

COMP1521 24T3 — Integers

<https://www.cse.unsw.edu.au/~cs1521/24T3/>

10 types of students

There are only 10 types of students ...

- those that understand binary
- those that don't understand binary

Decimal Representation

- Can interpret decimal number **4705** as:
 $4 \times 10^3 + 7 \times 10^2 + 0 \times 10^1 + 5 \times 10^0$
- The *base* or *radix* is 10 ... digits 0 – 9
- Place values:

...	1000	100	10	1
...	10^3	10^2	10^1	10^0

- Write number as 4705_{10}
 - Note use of subscript to denote base

- base 10 is an arbitrary choice
- can use any base
- e.g. could use base 7
- Place values:

...	343	49	7	1
...	7^3	7^2	7^1	7^0

- Write number as 1216_7 and interpret as:
 $1 \times 7^3 + 2 \times 7^2 + 1 \times 7^1 + 6 \times 7^0 == 454_{10}$

Binary Representation

- Modern computing uses binary numbers
 - because digital devices can easily produce high or low level voltages which can represent 1 or 0.
- The *base* or *radix* is 2
Digits 0 and 1
- Place values:

...	8	4	2	1
...	2^3	2^2	2^1	2^0

- Write number as 1011_2 and interpret as:
 $1 \times 2^3 + 0 \times 2^2 + 1 \times 2^1 + 1 \times 2^0 == 11_{10}$

Converting between Binary and Decimal

- Example: Convert 1101_2 to Decimal:

- Example: Convert 29 to Binary:

Hexadecimal Representation

- Binary numbers hard for humans to read — too many digits!
- Conversion to decimal awkward and hides bit values
- Solution: write numbers in hexadecimal!
- The *base* or *radix* is 16 ... digits 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F
- Place values:

...	4096	256	16	1
...	16^3	16^2	16^1	16^0

- Write number as $3AF1_{16}$ and interpret as:
 $3 \times 16^3 + 10 \times 16^2 + 15 \times 16^1 + 1 \times 16^0 == 15089_{10}$
- in C, **0x** prefix denotes hexadecimal, e.g. **0x3AF1**

Octal & Binary C constants

- Octal (based 8) representation used to be popular for binary numbers
- Similar advantages to hexadecimal
- in C a leading **0** denotes octal, e.g. **07563**
- binary constants were only recently added to C - some C compilers will not recognize them

```
printf("%d", 0x2A);    // prints 42
printf("%d", 052);    // prints 42
printf("%d", 0b101010); // might compile and print 42
```

Binary Constants

In hexadecimal, each digit represents 4 bits

	0100	1000	1111	1010	1011	1100	1001	0111
0x	4	8	F	A	B	C	9	7

In octal, each digit represents 3 bits

	01	001	000	111	110	101	011	110	010	010	111
0	1	1	0	7	6	5	3	6	2	2	7

In binary, each digit represents 1 bit

```
0b01001000111110101011110010010111
```

- Example: Convert 1011111000101001_2 to Hex:

- Example: Convert 10111101011100_2 to Hex:

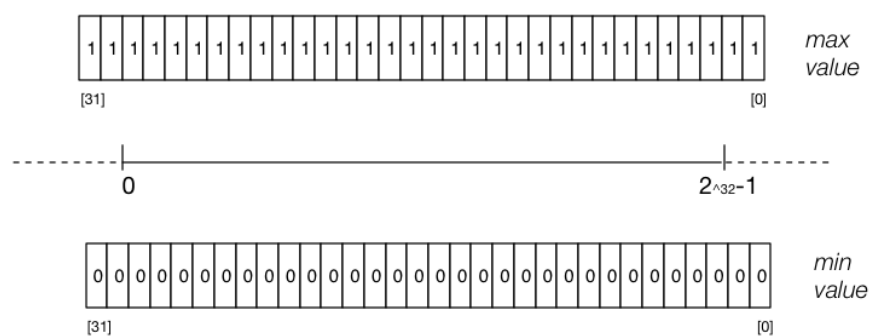
Hexadecimal to Binary

- Reverse the previous process ...
- Convert each hex digit into equivalent 4-bit binary representation
- Example: Convert $AD5_{16}$ to Binary:

Unsigned integers

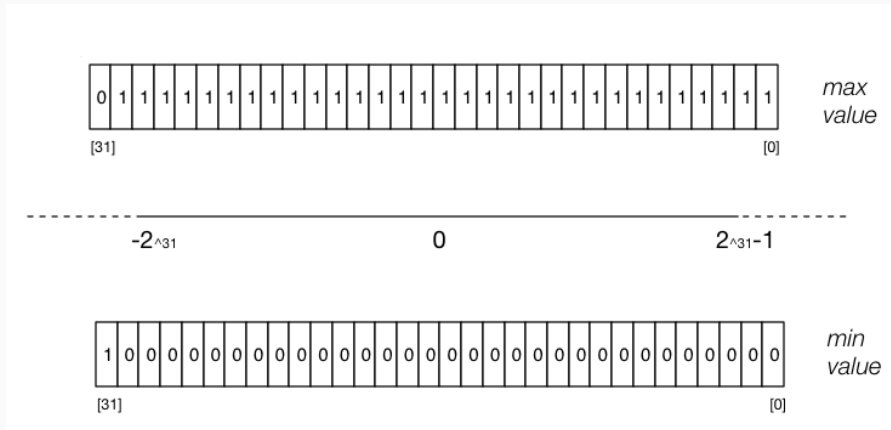
The `unsigned int` data type

- on cse machines is 32 bits, storing values in the range $0 \dots 2^{32}-1$



The `int` data type

- on cse machines is 32 bits, storing values in the range $-2^{31} .. 2^{31}-1$



Representing Negative Integers

- modern computers almost always use two's complement to represent integers
- positive integers and zero represented in obvious way
- negative integers represented in clever way to make arithmetic in silicon fast/simpler
- for an n -bit binary number the representation of $-b$ is $2^n - b$
- e.g. in 8-bit two's complement -5 is represented as $2^8 - 5 = 11111011_2$

Code example: printing all 8 bit twos complement bit patterns

- Some simple code to examine all 8 bit twos complement bit patterns.

```
for (int i = -128; i < 128; i++) {
    printf("%4d ", i);
    print_bits(i, 8);
    printf("\n");
}
```

source code for 8_bit_twos_complement.c

```
$ gcc 8_bit_twos_complement.c print_bits.c -o 8_bit_twos_complement
```

source code for print_bits.c source code for print_bits.h

```

$ ./8_bit_twos_complement
-128 10000000
-127 10000001
-126 10000010
...
-3 11111101
-2 11111110
-1 11111111
0 00000000
1 00000001
2 00000010
3 00000011
...
125 01111101
126 01111110
127 01111111

```

Code example: printing bits of int

```

int a = 0;
printf("Enter an int: ");
scanf("%d", &a);
// sizeof returns number of bytes, a byte has 8 bits
int n_bits = 8 * sizeof a;
print_bits(a, n_bits);
printf("\n");

```

source code for print_bits_of_int.c

```

$ gcc print_bits_of_int.c print_bits.c -o print_bits_of_int
$ ./print_bits_of_int
Enter an int: 42
0000000000000000000000000000101010
$ ./print_bits_of_int
Enter an int: -42
1111111111111111111111111111010110

```

Code example: printing bits of int

```

$ ./print_bits_of_int
Enter an int: 0
00000000000000000000000000000000
$ ./print_bits_of_int
Enter an int: 1
00000000000000000000000000000001
$ ./print_bits_of_int
Enter an int: -1
11111111111111111111111111111111
$ ./print_bits_of_int
Enter an int: 2147483647
01111111111111111111111111111111
$ ./print_bits_of_int
Enter an int: -2147483648
10000000000000000000000000000000
$

```

- Many hardware operations works with bytes: 1 byte == 8 bits
- C's **sizeof** gives you number of bytes used for variable or type
- **sizeof variable** - returns number of bytes to store *variable*
- **sizeof (type)** - returns number of bytes to store *type*
- On CSE servers, C types have these sizes
 - **char** = 1 byte = 8 bits, 42 is 00101010
 - **short** = 2 bytes = 16 bits, 42 is 0000000000101010
 - **int** = 4 bytes = 32 bits, 42 is 000000000000000000000000101010
 - **double** = 8 bytes = 64 bits, 42 = ?
- above are common sizes but not universal on a small embedded CPU
sizeof (int) might be 2 (bytes)

Code example: integer_types.c - exploring integer types

We can use **sizeof** and **limits.h** to explore the range of values which can be represented by standard C integer types **on our machine...**

```
$ gcc integer_types.c -o integer_types
$ ./integer_types
      Type Bytes Bits
      char      1   8
signed char      1   8
unsigned char    1   8
      short     2  16
unsigned short   2  16
      int       4  32
unsigned int     4  32
      long      8  64
unsigned long    8  64
      long long  8  64
unsigned long long 8  64
```

Code example: integer_types.c - exploring integer types

Type	Min	Max
char	-128	127
signed char	-128	127
unsigned char	0	255
short	-32768	32767
unsigned short	0	65535
int	-2147483648	2147483647
unsigned int	0	4294967295
long	-9223372036854775808	9223372036854775807
unsigned long	0	18446744073709551615
long long	-9223372036854775808	9223372036854775807
unsigned long long	0	18446744073709551615

source code for integer_types.c

```
#include <stdint.h>
```

- to get below integer types (and more) with guaranteed sizes
- we will use these heavily in COMP1521

```

// range of values for type
//           minimum           maximum
int8_t  i1; //           -128           127
uint8_t i2; //           0           255
int16_t i3; //          -32768          32767
uint16_t i4; //           0          65535
int32_t i5; //        -2147483648        2147483647
uint32_t i6; //           0          4294967295
int64_t i7; //    -9223372036854775808    9223372036854775807
uint64_t i8; //           0 18446744073709551615

```

source code for stdint.c

Code example: char_bug.c

Common C bug:

```

char c; // c should be declared int (int16_t would work, int is better)
while ((c = getchar()) != EOF) {
    putchar(c);
}

```

Typically `stdio.h` contains:

```
#define EOF -1
```

- most platforms: char is signed (-128..127)
 - loop will incorrectly exit for a byte containing 0xFF
- rare platforms: char is unsigned (0..255)
 - loop will never exit

source code for char_bug.c

Endian-ness

- The bytes of a multi-byte (2 byte, 4 byte, ...) quantity can be stored in various orders.
- **Endian-ness** is the order.
- Two common orders: big-endian & little-endian
- **big-endian** - most significant byte at the smallest memory address.
- **little-endian** - least significant byte at the smallest memory address.
- Most modern general-purpose computers little-endian
- Endian-ness configurable on some architectures e.g ARM

C

```
uint8_t b;
uint32_t u;
u = 0x03040506;
// load first byte of u
b = *(uint8_t *)&u;
// prints 6 if little-endian
// and 3 if big-endian
printf("%d\n", b);
```

source code for endian.c

MIPS

```
lbu $a0, u      # b = *(uint8_t *)&u;
li $v0, 1       # printf("%d", a0);
syscall
li $a0, '\n'    # printf("%c", '\n');
li $v0, 11
syscall
li $v0, 0       # return 0
jr $ra

.data
u:
.word 0x3040506 #u = 0x03040506;
```

source code for endian.s