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

Readings

- Companion
  - Ch 1, 2.1-2.2.
- Textbook
  - *Historical Perspective. Access to Information and Data Alignmnet*
  - 2nd Ed: 3.1-3.4, 3.9.3
  - 1st Ed: 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*** or ***word*** is 4 bytes, 32 bits, 8 hexits
  - ***long long*** is 8 byes, 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)

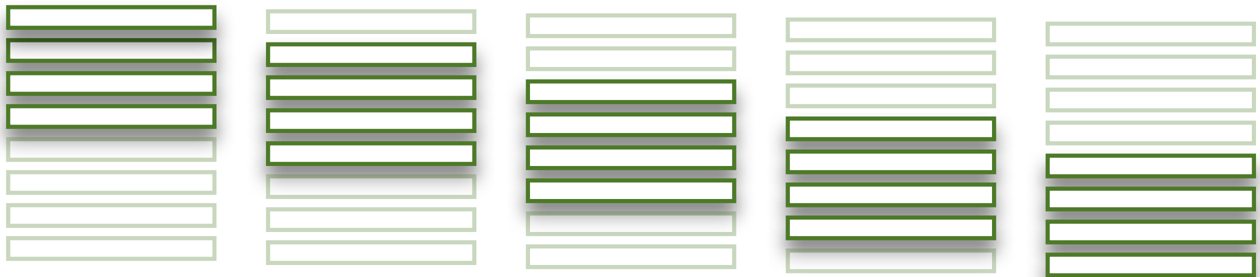
i	i + 1	i + 2	i + 3	
2^{31} to 2^{24}	2^{23} to 2^{16}	2^{15} to 2^{8}	2^{7} to 2^{0}	Register bits

  - 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

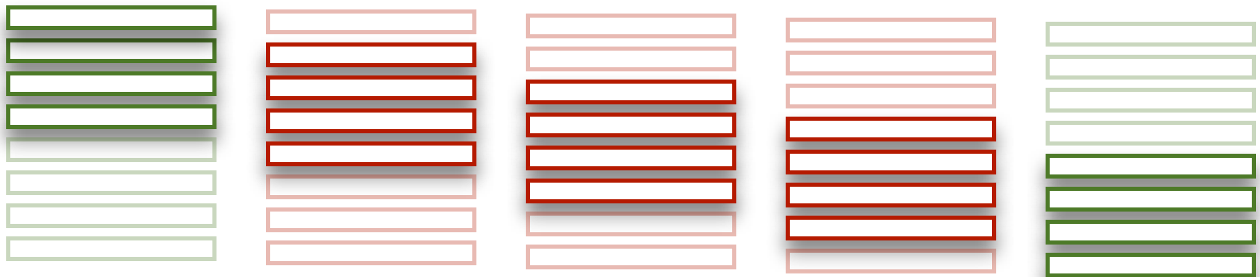
Aligned or Unaligned Addresses

- 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

```c
#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
  - [A] $6 == 110_2$ is aligned for addressing a *short*
  - [B] $6 == 110_2$ is aligned for addressing a *long*
  - [C] $20 == 10100_2$ is aligned for addressing a *long*
  - [D] $20 == 10100_2$ is aligned for addressing a *long long* (i.e., 8-byte int)

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

- Which of these are true
  - [A] The Java constants 16 and 0x10 are exactly the same integer
  - [B] 16 and 0x10 are different integers
  - [C] Neither
  - [D] I dont’ know

- What is the Big-Endian integer value at address 4 below?
  - [A] `0x1c04b673`
  - [B] `0xc1406b37`
  - [C] `0x73b6041c`
  - [D] `0x376b40c1`
  - [E] none of these
  - [F] 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?

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

- [A] `0x8b`
- [B] `0x0000008b`
- [C] `0x008b0000`
- [D] `0xff8b0000`
- [E] None of these
- [F] I don’t know

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

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

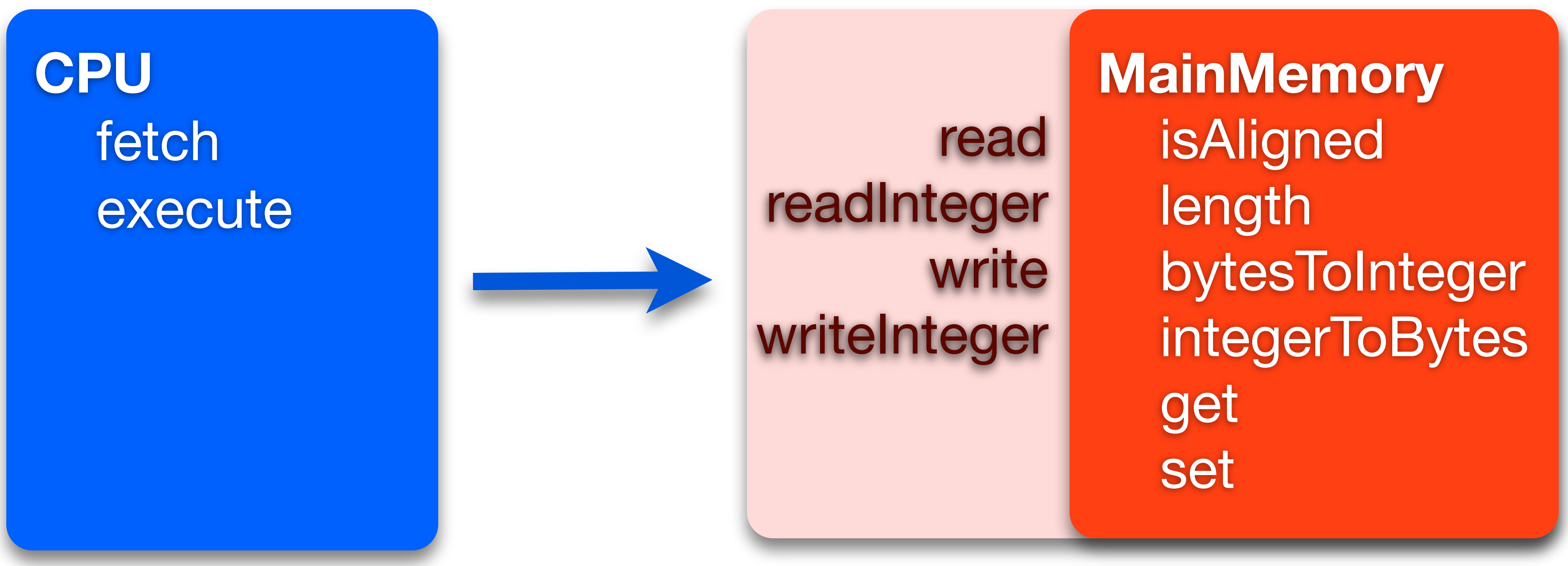
- [A] `0xffff0000`
- [B] `0xff8b0000`
- [C] `0x008b0000`
- [D] I don't know

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



The Code You Will Implement

```java
/**
 * 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;
}
```

```java
/**
 * 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 ... {
  UnsignedByte[] ub = new UnsignedByte [length];
  ub[0] = new UnsignedByte (0); // with appropriate value
  // repeat to ub[length-1] ...
  return ub;
}

/**
 * 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 ... {
  byte b[] = new byte [value.length];
  for (int i=0; i<value.length; i++)
    b[i] = (byte) value[i].value();
  // write b into memory ...
}
```