Functions

How to reuse code

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

int main() {
  int threeExpFour = 1;
  for (int i = 0; i < 4; i = i + 1) {
    threeExpFour = threeExpFour * 3;
  }
  cout << "3^4 is " << threeExpFour << endl;
  return 0;
}
```

Copy-paste coding

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

int main() {
  int threeExpFour = 1;
  for (int i = 0; i < 4; i = i + 1) {
    threeExpFour = threeExpFour * 3;
  }
  cout << "3^4 is " << threeExpFour << endl;
  int sixExpFive = 1;
  for (int i = 0; i < 5; i = i + 1) {
    sixExpFive = sixExpFive * 6;
  }
  cout << "6^5 is " << sixExpFive << endl;
  return 0;
}
```

Copy-paste coding (bad)

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

int main() {
  int threeExpFour = 1;
  for (int i = 0; i < 4; i = i + 1) {
    threeExpFour = threeExpFour * 3;
  }
  cout << "3^4 is " << threeExpFour << endl;
  int sixExpFive = 1;
  for (int i = 0; i < 5; i = i + 1) {
    sixExpFive = sixExpFive * 6;
  }
  cout << "6^5 is " << sixExpFive << endl;
  int twelveExpTen = 1;
  for (int i = 0; i < 10; i = i + 1) {
    twelveExpTen = twelveExpTen * 12;
  }
  cout << "12^10 is " << twelveExpTen << endl;
  return 0;
}
```

With a function

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

// some code which raises an arbitrary integer
// to an arbitrary power

int main() {
  int threeExpFour = raiseToPower(3, 4);
  cout << "3^4 is " << threeExpFour << endl;
  return 0;
}
```

With a function

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

// some code which raises an arbitrary integer
// to an arbitrary power

int main() {
  int threeExpFour = raiseToPower(3, 4);
  cout << "3^4 is " << threeExpFour << endl;
  int sixExpFive = raiseToPower(6, 5);
  cout << "6^5 is " << sixExpFive << endl;
  return 0;
}
```

With a function

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

// some code which raises an arbitrary integer
// to an arbitrary power

int main() {
  int threeExpFour = raiseToPower(3, 4);
  cout << "3^4 is " << threeExpFour << endl;
  int sixExpFive = raiseToPower(6, 5);
  cout << "6^5 is " << sixExpFive << endl;
  int twelveExpTen = raiseToPower(12, 10);
  cout << "12^10 is " << twelveExpTen << endl;
  return 0;
}
```

Why define your own functions?

- Readability: sqrt(5) is clearer than copy-pasting in an algorithm to compute the square root
- Maintainability: To change the algorithm, just change the function (vs changing it everywhere you ever used it)
- Code reuse: Lets other people use algorithms you’ve implemented

Function Declaration Syntax

Function name

```
int raiseToPower(int base, int exponent)
{
  int result = 1;
  for (int i = 0; i < exponent; i = i + 1) {
    result = result * base;
  }
  return result;
}
```

Function Declaration Syntax

Return type

```
int raiseToPower(int base, int exponent)
{
  int result = 1;
  for (int i = 0; i < exponent; i = i + 1) {
    result = result * base;
  }
  return result;
}
```

Function Declaration Syntax

Argument 1

```
int raiseToPower(int base, int exponent)
{
  int result = 1;
  for (int i = 0; i < exponent; i = i + 1) {
    result = result * base;
  }
  return result;
}
```

- Argument order matters:
  - raiseToPower(2,3) is 2^3=8
  - raiseToPower(3,2) is 3^2=9

Function Declaration Syntax

Argument 2

```
int raiseToPower(int base, int exponent)
{
  int result = 1;
  for (int i = 0; i < exponent; i = i + 1) {
    result = result * base;
  }
  return result;
}
```

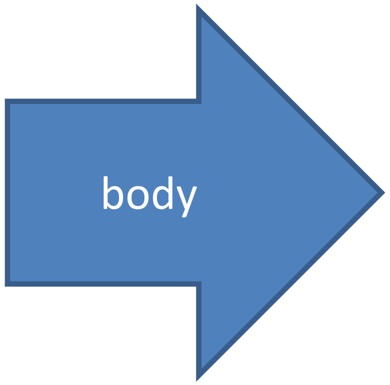
- Argument order matters:
  - raiseToPower(2,3) is 2^3=8
  - raiseToPower(3,2) is 3^2=9

Function Declaration Syntax

signature

```
int raiseToPower(int base, int exponent)
{
  int result = 1;
  for (int i = 0; i < exponent; i = i + 1) {
    result = result * base;
  }
  return result;
}
```

Function Declaration Syntax



```
int raiseToPower(int base, int exponent)
{
  int result = 1;
  for (int i = 0; i < exponent; i = i + 1) {
    result = result * base;
  }
  return result;
}
```

Function Declaration Syntax

```
int raiseToPower(int base, int exponent)
{
  int result = 1;
  for (int i = 0; i < exponent; i = i + 1) {
    result = result * base;
  }
  return result;
}
```

Return statement

Function declaration

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

int raiseToPower(int base, int exponent) {
  int result = 1;
  for (int i = 0; i < exponent; i = i + 1) {
    result = result * base;
  }
  return result;
}
```

Function invocation

```cpp
int main() {
  int threeExpFour = raiseToPower(3, 4);
  cout << "3^4 is " << threeExpFour << endl;
  return 0;
}
```

Returning a value

- Up to one value may be returned; it must be the same type as the return type.

```
int foo()
{
  return "hello"; // error
}
```

```
char* foo()
{
  return "hello"; // ok
}
```

Returning a value

- Up to one value may be returned; it must be the same type as the return type.
- If no values are returned, give the function a **void** return type

```
void printNumber(int num) {
  cout << "number is " << num << endl;
}

int main() {
  printNumber(4); // number is 4
  return 0;
}
```

Returning a value

- Up to one value may be returned; it must be the same type as the return type.
- If no values are returned, give the function a **void** return type
  - Note that you cannot declare a variable of type void

```
int main() {
  void x; // ERROR
  return 0;
}
```

Returning a value

- Return statements don’t necessarily need to be at the end.
- Function returns as soon as a return statement is executed.

```
void printNumberIfEven(int num) {
  if (num % 2 == 1) {
    cout << "odd number" << endl;
    return;
  }
  cout << "even number; number is " << num << endl;
}

int main() {
  int x = 4;
  printNumberIfEven(x);
  // even number; number is 3
  int y = 5;
  printNumberIfEven(y);
  // odd number
}
```

Argument Type Matters

```
void printOnNewLine(int x)
{
    cout << x << endl;
}
```

- `printOnNewLine(3)` works
- `printOnNewLine("hello")` will not compile

Argument Type Matters

```
void printOnNewLine(char *x)
{
    cout << x << endl;
}
```

- `printOnNewLine(3)` will not compile
- `printOnNewLine("hello")` works

Argument Type Matters

```
void printOnNewLine(int x)
{
    cout << x << endl;
}

void printOnNewLine(char *x)
{
    cout << x << endl;
}
```

- `printOnNewLine(3)` works
- `printOnNewLine("hello")` also works

Function Overloading

```
void printOnNewLine(int x)
{
    cout << "Integer: " << x << endl;
}

void printOnNewLine(char *x)
{
    cout << "String: " << x << endl;
}
```

- Many functions with the same name, but different arguments
- The function called is the one whose arguments match the invocation

Function Overloading

```
void printOnNewLine(int x)
{
    cout << "Integer: " << x << endl;
}

void printOnNewLine(char *x)
{
    cout << "String: " << x << endl;
}
```

- printOnNewLine(3) prints “Integer: 3”
- printOnNewLine(“hello”) prints “String: hello”

Function Overloading

```
void printOnNewLine(int x)
{
    cout << "1 Integer: " << x << endl;
}

void printOnNewLine(int x, int y)
{
    cout << "2 Integers: " << x << " and " << y << endl;
}
```

- printOnNewLine(3) prints “1 Integer: 3”
- printOnNewLine(2, 3) prints “2 Integers: 2 and 3”

- Function declarations need to occur before invocations

```
int foo()
{
    return bar()*2; // ERROR - bar hasn’t been declared yet
}

int bar()
{
    return 3;
}
```

- Function declarations need to occur before invocations
  - Solution 1: reorder function declarations

```
int bar()
{
    return 3;
}

int foo()
{
    return bar()*2; // ok
}
```

- Function declarations need to occur before invocations
  - Solution 1: reorder function declarations
  - Solution 2: use a function prototype; informs the compiler you'll implement it later

```
int bar();        function prototype

int foo()
{
    return bar()*2; // ok
}

int bar()
{
    return 3;
}
```

- Function prototypes should match the signature of the method, though argument names don’t matter

```
int square(int);
```

function prototype

```
int cube(int x)
{
    return x*square(x);
}

int square(int x)
{
    return x*x;
}
```

- Function prototypes should match the signature of the method, though argument names don't matter

```
int square(int x);
```

function prototype

```
int cube(int x)
{
    return x*square(x);
}

int square(int x)
{
    return x*x;
}
```

- Function prototypes should match the signature of the method, though argument names don't matter

```
int square(int z);
```

function prototype

```
int cube(int x)
{
    return x*square(x);
}

int square(int x)
{
    return x*x;
}
```

- Function prototypes are generally put into separate header files
  - Separates specification of the function from its implementation

```
// myLib.h - header
// contains prototypes

int square(int);
int cube (int);
```

```
// myLib.cpp - implementation
#include "myLib.h"

int cube(int x)
{
    return x*square(x);
}

int square(int x)
{
    return x*x;
}
```

Recursion

- Functions can call themselves.
- fib(n) = fib(n-1) + fib(n-2) can be easily expressed via a recursive implementation

```
int fibonacci(int n) {
  if (n == 0 || n == 1) {
    return 1;
  } else {
    return fibonacci(n-2) + fibonacci(n-1);
  }
}
```

Recursion

- Functions can call themselves.
- fib(n) = fib(n-1) + fib(n-2) can be easily expressed via a recursive implementation

```
int fibonacci(int n) {
  if (n == 0 || n == 1) {
    return 1;
  } else {
    return fibonacci(n-2) + fibonacci(n-1);
  }
}
```

Recursion

- Functions can call themselves.
- fib(n) = fib(n-1) + fib(n-2) can be easily expressed via a recursive implementation

recursive step

```
int fibonacci(int n) {
  if (n == 0 || n == 1) {
    return 1;
  } else {
    return fibonacci(n-2) + fibonacci(n-1);
  }
}
```

Global Variables

- How many times is function foo() called? Use a global variable to determine this.
  - Can be accessed from any function

```
int numCalls = 0;

void foo() {
  ++numCalls;
}

int main() {
  foo(); foo(); foo();
  cout << numCalls << endl; // 3
}
```

Global variable

Scope

- Scope: where a variable was declared, determines where it can be accessed from

```
int numCalls = 0;

int raiseToPower(int base, int exponent) {
  numCalls = numCalls + 1;
  int result = 1;
  for (int i = 0; i < exponent; i = i + 1) {
    result = result * base;
  }
  return result;
}

int max(int num1, int num2) {
  numCalls = numCalls + 1;
  int result;
  if (num1 > num2) {
    result = num1;
  }
  else {
    result = num2;
  }
  return result;
}
```

Scope

- Scope: where a variable was declared, determines where it can be accessed from
- numCalls has global scope – can be accessed from any function

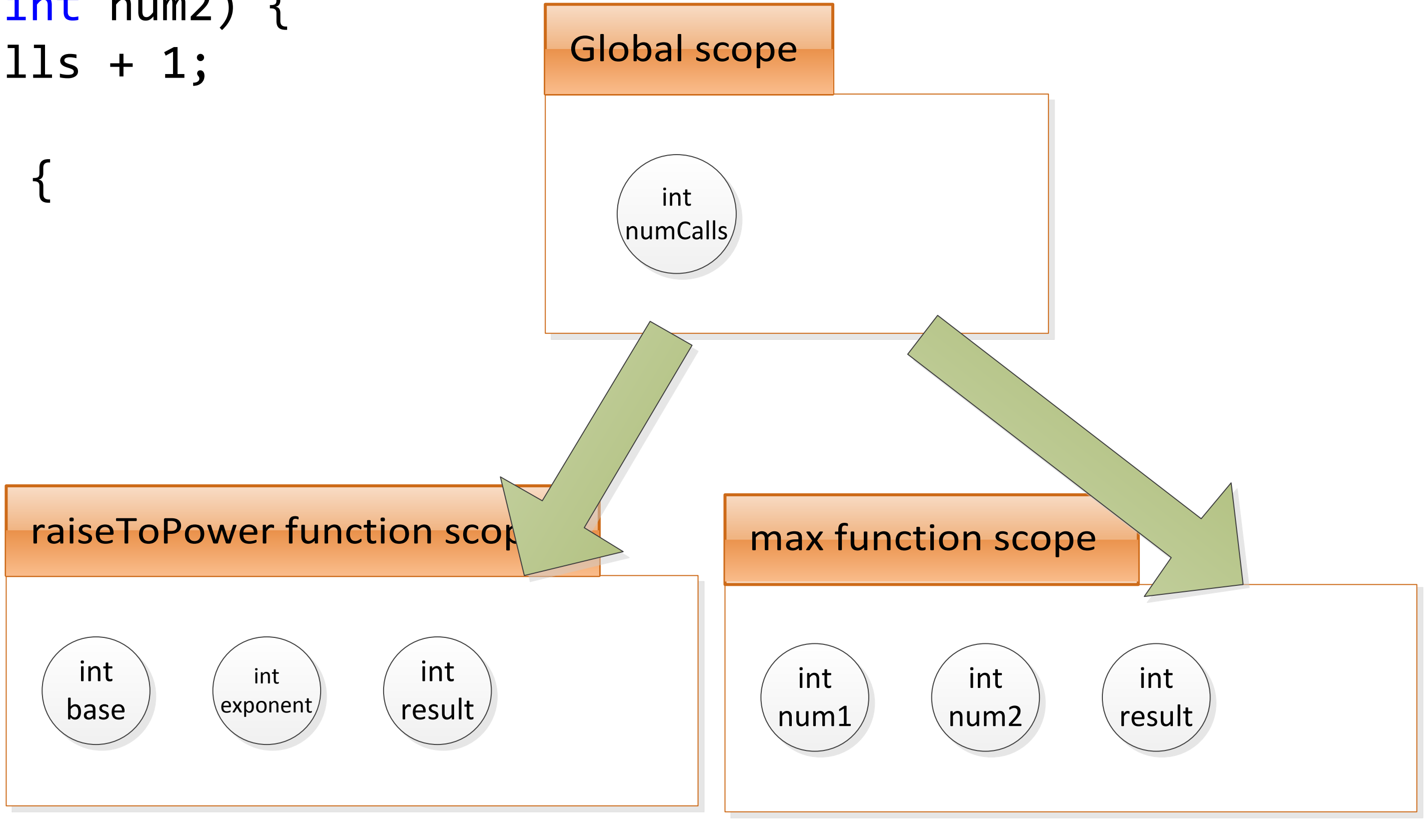
```
int numCalls = 0;

int raiseToPower(int base, int exponent) {
  numCalls = numCalls + 1;
  int result = 1;
  for (int i = 0; i < exponent; i = i + 1) {
    result = result * base;
  }
  return result;
}

int max(int num1, int num2) {
  numCalls = numCalls + 1;
  int result;
  if (num1 > num2) {
    result = num1;
  }
  else {
    result = num2;
  }
  return result;
}
```

Scope

- Scope: where a variable was declared, determines where it can be accessed from
- numCalls has global scope – can be accessed from any function
- result has function scope – each function can have its own separate variable named result

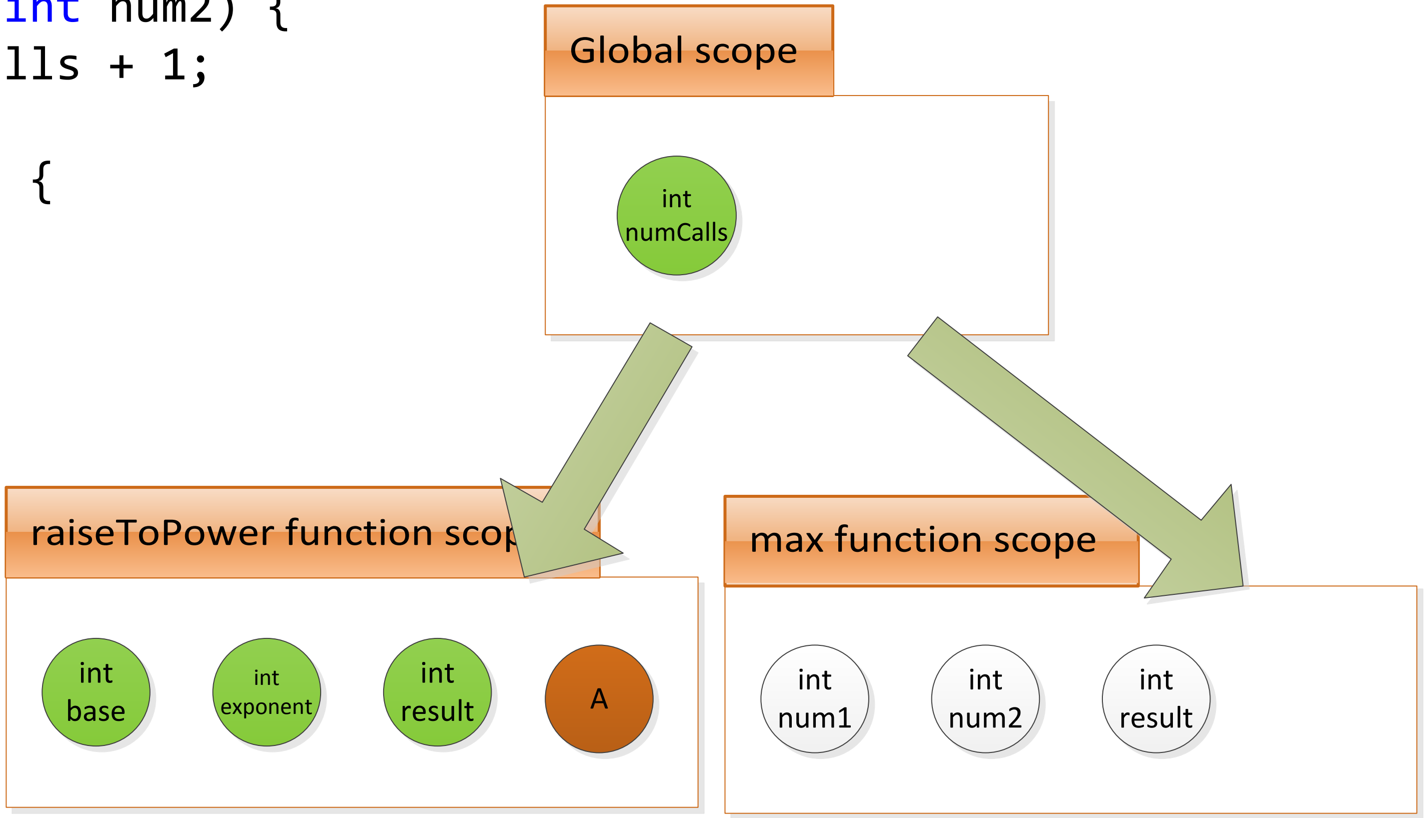
```
int numCalls = 0;

int raiseToPower(int base, int exponent) {
  numCalls = numCalls + 1;
  int result = 1;
  for (int i = 0; i < exponent; i = i + 1) {
    result = result * base;
  }
  return result;
}

int max(int num1, int num2) {
  numCalls = numCalls + 1;
  int result;
  if (num1 > num2) {
    result = num1;
  }
  else {
    result = num2;
  }
  return result;
}
```

```
int numCalls = 0;
int raiseToPower(int base, int exponent) {
  numCalls = numCalls + 1;
  int result = 1;
  for (int i = 0; i < exponent; i = i + 1) {
    result = result * base;
  }
  // A
  return result;
}
int max(int num1, int num2) {
  numCalls = numCalls + 1;
  int result;
  if (num1 > num2) {
    result = num1;
  }
  else {
    result = num2;
  }
  // B
  return result;
}
```



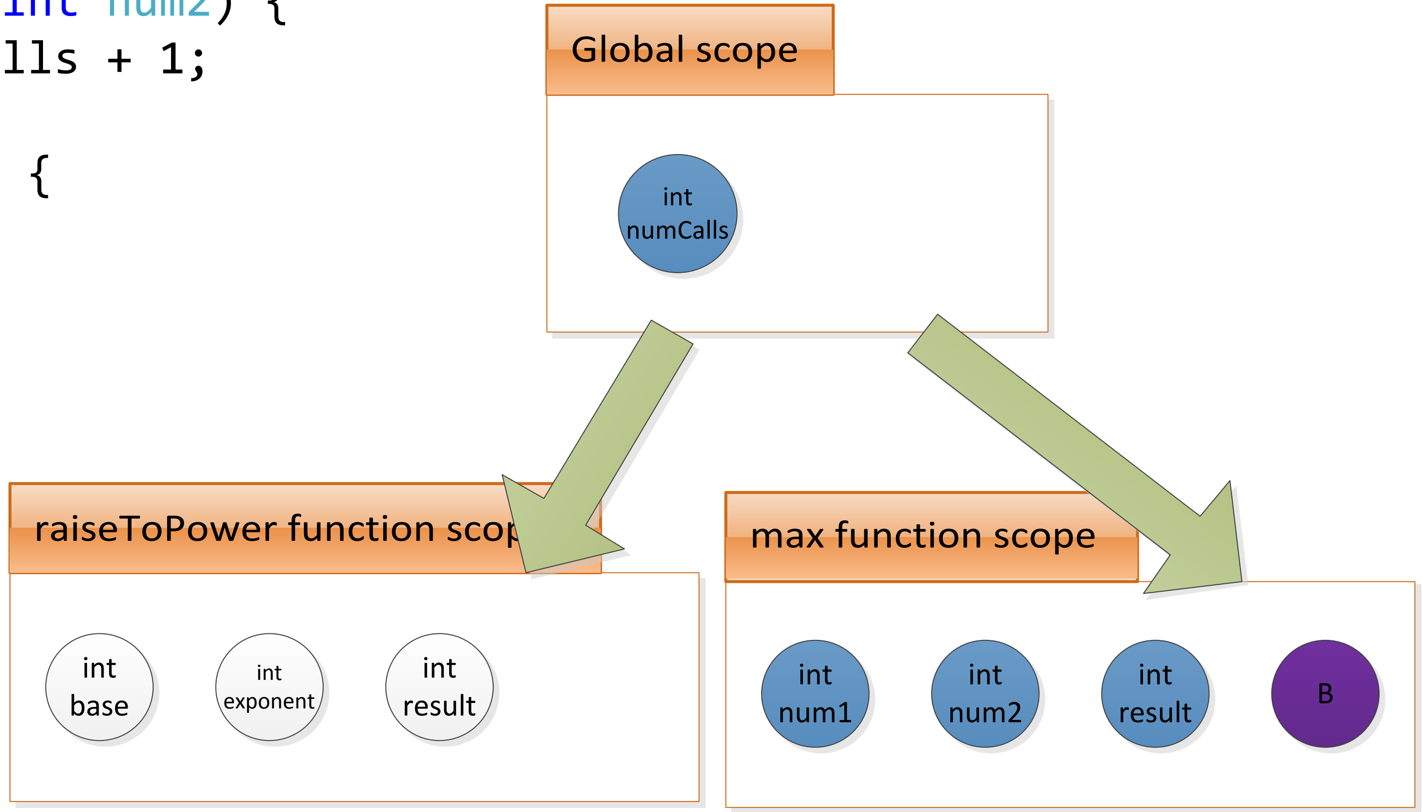
```
int numCalls = 0;
int raiseToPower(int base, int exponent) {
  numCalls = numCalls + 1;
  int result = 1;
  for (int i = 0; i < exponent; i = i + 1) {
    result = result * base;
  }
  // A
  return result;
}
int max(int num1, int num2) {
  numCalls = numCalls + 1;
  int result;
  if (num1 > num2) {
    result = num1;
  }
  else {
    result = num2;
  }
  // B
  return result;
}
```

- At A, variables marked in green are in scope



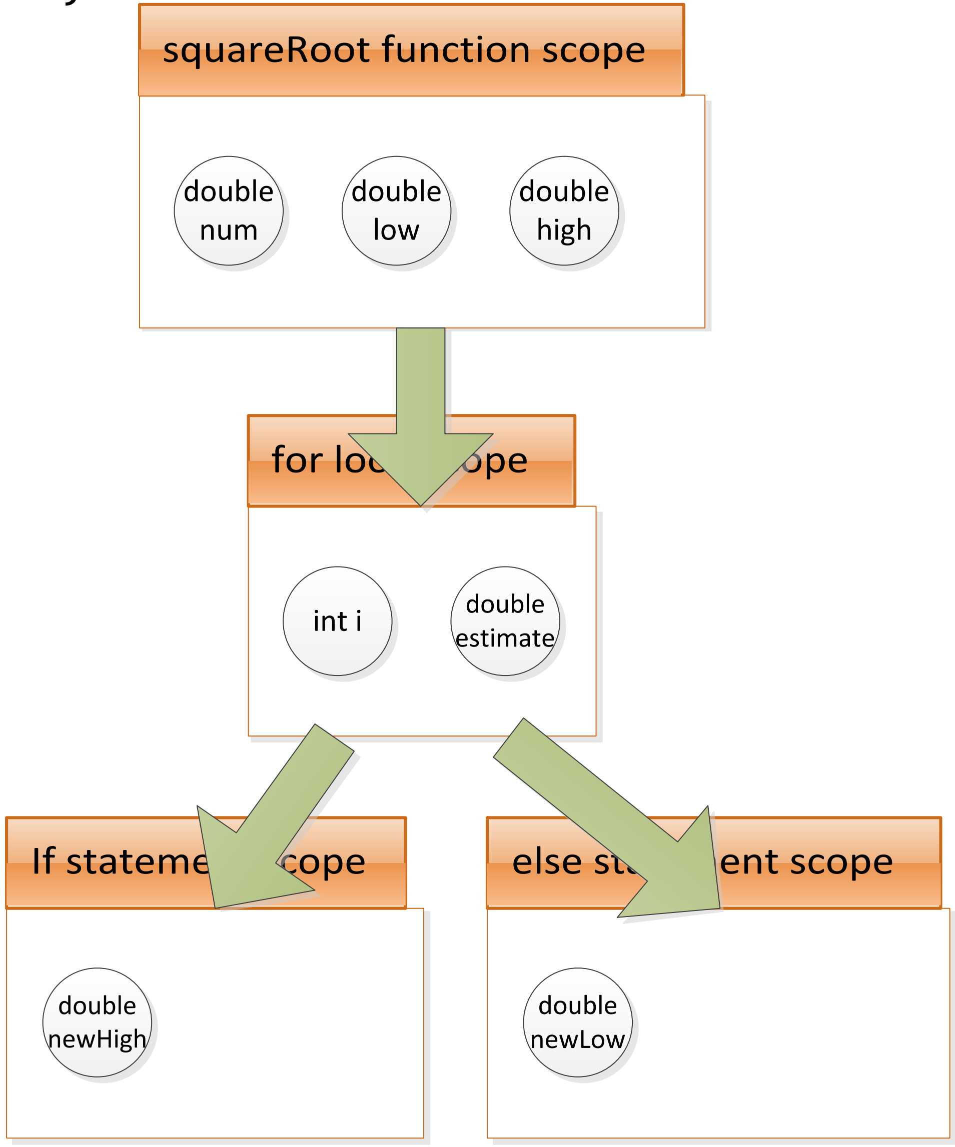
```
int numCalls = 0;
int raiseToPower(int base, int exponent) {
  numCalls = numCalls + 1;
  int result = 1;
  for (int i = 0; i < exponent; i = i + 1) {
    result = result * base;
  }
  // A
  return result;
}
int max(int num1, int num2) {
  numCalls = numCalls + 1;
  int result;
  if (num1 > num2) {
    result = num1;
  }
  else {
    result = num2;
  }
  // B
  return result;
}
```

- At B, variables marked in blue are in scope



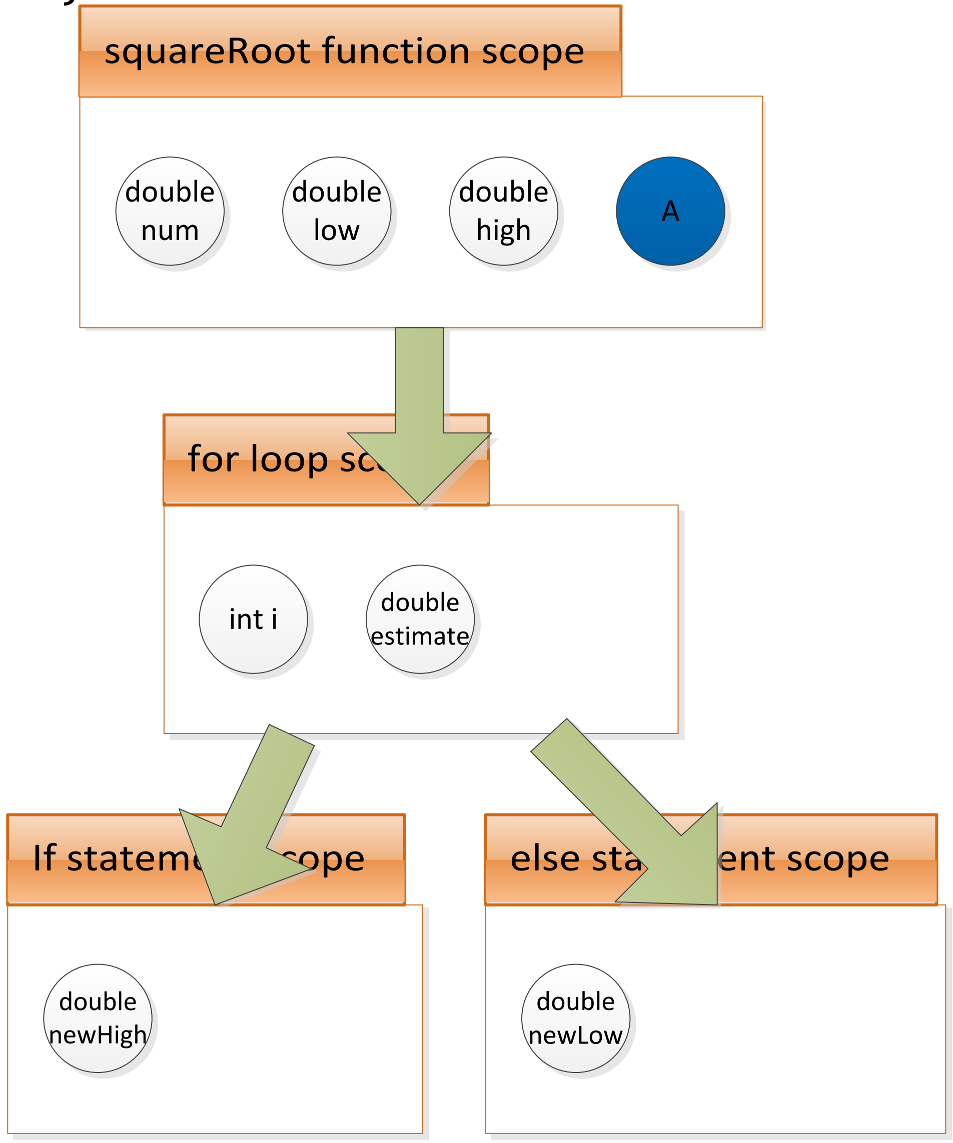
```
double squareRoot(double num) {
  double low = 1.0;
  double high = num;
  for (int i = 0; i < 30; i = i + 1) {
    double estimate = (high + low) / 2;
    if (estimate*estimate > num) {
      double newHigh = estimate;
      high = newHigh;
    } else {
      double newLow = estimate;
      low = newLow;
    }
  }
  return (high + low) / 2;
}
```

- Loops and if/else statements also have their own scopes
  - Loop counters are in the same scope as the body of the for loop



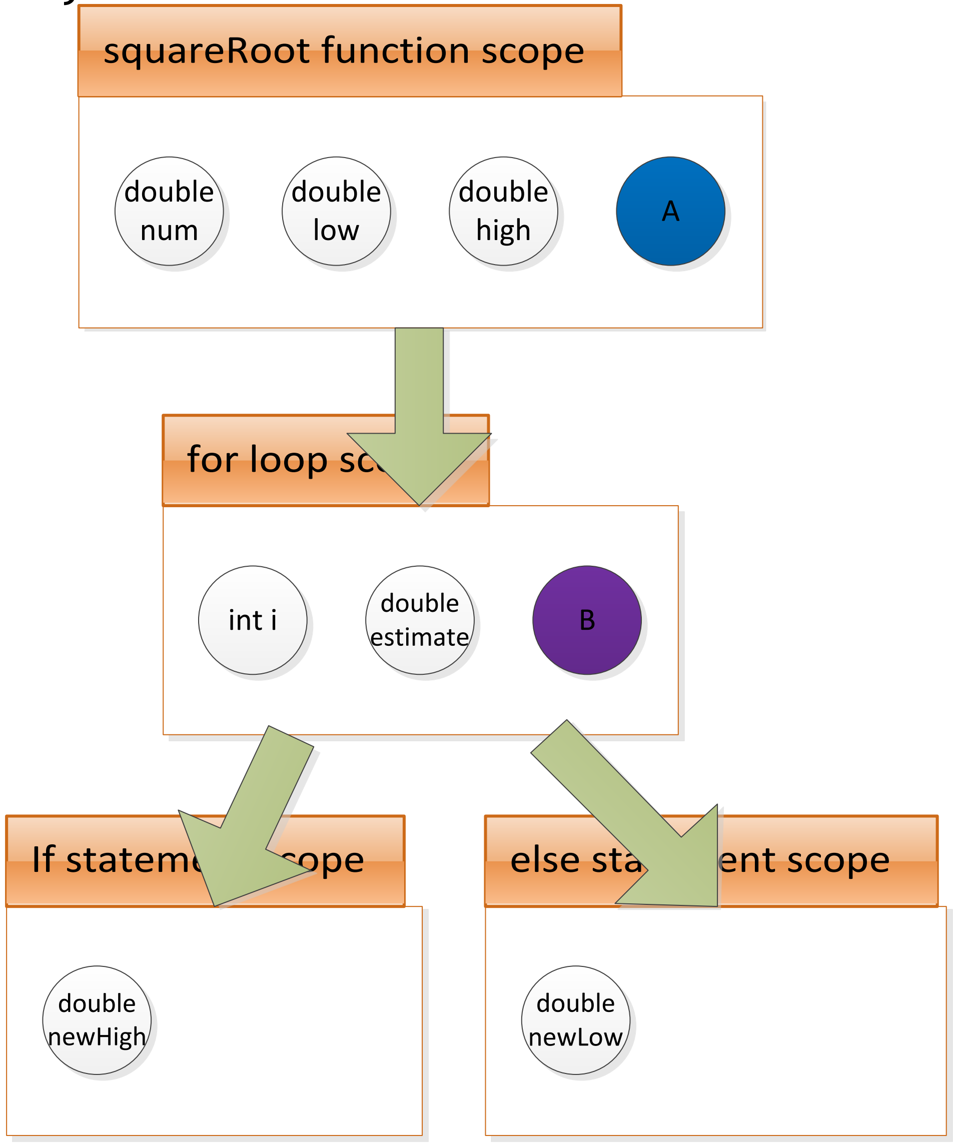
```
double squareRoot(double num) {
  double low = 1.0;
  double high = num;
  for (int i = 0; i < 30; i = i + 1) {
    double estimate = (high + low) / 2;
    if (estimate*estimate > num) {
      double newHigh = estimate;
      high = newHigh;
    } else {
      double newLow = estimate;
      low = newLow;
    }
  }
  // A
  return estimate; // ERROR
}
```

- Cannot access variables that are out of scope

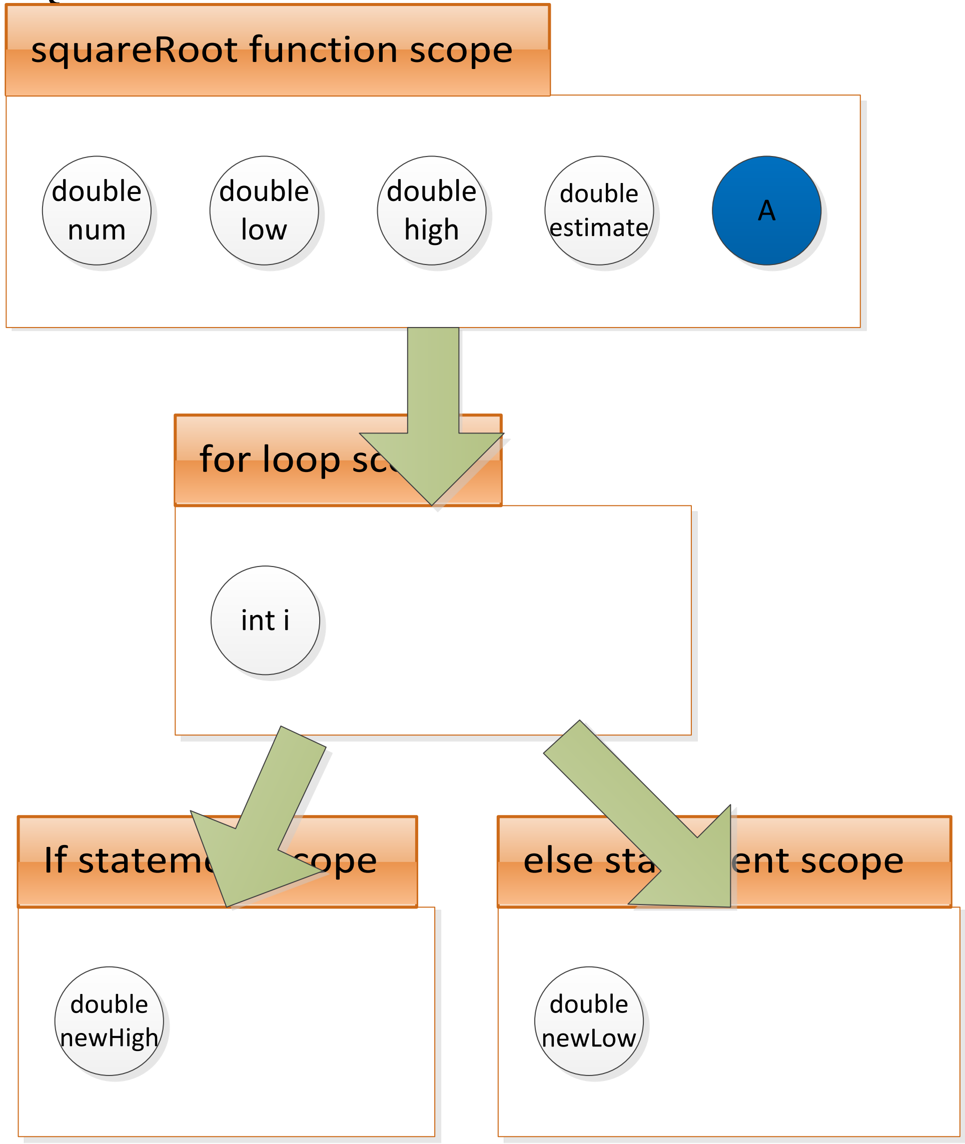


```
double squareRoot(double num) {
  double low = 1.0;
  double high = num;
  for (int i = 0; i < 30; i = i + 1) {
    double estimate = (high + low) / 2;
    if (estimate*estimate > num) {
      double newHigh = estimate;
      high = newHigh;
    } else {
      double newLow = estimate;
      low = newLow;
    }
    if (i == 29)
      return estimate; // B
  }
  return -1; // A
}
```

- Cannot access variables that are out of scope
- Solution 1: move the code



```
double squareRoot(double num) {
  double low = 1.0;
  double high = num;
  double estimate;
  for (int i = 0; i < 30; i = i + 1) {
    estimate = (high + low) / 2;
    if (estimate*estimate > num) {
      double newHigh = estimate;
      high = newHigh;
    } else {
      double newLow = estimate;
      low = newLow;
    }
  }
  return estimate; // A
}
```



- Cannot access variables that are out of scope
- Solution 2: declare the variable in a higher scope

Pass by value vs by reference

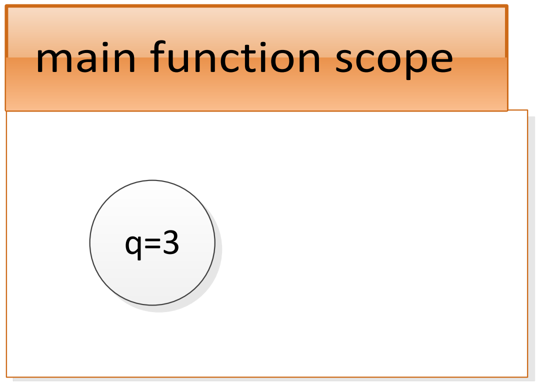
- So far we’ve been passing everything by value – makes a copy of the variable; changes to the variable within the function don’t occur outside the function

```
// pass-by-value
void increment(int a) {
  a = a + 1;
  cout << "a in increment " << a << endl;
}

int main() {
  int q = 3;
  increment(q); // does nothing
  cout << "q in main " << q << endl;
}
```

Output

```
a in increment 4
q in main 3
```

Pass by value vs by reference

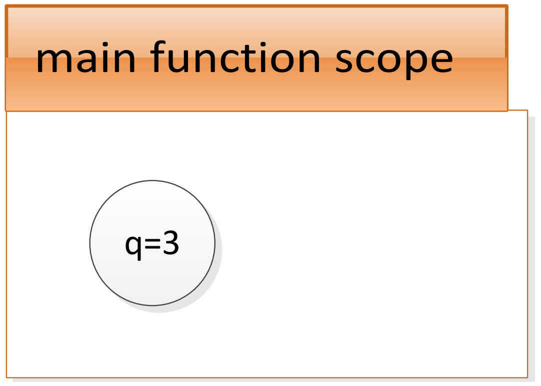


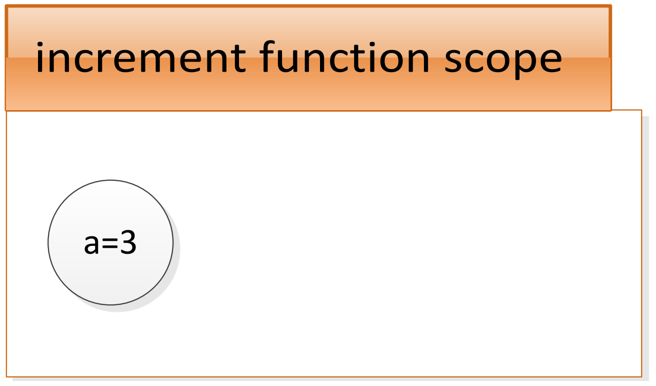
```
// pass-by-value
void increment(int a) {
  a = a + 1;
  cout << "a in increment " << a << endl;
}

int main() {
  int q = 3; // HERE
  increment(q); // does nothing
  cout << "q in main " << q << endl;
}
```

Output

```
a in increment 4
q in main 3
```

Pass by value vs by reference



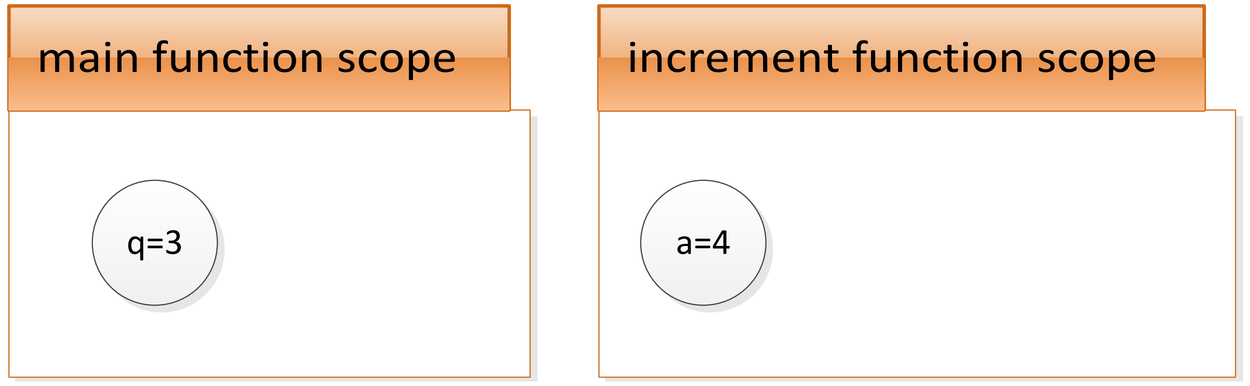


```
// pass-by-value
void increment(int a) { // HERE
  a = a + 1;
  cout << "a in increment " << a << endl;
}

int main() {
  int q = 3;
  increment(q); // does nothing
  cout << "q in main " << q << endl;
}
```

Output

```
a in increment 4
q in main 3
```

Pass by value vs by reference



```
// pass-by-value
void increment(int a) {
  a = a + 1; // HERE
  cout << "a in increment " << a << endl;
}

int main() {
  int q = 3;
  increment(q); // does nothing
  cout << "q in main " << q << endl;
}
```

Output

```
a in increment 4
q in main 3
```

Pass by value vs by reference

- If you want to modify the original variable as opposed to making a copy, pass the variable by reference (**int &a** instead of **int a**)

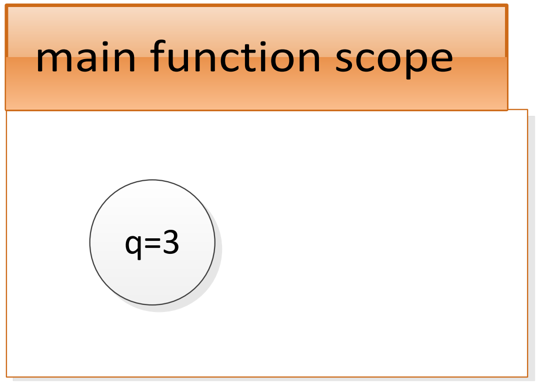
```
// pass-by-value
void increment(int &a) {
  a = a + 1;
  cout << "a in increment " << a << endl;
}

int main() {
  int q = 3;
  increment(q); // works
  cout << "q in main " << q << endl;
}
```

Output

a in increment 4

q in main **4**

Pass by value vs by reference

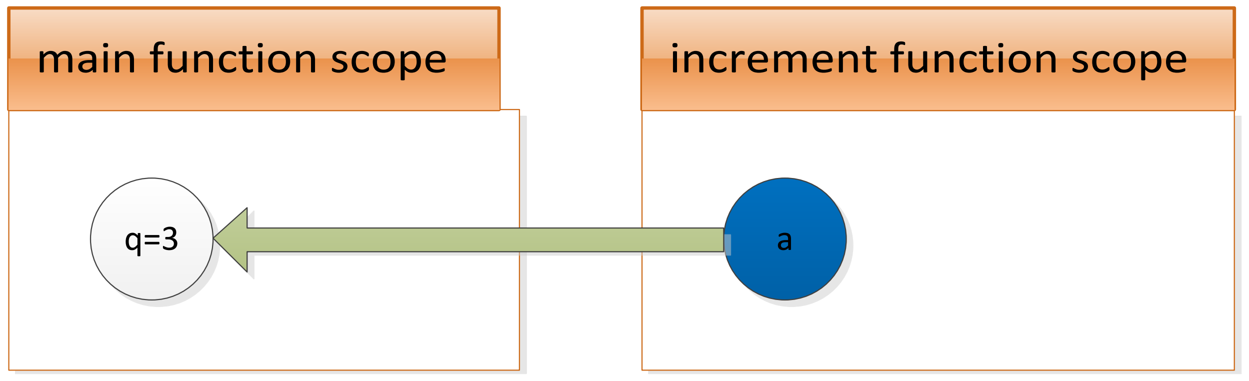


```
// pass-by-value
void increment(int &a) {
  a = a + 1;
  cout << "a in increment " << a << endl;
}

int main() {
  int q = 3; // HERE
  increment(q); // works
  cout << "q in main " << q << endl;
}
```

Output

```
a in increment 4
q in main 4
```

Pass by value vs by reference



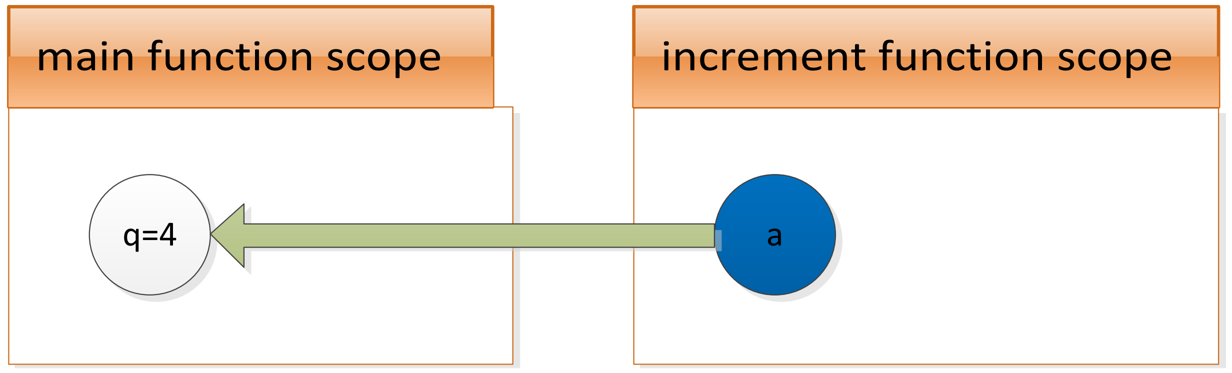
```
// pass-by-value
void increment(int &a) { // HERE
  a = a + 1;
  cout << "a in increment " << a << endl;
}

int main() {
  int q = 3;
  increment(q); // works
  cout << "q in main " << q << endl;
}
```

Output

a in increment 4

q in main **4**

Pass by value vs by reference



```
// pass-by-value
void increment(int &a) {
  a = a + 1; // HERE
  cout << "a in increment " << a << endl;
}

int main() {
  int q = 3;
  increment(q); // works
  cout << "q in main " << q << endl;
}
```

Output

a in increment 4

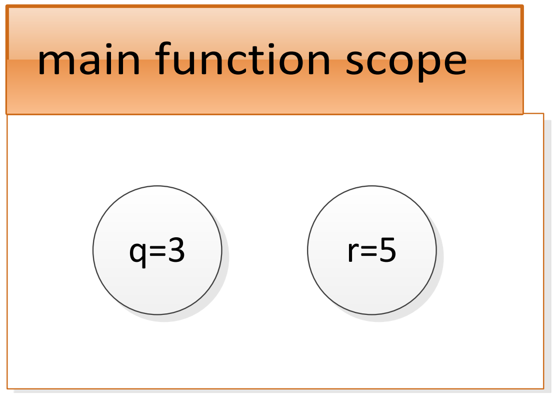
q in main **4**

Implementing Swap

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

int main() {
  int q = 3;
  int r = 5;
  swap(q, r);
  cout << "q " << q << endl; // q 5
  cout << "r " << r << endl; // r 3
}
```

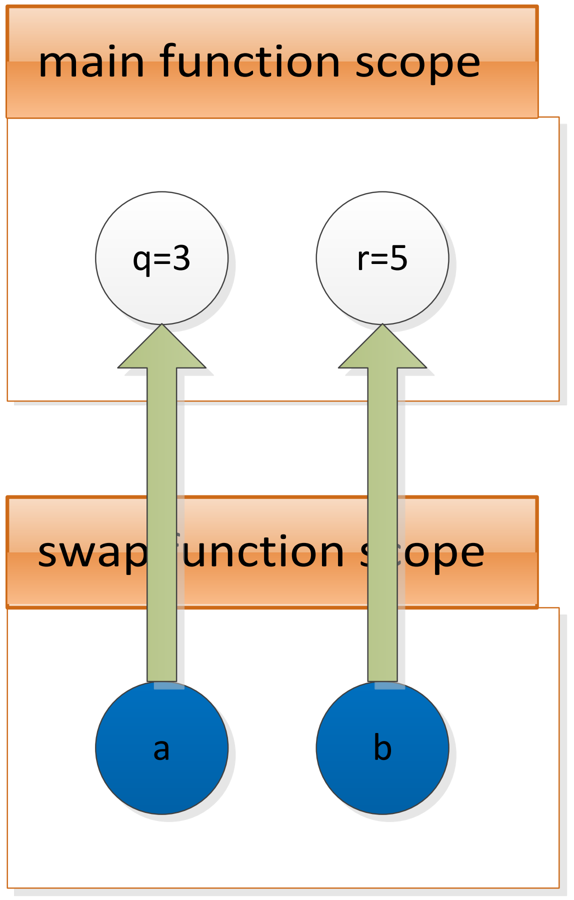
Implementing Swap

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

int main() {
  int q = 3;
  int r = 5; // HERE
  swap(q, r);
  cout << "q " << q << endl; // q 5
  cout << "r " << r << endl; // r 3
}
```



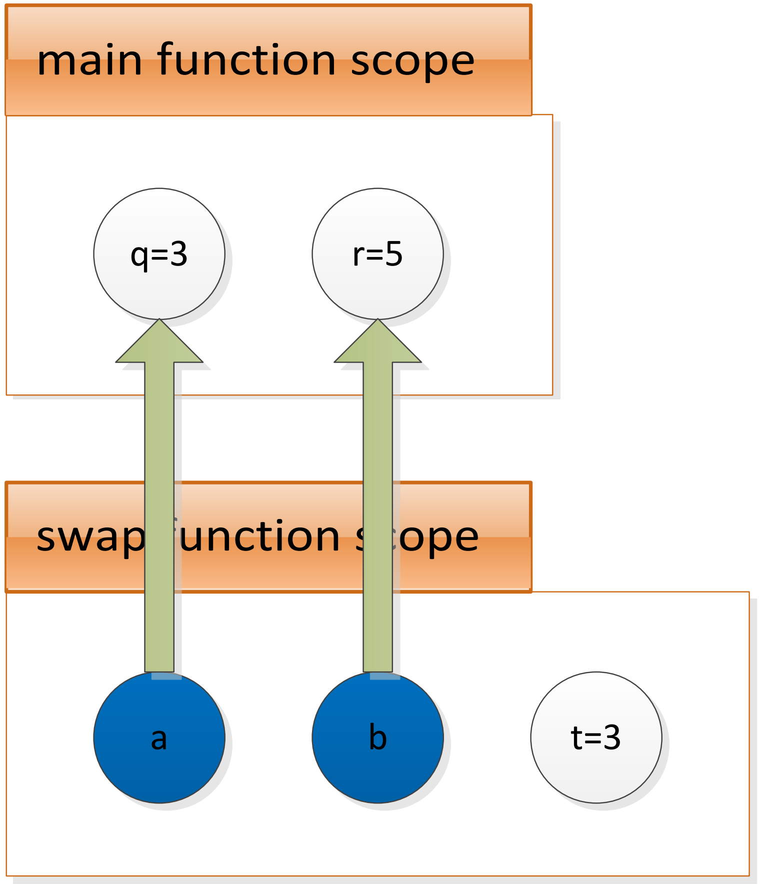
Implementing Swap

```
void swap(int &a, int &b) { // HERE
  int t = a;
  a = b;
  b = t;
}

int main() {
  int q = 3;
  int r = 5;
  swap(q, r);
  cout << "q " << q << endl; // q 5
  cout << "r " << r << endl; // r 3
}
```



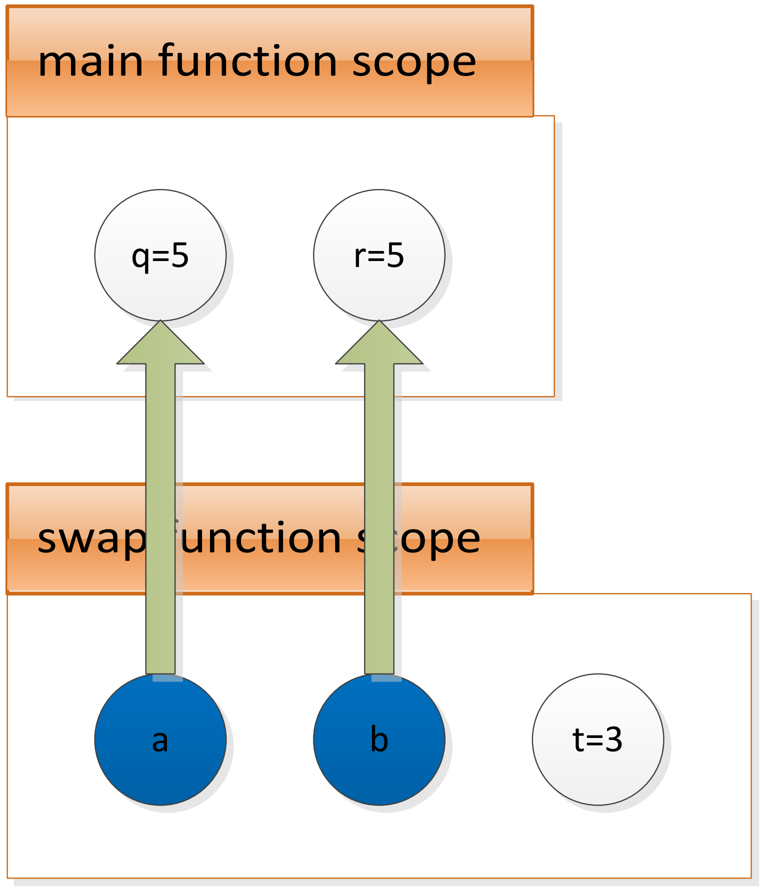
Implementing Swap

```
void swap(int &a, int &b) {
  int t = a; // HERE
  a = b;
  b = t;
}

int main() {
  int q = 3;
  int r = 5;
  swap(q, r);
  cout << "q " << q << endl; // q 5
  cout << "r " << r << endl; // r 3
}
```



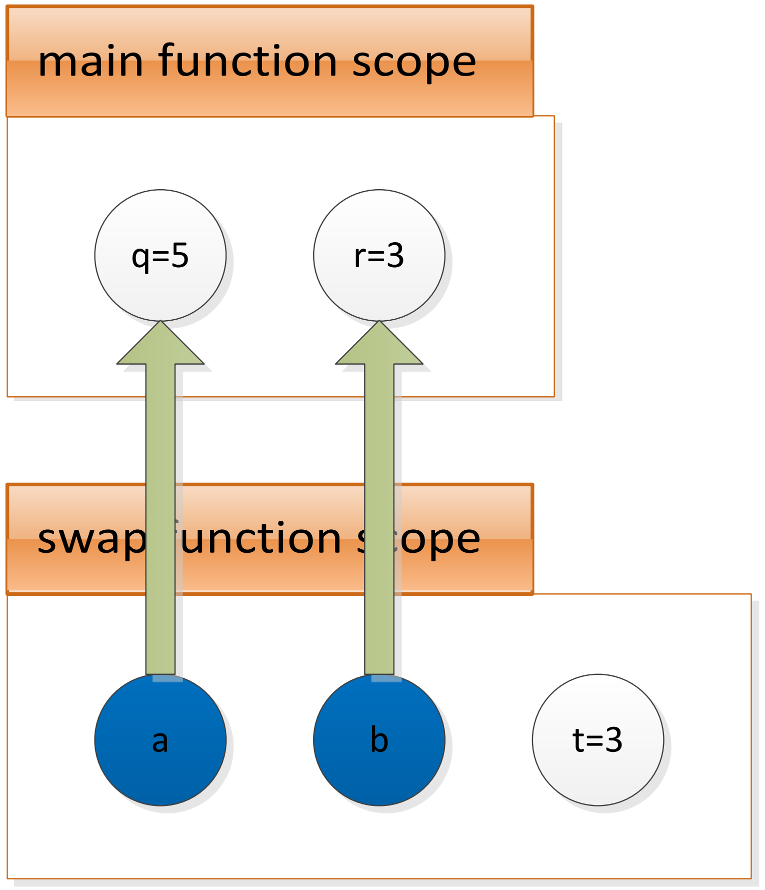
Implementing Swap

```
void swap(int &a, int &b) {
  int t = a;
  a = b; // HERE
  b = t;
}

int main() {
  int q = 3;
  int r = 5;
  swap(q, r);
  cout << "q " << q << endl; // q 5
  cout << "r " << r << endl; // r 3
}
```



Implementing Swap

```
void swap(int &a, int &b) {
  int t = a;
  a = b;
  b = t; // HERE
}

int main() {
  int q = 3;
  int r = 5;
  swap(q, r);
  cout << "q " << q << endl; // q 5
  cout << "r " << r << endl; // r 3
}
```



Returning multiple values

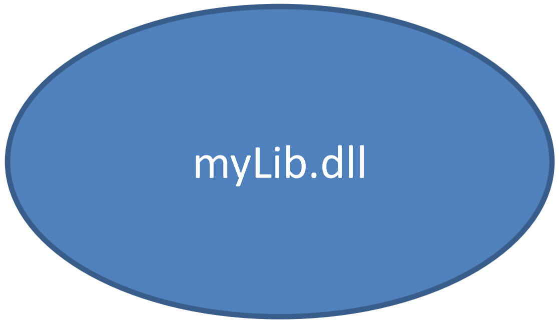
- The return statement only allows you to return 1 value. Passing output variables by reference overcomes this limitation.

```
int divide(int numerator, int denominator, int &remainder) {
  remainder = numerator % denominator;
  return numerator / denominator;
}

int main() {
  int num = 14;
  int den = 4;
  int rem;
  int result = divide(num, den, rem);
  cout << result << "*" << den << "+" << rem << "=" << num << endl;
  // 3*4+2=12
}
```

Libraries

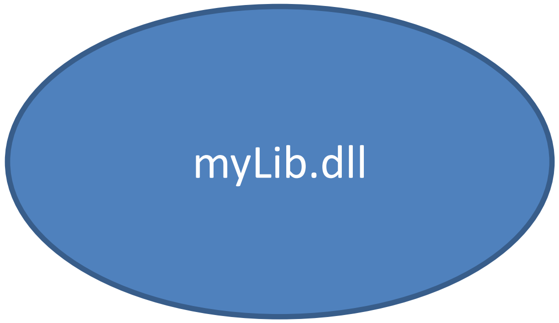
- Libraries are generally distributed as the header file containing the prototypes, and a binary .dll/.so file containing the (compiled) implementation
  - Don’t need to share your .cpp code

```
// myLib.h – header
// contains prototypes
double squareRoot(double num);
```



- Library user only needs to know the function prototypes (in the header file), not the implementation source code (in the .cpp file)
  - The **Linker** (part of the compiler) takes care of locating the implementation of functions in the .dll file at compile time

```
// myLib.h – header
// contains prototypes
double squareRoot(double num);
```



```
// libraryUser.cpp – some other guy’s code
#include "myLib.h"

double fourthRoot(double num) {
  return squareRoot(squareRoot(num));
}
```

Final Notes

- You don’t actually need to implement raiseToPower and squareRoot yourself; cmath (part of the standard library) contains functions **pow** and **sqrt**

```
#include <cmath>

double fourthRoot(double num) {
  return sqrt(sqrt(num));
}
```