Computer Systems, B1-2 2023-24

Introduction

Michael Kirkedal Thomsen

DIKU, September 4, 2023

Course structure

Representing information as bits

- Everything is bits
- Bit-level manipulation
- Integers

Overall outline

Week 36-37	Data representation and machine model
Week 38	C programming
Week 39-40	Memory and operating systems
Week 41	Concurrent and parallel programming
Week 42	Fall break
Week 43-45	Computer networks - application and transport layer
Week 46	No activities (reexam week)
Week 47	Computer networks - security and efficiency
Week 48-51	Machine architecture
Week 52	Christmas vacation
Week 1-2	Computer networks and security - network and link layer
Week 4	4-hour written exam

Lectures

- Mondays 13:15-15:00
- Wednesdays 10:15-12:00

Lecturers

 Michael Kirkedal Thomsen: Course root, Networks and Security

 Finn Schirmer Andersen: Computer Architecture

 David Gray Marchant: C programming, Operating Systems and Network programming

Teaching Material

COD Computer Organization and Design (RISC-V Edition), David A. Patterson and John L. Hennesy, second edition, ISBN: 978-0-12-820331-6

KR Computer Networking: A Top-Down Approach, James F. Kurose and Keith W. Ross, Pearson, 8th and Global Edition, ISBN 13: 978-1-292-40546-0 (This book will not be used before December)–7th edition is also acceptable

JG Modern C, Jens Gustedt, `https://hal.inria.fr/hal-02383654/document`

OSTEP Operating Systems: Three Easy Pieces, Remzi H. Arpaci-Dusseau and Andrea C. Arpaci-Dusseau, `https://pages.cs.wisc.edu/~remzi/OSTEP/`

?? Some notes and book chapters that will be made available through the detailed course schedule

COD is (and KR will be) available at Academic Books at Panum (`http://www.academicbooks.dk/`) and Polyteknisk Boghandel at Biocenteret (`http://www.polyteknisk.dk/`).

TAs

TAs:

- Axel Kanne
- Christian Franck
- Jakob Holst Svenningsen
- Jóhann Utne
- Kjartan Martin Johannesen
- Lars Peter Jeppesen
- Lucas Haahr Yri

TAs will gladly help with

- Group members
- The right way to the administration
- A fellow student that can answer questions (or help find the answers)

Exercises and Assignment Cafées

Exercises

- Mondays 15:15-17:00
- Wednesdays 13:15-15:00

Exercises are only for posted exercises. Work on the exercises as they will prepare you both for the exam and assignments.

Cafés

- Wednesdays 15:15-17:00
- Fridays 14:15-16:00

Cafés are primarily for help with assignments.

Details: `https://github.com/diku-compSys/compSys-e2023-pub`.
Also on Discord. See Absalon/Modules.

Groups

Size

2-3 student advised. 1 can be accepted but not recommended. More than 3 is only allowed is on special circumstances

- Sign up for classes with your group-mates on Absalon
- If you need one or more members
  - Look on announcements for details (use Absalon and Discord)
  - TA can help

Assignments

- There are 7 assignment in total during the course with deadline roughly every week or second week (all Sundays). The assignments will be evaluated with points.
- Assignments will be awarded zero to 4 points.
- You are required to achieve at least 50 % of the total number of points (equal to 12).
- Also we will require that you achieve points in each the of topics of the course to ensure that you have touched all parts of the curriculum.
- Assignments are made to be solved in groups of 2-3 students, but you can also do them alone.

Assignment rules

The Fundamental Principle of Group Assignments

Each group must make their own solution.

This means

- You can talk with other people about the assignments: Teachers, TAs, other students, etc.

- You cannot share written code with other groups.
- You are not allowed to use code that you did not write yourself without proper citation.
- You cannot share written text with other groups.
- You are not allowed to use text of material without proper citation
  - This also includes material provided on the course.
- You are only allowed to use ChatGPT and other AI as any other person.

Assignments vs. exercises

- Note! Both are equally important
- Assignments:
  - Seek to test learning goals that relates to implementation and development of computer systems.
  - Do not fully prepare you for the written exam.
- Exercises:
  - Help you understand the theoretical parts of the material.
  - Prepare you for part of the exam.

Tools

- RARS - RISC-V simulator
- C compiler – gcc (clang on macOS)
- C debugger – gdb (lldb on macOS)
- Profiler – Valgrind (perhaps leaks on macOS)
- You can also install all tools on you laptop
  - Linux: most available though apt
  - macOS: most available though Homebrew
  - Windows: Windows Subsystem for Linux

- Set up your tool chain
  - recommended using git to share code and reports in your group
  - Sign-up at GitHub today and apply for the *Student Developer Pack*
  - `https://education.github.com/`

- Tool-site is available on GitHub

Exam

- A 4-hour written exam; Jan 24 2024.
- The exam will be a BYOD-exam.
- The course syllabus is the exercises, assignments and reading material.
- Previous exams will available.

Questions?

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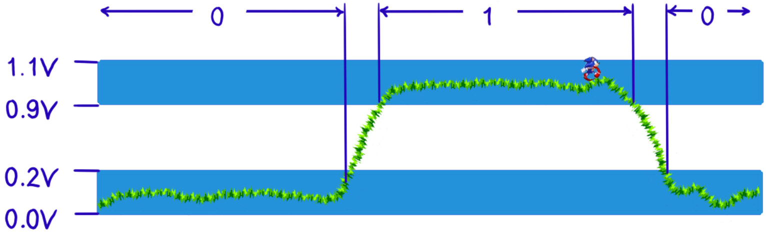
Everything is bits

- Each bit is 0 or 1.
- By interpreting sets of bits in various ways...
  - ...computers determine what to do.
  - ...represent and manipulate numbers, sets, strings—*data*.

Why bits? Why not decimals? Could it have been some some other way?

Everything is bits

- **Why bits? Electronic implementation.**
  - Easy to store with bistable elements.
  - Reliably transmitted on noisy and inaccurate wires (error correction).



- **... But there exist models that do not use bits.**
  - The Soviet Setun computer used ternary *trits*.
  - Quantum computers use *qubits* that are in a superposition of the two states.
    - ...error correction is the main challenge here.

Binary numbers

- **Base 2 number representation.**
  - Represent 15213_{10} as 11101101101101_2
  - Represent 1.20_{10} as $1.0011001100110011[0011]\ldots_2$
  - Represent 1.5213×10^4 as $1.1101101101101_2 \times 2^{13}$
- **Machine numbers are of some finite size.**
  - If we use k bits to represent a number, only 2^k distinct values are possible.
  - How we interpret those bits can vary.
  - **Why do we use finite-sized numbers?**

Binary numbers

- **Base 2 number representation.**
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  - **Why do we use finite-sized numbers?**
  - A "k-bit machine" handles numbers of up to k bits "natively" (meaning fast).

Encoding byte values

Byte = 8 bits

- (Machine-specific, but is true for all mainstream machines.)
- 256 different values.
- Binary 00000000_2 to 11111111_2.
- Decimal 0_{10} to 255_{10}.
- Hexadecimal 00_{16} to FF_{16}.
  - Base 16 number representation.
  - Uses characters 0–9 and A–F.
  - In C we write $FA1D37B_{16}$ as
    - `0xFA1D37B`
    - `0xfa1d37b` (case does not matter)

Hex	Dec	Bin
0	0	0000
1	1	0001
2	2	0010
3	3	0011
4	4	0100
5	5	0101
6	6	0110
7	7	0111
8	8	1000
9	9	1001
A	10	1010
B	11	1011
C	12	1100
D	13	1101
E	14	1110
F	15	1111

Example sizes of C types on various computers

C data type	Typical 16-bit	Typical 32-bit	Typical 64-bit	x86-64
`char`	1	1	1	1
`short`	1	2	2	2
`int`	2	4	4	4
`long`	4	4	8	8
`int32_t`	4	4	4	4
`int64_t`	8	8	8	8
`float`	4	4	4	4
`double`	8	8	8	8
`long double`	-	-	-	10
`pointer`	2	4	8	8

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Boolean algebra

Developed by George Boole in 19th century

- Algebraic representation of logic (“truth values”).
- Encode *true* as 1 and *false* as 0.

And

&	0	1
0	0	0
1	0	1

Or

|	0	1
0	0	1
1	1	1

Not

~	
0	1
1	0

Exclusive-or

^	0	1
0	0	1
1	1	0

- These operations can be implemented with tiny electronic *gates*.

General boolean algebras

- The truth tables generalise to operate on *bit vectors*, applied elementwise.

```
    01101001       01101001       01101001
  & 01010101     | 01010101     ^ 01010101     ~ 01101001
  ----------     ----------     ----------     ----------
    01000001       01111101       00111100       10010110
```

- This is the form they take in programming languages such as C.

Bit-level operations in most C-like languages

Operations `&`, `|`, `~`, `^` available in C.

- Apply to any integral type.
  - E.g. `long`, `int`, `short`, `char`...
- Interpret operands as bit vectors.
- Applied bit-wise.

Examples

- `~0x41 = 0xBE`
  - $\sim 01000001_2 = 10111110_2$
- `~0x00 = 0xFF`
  - $\sim 00000000_2 = 11111111_2$
- `0x69 & 0x55 = 0x41`
  - $01101001_2 \; \& \; 01010101_2 = 01000001_2$
- `0x69 & 0x55 = 0x7D`
  - $01101001_2 \; \& \; 01010101_2 = 01111101_2$

Shift operations

- **Left shift `x << y`**
  - Shift bit-vector `x` left by `y` positions.
    - Throws away excess bits on the left.
    - Fills with zeroes on right.
- **Right shift `x >> y`**
  - Shift bit-vector `x` right by `y` positions.
    - Throws away excess bits on the left.
  - Logical shift: Fill with 0s on left.
  - Arithmetic shift: Replicate most significant bit on left.
- **Undefined behaviour**
  - Shifting a negative amount or by the vector size or more.

`x`	`01100010`
`x << 3`	`00010000`
`x >> 2 (log)`	`00011000`
`x >> 2 (arith)`	`00011000`

`x`	`10100010`
`x << 3`	`00010000`
`x >> 2 (log)`	`00101000`
`x >> 2 (arith)`	`11101000`

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Encoding integers

Suppose x_i is the ith bit of a w-bit word (with x_0 being the least significant bit).

Unsigned

$$B2U(X) = \sum_{i=0}^{w-1} x_i \cdot 2^i$$

Two's complement

$$B2S(X) = -x_{w-1} \cdot 2^{w-1} + \sum_{i=0}^{w-2} x_i \cdot 2^i$$

```
int16_t x =  15213;
int16_t y = -15213;
```

	Decimal	Hex	Binary
x	15213	3 B 5 D	0011 1011 0110 1101
y	-15213	C 4 9 3	1100 0100 1001 0011

Sign bit

- For 2's complement, most significant bit (x_{w-1}) indicates sign.
  - 0 for non-negative.
  - 1 for negative.

Two's complement encoding example

```
int16_t x =  15213; // 0011 1011 0110 1101
int16_t y = -15213; // 1100 0100 1001 0011
```

Weight	15213		-15213	
1	1	1	1	1
2	0	0	1	2
4	1	4	0	0
8	1	8	0	0
16	0	0	1	16
32	1	32	0	0
64	1	64	0	0
128	0	0	1	128
256	1	256	0	0
512	1	512	0	0
1024	0	0	1	1024
2048	1	2047	0	0
4096	1	4096	0	0
8192	1	8192	0	0
16384	0	0	1	16384
-32768	0	0	1	-32768
Sum		**15213**		**-15213**

Let's play a game

`http://topps.diku.dk/compsys/integers.html`

Numeric ranges, here for 16-bit signed and unsigned integers

Unsigned

$$\text{UMin} = 0 = 0\ldots0_2$$
$$\text{UMax} = 2^w - 1 = 1\ldots1_2$$

Two's complement signed

$$\text{SMin} = -2^{w-1} = 10\ldots0_2$$
$$\text{SMax} = 2^{w-1} - 1 = 01\ldots1_2$$
$$-1 = 1\ldots1_2$$

Values for $w = 16$:

	Decimal	Hex	Binary
UMax	65535	F F F F	1111 1111 1111 1111
SMax	32767	7 F F F	0111 1111 1111 1111
SMin	-32768	8 0 0 0	1000 0000 0000 0000
-1	-1	F F F F	1111 1111 1111 1111
0	0	0 0 0 0	0000 0000 0000 0000

Values for different word sizes

	W			
	8	**16**	**32**	**64**
UMax	255	65,535	4,294,967,295	18,446,744,073,709,551,615
SMax	127	32,767	2,147,483,647	9,223,372,036,854,775,807
SMin	-128	-32,768	-2,147,483,648	-9,223,372,036,854,775,808

Observations

$$|\text{SMin}| = \text{SMax} + 1$$
$$|\text{UMax}| = 2 \cdot \text{SMax} + 1$$

Note the assymetric range.

C Programming

- `#include <limits.h>`
- Declares constants, e.g:
  - `ULONG_MAX`
  - `LONG_MAX`
  - `LONG_MIN`
- Values are platform-specific.

Unsigned and signed numeric values (here $w = 4$)

x	$B2U(x)$	$B2S(x)$
0000	0	0
0001	1	1
0010	2	2
0011	3	3
0100	4	4
0101	5	5
0110	6	6
0111	7	7
1000	8	-8
1001	9	-7
1010	10	-6
1011	11	-5
1100	12	-4
1101	13	-3
1110	14	-2
1111	15	-1

- **Equivalence**
  - Same encoding for non-negative values.
- **Uniqueness**
  - Every bit pattern represents distinct integer value.
  - Each representable integer has unique bit encoding.
  - The representation is **bijective**.
- **Can invert mappings**
  - $U2B(x) = B2U^{-1}(x)$
    - Bit pattern for unsigned integer.
  - $S2B(x) = B2S^{-1}(x)$
    - Bit pattern for two's complement integer.

Main takeaways

- Distinguish between **representation** and **interpretation**.
- Low-level values **do not describe their own structure**.
- Everything is built in layers.
- A good computer scientist adds new, clean, layers of abstraction.
    - A bad one adds layers that hide without simplifying.
    - A terrible one adds layers that complicate and obfuscate.
- **The point of this course is to show that there is no magic, only the work of careful people who put in a lot of effort.**