COMP 201

Fall 2025

KOÇ UNIVERSITY

Lab 5

Constants, Structs, Linked Lists, and Makefiles

const

- Define **constants** in your program (not changeable after created)
- Variable declaration:

```
const int x = 0 // Cannot modify x
```

- Pointer declaration:

```
const int *arr = … // Cannot modify ints that arr points to
```

- Double pointer declaration:

```
const char **strPtr = … // Cannot modify chars that *strPtr points to
```

- Function declaration:

```
int length(const char *str) {...} // Won’t change strings characters
```

struct

- A new variable type that is a group of other variables

```
struct point {
    int x;
    int y;
};

struct point point_1;
point1.x = 0;
point1.y = 0;

// You can combine declaration and assignments
struct point point2 = {1, 2};
```

struct

- **typedef**: creates a new type name that refers to the same struct type, so you can avoid having to write struct everytime.

```
typedef struct point {
    int x;
    int y;
} point;

// Instead of “struct point point_1” you can write:
point point_1;
point1.x = 1
point1.y = 2

point point2 = {2, 3};
```

Note: typedef is not limited to structs. You can define new type names for other types too:

```
typedef int* int_ptr;
```

struct

- If you pass a struct as a parameter, it passes a copy of the struct.

```
void increase_x(point p) {
    p.x++;
}
…
point point2 = {2, 3};
increase_x(point2)
printf(“%d”, point2.x) // prints 2
```

struct

- If you want to modify the struct, pass a pointer of the struct to the function

```
void increase_x(point *p) {
    (*p).x++;
}
…
point point2 = {2, 3};
increase_x(point2)
printf(“%d”, point2.x) // prints 3
```

`struct`

- The **arrow (->) operator** lets you access the field of a struct via its pointer:

```
point1_ptr->x++; // equivalent to (*point1_ptr).x++;
```

- If a function returns a struct, it returns a copy of it (return by value):

```
point create_origin() {
    point origin = {0,0};
    return origin; // returns a copy of origin with x=0, y=0
}
```

- **`sizeof`** gives you the entire size of struct:

```
sizeof(point) // 8
```

- You can use arrays of structs like any other variable type:

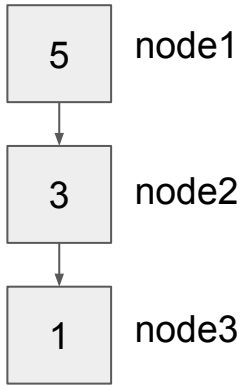
```
point points[3]; // array of 3 struct points
```

Linked Lists

- A sequence of nodes arranged linearly. Each node contains some data and a reference to the next node in the sequence.
- **Doubly linked list**: each node also contains a reference to the previous node.
- **Circular linked list**: last node points to the first node
- Example linked list implementation:

```
typedef struct node {
    int number;
    node* next;
} node;
node node1, node2, node3;
```

```
node1.number = 5;
node1.next = &node2;
node2.number = 3;
node2.next = &node3;
node3.number = 1;
```



(Singly) Linked Lists vs Arrays

- Insertion and deletion operations are generally faster for linked lists.
- Linked lists use more memory per element because each node stores additional pointer fields alongside the data
- Nodes in a linked list must be read sequentially
- Singly linked lists make reverse traversal difficult because nodes do not store points to their predecessors

Working with Multiple Files

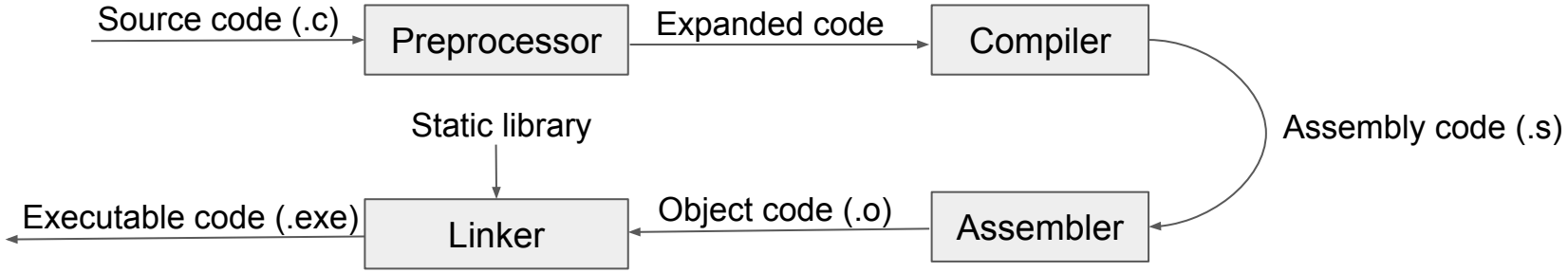
- A large C program should be split into multiple source files because this improves manageability and maintainability.
    - It also enables reusable components, such as utility functions, to be shared with other programs.
- For example, the Linux kernel has more than 50,000 C files: (https://github.com/torvalds/linux)

Working with Multiple Files - Dividing by Topic

- Each file should group together functions that perform related tasks.
- Examples include:
  - Functions for file or graphical input/output
  - Functions that manage access to a database
  - Implementations of abstract data types, such as linked lists or binary search trees
  - Groups of related numerical routines, such as matrix-manipulation functions or statistical utilities
- A large program may consist of several such files, along with a separate main program file.

Working with Multiple Files - Compilation & Linking

- **Compilation** is the process of translating a source file (.c) into an object file containing the machine instructions generated from that source.
- **Linker** combines multiple object files to produce a single executable.
- During compilation, if the compiler encounters a function that is declared but not defined, it assumes the definition exists in another file.
- The **linker** then resolves these external references by searching the object files and libraries for the missing function definitions.



Working with Multiple Files - Compilation & Linking

- Let's say we have 3 files: `file1.c`, `file2.c`, `file3.c`. we can compile them with:

```
$ gcc -c file1.c file2.c file3.c
```

- GCC will generate corresponding object files: `file1.o`, `file2.o`, `file3.o`
- We can link these object files with:

```
$ gcc -o myprogram file1.o file2.o file3.o
```

- GCC will generate an executable file with name `myprogram`.
- We can also compile and link with a single command:

```
$ gcc -o myprogram file1.c file2.c file3.c
```

Function Declarations

- Declarations (function prototypes) are used when the compiler needs to know about a function before its full definition is available. This is necessary in situations such as:
  - A function defined in one file is called from another file
  - Two functions call each other (mutual recursion)
  - You want to reorder functions within a file, for example placing `main` function at the top
- Declarations provide only the function's type information, not its implementation. For example:

```
int min(int, int);
double cbrt(double x); // including parameter names is preferred
```

Function Declarations - Header Files

- A function's declaration can be placed in the source file that calls it, typically near the top.
- **Header files** exist to make declarations and definitions accessible to multiple source files.

- If multiple source files need to use the same global constant, then:
  - The **declaration** goes in the header file:

```
extern const double PI;
```

  - The **definition** goes in exactly one .c file:

```
const double PI = 3.141592653589793;
```

Function Declarations - Header Files

- During preprocessing, the compiler expands `#include` by inserting the contents of the header file.
- This lets each source file see the declaration it needs.

square.h

```
double square(double x);
```

square.c

```
#include “square.h”
double square(double x) {
    return x * x;
}
```

main.c

```
#include “square.h”
int main(void) {
    printf(“%d”, square(5))
    return 0;
}
```

Makefiles

- Makefile is a build tool that automates compiling programs composed of multiple source files.
- A Makefile is a specially formatted file that defines how a project should be built and rebuilt automatically.
- General syntax:

```
target : dependencies
<TAB> command
```

- `target`: the file you want to build (usually an executable or an object file)
- `dependencies`: the files that the target depends on (source files, headers etc.)
- `command`: the shell command used to build the target. It must start with a TAB.

Makefiles

- Example:
  - `myprogram: file1.c file2.c file3.c`

    ```
    gcc -o myprogram file1.c file2.c file3.c
    ```
  - `myprogram` is the target
  - It depends on `file1.c`, `file2.c` and `file3.c`. If any of these files change, myprogram must be rebuilt.
  - Command `gcc -o myprogram file1.c file2.c file3.c` tells make how to build the target from the dependencies
  - When you run **`$ make myprogram`** command, make checks:
    1. Does the file `myprogram` exist?
    2. Is its timestamp older than any of the dependencies?
    3. If yes, run the provided command to rebuild the target

Makefiles - Variables

- Makefile variables (sometimes called macros) behave like C `#define` macros.
- Variables are defined with `name = value` pairs.
- To use a macro, reference it with: `$(MACRONAME)`
- Example:

```
CC      = gcc
CFLAGS  = -Wall
MYFACE  = ":*)"

myprogram: file1.c file2.c
     $(CC) $(CFLAGS) -o myprogram file1.c file2.c

printmyface:
     echo $(MYFACE)
```

- Here, CC and CFLAGS are conventional macros used to refer to the compiler program and the compiler flags (options) respectively

Makefiles - Conventions

- Before running any make command, it is useful to inspect the Makefile. It is common to find the following conventional targets:
  - **`make all`:** Builds the entire project. This is typically used for compiling everything needed for local testing.
  - **`make install`:** Copies the built files to their installation locations.
  - **`make clean`:** Removes build artifacts such as executables, object files, and temporary files.
- These standard targets (all, install, clean) are conventionally included in Makefiles so users know what to expect.

Makefiles - Complete Example

```
CC = gcc

all: clean install run

install: myprogram

clean:
    rm -f file1.o file2.o myprogram

run: myprogram
    ./myprogram

myprogram: file1.o file2.o
    $(CC) -o myprogram file1.o file2.o

file1.o: file1.c
    $(CC) -c file1.c

file2.o: file2.c
    $(CC) -c file2.c
```

- **`CC`** is set to the compiler program (`gcc`).
- **`all`** depends on the targets **`clean`**, **`install`** and **`run`**. Running `make all` executes those targets in that order.
- **`install`** depends on **`myprogram`**, so running **`make install`** will build **`myprogram`** if needed.
- **`clean`** removes generated files (`file1.o`, `file2.o`, and `myprogram`).
- **`run`** depends on **`myprogram`** and executes the resulting program.
- The rule for **`myprogram`** builds the executable from the object files `file1.o` and `file2.o`.
- The rules for **`file1.o`** and **`file2.o`** compile `file1.c` and `file2.c` into object files.

More about Makefiles

- Makefiles support many additional useful features, including:
  - **Suffix rules:** Define rules that apply to all files with a given suffix (e.g., `.c` → `.o`).
  - **Conditional directives:** Allow Makefiles to execute different rules based on conditions (similar to `if` statements).
  - **Include directive:** Allows one Makefile to include others, letting you split build logic across multiple files.
  - **Override directive:** Allows overriding the value of a macro, even if it was set on the command line.

- **Further reading:**
  - https://www.tutorialspoint.com/makefile/makefile_quick_guide.html
  - https://www.gnu.org/software/make/manual/make.pdf

Acknowledgements and References

The slides are compiled and/or adapted from the following sources:

- https://www.cs.hmc.edu/~geoff/classes/hmc.cs070.200401/notes/multi-file.html
- https://cgi.cse.unsw.edu.au/~cs1511/19T1/lec/multiple_file_C/slides
- https://www.cprogramming.com/compilingandlinking.html
- https://www.tutorialspoint.com/makefile/makefile_quick_guide.html
- https://www.gnu.org/software/make/manual/make.pdf
- https://en.wikipedia.org/wiki/Linked_list