Software Lesson 2 Outline

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 symbols together to get valid statements
- ***Semantics***: a set of rules for interpreting the **meaning** of a grammatically valid statement

Kinds of Languages

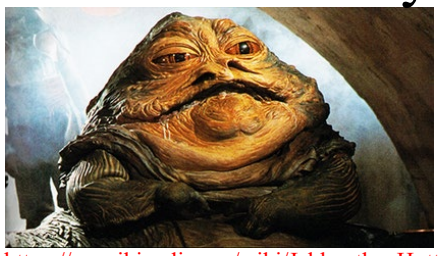
- ***Natural languages***: used in human communication
- ***Programming languages*** (also known as ***formal languages***): used by computers (among others)

Natural Languages #1

- There are said to be 7000+ natural languages in the world:

https://www.ethnologue.com/guides/how-many-languages

- Examples: English, Chinese, Swahili, Navajo, Quechua, Maori
- Not all natural languages arise naturally – some are created by people, on purpose.



https://en.wikipedia.org/wiki/Jabba_the_Hutt

https://en.wikipedia.org/wiki/Legolas

https://en.wikipedia.org/wiki/Worf

https://en.wikipedia.org/wiki/Incubus_(1966_film)

- 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 pachisi game while we watch your anime?"

https://en.wikipedia.org/wiki/Parcheesi

https://www.indiewire.com/gallery/the-20-most-iconic-characters-in-studio-ghibli-history/big-totoro/

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."

  OR

  - According to him, at what time was she going?

- **"You can't put too much water in a nuclear reactor."**

  could be interpreted as:

  - You shouldn't put a lot of water in a nuclear reactor.

  OR

  - There's no upper limit to how much water you can put in a nuclear reactor.

https://www.onesnladay.com/wp-content/uploads/2019/02/11-17-1984_0.53.55.00-300x225.jpg

Natural Languages #4

- **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

PROPERTY	*NAT'L*	*PROG*
Completely described and **rigidly governed** by formal rules	no	**YES**
CAN mix the words of multiple languages, or the syntax of multiple languages, in the same program	**YES**	no
CAN be ambiguous	**YES**	no
Words and syntax must be **EXACTLY** correct in every way	no	**YES**

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 embedded systems (originally designed for interactive TV)
  - HTML for hypertext (webpages)
  - SAS for statistics

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

Assembly Languages

- **Human-readable**
- **Specific to a particular CPU family**; for example:
  - Intel/AMD x86 (PCs, servers, some handhelds)
  - ARM (handhelds such as cell phones and tablets)
  - IBM POWER (server computers)
- 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

Converting Between Languages

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 done before executing the program
- Example compiled languages: Fortran, 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
- Example interpreted languages: Perl, HTML, SAS, Mathematica, Unix "shell" (interactive system within Unix)

Assembler

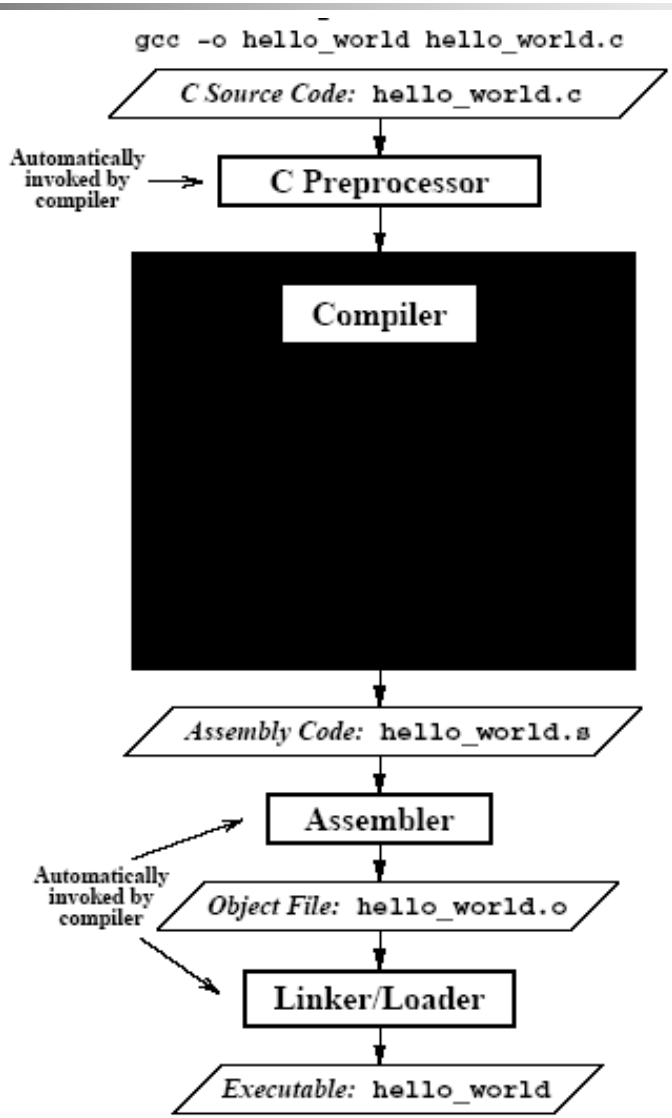
- Converts a human-readable CPU-specific **assembly code** into CPU-specific, non-human-readable **machine language**
- Like a compiler, but for a low level assembly language instead of for a high level language

Our Old Friend `hello_world.c`

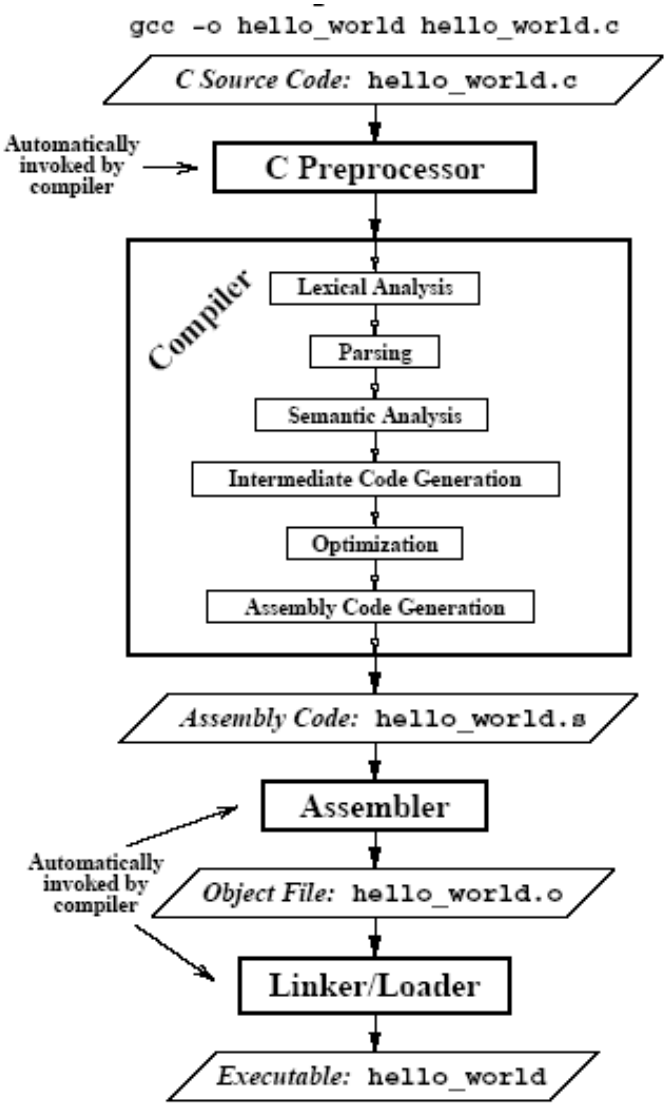
```
% cat hello_world.c
/*
 ************************************************
 *** Program: hello_world                     ***
 *** Author: Henry Neeman (hneeman@ou.edu)    ***
 *** Course: CS 1313 010 Fall 2022            ***
 *** Lab: Sec 014 Fridays 1:30pm              ***
 *** Description: Prints 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



Compiler Details (cont'd)



Elements of a Compiler #1

- ***Lexical Analyzer***: identifies a program's "word" elements:
  - ***Keywords*** (for example, `int`, `while`)
    - These are built into the programming language and cannot be changed by programmers.
  - ***Constants*** (for example, `5`, `0.725`, `"Hello, world!"`, delimited by double quotes on both ends)
  - User-defined ***identifiers*** (for example, `addend`)
  - ***Operators***; for example:
    - Arithmetic: `+` `-` `*` `/` `%`
    - Relational: `==` `!=` `<` `<=` `>` `>=`
    - Logical: `&&` `||` `!`

These will be explained soon.

Elements of a Compiler #2

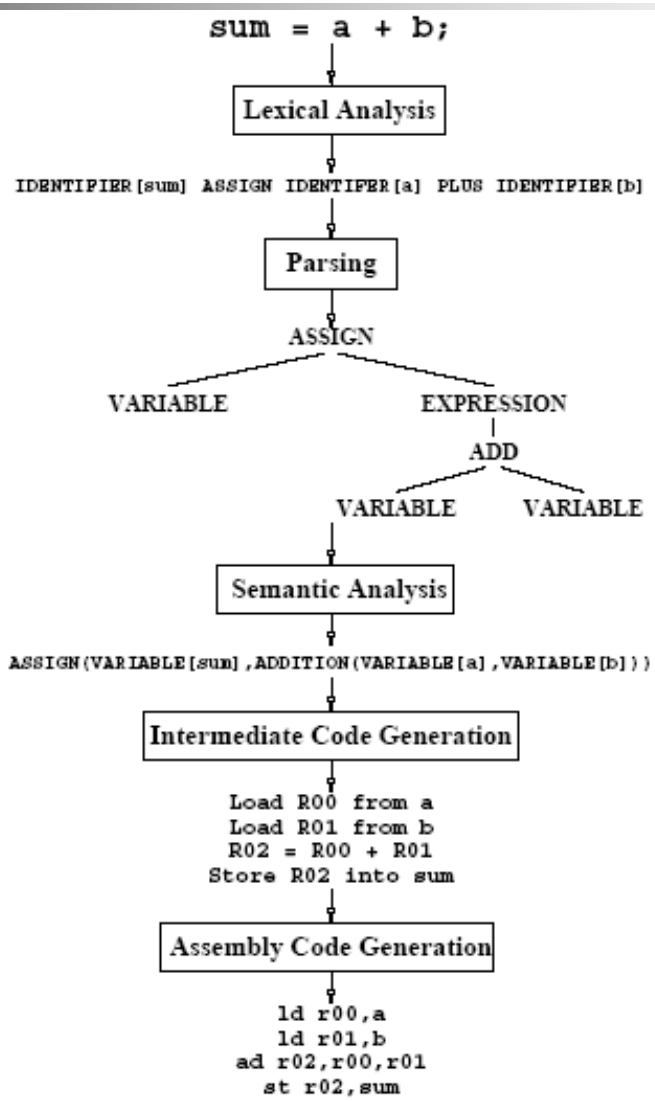
- ***Parser***: determines the program's grammar
- ***Semantic Analyzer***: determines what the program does
- ***Intermediate Code Generator***: expresses, as an assembly-like program, what the program does
- ***Optimizer***: makes code more efficient (faster)
- ***Assembly Code Generator***: produces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



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
```

Different ***opcodes***!

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
```

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
```

Different sequences of instructions!

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
```

Machine Code for `hello_world.c`

```
10111101010100010101011110101001
10111010101000010101101011101000
01110101010000101011010111010001
01010100101010101101010101011010
...
```

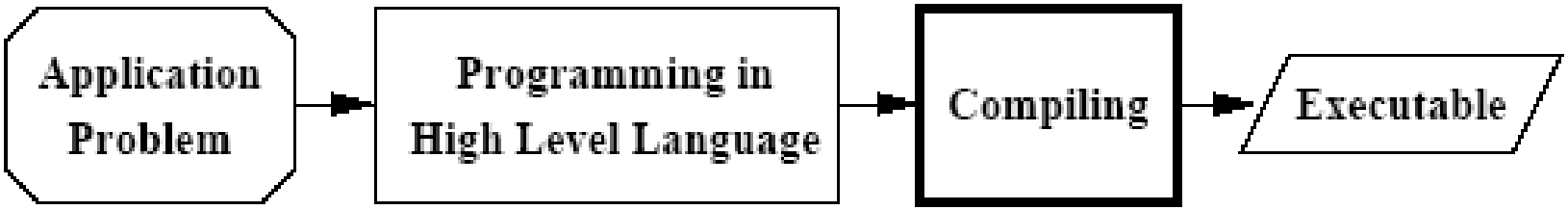
How to Program in Machine Language Directly

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.

On modern computers, programming directly in machine language is just about impossible.

Why Not Do Everything in Machine Language?

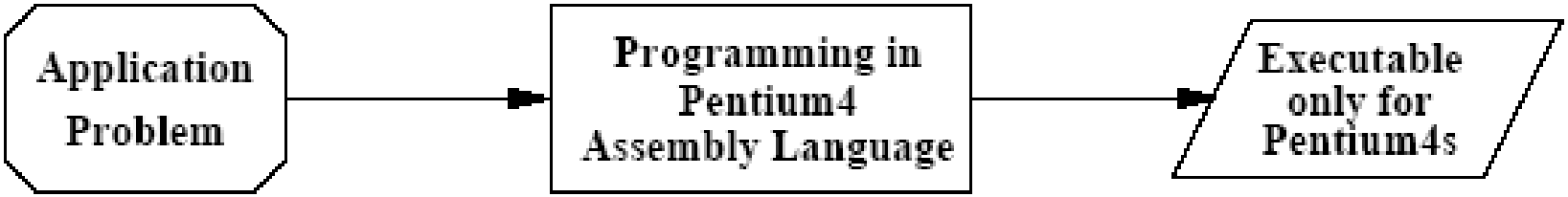
Incredibly tedious and ridiculously error-prone!



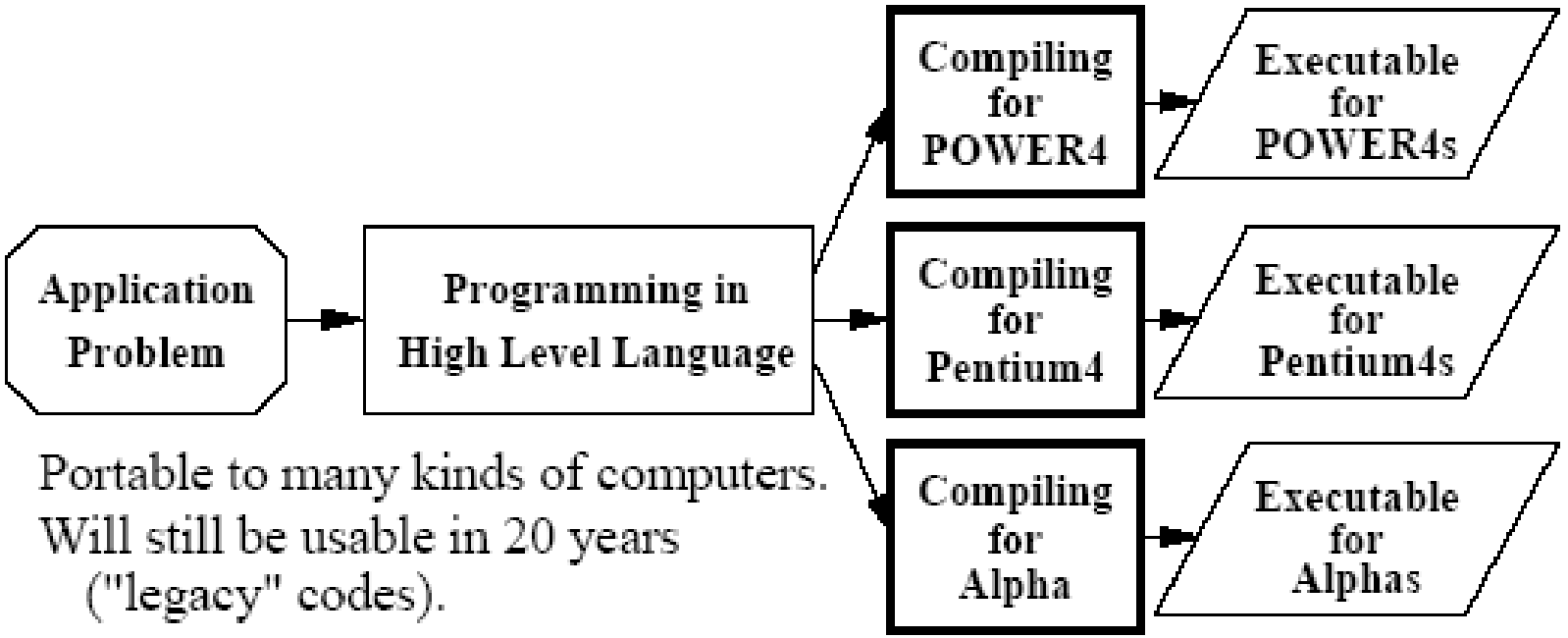
~~Fun and easy!~~

Not nearly as tedious or error-prone!

Why Not Do Everything in Assembly Language?

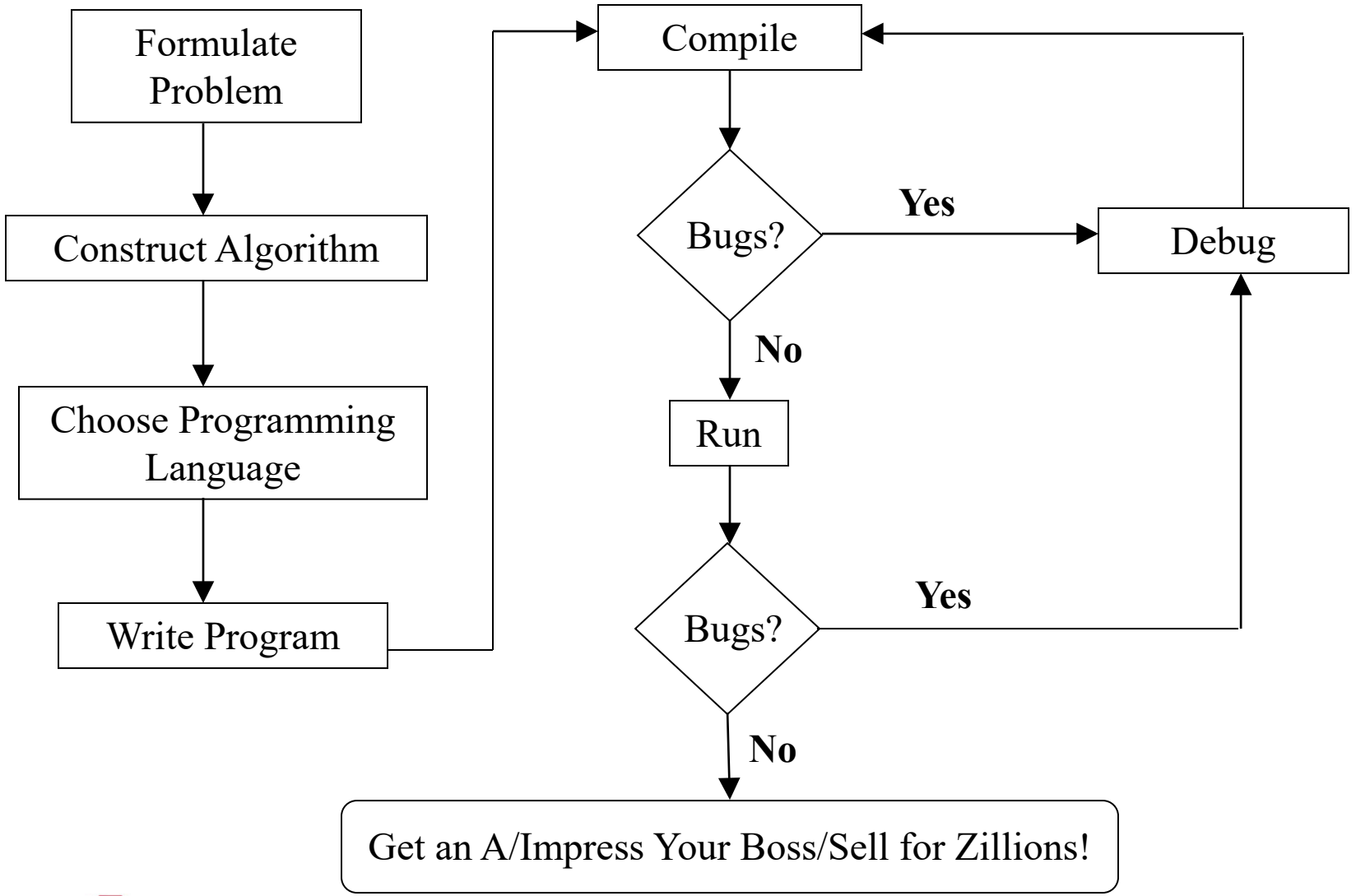


Can't be run on any other kind of computer.
May be completely obsolete in a few years.



Portable to many kinds of computers.
Will still be usable in 20 years
("legacy" codes).

The Programming Process



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), instead of 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).

Algorithms

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.

Programs that don't implement algorithms often implement ***heuristics***, which typically are inexact but good enough.

The word "algorithm" comes from the name of the 9th century mathematician, Muhammad ibn Musa al-Khwarizmi.

https://en.wikipedia.org/wiki/Algorithm

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