Machine Called Computer

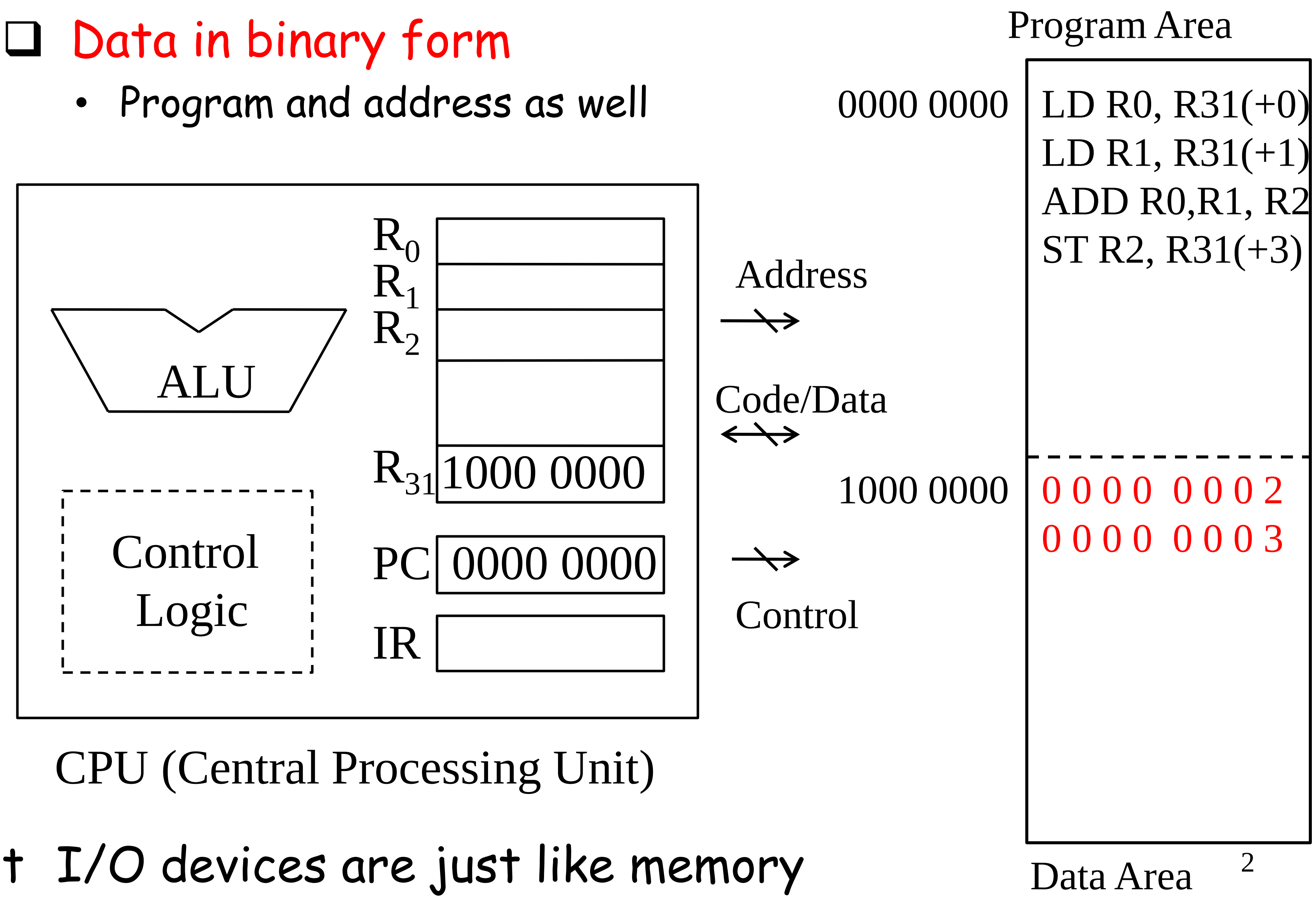
Part 4: Data

Reference:

1. Fundamentals of Computer Science, Forouzan and Mosharraf

Machine Called Computer

- Data in binary form
  - Program and address as well



† I/O devices are just like memory

Program vs. Data

- Computation or running programs
  - Data
    - Data representation
  - Code (or program or instructions)
    - Data manipulation
- Which is more fundamental, data or code?

Evolution of Data

- Evolution of computer applications
- Scientific computing
  - Solve differential equations
  - Data: numbers
    - Integer, floating-point numbers (e.g., $6.02 * 10^{38}$)
- Business computing (e.g., IBM)
  - Database
  - Data: characters or text (ASCII, Unicode)
- Internet applications
  - Multimedia data: audio, image, video

Data, program, address in binary form

- Focus on data
  - Numeric data first

    (meaning of data in 1945)
    - Integer first

Number Systems

- Positional number systems
  - Position of symbol determine value it represent
  - Decimal number system
    - {0, 1, 2, 3, 4, 5, 6, 7, 8, 9}
      - Concept more than 5000 years old
  - Binary number system
    - {0, 1}
      - Binary digit or bit
      - Concept more than 2000 years old

Decimal Integers

10^2	10^1	10^0	Weight
3	2	5	Number

$N = +3 \times 10^2 + 2 \times 10^1 + 5 \times 10^0$ Value

Binary Integers

2^4	2^3	2^2	2^1	2^0	Weight
1	0	1	1	0	Number

$N = + 1 \times 2^4 + 0 \times 2^3 + 1 \times 2^2 + 1 \times 2^1 + 0 \times 2^0$ Value

- "10110" in binary: 5-bit notation
  - Bit: binary digit
  - Equivalent decimal value N = 16 + 4 + 2 = 22
- As natural as decimal notation
  - Only need more digits

Converting 22_{10} into Binary Integer

$22 = 2 \times 11$	remainder 0
$11 = 2 \times 5$	remainder 1
$5 = 2 \times 2$	remainder 1
$2 = 2 \times 1$	remainder 0
$1 = 2 \times 0$	remainder 1

10110

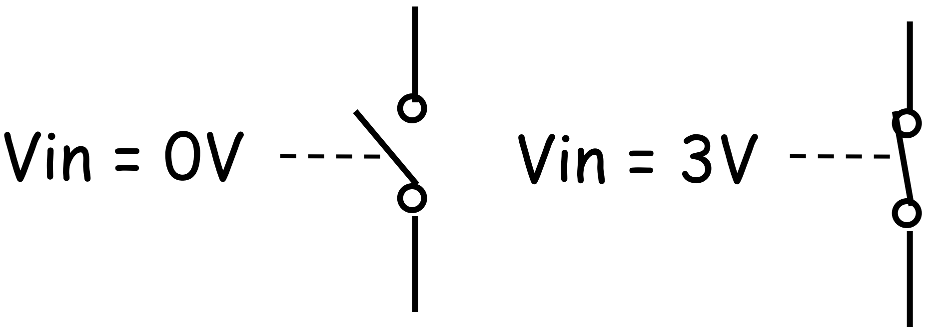
010110

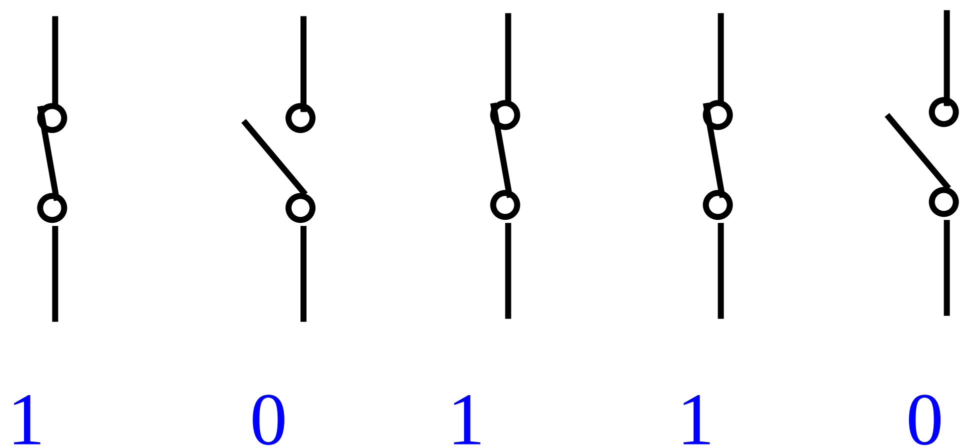
$$22 = 2 \times \underbrace{(2 \times \underbrace{(2 \times \underbrace{(2 \times \underbrace{(2 \times 0 + 1)}_{1} + 0)}_{2} + 1)}_{5} + 1)}_{11} + 0$$

$$= 0 \times 2^5 + 1 \times 2^4 + 0 \times 2^3 + 1 \times 2^2 + 1 \times 2^1 + 0 \times 2^0$$

Why binary numbers in computer?

- Transistor (underlying hardware)
  - 3-terminal digital switch: two stable states (ON, OFF)





Why do we not see binary numbers?

- Software
  - Translation between human users and machine

Human Users

Human-friendly form

Software (OS, Application)

Binary form

Machine called computer

(Unsigned) Binary Integers

- Range of expression: simply need more bits than decimal
  - 1-bit: 0 to 1
  - 2-bit: 00 to 11 (0 to 3 in decimal)
  - 4-bit: 0000 to 1111 (0 to 15 in decimal)
  - 8-bit ("byte"): 0000 0000 to 1111 1111 (0 to 255_{10})
  - 16-bit: 0 to 2^{16} - 1
    - 64K (65,636)
  - 32-bit: 0 to 2^{32} - 1
    - 4G (4,294,967,296)

CS-related Prefix in Metric System

			CS	CS	
yotta	Y	10^{24}	2^{80}		septillion
zetta	Z	10^{21}	2^{70}		sextillion
exa	E	10^{18}	2^{60}		quintillion
peta	P	10^{15}	2^{50}		quadrillion
tera	T	10^{12}	2^{40}		trillion
giga	G	10^{9}	2^{30}	1,073,741,824	billion
mega	M	10^{6}	2^{20}	1,048,576	million
kilo	K	10^{3}	2^{10}	1024	thousand

32-bit Computer

- Memory: many slots to store data

CPU

Memory: 32-bit wide main memory

Program

Data

0000 0000 0000 0000 0000 0000 0000 0100

Auxiliary storage: files and folders

I/O: Monitor, keyboard, LAN-Internet, …

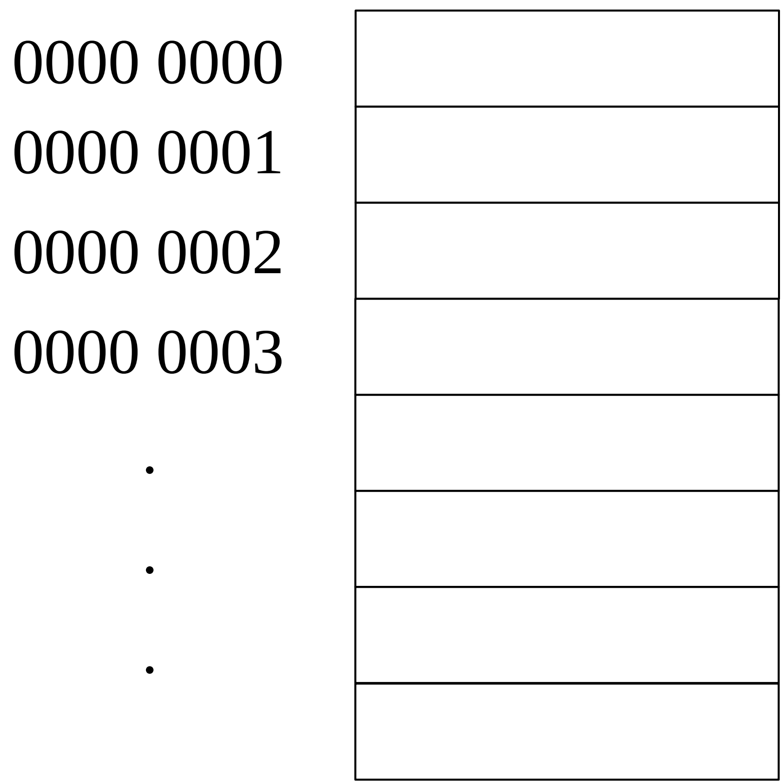
Hexadecimal Notation

- 0000 0000 0000 0000 0000 0000 0000 0100 (32-bit binary)
  - 00000004 in hex (8 hex digits)
  - Pure mnemonic (for easy human recognition)

Binary	Hex	Binary	Hex	Binary	Hex	Binary	Hex
0000	0	0100	4	1000	8	1100	C, c
0001	1	0101	5	1001	9	1101	D, d
0010	2	0110	6	1010	A, a	1110	E, e
0011	3	0111	7	1011	B, b	1111	F, f

Memory Model

- What's stored in a single memory address
  - Bit, byte or what?



Memory Model - 32-Bit Machine

- 32-bit access, 4열 종대
  - Addresses for “char”, “short int”, “int”?
  - Address for instruction?

0000 0000	3	2	1	0
0000 0004				
0000 0008				
0000 000C				
.				
.				
.				

Built-in Data Types in C

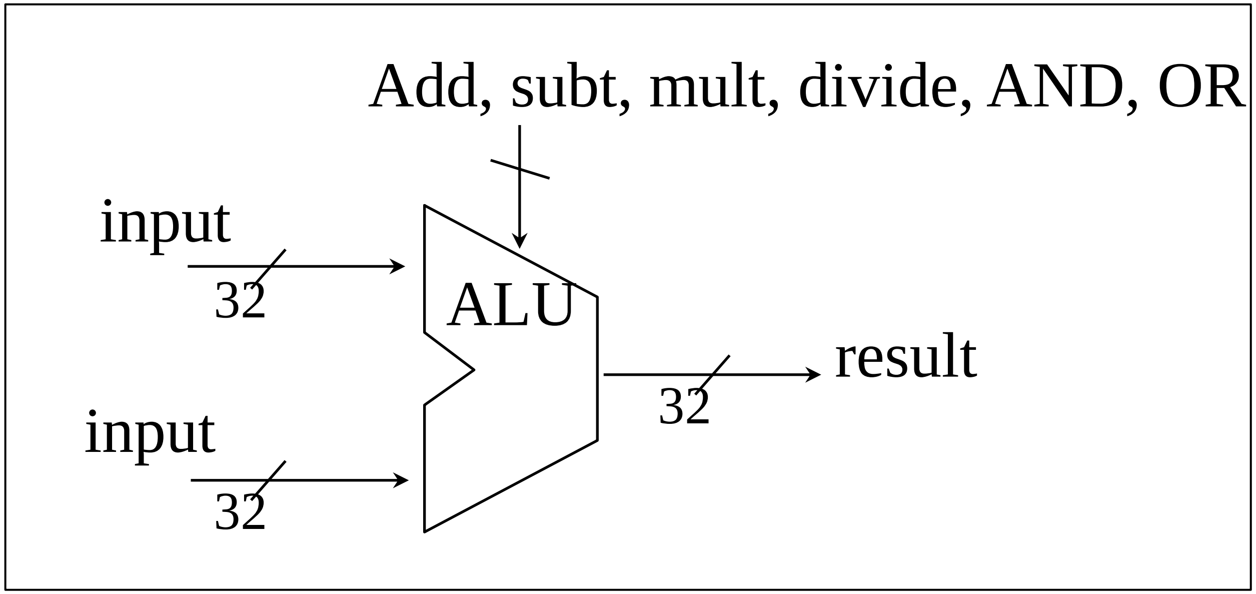
- Integer
  - short or long, signed or unsigned
  - Size is machine dependent (but int is at least 16 bits)
- Character (char)
  - Single byte capable of holding one character
  - Signed or unsigned; in a sense, small integer
- Floating point number (float, double)
  - Single-/double-precision (IEEE 754; 32/64 bits)
- † Boolean, string (implicit in C)

Binary integer

- Arithmetic: +, - , *, /
  - ALU design
- Negative integer
- Real number

Operation on Numbers and ALU

- Representation of numbers: binary
- Operation on numbers
  - ALU (Arithmetic and Logic Unit) in CPU



Add Binary Numbers

- Same with decimal add
  - Limitation of 8-bit addition
  - Speed of addition?

$$
\begin{array}{rcll}
 & & 0\,0\,0\,1\;\;0\,0\,0 & \text{carry} \\
9_{10} & = & 0\,0\,0\,0\;\;1\,0\,0\,1 & \\
12_{10} & = & \underline{0\,0\,0\,0\;\;1\,1\,0\,0} & \\
 & & 0\,0\,0\,1\;\;0\,1\,0\,1 & = 21_{10}
\end{array}
$$

Multiply Binary Numbers

- Same with decimal multiply
  - Multiply: many shifts and adds (result: double precision)
    - Speed?
  - Divide

$$
\begin{array}{r}
1100 \\
1001 \\
\hline
1100 \\
0000 \\
0000 \\
1100 \\
\hline
1101100
\end{array}
\qquad
\begin{array}{l}
= 12_{10} \\
= 9_{10} \\
\\
\\
\\
\\
\\
= 108_{10}
\end{array}
$$

Binary Representation and ALU

- How to represent negative integers

Unsigned binary	Two's complement
000 = +0	000 = +0
001 = +1	001 = +1
010 = +2	010 = +2
011 = +3	011 = +3
100 = +4	100 = -4
101 = +5	101 = -3
110 = +6	110 = -2
111 = +7	111 = -1

Binary Rational Numbers (유한소수)

- Fixed-point representation

2^2	2^1	2^0		2^{-1}	2^{-2}	Weight
1	0	1	.	1	1	Number

$$N = +1 \times 2^2 + 0 \times 2^1 + 1 \times 2^0 + 1 \times 2^{-1} + 1 \times 2^{-2} \quad \text{Value}$$

- Equivalent decimal value N = 4 + 1 + 0.5 + 0.25 = 5.75
- ALU not aware of the binary point
  - Software perform translation

† Irrational numbers (무한소수): truncation, lose accuracy

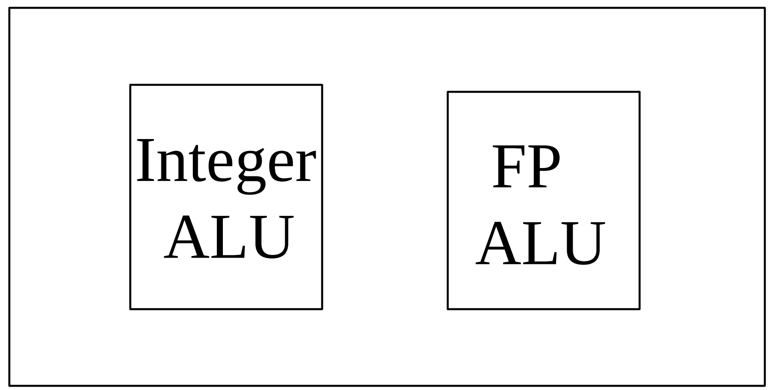
Floating-Point Numbers

- What is floating-point representation?
  - Very big and small numbers (i.e., scientific numbers)
    - 1.011×2^{-97}, 1.101×2^{68}
    - Need too many bits: store mantissa and exponent
  - Arithmetic becomes quite complex
  - Quite different from binary arithmetic

- Two types of applications: integer and floating-point
  - Two types of ALU: integer ALU and FP ALU
  - Does your PC have both?
    - What about your smartphone?

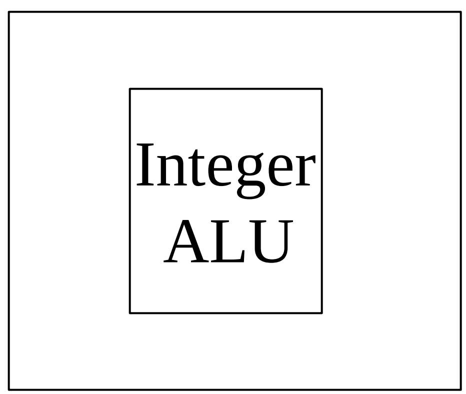
Integer and FP ALUs

- Processor for general-purpose computers:



Pentium

- Processors for embedded systems can be like:



Smaller
Cheaper
Low-power

Non-Positional Number System (skip)

- Roman numerals
  - {I, V, X, L, C, D, M}

I	V	X	L	C	D	M
1	5	10	50	100	500	1000

- Need specific rules to determine value
  - IV: $5 - 1 = 4$
  - XVIII: $10 + 5 + 1 + 1 + 1 = 18$
  - XIX: $10 + 10 - 1 = 19$
  - LXXII: $50 + 10 + 10 + 1 + 1 = 72$
- Easy to build ALU?

Computer Arithmetic

- Can you imagine
  - Many algorithms for addition,
    - Multiplication, division, FP operations as well
- Focus of building computer in 1945
  - Faster ALU
    - How to represent numbers
- Computer arithmetic
  - Matured in 1950s and 1960s
- Today, can buy ALU as IP (Intellectual Property)

Computation:

- More than arithmetic
- Different types of data:
  - Numbers
  - Text
  - Audio, image, video

Different Types of Data

- The term “multimedia”
  - Text, audio, image, video
  - All in binary pattern

Data Type	Program	Representation
Numbers	Math. routine	All in binary pattern
Text	Text editor	
Audio	Voice recorder	
Image	Image recorder	
Video	Video recorder	

ASCII Code

ASCII code chart, image file in Wikipedia:

http://en.wikipedia.org/wiki/File:ASCII_Code_Chart-Quick_ref_card.jpg

32-bit Computer

- Memory: many slots to store data

CPU

Memory: 32-bit wide main memory

Program

0000 0000 0000 0000 0000 0000 0000 0100

Data

‘4’ if integer

0101 0100 0100 0101 0101 1000 0101 0100

‘TEXT’ if ASCII

Auxiliary Storage (files, folders)

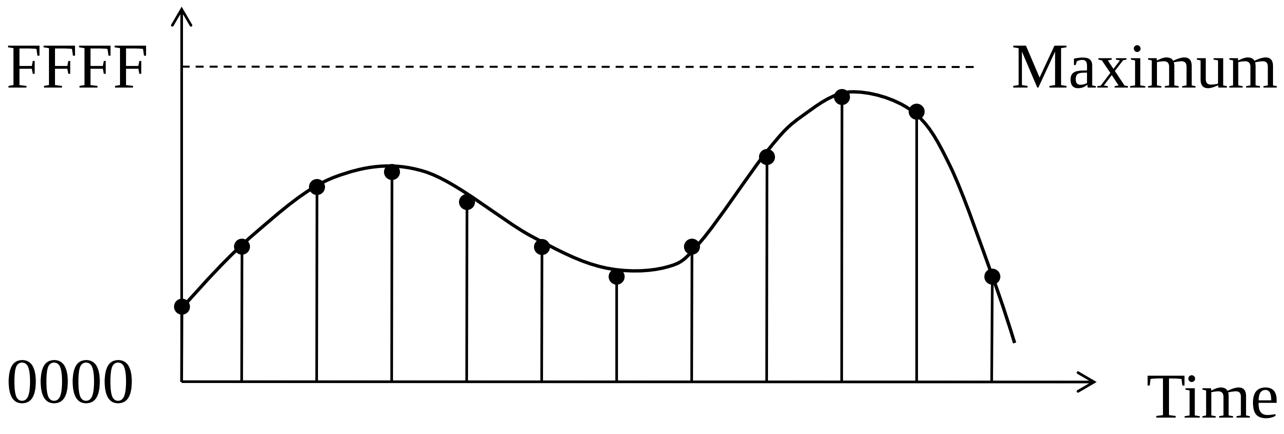
I/O: Monitor/keyboard, LAN-Internet, …

Representing Text

- Each character is assigned a unique bit pattern
  - ASCII
    - 7-bit to represent 128 symbols in English text
  - ISO: a number of 8-bit extensions to ASCII
    - To accommodate different language groups
  - Unicode (e.g., Java): 32-bit characters
    - Represent alphabets in world's languages plus symbols
      - "Internationalization"
    - Characters encoded in 1 byte to 4 bytes

Storing Audio

- Speech or music represented by sequence
- Dominant standard: MP3 (short for MPEG Layer 3)
  - 44100 samples per second
    - Sampling theorem
  - 16 bits per sample: 0000 to FFFF in hexadecimal



Storing Images

- JPEG standard
  - True color: 24 bits per pixel (R,G,B 각각 8 bits)
  - Compress to reduce size

Color	Red	Green	Blue	Color	Red	Green	Blue
Black	0	0	0	Yellow	255	255	0
Red	255	0	0	Cyan	0	255	255
Green	0	255	0	Magenta	255	0	255
Blue	0	0	255	White	255	255	255

- HD 1080: $(1920 \times 1080) \times 3$ bytes ≈ 6 MB

Display Resolution

Image file showing display resolution:

http://en.wikipedia.org/wiki/File:Vector_Video_Standards4.svg

Storing Video

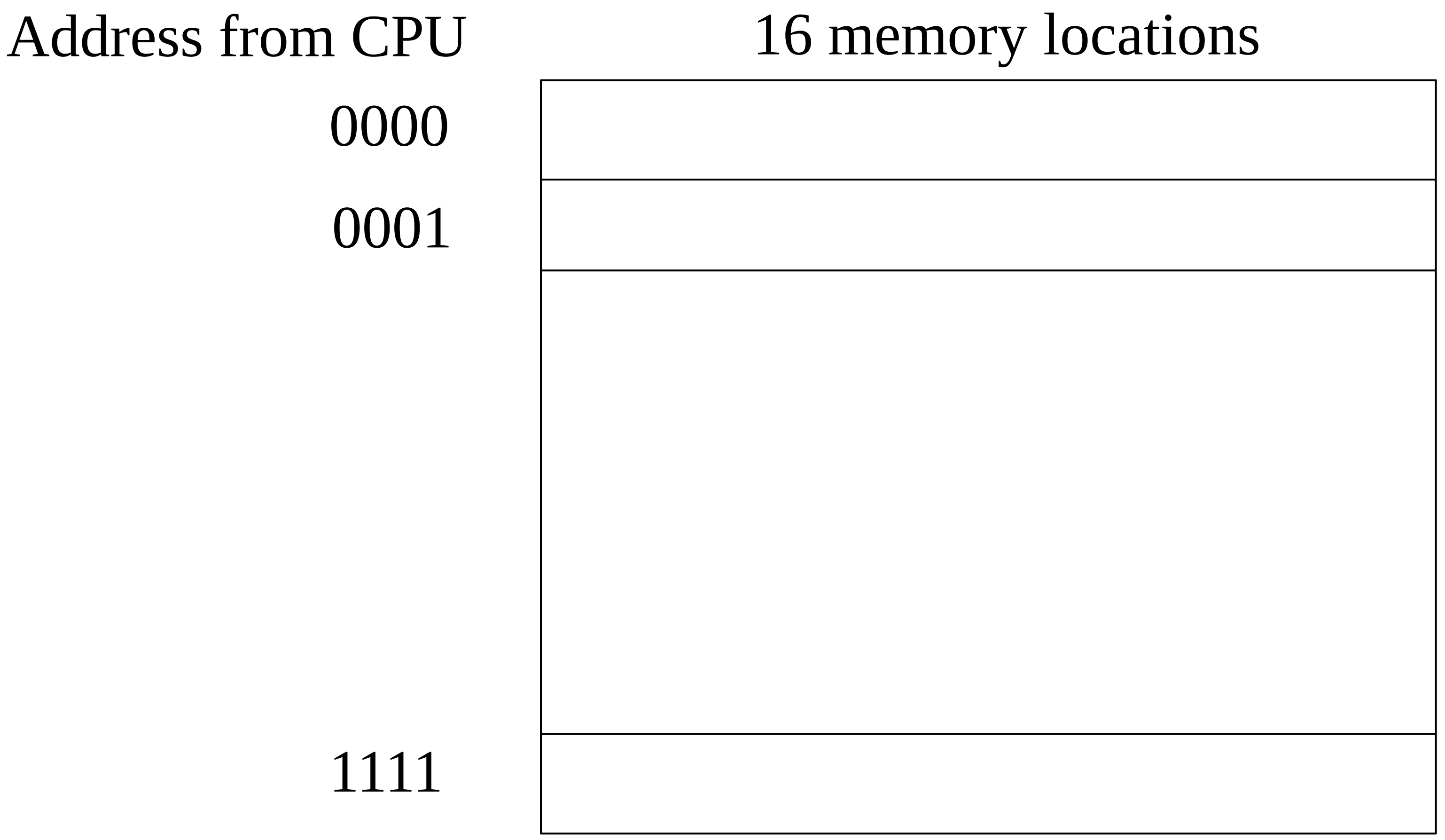
- Images (or frames) over time
  - e.g., 24 frames per second
- MPEG (Moving Picture Experts Group) standard
  - Lossy compression
    - MPEG-2
    - MP3 (MPEG audio layer 3)
- Lossless compression
  - ALZip

All in Binary Form:

Address, (Data and Program)

Meaning of Address (반복)

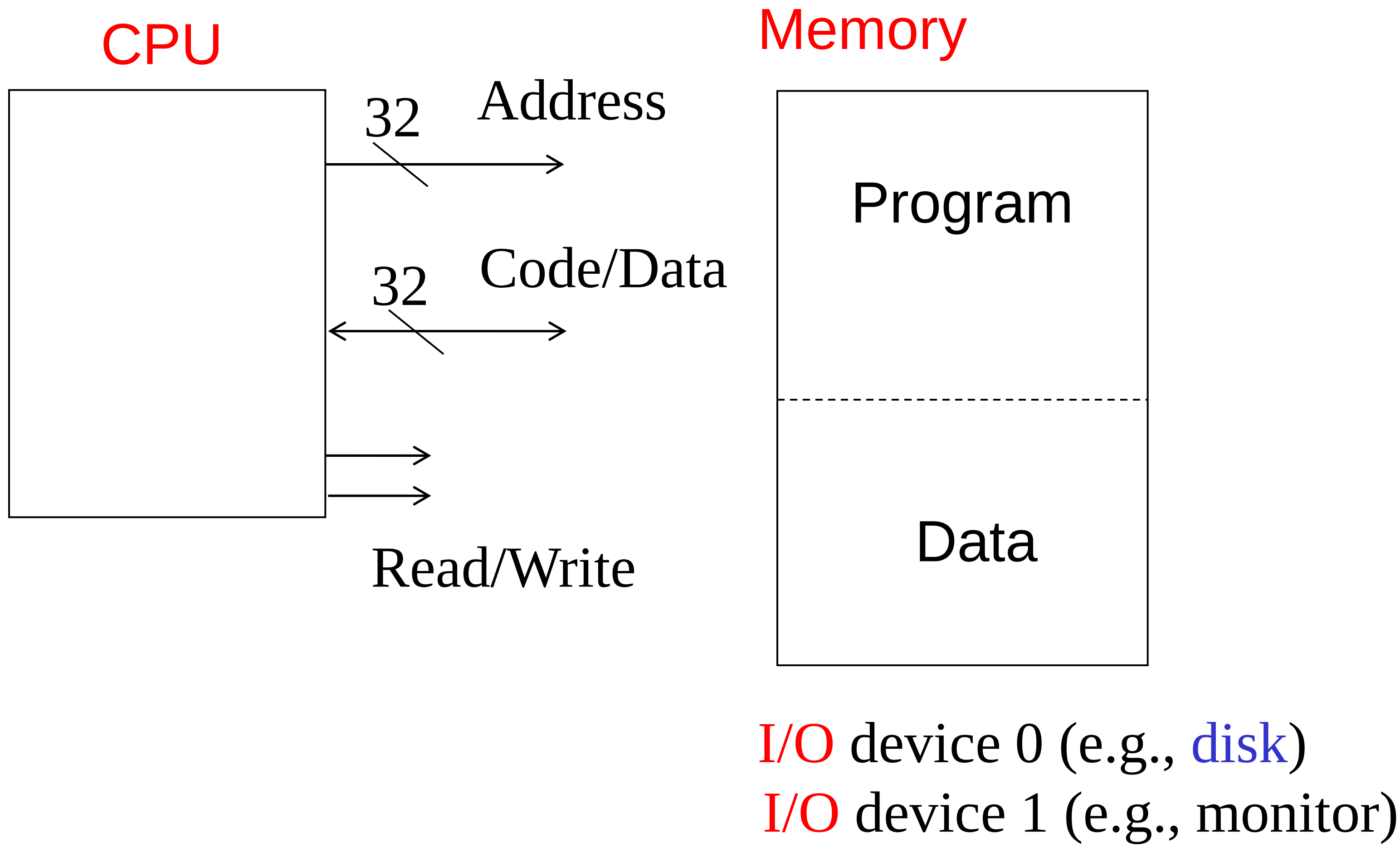
- Unique identifier for locations



Number of Address Bits (반복)

- 256 = 2^8 memory locations: 8-bit address
- 64K = 2^{16} memory locations: 16-bit address
  - 8-bit microprocessor
- 4G = 2^{32} memory locations: 32-bit address
  - 32-bit processor

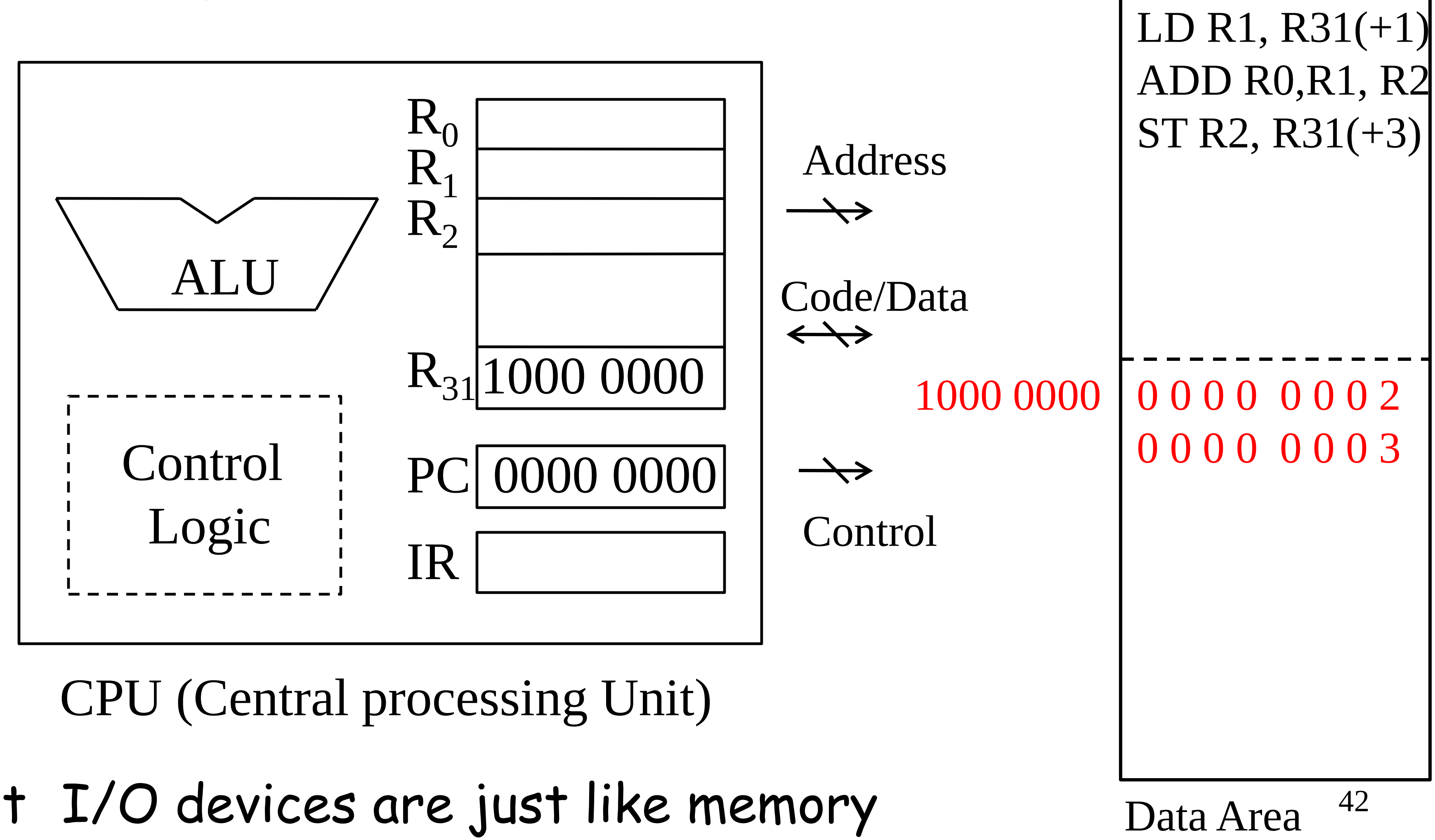
32-bit Computer (반복)



- 4G = 2^{32} memory and I/O locations
- Given address, enable corresponding location

Machine Called Computer

- Data, address in binary form
  - Program as well



CPU (Central processing Unit)

† I/O devices are just like memory

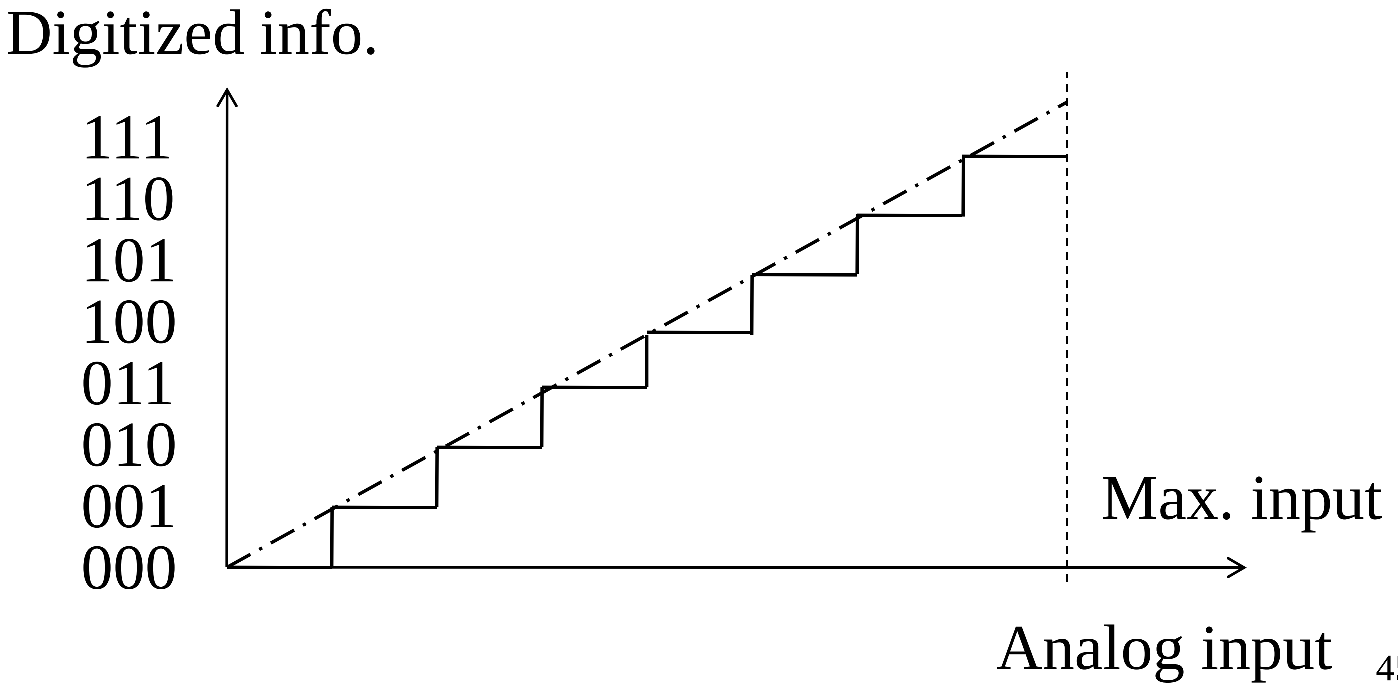
Summary

- Look into "data" first (data and program in computer)
  - Numeric data for computation
    - Binary numbers (binary integers)
      - Add, subtract, multiply, divide (ALU)
    - Rational and irrational numbers
    - Floating-point numbers
  - Business computing: text data
  - Multimedia data: audio, image, video
- (Memory and I/O) "address"

To Think About

Why "Digital" Computer?

- Nature: continuous differential equation (i.e., analog)
- Quantization error
  - Can reduce it with more bits
- Processing and communication error



Error Detection and Correction

- Single-bit parity and error detection

0100 100 | 1

data | parity (odd or even)

- Two-dimensional bit parity

data

10101	0	10101	0	01101	0
10010	1	11010	1	01010	1
11100	0	11100	0	11100	0
00100	0	00100	0	00100	0

parity

1-bit error, correctable

4-bit error, undetectable

† Notion of redundancy (in Korean, English)