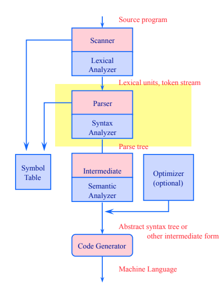
Scanning

- **Divides the program into "tokens"**
  - » **These are the smallest meaningful units; this saves time, since character-by-character processing is slow**
    - – **you can design a parser to take characters instead of tokens as input, but it isn't pretty**
- **We can tune the scanner better if its job is simple; it also saves complexity (lots of it) for later stages**
- **Scanning is recognition of a *regular language*, e.g., via DFA**
- **Examples: Lex, Flex (tutorial next week)**



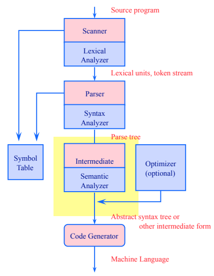
Parsing

- **A parser recognize how the tokens are combined in more complex syntactic structures determining its grammatical structure given a grammar.**
- **Informally, it finds the structure you can describe with syntax diagrams (the "circles and arrows" in a Pascal manual)**
- **Example Tools: Yacc, Bison (tutorial next week).**



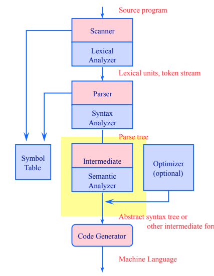
Semantic Analysis

- Discovery of meaning in the program
- The compiler actually does what is called STATIC semantic analysis. That's the meaning that can be figured out at compile time
- Some things (e.g., array subscript out of bounds) can't be figured out until run time. Things like that are part of the program's DYNAMIC semantics



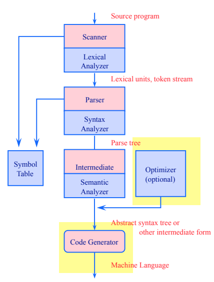
Intermediate Form (IF)

- Done after semantic analysis (if the program passes all checks)
- IFs are often chosen for machine independence, ease of optimization, or compactness (these are somewhat contradictory)
- They often resemble machine code for some imaginary idealized machine; e.g. a stack machine, or a machine with arbitrarily many registers
- Many compilers actually move the code through more than one IF



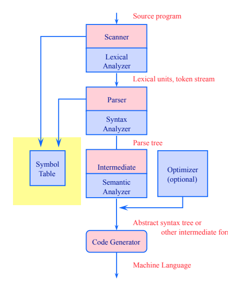
Optimization and Code Generation Phase

- Optimization takes an intermediate code program and produces another one that does the same thing faster, or in less space
  - » The term is a misnomer; we just improve code
  - » The optimization phase is optional
  - » Certain machine-specific optimizations (use of special instructions or addressing modes, etc.) may be performed during or after code generation
- Code generation phase produces assembly language or (sometime) relocatable machine language



Symbol Table

- All phases rely on a symbol table that keeps track of all the identifiers in the program and what the compiler knows about them
- This symbol table may be retained (in some form) for use by a debugger, even after compilation has completed



- Next week more details on syntax (tutorial)
- This week:
  - » Programming language history
  - » Overview of different programming paradigms
    - – Imperative, Functional, Logical, …