# EECS 10: Computational Methods in Electrical and Computer Engineering

Lecture 21

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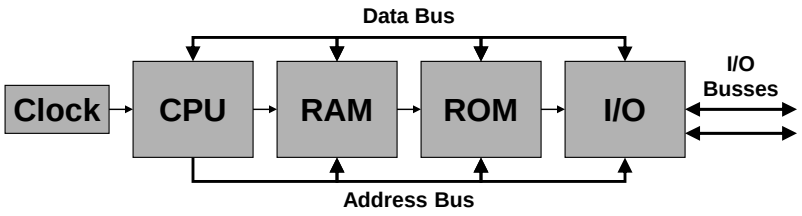
## Lecture 21: Overview

- Basic Computer Architecture
  - Computer components
- Binary Data Representation
  - Bits, bytes, and words
  - Memory sizes
  - Memory format
  - Number systems
  - Memory segmentation

# Basic Computer Architecture

- Essential Computer Components
  - Central Processing Unit (CPU)
    - e.g. Intel Pentium, Motorola PowerPC, Sun SPARC, ...
  - Random Access Memory (RAM)
    - storage for program and data, read and write access
  - Read Only Memory (ROM)
    - fixed storage for basic input/output system (BIOS)
  - I/O Units
    - Input/output units connecting to peripherals

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# Binary Data Representation

- Programs and data in a computer are represented in binary format
  - 1 *bit* (binary digit), 2 possible values ■ □
    - 0 (false, “no”, power off, “empty”, ...)
    - 1 (true, “yes”, power on, “solid”, ...)
  - 1 *byte* = 8 bits ($2^8$ = 256 values) ■□■□□□■□
    - in C, type **`char`** equals one byte*
  - 1 *word* = 4 bytes* ($2^{32}$ = 4294967296 values) ■□■□□□■■ □■■□■□■□ ■□■□□■■□ ■□■■□□■■
    - in C, type **`int`** equals one word
- Memory size is measured in Bytes
  - 1 KB = 1024 byte = 1 “kilo byte”
  - 1 MB = 1024*1024 byte = 1 “mega byte”
  - 1 GB = 1024*1024*1024 byte = 1 “giga byte”

*(*architecture dependent!)*

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# Binary Data Representation

- Memory is composed of addressable bytes
  - Example:
    1 KB of memory
  - What is the value at address 7?

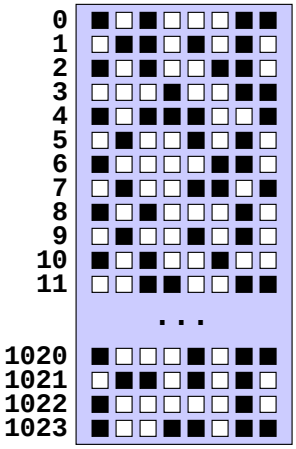
7 □■□□■■□■
7 6 5 4 3 2 1 0

$= 0*2^7 + 1*2^6 + 0*2^5 + 0*2^4 + 1*2^3 + 1*2^2 + 0*2^1 + 1*2^0$

$= 0*128 + 1*64 + 0*32 + 0*16 + 1*8 + 1*4 + 0*2 + 1*1$

$= 64 + 8 + 4 + 1$

$= 77$






# Binary Data Representation

- Number Systems
  - DEC: Decimal numbers
    - Base 10, digits 0, 1, 2, 3, ..., 9
    - e.g. $157 = 1*10^2 + 5*10^1 + 7*10^0$
  - BIN: Binary numbers
    - Base 2, digits 0, 1
    - e.g. $10011101_2 = 1*2^7 + 0*2^6 + ... + 1*2^0$
  - OCT: Octal numbers
    - Base 8, digits 0, 1, 2, 3, ..., 7
    - e.g. $235_8 = 2*8^2 + 3*8^1 + 5*8^0$
  - HEX: Hexadecimal numbers
    - Base 16, digits 0, 1, 2, 3, ..., 9, A, B, C, ..., F
    - e.g. $9D_{16} = 9*16^1 + 13*16^0$

# Binary Data Representation

- Number Systems

| DEC | BIN | OCT | HEX |
|---|---|---|---|
| 0 | 0000 | 0 | 0 |
| 1 | 0001 | 1 | 1 |
| 2 | 0010 | 2 | 2 |
| 3 | 0011 | 3 | 3 |
| 4 | 0100 | 4 | 4 |
| 5 | 0101 | 5 | 5 |
| 6 | 0110 | 6 | 6 |
| 7 | 0111 | 7 | 7 |
| 8 | 1000 | 10 | 8 |
| 9 | 1001 | 11 | 9 |
| 10 | 1010 | 12 | A |
| 11 | 1011 | 13 | B |
| 12 | 1100 | 14 | C |
| 13 | 1101 | 15 | D |
| 14 | 1110 | 16 | E |
| 15 | 1111 | 17 | F |



# Binary Data Representation

- Number Systems (signed vs. unsigned)

| SDEC | UDEC | BIN | OCT | HEX |
|---|---|---|---|---|
| 0 | 0 | 0000 | 0 | 0 |
| 1 | 1 | 0001 | 1 | 1 |
| 2 | 2 | 0010 | 2 | 2 |
| 3 | 3 | 0011 | 3 | 3 |
| 4 | 4 | 0100 | 4 | 4 |
| 5 | 5 | 0101 | 5 | 5 |
| 6 | 6 | 0110 | 6 | 6 |
| 7 | 7 | 0111 | 7 | 7 |
| -8 | 8 | 1000 | 10 | 8 |
| -7 | 9 | 1001 | 11 | 9 |
| -6 | 10 | 1010 | 12 | A |
| -5 | 11 | 1011 | 13 | B |
| -4 | 12 | 1100 | 14 | C |
| -3 | 13 | 1101 | 15 | D |
| -2 | 14 | 1110 | 16 | E |
| -1 | 15 | 1111 | 17 | F |

# Binary Data Representation

- Number Systems
  - Signed representation: *two's complement*
    - to obtain the negative of any number in binary representation, ...
      - ... invert all bits,
      - ... and add 1
  - Example: 4-bit two's complement

| SDEC | UDEC | BIN | OCT | HEX |
|---|---|---|---|---|
| ... | ... | ... | ... | ... |
| 7 | 7 | 0111 | 7 | 7 |
| -8 | 8 | 1000 | 10 | 8 |
| -7 | 9 | 1001 | 11 | 9 |
| ... | ... | ... | ... | ... |

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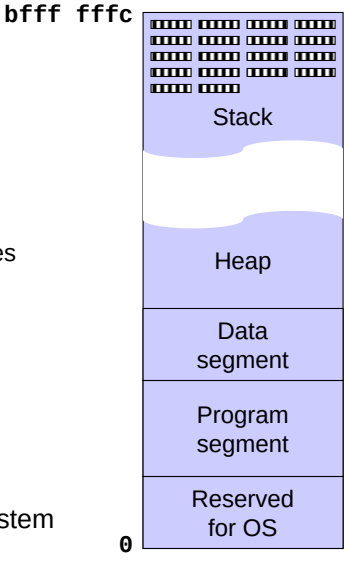
# Binary Data Representation

- Memory Segmentation
  - typical (virtual) memory layout on processor with 4-byte words and 1 GB of memory
  - Stack
    - grows and shrinks dynamically
    - function call hierarchy
    - stack frames with local variables
  - Heap
    - "free" storage
    - dynamic allocation by the user
  - Data segment
    - global (and static) variables
  - Program segment
    - stores binary program code
  - Reserved area for operating system

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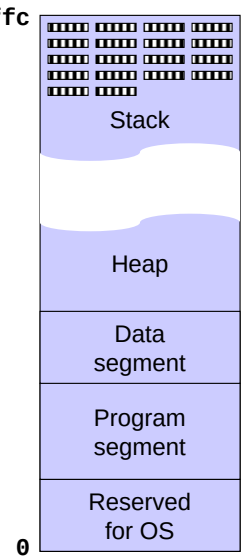
# Binary Data Representation

- Memory Segmentation
  - typical (virtual) memory layout on processor with 4-byte words and 1 GB of memory
- Memory errors
  - *Out of memory*
    - Stack and heap collide
  - *Segmentation fault*
    - access outside allocated segments
    - e.g. access to segment reserved for OS
  - *Bus error*
    - mis-aligned word access
    - e.g. word access to an address that is not divisible by 4

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