Numbers and Computers

- We think of numbers as integers or decimals, positive, or negative
- Computer logic is simplest with positive integers
- Workarounds are needed for negative integers and decimal numbers

Memory Allocation

- Computers need to assign space to hold a number in memory
- Memory in early computers was expensive, limited, and slow so memory was “rationed” out
  - char - 8 bits
  - int - 16 bits*
  - long – 32 bits*

  * Varies with device

Base N Numbers

- We are used to Base 10 integers

$$1011 = 1 \times 10^3 + 0 \times 10^2 + 1 \times 10^1 + 1 \times 10^0$$

- Computer people often use
  - Base 2 – Binary
  - Base 8 – Octal
  - Base 16 – Hexidecimal

Examples

Binary (only 0s and 1s)

$1011 = 1 \times 2^3 + 0 \times 2^2 + 1 \times 2^1 + 1 \times 2^0$

Octal (0, 1, 2, 3, 4, 5, 6, 7)

$1011 = 1 \times 8^3 + 0 \times 8^2 + 1 \times 8^1 + 1 \times 8^0$

Hex (0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F)

$1011 = 1 \times 16^3 + 0 \times 16^2 + 1 \times 16^1 + 1 \times 16^0$

Notation to Avoid Confusion

1011 (decimal)

0b1011 (binary)

01011 (octal)

0x1011 (hex)

Converting bases (10 →16)

1121 (decimal) to Hex.

Remember 16, $16^2 = 256$, $16^3 = 4096$

$$\begin{array}{r} 4 \\ 256\overline{)1121} \\ \underline{1024} \\ 97 \end{array} \qquad \begin{array}{r} 6 \\ 16\overline{)97} \\ \underline{96} \\ 1 \end{array}$$

1121 = 4*256 + 6*16 + 1 = 0x461

Converting bases (10 → 8)

1121 (decimal) to Octal.

Remember 8, $8^2 = 64$, $8^3 = 512$, $8^4 = 4096$

$$\begin{array}{r} 2 \\ 512\overline{)1121} \\ \underline{1024} \\ 97 \end{array} \qquad \begin{array}{r} 1 \\ 64\overline{)97} \\ \underline{64} \\ 33 \end{array} \qquad \begin{array}{r} 4 \\ 8\overline{)33} \\ \underline{32} \\ 1 \end{array}$$

1121 = 2*512 + 1*64 + 4*8 + 1 = 02141

Hex ↔ Binary

$2^{11}\ 2^{10}\ 2^9\ 2^8 \quad 2^7\ 2^6\ 2^5\ 2^4 \quad 2^3\ 2^2\ 2^1\ 2^0$

0b1010 0110 0101

$2^3\ 2^2\ 2^1\ 2^0 \quad 2^3\ 2^2\ 2^1\ 2^0 \quad 2^3\ 2^2\ 2^1\ 2^0$

$\times 2^8$ $\times 2^4$ $\times 2^0$

(256) (16) (1)

= A(or 10) * 256 + 6*16 + 5 (= 357)

= 0xA65

0xFA0 = 0b1111 1010 0000

Octal ↔ Binary

0b1010 0110 0101

= 0b101 001 100 101

= $5x8^3$ $1x8^2$ $4x8^1$ $5x8^0$

= 05145

02653 = 0b010 110 101 011

Remember!
Hex-Binary Conversion Table

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

Octal-Binary

1000	8
1001	9
1010	A (10)
1011	B (11)
1100	C (12)
1101	D (13)
1110	E (14)
1111	F (15)

Convert *unsigned char* values

binary	octal	hex	decimal
0b1001 1001			
	0245		
		0xA1	
			201

Windows Scientific Calculator

Displaying Numbers

```
#include <stdio.h> // has printf function

void main(void)
{
int number = 53;
printf("Number (base 2) = %b, Number (base 8) =
   %o, Number (base 10) = %u, Number (base 16)
   = %x", number, number, number, number);
}
```

Number (base 2) = 0b110101, Number (base 8) = 065,
Number (base 10) = 53, Number (base 16) = 0x35

C does not care about input format

```
#include <stdio.h> // has printf function

void main(void)
{
int number = 0x35;   // decimal 3*16+5=53
printf("Number (base 2) = %b, Number (base 8) =
   %o, Number (base 10) = %u, Number (base 16)
   = %x", number, number, number, number);
}
```

Number (base 2) = 0b110101, Number (base 8) = 065,

Number (base 10) = 53, Number (base 16) = 0x35

Memory Space and Rollover

Char – 8 bits

0000 0000 = 0

1111 1111 = 2^8 -1 = 255

What about *char* x = 280?

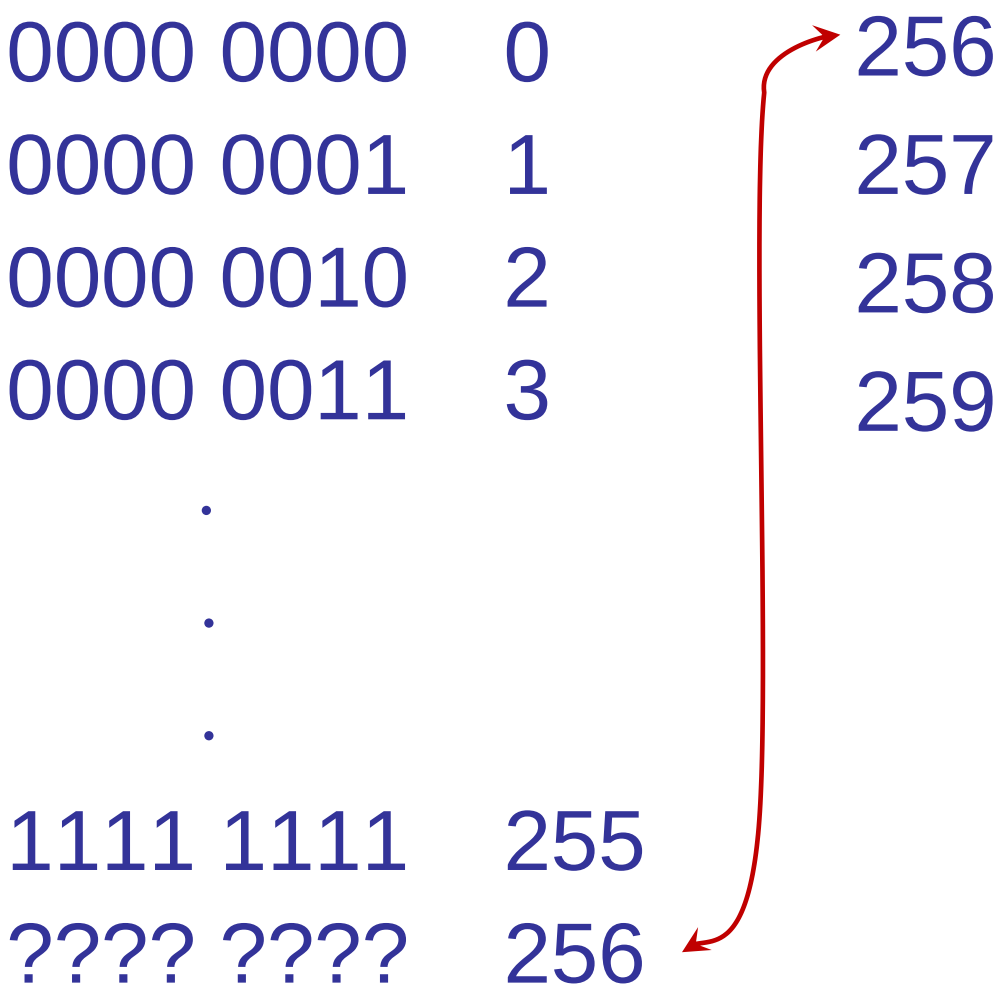
280 = 256 + 16 + 8

= 0001 0001 1000

= lost 0001 1000

= 24

Digits above 8 are lost!



Modulo 2^8 = modulo 256

Example (*unsigned char* values)

Unrounded Decimal	Rounded Decimal	Binary
300		
350		
400		
600		

Negative Numbers

Variables can be *unsigned* (defaults) which only hold non-negative integers or *signed*

But how you represent

signed char x = -27

in binary memory?

Remember only 8 spaces that can only hold 0 or 1

Solution – 2^s Complement Mapping

0111 1111 = 127

0000 0001 = 1

0000 0000 = 0

1111 1111 = -1

1111 1110 = -2

1000 0000 = -128

Example - Converting to base 10

signed char x = 0b1010 1101

8^{th} bit is 1 $\rightarrow$ negative.

To find decimal value, flip digits and add 1

1010 1101 $\rightarrow$ - (0101 0010 + 1)

= - (0101 0011)

= - (64 + 16 + 2 + 1)

= -83

Alternate

Note *unsigned char* x = 0b1010 1101 = 173

173 – 256 = -83

So *signed char* x = 0b1010 1101 = -83

Example - Converting to binary

signed char x = -33

What is this in binary?

-33 + 256 = 223 = 128+64+16+8+4+2+1

signed char x = 0b1101 1111

- Still Mod 256
- But remember which are

  + and which are -

Convert *signed char* values

Dec	Bin	Bin	Dec
72		1010 0001	
-37		1111 0100	
-111		1001 1111	
-64		0111 1001	
-129			
-200			
-300			
500			

Printing signed and unsigned variables

In printf() function must match formatting to variable type or the results may not make sense

```
char a = 0b11111111;                // -1  NB signed is default type
unsigned char b = 0b11111111;  // 255
printf(“Unsigned a = %u - Signed a = %i\n”, a, a);
printf(“Unsigned b = %u - Signed b = %i\n”, b, b);
```

Output

Unsigned a = 65355 - Signed a = -1

Unsigned b = 255 - Signed b = 255

Common mistakes in arithmetic expressions

- Compiler tries to make any expression correct to the appropriate number of sig figs, but it doesn’t always read your mind
- int/int produces int (rounds down)
- Mixing unsigned and signed variables
- Numbers bigger than 32767

Memory and Arithmetic

Limited space and datatypes cause common mistakes

```
int a = 8;
int b = 52;
int c = 100;
int d;
d = a/b*c;
printf("%i",d);
```

Output is d = 0!

Cast Operator

```
int a = 8;
int b = 52;
int c = 100;
int d;
d = (float)a/b*c;
printf("%i",d);
```

Now d = 15. More space and no inappropriate rounding

Or write d = (a*c)/b

Big Numbers

```
printf("%i\n",50000);
printf("%i\n",(unsigned int)50000);
printf("%u ",(unsigned int)50000);
printf("%u\n",50000u);
```

Output

```
195         (odd - treated it like char!)
-15536
50000
50000
```

```
unsigned int a = 670, b = 100, c = 350, d;
signed int e;
d = a*b;
e = b*c;
printf("d = %u \n",d);
printf("e = %i \n",e);
```

Output

```
d = 1464
e = -30536
```

ASCII

```
char a, b, c;
int d = 65*256 + 66.
a = 36;
b = '$';
c = a + b;
printf("a = %c b = %c c = %c\n",a,b,c);

printf("d = %c", d);
```

Output

```
a = $ b = $ c = H
d = B
```

Some ASCII code [p63-64]

Char	Dec	Oct	Hex	Bin
A	65	101	0x41	0b01000001
B	66	102	0x42	0b01000010
C	67	103	0x43	0b01000011
a	97	141	0x61	0b01100001
b	98	142	0x62	0b01100010
c	99	143	0x63	0b01100011
.	46	56	0x2e	0b00101110
/	47	57	0x2f	0b00101111
0	48	60	0x30	0b00110000
1	49	61	0x31	0b00110001

Structures

- User defined datatype
- Combination of regular datatypes

```
typedef struct studentID {
  char studentname[20];
  long studentnumber;
}
studentID APSCStudents[70];
```

- “.” Is “member of” operator

```
strcpy(APSCStudents[1].studentname, “Smith”);
APSCStudents[1].studentnumber = 10123456;
```

Bitfield

- Bitfield is a structure of bits

```
struct setLED
{
    unsigned  Zero:1;
    unsigned  One:1;
    unsigned  Two:1;
    unsigned  Three:1;
    unsigned  Four:1;
    unsigned  Five:1;
    unsigned  Six:1;
    unsigned  Seven:1;
};
```

Union

- Save space by using same memory space for two related variables.

```
union sensor_union
{
    unsigned char Byte;
    struct setLEDs bits;
};

union sensor_union IndicatorLEDs = 0;

indicatorLEDs.bits.Zero = 0;
indicatorLEDs.bits.One = 1;
…
indicatorLEDs.bits.Seven = 1;
```

or

```
indicatorLEDs.Byte = 0b011111111;
```

Bitwise Operators

AND
0 & 0 = 0
0 & 1 = 0
1 & 0 = 0
1 & 1 = 1

OR
0 | 0 = 0
0 | 1 = 1
1 | 0 = 1
1 | 1 = 1

XOR
0 ^ 0 = 0
0 ^ 1 = 1
1 ^ 0 = 1
1 ^ 1 = 0

NOT
~0 = 1
~1 = 0

What happens to the lights?

```
// LEDn controls a light – initially off (0) or on (1)
unsigned char LED1 = 0, LED2 = 1, LED3 = 0, LED4 = 1;

while(1) {
    LED1 = LED1 & 1;
    LED2 = LED2 | 1;
    LED3 = LED3 ^ 1;
    LED4 = ~LED4;
    Delay();
}
```

Shift Operators

Easiest to understand in Binary

0b1101 1100 >> 3 = 0b0001 1011
220 >> 3 = 27 (equiv. to $220/2^3$ rounded)

0b0001 1100 << 3 = 0b1110 0000
28 << 3 = 224 (equiv. to $28*2^3$)

Fast!
Be careful of rollover!
Be careful with signed integers & chars

Bitmask

- Special unsigned char variables are used to control features of the PIC
- Each bit sets (bit = 1) or clears (bit = 0) some user choice
- C does not address single bits directly! (no set bit 3 to 1)
- C18 defines variables that help with the configuring

void OpenUSART(unsigned char config, unsigned int spbrg)

Input Parameters	Description
config	Interrupt on Transmission: * USART_TX_INT_ON * USART_TX_INT_OFF * USART_TX_INT_MASK Interrupt on Receipt: * USART_RX_INT_ON * USART_RX_INT_OFF * USART_RX_INT_MASK usart Mode: * USART_ASYNCH_MODE * USART_SYNCH_MODE * USART_MODE_MASK Transmission Width: * USART_EIGHT_BIT * USART_NINE_BIT * USART_BIT_MASK Slave/Master Select (Applicable to Synchronous mode only): * USART_SYNC_SLAVE * USART_SYNC_MASTER * USART_SYNC_MASK Reception mode: * USART_SINGLE_RX * USART_CONT_RX * USART_CONT_RX_MASK Baud rate: * USART_BRGH_HIGH * USART_BRGH_LOW * USART_BRGH_MASK Address Detect Enable: * USART_ADDEN_ON * USART_ADDEN_OFF * USART_ADDEN_MASK
spbrg	This is the value that is written to the baud rate generator register which determines the baud rate at which the usart operates. The formulas for baud rate are: Asynchronous mode, high speed: Fosc / (16 * (spbrg + 1)) Asynchronous mode, low speed: Fosc / (64 * (spbrg + 1)) Synchronous mode: Fosc / (4 * (spbrg + 1)) Where Fosc is the oscillator frequency

Figure Error! No text of specified style in

From xc.h

```
#define USART_TX_INT_ON          0b11111111  // Transmit interrupt on
#define USART_TX_INT_OFF         0b01111111  // Transmit interrupt off
#define USART_RX_INT_ON          0b11111111  // Receive interrupt on
#define USART_RX_INT_OFF         0b10111111  // Receive interrupt off
#define USART_BRGH_HIGH          0b11111111  // High baud rate
#define USART_BRGH_LOW           0b11101111  // Low baud rate
#define USART_CONT_RX            0b11111111  // Continuous reception
#define USART_SINGLE_RX          0b11110111  // Single reception
#define USART_SYNC_MASTER        0b11111111  // Synchronous master mode
#define USART_SYNC_SLAVE         0b11111011  // Synchronous slave mode
#define USART_NINE_BIT           0b11111111  // 9-bit data
#define USART_EIGHT_BIT          0b11111101  // 8-bit data
#define USART_SYNCH_MODE         0b11111111  // Synchronous mode
#define USART_ASYNCH_MODE        0b11111110  // Asynchronous mode
```

Notice pairs – ON and OFF – acting on different bits .

Example

0b01111111

& 0b10111111

& 0b11111110

& 0b11111101

& 0b11111111

& 0b11111111

0b00111100

Column is 0 unless all entries are 1