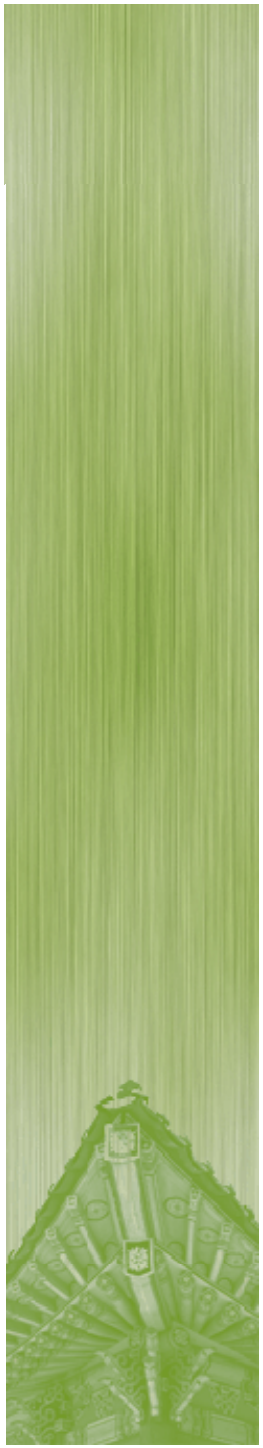

Byte Ordering

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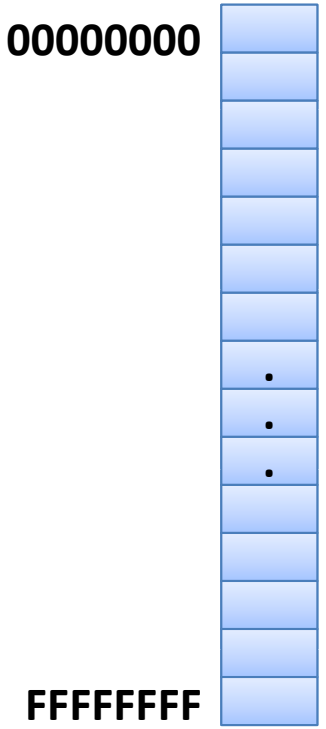
Memory Model

- **Physical memory**
  - DRAM chips can read/write 4, 8, 16 bits.
  - DRAM modules can read/write 64 bits.

- **Programmer's view of memory**
  - Conceptually 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

- **Machine has "word size"**
  - Nominal size of integer-valued data
    - Including addresses (= pointer size)
  - Most current machines use 32 bits (4 bytes) words
    - Limits addresses to 4GB
    - Becoming too small for memory-intensive applications
  - High-end systems use 64 bits (8 bytes) words
    - Potential address space ≈ 1.8 X 10^{19} bytes
    - x86-64 machines support 48-bit addresses: 256 Terabytes
  - Machines support multiple data formats
    - Fractions or multiples of word size
    - Always integral number of bytes

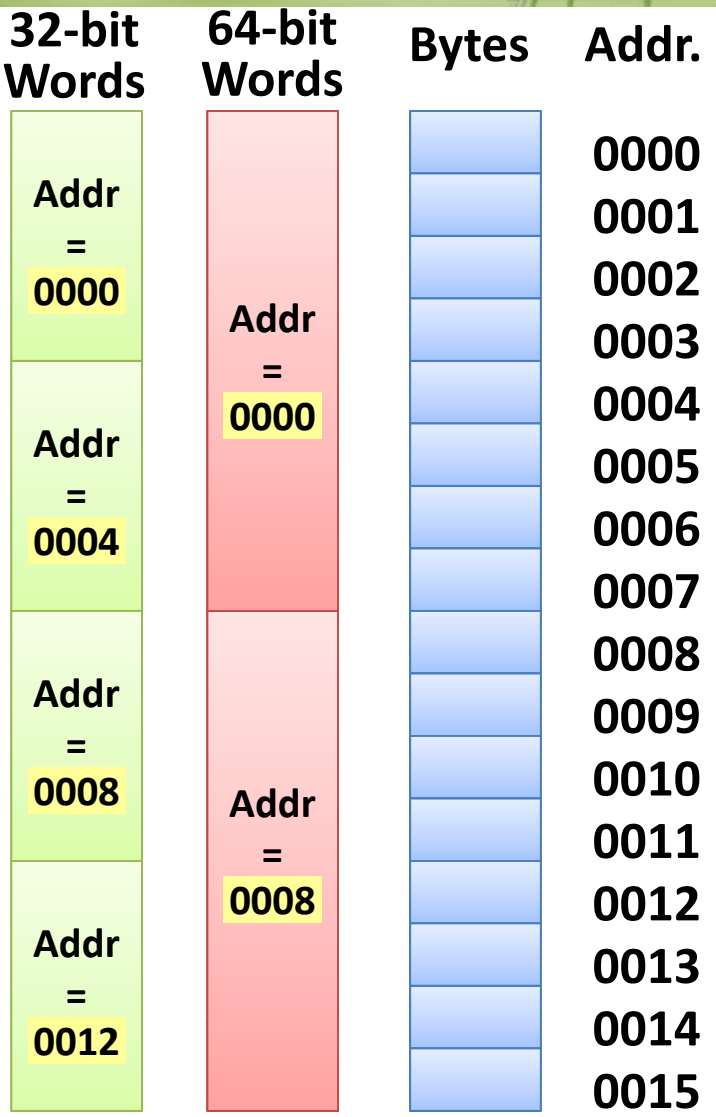
Data Representations

- **Sizes of C Objects (in bytes)**

C Data Type	Typical 32-bit	Intel IA-32	x86-64
char	1	1	1
short	2	2	2
int	4	4	4
long	4	4	8
long long	8	8	8
float	4	4	4
double	8	8	8
long double	8	10/12	10/16
char * or any other pointer	4	4	8

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

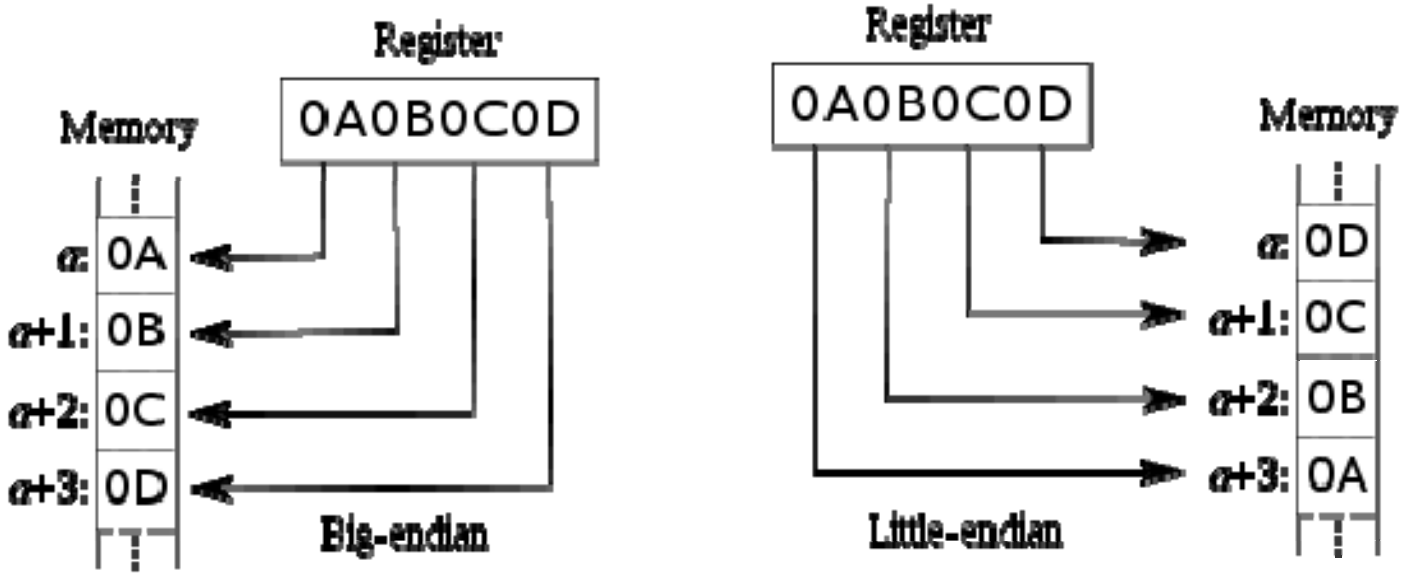


Byte Ordering

- **How should bytes within multi-byte word be ordered in memory?**
- **Conventions**
  - **Big Endian**: Sun, PowerPC Mac, Internet
  - **Little Endian**: x86
- **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.

Byte Ordering Example (1)

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



Byte Ordering Example (2)

- **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**

Byte Ordering Example (3)

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

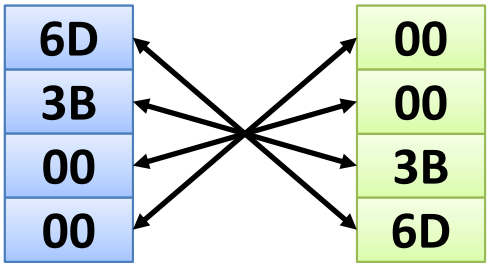
```
#include    <stdio.h>

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;
```

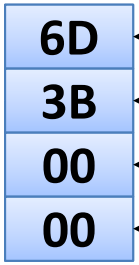
Decimal:	15213
Binary:	0011 1011 0110 1101
Hex:	3 B 6 D

IA32, x86-64 A

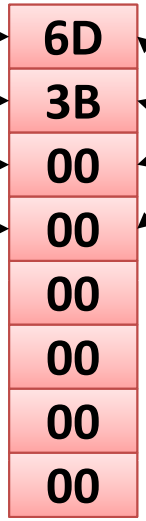


Sun A

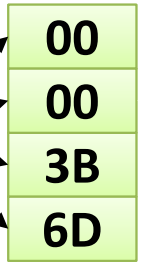
IA32 C



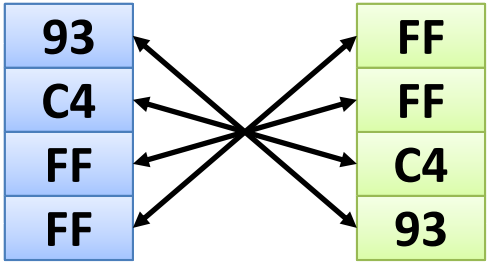
x86-64 C



Sun C



IA32, x86-64 B

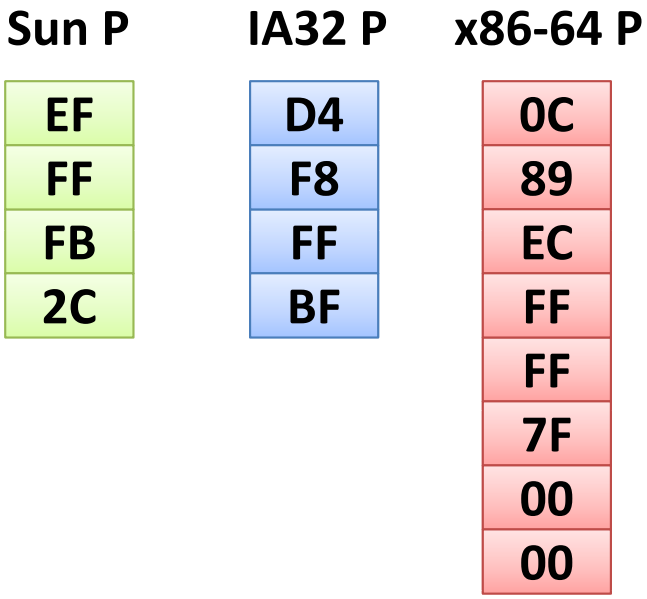


Sun B

Two's complement representation

Representing Pointers

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

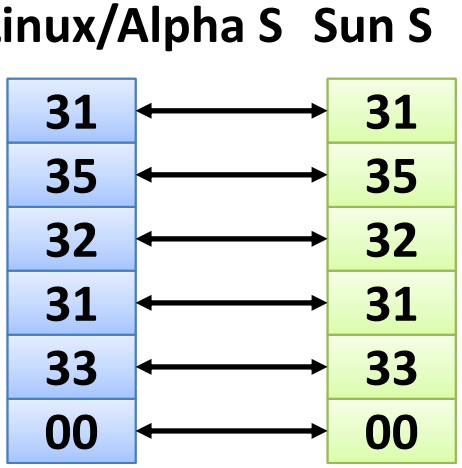


Different compilers & machines assign different locations to objects

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

char S[6] = "15213";



- **Compatibility**
  - Byte ordering not an issue

Main Points

- **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