CPSC 213

Introduction to Computer Systems

Unit 1a

Numbers and Memory

The Big Picture

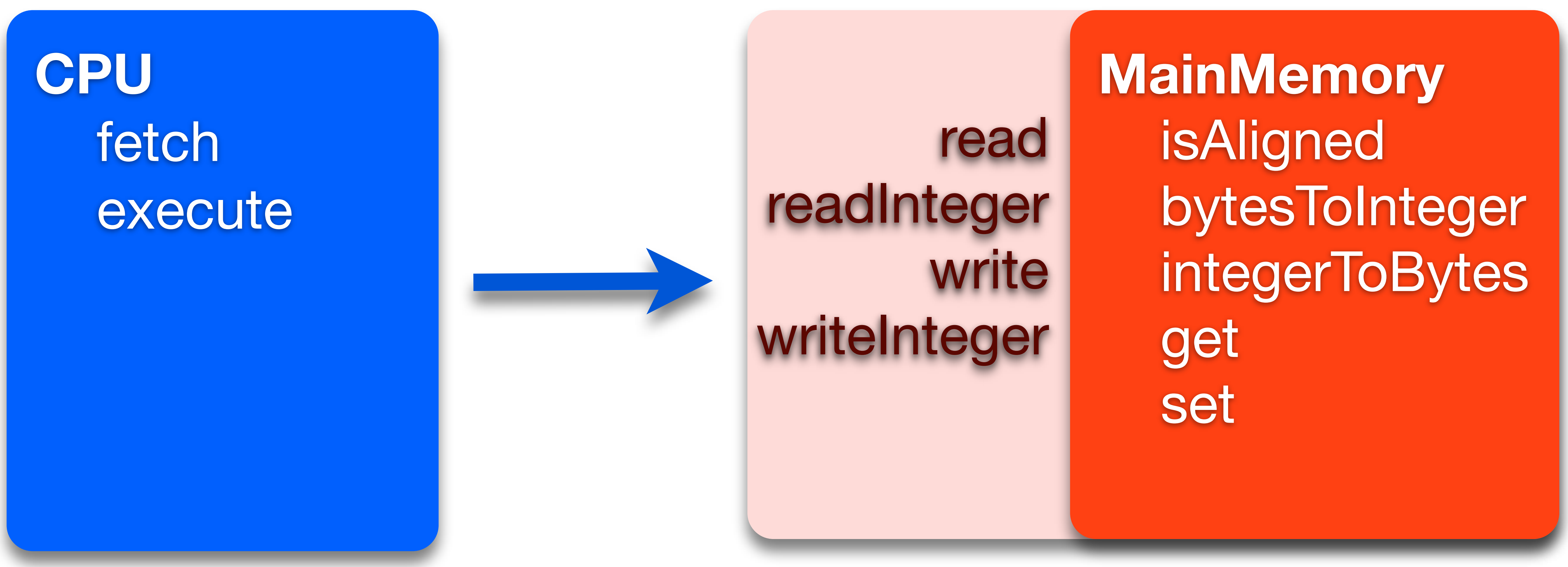
- Build machine model of execution
  - for Java and C programs
  - by examining language features
  - and deciding how they are implemented by the machine
- What is required
  - design an ISA into which programs can be compiled
  - implement the ISA in the hardware simulator
- Our approach
  - examine 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

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: galiano.ugrad.cs.ubc.ca
  - 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;
}
```

```java
**
 * 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 ...
}
```

Reading

- Companion
  - previous module: 1, 2.1
  - new: 2.2 (focus on 2.2.2 for this week)
- Textbook
  - *A Historical Perspective, Machine-Level Code, Data Formats, "New to C", Data Alignment.*
  - 2ed: 3.1-3.2.1, 3.3, "New to C" sidebar of 3.4, 3.9.3
    - (skip 3.2.2 and 3.2.3)
  - 1ed: 3.1-3.2.1, 3.3, "New to C" sidebar of 3.4, 3.10

Numbers in Memory

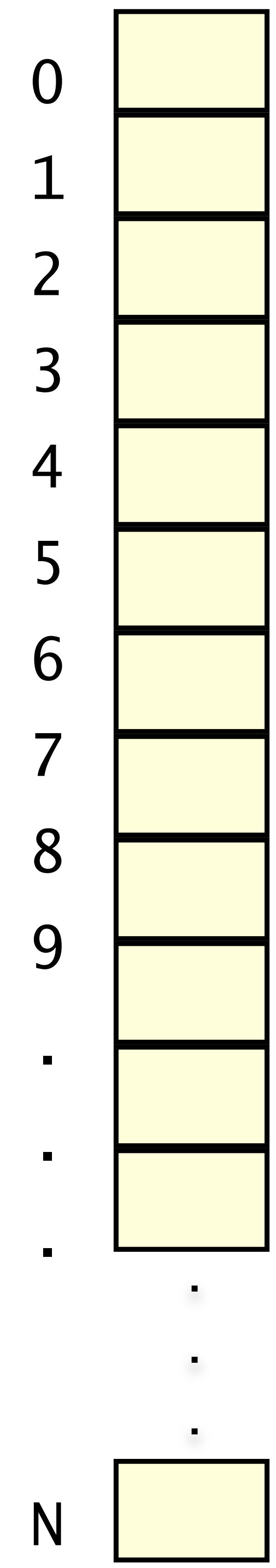
Binary, Hex, and Decimal Refresher

- Hexadecimal notation
  - number starts with “0x” , each digit is base 16 not base 10
  - 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
- Examples
  - 0x10 in binary? in decimal?
  - 0x2e in binary? in decimal?
  - 1101 1000 1001 0110 in hex? in decimal?
  - 102 in binary? in hex?

B	H	D
0000	0	0
0001	1	1
0010	2	2
0011	3	3
0100	4	4
0101	5	5
0110	6	6
0111	7	7
1000	8	8
1001	9	9
1010	a	10
1011	b	11
1100	c	12
1101	d	13
1110	e	14
1111	f	15

Memory and Integers

- Memory is byte addressed
  - every byte of memory has a unique address, numbered from 0 to N
  - N is huge: billions is common these days (2-16 GB)
- Integers can be declared at different sizes
  - ***byte*** is 1 byte, 8 bits, 2 hexits
  - ***short*** is 2 bytes, 16 bits, 4 hexits
  - ***int*** or ***word*** or ***long*** is 4 bytes, 32 bits, 8 hexits
  - ***long long*** is 8 bytes, 64 bits, 16 hexits
- Integers in memory
  - 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 it's "***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 (end means where start from, not finish)
  - we could start with the BIG END of the number (most everyone but Intel) ✓

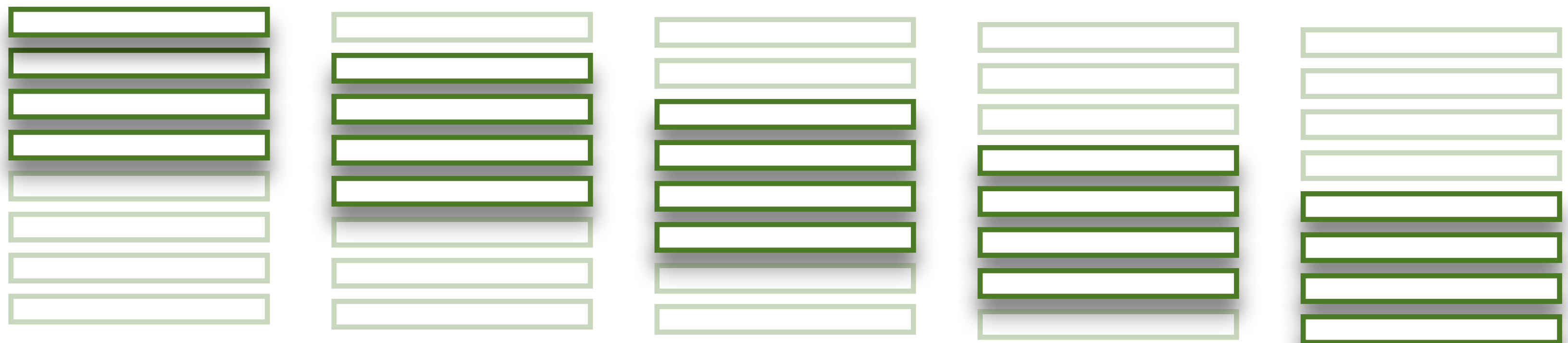
i	i + 1	i + 2	i + 3	
2^{31} to 2^{24}	2^{23} to 2^{16}	2^{15} to 2^{8}	2^{7} to 2^{0}	Register bits

  - or we could start with the LITTLE END (Intel x86, some others)

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 many architectures
* allowed on Intel, but slower

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

* SM213 alignment: 4-byte words

address modulo chunk-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 from integer address: divide by power to two, which is just shifting bits

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

Computing Alignment

- boolean align(number, size)
  - does a number fit nicely for a particular size (in bytes)?
- divide number n by size s (in bytes), aligned if no remainder
  - easy if number is decimal
  - otherwise convert from hex or binary to decimal
- check if n mod s = 0
  - mod notation usually '%'. same as division, of course...
- check if certain number of final bits are all 0
  - pattern?
    - last 1 digit for 2-byte short
    - last 2 digits for 4-byte world
    - last 3 digits for 8-byte longlong
  - last k digits, where $2^k = s$ (size in bytes)
  - easy if number is hex: convert to binary and check

B	H	D
0000	0	0
0001	1	1
0010	2	2
0011	3	3
0100	4	4
0101	5	5
0110	6	6
0111	7	7
1000	8	8
1001	9	9
1010	a	10
1011	b	11
1100	c	12
1101	d	13
1110	e	14
1111	f	15

Question

- 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)

Interlude
A Quick C Primer

Java Syntax... vs. C Syntax

Java:

- source files
  - .java is source file
- including packages in source
  - import java.io.*
- printing
  - System.out.println("blah blah");
- compile and run
  - javac foo.java
  - java foo

C:

- source files
  - .c is source file
  - .h is header file
- including headers in source
  - #include <stdio.h>
- printing
  - printf("blah blah\n");
- compile and run
  - gcc -o foo foo.c
  - ./foo
  - do this at a Unix shell prompt (Linux, Mac Terminal, Sparc, Cygwin on Windows)

Java Hello World...

```
import java.io.*;
public class HelloWorld {
  public static void main (String[] args) {
    System.out.println("Hello world");
 }
}
```

C Hello World...

```
#include <stdio.h>
main() {
    printf("Hello world\n");
}
```

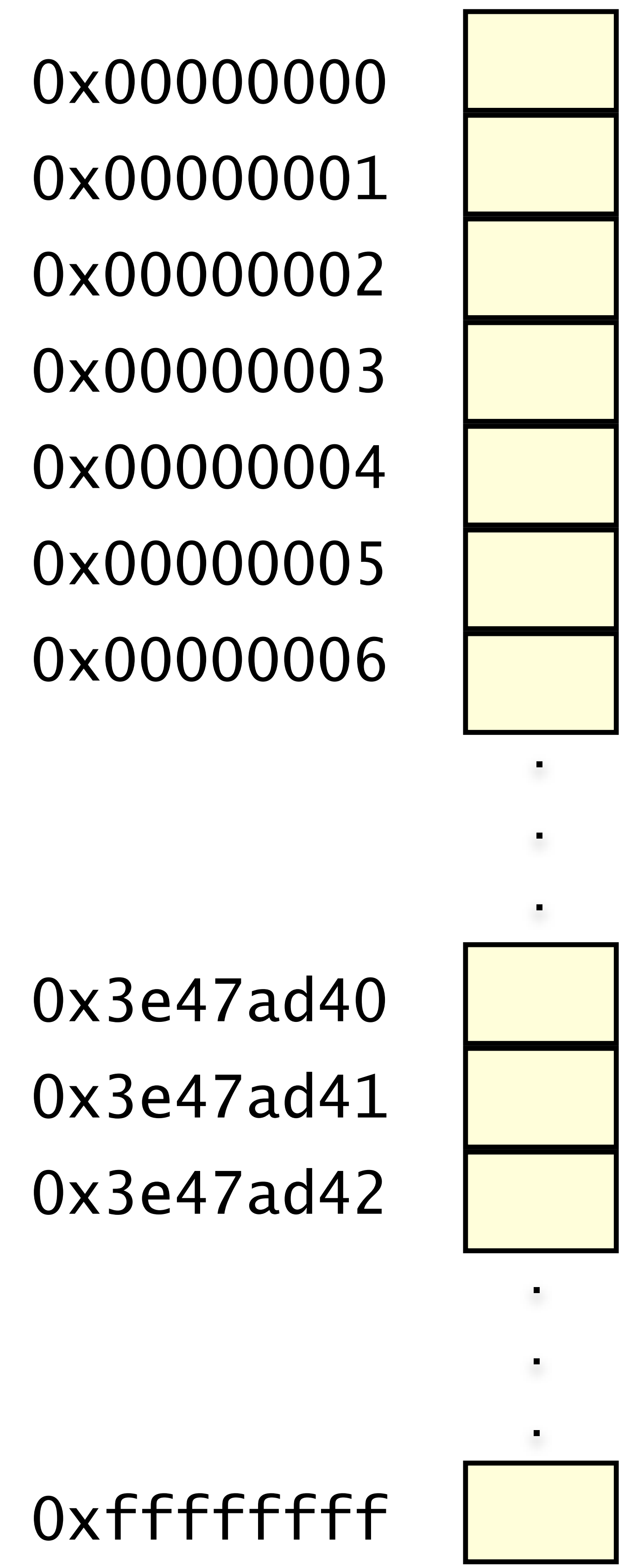
Java and C: Similarities

- declaration, assignment
  - int a = 4;
- control flow (often)
  - if (a == 4) ... else ...
  - for (int i = 0; i < 10; i++) {...}
  - while (i < 10) {...}
- casting

```
int a;
long b;
a = (int) b;
```

New in C: Pointers

- pointers: addresses in memory
  - locations are first-class citizens in C
  - can go back and forth between location and value!
- pointer declaration: <type>*
  - 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) = 1;   // treat those four bytes as an INT



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]);
}
```

- 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 don't 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