ENPM702

Introductory Robot Programming

L5: Functions

v1.0

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Semester/Year: Summer/2025

MARYLAND APPLIED
GRADUATE ENGINEERING

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Changelog

- **v1.0**: Original version.

Learning Objectives

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

- Understand function fundamentals including benefits, declarations vs definitions, and file organization with headers.
- Master function mechanics including calls, parameter passing (by value, reference, pointer), and proper documentation practices.
- Implement advanced function features including static variables, return value handling, function overloading, and default parameters.
- Analyze program execution using stack frames and implement recursive functions with proper base cases.

Introduction to Functions

A function is a named group of statements that can be executed as a unit.

- 🚀 F: Functions

Code Reusability

Write once, use everywhere! Functions eliminate the need to copy and paste code blocks (DRY = Don't Repeat Yourself). Create a function once and call it multiple times throughout your program.

```
int calculate_area(int length, int width) {
    return length * width;
}
// Use it anywhere:
int room1 = calculate_area(10, 12);
int room2 = calculate_area(8, 15);
```

Modularity & Organization

Break complex programs into smaller, manageable pieces. Functions help organize code logically, making it easier to understand and maintain large projects.

```
// Each function has a specific purpose
void get_user_input();
void process_data();
void display_results();

int main() {
    get_user_input();
    process_data();
    display_results();
}
```

Easier Debugging & Testing

Isolate problems quickly! When code is organized in functions, you can test and debug individual components separately, making bug fixing much more efficient.

```
// Test individual functions
bool is_valid_email(string email) {
    // Validation logic here
    return email.find("@") != string::npos;
}

// Easy to test:
is_valid_email("test@email.com")
```

Abstraction of Complex Operations

Hide complexity behind simple interfaces. Functions allow you to use complex operations without worrying about implementation details.

```
// Complex math hidden behind simple function
double calculate_interest(double principal, double rate, int years) {
    // Complex formula abstracted away
    return principal * pow(1 + rate, years);
}
```

Function Declarations

A function declaration (or prototype) consists of the return type, the function identifier, and optional parameters (types and names). The body of the function is not part of the header.

```
type identifier(<parameters>); // e.g., int add_numbers(int a, int b);
```

- `type` – What kind of value the function is expected to return to the calling function (the caller) or main program. When a function does not return anything, its `type` should be `void`.
- `identifier` – The name given to a function.

- We will use the same naming convention as for variables (snake_case).
- A function does an action, therefore, the identifier should include a verb.

- `<parameters>` – If the function takes parameters, the parameters are listed in the parentheses. Each parameter has the form `type identifier`. If the function does not use any parameter, the parentheses are left empty.

NL.25: Don't use void as an argument type

How are Function Declarations Used?

- The function declaration provides a promise that the function will be implemented (defined) elsewhere in the code, either later in the same source file or in a different source file.
- A function declaration allows you to use (call) that function before its actual definition in the code. This is particularly useful in scenarios where multiple functions call each other.
- During compilation, the linker will look for the actual definition of the function.

Exercise #1

1. Declare a function which sums two integers and returns the result.
2. Call this function in the `main()` function.
3. Generate the `.o` file: `g++ -std=c++17 -c lecture5.cpp -o lecture5.o`
   - `g++` : The GNU C++ compiler.
   - `-c` : Tells the compiler to generate the object file **without linking**.
   - `lecture5.cpp` : The source file you want to compile.
   - `-o lecture5.o` : Specifies the output object file name. If you omit the `-o lecture5.o`, it will default to `lecture5.o`.
4. Generate the executable: `g++ lecture5.o -o lecture5`
   - This command will link the object file `lecture5.o` and create an executable named `lecture5`. If you do not specify the `-o` option, the output will default to an executable named `a.out`.

Function Definitions

A function definition (often referred to as a function implementation) consists of the `return_type`, the `identifier`, the `parameters`, and the actual body of the function.

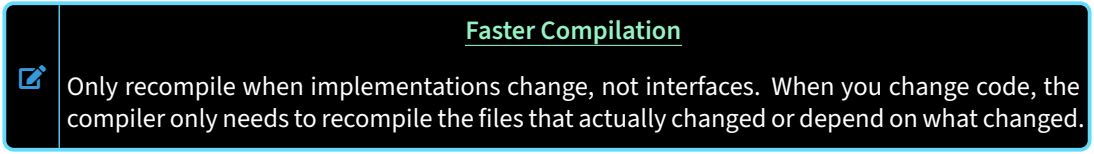
```
type identifier(<parameters>) {
    // body of the function
}
```

```cpp
// function declaration/prototype
int add_numbers(int a, int b);

// function definition/implementation
int add_numbers(int a, int b) {
    return a + b;
}

int main(){
    std::cout << add_numbers(3, 5) << '\n';
}
```

Header Files

Function declarations and definitions are usually split in different files. This separation improves modularity, maintainability, and code organization.

- Function declarations are located in header files (***.hpp**)
  - Header files are never compiled and always included.
- Function definitions are located in source files (***.cpp**)
  - Source files are always compiled and never included.


Faster Compilation
Only recompile when implementations change, not interfaces. When you change code, the compiler only needs to recompile the files that actually changed or depend on what changed.

Demonstration

- **Without headers (everything in one file)**

```
// big_file.cpp - 10,000 lines
void funcA() { /* implementation */ }
void funcB() { /* implementation */ }
void funcC() { /* implementation */ }
int main() { /* uses all functions */ }
```

Change one line in `funcA()` → entire 10,000-line file must be recompiled.

Demonstration

- With headers

```
// math.hpp
void funcA();
void funcB();
void funcC();
// math.cpp
#include "math.hpp"
void funcA() { /* implementation */ }
//  ... other implementations
// main.cpp
#include "math.hpp"
int main() { /* uses functions */ }
```

  - **Scenario 1**: Change implementation of `funcA()` in **math.cpp**
    - Only **math.cpp** gets recompiled **main.cpp** doesn't recompile because **math.hpp** (the interface) didn't change.
    - **main.cpp** still knows how to call `funcA()` from the unchanged header.
  - **Scenario 2:** Change `funcA()` signature in **math.hpp**
    - Both **math.cpp** AND **main.cpp** must recompile. Because the interface changed, everything that uses it needs updating.

Code Reuse

Header files let you declare something once and use it everywhere, avoiding duplication.

Demonstration

- **Without headers:** Declaration must be repeated.

```cpp
// file1.cpp
int add(int a, int b);  // declare it
int main() {
    int result = add(5, 3);  // use it
}
// file2.cpp
int add(int a, int b);  // declare it AGAIN
void some_function() {
    int x = add(10, 20);  // use it
}
```

- Problems:
  - Same declaration written 2 times.
  - If you change the function signature, you must update it in 2 places.
  - Easy to make mistakes and have mismatched declarations.

Demonstration

- **With headers:** Declare once, use everywhere.

```cpp
// math.hpp
int add(int a, int b);  // declare ONCE

// file1.cpp
#include "math.hpp"  // get the declaration
int main() {
    int result = add(5, 3);
}

// file2.cpp
#include "math.hpp"  // get the same declaration
void some_function() {
    int x = add(10, 20);
}
```

- Benefits:
  - Declaration written only once.
  - Change signature in one place, all files get the update.
  - Guaranteed consistency across all files.
  - Less typing, fewer errors.

Better Organization

Header files let you organize code into focused, logical units instead of having everything jumbled together.

Demonstration

- **Without headers:** Everything in one giant file.

```
// mess.cpp - 5000 lines
struct Customer { /* customer stuff */ };
void saveCustomer() { /* database code */ }
void loadCustomer() { /* more database code */ }

struct Product { /* product stuff */ };
void calculatePrice() { /* pricing logic */ }
void applyDiscount() { /* more pricing */ }

void sendEmail() { /* email code */ }
void logMessage() { /* logging code */ }

int main() { /* uses everything */ }
```

- Problems:
  - Hard to find specific functionality.
  - Customer code mixed with email code mixed with pricing.
  - Multiple developers stepping on each other.
  - Difficult to test individual parts.

Demonstration

- **With headers:** Organized into logical modules.

```cpp
// customer.hpp
struct Customer { /* */ };
void saveCustomer();
void loadCustomer();

// pricing.hpp
struct Product { /* */ };
void calculatePrice();
void applyDiscount();

// utils.hpp
void sendEmail();
void logMessage();

// main.cpp
#include "customer.hpp"
#include "pricing.hpp"
#include "utils.hpp"
int main() { /* clean and focused */ }
```

- Benefits:
  - **Find code faster** - need pricing logic? Look in pricing.hpp/cpp
  - **Clear responsibilities** - each module has one job.
  - **Easier maintenance** - bug in email? Only check utils.cpp
  - **Team workflow** - one person works on customer module, another on pricing.
  - **Selective inclusion** - only include what you need.

Function Calls

When a function is called, the execution of the program jumps to the function definition, runs the code inside the function, and then returns back to the point from where the function was called, continuing from the next statement.

Demonstration

- Line **15** – `main()` is called automatically.
- Line **16** – Control is passed to `print_hello()`.
- Lines **11**-**12** – The body of `print_hello()` is executed.
- Line **12** – Control is passed to `print_world()`.
- Line **7** – The body of `print_world()` is executed.
- Line **8** – Control is returned to `print_hello()`, which executes the remaining code.
- Line **13** – Control is returned to `main()`, which executes the remaining code.
- Line **18** – The program exits.

```
1  // function declarations
2  void print_hello();
3  void print_world();
4
5  // function definitions
6  void print_world() {
7      std::cout << "world\n";
8  }
9
10 void print_hello() {
11     std::cout << "hello, ";
12     print_world();
13 }
14
15 int main() {
16     print_hello();
17     std::cout << "exit main\n";
18 }
```

Exercise #2

Inspect the code.

```
void print_hello() {
    std::cout << "hello, ";
    print_world();
}

void print_world() {
    std::cout << "world\n";
}

int main() {
    print_hello();
    std::cout << "exit main\n";
}
```

Exercise #3

Inspect the code.

```
void prompt_user() {
    std::cout << "Enter a number: ";
    int num{};
    std::cin >> num;
    print_number(num);
}

void print_number(int number) {
    if (number == -1)
        return;

    if (number > 0)
        std::cout << "The number is: " << number << "\n";
    else
        prompt_user();
}

int main(){
  prompt_user();
}
```

Always provide function declarations.

- Projects can be very large and have many functions. You cannot afford spending time defining functions before other functions (see slide 25).
- Programs can contain cyclic references and there is no other way to solve them besides declaring functions (see slide 26).

Documentation

All functions must be documented (with Doxygen in this course). It is generally recommended to document function declarations rather than function definitions for the following reasons:

- The declaration of a function represents its interface (what the function does, its purpose, and how to use it). It is the part of the code that users of the function need to know about.
- Documenting declarations allows developers to understand how to use the function without having to navigate to its implementation (which may be in a separate source file).
- If you document both the declaration and the definition, you risk duplicating comments, leading to potential inconsistency if the comments in one place are updated but not the other.

Document function declarations (located in *.hpp files)

Do not document both function declarations and function definitions.

Example

```
/**
 * @brief Print the number @p number to the console
 *
 * @param number The number to be printed
 */
void print_number(int number);
```

Parameters vs. Arguments

The terms Parameters and Arguments are often used interchangeably. However, they do have distinct meanings.

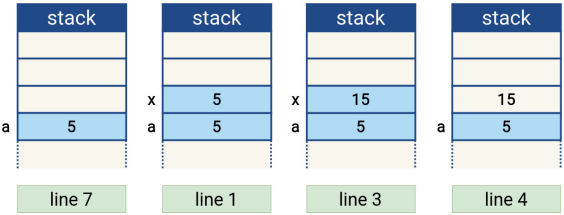
- Parameters (or formal parameters) are the variables listed in the function's declaration (or definition). They act as placeholders for the values that the function operates on.
- Arguments (or actual parameters) are the actual values that are passed to a function when it is called. They are substituted for the function's parameters when the function executes.

```
int add_numbers(int x, int y) {  // x and y are parameters
    return x + y;
}

int main() {
    std::cout << add_numbers(3,4) << '\n'; // 3 and 4 are arguments
}
```

Pass-by-Value

When an argument is passed by value, a copy of that argument's value is made, and the function receives that copy. Changes made to the parameter inside the function do not affect the original value outside of the function.

```
1  void add_ten(int x) {
2      // Implicit int x{a};
3      x += 10;  // 15
4  }
5
6  int main() {
7      int a{5};
8      add_ten(a);
9      std::cout << a << '\n'; // 5
10 }
```



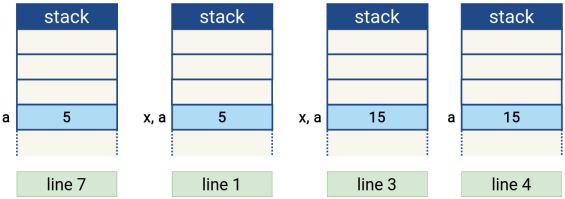
Pass-by-Value

- Memory – Since pass-by-value involves making a copy of the argument, it can be inefficient for large data structures as it consumes additional memory.
- Safety – Functions cannot modify the original data when using pass-by-value, making it a safer choice in scenarios where you want to ensure that the original data remains unchanged.
- Performance – For basic data types (`int`, `char`, etc), the overhead is minimal, and pass-by-value is common. However, for large objects, pass-by-reference or pass-by-const-reference is often preferred to avoid unnecessary copying and improve performance.

Pass-by-Reference

Unlike pass-by-value, where a copy of the argument's value is passed to the function, with **pass-by-reference**, the function receives a reference to the original data. This means any modification made to the parameter inside the function will reflect on the original value outside of the function.

```cpp
void add_ten(int &x) {
    // Implicit: int &x{a};
    x = x + 10;  // 15
}

int main() {
    int a{5};
    add_ten(a);
    std::cout << a << '\n'; //
     ↪  15
}
```



Exercise #4

Write the function `swap_values` which exchanges the values of two variables.

```
int main(){
    int x{5};
    int y{10};

    std::cout << x << ", " << y << '\n'; // 5, 10
    swap_values(x, y);
    std::cout << x << ", " << y << '\n'; // 10, 5
}
```

For future reference, the standard library provides `std::swap`

Example

```cpp
void push_ten(std::vector<int> &v) {  // Passed by reference
    // Implicit: std::vector<int> &v{num_vect};
    v.push_back(6);
}

int main() {
    std::vector<int> num_vect{1, 2, 3, 4, 5};
    push_ten(num_vect);
    for (const auto &item : num_vect) {
        std::cout << item << " ";  // 1 2 3 4 5 6
    }
    std::cout << '\n';
}
```

Pass-by-Reference

- Memory – Pass-by-reference is memory-efficient, especially for large data structures, as it avoids copying. Only the memory address (reference) is passed.
- Safety – Since functions can modify the original data when using pass-by-reference, you need to be cautious. This can lead to unintended side effects if not handled properly.
- Usage with `const` (see next slide) – If you want to pass an argument by reference but don't want to allow the function to modify it, you can use `const` before the reference type. This is called pass-by-const-reference and is common for efficient read-only operations on large data structures.
- Performance – Passing by reference is often faster for large data structures because it avoids the cost of copying. For basic types, though, the performance difference might be negligible.

Pass-by-const-Reference

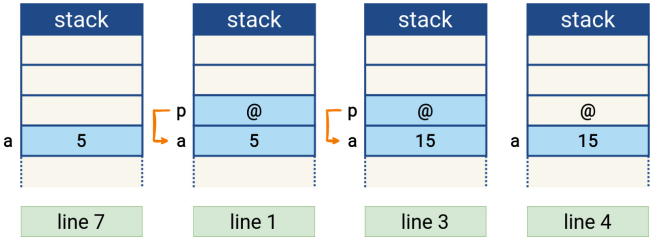
Pass-by-**const**-reference combines two concepts: passing by reference and the use of the **const** keyword. When you pass an argument by **const** reference, you pass a reference (i.e., the memory address) of the argument to the function, but the function is prohibited from modifying the data being referred to.

```
void print_vector(const std::vector<int> &v) {  // Passed by const reference
    // Implicit: const std::vector<int> &v{num_vect};
    for (const int &item : v) {
        std::cout << item << " ";  // 1 2 3 4 5
    }
    // v.push_back(100);  // This would be an error since v is const
}

int main() {
    std::vector<int> num_vect{1, 2, 3, 4, 5};
    print_vector(num_vect);
}
```

Pass-by-Pointer

Pass by pointer involves passing the memory address of a variable to the function.

```
1  void add_ten(int* p) {
2      // Implicit: int* p{&a};
3      *p += 10;
4  }
5
6  int main() {
7      int a{5};
8      add_ten(&a);
9      std::cout << a << '\n';  //
       ↪  15
10 }
```

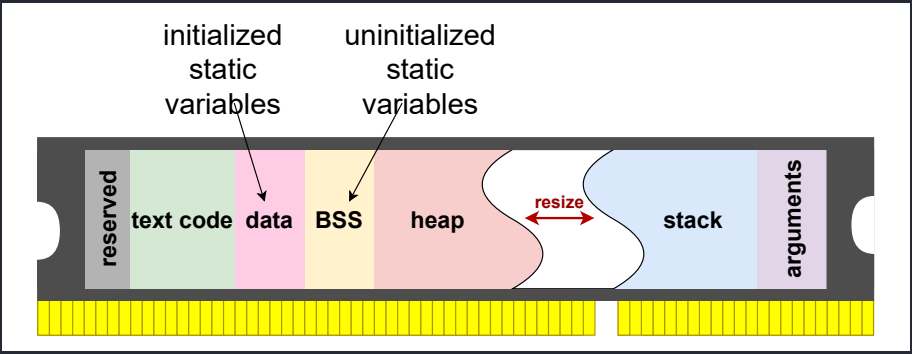


Pass-by-Pointer

- Null Pointers – One notable difference between references and pointers is that pointers can be null (pointing to no valid memory location). Before dereferencing a pointer inside a function, you should ensure it's not null.
- Safety – Because pointers can be null or can be inadvertently modified to point to invalid memory locations, there's an inherent risk when working with them.
- Usage – Pass-by-pointer is especially common in scenarios involving dynamic memory allocation with `new` (though modern C++ encourages the use of smart pointers).

Static Variables

A `static` variable is used to preserve the state of a function between different invocations. Unlike regular local variables, which get destroyed and recreated every time a function is called, a `static` variable remains in memory throughout the lifetime of the program.



Example

Count how many times a function is called.

```cpp
void count_calls() {
    // static variable
    static int count{0};
    count++;
    std::cout << count << " time(s)\n";
}

int main() {
    count_calls();  // 1 time(s);
    count_calls();  // 2 time(s);
    count_calls();  // 3 time(s);
}
```

- **Lifetime** – Static variables are initialized only once and retain their value between function calls. They exist until the end of the program execution.
- **Storage** – They are stored in the static storage area, not in the stack memory.
- **Default Value** – If a static variable is not explicitly initialized, it is automatically initialized to zero (or for its respective type).
- **Scope** – While the lifetime of a static variable is the entire program, its scope is limited to where it is defined.
- **Use Cases** – Counting the number of times a function is called, preserving values between function calls, or managing resources that should be shared across instances (OOP).

Exercise #5

Create a function `add_to_sum` that takes an integer and adds it to a running total. Also, print the running total in `add_to_sum`.

```
// Write the function add_to_sum here

int main() {
    add_to_sum(1); // 1
    add_to_sum(2); // 3
    add_to_sum(3); // 6
    add_to_sum(4); // 10
}
```

Returning Values

Functions in C++ must handle return values according to their declared return type:

- `void` **functions** do not return any value. The function ends when it reaches a `return;` statement or the closing brace.

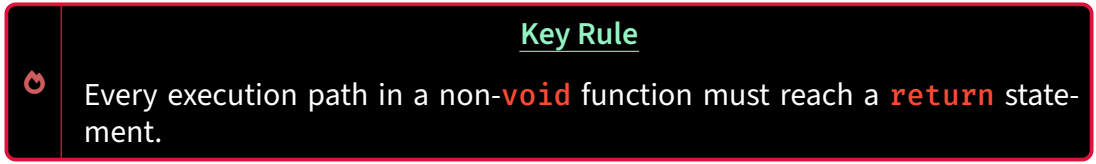
```cpp
void print_message() {
    std::cout << "Hello World\n";
    // No return statement needed
}
```

- **Non-`void` functions** must explicitly return a value of the specified type. Failing to return a value results in UB.
  - Incorrect - causes UB:

```cpp
int calculate_sum() {
    auto result{5 + 3};
    // UB - missing return statement
}
```

  - Correct - explicit return:

```cpp
int calculate_sum() {
    return 5 + 3;
}
```


Key Rule
Every execution path in a non-void function must reach a return statement.

Return-by-Value

Return-by-value means the function returns a copy of the value, not a reference or pointer to the original data. This is the default and most common way to return values from functions, particularly for fundamental data types.

```cpp
int add(int a, int b) {
    int sum{a + b};
    return sum;  // Returns copy of sum
}

int main() {
    int result{add(1, 2)};
    std::cout << result << '\n'; // 3
}
```

- The function `add` creates a copy of `sum`'s value and returns it to the caller.
- The local variable `sum` is destroyed when the function ends, but the returned copy persists.
- This returned value is used to initialize `result` in `main()`.
- **Key point:** Changes to `result` don't affect the original `sum` variable (which no longer exists anyway).

Copy Elision

Copy elision is a compiler optimization that eliminates unnecessary copying or moving of objects during function returns, parameter passing, and object construction.

Compiler Strategy for Return Values

1. **Copy Elision (RVO/NRVO):**
   - Constructs the object directly at the destination
   - **Return Value Optimization (RVO):** for temporary objects.
   - **Named Return Value Optimization (NRVO):** for named local objects.
   - Most efficient – no copying or moving required.
2. **Implicit Move:**
   - Moves the object instead of copying (from C++11).
   - Applies to local objects and rvalue expressions.
   - Much more efficient than copying for expensive objects.
3. **Copy Construction:**
   - Creates a copy of the object.
   - Fallback when elision and move are not possible.
   - Most expensive option for complex objects.
4. **Compilation Error:** If the object is neither copyable nor movable.

Return Value Optimization (RVO)

Return Value Optimization (RVO) is a compiler optimization that eliminates temporary objects created during function returns by constructing the return value directly at the caller's destination.

Since C++17, RVO is guaranteed for prvalue expressions (pure rvalues) - temporary objects created in `return` statements.

```cpp
std::vector<int> create_vector() {
    return std::vector<int>{1, 2, 3};
    //      ^^^^^^^^^^^^^^^^^^^^^^^^
    //      Prvalue - guaranteed RVO
}

int main() {
    std::vector<int> vect{create_vector()};
    // Construction directly in vect's location
}
```

- **Without RVO:** Function would create temporary vector, then copy/move it to `vect`
- **With RVO:** The vector `{1, 2, 3}` is constructed directly in `vect`'s memory location
- **Result:** No temporary object creation, no copy/move operations
- **Performance:** Eliminates potentially expensive copy/move operations for large objects

Named Return Value Optimization (NRVO)

Named RVO (NRVO) is a compiler optimization that eliminates copying/moving when returning a named local object by constructing it directly at the caller's destination.

Unlike RVO, NRVO is not guaranteed by the C++ standard - it's an optional optimization that compilers may or may not perform.

```cpp
std::vector<int> create_vector() {
    std::vector<int> local_vec{1, 2, 3};
    // ... potential operations on local_vec ...
    return local_vec;  // Named object return
}

int main() {
    std::vector<int> result{create_vector()};
}
```

- **With NRVO:** `local_vec` is constructed directly in `result`'s memory location.
- **Without NRVO:** `local_vec` is constructed locally, then moved/copied to `result`.
- **Detection:** Print the memory address for `local_vec` and `result`.
- **Limitations:** NRVO may fail in some situations.

Example: When Copy Elision Fails – Control Flow

```cpp
std::vector<int> conditional_return(bool flag) {
    std::vector<int> vec1{1, 2, 3};
    std::vector<int> vec2{4, 5, 6};
    return flag ? vec1 : vec2;  // NRVO fails!
}

std::vector<int> multiple_paths(int choice) {
    std::vector<int> result{};
    if (choice == 1) {
        result = {1, 2, 3};
        return result;          // NRVO fails!
    } else if (choice == 2) {
        result = {4, 5, 6};
        return result;          // NRVO fails!
    }
    return result;              // NRVO fails!
}
```

Why NRVO fails

- Compiler cannot determine at compile-time which object will be returned.
- Multiple named objects are potential return candidates.
- NRVO requires a single, unambiguous return object.

Example: When Copy Elision Fails – Assignment

```cpp
std::vector<int> create_vector() {
  std::vector<int> local_vect{1, 2, 3};
  std::cout << "&local_vect: " << &local_vect << '\n';  //@1
  return local_vect;
}

int main() {
  std::vector<int> v1{};
  v1 = create_vector(); // No copy elision
  std::cout << "&v1: " << &v1 << '\n';  //@2
}
```

Why NRVO fails

- Copy elision only works during object initialization, not assignment.
- Assignment sequence:
  1. Objects `v1` already exists (default constructed).
  2. Function returns temporary object.
  3. Assignment operator copies/moves temporary to `v1`.
  4. Temporary is destroyed.

Copy Elision Summary

- RVO: Eliminates temporaries - guaranteed C++ 17
- NRVO: Eliminates named object copies - optional
- Fails when: Assignment (not initialization), multiple return paths.
- Fallback: Move → Copy → Compile error.

Return-by-Reference

Return-by-reference means the function returns a reference (alias) to an existing object rather than a copy of the object.

- Returning by reference can be useful when you want to:
  - Allow the caller to modify the returned object directly.
  - Avoid the overhead of copying large objects.

Example

```cpp
// Function to return a reference to the element at a given index
int& get_element(std::vector<int>& vec, int index) {
  return vec[index];  // Returning a reference to the element
}

int main() {
  std::vector<int> my_vector{1, 2, 3, 4, 5};

  // Get a reference to the element at index 2
  int& ref = get_element(my_vector, 2);

  // Modify the element via the reference
  ref = 10;

  // Check the new value
  std::cout << my_vector[2] << '\n';
}
```

Example

```cpp
// Function to return a const reference to the element at a given index
const int& get_element(std::vector<int>& vec, int index) {
  return vec[index];  // Returning a reference to the element
}

int main() {
  std::vector<int> my_vector = {1, 2, 3, 4, 5};

  // Get a reference to the element at index 2
  const int& ref = get_element(my_vector, 2);

  // No intention of modifying the returned reference
  std::cout << ref << '\n';
}
```

Example

```cpp
// Function to return a reference to a static variable
int& f() {
  static int var{1};
  std::cout << var << '\n';
  return var;
}

// usage
int main() {
  f() = 5;           // 1
  auto& ref = f();   // 5
  ref = 10;
  f();  // 10
}
```

Potential Pitfall

Returning a reference to a local variable is **UB**

```cpp
int& get_value() {
    int local_value = 10;
    return local_value;  // Dangerous
} // local_value goes out of scope

int main() {
    int& ref = get_value();
    std::cout << ref << '\n';  // UB
}
```

Return Type Deduction

In C++14 and later, you can simply declare the return type of a function as `auto`, and the compiler will deduce the return type based on the return statement within the function.

```cpp
// Declaration
auto add(int a, int b);

// Definition
auto add(int a, int b) { return a + b; }

int main() {
    std::cout << add(2, 3) << '\n';
}
```

It is recommended to clearly write the return type instead of using return type deduction.

Return Type Conversion

When a function's return expression type differs from the declared return type, C++ performs type conversion to match the function signature.

```cpp
int truncate_double() {
    double value = 10.75;
    return value;         // 10.75 → 10 (truncated)
}

bool to_bool() {
    int value = 0;
    return value;         // 0 → false, non-zero → true
}

char to_char() {
    int ascii = 65;
    return ascii;         // 65 → 'A'
}
```

- Use explicit casts for clarity.
- Avoid narrowing conversions.
- Consider compiler warnings.
- Use appropriate return types.

Function Overloading

Function overloading is the ability to define multiple functions with the same name in the same scope, but with different parameters.

- The function called is determined at compile-time based on the number and types of arguments passed to the function.
- This allows functions to be tailored for different data types or different numbers of parameters while using a consistent name.

Uniqueness of Functions

The uniqueness of a function is characterized by the list of formal parameters.

```cpp
int add(int a, int b) { return a + b; }
double add(double a, double b) { return a + b; }
double add(int a, double b) { return a + b; }
double add(double a, int b) { return a + b; }
double add(double a, double b, double c) { return a + b + c; }

int main() {
  std::cout << add(2, 3) << '\n';            // add(int, int)
  std::cout << add(2, 3.5) << '\n';          // add(int, double)
  std::cout << add(2.5, 3) << '\n';          // add(double, int)
  std::cout << add(2.5, 3.2) << '\n';        // add(double, double)
  std::cout << add(2.5, 3.2, 4.75) << '\n';  // add(double, double, double)
}
```

The return type of the function is **NOT** considered for uniqueness in function overloading.

```
double return_value(double a) {
  return a;
}

int return_value(double a) { //Error: redefinition of 'return_value'
  return a;
}
```

Overload Resolution Process

1. **Exact Match** – The compiler first looks for an overload with parameters that match the types of the arguments in the function call exactly. If found, this overload is chosen.
2. **Promotion** – If an exact match isn't found, the compiler looks for a function where the argument can be promoted to match the parameter type.
3. **Standard Conversion** – If no promotions are suitable, the compiler looks for a function where the argument can undergo a standard type conversion to match the parameter type.
4. If none of the above can be applied, a compiler error is raised.

Example

```
int add(int a, int b) { return a + b; }
int add(int a, float b) { return a + b; }

int main() {
  std::cout << add(2, 3) << '\n';      // add(int, int) -- exact match
  std::cout << add(2, 3.5f) << '\n';  // add(int, float) -- exact match
}
```

Example

```
1 int add(int a, int b) { return a + b; }
2 int add(int a, float b) { return a + b; }
3 int add(int a, double b) { return a + b; }
4
5 int main() {
6   std::cout << add(2.5, 3) << '\n';   // add(double, int) -- ???
7   std::cout << add('h', false) << '\n';   // add(char, bool) -- ???
8 }
```

? Which overloaded functions will lines 6 and 7 call?

Default Parameters

Default parameters allow a function to be called without providing **one or more trailing parameters**

- If the user does not supply an explicit argument, the default value will be used.
- If the user does supply an argument, the user-supplied argument is used.

```
void add(int a, int b=0, int c=0){
    std::cout << a + b + c << '\n';
}

int main(){
    add(1);       // a=1, b=0, c=0
    add(1, 2);    // a=1, b=2, c=0
    add(1, 2, 3); // a=1, b=2, c=3
    add();        // Error: no matching function for call to 'add()'
}
```

Where to Declare Default Parameters?

Default parameters can be specified either in the declaration or in the definition, but not in both.

```
void add(int a, int b=0, int c=0); // Declaration with defaults
void add(int a, int b=0, int c=0){ // ERROR: Defaults repeated!
    std::cout << a + b + c << '\n';
}
```

Single Source of Truth Principle

Having defaults in multiple places could lead to inconsistencies. The compiler needs one authoritative source for default values.

1. Default parameters are specified ONLY in the declaration, not in the definition.
2. The definition should not repeat the default values.
3. If no separate declaration exists, defaults can be specified in the definition.

Default Parameters in Overloading

Default parameters can be used in overloading but they are not considered for uniqueness.

```
// COMPILATION ERROR: These are considered identical signatures!
void func(int a, int b);          // Signature: func(int, int)
void func(int a, int b = 5);      // Signature: func(int, int) - defaults ignored!
```

Default Parameters vs. Overloading

F.51: Where there is a choice, prefer default arguments over overloading

Example

```
int return_int(int a){
  return a;
}

int return_int(int a, int b){
  return a * b;
}
```

Example

```
int return_int(int a, int b=1){
  return a*b;
}
```

Stack Frame

A stack frame, often just called a **frame**, is a section of the stack segment that contains information about a single function call. When a function is called, its information is **pushed** onto the stack in a stack frame, and when the function returns, its stack frame is **popped off** the stack.

Exercise #6

1. Analyze the stack frames for the following program (manual).
2. Analyze the stack frames for the following program (debugger).

```
void f(int& x, int y, int z) {
  x += y + z;
}

int g(int a, int b) {
  int result{};
  result = a + b;
  f(result, a, b);
  return result;
}

int main() {
  int x{10};
  int y{20};
  int z{};
  z = g(x, y);
  std::cout << z << '\n';
}
```

Recursive Functions

A recursive function is a function that calls itself, either directly or indirectly, in order to achieve a task. Recursive solutions are often used for problems that can be naturally divided into subproblems of the same kind.

When designing recursive functions, there are two main components to consider:

- Base Case(s) – These are conditions under which the function will not call itself, preventing infinite recursion. The base case offers a definitive answer without further recursion.
- Recursive Case(s) – This is where the function calls itself, usually with a modified version of the original input.

Example

```cpp
long long factorial(int n) {
    if (n <= 1) return 1;       // Base case: 0! or 1! is 1
    return n * factorial(n-1); // Recursive call
}

int main() {
    int n{};
    std::cout << "Enter a number: ";
    std::cin >> n;
    std::cout << "Factorial of " << n << " is " << factorial(n) << '\n';
}
```

The main Function

The `main` function is the entry point of the program.

```
int main();
```

or

```
int main(int argc, char *argv[]);
```

- `argc` stands for argument count. It represents the number of command-line arguments passed to the program, including the program's name itself.
- `char *argv[]` stands for argument vector. This is an array of character pointers that represents the actual command-line arguments passed to the program.
- The `main()` function returns an `int`. By convention, `return 0;` indicates successful execution and `return 1;` (or other non-zero values) indicates an error.
  - If you don't provide a return statement, the compiler will implicitly insert `return 0;` at the end of the function.

Example

```
int main(int argc, char *argv[]) {
    std::cout << "Number of arguments: " << argc << '\n';
    for (int i{0}; i < argc; i++) {
        std::cout << "Argument " << i << ": " << argv[i] << '\n';
    }
}
```

- ./lecture5 hello 1 2 world 3

Next Class

- Lecture6: Smart Pointers.