

-42

The hitchhiker's guide to staying alive at
Wethinkcode_ South Africa

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“The answer to all things in Bootcamp is -42”

-e5r8p4

*This is a notebook on the C Programming language I wrote whilst attending the **Wethinkcode_** bootcamp in Johannesburg South Africa in preparation for daily exercises to help fellow bootcampers who want to avoid the dreaded “0/100” Fail screen. All improvements/suggestions welcome at:*

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Lesson 1

- C does not support object oriented programming
- C does not support information hiding (no support for polymorphism, encapsulation, and inheritance)
- C does not allow functions to be defined inside structures.
- C uses functions for input/output. For example `scanf` and `printf` .
(FORBIDDEN by 42 Norm)
- C provides `malloc` and `calloc` functions for dynamic memory allocation, and `free` for memory de-allocation.
(FORBIDDEN by 42 Norm... Before day06)
- C does not provide String or Boolean data types. It supports primitive & built-in data types.
- C supports only Pointers (no references)

HOW TO COMPILE IN UNIX (using gcc)

Moulinette uses `-Wall -Wextra -Werror` when compiling, and uses `gcc`. All warnings in the compiler basically turn to errors
So anything that even looks like it will crash will cause you to get a fail grade ☹

Example 1: Compile command

```
$> gcc -Wall -Wextra -Werror test.c  
$> ./a.out
```

You can also compile multiple C files for the same program.

```
gcc -O0 -Wall -Wextra -Werror -ansi -o my_executable my_code.c
```

PRO TIP: Make an alias

To avoid having to type this long command at each compilation, make yourself an alias!

Open the `~ / SHELLrc` file (replacing SHELL with sh, csh, tcsh, bash, 42sh, ...)

Add a line of type:

```
alias mycc 'gcc -O0 -Wall -Wextra -Werror -ansi'
```

Then type

```
source ~ / SHELLrc
```

And finally, to compile, do

```
mycc -o my_executable my_code.c
```

Lesson 2 – Variables & Character handling

Variables are little boxes that help us store stuff in programming.

To know the ASCII values of each letter, we use the ASCII table that can be accessed through `man ASCII`.

```
48 - 57 | '0' - '9'
65 - 90 | 'A' - 'Z'
97 - 122 | 'a' - 'z'
```

Example: The letter 'F' is set to ASCII 70 while the letter 'f' is ASCII 102.
Other non-visible characters that may be useful:

```
00 | '\0' | NULL, 0 //Usually at the end of strings, so
                                our compiler knows when to stop
                                reading a string

07 | '\a' | bell, beep
08 | '\b' | backspace
09 | '\t' | tabulation
10 | '\n' | Return to the line //Skips to next line
11 | '\v' | Vertical tabulation
13 | '\r' | Come back to the beginning of the line
```

To display a letter, we will use this small function:

```
#include <unistd.h>

void ft_putchar(char c)
{
    write (1, &c, 1);
}
```

You can send a string to a function by using double quotes (" ") my string of characters `\n`.
Single quotes (') are used for single characters.

PRO TIP: Understanding NULL or `'\0'`

NB: NULL in c languages is for NOTHING. It is not the same as zero. If you return 0 in a function it has a meaning but if you return NULL it can crash your program. NULL is typically more useful in things like arrays and memory allocation. (i.e. set all values of an array to NULL before use so that if one result is stored as '0' you can be aware of the fact that a value went in that index, the value just happened to be zero)

Lesson 3 - Useful (And Useless) Functions

Write

- call to system
- uses the `#include <unistd.h>` directive
Remember, numbers still fall on the ascii table. So don't try convert, treat them the SAME as you would a normal char.

in the form

```
write(fd, buf, nbytes);
```

fd	It is the file descriptor which has been obtained from the call to open. It is an integer value. The values 0, 1, 2 can also be given, for standard input, standard output & standard error, respectively .
buf	It points to a character array, which can be used to store content obtained from the file pointed to by fd
nbytes	It specifies the number of bytes (essentially characters) to be written from the file into the character array.

To display words to screen

```
#include <unistd.h>
```

```
int main(void)
```

```
{  
    if (write(1, "Hello World!\n", 13) != 14)  
    {  
        write(2, "There was an error writing to standard out\n", 44);  
        return -1;  
    }  
  
    return 0;  
}
```

PRO TIP: Some useless information

What is a descriptor? (Used for Manipulation of files)

In simple words, when you open a file, the operating system creates an entry to represent that file and store the information about that opened file. So if there are 100 files opened in your OS then there will be 100 entries in OS (somewhere in kernel). These entries are represented by integers like (...100, 101, 102....). This entry number is the file descriptor. So it is just an integer number that uniquely represents an opened file in operating system. If your process opens 10 files then your Process table will have 10 entries for file descriptors.

Printf

(FORBIDDEN by 42 Norm but... It's super useful for testing)

- Provides FORMATTED output
- Used with a number of `specifiers`, use them when you know what type of variable you are outputting
- uses the `#include <stdio.h>` directive
- In the const char part, use `\n` if you need to output stuff after printing

in the form

```
#include <stdio.h>
```

```
int main()
{
    printf ("Characters: %c %c \n", 'a', 65);
    printf ("Decimals: %d %ld\n", 1977, 650000L);
    printf ("Width trick: %*d \n", 5, 10);
    printf ("%s \n", "A string");
}
```

A list of some specifiers

d or i	Signed decimal integer	392
u	Unsigned decimal integer	7235
f	Decimal floating point, lowercase	392.65
e	Scientific notation (mantissa/exponent), lowercase	3.9265e+2
c	Character	a
s	String of characters	sample
p	Pointer address	b8000000
n	Nothing printed.	

Scanf

(FORBIDDEN by 42 Norm)

- The scanf function allows you to accept input from standard in, which for us is generally the keyboard.
- uses the `#include <stdio.h>` directive
- The scanf function uses the same placeholders as printf:

int uses %d

float uses %f

char uses %c

character strings (discussed later) use %s

Void type

- is a type, goes for BOTH function parameters & function returns
- So, a void pointer in c is one without a type, but this actually doesn't matter (in the example, a VP function with a VP variable is created to act as a place holder to convert a char to an int)
- Therefore, void pointers are POLYMORPHIC

- In c++, when void is used as a parameter, it's basically casting a variable (i.e void void_one) but in c it's much simpler, just use void (i.e void) as a parameter

Ternary operators (Use only ONE per function as per 42 Norm)

- Different from Boolean operators because they have three sides instead of two.
- shortens and replaces need for if else
- if condition is true to left of question mark, returns first operand, if condition is false, returns second operand

In the form of:

```
(condition ? return_true : return_false)
```

Example 1 - Shortening and if else statement using ternary operators:

```
int opening_time = (day == SUNDAY) ? 12 : 9;
```

Instead of:

```
int opening_time;
```

```
if (day == SUNDAY)
    opening_time = 12;
else
    opening_time = 9;
```

Ternary operators can also be parameters for other functions (since ternary operators have specified output)

```
#include <stdio.h>
```

```
main()
{
    int a , b;
    a = 10;
    printf( "Value of b is %d\n", (a == 1) ? 20 : 30 );
    printf( "Value of b is %d\n", (a == 10) ? 20 : 30 );
}
```

Typedef (Useful for when we create classes in C)

alias for a type name

signified with _t (i.e. cards_t)

Not much to it, just saves you time cause pointer definitions or even variables can take a while to type

Lesson 4 – Arrays

Arrays

- Little bookshelves that help you store information. More like badass variables
- Same as in C++, same logic and use
- Difference here is that the functions `new` and `delete` for allocating and de-allocating memory are now `malloc` and `free` (*FORBIDDEN by 42 Norm... Before day06*)

Process for allocation

1. Declare pointer variable to point to allocated heap space
2. Call to allocate the correct number of space in memory
3. Initialize array (If you can)
- 4.

Example 1 – How to dynamically allocate in C

```
//declare a pointer variable to point to allocated heap space
int    *p_array;
double *d_array;

//call malloc to allocate that appropriate number of bytes for the array

p_array = (int *)malloc(sizeof(int)*50);    // allocate 50 ints
d_array = (int *)malloc(sizeof(double)*100); // allocate 100 doubles

// always CHECK RETURN VALUE of functions and HANDLE ERROR return values

if(p_array == NULL)
{
    printf("malloc of size %d failed!\n", 50); exit(1);
}
```

Passing array as a parameter

When passing an array as a parameter, this:

```
void arraytest(int a[])
```

means exactly the same as:

```
void arraytest(int *a)
```

Dynamically changing the size of an array

(*FORBIDDEN by 42 Norm... Before day06*)

```
/* Initial memory allocation, use (char *c) to cast as char array */
str = (char *) malloc(15);

/* Reallocating memory */
str = (char *) realloc(str, 25);
free(str);
```

Lesson 5 – Pointers

- when you declare a pointer, it's not "a pointer of the type int" but rather "a pointer of the type point to int"
So a pointer is **Geff pointing to the box he will put your body in.**
A Variable is **Geff storing your body in the box.**
- So it's technically not a variable. Instead of making space in memory (stack), it just waits and points to it until you decide to use it

key to understanding pointers?

1. The address of "&" operator changes what the pointer is pointing to
`int *ip;`
2. the pointer ip only points to something (point to the same thing that variable x is pointing to)
`ip = &x;`

OR

2. you assign the pointers value to something it should point at
`*ip = *x;`
- For arrays, `*ip=2;` assigns 2 to the first element, because the pointer points to the first element of the array
 - If you increment the pointer using `++ip;` , it will point to the second element
 - after incrementing, you can use `ip=3;` to assign to the second element

PRO TIP: Increment AND use a pointer at the same time

you can increment AND use a pointer at the same time using `*(++ip) = 4;`
This is useful for when you want to quickly store something in a pointer array

```
int ia[5];           *ip = 2;
ia[0] = 1;           ++p;
int *ip = ia;        *ip = 3;
                    *(++ip) = 4;
```

C strings

- in the c language, strings are a special case of an array (unlike in c++ where they are objects)
- they are an array of characters terminated by a zero value
- `char s[] = {'s','t','r','i','n','g',0}`
is the same as
`char s[] = "string".`
Use the second, it's more common

You can use a pointer as the i iterator in a loop when outputting an array.
The pointer actually even replaces the need for `s[i]` entirely (example: use a character pointer as an iterator/i)

```
#include <stdio.h>

int main(int argc, char ** argv)
{
    Char s[ ] = "string";
    Printf("String is: %s\n",s);
    For (char * cp = s; *cp; ++cp)
    {
        Printf("Char is: %c\n", *cp);
    }
    Return (0);
}
```

Pointer to a pointer (Pass by reference)

A pointer to a pointer is a form of multiple indirection, or a chain of pointers



```
#include <stdio.h>
int main(void)
{
    int **a;
    **a = 42;
    Printf("%i\n",**a);
}
```

The code above actually prints "42"

PRO TIP: So why use pointer to a pointer?

In C, double pointers are more common, since C does not have a reference type. Therefore, you also use a pointer to "pass by reference."

Where "&" is used in a parameter type in the C++, "*" would be used in C (and dereferenced when manipulating the parameter). A function is not able to change the actual parameter's value. One example:

```
void SomeFun1(int *);
void SomeFun2(int **);
int i;int *ptr = &i;

//when you want value of ptr should remain
//unchanged, but you want to change only value of
//i, use,

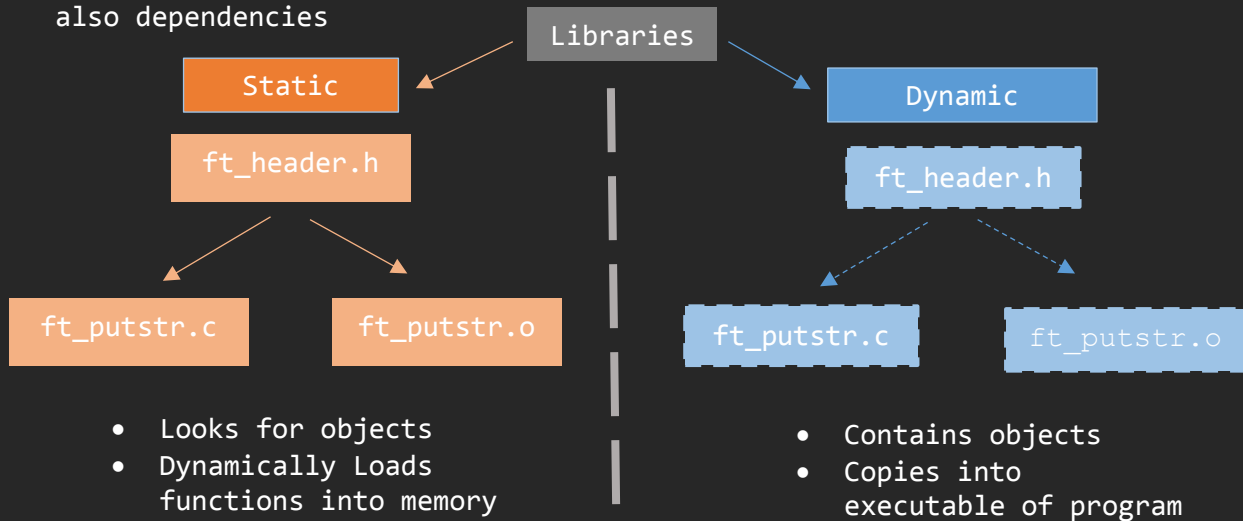
SomeFun1(int *)

SomeFun2(int **);

//when you want value of ptr should change.
//i.e, it should point to some other memory other
//than i, use,
```

Lesson 6: Libraries, Objects & Header files

- Libraries essentially bundle code/functions/objects together in order to reuse and access everything easily
- Archives describe how everything is housed
- These are further separated into Static & Dynamic/Shared Libraries
- Dependencies are created between the Program and the archive. There are also dependencies



Libwacky.a Archive
- Wacky.o Object of
 Archive
- Wackier.c Function of
 Archive
- Wackiest.o Object of
 Archive

How to create Objects

- These are usually created from the .c extension, .c files which are put through the compiler are used to create object files.
- The command line or shell scripts are used to execute the different calls we will need to create object files, creating a library, creating an index in the library and even removing all the object files once they have been created

Example - Some shell script to help build up a library (with .c files located in current directory)

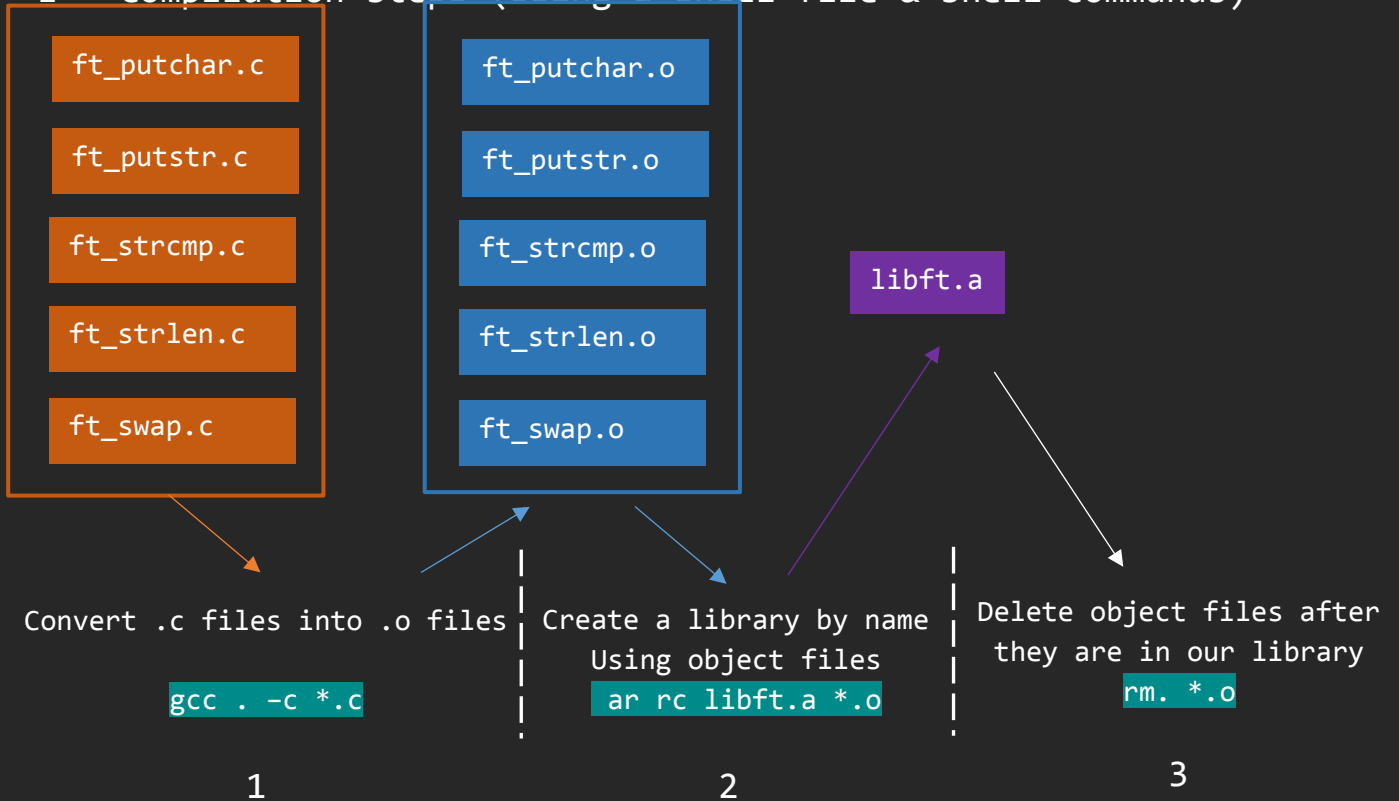
lib_creator.sh

```
#!/bin/sh
gcc . -c *.c           //Create object files from ALL .c files in current directory
ar rc libft.a *.o       //Create a library by name
ranlib libft.a          //Creates index in library (Not always needed)
rm. * .o                //remove/delete all object files
```

- The ar tool can also help us list the files inside a library

```
ar rc libft.a *.o
```

I - Compilation steps (Using a shell file & shell commands)



Makefile

- These compilation steps can be put into a file that lets us control which specific step numbers we want to use (Just like commands in the terminal)
- This is called using a makefile. Using the commands is called make commands
- In order to shorten our compile commands, we can put things like the names or directory paths of files in variables and create rules that basically use the shortened versions of those commands

Example:

```
gcc . -c ft_putchar.c ft_putstr.c ft_strcmp.c ft_strlen.c ft_swap.c
```

could be shortened to...

```
gcc -c $(SRC)
```

where the variable `$(SRC)` contains all the names of your function .c files

- To run each rule individually you need to use `make + rule_name`

Example:

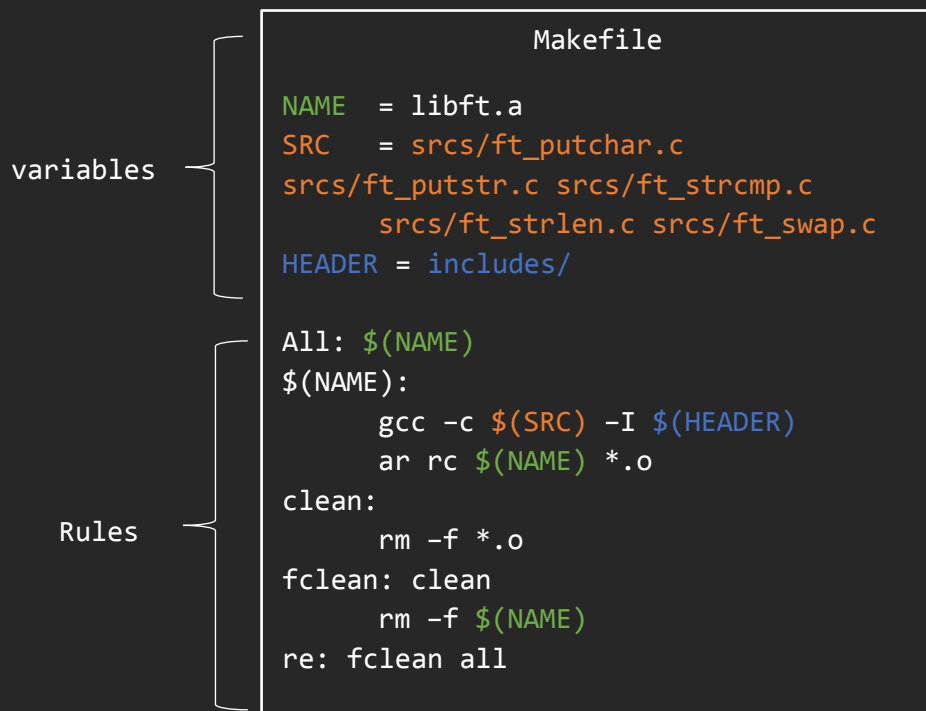
```
rm. *.o
```

would be run using...

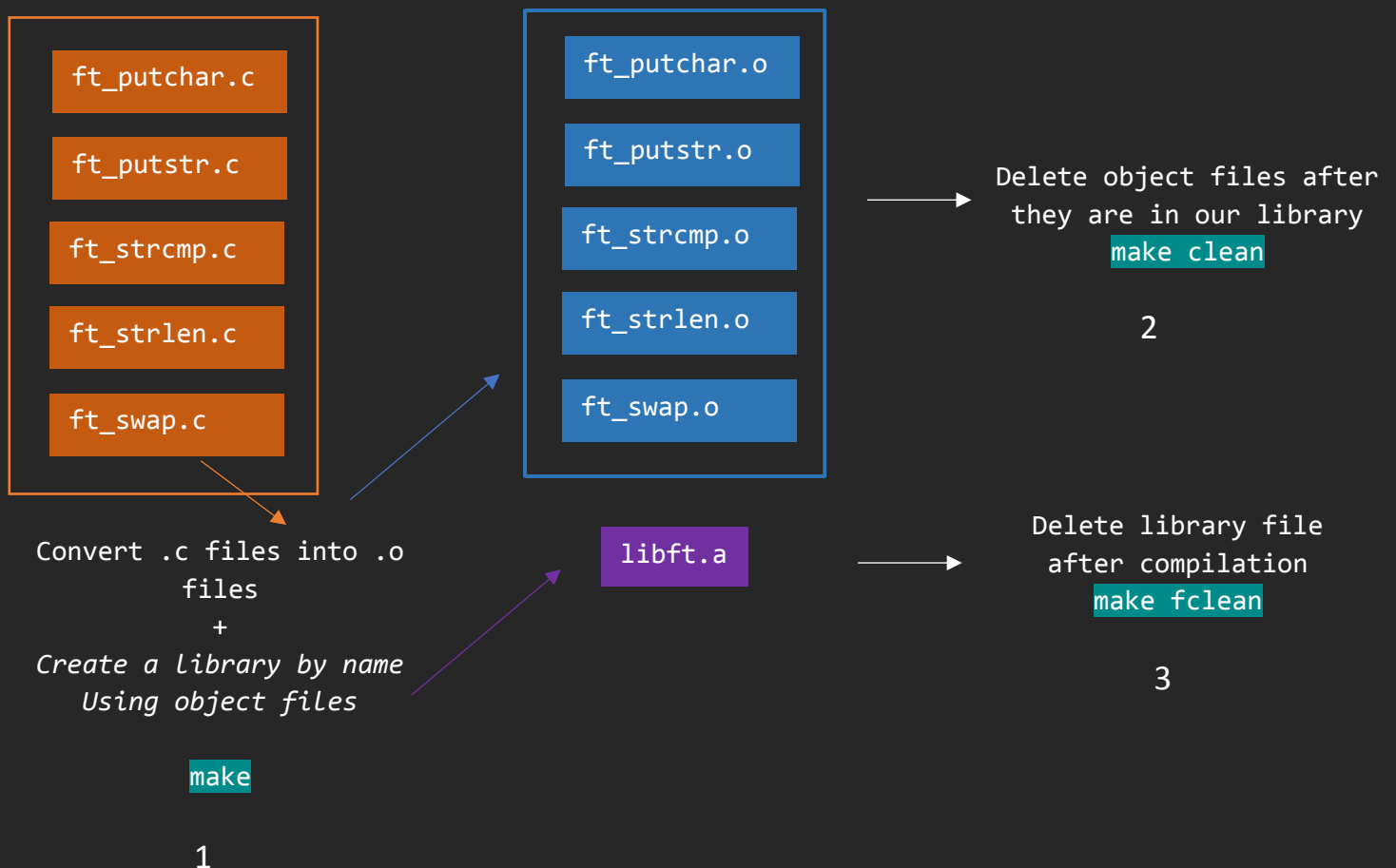
```
make clean
```

1
2
3

Example:



II - Compilation steps (Using a makefile & makefile commands)



Header files

- These files contain prototypes for the functions we might want to use but not have to type again and again (i.e. ft_putchar)
- We would define the prototypes for the functions here but usually the logic with the algorithms is contained with a dependant .c file
- So if I create a ft_header.h file with my prototypes, I must create a corresponding ft_functions.c file with my algorithms
- In my ft_functions.c file, I should have an #include "ft_header.h" line to let my compiler know to access prototypes in the ft_header.h header file

ft_header.h

```
#ifndef FT_HEADER_H
# define FT_HEADER_H

Void ft_putchar(cahr c);
Void ft_putstr(char *c);
Int  ft_strcmp(char *s1, char *s2);
Int  ft_strlen(char *str);
Void ft_swap(cahr c);

#endif
```

ft_functions.c

```
#include <unistd.h>
Void ft_putchar(cahr c)
{
    Write(1, &c, 1);
}

Void ft_putstr(char *c)
{
    //Blah blah blah
}

...
```

Using #ifndef ... #endif helps us avoid prototype conflicts.

#ifndef

- “If not defined” or if (ft_header == false)
- FT_HEADER is not defined
- So if your compiler cannot find the prototypes anywhere else in your .c files, it will just use the one in ft_header

(USE THIS ONE, PREVENTS DOUBLE INCLUDES)

#ifdef

- “If defined” or if (ft_header == true)
- FT_HEADER is defined
- So if your compiler can find another instance of one your prototypes, it will just skip over the one in ft_header.h and use the newly defined one elsewhere.

Lesson 7: Makefiles

- To make better makefiles we need to understand dependencies a bit better
- We also need a better understanding of Linking, Compiling and Including
- Regarding the former, I HIGHLY recommend drawing a quick dependency map using pen and paper. If you are trying to create a library (or code in C++) these will save you hours when you mess up can't understand why your .cpp files don't have access to certain headers

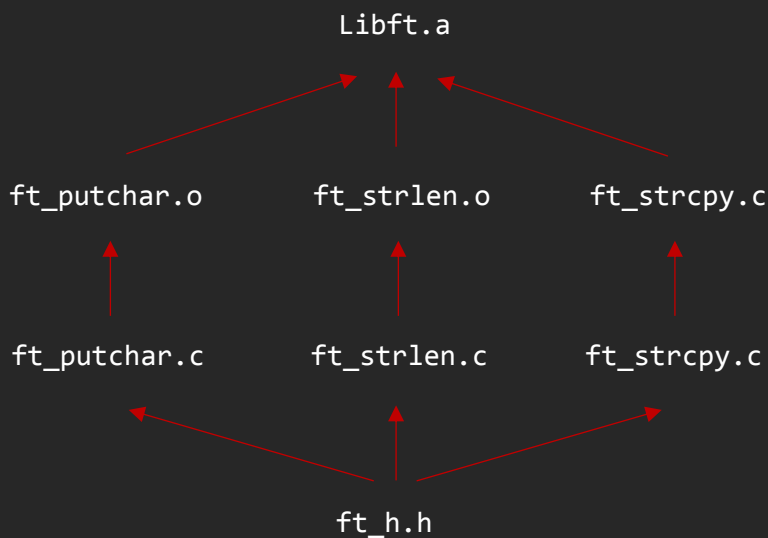
Dependencies

- In C, **libraries have dependencies**: some files/programs need other files to work correctly
- If you've ever been heroic and attempted to install programs in Linux operating using the compile from source code method, you should understand why this is a big deal.

My condolences to you if some dude with a long beard on stack overflow convinced you that this is ever a good idea. It's not. It only ends with you staring at a program that takes up space and does not actually work because of the 15 different dependencies you still need to install after wasting 6 hours of your life trying to install the 100 other dependencies that the program requires. I need new hobbies.



Example: Dependency map for libft.a

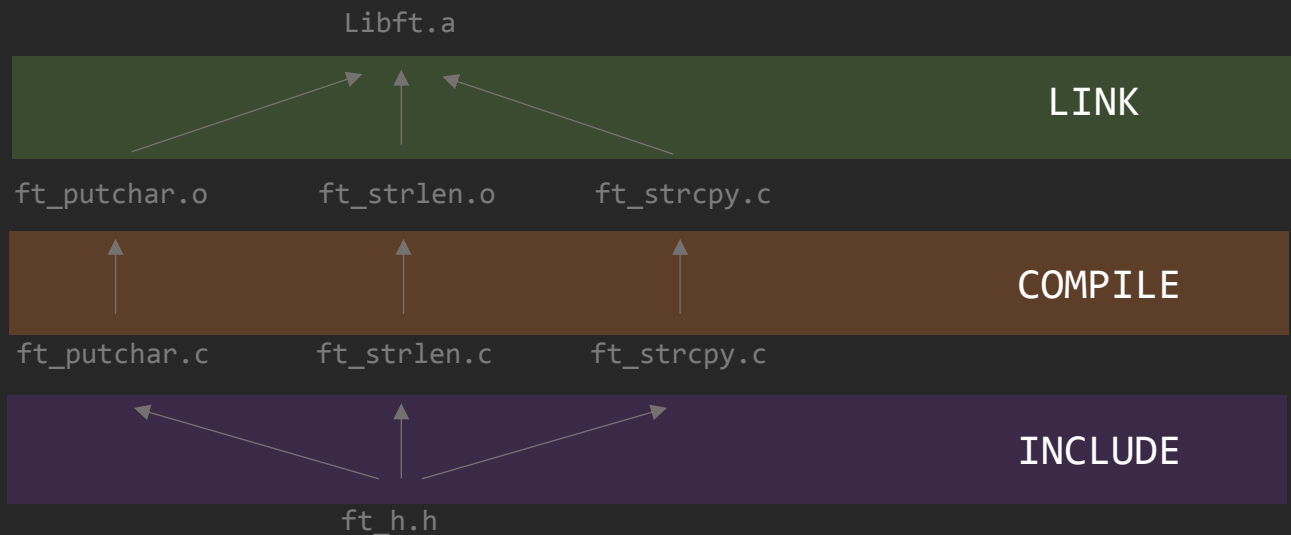


Linking, Compiling, Including

- Now that we understand dependencies, we can do compilation steps. Properly this time

3 Steps in Compilation

1. INCLUDE
(Stating the header files we need. These can be self-created, system or packaged)
2. COMPILE
(Turning the code you have written into machine code. It's so that the computer hardware can read our code)
3. LINK
(turns object files into a single archive/ executable)



Example: Make file using Link, Compile & Include

```
NAME =      objects_SDL
FILENAMES = Game.cpp Main.c TextureManager.c GameObject.c
_DEPS =     Game.h TextureManager.h GameObject.h
DEPS =      $(patsubst %, $(HDIR)/%, $(DEPS))
```

```
all: $(NAME)
```

```
$(ODIR)/%.o: $(SDIR)/%.c $(DEPS)
    $(CC) $< $(HFLAGS) $(IFLAGS) $(CFLAGS) $(LFLAGS) -c -o $@
$(NAME): $(OBJ)
    @echo      Object files generated!
    @echo      Compiling library...
    $(CC) $^ $(HFLAGS) $(IFLAGS) $(CFLAGS) $(LFLAGS) -o $@
    @echo      Done! Type \"make run\" to run executable
```

Explanation of dependencies:

`all: $(NAME)`

*The “all” rule depends on the library/
program objects_*SDL

`$(ODIR)/%.o: $(SDIR)/%.c`

*The “create .o files” rule depends on the
.c files with similar names (i.e.
ft_putchar.o depends on ft_putchar.c)*

`$(DEPS)`

*The c files in the above rule depend on the
header files in the variable called _DEPS*

Lesson 8: Arguments

- This is a super convenient feature to use at compilation for easy testing and to make your programs easier for users to use
- Instead of creating a printf main testing function, you could rather bake in arguments so that you can test at the ./a.out compilation step

argc - Argument **COUNT**. This counts the number of entered arguments (i.e. the number of strings entered by user)

- Is always +1 higher than the actual number, this is because the program name (./a.out) takes up the first index

****argv** - Argument **VECTOR**. This is a 2D array that holds arguments entered as strings. Is A *NULL POINTER*

0	./a.out
1	Hello
2	There!

Example: A program to reverse a string inputted by the user

WITHOUT arguments

```
void ft_putchar(char c);
void ft_putstr(char *c);
char *ft_strrev(char *c);

int main(void)
{
    char *str;
    ft_putstr("Please enter your string:");
    scanf("%s",str);
    ft_putstr(ft_strrev(str));
    return (0);
}
```

Terminal:

```
$> gcc Reverse_Prog.c
$> ./a.out
$> Please enter your string:
$> ReverseMe
$> eMesrever
```

WITH arguments

```
void ft_putchar(char c);
void ft_putstr(char *c);
char *ft_strrev(char *c);

int main(int argc, **argv)
{
    char *str;
    int k;

    k = 1;
    while (argc > 1)
    {
        ft_putstr(ft_strrev(argv[k]));
        --argc;
        k++;
    }
    ft_putchar('\n');
    return (0);
}
```

Terminal:

```
$> gcc Reverse_Prog.c
$> ./a.out Reverse Me
$> eMesrever
```

HOW TO PRINT ARGUMENTS

- Remember to ALWAYS use both `argc` & `argv` in your main function to avoid a compiling error (caused by unused parameters/variables).

WHOLE ARGUMENTS (as strings)

```
int k;

k = 1;
if (argc > 1)
while (k < argc)
{
    ft_putstr(argv[k]);
    ft_putchar('\n');
    k++;
}
```

(I prefer this method to avoid spaghetti code)

WHOLE ARGUMENTS (as char array)

```
int k;
int m;

k = 1;
m = 0;
if (argc > 1)
while (k < argc)
{
    while (argv[k][m] != '\0')
    {
        ft_putchar(argv[k][m]);
        m++;
    }
    k++;
    ft_putchar('\n');
}
```

(>.<) FML

PRO TIP: Use `argc` & `argv` as parameters in functions other than `int main`

In C, `argv` works like a char array where the final element is guaranteed to be a null pointer. Pass them as normal if you want to use them outside main.

```
int main(int argc, **argv)
{
}
```

Is the same as...

```
char some_or_other_function(int argc, **argv);
```

Is the same as...

```
int some_or_other_function(int size, char **argspooppoop);
```

Is the same as...

```
void some_or_other_function(int size_t, char *argblahlah[]);
```

Lesson 9: Pointers to functions

- This is a great way of managing and debugging complex code
- Instead of having to fix a written function that appears 100 times, you can basically alter your function once in a single location and fix all your problems in the original function definition.

Example : fix a function that originally created cows with 3 legs

```
void create_cows(int *f)(int **legs, int **head, char **color)
{
    legs = 3;           //We should give a cow 4 legs instead of 3
    head = 1;
    color = "black and white"
}

int main ()
{
    int no_legs = 0;
    int no_heads = 0;
    char str_color = 0;
    f(no_legs, no_heads, str_color);
}
```

- In this example we can see that in the future we might create more cows and use the create_cows function.
- If we were coding a farm simulator, we would probably call the function thousands of times, but to neaten our code we could call it using `f(m,n,p)`; where m, n and p are different values
- Instead of wasting space in memory and storing & executing the function thousands of times, we could just point to it and execute to create a cow when needed.
- Even when we fix our original function, we only need to change 3 to 4 and all the other pointers to our function will adjust themselves accordingly.

TESTING: HOW TO USE A POINTER TO A FUNCTION IN AN ARGUMENT

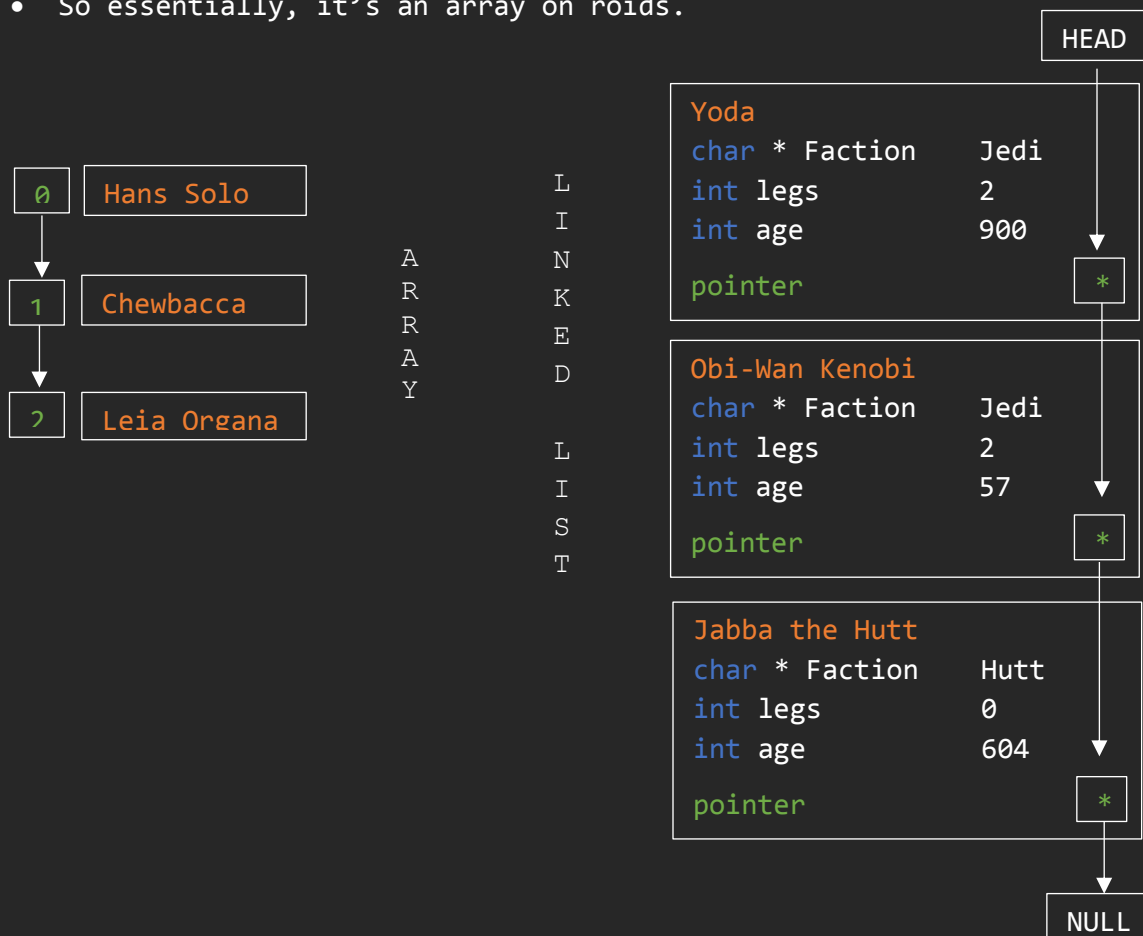
```
void ft_putnbr (int nb);
int main (void)
{
    int a[] = {0,1,2,3,4,5}
    ft_foreach(a, 7, &ft_putnbr);
}
```

TESTING: HOW TO ALLOCATE SPACE IN MEMORY AND DECLARE AN ARRAY OF STRINGS

```
int main (void)
{
    char **tab;
    tab = (char **)malloc(12);
    tab[0] = "tutu";
    tab[1] = "tata";
    tab[2] = "toto";
}
```

Lesson 10: Linked Lists

- A linked list is a list constructed using pointers
- It can grow and shrink in size while your program is running
- It can also contain more than a single data type (using nodes)
- So essentially, it's an array on roids.



- Each box in an array is an index but each box in a linked list is a node. Each node contains a pointer.
- We create nodes using structs in C. A struct is sort of like a class, you can add multiple properties of different data types as show above
- We can add nodes wherever we want to unlike arrays, where we would need to shift other indexes just to insert an element in the middle.
- To fully understand how adding nodes works, we start with what we call the **head** pointer. It ALWAYS points to the first element in a linked list.

What a node looks like

ft_list.h

```
typedef struct node    s_list
{
    struct s_list    *next;
    Void              *data;
}                      t_list
```

//Holds address of next node
//This could be any random data

In both examples below, `begin_list`, is a head pointer that will point to the first node on the list

Add a node at: BEGINNING of the list

ft_list_push_front.h

```
void ft_list_push_front(t_list **begin_list, void *data)
{
    t_list *cursor;
    cursor = ft_create_elem(data);

    if (*begin_list == NULL)
        *begin_list = cursor;
    else
    {
        cursor->next = *begin_list;
        *begin_list = cursor;
    }
}
```

Create a new node

If head pointer points to NULL
-point head pointer to new node

Otherwise,
-point new node to existing node
-point head pointer to new node.

Add a node at: END of the list

ft_list_push_back.h

```
void ft_list_push_back(t_list **begin_list, void *data)
{
    t_list *cursor;
    cursor = *begin_list;

    if (*begin_list == NULL)
        *begin_list = ft_create_elem(data);

    while (cursor->next != NULL)
        cursor = cursor->next
    cursor->next = ft_create_elem(data);
}
```

Place a header pointer before first element

If head pointer points to NULL
- create new node
-point head pointer to new node.

Otherwise,
-iterate till end of list
-create new node

Stuff for nerds I : Space & Time Complexity of an algorithm

Time complexity of an algorithm quantifies the amount of time taken by an algorithm to run as a function of the length of the input. Similarly, **Space** complexity of an algorithm quantifies the amount of space or memory taken by an algorithm to run as a function of the length of the input. This usually shows the number of times an algorithm will have to execute in the worst case scenario.

There are some common running times when analyzing an algorithm:

Big O Notation

(In order of speed)

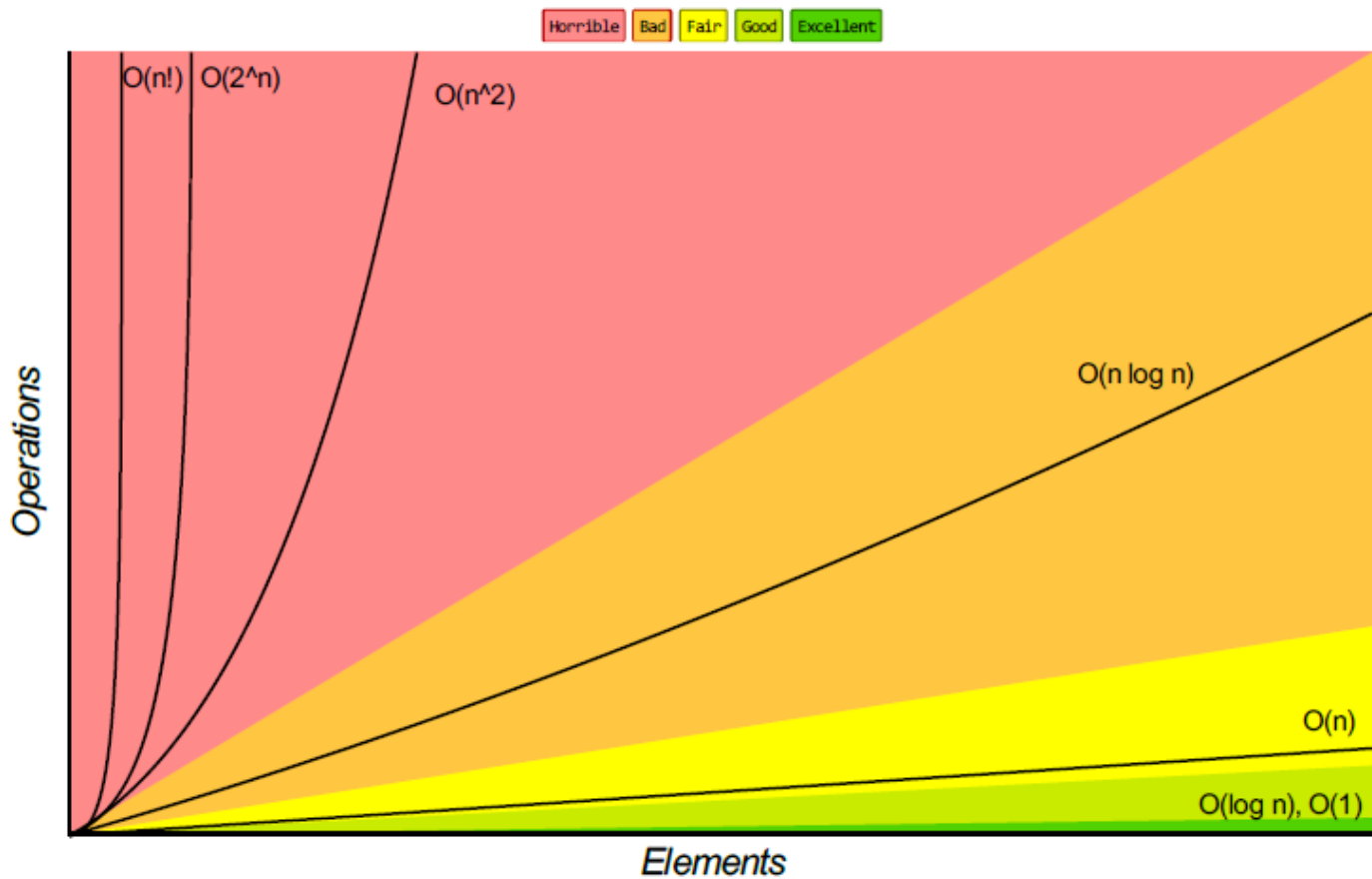
$O(1)$ "Order of 1"	Constant	Running time is constant, it's not affected by the input size. Example: Adding item to array.
$O(\log N)$	Logarithmic	Algorithm that has running time $O(\log n)$ is slightly faster than $O(n)$. Commonly, algorithm divides the problem into sub problems with the same size. Example: Binary search algorithm, binary conversion algorithm.
$O(N)$	Linear	When an algorithm accepts n input size, it would perform n operations as well. Example: Linear search
$O(n \log_n)$	Linearithmic	This running time is often found in "divide & conquer algorithms" which divide the problem into sub problems recursively and then merge them in n time. Example: Merge Sort algorithm.
$O(N^2)$	Quadratic	Look Bubble Sort algorithm! Example: Bubble Sort algorithm (nested loops, swap elements)
$O(N^3)$	Cubic	Same as above
$O(2^n)$	Exponential	Time It is very slow as input get larger, if $n = 1000.000$, $T(n)$ would be $2^{1000.000}$. Brute Force algorithm has this running time.
$O(N!)$	Factorial	THE SLOWEST !!! Example : Travel Salesman Problem (TSP)

So if you did `ft_fibonacci.c` from day04 and tested it, you might have noted that it was REALLY slow, especially at higher values. This is because it has a $O(2^n)$ Time complexity (SUPER inefficient).

So typically, the more data we have, the "N-times" or "N-squared times" etc the algorithm will have to execute in the worst case scenario.

Remember, we always look at the part of the algorithm with the BIGGEST effect on the performance of the algorithm.

Big-O Complexity Chart



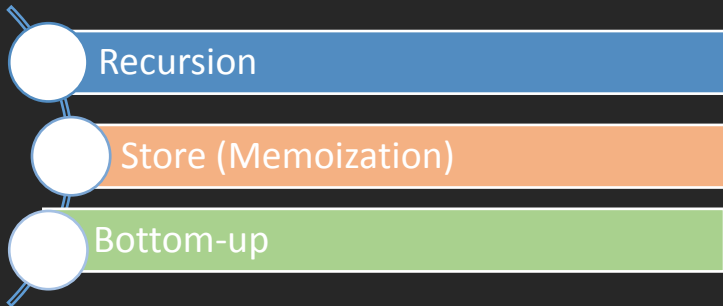
PRO TIP: TSP for nerds

- A salesman must travel between N cities (in any order) and finishes where he started
- This is an NP-hard problem
- For n cities, you have $N-1$ Factorial solutions (for only 10 cities you have over 180 000 combinations)
- Therefore this has the complexity of $O(n!)$

Stuff for nerds II: Dynamic Programming

(Stuff to know for when we do searches)

- Dynamic programming can make an algorithm more efficient by storing some of the intermediate results (where there are repetitive computations)
- Seems like this is used where we have super slow/inefficient algorithms (like ones that compute in exponential $O(2^n)$ or even factorial $O(n!)$ time)
- Normally 3 approaches to a Dynamic Programming problem:



Recursion

- In programming languages, if a program allows you to call a function inside the same function, then it is called a recursive call of the function.
- But while using recursion, programmers need to be careful to define an exit condition from the function; otherwise it will go into an infinite loop.

The base case = exit condition for function

Steps for writing recursive functions:

1. Define what the recursive function does in English (i.e. the prototype)
2. Think about solving the next smaller sized problem
Recursion solves a big problem (of size n , say) by solving one or more smaller problems, and using the solutions of the smaller problems, to solve the bigger problem
3. Finally, you should deal with the base case, which is the smallest problem

```
int sum( int arr[], int n )           //1) Function prototype
{
    if ( n == 0 )                     //3) base case
        return 0 ;    // no recursive call
    else
    {
        int small = sum( arr, n - 1 ) ;    //2) solve smaller problem
        return small + arr[ n - 1 ] ;
    }
}
```

Recursion will help solve complex scenarios elegantly and most importantly, will result in readable/understandable code.

Memoization

- Simply storing the results obtained from a recursive solution
- Best example would be the Fibonacci sequence program

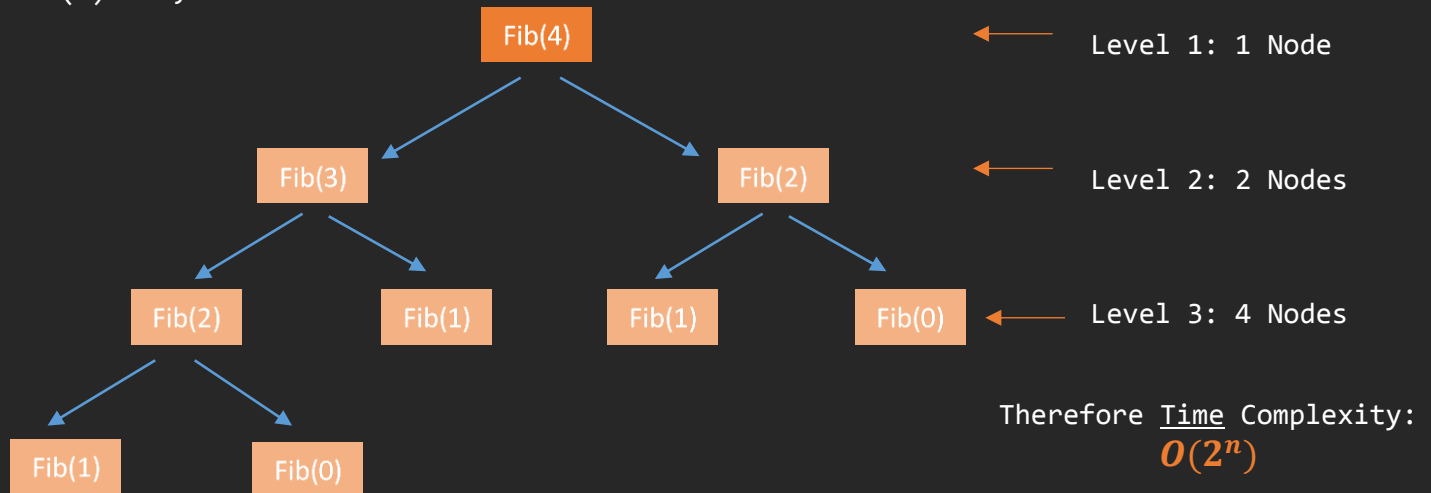
Example:

$\text{Fib}(n) = \text{Fib}(n-1) + \text{Fib}(n-2)$

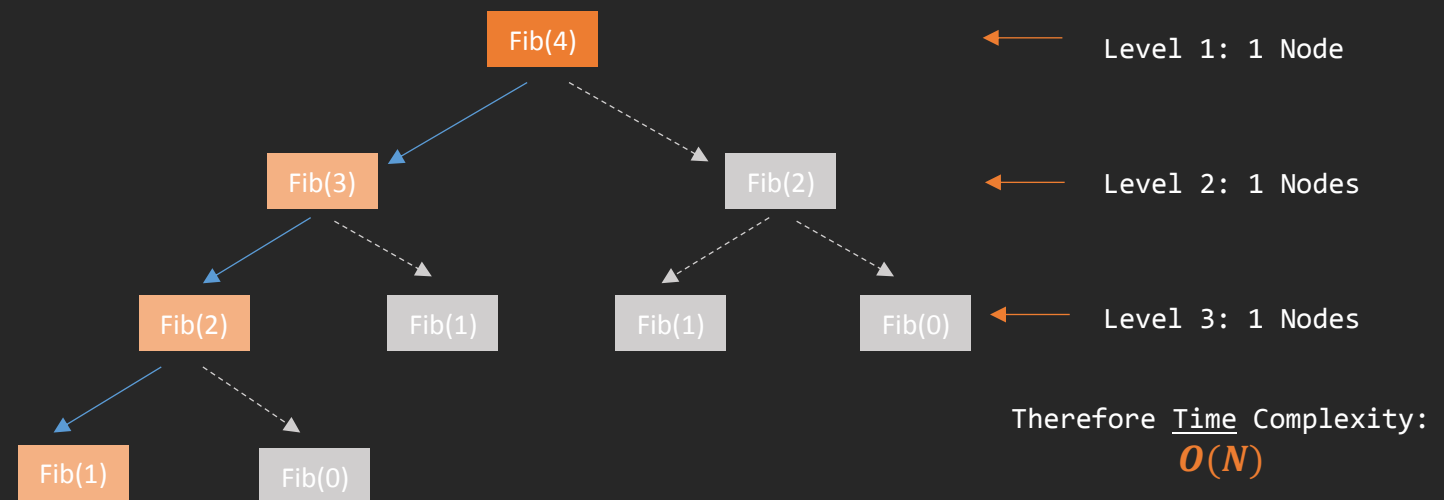
With the starting conditions of:

$\text{Fib}(0) = 0;$

$\text{Fib}(1) = 1;$



A treemap of the $\text{fib}(4)$ function (WITHOUT Memoization)



A treemap of the $\text{fib}(4)$ function (WITH Memoization)

Bottom-up

- Better logical approach, instead of recursively trying to find a solution, figure out a relationship on the sequence and store indexes in array

Algorithms for fibonacci using all 3 methods:

Recursion

```
int fib (int n)
{
    int result = NULL;
    if (n == 1) || (n == 2)
        result 1;
    else
        result = fib(n-1) + fib(n-2);
    return result;
}
```

Therefore Time Complexity:
 $O(2^n)$

Memoization

```
int fib (int n, int *memo)
{
    int result = NULL;
    if (memo[n] != NULL)
        return memo[n]
    if (n == 1) || (n == 2)
        result 1;
    else
        result = fib(n-1) + fib(n-2);
    memo[n]= result;
    return result;
}
```

Therefore Time Complexity:
 $T \leq (2n + 1).O(1)$
 $= O(N)$

Bottom-up

```
int fib (int n){
int result = NULL;
    if (n == 1) || (n == 2)
        result 1;
bottom = new int[n+1];           //Define an array
bottom[1]= 1;
bottom[2]= 1;
for (int i=3; i <= n; i++)
    bottom[i]= bottom[i-1]+ bottom[i-2];
    return bottom[n];
}
```

Therefore Time Complexity:
 $= O(N)$

Stuff for nerds III: Other algorithms

Binary search

- This is an interesting search method that relies on the property that a set is sorted
- This algorithm divides a set in two, compares the search item to the middle of the set, and decides whether it should recursively search the top or bottom of the set.
- Each search level has half the number of results therefore has a logarithmic time complexity $O(\log_n)$
- This search can be iterative or recursive (prefer iterative as you can use a single parameter for a function)

Steps:

1. *While left <= right...*
2. *mid = (left + right)/2... OR mid = (left + right)/2 to prevent integer overflow*
3. *Check if x < mid (then adjust right boundary, right = mid-1)*
4. *Else adjust left boundary (left = mid+1)*

```
int binsearch(int nb)
{
    int * arr[nb] , left = 0, right = nb-1, x, mid;
    char * result;
    while (left <= right){
        mid = (left+right)/2;
        if (arr[mid] == x)
            result = mid ;
        else if (x < arr[mid])           //Check left, adjust right
            right = mid-1;
        else if (x > arr[mid])           //Check right, adjust left
            left = mid+1;
    }
    result = '\0'
}
```