Computer Science Practice and Experience: Development Basics - COMPSCI 1XC3

Pedram Pasandide (pasandip@mcmaster.ca)

GitHub

McMaster University

Contents

1 Introduction

1.1 A Short Overview of Programming Languages

Programming languages can be categorized based on their level of abstraction, which refers to how closely they resemble the underlying hardware operations of a computer. At the lowest level, we have **machine code**, which consists of binary instructions that are directly executed by the computer's hardware. Above machine code, we have **assembly language**, which uses **human-readable** characters to represent the low-level instructions. However, assembly language is specific to each CPU architecture, so it can differ between different types of processors.

Moving up the hierarchy, we encounter **C**, which was created in around 1970 as a by- product of UNIX based operating systems. **C** is considered a slightly higher-level language compared to **assembly language**. It provides a set of abstract statements and constructs that are closer to human-readable text. **C** code can be compiled using a program called **compiler**, which translates the **C** code into **machine code** that can be executed on any CPU. This portability is one of the reasons why C is often referred to as "**portable assembly**." **C** allows programmers to efficiently write code with a relatively low level of abstraction.

Above **C**, we find **C++**, which was created around 1985. **C++** is an extension of **C** and introduces **object-oriented programming** concepts. It includes the ability to define **classes**, which encapsulate data and behavior into reusable structures. However, for the purpose of this course, we won't delve into the specifics of object-oriented programming.

Moving further up the ladder, we have **Java** and **C#**, which are considered **mid-level** languages. These languages restrict certain low-level operations available in **C** and **C++**, for example, managing memory environments. Instead of allowing direct memory allocation, **Java** and **C#** handle memory management themselves, offering automatic memory allocation and garbage collection. This trade-off provides programmers with increased security and simplifies memory management, but it also limits some of the flexibility and control offered by lower-level languages.

At the **highest level**, we have interpreted languages like **Python** and **JavaScript**. These languages are considered highly abstracted and provide significant levels of convenience and ease of use for developers. Interpreted languages do not require a separate compilation step; instead, they use an **interpreter** to execute the source code directly. The interpreter reads the code **line-by-line**, executing each instruction as it encounters it. This line-by-line execution allows for more dynamic and interactive programming experiences but can result in slower performance compared to compiled languages.

1.1.1 C, Strengths and Weaknesses

Weaknesses

While C has many strengths, it also has a few weaknesses that developers should be aware of:

1. Error-prone: Due to its flexibility, C programs can be prone to errors that may not be easily detectable by the compiler. For example, missing a semicolon or adding an extra one can lead to unexpected behavior, such as infinite loops! It means you are waiting for hours to get the result, then you figure out it shouldn't take that much time! Don't worry there are some ways to avoid it!

2. Difficulty in Understanding: C can be more difficult to understand compared to higher-level languages. It requires a solid understanding of low-level concepts, such as memory management and pointers. The syntax and usage of certain features, like pointers and complex memory operations, may be unfamiliar to beginners or programmers coming from higher-level languages. This learning curve can make it more challenging for individuals new to programming to grasp and write code in C effectively.

3. Limited Modularity: C lacks built-in features for modular programming, making it harder to divide large programs into smaller, more manageable pieces. Other languages often provide mechanisms like namespaces, modules, or classes that facilitate the organization and separation of code into logical components. Without these features, developers must rely on manual techniques, such as using header files and carefully organizing code structure, to achieve modularity in C programs. This can lead to codebases that are harder to maintain and modify as the project grows in complexity.

Strength

C programming language possesses several strengths that have contributed to its enduring popularity and wide-ranging applicability:

1. Efficiency: C is renowned for its efficiency, allowing programs written in C to execute quickly and consume minimal memory resources. It provides low-level access to memory and hardware, enabling developers to optimize their code for performance-critical applications.

2. Power: C offers a rich set of data types and a flexible syntax, enabling developers to express complex algorithms and manipulate data efficiently. Its extensive standard library provides numerous functions for tasks such as file I/O, memory management, and string manipulation, allowing programmers to accomplish a lot with concise and readable code.

3. Flexibility: The versatility of C is evident in its widespread use across different domains and industries. C has been employed in diverse applications, including embedded systems, operating systems, game development, scientific research, commercial data processing, and more. Its flexibility makes it a suitable choice for a broad range of programming tasks.

4. Portability: C is highly portable, meaning that programs written in C can be compiled and run on a wide range of computer systems, from personal computers to supercomputers. The C language itself is platform-independent, and compilers are available for various operating systems and architectures.

5. UNIX Integration: C has deep integration with the UNIX operating system, which includes Linux. This integration allows C programs to interact seamlessly with the underlying system, making it a favored language for system-level programming and development on UNIX-based platforms.

1.2 Shell Basics on Linux

To create a new folder (directory) in Linux using the terminal, you can use the `mkdir` command. Here's how you can do it:

Open your terminal application. This can vary depending on the Linux distribution you're using. You can typically find the terminal in Applications menu or by pressing `Ctrl+Alt+T`. Navigate to the location where you want to create the new folder. You can use the `cd` command to change directories. For example, if you want to create the folder in your home directory, you can use `cd ~` to navigate there. Once you're in the desired location, use the `mkdir` command followed by the name you want to give to the new folder. For example, to create a folder called "COMPSCI1XC3," you would type `mkdir COMPSCI1XC3`. Press `Enter` to execute the command.

In the world of Linux commands hold the power to shape the digital landscape. Let's do start with some basic commands:

1. Current directory: To know your current directory, use the command `pwd`. It will display the path of the directory you are currently in. To view all the files and folders in the current directory, use the command `ls`. This will provide a list of all the files and folders. Look for a folder named `COMPSCI1XC3` in the list of files and folders (if you have did the previous step successfully!). Once you find it, you'll use the following steps to navigate and work within that folder. To open the `COMPSCI1XC3` folder in the file manager, use the command `open COMPSCI1XC3`.

2. Moving back and forth in directories: To change your current directory to the `COMPSCI1XC3` folder, use the command `cd COMPSCI1XC3` in the terminal. This command allows you to move into the specified folder (use `pwd` to double check!) If you want to go back to the initial directory, simply use the command `cd` without any arguments. This will take you back to the `/home/username` directory, where `username` is what you picked during installation of Linux. To go back one folder, use the command `cd ..`. This will navigate you up one level in the directory structure.

3. Making a file: Now, go back to `COMPSCI1XC3` directory. If you want to create a text file named "AnneMarie", use the command `nano AnneMarie.txt`. This will open the file editor where you can write and edit text. To open the `AnneMarie.txt` file in the Nano text editor, use the command `nano AnneMarie.txt` again. This allows you to make changes to the file. If you wish to save your changes, press `Ctrl+O` and then press `Enter`. This will save the file. Alternatively, if you want to save and exit the Nano text editor, press `Ctrl+X` and then press `Enter`. This will save the changes and return you to the terminal.

To reopen the `AnneMarie.txt` file in the terminal using the Nano text editor, use the command `nano AnneMarie.txt`. If you prefer to open the `AnneMarie.txt` file in the Windows environment, use the command open `AnneMarie.txt` after saving the file. This will open the file using the default application associated with `.txt` files.

4. Copy and Paste: To copy the `AnneMarie.txt` file and paste it into another directory, you can use the `cp` command, like:

```
cp AnneMarie.txt /path/to/destination/directory/
```

Replace `/path/to/destination/directory/`. with the actual path of the directory where you want to paste the file.

5. View a file: The `cat` command is used to display the contents of a file in the terminal. It can be helpful when you want to quickly view the contents of files. Here's an `.txt` file example: `cat AnneMarie.txt`. Running this command will print the contents of `AnneMarie.txt` in the terminal window. Easier way just double click on the file!

6. Finding a folder of file: To find a file or folder using the `locate` command or similar commands, you need to have the appropriate indexing database set up on your system. The `locate` command searches this database for file and folder names. For example, `locate AnneMarie.txt`, will search the indexing database for any files or folders with the name `AnneMarie.txt` and display their paths if found. In this case, nothing is shown in terminal. Since we just made this file, the database including directories is not updated to include this file. To update the directory database in all memory, we have to use the command `updatedb`, and you will probably get the following message:

```
/var/lib/plocate/:  Permission denied
```

indicating that you do not have the necessary permissions to access the directory. To solve the issue and update the directories index successfully, use the `sudo updatedb` which prompts you to a password which you picked. Enter the password, it might not be shown when you are entering the password, then press `Enter`. By this command, you are running the `updatedb` with superuser (root) privileges. `sudo` stands for "Super User Do" and is a command that allows regular users to execute commands with the security privileges of the superuser. Now you can use command `locate`, but this time it shows the directory that the file is saved.

Alternatively, you can use:

`find /path/to/search/directory -name AnneMarie.txt`

Replace `/path/to/search/directory` with the directory where you want to start the search.

Tips! Debugging is an essential aspect of programming. No programmer possesses complete knowledge or can remember every command, especially when working with multiple programming languages. However, it is crucial to know where to find the answers. Here are two approaches to tackle a specific issue:

1. Use internet. For instance, search for "permission denied on Linux." Take a quick look at the top search results, paying particular attention to reputable sources such as Stack Overflow. Spend a few minutes scrolling through the search results.

2. Engage with ChatGPT by asking a specific question related to the problem you encountered. For example, you could ask, "I tried `updatedb` on Linux terminal, and it gives me Permission denied. How can I solve it?"

7. Remove: The `rm` command is used to remove (delete) files and directories. It's important to exercise caution when using this command, as deleted files cannot be easily recovered. Here's an example to remove the `AnneMarie.txt` file: `rm AnneMarie.txt`. This command will permanently delete the `AnneMarie.txt` file. Be sure to double-check the file name and verify that you want to delete it.

The `rmdir` command is used to remove (delete) empty directories. It cannot remove directories that have any files or subdirectories within them. Here's an example: `rmdir empty_directory`. Replace `empty_directory` with the name of the directory you want to remove. This command will only work if the directory is empty. If there are any files or subdirectories inside it, you'll need to delete them first or use the `rm` command with appropriate options to remove them recursively.

8. Let's checkout some OS characteristics.

Linux distribution: distThe `lsb_release -a` command provides comprehensive information about your Linux distribution, including the release version, codename, distributor ID, and other relevant details. The `-a` option is a command-line option or flag that stands for "all." When used with the `lsb_release` command, it instructs the command to display all available information about the Linux distribution. It is a convenient way to quickly check the specifics of your Linux distribution from the command line. My Linux distribution is:

```
Distributor ID: Ubuntu
Description: Ubuntu 22.04.2 LTS
Release: 22.04
Codename: jammy
```

CPU: The `lscpu` command is used to gather and display information about the CPU (Central Processing Unit) and its architecture on a Linux system. It provides detailed information about the processor, including its model, architecture, number of cores, clock speed, cache sizes, and other relevant details. **Some** of details for my system:

```
Architecture:            x86_64
  CPU op-mode(s):        32-bit, 64-bit
  Address sizes:         39 bits physical, 48 bits virtual
  Byte Order:            Little Endian
CPU(s):                  8
  On-line CPU(s) list:   0-7
Vendor ID:               GenuineIntel
  Model name:            Intel(R) Core(TM) i7-7700HQ CPU @ 2.80GHz
  CPU family:            6
  Model:                 158
  Thread(s) per core:    2
```

Disk space available: The `df -h` command is used to display information about the disk space usage on your Linux system. In this command, `df` stands for **disk free**, and `-h` is a command-line option or flag that stands for **human-readable**. The

```
Filesystem      Size  Used Avail Use% Mounted on
/dev/sda2       228G  113G  104G  53% /
```

`/dev/sda2` is a partition identifier that represents the second partition on the first SATA (or SCSI) disk (sda). It typically contains the main file system of your Linux system. The actual partition identifiers may differ depending on your system's configuration and the number of disks or partitions present.

Information about the RAM: In the command `free -h`, `free` represents the command used to display memory usage statistics, and `-h` is a command-line option that stands for **human-readable**.

```
            total    used     free     shared  buff/cache   available
```

```
Mem:        15Gi      4.4Gi     3.3Gi     637Mi     7.8Gi          10Gi
Swap:       2.0Gi     0B        2.0Gi
```

The **Swap** space is a portion of the hard drive that is used as virtual memory by the operating system. It acts as an extension to the physical memory (RAM) and allows the system to temporarily store data that doesn't fit into the RAM.

9. Short keys in terminal: `Ctrl+L` to remove the history of terminal. Pressing up key takes you to previous commands. To copy from terminal you have to press `Cntrl + Shift + C` and to paste a command press `Ctrl + shift + V`.

2 Fundamentals of C Language

This section is designed to provide an introduction to fundamental concepts in C, including data types, variables, and control flow statements such as if and loops. Some of students with prior knowledge of programming might already know these concepts, but we will delve into each topic extensively and provide detailed explanations. Our goal is to ensure that everyone, regardless of their programming background, can grasp these essential concepts effectively. We will illustrate each concept with practical examples and problem-solving exercises to enhance understanding, as these concepts form the backbone of C programming.

2.1 Writing a Simple Program, `Hello, McMaster!`

2.1.1 A General Form of a Program

Let's make a new file using `nano Hello.c` where the **.c** extension represent a C file. Before closing the the opened file in terminal copy and paste the following code in the file and save it. To paste the the copied section you have to use `Ctrl + shift + V`. Press `Ctrl + X` then `y` and press Enter to save before exit.

```c
// this code is written by Pedram
#include <stdio.h>

// the main function
int main(void) {
 /* calling "printf" function
 the "defination" is included in "stdio" library */
 printf("Hello, McMaster!\n");
```

```
}
```

Open the file by `open Hello.c`. This is a more user friendly environment to edit the code. Maybe the main difference is I can click different parts of the code and edit the code. During you lab lectures this week, you TAs will discuss Visual Studio Code IDE (Integrated Development Environment) which support many programming languages, including C, as well as many useful tools such as automatic code formatting. I strongly suggest to install it and set it up for C format for the next lectures. If I want to modify the code in terms of extra spaces in the code using `open Hello.c` it will take me some time. But if you have Visual Studio Code installed, in the terminal enter `code Hello.c` to open the same code in Visual Studio Code (VSC).Right click on the code and choose **Format Document** which automatically modifies the code in C format.

> **Tips!** Get your hands dirty! I promise you that by only reading these notes you will NOT be able to learn programming. You have to write, modify, and change every code in these notes. Play with them like you play video games!

Anything starts with two slashes, `//`, until the end of the line is a comment and it will not be executed. To make multiple lines as comments, you can place them between `/*` and `*/`. The following lines in the code are all comments:

```
    // this code is written by Pedram

    // the main function

    /* calling "printf" function
    the "defination" is included in "stdio" library */
```

Based on the IDE that you are using the colour of the comments might be different. I have said earlier that understanding C codes especially written by someone else might be difficult. Comments are supposed to be helpful to remember or tell others what is the purpose of each part of the code or even how it works.

So the first line which is really executed is `include <stdio.h>`. Usually at the beginning of a code, we include libraries used in the code. `include <stdio.h>` tells C to read **header file** named `stdio` with extension `.h` which stands for **header file**. In this library the definition of function `printf` is mentioned. Any time you forget what library a function is in, you can ask your best friend **Google** or **ChatGPT** by simply asking "what library in C printf is in."

The second line that will be executed is `int main(void)` as a function. In C, defining a function starts with the type of value the function returns, which in this case it is `int`. The `int` means **integer** and the function `main` will automatically return the value **0** if there is no error in the code.

The `main` is the name of function. This function must be included in all C programs, and you have to write your code inside this function.

Between the parentheses, `void` what inputs your program needs and requires the user to give the input(s) every time the code is going to be executed. In this case, we don't have any input so it is `void`, or we can define `int main()` instead of `int main(void)`. Both means the program requires no input(s).

Anything between `{`, right after `int main(void)`, and `}`, at the end of the code, is called **compound statement** or **code block**, which belongs to `main` function. So the following statement is the general format that we have to include in all C programs:

```
Inclduing Library

int main(){

your statements

   }
```

In this code, `printf("Hello, McMaster!\n")` is the only statement we have and `printf` function is used to print a text. Between `(` and `)` the arguments for the function `printf` is given, which is a string or text to be printed!

A string is sequence of characters enclosed within quotation marks. `"Hello, McMaster!\n"` is the string that will be printed. The backslash `\` before `n` tells C to go to (**n**)ext line after printing `Hello, McMaster!`. Try to compile and run the code two times with `\n` and two times without `\n` and see the difference in the terminal! At the end of this line there is `;` indicating the command for this line has ended.

A reminder, the closing bracket `}` at the end, means the end of function `main`!

2.1.2 Compiling and Executing the Program

Now we have to convert the program, the file `Hello.c`, to a format that machine can understand and execute. It usually involves, **Pre-processing**, **Compiling**, and **Linking**. During **Pre-processing** some modification will be done automatically to the code, before making the executable **object** code in **Compiling** step. These two steps are done at the same time and automatically, so won't need to be worried about it! In the Linking step, the library included will be linked to the executable file. Since this code is using a standard library, `<stdio.h>`, it happens automatically. Again, you don't need to be worried!!!

To compile the program in UNIX based OS, usually `cc` is used. Open a terminal in the directory where `Hello.c` file is located (please refer to the section Shell Basics on Linux). Type `cc Hello.c`. Check out the directory. A new executable **object** file named `a.out` by default will be created.

If you see the following error after executing `cc Hello.c`, it means you are not in the same directory where `Hello.c` is located. A reminder, use `pwd` to check your current directory.

```
cc1: fatal error: Hello.c: No such file or directory
compilation terminated.
```

Visual Studio Code! You may open the code in Visual Studio Code (VSCode) by running `code Hello.c` in the terminal. Again make sure current directory is where `Hello.c` is located, otherwise you will see an error indicating the is no such a file in this directory. At the top of VSCode opened, press **View** and click **Terminal**. A window will be opened at the bottom, named **TERMINAL**. There is no difference between this Terminal and terminal you open using `Ctrl + Alt + T`. Make sure the directory of this Terminal in VScode is the where `Hello.c` is located to avoid the error I have mention before running `cc Hello.c` in the terminal.
After `cc Hello.c` if there is no problem, you should be able to see a new executable **object** file named `a.out` by default in the directory.

At this stage the code is compiled, the **object** `a.out` readable by machine is created. This means the program is translated to a language that machine can understand and it saved in the **object** file `a.out`. Now it is time to tell the machine to run the translated code and show us the result. Run `./a.out` in the terminal. Again, make sure you are in the directory where `a.out` is located. It is done! you should be able to see the result!

Hello, McMaster!

I have mentioned the name `a.out` is given to the **object** file by default. I can define any name I want. Lets remove the previous object file by `rm a.out` and make a new one with the name "**Brad**" by using `cc -o Brad Hello.c`. The compiler `cc` has many options, and `-o` means translate the program `Hello.c` to the machine language with an (**o**)bject file named `Brad`. Now you must be able to see an **object** file named `Brad` in the same directory. If you run the command line `./Brad` in the same directory, you should be able to see the output.

GCC compiler Another popular compiler in C is GCC (GNU Compiler Collection) compiler supported by Unix OS. It is known for its robustness, efficiency, and compatibility with multiple platforms. GCC supports various optimizations and provides comprehensive error checking, making it a reliable choice for compiling C code.
One notable feature of GCC is its similarity to the "cc" compiler command. This similarity stems from the fact that on many Unix-like systems, the "cc" command is often a symbolic link or an alias for GCC. Therefore, using "cc" to compile your code essentially invokes the GCC compiler with its default settings. GCC offers numerous options to control various aspects of the compilation process, such as optimization levels, debugging symbols, and specific target architectures.
You can compile the same program using GCC instead of `cc` by executing `gcc -o Brad Hello.c` in the terminal.

The **object** file `./Brad` is executable in any Unix based OS. It is software of application you developed!

2.2 Integer Data Type

In contemporary C compilers, there is support for a range of integer sizes spanning from 8 to 64 bits. However, it is worth noting that the specific names assigned to each size of integer may differ among different compilers, leading to potential confusion among developers. First we need to know how data is stored in computers.

2.2.1 Binary Representation

In the world of computers, information is stored and processed as sequences of bits, representing either a 0 or a 1. This fundamental concept forms the basis of how data is handled by computer systems.

Consider the scenario where we have a fixed number of bits, denoted by N, to represent our numbers. Let's take **N=4** to save an `int` number where `int` in C stands for **integer** number. In this case, we are allocating nine bits to express our numerical values. If the integer is `unsigned` then:

- 0 = 0000
- 1 = 0001
- 2 = 0010
- 3 = 0011

- $4 = 0100$
- $5 = 0101$
- $6 = 0110$
- $7 = 0111$
- $8 = 1000$
- $9 = 1001$
- $10 = 1010$
- $11 = 1011$
- $12 = 1100$
- $13 = 1101$
- $14 = 1110$
- $15 = 1111 = 2^N - 1$

More example?! If N = 3 then for `unsigned` integer we would have:

- $0 = 000$
- $1 = 001$
- $2 = 010$
- $3 = 011$
- $4 = 100$
- $5 = 101$
- $6 = 110$
- $7 = 111 = 2^N - 1$

which means the range of numbers can be saved as `unsigned` integer in C is from 0 to $2^N - 1$. For `signed` integers, the negative numbers can be obtained by inverting the bits then adding one to the result. This method is called the two's complement operation.

- **-8 = 1000** $= -2^{N-1}$
- -7 = (inverting 0111, we have 1000, +1 is:)1001
- -6 = (inverting 0110, we have 1001, +1 is:)1010
- -5 = (inverting 0101, we have 1010, +1 is:)1011
- -4 = (inverting 0100, we have 1011, +1 is:)1100
- -3 = (inverting 0011, we have 1100, +1 is:)1101
- -2 = (inverting 0010, we have 1101, +1 is:)1110
- -1 = (inverting 0001, we have 1110, +1 is:)1111
- $0 = 0000$
- $1 = 0001$
- $2 = 0010$

- $3 = 0011$
- $4 = 0100$
- $5 = 0101$
- $6 = 0110$
- $7 = 0111 = 2^{N-1} - 1$

If you have noticed, you can see the 1000 is signed to -8. In total with 4 bits, machine can have a combination of 2^4 zero and ones. It can be seen that all positive numbers starts with 0, and negative ones start with one. Therefore, it is accepted to sign 1000 bit sequence to the lowest number -8.

More example?! If N = 3 then for `unsigned` integer we would have:

- **-4 = 100** $= -2^{N-1}$
- -3 = (inverting 011, we have 100, +1 is:)101
- -2 = (inverting 010, we have 101, +1 is:)110
- -1 = (inverting 001, we have 110, +1 is:)111
- $0 = 000$
- $1 = 001$
- $2 = 010$
- $3 = 011 = 2^{N-1} - 1$

which means the range of numbers can be saved as `signed` integer in C is from -2^{N-1} to $2^{N-1} - 1$. Exceeding this range can cause errors, probably unseen, which it is called **integer overflow**.

2.2.2 Using `printf` and `limits.h` to Get the Limits of Integers

Let's see some of these limits using `limits.h` library. Make a new file using `nano limit.c` which `limit` is the name of program given by you, and `.c` is the extension which stands for C files. Copy and past the following code. Press `Ctrl + X` then `y` and Enter to save and close the file. Open the code in VScode, if you have it as IDE, by entering `code limit.c` in your terminal. Make sure you are in the same directory where you made this file.

```c
// This code is written by ChatGPT
#include <stdio.h>
#include <limits.h>

int main() {
```

```
    printf("Size of char: %zu bits\n", 8 * sizeof(char));
    printf("Signed char range: %d to %d\n", SCHAR_MIN, SCHAR_MAX);
    printf("Unsigned char range: %u to %u\n", 0, UCHAR_MAX);
    printf("\n");

    printf("Size of int: %zu bits\n", 8 * sizeof(int));
    printf("Signed int range: %d to %d\n", INT_MIN, INT_MAX);
    printf("Unsigned int range: %u to %u\n", 0, UINT_MAX);
    printf("\n");

    printf("Size of short: %zu bits\n", 8 * sizeof(short));
    printf("Signed short range: %d to %d\n", SHRT_MIN, SHRT_MAX);
    printf("Unsigned short range: %u to %u\n", 0, USHRT_MAX);
    printf("\n");

    printf("Size of long: %zu bits\n", 8 * sizeof(long));
    printf("Signed long range: %ld to %ld\n", LONG_MIN, LONG_MAX);
    printf("Unsigned long range: %u to %lu\n", 0, ULONG_MAX); //
       change %u to lu
    printf("\n");

    printf("Size of long long: %zu bits\n", 8 * sizeof(long long));
    printf("Signed long long range: %lld to %lld\n", LLONG_MIN,
       LLONG_MAX);
    printf("Unsigned long long range: %u to %llu\n", 0, ULLONG_MAX);
        // change %u to llu
  }
```

Let's check the code line-by-line.

1. `#include <limits.h>`: This is a preprocessor directive that includes the header file `limits.h` in the C program. The `limits.h` header provides constants and limits for various data types in the C language, such as the minimum and maximum values that can be represented by different types.

2. Placeholders: is a special character or sequence of characters that is used within a formatted string to represent a value that will be substituted during runtime. Placeholders are typically used in functions like `printf` or `sprintf` to dynamically insert values into a formatted output. When the program runs, the placeholders are replaced with the actual values passed as arguments to the formatting function. The values are appropriately converted to match the format specifier specified by the corresponding placeholders.

Placeholders provide a flexible way to format output by allowing dynamic insertion of values. They help in producing formatted and readable output based on the specified format specifiers and the provided values.

- `%zu`: This is a placeholder used with `printf` to print the value of an `unsigned` **integer**.
- `%d`: This is a placeholder used to `printf` the value of a `signed integer`.
- `%u`: This is a placeholder used to `printf` the value of an `unsigned` **integer**.
- `%ld`: This is a placeholder used to `printf` the value of a `signed long` **integer**.
- `%lu`: This is a placeholder used to `printf` the value of an `unsigned long` **integer**.
- `%lld`: This is a placeholder used to `printf` the value of a `signed long long` **integer**.
- `%llu`: This is a placeholder used to `printf` the value of an `unsigned long long` **integer**.

3. `sizeof()`: This is an operator in C that returns the size of a variable or a data type in bytes. In the given code, `sizeof()` is used to determine the size of different data types (e.g., char, int, long, long long). The result of `sizeof()` is then multiplied by 8 to obtain the size in bits.

4. `printf("\n")`: This line of code is using `printf` to print a newline character `\n`. It adds a line break, resulting in a new line being displayed in the console output.

5. `NAME_MIN` and `NAME_MAX`: The code refers to variables like `SCHAR_MIN`, `SCHAR_MAX`, `INT_MIN`, `INT_MAX`, etc. These variables are predefined in the C library, specifically in the limits.h header file. They represent the minimum and maximum values that can be stored in the respective data types (e.g., `char`, `int`, `short`, `long`, `long long`).

6. `char`, `int`, `short`, `long`, and l`long long`: These are data types in the C language. They represent different ranges of integer values that can be stored. The code provided displays the size and range of each of these data types, both signed and unsigned.

This time we compiler the code with more options `gcc -Wall -W -std=c99 -o limit limit.c`, where:

`-Wall`: This flag enables a set of warning options, known as "**all warnings**." It instructs the compiler to enable a comprehensive set of warning messages during the compilation process. These warnings help identify potential issues in the code, such as uninitialized variables, unused variables, type mismatches, and other common programming mistakes. By enabling `-Wall`, you can ensure that a wide range of warnings is reported, assisting in the production of cleaner and more reliable code.

`-W`: This flag is used to enable additional warning options beyond those covered by `-Wall`. It allows you to specify specific warning options individually. Without any specific options following `-W`, it enables a set of commonly used warnings similar to `-Wall`. By using `-W`, you have more control over the warning messages generated by the compiler.

`-std=c99`: This flag sets the C language standard that the compiler should adhere to. In this case, c99 indicates the **C99 standard**. The **C99 standard** refers to the ISO/IEC 9899:1999 standard for the C programming language. It introduces several new features and improvements compared to earlier versions of the C standard, such as support for variable declarations anywhere in a block, support for `//` single-line comments, and new data types like `long long`. By specifying `-std=c99`, you ensure that the compiler follows the **C99 standard** while compiling your code.

`-o limit`: This flag is used to specify the output file name. In this case, it sets the output file name as "limit". The compiled binary or executable will be named "limit" as a result.

`limit.c`: This is the source file that contains the C code to be compiled.

After compiling the code, I can run the object file `limit` in the directory by `./limit`. This is the result I get in **my computer**!

```
Size of char: 8 bits
Signed char range: -128 to 127
Unsigned char range: 0 to 255

Size of int: 32 bits
Signed int range: -2147483648 to 2147483647
Unsigned int range: 0 to 4294967295

Size of short: 16 bits
Signed short range: -32768 to 32767
Unsigned short range: 0 to 65535

Size of long: 64 bits
Signed long range: -9223372036854775808 to 9223372036854775807
Unsigned long range: 0 to 18446744073709551615

Size of long long: 64 bits
Signed long long range: -9223372036854775808 to 9223372036854775807
Unsigned long long range: 0 to 18446744073709551615
```

We will find out about the importance of knowing limits in section A Simple Example for

Integer Overflows.

2.2.3 Declaring and Naming with and without Initializing

To declare a variable you can simply:

```
int Pedram;
```

where `int` is the type of variable and `Pedram` is the name of variable. You can after this line of code calculate the value of `Pedram`. You may also declare the value for this variable when it is initialized:

```
int Pedram = 10;
```

Tips! There are some reserved names that you cannot use for your variables, including: `auto`, `break`, `case`, `char`, `const`, `continue`, `default`, `do`, `double`, `else`, `enum`, `extern`, `float`, `for`, `goto`, `if`, `inline`, `int`, `long`, `register`, `restrict`, `return`, `short`, `signed`, `sizeof`, `static`, `struct`, `switch`, `typedef`, `union`, `unsigned`, `void`, `volatile`, `while`, `_Bool`, `_Complex`, `_Imaginary`, `#define`, `#include`, `#undef`, `#ifdef`, `#endif`, `#ifndef`, `#if`, `#else`, `#elif`, `#pragma`, and more! Don't worry if you use these you will see some errors and warnings when compiling the the code!

More Tips! About naming style, if you use only characters like `a,b,c, ..., z`, no one can follow your code or what is the purpose of this variable. So:

- Use meaningful and descriptive names that convey the purpose or nature of the variable. for example, `rectangle_height` and `triangle_width`
- Avoid excessively long names, but provide enough clarity to understand the purpose of the variable.
- Follow a consistent naming convention, such as `camelCase` or `snake_case`.
- use comments if necessary to explain the purpose or usage of a variable.

If you are compiling the code you can use `-Wextra` flag for uninitialized variables. Let's try the following code with and without.

```
#include <stdio.h>

int main() {
```

```
    int x;
    int y = x + 5;  // Using uninitialized variable x
    printf("%d\n", y);
   }
```

Compiling the code with `gcc -o Pedram Pedram.c`, then executing the program with `./Pedram`. I get the following result:

```
   -1240674203
```

If I execute the code one more time, `./Pedram`, without even compiling the code, I get:

```
   233918565
```

What is going one???? When you run this code, you may get different output each time because the value of x is unspecified and can contain any arbitrary value. The variable x could be storing whatever value was previously in that memory location, and performing calculations with such a value can lead to unexpected results.

Let's compile the code but this time with `gcc -Wextra -o Pedram Pedram.c`. In my terminal it tells me `Using uninitialized variable x` and mentioning the line of code this issue is happening. At this point, the source code `Pedram.c` is compiled and the Pedram object is available. It means I can execute the program, but I am aware of the fact that this will result a wrong and an unexpected result. There are some warning you have to take serious even more than error! I could see the same warning by compiling the code using `gcc -Wall -W -std=c99 -o Pedram Pedram.c`

2.2.4 Constant Variables

Constant variables are declared using the const keyword, indicating that their value cannot be modified once assigned. Here's an example:

```
#include <stdio.h>

int main() {
 const int MAX_VALUE = 100;

 printf("Max value: %d\n", MAX_VALUE);;
}
```

Start developing this habit to mention the constant values during programming which make you code to be more understandable. After using `const` for variable `MAX_VALUE`, I cannot change the value for this variable. You can try to do it and you will see errors like:

`expression must be a modifiable lvalue`

or

`assignment of read-only variable 'MAX_VALUE'`

2.2.5 Arithmetic Operations on Integers

Let's play with some of these integer numbers using arithmetic operations.

```
#include <stdio.h>

int main() {
 int a = 5;
 int b = 3;
 int sum = a + b;
 int difference = a - b;
 int product = a * b;
 int quotient = a / b;
 int remainder = a % b;

 printf("Sum: %d\n", sum);
 printf("Difference: %d\n", difference);
 printf("Product: %d\n", product);
 printf("Quotient: %d\n", quotient);
 printf("Remainder: %d\n", remainder);

 return 0;
}
```

after compiling the code and executing the object file, you should get the following results:

```
Sum: 8
Difference: 2
Product: 15
Quotient: 1
Remainder: 2
```

2.2.6 A Simple Example for Integer Overflows

Why we tried to understand the limits of integer variables? If you define an `int` value equal to 2,147,483,647 + 1, you will encounter a phenomenon known as **integer overflow**. In C, when an arithmetic operation results in a value that exceeds the maximum representable value for a given integer type, the behavior is undefined.

In most cases, when an integer overflow occurs, the value will "wrap around" and behave as if it has rolled over to the minimum representable value for that integer type. In the case of a 32-bit int, which has a maximum value of 2,147,483,647, adding 1 to it will result in an **integer overflow**.

The exact behavior after the overflow is undefined, meaning it's not guaranteed what will happen. However, it is common for the value to wrap around to the minimum value for the int data type, which is typically -2,147,483,648 for a 32-bit signed integer. Let's try an example:

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

int main() {
 int value = INT_MAX + 1;
 printf("Value: %d\n", value);

 return 0;
}
```

Compile the code using `gcc -o Anna Anna.c` where `Anna.c` is the source code, and `Anna` is the object file. Run the code with `./Anna`. The result I get in **my machine** is:

```
Value: -2147483648
```

while I was expecting to see 2,147,483,64**8**.

Let's see another example. Make a new file using terminal by `nano Pedram.c`. Copy and paste the following code using `Ctrl + Shift + V`. Press `Ctrl + X`, then press `y` and Enter to save the changes made to new file named `Pedram` with extension `.c`. In the following code the limits for each type is given in comments, which these limits are based on **my machine** and it might be different in yours. We found these limits by running the code in section Using `printf` and `limits.h` to Get the Limits of Integers.

```
#include <stdio.h>

int main() {
```

```
// -------------------------- char --------------------------
char Ped_RealChar = 'P';
// char range: -128 to 127
char Ped_NumChar = 80;
// unsigned char range: 0 to 255
unsigned char Ped_NumChar_unsigned = 252;
// ------------------------- short --------------------------
// short range: -32768 to 32767
short Ped_sh = -1234;
// unsigned short range: 0 to 65535
unsigned short Ped_sh_unsigned = 56789;
//--------------------------- int ---------------------------
// int range: -2147483648 to 2147483647
int Ped_int = -42;
// unsigned int range: 0 to 4294967295
unsigned int Ped_int_unsigned = 123456;
// -------------------------- long --------------------------
// long range: -9223372036854775808 to 9223372036854775807
long Ped_long = -9876543210;
// unsigned long range: 0 to 18446744073709551615
unsigned long Ped_long_unsigned = 9876543210;
// #----------------------- long long ------------------------
// long long range: -9223372036854775808 to
   9223372036854775807
long long Ped_longlong = -123456789012345;
// unsigned long long range: 0 to 18446744073709551615
unsigned long long Ped_longlong_unsigned = 123456789012345;

// ------------------------ printing ------------------------
printf("char used for saving character: %c\n", Ped_RealChar);
printf("char used saving integer BUT the character is printed
   : %c\n", Ped_NumChar);
printf("char used saving integer: %d\n", Ped_NumChar);
printf("unsigned char saving integer: %u\n",
   Ped_NumChar_unsigned);
printf("short: %hd\n", Ped_sh);
printf("unsigned short: %hu\n", Ped_sh_unsigned);
printf("int: %d\n", Ped_int);
```

```
    printf("unsigned int: %u\n", Ped_int_unsigned);
    printf("long: %ld\n", Ped_long);
    printf("unsigned long: %lu\n", Ped_long_unsigned);
    printf("long long: %lld\n", Ped_longlong);
    printf("unsigned long long: %llu\n", Ped_longlong_unsigned);
}
```

Now you have the source code `Pedram.c`, open it in VScode by executing `code Pedram.c` in the terminal. You should be able to see the code in the opened window. Now we need another terminal inside the VScode to compile and run the code. To open a terminal in VScode, go to the View menu at the top of the window. From the View menu, select "Terminal". You can see which directory this terminal is in by executing `pwd` in the terminal. Change your directory to the one where source code `Pedram.c` is. We need to do this so when we are compiling the code, the compiler can find the source code and translate it to the machine's language!

Let's checkout the code. A `char` is a type used to save a single character, like `a` or `G` or anything else. But you can assign a numeric value to a `char` variable in C. In fact, a `char` variable is internally represented as a small integer. So, you can assign a number within the range of -128 to 127 a `char` variable.

In this example, the decimal value 80 is assigned to the `char` variable `Ped_RealChar`, which I have picked this name to save this value. The `%c` format specifier in the `printf` statement is used to print the character representation of `Ped_RealChar`. In this case, it will print the character 'P', as the ASCII value 80 corresponds to the character 'P'.

So, while a `char` variable is primarily used to represent characters, it can also store numeric values within its valid range. We will learn more about characters and strings in section Characters and strings. This is what the output should be:

```
char used for saving character: P
char used saving integer BUT the character is printed: P
char used saving integer: 80
unsigned char saving integer: 252
short: -1234
unsigned short: 56789
int: -42
unsigned int: 123456
long: -9876543210
unsigned long: 9876543210
long long: -123456789012345
```

```
    unsigned long long: 123456789012345
```

Run this code after the lecture, by exceeding the limits and see the warnings **OR** errors **OR** **wrong** results. Let's say, change the value `Ped_NumChar_unsigned` to 256 which is higher than then maximum allowed for this type. The other thing you can do, is applying arithmetic operations on different types of variables that we have learned in section Arithmetic Operations on Integers.

What is the problem with this code? Variable names are too long. I can just search for a variable in VScode to see the type of variable when it is initialized!

2.2.7 Fixed-width Integer types

In the section Using `printf` and `limits.h` to Get the Limits of Integers we talked about the limits of integer that might be different in different platforms. **How we can write a code that is portable to any OS?**

The C99 standard introduced fixed-width integer types in order to provide a consistent and portable way of specifying integer sizes across different platforms. Prior to C99, the sizes of integer types like `int` and `long` were implementation-dependent, which could lead to issues when writing code that relied on specific bit widths.

By adding fixed-width integer types such as `int8_t`, `int16_t`, `int32_t`, and `int64_t`, the C99 standard ensured that programmers had precise control over the sizes of their integer variables. These types have guaranteed widths in bits, making them useful in situations where exact bit-level manipulation with low-level systems is required.

To use the fixed-width integer types, the header `<stdint.h>` needs to be included. This header provides the type definitions for these fixed-width types, ensuring consistency across different platforms. By including `<stdint.h>`, programmers can use these types with confidence, knowing the exact size and range of the integers they are working with.

In addition to `<stdint.h>`, the header ¡inttypes.h¿ is included to access the placeholders associated with the fixed-width integer types. These format specifiers, such as `PRId8`, `PRIu16`, and so on, enable proper printing and scanning of these types using the `printf` function. Make a new source code by `nano FixedInteger.c`, and paste the following code inside the file and save this program. Open the code in VScode using `code FixedInteger.c` and change the directory where the source code `FixedInteger.c` is in. Compile and execute the code by:

`gcc -o FixedInteger FixedInteger.c`

and

./FixedInteger.

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

int main() {

 printf("Size of int8_t: %zu bits\n", 8 * sizeof(int8_t));
 printf("Signed int8_t range: %" PRId8 " to %" PRId8 "\n",
    INT8_MIN, INT8_MAX);
 printf("\n");

 printf("Size of uint8_t: %zu bits\n", 8 * sizeof(uint8_t));
 printf("uint8_t range: %d to %" PRIu8 "\n", 0, UINT8_MAX);
 printf("\n");

 printf("Size of int16_t: %zu bits\n", 8 * sizeof(int16_t));
 printf("Signed int16_t range: %" PRId16 " to %" PRId16 "\n",
    INT16_MIN, INT16_MAX);
 printf("\n");

 printf("Size of uint16_t: %zu bits\n", 8 * sizeof(uint16_t));
 printf("uint16_t range: %d to %" PRIu16 "\n", 0, UINT16_MAX);
 printf("\n");

 printf("Size of int32_t: %zu bits\n", 8 * sizeof(int32_t));
 printf("Signed int32_t range: %" PRId32 " to %" PRId32 "\n",
    INT32_MIN, INT32_MAX);
 printf("\n");

 printf("Size of uint32_t: %zu bits\n", 8 * sizeof(uint32_t));
 printf("uint32_t range: %d to %" PRIu32 "\n", 0, UINT32_MAX);
 printf("\n");

 printf("Size of int64_t: %zu bits\n", 8 * sizeof(int64_t));
 printf("Signed int64_t range: %" PRId64 " to %" PRId64 "\n",
    INT64_MIN, INT64_MAX);
 printf("\n");
```

```
    printf("Size of uint64_t: %zu bits\n", 8 * sizeof(uint64_t));
    printf("uint64_t range: %d to %" PRIu64 "\n", 0, UINT64_MAX);
}
```

The result not only in my machine, but also in any platform must be the same.

```
Size of int8_t: 8 bits
Signed int8_t range: -128 to 127

Size of uint8_t: 8 bits
uint8_t range: 0 to 255

Size of int16_t: 16 bits
Signed int16_t range: -32768 to 32767

Size of uint16_t: 16 bits
uint16_t range: 0 to 65535

Size of int32_t: 32 bits
Signed int32_t range: -2147483648 to 2147483647

Size of uint32_t: 32 bits
uint32_t range: 0 to 4294967295

Size of int64_t: 64 bits
Signed int64_t range: -9223372036854775808 to 9223372036854775807

Size of uint64_t: 64 bits
uint64_t range: 0 to 18446744073709551615
```

2.3 Characters and strings

In C, a string is defined as a sequence of characters. Individual characters are enclosed in single quotes `' '`, while strings are enclosed in double quotes `" "`.

To print a character, we use the placeholder `%c` in the printf function. For example, if `char c = 'P'`, then `printf("%c", c)`; will print the value of the character variable `c`.

To print a string, we use the placeholder `%s` in `printf`. For example, if `char s[] = "Pedram"`, then `printf("%s", s);` will print the contents of the string variable `s`.

The size of a string can be determined using the `sizeof` operator (the same as finding the size of integer values), which returns the number of bytes occupied by the string. To print the size, we can use `%zu` as the placeholder in `printf`.

Strings in C are null-terminated, meaning they end with a **null character** (represented by 0). When accessing elements of a string, the index starts from 0, and the last character is always the null character. For example, in the `string s[] = "Pedram"`, `s[6]` refers to the null character. Don't for get the indexing in C starts from 0! Look at the following example:

```
#include <stdio.h>
// Compile and run the code with and without string.h
#include <string.h>

int main() {
 char c = 'P';
 char s[] = "Pedram";
 char s2[] = "Pasandide";

 printf("Character: %c\n", c);
 printf("String: %s\n", s);
 printf("s[0]: %c\n", s[0]);
 printf("s[5]: %c\n", s[5]);
 printf("Size of s: %zu\n", sizeof(s));
 printf("s[6] (null character): %d\n", s[6]);


 char s3[20]; // Make sure s3 has enough space to hold the
    concatenated string

 strcpy(s3, s); // Copy the content of s to s3
 strcat(s3, s2); // Concatenate s2 to s3

 printf("s3: %s\n", s3);

 return 0;
}
```

Open a terminal, checkout the directory you are in, using `pwd`. Make sure you are still in

`/home/username/COMPSCI1XC3`.

Make a new source code with `nano PedramString.c`, and copy-paste the code mentioned above. Open it in VScode with `code PedramString.c`. Change the directory to where you saved the source code. Compile the program with `gcc` and execute the code with `./PedramString`.

To concatenate two strings `s` and `s2` and store the result in `s3`, you can use the `strcpy` function from the `<string.h>` header.

In this code, `s` and `s2` are two strings that you want to concatenate. The variable `s3` is declared as an array of characters, with enough space to hold the concatenated string.

First, the `strcpy` function is used to copy the contents of `s` to `s3`, ensuring that `s3` initially holds the value of `s`. Then, the `strcat` function is used to concatenate `s2` to `s3`, effectively appending the contents of `s2` to `s3`.

Tips! There are many more functions dealing with string, and this one was just an example. Depending on you problem, you can search on Google and find how you can tackle your specific problem. Otherwise, remembering all these functions would be ALMOST impossible.

The result must be like:

```
Character: P
String: Pedram
s[0]: P
s[5]: m
Size of s: 7
s[6] (null character): 0
s3: PedramPasandide
```

2.4 Floating-point Numbers

In scientific programming, integers are often insufficient for several reasons:

- **1. Precision**: Integers have a finite range, and they cannot represent numbers with fractional parts. Many scientific computations involve non-integer values, such as real numbers, measurements, and physical quantities. Floating-point arithmetic allows for more precise representation and manipulation of these non-integer numbers.

- **2. Range**: While `long long int` can store larger integer values compared to regular `int`, it still has a limit. Scientific calculations often involve extremely large or small numbers, such as astronomical distances or subatomic particles. Floating-point numbers provide a wider range of values, accommodating these large and small magnitudes.

Floating-point numbers are represented and manipulated using floating-point arithmetic in CPUs. The encoding of floating-point numbers is based on the IEEE 754 standard, which defines formats for single-precision (32 bits) and double-precision (64 bits) floating-point numbers.

The basic structure of a floating-point number includes three components: the **sign** (positive or negative which can 0 or 1), the base (also known as the significant or **mantissa**), and the **exponent**. The base represents the significant digits of the number, and the exponent indicates the scale or magnitude of the number. Any floating-point number is represented in machine by:

$(-1)^{\text{sign}} \times \text{mantissa} \times 2^{\text{exponent}}$

For example, let's consider the number 85.3. In binary, it can be represented as approximately 1010101.01001100110011... In the IEEE 754 format, this number would be encoded as per the specifications of single-precision or double-precision floating-point representation. You can use online converters to get this number or you can read more how to do it. Right now in this course you don't need to necessary learn how to do it, and I am mentioning this to illustrate everything clearly!

In the case of decimal fraction 0.3, its binary representation is non-terminating and recurring (0.0100110011...), meaning the binary fraction repeats infinitely. However, due to the finite representation of floating-point numbers in IEEE 754 format, the repeating binary fraction is rounded or truncated to fit the available number of bits. As a result, the exact decimal value of 0.3 cannot be represented accurately in binary using a finite number of bits.

So, when converting 0.3 to binary in the context of IEEE 754 floating-point representation, it will be approximated to the closest binary fraction that can be represented with the available number of bits. The accuracy of the approximation depends on the precision (number of bits) of the floating-point format being used.

The floating-point types used in C are `float`, `double` and `long double`. All these types are always signed meaning that they can represent both positive and negative value.

- `float` **or single-precision** has a precision of approximately 7 decimal digits. With smallest positive value of $1.17549435 \times 10^{-38}$ and largest positive value of $3.40282347 \times 10^{38}$
- `double` **or double-precision** has a precision of approximately 15 decimal digits. With smallest positive value of $2.2250738585072014 \times 10^{-308}$ and the largest positive value of $1.7976931348623157 \times 10^{308}$.

- `long double` **or extended-precision** format can vary in size depending on the platform. In x86 systems, it commonly uses 80 bits, but the specific number of bits for long double can differ across different architectures and compilers. In this course we won't use it!

Get the same results in **your machine** using the following code:

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

int main() {
 printf("Precision:\n");
 printf("Float: %d digits\n", FLT_DIG);
 printf("Double: %d digits\n", DBL_DIG);
 printf("Long Double: %d digits\n\n", LDBL_DIG);

 printf("Minimum and Maximum Values:\n");
 printf("Float: Minimum: %e, Maximum: %e\n", FLT_MIN, FLT_MAX);
 printf("Double: Minimum: %e, Maximum: %e\n", DBL_MIN, DBL_MAX);
 printf("Long Double: Minimum: %Le, Maximum: %Le\n", LDBL_MIN,
    LDBL_MAX);
}
```

The results for float and double in any computer should be the same showing the portability of these two types. I suggest you to use only these two at least in this course. In **my machine**, the results are:

```
Precision:
Float: 6 digits
Double: 15 digits
Long Double: 18 digits

Minimum and Maximum Values:
Float: Minimum: 1.175494e-38, Maximum: 3.402823e+38
Double: Minimum: 2.225074e-308, Maximum: 1.797693e+308
Long Double: Minimum: 3.362103e-4932, Maximum: 1.189731e+4932
```

Let's initialize a `double` value and print it using `printf`. This example defines a constant `double Ped` as 1.23456789 and demonstrates different printing options using the `%a.bf` placeholder, where `a` represents the minimum width and `b` specifies the number of digits after the decimal point:

```c
#include <stdio.h>

int main() {
 const double Ped = 1.23456789;

 // Printing options with different placeholders
 // Minimum width = 0, 2 digits after decimal
 printf("Printing options for Ped = %.2f:\n", Ped);

 // Minimum width = 10, 4 digits after decimal
 printf("Printing options for Ped = %10.4f:\n", Ped);

 // Minimum width = 6, 8 digits after decimal
 printf("Printing options for Ped = %6.8f:\n", Ped);
}
```

In the first `printf` statement, `%2.2f` is used, where 2 represents the minimum width (minimum number of characters to be printed) and .2 specifies 2 digits after the decimal point. This will print 1.23 as the output.

In the second printf statement, `%10.4f` is used. Here, 10 represents the minimum width, specifying that the output should be at least 10 characters wide, and .4 indicates 4 digits after the decimal point. This will print 1.2346 as the output, with 4 digits after the decimal and padded with leading spaces to reach a width of 10 characters.

In the third printf statement, `%6.8f` is used. The 6 represents the minimum width, and .8 specifies 8 digits after the decimal point. This will print 1.23456789 as the output, with all 8 digits after the decimal point.

By running this code, you can see the different printing options for the Ped value with varying widths and decimal precision.

```
Printing options for Ped = 1.23:
Printing options for Ped =     1.2346:
Printing options for Ped = 1.23456789:
```

2.4.1 Rounding Error in Floating-point Numbers

Rounding errors occur in floating-point arithmetic due to the finite number of bits allocated for representing the fractional part of a number. The rounding error becomes more prominent as we require higher precision or perform multiple arithmetic operations. The magnitude of the rounding error is typically on the order of the smallest representable number, which is commonly referred to as machine epsilon. **Run the following code!**

```c
#include <stdio.h>

int main() {
 const float F = 1.23456789f;
 const double D = 1.23456789;
 const long double L = 1.23456789L;

 printf("Original values:\n");
 printf("Float: %.8f\n", F);
 printf("Double: %.8lf\n", D);
 printf("Long Double: %.8Lf\n\n", L);


 printf("Rounded values:\n");
 printf("Float: %.20f\n", F);
 printf("Double: %.20lf\n", D);
 printf("Long Double: %.20Lf\n", L);
}
```

In the provided code, the original values of `F`, `D`, and `L` are set to 1.23456789f, 1.23456789, and 1.23456789L, respectively. These values are printed with 8 digits of precision using printf statements.

When we examine the output, we can observe some differences between the original values and the rounded values. These differences arise due to the limitations of representing real numbers in the computer's finite memory using floating-point arithmetic.

In the original values section:

The original float value F is printed as 1.23456788, which differs from the original value due to the limited precision of the float data type. The original double value D is printed as 1.23456789, and in this case, there is no visible difference since the double data type provides sufficient precision to represent the value accurately. The original long double value L is also printed as 1.23456789, indicating that the long double data type preserves the precision without any visible loss in this case.

In the rounded values section:

The float value `F` is printed with increased precision using `%.20f`. The rounded value is 1.23456788063049316406, which introduces rounding error due to the limited number of bits available for representing the fractional part of the number. The double value `D` is printed with increased precision using `%.20lf`. Here, we can see a slight difference between the original value and the rounded value, with the rounded value being 1.23456788999999989009. This difference is attributed to the rounding error that occurs in the 16th digit after the decimal point. The long double value `L` is printed with increased precision using `%.20Lf`. The rounded value is 1.23456789000000000003, demonstrating that even with the long double data type, there can still be a small rounding error.

In the case of `double` precision, the rounding error is approximately on the order of 10^{-16}, meaning that the least significant digit after the 16th decimal place can be subject to rounding error.

It's important to be aware of these limitations and potential rounding errors when performing calculations with floating-point numbers, especially in scientific and numerical computing, where high precision is often required.

```
Original values:
Float: 1.23456788
Double: 1.23456789
Long Double: 1.23456789

Rounded values:
Float: 1.23456788063049316406
Double: 1.23456788999999989009
Long Double: 1.23456789000000000003
```

2.4.2 Type Conversion

In C, type conversion refers to the process of converting a value from one data type to another. There are two types of type conversion: explicit type conversion (also known as type casting) and implicit type conversion (also known as type coercion).

1. Implicit Type Conversion (Type Coercion): Implicit type conversion occurs automatically by the C compiler when performing operations between different data types. The conversion is done to ensure compatibility between operands. Here's an example:

```c
#include <stdio.h>

int main() {
 int num = 10;
 double result = num / 3;  // Implicitly convert int to double
 printf("Result: %f\n", result);

 int num2 = 10.6;
 printf("num2: %d\n", num2); // Implicitly convert double to int
}
```

In the above code, `num` is an integer with a value of `10`. When dividing it by `3`, the division operation requires a common data type for both operands. In this case, the compiler implicitly converts `num` to a double before performing the division. The result is stored in the result variable, which is of type double. When printing `result`, `%f` is used as the format specifier for floating-point numbers. In the other example, `num2` is also defined to be equal to `10.6`, but since the type is `int` anything after decimal will be neglected. Here is the output you should get:

```
Result: 3.000000
num2: 10
```

Implicit type conversion is performed based on a set of rules defined by the C language. It ensures that the operands are of compatible types to perform the desired operation.

2. Explicit Type Conversion (Type Casting): Explicit type conversion involves manually specifying the desired data type for the conversion. It is performed using type casting operators.

```c
#include <stdio.h>

int main() {
 const int num1 = 10;
 const int num2 = 3;

 // 1. Print the division using int placeholder, ignoring
    anything after the decimal
 int resultInt = num1 / num2;
 printf("Division without casting using int placeholder: %d\n",
    resultInt);

 // 2. Print the division using double placeholder without
    casting (warning expected)
```

```
    int resultDoubleNoCast = num1 / num2;
    printf("Division without casting floating-point placeholder %f\n", resultDoubleNoCast);

    // 3. Print the division by casting one of the operands
    printf("Division (double with cast): %f\n", num1 / (double)num2);

    // 4. Print the division by casting both operands
    double resultDoubleBothCasted = (double)num1 / (double)num2;
    printf("Division (double with both cast): %f\n", resultDoubleBothCasted);
}
```

Let's go through the code.

The division of `num1` by `num2` is stored in the `resultInt` variable, which is of type int. When using `%d` as the format specifier, the output will be an integer, ignoring anything after the decimal point.

The division without casting `(num1  num2)` is assigned to `resultDoubleNoCast`, which is of type double. However, this can lead to unexpected results due to integer division. The warning suggests that an implicit conversion is happening from int to double, which may not yield the desired precision.

To ensure proper division with decimal points, we cast one of the operands (`num2`) to double explicitly. This casting allows for a more accurate calculation. In some compiler you might see a warning here! To avoid that:

To perform the division correctly, both `num1` and `num2` are explicitly cast to double. This ensures that the division is carried out using floating-point arithmetic and produces the desired result. The `%f` format specifier is used to print the double value.

```
Division without casting using int placeholder: 3
Division without casting floating-point placeholder 0.000000
Division (double with cast): 3.333333
Division (double with both cast): 3.333333
```

2.4.3 Arithmetic Operations on Floating-point Numbers

.

The same as applying arithmetic operations on integer values, we can do the same on floating-point numbers. Here's a comprehensive example demonstrating arithmetic operations on floating-point numbers, including different data types, const and non-const values, and various arithmetic operators:

```c
#include <stdio.h>

int main() {
 const float num1 = 10.5;
 float num2 = 5.2;
 double num3 = 7.8;
 const long double num4 = 3.14;
 long double num5 = 2.71;

 // Addition
 float sumFloat = num1 + num2;
 double sumDouble = num1 + num3;
 long double sumLongDouble = num4 + num5;

 printf("Addition:\n");
 printf("%.2f + %.2f = %.2f\n", num1, num2, sumFloat);
 printf("%.2f + %.2f = %.2f\n", num1, num3, sumDouble);
 printf("%.2Lf + %.2Lf = %.2Lf\n", num4, num5, sumLongDouble);
 printf("\n");

 // Subtraction
 float diffFloat = num1 - num2;
 double diffDouble = num1 - num3;
 long double diffLongDouble = num4 - num5;

 printf("Subtraction:\n");
 printf("%.2f - %.2f = %.2f\n", num1, num2, diffFloat);
 printf("%.2f - %.2f = %.2f\n", num1, num3, diffDouble);
 printf("%.2Lf - %.2Lf = %.2Lf\n", num4, num5, diffLongDouble);
 printf("\n");

 // Multiplication
 float productFloat = num1 * num2;
 double productDouble = num1 * num3;
 long double productLongDouble = num4 * num5;
```

```
    printf("Multiplication:\n");
    printf("%.2f * %.2f = %.2f\n", num1, num2, productFloat);
    printf("%.2f * %.2f = %.2f\n", num1, num3, productDouble);
    printf("%.2Lf * %.2Lf = %.2Lf\n", num4, num5, productLongDouble)
        ;
    printf("\n");

    // Division
    float quotientFloat = num1 / num2;
    double quotientDouble = num1 / num3;
    long double quotientLongDouble = num4 / num5;

    printf("Division:\n");
    printf("%.2f / %.2f = %.2f\n", num1, num2, quotientFloat);
    printf("%.2f / %.2f = %.2f\n", num1, num3, quotientDouble);
    printf("%.2Lf / %.2Lf = %.2Lf\n", num4, num5, quotientLongDouble
        );
    printf("\n");

    // Compound Assignment Operators
    num2 += num1;
    num3 -= num4;
    num5 *= num4;
    float P1 = num1; // since I cannot change the value of num1
    P1 /= num2;

    printf("Compound Assignment Operators:\n");
    printf("num2 += num1: %.2f\n", num2);
    printf("num3 -= num4: %.2f\n", num3);
    printf("num5 *= num4: %.2Lf\n", num5);
    printf("num1 /= num2: %.2f\n", P1);
}
```

There are some compound assignment operators in the code including `+=`, `-=`, `*=`, and `/=`. How they work?

`+=` (Addition Assignment): It adds the value on the right-hand side to the variable on the left-hand side and assigns the result back to the variable. Example: a += b; is equivalent to a =

a + b;

`-=` (Subtraction Assignment): It subtracts the value on the right-hand side from the variable on the left-hand side and assigns the result back to the variable. Example: a -= b; is equivalent to a = a - b;

`*=` (Multiplication Assignment): It multiplies the variable on the left-hand side by the value on the right-hand side and assigns the result back to the variable. Example: a *= b; is equivalent to a = a * b;

`/=` (Division Assignment): It divides the variable on the left-hand side by the value on the right-hand side and assigns the result back to the variable. Example: a /= b; is equivalent to a = a / b;

Note that we can use these compounds on inter values! The result you should get is:

```
Addition:
10.50 + 5.20 = 15.70
10.50 + 7.80 = 18.30
3.14 + 2.71 = 5.85

Subtraction:
10.50 - 5.20 = 5.30
10.50 - 7.80 = 2.70
3.14 - 2.71 = 0.43

Multiplication:
10.50 * 5.20 = 54.60
10.50 * 7.80 = 81.90
3.14 * 2.71 = 8.51

Division:
10.50 / 5.20 = 2.02
10.50 / 7.80 = 1.35
3.14 / 2.71 = 1.16

Compound Assignment Operators:
num2 += num1: 15.70
num3 -= num4: 4.66
num5 *= num4: 8.51
num1 /= num2: 0.67
```

2.5 Mathematical Functions

Mathematical functions in C are a set of functions provided by the standard library to perform common mathematical operations. These functions are declared in the `<math.h>` header file. They allow you to perform calculations involving numbers, trigonometry, logarithms, exponentiation, rounding, and more.

Some of the important and commonly used mathematical functions in C include:

- `sqrt(x)`: Calculates the square root of a number x.
- `pow(x, y)`: Raises x to the power of y.
- `fabs(x)`: Computes the absolute value of x.
- `sin(x)`, `cos(x)`, `tan(x)`: Computes the sine, cosine, and tangent of an angle x, respectively.
- `log(x)`: Computes the natural logarithm of x.
- `exp(x)`: Calculates the exponential value of x.
- `floor(x)`, ceil(x), round(x): Perform different types of rounding operations on x.
- `fmod(x, y)`: Calculates the remainder of dividing x by y.

Here is an example using these functions. Compile the code using `gcc -o pedram pedram.c`.

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

int main() {
 const double num1 = 4.0;
 const double num2 = 2.5;

 double sqrtResult = sqrt(num1);
 double powResult = pow(num1, num2);
 double sinResult = sin(num1);
 double logResult = log(num1);
 double ceilResult = ceil(num2);
 double fmodResult = fmod(num1, num2);

 printf("Square root of %.2f: %.2f\n", num1, sqrtResult);
```

```
    printf("%.2f raised to the power of %.2f: %.2f\n", num1, num2,
        powResult);
    printf("Sine of %.2f: %.2f\n", num1, sinResult);
    printf("Natural logarithm of %.2f: %.2f\n", num1, logResult);
    printf("Ceiling value of %.2f: %.2f\n", num2, ceilResult);
    printf("Remainder of %.2f divided by %.2f: %.2f\n", num1, num2,
        fmodResult);
}
```

Probably, you see the following error:

```
/usr/bin/ld: /tmp/ccaR3sn3.o: in function ‘main’:
pedram.c:(.text+0x30): undefined reference to ‘sqrt’
/usr/bin/ld: pedram.c:(.text+0x50): undefined reference to ‘pow’
/usr/bin/ld: pedram.c:(.text+0x67): undefined reference to ‘sin’
/usr/bin/ld: pedram.c:(.text+0x7e): undefined reference to ‘log’
/usr/bin/ld: pedram.c:(.text+0x95): undefined reference to ‘ceil’
/usr/bin/ld: pedram.c:(.text+0xb5): undefined reference to ‘fmod’
collect2: error: ld returned 1 exit status
```

Why? By default, the GCC compiler includes standard C libraries, but it does not automatically include all other libraries such as the `math` library. Therefore, when you use math functions like `sqrt`, `pow`, or `log`, the linker needs to know where to find the implementation of these functions.

Including the `<math.h>` header file in your code is necessary to provide the function prototypes and declarations for the math functions. It allows the compiler to understand the function names, parameter types, and return types when you use these functions in your code. However, including `<math.h>` alone is not sufficient to resolve references to the math functions during the linking phase (run the code without including `<math.h>` and check the errors!). The math library (`libm`) that contains **the actual implementation** of the math functions needs to be linked explicitly.

To solve this issue, the `-lm` flag explicitly tells the compiler to link with the math library (`libm`), allowing it to resolve the references to the math functions used in your code. You don't need to remember all these flags you can always use Google. Now compiler the code using `gcc -o pedram pedram.c -lm`. Execute the object, and the result must be:

```
Square root of 4.00: 2.00
4.00 raised to the power of 2.50: 32.00
Sine of 4.00: -0.76
```

```
Natural logarithm of 4.00: 1.39
Ceiling value of 2.50: 3.00
Remainder of 4.00 divided by 2.50: 1.50
```

2.6 Statements

2.6.1 Comparison: `if` and `switch`

1. `if` **statement**:

The `if` statement in C is a conditional statement that allows you to perform different actions based on the evaluation of a condition. It follows a general format:

```c
if (condition) {
 // Code to execute if the condition is true
}
```

What does it mean? The `condition` is an expression that evaluates to either **true** or **false**. If the condition is **true**, the code inside the if block will be **executed**. If the condition is **false**, the code inside the if block will be **skipped**. Let's say if **a** greater that **b** (`a>b`), execute the code inside the `if` block. Note that `condition` is replaced by `a>b`, and it is called **Comparison operators**. Comparison operators used in `if` statements:

- `==`: Checks if two values are equal.
- `!=`: Checks if two values are not equal.
- `<`: Checks if the left operand is less than the right operand.
- `>`: Checks if the left operand is greater than the right operand.
- `<=`: Checks if the left operand is less than or equal to the right operand.
- `>=`: Checks if the left operand is greater than or equal to the right operand.

There are also some **Logical operators** for combining conditions. Let's say **A** is the first `condition` and B is the second `condition`:

- `!A`: Logical **NOT** operator. It means if the condition **A** is not true, execute the statement in the `if` block. For example. in `!(a>b)`, execute the code if **a** is **NOT** greater than **b**.

- `A || B`: Logical **OR** operator. It evaluates to true if **either** operand **A or B** is true. So, one of these conditions at least must be true to execute the `if` block.

- `A && B`: Logical **AND** operator. It evaluates to true only if both operands **A and B** are true. It means both **A and B** conditions **MUST** be **true**.

Another way to include more complex `if` statement with multiple conditions is to use the general format using `if`, `else if`, and `else`:

```
if (condition1) {
 // Code to execute if condition1 is true
} else if (condition2) {
 // Code to execute if condition2 is true
} else {
 // Code to execute if all previous conditions are false
}
```

In this format, each condition is checked sequentially. If the first condition is true, the corresponding code block is executed. If it's false, the next condition is checked. If none of the conditions are true, the code block inside the `else` block is executed. Here is an example:

```
#include <stdio.h>

int main() {
 int a = 5;
 int b = 10;

 if (a == b) {
  printf("a is equal to b\n");
 } else if (a != b) {
  printf("a is not equal to b\n");
 } else if (a < b) {
  printf("a is less than b\n");
 } else if (a > b) {
  printf("a is greater than b\n");
 } else if (a <= b) {
  printf("a is less than or equal to b\n");
 } else if (a >= b) {
  printf("a is greater than or equal to b\n");
 } else {
  printf("None of the conditions are true\n");
```

```
  }

  int A = 1;
  int B = 0;

  if (!A) {
   printf("A is false\n");
  }

  if (A || B) {
   printf("At least one of A or B is true\n");
  }

  if (A && B) {
   printf("Both A and B are true\n");
  }
}
```

You should see the following results:

```
a is not equal to b
At least one of A or B is true
```

A and B were supposed to be conditions why they are equal to 0 and 1? In C, the value **0** is considered **false**, and any **non-zero** value is considered **true**. Take a look at the following example:

```
#include <stdio.h>

int main() {
  int condition1 = 0;
  int condition2 = 1;

  if (condition1) {
   printf("Condition 1 is true\n");  //statement 1.1
  } else {
   printf("Condition 1 is false\n"); //statement 1.2
  }

  if (condition2) {
```

```
    printf("Condition 2 is true\n");  //statement 2.1
  } else {
    printf("Condition 2 is false\n"); //statement 2.2
  }
}
```

The result is given here. based on the results we can say **statement 1.2** and **statement 2.1** are executed and the rest is skipped.

```
Condition 1 is false
Condition 2 is true
```

In C, the `stdbool.h` header provides a set of definitions for Boolean data types and values. It introduces the `bool` type, which is specifically designed to represent **Boolean values**. The `bool` type can have two possible values: `true` and `false`. This header also defines the constants true and false as macro **constants**.

Using `stdbool.h` and the `bool` type can improve code readability and express the intent more clearly when dealing with **Boolean values**. It enhances code portability, as it ensures consistent Boolean semantics across different platforms and compilers. Here's an example that demonstrates the usage of `stdbool.h` and the `bool` type:

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

int main() {
  bool condition1 = true;
  bool condition2 = false;

  if (condition1) {
    printf("Condition 1 is true\n");  // statement 1.1
  } else {
    printf("Condition 1 is false\n"); // statement 1.2
  }

  if (condition2) {
    printf("Condition 2 is true\n");  // statement 2.1
  } else {
    printf("Condition 2 is false\n"); // statement 2.2
  }
}
```

The result is given here. based on the results we can say **statement 1.1** and **statement 2.2** are executed and the rest is skipped. In this example, we include the `stdbool.h` header and declare two `bool` variables `condition1` and `condition2`. We assign `true` to `condition1` and `false` to `condition2`. We then use these variables in if statements to check their values and print corresponding messages.

```
Condition 1 is true
Condition 2 is false
```

By using `stdbool.h` and the `bool` type, the code becomes more self-explanatory, as it explicitly shows the usage of Boolean values. The constants true and false provide clarity in expressing the intent of conditions, making the code more readable and maintainable.

2. `switch` **statement**:

The switch statement in C is a control flow statement that allows you to select one of several execution paths based on the value of an expression. It provides an alternative to using multiple `if` statements when you have a series of conditions to check against a single variable.

The general format of the switch statement in C is as follows:

```
switch (expression) {
 case value1:
 // code to be executed if expression matches value1
 break;
 case value2:
 // code to be executed if expression matches value2
 break;
 case value3:
 // code to be executed if expression matches value3
 break;
 // more cases...
 default:
 // code to be executed if expression doesn't match any case
}
```

Warning! The `break` statement is used to exit the `switch` statement after executing the corresponding code block. Without the break statement, the execution would **fall through** to the next case, resulting in unintended behavior.

Here's an example that demonstrates the usage of the `switch` statement:

```c
#include <stdio.h>

int main() {
 int choice;

 printf("Enter a number between 1 and 3: ");
 scanf("%d", &choice);

 switch (choice) {
  case 1:
  printf("You chose option 1.\n");
  break;
  case 2:
  printf("You chose option 2.\n");
  break;
  case 3:
  printf("You chose option 3.\n");
  break;
  default:
  printf("Invalid choice.\n");
 }
}
```

Here, we have used `scanf` function. The `scanf` function in C is used to read input from the standard input (usually the keyboard) and assign it to variables based on specified format specifiers. It allows you to accept user input during program execution, making your program more interactive. The general format of the `scanf` function is `scanf(format, argument_list);`, where the `format` parameter specifies the format of the expected input, while the `argument_list` contains the addresses of variables where the input will be stored. Here we have `scanf("%d", &choice)`, which means the given number will be saved in `choice` with format of `int` since we used placeholder `%d`.

In this example, the user is prompted to enter a number between 1 and 3. The input is stored in the variable `choice`. The `switch` statement is then used to check the value of choice and execute the corresponding code block. The output will be different based on the value you enter every time you execute the object file by `./pedram`.

If the user enters 1, the code inside the case 1 block is executed, printing "You chose option 1." If the user enters 2, the code inside the case 2 block is executed, printing "You chose option 2." If the user enters 3, the code inside the case 3 block is executed, printing "You chose option 3."

If the user enters any other value, the code inside the default block is executed, printing "Invalid choice."

More example of `scanf()`! The `scanf` function scans the input stream and tries to match the input with the specified format. It skips whitespace characters by default and stops scanning when it encounters a character that doesn't match the format specifier. Here's an example to illustrate the usage of `scanf`:

```
#include <stdio.h>

int main() {
 int age;
 float height;

 printf("Enter your age: ");
 scanf("%d", &age);

 printf("Enter your height in meters: ");
 scanf("%f", &height);

 printf("You are %d years old and %.2f meters tall.\n", age,
     height);
}
```

In this example, the `scanf` function is used to read user input for age and height. The `%d` format specifier is used to read an integer value, and the `%f` format specifier is used to read a floating-point value. The `&` operator is used to obtain the address of the variables age and height for `scanf` to store the input values.
After the input is read, the program prints the values of `age` and `height` using `printf`.
It's important to note that `scanf` requires correct format specifiers to match the input data type. Failure to use the correct format specifier can lead to unexpected behavior or errors in your program. Additionally, input validation and error handling are crucial when using `scanf` to ensure that the input is valid and the expected values are successfully read.

2.6.2 Loops and Iterations: `while`

The `while` statement in C is a control flow statement that allows you to repeatedly execute a block of code as long as a specified condition is true. It provides a way to create loops in your program.

The general format of the while statement in C is as follows:

```
while (condition) {
 // code to be executed while the condition is true
}
```

The `condition` is a **Boolean** expression that determines whether the loop should continue or terminate. **As long as the condition evaluates to true**, the code inside the loop will be executed repeatedly. If the condition becomes false, the loop will be exited, and the program will continue with the next statement after the loop. Here's an example that demonstrates the usage of the `while` statement:

```
#include <stdio.h>

int main() {
 int count = 1;

 while (count <= 5) {
  printf("Count: %d\n", count);
  count++;
 }
}
```

In this example, the while loop is used to print the value of the count variable as long as it is less than or equal to 5. The count variable is **incremented** by 1 in each iteration using the `count++` statement.

The while loop continues to execute as long as the condition count ¡= 5 is true. Once the count value becomes 6, the condition becomes **false**, and the loop is terminated. Here is the output in terminal.

```
Count: 1
Count: 2
Count: 3
```

```
Count: 4
Count: 5
```

Something that I forgot to tell you! **Incrementing** and **decrementing** are unary **operators** in C that are used to increase or decrease the value of a variable by a specific amount.

The **increment** operator ++ is used to **increment** the value of a variable by 1. It can be applied as a prefix (`++x`) or a postfix (`x++`) operator. When used as a prefix, the increment operation is performed before the value is used in an expression. When used as a postfix, the increment operation is performed after the value is used in an expression. Similarly, the decrement operator – is used to decrease the value of a variable by 1. It follows the same prefix and postfix notation as the increment operator. Here is an example:

```c
#include <stdio.h>

int main() {
 int x = 5;
 printf("Original value: %d\n", x);

 printf("After x++: %d\n", x++);  // Postfix increment
 printf("Print x after x++ is applied: %d\n", x);
 printf("Print x again: %d\n", x);
 printf("After ++x: %d\n", ++x);  // Prefix increment

 printf("After x--: %d\n", x--);  // Postfix decrement
 printf("Print x after x-- is applied: %d\n", x);
 printf("Print x again: %d\n", x);
 printf("After --x: %d\n", --x);  // Prefix decrement
}
```

and the result is:

```
Original value: 5
After x++: 5
Print x after x++ is applied: 6
Print x again: 6
After ++x: 7
After x--: 7
Print x after x-- is applied: 6
Print x again: 6
After --x: 5
```

2.6.3 Loops and Iterations: `do`

The `do` statement is another type of loop in C that is similar to the `while` loop. The main difference is that the `do` loop executes the code block first and then checks the condition. This guarantees that the code inside the loop will be executed **at least once**, even if the condition is initially false.

The general format of the do statement in C is as follows:

```c
do {
 // code to be executed
} while (condition);
```

Here's an example to illustrate the usage of the `do` statement:

```c
#include <stdio.h>

int main() {
 int count = 1;

 do {
  printf("Count: %d\n", count);
  count++;
 } while (count <= 5);
}
```

In this example, the `do` loop is used to print the value of the `count` variable and increment it by 1. The loop continues to execute as long as the condition `count <= 5` is true. Since the initial value of count is 1, the loop body will be executed once, and then the condition is checked. If the condition is true, the loop will repeat, and if the condition is false, the loop will be exited. Here is the result:

```
Count: 1
Count: 2
Count: 3
Count: 4
Count: 5
```

2.6.4 Loops and Iterations: `for`

The `for` statement in C is a looping construct that allows you to execute a block of code repeatedly based on a specific condition. It is typically used when you know the exact number of iterations or when you need to perform a specific action for a fixed range of values. The general format of the for statement is as follows:

```
for (initialization; condition; increment/decrement) {
 // Code to be executed in each iteration
}
```

The `initialization` step is used to initialize the loop control variable before the loop starts. It is typically used to set an initial value.

The `condition` is evaluated before each iteration. If the condition is true, the loop body is executed; otherwise, the loop terminates.

The **increment** or **decrement** step is performed after each iteration and updates the loop control variable. It is used to control the termination condition of the loop.

Here's an example that demonstrates the usage of the `for` loop to print numbers from 5 to 0 using **decrement**:

```
#include <stdio.h>

int main() {
 for (int i = 5; i >= 0; i--) {
  printf("%d \n", i);
 }
}
```

In this example, the loop is initialized with `int i = 5`, the condition is `i >= 0`, and `i` is decremented by `i--` after each iteration. The loop iterates as long as the condition `i >= 0` is **true**. In each iteration, the value of `i` is printed using `printf`.

```
5
4
3
2
1
0
```

2.6.5 Nested loops

Nested loops in C are loops that are placed inside another loop. They allow you to perform repetitive tasks in a structured and organized manner when dealing with multiple dimensions or when you need to iterate over a combination of rows and columns. The general structure of nested loops is as follows:

```
for (outer initialization; outer condition; outer increment/
   decrement) {
 // Code before the inner loop

 for (inner initialization; inner condition; inner increment/
    decrement) {
  // Code inside the inner loop
 }

 // Code after the inner loop
}
```

Here's an example that demonstrates nested loops by printing out a matrix-like pattern based on rows and columns:

```
#include <stdio.h>

int main() {
 int rows = 5;
 int columns = 3;

 for (int i = 1; i <= rows; i++) {
  for (int j = 1; j <= columns; j++) {
```

```
      printf("(%d, %d) ", i, j);
    }
    printf("\n");
  }
}
```

In this example, we have an outer loop that iterates over the rows and an inner loop that iterates over the columns. The outer loop is controlled by the variable `i`, which represents the current row, while the inner loop is controlled by the variable `j`, which represents the current column.

The inner loop prints the coordinates `(row, column)` for each position in the matrix-like pattern. After printing the values for a row, we insert a newline character using `printf("n")` to move to the next row.

```
(1, 1) (1, 2) (1, 3)
(2, 1) (2, 2) (2, 3)
(3, 1) (3, 2) (3, 3)
(4, 1) (4, 2) (4, 3)
(5, 1) (5, 2) (5, 3)
```

As you can see, the nested loops allow us to iterate over each row and column combination, printing out the corresponding coordinates in the pattern.

Nested loops are commonly used when working with multi-dimensional arrays, matrix operations, nested data structures, or any situation that requires iteration over multiple levels or dimensions. They provide a powerful tool for handling complex repetitive tasks in a structured manner.

2.6.6 Loops and Iterations: Controlling the Loop

Controlling loops in C involves using certain statements like `break`, `continue`, and `goto` to alter the flow of execution within the loop. These statements provide control over how and when the loop iterations are affected or terminated.

- `break` statement is used to immediately exit the loop, regardless of the loop condition. When encountered, the program flow continues to the next statement after the loop. It is typically used to prematurely terminate a loop based on a specific condition.
- `continue` statement is used to skip the current iteration of the loop and move to the next iteration. It allows you to bypass the remaining code in the current iteration and start the

next iteration immediately. It is often used to skip certain iterations based on a condition.

- `goto` statement allows you to transfer the control of the program to a labelled statement elsewhere in the code. It is a powerful but potentially risky construct, as it can lead to complex and less readable code. It is generally advised to use `goto` sparingly and with caution.

Here's an example that demonstrates the usage of `break`, `continue`, and `goto` statements within a loop:

```c
#include <stdio.h>

int main() {
 int i;

 // Example with break
 for (i = 1; i <= 10; i++) {
  if (i == 5) {
   break;
  }
  printf("%d ", i);
 }
 printf("\n");

 // Example with continue
 for (i = 1; i <= 10; i++) {
  if (i % 2 == 0) {
   continue;
  }
  printf("%d ", i);
 }
 printf("\n");

 // Example with goto
 for (i = 1; i <= 3; i++) {
  printf("Outer loop iteration: %d\n", i);
  for (int j = 1; j <= 3; j++) {
   printf("Inner loop iteration: %d\n", j);
   if (j == 2) {
    goto end;
```

```
      }
    }
  }
  end:
  printf("Goto example finished.\n");
}
```

In this example, we have three loops that demonstrate the usage of `break`, `continue`, and `goto`:

The first loop uses break to exit the loop when `i` is equal to **5**. As a result, the loop terminates prematurely and only prints the numbers from **1** to **4**.

The second loop uses `continue` to skip printing even numbers. When `i` is divisible by 2, the loop skips the remaining code and moves to the next iteration. As a result, only odd numbers from 1 to 10 are printed.

The third loop demonstrates the usage of `goto`. In this case, when the inner loop reaches iteration 2, the `goto` statement is encountered, and the control jumps to the `end` label, bypassing the remaining iterations of the inner and outer loops. Finally, the message "Goto example finished" is printed.

These control statements provide flexibility and allow you to alter the flow of execution within loops, making your code more efficient and concise in certain situations. However, it's important to use them judiciously and maintain code readability and clarity.

```
1 2 3 4
1 3 5 7 9
Outer loop iteration: 1
Inner loop iteration: 1
Inner loop iteration: 2
Goto example finished.
```

2.6.7 Variable Scope

Variable scope refers to the portion of a program where a variable is accessible and can be used. In C, the scope of a variable is determined by its declaration and the block of code within which it is declared. Understanding variable scope is crucial for writing well-structured and maintainable code.

Let's consider an example using a for loop to illustrate different scenarios of variable scope:

```
#include <stdio.h>

int main() {
 int x = 5;  // Variable x declared in the main function

 printf("Before the for loop: x = %d\n", x);

 for (int i = 0; i < 3; i++) {
  int y = i * 2;  // Variable y declared inside the for loop

  printf("Inside the for loop: y = %d\n", y);
  printf("Inside the for loop: x = %d\n", x);
 }

 printf("Outside the for loop: y = %d\n", y);

 printf("After the for loop: x = %d\n", x);
}
```

In this code, we have two variables: x and y. Here's a breakdown of the variable scope in different scenarios:

x has a global scope as it is declared in the main function. It can be accessed and used anywhere within the main function, including inside the for loop.

y has a local scope limited to the block of code within the for loop. It is only accessible inside the for loop's block and ceases to exist once the loop iteration ends. Each iteration of the loop creates a new instance of the variable y.

Inside the for loop, both x and y are accessible because variables declared in outer scopes can be accessed in inner scopes.

Outside the for loop, attempting to access y will result in a compilation error since it is no longer in scope. The y variable is limited to the block of code within the for loop.

By observing the output of the `printf` statements, you can see the value of x remains the same throughout the program since it has a wider scope. However, the value of y changes with each iteration of the for loop, demonstrating the limited scope of the variable.

Compiling this program will result the following error:

```
Pedram.c: In function ‘main’:
pedram.c:16:46: error: ‘y’ undeclared (first use in this function)
```

If we declare the variable `y` without initialization (like the following code), by `int y;` right after `int x = 5;`, there is an address in memory allocated to save it. If I compile and run it, in **my computer**, every time I see an irrelevant and different value for `y`. This is the same problem as we saw in Declaring and Naming with and without Initializing.

```c
#include <stdio.h>

int main() {
 int x = 5;  // Variable x declared in the main function
 int y;

 printf("Before the for loop: x = %d\n\n", x);

 for (int i = 0; i < 3; i++) {
  int y = i * 2;  // Variable y declared inside the for loop

  printf("Iteration: %d\n",i);
  printf("Inside the for loop: y = %d\n", y);
  printf("Inside the for loop: x = %d\n\n", x);
 }

 printf("Outside the for loop: y = %d\n", y);

 printf("After the for loop: x = %d\n", x);
}
```

This is because inside the loop, the variable `y` is declared again and another address in memory is allocated to save it, which is not the same as previous one. Let's remove re-declaration inside the loop by:

```c
#include <stdio.h>

int main() {
 int x = 5;  // Variable x declared in the main function
 int y;

 printf("Before the for loop: x = %d\n\n", x);
```

```
  for (int i = 0; i < 3; i++) {
   y = i * 2;

   printf("Iteration: %d\n",i);
   printf("Inside the for loop: y = %d\n", y);
   printf("Inside the for loop: x = %d\n\n", x);
  }

  printf("Outside the for loop: y = %d\n", y);

  printf("After the for loop: x = %d\n", x);
 }
```

This time I get the following results. Inside the loop, the value of `y` in every iteration is updated and save in the initial address given to this variable. Another example variable that has been declared inside the loop is `i`. Try different scenarios of this variable at home!

```
Iteration: 0
Inside the for loop: y = 0
Inside the for loop: x = 5

Iteration: 1
Inside the for loop: y = 2
Inside the for loop: x = 5

Iteration: 2
Inside the for loop: y = 4
Inside the for loop: x = 5

Outside the for loop: y = 4
After the for loop: x = 5
```

If you don't need the variable `y` after the loop the best code is just not initialize and not print it out after the loop is over like:

```
 #include <stdio.h>

 int main() {
  int x = 5;  // Variable x declared in the main function
```

```
  printf("Before the for loop: x = %d\n\n", x);

  for (int i = 0; i < 3; i++) {
   int y = i * 2;  // Variable y declared inside the for loop

   printf("Iteration: %d\n",i);
   printf("Inside the for loop: y = %d\n", y);
   printf("Inside the for loop: x = %d\n\n", x);
  }

  printf("After the for loop: x = %d\n", x);
}
```

2.7 Arrays

In C, an array is a collection of elements of the same data type that are stored in contiguous memory locations. Arrays provide a way to store and access multiple values under a single variable name. They are widely used for storing and manipulating data efficiently.

The general format of declaring an array is:

```
type arrayName[numberOfElements];
```

Here's an example of declaring an array without initializing the values for its elements:

```
int numbers[5];
```

In this example, we declare an array named `numbers` that can hold 5 integer elements. The individual elements within the array are accessed using indices ranging from 0 to 4 (`numbers[0]` to `numbers[4]`).

If you want to initialize the values for the elements at the time of declaration, you can use the following format:

```
type arrayName[numberOfElements] = {value1, value2, ..., valueN};
```

Here's an example of declaring an array and initializing the values for its elements:

```
int numbers[5] = {10, 20, 30, 40, 50}; // Initializing an integer
    array with specific values
```

In this example, we declare and initialize an integer array named `numbers` with 5 elements. The elements of the array are initialized with the values 10, 20, 30, 40, and 50 respectively.

It's important to note that if you provide fewer values in the initialization list than the size of the array, the remaining elements will be automatically initialized to the default value for their respective type (e.g., 0 for integers, 0.0 for floating-point numbers, and '\0' for characters).

The following example shows the concept discussed in about arrays.

```c
#include <stdio.h>

int main() {
 int numbers1[5];  // Declaration of an integer array with size 5

 int numbers2[5] = {10, 20, 30, 40, 50};

 // Printing the array elements without initializing
 printf("without initializing:\n");
 for (int i = 0; i < 5; i++) {
  printf("numbers1[%d] = %d\n", i, numbers1[i]);
 }

 printf("\nwith initializing\n");

 // Printing the array elements with initializing
 for (int i = 0; i < 5; i++) {
  printf("numbers2[%d] = %d\n", i, numbers2[i]);
 }
}
```

Tips! In C, arrays are zero-indexed, which means the first element in an array is accessed using the index 0. This indexing convention is consistent throughout the language and is an important concept to understand when working with arrays.

In my machine I get the following results:

```
without initializing:
numbers1[0] = -648048640
numbers1[1] = 32764
numbers1[2] = 16777216
```

```
numbers1[3] = 257
numbers1[4] = 2

with initializing
numbers2[0] = 10
numbers2[1] = 20
numbers2[2] = 30
numbers2[3] = 40
numbers2[4] = 50
```

You can declare and initialize the array with an initializer list:

```c
int numbers[5] = {0};  // Initializes all elements to zero
```

In this example, the first element is explicitly initialized to 0, and the remaining elements will be automatically initialized to 0 as well.

Accessing an array element out of its valid range in C leads to undefined behavior. It means that the program's behavior becomes unpredictable, and it may result in crashes, errors, or unexpected output. Here's an example that demonstrates accessing an array element out of range:

```c
#include <stdio.h>

int main() {
 int numbers[5] = {10, 20, 30, 40, 50};

 printf("Accessing elements within the valid range:\n");
 for (int i = 0; i < 5; i++) {
  printf("numbers[%d] = %d\n", i, numbers[i]);
 }

 printf("\nAccessing elements out of the valid range:\n");
 printf("numbers[6] = %d\n", numbers[6]);  // Accessing element
    outside the valid range
}
```

What I get in **my machine** is:

```
Accessing elements within the valid range:
numbers[0] = 10
numbers[1] = 20
```

```
numbers[2] = 30
numbers[3] = 40
numbers[4] = 50

Accessing elements out of the valid range:
numbers[6] = -317639680
```

The general format of a multi-dimensional array in C is as follows:

```
type arrayName[size1][size2]...[sizeN];
```

Here, type represents the data type of the elements in the array, and `size1`, `size2`, ..., `sizeN` represent the sizes of each dimension of the array. Here's an example of a two-dimensional array and how to print its elements:

```c
#include <stdio.h>

int main() {
 int matrix[3][4] = {
  {1, 2, 3, 4},
  {5, 6, 7, 8},
  {9, 10, 11, 12}
 };

 printf("Printing the elements of the two-dimensional array:\n");
 for (int i = 0; i < 3; i++) {
  for (int j = 0; j < 4; j++) {
   printf("%d ", matrix[i][j]);
  }
  printf("\n");
 }
}
```

In this example, we declare a two-dimensional array named matrix with 3 rows and 4 columns. The elements of the array are initialized using an initializer list. The outer loop iterates over the rows, and the inner loop iterates over the columns.

The nested loops allow us to access and print each element of the two-dimensional array using the indices `matrix[i][j]`, where i represents the row index and j represents the column index. The outer loop controls the row iteration, and the inner loop controls the column iteration.

By iterating through the rows and columns, we can print out each element of the two-dimensional array in a structured manner.

Keep in mind that you can extend this pattern to higher-dimensional arrays by adding additional nested loops to iterate through each dimension.

The results should be:

```
Printing the elements of the two-dimensional array:
1 2 3 4
5 6 7 8
9 10 11 12
```

2.8 Functions

Functions in C are reusable blocks of code that perform a specific task. They help organize and modularize code by breaking it into smaller, manageable units. Functions provide a way to encapsulate a set of instructions, making code more readable, maintainable, and reusable.

Here are some examples of functions that we used so far:

- `int main()`: The main function serves as the entry point of a C program. It is required in every C program and acts as the starting point for execution.
- `printf`: The `printf` function is part of the standard C library and is used to output formatted text to the console or other output streams. It takes a format string and additional arguments, allowing you to display values and formatted text.

The general format of a function declaration in C is as follows:

```
returnType functionName(parameter1, parameter2, ... parameterN) {
 // Function body
 // Statements and computations
 // Optional return statement
 return output; // the types of variable output is returnType
}
```

- `returnType` specifies the data type of the value that the function returns. It can be `void` if the function does not return any value.
- `functionName` represents the name of the function, which is used to call the function from other parts of the program. Let's say in `printf()` function the name of the function is `printf`

- parameters are optional and define the variables that the function receives as input. They act as placeholders for values that are passed to the function when it is called. Let's say in `printf()` the parameter that function can receive is a string, placeholder, and a value to print out.
- FunctionBody contains the statements and computations that make up the function's logic. It specifies what the function does when it is invoked.

It's important to note that functions cannot be nested in C. Nested functions are not supported in standard C; only the main function can be defined within another function.

Functions provide a way to modularize code, improve code re-usability, and enhance code readability. They allow you to break down complex tasks into smaller, more manageable pieces, making it easier to understand and maintain your code. By organizing code into functions, you can also promote code reuse, as functions can be called multiple times from different parts of a program.

Here's an example that includes two functions: one to calculate the surface area of a circle and another to calculate the area of a circle based on its radius.

```
#include <stdio.h>

float calculateSurfaceArea(float radius) {
 const float pi = 3.14159;
 float surfaceArea = 2 * pi * radius;
 return surfaceArea;
}

float calculateArea(float radius) {
 const float pi = 3.14159;
 float area = pi * radius * radius;
 return area;
}

int main() {
 float radius = 5.0; // in meter

 float surfaceArea = calculateSurfaceArea(radius);
 printf("Surface area of the circle [m]: %.2f\n", surfaceArea);

 float area = calculateArea(radius);
```

```
  printf("Area of the circle [m^2]: %.2f\n", area);

  return 0;
}
```

In this example, we define two functions: `calculateSurfaceArea` and `calculateArea`. The `calculateSurfaceArea` function takes a float parameter radius and returns the surface area of the circle using the formula $2 \cdot \pi \cdot radius$. Similarly, the `calculateArea` function also takes a float parameter radius and returns the area of the circle using the formula $pi \cdot \pi \cdot radius$.

In the main function, we declare a float variable radius with a value of 5.0. We then call the `calculateSurfaceArea` function with radius as an argument and store the result in the `surfaceArea` variable. We also call the `calculateArea` function with radius as an argument and store the result in the area variable.

Finally, we use `printf` to display the calculated surface area and area of the circle on the console, with two decimal places of precision (%.2f). The result must be:

```
Surface area of the circle [m]: 31.42
Area of the circle [m^2]: 78.54
```

By encapsulating the calculation logic within separate functions, we can easily reuse these functions for different radii in our program. This approach promotes code modularity and improves readability by separating the specific calculations into individual functions.

Here's an example of a function that prints a two-dimensional array without a return value:

```
#include <stdio.h>

void printArray(int rows, int cols, int array[rows][cols]) {
 for (int i = 0; i < rows; i++) {
  for (int j = 0; j < cols; j++) {
   printf("%d ", array[i][j]);
  }
  printf("\n");
 }
}

int main() {
 int matrix[3][4] = {
  {1, 2, 3, 4},
  {5, 6, 7, 8},
```

```
    {9, 10, 11, 12}
  };

  printArray(3, 4, matrix);  // Call the function to print the
     array

  return 0;
}
```

The result must be exactly when we printed the element inside the `main` function in the previous section.

In this example, the function `printArray` takes three parameters: `rows`, `cols`, and `array`. It receives the dimensions of the array as well as the array itself. The function then uses nested loops to iterate over each element of the two-dimensional array and prints its value.

Inside the main function, we declare a two-dimensional array named matrix with 3 rows and 4 columns. We initialize the array with some values. Then, we call the `printArray` function, passing the dimensions of the array (3 for rows and 4 for columns) as well as the array itself (matrix). The function prints the elements of the array in a structured manner.

Since the `printArray` function does not need to return a value, its return type is specified as void. The function solely focuses on printing the array and does not perform any other operations.

By using a function with a void return type, we can encapsulate the logic of printing a two-dimensional array and reuse it whenever needed.

2.8.1 Variable Scope in Functions

The same concept about Variable Scope matters here. Take a look at the following example:

```
#include <stdio.h>

void printNumber() {
  int number = 10;  // Variable declared inside the function

  printf("Number inside the function: %d\n", number);
}

int main() {
  int number = 5;  // Variable declared inside the main function
```

```
    printf("Number inside the main function: %d\n", number);

    printNumber();
}
```

In this example, we have two variables named number declared in different scopes: one inside the `main` function and another inside the `printNumber` function.

Inside the main function, we declare and initialize the variable number with a value of `5`. We then print the value of number within the main function, which outputs `5`.

Next, we call the `printNumber` function from within the main function. Inside the `printNumber` function, we declare and initialize a separate variable number with a value of `10`. We then print the value of number within the `printNumber` function, which outputs `10`.

The key point here is that the two number variables have separate scopes. The number variable inside the `printNumber` function is local to that function and exists only within the function's block. It does not interfere with the number variable declared in the main function. The result must be:

```
Number inside the main function: 5
Number inside the function: 10
```

2.8.2 Passing a Constant Value to a Function

Passing a constant value to a function can be beneficial in several ways:

- It provides clarity: Declaring a parameter as a constant indicates that the function will not modify the value, making the function's behavior more explicit and self-documenting.
- It prevents unintentional modifications: Using a constant parameter ensures that the value passed to the function remains unchanged within the function's scope. This can help prevent accidental modifications and maintain the integrity of the original value.
- It enhances code safety: By using constants, you establish a contract between the calling code and the function, ensuring that the passed value will not be modified. This promotes safer and more predictable code execution.

Here's an example that demonstrates passing a constant value to a function:

```c
#include <stdio.h>

void printNumber(const int value) {
 printf("Value inside the function: %d\n", value);
}

int main() {
 int number = 5;

 printf("Number inside the main function: %d\n", number);

 printNumber(number);
}
```

Since value is declared as a constant parameter in the `printNumber` function, it cannot be modified within the function. This provides the assurance that the value passed to the function will not be accidentally changed within the function's scope.

A function can also itself. When a function calls itself, it is known as **recursion**. Recursion is a powerful programming technique where a function solves a problem by breaking it down into smaller, similar subproblems. It is a fundamental concept in computer science and often provides elegant solutions for problems that exhibit repetitive or self-similar structures.

Recursion involves the following key elements:

- Base Case: It is the condition that defines the simplest form of the problem and provides the termination condition for the recursive calls. When the base case is reached, the recursion stops, and the function starts returning values.
- Recursive Case: It is the condition where the function calls itself, typically with modified input parameters, to solve a smaller instance of the same problem. The recursive case leads to further recursive calls until the base case is reached.
- Progress towards the Base Case: Recursive functions must ensure that each recursive call brings the problem closer to the base case. Otherwise, the recursion may result in an infinite loop.

Here's an example of a recursive function to calculate the factorial of a positive integer:

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

```c
#include <inttypes.h>

uint64_t factorial(uint32_t n) {
 // Base case: factorial of 0 or 1 is 1
 if (n == 0 || n == 1) {
  return 1;
 }

 // Recursive case: factorial of n is n multiplied by factorial
    of (n-1)
 return n * factorial(n - 1);
}

int main() {
 uint32_t num = 5;

 uint64_t result = factorial(num);
 printf("Factorial of %"PRIu32" is %"PRIu64"\n", num, result);
}
```

In this example, the factorial function takes an unsigned integer `n` as input and recursively calculates the factorial of `n`. The base case is defined for n equal to 0 or 1, where the function returns 1 since the factorial of 0 or 1 is 1. In the recursive case, the function calls itself with the parameter n - 1, effectively reducing the problem size with each recursive call until the base case is reached.

When the program runs, the main function calls the factorial function with `num` as an argument. The factorial function uses recursion to calculate the factorial of `num`, and the result is printed. The result must be:

```
Factorial of 5 is 120
```

Recursion is a powerful technique that allows functions to solve complex problems by dividing them into smaller, manageable sub-problems. However, it's essential to ensure that recursive functions have a well-defined base case and progress towards that base case to avoid infinite recursion.

2.8.3 Forward Declaration of a Function

The provided code demonstrates the definition of the `factorial` function before the `main` function. This approach is valid and does not cause any errors.

However, if you attempt to define the `factorial` function after the `main` function, it will result in a compilation error. Compiler the following code:

```c
#include <stdio.h>
#include <stdint.h>
#include <inttypes.h>

int main() {
 uint32_t num = 5;

 uint64_t result = factorial(num);
 printf("Factorial of %"PRIu32" is %"PRIu64"\n", num, result);
}

uint64_t factorial(uint32_t n) {
 // Base case: factorial of 0 or 1 is 1
 if (n == 0 || n == 1) {
  return 1;
 }

 // Recursive case: factorial of n is n multiplied by factorial
    of (n-1)
 return n * factorial(n - 1);
}
```

This is because C requires functions to be declared or defined before they are used. When the `factorial` function is defined after the `main` function, the compiler encounters the function call in main before it sees the actual definition of factorial. As a result, the compiler doesn't have information about the function's implementation, leading to an error.

To overcome this issue, you can provide a function declaration before the `main` function. A function declaration specifies the function's name, return type, and parameter types without including the function body. It informs the compiler about the existence and signature of the function, allowing you to call it before the actual definition.

Here's an example of how you can declare the `factorial` function before the `main` function:

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

uint64_t factorial(uint32_t n);  // Function declaration

int main() {
 uint32_t num = 5;

 uint64_t result = factorial(num);
 printf("Factorial of %" PRIu32 " is %" PRIu64 "\n", num, result)
    ;
}

uint64_t factorial(uint32_t n) {
 // Function definition
 if (n == 0 || n == 1) {
  return 1;
 }

 return n * factorial(n - 1);
}
```

This must give you the same output we have got in the previous section. In this updated code, the function `factorial` is declared before the `main` function with a function prototype that specifies the function's name, return type, and parameter types. This informs the compiler about the existence of the factorial function and its signature.

By providing a function declaration, you can call the `factorial` function in `main` even before its actual definition. The function definition is later provided after the `main` function, and the code compiles successfully.

This approach of declaring a function before its actual definition is known as providing a forward declaration or function prototype. It allows you to use the function before its implementation, satisfying the requirement of declaring functions before they are used in C.

It was said that `int main` is also a function that can receive inputs. Here's an example of a C code that demonstrates the usage of input arguments in the `main` function, checks the number of inputs, and utilizes the input arguments with different types:

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

```c
#include <stdlib.h> // Include this header for atoi and atof

int main(int argc, char *argv[]) {
 // Check the number of inputs
 if (argc != 3) {
  printf("Incorrect number of inputs. Expected 2 inputs.\n");
  return 1; // Exit the program with an error status
 }

 // Retrieve the input arguments
 int arg1 = atoi(argv[1]); // Convert the first argument to an
    integer
 float arg2 = atof(argv[2]); // Convert the second argument to a
    float

 // Use the input arguments
 printf("First argument: %d\n", arg1);
 printf("Second argument: %.2f\n", arg2);

 return 0; // Exit the program with a success status
}
```

In this example, the main function receives two input arguments: `argc` and `argv`. `argc` represents the number of input arguments passed to the program, and `argv` is an array of strings that holds the actual input arguments.

The code first checks if the number of inputs is equal to `3` (the program name itself counts as an argument). If it's not, an error message is printed, and the program exits with an error status (`return 1`).

If the number of inputs is correct, the code converts the first argument (`argv[1]`) to an integer using the `atoi` function and stores it in the `arg1` variable. Similarly, the second argument (`argv[2]`) is converted to a float using the `atof` function and stored in the `arg2` variable.

Finally, the program uses the input arguments by printing them to the console. The `%d` format specifier is used to print the integer `arg1`, and the `%.2f` format specifier is used to print the float `arg2` with two decimal places.

To compile you can simply use `gcc -o pedram pedram.c`. To run the code as an example you can execute `./pedram 10 3.14`. Here, 10 and 3.14 are the input arguments passed to the program. You can modify them as needed.

```
First argument: 10
Second argument: 3.14
```

2.9 Global Variables

A global variable in C is a variable that is defined outside of any function and is accessible throughout the entire program. It has global scope, meaning it can be accessed and modified by any function within the program.

Global variables are declared outside of any function, typically at the top of the program, before the main function. They can be used to store values that need to be shared across multiple functions or accessed from different parts of the program. Here's an example of a global variable:

```c
#include <stdio.h>

// Global constant variable
const int MAX_VALUE = 100;

// Global non-constant variable
int globalVariable = 50;

void function1() {
 // Access the global constant variable
 printf("Max value: %d\n", MAX_VALUE);

 // Access the global non-constant variable
 printf("Global variable: %d\n", globalVariable);

 // Modify the global non-constant variable
 globalVariable = 75;
}

void function2() {
 // Access the modified global variable from function1
 printf("Updated global variable: %d\n", globalVariable);
}

int main() {
 function1();
```

```
    function2();

}
```

In this example, we have both a global constant variable named `MAX_VALUE` and a global non-constant variable named `globalVariable`.

The global constant variable `MAX_VALUE` is declared with the `const` keyword, indicating that its value cannot be modified throughout the program. It can be accessed from any function, and its value remains constant.

The global non-constant variable `globalVariable` is declared without the `const` keyword, allowing its value to be modified. It can also be accessed from any function, and any changes made to it will be reflected in other parts of the program that access the variable.

The functions `function1` and `function2` are able to access and modify the global variables. `function1` accesses and modifies the global non-constant variable `globalVariable`, and `function2` accesses the modified value of `globalVariable` from function1.

Global variables can be useful for sharing data between functions, but it is important to use them judiciously, as they can make code harder to understand and maintain due to their global scope. It's generally recommended to limit the use of global variables and favour local variables within functions whenever possible.

2.9.1 Using `define`

The `#define` preprocessor directive in C is used to define symbolic constants and perform textual substitutions during the compilation process. It allows you to define a name as a replacement for a value or a piece of code, which is then substituted wherever the name is encountered in the source code.

Here are a few key points about `#define`:

- Symbolic Constants: With `#define`, you can define symbolic names for constant values, making the code more readable and maintainable. These names act as placeholders for specific values or expressions, providing a way to give meaningful names to commonly used values or configurations.
- Textual Substitution: `#define` performs textual substitution, replacing every occurrence of the defined name with its associated value during the pre-processing phase of compilation. The substitution is done before the actual compilation of the code begins.

- No Memory Allocation: `#define` does not allocate memory. It simply replaces text, allowing you to define aliases or constants without occupying memory space.
- No Type Checking: `#define` does not perform type checking because it is a simple textual substitution. It is important to ensure that the substituted text is valid and compatible with the context where it is used.
- No Scope Limitation: `#define` constants have global visibility and are not bound to any specific scope. They can be accessed and substituted throughout the entire program, regardless of their location.
- No Runtime Overhead: Since `#define` is resolved during the compilation process, there is no runtime overhead associated with its usage. The substituted values or code are already present in the compiled program.

Take a look at the following example:

```
#include <stdio.h>

// Global variable
int globalVariable = 50;

// Using #define
#define CONSTANT_VALUE 50

void function1() {
 globalVariable = 75;  // Modify the global variable
}

void function2() {
 printf("Global variable: %d\n", globalVariable);
 printf("Constant value: %d\n", CONSTANT_VALUE);
}

int main() {
 function1();
 function2();
}
```

In this example, we have a global variable named `globalVariable` and a constant value defined using `#define` called `CONSTANT_VALUE`, both set to 50.

The global variable `globalVariable` is mutable, and its value can be modified by functions within the program. In the function1 function, we modify the value of `globalVariable` to 75.

On the other hand, the constant value `CONSTANT_VALUE` defined using `#define` is a symbolic name that represents the value 50. It cannot be modified or reassigned since it is a pre-processor directive for text substitution. In the `function2` function, we print both the value of the global variable and the constant value.

The difference between the two becomes apparent when considering their characteristics:

The global variable `globalVariable` has a data type (integer in this case) and occupies memory space. It can be modified and accessed within the program.

The `#define` constant `CONSTANT_VALUE` is a symbolic representation of the value 50. It does not occupy memory space since it is substituted during the compilation process. It cannot be modified or assigned a different value.

In summary, the global variable allows for mutable data storage, while the `#define` constant provides a way to define symbolic names for values without occupying memory.

3 Intermediate Topics in C

3.1 Debugging in C

Debugging in C using the GNU Debugger (GDB) is a powerful technique for identifying and resolving issues in your C programs. GDB allows you to examine and manipulate the execution of your program, helping you understand and fix bugs, analyze program behavior, and gain insights into code execution.

Do you have GDB on your OS?! GDB is developed by the GNU Project, GDB is the standard debugger for many Unix-like operating systems, including Linux. It is widely used and supported across various platforms. To check if you have GDB installed on your OS you can use `gdb --version`. For any reason if it was not installed:

- On Linux: GDB comes with the compiler but you didn't have it, use `sudo apt install gdb`.
- macOS or iOS: Follow these steps:
  1. Open Terminal and Install Homebrew, a popular package manager for macOS, by executing the following command in Terminal: `/bin/bash -c "$(curl -fsSL https://raw.githubusercontent.com/Homebrew/install/HEAD/install.sh)"`
  2. Once Homebrew is installed, use it to install GDB by running the following command: `brew install gdb`
  3. After the installation is complete, you may need to create a certificate to allow GDB to control other processes on your system. Run the following command: `codesign --entitlements gdb-entitlement.xml -fs gdb-cert /usr/local/bin/gdb`
     This step is necessary to grant GDB the necessary permissions for debugging.
  4. Finally, you can verify the installation by running: `gdb --version`

  Please note that starting with macOS Catalina (10.15) and later versions, the system's security measures restrict the use of GDB for debugging certain processes, such as system processes or processes that you do not have appropriate permissions for. Additionally, you may need to adjust your system's security settings to allow GDB to function properly. Refer to the GDB documentation or online resources for more information on using GDB on macOS and any additional steps that may be required.

To enable debugging with GDB, you need to compile your C code with the `-g` flag. This flag includes debugging information in the compiled executable, such as symbol tables, source file names, and line number information. This information is crucial for GDB to provide meaningful debugging capabilities.

Instead of `-g` flag we may use `-ggdb3` which the debugging information provided in executable object file is in the format of GDB debugger, while `-g` is more generic and can be used with different debuggers. So, if you are using LLDB, you must use `-g`.

Still have problem with GDB?! There is another debugger called `lldb` that you can use both on Linux or macOS. LLDB (LLVM Debugger) is developed as part of the LLVM project, LLDB is a relatively newer debugger and was designed to be a replacement for GDB. Initially focused on macOS and iOS, it has since expanded to support other platforms like Linux and Windows. This time I am sure `lldb` should be on macOS because it comes with the compiler!! But if it doesn't please let me know. Because I don't have macOS I might be wrong!
On Linux although you may need to install it. To check if you have it use: `lldb --version`. If you don't install it with `sudo apt install lldb`.

Here are the differences between different levels of `-ggdb` flags:

- `-ggdb0`: This level disables debugging information generation. It is equivalent to not using the -g flag at all.
- `-ggdb1`: This level generates minimal debugging information. It includes basic symbol table entries and line number information. It is the minimum level recommended for effective debugging.
- `-ggdb2`: This level generates additional debugging information, including macro definitions and more detailed symbol table entries. It provides more comprehensive debugging support than -ggdb1.
- `-ggdb3`: This level generates the maximum amount of debugging information. It includes extra information for local variables and optimizations. It provides the most detailed debugging support but may increase compilation time and executable size.

When using GDB or LLDB, you can set breakpoints, step through the code, inspect variable values, examine the call stack, and perform various debugging operations to understand the program's behavior. GDB or LLDB allows you to interactively debug your program, making it a valuable tool for troubleshooting complex issues.

To start debugging with GDB, use the command `gdb <executable_name>` or in your terminal, where `<executable_name>` is the name of the compiled executable. If you are using LLDB you can do the same by `lldb <executable_name>`. Once in the GDB environment (or LLDB), you can use various commands to navigate, inspect, and manipulate your program's execution.

Remember to remove the `-ggdb` or `-g` flag when compiling your code for production or release builds, as it adds extra information and increases the executable's size. The `-ggdb` or `-g` flags are intended for development and debugging purposes only.

Here's an example of C code that uses a while loop, along with some common GDB commands:

```
#include <stdio.h>

int main() {
 int i = 0;

 while (i < 10) {
  printf("Iteration %d\n", i);
  i++;
 }
 printf("The end of loop\n");
}
```

To compile this code with the -ggdb3 flag for maximum debugging information, you can use the following command:

`gcc -ggdb3 pedram.c -o pedram`

Tips! There is no different between
`gcc -ggdb3 pedram.c -o pedram`
and
`gcc -ggdb3 -o pedram pedram.c`

Once compiled, you can start debugging the program using `gdb ./pedram`(or `lldb ./pedram` if you are using LLDB). Here's an example of using some common GDB or LLDB commands:

- **Setting a Breakpoint**: You can set a breakpoint at a specific line of code using the break command. For example, to set a breakpoint at line 8 (inside the while loop), use `break 8`. If you are using LLDB you can do the same by `breakpoint set --line 8`.
- **Starting Execution**: In both GDB and LLDB, once a breakpoint is set, you can start the execution of the program using the `run` command. Although you may set more breakpoints during debugging.
- **Stepping through the Code**: In both GDB and LLDB, to step through the code line by line, you can use the `next` or `n` command. It will execute the current line and stop at the next line.
- **Continuing Execution**: In both GDB and LLDB, if you want to continue execution after hitting a breakpoint or stopping at a specific line, you can use the `continue` or `c` command.

- **Printing Variable Values**: In both GDB and LLDB, to print the value of a variable during debugging, you can use the `print` or `p` command. For example, `print i` will print the value of the variable `i`.

- **Quitting GDB or LLDB**: To exit the GDB or LLDB debugger, you can use the `quit` command.

Here's an example of how you might interact with GDB using the code provided:

```
For help, type "help".
--Type <RET> for more, q to quit, c to continue without paging--c
Type "apropos word" to search for commands related to "word"...
Reading symbols from ./pedram...
(gdb) break 7
Breakpoint 1 at 0x117e: file pedram.c, line 7.
(gdb) run
Starting program: /home/pedram/COMPSCI1XC3/pedram
[Thread debugging using libthread_db enabled]
Using host libthread_db library "/lib/x86_64-linux-gnu/libthread_db.so.1".

Breakpoint 1, main () at pedram.c:7
7               printf("Iteration %d\n", i);
(gdb) continue
Continuing.
Iteration 0

Breakpoint 1, main () at pedram.c:7
7               printf("Iteration %d\n", i);
(gdb) next
Iteration 1
8               i++;
(gdb) print i
$1 = 1
(gdb) c
Continuing.

Breakpoint 1, main () at pedram.c:7
7               printf("Iteration %d\n", i);
(gdb) c
Continuing.
```

```
Iteration 2

Breakpoint 1, main () at pedram.c:7
7               printf("Iteration %d\n", i);
(gdb) p i
$2 = 3
(gdb) exit
A debugging session is active.

Inferior 1 [process 61784] will be killed.

Quit anyway? (y or n) y
```

Using these additional flags can provide more comprehensive warning messages and enforce stricter adherence to the C language standard. They can help catch potential issues, improve code quality, and ensure compliance with best practices. Here is a list of some useful flags:

- `-Wall` enables additional warning messages during compilation. It enables common warnings that help catch potential issues and improve code quality.
- `-Wextra` enables even more warning messages beyond those enabled by -Wall. It includes additional warnings that are not included in -Wall.
- `-Wconversion` generates warnings for implicit type conversions that may cause loss of data or unexpected behavior.
- `-Wsign-conversion` generates warnings for implicit sign conversions, where signedness is changed during assignments or comparisons.
- `-Wshadow` generates warnings for variable shadowing, which occurs when a variable in an inner scope has the same name as a variable in an outer scope.
- `-Wpedantic` generates warnings for strict ISO C adherence. It enables additional warnings that follow the strictest interpretation of the C language standard.
- `-std=c17` specifies the C language standard to be used during compilation. In this case, it specifies the C17 standard, which is the ISO/IEC 9899:2017 standard for the C programming language.

Quite easy to use! To compile the same program you can use:

`gcc -ggdb3 -Wall -Wextra -Wconversion -Wsign-conversion -Wshadow -Wpedantic`

`-std=c17 pedram.c -o pedram`

Debugger uses these flags to include almost full information about the code in the object file during compiling. Sometimes you are testing your program and you may need to compile your code many times. Every time adding these flags might be time consuming. That's where we might need Makefile.

3.2 Makefile

A Makefile is a text file that contains a set of rules for compiling and building programs. It is used to automate the compilation process by specifying dependencies, compilation flags, and target outputs. Makefiles are commonly used in C projects to simplify building and managing complex codebases.

Why we need Makefile? Makefiles provide a convenient way to manage the compilation process and handle dependencies in C projects. They allow developers to specify the relationships between different source files and ensure that only the necessary files are recompiled when changes are made. Makefiles also make it easier to manage build configurations, compilation flags, and linking options. Overall, Makefiles streamline the build process and help maintain code consistency and reproducibility.

Makefiles consist of rules, targets, dependencies, and commands. Here's an overview of some key components:

- **Rules**: Rules define the relationship between targets and dependencies. They specify how to build targets from dependencies.
- **Targets**: Targets represent the desired outputs, such as executable files or object files. They can be source files, intermediate files, or final build artifacts.
- **Dependencies**: Dependencies are files or other targets that are required to build a specific target. If a dependency is modified, the corresponding target needs to be rebuilt.
- **Commands**: Commands are the actual shell commands executed to build a target. They specify how to compile source files, link object files, and generate the final output.

A simple example of Makefile could be:

```
CC = gcc
CFLAGS = <this is where flags are added>
SOURCES = main.c
OBJECTS = $(SOURCES:.c=.o)
```

```
EXECUTABLE = myprogram

all: $(EXECUTABLE)

$(EXECUTABLE): $(OBJECTS)
	$(CC) $(OBJECTS) -o $(EXECUTABLE)

%.o: %.c
	$(CC) $(CFLAGS) -c $< -o $@

clean:
	rm -f $(OBJECTS) $(EXECUTABLE)
```

The Makefile defines the following rules:

- `all`: The default target that builds the executable.
- `$(EXECUTABLE)`: Specifies the dependencies and commands to build the executable.
- `%.o`: Specifies the rule for compiling object files from C source files.
- `clean`: A target to clean the generated object files and executable.

By running make in the directory with this Makefile, it will compile the source files using the specified flags and generate the `myprogram` executable. Running make clean will remove the generated object files and executable.

Let's take a look at the following example save in the source code named `factorial.c`.

```c
#include <stdio.h>

int factorial(int n) {
 if (n == 0 || n == 1) {
  return 1;
 }
 return n * factorial(n - 1);
}

int main() {
 int num = 5;
 int result = factorial(num);
```

```
  printf("Factorial of %d is %d\n", num, result);
  return 0;
}
```

Open a terminal and use `nano Makefile` commend to make a new makefile. Copy and paste the following code and save the file.

```
CC = gcc
CFLAGS = -Wall -Wextra -std=c99
EXECUTABLE = pedram

all: $(EXECUTABLE)

$(EXECUTABLE): factorial.c
	$(CC) $(CFLAGS) -o $(EXECUTABLE) factorial.c

clean:
	rm -f $(EXECUTABLE)
```

Make sure that you have created `Makefile` in the same directory that the source code `factorial.c` is saved. In a terminal with the directory that both files are located in, execute `make`. This will generate an executable object file (`EXECUTABLE`) named `pedram`. To run the code I can simply do `./pedram`. To remove `EXECUTABLE` created I can use `make clean`.

Warning! I you have noticed there a `TAB` space before the line starting with `$(CC) ...` and `rm -f ...`. For some reason that baffle even the most seasoned programmers!!! This `TAB` space format is different in VScode when you are writing a Makefile and probably you would encounter errors like:

```
Makefile:7: *** missing separator.  Stop.
```

To avoid this problem forget about VScode when writing Makefiles. Format you Makefile when you run `nano Makefile` by removing extra spaces and entering `TAB` spaces before mentioned lines. You can also edit your Makefile in the **Text Editor** environment by running `open Makefile`, which opens the file by **Text Editor** after making it with `nano`

3.3 Splitting Code into Multiple Files

Splitting code into multiple files is a common practice in programming, including in languages like C. This modular approach offers several benefits and allows for better organization, readability, and maintainability of codebases. Splitting code into multiple files offers advantages such as:

- **Modularization**: Breaking code into smaller, more manageable units improves organization and readability.
- **Re-usability**: Code can be reused across different projects by linking or including the appropriate files.
- **Maintainability**: Isolating different functionalities or modules in separate files makes it easier to update or modify specific parts without affecting the entire codebase.
- **Compilation Efficiency**: When changes are made to a single file, only that file and its dependencies need to be recompiled, saving compilation time.

By separating code into multiple files, developers can better structure their projects, collaborate more effectively, and build scalable and maintainable software systems.

So far we have programmed only in Source Code Files (`.c` in C or `.cpp` in C++).

- Source code files contain the actual implementation of functions, variables, and other program logic.
- Each source code file typically corresponds to a specific module or functionality of the program.
- They include the necessary header files to gain access to the declarations and definitions needed for the code to compile and run.

You can make your own Header Files (`.h` in C or `.hpp` in C++).

- Header files contain function prototypes, type definitions, macro definitions, and other declarations that need to be shared across multiple source code files. They typically define interfaces and provide a way to communicate between different parts of a program.
- Header files are meant to be included in source code files (.c or .cpp) using the `#include` directive.

- They help in maintaining a separation between interface and implementation, making the code more modular and reusable.

Here's an example of C code with a main source file (`main.c`) and a corresponding header file (`functions.h`).

Save the following code in `main.c`:

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

int main() {
 int num = 5;
 int result = square(num);

 printf("Square of %d is %d\n", num, result);
}
```

By now you can see VScode even without compiling is giving you an error indicating that it cannot find `functions.h`. Create a file named `functions.h` and paste the following code into it:

```
#ifndef FUNCTIONS_H
#define FUNCTIONS_H

int square(int num) {
 return num * num;
}

#endif
```

The `#ifndef FUNCTIONS_H` and `#define FUNCTIONS_H` directives are known as include guards or header guards. They are used to prevent multiple inclusions of the same header file within a single compilation unit.

When a header file is included in multiple source files, there is a possibility of multiple definitions and declarations, which can lead to compilation errors due to redefinition of symbols. The include guards help avoid these errors by ensuring that the contents of the header file are processed only once during the compilation process.

Create a file named Makefile (no file extension) and paste the following code into it. To avoid the format errors mentioned in the previous section do it on terminal or Text Editor.

```
CC = gcc
CFLAGS = -Wall -Wextra

all: main

main: main.c functions.h
	$(CC) $(CFLAGS) -o main main.c

clean:
	rm -f main
```

Let's go through each line of the provided Makefile syntax:

- `CC = gcc`: This line assigns the value `gcc` to the variable `CC`. Here, `CC` represents the compiler to be used for compilation.
- `CFLAGS = -Wall -Wextra`: This line assigns the value `-Wall -Wextra` to the variable `CFLAGS`. Here, `CFLAGS` represents the compiler flags or options that are passed to the compiler during compilation. In this case, `-Wall and -Wextra` are flags that enable additional compiler warnings.
- `all: main`: This line defines a target **named** `all`. The `all` target is considered the default target, meaning that it will be executed if no specific target is provided when running make. In this case, the all target depends on the `main` target.
- `main: main.c functions.h`: This line defines the main target. It states that the `main` target **depends** on `main.c` and `functions.h` files. If any of these files are modified, the main target will be considered outdated and need to be rebuilt.
- `$(CC) $(CFLAGS) -o main main.c`: This line is the recipe for building the `main` target. It specifies the commands to be executed to create the `main` executable file.

  Here's a breakdown of the syntax:

  1. `$(CC)`: This expands the value of the CC variable, which is gcc. So, this represents the compiler command.
  2. `$(CFLAGS)`: This expands the value of the CFLAGS variable, which is -Wall -Wextra. So, this represents the compiler flags.
  3. `-o main`: This specifies the output file name as main.
  4. `main.c`: This is the source file that is passed to the compiler for compilation.

5. `clean: rm -f main`: This line defines the clean target. The clean target is typically used to remove generated files or clean up the project directory. In this case, the clean target specifies the command `rm -f main` to remove the `main` executable file.

In summary, this Makefile specifies a compilation process for building the main executable file. It uses the gcc compiler with the flags -Wall and -Wextra to compile main.c and functions.h. The resulting executable file is named main. Additionally, there is a clean target to remove the generated main file.

Open a terminal, navigate to the directory where the files are saved, and run the following command to compile `make`. This will compile the code and generate an executable file named `main`. Run the program by executing `./main`. You should see the output: "**Square of 5 is 25**".

In this example the implementation of the `square` function was defined directly inside the `functions.h`. The other scenario is to declare the function in the header file `function.h`, but write the actual implementation of `square` in another source code. This approach has some considerations:

- **Code Organization**: Separating the function implementation into a separate source file (functions.c) allows for better code organization. By having separate files for declarations (header file) and definitions (source file), the codebase becomes more modular and maintainable. It also helps in managing larger projects with multiple functions.
- **Compilation Efficiency**: If the function square is defined directly in the header file and included in multiple source files, each source file would have its own copy of the function code. This can lead to code duplication and potentially larger executable sizes. By placing the function definition in a separate source file, the function is compiled only once, and all source files can share the same compiled code.
- **Reducing Rebuilds**: When modifications are made to the function implementation in functions.c, only that file needs to be recompiled. If the function definition is directly in the header file, any change to the function will require recompiling all source files that include the header file, even if they don't directly use the function.
- **Encapsulation and Information Hiding**: Separating the function implementation in a source file helps hide the implementation details from other source files. The header file provides a clean interface (declarations) for other source files to use the functions without exposing the internal implementation.

If you remember when we are using `math.h` by including the header file we still get some error saying that the compiler cannot find the actual implementation of the functions used in our code.

That's why we used `-lm` flag to tell compiler where it can find the corresponding source code containing the implementations.

The C library is typically distributed as compiled code, and its source code may not be readily available or accessible to users. The implementation details of library functions, including `sin()` from `math.h`, are considered part of the library's internal implementation and are not exposed to the user.

However, the behavior and specifications of these functions are defined in the C standard, and their functionality is well-documented. The C standard provides guidelines on how functions like `sin()` should behave and what the expected results and behavior are for different input values. In this way, the developer, will not share the codes with users.

This is the most important reason of why sometimes we need to declare the functions in `.h` files but leave the definitions in a another source code with `.c` extension. Keep the `main.c` the same way it was. Change the file `functions.h` into following code where it contains only declaration of the function:

```
#ifndef FUNCTIONS_H
#define FUNCTIONS_H

int square(int num);

#endif
```

Create a file named `functions.c` and paste the following code into it:

```
#include "functions.h"

int square(int num) {
 return num * num;
}
```

Create a file named Makefile (no file extension) and paste the following code into it:

```
CC = gcc
CFLAGS = -Wall -Wextra

all: main

main: main.o functions.o
$(CC) $(CFLAGS) -o main main.o functions.o
```

```
main.o: main.c functions.h
$(CC) $(CFLAGS) -c main.c

functions.o: functions.c functions.h
$(CC) $(CFLAGS) -c functions.c

clean:
rm -f main *.o
```

Let's go through each line of the provided syntax in the context of a Makefile:

- `main: main.o functions.o`: This line specifies the target main and lists its dependencies as `main.o` and `functions.o`. This means that the target main depends on the object files `main.o` and `functions.o`. If any of these object files are modified, the main target will be considered outdated and need to be rebuilt.
- `main.o: main.c functions.h`: This line specifies the target `main.o` and lists its dependencies as `main.c` and `functions.h`. This means that the target `main.o` depends on the source file `main.c` and the header file `functions.h`. If any of these files are modified, the `main.o` target will be considered outdated and need to be rebuilt.
- `functions.o: functions.c functions.h`: This line specifies the target `functions.o` and lists its dependencies as `functions.c` and `functions.h`. This means that the target functions.o depends on the source file `functions.c` and the header file `functions.h`. If any of these files are modified, the `functions.o` target will be considered outdated and need to be rebuilt.

In summary, this Makefile defines targets for building the main executable, `main.o`e object file, and `functions.o` object file. The main target depends on the `main.o` and `functions.o` object files, which in turn depend on the corresponding source files and header files. The compiler commands specified in the recipes compile the source files into object files using the provided flags (`$(CFLAGS)`) and link the object files together to create the final executable. If any of the source files or header files are modified, the respective targets will be considered outdated and need to be rebuilt.

To practice this program, put some breakpoints in the code, using GDB or LLDB, to see the order of the lines being executed. To so this:

1. First you need to put `-g` flag in the Makefile. So the object file made by compiler will include some information about GDB. If you skip this part, you might see messages like:

```
No symbol table is loaded.  Use the "file" command.
```

when trying to set break points, indicating that `gdb` or `lldb` cannot define your make file must be like:

`CFLAGS = -g -Wall -Wextra`

2. Execute `make` in the Terminal to make the object file, in this case it must `main`.

3. Run the `main` executable under GDB compiler by `gdb ./main`.

4. If you have copied the code exactly with the same format mentioned above you should have the same order of numbering for the line. Let's say in the `main.c`, the line number 7 is: `int result = square(num);`. Define the following break points:

   - `break main.c:7` will set a breakpoint at line 7:
     `int result = square(num);`

   - `break main.c:9` will set a breakpoint at line 9:
     `printf("Square of %d is %d\n", num, result);`.

   - `break functions.h:4` will set a breakpoint in `functions.h` at line 4:
     `int square(int num);`.

   - `break functions.c:5` will set a breakpoint in `functions.c` at line 5:
     `return num * num;`.

5. Start the debugging by executing `run` in the Terminal.

6. Use `print`, `next`, `continue` and so on, to go through the code. If you don't remember this part go back to Debugging in C.

3.4 Pointer

I think Pointer are the most confusing concept in C. I need your full attention here!!

In C programming, memory is divided into bytes, and each byte consists of 8 bits (one byte). Each byte in memory has a unique address that can be used to access or manipulate the data stored in that memory location.

A pointer in C is a variable that holds the address of another variable. Pointers allow us to indirectly access and manipulate the data stored in a particular memory location. The syntax for declaring a pointer variable is to use an asterisk (`*`) before the variable name, followed by the data type it points to. For example:

```
int *p;            // p is a pointer to an integer
double *Pedram;    // Pedram is a pointer to a double
```

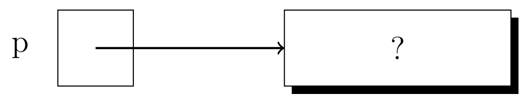
When we declare a pointer variable like `int *p`;, the pointer `p` is capable of storing memory addresses that point to an integer. The unary operator `*` is used to **de-reference** a pointer, which means accessing the value at the memory location that the pointer points to. For example, if `p` points to a memory location that contains an integer, `*p` gives us the value of that integer. The other way around is if a variable is initialized and you want to access the address. If `a` is a variable in memory, then `&a` represents the address where the value of a is stored. In another word, `*` is the inverse of `&`, like a=*&b is equal to a = b!

Take a look at the following example:

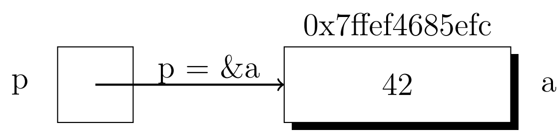
```
#include <stdio.h>

int main() {
 int a = 42;    // Declare and initialize an integer variable

 int *p;        // Declare a pointer to an integer
 p = &a;        // Assign the address of 'a' to the pointer 'p'
 /*or we could use int *p = &a;*/

 printf("Value of 'a': %d\n", a);
 printf("Address of 'a': %p\n", &a); // %p is placeholder
 printf("Value of 'p' (address of 'a'): %p\n", p);

 printf("Value pointed by 'p': %d\n", *p); // De-reference p

 *p = 500;
 printf("\nPrint out after *p=500.\n");
 printf("Value of 'a': %d\n", a);
 printf("Value pointed by 'p': %d\n", *p);

 a = 98;
 printf("\nPrint out after a = 98.\n");
 printf("Value of 'a': %d\n", a);
```

```
    printf("Value pointed by 'p': %d\n", *p);
}
```

In this example, we declared an integer variable `a` and a pointer `p` to an integer. At this moment the pointer is not initialized to point to any address. This figure shows how it looks like:



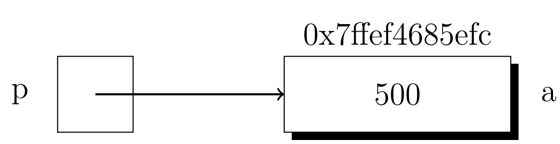
The, we assigned the address of `a` to the pointer `p` using the address-of operator `&`, like the following figure.



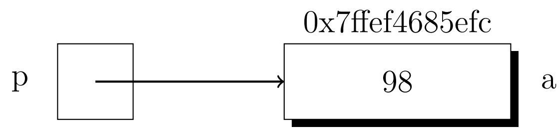
By de-referencing `p` with `*p`, we can access the value stored at the address pointed by `p`, which is the value of `a`. Here is the output in **my computer**. I am saying **my computer**, because the address given to the value `a` to save it, in your computer will be different. Actually, every time you run the code, you can see a new address is given to save this value. Here is results in my computer:

```
Value of 'a': 42
Address of 'a': 0x7ffef4685efc
Value of 'p' (address of 'a'): 0x7ffef4685efc
Value pointed by 'p': 42

Print out after *p=500.
Value of 'a': 500
Value pointed by 'p': 500

Print out after a = 98.
Value of 'a': 98
Value pointed by 'p': 98
```

After `*p = 500`:



At last after `a = 98`:



It is important that the address `0x7ffef4685efc` was not changed during the whole time, since we changed the value saved in the same location of the memory. Doesn't make sense right!? I know I have been there! Let's try another example:

```
#include <stdio.h>

int main()
{
 int a, b, *p1, *p2;

 printf("The initial values:\n");
 printf("a=%d\n", a);
 printf("b=%d\n", b);
 printf("The address of a is: %p\n", &a);
 printf("The address of b is: %p\n", &b);
 printf("The address p1 is: %p\n", p1);
 printf("The address p2 is: %p\n", p2);
 printf("\n");

 p1 = &a;
 p2 = p1;
 printf("Result after p1 = &a and p2 = p1:\n");
 printf("Value of *p1: %d\n", *p1);
 printf("Value of *p2: %d\n", *p2);
 printf("Value of a: %d\n", a);
 printf("The address p1 is: %p\n", p1);
 printf("The address p2 is: %p\n", p2);
 printf("\n");

 *p1 = 1;
 printf("Step 1, after *p1 = 1:\n");
 printf("Value of *p1: %d\n", *p1);
 printf("Value of *p2: %d\n", *p2);
 printf("Value of a: %d\n", a);
```

```
    printf("The address p1 is: %p\n", p1);
    printf("The address p2 is: %p\n", p2);
    printf("\n");

    *p2 = 2;
    printf("Step 2, after *p2 = 2;\n");
    printf("Value of *p1: %d\n", *p1); // Output: 2
    printf("Value of *p2: %d\n", *p2); // Output: 2
    printf("Value of a: %d\n", a);     // Output: 2
    printf("The address p1 is: %p\n", p1);
    printf("The address p2 is: %p\n", p2);
}
```

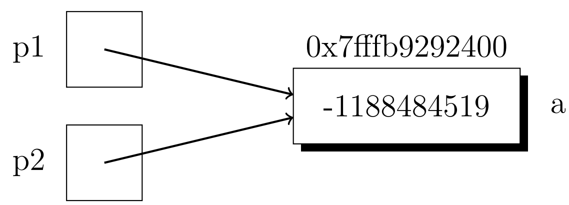
In the first part, `p1` and `p2` are declared as integer pointers. `p1` is set to point to the address of variable `a`. Then `p2` is assigned the value of `p1`. Now both `p1` and `p2` point to the address of `a`, and the value of `a` becomes 1.

Next, `*p2` is modified to 2. Since `p2` is pointing to the same address as `p1`, both `*p1` and `*p2` change to 2, and the value of a also becomes 2. The output in **my computer** is:

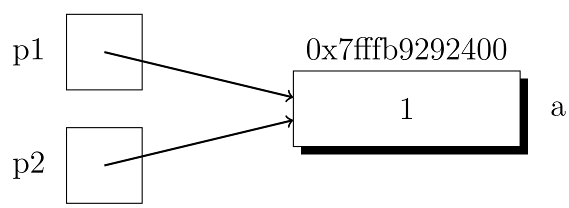
```
The initial values:
a=-1188484519
b=32767
The address of a is: 0x7fffb9292400
The address of b is: 0x7fffb9292404
The address p1 is: 0x64
The address p2 is: 0x1000

Result after p1 = &a and p2 = p1:
Value of *p1: -1188484519
Value of *p2: -1188484519
Value of a: -1188484519
The address p1 is: 0x7fffb9292400
The address p2 is: 0x7fffb9292400

Step 1, after *p1 = 1:
Value of *p1: 1
Value of *p2: 1
Value of a: 1
```

```
The address p1 is: 0x7fffb9292400
The address p2 is: 0x7fffb9292400

Step 2, after *p2 = 2;
Value of *p1: 2
Value of *p2: 2
Value of a: 2
The address p1 is: 0x7fffb9292400
The address p2 is: 0x7fffb9292400
```

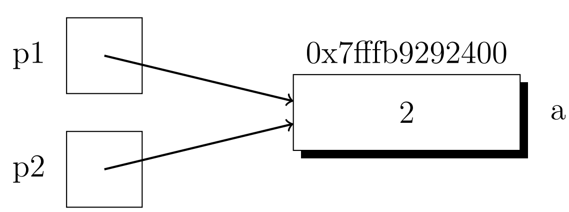
Let's go step by steps through schematic process! At the beginning `a` and `b` integers were declared without initialization. The same as `p1` and `p2` pointers. After `p1=&a`, `p1` will point at the the address of `a`. Using `p1=p2`, `p2` will point at the same address (`&a`) that `p1` is pointing at:



By `*p1 = 1` we are changing the value saved in `p1` address which is the same as `p2` and `&a`:



Like it was said, `p2` is pointing at the same address, so we can change the value saved in this address using `*p2=2`:



Warning! Do not confuse `p1 = p2` with `*p1 = *p2`. Take a look at the following example and compare it with the previous one!

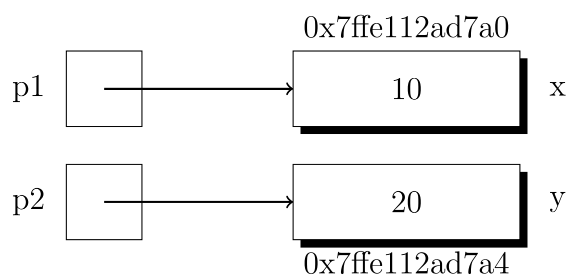
```c
#include <stdio.h>

int main()
{

 int x = 10, y = 20, *p1, *p2;
 p1 = &x;
 p2 = &y;

 printf("The initial values:\n");
 printf("x=%d\n", x);
 printf("y=%d\n", y);
 printf("The address of x is: %p\n", &x);
 printf("The address of y is: %p\n", &y);
 printf("The address p1 is: %p\n", p1);
 printf("The address p2 is: %p\n", p2);
 printf("\n");


 *p1 = *p2;
 printf("After *p1 = *p2:\n");
 printf("x=%d\n", x);
 printf("y=%d\n", y);
 printf("Value at address pointed by p1: %d\n", *p1);
 printf("Value at address pointed by p2: %d\n", *p2);

 printf("The address of x is: %p\n", &x);
 printf("The address of y is: %p\n", &y);
 printf("The address p1: %p\n", p1);
 printf("The address p2: %p\n", p2);
}
```

In this example, new integer variables `x` and `y` are declared, and `p1` is set to point to the address of `x`, while `p2` is set to point to the address of `y`. Then, the addresses and values stored at those addresses are printed.

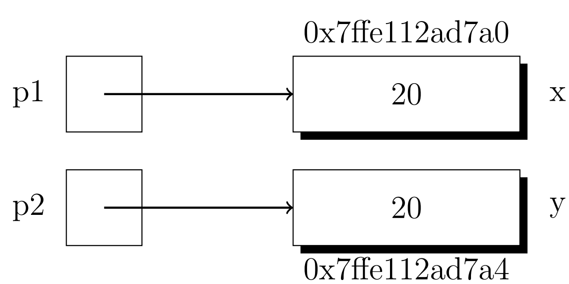
Finally, `*p1` is assigned the value of `*p2`. This means the value stored at the address pointed by `p2` (value of `y`) is **copied** to the address pointed by `p1` (value of `x`). After this step, both `*p1` and `*p2` become 20, and the addresses of `p1` and `p2` remain unchanged.

```
The initial values:
x=10
y=20
The address of x is: 0x7ffe112ad7a0
The address of y is: 0x7ffe112ad7a4
The address p1 is: 0x7ffe112ad7a0
The address p2 is: 0x7ffe112ad7a4

After *p1 = *p2:
x=20
y=20
Value at address pointed by p1: 20
Value at address pointed by p2: 20
The address of x is: 0x7ffe112ad7a0
The address of y is: 0x7ffe112ad7a4
The address p1: 0x7ffe112ad7a0
The address p2: 0x7ffe112ad7a4
```

At the first place we used `p1` and `p2` to point at the addresses of saved variables `x` and `y`, using `p1 = &x` and `p2 = &y`:



After `*p1 = *p2`, we are saying the value saved in the address `p1` (accessible by `*p1`) must be equal to the value saved in the address `p2`:



Let's take a break! Are you still following? Good! Why we are doing this? **why we need pointers?** Pointers are used when passing variables to functions for several reasons:

- **Passing by Reference**: In C, function arguments are typically passed by value, which means a copy of the argument is made and passed to the function. However, when we need to modify the original variable inside the function and reflect those changes outside the function, we use pointers. By passing the address of the variable (a pointer) to the function, the function can directly modify the original variable in memory, not just a copy of it.
- **Memory Efficiency**: When dealing with large data structures or arrays, passing them by value can be memory-intensive because it creates copies. By passing pointers to these structures or arrays, we avoid unnecessary memory consumption and improve the program's efficiency.
- **Dynamic Memory Allocation**: Pointers are essential when working with dynamically allocated memory. Functions that allocate memory (e.g., using malloc) return pointers to the allocated memory, allowing us to access and manage the allocated memory effectively (Dynamic Memory Allocation).
- **Sharing Data Across Functions**: Pointers enable sharing data between different functions without the need for global variables. Functions can access and modify the same data by using pointers, promoting modularity and encapsulation.
- **Function Return Multiple Values**: C functions can return only a single value, but using pointers as function arguments, we can return multiple values from a function.
- **Data Structures**: Pointers are widely used in creating complex data structures like linked lists, trees, and graphs, where each element points to the next or previous element.

3.4.1 Constant Pointers

Like any other data type, pointers can also be defined as constant using the const keyword. When a pointer is defined as constant, it means that the memory address it points to cannot be changed, making it a constant pointer.

Let's consider an example to illustrate the concepts. This example is taken from Prof. Barak Shoshany:

```c
#include <stdio.h>

int main() {
 int variable1 = 10;
 double variable2 = 3.14;

 const int const1 = 20;
 const double const2 = 2.71;

 int *variable_pointer_to_variable = &variable1;
 int *const const_pointer_to_variable = &variable2;

 const int *variable_pointer_to_const = &const1;
 const int *const const_pointer_to_const = &const2;

 // Allowed: var is not const, so can be changed.
 variable1 = 12;
 // Not Allowed: con is const, so cannot be changed.
 const1 = 30;

 // Allowed: pointer itself is not const, so can be changed.
 variable_pointer_to_variable = &variable2;
 // Allowed: variable pointed to is not const, so can be changed.
 *variable_pointer_to_variable = 30;

 // Not Allowed: pointer itself is const, so cannot be changed.
 const_pointer_to_variable = &variable1;
 // Allowed: variable pointed to is not const, so can be changed.
 *const_pointer_to_variable = 30;

 // Allowed: pointer itself is not const, so can be changed.
 variable_pointer_to_const = &const2;
 // Not Allowed: variable pointed to is const, so cannot be
    changed.
 *variable_pointer_to_const = 50;

 // Not Allowed: pointer itself is const, so cannot be changed.
 const_pointer_to_const = &const1;
 // Not Allowed: variable pointed to is const, so cannot be
```

```
    changed.
  *const_pointer_to_const = 30;
}
```

- `type <variable>`: This declares a variable of type `type`. The value of the variable can be modified throughout its lifetime!
- `const type <variable>`: This declares a constant variable of type `type`. The value of the variable cannot be modified after it is initialized.
- `type *<pointer>`: This declares a pointer variable of type `type*`. The pointer can store the memory address of a variable of type `type`, and the value pointed to by the pointer can be modified.
- `type *const <pointer>`: This declares a constant pointer variable of type `type*`. The memory address stored in the pointer cannot be modified after it is initialized, but the value pointed to by the pointer can be modified.
- `const type *<pointer>`: This declares a pointer variable of type `const type*`. The pointer can store the memory address of a variable of type `const type`, and the value pointed to by the pointer cannot be modified.
- `const type *const <pointer>`: This declares a constant pointer variable of type `const type*`. The memory address stored in the pointer cannot be modified after it is initialized, and the value pointed to by the pointer cannot be modified.

Tips! There is no difference between:
`const int *variable_pointer_to_const`
and
`int const *variable_pointer_to_const`
In both cases, `const` is before `*`, indicating that the variable itself is constant NOT the pointer.

3.4.2 Pointers and Arrays

In C, arrays have a close relationship with pointers. When an array is declared, it automatically creates a pointer that points to the memory location of its first element. This means that arrays are essentially a contiguous block of memory, and each element in the array can be accessed using pointer arithmetic.

Here's a C code that demonstrates initializing an array, printing out the address for each element, and printing the value of each element:

```c
#include <stdio.h>

int main() {
 int arr[] = {10, 20, 30, 40, 50};  // Initializing an array with values

 // Printing the address and value of each element in the array
 for (int i = 0; i < 5; i++) {
  printf("arr[%d] = %d with address %p\n", i, arr[i], &arr[i]);
 }
}
```

In this example, we declare an array `arr` with five elements. We then use a loop to iterate through each element of the array. By using the `&` operator, we can get the address of each element and print it using `%p` format specifier. Additionally, we print the value of each element using `%d` format specifier. The output shows that each element of the array is stored at a unique memory address, and we can access their values using the pointers to those addresses.

Array of Strings

In C, strings are represented as arrays of characters, where each character represents a single element of the string. A C string is terminated with a null character `'\0'`, which indicates the end of the string. Therefore, a string of length n requires an array of n+1 characters, with the last element being the null character.

Both of the following statements are valid ways to initialize a string in C:

```c
char date[] = "July 24"; // Initializing using an array
char *date = "July 24";  // Initializing using a pointer
```

In the first example, date is declared as an array of characters, and the compiler automatically determines the size of the array based on the length of the string literal "July 24". Here is how `date` will look like:

J	u	l	y		2	4	\0	date

In the second example, date is declared as a pointer to a character, and it is assigned the address of the string literal "July 24". Note that in this case, the size of the array is not explicitly specified, as the compiler automatically allocates the appropriate memory to store the string literal. To find the last element of an array you can use a the following code:

```
#include <stdio.h>

// Function to find the end of a string using a pointer
void findEndOfString(const char *str) {
 while (*str != '\0') {
  str++; // Move the pointer to the next character
 }
 // Print the last character of the string
 printf("End of string: %c\n", *(str - 1));
}

int main() {
 // Single string
 const char myString[] = "Hello, this is a test string.";

 // Send the string as a pointer to the function to find the end
 findEndOfString(myString);
}
```

Or if you want to find the length of a string something like strlen function you can use the following code:

```
#include <stdio.h>

// Function to find the end of a string using a pointer with a
   for loop
char findEndOfString(const char *str) {
 int n;
 for (n = 0; *str != '\0'; str++) {
  n++;
 }
 return str[-1]; // Return the last character of the string
}

int main() {
 // Single string
 const char myString[] = "Hello, this is a test string.";
```

```
  // Send the string as a pointer to the function to find the end
  char lastCharacter = findEndOfString(myString);

  printf("End of string: %c\n", lastCharacter);
}
```

Both codes use `‘\0‘` to find the last character. I can do the same by using an array notation for function parameter:

```
#include <stdio.h>

// Function to find the end of a string using an array
int findEndOfString(const char str[]) {
 int n;
 for (n = 0; str[n] != '\0'; n++) {
  // Loop until the null terminator is found
  // it was better to use while
  // I did to make it similar to the previous version
 }
 return n - 1; // Return the index of the last character in the
    string
}

int main() {
 // Single string
 const char myString[] = "Hello, this is a test string.";

 // Send the string as an array to the function to find the end
 int lastCharacter = findEndOfString(myString);

 printf("End of string: %c\n", myString[lastCharacter]);
}
```

The difference between `(const char str[])` and `(const char *str)` lies in how the function can access the characters of the string.

`(const char str[])`: This is an array notation for function parameters, also known as array notation for passing strings. When you pass a string as `const char str[]`, the function treats it as an array of characters. Inside the function, you can access the characters of the string using array indexing `(str[n])`. The compiler will automatically adjust the pointer to the first element of the array, so you can use it as if it were a regular array.

`(const char *str)`: This is a pointer notation for function parameters, also known as pointer notation for passing strings. When you pass a string as `const char *str`, the function treats it as a pointer to the first character of the string. Inside the function, you can access the characters of the string using pointer arithmetic (`*(str + n)` or `str[n]`). In this case, you explicitly use pointer arithmetic to traverse the characters.

Both notations allow you to pass strings to functions, and both versions of the function will work correctly to find the end of the string. In both the pointers are sent and there will not be another copy of array (waste of memory)in the function. You can used **GDB** to print out the addresses. The choice between array notation and pointer notation is mostly a matter of preference and coding style. Array notation may be more intuitive and familiar to some developers, while pointer notation may be preferred for its similarity to working with arrays and dynamic memory. Ultimately, both notations achieve the same goal of accessing the characters of the string within the function.

Let's discuss the `scanf` function and why we use `&` before the string variable when reading input:

```
char str[50];
scanf("%s", &str);
```

The `scanf` function is used for reading input from the user. When using`scanf` to read a string, you need to provide the address of the variable where the string will be stored. Since str is an array of characters, it already represents a memory address. However, when using `scanf`, you need to **explicitly** specify the address using the `&` (address-of) operator.

In this case, `&str` represents the address of the first element of the `str` array, which is the starting address where the string entered by the user will be stored. The `scanf` function reads characters from the standard input and stores them in the memory pointed to by `&str`, until it encounters a whitespace character (space, tab, or newline), effectively reading a single word (no spaces) as input. The null character `'\0'` is automatically appended at the end of the input, ensuring that the array `str` is properly terminated as a C string.

3.4.3 Pointers as Arguments of a Function

It was mentioned that one of the benefits of Pointers is **Passing by Reference**, allowing us to modify a variable in another scope. In Section Variable Scope in Functions, we had a function `printNumber()` that declares a local variable number inside the function. We also have a variable `number` declared in the `main()` function. Let's modify the code to explain how using pointers can help us modify a value passed to a function.

```
#include <stdio.h>

void printNumber(int *ptr) {
 // Using a pointer to modify the value passed to the function
 *ptr = 10;

 printf("Number inside the function: %d\n", *ptr);
}

int main() {
 int number = 5;  // Variable declared inside the main function

 printf("Number inside the main function: %d\n", number);

 // Pass the address of 'number' to the function
 printNumber(&number);

 // The value of 'number' has been modified by the function
 printf("Number after the function call: %d\n", number);
}
```

In this modified code, we have made the following changes:

The function `printNumber()` now takes a pointer to an integer (`int *ptr)` as an argument instead of having a local variable. By passing the address of number to this function, we can access and modify the original number variable inside the `main()` function.

Inside the `printNumber()` function, we use the pointer `ptr` to modify the value of number to 10. We do this by de-referencing the pointer using `*ptr`, which gives us access to the value stored at the address pointed to by the pointer.

After the function call, we print the value of number again in the `main()` function. Since we passed the address of number to the `printNumber()` function and modified it using the pointer, the value of number has been changed to 10 even outside the `printNumber()` function. The result must be:

```
Number inside the main function: 5
Number inside the function: 10
Number after the function call: 10
```

Using pointers allows us to directly access and modify the original variable's value inside the function, which can be helpful when we need to modify the value of a variable passed to a function. This is particularly useful when we want to achieve pass-by-reference behavior in C, as C functions are typically pass-by-value by default.

Let's try another example. This C code passes a double value and pointers to a function, performs some calculations inside the function, and updates the values pointed to by the pointers:

```
#include <stdio.h>

void calculate(double num, double *square, double *cube) {

 // update the value stored at square pointer
 *square = num * num;

 // update the value stored at cube pointer
 *cube = num * num * num;
}

int main() {
 // Initial value
 double number = 5.0;

 // Variables to store the results
 double result_square, result_cube;

 // Call the function to calculate the square and cube
 calculate(number, &result_square, &result_cube);

 // Print the results
 printf("Number: %.2f\n", number);
 printf("Square: %.2f\n", result_square);
 printf("Cube: %.2f\n", result_cube);
}
```

Let's go through the code using GDB (LLDB). So compile the code with `gcc -g -o pedram pedram.c`. Run the executable object with `gdb ./pedram` (lldb ./pedram). Define the following breakpoints. If you have copied the code with same format of spaces between lines, the numbering here must be the same as yours, otherwise you need to change the number mentioned here.

- `break 20` at `calculate(number, &result_square, &result_cube);` right before calling the function.
- `break 6` at `*square = num * num;` right before updating the value stored at the address pointed by pointer `square`.
- `break 9` at `*cube = num * num * num` before updating the value stored at the address pointed by pointer `cube`.

Enter `run` to start debugging the program. Follow the output in **my computer** line by line. **This is really important!**

```
Breakpoint 1, main () at pedram.c:20
20          calculate(number, &result_square, &result_cube);
$1 = 6.9533558070931648e-310
(gdb) p result_cube
$2 = 4.9406564584124654e-322
(gdb) n
Breakpoint 2, calculate (num=5, square=0x7fffffffbef0, cube=0x7fffffffbef8)
6               *square = num * num;
(gdb) p num
$3 = 5
(gdb) p square
$4 = (double *) 0x7fffffffbef0
(gdb) p cube
$5 = (double *) 0x7fffffffbef8
(gdb) p *square
$6 = 6.9533558070931648e-310
(gdb) p *cube
$7 = 4.9406564584124654e-322
(gdb) n

Breakpoint 3, calculate (num=5, square=0x7fffffffbef0, cube=0x7fffffffbef8)
9           *cube = num * num * num;
(gdb) p square
$8 = (double *) 0x7fffffffbef0
(gdb) p *square
$9 = 25
(gdb) n
10      }
```

```
(gdb) p *cube
$10 = 125
(gdb) n
main () at pedram.c:23
23          printf("Number: %.2f\n", number);
(gdb) p result_square
$11 = 25
(gdb) p result_cube
$12 = 125
(gdb) c
Continuing.
Number: 5.00
Square: 25.00
Cube: 125.00
[Inferior 1 (process 95816) exited normally]
(gdb) q
```

Let's go through it step by step:

- The program starts at `main()` on line 20. It halts at Breakpoint 1 on line 20, where the call to the `calculate()` function is about to be made.
- When we print the values of `result_square` and `result_cube`, GDB shows that their values are initially uninitialized and contain garbage values. The garbage values are displayed in scientific notation.
- We proceed with the program execution using `n` (next) command, and it reaches Breakpoint 2 inside the `calculate()` function.
- When we print the values of `num`, `square`, and `cube`, GDB shows the correct values of the arguments passed to the function. `num` is 5, and square and cube are pointers to `result_square` and `result_cube` in the `main()` function.
- Printing `*square` and `*cube` shows that they still contain the initial garbage values.
- We continue the execution using `n`, and it reaches Breakpoint 3 inside the `calculate()` function.
- After calculating the square and cube and updating the values using pointers, we print `*square` again, which now correctly shows 25, the square of `num`. Similarly, `*cube` correctly shows 125, the `cube` of `num`.

- We continue the execution using `n`, and it returns to `main()`.
- After the `calculate()` function call, we print the values of `result_square` and `result_cube` in `main()`, which now correctly show 25 and 125, respectively.
- The program continues execution using `c` (continue) command, and it reaches the end. The final output shows the values of number, `result_square`, and `result_cube`, confirming that the calculations were performed correctly.

How we can pass an array to a function?

1. Passing one dimensional arrays: Here's an example of passing a one-dimensional array to a function using pointers and printing the value and the address of each element inside the function:

```c
#include <stdio.h>

void printArrayElements(int *arr, int size) {
 for (int i = 0; i < size; i++) {
  printf("Element %d: Value = %d, Address = %p\n", i, arr[i], &
     arr[i]);
 }
}

int main() {
 int array[] = {10, 20, 30, 40, 50};
 int size = sizeof(array) / sizeof(array[0]);

 printf("Array elements in main function:\n");
 printArrayElements(array, size);
}
```

In this example, we define a function called `printArrayElements`, which takes a pointer to an integer array `arr` and the `size` of the array size. Inside the function, we use a `for` loop to iterate through the array and print the value and address of each element using the pointer arithmetic `&arr[i]`.

In the `main` function, we declare an integer array `array` and initialize it with some values. We then calculate the size of the array using `sizeof`, and call the `printArrayElements` function, passing the array and its size as arguments.

The output shows the value and address of each element in the array, printed inside the `printArrayElements` function.

Output:

```
Array elements in main function:
Element 0: Value = 10, Address = 0x7ffd9b1aa940
Element 1: Value = 20, Address = 0x7ffd9b1aa944
Element 2: Value = 30, Address = 0x7ffd9b1aa948
Element 3: Value = 40, Address = 0x7ffd9b1aa94c
Element 4: Value = 50, Address = 0x7ffd9b1aa950
```

2. Passing multi dimensional arrays: To pass a 2-dimensional array to a function using pointers and print out the value and address of each element inside the function, you can use pointer-to-pointer notation to handle the array. Here's an example:

```c
#include <stdio.h>

// Function to print the value and address of each element in a
   2-dimensional array
void printArrayElements(int rows, int cols, int arr[rows][cols])
    {
 for (int i = 0; i < rows; i++) {
  for (int j = 0; j < cols; j++) {
   printf("Element [%d][%d]: Value = %d, Address = %p\n", i, j,
      arr[i][j], &arr[i][j]);
  }
 }
}

int main() {
 int array[][3] = {{10, 20, 30}, {40, 50, 60}, {70, 80, 90}};
 int rows = sizeof(array) / sizeof(array[0]);
 int cols = sizeof(array[0]) / sizeof(array[0][0]);

 printf("Array elements in main function:\n");
 printArrayElements(rows, cols, array);
}
```

In this example, we declare a 2-dimensional array `array` in the `main` function and initialize it with some values. We then calculate the number of rows and columns in the array. Next, we call the `printArrayElements` function, passing the 2-dimensional array, the number of rows, and the number of columns as arguments.

The `printArrayElements` function takes a pointer to an array of integers as its first argument, which allows it to receive a 2-dimensional array of any size. Inside the function, we use nested `for` loops to iterate through the 2-dimensional array and print the value and address of each element using pointer arithmetic `&arr[i][j]`.

The output shows the value and address of each element in the 2-dimensional array, printed inside the `printArrayElements` function.

It is important to know, the function `printArrayElements` receives the 2-dimensional array `arr` as a pointer to its first element. This means that `arr` is not a copy of the original `array` but rather a pointer to the same memory location where array is stored. The address of the first element of the 2-dimensional array is passed to the function.

When you pass a multi-dimensional array to a function, the compiler treats it as a pointer to an array. In this case, `arr` is treated as a pointer to an array of `cols` integers, where each element of this array is itself an array of `int`. The size of this array is not known to the function, so the dimensions `rows` and `cols` are required to be passed as separate arguments.

Therefore, modifications made to the `arr` variable inside the `printArrayElements` function will directly affect the original `array` in the `main` function because they point to the same memory location.

Run the following code using GDB and set breakpoints and see the address of elements inside `printArrayElements` and `main` separately, to check if I am right!

```
#include <stdio.h>

// Function to print the value and address of each element in a
   2-dimensional array
void printArrayElements(int rows, int cols, int arr[rows][cols])
    {
 for (int i = 0; i < rows; i++) {
  for (int j = 0; j < cols; j++) {
   int* elementPtr = &arr[i][j]; // Pointer to the element
   printf("Element [%d][%d]: Value = %d, Address = %p\n", i, j,
      *elementPtr, elementPtr);

   // Modify the element using the pointer
   *elementPtr = *elementPtr * 2; // Doubling the value of the
      element
  }
 }
```

```
}

int main() {
 int array[][3] = {{10, 20, 30}, {40, 50, 60}, {70, 80, 90}};
 int rows = sizeof(array) / sizeof(array[0]);
 int cols = sizeof(array[0]) / sizeof(array[0][0]);

 printf("Array elements in main function before modification:\n"
    );
 printArrayElements(rows, cols, array);

 printf("\nArray elements in main function after modification:\n
    ");

 for (int i = 0; i < rows; i++) {
  for (int j = 0; j < cols; j++) {
   printf("Element [%d][%d]: Value = %d, Address = %p\n", i, j,
      array[i][j], &array[i][j]);

  }
 }
}
```

Warning! To implement the function you need to pass `rows` and `cols` before `arr[rows][cols]` like:
`void printArrayElements(int rows, int cols, int arr[rows][cols])`.
But the following format will cause errors during compile:
`void printArrayElements(int arr[rows][cols], int rows, int cols)`.
Why? Try it and see what happens!

Tips! Since the arrays are sent to function as pointers not as a copy, I still see the same results if instead of

```
int* elementPtr = &arr[i][j]; // Pointer to the element
printf("Element [%d][%d]: Value = %d, Address = %p\n", i, j,
    *elementPtr, elementPtr);
*elementPtr = *elementPtr * 2; // Doubling the value of the
   element
```

we use

```
printf("Element [%d][%d]: Value = %d, Address = %p\n", i, j,
    arr[i][j], &arr[i][j]);
arr[i][j] = arr[i][j] * 2; // Doubling the value of the
   element
```

Need more example!? Write a C program that prompts the user to enter 5 double numbers and stores them in an array. Define a constant n with a value of 5 to indicate the size of the array. After reading the numbers, the program should find and print the minimum and maximum values among the entered numbers using a separate function.

Solution:

```
#include <stdio.h>

#define n 5

// Function to find the minimum and maximum values in an array
void findMinMax(const double arr[], int size, double* min, double
   * max) {
 *min = arr[0];
 *max = arr[0];

 for (int i = 1; i < size; i++) {
  if (arr[i] < *min) {
   *min = arr[i];
  }

  if (arr[i] > *max) {
   *max = arr[i];
```

```
    }
  }
}

int main() {
  double numbers[n];
  double max, min;

  printf("Enter %d double numbers:\n", n);

  // Read numbers from the user and store them in the array
  for (int i = 0; i < n; i++) {
    scanf("%lf", &numbers[i]);
  }

  // Call the function to find the minimum and maximum values
  findMinMax(numbers, n, &min, &max);

  // Print the result
  printf("Minimum value: %.2lf\n", min);
  printf("Maximum value: %.2lf\n", max);
}
```

3. Arrays of strings:

In C, an array of strings is a two-dimensional array of characters, where each element of the array represents a string. Each string is a sequence of characters terminated by a null character `'\0'`. The array is organized in rows, where each row represents a separate string. Since each array might have combination of long and short stings we need to save them in a two dimensional array with different length in each row, which is called **ragged array**.

```
#include <stdio.h>

int main()
{
  // Ragged array of strings
  char names[][11] = {"Anne-Marie", "Anna", "Mahmoud", "Kian", "
     Raouf", "Nikki"};

  // Accessing and printing the elements and their lengths
```

```
    for (int i = 0; i < 6; i++)
    {
     int length = 0;
     while (names[i][length] != '\0')
     {
      length++;
     }
     printf("Name %d: %s (Length: %d) - After '\\0': '%c'\n", i + 1,
         names[i], length, names[i][length]);
    }
   }
```

In this example the size of stings is between 4 to 10, and this is how it is saved:

A	n	n	e	-	M	a	r	i	e	\0
A	n	n	a	\0	\0	\0	\0	\0	\0	\0
M	a	h	m	o	u	d	\0	\0	\0	\0
K	i	a	n	\0	\0	\0	\0	\0	\0	\0
R	a	o	u	f	\0	\0	\0	\0	\0	\0
N	i	k	k	i	\0	\0	\0	\0	\0	\0

The given code is not ragged because it uses a 2-dimensional array to store the strings. In a ragged array, the array elements are pointers, and each element can point to an array of different sizes. In the provided code, names is a 2-dimensional array of characters, and all the strings have a fixed length of 11 characters (including the null-terminating character `'\0'`).

A **ragged array** is a two-dimensional array where the rows can have different sizes (different number of elements). In contrast, a regular two-dimensional array has fixed sizes for all rows and columns. Ragged arrays are useful when you have data with varying sizes or when you want to optimize memory usage. For example, if you have a table of data with different lengths of rows, a ragged array can efficiently store this data without wasting memory on empty elements. For example:

```
#include <stdio.h>

int main()
{
 // Ragged array of strings
```

```
  char *names[] = {"Anne-Marie", "Anna", "Mahmoud", "Kian", "Raouf
    ", "Nikki"};

  // Accessing and printing the elements and their lengths
  for (int i = 0; i < 6; i++)
  {
   int length = 0;
   while (names[i][length] != '\0')
   {
    length++;
   }
   printf("Name %d: %s (Length: %d) - After '\\0': '%c'\n", i + 1,
       names[i], length, names[i][length]);
  }
 }
```

Here's an explanation of the code:

`char *names[]`: This declares an array of pointers to characters. Each element of names is a pointer that can point to the first character of a string.

`"Anne-Marie", "Anna", "Mahmoud", "Kian", "Raouf", "Nikki";`: This initializes the names array with string literals. Each string literal is stored in a separate memory location, and the pointers in the names array point to the first character of each string.

The for loop iterates through each element of the names array.

Inside the loop, length is initialized to 0. The while loop is used to find the length of each string in the names array. It continues until it reaches the null-terminating character `'\0'`, which marks the end of the string.

After finding the length of the string, the code prints the details using `printf`. This line prints the information for each string. It displays the name's index, the string itself, its length, and the character that appears after the null-terminating character. Note that `names[i][length]` is used to check the character after `'\0'`! This is how the array is save while each pointer to the row will point only to the first element of the row (`*names[i]`).

A	n	n	e	-	M	a	r	i	e	\0
A	n	n	a	\0						
M	a	h	m	o	u	d	\0			
K	i	a	n	\0						
R	a	o	u	f	\0					
N	i	k	k	i	\0					

Output:

```
Name 1: Anne-Marie (Length: 10) - After '\0': ''
Name 2: Anna (Length: 4) - After '\0': ''
Name 3: Mahmoud (Length: 7) - After '\0': ''
Name 4: Kian (Length: 4) - After '\0': ''
Name 5: Raouf (Length: 5) - After '\0': ''
Name 6: Nikki (Length: 5) - After '\0': ''
```

The effects of using a ragged array are that the individual strings (sub-arrays) can have different lengths, making it more flexible in handling data with varying sizes.

The difference between the first code and this ragged array is that the ragged array code used a 1-dimensional array of pointers, and each pointer pointed to a separate memory location holding a string of different lengths. In contrast, the updated code uses a 2-dimensional array of characters, where each row represents a string with a fixed length. To see the effects of one dimensional array in ragged code, we can print out `names[i][length+1]` which is the character after null-terminating character. In the first one, it still prints out `''` (`'\0'`). But in the ragged array it gives us the first character of of the next string:

```
Name 1: Anne-Marie (Length: 10) - After '\0': 'A'
Name 2: Anna (Length: 4) - After '\0': 'M'
Name 3: Mahmoud (Length: 7) - After '\0': 'K'
Name 4: Kian (Length: 4) - After '\0': 'R'
Name 5: Raouf (Length: 5) - After '\0': 'N'
Name 6: Nikki (Length: 5) - After '\0': ''
```

3.4.4 Pointers as Return Values

In C, a function can return a pointer as its return value. This allows the function to dynamically allocate memory on the heap and return a pointer to that memory. When using a pointer as a return value, you should be careful to manage the memory properly to avoid memory leaks or accessing invalid memory locations.

Here's an example of a function that returns a pointer to the minimum of two integers:

```
#include <stdio.h>

int *min(int *n1, int *n2) {
 return (*n1 < *n2) ? n1 : n2;
}

int main() {
 int num1 = 10;
 int num2 = 5;
 int *result = min(&num1, &num2);

 printf("The minimum value is: %d\n", *result);
}
```

This will give us:

```
The minimum value is: 5
```

3.5 Dynamic Memory Allocation

4 Advanced Topics in C

structs and typedefs

input and output: command line, during run time, from a file, reading a file or output a file

by 6th W/2

parallel computing

further topics maybe Vtune

by 7th W/1

5 A Short Overview of ANN (Optional)

by 7th W/1