COMP1521 25T2

Week 4 Lecture 1

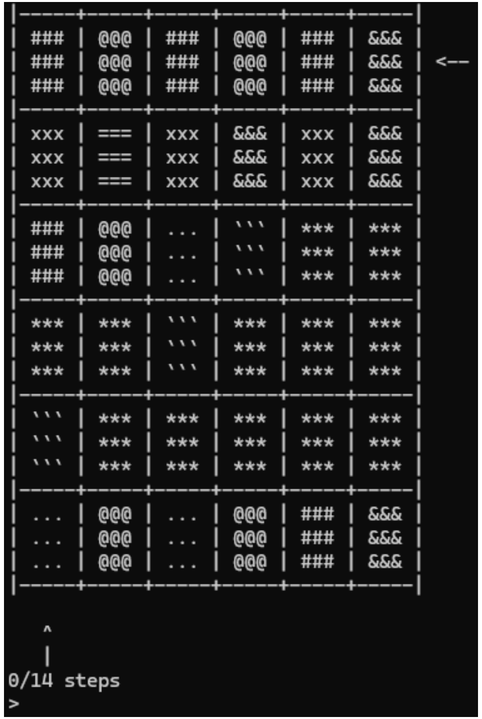
Integers and Bitwise Operators

Announcements

- Lab 3 Due: Today midday (2 hours ago 😱)
- Weekly Test 3 Due: Thursday 21:00:00.
- Assignment 1 Due: Week 5 Friday 18:00 (next week)
    - Spec, code, walkthrough video are all available
- See Help Session Schedule for assistance
- Census Date: Thursday 26th Jun
    - Last day to drop T2 courses without financial liability

Assignment 1

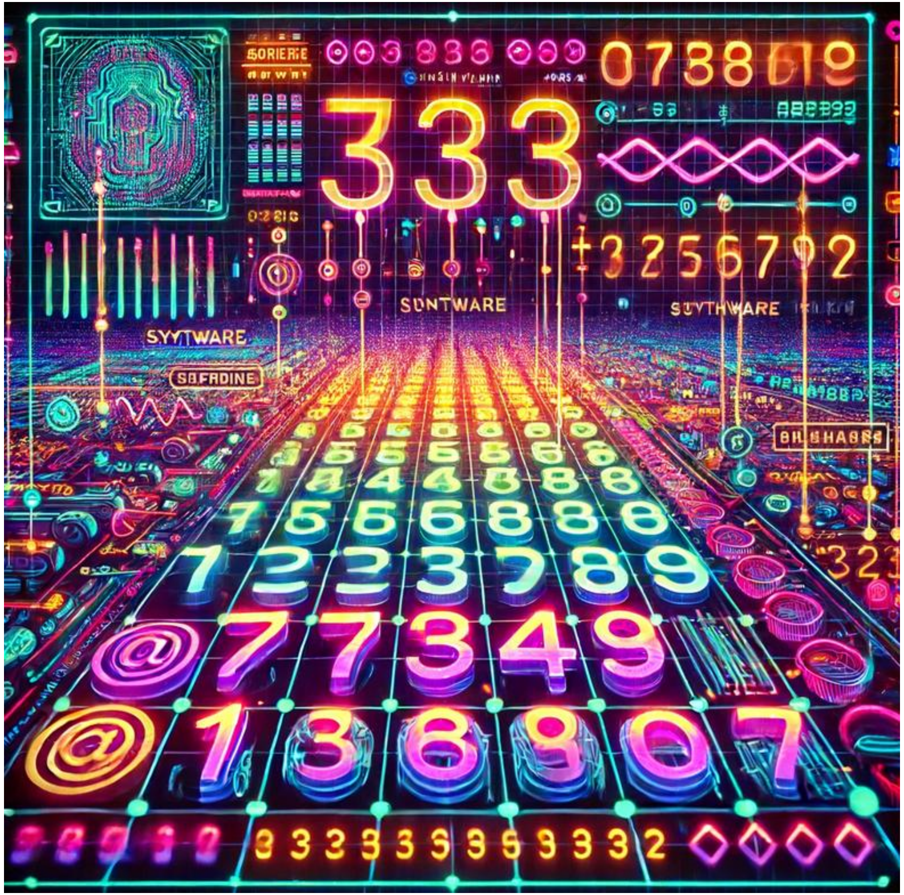
- Watch Video
- Fetch Code
- Run C Code
- For each subset 0-3
    - Write simplified C 1 function at a time.
    - Compile and autotest
    - Write MIPS function
    - Autotest MIPS
    - Start next subset



- Follow style in supplied .s code
    - including function comments and equivalent C comments.

Today’s Lecture

- Integers
- Bitwise Operations



1ntegers

Why Learn About Integers

- Fundamental topic in computing
  - Understand what you are seeing in mipsy web!
  - Understand limits of types and help you understand and debug code
- Prepare you for the next topic: bitwise operators
- Understand the jokes in these slides

There are 10 types of students

There are 10 types of students

Those that understand binary,
And those that don’t

-Andrew Taylor

Numbers

4705

It is equivalent to: $4*10^3 + 7*10^2 + 0*10^1 + 5*10^0$

$= 4000 + 700 + 0 + 5$

Numbers

4705

It is equivalent to: $4*10^3 + 7*10^2 + 0*10^1 + 5*10^0$

$= 4000 + 700 + 0 + 5$

If we assume it is base 10!

Base 10: Decimal

- In Base (or radix) 10 we have 10 digits e.g. 0..9
  - Then to get bigger numbers we start combining the digits e.g. 10
- Place Values

10^3	10^2	10^1	10^0
1000_{10}	100_{10}	10_{10}	1_{10}

- Example:

$$
\begin{aligned}
4705_{10} &= 4 * 10^3 + 7 * 10^2 + 0 * 10^1 + 5 * 10^0 \\
&= 4000 + 700 + 0 + 5 \\
&= 4705_{10}
\end{aligned}
$$

Base 10 was an arbitrary choice

- Possibly exists because we have 10 digits (fingers)
- Ancient Egyptians, Brahmi Numerals, Greek Numerals, Hebrew Numerals, Roman Numerals and Chinese Numerals:
  - All base 10!

Code Demo

digits.c

What about some other bases?

- Let's think about base 7
  (not a very useful base)
- We have 7 digits 0..6
  - Then we start combining the digits
    e.g. 10 represents 7_{10}

7^3	7^2	7^1	7^0
343_{10}	49_{10}	7_{10}	1_{10}

- Here, 1216_7 =

What about some other bases?

- Let's think about base 7 (not a very useful base)
- We have 7 digits 0..6
  - Then we start combining the digits e.g. 10 represents 7_{10}

7^3	7^2	7^1	7^0
343_{10}	49_{10}	7_{10}	1_{10}

- Here, $1216_7 = 1 * 7^3 + 2 * 7^3 + 1 * 7^1 + 6 * 7^0$

  $= 1 * 343 + 2 * 47 + 1 * 7 + 6 * 1$

  $= 454_{10}$

Base 2: Computers like binary

- In Base (or radix) 2 we have 2 digits -- 0 and 1
  - Easy to represent using “electricity” -- Off and On
  - Then we start combining the digits e.g. 10_2 represents 2_{10}
- Place Values

2^3	2^2	2^1	2^0
8_{10}	4_{10}	2_{10}	1_{10}

$\mathbf{1011_2}$ = $?_{10}$

Base 2: Computers like binary

- In Base (or radix) 2 we have 2 digits -- 0 and 1
  - Easy to represent using “electricity” -- Off and On
  - Then we start combining the digits e.g. 10_2 represents 2_{10}
- Place Values

2^3	2^2	2^1	2^0
8_{10}	4_{10}	2_{10}	1_{10}

$$\mathbf{1011_2} = 1 * 2^3 + 0 * 2^2 + 1 * 2^1 + 1 * 2^0$$
$$= 1 * 8 + 0 * 4 + 1 * 2 + 1 * 1$$
$$= 11_{\mathbf{10}}$$

More examples

Question: Convert 1101_2 to decimal?

Question: Convert 29_{10} to binary?

More examples

Question: Convert 1101_2 to decimal?

Answer: $1 * 2^3 + 1 * 2^2 + 0 * 2^1 + 1 * 2^0$

$= 1 * 8 + 1 * 4 + 0 * 2 + 1 * 1$

$= 13$

Question: Convert 29_{10} to binary?

More examples

Question: Convert 1101_2 to decimal?

Answer: $1 * 2^3 + 1 * 2^2 + 0 * 2^1 + 1 * 2^0$

= $1 * 8 + 1 * 4 + 0 * 2 + 1 * 1$

= 13

Question: Convert 29_{10} to binary? 11101

- 29/2 = 14 R 1
- 14/2 = 7 R 0
- 7/2 = 3 R 1
- 3/2 = 1 R 1
- 1/2 = 0 R 1

Binary numbers are hard to read!

- They get very long, very fast
- E.g. $12345678_{10} = 101111000110000101001110_2$

Binary numbers are hard to read!

- They get very long, very fast
- E.g. $12345678_{10} = 101111000110000101001110_2$
- Solution: Write numbers in hexadecimal!
  - More compact than binary
  - Maps more easily to binary than decimal.
    - Bit patterns remain more obvious than in decimal

Base 16: Hexadecimal

- In Base (or radix) 16 we have 16 digits
  - 0 1 2 3 4 5 6 7 8 9 A B C D E F
  - Then we start combining the digits e.g. 10 represents 16_{10}
- Place Values

16^3	16^2	16^1	16^0
4096_{10}	256_{10}	16_{10}	1_{10}

- $3AF1_{16} = ?_{10}$

Base 16: Hexadecimal

- In Base (or radix) 16 we have 16 digits
    - 0 1 2 3 4 5 6 7 8 9 A B C D E F
    - Then we start combining the digits e.g. 10 represents 16_{10}
- Place Values

16^3	16^2	16^1	16^0
4096_{10}	256_{10}	16_{10}	1_{10}

- $3AF1_{16} = 3 * 16^3 + 10 * 16^2 + 15 * 16^1 + 1 * 16^0$

  $= 15089_{10}$

More hexadecimal examples

Question: Convert $1FF_{16}$ to decimal?

Question: Convert 13_{10} to hexadecimal?

More hexadecimal examples

Question: Convert $1FF_{16}$ to decimal?

Answer: $1 * 16^2 + 15 * 16^1 + 15 * 16^0 = 511_{10}$

Question: Convert 13_{10} to hexadecimal?

More hexadecimal examples

Question: Convert $1FF_{16}$ to decimal?

Answer: $1 * 16^2 + 15 * 16^1 + 15 * 16^0 = 511_{10}$

Question: Convert 13_{10} to hexadecimal?

Answer: D_{16}

Binary -> Hexadecimal

- Binary gets very long very quick
  - e.g. $12345678_{10} = 101111000110000101001110_2$
- Solution: Write numbers in hexadecimal!

16^3	16^2	16^1	16^0
4096_{10}	256_{10}	16_{10}	1_{10}

- **16 == 2^4**
  - We can separate the bits into groups of **4**…

Binary -> Hexadecimal

- 12345678_{10} = $101111000110000101001110_2$
  = 1011 1100 0110 0001 0100 1110_2

Each 4 bit group can be represented by **one** hexadecimal digit!

Base 10	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Base 16	F	E	D	C	B	A	9	8	7	6	5	4	3	2	1	0
Base 2	1111	1110	1101	1100	1011	1010	1001	1000	0111	0110	0101	0100	0011	0010	0001	0000

Binary -> Hexadecimal

- 12345678_{10} = $101111000110000101001110_2$
  = $1011\ 1100\ 0110\ 0001\ 0100\ 1110_2$
  = B C 6 1 4 E

  Each 4 bit group can be represented by **one** hexadecimal digit!

Base 10	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Base 16	F	E	D	C	B	A	9	8	7	6	5	4	3	2	1	0
Base 2	1111	1110	1101	1100	1011	1010	1001	1000	0111	0110	0101	0100	0011	0010	0001	0000

More examples

Binary 01101111_2 =

Hexadecimal $BAD2_{16}$ =

More examples

Binary 01101111_2 = $6F_{16}$

Hexadecimal $BAD2_{16}$ =

More examples

Binary 01101111_2 = $6F_{16}$

Hexadecimal $BAD2_{16}$ = 1011101011010010_2

Base 8: Octal

- In Base (or radix) 8 we have 8 digits
    - 0 1 2 3 4 5 6 7
    - Then we start combining the digits e.g. 10 represents 8_{10}
- Similar advantages to hexadecimal
    - $8 = 2^3$ so group bits into 3:
    - Example: $72_8 = 111\ 010_2 = 3A_{16} = 58_{10}$

Base 10	7	6	5	4	3	2	1	0
Base 8	7	6	5	4	3	2	1	0
Base 2	111	110	101	100	011	010	001	000

Binary, Octal, Hexadecimal Summary

- In **binary**, (base 2), each digit represents **1** bit:
  - $0100100011111010101111001001 0111_2$
- In **octal**, (base 8), each digit represents **3** bits
  - $01\ 001\ 000\ 111\ 110\ 101\ 011\ 110\ 010\ 010\ 111_2$
  - $1\ \ 1\ \ 0\ \ 7\ \ 6\ \ 5\ \ 3\ \ 6\ \ 2\ \ 2\ \ 7_8$
- In **hexadecimal**, (base 16), each digit represents **4** bits:
  - $0100\ 1000\ 1111\ 1010\ 1011\ 1100\ 1001\ 0111_2$
  - $4\ \ 8\ \ F\ \ A\ \ B\ \ C\ \ 9\ \ 7_{16}$

Constants in C and MIPS assembly

- A number beginning with **0x** is hexadecimal
- A number beginning with **0** is octal
- A number beginning with **0b** is binary
- Otherwise, it is decimal

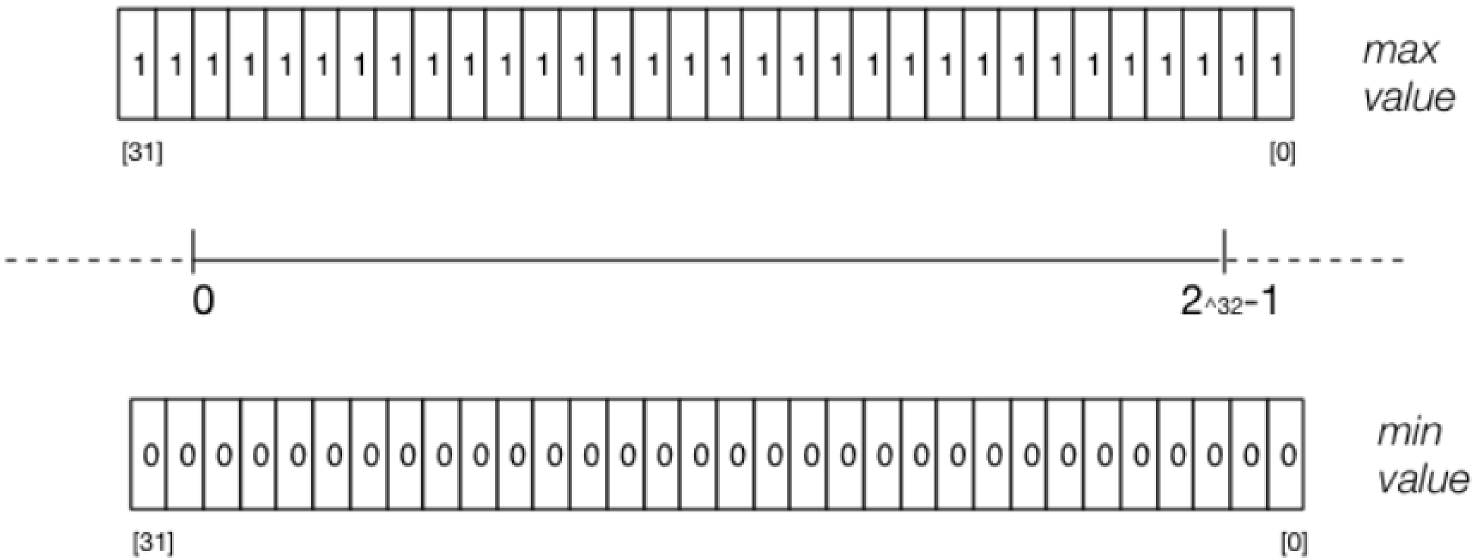
```
printf("%d", 0x2A);      // prints 42
printf("%d", 052);       // prints 42
printf("%d", 0b101010); // prints 42
printf("%d", 42);        // prints 42
```

Easy Base Conversions in C

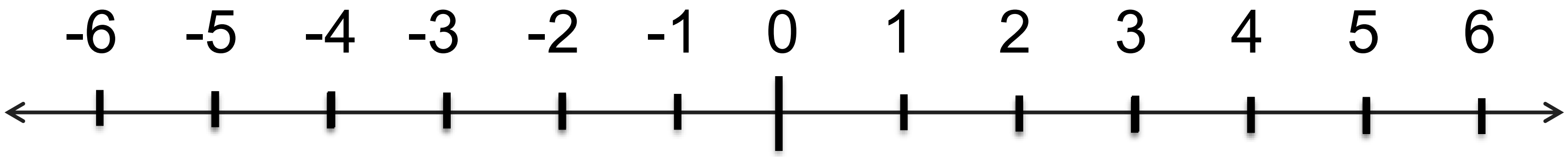
[integer_prefixes.c]

Unsigned integers

- In C the **`unsigned int`** data type is 4 bytes on our system
  - means we can store values from the range 0 .. 2^{32}-1

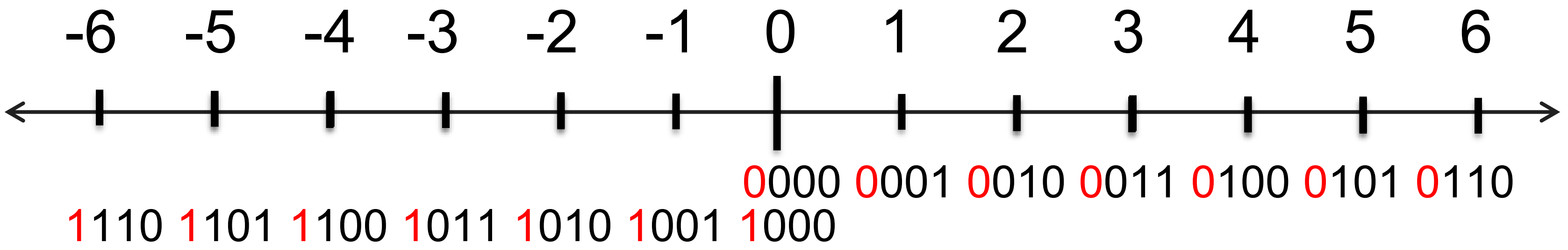


How do we store signed integers?



How do we store signed integers?

- What if we use 1 of the bits to represent the sign?



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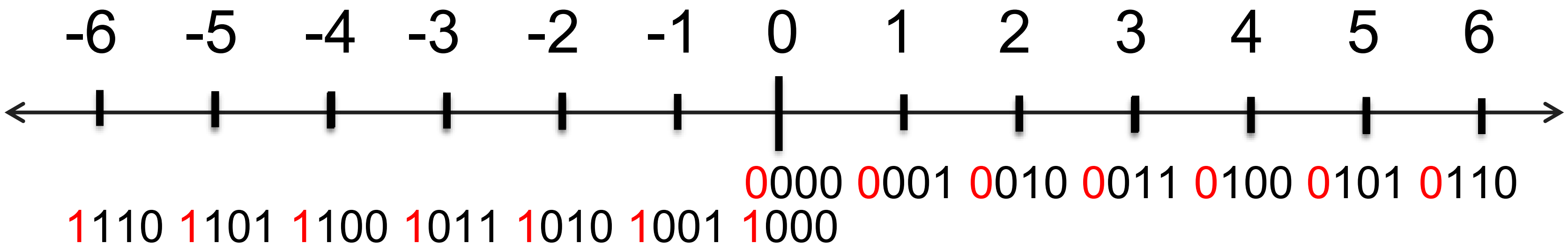


- Okay, but what algorithm for adding/subtracting numbers?

How we really represent negative numbers

4 = 00000100

3 = 00000011

2 = 00000010

1 = 00000001

0 = 00000000

-1 =

How we really represent negative numbers

4 = 00000100

3 = 00000011

2 = 00000010

1 = 00000001

0 = 00000000

-1 = 11111111

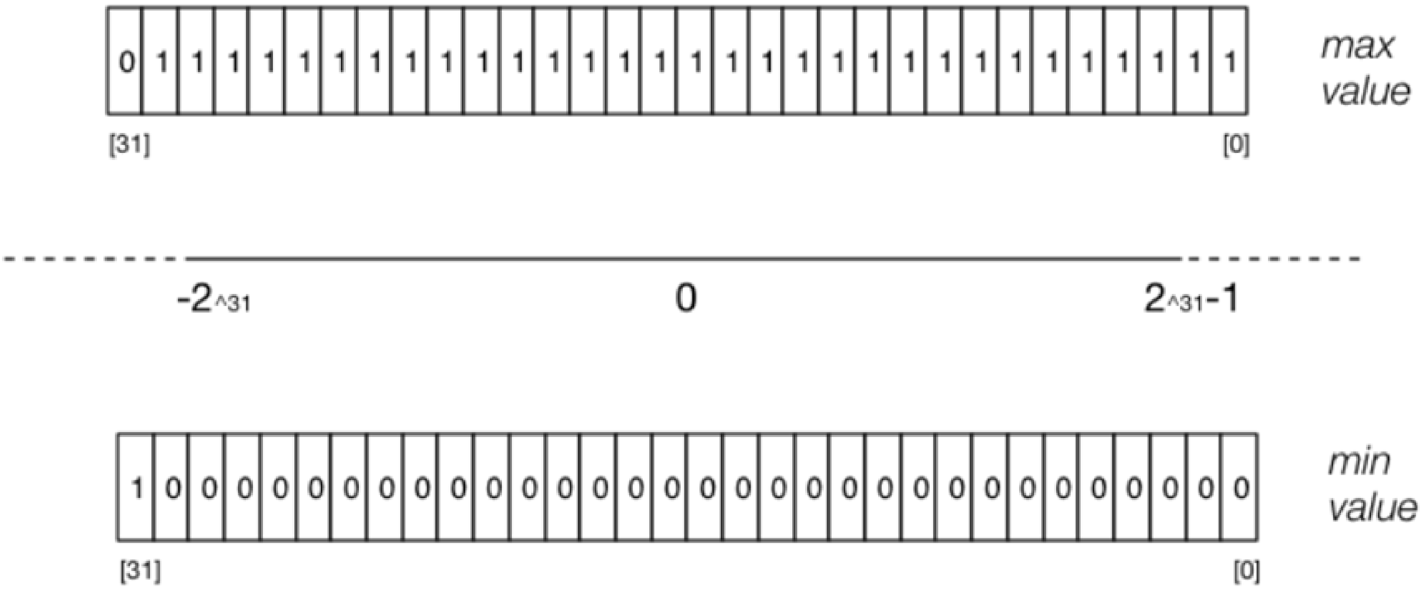
How we really represent negative numbers

4 = 00000100
3 = 00000011
2 = 00000010
1 = 00000001
0 = 00000000

-1 = 11111111
-2 = 11111110
-3 = 11111101

Signed integers

- In C the `int` data type is 4 bytes on our system
    - we can store values from the range $-2^{31} .. 2^{31} - 1$



What do signed binary numbers look like?

- Modern computers use **two's complement** for integers
- Positive integers and zero represented as normal
- Negative integers represented in a way to make maths ✨easy✨ for the computer (not humans)
  - For an *n*-bit binary number, the number $-b$ is $2^n - b$
  - E.g. 8-bit number "-5" is represented as $2^8 - 5 = 1111\ 1011_2$

Two’s Complement Tips and Tricks

- A shortcut for doing 2’s complement
  - If you are trying to represent -5 in 8 bits
  - Take the +5 representation
    - 0000 0101
  - invert all the bits
    - 1111 1010
  - add 1
    - 1111 1011
- Repeat the process to go from -5 back to 5 again!

Example: 2's Complement Example

- Some simple code to examine 8-bit 2's complement numbers:

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

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

Example: Printing all 8-bit 2's complement

```
$ ./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
```

Example: print_bits_of_int.c

```
$ ./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
$
```

Bits and Bytes on cse Servers

- 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 00000000000000000000000000101010
  - double = 8 bytes = 64 bits,
    - 42 = ?
- above are common sizes but not universal
- sizeof (int) might be 2 (bytes) on a small embedded CPU

integer_types.c - exploring 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

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

stdint.h - guaranteed size integer types

- `#include <stdint.h>` to get below int types (and more) with known sizes
- We use these a lot 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
```

Code Examples

overflow_int.c

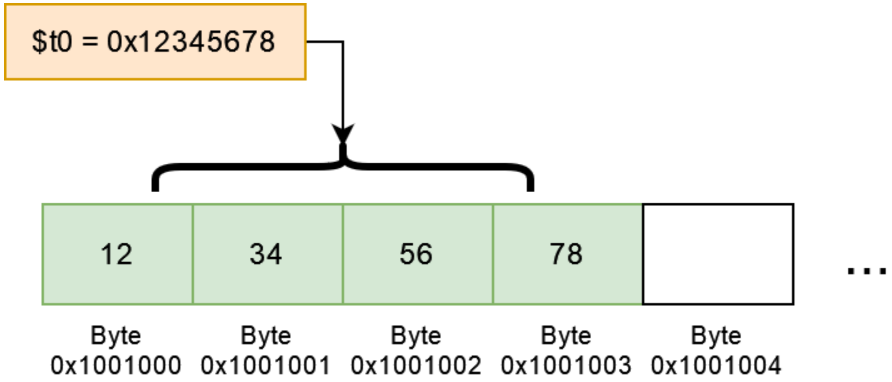
wrap_around_uint.c

char_bug.c

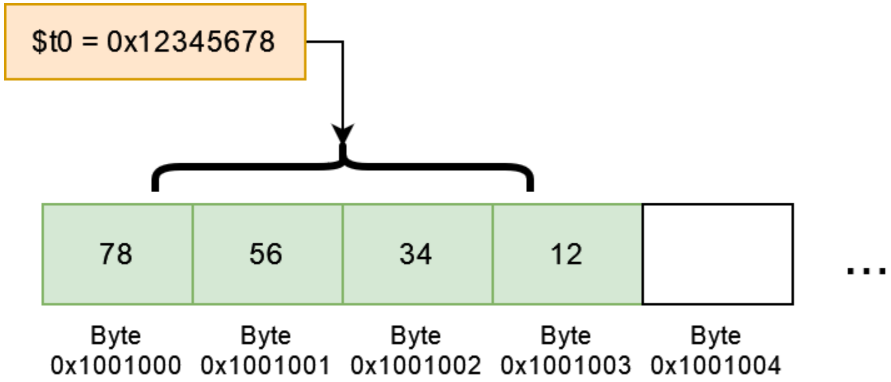
New? concept: Endian-ness

- “What order to put things in” is a hard question to answer
- Two schools of thought:
  - **Big**-endian: MSB at the “low address” - big bytes “first!”
  - **Little**-endian: LSB at the “low address” - little bytes “first!”

BIG:



LITTLE:

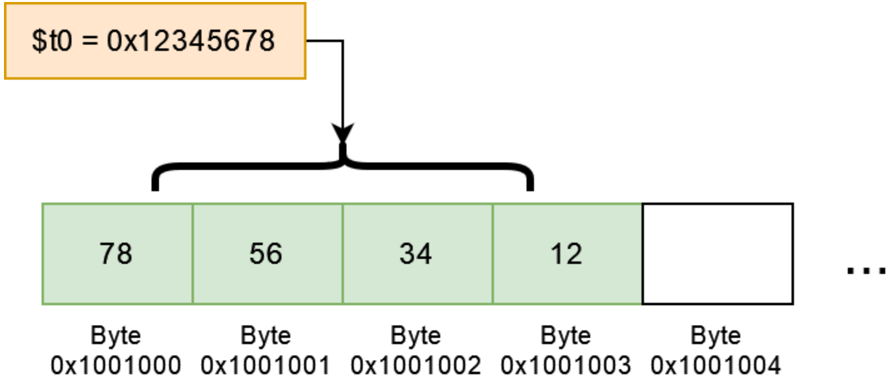


Code example

- Mipsy-web is **little-endian**

```
        .text
main:
        li $t0, 0x12345678
        sw $t0, my_word

        .data
my_word:
        .space 4
```



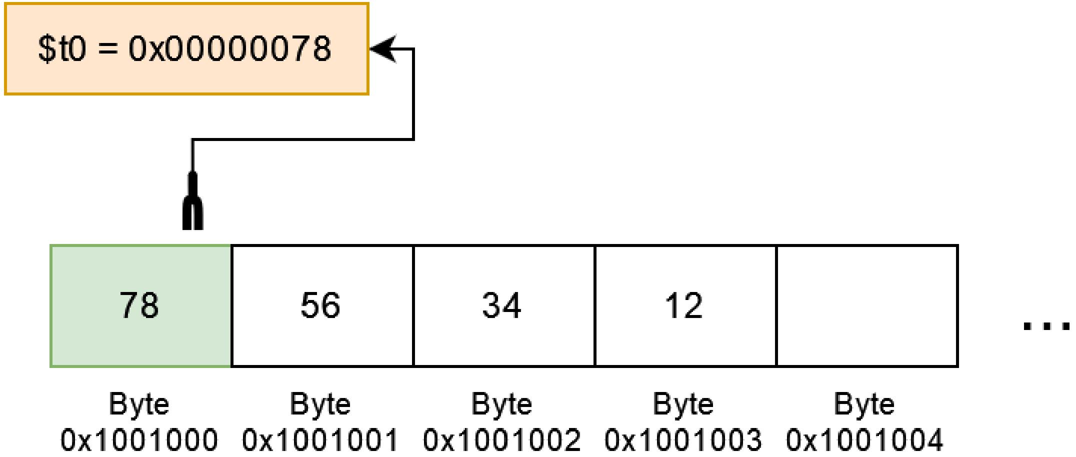
Loading bytes, half-words

The results of these will depend on endianness:

- `lh/lb` assume the loaded byte/halfword is signed
  - The destination register top bits are set to the sign bit
- `lhu/lbu` for doing the same thing, but unsigned

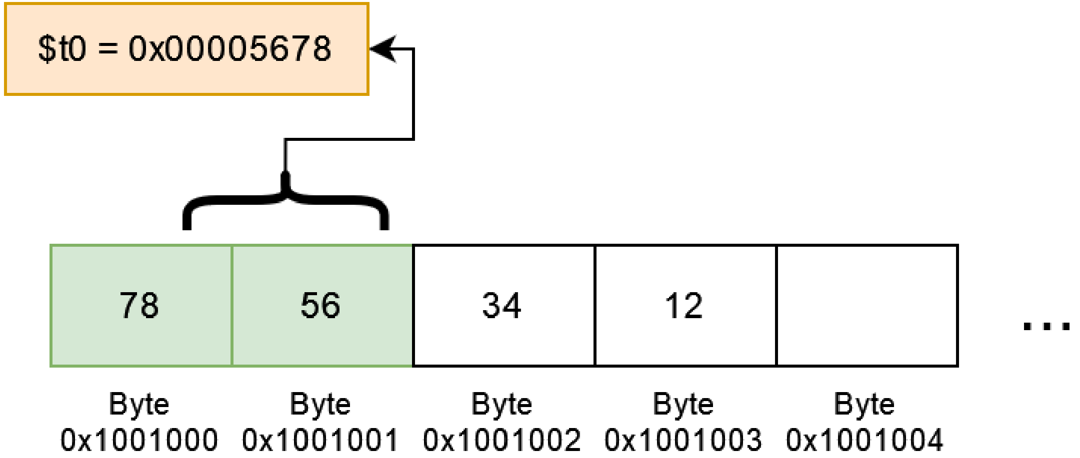
Loading Examples: lb

```
.text
main:
        lb $t0, my_label
.data
my_label:
        .word 0x12345678
```



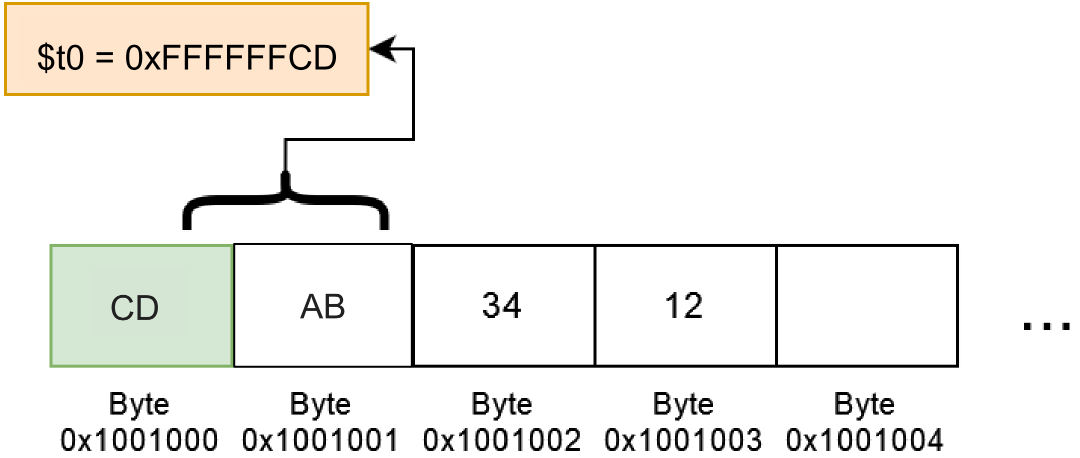
Loading Examples: lh

```
.text
main:
        lh $t0, my_label
.data
my_label:
        .word 0x12345678
```



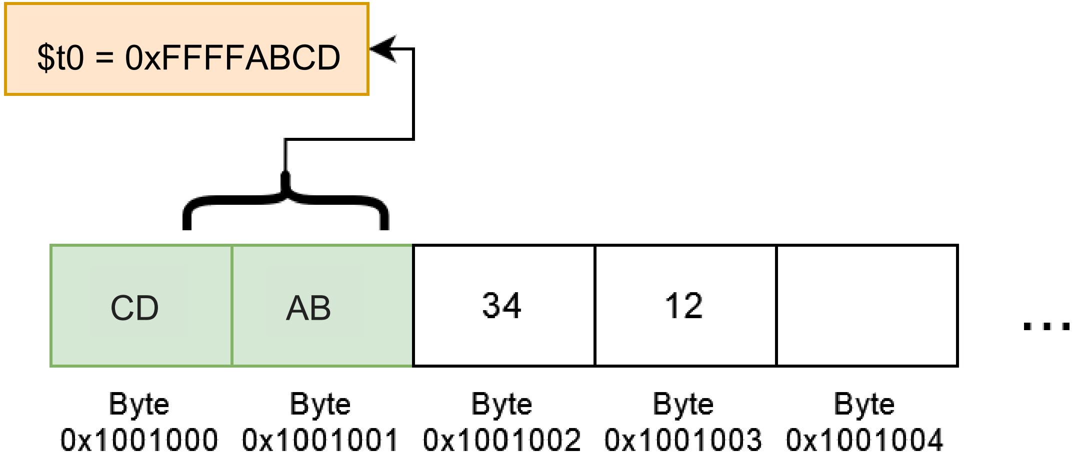
Loading Examples Negative: lb

```
.text
main:
        lb $t0, my_label
.data
my_label:
        .word 0x1234ABCD
```



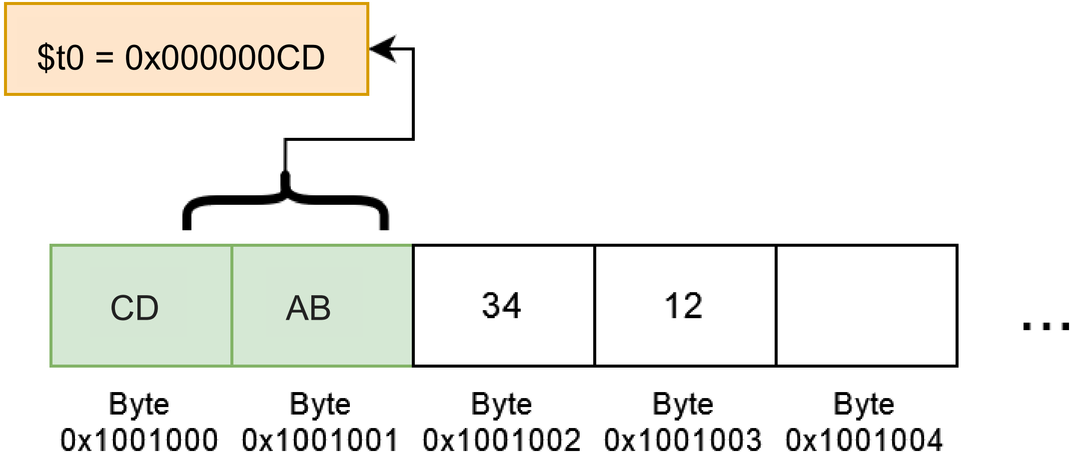
Loading Examples Negative: lh

```
.text
main:
        lh $t0, my_label
.data
my_label:
        .word 0x1234ABCD
```



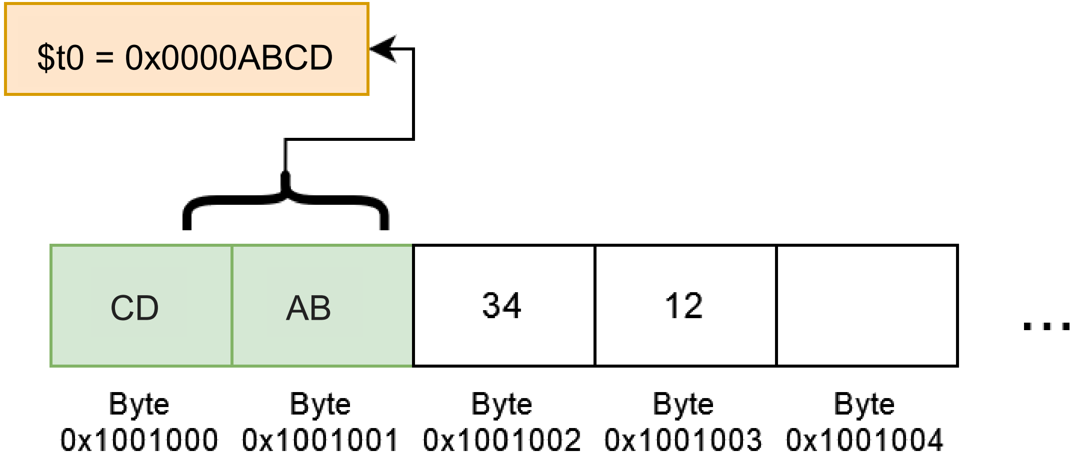
Loading Examples: lbu

```
.text
main:
        lbu $t0, my_label
.data
my_label:
        .word 0x1234ABCD
```



Loading Examples Negative: lhu

```
.text
main:
        lhu $t0, my_label
.data
my_label:
        .word 0x1234ABCD
```



Endianness in C

endianness.c

Bitwise Operations

- CPUs provide instructions which implement bitwise operations
  - Provide us ways to manipulating the individual bits of a value.
  - MIPS provides 13 bit manipulation instructions
  - C provides 6 bitwise operators

```
&  bitwise AND
|  bitwise OR
^  bitwise XOR (eXclusive OR)
~  bitwise NOT
<< left shift
>> right shift
```

Bitwise AND (&)

- takes two values (eg. **a & b**) and performs a logical AND between pairs of corresponding bits
  - resulting bits are set to 1 if **both** the original bits in that column are 1

Example:

	128	64	32	16	8	4	2	1
	0	0	1	0	0	1	1	1
&	1	1	1	0	0	0	1	1
	0	0	1	0	0	0	1	1

&	0	1
0	0	0
1	0	1

Used for eg. checking if a particular bit is set (that is, set to 1)

Checking if a number is odd

The obvious way to check if a number is odd in C:

```
int is_odd(int n) {
    return n % 2 != 0;
}
```

Checking if a number is odd

However, an odd value must have a 1 bit in the 1s place:

128	64	32	16	8	4	2	1
0	0	1	0	0	1	1	1

We can use bitwise AND to check if the last bit is set .

Checking if a number is odd

```
int is_odd(int n) {
    return n & 1;
}
```

If the value is **ODD** (eg 39):

	128	64	32	16	8	4	2	1
	0	0	1	0	0	1	1	1
&	0	0	0	0	0	0	0	1
	0	0	0	0	0	0	0	1

If the value is **EVEN** (eg 38):

	128	64	32	16	8	4	2	1
	0	0	1	0	0	1	1	0
&	0	0	0	0	0	0	0	1
	0	0	0	0	0	0	0	0

Bitwise OR (|)

- takes two values (eg. **a | b**) and performs a logical OR between pairs of corresponding bits
    - resulting bits are set to 1 if **at least** one of the original bits are 1

Example:

	0	0	1	0	0	1	1	1
|	1	1	1	0	0	0	1	1
	1	1	1	0	0	1	1	1

|	0	1
0	0	1
1	1	1

Used for eg. setting a particular bit

What did we learn today?

- Recursive MIPS functions, invalid C
- Integers
- Bitwise & and |
- Next lecture:
    - More bitwise operators

Reach Out

Content Related Questions:
[Forum]

Admin related Questions email:
cs1521@cse.unsw.edu.au

Student Support | I Need Help With…

My Feelings and Mental Health Managing Low Mood, Unusual Feelings & Depression	**Mental Health Connect**	student.unsw.edu.au/**counselling** Telehealth	
	Mind HUB	student.unsw.edu.au/**mind-hub** Online Self-Help Resources	
	In Australia Call Afterhours UNSW Mental Health Support Line	1300 787 026 5pm-9am	
	Outside Australia Afterhours 24-hour Medibank Hotline	+61 (2) 8905 0307	
Uni and Life Pressures Stress, Financial, Visas, Accommodation & More	**Student Support Indigenous Student Support**	— student.unsw.edu.au/**advisors**	
Reporting Sexual Assault/Harassment	**Equity Diversity and Inclusion (EDI)**	— edi.unsw.edu.au/**sexual-misconduct**	
Educational Adjustments To Manage my Studies and Disability / Health Condition	**Equitable Learning Service (ELS)**	— student.unsw.edu.au/**els**	
Academic and Study Skills	**Academic Language Skills**	— student.unsw.edu.au/**skills**	
Special Consideration Because Life Impacts our Studies and Exams	Special Consideration	— student.unsw.edu.au/**special-consideration**	