

A Tour of Computer Systems

CSE 220: Systems Programming

Ethan Blanton & Carl Alphonse

Department of Computer Science and Engineering
University at Buffalo



Time Management

Make progress by **setting a timer**.

Set a timer for **15 minutes**. When it expires:

- Are you still working?
 - If not, why not? Fix the problem!
- Are you **making progress**?
 - If not, why not? Fix the problem!

Time spent is different from **results achieved**.

Concept versus Implementation

The C language and POSIX are **implementations** of systems.

There are many possible implementations.

Certain **conceptual considerations** are presented by underlying architecture.

We will look at some of those concepts.

Understanding How Things Work

“Why do I need to know this stuff?”

Abstraction is good, but don't forget reality!

Most CS courses emphasize abstraction

- Abstract data types
- Asymptotic analysis

These abstractions have limits

- Sometimes you need to understand the underlying implementation
- Sometimes the abstract interfaces are not as flexible or performant as you need
- Sometimes there are bugs

TopHat question

Poll a TopHat question!

Numeric Representations

`ints` are not integers, `floats` are not real numbers!

Example 1: Is $x^2 \geq 0$?

- `float`: yes!
- `int`: well ...
 - $40000 * 40000 \rightarrow 1600000000$
 - $50000 * 50000 \rightarrow ???$

Example 2: Is $(x + y) + z = x + (y + z)$?

- `int`: yes!
- `float`:
 - $(1e20 + -1e20) + 3.14 \rightarrow 3.14$
 - $1e20 + (-1e20 + 3.14) \rightarrow ???$

Computer Arithmetic

Computer operations **do have** mathematical properties.

However, you **cannot assume** all usual mathematical properties!

- Finite representations cause various effects
- Integer operations satisfy **ring** properties:
 - Commutativity, associativity, distributivity
- Floating point operations satisfy **ordering** properties:
 - Monotonicity, sign values

You must understand **which abstractions apply where**.

These are important issues for compiler writers, systems programmers, **serious application programmers**.

TopHat question

Poll a TopHat question!

Assembly Language

You **need to know** something about assembly.
You'll see it next (and learn it!) in CSE 341!

You'll probably never **write programs** in assembly.
(Compilers are better at it and much more patient than you are!)

Understanding assembly is key to understanding the machine.

Where Will I Use Assembly?

Understanding the behavior of programs in the presence of bugs

- High-level language models break down

Tuning program performance

- Understand optimizations the compiler can and cannot do
- Understand sources of program inefficiency

Implementing system software

- Compilers target assembly
- Operating systems manage hardware state

Creating and fighting malware

- Most malware uses assembly!

Memory Management and Layout

Memory matters.

Memory is not unbounded!

- It must be allocated and managed
- Many applications are memory-dominated

Memory referencing bugs are especially pernicious

- Their effects may be **distant in both time and space**

Memory performance is not uniform

- Cache and virtual memory effects can affect program performance
- Adapting programs to the memory system can have major speed implications

Why Memory Performance Matters

```
void copyij(int src[2048][2048],
            int dst[2048][2048]) {
    for (int i = 0; i < 2048; i++) {
        for (int j = 0; j < 2048; j++)
            dst[i][j] = src[i][j];
    }
}
```

3.8 ms

```
void copyji(int src[2048][2048],
            int dst[2048][2048]) {
    for (int j = 0; j < 2048; j++) {
        for (int i = 0; i < 2048; i++)
            dst[i][j] = src[i][j];
    }
}
```

72.2 ms

All that changed is **the order of the loops!**

Therac-25

An infamous accident in software engineering: Therac-25



<https://medium.com/swlh/software-architecture-therac-25-the-killer-radiation-machine-8a05e0705d5b>

- People died.
 - Arithmetic bugs were involved.
 - Poorly understood copied code was involved.
- (Stack Overflow kills!)

Toyota Acceleration

Some Toyota vehicles experienced unintended acceleration in the late 2000s.

- Toyota was fined **1.2 billion dollars**
- ~9 million vehicles were recalled

Expert analysis identified:

- Memory corruption from software bugs
- Copied code (“Stack overflow ...bugs led to memory corruption”)

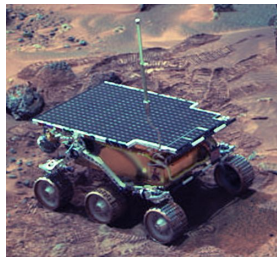
From material Copyright Phil Koopman, CC-BY-4.0

https://users.ece.cmu.edu/~koopman/pubs/koopman14_toyota_ua_slides.pdf

Mars Pathfinder

The Pathfinder Mars rover frequently stopped responding.

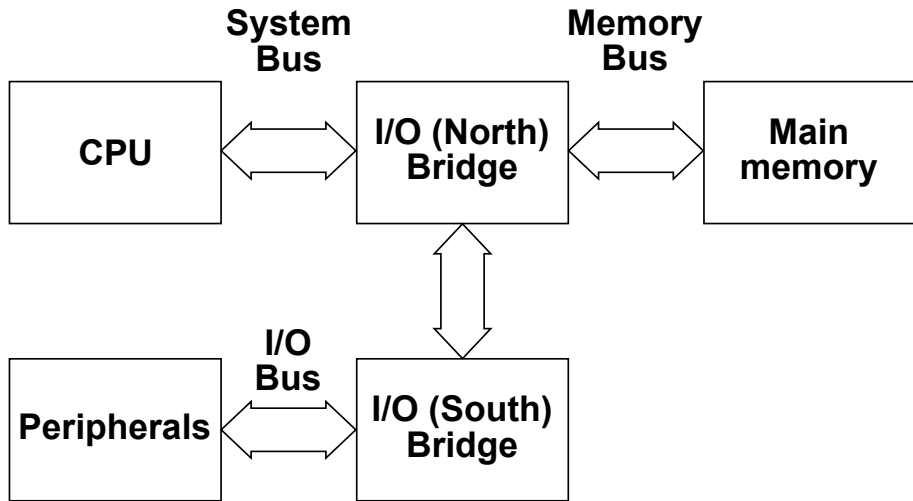
- The problem was **system scheduling**
- Low-level debugging identified the issue
- Testing **could have identified the problem** on the ground



(Credit: NASA)

<https://www.rapitasystems.com/blog/what-really-happened-to-the-software-on-the-mars-pathfinder-spacecraft>

A Bit About Architecture



Buses

A bus has a **width**, which is literally the **number of wires** it has.[¶]

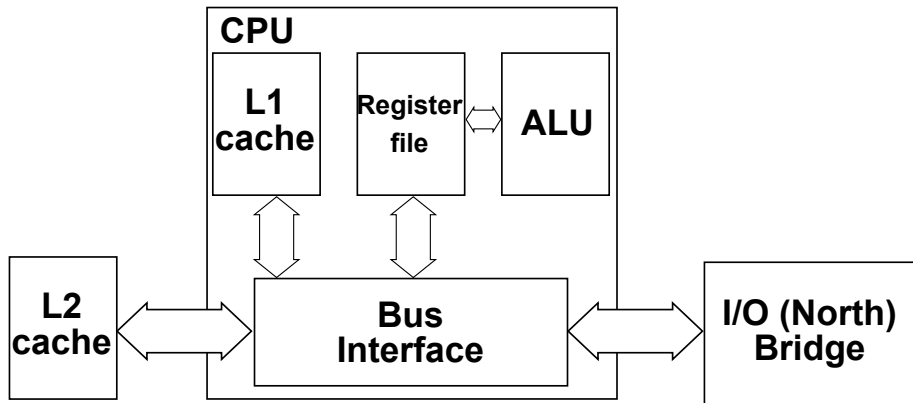
(This is a little less clear on a **serial bus**, where the width is a protocol convention.)

Each wire transmits **one bit per transfer**.

Every bus transfer is of that width, though some bits may be ignored.

Therefore, memory has a **word size** from the view of the CPU: the number of wires on that bus.

A Modern CPU



CPU Properties

Both **internal** and **external** busses have fixed widths.

A small number of storage locations called **registers**:

- Have **very fast** access time[¶]
- Have a fixed width
- Are fixed in number

The **ALU** performs computation.

- It may be able to access **only registers**
- It may be able to access **memory**
- It may have **arbitrary restrictions**

CPU ↔ Memory Transfer

The CPU **fetches data from memory** in **words** the width of the **memory bus**.

It places those words in **registers** the width of a **cpu word**.
This register width is the **native integer size**.¹

These word widths **may or may not be the same**.

If they're not, a transfer may require:

- multiple registers, or
- multiple memory transfers.

¹Some CPUs (including x86-64) can manipulate more than one size of integer in a single register.

Imposing Structure on Memory

That said, programming languages expose things like:

- Booleans
- classes
- strings
- structures

How is that?

We **impose meaning** on words in memory by **convention**.

E.g., as we saw before, a C string is a **sequence of bytes** that happen to be adjacent in memory.

Summary

- Architectural details matter
 - Bus widths
 - Numeric properties
 - Performance details
- C and POSIX are just one possible system
- All systems have those details
- Software correctness can be critically important

Next Time ...

- Memory allocation
- The program heap

References I

Optional Readings

- [1] Randal E. Bryant and David R. O'Hallaron. *Computer Science: A Programmer's Perspective*. Third Edition. Chapter 1: Intro, 1.1–1.7. Pearson, 2016.

License

Copyright 2020–2025 Ethan Blanton, All Rights Reserved.

Copyright 2024 Eric Mikida, All Rights Reserved.

Copyright 2022–2025 Carl Alphonc, All Rights Reserved.

Copyright 2019 Karthik Dantu, All Rights Reserved.

These slides use material from the CMU 15-213: Intro to Computer Systems lecture notes provided to instructors using CS:APP3e.

Reproduction of this material without written consent of the author is prohibited.

To retrieve a copy of this material, or related materials, see <https://www.cse.buffalo.edu/~eblanton/>.