Byte Ordering

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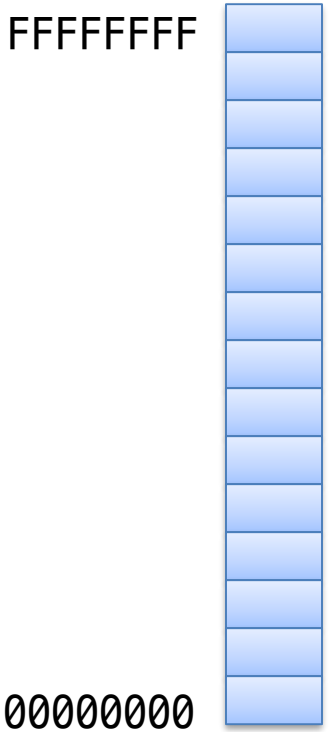
Memory Model

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 X 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

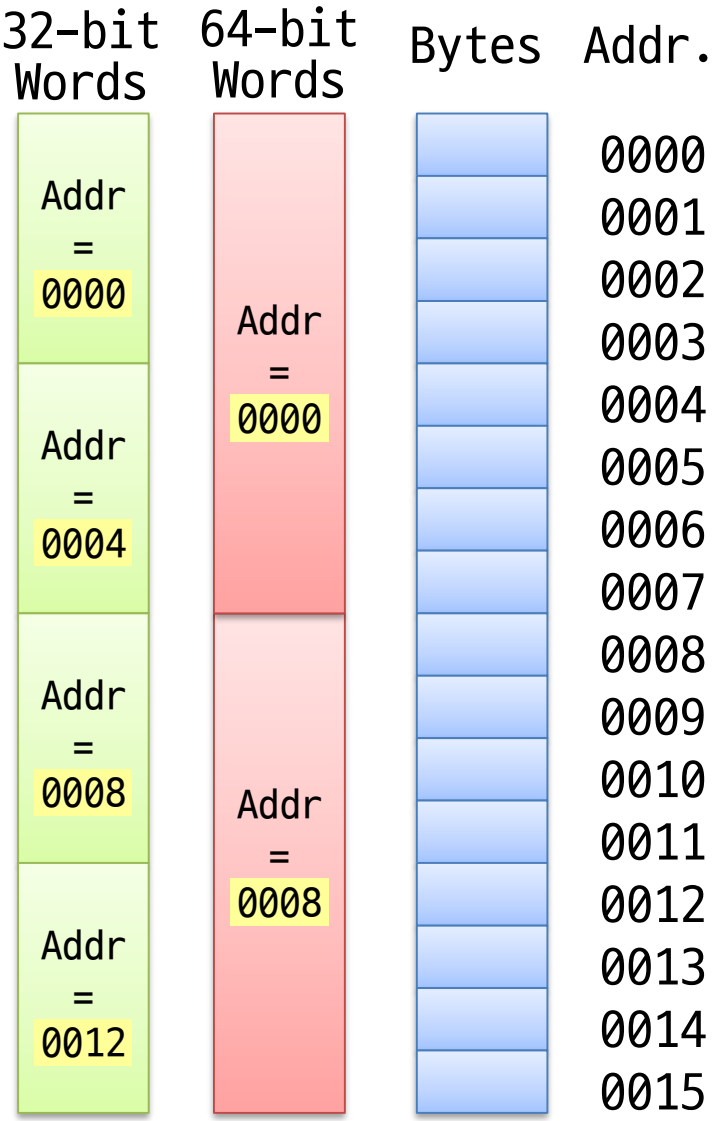
Sizes of C Objects (in bytes)

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
char *	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

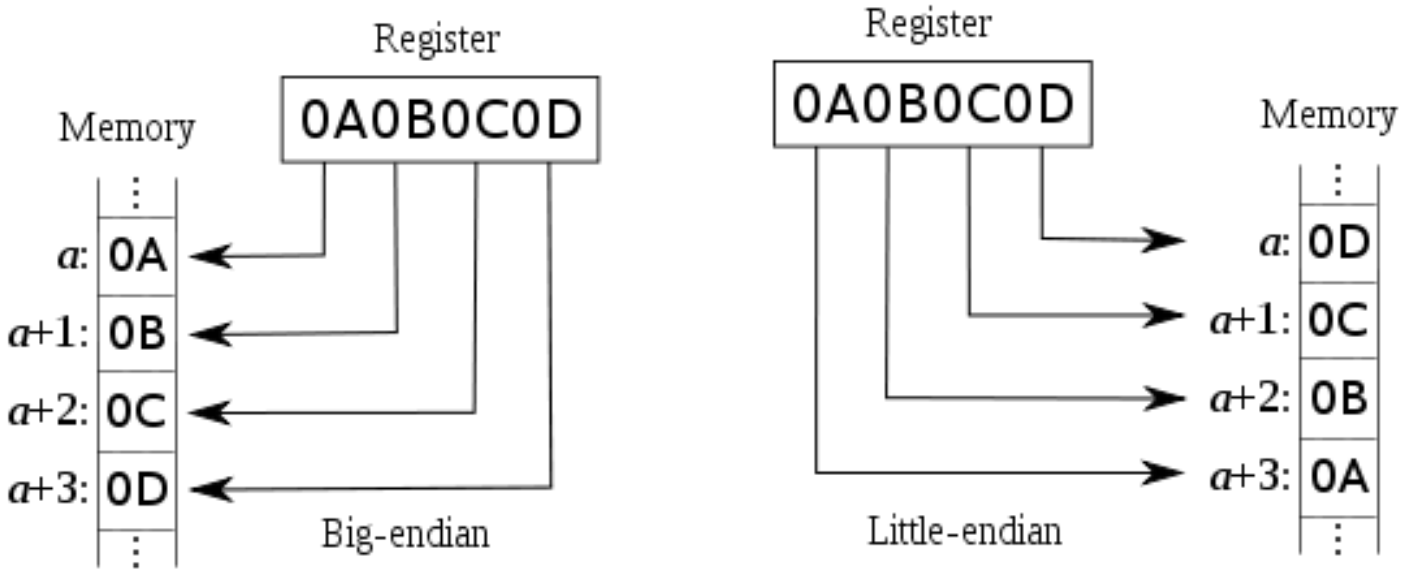
Byte Ordering Example (1)

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?

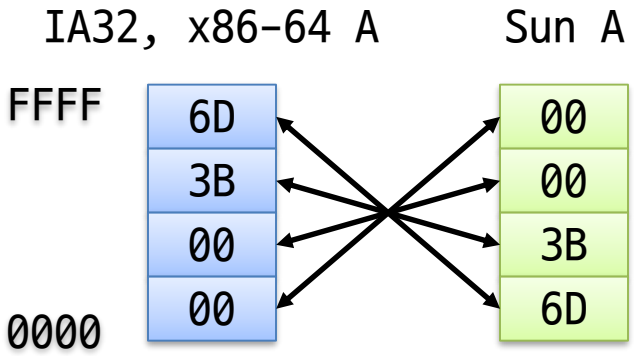
- Solaris/SPARC: ?
- Linux/x86: ?

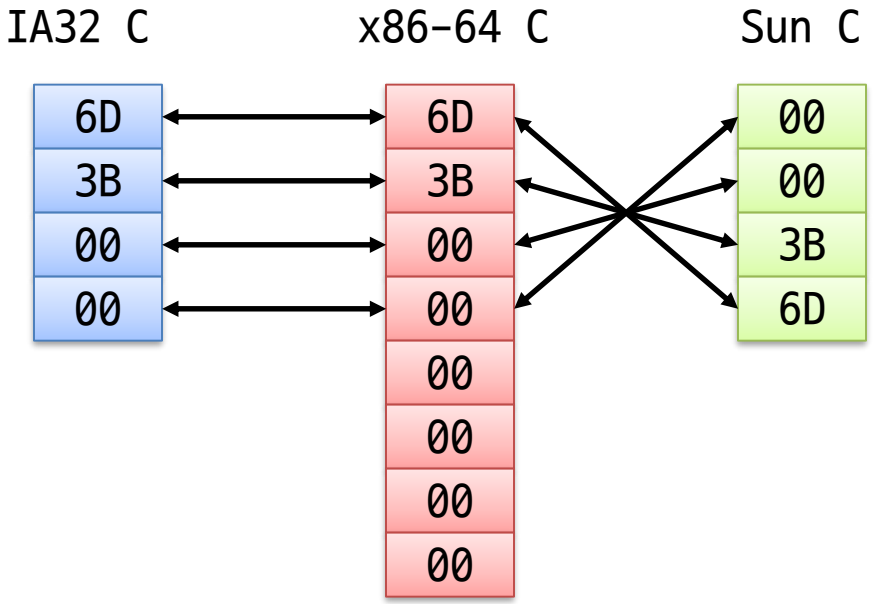
```
#include     <stdio.h>

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]);
}
```

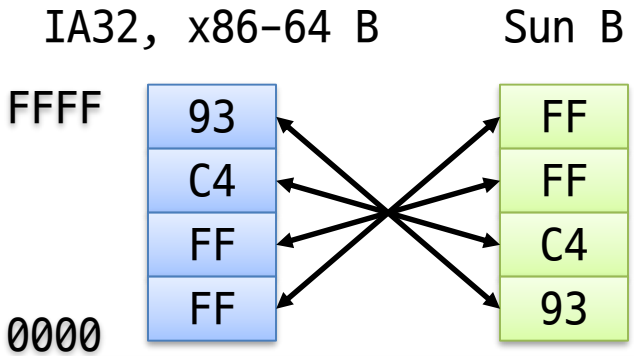
Representing Integers

```
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
```





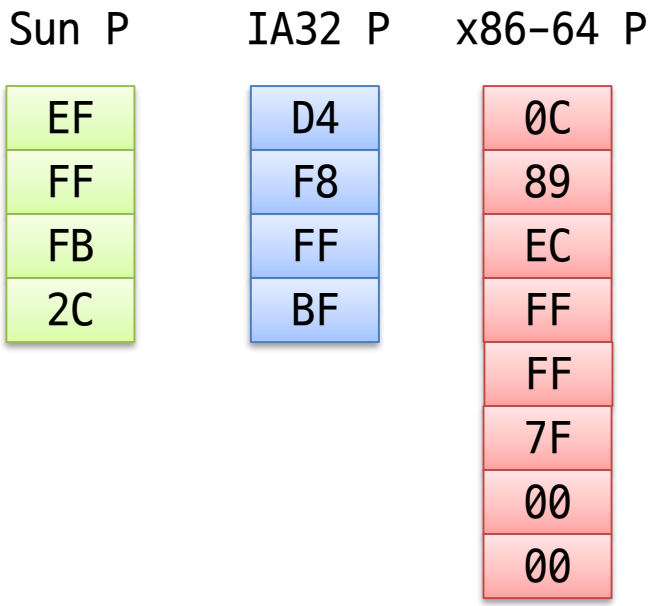


Two's complement representation

```
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;
```



Different compilers & machines assign different locations to objects

Representing Strings

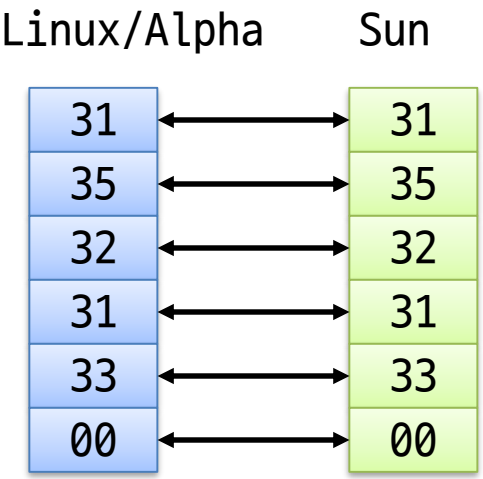
Strings in C

- 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";
```



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