SWEG2102 Fall 2026

Fundamentals of Programming II

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Lecture 04

Modular Programming (Part III)

Recursion and Modular Design

C++ **Standard ISO/IEC 14882**
Programming Language

Outline

Topics Covered

01 Recursion concepts

02 Recursive Function

03 Modular Design and Core Principles

04 Header Files and Code Reuse

05 Common Design Mistake & best Practices

Learning Objectives

By the end of this lecture, you will be able to:

- Describe recursion concepts and its application.
- Define and use recursive functions.
- Explain and apply modular design principles.
- Create header files and implement code reusing.
- Identify common pitfalls and apply best practices.

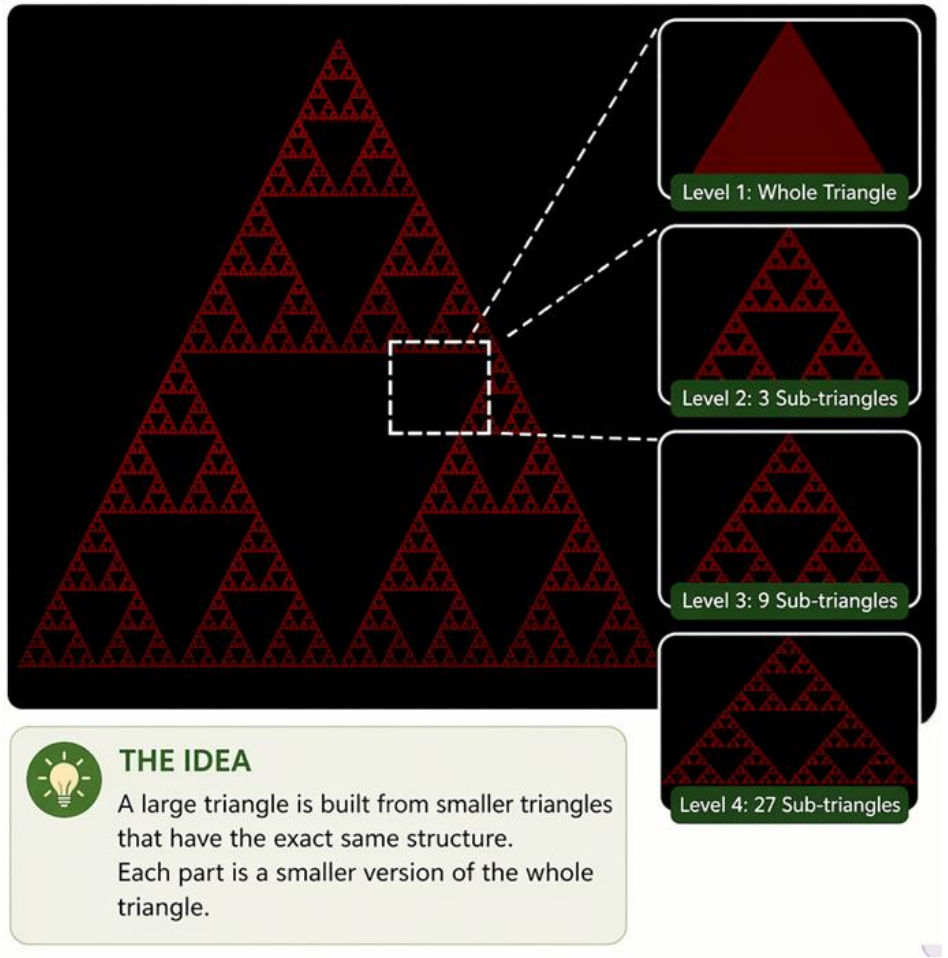
Recursive Concepts and Recursive Functions

1.1 Recursion Concepts

What is Recursion?

- Recursion is a **problem-solving technique** by breaking it down into **smaller instances, self-similar sub-problems**.
- The sub-problems become **simple enough** to solve directly.
- It is a **divide and conquer** method

Sierpiński Triangle:
the perfect example of recursion



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Recursive Thinking

🍎 Case Study: Counting Apples in a Line

Problem:

- You want to count how many students in a long line are holding an apple.
- But the you can’t count everyone directly (too many students).

Recursive Thinking Approach:

- Let’s use a **line of students** to show how recursion works in real life.
- The **goal** is to count how many students are holding an apple by **passing a simple question along the line**, allowing each student to **add their own contribution** to the final answer step by step.

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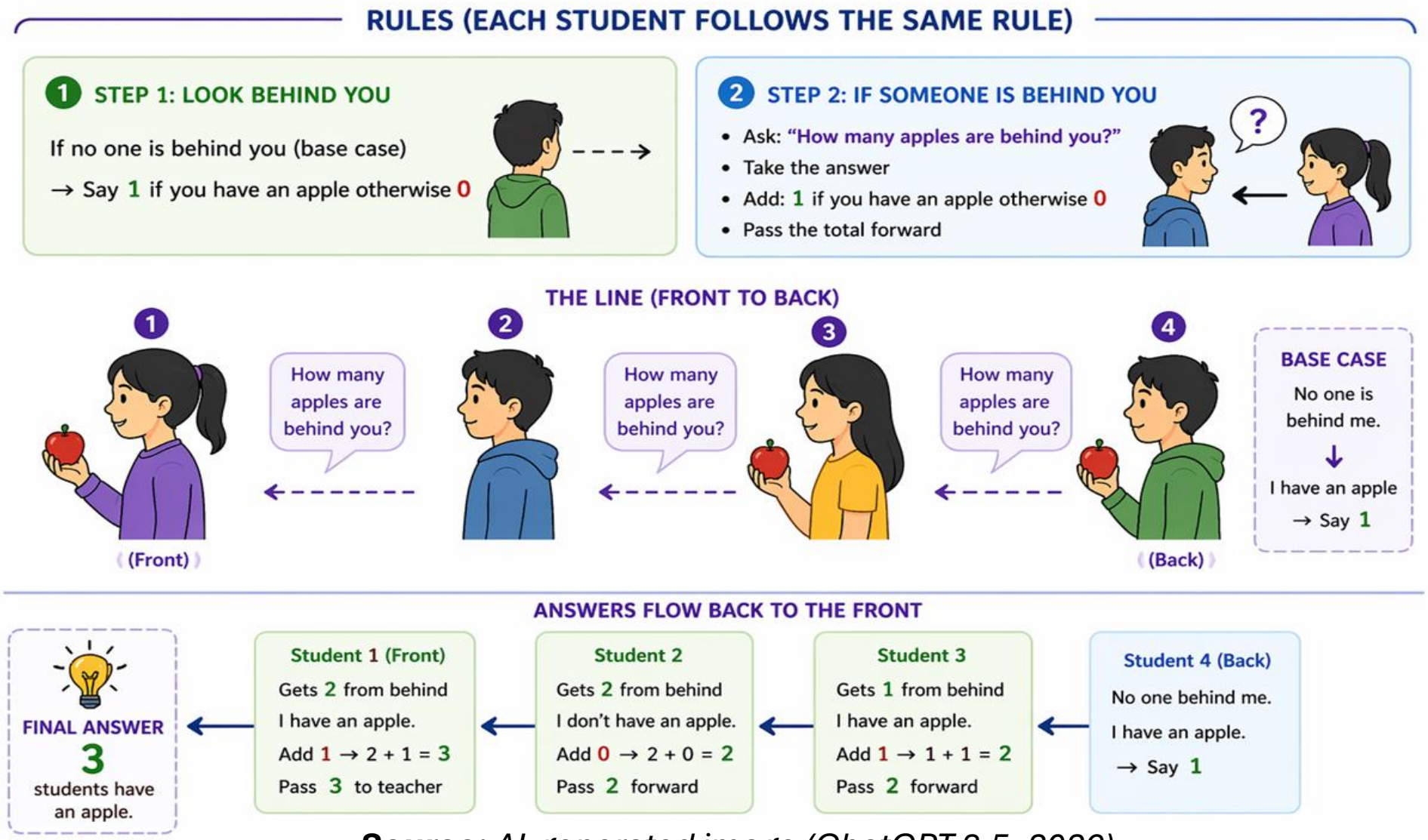
Solution:

Recursive Call



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Key Components of Recursion

1. Base Case

- ✓ The **stopping condition** of recursion
- ✓ It defines when the **process should end** and prevents **infinite repetition**.
- ✓ It is the **simplest version** of the problem
- ✓ It **does not call itself** and just it **directly returns** a result/solution

Example: *A student with no one behind them simply returns 0 or 1.*

2. Recursive Case

- ✓ This is the part where the **problem is broken down** into smaller sub-parts.
- ✓ The process **calls itself** with a smaller or simpler version of the problem
- ✓ It moves **closer to the base case** each time
- ✓ It **combines the result** from the recursive call with the current step

Example:
A student asks the next student:
"How many apples are behind you?".

Cont’d

Key Components of Recursion

3. Recursive Call

- ✓ This is the actual **self-referencing** step
- ✓ The process **invokes itself**
- ✓ Each call works on a **reduced problem** size
- ✓ Think of it as **passing the same question** forward in a chain (line).

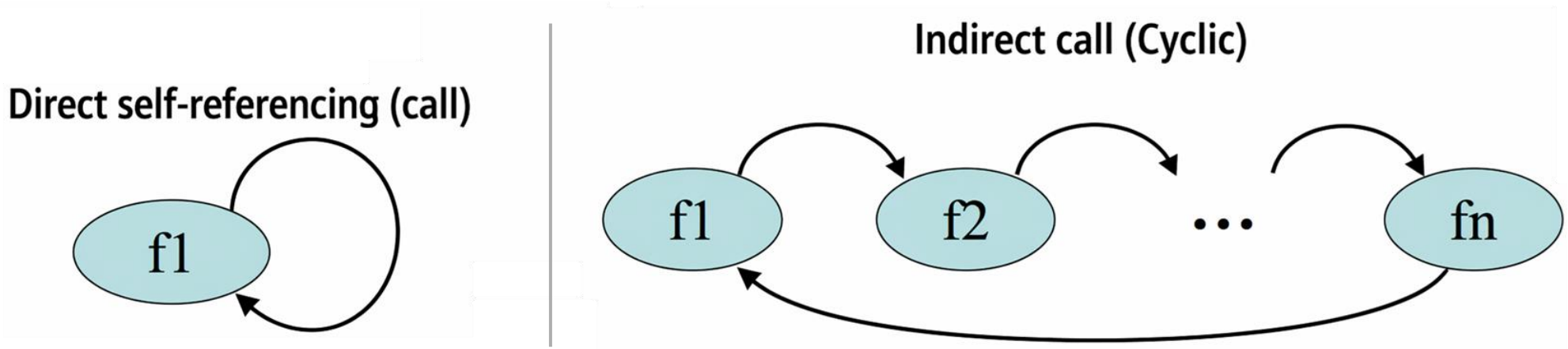
4. Stack / Call Stack Behavior

- ✓ Recursion **relies on memory** to keep track of unfinished work.
- ✓ Each call is **stored** until the base case is reached
- ✓ Once the **base case reached** and returns, results are passed back step by step
- ✓ This is why recursion “**returns backward**” after going forward.

1.2 Recursive Function

Definition

- A function that **calls itself** during execution directly or indirectly.
- Also called **self-referencing** functions
- Simply, it is a function that uses recursion
- And it comprising a **base case** and a **recursive case**



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How a Recursive Function Works?

- A **recursive function** solves a problem by **calling itself** with a **smaller version of the same problem** until it reaches a condition where it stops.
- A recursive function typically works in **two phases**:

Phase 1: Going Down (Breaking the Problem)

- The function keeps calling itself
- Each call moves closer to the base case
- The problem size keeps shrinking

Phase 2: Coming Back Up (Building the Result)

- Once the base case is reached,
- it returns a value
- Each previous call receives the result
- The final answer is built step by step

Cont'd

Recursive Program Structure

```
recursiveFunc() {
  // ✅ Base Case (Stopping condition)
  if (simple_case) {
    // Solve directly (no recursion)
    return solution;  //Recursion stops here and returns results
  }

  // 🔄 Recursive Case
  else {
    // 1. Break problem into smaller sub-problems
    smaller_inputs = divide(problem);

    // 2. Recursion Call: solve each subproblem using recursion
    partial_results = recursiveFunc(smaller_inputs);

    // 3. Combine results
    return combine(partial_results);

     //Repeat: Function calls itself with smaller input
  }              until base case is reached
}
```

1. Base Case

- ✓ Stops recursion
- ✓ Direct solution
- ✓ No further function calls

2. Recursive Case

- ✓ Breaks problem into smaller unit
- ✓ Calls itself again
- ✓ Combines results on return

3. Execution Flow

- ✓ ↓ going down
  => **problem decomposition**
- ✓ ↑ coming up
  => **result aggregation**

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Steps to Implement Recursion Function

Step1: Define a base case

- Identify the simplest (or base) case for which the solution is **known or trivial**.
- This prevents the function from infinitely calling itself.

Step2: Define a recursive case

- Define the problem in terms of smaller subproblems (breakdown into smaller unit).
- Call the function recursively to solve each subproblem.

Step3: Ensure the recursion terminates

- Make sure that the recursive function eventually reaches the base case, and does not enter an infinite loop

Step4: Combine the solutions

- Combine the solutions of the subproblems to solve the original problem.

Cont'd

Example 1: Digits Printing

- Implement a **recursive program** that print each digit of a given number,

  => Say, you given a number **2345**

Solutions:

Step 1: **Define Base Case**

- If the number (reminder) becomes **0**, stop recursion

Step 2: **Recursive Case**

- Break the number into separate digit:
  - Continuously divided remaining digits by 10

    → n / 10 and the last digit → n % 10

Step 3: **Ensure Termination**

- Each recursive call reduces the number:

  → 2345 → 234 → 23 → 2 → 0

  So it must eventually stop

Step 4: **Combine Results**

- First process smaller number
- Then print the last digit:

Cont'd

Recursive program to print digits of a number

```cpp
#include <iostream>
using namespace std;

void printDigits(int n) {
    if (n == 0)
        return; // Base Case

    printDigits(n / 10);    // Recursive Case

    cout << (n % 10) << "\n";    // Combine (print digit)
}

int main() {
    int number;

    cout << "Enter a number: ";
    cin >> number;

    // Handle zero case
    if (number == 0) {
        cout << 0;
    }
    else {
        cout << "\nOutput: ";
        printDigits(number);
    }

    return 0;
}
```

```
Enter a number: 2345

Output:
2
3
4
5
```

Phase 1: Going Down (Function Calls

The function keeps calling itself with n / 10:

```
printDigits(2345)
 └─ printDigits(234)
      └─ printDigits(23)
           └─ printDigits(2)
                └─ printDigits(0)  ← Base Case (stop)
```

Phase 2: Coming Back Up (Returning

```
printDigits(0)   → returns

printDigits(2)
 → prints: 2

printDigits(23)
 → prints: 3

printDigits(234)
 → prints: 4

printDigits(2345)
 → prints: 5
```

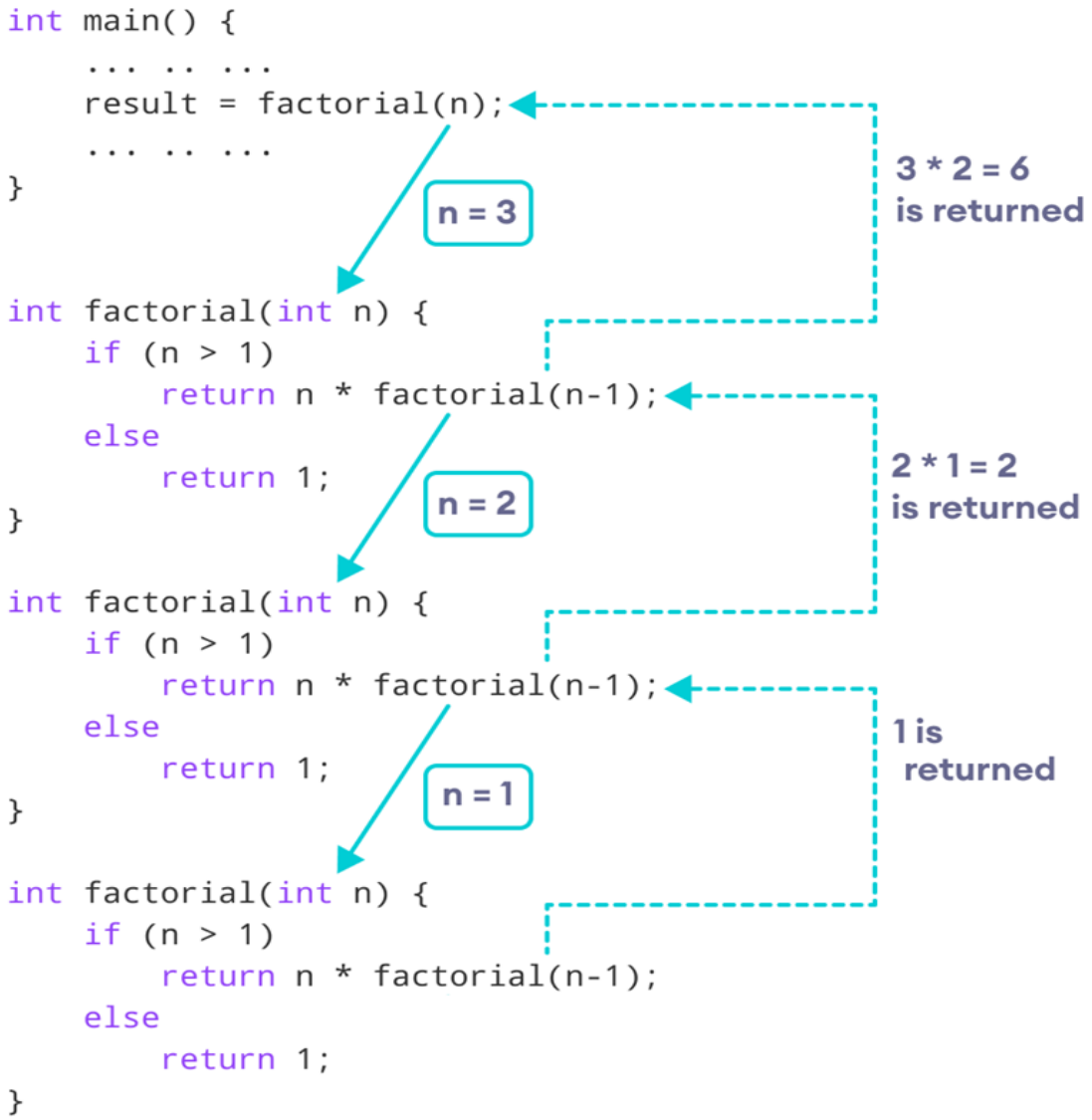
Cont'd

Example 2: Recursive Factorial

```cpp
#include <iostream>
using namespace std;

int factorial(int n) {

    if (n == 0 || n == 1) // Base case
        return 1;

    return n * factorial(n - 1);  // Recursive case
}

int main() {
    int n;

    cout << "Enter a number: ";
    cin >> n;

    if (n < 0) {
        cout << "Negative number has factorial.";
    } else {
        cout << "Factorial of " << n << " = " << factorial(n);
    }

    return 0;
}
```

Output

```
Enter a number: 5
Factorial of 5 = 120
```



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Example 3: Fibonacci Sequence

- Suppose the user wants to calculate the nth Fibonacci number.
- The Fibonacci sequence is: 0, 1, 1, 2, 3, 5,...
- Each number is the sum of the previous two numbers.

Solutions:

Step 1: Define Base Case

- If **n == 0** → return 0 & n == 1 → return 1
- These are the simplest known answers.

Step 2: Recursive Case

- The **nth** Fibonacci number is calculated recursively as follows:

fib(n) = fib(n-1) + fib(n-2)

- This formula allow us to break the problem into smaller subproblems:

Step 3: Ensure Termination

- Each recursive call reduces **n**. e.g. **n = 4**

4 → fib(3) & fib(2)

→ (fib(2) + fib(1)) + fib(2))

→ ((fib(1) + fib(0)) + fib(1) + (fib(1) + fib(0))

So recursion eventually stops.

Cont’d

Step 4: Combine Results

→ fib(2) = (fib(1) + fib(0)

= 1 + 0 = 1

→ fib(3) = fib(2) + fib(1)

= 1 + 1 = 2

→ fib(4) = fib(3) + fib(2)

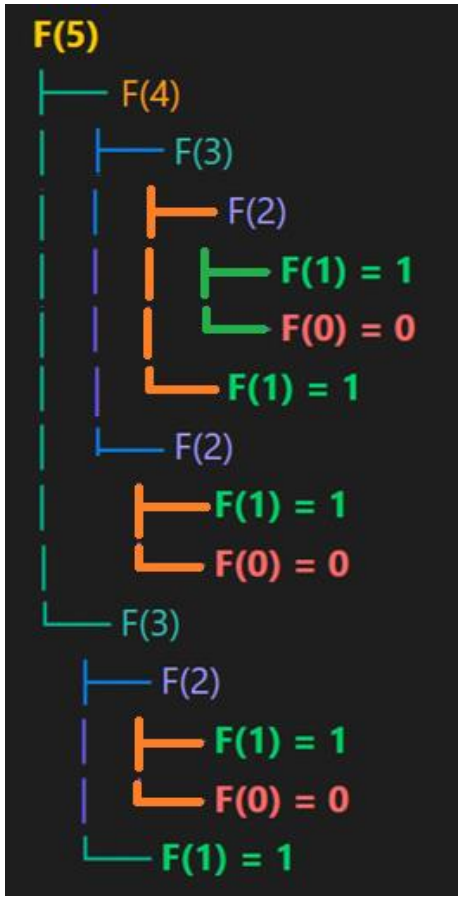
= 2 + 1 = 3

→ Answer: fib(4) = 3

Implementation in C++

```cpp
#include <iostream>
using namespace std;

int fibonacci(int n) {
    // Base cases
    if (n == 0)
        return 0;

    if (n == 1)
        return 1;

    // Recursive case
    return fibonacci(n - 1) + fibonacci(n - 2);
}

int main() {
    int n = 6;

    cout << "Fibonacci(" << n << ") = "
         << fibonacci(n);

    return 0;
}
```

Call Stack View



1.3 Use Cases

👉 Common Use Cases of **Recursion Function**:

✅ Data Structure Traversal

- It is the standard way to **navigate hierarchical or nested structures** like Binary Search Trees (BST), File System Operations, etc.

✅ Backtracking and Search

- Essential for exploring all possible solutions to a puzzle or decision tree and "backtracking" when a dead end is reached

✅ Divide-and-Conquer Algorithms

- Sorting algorithms like **Merge Sort and Quick Sort** rely on recursive partitioning.

✅ Mathematical Computations:

- Many mathematical problems like Factorials, Fibonacci Sequence etc. are inherently recursive, making them straightforward to implement this way.

1.4 Common Recursion Pitfalls

✕ Missing or Broken Base Cases

- ✓ No termination condition
- ✓ Forgetting a return particularly in the base case
- ✓ Leads to **infinite recursion** and stack overflow

✕ No Progress / Moving Out of Bounds

- ✓ Recursive calls don't move toward base
  e.g. **n+1** instead of **n-1**
- ✓ Same parameters passed in recursive call
- ✓ Also, leads to **infinite recursion** and stack overflow

✕ Wrong Returns

- ✓ Incorrect return values or combinations
- ✓ Wrong base case value or incorrect combine logic

✕ Side Effects

- ✓ Modifying external or global state inside recursive function
- ✓ Make debugging difficult and recursive call become hard to trace

✕ Stack Overflow

- ✓ Deep recursion logic consumes too much stack memory
- ✓ Cause program to crash when stack limit exceeds

Quick Check: Pause & Predict

1. What will happen when this function is called?

```
int fun(int n) {
    cout << n << " ";
    return fun(n - 1);
}
```

Answer: Error

→ *infinite recursion because no base cases.*

→ *The program will crash*

2. What happens if a recursive function has no base case?

A) Faster execution
B) Infinite recursion
C) Better memory usage
D) Compilation error

Answer: B

→ *The function keeps calling itself until the program crashes due to stack overflow.*

3. What happens first in a recursive function?

A) Base case is checked
B) Stack is emptied
C) Program ends
D) Return value is printed

Answer: A

→ *The stopping condition should be checked before making recursive calls.*

Modular Design and Its Core Principles

2.1. Modular Design Concepts

Definition

Modular design is a **software design technique** where a program is organized into well-structured, **independent, self-contained modules**, each handling a specific part of the system.

- *The core concepts is dividing a **complex system** into manageable parts that can **work independently.***

Goal: Manage complexity through structure

Emphasis: Design before coding

Why Modular Design?

A well-written code (function/module)
≠
a well-designed program

Modular design helps developers:

- Reduce program complexity
- Improve code readability
- Simplify debugging and testing
- Enhance maintainability
- Promote code reuse
- Enable team collaboration

Cont'd

Module Design Strategies

1. Top-Down Design Approach:

The design starts with the **whole system** and gradually breaks it into smaller modules.

- *Focuses on the big picture first*
  → high-level overview
- *Break down into sub-system/components*
  → Gradually adds detail
- *Move from general to specific*

2. Bottom-up Design Approach :

This approach starts by **creating small reusable modules/components** first and then combining them to form larger systems.

- *Build low-level modules first*
- *Test each modules separately*
- *Integrate individual modules step by step into higher-level components*
- *And eventually assemble the complete system*

Efficient for object-oriented systems.

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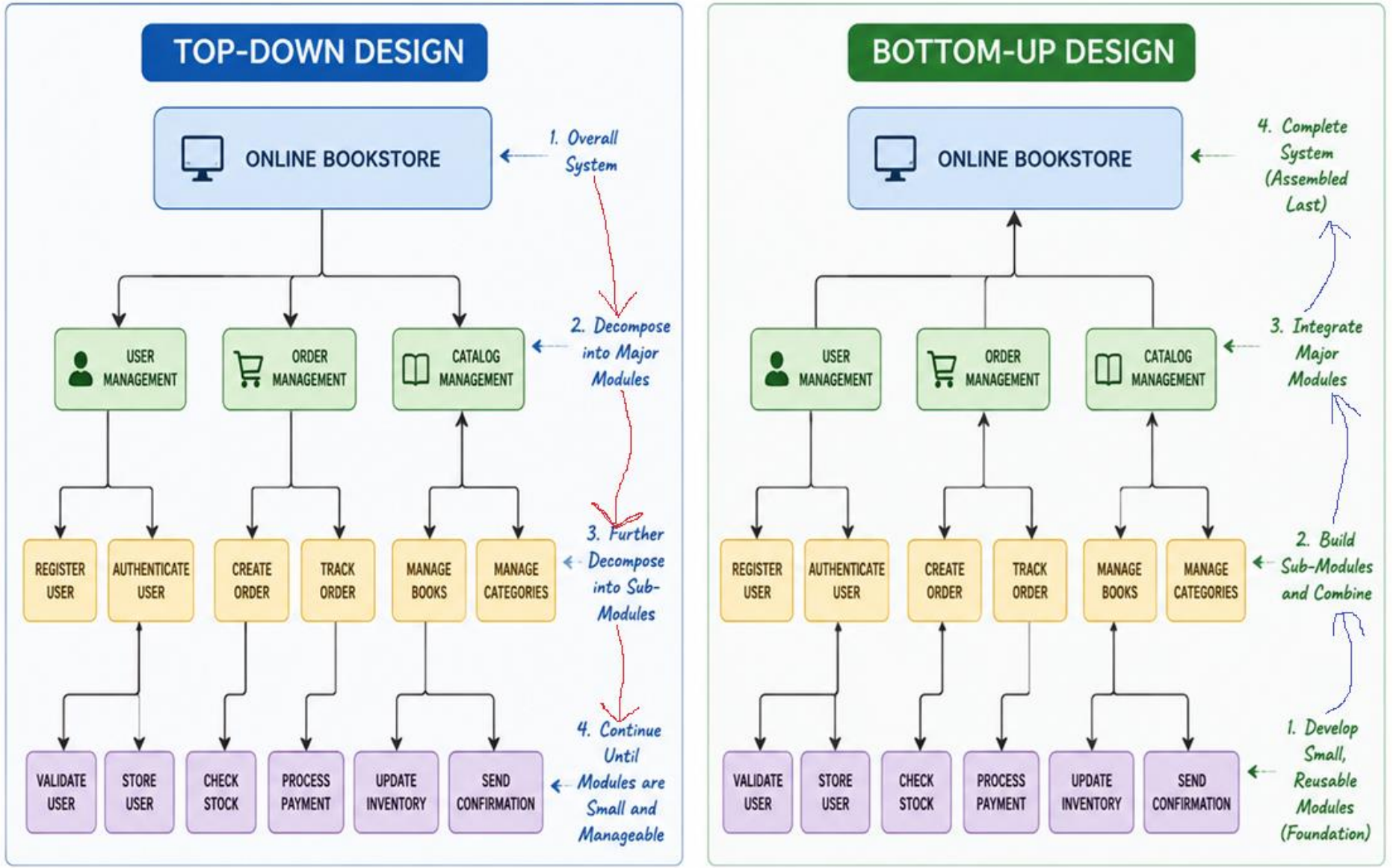
Visual illustration



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2.2 Core Principles of Modular Design

1. Decomposition:

- Break a large problem into smaller, manageable modules.
- Reduces complexity.
- Top-down or bottom-up approach.

2. Abstraction:

- Hiding unnecessary details.
- Focus on **what** a module does rather than **how** it does it.

3. Information Hiding (Encapsulation):

- Restricting direct access to module internals data.
- Bundling data & related operations together.

4. High Cohesion:

- Each module should perform one well-defined task.
- Easier testing, easier maintenance and better readability

5. Low Coupling:

- There should be have minimal dependencies between modules.
- A module should be able to perform its task with minimal interaction with other modules.

6. Reusability:

- Modules should be designed so that they can be reused in other systems.

Cont’d

Code Reuse (Reusability)

It is refers to the **ability to use existing software modules, or components** in multiple applications or different parts of a system without need to rewrite or redefine them.

Example:

A **discount calculation module** that used in an e-commerce system can also be reused in:

- *Supermarket software*
- *Hotel booking systems*
- *Restaurant billing systems*

Why it is important?

- Saves development time
- Reduces code duplication
- Improves consistency
- Simplify maintenance
- Increases productivity

Code reuse is more effective when software modules are designed with high cohesion and low coupling.

2.3 Header Files

Definition:

👉 **Header files** are **special files** in programming (mainly in C and C++) that contain *declarations of functions, classes definition, constants and macros, and type definition* which can be shared across multiple source files.

👉 In C/C++, header files usually have the extension:

```
</> C / C++
.h or .hpp
```

Why Header Files?

- ➤ Separate declaration from implementation
- ➤ Support modular programming
- ➤ Enable code reuse across multiple files
- ➤ Avoid writing the same code repeatedly
- ➤ Improve code organization
- ➤ Make programs easier to maintain

Cont'd

Example of a Header File

👉 **Create a reusable header file**

math_utils.h

```
#ifndef MATH_UTILS_H
#define MATH_UTILS_H

// Function declarations
// (reusable interface)

int add(int a, int b);
int subtract(int a, int b);
int multiply(int a, int b);
float divide(int a, int b);

#endif
```

👉 **Implement the functions**

math_utils.cpp

```
#include "math_utils.h"

// Function definitions
int add(int a, int b) {
    return a + b;
}

int subtract(int a, int b) {
    return a - b;
}

int multiply(int a, int b) {
    return a * b;
}

float divide(int a, int b) {
    if (b == 0) return 0;
    return (float)a / b;
}
```

👉 **Reuse in Program 1** (main_1.cpp)

```
#include <iostream>
#include "math_utils.h"

// Function usage in main program
int main() {
    cout<<"Sum: "<<add(10, 5)<<endl;
    cout<<"Product: "<<multiply(4, 6)<<endl;

    return 0;
}
```

👉 **Reuse in Program 2** (main_2.cpp)

```
#include <iostream>
#include "math_utils.h"

// Function usage in main program
int main() {
    cout<<"Difference: "<<subtract(10, 5)<<endl;

    return 0;
}
```

Practical Exercises

Practical Exercise:

Course Enrollment System Design

Objective

To design a College Course Enrollment System using **modular design principles** by decomposing the system into **input, processing**, and **output** modules.

The system should allow:

- *Allow students to select one or more courses.*
- *Verify prerequisite requirements.*
- *Check course capacity.*
- *Validate maximum credit-hour limits.*
- *Register eligible students.*
- *Display registration results and any validation errors.*

Your Task

Decompose the system into smaller modules by identifying:

1. Input Modules:

- *What data must be captured from users?*

2. Input Modules:

- What validation must be performed?
- What operations are required?

3. Output Modules:

- What information should be displayed?

Cont’d

Design Requirements

Abstraction:

- *What unnecessary details to hide?*

Encapsulation:

- *What internal details of a module to hide?*

Cohesion:

- *Identify the cohesion of each module.*

Coupling:

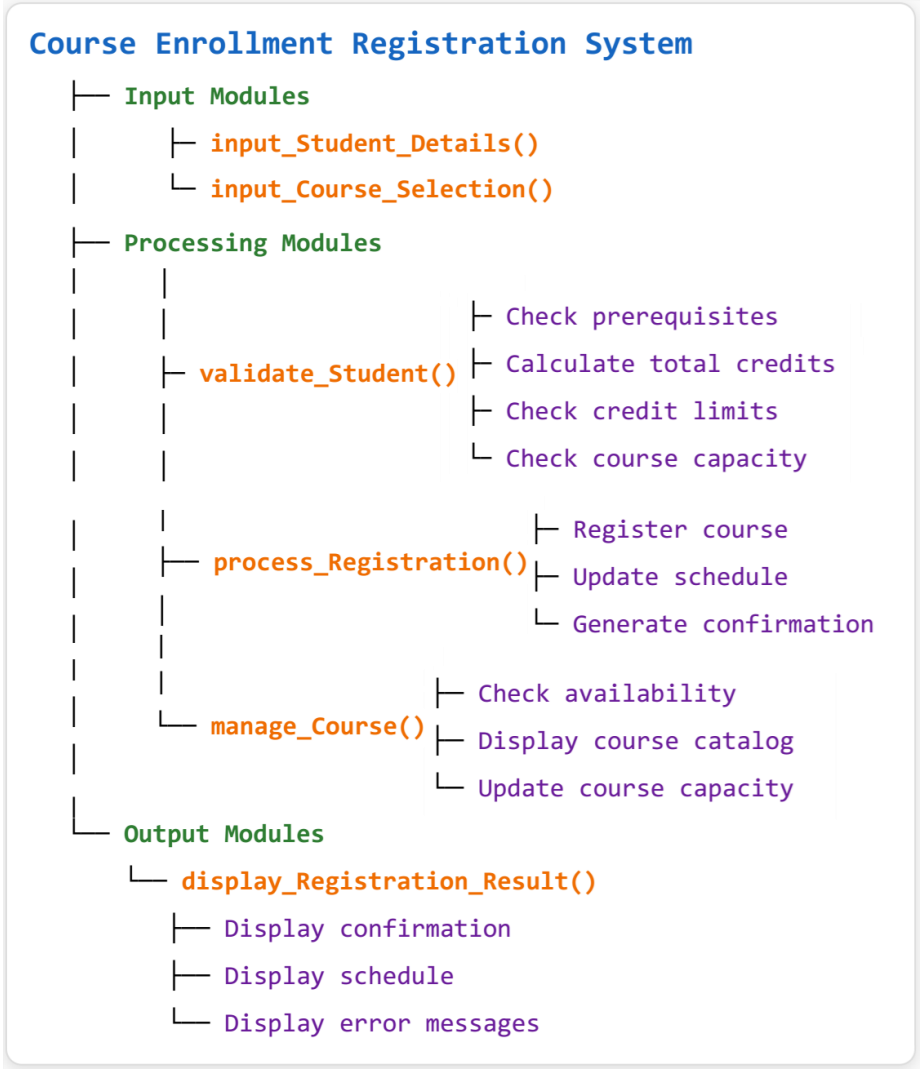
- *Identify any coupling between modules.*

Suggestion:

- *What improvements are required to achieve high cohesion and low coupling.*

System Decomposition & Module Identification

Solution



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Design Issues:

COHESION PROBLEMS

1. **validate_Student()** performs several unrelated validation tasks.
2. **manage_Course()** mixes processing and display responsibilities.
3. **display_Registration_Result()** handles multiple output responsibilities.

COUPLING PROBLEMS

1. **process_Registration()** depends heavily on **validate_Student()**.
2. **process_Registration()** relies on **manage_Course()**.
3. Changes in one processing module can affect several others.

Solution

High-Cohesion:

- *Ensure each module performs a single, well-defined responsibility.*

Low-Coupling:

- *Reduce heavy dependency among modules.*
- *Make modules interact through parameters and return values rather than sharing internal data.*

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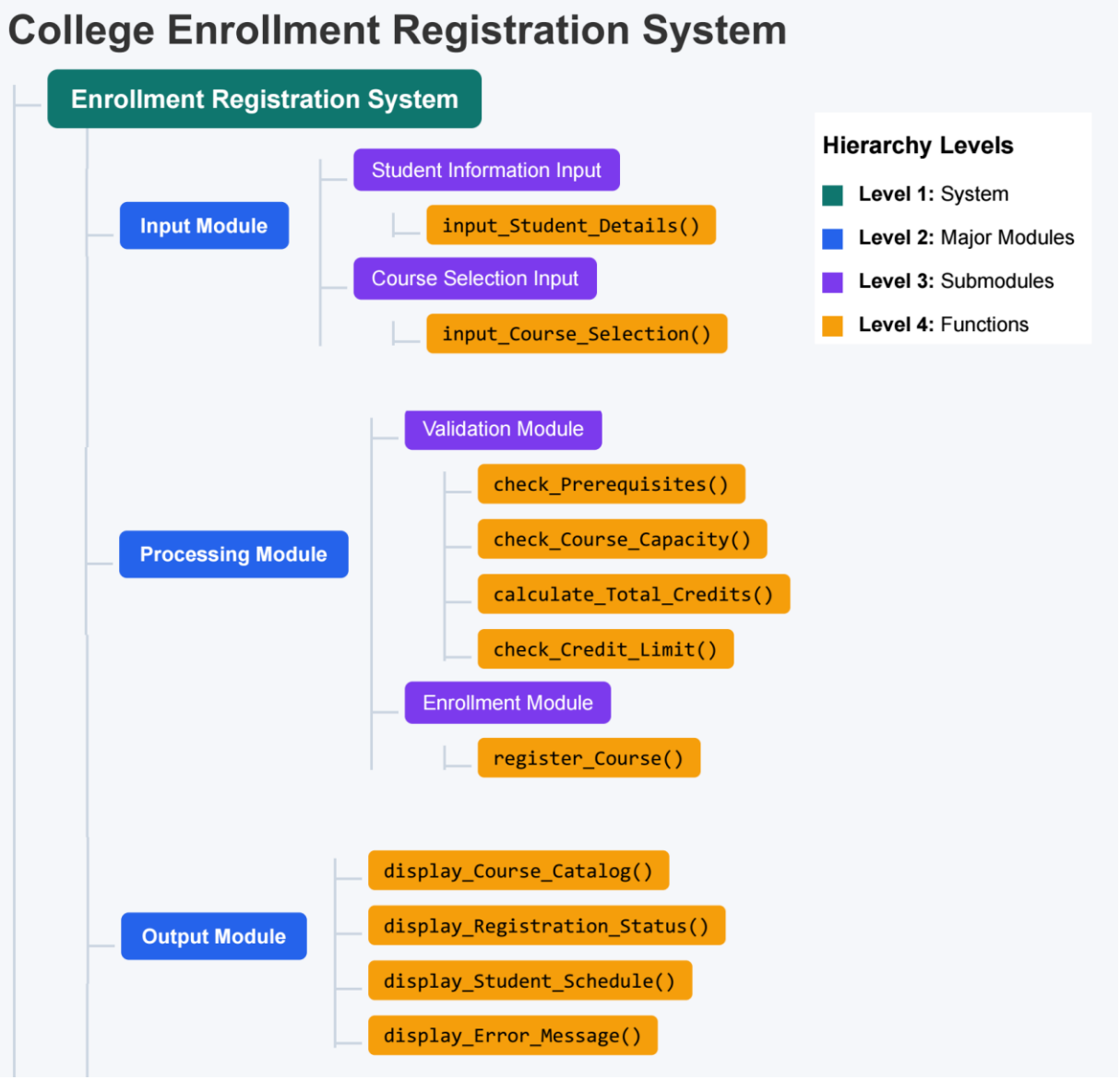
Refined

System Decomposition



High-Cohesion:

- *Each module focuses on a single responsibility.*

Low-Coupling:

- *Minimized dependency between modules*
- *Modules interact through parameters and return values*

References

Textbooks

- **C++ How to Program** [10th edition], Deitel, P. & Deitel, H., Global Edition, Global Edition (2017).
- **Problem Solving With C++** [10th edition], Walter Savitch, University of California, San Diego, 2018.

Reference Books

- **Programming: Principles and Practice Using C++** by Bjarne Stroustrup, Addison-Wesley, 2014.
- **An Introduction to Programming with C++** (8th Edition), Diane Zak, Cengage Learning, 2016

Online Resources

- https://www.geeksforgeeks.org/cpp/c-plus-plus/
- https://www.w3schools.com/cpp/default.asp
- https://programiz.pro/resources/cpp
- https://www.hackerrank.com/domains/cpp
- https://cplusplus.com/doc/tutorial/

💡 ***Study Tip:*** *Don't just read the code! Retype the examples from these slides and resources into your IDE, compile them, and modify them to see what happens.*

Thank You!

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