Compilation Pipeline

CS 2130: Computer Systems and Organization 1

Xinyao Yi Ph.D.
Assistant Professor

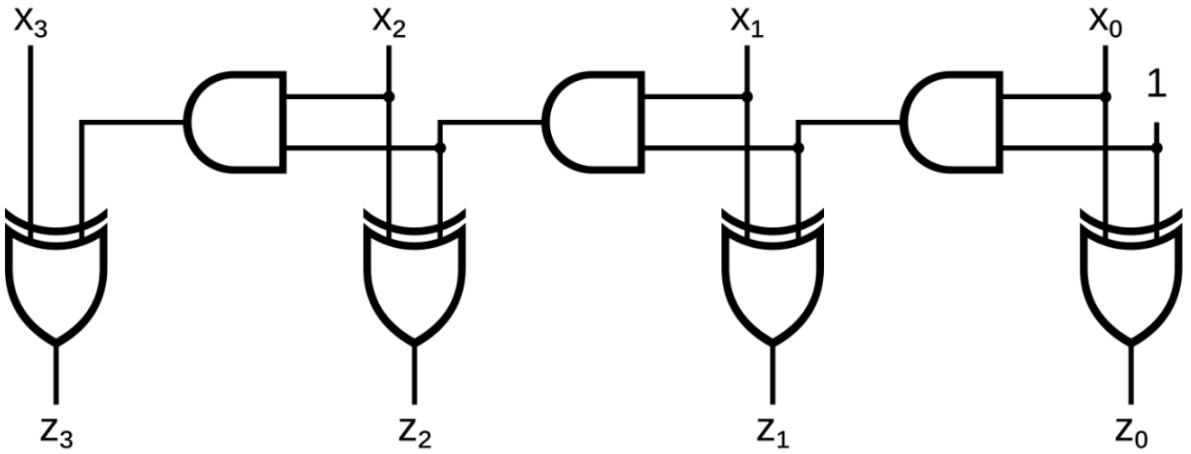
UNIVERSITY of VIRGINIA | ENGINEERING

Announcements

- Homework 6 due Monday at 11:59pm

10. [14 points] Using only 2-input `and`, `or`, `xor` gates, 1-input `not` gates, and constants `0` and/or `1`, draw a circuit that has 3-bit input x with bits labeled x_2, x_1, and x_0; 3-bit output with bits labeled z_2, z_1, z_0; which computes $z = -x$ in 3-bit two's complement. *Clearly label your inputs and output bits individually.*

Increment Circuit



Category	**Patent**	**Copyright**	**License Agreement**
Protected Object	Technological inventions and innovations	Creative expressions and forms (e.g., code, text, images)	Usage rights of protected content
Source of Right	Granted by government agencies after examination	Automatically arises upon creation	Established through contractual agreement
Automatic Acquisition	❌ No	✅ Yes	❌ No (requires signing)
Duration	Typically 20 years	Author's lifetime + a number of years (e.g., 70 years in the U.S.)	Determined by contract terms
Nature of Right	Exclusive right to make, use, or sell an invention	Prevents copying or unauthorized reproduction	Defines how others can use or distribute the work
Examples	A new GPU scheduling algorithm, hardware design	Source code, research paper, textbook	MIT License, GPL, Apache 2.0, commercial EULA
Key Focus	Innovation and technical exclusivity	Expression and originality	Permission and terms of use

Patents Cold War

- The "Patent Cold War" describes a modern corporate phenomenon where major technology companies (Apple, Google, IBM, Microsoft, Qualcomm, etc.) stockpile patents—not primarily to innovate, but to defend against lawsuits or block competitors.
- It's called a "cold war" because companies deter each other through mutual threats of litigation, much like nuclear deterrence.

📱 *Apple vs. Samsung (2011–2020):* Massive smartphone patent battles over design and gestures.

🔍 *Google vs. Oracle:* Decade-long litigation over Java API copyrights, shaping software development law.

💾 *IBM and Microsoft patent pools:* Used to maintain dominance and restrict new entrants.

Some Facts

- IBM files **8,000+ patents annually**, but many are never implemented.
- Studies show that in **high-patent-density fields** (semiconductors, software), innovation rates may decline.
- The U.S. Supreme Court's *Alice Corp. v. CLS Bank (2014)* decision ruled that **abstract software algorithms are not patentable**, aiming to limit excessive claims.
- In contrast, **Tesla (2014)** opened all its electric vehicle patents to promote industry-wide innovation—a symbolic move against the "patent cold war."

Discuss

- Do modern patent systems still promote innovation—or do they mostly protect big companies?
- Should algorithms and software be patentable, given that they are often abstract ideas?
- How can startups survive in industries dominated by patent-rich corporations?
- Is it ethical for companies to file thousands of patents purely to block competition?
- Should universities and researchers embrace open-source sharing instead of patent races?

Lessons

- **The system needs rebalancing.**
  - Patent protection is still essential — without it, true innovators might lose incentives.
  - But reform is needed to ensure **patents serve the public good**, not just corporate power.
  - Solutions include improving patent quality, limiting software patentability, shortening terms for fast-moving fields, and encouraging open innovation models.
- **Emerging trend: "Open Innovation" as an antidote.**
  - Companies like Tesla, IBM (with open-source AI frameworks), and several universities are embracing openness.
  - Sharing technology publicly can **accelerate collective progress** and reduce the wasteful "arms race" of patents.

Compilation Pipeline

Turning our code into something that runs

- **Pipeline -** a sequence of steps in which each builds off the last

Why did we discuss assembly?

C

C is a thin wrapper around assembly

- This is by design!
- Invented to write an operating system
  - Can write inline assembly in C
- Many other languages decided to look like C

Simple C Example

```
int main() {
    int y = 5;
    return 0;
}
```

Compilation Pipeline

Earlier, we saw:

- C files (`.c`) compiled to assembly (`.s`)
- Assembly (`.s`) assembled into object files (`.o`)
- Object files (`.o`) linked into a program / executable

Compiling C to Assembly

Multiple stages to compile C to assembly

- Preprocess - produces C
  - C is actually implemented as 2 languages:
    C preprocessor language, C language
  - Removes comments, handles preprocessor directives (#)
  - `#include`, `#define`, `#if`, `#else`, …
- Lex - breaks input into individual tokens
- Parse - assembles tokens into intended meaning (parse tree)
- Type check - ensures types match, adds casting as needed
- Code generation - creates assembly from parse tree

Compiling C to Assembly

Compiling C to Assembly

Errors

Compile-time errors

- Errors we can catch during compilation (this process)
- **Before** running our program

Runtime errors

- Errors that occur when running our programs

Simple C Example

```
int main() {
    return 0;
}
```

The `main` function

- Start running the `main()` function
- `main` must return an integer - **exit code**
  - 0 = everything went okay
  - Anything else = something went wrong
- There *should* be arguments to main

Data Types in C

Integer data types

Data type	Size
char	
short	
int	
long	
long long	

Each has 2 versions: *signed* and *unsigned*

Data Types in C

Floating point

- float
- double

Data Types in C

Data Types in C

Pointers - how C uses addresses!

Data Types in C

Pointers - how C uses addresses!

- Hold the address of a position in memory
- Need to know the kind of information stored at that location

Example

```
int main() {
    int x = 3;
    long y = 4;
    int *a = &x;
    long *b = &y;
    long z = *a;
    int w = *b;
    return 0;
}
```

Example

```
int main() {
    int x = 3;
    long y = 4;
    int *a = &x;
    long *b = &y;
    long z = *a;
    int w = *b;
    return 0;
}
```

```
0000000000000000 <main>:
   0:   55                          push   %rbp
   1:   48 89 e5                    mov    %rsp,%rbp
   4:   31 c0                       xor    %eax,%eax
   6:   c7 45 fc 00 00 00 00        movl   $0x0,-0x4(%rbp)
   d:   c7 45 f8 03 00 00 00        movl   $0x3,-0x8(%rbp)
  14:   48 c7 45 f0 04 00 00        movq   $0x4,-0x10(%rbp)
  1b:   00
  1c:   48 8d 4d f8                 lea    -0x8(%rbp),%rcx
  20:   48 89 4d e8                 mov    %rcx,-0x18(%rbp)
  24:   48 8d 4d f0                 lea    -0x10(%rbp),%rcx
  28:   48 89 4d e0                 mov    %rcx,-0x20(%rbp)
  2c:   48 8b 4d e8                 mov    -0x18(%rbp),%rcx
  30:   48 63 09                    movslq (%rcx),%rcx
  33:   48 89 4d d8                 mov    %rcx,-0x28(%rbp)
  37:   48 8b 4d e0                 mov    -0x20(%rbp),%rcx
  3b:   48 8b 09                    mov    (%rcx),%rcx
  3e:   89 4d d4                    mov    %ecx,-0x2c(%rbp)
  41:   5d                          pop    %rbp
  42:   c3                          retq
```