Data Representation

Ref: 2.1

Bits/Bytes and Words

- A bit is a single value, either 1 or 0.
- A byte is an ordered sequence of 8 bits.
  - memory is typically *byte addressed* – each byte has a unique address.
- A word is an ordered sequence of bits, the length depends on the processor architecture.
  - typical value for modern computers is 32 bits.
  - word size reflects the size of addresses (a word is typically large enough to hold any address).

Byte Values

- There are 256 different byte values

00000000

00000001

00000010

00000011

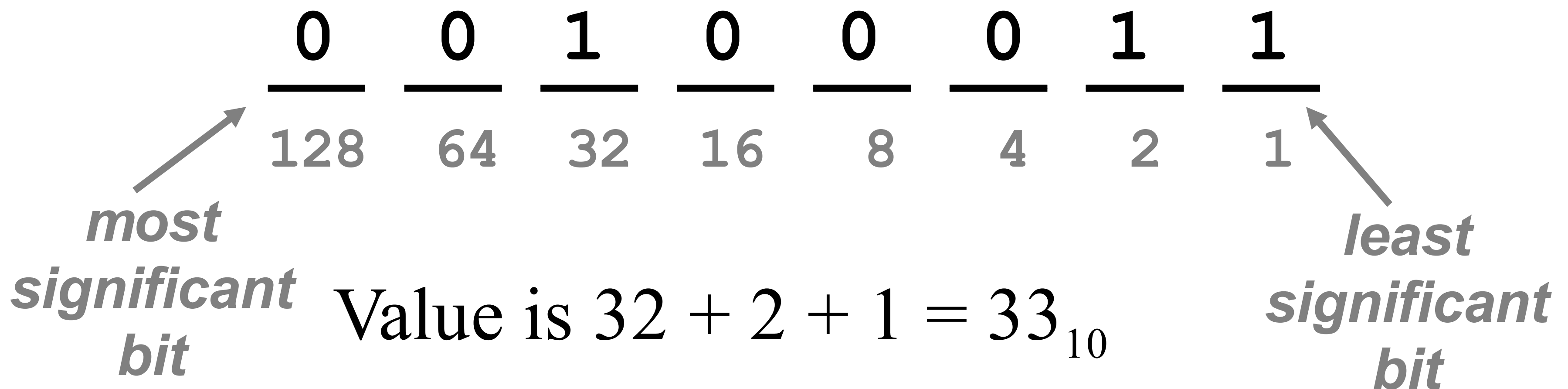
...

11111110

11111111

Bytes as unsigned integers

- Base 2 number using positional notation



Value is $32 + 2 + 1 = 33_{10}$

Hexadecimal

- Values are often expressed in base 16.
- One sequence of 4 bits is reduced to a single hexadecimal *digit*:

binary	0000	0001	0010	0011	0100	0101	0110	0111
hex	0	1	2	3	4	5	6	7

binary	1000	1001	1010	1011	1100	1101	1110	1111
hex	8	9	A	B	C	D	E	F

Specifying hex values in C/C++

- **`0x07`** specifies the 8 bit value **`0000 0111`**
- **`0xF2`** specifies the 8 bit value **`1111 0010`**
- The compiler determines the length (number of bits) depending on the context
  - and assumes leading 0s

C Programming and bytes

- Data type **`char`** is one byte.
  - there are 256 different char values!
- Some operations treat a **`char`** as an 8 bit integer:

```
char x = 12;
x++;
if (x>3) y++;
```

C `char` data type

- C allows you to specify a byte value using a *character literal*.

```
char x = 'E';
x = x+'A';
x = x+3;
```

- ASCII codes are used by C to represent text characters, each text character has a unique 8 bit code.

Other C integral data types

- Actual length (number of bits) depends on the compiler and machine architecture.
- Common lengths are shown:

`short int, unsigned short`
  - 16 bits (2 bytes)

`int, unsigned int`
  - 32 bits (4 bytes)

`long int, unsigned long`
  - 32 or 64 bits (4 or 8 bytes)

Unsigned Integers

- We are already familiar with the representation of positive (unsigned) 1 byte integers.
- larger size integers use the same scheme:
  - Positional Notation: each bit represents a power of 2.

ms ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ls

… 512 256 128 64 32 16 8 4 2 1

16 Bit (unsigned) Integers

Range of values is:

0_{10} : 0000000000000000

$65{,}535_{10}$: 1111111111111111

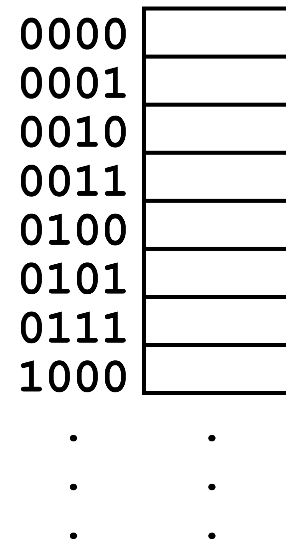
32 Bit (unsigned) Integers

Range of values is:

0_{10} : 00000000000000000000000000000000

$4{,}294{,}967{,}295_{10}$: 11111111111111111111111111111111

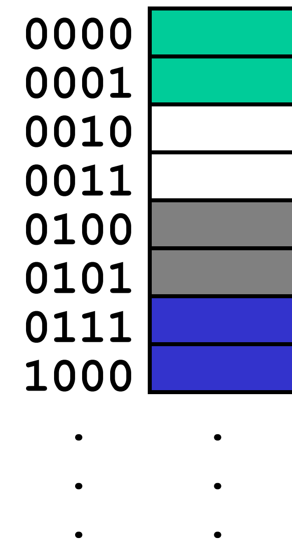
Memory



- Holds all data that is directly available to the processor.
- Each byte in memory has a unique name (called it's address).
- Addresses are binary values (with a fixed length).
  - address length determines maximum size of addressable memory

16 bit integers and memory

- A 16 bit (2 byte) word is stored in adjacent memory locations.
  - typically the smaller address must be divisible by 2.
- There are 2 possible arrangements of the bytes:
  - most significant is at lower address
  - most significant is at higher address



Byte Ordering

- Not all processor architectures use the same byte ordering!
- Big-Endian: The most significant byte has the lowest address
- Little Endian: The least significant byte has the lowest address
- Byte ordering is an issue with all multi-byte integers (32 bit and 64 bit).

Programming and byte order

- Generally a programmer doesn't need to know which byte ordering is used!
  - network programs are one exception.
  - debugging assembly language programs often requires knowledge of byte order.

C Programming and data

- It's easy to write C programs that can print out some data in various formats.
- Check out the sample code on the course home page .
- You need to understand *casting*, *pointers* and the C *printf* function.

printf

- C doesn't have cout (or cin, or any object-oriented stuff that is in C++!).

```
int printf(char *fmt, …);
```

`printf` examples

```
char x = 35;

printf("x is %d\n",x);

printf("x is %2x\n",x);

printf("x is %c\n",x);
```

print x as decimal value

print x as hex value

print x as ASCII character

Strings in C

- C does not have a *string* data type!
- There are some functions that treat a sequence of bytes (**`char`**) as a string.
  - each character is specified as the ASCII encoded value found in one byte.
- A string is terminated with the byte value 0.

Strings and C

- C functions that deal with strings generally only *know* the starting address of the string.
  - step through memory one byte at a time until a byte with value 0 is found.
- Pointers!

Sample Code

```
char *s = "Pointers are fun!";
printf("The length of the string is %d\n",
  strlen(s) );

printf("The string is: %s\n", s);
```