Lecture 1: Introduction to Computer Systems

CS 105

Abstraction

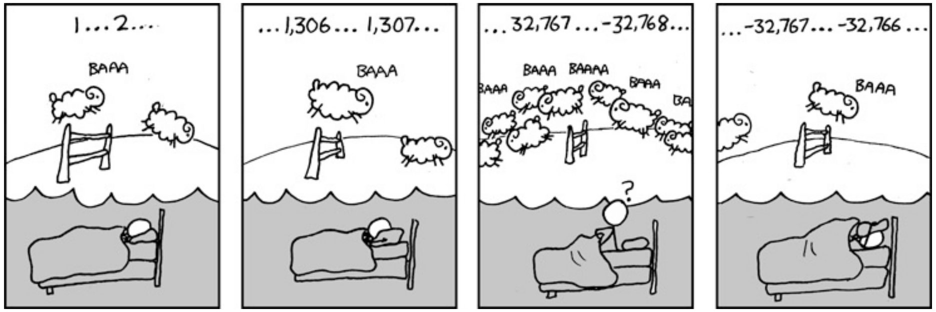
Correctness

- **Example 1: Is “$x^2 \geq 0$”?**
  - Floats: Yes!
  - Ints: ???
  - DEMO

Correctness

- **Example 1: Is "$x^2 \geq 0$"?**
  - Floats: Yes!
  - Ints: ???
    - 40000 * 40000 → 1600000000
    - 50000 * 50000 → ??

Source: xkcd.com/571



- **Example 2: Is "$(x + y) + z = x + (y + z)$"?**
  - Ints: Yes!
  - Floats: ???
  - DEMO

Correctness

- **Example 1: Is "$x^2 \geq 0$"?**
  - Floats: Yes!
  - Ints: ???
    - 40000 * 40000 → 1600000000
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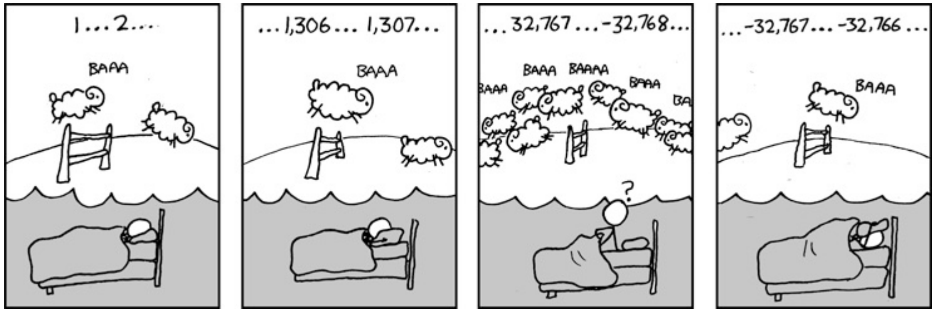
Source: xkcd.com/571



- **Example 2: Is "$(x + y) + z = x + (y + z)$"?**
  - Ints: Yes!
  - Floats:
    - (2^30 + -2^30) + 3.14 → 3.14
    - 2^30 + (-2^30 + 3.14) → ??

Performance

How do these function compare asymptotically?

```
void copyij(int src[2048][2048],
            int dst[2048][2048]){
  int i,j;
  for (i = 0; i < 2048; i++){
    for (j = 0; j < 2048; j++){
      dst[i][j] = src[i][j];
    }
  }
}
```

4.3ms

```
void copyji(int src[2048][2048],
            int dst[2048][2048]){
  int i,j;
  for (j = 0; j < 2048; j++){
    for (i = 0; i < 2048; i++){
      dst[i][j] = src[i][j];
    }
  }
}
```

81.8ms

- Hierarchical memory organization
- Performance depends on access patterns
  - Including how step through multi-dimensional array

Security

```
void admin_stuff(int authenticated){
  if(authenticated){
    // do admin stuff
  }
}

int dontTryThisAtHome(char * user_input, int size) {
  char data[size];
  int ret = memcpy(*user_input, data);
  return ret;
}
```

Let’s start at the beginning… Bits

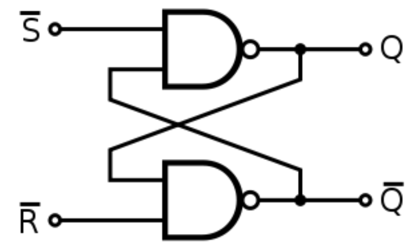
Bits

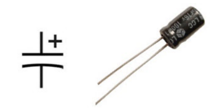
- a **bit** is a binary digit that can have two possible values

- can be physically represented with a two-state device

Storing bits

- Static random-access memory (SRAM): stores each bit of data in a flip-flop, a circuit with two stable states
- Dynamic Memory (DRAM): stores each bit of data in a capacitor, which stores energy in an electric field (or not)
- Magnetic Disk: regions of the platter are magnetized with either N-S polarity or S-N polarity
- Optical Disk: stores bits as tiny indentations (pits) or not (lands) that reflect light differently
- Flash Disk: electrons are stored in one of two gates separated by oxide layers





Boolean Algebra

- Developed by George Boole in 19th Century
- Algebraic representation of logic---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 (Xor)

^	0	1
0	0	1
1	1	0

Exercise 1: Boolean Operations

- Evaluate each of the following expressions
  1. `1 | (~1)`
  2. `~( 1 | 1)`
  3. `(~1) & 1`
  4. `~( 1 ^ 1)`

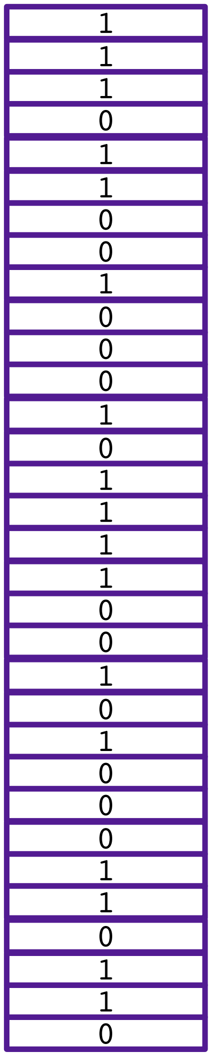
Exercise 1: Boolean Operations

- Evaluate each of the following expressions

```
1.  1 | (~1)        =  1 | 0 = 1
2.  ~( 1 | 1)       = ~1     = 0
3.  (~1) & 1        =  0 & 1 = 0
4.  ~( 1 ^ 1)       = ~0     = 1
```

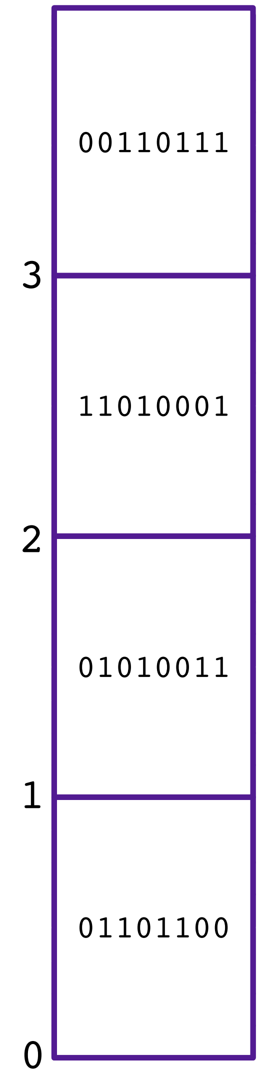
Bytes and Memory

- **Memory** is an array of bits



Bytes and Memory

- **Memory** is an array of ~~bits~~ bytes
- A **byte** is a unit of eight bits
- An index into the array is an **address**, **location**, or **pointer**
  - Often expressed in hexadecimal
- We speak of the *value* in memory at an address
  - The value may be a single byte …
  - … or a multi-byte quantity starting at that address



General Boolean algebras

- Bitwise operations on bytes

```
  01101001     01101001     01101001
& 01010101   | 01010101   ^ 01010101   ~ 01010101
  01000001     01111101     00111100     10101010
```

- How does this map to set operations?

Exercise 2 : Bitwise Operations

- Assume:

```
a = 01101100
b = 10101010
```

- What are the results of evaluating the following Boolean operations?
  - `~a`
  - `~b`
  - `a & b`
  - `a | b`
  - `a ^ b`

Exercise 2 : Bitwise Operations

- Assume:

```
a = 01101100
b = 10101010
```

- What are the results of evaluating the following Boolean operations?

  - `~a      = ~01101100 = 10010011`
  - `~b      = ~10101010 = 01010101`
  - `a & b   =  01101100 & 10101010 = 00101000`
  - `a | b   =  01101100 | 10101010 = 11101110`
  - `a ^ b   =  01101100 ^ 10101010 = 11000110`

Bitwise vs Logical Operations in C

- Bitwise Operators &, |, ~, ^
  - View arguments as bit vectors
  - operations applied bit-wise in parallel
- Logical Operators &&, ||, !
  - View 0 as “False”
  - View anything nonzero as “True”
  - Always return 0 or 1
  - With short circuiting

Exercise 3: Bitwise vs Logical Operations

- `~01000001`
- `~00000000`
- `~~01000001`

- `!01000001`
- `!00000000`
- `!!01000001`

- `01101001 & 01010101`
- `01101001 | 01010101`

- `01101001 && 01010101`
- `01101001 || 01010101`

Exercise 3: Bitwise vs Logical Operations

- `~01000001` 10111110
- `~00000000` 11111111
- `~~01000001` 01000001

- `!01000001` 00000000
- `!00000000` 00000001
- `!!01000001` 00000001

- `01101001 & 01010101` 01000001
- `01101001 | 01010101` 01111101

- `01101001 && 01010101` 00000001
- `01101001 || 01010101` 00000001

Bit Shifting

- Left Shift: `x << y`
  - Shift bit-vector **x** left **y** positions
  - Throw away extra bits on left
  - Fill with 0's on right

Undefined Behavior if you shift amount < 0 or ≥ word size

- Right Shift: `x >> y`
  - Shift bit-vector **x** right **y** positions
  - Throw away extra bits on right
  - <u>Logical shift</u>: Fill with 0's on left
  - <u>Arithmetic shift</u>: Replicate most significant bit on left

Choice between logical and arithmetic depends on the type of data

Example: Bit Shifting

- `01101001 << 4` → `10010000`
- `01101001` $>>_l$ `2` → `00011010`
- `01101001` $>>_a$ `4` → `00000110`

Exercise 4: Bit Shifting

- `10101010 << 4` → 10100000
- `10101010` $>>_l$ `4` → 00001010
- `10101010` $>>_a$ `4` → 11111010

Bits and Bytes Require Interpretation

00000000 00110101 00110000 00110001

might be interpreted as

- The integer $3{,}485{,}745_{10}$
- A floating-point number close to 4.884569×10^{-39}
- The string “105”
- A portion of an image or video
- An address pointing to another place in memory
- Or… some user-defined type

Information is Bits + Context