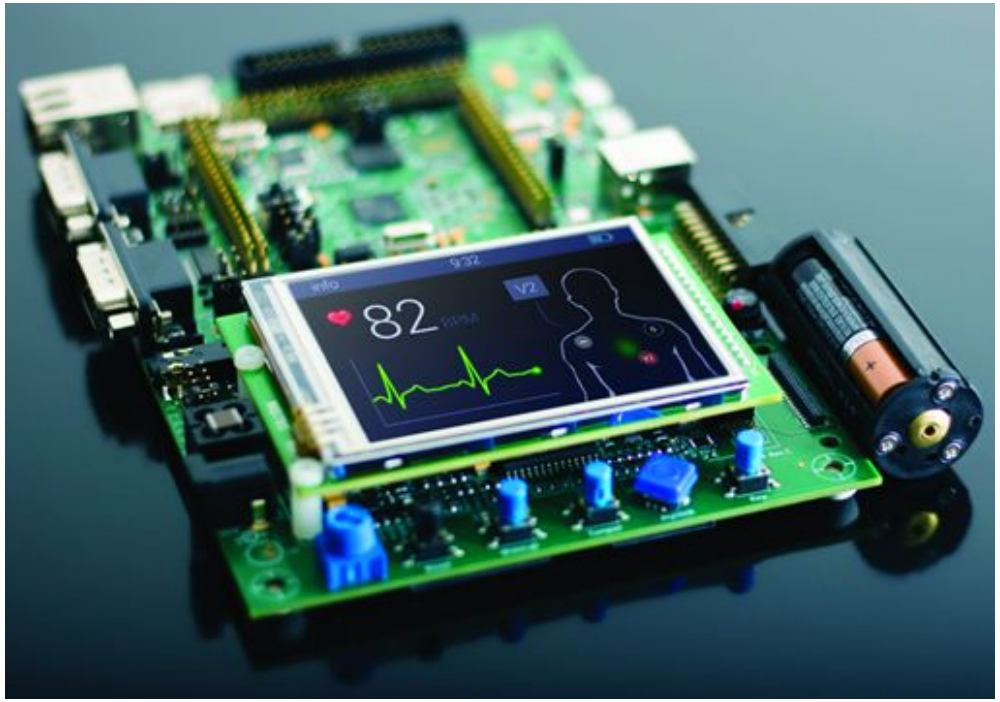
Embedded Software

CS 145/145L

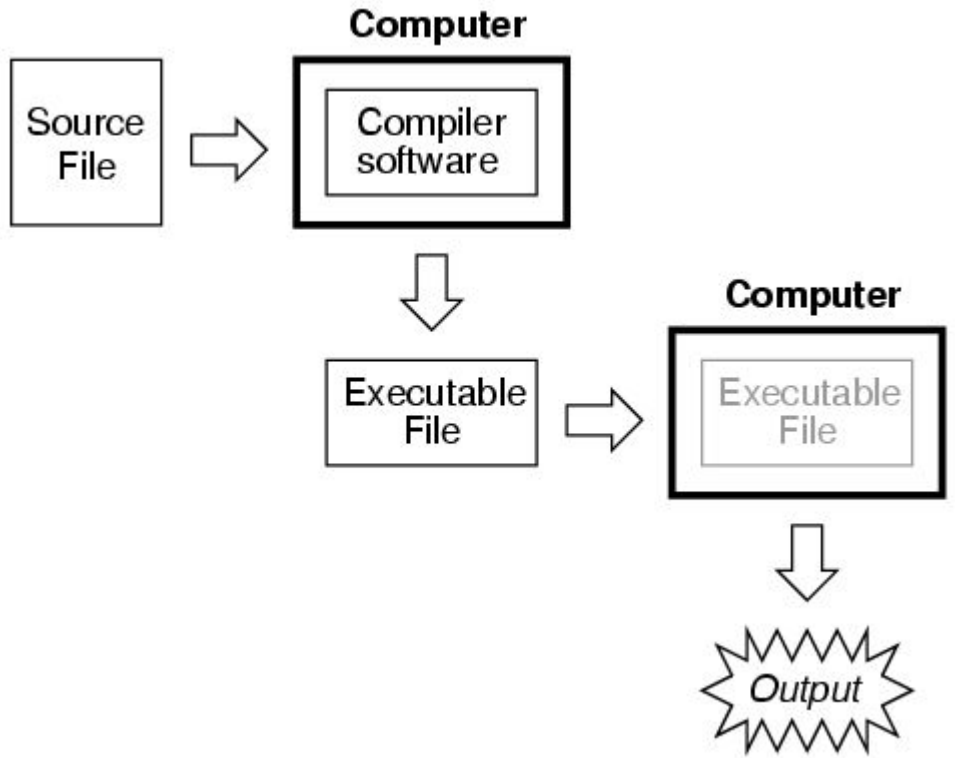


Caio Batista de Melo

Recap

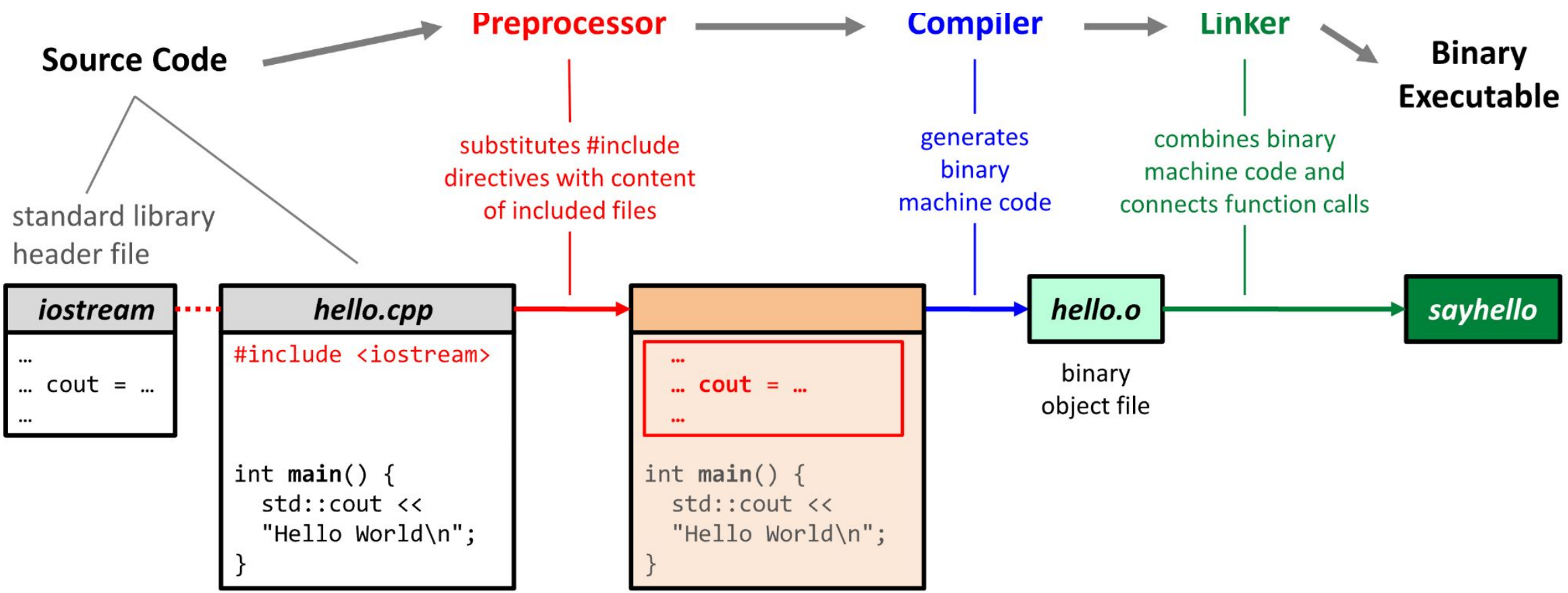
- Project 1 was extended until Wednesday (2022-04-20);
- You should have all the tools to work on Project 2
  - Keypad
  - LCD
- If your LCD randomly resets at times…
  - https://edstem.org/us/courses/20963/discussion/1412547
  1. Replace libraries (avr/lcd) with new ones: https://caiobatista.com/courses/uci/s22/cs145-project-2/;
  2. Where you used lcd_puts before, replace it with lcd_puts2;
  3. Add avr_init() before your lcd_init() call.

Interpreter vs Compiler



https://www.learningelectronics.net/vol_5/chpt_7/3.html

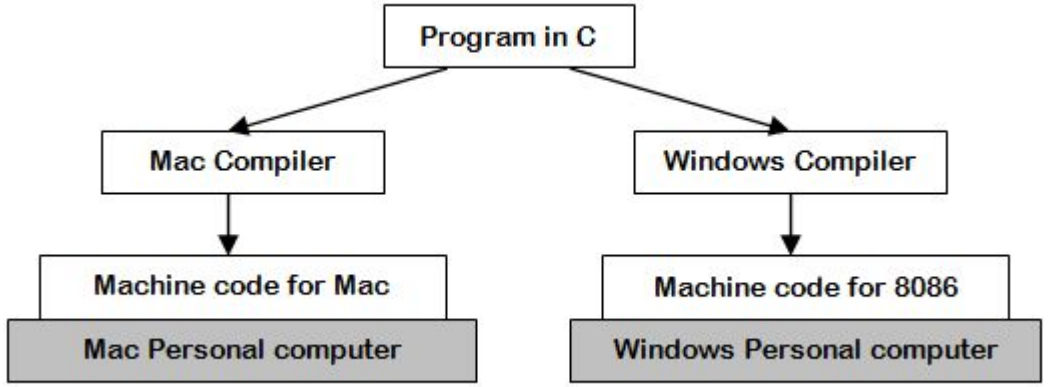
Compiler



https://hackingcpp.com/cpp/hello_world.html

Available Compilers

- gcc is the most popular one
  - have different versions, e.g., xc8, avr-gcc, arm-gcc
- clang is an alternative that you might have used (default on Macs)
- usually a compiler works for a specific architecture (e.g., Windows)



http://www.edu4java.com/en/concepts/compiler-interpreter-virtual-machine.html

gcc -Flags

-Wall: shows all warnings

-Wextra: shows more warnings

-Werror: treats warnings as errors

-ansi: uses the ANSI version of C (universally compatible)

-pedantic: turns off even more features than *ansi*

-o: output file

-O*n*: optimization level (O0…3, Ofast, Os)

gcc -O*n*

option	optimization level	execution time	code size	memory usage	compile time
-O0	optimization for compilation time (default)	+	+	-	-
-O1 or -O	optimization for code size and execution time	-	-	+	+
-O2	optimization more for code size and execution time	--		+	++
-O3	optimization more for code size and execution time	---		+	+++
-Os	optimization for code size		--		++
-Ofast	O3 with fast none accurate math calculations	---		+	+++

https://www.rapidtables.com/code/linux/gcc/gcc-o.html

Testing

After you've written your code and it compiles, you need to make sure it works.
Testing helps setting up a framework that verifies it's working as intended.
Also helps make sure that changes will not break previous versions.

gcov: https://gcc.gnu.org/onlinedocs/gcc/Gcov.html

- Included in the GNU toolchain (if you have gcc, you have gcov)
- Calculates the coverage of the code

unity: https://github.com/ThrowTheSwitch/Unity

- Lightweight framework to create unit tests for C embedded software

googletest: https://github.com/google/googletest

- C++ test framework (can be used for C code as well)

Testing Example

```h
#ifndef __DATETIME_H__
#define __DATETIME_H__

typedef struct {
    // Other things...
    int seconds;
} DateTime;

void advance_one_second(DateTime *dt);

void advance_hours(DateTime *dt,
                   const int hours);

#endif // __DATETIME_H__
```

datetime.h

```c
#include "datetime.h"

void advance_one_second(DateTime *dt) {
    ++dt->seconds;
}

void advance_hours(DateTime *dt,
                   const int hours) {
    int total_seconds = 60 * 60 * hours;
    while (total_seconds--) {
        advance_one_second(dt);
    }
}
```

datetime.c

Testing Example (unity)

```c
#include "datetime.h"
#include "unity.h"

void setUp (void) {}
void tearDown (void) {}

void test_advance_one_second(void) {
    DateTime dt;
    dt.seconds = 0;
    TEST_ASSERT_EQUAL(0, dt.seconds);
    advance_one_second(&dt);
    TEST_ASSERT_EQUAL(1, dt.seconds);
}
```

testDatetime.c

```c
void test_advance_hours(void) {
    DateTime dt;
    dt.seconds = 0;
    TEST_ASSERT_EQUAL(0, dt.seconds);
    advance_hours(&dt, 0);
    TEST_ASSERT_EQUAL(0, dt.seconds);
    advance_hours(&dt, 1);
    TEST_ASSERT_EQUAL(3600, dt.seconds);
    advance_hours(&dt, 2);
    TEST_ASSERT_EQUAL(10800, dt.seconds);
}

int main(void) {
    UNITY_BEGIN();
    RUN_TEST(test_advance_one_second);
    RUN_TEST(test_advance_hours);
    return UNITY_END();
}
```

Testing Example (unity + gcov)

```
$ gcc testDatetime.c datetime.c unity.c -fprofile-arcs -ftest-coverage
$ ./a.out
testDatetime.c:29:test_advance_one_second:PASS
testDatetime.c:30:test_advance_hours:PASS

-----------------------
2 Tests 0 Failures 0 Ignored
OK
$ gcov a-datetime.c
File 'datetime.c'
Lines executed:100.00% of 8
Creating 'datetime.c.gcov'
```

flags for gcov

all tests passed!

covered all lines!

These results are only as good as our tests…
We might still have problems in the code!
What if hours < 0?

Debugging

If your code isn't working as intended (maybe a test failed?), how can you fix it? Debugging helps you pinpoint what's going wrong.

gdb: https://www.sourceware.org/gdb/

- Most popular C debugger
- Let's you pause execution and check values, step-by-step

Debugging Example (gdb)

- https://onlinegdb.com/E4M3dnhv7
- https://u.osu.edu/cstutorials/2018/09/28/how-to-debug-c-program-using-gdb-in-6-simple-steps/

After finding out the bug (negative hours -> *really long* loop), we can fix that.

Profiling

After you make sure your code works as intended, you should make it faster!
Profiling helps you find bottlenecks and points in your code where you can improve.

gprof: https://users.cs.duke.edu/~ola/courses/programming/gprof.html

Show time spent of functions, number of calls, other stats.

valgrind: https://valgrind.org/

Help analyze memory management (e.g., find leaks).

gperftools: https://github.com/gperftools/gperftools

Can profile CPU and memory.

Profiling Example (gprof)

```
gcc main.c datetime.c -pg
./a.out
32400
gprof
...
-----------------------------------------------
                0.00    0.00       1/1           main [8]
[2]      0.0    0.00    0.00       1          advance_hours [2]
                0.00    0.00   32400/32400        advance_one_second [1]
-----------------------------------------------
...
```

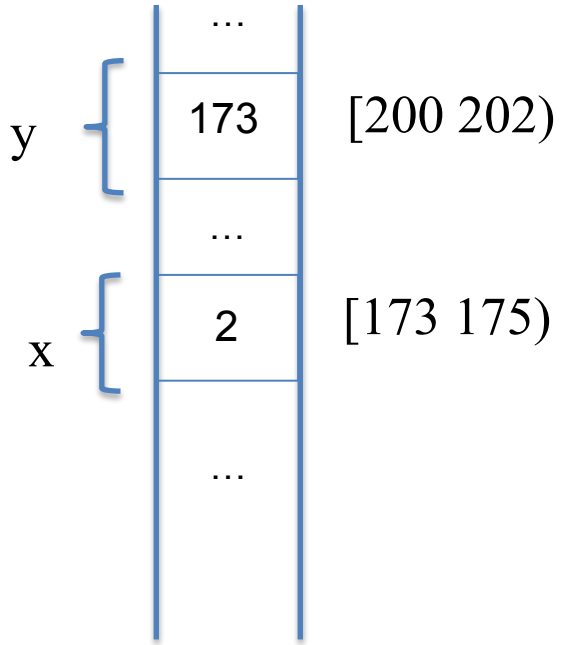
gprof flag

Maybe we don't need to call this function that many times?

C Topics

Pointers

```
int x;
int *y;
x = 2;
y = &x;          // st #200, 173
*y = 5;          // st (#200), 5    (an indirect store)
```



Attributes in the compiler:
(x: 173, 2, Integer)
(y: 200,4, Pointer)

Pointers… why?!?!

```
void init_dt(DateTime *dt) {
  dt->year = 2022;
  ...
  dt->second = 0;
}
```

Side-effects: change things in other scopes.

```
void print_dt(const DateTime *dt) {
  char buf[17];
  // Print date on top row.
  lcd_pos(0, 0);
  sprintf(buf, "%04d-%02d-%02d",
                          dt->year,
                          dt->month,
                          dt->day)
  lcd_puts(buf);
  // Do similar thing to print time on bottom row.
}
```

Efficiency: only pass one address (2 bytes) instead of the whole DateTime (7 bytes) to the function. (ATmega32)

Pointers and consts

Regular pointer to a regular variable, both ops ok!

Regular pointer to a const variable, second op is bad!

```
test-const-pointers.c:10:6: error: read-only variable is not assignable
        *p2 = 2;
        ~~~ ^
```

Const pointer to a regular variable, first op is bad!

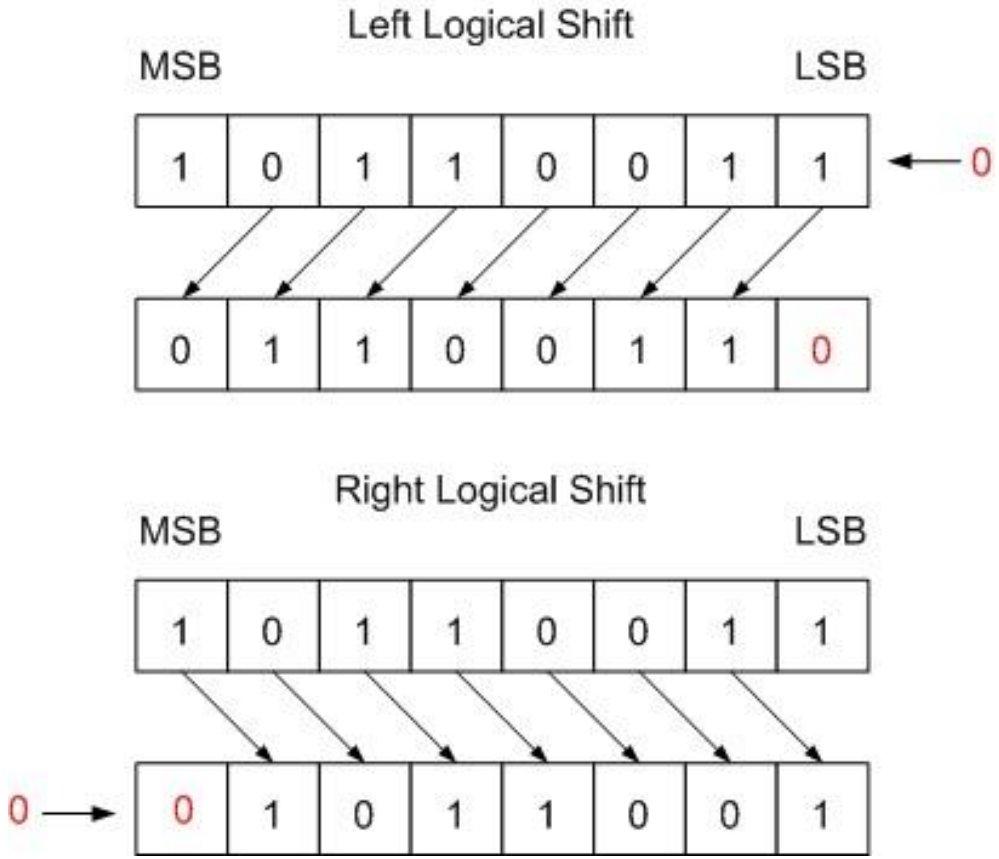
```
test-const-pointers.c:13:4: error: cannot assign to variable 'p3' with
const-qualified type 'int *const'
        p3++;
        ~~^
test-const-pointers.c:12:13: note: variable 'p3' declared const here
        int* const p3 = &x;
        ~~~~^~~~~~
```

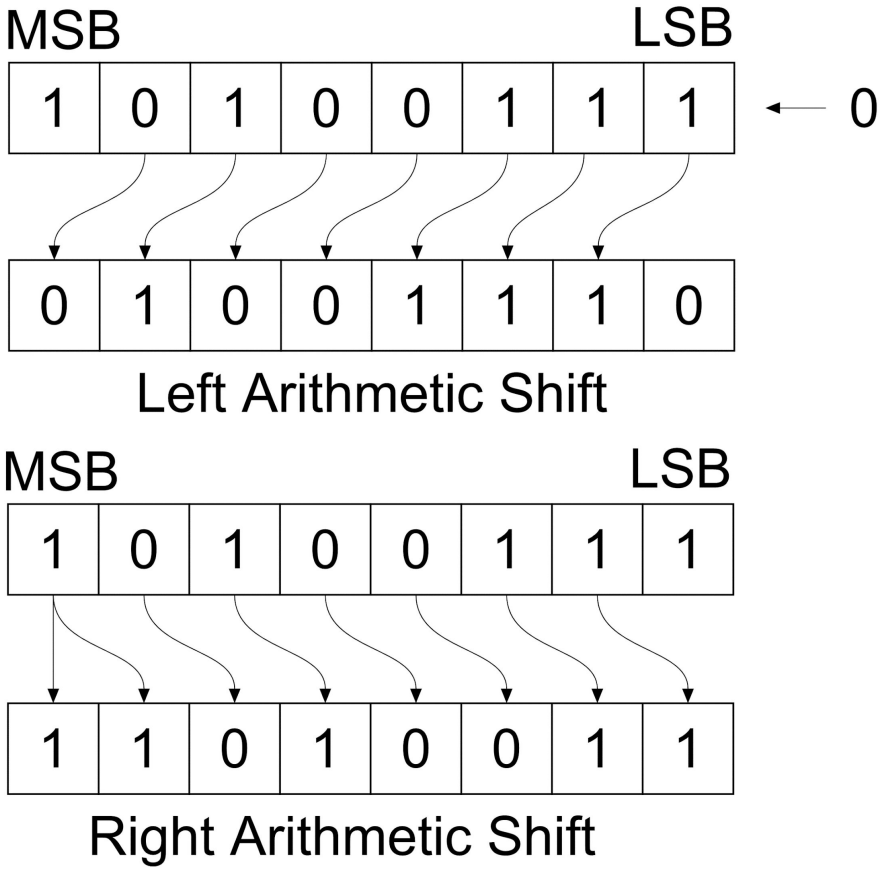
Const pointer to a const variable, both ops bad!

```
test-const-pointers.c:17:4: error: cannot assign to variable 'p4' with
const-qualified type 'const int *const'
        p4++;
        ~~^
test-const-pointers.c:16:19: note: variable 'p4' declared const here
        const int* const p4 = &x;
        ~~~~~~~~~~^~~~~~~
test-const-pointers.c:18:6: error: read-only variable is not
assignable
        *p4 = 4;
        ~~~ ^
```

```c
int main () {
    int x;

    int* p1 = &x;
    p1++;
    *p1 = 1;

    const int* p2 = &x;
    p2++;
    *p2 = 2;

    int* const p3 = &x;
    p3++;
    *p3 = 3;

    const int* const p4 = &x;
    p4++;
    *p4 = 4;

    return 0;
}
```

Shifts





Retains the sign!

Shifts

- Type of the operand:
  - Unsigned -> logic shift
  - Signed -> arithmetic shift

- You can use casting to force the one you want:

```
int x = -1;
x = (unsigned) x >> 1;
printf("%d\n", x);
```

See you next time :)

Q & A