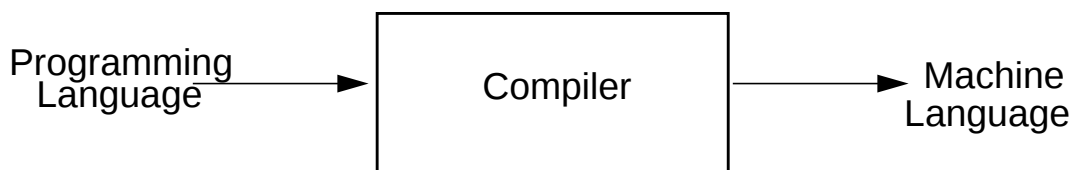


Compilers

Compilers are fundamental to modern computing.

They act as *translators*, transforming human-oriented *programming languages* into computer-oriented *machine languages*.

To most users, a compiler can be viewed as a “black box” that performs the transformation shown below.



A compiler allows programmers to ignore the machine-dependent details of programming.

Compilers allow programs and programming skills to be *machine-independent*.

Compilers also aid in detecting programming errors (which are all too common).

Compiler techniques also help to improve computer security. For example, the Java Bytecode Verifier helps to guarantee that Java security rules are satisfied.

Compilers currently help in protection of intellectual property (using *obfuscation*) and provenance (through *watermarking*).

History of Compilers

The term *compiler* was coined in the early 1950s by Grace Murray Hopper. Translation was viewed as the “compilation” of a sequence of machine-language subprograms selected from a library.

One of the first real compilers was the FORTRAN compiler of the late 1950s. It allowed a programmer to use a problem-oriented source language.

Ambitious “optimizations” were used to produce efficient machine code, which was vital for early computers with quite limited capabilities.

Efficient use of machine resources is still an essential requirement for modern compilers.

Compilers Enable Programming Languages

Programming languages are used for much more than “ordinary” computation.

- TeX and LaTeX use compilers to translate text and formatting commands into intricate typesetting commands.
- Postscript, generated by text-formatters like LaTeX, Word, and FrameMaker, is really a programming language. It is translated and executed by laser printers and document previewers to produce a readable form of a document. A standardized document representation language allows documents to be freely interchanged, independent of how

they were created and how they will be viewed.

- Mathematica is an interactive system that intermixes programming with mathematics; it is possible to solve intricate problems in both symbolic and numeric form. This system relies heavily on compiler techniques to handle the specification, internal representation, and solution of problems.
- Verilog and VHDL support the creation of VLSI circuits. A *silicon compiler* specifies the layout and composition of a VLSI circuit mask, using standard cell designs. Just as an ordinary compiler understands and enforces programming language rules, a silicon compiler understands and enforces the design rules that dictate the feasibility of a given circuit.

- Interactive tools often need a programming language to support automatic analysis and modification of an artifact.
How do you *automatically* filter or change a MS Word document? You need a text-based specification that can be processed, like a program, to check validity or produce an updated version.

When do We Run a Compiler?

- **Prior to execution**

This is standard. We compile a program once, then use it repeatedly.

- **At the start of each execution**

We can incorporate values known at the start of the run to improve performance.

A program may be partially compiled, then completed with values set at execution-time.

- **During execution**

Unused code need not be compiled. Active or “hot” portions of a program may be specially optimized.

- **After execution**

We can profile a program, looking for heavily used routines, which can be specially optimized for later runs.

WHAT do Compilers Produce?

Pure Machine Code

Compilers may generate code for a particular machine, not assuming any operating system or library routines. This is “pure code” because it includes nothing beyond the instruction set. This form is rare; it is sometimes used with system implementation languages, that define operating systems or embedded applications (like a programmable controller). Pure code can execute on bare hardware without dependence on any other software.

Augmented Machine Code

Commonly, compilers generate code for a machine architecture *augmented* with operating system routines and run-time language support routines.

To use such a program, a particular operating system must be used and a collection of run-time support routines (I/O, storage allocation, mathematical functions, etc.) must be available. The combination of machine instruction and OS and run-time routines define a *virtual machine*—a computer that exists only as a hardware/software combination.

Virtual Machine Code

Generated code can consist *entirely* of virtual instructions (no native code at all). This allows code to run on a variety of computers.

Java, with its JVM (Java Virtual Machine) is a great example of this approach.

If the virtual machine is kept simple and clean, its interpreter can be easy to write. Machine interpretation slows execution by a factor of 3:1 to perhaps 10:1 over compiled code.

A “Just in Time” (*JIT*) compiler can translate “hot” portions of virtual code into native code to speed execution.

Advantages of Virtual Instructions

Virtual instructions serve a variety of purposes.

- They simplify a compiler by providing suitable primitives (such as method calls, string manipulation, and so on).
- They aid compiler transportability.
- They may decrease in the size of generated code since instructions are designed to match a particular programming language (for example, JVM code for Java).

Almost all compilers, to a greater or lesser extent, generate code for a virtual machine, some of whose operations must be interpreted.