Object Oriented Programming by C++

Functions (2/2)

Advanced: Local & Global Variable, Call by Value & Reference

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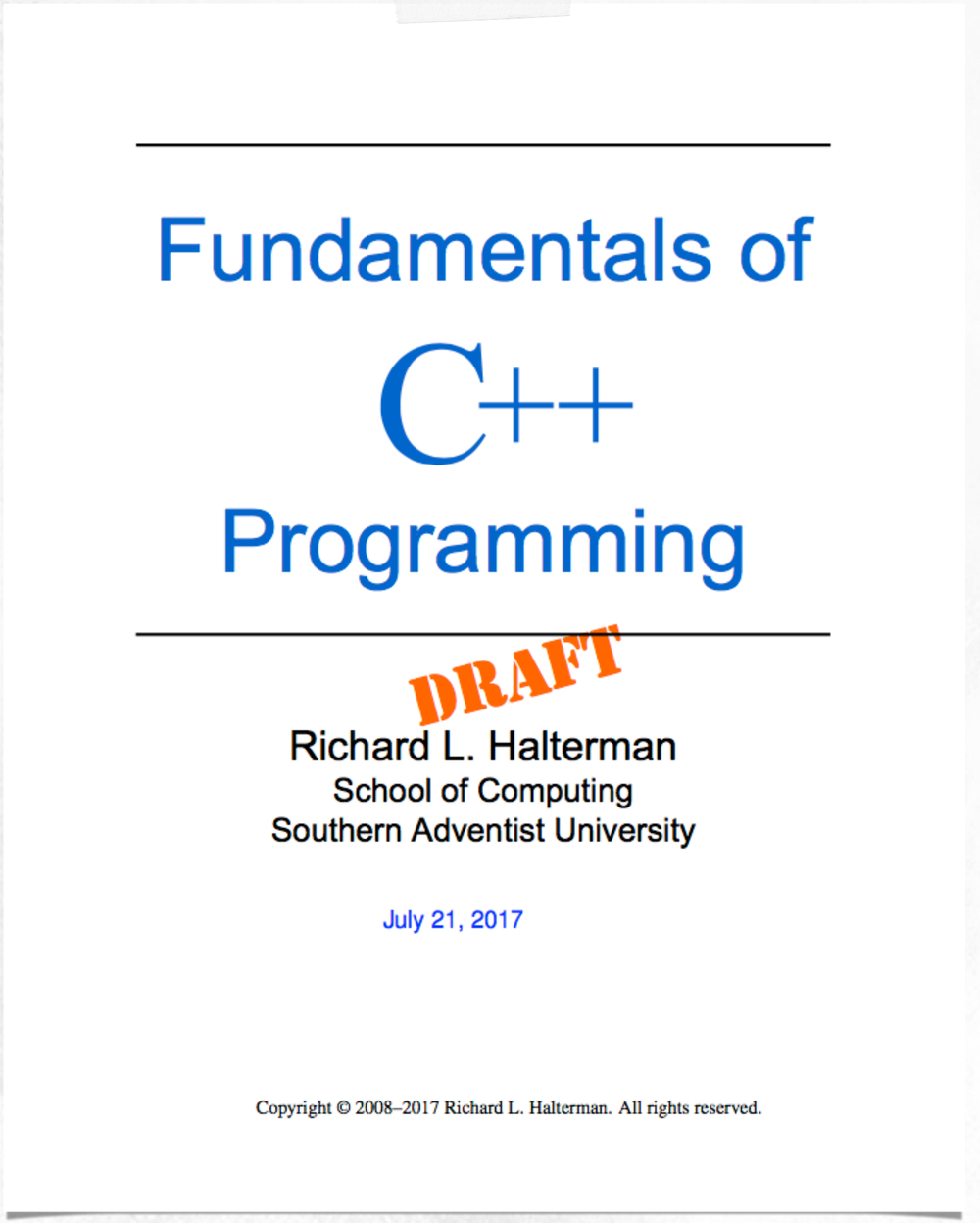
Textbook & Copyright

- Textbook: http://python.cs.southern.edu/cppbook/progcpp.pdf
- Sample Codes: https://github.com/halterman/CppBook-SourceCode



Fundamentals of

C++

Programming

DRAFT

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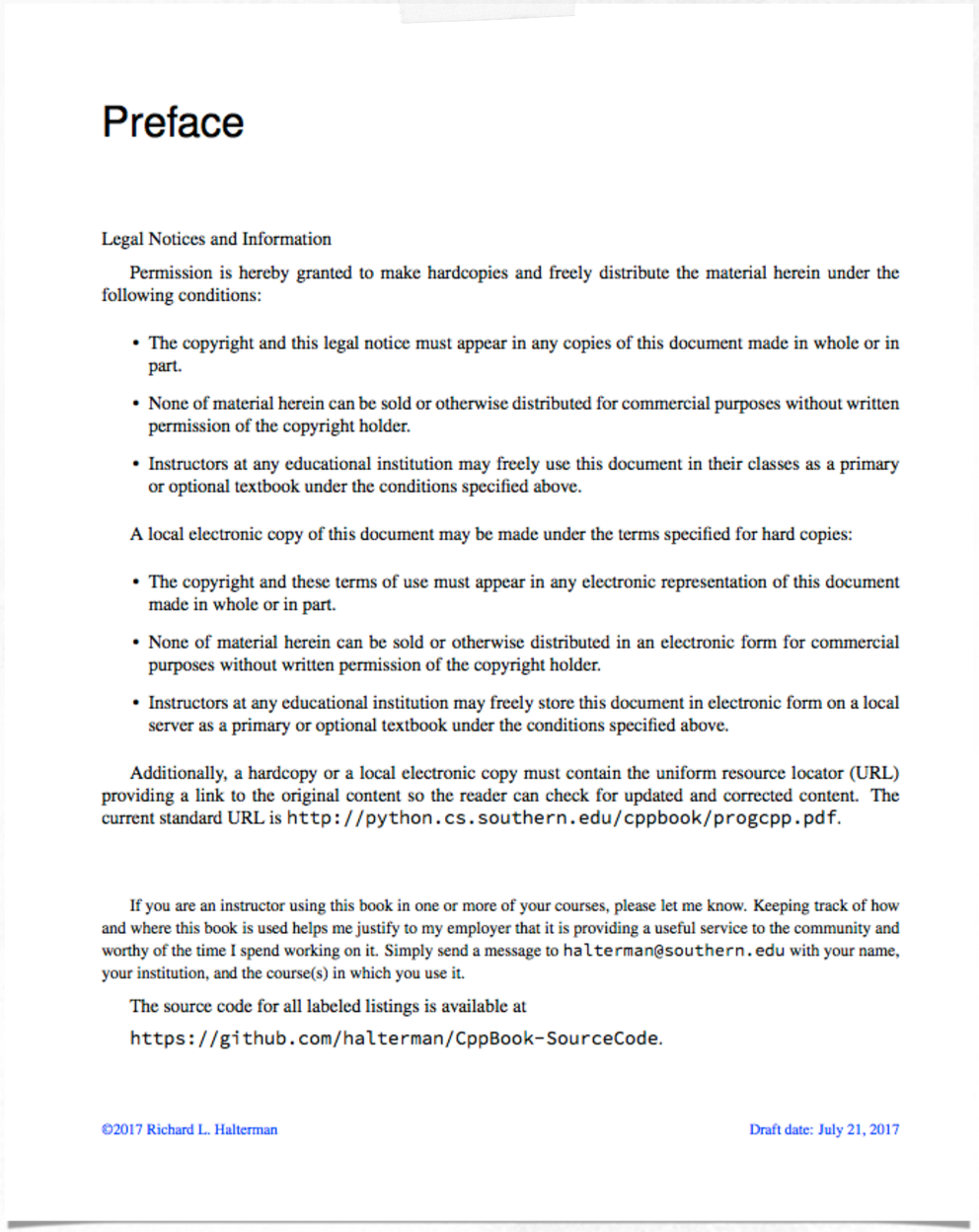

Preface

If you are an instructor using this book in one or more of your courses, please let me know. Keeping track of how and where this book is used helps me justify to my employer that it is providing a useful service to the community and worthy of the time I spend working on it. Simply send a message to `halterman@southern.edu` with your name, your institution, and the course(s) in which you use it.

The source code for all labeled listings is available at

`https://github.com/halterman/CppBook-SourceCode`.

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- Local Variable
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- Pass by Reference

Local Variables

```
#include <iostream>

using namespace std;

int makeDouble( int param )
{
    int x;

    cout << "03: " << x << '\n';

    x = param;

    cout << "04: " << x << '\n';

    return param * 2;
}

int main()
{
    int x = 10;

    cout << "01: " << x << '\n';

    x = makeDouble( x );

    cout << "02: " << x << '\n';

    return 0;
}
```

```
[Output]

01: 10
03: -1031346592
04: 10
02: 20
Program ended with exit code: 0
```

Local Variables Life-Cycle

```
#include <iostream>

using namespace std;

int makeDouble( int param )
{
    int x;

    cout << "03: " << x << '\n';

    x = param;

    cout << "04: " << x << '\n';

    return param * 2;
}

int main()
{
    int x = 10;

    cout << "01: " << x << '\n';

    x = makeDouble( x );

    cout << "02: " << x << '\n';

    return 0;
}
```

Located at Memory A

Located at Memory B

Local Variables Life-Cycle

```
#include <iostream>

using namespace std;

int makeDouble( int param )
{
    int x;

    cout << "03: " << x << '\n';

    x = param;

    cout << "04: " << x << '\n';

    return param * 2;
}

int main()
{
    int x = 10;

    cout << "01: " << x << '\n';

    x = makeDouble( x );

    cout << "02: " << x << '\n';

    return 0;
}
```

Creation: function invoked

Termination: function returning

Creation: main() executed

Termination: main() ended

Local Variables

```
01: #include <iostream>

02: using namespace std;

03: int makeDouble( int param )
04: {
05:     int x;

06:     cout << "03: " << x << '\n';

07:     x = param;

08:     cout << "04: " << x << '\n';

09:     return param * 2;
10: }

11: int main()
12: {
13:     int x = 10;

14:     cout << "01: " << x << '\n';

15:     x = makeDouble( x );

16:     cout << "02: " << x << '\n';

17:     return 0;
18: }
```

[Execution Sequence]

13: **x@main created** & set to 10
14: print x@main(= 10)
15: copy x@main's 10 to makeDouble
03: copy 10 to param@makeDouble
05: **x@makeDouble created** & *no value*
06: print x@makeDouble(= *Garbage*)
07: copy param@makeDouble(= 10) to x@makeDouble
08: print x@makeDouble(= 10)
09: return param@makeDouble(= 10)*2
10: **x@makeDouble** & param@makeDouble **terminated**
15: copy param@makeDouble(= 10)*2 to x@main
16: print x@makeDouble(= 20)
18: **x@main terminated**

Global Variables

```
01: #include <iostream>

02: using namespace std;

03: int x = 10;

04: int makeDouble( int param )
05: {
06:     int x;

07:     cout << "03: " << x << '\n';

08:     x = param;

09:     cout << "04: " << x << '\n';

10:     return param * 2;
11: }

12: int main()
13: {
14:     cout << "01: " << x << '\n';

15:     x = makeDouble( x );

16:     cout << "02: " << x << '\n';

17:     return 0;
18: }
```

```
[Execution Sequence]

03: x@global created & set to 10
14: print x@global(= 10)
15: copy x@global's 10 to
    makeDouble
04: copy 10 to param@makeDouble
06: x@makeDouble created & no value
07: print x@makeDouble(= Garbage)
08: copy param@makeDouble(= 10) to
    x@makeDouble
09: print x@makeDouble(= 10)
10: return param@makeDouble(= 10)*2
11: x@makeDouble & param@makeDouble
    terminated
15: copy param@makeDouble(= 10)*2
    to x@global
16: print x@makeDouble(= 20)
18: x@global terminated
```

Global Variables

```
01: #include <iostream>

02: using namespace std;

03: int x = 10;

04: int makeDouble( int param )
05: {
06:     int x;

07:     cout << "03: " << x << '\n';

08:     x = param;

09:     cout << "04: " << x << '\n';

10:     return param * 2;
11: }

12: int main()
13: {
14:     cout << "01: " << x << '\n';

15:     x = makeDouble( x );

16:     cout << "02: " << x << '\n';

17:     return 0;
18: }
```

Creation: program executed

Termination: program terminated

Global Variables

```
01: #include <iostream>

02: using namespace std;

03: int x = 10;

04: int makeDouble( int param )
05: {
06:     int x;

07:     cout << "03: " << x << '\n';

08:     x = param;

09:     cout << "04: " << x << '\n';

10:     return param * 2;
11: }

12: int main()
13: {
14:     cout << "01: " << x << '\n';

15:     x = makeDouble( x );

16:     cout << "02: " << x << '\n';

17:     return 0;
18: }
```

```
[Output]

01: 10
03: -1031346592 (Garbage)
04: 10
02: 20
Program ended with exit code: 0
```

Parameter Transfer to Functions

Pass by Value

```
01: #include <iostream>

02: using namespace std;

03: int makeDouble( int param )
04: {
05:     int x;

06:     cout << "03: " << x << '\n';

07:     x = param;

08:     cout << "04: " << x << '\n';

09:     return param * 2;
10: }

11: int main()
12: {
13:     int x = 10;

14:     cout << "01: " << x << '\n';

15:     x = makeDouble( x );

16:     cout << "02: " << x << '\n';

17:     return 0;
18: }
```

COPY

[Execution Sequence]

```
13: x@main created & set to 10
14: print x@main(= 10)
15: copy x@main's 10 to makeDouble
03: copy 10 to param@makeDouble
05: x@makeDouble created & no value
06: print x@makeDouble(= Garbage)
07: copy param@makeDouble(= 10) to
    x@makeDouble
08: print x@makeDouble(= 10)
09: return param@makeDouble(= 10)*2
10: x@makeDouble & param@makeDouble
    terminated
15: copy param@makeDouble(= 10)*2
    to x@main
16: print x@makeDouble(= 20)
18: x@main terminated
```

Pass by Value Example

Listing 9.9: passbyvalue.cpp

```
#include <iostream>

/*
 *  increment(x)
 *      Illustrates pass by value protocol.
 */
void increment(int x) {
   std::cout << "Beginning execution of increment, x = "
             << x << '\n';
   x++;   // Increment x
   std::cout << "Ending execution of increment, x = "
             << x << '\n';
}

int main() {
    int x = 5;
    std::cout << "Before increment, x = " << x << '\n';
    increment(x);
    std::cout << "After increment, x = " << x << '\n';
}
```

Pass by Value Example Results

Listing 9.9 (passbyvalue.cpp) produces

```
Before increment, x = 5
Beginning execution of increment, x = 5
Ending execution of increment, x = 6
After increment, x = 5
```

```
 */
void increment(int x) {
   std::cout << "Beginning execution of increment, x = "
             << x << '\n';
   x++;   // Increment x
   std::cout << "Ending execution of increment, x = "
             << x << '\n';
}

int main() {
    int x = 5;
    std::cout << "Before increment, x = " << x << '\n';
    increment(x);
    std::cout << "After increment, x = " << x << '\n';
}
```

Function calls itself

- Why?

The *factorial* function is widely used in combinatorial analysis (counting theory in mathematics), probability theory, and statistics. The factorial of n is often expressed as $n!$. Factorial is defined for nonnegative integers as

$$n! = n \cdot (n-1) \cdot (n-2) \cdot (n-3) \cdots 2 \cdot 1$$

and 0! is defined to be 1. Thus $6! = 6 \cdot 5 \cdot 4 \cdot 3 \cdot 2 \cdot 1 = 720$. Mathematicians precisely define factorial in this way:

$$n! = \begin{cases} 1 & \text{if } n = 0 \\ n \cdot (n-1)! & \text{otherwise.} \end{cases}$$

This definition is *recursive* since the ! function is being defined, but ! is also used in the definition. A C++ function can be defined recursively as well. Listing 10.6 (factorialtest.cpp) includes a factorial function that exactly models the mathematical definition.

Example

Listing 10.6: factorialtest.cpp

```
#include <iostream>

/*
 *   factorial(n)
 *      Computes n!
 *      Returns the factorial of n.
 */
int factorial(int n) {
    if (n == 0)
        return 1;
    else
        return n * factorial(n - 1);
}

int main() {
    // Try out the factorial function
    std::cout << " 0! = " << factorial(0) << '\n';
    std::cout << " 1! = " << factorial(1) << '\n';
    std::cout << " 6! = " << factorial(6) << '\n';
    std::cout << "10! = " << factorial(10) << '\n';
}
```

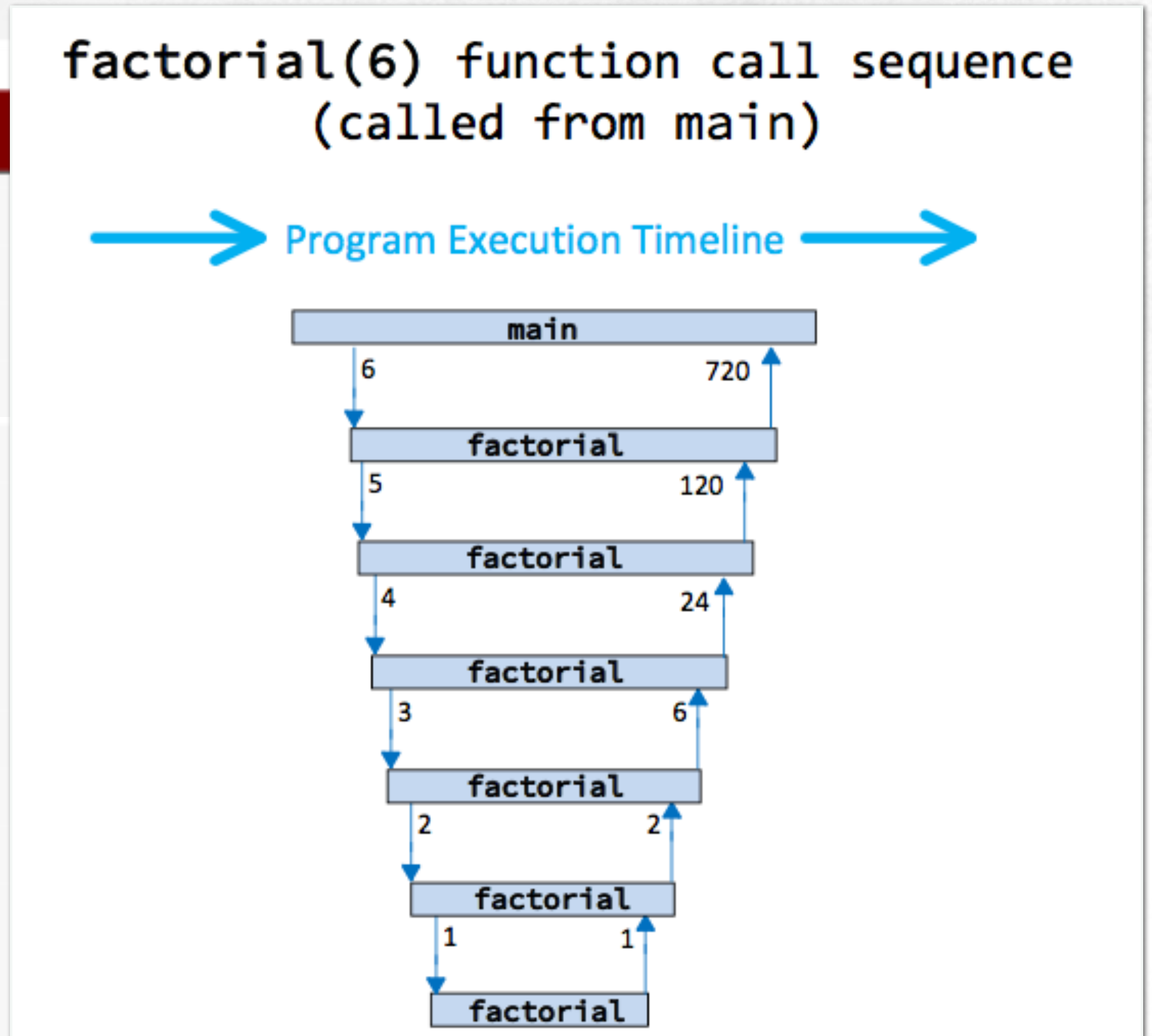
Example Results

Listing 10.6: factorialtest.cpp

```
#include <iostream>

/*
 *   factorial(n)
 *      Computes n!
 *      Returns the factorial of n.
 */
int factorial(int n) {
    if (n == 0)
        return 1;
    else
        return n * factorial(n - 1);
}

int main() {
    // Try out the factorial function
    std::cout << " 0! = " << factorial(0) << '\n';
    std::cout << " 1! = " << factorial(1) << '\n';
    std::cout << " 6! = " << factorial(6) << '\n';
    std::cout << "10! = " << factorial(10) << '\n';
}
```



Example Results

Listing 10.6: factorialtest.cp

```
#include <iostream>

/*
 *   factorial(n)
 *      Computes n!
 *      Returns the factoria
 */
int factorial(int n) {
    if (n == 0)
        return 1;
    else
        return n * factorial(n - 1);
}

int main() {
    // Try out the factorial function
    std::cout << " 0! = " << factorial(0) << '\n';
    std::cout << " 1! = " << factorial(1) << '\n';
    std::cout << " 6! = " << factorial(6) << '\n';
    std::cout << "10! = " << factorial(10) << '\n';
}
```

```
factorial(6) = 6 * factorial(5)
             = 6 * 5 * factorial(4)
             = 6 * 5 * 4 * factorial(3)
             = 6 * 5 * 4 * 3 * factorial(2)
             = 6 * 5 * 4 * 3 * 2 * factorial(1)
             = 6 * 5 * 4 * 3 * 2 * 1 * factorial(0)
             = 6 * 5 * 4 * 3 * 2 * 1 * 1
             = 6 * 5 * 4 * 3 * 2 * 1
             = 6 * 5 * 4 * 3 * 2
             = 6 * 5 * 4 * 6
             = 6 * 5 * 24
             = 6 * 120
             = 720
```

Aliasing

- When the & symbol is used as part of the type name during a variable declaration, as in

$$int\ x;$$

$$int\&\ r = x;$$

- We say ***r*** is a ***reference variable***.
- This declaration creates a variable r that refers to the ***same memory*** location as the variable x.
- We say that ***r aliases x***.

Reference Variable Example

Listing 10.16: referencevar.cpp

```
#include <iostream>

int main() {
    int x = 5;
    int y = x;
    int& r = x;
    std::cout << "x = " << x << '\n';
    std::cout << "y = " << y << '\n';
    std::cout << "r = " << r << '\n';
    std::cout << "Assign 7 to x\n";
    x = 7;
    std::cout << "x = " << x << '\n';
    std::cout << "y = " << y << '\n';
    std::cout << "r = " << r << '\n';
    std::cout << "Assign 8 to y\n";
    y = 8;
    std::cout << "x = " << x << '\n';
    std::cout << "y = " << y << '\n';
    std::cout << "r = " << r << '\n';
    std::cout << "Assign 2 to r\n";
    r = 2;
    std::cout << "x = " << x << '\n';
    std::cout << "y = " << y << '\n';
    std::cout << "r = " << r << '\n';
}
```

Reference Variable Example Result

Listing 10.16: referencevar.cpp

```
#include <iostream>

int main() {
    int x = 5;
    int y = x;
    int& r = x;
    std::cout << "x = " << x << '\n';
    std::cout << "y = " << y << '\n';
    std::cout << "r = " << r << '\n';
    std::cout << "Assign 7 to x\n";
    x = 7;
    std::cout << "x = " << x << '\n';
    std::cout << "y = " << y << '\n';
    std::cout << "r = " << r << '\n';
    std::cout << "Assign 8 to y\n";
    y = 8;
    std::cout << "x = " << x << '\n';
    std::cout << "y = " << y << '\n';
    std::cout << "r = " << r << '\n';
    std::cout << "Assign 2 to r\n";
    r = 2;
    std::cout << "x = " << x << '\n';
    std::cout << "y = " << y << '\n';
    std::cout << "r = " << r << '\n';
}
```

The output Listing 10.16 (referencevar.cpp):

```
x = 5
y = 5
r = 5
Assign 7 to x
x = 7
y = 5
r = 7
Assign 8 to y
x = 7
y = 8
r = 7
Assign 2 to r
x = 2
y = 8
r = 2
```

Wrong Example using Pass by Value

Listing 10.17: faultyswap.cpp

```
#include <iostream>

/*
 *  swap(a, b)
 *     Attempts to interchange the values of
 *     its parameters a and b.  That it does, but
 *     unfortunately it only affects the local
 *     copies.
 */
void swap(int a, int b) {
   int temp = a;
   a = b;
   b = temp;
}

/*
 *  main
 *     Attempts to interchange the values of
 *     two variables using a faulty swap function.
 */
int main() {
    int var1 = 5, var2 = 19;
    std::cout << "var1 = " << var1 << ", var2 = " << var2 << '\n';
    swap(var1, var2);
    std::cout << "var1 = " << var1 << ", var2 = " << var2 << '\n';
}
```

Wrong Example Results

Listing 10.17: faultyswap.cpp

The output of Listing 10.17 (faultyswap.cpp) is

```
var1 = 5, var2 = 19
var1 = 5, var2 = 19
```

```
 *      copies.
 */
void swap(int a, int b) {
    int temp = a;
    a = b;
    b = temp;
}

/*
 *  main
 *      Attempts to interchange the values of
 *      two variables using a faulty swap function.
 */
int main() {
    int var1 = 5, var2 = 19;
    std::cout << "var1 = " << var1 << ", var2 = " << var2 << '\n';
    swap(var1, var2);
    std::cout << "var1 = " << var1 << ", var2 = " << var2 << '\n';
}
```

Pass by Reference Example

Listing 10.19: swapwithreferences.cpp

```
#include <iostream>

/*
 *  swap(a, b)
 *     Interchanges the values of memory
 *     referenced by its parameters a and b.
 *     It effectively interchanges the values
 *     of variables in the caller's context.
 */
void swap(int& a, int& b) {
   int temp = a;
   a = b;
   b = temp;
}

/*
 *  main
 *     Interchanges the values of two variables
 *     using the swap function.
 */
int main() {
    int var1 = 5, var2 = 19;
    std::cout << "var1 = " << var1 << ", var2 = " << var2 << '\n';
    swap(var1, var2);
    std::cout << "var1 = " << var1 << ", var2 = " << var2 << '\n';
}
```

Pass by Reference Example Result

Listing 10.19: swapwithreferences.cpp

```
#include <iostream>

/*
 *  swap(a, b)
 *     Interchanges the values of memory
 *     referenced by its parameters a and b.
 *     It effectively interchanges the values
 *     of variables in the caller's context.
 */
void swap(int& a, int& b) {
   int temp = a;
   a = b;
   b = temp;
}

/*
 *  main
 *     Interchanges the values of two variables
 *     using the swap function.
 */
int main() {
    int var1 = 5, var2 = 19;
    std::cout << "var1 = " << var1 << ", var2 = " << var2 << '\n';
    swap(var1, var2);
    std::cout << "var1 = " << var1 << ", var2 = " << var2 << '\n';
}
```

```
var1 = 5, var2 = 19
var1 = 19, var2 = 5
```

Object Oriented Programming by C++

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