# Software Lesson 2 Outline

1. Software Lesson 2 Outline
2. Languages
3. Ingredients of a Language
4. Kinds of Languages
5. Natural Languages #1
6. Natural Languages #2
7. Natural Languages #3
8. Natural Languages #4
9. Programming Languages
10. Natural Languages vs Programming Languages
11. Programming Language Hierarchy
12. High Level Languages
13. Assembly Languages
14. Machine Languages
15. Converting Between Languages
16. Compiler
17. Interpreter
18. Assembler
19. Our Old Friend `hello_world.c`
20. Compiler Details
21. Compiler Details (cont’d)
22. Elements of a Compiler #1
23. Elements of a Compiler #2
24. Phases of Compiling
25. Compiling a C Statement
26. Assembly Code for `hello_world.c` #1
27. Assembly Code for `hello_world.c` #2
28. Machine Code for `hello_world.c`
29. How to Program in Machine Language Directly
30. Why Not Do Everything in Machine Language?
31. Why Not Do Everything in Assembly Language?
32. The Programming Process
33. What is an Algorithm?
34. Algorithms
35. Algorithm Example: Eating a Bowl of Corn Flakes
36. Top-Down Design
37. Eating Cornflakes: Top Level
Languages

- What is a language?
- Kinds of languages
  - *Natural* languages
  - *Programming* languages (also known as *Formal* languages)
- Converting between programming languages
  - *Compilers*
  - *Interpreters*
  - *Assemblers*
Ingredients of a Language

- **Symbols**: a set of words and punctuation (in computing, words and punctuation are collectively known as *tokens*)
- **Grammar** (also known as *syntax*): a set of rules for putting tokens together to get valid statements
- **Semantics**: a set of rules for interpreting the meaning of a grammatically valid statement
Kinds of Languages

- **Natural languages**: used in human communication
- **Programming languages** (also known as *formal languages*): used by computers (among others)
Examples: English, Chinese, Swahili, Navajo, Quechua, Maori

Typically can be described by formal rules (grammar), but often aren’t rigidly governed by these rules in everyday use:
“Any noun can be verbed.”
“I might could get me one o’ them there computers.”
Natural Languages #2

- Can mix words from different languages – and even *syntax* (elements of grammar) from different languages – in a single sentence:

  “Hey, amigo, is it all right by you if I kibbitz your parcheesi game while we watch your anime?”
Natural Languages #3

- **Can be ambiguous:**
  
  “When did he say she was going?”

  could be interpreted as:
  - State the time at which he said, “She was going.”
  - According to him, at what time was she going?
Plenty of flexibility regarding “correctness;” for example, “ain’t,” split infinitives, ending a sentence with a preposition

“That is something up with which I will not put.”
Programming Languages

- Examples: C, Java, HTML, Haskell, Prolog, SAS
- Also known as formal languages
- Completely described and rigidly governed by formal rules
- Cannot mix the words of multiple languages, or the syntax of multiple languages, in the same program
- Cannot be ambiguous
- Words and syntax must be EXACTLY correct in every way
## Natural Languages vs Programming Languages

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>NAT’L</th>
<th>PROG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completely described and rigidly governed by formal rules</td>
<td>no</td>
<td>YES</td>
</tr>
<tr>
<td><strong>CAN</strong> mix the words of multiple languages, or the syntax of multiple</td>
<td>YES</td>
<td>no</td>
</tr>
<tr>
<td>languages, in the same program</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CAN</strong> be ambiguous</td>
<td>YES</td>
<td>no</td>
</tr>
<tr>
<td>Words and syntax must be <strong>EXACTLY</strong> correct in every way</td>
<td>no</td>
<td>YES</td>
</tr>
</tbody>
</table>
Programming Language Hierarchy

- High Level Languages
- Assembly Languages
- Machine Languages
High Level Languages

- **Human-readable**
- Most are *standardized*, so they can be used on just about any kind of computer.
- Examples: C, Fortran 90, Java, HTML, Haskell, SAS
- Typically they are designed for a particular kind of application; for example:
  - C for operating system design
  - Fortran 90 for scientific & engineering applications
  - Java for web applets and embedded systems
  - HTML for hypertext (webpages)
  - SAS for statistics

But often, their uses in real life are broader than their original purpose.
Assembly Languages

- **Human-readable**
- **Specific to a particular CPU family**; for example:
  - Intel/AMD x86 (PC)
  - IBM POWER (big IBM machines)
  - ARM (cell phones)

So, for example, a program in x86 assembly language cannot be directly run on a POWER or ARM machine.

- **Set of simple commands**; for example:
  - Load a value from a location in main memory
  - Add two numbers
  - Branch to an instruction out of sequence
Machine Languages

- Not human-readable, except with immense effort
- Binary code that the CPU family understands directly
- Binary representation of the CPU family’s assembly language
Compilers, interpreters and assemblers are programs that convert human-readable source code into machine-readable executable code.
Compiler

- Converts a human-readable high level language source code of a program into a machine language *executable* program
- Converts an entire source code all at once
- Must be completed before executing the program
- Examples: Fortran 90, C, C++, Pascal
Interpreter

- Converts a human-readable high level language source code into actions that are immediately performed
- Converts and executes one statement at a time
- Conversion and execution alternate
- Examples: Perl, HTML, SAS, Mathematica, Unix “shell” (interactive system within Unix)
Assembler

- Converts a human-readable CPU-specific assembly code into CPU-specific, non-human-readable machine language
- Like a compiler, but for a low level assembly language instead of for a high level language
Our Old Friend hello_world.c

```c
/*
 *****************************************
 *** Program: hello_world            ***
 *** Author: Henry Neeman (hneeman@ou.edu) ***
 *** Course: CS 1313 010 Spring 2015 ***
 *** Lab: Sec 012 Fridays 1:00pm ***
 *** Description: Prints the sentence ***
 ***   "Hello, world!" to standard output. ***
 *****************************************
*/
#include <stdio.h>

int main ()
{
    /* main */
    /*
     *****************************************
     *** Execution Section (body) ***
     *****************************************
    *
    * Print the sentence to standard output
    * (i.e., to the terminal screen).
    */
    printf("Hello, world!\n");
} /* main */
```

% gcc -o hello_world hello_world.c
% hello_world
Hello, world!
Compiler Details

```bash
gcc -o hello_world hello_world.c
```

C Source Code: `hello_world.c`

Automatically invoked by compiler

C Preprocessor

Compiler

Assembly Code: `hello_world.s`

Automatically invoked by compiler

Assembler

Object File: `hello_world.o`

Linker/Loader

Executable: `hello_world`

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CS1313 Spring 2015
Compiler Details (cont’d)

```
gcc -o hello_world hello_world.c
```

**C Source Code:** hello_world.c

Automatically invoked by compiler

**C Preprocessor**

**Compiler**
- Lexical Analysis
- Parsing
- Semantic Analysis
- Intermediate Code Generation
- Optimization
- Assembly Code Generation

**Assembly Code:** hello_world.s

**Assembler**

Automatically invoked by compiler

**Object File:** hello_world.o

**Linker/Loader**

**Executable:** hello_world
Elements of a Compiler #1

- **Lexical Analyzer**: identifies program’s “word” elements
  - Comments (ignored by compiler)
  - *Keywords* (for example, `int`, `while`)
  - *Constants* (for example, `5`, `0.725`, "Hello, world!")
  - User-defined *Identifiers* (for example, `addend`)
- **Operators**; for example:
  - Arithmetic: `+`, `-`, `*`, `/`, `%`
  - Relational: `==`, `!=`, `<`, `<=`, `>`, `>=`
  - Logical: `&&`, `||`, `!`
Elements of a Compiler #2

- **Parser**: determines the program’s grammar
- **Semantic Analyzer**: determines what the program does
- **Intermediate Code Generator**: expresses, as an assembly-like program, what the program does
- **Optimizer**: makes code more efficient (faster)
- **Assembly Code Generator**: produces the final assembly code that represents what the program does
Phases of Compiling

- Compiler
- **Assembler**: turns assembly code into machine code
- **Linker/loader**: turns machine code into an *executable* file

Both the assembler and the linker/loader are invoked automatically by the compiler, so you don’t have to worry about them.
Compiling a C Statement

```
sum = a + b;
```

1. **Lexical Analysis**
   - IDENTIFIER [sum]
   - ASSIGN IDENTIFIER [a]
   - PLUS IDENTIFIER [b]

2. **Parsing**
   - ASSIGN
     - VARIABLE
     - EXPRESSION
       - ADD
         - VARIABLE
         - VARIABLE

3. **Semantic Analysis**
   - ASSIGN (VARIABLE [sum], ADDITION (VARIABLE [a], VARIABLE [b]))

4. **Intermediate Code Generation**
   - Load R00 from a
   - Load R01 from b
   - R02 = R00 + R01
   - Store R02 into sum

5. **Assembly Code Generation**
   - ld r00, a
   - ld r01, b
   - ad r02, r00, r01
   - st r02, sum
Assembly Code for hello_world.c #1

On Pentium4 Using gcc

pushl %ebp
movl %esp, %ebp
subl $8, %esp
subl $12, %esp
pushl $.LC0
call printf
addl $16, %esp
leave
ret

On IBM POWER4 Using gcc

mflr 0
stw 31,-4(1)
stw 0,8(1)
stwu 1,-64(1)
mr 31,1
lwz 3,LC..1(2)
bl .printf
nop
lwz 1,0(1)
lwz 0,8(1)
mtlr 0
lwz 31,-4(1)
blr

Different opcodes!
Assembly Code for hello_world.c #2

On Pentium4 Using gcc (GNU compiler)

pushl %ebp
movl %esp, %ebp
subl $8, %esp
subl $12, %esp
pushl $.LC0
call printf
addl $16, %esp
leave
ret

On Pentium4 Using icc (Intel compiler)

pushl %ebp
movl %esp, %ebp
subl $3, %esp
andl $-8, %esp
addl $4, %esp
push $__STRING.0
call printf
xorl %eax, %eax
popl %ecx
movl %ebp, %esp
popl %ebp
ret

Different sequences of instructions!
Machine Code for `hello_world.c`

10111101010100010101011110101001  
10111010101000010101101011101000  
01110101010000101011010111010001  
01010100101010101101010101011010  

...
How to Program in Machine Language Directly

1. Write the assembly code for the program directly by hand; that is, not in a high level language.

2. For each assembly language instruction, look up the bit pattern of the associated machine code.

3. On the computer console, flip switches to match the bit pattern of the machine code.

4. Press the “Run” button.

Actually, on modern computers, programming directly in machine language is just about impossible.
Why Not Do Everything in Machine Language?

Incredibly tedious and ridiculously error-prone!

Fun and easy!
Not nearly as tedious or error-prone!
Why Not Do Everything in Assembly Language?

Can’t be run on any other kind of computer. May be completely obsolete in a few years.

Portable to many kinds of computers. Will still be useable in 20 years (“legacy” codes).
The Programming Process

1. Formulate Problem
2. Construct Algorithm
3. Choose Programming Language
4. Write Program
5. Compile
6. Run
7. Bugs?
   - Yes: Debug
   - No: Go back to Run
8. Bugs?
   - Yes: Go back to Compile
   - No: Get an A/Impress Your Boss/Sell for Zillions!
What is an Algorithm?

An *algorithm* is:
- a step-by-step method
- that is written in a natural language (for example, English) or in *pseudocode* (something that sort of looks like a programming language but isn’t as precise), rather than in a programming language,
- that solves a well-defined (though not necessarily useful) problem,
- on a well-defined set of inputs (which may be empty),
- using finite *resources* (for example, computing time and storage),
- and that produces a well-defined set of outputs (which may be empty).
An algorithm is a language-independent way of expressing the method of solving a problem; that is, an algorithm could be expressed in two different languages (for example, English and Japanese) and still be the same algorithm.

A program, by contrast, is a language-dependent implementation of the method of solving a problem; that is, the same set of steps expressed in two different programming languages would be two different programs, even if the two programs accomplished exactly the same result.

Many programs, but not all, implement algorithms.
Algorithm Example: Eating a Bowl of Corn Flakes

- Get bowl from cupboard
- Get spoon from drawer
- Get box of corn flakes from pantry
- Get jug of milk from refrigerator
- Place bowl, spoon, corn flakes and milk on table
- Open box of corn flakes
- Pour corn flakes from box into bowl
- Open jug of milk
- Pour milk from jug into bowl
- Close jug of milk
- Go to table
- Pick up spoon
- Repeat until bowl is empty of corn flakes
  - Using spoon, pick up corn flakes and milk from bowl
  - Put spoon with corn flakes and milk into mouth
  - Pull spoon from mouth, leaving corn flakes and milk
  - Repeat ...
    - Chew
    - ... until mouthful is mush
    - Swallow
- Leave mess for housemates to clean up
Top-Down Design

Algorithms for most non-trivial problems tend to be fairly complicated.

As a result, it may be difficult to march from an algorithm’s beginning to its end in a straight line, because there may be too many details to keep in your head all at one time. Instead, you can use a technique called *top-down design*: start with the whole problem, then break it into a few pieces, then break each of those pieces into a few pieces, then break each of those pieces into a few pieces, and so on, until each piece is pretty small.
Eating Cornflakes: Top Level

- Get stuff
- Transport stuff
- Set up stuff
- Eat
- Finish