# Computer Systems, B1-2 2024-25

# Introduction

David Marchant

DIKU, September 2, 2024

# 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:

- 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)

# 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 |

# 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/`).

# 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

# 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-e2024`. Also on Discord. See Absalon/Modules.

# 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.

## Course structure

- Course Content
- Flipped Learning

## Representing information as bits

- Everything is bits
- Bit-level manipulation
- Integers

# We're trying something new

- Feedback about this course has been essentially fine
- But understanding of how everything fits together isn't quite there
- We want to keep our teaching up to date
- Flipped Learning seems to offer some potential improvements
- This is very much an experiment however

# Flipped Learning

- Teaching topics will be introduced in your own time.
- Could be through videos, papers, activities etc.
- You should go through this material before each lecture.
- There will be some short self-assessment quizzes before each lecture to give you (and me) and idea of how well you've picked it up.
- Lecture time will be dedicated to going over the difficult parts, answering questions and additional activities.
- The initial plan is to run like this for the first few weeks, before reviewing to see if its worth continuing.

# Lectures

- Mondays 13:15-15:00
- Wednesdays 10:15-12:00
- Before each lecture you should complete the appropriate Absalon quiz. These aren't graded, but should tell you if you need to review the material more, and gives me an idea what I need to explain further.
- Generally, the first 45 mins will be used to answer questions about the weeks material and review the more difficult bits.
- The second 45 mins will be used to hopefully reinforce the core concepts and show how they connect to other parts of the course.

Questions?

## Course structure

- Course Content
- Flipped Learning

## Representing information as bits

- Everything is bits
- Bit-level manipulation
- Integers

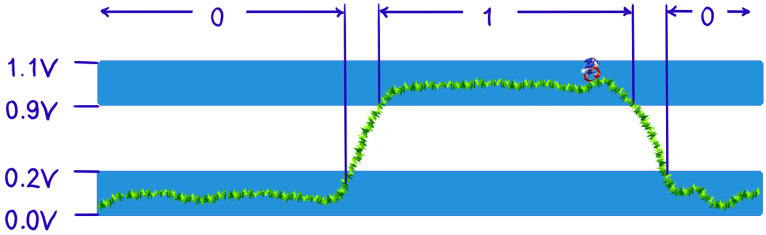
# Everything is bits

- 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 $1.5213 \times 10^4$ 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.**
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  - 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)

2whitegray!25

| 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

2whitegray!25

| 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 |

# Boolean algebra

**Developed by George Boole in 19th century**

- Algebraic representation of logic ("truth values").
- Encode *true* as 1 and *false* as 0. g>gray!25c

**And**

| gray!25 & | 0 | 1 |
|---|---|---|
| 0 | 0 | 0 |
| 1 | 0 | 1 |

**Or**

| gray!25 \| | 0 | 1 |
|---|---|---|
| 0 | 0 | 1 |
| 1 | 1 | 1 |

**Not**

| gray!25 ~ | |
|---|---|
| 0 | 1 |
| 1 | 0 |

**Exclusive-or**

| gray!25 ^ | 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 $i$th 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 | green!300 | green!300 |
| 0001 | green!301 | green!301 |
| 0010 | green!302 | green!302 |
| 0011 | green!303 | green!303 |
| 0100 | green!304 | green!304 |
| 0101 | green!305 | green!305 |
| 0110 | green!306 | green!306 |
| 0111 | green!307 | green!307 |
| 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.**