COMP 2012H Honors Object-Oriented Programming and Data Structures

Topic 4: Function

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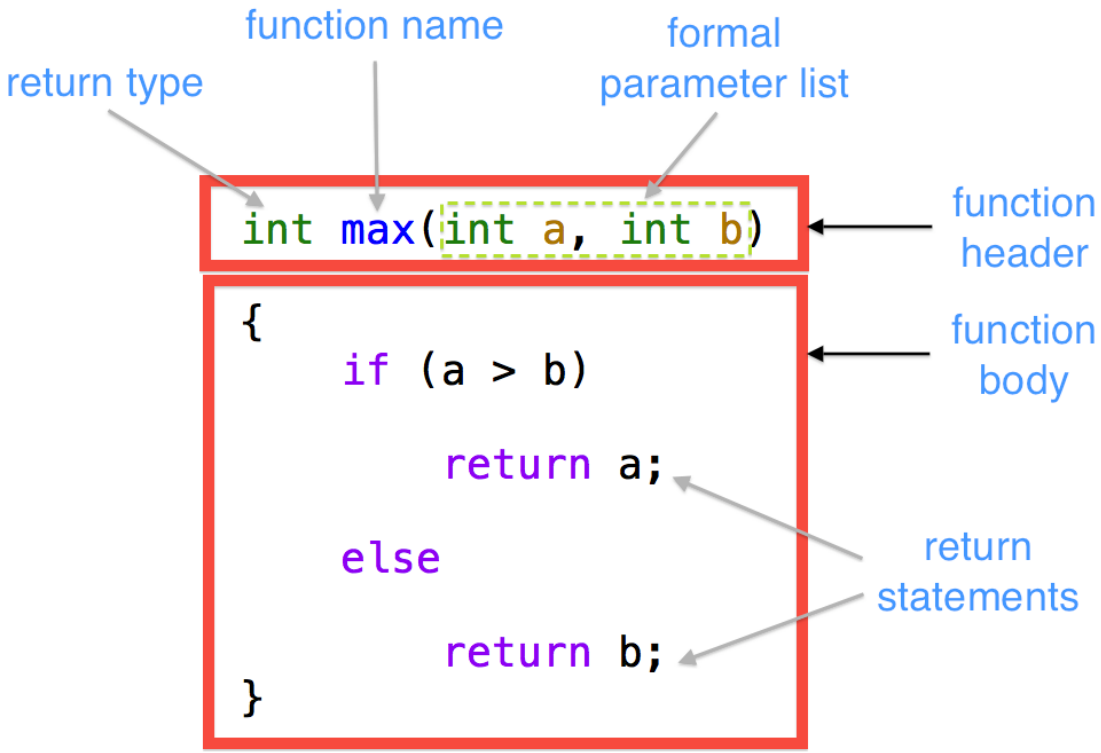
Part I

Function Basics



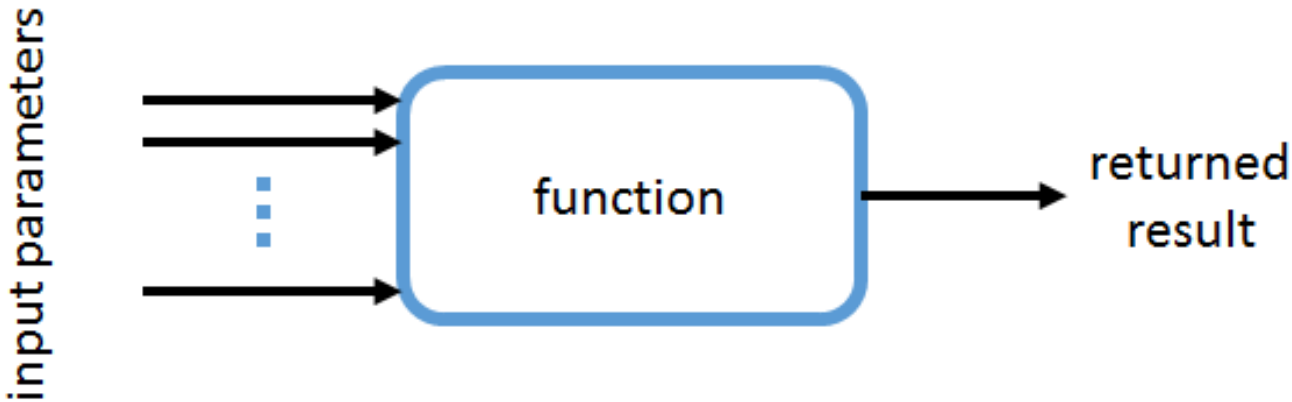
Basic Function Syntax

Syntax: Function Definition

<return-type> <function-name> (<formal-parameter-list>)
{ <function-body> }

Syntax: Function Call

<function-name> (<actual-parameter-list>)



Function Name

- Any legal C++ identifier can be used for <function-name>.
- Just like naming variables and constants, you should use meaningful names for function names.
  - The name should describe what the function does.
- The function name "main" is reserved; you must define it, and define it exactly once.
  - Recall that each program can only have one "main( )" function.
  - When a program is run, the shell — command interpreter of the operating system — looks for the "main( )" function and starts execution from there.

Formal Parameter List & Actual Parameter List

- <formal-parameter-list> appears in the function definition, and is basically a list of variable declarations separated by commas.

Syntax: <formal-parameter-list>

$< type_1 \ variable_1 >, < type_2 \ variable_2 >, \cdots, < type_N \ variable_N >$

- <actual-parameter-list> appears in a function call, and is a list of objects separated by commas that are passed to the called function.

Syntax: <actual-parameter-list>

$< object_1 >, < object_2 >, \cdots, < object_N >$

- There is a one-to-one correspondence between the actual parameters (aka arguments) and the formal parameters.

Formal Parameter List & Actual Parameter List ..

- During the function call, the following initializations are performed,

$$
\begin{aligned}
&< type_1 \ variable_1 >= object_1, \\
&< type_2 \ variable_2 >= object_2, \\
&\vdots \\
&< type_N \ variable_N >= object_N
\end{aligned}
$$

- Since C++ is a strongly typed programming language, the data types of an actual parameter and its corresponding formal parameters must be the same.
- A C++ compiler will perform type checking to make sure that their types match with each other.
- Exception: unless an automatic type conversion — coercion — can be done, just like normal initialization or assignment of an object to a variable of a different type. (More later.)

Function Header & Function Body

- In <return-type> <function-name> (<formal-parameter-list>)
  is also called the function header, and the rest is the function body enclosed in curly braces.
- The <function-body> usually consists of the following parts:
  - constant declarations
  - variable declarations and definitions
  - other C++ statements
  - return statement
- It is legal to have an empty function body!
- The curly braces must be there, even if there is only one single statement inside the function body! (That is different from the if-statement or while-statement, etc.)

Return Type

- Usually a function returns something — in C++, we call it an object.
- The returned object may be
  - a signal to tell the caller about the status of the function: does it run successfully? does it fail?
  - the result of some computation. e.g. factorial, sum, etc.
  - a new object created by the function. e.g. a new window.
- <return-type> specifies the data type of the single returned object.
- <return-type> can be any of the C++ built-in data types (e.g., char, int, etc.) or user-defined types, except the array type. (Array type will be talked later.)

Question: Since only a single object is returned by a function, how can you return multiple objects back to the caller?

return Statement

Syntax: return Statement

return < *expression* > ;

- The return statement generally returns "2" things to the caller:
  - program control: it stops running the called function, and the function caller takes back the control and continue its execution.
  - an object: the object (or value) represented by the < *expression* > is returned to the caller.
- The value of < *expression* > in the return statement should have the same type as the <return-type>. Or, if it can be converted to the <return-type> by coercion, otherwise it will be a compilation error.
- If a function has a return value, the function body must have at least one return statement.

Example: max

```
#include <iostream>      /* File: max.cpp */
using namespace std;          /* To find the greater value between x and y */

int max(int a, int b)
{
    if (a > b)
            return a;
    else
            return b;
}   // Question: can you write with only 1 return statement?

int main()
{
    int x, y;
    cout << "Enter 2 numbers: ";
    cin >> x >> y;

    cout << "The bigger number is " << max(x, y) << endl;
    return 0;
}
```

void: a New Type

- "void" means *nothing*, *emptiness*.
- A function that returns nothing back to the caller has a return type of void.
- A function that does not take any arguments from the caller may
  - leave the <formal-parameter-list> empty.

```
int fcn_example( ) { ... }
```

  - put the <formal-parameter-list> as void.

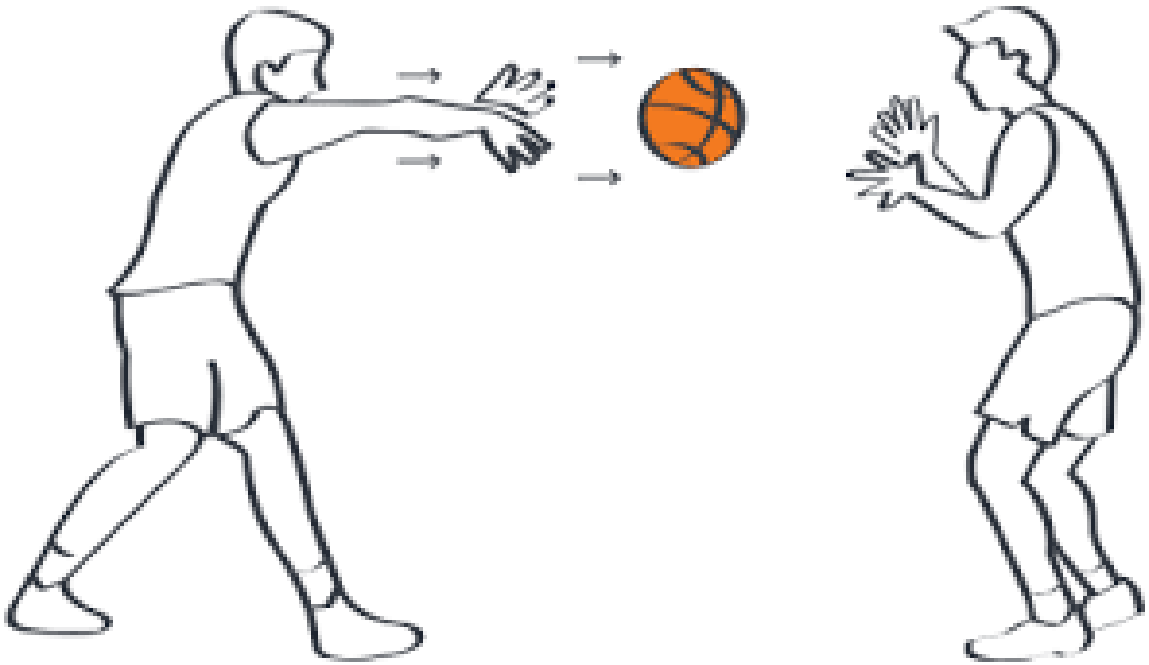
```
void print_hkust(void) { cout << "hkust" << endl; }
```

Remarks: Why Function?

- When you have several segments of codes doing similar things, then they are good candidates for a function.
- A function allows "write-once-call-many": you only write it once they can be called several times in the same program with the same or different arguments.
- Functions make programs easier to understand.
- Functions make programs easier to modify.
- Functions allow reusable code. (e.g. log, sqrt, sin, etc.)
- Functions separate the concept (what is done) from the implementation (how it is done).
- The last two remarks lead to the creation of binary libraries which are a set of compiled functions. These libraries can be shared, yet the users do not know their implementation. (You'll learn how to do this later.)

Part II

Parameter Passing Methods



How Actual Parameters are Passed to Formal Parameters

Actual Parameter		Formal Parameter
$object_1$	$\longrightarrow$	$variable_1$
$object_2$	$\longrightarrow$	$variable_2$
$\vdots$	$\vdots$	$\vdots$
$object_N$	$\longrightarrow$	$variable_N$

- C++ supports 2 ways to pass arguments to a function:
  1. pass-by-value (PBV), or call-by-value
  2. pass-by-reference (PBR), or call-by-reference
- Notice that if you call a function with an expression, the expression is first evaluated, and the result is then passed to the function.
  e.g. $\boxed{\max(3+5,\ 2+9)} \rightarrow \boxed{\max(8,\ 11)}$ before calling the max function.

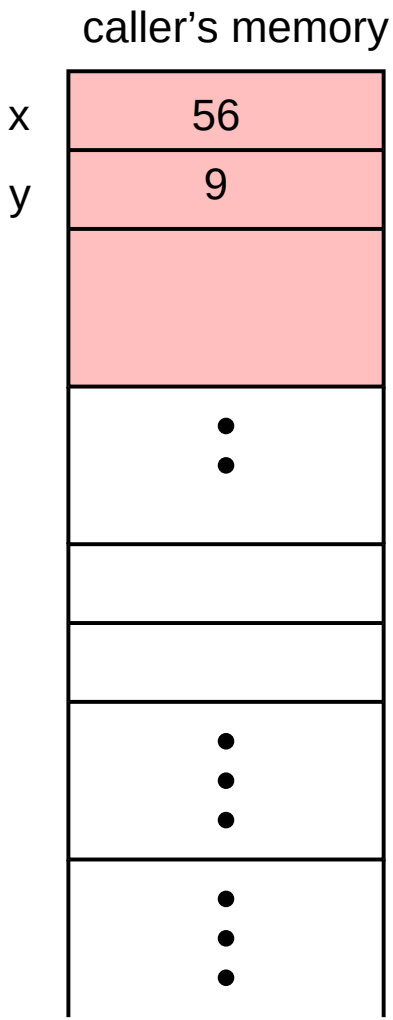
Pass-by-Value

- In pass-by-value, the value of an actual parameter is copied into the formal parameters of the function.
- If the actual parameter is a literal constant (e.g. calling `max(2, 3)`), obviously it won't change.
- If the actual parameter is a variable (e.g. calling `max(x, y)`), only its value is copied to the function, otherwise it has nothing to do with the operation of the function. In particular, its value cannot be modified by the function.
- All the function examples presented so far use pass-by-value to pass the arguments.

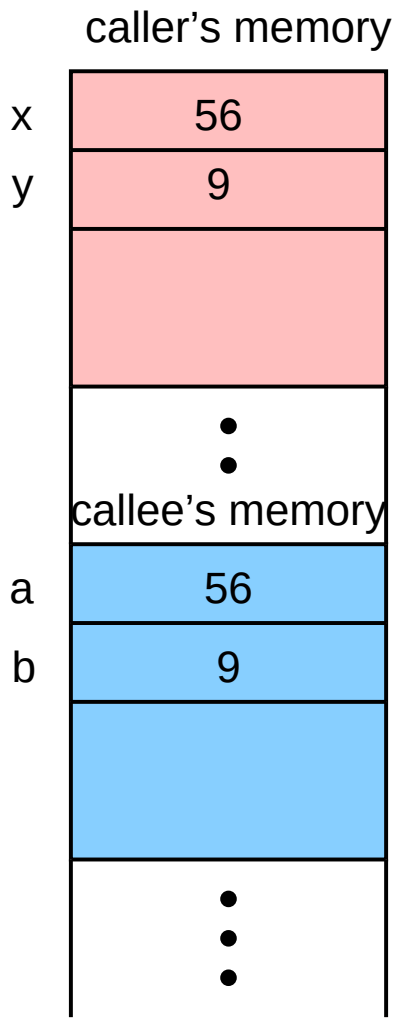
Question: What happens if the argument is a big object (e.g. of several MB)?

Pass-by-Value Illustration

Before calling max(x, y)



After calling max(x, y)



Reference Variable

Syntax: Reference Variable Definition

<type>& <variable$_1$> = <variable$_2$ >;
<type> &<variable$_1$> = <variable$_2$ >;
...

- A reference variable is an alias of another variable.
- A reference variable must always be bound to an object. Therefore, it must be initialized when they are defined.
- Once a reference variable is defined and bound with a variable, you cannot "re-bind" it to another object.

In the example,

- Variables a, x, w all refer to the same integer object; similarly, variables b, y, z also all refer to the same integer object.
- Variables a, x, w share the same memory space, so that you may modify the value in that memory space through any of them! (Same for b, y, z.)
- In the line `z = a;`, the reference variable z is not re-bound to a, but the value of a is assigned to z.

Example: Reference Variables

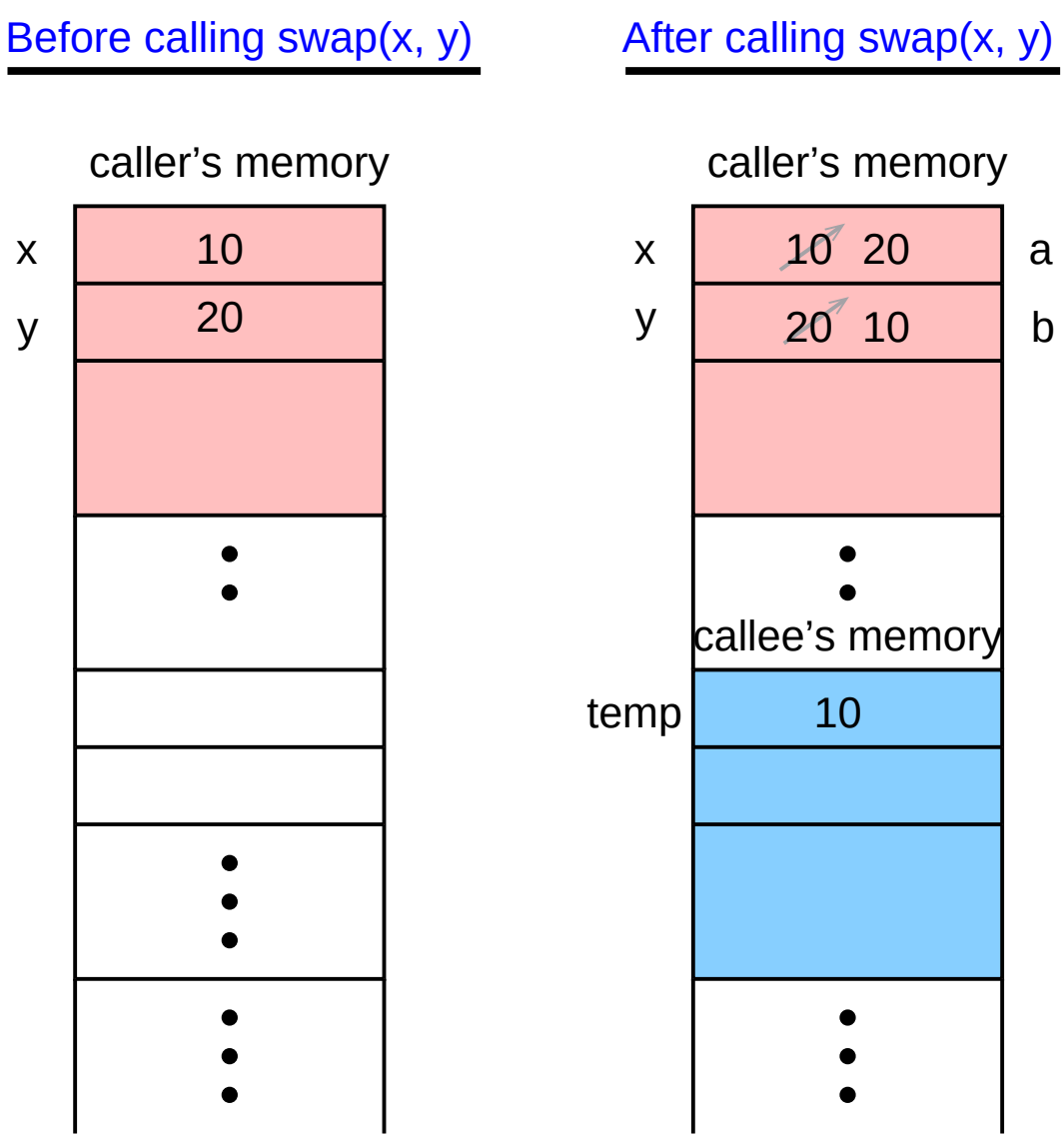
```cpp
#include <iostream>     /* File: ref-declaration.cpp */
using namespace std;

int main()
{
    int a = 1, b = 2;
    int& x = a;          // now x = a = 1
    int &y = b;          // now y = b = 2
    int &w = a, &z = y; // now w = a = x = 1, z = b = y = 2

    a++; cout << a << '\t' << x << '\t' << w << endl;
    x += 5; cout << a << '\t' << x << '\t' << w << endl;
    a = w - x; cout << a << '\t' << x << '\t' << w << endl;

    y *= 10; cout << b << '\t' << y << '\t' << z << endl;
    b--; cout << b << '\t' << y << '\t' << z << endl;
    z = 999; cout << b << '\t' << y << '\t' << z << endl;

    z = a;               // that is not re-binding z to a
    cout << b << '\t' << y << '\t' << z << endl;
    return 0;
}
```

Pass-by-Reference Example: swap

```
/* File: pbr-swap.cpp */
#include <iostream>
using namespace std;

void swap(int& a, int& b)
{
    int temp = a;
    a = b;
    b = temp;
}

int main()
{
    int x = 10, y = 20;
    swap(x, y);
    cout << "(x , y) = " << '(' << x
         << " , " << y << ')' << endl;
    return 0;
}
```

```
// execution of swap is
// equivalent to running
// the following codes
int& a = x;
int& b = y;
int temp = a;
a = b;
b = temp;

// OR, equivalently
int temp = x;
x = y;
y = temp;
```

Pass-by-Reference Illustration



Pass-by-Reference

- Pass-by-reference does not copy the value of actual parameters to the formal parameters of the function.
- When an actual parameter is passed by reference, its corresponding formal parameter becomes its reference variable (alias).
- In the swap example, on entering the swap function, the following codes are run: `int& a = x;` `int& b = y;` That is, the formal parameters *a* and *b* are declared as reference variables and are initialized or bound to their corresponding actual parameters *x* and *y* respectively.
- You must add the symbol "&" after the type name of the formal parameter if you want pass-by-reference.
- When an actual parameter is passed by reference to its formal parameter, since they share the same memory, any modification made to the formal parameter also changes the value of the corresponding actual parameter.

Remarks ...

- All the local variables defined inside a function, including the formal parameters, are destroyed on return of the function call.
  - These local variables are created every time the function is called.
  - These local variables created on the current call are different from those created in the previous calls.
  - However, if a formal parameter is a reference variable, only itself is destroyed when the function returns, the variable (actual parameter) bound to it still exists afterwards.
- Pass-by-reference is more efficient when a large object has to be passed to a function as no copying takes place. However, there is a risk that you may accidentally modify the object.

Question: Is there a way to pass a large object to a function such that the function cannot modify its value?

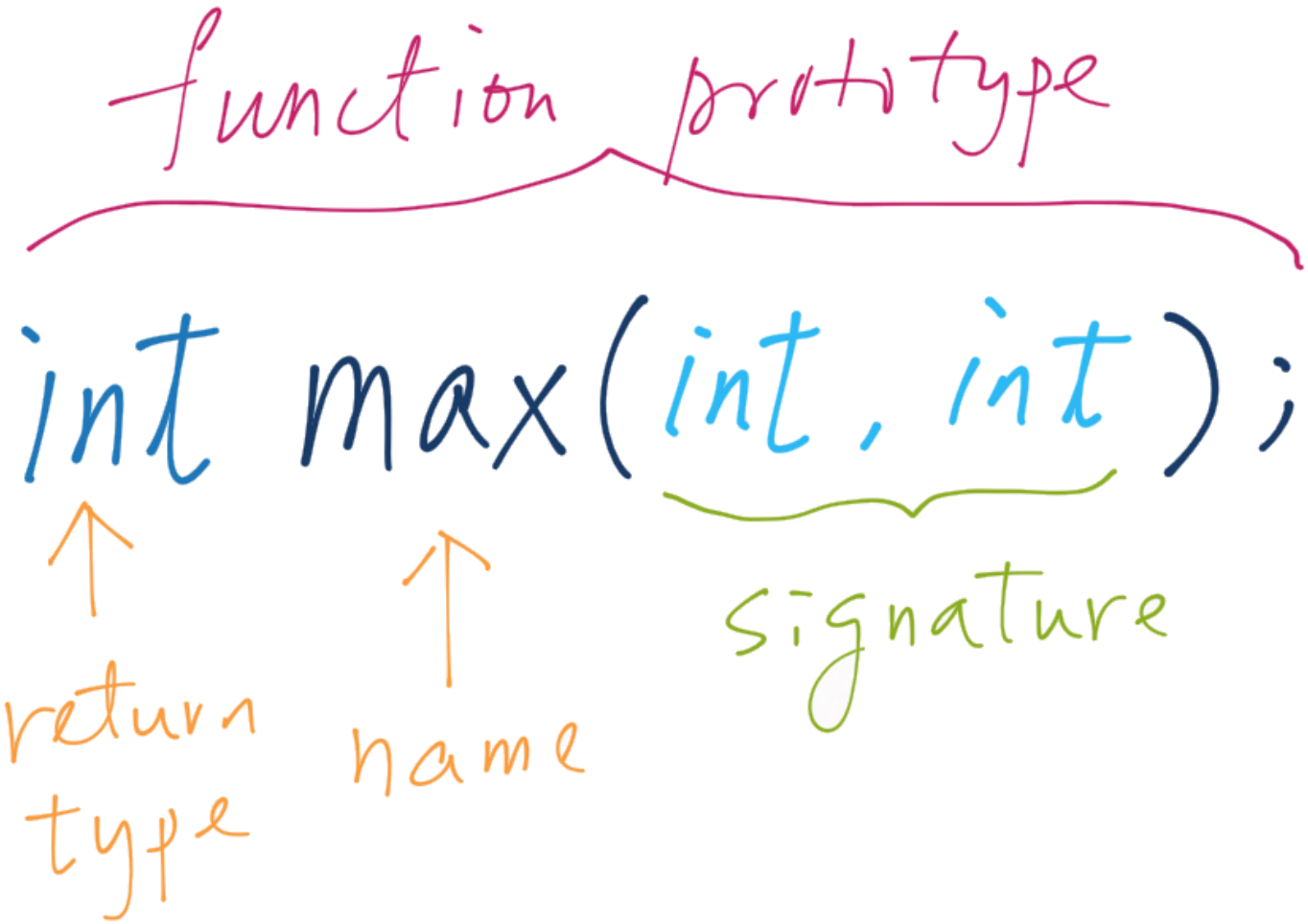
Example: Some PBV, Some PBR

```cpp
#include <iostream>     /* File: sum-and-difference.cpp */
using namespace std;

// To find the sum and difference of 2 given numbers
void sum_and_difference(int x, int y, int& sum, int& difference)
{
    sum = x + y;
    difference = x - y;
}

int main()
{
    int x, y, sum, difference;
    cout << "Enter 2 numbers: ";
    cin >> x >> y;

    sum_and_difference(x, y, sum, difference);
    cout << "The sum of " << x << " and " << y << " is " << sum << endl;
    cout << "The difference between " << x << " and " << y << " is "
         << difference << endl;
    return 0;
}
```

Part III

Function Declaration and Function Definition

Some Function Terminology



Function Prototype

A function prototype consists of

1. function name
2. return data type
3. the number of formal parameters
4. the data type of the formal parameters

Example: Function Prototypes

```
// int factorial(int n) { ... }
int factorial(int);

// float distance(float x1, float y1, float x2, float y2) { ... }
float distance(float, float, float, float);

/* void print_tree(int tree_height, char tree_symbol,
                   char trunk_symbol, char pot_symbol) { ... } */
void print_tree(int, char, char, char);
```

Function Prototype ..

- The identifier names of the formal parameters are not part of the signature as the names are immaterial.

Example: Variable Names are Immaterial in a Function Prototype

```
/* All the following 3 function definitions are equivalent */

int max(int x, int y) { return (x > y) ? x : y; }

int max(int a, int b) { return (a > b) ? a : b; }

int max(int f, int g) { return (f > g) ? f : g; }
```

- A function prototype describes the interface of the function: what parameters it takes in and what value it returns.
- Technically, a function prototype is also called the application programming interface (API).

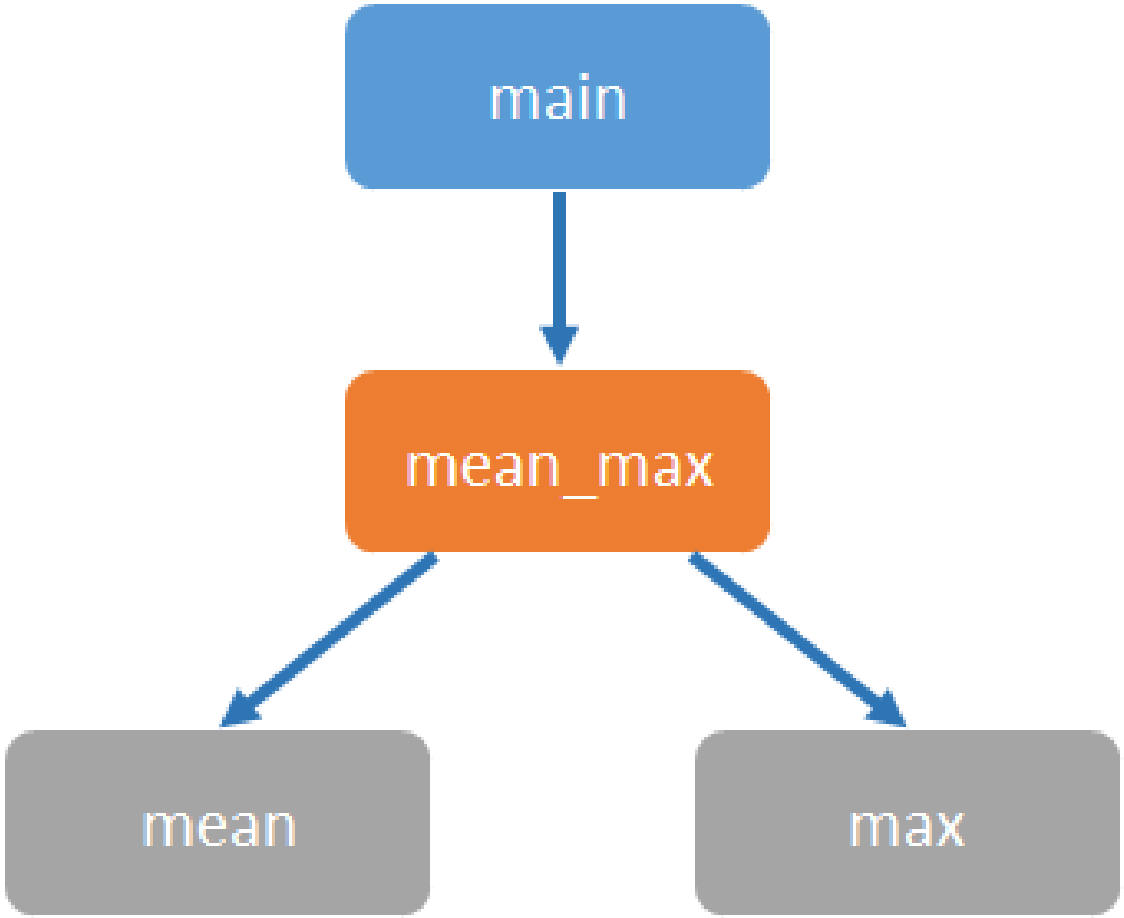
Function Declaration vs. Definition

- A function is declared by writing down its interface — its function prototype.
- A function is defined by writing down its function header *plus* its function body.
- A function definition will ask the compiler to generate machine codes according to the C++ codes in its function body.
- A function declaration just informs the compiler about the function's interface *without* generating any machine codes.
- A function may be declared many times, but a function can be defined only once.
- Of course, when a function is defined, it is also declared.
- But, simply declaring a function does **not** define the function.

Function Declaration vs. Definition ..

- In C++, all functions must be declared before they can be used, so that the compiler can
  - make sure the exact number of arguments are passed.
  - do type checking on the arguments passed to the function.
- That is, if function A wants to call function B, function B must be
  - declared/defined before, or
  - declared inside function A before calling function B.
- However, a function need not be defined before it can be used, although it must be defined eventually somewhere in the whole program in order that the program can be compiled to an executable.

Example: A Program with 3 Levels of Functions



Example: Declare Functions by Defining the Functions

```
#include <iostream>     /* File: fcn-prototype1.cpp */
using namespace std;

int max(int x, int y) { return (x > y) ? x : y; }
int mean(int x, int y) { return (x + y)/2; }

void mean_max(int x, int y, int& mean_num, int& max_num)
{
    mean_num = mean(x, y);
    max_num = max(x, y);
}

int main()
{
    int average, bigger;

    mean_max(6, 4, average, bigger);
    cout << "mean = " << average << endl << "max = " << bigger << endl;
    return 0;
}
```

Example: Declare Functions Globally

```
#include <iostream>     /* File: fcn-prototype2.cpp */
using namespace std;

void mean_max(int, int, int&, int&); // main only needs to know mean_max

int main()
{
    int average, bigger;
    mean_max(6, 4, average, bigger);
    cout << "mean = " << average << endl << "max = " << bigger << endl;
    return 0;
}

int max(int, int);      // mean_max needs to know max and mean
int mean(int, int);

void mean_max(int x, int y, int& mean_num, int& max_num)
{
    mean_num = mean(x, y);
    max_num = max(x, y);
}

int max(int x, int y) { return (x > y) ? x : y; }
int mean(int x, int y) { return (x + y)/2; }
```

Example: Declare Functions Locally

```
#include <iostream>     /* File: fcn-prototype3.cpp */
using namespace std;

int main()
{
    void mean_max(int, int, int&, int&);
    int average, bigger;

    mean_max(6, 4, average, bigger);
    cout << "mean = " << average << endl << "max = " << bigger << endl;
    return 0;
}

void mean_max(int x, int y, int& mean_num, int& max_num)
{
    int max(int, int);
    int mean(int, int);

    mean_num = mean(x, y);
    max_num = max(x, y);
}

int max(int x, int y) { return (x > y) ? x : y; }
int mean(int x, int y) { return (x + y)/2; }
```

Example: Forward Function Declaration

```
#include <iostream>     /* File: odd-even.cpp */
using namespace std;

bool even(int);

bool odd(int x) { return (x == 0) ? false : even(x-1); }

bool even(int x) { return (x == 0) ? true : odd(x-1); }

int main()
{
    int x;
    cin >> x;           // Assume x > 0

    cout << boolalpha << odd(x) << endl;
    cout << boolalpha << even(x) << endl;

    return 0;
}
```

Part IV

Function Overloading

Signature of a Function

- Recall that in C++, all functions are global. That means, in general, all functions can "see" each other.
- Just as we use one's signature to identify the person, we identify a function by its name and signature.
- A function's signature is the list of formal parameters without their identifier names.
- No two C++ functions can have the same name *and* same signature but different return type.
- BUT two C++ functions can have the same name *but* different signature $\Rightarrow$ function overloading.

Example: No 2 Function Prototypes Differ Only in Return Type

```
// The following 2 function definitions of
// pick_one cannot appear in the same program

int pick_one(int x, float y) { return x; }
float pick_one(int x, float y) { return y; }
```

Function Overloading

C++ allows several functions to have the same name but different types of input parameters.

Example: Overloaded Functions

```
int max(int x, int y) { return (x > y) ? x : y; }
int max(int x, int y, int z) { return max(max(x,y), z); }
double max(double a, double b) { return (a > b) ? a : b; }

void swap(int& a, int& b) { int temp = a; a = b; b = temp; }
void swap(float& a, float& b) { float temp = a; a = b; b = temp; }
void swap(double& a, double& b) { double temp = a; a = b; b = temp; }

int absolute(int a) { return (a < 0) ? -a : a; }
int absolute(int& a) { return (a = (a < 0) ? -a : a); }
```

Question: How can you call the following version of absolute( )?

```
int absolute(int&);
```

Example: Invalid Function Overloading

```
/* Identifier names of formal parameters are immaterial */

int max(int x, int y) { return (x > y) ? x : y; }
int max(int a, int b) { return (a > b) ? a : b; }



/* Return type is not part of the signature */

void swap(int& a, int& b) { int temp = a; a = b; b = temp; }
int swap(int& a, int& b) { int temp = a; a = b; b = temp; return a; }
```

Overloaded Function Resolution

- When an overloaded function is called, C++ will determine exactly which function among those with the same name should be called — function resolution.
- Function resolution is done by analyzing the type of actual parameters being passed during a function call.
- If there are exact matches between the types of formal parameters in an overloaded function and those of actual parameters, that function is picked.
- If there is no exact match, C++ uses a set of pre-defined rules for function resolution.
- The basic idea is to try to match their data types by:
  - first, widening conversion (coercion)
  - then, narrowing conversion (coercion)

Example: Function Resolution

```
int test(int a, double b);
int test(double a, int b);
```

- If you make the following function call: `test(3, 4.6)`, the compiler will pick the first version.
- If you make the following function call: `test('a', 4.6)`, the compiler will again pick the first version by converting 'a' to an int.
- If you make the following function call: `test(3.2, 4.6)`, it can either
  - match to the first version by narrowing conversion of the first parameter to int.
  - match to the second version by narrowing conversion of the second parameter to int.
  - since neither one is more preferable than the other one
    $\Rightarrow$ compilation error!

Default Function Argument

- Sometimes, we would like a function to have certain default behaviour, but still allow the user to change it.
- C++ allows the user to call a function with fewer arguments if all he wants is its default behaviour, and with more arguments if he wants some particular behaviour of the function.
- A function may have more than 1 default argument.
- But all default arguments must be specified at the end of the formal parameter list.

```
/* The following 2 prototypes are equivalent */
void func(int x, float& y, char gender = 'M', bool alive = true);
void func(int, float&, char = 'M', bool = true);
```

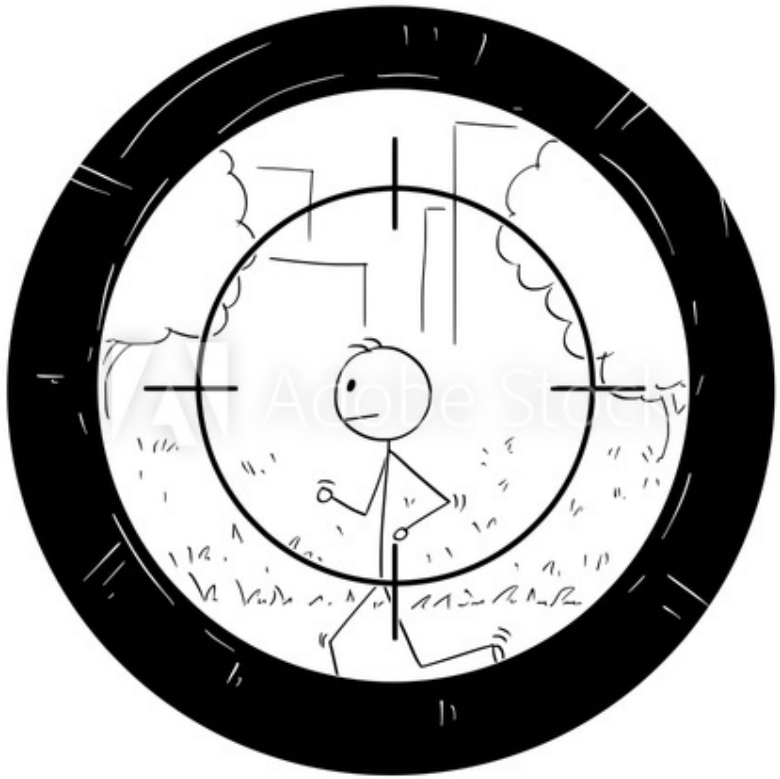
- The default argument(s) may be specified in a function declaration or function definition, but not both.
  - usually we put it on the function declaration. Why?
- A function with default arguments looks like several overloaded functions, but it is not.

Example: Increment with Default Argument

```
#include <iostream>     /* File: increment-default-arg.cpp */
using namespace std;

int increment(int x, int step = 1)
{
    return (x + step);
}

int main()
{
    cout << increment(10) << endl;
    cout << increment(10, 5) << endl;

    return 0;
}
```

Part V

Scope of Identifiers



Scope

What is the Scope of an Identifier?

Scope is the region of codes
in which an identifier declaration is active.

- Scope for an identifier is determined by the location of its declaration.
- In general, an identifier is active from the location of its declaration to the end of its scope.
- In C++, there is a big difference between identifiers declared outside or inside a function.
- Programmers commonly talk about the following 2 kinds of scope, though they are *not* official in C++'s standard:
  - global scope: when an identifier is declared outside any function.
  - local scope: when an identifier is declared inside a function.
- Technically, there are at least 3 kinds of scope: file scope, function scope, and block scope.

Example: File/Function/Block Scope

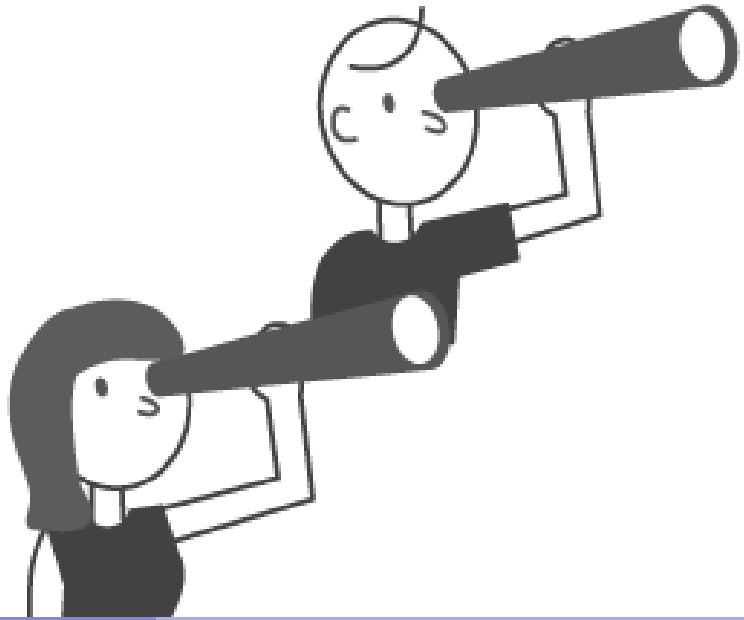
```
#include <iostream>     /* File: scope.cpp */
using namespace std;

void my_print(const int b[], int size) // b and size are local variables with a FUNCTION SCOPE
{
    for (int j = 0; j < size; j++) // j is a local variable with a BLOCK SCOPE
    {
        int k = 10;     // k is a local variable with a BLOCK SCOPE
        cout << "array[" << j <<"] = " << b[j] << '\t' << k*b[j] << endl;
    }
    cout << endl;
}

int a[] = {1,2,3,4,5}; // a is a global variable with a FILE SCOPE

void bad_swap(int& x, int& y) // x, y are local variables with a FUNCTION SCOPE
{
    int temp = x;       // temp is a local variable with a FUNCTION SCOPE
    x = y;
    y = temp;

    a[3] = 100;
}

int main()
{
    // num_array_elements is a local variable with a FUNCTION SCOPE
    int num_array_elements = sizeof(a)/sizeof(int);

    bad_swap(a[1], a[2]); my_print(a, num_array_elements);
    bad_swap(a[3], a[4]); my_print(a, num_array_elements);
    return 0;
}
```

File Scope

- File scope is the technical term for global scope.
- Variables with file scope are global variables and can be accessed by any functions in the same file or other files with proper external declarations. (More about this later.)
- Unlike local variables, global variables are initialized to 0 when they are defined without an explicit initializer.
- All function identifiers have file scope; thus, *all functions* are global in C++.
- Undisciplined use of global variables may lead to confusion and makes a program hard to debug.
  - $\Rightarrow$ try to avoid using global variables!
  - $\Rightarrow$ use only local variables, and pass them between functions.

Function Scope

- Function scope is one kind of local scope.
- All variables/constants declared in the formal parameter list, or inside the function body have function scope.
- They are also called local variables/constants because they can only be accessed within the function — and not by any other functions.
- They are short-lived. They come and go: they are created when the function is called, and are destructed when the function returns.



Block Scope

- Block scope is also a kind of local scope.
- A block of codes is created when you enclose codes within a pair of braces { }. For example,
  - codes inside the body of for, while, do-while, if, else, switch, etc.
- Variables/constants with block scope are also local because they can only be used within the block.
- Similarly to the function scope, variables or constants having block scope are short-lived: they are created when the block is entered, and are destructed when the block is finished.

(There are also namespace scope and class scope but we won't talk about them now.)

Example: Problems with a Global Variable

```
#include <iostream>     /* File: global-var-confusion.cpp */
using namespace std;

int number; // Definition of the global variable, number, with FILE scope. It is initialized to 0.

void increment_pbv(int x)
{
    x++;                // x is a local variable with a FUNCTION scope
    cout << "x = " << x << endl;

    number++; // global variable, number, used in the function, void increment_pbv(int)
}

void increment_pbr(int& y)
{
    y++;              // y is a local reference variable with a FUNCTION scope
    cout << "y = " << y << endl;

    number++; // global variable, number, used in the function, void increment_pbr(int&)
}

int main()
{
    increment_pbv(number); // global variable, number, used in the function, int main()
    cout << "number = " << number << endl;

    increment_pbr(number);  // global variable, number, used in the function, int main()
    cout << "number = " << number << endl;
    return 0;
}
```

Identifiers of the Same Name

The notion of scope has the following implications:

- An identifier can only be declared once in the same scope.
- Only the name matters: you cannot declare 2 variables/constants of the same name in the same scope even if they have different types.

```
int x = 1;
char x = 'b'; // error!
```

- However, the same identifier name may be "re-used" for variables or constants in different scopes.
- The different scopes may not overlap with each other, or, one scope may be inside another scope.

Compiler Scope Rule

When an identifier is declared more than once but under different scopes, the compiler associates an occurrence of the identifier with its declaration in the innermost enclosing scope.

Example: Scope Resolution

```
int main()
{
    int j;                  // Apply to S1,S5,S6
    int k;                  // Apply to S1,S2,S3,S4,S6
    S1;

    for (...)
    {
        int j;              // Apply to S2,S4
        S2;
        while (...)
        {
            int j;          // Apply to S3
            S3;
        }
        S4;
    }

    while (...)
    {
        int k;              // Apply to S5
        S5;
    }
    S6;
}
```

Quiz: Which j applies to S7?

```
int main()
{
    int j;                  // Apply to S1,S5,S6
    int k;                  // Apply to S1,S2,S3,S4,S6
    S1;

    for (...)
    {
        int j;              // Apply to S2,S4
        S2;
        while (...)
        {
            S7;             // <---  Which j?
            int j;          // Apply to S3
            S3;
        }
        S4;
    }
    while (...)
    {
        int k;              // Apply to S5
        S5;
    }
    S6;
}
```

That's all!

Any questions?