

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)
- Machines use 32 bits (4 bytes) words
 - Limits addresses to 4GB
 - Becoming too small for memory-intensive applications
- Most current systems use 64 bits (8 bytes) words
 - Potential address space $\approx 1.8 \times 10^{19}$ bytes (18 Exabyte)
 - 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

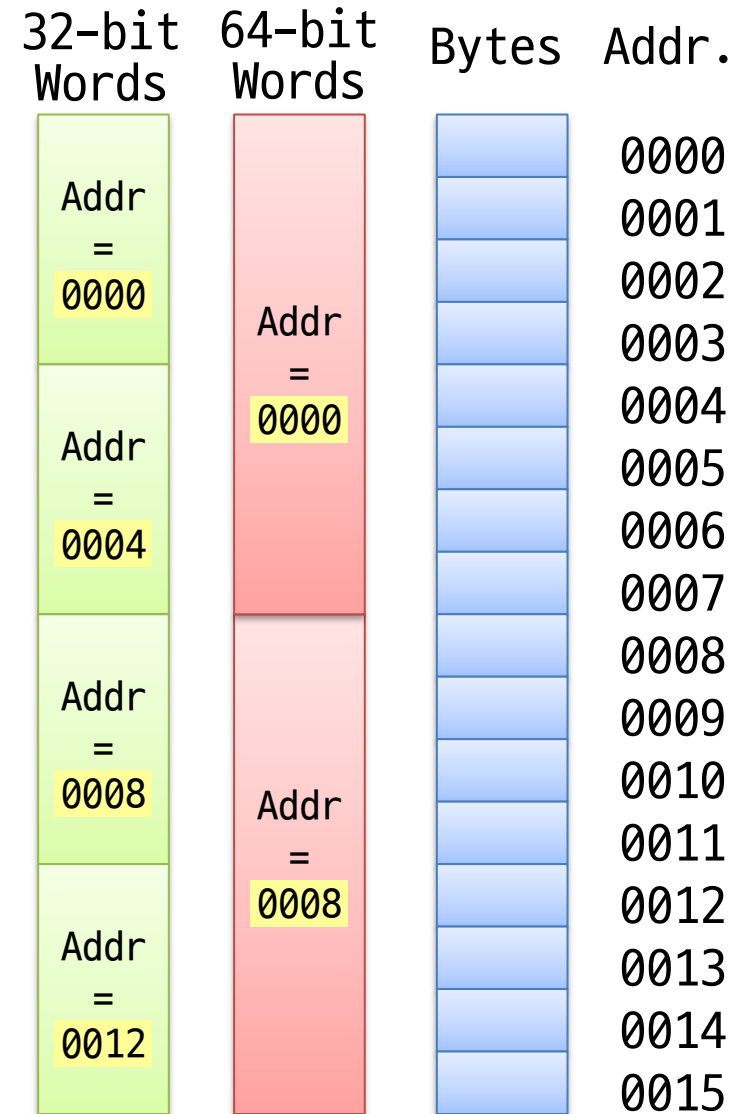
Sizes of C Objects (in bytes)

• 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
- int *	4	4	8
- double *	??		

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
 - Bi Endian: ARM (Mostly, little endian)
- **Problem when the binary data is communicated over a network between different machines**

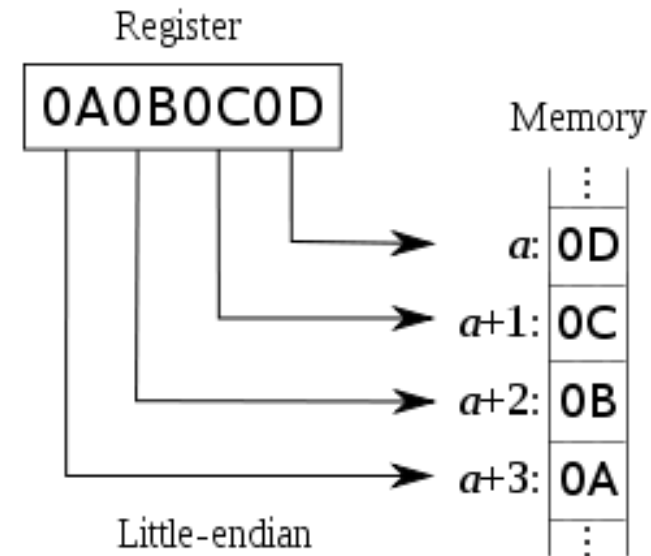
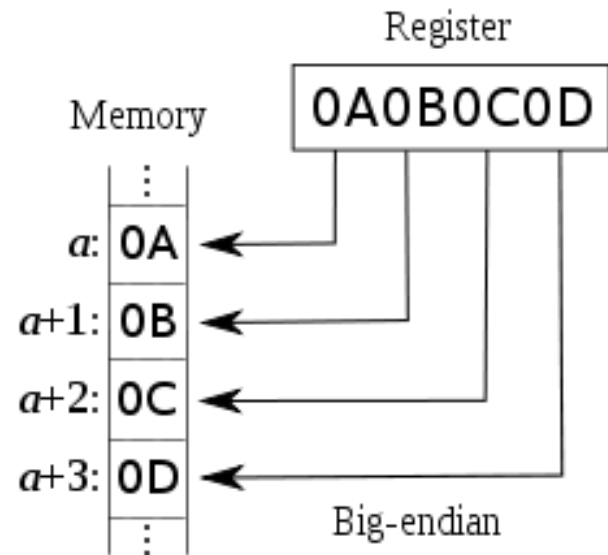
Byte Ordering Example (1)

Big endian

- Least significant byte has highest address

Little endian

- Least significant byte has lowest address



Byte Ordering Example (2)

Disassembly

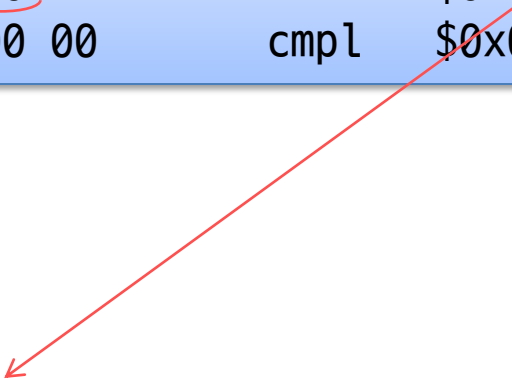
- Text representation of binary machine code
- Generated by program that reads the machine code

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>

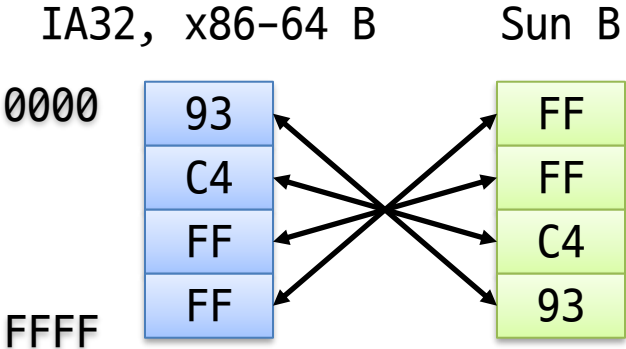
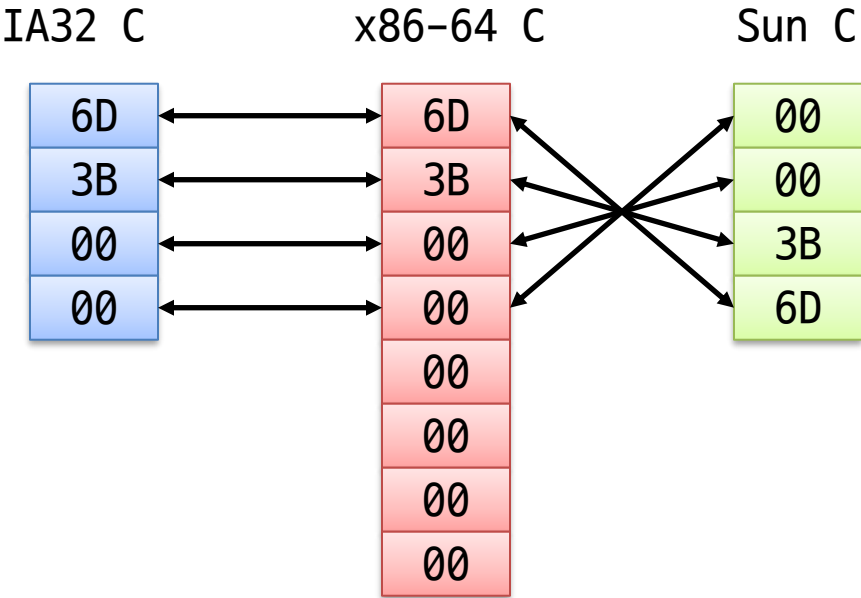
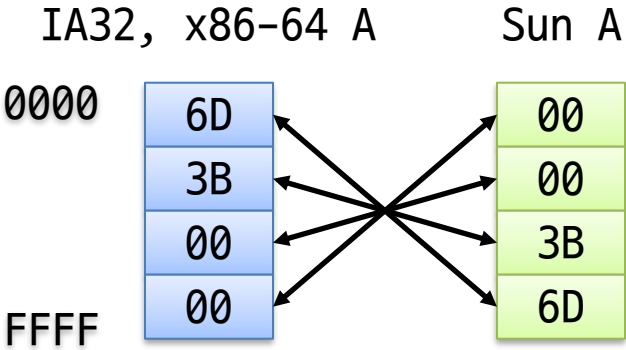
union {
    int      i;
    unsigned char c[4];
} u;

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:	0000 0000 0000 0000 0011 1011 0110 1101
Hex:	0 0 0 0 3 B 6 D



Two's complement representation

Decimal:	-15213
Binary:	1111 1111 1111 1111 1100 0100 1001 0011
Hex:	F F F F C 4 9 3

Representing Pointers

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

Sun P	IA32 P	x86-64 P
EF	D4	0C
FF	F8	89
FB	FF	EC
2C	BF	FF
		FF
		7F
		00
		00

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 = '\0'
 - Not '\n'

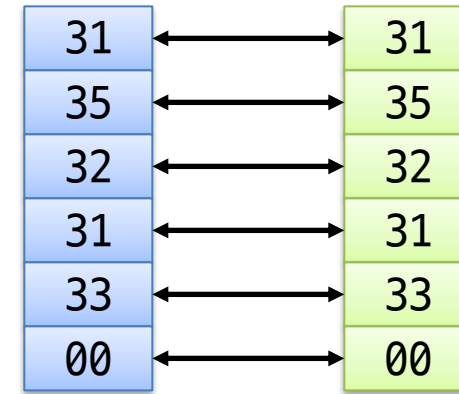
Compatibility

- Byte ordering not an issue
- When sending data, you should use string!

```
char S[5] = "15213";
```

Linux/IA32

Sun



Lessons

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