Byte Ordering

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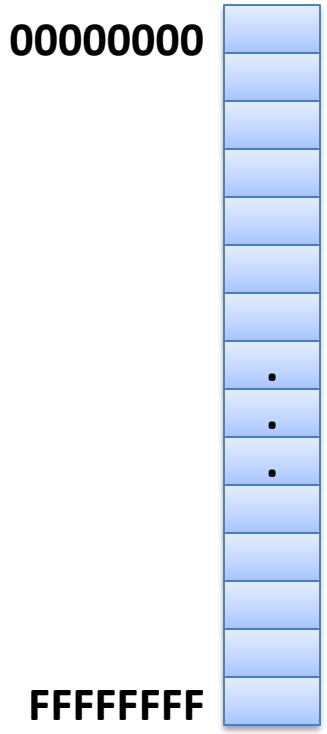
Memory Model

- Physical memory
  - DRAM chips can read/write 4, 8, 16 bits
  - DRAM modules can read/write 64 bits
- Programmer's view of memory
  - Conceptually, a very large array of bytes
  - Stored-program computers: keeps program codes and data in memory
  - Running programs share the physical memory
  - OS handles memory allocation and management

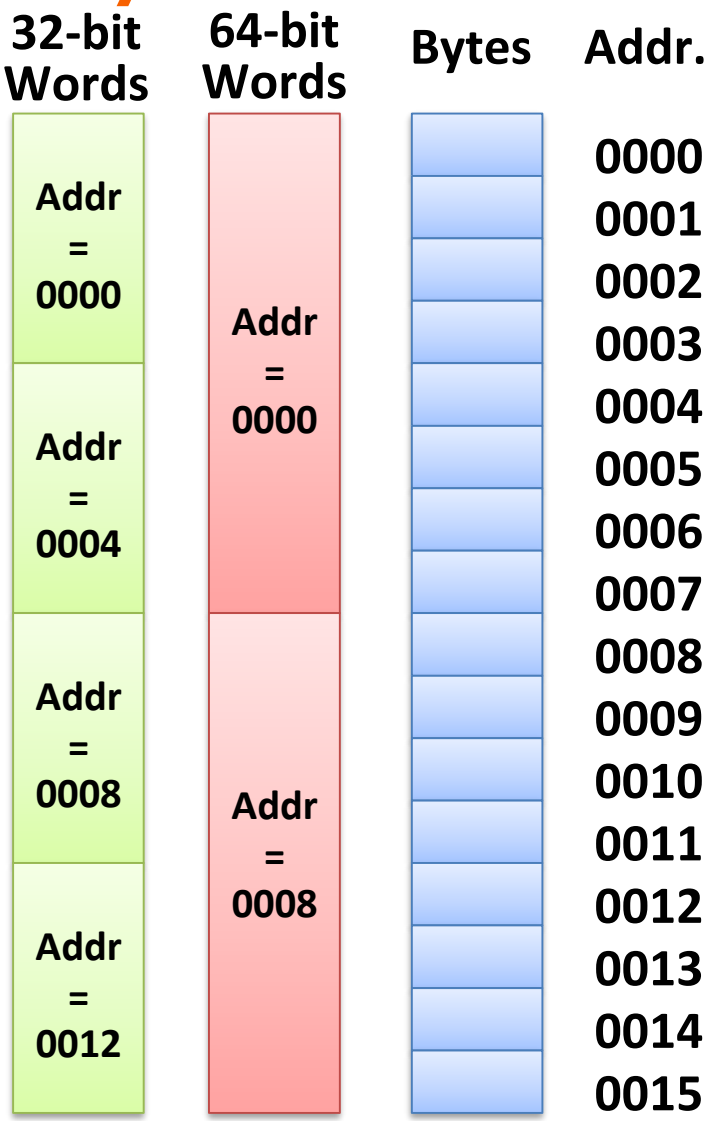


Machine Words

- Each computer has a "word size"
  - Nominal size of integer-valued data
    - Including addresses (= pointer size)
  - Until recently, most machines used 32-bit (4-byte) words
    - Limits addresses to 4 GB
    - Becoming too small for memory-intensive applications
  - Increasingly, machines have 64-bit (8-byte) word size
    - Potential address space $\simeq 18.4 \times 10^{18}$ bytes (18 EB)
    - x86-64 machines support 48-bit addresses: 256 TB
  - Machines support multiple data formats
    - Fractions or multiples of word size
    - Always integral number of bytes

Word-level Memory Access

- Addresses specify byte locations
  - Address of first byte in word
  - Addresses of successive words differ by 4 (32-bit) or 8 (64-bit)
  - Usually, addresses should be aligned to the word boundary



Data Types in C

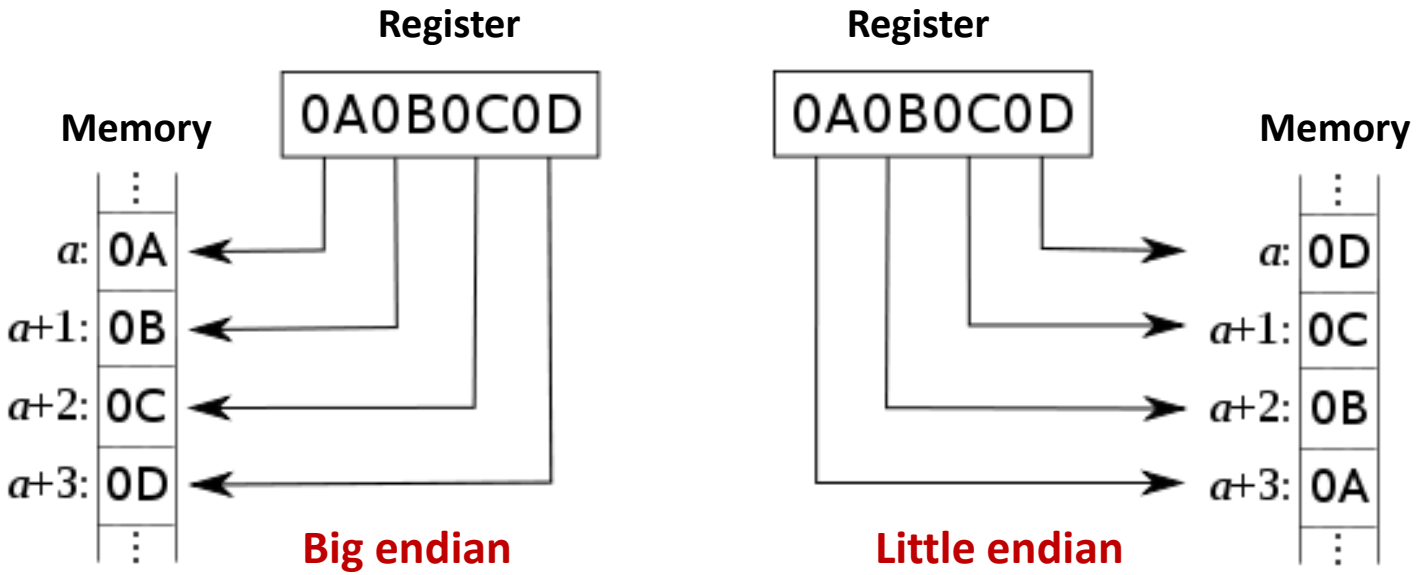
C Data Type	Typical 32-bit	Typical 64-bit	x86-64
char	1	1	1
short	2	2	2
int	4	4	4
long	4	8	8
long long	8	8	8
float	4	4	4
double	8	8	8
long double	-	-	10/16
pointer	4	8	8

Byte Ordering

- How are the bytes within a multi-byte word ordered in memory?
- Conventions
  - Big endian: Sun, PowerPC Mac, Internet
  - Little endian: Intel x86, ARM running Android & iOS
- Note:
  - Alpha and PowerPC can run in either mode, with the byte ordering convention determined when the chip is powered up
  - Problem when the binary data is communicated over a network between different machines

Big vs. Little Endian

- Big endian
  - Least significant byte has highest address
- Little endian
  - Least significant byte has lowest address



Example 1

- Disassembly
  - Text representation of binary machine code
  - Generated by program that reads the machine code
- Example fragment

```
Address        Instruction Code                  Assembly Rendition
8048365:       5b                                pop    %ebx
8048366:       81 c3 ab 12 00 00                 add    $0x12ab,%ebx
804836c:       83 bb 28 00 00 00 00              cmpl   $0x0,0x28(%ebx)
```

- Deciphering numbers:

```
Value:                0x12ab
Pad to 32 bits:       0x000012ab
Split into bytes:     00 00 12 ab
Reverse:              ab 12 00 00
```

Example 2

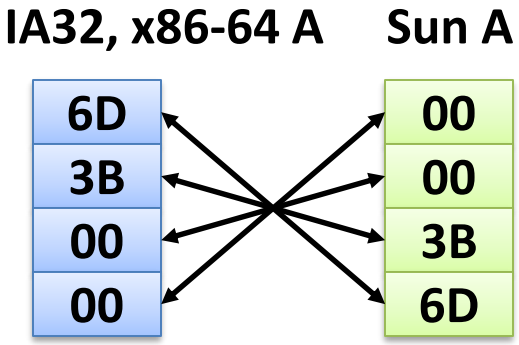
- What is the output of this program?
  - Solaris/SPARC: ?
  - Linux/x86: ?

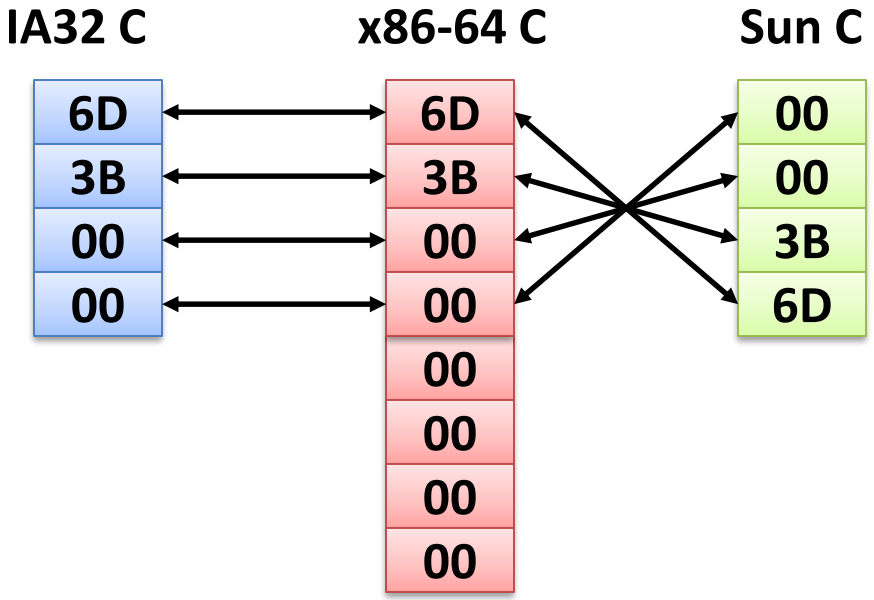
```
#include   <stdio.h>

union {
    int             i;
    unsigned char   c[4];
} u;

int main ()  {
    u.i = 0x12345678;
    printf ("%x %x %x %x\n",
            u.c[0], u.c[1], u.c[2], u.c[3]);
}
```

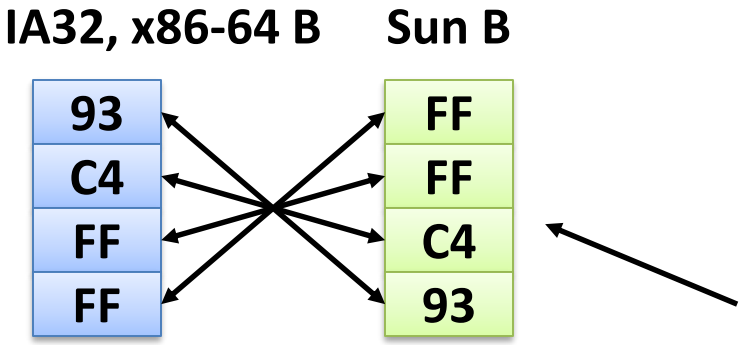
Representing Integers

```
int A = 15213;
int B = -15213;
long int C = 15213;
```

Decimal:	15213
Binary:	0011 1011 0110 1101
Hex:	3 B 6 D



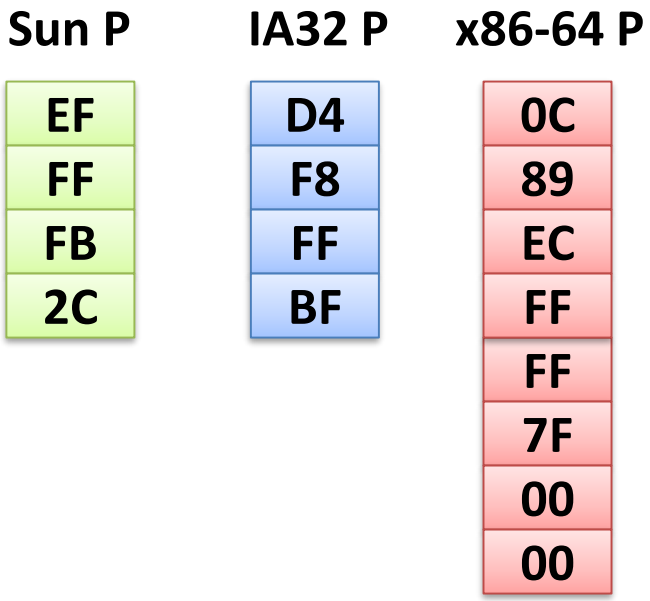




Two's complement representation

Representing Pointers

```
int B = -15213;
int *P = &B;
```

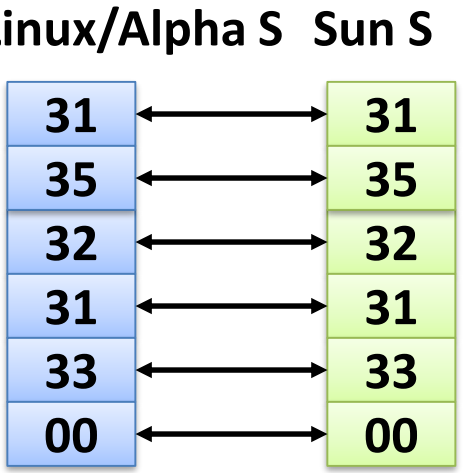


Different compilers & machines assign different locations to objects
Even get different results each time run program

Representing Strings

- Strings in C
  - Represented by array of characters
  - Each character encoded in ASCII format
    - Standard 7-bit encoding of character set
    - Character '0' has code 0x30
    - Digit *i* has code 0x30 + *I*
  - String should be null-terminated
    - Final character = 0x00
- Compatibility
  - Byte ordering not an issue

char S[6] = "15213";



Summary

- It's all about bits & bytes
  - Numbers, programs, text, …
- Different machines follow different conventions
  - Word size
  - Byte ordering
  - Representations (integer, floating-point)
- When programming, be aware of
  - Type casting & mixed signed/unsigned expressions
  - Overflow
  - Error propagation
  - Byte ordering