Computer Systems, B1-2 2025-26

Introduction

David Marchant

DIKU, September 1, 2025

Course structure

Course Content

Representing information as bits

Everything is bits

Bit-level manipulation

Integers

Hello

- David on the Discord, david.marchant@di.ku.dk, 772-01-0-s06
- Mit dankse er ikke godt
- I will make an appearance at exercise classes and assignment cafes
- I run Linux, not Mac, not Windows
- Questions and comments are always welcome

Lecturers

 Michael Kirkedal Thomsen: Course root, Networks and Security

 Finn Schirmer Andersen: Computer Architecture

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

TAs

TAs:

- Carl August Gjerris Hartmann
- Emil Viggo Dalsgaard
- Mads Presfeldt
- Malte Emil Wechter
- Philip Shun Buenaventura Jensen
- Tobias Andersen

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)

Who to contact

- Your TA - Should be able to at least guide you in the right direction about anything
- Me/Finn - We are responsible for most of the course material and assignments
- Michael - Course admin and exam qualification

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

Reading 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/`).

How to Use This Course

- Reading + Videos
  - Designed to compliment each other
  - Videos released the week before
  - Introduces the topic of the week
- Monday: Exercise class
  - Will assume you've seen the videos
  - First shot at playing around with the topics in practice
- Monday: Review lecture
  - Review videos, answer questions, go over material as more traditional lecture
  - Won't add anything not covered in videos or exercise. Attendance optional
- Wednesday: Exercise class
  - More practical practice
- Wednesday: Advanced lecture
  - Additional material not covered by videos.

Lectures

- Review Lecture:
  - Mondays 15:15-17:00
  - Reviews the material already covered in the reading + videos
  - Intended for those with questions from the material or exercises
  - Or those who would just rather learn from a lecture
  - If you're already ahead, this can be skipped
- Advanced Lecture:
  - Wednesdays 15:15-17:00
  - Additional course material not covered in the videos
  - Questions are also welcome here as always, but not the focus
  - Attendance is expected at these

Exercises and Assignment Cafés

Exercises

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

Cafés are primarily for help with assignments.

Details: `https://github.com/diku-compSys/compSys-e2025`. Also on Discord. See Absalon/Modules.

Assignments

- There are 6 assignment in total during the course with deadlines every two or three weeks (all Sundays). The assignments will be evaluated with points.
- Assignments will be awarded varying points (typically 4-6).
- 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.
- If you are resitting the course you do not need to resubmit assignments you've already completed, but practice is always best

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.
- *MUST* include a KU Generative AI Declaration

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.

Groups

Size

2-3 student advised. 1 can be accepted but not recommended. More than 3 is only allowed is in 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
- You can change groups at any time, but be reasonable to your colleagues

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

LLMs

- You are allowed to use them
- But we'd prefer you didn't for the programming tasks
- I won't be using them for this course, either to make or mark material
- Most of the programming tasks we're going to ask of you are not things you'd have to do in your regular work
- But the point is to do them to really learn what is important and why
- Learning these concepts are what makes you a Computer Scientist
- Remember the KU Generative AI Declaration

CompSys Masterclass

- September 3rd, 10.15-12.00
- DIKU 1-0-30, 1-0-34, and 1-0-37
- Introductions to many of the ancillary tools that will make life easier
  - Git
  - Unix
  - GDB
- Has been very helpful in previous years...

Exam

- A 4-hour written exam; Jan 21st 2025.
- The exam will be a BYOD-exam.
- The course syllabus is the exercises, assignments and reading material/videos.
- Previous exams will be available.

Registers

- I've been researching different methodologies for teaching and their effects on final grades
- But to present my findings I need actual data
- So I'll be collecting registers are lectures and exercise classes
- For research only! Will not affect your grades or whatnot, in fact probably won't be looked at till after the course is done
- Any research will only be in aggregate, e.g. everyone attending week 4 got a 12 on the exam
- Please be honest.
- KU numbers are most helpful, but anonymous responses are more helpful than nothing

Course structure

Course Content

Representing information as bits

Everything is bits

Bit-level manipulation

Integers

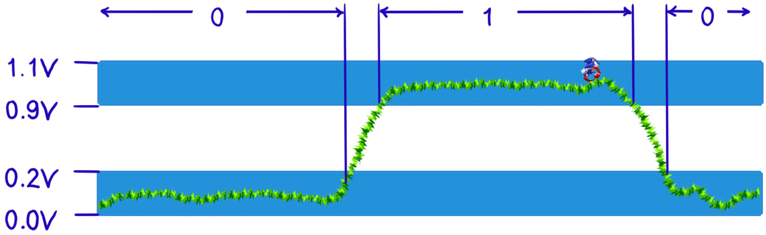
Everything is bits

- 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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- **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?**
  - 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`

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

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

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.**