CMSC 330: Organization of Programming Languages

Introduction

Course Goal

Learn how programming languages "work"

- Broaden your language horizons
  - Different programming languages
  - Different language features and tradeoffs
- Study how languages are implemented
  - What really happens when I write x.foo(…)?
- Study how languages are described / specified
  - Mathematical formalisms

Course Subgoals

- Learn some fundamental CS concepts
  - Regular expressions
  - Context free grammars
  - Automata theory
  - Compilers & parsing
  - Parallelism & synchronization
- Improve programming skills
  - Learn how to learn new programming languages
  - Learn how to program in a new programming style

Calendar / Course Overview

- Tests
  - 4-5 Quizzes, 2 midterms, final exam
- Projects
  - Project 1, 2 – Ruby
  - Project 3, 4 – OCaml
  - Project 5 – Multithreading
- Programming languages
  - Ruby
  - OCaml
  - Java

Rules and Reminders

- Use lecture notes as your text
  - To be supplemented by readings, internet
- Keep ahead of your work
  - Get help as soon as you need it
    - Office hours, CS forum, email
- Don't disturb other students in class
  - Keep cell phones quiet
  - Use laptops only for school work

Academic Integrity

- All written work (including projects) must be done on your own
  - Do not copy code from other students
  - Do not copy code from the web
- Work together on high-level project questions
  - Do not look at/describe another student's code
  - If unsure, ask instructor!
  - Software used to find suspicious code similarities
    - Very effective
- Can work together on practice questions

Syllabus

- Scripting languages (Ruby)
- Regular expressions and finite automata
- Context-free grammars
- Functional programming (OCaml)
- Concurrency
- Object-oriented programming (Java)
- Environments, scoping, and binding
- Advanced topics

All Languages Are Equivalent

- A language is Turing complete if it can compute any function computable by a Turing Machine
- Essentially all general-purpose programming languages are Turing complete
  - I.e., any program can be written in any programming language
- Therefore this course is useless?!
  - Learn only 1 programming language, always use it

Why Study Programming Languages?

- To allow you to choose between languages
  - Using the right programming language for a problem may make programming
    - Easier, faster, less error-prone
  - Programming is a human activity
    - Features of a language make it easier or harder to program for a specific application

Why Study Programming Languages?

- To make you better at learning new languages
  - You may need to add code to a legacy system
    - E.g., FORTRAN (1954), COBOL (1959), …
  - You may need to write code in a new language
    - Your boss says, "From now on, all software will be written in {C++/Java/C#/Python…}"
  - You may think Java is the ultimate language
    - But if you are still programming or managing programmers in 20 years, they probably won't be programming in Java!

Why Study Programming Languages?

- To make you better at using languages you think you already know
  - Many "design patterns" in Java are functional programming techniques
  - Understanding what a language is good for will help you know when it is appropriate to use

Changing Language Goals

- 1950s-60s – Compile programs to execute efficiently
  - Language features based on hardware concepts
    - Integers, reals, goto statements
  - Programmers cheap; machines expensive
    - Keep the machine busy

Changing Language Goals

- Today
  - Language features based on design concepts
    - Encapsulation, records, inheritance, functionality, assertions
  - Processing power and memory very cheap; programmers expensive
    - Ease the programming process

Language Attributes to Consider

- Syntax
  - What a program looks like
- Semantics
  - What a program means
- Implementation
  - How a program executes

Imperative Languages

- Also called procedural or von Neumann
- Building blocks are functions and statements
  - Programs that write to memory are the norm

```
int x = 0;
while (x < y) x := x + 1;
```

  - FORTRAN (1954)
  - Pascal (1970)
  - C (1971)

Functional Languages

- Also called applicative languages
- No or few writes to memory
  - Functions are higher-order

```
let rec map f = function [] -> []
                | x::l -> (f x)::(map f l)
```

  - LISP (1958)
  - ML (1973)
  - Scheme (1975)
  - Haskell (1987)
  - OCaml (1987)

Logical Languages

- Also called rule-based or constraint-based
- Program consists of a set of rules
  - "A :- B" – If B holds, then A holds
    - `append([], L2, L2).`
    - `append([X|Xs],Ys,[X|Zs]) :- append(Xs,Ys,Zs).`
  - PROLOG (1970)
  - Various expert systems

Object-Oriented Languages

- Programs are built from objects
  - Objects combine functions and data
  - Often have classes and inheritance
  - "Base" may be either imperative or functional

```
class C { int x; int getX() {return x;} … }
class D extends C { … }
```

  - Smalltalk (1969)
  - C++ (1986)
  - OCaml (1987)
  - Java (1995)

Scripting Languages

- Rapid prototyping languages for "little" tasks
  - Typically with rich text processing abilities
  - Generally very easy to use
  - "Base" may be imperative or functional; may be OO

```
#!/usr/bin/perl
for ($j = 0; $j < 2*$lc; $j++) {
    $a = int(rand($lc));
…
```

  - sh (1971)
  - perl (1987)
  - Python (1991)
  - Ruby (1993)

"Other" Languages

- There are lots of other languages w/ various features
  - COBOL (1959) – Business applications
    - Imperative, rich file structure
  - BASIC (1964) – MS Visual Basic widely used
    - Originally an extremely simple language
    - Now a single word oxymoron
  - Logo (1968) – Introduction to programming
  - Forth (1969) – Mac Open Firmware
    - Extremely simple stack-based language for PDP-8
  - Ada (1979) – The DoD language
    - Real-time
  - Postscript (1982) – Printers- Based on Forth

Ruby

- An imperative, object-oriented scripting language
  - Created in 1993 by Yukihiro Matsumoto
  - Similar in flavor to many other scripting languages (e.g., perl, python)
  - Much cleaner than perl
  - Full object-orientation (even primitives are objects!)

A Small Ruby Example

intro.rb:

```
def greet(s)
  print("Hello, ")
  print(s)
  print("!\n")
end
```

```
% irb     # you'll usually use "ruby" instead
irb(main):001:0> require "intro.rb"
=> true
irb(main):002:0> greet("world")
Hello, world!
=> nil
```


OCaml

- A mostly-functional language
  - Has objects, but won't discuss (much)
  - Developed in 1987 at INRIA in France
  - Dialect of ML (1973)
- Natural support for pattern matching
  - Makes writing certain programs very elegant
- Has a really nice module system
  - Much richer than interfaces in Java or headers in C
- Includes type inference
  - Types checked at compile time, but no annotations

A Small OCaml Example

intro.ml:

```
let greet s =
  begin
    print_string "Hello, ";
    print_string s;
    print_string "!\n"
  end
```

```
$ ocaml
        Objective Caml version 3.08.3

# #use "intro.ml";;
val greet : string -> unit = <fun>
# greet "world";;
Hello, world!
- : unit = ()
```

Attributes of a Good Language

1. Clarity, simplicity, and unity
   - Provides both a framework for thinking about algorithms and a means of expressing those algorithms
2. Orthogonality
   - Every combination of features is meaningful
   - Features work independently
     - What if, instead of working independently, adjusting the volume on your radio also changed the station? You would have to carefully change both simultaneously and it would become difficult to find the right station and keep it at the right volume.

Attributes of a Good Language

3. Naturalness for the application
   - Program structure reflects the logical structure of algorithm
4. Support for abstraction
   - Program data reflects problem being solved
5. Ease of program verification
   - Verifying that program correctly performs its required function

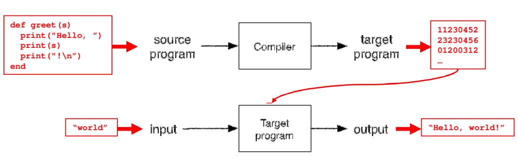
Attributes of a Good Language

6. Programming environment
   - External support for the language
7. Portability of programs
   - Can develop programs on one computer system and run it on a different computer system
8. Cost of use
   - Program execution (run time), program translation, program creation, and program maintenance
9. Security & safety
   - Should be very hard to write unsafe program

Executing Languages

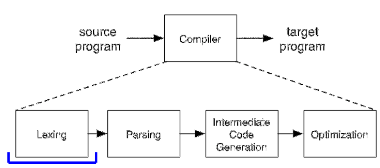
- Suppose we have a program P written in a high-level language (i.e., not machine code)
- There are two main ways to run P
  1. Compilation
  2. Interpretation

Compilation or Translation



- Source program translated to another language
  - Often machine code, which can be directly executed

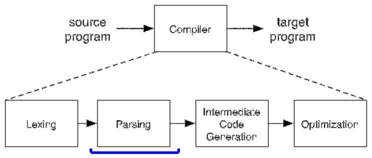
Steps of Compilation



FOR
ID:i
LESSTHAN
NUM:6

1. Lexical Analysis (Scanning) – Break up source code into *tokens* such as numbers, identifiers, keywords, and operators

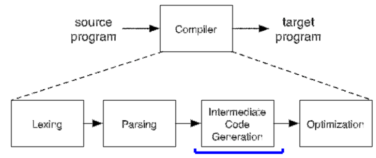
Steps of Compilation



For loop

2. Parsing (Syntax Analysis) – Group tokens together into higher-level language constructs (conditionals, assignment statements, functions, …)

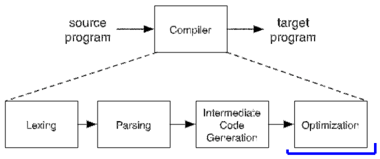
Steps of Compilation



for 0:i:6
or
Load 0
Load i
Etc…

3. Intermediate Code Generation – Verify that the source program is valid and translate it into an internal representation
   - May have more than one intermediate rep

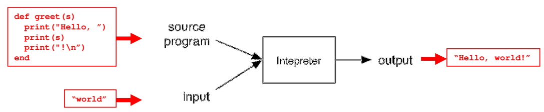
Steps of Compilation



4. Optimization (optional) – Improve the efficiency of the generated code
   - Eliminate dead code, redundant code, etc.
   - Change algorithm without changing functionality (e.g., X=Y+Y+Y+Y ➔ X=4*Y ➔ X = Y shift left 2)

[If interested in compilation, take CMSC 430]

Interpretation



- Interpreter executes each instruction in source program one step at a time
  - No separate executable

Compiler or Intepreter?

- gcc
  - Compiler – C code translated to object code, executed directly on hardware
- javac
  - Compiler – Java source code translated to Java byte code
- tcsh/bash
  - Interpreter – commands executed by shell program
- java
  - Interpreter – Java byte code executed by virtual machine

Decision Less Simple Today

- Previously
  - Build program to use hardware efficiently
  - Often use of machine language for efficiency
- Today
  - No longer write directly in machine language
  - Use of layers of software
  - Concept of virtual machines
    - Each layer is a machine that provides functions for the next layer (e.g., javac/java distinction)
    - This is an example of abstraction, a basic building block in computer science

Summary

- Many types of programming languages
  - Imperative, functional, logical, OO, scripting
- Many programming language attributes
  - Clear, orthogonal, natural…
- Programming language implementation
  - Compiled, interpreted