Functions

How to reuse code

```
#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)

```
#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 Sy

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

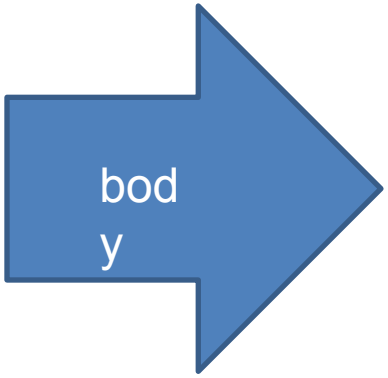
```
int raiseToPower(int base, int exponent)
{
    int result = 1;
    for (int i = 0; i < exponent; i = i + 1) {  result = result
        * base;
    }
    return result;
}
```

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

Function Declaration Syntax


```
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;
}
```

Function declaratio

```
#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;
}

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

Function invocation

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();

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);

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);

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);

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


```
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
}
```

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

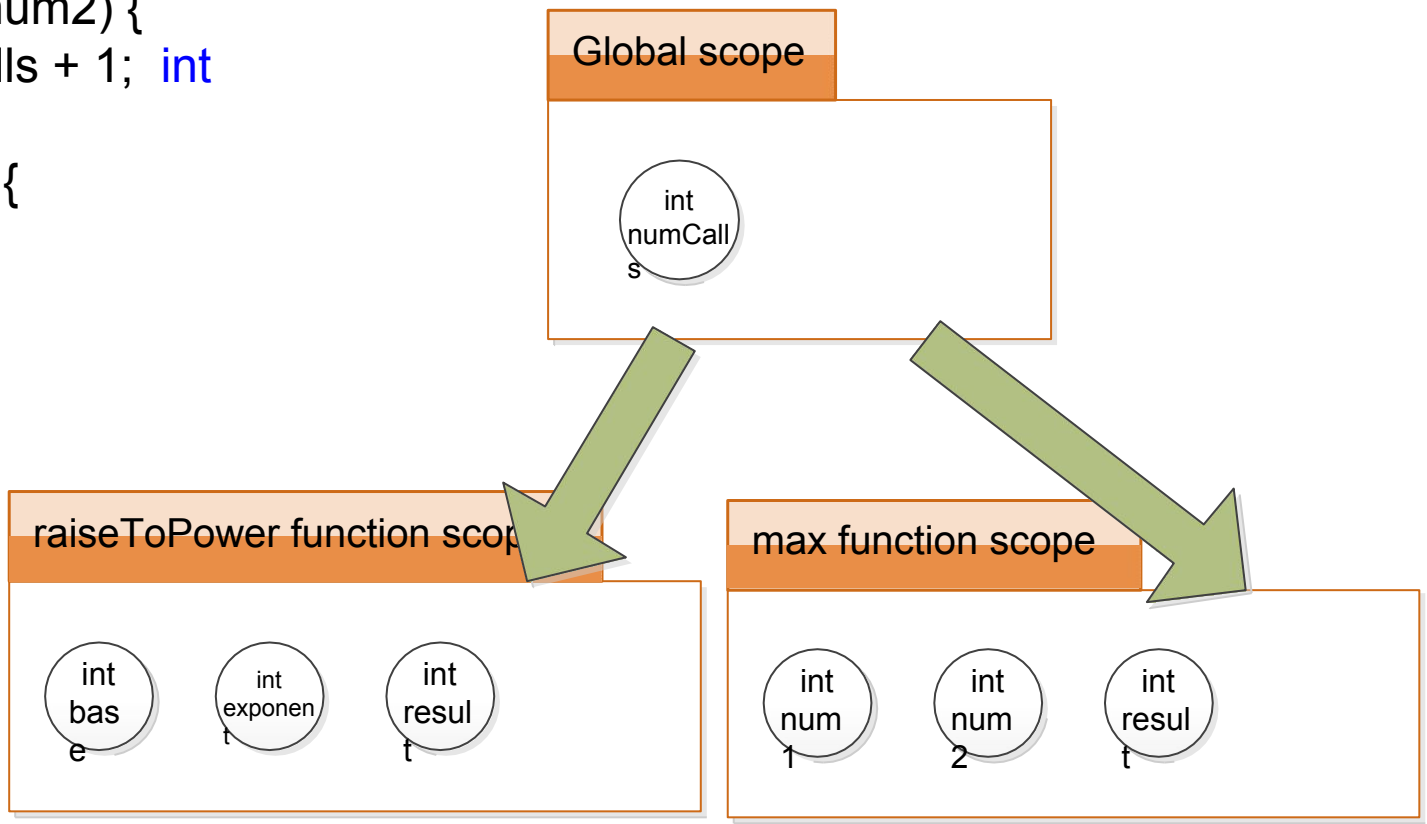
```
int numCalls = 0;

int raiseToPower(int base, int exponent) {
    numCalls =   numCalls   + 1;
    int result  for  = 1;
    (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

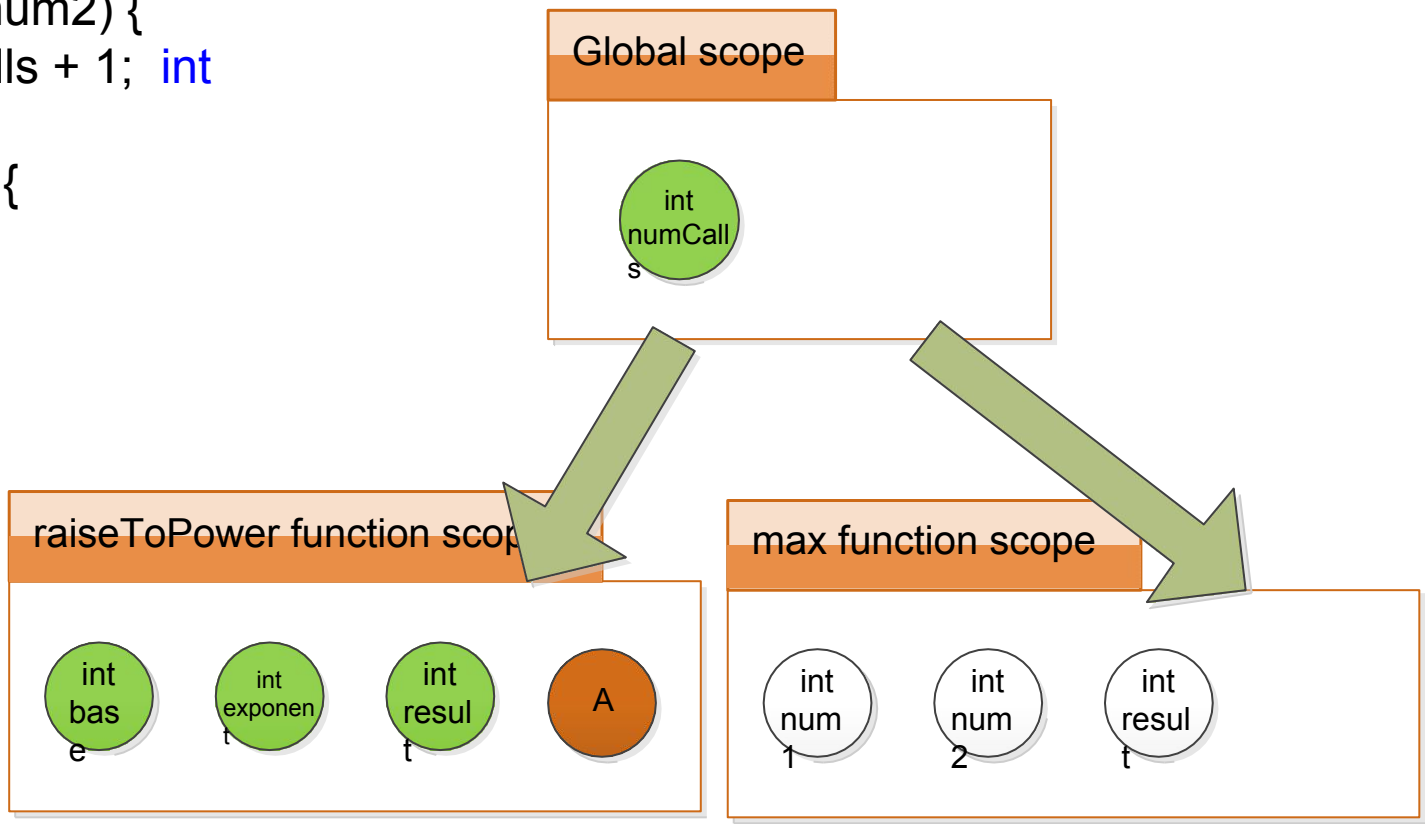
```
int numCalls = 0;

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;
}
```



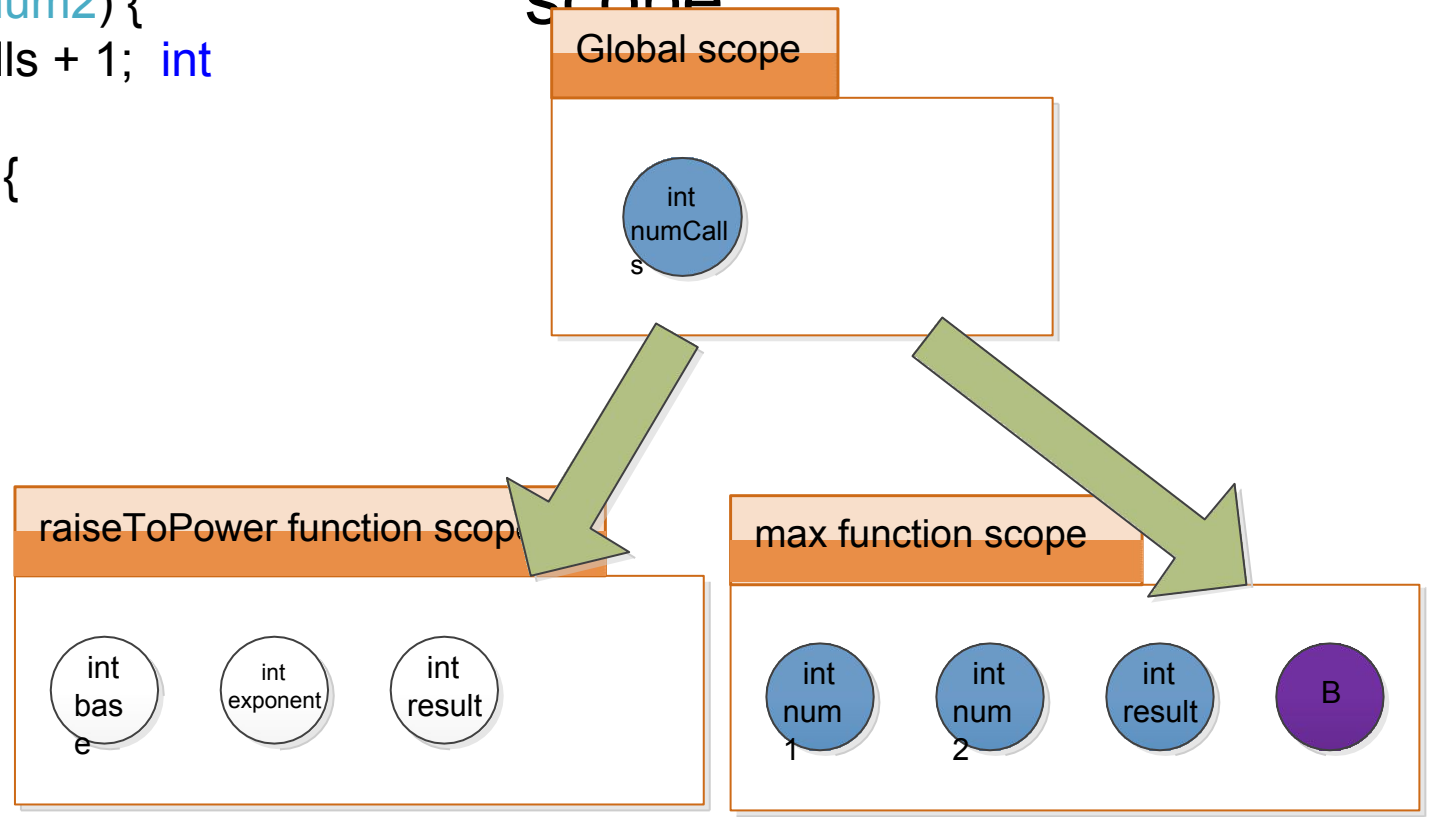
```
int numCalls = 0;
int raiseToPower(int base, int exponent) {  numCalls
    = numCalls + 1;
    int result = 1;
    for (int i = 0; i < exponent; i = i + 1) {  result = result
        * base;
    }
    // A
    return result;
}
int max(int num1, int num2) {
    numCalls = numCalls + 1;  int
    result;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

- At A, variables marked in green are in scope



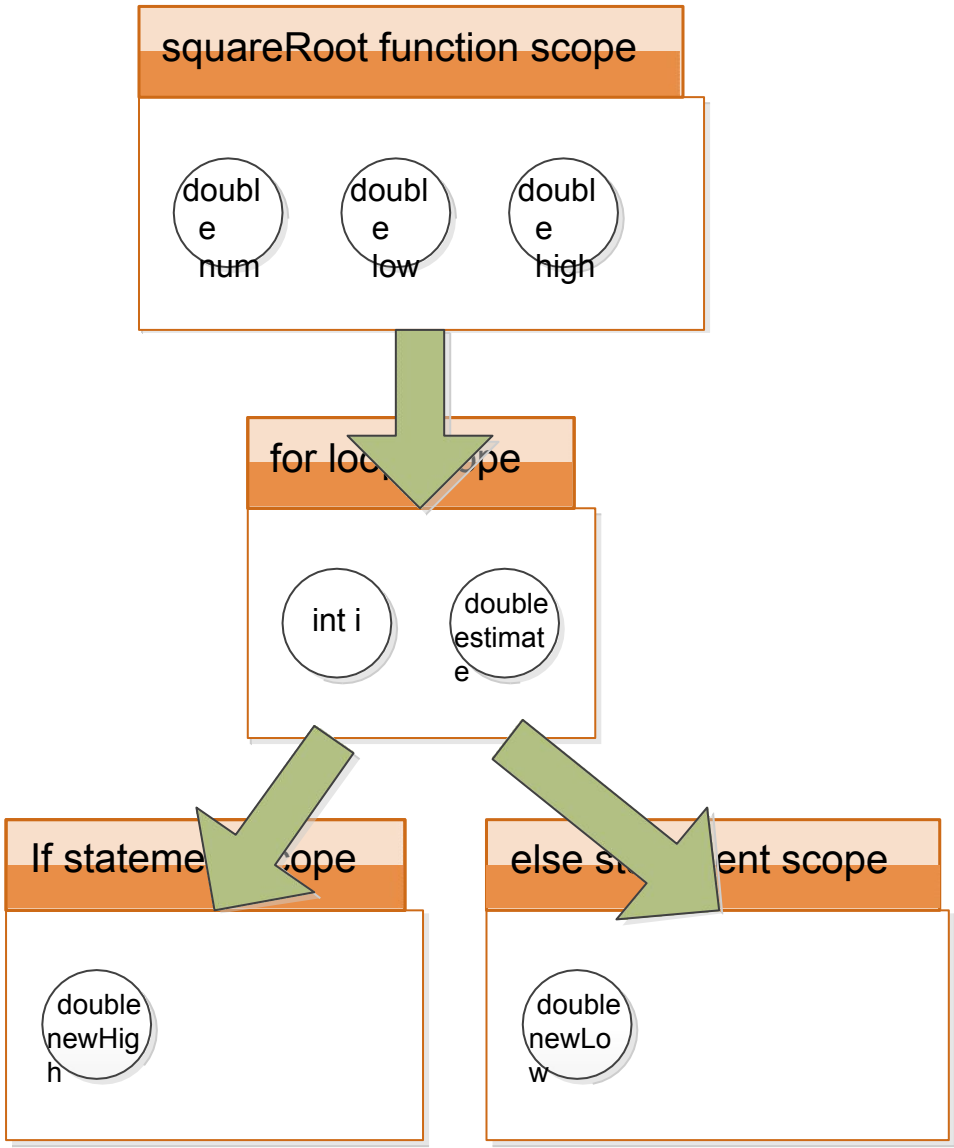
```
int numCalls = 0;
int raiseToPower(int base, int exponent) {  numCalls
    = numCalls + 1;
    int result = 1;
    for (int i = 0; i < exponent; i = i + 1) {  result = result
        * base;
    }
    // A
    return result;
}
int max(int num1, int num2) {
    numCalls = numCalls + 1;  int
    result;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

- At B, variables marked in blue are in scope



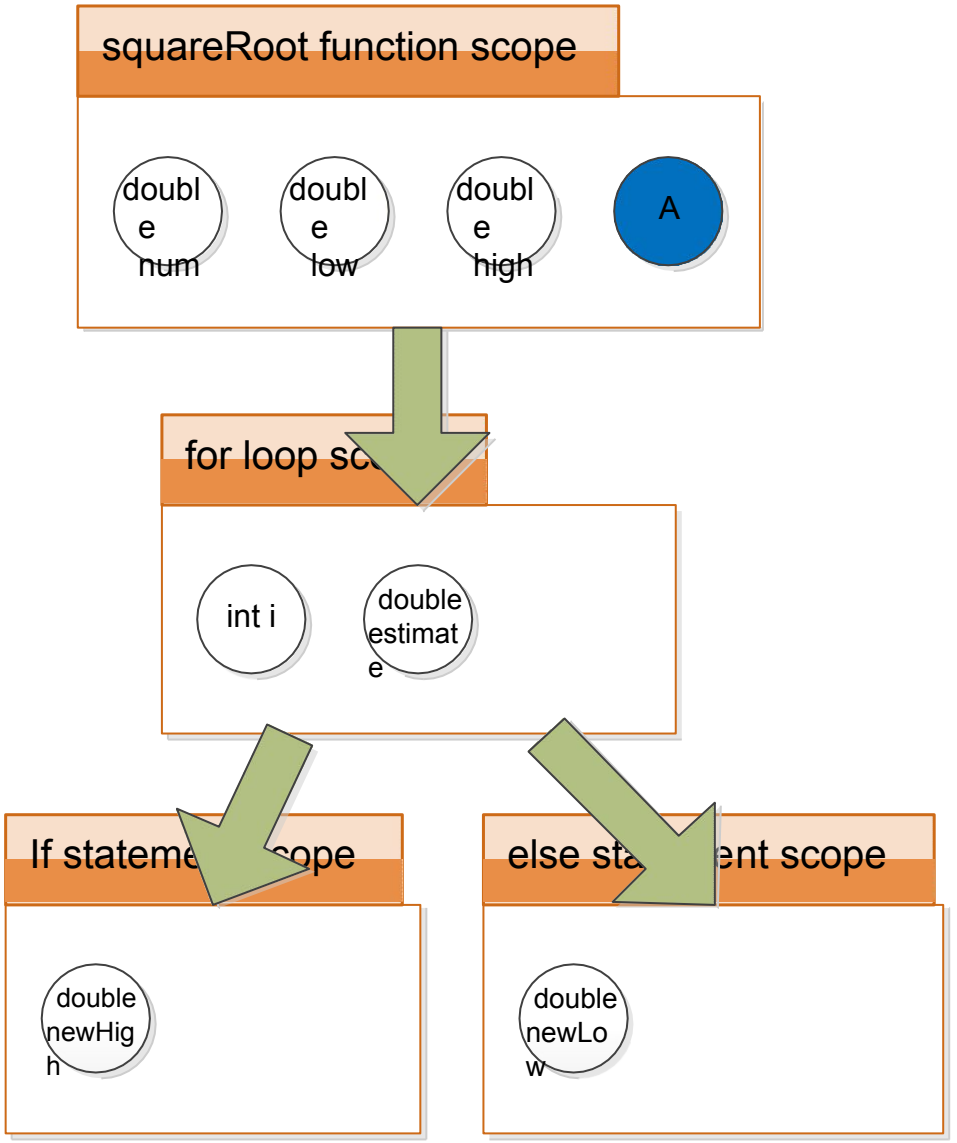
```
double squareRoot(double num) {
    double low = 1.0;
    double high = num;
    for (int i = 0; i < 30; i = i + 1) {  double
        estimate = (high + low) / 2;  if
        (estimate*estimate > num) {
            double newHigh = estimate;
            high = newHigh;
        } else {
         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



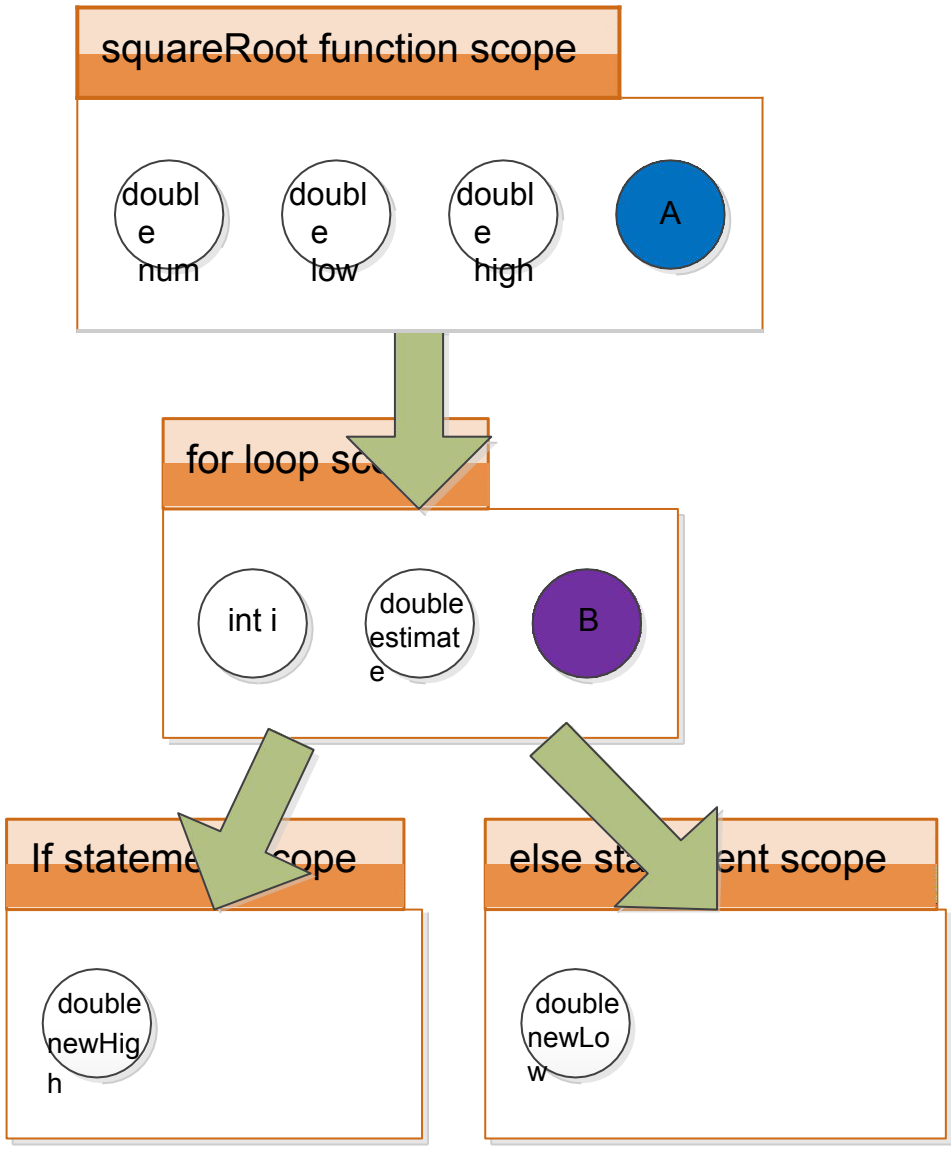
```
double squareRoot(double num) {
    double low = 1.0;
    double high = num;
    for (int i = 0; i < 30; i = i + 1) {  double
        estimate = (high + low) / 2;
        if (estimate*estimate > num) {
            double newHigh = estimate;  high
            = newHigh;
        } else {
         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

- Cannot access variables that are out of scope



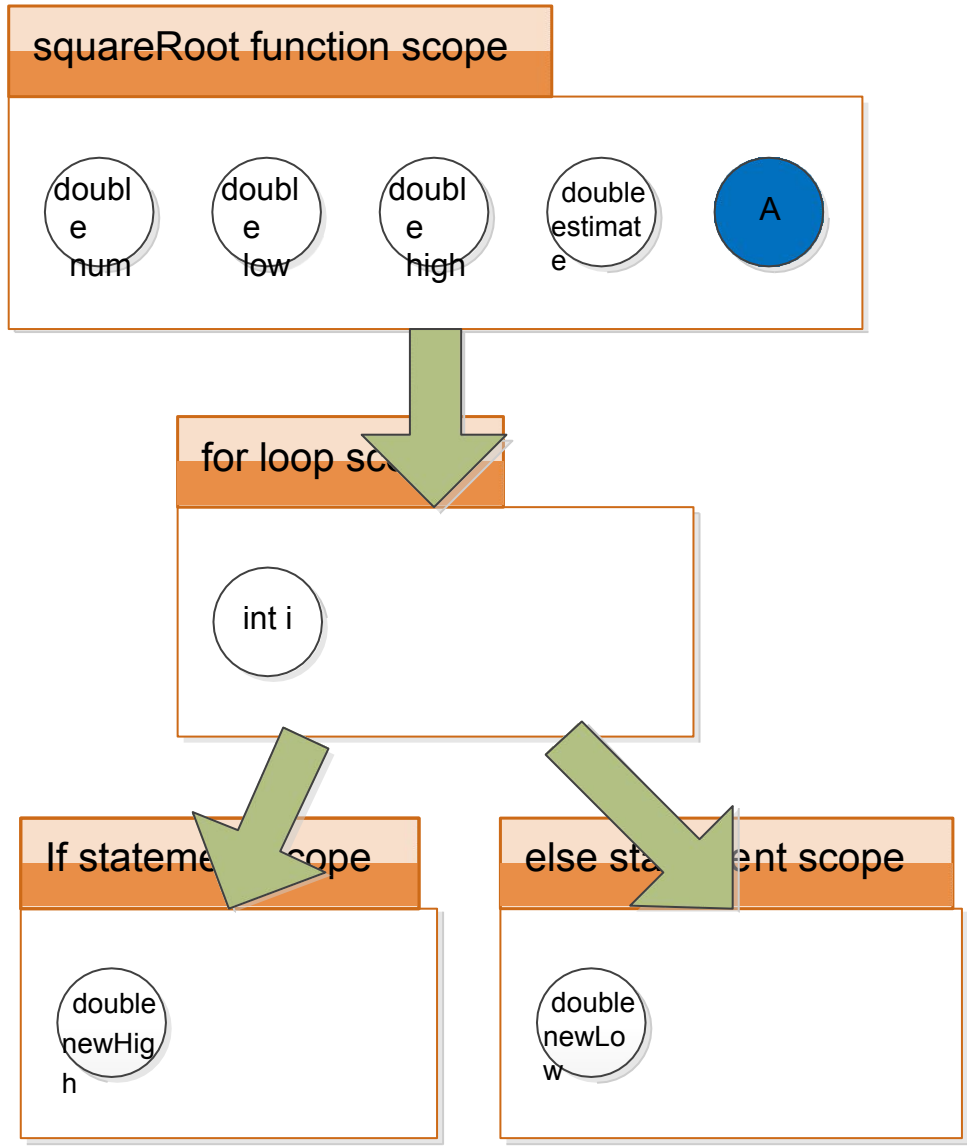
```
double squareRoot(double num) {
    double low = 1.0;
    double high = num;
    for (int i = 0; i < 30; i = i + 1) {  double
        estimate = (high + low) / 2;
        if (estimate*estimate > num) {
            double newHigh = estimate;  high
            = newHigh;
        } else {
         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



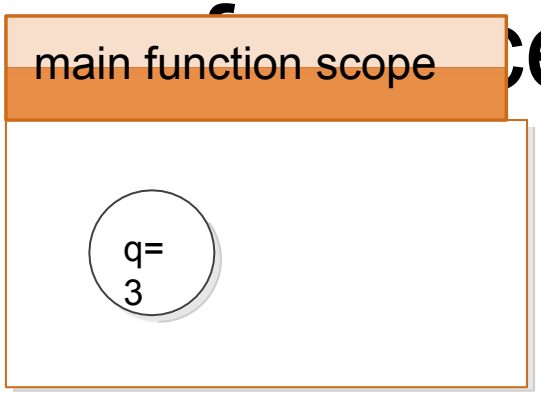
Pass by value vs by reference

- 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;
}
```

Outpu
t
a in increment
4
q in main **3**

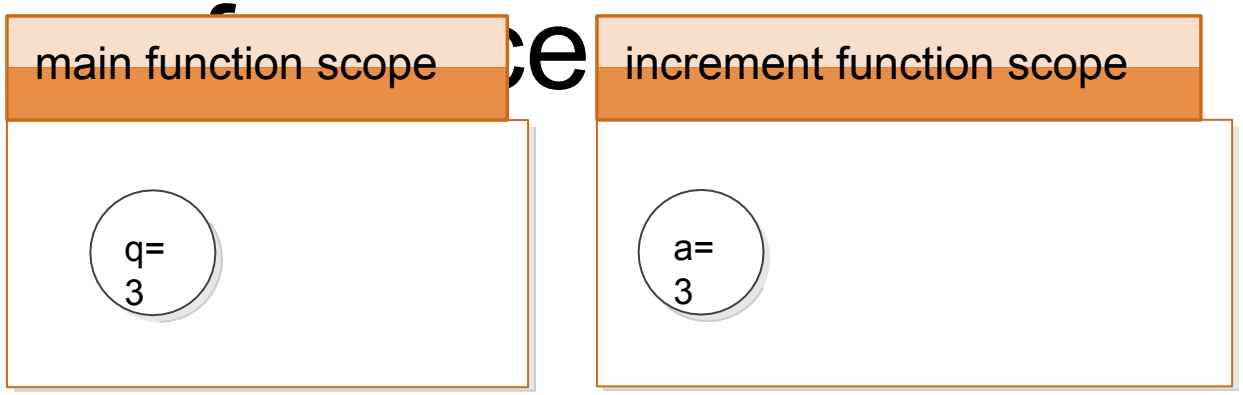
Pass by value vs by ce




```
// 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;
}
```

Outpu
t
a in increment
4
q in main 3

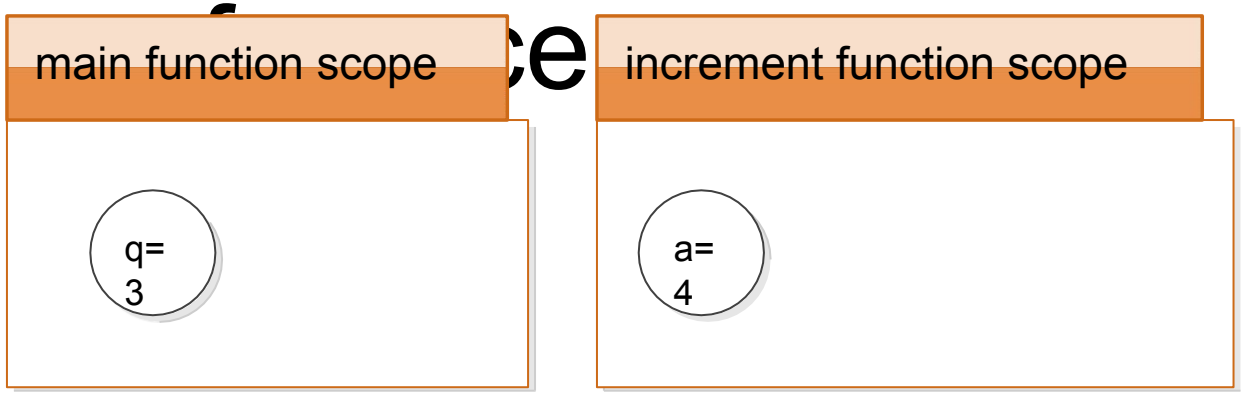
Pass by value vs by




```
// 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;
}
```

Outpu
t
a in increment
4
q in main **3**

Pass by value vs by




```
// 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;
}
```

Outpu
t
a in increment
4
q in main **3**

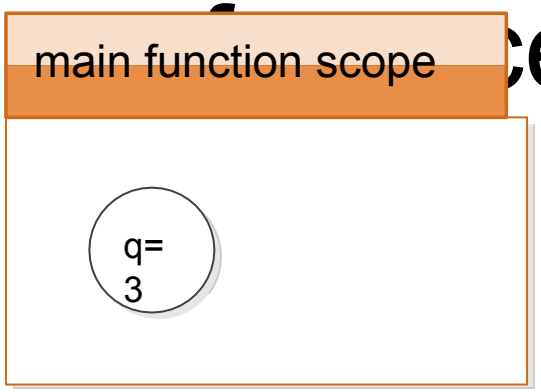
Pass by value vs by reference

- 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;
}
```

Outpu
t
a in increment
4
q in main **4**

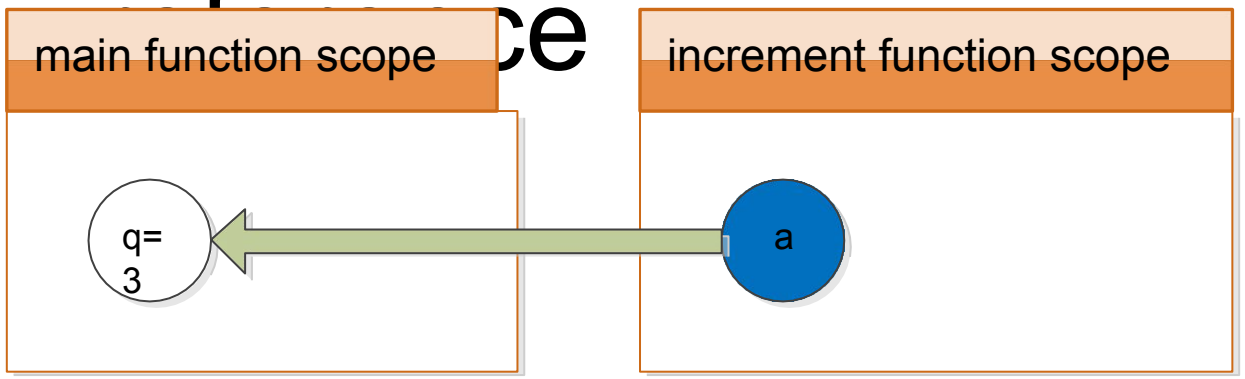
Pass by value vs by




```
// 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;
}
```

Outpu
t
a in increment
4
q in main 4

Pass by value vs by reference

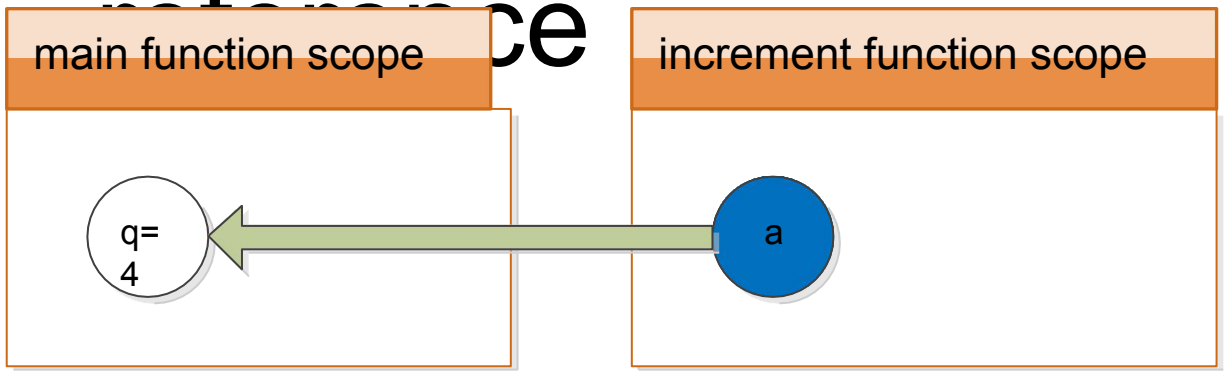



```
// pass-by-value
void increment(int &a) { // HERE  a = a
    + 1;
    cout << "a in increment " << a << endl;
}

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;
}
```

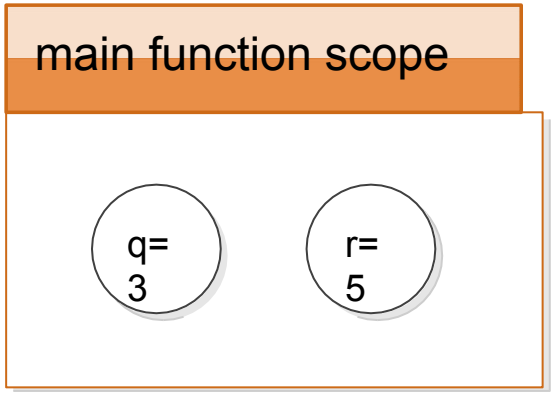
Outpu
t
a in increment
4
q in main 4

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
}
```

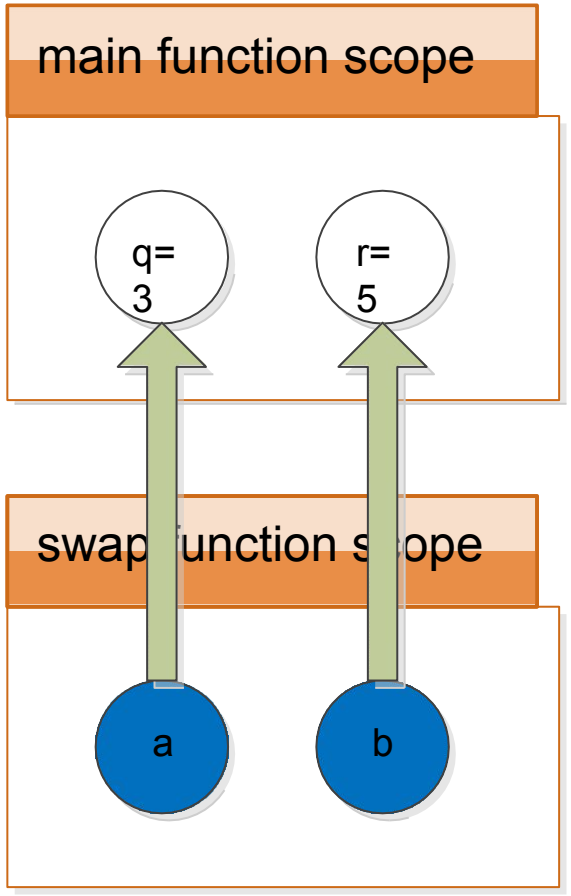
Implementing Swap

```
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
}
```



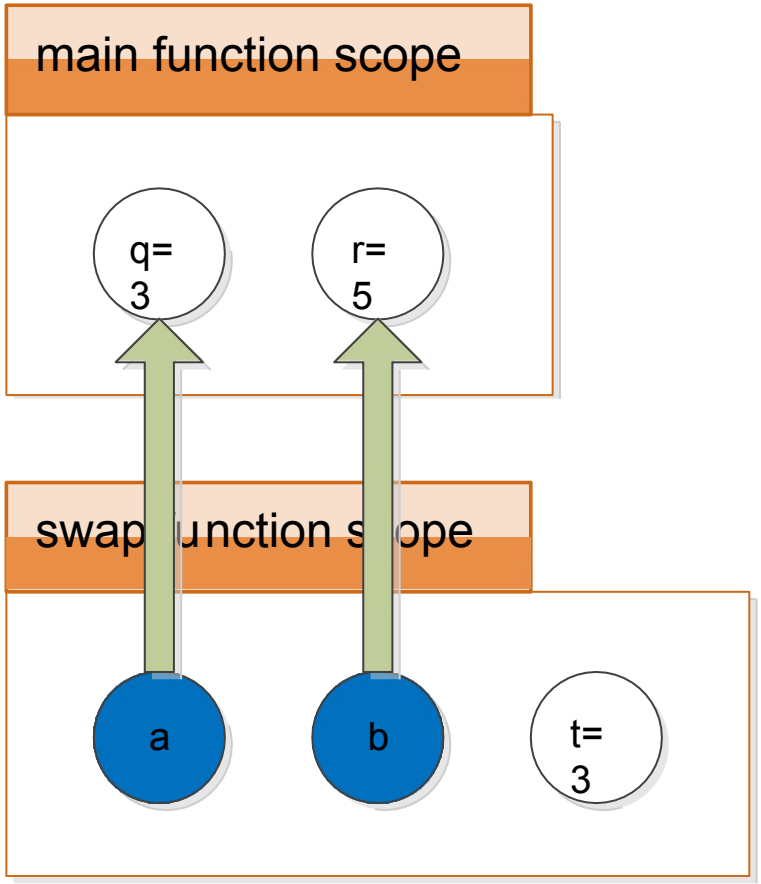
Implementing Swap

```
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
}
```



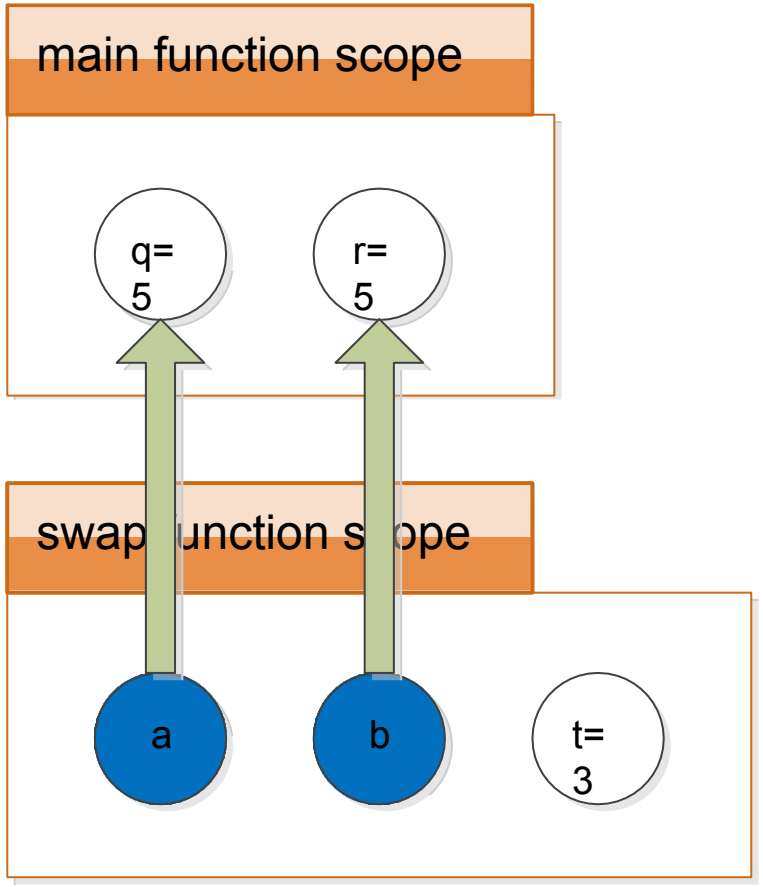
Implementing Swap

```
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
}
```



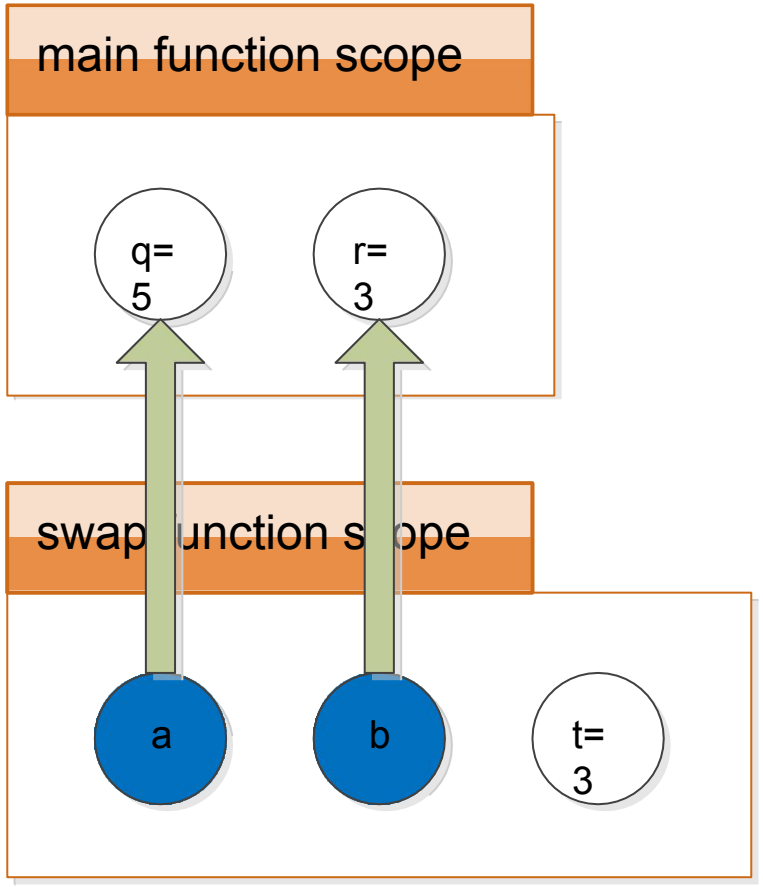
Implementing Swap

```
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
```