COMP1521 25T1

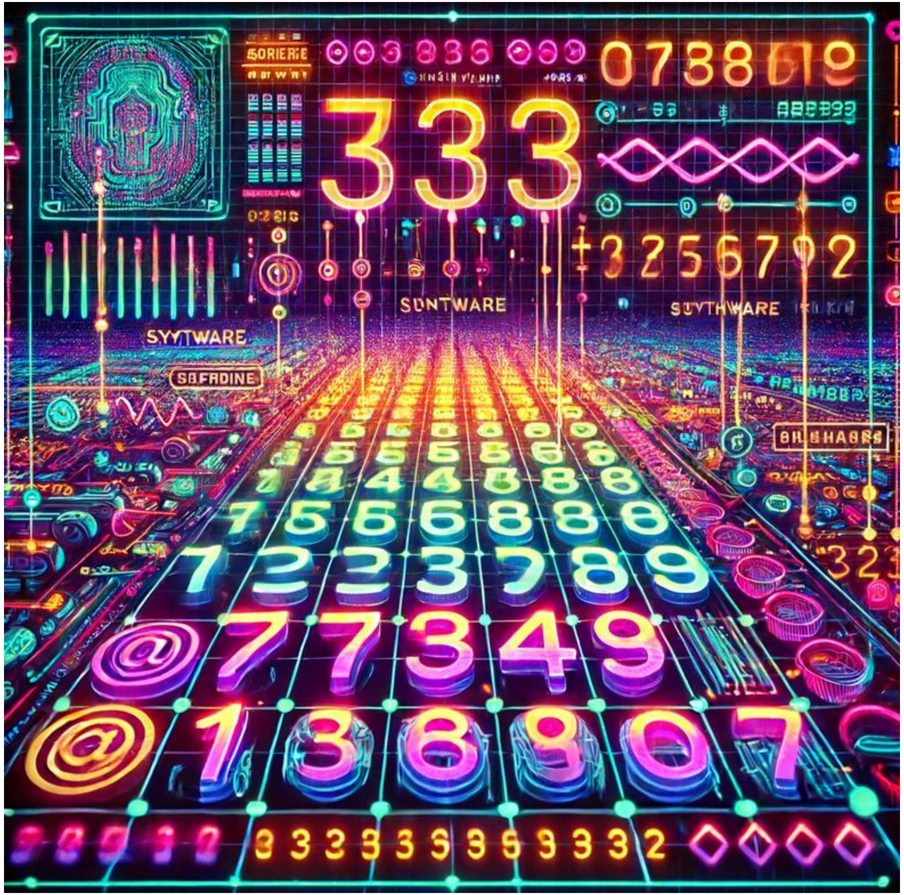
Week 4 Lecture 1

Integers and Bitwise Operators

Adapted from Hammond Pearce,
Andrew Taylor and John Shepherd's slides

Today's Lecture

- Assignment 1
- Stacks and Frames
  - Recursive MIPS function
  - Invalid C
- Integers
- Bitwise Operations



Announcements

- Lab 3 Due: Today midday
- Weekly Test 3 Due: Thursday 21:00:00.
- Census Date : Thursday 13th Mar
  - Last day to drop T1 courses without financial liability
- Assignment 1 Due: Week 5 Friday 18:00 (next week)
- See Help Sessions Schedule

Assignment 1

- Watch Video
- Fetch Code
- Run C Code
- For each subset
  - Write simplified C 1 function at a time.
  - Compile and autotest
  - Write MIPS function
  - Autotest MIPS
- Follow style in supplied .s code
  - including function comments and equivalent C comments.

Code Demos: Stacks and Frames

sum_to_r.c, sum_to_r.s

invalid_1.c

invalid_4.c

Integers

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

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

  $= 454_{10}$

Base 2: Computers like binary

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

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

$\mathbf{1011_2} = 1 * 2^3 + 0 * 2^2 + 1 * 2^1 + 1 * 2^0$

$= 1 \times 8 + 0 \times 4 + 1 \times 2 + 1 \times 1$

$= 11_{\mathbf{10}}$

More examples

Question: Convert 1101_2 to decimal?

Question: Convert 29_{10} to binary?

More examples

Question: Convert 1101_2 to decimal?

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

$= 1 \times 8 + 1 \times 4 + 0 \times 2 + 1 \times 1$

$= 13$

Question: Convert 29_{10} to binary?

More examples

Question: Convert 1101_2 to decimal?

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

$= 1 \times 8 + 1 \times 4 + 0 \times 2 + 1 \times 1$

$= 13$

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}

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

  $= 15089_{10}$

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: $1 \times 16^2 + 15 \times 16^1 + 15 \times 16^0 = 511_{10}$

Question: Convert 13_{10} to hexadecimal?

More hexadecimal examples

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

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

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

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

Binary -> Hexadecimal

- $12345678_{10} = 101111000110000101001110_2$
  $= 1011\ 1100\ 0110\ 0001\ 0100\ 1110_2$
  $=$
- Each 4 bit group can be represented by **one** hexadecimal digit!

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 =

Hexadecimal BAD2 =

More examples

Binary 01101111 = $6F_{16}$

Hexadecimal BAD2 =

More examples

Binary 01101111 = $6F_{16}$

Hexadecimal BAD2 = 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:
    - $01001000111110101011110010010111_2$
- In **octal**, (base 8), each digit represents **3** bits
    - $01\ 001\ 000\ 111\ 110\ 101\ 011\ 110\ 010\ 010\ 111_2$
    - $1\quad 1\quad 0\quad 7\quad 6\quad 5\quad 3\quad 6\quad 2\quad 2\quad 7_8$
- In **hexadecimal**, (base 16), each digit represents **4** bits:
    - $0100\ 1000\ 1111\ 1010\ 1011\ 1100\ 1001\ 0111_2$
    - $4\quad 8\quad F\quad A\quad B\quad C\quad 9\quad 7_{16}$

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
```

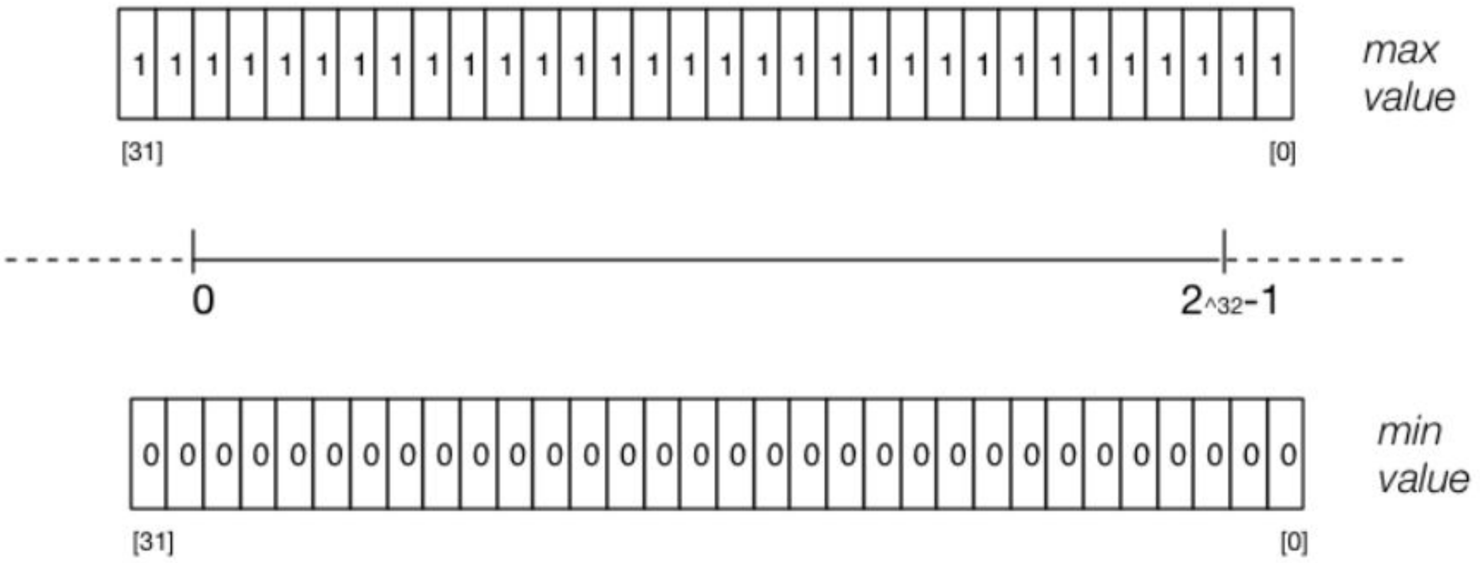
Easy Base Conversions in C

integer_prefixes.c

integer_prefixes_args.c

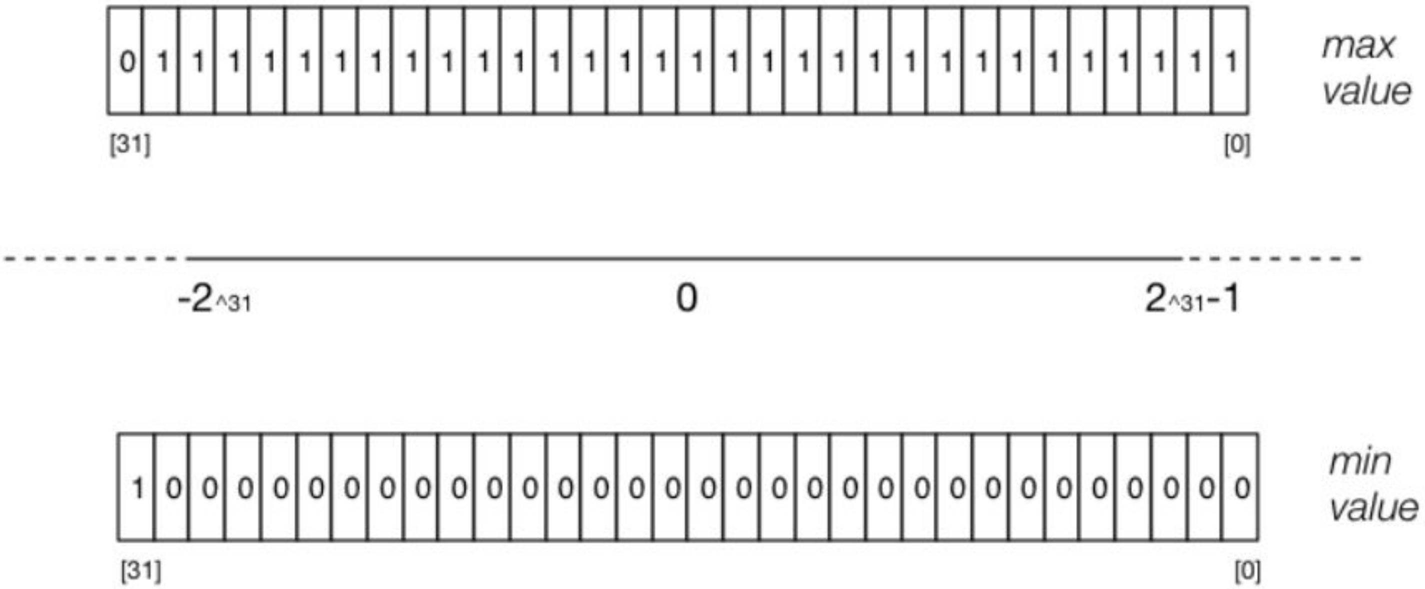
Unsigned integers

- 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



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

- Another 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");
}
```

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!

```c
                    // 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

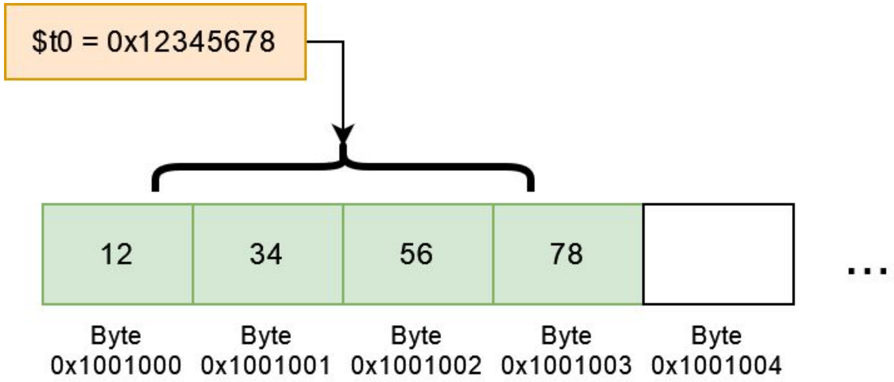
wrap_around_uint.c

char_bug.c

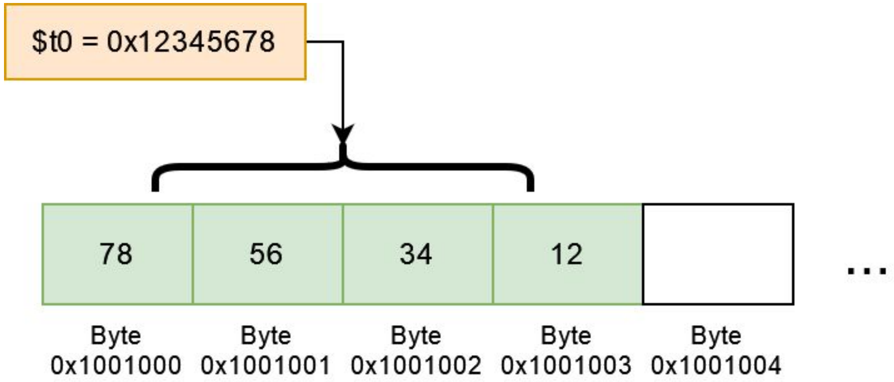
New concept: Endian-ness

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

BIG:



LITTLE:

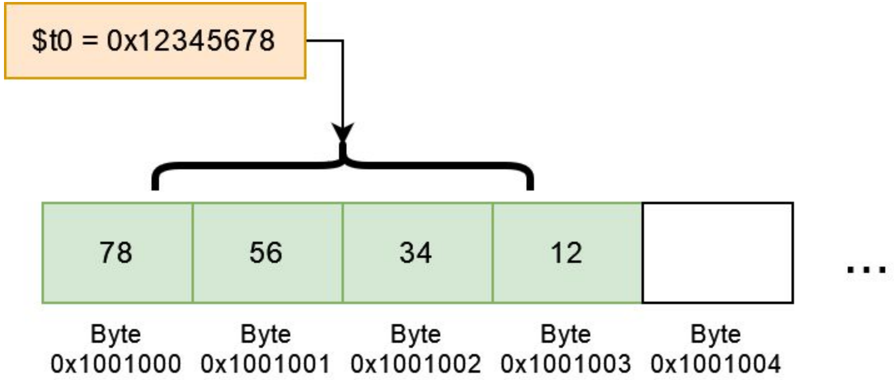


Code example

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

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

        .data
my_word:
        .space 4
```



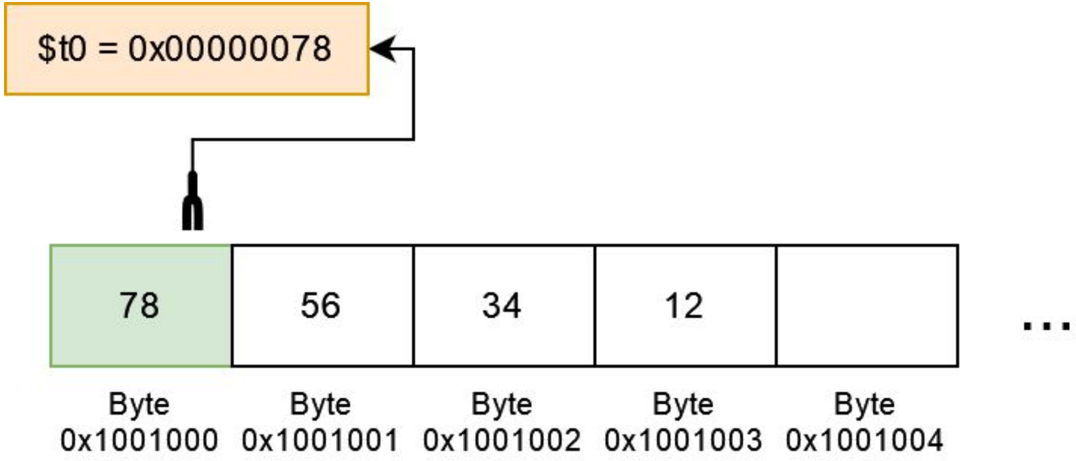
Loading bytes, half-words

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

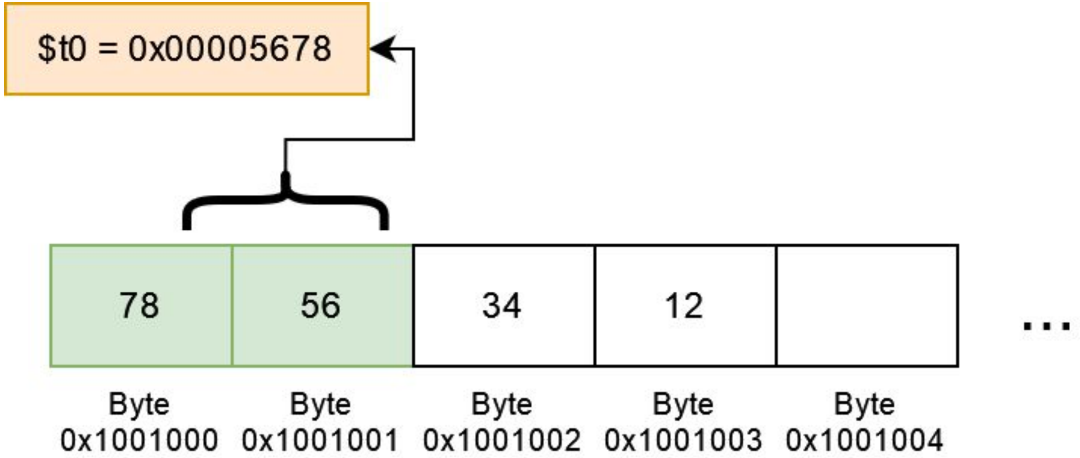
Loading Examples: lb

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



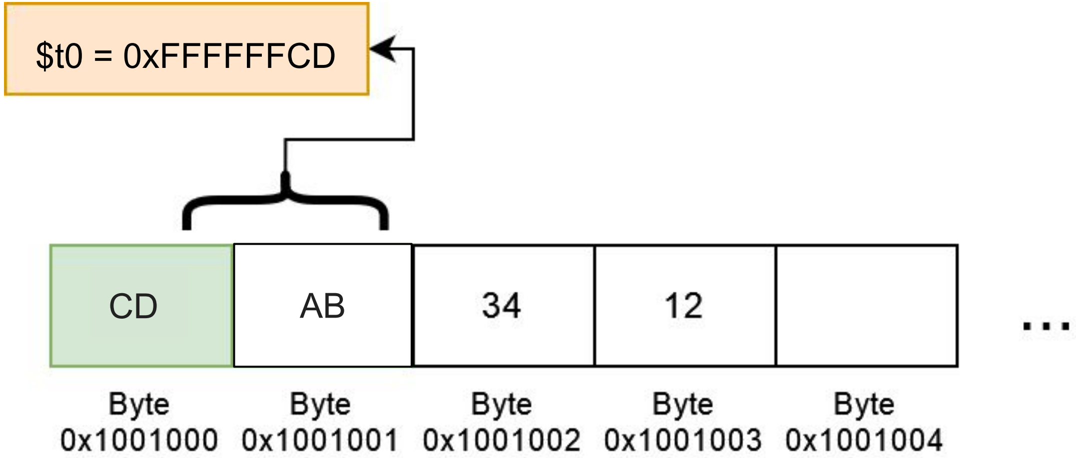
Loading Examples: lh

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



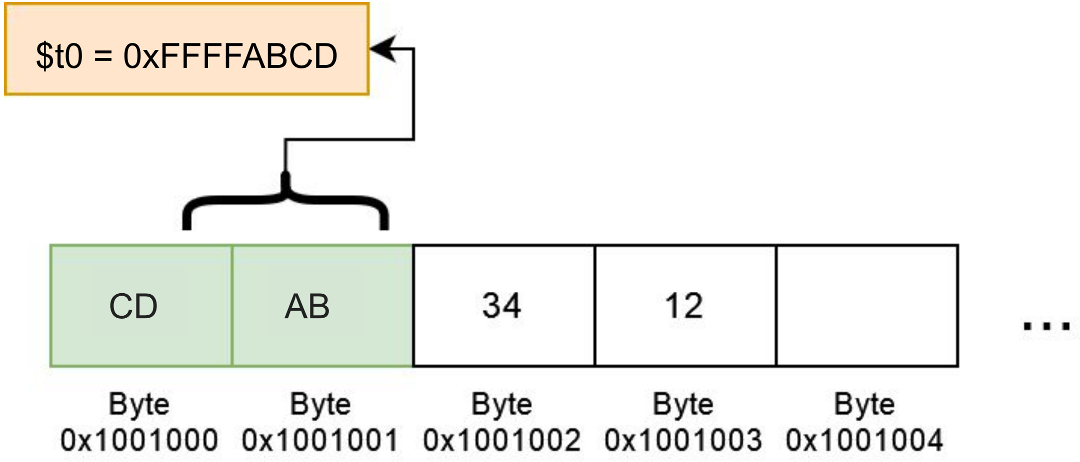
Loading Examples Negative: lb

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



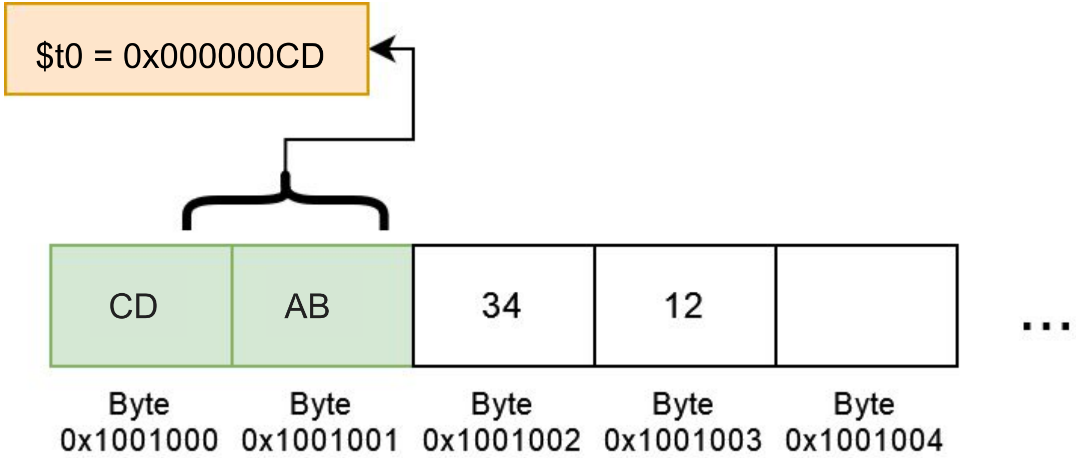
Loading Examples Negative: lh

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



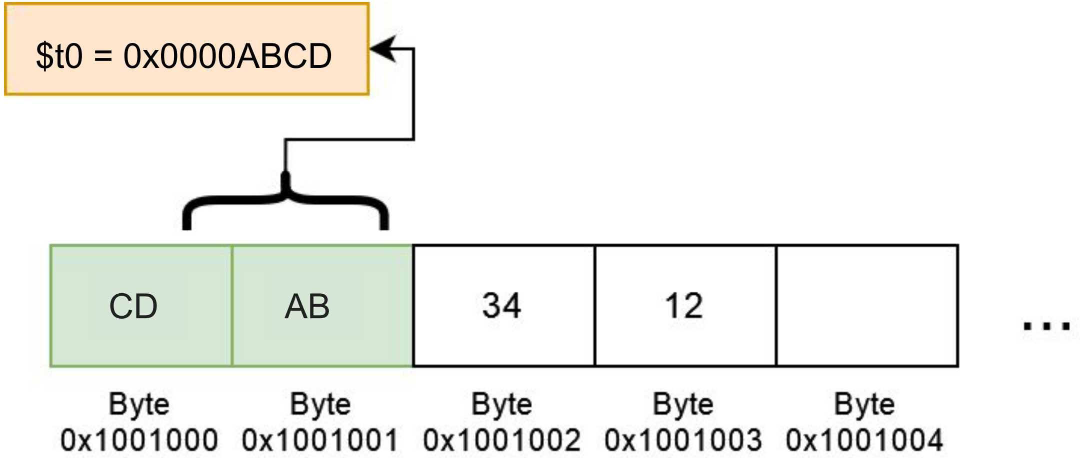
Loading Examples: lbu

```
.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:

```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 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

Feedback Please!

Your feedback is valuable!

If you have any feedback from today's lecture, please follow the link below or use the QR Code.

Please remember to keep your feedback constructive, so I can action it and improve your learning experience.

https://forms.office.com/r/GXGX6vKDG6

Reach Out

Content Related Questions:

Forum

Admin related Questions email:

cs1521@cse.unsw.edu.au

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	Mind HUB	student.unsw.edu.au/**mind-hub** Online Self-Help Resources	**Outside Australia Afterhours 24-hour Medibank Hotline**	+61 (2) 8905 0307
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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**		
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