EECS 10: Computational Methods in Electrical and Computer Engineering

Lecture 20

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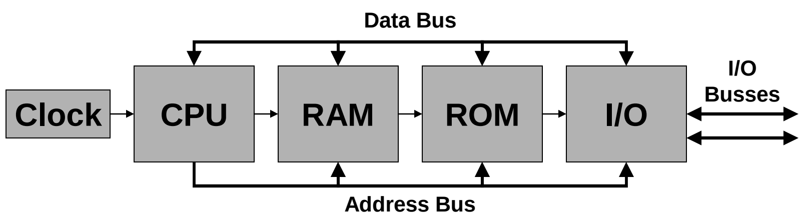
Lecture 20: Overview

- 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



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

■□■□□□■■
□■■□■□■□
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- 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!)*

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
```

```
   0 ■□■□□□■■
   1 □■■□■□■□
   2 ■□■□□■■□
   3 □□□■□□■■
   4 ■□■■■□□■
   5 □■□□■□■□
   6 ■□□□□■■□
   7 □■□□■■□■
   8 ■□■□□□■□
   9 □■□□■□■□
  10 ■□■□□■□□
  11 □□■■□□■■
        ...
1020 ■□□□■□■■
1021 □■■□■□■□
1022 ■□□□□□■□
1023 ■□□■■□■■
```

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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. $9D_{16} = 9*16^1 + 13*16^0$

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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

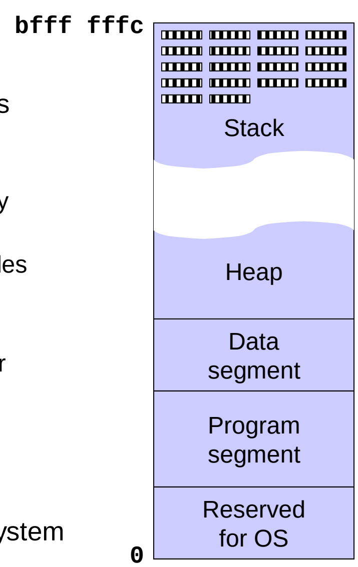
Binary Data Representation

- 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
...	...	...	...	...

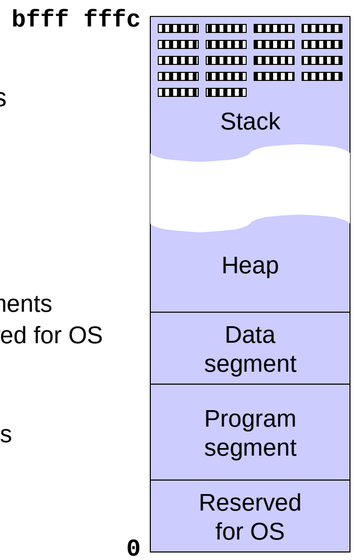
Binary Data Representation

- 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



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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