# CPSC 213

## Introduction to Computer Systems

*Unit 1a*

## *Numbers and Memory*

# The Big Picture

- Build machine model of execution
  - for Java and C programs
  - by examining language features
  - and deciding how they are implemented by the machine
- What is required
  - design an ISA into which programs can be compiled
  - implement the ISA in the hardware simulator
- Our approach
  - examine code snippets that exemplify each language feature in turn
  - look at Java and C, pausing to dig deeper when C is different from Java
  - design and implement ISA as needed
- The simulator is an important tool
  - machine execution is hard to visualize without it
  - this visualization is really our WHOLE POINT here

# Reading For Next 2 Lectures

- Companion
  - 1-2.3
- Textbook
  - A Historical Perspective - Accessing Information, Data Alignment
  - 2nd edition: 3.1-3.4, 3.9.3
  - 1st edition: 3.1-3.4, 3.10

# Numbers in Memory

# Initial thoughts

- Hexadecimal notation
  - “0x” followed by number (e.g., 0x2a3 = $2 \times 16^2 + 10 \times 16^1 + 3 \times 16^0$)
  - a convenient way to describe numbers when binary format is important
  - each hex digit (hexit) is stored by 4 bits: (0|1)x8 + (0|1)x4 + (0|1)x2 + (0|1)x1
  - some examples ...
- Integers of different sizes
  - ***byte*** is 8 bits, 2 hexits
  - ***short*** is 2 bytes, 16 bits, 4 hexits
  - ***int / word*** is 4 bytes, 32 bits, 8 hexits
  - ***long long*** is 8 bytes, 64 bits, 16 hexits
- Memory is byte addressed
  - every byte of memory has a unique address, number from 0 to N
  - reading or writing an integer requires specifying a range of byte addresses

# Making Integers from Bytes

Memory

...
i
i + 1
i + 2
i + 3
...

- Our first architectural decisions
  - assembling memory bytes into integer registers
- Consider 4-byte memory word and 32-bit register
  - it has memory addresses i, i+1, i+2, and i+3
  - we'll just say its "***at address i and is 4 bytes long***"
  - e.g., the word at address 4 is in bytes 4, 5, 6 and 7.
- Big or Little Endian
  - we could start with the BIG END of the number (everyone but Intel)

| i | i + 1 | i + 2 | i + 3 | ✓ |
|---|---|---|---|---|
| $2^{31}$ to $2^{24}$ | $2^{23}$ to $2^{16}$ | $2^{15}$ to $2^{8}$ | $2^{7}$ to $2^{0}$ | Register bits |

  - or we could start with the LITTLE END (Intel)

| i + 3 | i + 2 | i + 1 | i | |
|---|---|---|---|---|
| $2^{31}$ to $2^{24}$ | $2^{23}$ to $2^{16}$ | $2^{15}$ to $2^{8}$ | $2^{7}$ to $2^{0}$ | Register bits |

# Aligned or Unaligned Addresses

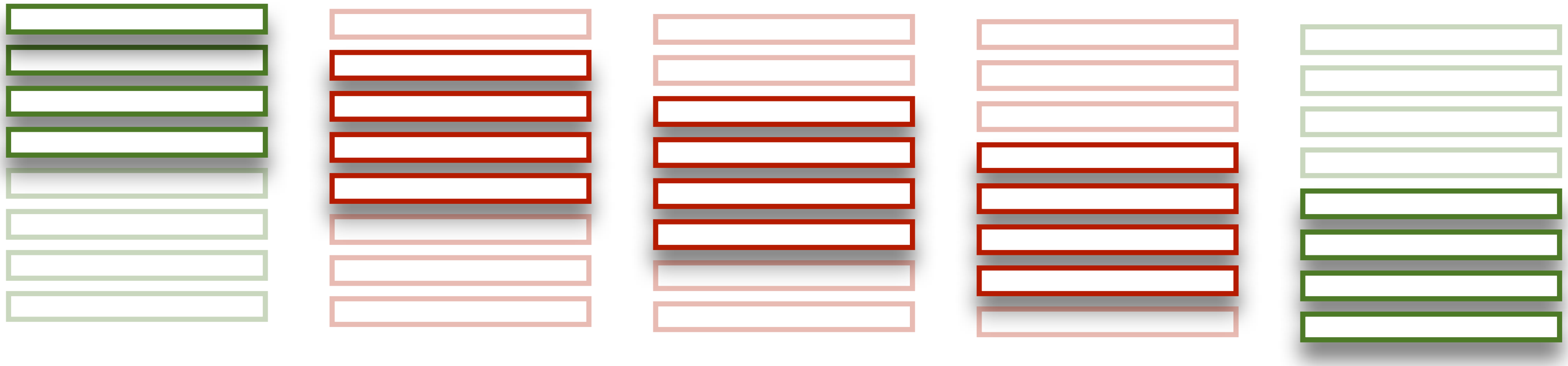
- we could allow any number to address a multi-byte integer

✗

* disallowed on most architectures

* allowed on Intel, but slower

- or we could require that addresses be aligned to integer-size boundary



✓

address modulo chuck-size is always zero

- Power-of-Two Aligned Addresses Simplify Hardware
  - smaller things always fit complete inside of bigger things

word contains exactly two complete shorts

  - byte address to integer address is division by power to two, which is just shifting bits

$j / 2^k == j >> k$ (j shifted k bits to right)

# Interlude
# A Quick C Primer

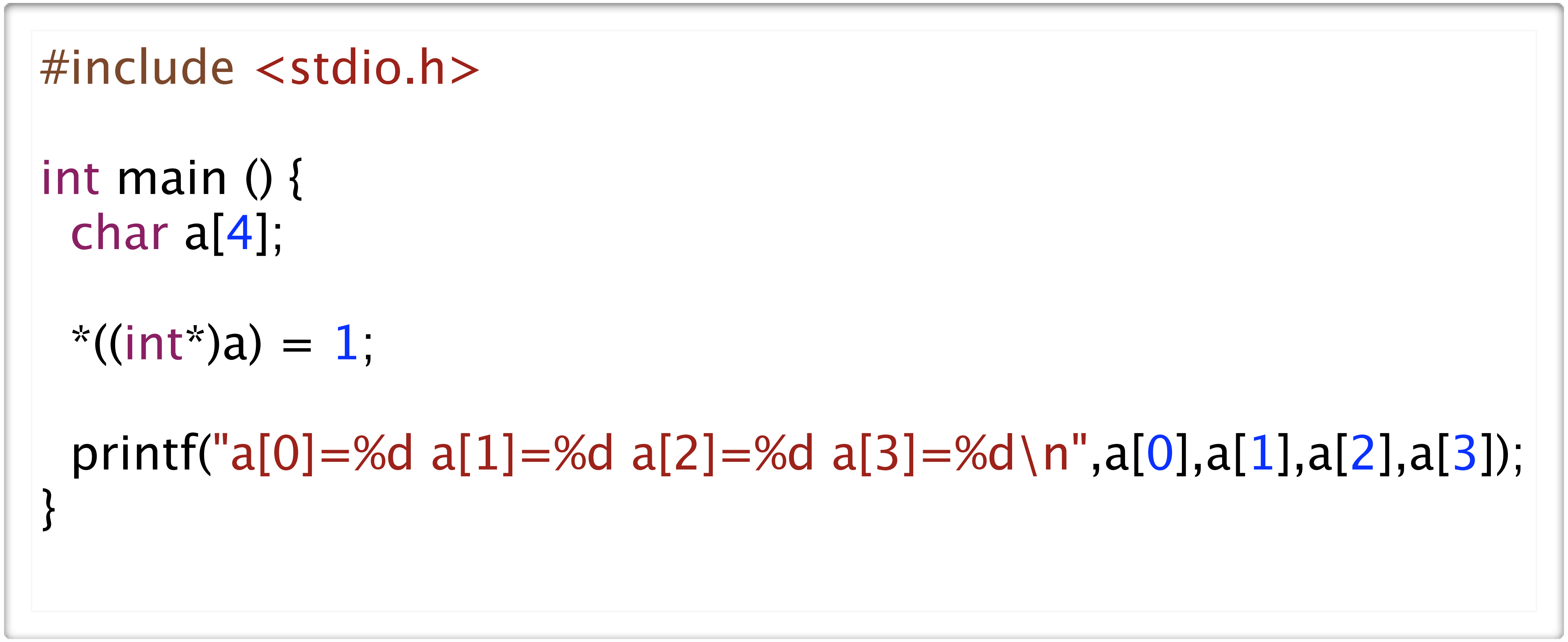
# A few initial things about C

- source files
  - .c    is source file
  - .h    is header file
- including headers in source
  - `#include <stdio.h>`
- pointer types
  - `int* b;            // b is a POINTER to an INT`
- getting address of object
  - `int  a;            // a is an INT`
  - `int* b = &a;       // b is a pointer to a`
- de-referencing pointer
  - `a  = 10;           // assign the value 10 to a`
  - `*b = 10;           // assign the value 10 to a`
- type casting is not typesafe
  - `char a[4];         // a 4 byte array`
  - `*((int*) &a[0]) = 1;  // treat those four bytes as an INT`

- compile and run
  - at UNIX (e.g., Linux, MacOS, or Cygwin) shell prompt
  - `gcc -o foo foo.c`
  - `./foo`

# Back to Numbers …

# Determining Endianness of a Computer



```
#include <stdio.h>

int main () {
  char a[4];

  *((int*)a) = 1;

  printf("a[0]=%d a[1]=%d a[2]=%d a[3]=%d\n",a[0],a[1],a[2],a[3]);
}
```

# Questions

- Which of the following statement (s) are true
    - [R] 6 == $110_2$ is aligned for addressing a *short int*
    - [Y] 6 == $110_2$ is aligned for addressing a *long int* (i.e., 4-byte int)
    - [G] 20 == $10100_2$ is aligned for addressing a *long int*
    - [B] 20 == $10100_2$ is aligned for addressing a *long long* (i.e., 8-byte int)

- Which of the following statements are true
  - [R] memory stores Big Endian integers
  - [Y] memory stores bytes interpreted by the CPU as Big Endian integers
  - [G] Neither
  - [B] I don’t know

## Which of these are true

- [R] The Java constants 16 and 0x10 are exactly the same integer
- [Y] 16 and 0x10 are different integers
- [G] Neither
- [B] I don’t know

- What is the Big-Endian integer value at address 4 below?
  - [R] `0x1c04b673`
  - [Y] `0xc1406b37`
  - [G] `0x73b6041c`
  - [B] `0x376b40c1`
  - [R+Y] none of these
  - [G+B] I don’t know

## Memory

```
0x0:    0xfe
0x1:    0x32
0x2:    0x87
0x3:    0x9a
0x4:    0x73
0x5:    0xb6
0x6:    0x04
0x7:    0x1c
```

- What is the value of i after this Java statement executes?

```
int i = (byte)(0x8b) << 16;
```

- [R] `0x8b`
- [Y] `0x0000008b`
- [G] `0x008b0000`
- [B] `0xff8b0000`
- [R+Y] None of these
- [G+B] I don’t know

- What is the value of i after this Java statement executes?

```
i = 0xff8b0000 & 0x00ff0000;
```

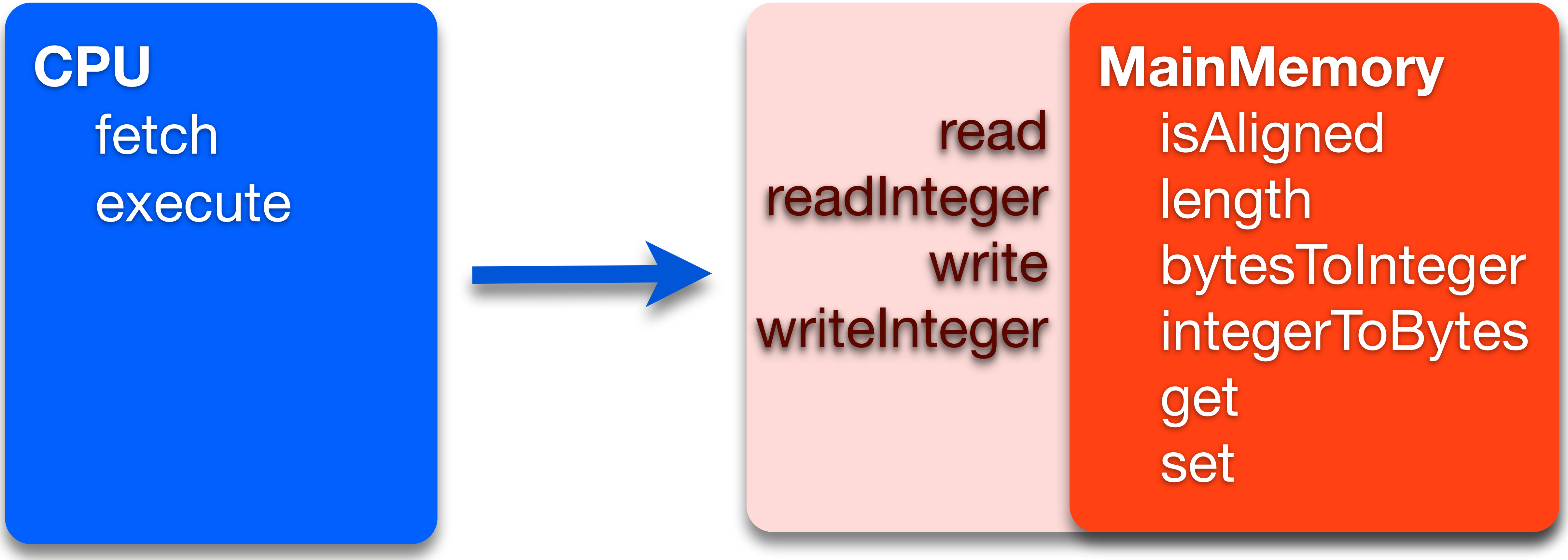
- [R] `0xffff0000`
- [Y] `0xff8b0000`
- [G] `0x008b0000`
- [B] I don’t know

# In the Lab ...

- write a C program to determine Endianness
  - prints “Little Endian” or “Big Endian”
  - get comfortable with Unix command line and tools (important)
- compile and run this program on two architectures
  - IA32: lin01.ugrad.cs.ubc.ca
  - Sparc: any of the other undergrad machines
  - you can tell what type of arch you are on
    - % uname -a
- SimpleMachine simulator
  - load code into Eclipse and get it to build
  - write and test MainMemory.java
  - additional material available on the web page at lab time

# The Main Memory Class

- The SM213 simulator has two main classes
  - CPU implements the fetch-execute cycle
  - MainMemory implements memory
- The first step in building our processor
  - implement 6 main internal methods of MainMemory



**CPU**
fetch
execute

read
readInteger
write
writeInteger

**MainMemory**
isAligned
length
bytesToInteger
integerToBytes
get
set

# The Code You Will Implement

```
/**
 * Determine whether an address is aligned to specified length.
 * @param address memory address
 * @param length byte length
 * @return true iff address is aligned to length
 */
protected boolean isAccessAligned (int address, int length) {
  return false;
}


/**
 * Determine the size of memory.
 * @return the number of bytes allocated to this memory.
 */
public int length () {
  return 0;
}
```

```
/**
 * Convert an sequence of four bytes into a Big Endian integer.
 * @param byteAtAddrPlus0 value of byte with lowest memory address
 * @param byteAtAddrPlus1 value of byte at base address plus 1
 * @param byteAtAddrPlus2 value of byte at base address plus 2
 * @param byteAtAddrPlus3 value of byte at base address plus 3
 * @return Big Endian integer formed by these four bytes
 */
public int bytesToInteger   (UnsignedByte byteAtAddrPlus0,
                             UnsignedByte byteAtAddrPlus1,
                             UnsignedByte byteAtAddrPlus2,
                             UnsignedByte byteAtAddrPlus3) {
  return 0;
}

/**
 * Convert a Big Endian integer into an array of 4 bytes
 * @param  i an Big Endian integer
 * @return an array of UnsignedByte
 */
public UnsignedByte[] integerToBytes (int i) {
  return null;
}
```

```
/**
 * Fetch a sequence of bytes from memory.
 * @param address address of the first byte to fetch
 * @param length  number of bytes to fetch
 * @return an array of UnsignedByte
 */
protected UnsignedByte[] get (int address, int length) throws ... {
  return null;
}

/**
 * Store a sequence of bytes into memory.
 * @param  address                   address of the first memory byte
 * @param  value                     an array of UnsignedByte values
 * @throws InvalidAddressException  if any address is invalid
 */
protected void set (int address, UnsignedByte[] value) throws ... {
  ;
}
```