

Functions

Victor Eijkhout, Harika Gurram,
Je'aime Powell, Charley Dey

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Function basics

Turn blocks of code into functions

- Code fragment with clear function:
- Turn into *subprogram*: function *definition*.
- Use by single line: function *call*.

Function definition and call

```
for (int i=0; i<N; i++) {  
    cout << i;  
    if (i%2==0)  
        cout << " is even";  
    else  
        cout << " is odd";  
    cout << endl;  
}
```

```
void report_evenness(int n) {  
    cout << n;  
    if (n%2==0)  
        cout << " is even";  
    else  
        cout << " is odd";  
    cout << endl;  
}  
...  
int main() {  
    ...  
    for (int i=0; i<N; i++)  
        report_evenness(i);  
}
```

Code becomes more readable (though not necessarily shorter):
introduce application terminology.

Program with function

Code:

```
int double_this(int n) {  
    int twice_the_input = 2*n;  
    return twice_the_input;  
}  
  
/* ... */  
int number = 3;  
cout << "Twice three is: " <<  
    double_this(number) << endl;
```

Output [func] twicein:

Twice three is: 6

Why functions?

- Easier to read
- Shorter code: reuse
- Cleaner code: local variables are no longer in the main program.
- Maintenance and debugging

Code reuse

```
double x,y, v,w;  
y = ..... computation from x .....  
w = ..... same computation, but from v .....
```

can be replaced by

```
double computation(double in) {  
    return .... computation from 'in' ....  
}  
  
y = computation(x);  
w = computation(v);
```

Code reuse

Example: multiple norm calculations:

Repeated code:

```
float s = 0;
for (int i=0; i<nx; i++)
    s += abs(x[i]);
cout << "Inf norm x: " << s << endl;
s = 0;
for (int i=0; i<ny; i++)
    s += abs(y[i]);
cout << "Inf norm y: " << s << endl;
```

becomes:

```
int InfNorm( vector<float> a ) {
    float s = 0;
    for (int i=0; i<n.size(); i++)
        s += abs(a[i]);
    return s;
}

int main() {
    ... // stuff
    cout << "Inf norm x: "
         << InfNorm(x,nx) << endl;
    cout << "Inf norm y: "
         << InfNorm(y,ny) << endl;
```

Code becomes shorter, easier to maintain.

(Don't worry about array stuff in this example)

Introduces application terminology.

Review quiz 1

True or false?

- The purpose of functions is to make your code shorter.
- Using functions makes your code easier to read.
- Functions have to be defined before you can use them.

Anatomy of a function definition

- Result type: what's computed.
void if no result
- Name: make it descriptive.
- Parameters: zero or more.
int i, double x, double y
These act like variable declarations.
- Body: any length. This is a scope.
- Return statement: usually at the end, but can be anywhere;
the computed result.

Function call

The function call

1. copies the value of the *function argument* to the *function parameter*;
2. causes the function body to be executed, and
3. the function call is replaced by whatever you return.
4. (If the function does not return anything, for instance because it only prints output, you declare the return type to be void.)

Functions without input, without return result

```
void print_header() {  
    cout << "*****" << endl;  
    cout << "* Output      *" << endl;  
    cout << "*****" << endl;  
}  
  
int main() {  
    print_header();  
    cout << "The results for day 25:" << endl;  
    // code that prints results ....  
    return 0;  
}
```

Functions with input

```
void print_result(int day,float value) {
    cout << "*****" << endl;
    cout << "* Output      *" << endl;
    cout << "*****" << endl;
    cout << "The results for day " << day << ":" << endl;
    cout << "      " << value << endl;
}

int main() {
    print_result(25,3.456);
    return 0;
}
```

Functions with return result

```
#include <cmath>
double pi() {
    return 4*atan(1.0);
}
```

The atan is a *standard function*

Review quiz 2

True or false?

- A function can have only one input
- A function can have only one result

Exercise 1

Write a function with (float or double) inputs x, y that returns the distance of point (x, y) to the origin.

Test the following pairs: 1, 0; 0, 1; 1, 1; 3, 4.

Project Exercise 2

Write a function `is_prime` that has an integer parameter, and returns a boolean corresponding to whether the parameter was prime.

```
int main() {  
    bool isprime;  
    isprime = primality_test(13);  
}
```

Read the number in, and print the value of the boolean.

Does your function have one or two return statements? Can you imagine what the other possibility looks like? Do you have an argument for or against it?

Project Exercise 3

Take your prime number testing function `is_prime`, and use it to write program that prints multiple primes:

- Read an integer `how_many` from the input, indicating how many (successive) prime numbers should be printed.
- Print that many successive primes, each on a separate line.
- (Hint: keep a variable `number_of_primes_found` that is increased whenever a new prime is found.)

Turn it in!

- If you have compiled your program, do:

```
sdstestprime yourprogram.cc
```

where 'yourprogram.cc' stands for the name of your source file.

- Is it reporting that your program is correct? If so, do:

```
sdstestprime -s yourprogram.cc
```

where the -s flag stands for 'submit'.

- If you don't manage to get your code working correctly, you can submit as incomplete with

```
sdstestprime -i yourprogram.cc
```

Background Square roots through Newton

Early computers had no hardware for computing a square root. Instead, they used *Newton's method*. Suppose you have a value y and you want to compute $x \leftarrow \sqrt{y}$. This is equivalent to finding the zero of

$$f(x) = x^2 - y$$

where y is fixed. To indicate this dependence on y , we will write $f_y(x)$. Newton's method then finds the zero by evaluating

$$x_{\text{next}} = x - f_y(x)/f'_y(x)$$

until the guess is accurate enough, that is, until $f_y(x) \approx 0$.

Exercise 4

- Write functions `f(x,y)` and `deriv(x,y)`, that compute $f_y(x)$ and $f'_y(x)$ for the definition of f_y above.
- Read a value y and iterate until $|f(x,y)| < 10^{-5}$. Print x .
- Second part: write a function `newton_root` that computes \sqrt{y} .

Parameter passing

Mathematical type function

Pretty good design:

- pass data into a function,
- return result through `return` statement.
- Parameters are copied into the function. (Cost of copying?)
- *pass by value*
- 'functional programming'

Pass by value example

Note that the function alters its parameter x:

Code:

```
double squared( double x ) {  
    x = x*x;  
    return x;  
}  
  
/* ... */  
number = 5.1;  
cout << "Input starts as: "  
    << number << endl;  
other = squared(number);  
cout << "Input var is now: "  
    << number << endl;  
cout << "Output var is: "  
    << other << endl;
```

Output [func] passvalue:

```
Input starts as: 5.1  
Input var is now: 5.1  
Output var is: 26.01
```

but the argument in the main program is not affected.

Reference

A reference is indicated with an ampersand in its definition, and it acts as an alias of the thing it references.

Code:

```
int i;  
int &ri = i;  
i = 5;  
cout << i << "," << ri << endl;  
i *= 2;  
cout << i << "," << ri << endl;  
ri -= 3;  
cout << i << "," << ri << endl;
```

Output [basic] ref:

```
5,5  
10,10  
7,7
```

(You will not use references often this way.)

Parameter passing by reference

The function parameter `n` becomes a reference to the variable `i` in the main program:

```
void f(int &n) {  
    n = /* some expression */ ;  
};  
int main() {  
    int i;  
    f(i);  
    // i now has the value that was set in the function  
}
```

Results other than through return

Also good design:

- Return no function result,
- or return *return status* (0 is success, nonzero various informative statuses), and
- return other information by changing the parameters.
- *pass by reference*
- Parameters are also called 'input', 'output', 'throughput'.

Pass by reference example 1

Code:

```
void f( int &i ) {  
    i = 5;  
}  
int main() {  
  
    int var = 0;  
    f(var);  
    cout << var << endl;
```

Output [basic] setbyref:

5

Compare the difference with leaving out the reference.

Pass by reference example 2

```
bool can_read_value( int &value ) {
    int file_status = try_open_file();
    if (file_status==0)
        value = read_value_from_file();
    return file_status!=0;
}

int main() {
    int n;
    if (!can_read_value(n))
        // if you can't read the value, set a default
        n = 10;
}
```

Exercise 5

Write a void function `swapij` of two parameters that exchanges the input values:

```
int i=2,j=3;  
swapij(i,j);  
// now i==3 and j==2
```

Exercise 6

Write a `bool` function that tests divisibility and returns a remainder:

```
int number,divisor,remainder;
// read in the number and divisor
if ( is_divisible(number,divisor,remainder) )
    cout << number << " is divisible by " << divisor << endl;
else
    cout << number << "/" << divisor <<
        " has remainder " << remainder << endl;
```

Exercise 7

Write a function with inputs x, y, α that alters x and y corresponding to rotating the point (x, y) over an angle θ .

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix}$$

Your code should look like:

```
double x,y,alpha;  
// set x,y to some point  
rotate(x,y,alpha);  
// now x,y are rotated over alpha
```


Recursion

Recursion

A functions is allowed to call itself, making it a *recursive function*.
For example, you can define factorial as

$$F(n) = n \times F(n - 1) \quad \text{if } n > 1, \text{ otherwise } 1$$

```
int factorial( int n ) {  
    if (n==1)  
        return 1;  
    else  
        return n*factorial(n-1);  
}
```

Exercise 8

The sum of squares:

$$S_n = \sum_{n=1}^N n^2$$

can be defined recursively as

$$S_1 = 1, \quad S_n = n^2 + S_{n-1}.$$

Write a recursive function that implements this second definition.
Test it on numbers that are input interactively.

Then write a program that prints the first 100 sums of squares.

Exercise 9

Write a recursive function for computing Fibonacci numbers:

$$F_0 = 1, \quad F_1 = 1, \quad F_n = F_{n-1} + F_{n-2}$$

First write a program that computes F_n for a value n that is input interactively.

Then write a program that prints out a sequence of Fibonacci numbers; set interactively how many.

More about functions

Default arguments

Functions can have *default argument(s)*:

```
double distance( double x, double y=0. ) {  
    return sqrt( (x-y)*(x-y) );  
}  
  
...  
d = distance(x); // distance to origin  
d = distance(x,y); // distance between two points
```

Any default argument(s) should come last in the parameter list.

Polymorphic functions

You can have multiple functions with the same name:

```
double sum(double a,double b) {  
    return a+b; }  
double sum(double a,double b,double c) {  
    return a+b+c; }
```

Distinguished by type or number of input arguments: can not differ only in return type.

Scope

Lexical scope

Visibility of variables

```
int main() {  
    int i;  
    if ( something ) {  
        int j;  
        // code with i and j  
    }  
    int k;  
    // code with i and k  
}
```

Shadowing

```
int main() {  
    int i = 3;  
    if ( something ) {  
        int i = 5;  
    }  
    cout << i << endl; // gives 3  
    if ( something ) {  
        float i = 1.2;  
    }  
    cout << i << endl; // again 3  
}
```

Variable `i` is shadowed: invisible for a while.

After the lifetime of the shadowing variable, its value is unchanged from before.

Exercise 10

What is the output of this code?

```
bool something{false};
int i = 3;
if ( something ) {
    int i = 5;
    cout << "Local: " << i << endl;
}
cout << "Global: " << i << endl;
if ( something ) {
    float i = 1.2;
    cout << i << endl;
    cout << "Local again: " << i << endl;
}
cout << "Global again: " << i << endl;
```

Life time vs reachability

Even without shadowing, a variable can exist but be unreachable.

```
void f() {  
    ...  
}  
int main() {  
    int i;  
    f();  
    cout << i;  
}
```