Computer Programming C++ Data Types, Functions, and Overloading 7th Lecture

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Outline

- Function Definitions
- Function Prototypes
- Data Types
- Storage Classes and Scope Rules
- C++ Function Call Stack and Activation Records
- References
- Default Arguments
- Function Overloading and Templates
- Recursion
- Q&A

Function Definitions

- Three ways to return control to the calling statement:
  - If the function does not return a result:
    - Program flow reaches the function-ending right brace or
    - Program executes the statement **return;**
  - If the function does return a result:
    - Program executes the statement **return** *expression*;
      - *expression* is evaluated and its value is returned to the caller

Function Prototypes and Argument Coercion

- Function prototype
  - Also called a function declaration
  - Indicates to the compiler:
    - Name of the function
    - Type of data returned by the function
    - Parameters the function expects to receive
      - Number of parameters
      - Types of those parameters
      - Order of those parameters

Software Engineering Observation 1

Function prototypes are required in C++. Use **`#include`** preprocessor directives to obtain function prototypes for the C++ Standard Library functions from the header files for the appropriate libraries (e.g., the prototype for math function **`sqrt`** is in header file **`<cmath>`**).

Math Library Functions

- Global functions
  - Do not belong to a particular class
  - Have function prototypes placed in header files
    - Can be reused in any program that includes the header file and that can link to the function's object code
  - Example: **sqrt** in **<cmath>** header file
    - **sqrt(900.0)**
    - All functions in **<cmath>** are global functions

Math library functions Cont'd

Function	Description	Example
`ceil( x )`	rounds *x* to the smallest integer not less than *x*	`ceil( 9.2 )` is `10.0` `ceil( -9.8 )` is `-9.0`
`cos( x )`	trigonometric cosine of *x* (*x* in radians)	`cos( 0.0 )` is `1.0`
`exp( x )`	exponential function e^x	`exp( 1.0 )` is `2.71828` `exp( 2.0 )` is `7.38906`

`fabs( x )`	absolute value of *x*	`fabs( 5.1 )` is `5.1`
		`fabs( 0.0 )` is `0.0`
		`fabs( -8.76 )` is `8.76`

`floor( x )`	rounds *x* to the largest integer not greater than *x*	`floor( 9.2 )` is `9.0` `floor( -9.8 )` is `-10.0`
`fmod( x, y )`	remainder of *x*/*y* as a floating-point number	`fmod( 2.6, 1.2 )` is `0.2`
`log( x )`	natural logarithm of *x* (base *e*)	`log( 2.718282 )` is `1.0` `log( 7.389056 )` is `2.0`
`log10( x )`	logarithm of *x* (base 10)	`log10( 10.0 )` is `1.0` `log10( 100.0 )` is `2.0`
`pow( x, y )`	*x* raised to power *y* (x^y)	`pow( 2, 7 )` is `128` `pow( 9, .5 )` is `3`
`sin( x )`	trigonometric sine of *x* (*x* in radians)	`sin( 0.0 )` is `0`
`sqrt( x )`	square root of *x* (where *x* is a nonnegative value)	`sqrt( 9.0 )` is `3.0`
`tan( x )`	trigonometric tangent of *x* (*x* in radians)	`tan( 0.0 )` is `0`

Function Prototypes and Argument Coercion Cont'd

- Function signature (or simply signature)
  - The portion of a function prototype that includes the name of the function and the types of its arguments
    - Does not specify the function's return type
  - Functions in the same scope must have unique signatures
    - The scope of a function is the region of a program in which the function is known and accessible

Common Programming Error 1

It is a compilation error if two functions in the same scope have the same signature but different return types.

Function Prototypes and Argument Coercion Cont'd

- Argument Coercion
  - Forcing arguments to the appropriate types specified by the corresponding parameters
    - For example, calling a function with an integer argument, even though the function prototype specifies a double argument
      - The function will still work correctly

Function Prototypes and Argument Coercion Cont'd

- C++ Promotion Rules
  - Indicate how to convert between types without losing data
  - Apply to expressions containing values of two or more data types
    - Such expressions are also referred to as mixed-type expressions
    - Each value in the expression is promoted to the "highest" type in the expression
      - Temporary version of each value is created and used for the expression
        - Original values remain unchanged

Function Prototypes and Argument Coercion Cont'd

- C++ Promotion Rules Cont'd
  - Converting a value to a lower fundamental type
    - Will likely result in the loss of data or incorrect values
    - Can only be performed explicitly
      - By assigning the value to a variable of lower type (some compilers will issue a warning in this case) or
      - By using a cast operator

Promotion hierarchy for fundamental data types

Data types	
long double	
double	
float	
unsigned long int	(synonymous with unsigned long)
long int	(synonymous with long)
unsigned int	(synonymous with unsigned)
int	
unsigned short int	(synonymous with unsigned short)
short int	(synonymous with short)
unsigned char	
char	
bool	

long double: 12 B
double: 8 B
float: 4 B

long: 4 B

int: 4 B

short: 2 B

char: 1 B

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C++ Standard Library Header Files

- C++ Standard Library header files
  - Each contains a portion of the Standard Library
    - Function prototypes for the related functions
    - Definitions of various class types and functions
    - Constants needed by those functions
  - Header file names ending in `.h`
    - Are "old-style" header files
    - Superseded by the C++ Standard Library header files

Enumeration

- A set of integer constants represented by identifiers
  - The values of enumeration constants start at 0, unless specified otherwise, and increment by 1
- Defining an enumeration
  - Keyword **enum**
  - Comma-separated list of identifier names enclosed in braces
  - `enum Months { JAN = 1, FEB, MAR, APR };`

Common Programming Error 2

Assigning the integer equivalent of an enumeration constant to a variable of the enumeration type is a compilation error.

Storage Classes

- Each identifier has several attributes
  - Name, type, size and value
  - Also storage class, scope and linkage
- C++ provides five storage-class specifiers:
  - **auto**, **register**, **extern**, **mutable** *and* **static**
- Identifier's storage class
  - Determines the period during which that identifier exists in memory

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Storage Classes Cont'd

- Identifier's scope
  - Determines where the identifier can be referenced in a program
- Identifier's linkage
  - Determines whether an identifier is known only in the source file where it is declared or across multiple files that are compiled, then linked together
- An identifier's storage-class specifier helps determine its storage class and linkage

Storage Classes Cont'd

- Automatic storage class
  - Declared with keywords **auto** and **register**
  - Automatic variables
    - Created when program execution enters block in which they are defined
    - Exist while the block is active
    - Destroyed when the program exits the block
  - Only local variables and parameters can be of automatic storage class
    - Such variables normally are of automatic storage class

Performance Tip 1

Automatic storage is a means of conserving memory, because automatic storage class variables exist in memory only when the block in which they are defined is executing.

Performance Tip 2

The storage-class specifier **register** can be placed before an automatic variable declaration to suggest that the compiler maintain the variable in one of the computer's high-speed hardware registers. If intensely used variables such as counters or totals are maintained in hardware registers, the overhead of repeatedly loading the variables from memory into the registers and storing the results back into memory is eliminated.

Storage Classes Cont'd

- Storage-class specifier **auto**
  - Explicitly declares variables of automatic storage class
  - Local variables are of automatic storage class by default
    - So keyword **auto** rarely is used

Storage Classes Cont'd

- Storage-class specifier **register**
  - Data in the machine-language version of a program is normally loaded into registers for calculations and other processing
    - Compiler tries to store register storage class variables in a register
  - The compiler might ignore **register** declarations
    - May not be sufficient registers for the compiler to use

Common Programming Error 3

Using multiple storage-class specifiers for an identifier is a syntax error. Only one storage class specifier can be applied to an identifier. For example, if you include **register**, do not also include **auto**.

Performance Tip 3

Often, **register** is unnecessary. Today's optimizing compilers are capable of recognizing frequently used variables and can decide to place them in registers without needing a **register** declaration from the programmer.

Storage Classes Cont'd

- Two types of identifiers with static storage class
  - External identifiers
    - Such as global variables and global function names
  - Local variables declared with the storage class specifier **static**
- Global variables
  - Created by placing variable declarations outside any class or function definition
  - Can be referenced by any function

Storage Classes Cont'd

- Local variables declared with **static**
  - Known only in the function in which they are declared
  - Retain their values when the function returns to its caller
    - Next time the function is called, the **static** local variables contain the values they had when the function last completed
  - If numeric variables of the static storage class are not explicitly initialized by the programmer
    - They are initialized to zero

Scope Rules

- Scope
  - Portion of the program where an identifier can be used
  - Four scopes for an identifier
    - Function scope
    - File scope
    - Block scope
    - Function-prototype scope

Scope Rules Cont'd

- File scope
  - For an identifier declared outside any function or class
  - Global variables, function definitions and function prototypes placed outside a function all have file scope
- Function scope
  - Labels (identifiers followed by a colon such as **start:**) are the only identifiers with function scope
    - Cannot be referenced outside the function body
    - Labels are implementation details that functions hide from one another

Scope Rules Cont'd

- Block scope
  - Identifiers declared inside a block have block scope
    - Block scope begins at the identifier's declaration
    - Block scope ends at the terminating right brace (}) of the block in which the identifier is declared
  - Local variables and function parameters have block scope
    - The function body is their block

Scope Rules Cont'd

- Block scope Cont'd
  - Any block can contain variable declarations
  - Identifiers in an outer block can be "hidden" when a nested block has a local identifier with the same name
  - Local variables declared **static** still have block scope, even though they exist from the time the program begins execution
    - Storage duration does not affect the scope of an identifier

Scope Rules Cont'd

- Function-prototype scope
  - Only identifiers used in the parameter list of a function prototype have function-prototype scope
  - Parameter names appearing in a function prototype are ignored by the compiler
    - Identifiers used in a function prototype can be reused elsewhere in the program without ambiguity
    - However, in a single prototype, a particular identifier can be used only once

Scoping Example

```
// Fig. 6.12: fig06_12.cpp
// A scoping example.
#include <iostream>
using std::cout;
using std::endl;

void useLocal( void ); // function prototype
void useStaticLocal( void ); // function prototype
void useGlobal( void ); // function prototype

int x = 1; // global variable

int main()
{
   int x = 5; // local variable to main

   cout << "local x in main's outer scope is " << x << endl;

   { // start new scope
      int x = 7; // hides x in outer scope

      cout << "local x in main's inner scope is
   } // end new scope

   cout << "local x in main's outer scope is " << x << endl;
```

Declaring a global variable outside any class or function definition

Local variable `x` that hides global variable `x`

Local variable `x` in a block that hides local variable `x` in outer scope

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Scoping Example Cont'd

```
   useLocal(); // useLocal has local x
   useStaticLocal(); // useStaticLocal has static local x
   useGlobal(); // useGlobal uses global x
   useLocal(); // useLocal reinitializes its local x
   useStaticLocal(); // static local x retains its prior value
   useGlobal(); // global x also retains its value

   cout << "\nloca
   return 0; // in
} // end main

// useLocal reinitializes local variable x during each call
void useLocal( void )
{
   int x = 25; // initialized each time useLocal is called

   cout << "\nlocal x is " << x << " on entering useLocal" << endl;
   x++;
   cout << "local x is " << x << " on exiting useLocal" << endl;
} // end function useLocal
```

Local variable that gets recreated and reinitialized each time **`useLocal`** is called

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Scoping Example Cont'd

`static` local variable that gets initialized only once

```
// useStaticLocal initializes static local variable x only the
// first time the function is called; value of x is saved
// between calls to this function
void useStaticLocal( void )
{
   static int x = 50; // initialized first time useStaticLocal is called

   cout << "\nlocal static x is " << x << " on entering useStaticLocal"
      << endl;
   x++;
   cout << "local static x is " << x << " on exiting useStaticLocal"
      << endl;
} // end function useStaticLocal

// useGlobal modifies global variable x during each call
void useGlobal( void )
{
   cout << "\nglobal x is " << x << " on entering useGlobal" << endl;
   x *= 10;
   cout << "global x is " << x << " on exiting useGlobal" << endl;
} // end function useGlobal
```

Statement refers to global variable `x` because no local variable named `x` exists

Scoping Example Cont'd

```
local x in main's outer scope is 5
local x in main's inner scope is 7
local x in main's outer scope is 5

local x is 25 on entering useLocal
local x is 26 on exiting useLocal

local static x is 50 on entering useStaticLocal
local static x is 51 on exiting useStaticLocal

global x is 1 on entering useGlobal
global x is 10 on exiting useGlobal

local x is 25 on entering useLocal
local x is 26 on exiting useLocal

local static x is 51 on entering useStaticLocal
local static x is 52 on exiting useStaticLocal

global x is 10 on entering useGlobal
global x is 100 on exiting useGlobal

local x in main is 5
```

Function Call Stack and Activation Records

- Data structure: collection of related data items
- Stack data structure
  - Analogous to a pile of dishes
  - When a dish is placed on the pile, it is normally placed at the top
    - Referred to as pushing the dish onto the stack

Function Call Stack and Activation Records Cont'd

- Stack data structure Cont'd
  - Similarly, when a dish is removed from the pile, it is normally removed from the top
    - Referred to as popping the dish off the stack
  - A last-in, first-out (LIFO) data structure
    - The last item pushed (inserted) on the stack is the first item popped (removed) from the stack

Function Call Stack and Activation Records Cont'd

- Function Call Stack
  - Sometimes called the program execution stack
  - Supports the function call/return mechanism
    - Each time a function calls another function, a stack frame (also known as an activation record) is pushed onto the stack
      - Maintains the return address that the called function needs to return to the calling function
      - Contains automatic variables—parameters and any local variables the function declares

Function Call Stack and Activation Records Cont'd

- Function Call Stack Cont'd
  - When the called function returns
    - Stack frame for the function call is popped
    - Control transfers to the return address in the popped stack frame
  - If a function makes a call to another function
    - Stack frame for the new function call is simply pushed onto the call stack
    - Return address required by the newly called function to return to its caller is now located at the top of the stack.

Function Call Stack and Activation Records Cont'd

- Stack overflow
  - Error that occurs when more function calls occur than can have their activation records stored on the function call stack (due to memory limitations)

```cpp
// Fig. 6.13: fig06_13.cpp
// square function used to demonstrate the function
// call stack and activation records.
#include <iostream>
using std::cin;
using std::cout;
using std::endl;

int square( int ); // prototype for function square

int main()
{
   int a = 10; // value to square (local automatic variable in main)

   cout << a << " squared: " << square( a ) << endl; // display a squared
   return 0; // indicate successful termination
} // end main

// returns the square of an integer
int square( int x ) // x is a local variable
{
   return x * x; // calculate square and return result
} // end function square
```

Calling function **square**

```
10 squared: 100
```

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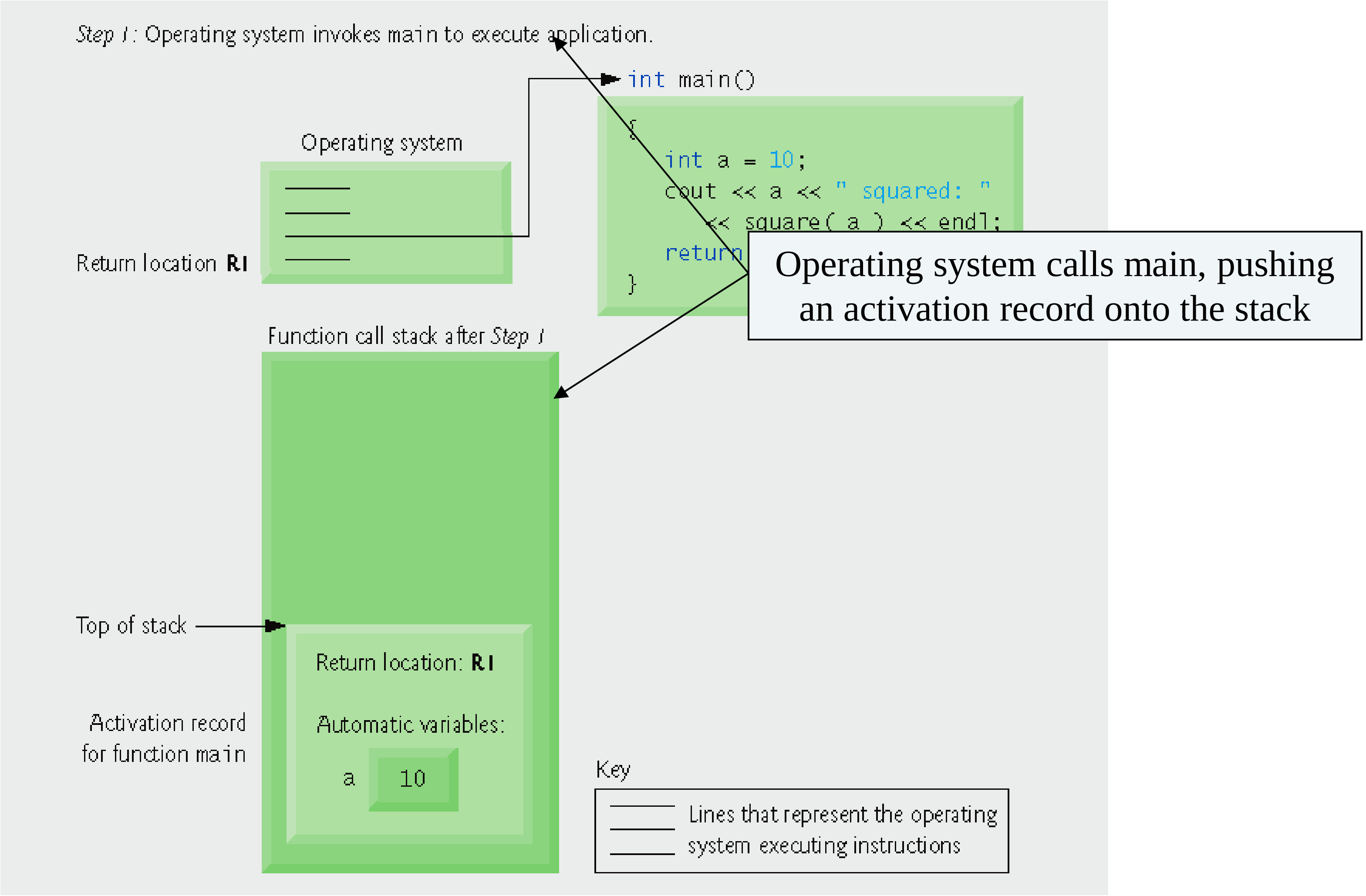
Function call stack after the operating system invokes `main`



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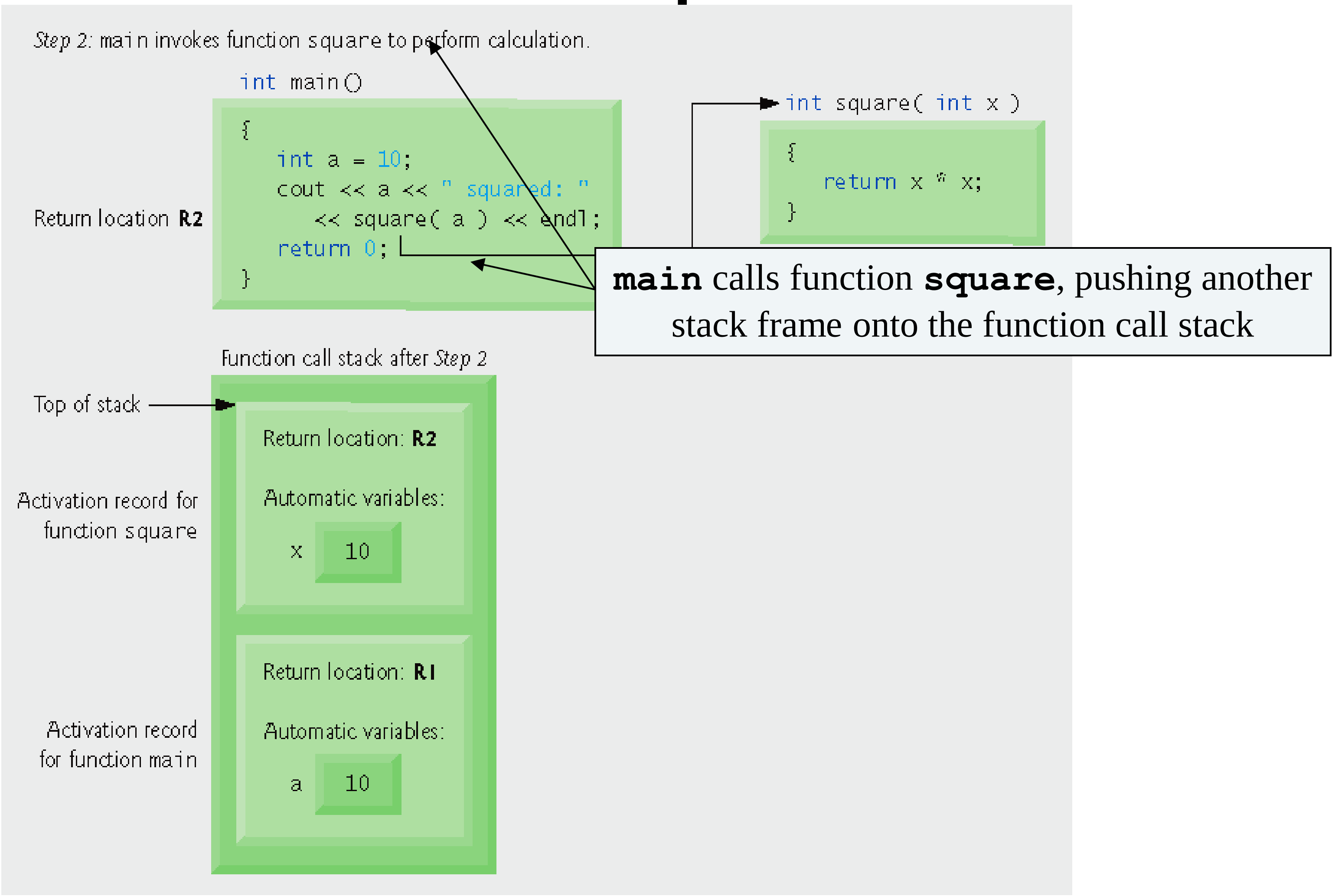
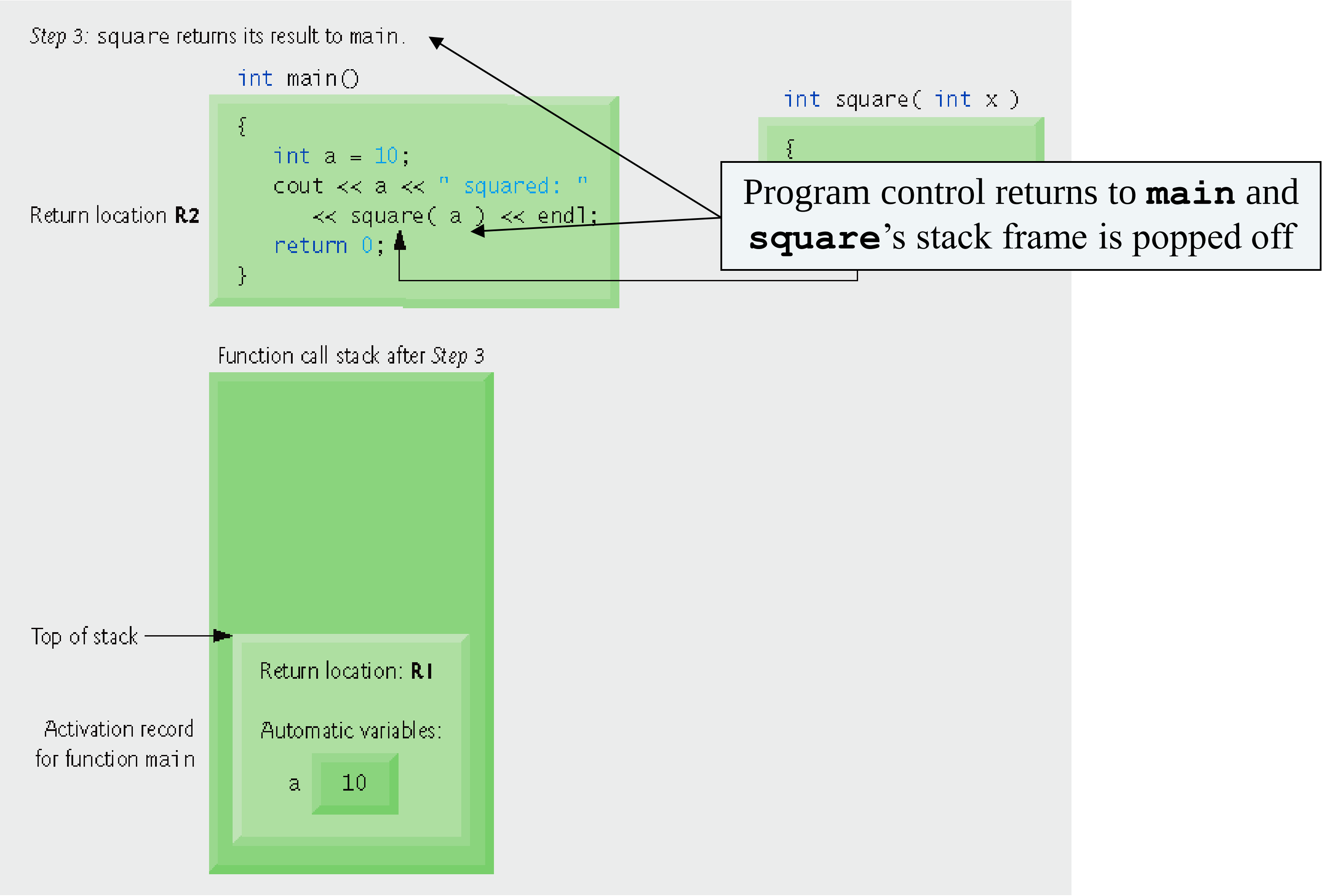
Function call stack after main invokes function square



Function call stack after function square returns to main.



Inline Functions

- Inline functions
  - Reduce function call overhead—especially for small functions
  - Qualifier **`inline`** before a function's return type in the function definition
    - "Advises" the compiler to generate a copy of the function's code in place (when appropriate) to avoid a function call

Inline Functions Cont'd

- Inline functions Cont'd
  - Trade-off of inline functions
    - Multiple copies of the function code are inserted in the program (often making the program larger)
  - The compiler can ignore the **`inline`** qualifier and typically does so for all but the smallest functions

Software Engineering Observation 2

Any change to an **inline** function could require all clients of the function to be recompiled. This can be significant in some program development and maintenance situations.

Good Programming Practice 1

The `inline` qualifier should be used only with small, frequently used functions.

Performance Tip 4

Using **`inline`** functions can reduce execution time but may increase program size.

Software Engineering Observation 3

The const qualifier should be used to enforce the principle of least privilege. Using the principle of least privilege to properly design software can greatly reduce debugging time and improper side effects and can make a program easier to modify and maintain.

```cpp
// Fig. 6.18: fig06_18.cpp
// Using an inline function to calculate the volume of a cube.
#include <iostream>
using std::cout;
using std::cin;
using std::endl;

// Definition of inline function cube. Definition of function appears
// before function is called, so a function prototype is not required.
// First line of function definition acts as the prototype.
inline double cube( const double side )
{
   ret                                de; // calculate cube
} // end function cube

int main()
{
   double sideValue; // stores value entered by user
   cout << "Enter the side length of your cube: ";
   cin >> sideValue; // read value from user

   // calculate cube of sideValue and display result
   cout << "Volume of cube with side "
      << sideValue << " is " << cube( sideValue ) << endl;
   return 0; // indicates successful termination
} // end main
```

inline qualifier

Complete function definition so the compiler knows how to expand a **cube** function call into its inlined code.

cube function call that could be inlined

```
Enter the side length of your cube: 3.5
Volume of cube with side 3.5 is 42.875
```

References and Reference Parameters

- Two ways to pass arguments to functions
  - Pass-by-value
    - A *copy* of the argument's value is passed to the called function
    - Changes to the copy do not affect the original variable's value in the caller
      - Prevents accidental side effects of functions
  - Pass-by-reference
    - Gives called function the ability to access and modify the caller' s argument data directly

References and Reference Parameters Cont'd

- Reference Parameter
  - An alias for its corresponding argument in a function call
  - & placed after the parameter type in the function prototype and function header
  - Example

    `int &count` in a function header

    - Pronounced as "`count` is a reference to an `int`"
  - Parameter name in the body of the called function actually refers to the original variable in the calling function

Parameter Passing

```
// Fig. 6.19: fig06_19.cpp
// Comparing pass-by-value and pass-by-reference with references.
#include <iostream>
using std::cout;
using std::endl;

int squareByValue( int ); // function prototype (value pass)
void squareByReference( int & ); // function prototype (reference pass)

int main()
{
   int x = 2; // value to square using squareByValue
   int z = 4; // value to square using squareByReference

   // demonstrate squareByValue
   cout << "x = " << x << " before squareByValue\n";
   cout << "Value returned by squareByValue: "
      << squareByValue( x ) << endl;
   cout << "x = " << x << " after squareByValue\n" << endl;

   // demonstrate squareByReference
   cout << "z = " << z << " before squareByReference" << endl;
   squareByReference( z );
   cout << "z = " << z << " after squareByReference" << endl;
   return 0; // indicates successful termination
} // end main

```

Function illustrating pass-by-value

Function illustrating pass-by-reference

Variable is simply mentioned by name in both function calls

Parameter Passing Cont'd

```
// squareByValue multiplies number by itself, stores the
// result in number and returns the new value of number
int squareByValue( int number )
{
   return number *= number; // caller's argument not modified
} // end function squareByValue

// squareByReference multiplies numberRef by itself and stores the result
// in the variable to which numberRef refers in function main
void squareByReference( int &numberRef )
{
   numberRef *= numberRef; // caller's argument modified
} // end function squareByReference
```

Receives copy of argument in `main`

Receives reference to argument in `main`

Modifies variable in `main`

```
x = 2 before squareByValue
Value returned by squareByValue: 4
x = 2 after squareByValue

z = 4 before squareByReference
z = 16 after squareByReference
```

Software Engineering Observation 4

Many programmers do not bother to declare parameters passed by value as **const**, even though the called function should not be modifying the passed argument. Keyword **const** in this context would protect only a copy of the original argument, not the original argument itself, which when passed by value is safe from modification by the called function.

Software Engineering Observation 5

For the combined reasons of clarity and performance, many C++ programmers prefer that modifiable arguments be passed to functions by using pointers, small nonmodifiable arguments be passed by value and large nonmodifiable arguments be passed to functions by using references to constants.

References and Reference Parameters Cont'd

- References
  - Can also be used as aliases for other variables within a function
    - All operations supposedly performed on the alias (i.e., the reference) are actually performed on the original variable
    - Must be initialized in their declarations
      - Cannot be reassigned afterward
  - Example

```
int count = 1;
int &cRef = count;
cRef++;
```

References and Reference Parameters Cont'd

- Returning a reference from a function
  - Functions can return references to variables
    - Should only be used when the variable is `static`
  - Dangling reference
    - Returning a reference to an automatic variable
      - That variable no longer exists after the function ends

Common Programming Error 4

Attempting to reassign a previously declared reference to be an alias to another variable is a logic error. The value of the other variable is simply assigned to the variable for which the reference is already an alias.

Default Arguments

- Default argument
  - A default value to be passed to a parameter
    - Used when the function call does not specify an argument for that parameter
  - Must be the rightmost argument(s) in a function's parameter list
  - Should be specified with the first occurrence of the function name
    - Typically the function prototype

```cpp
// Fig. 6.22: fig06_22.cpp
// Using default arguments.
#include <iostream>
using std::cout;
using std::endl;

// function prototype that specifies default arguments
int boxVolume( int length = 1, int width = 1, int height = 1 );

int main()
{
   // no arguments--use default values for all dimensions
   cout << "The default box volume is: " << boxVolume();

   // specify length; default width and height
   cout << "\n\nThe volume of a box with length 10,\n"
      << "width 1 and height 1 is: " << boxVolume( 10 );

   // specify length and width; default height
   cout << "\n\nThe volume of a box with length 10,\n"
      << "width 5 and height 1 is: " << boxVolume( 10, 5 );

   // specify all arguments
   cout << "\n\nThe volume of a box with length 10,\n"
      << "width 5 and height 2 is: " << boxVolume( 10, 5, 2 )
      << endl;
   return 0; // indicates successful termination
} // end main
```

Default arguments

Calling function with no arguments; uses three defaults

Calling function with one argument; uses two defaults

Calling function with two arguments; uses one default

Calling function with three arguments; uses no defaults

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Default Arguments Example

```

// function boxVolume calculates the volume of a box
int boxVolume( int length, int width, int height )
{
   return length * width * height;
} // end function boxVolume
```

```
The default box volume is: 1

The volume of a box with length 10,
width 1 and height 1 is: 10

The volume of a box with length 10,
width 5 and height 1 is: 50

The volume of a box with length 10,
width 5 and height 2 is: 100
```

Note that default arguments were specified in the functio
prototype, so they are not specified in the function heade

Unary Scope Resolution Operator

- Unary scope resolution operator (::)
  - Used to access a global variable when a local variable of the same name is in scope
  - Cannot be used to access a local variable of the same name in an outer block

Unary Scope Resolution Operator Example

```cpp
// Fig. 6.23: fig06_23.cpp
// Using the unary scope resolution operator.
#include <iostream>
using std::cout;
using std::endl;

int number = 7; // global variable named number

int main()
{
   double number = 10.5; // local variable named number

   // display values of local and global variables
   cout << "Local double value of number = " << number
      << "\nGlobal int value of number = " << ::number << endl;
   return 0; // indicates successful termination
} // end main
```

```
Local double value of number = 10.5
Global int value of number = 7
```

Unary scope resolution operator used to access global variable `number`

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Function Overloading

- Overloaded functions
  - Overloaded functions have
    - Same name
    - Different sets of parameters
  - Compiler selects proper function to execute based on number, types and order of arguments in the function call
  - Commonly used to create several functions of the same name that perform similar tasks, but on different data types

Good Programming Practice 2

Overloading functions that perform closely related tasks can make programs more readable and understandable.

Function Overloading Cont'd

- How the compiler differentiates overloaded functions
  - Overloaded functions are distinguished by their signatures
  - Name mangling or name decoration
    - Compiler encodes each function identifier with the number and types of its parameters to enable type-safe linkage
  - Type-safe linkage ensures that
    - Proper overloaded function is called
    - Types of the arguments conform to types of the parameters

Common Programming Error 5

Creating overloaded functions with identical parameter lists and different return types is a compilation error.

Common Programming Error 6

A function with default arguments omitted might be called identically to another overloaded function; this is a compilation error. For example, having in a program both a function that explicitly takes no arguments and a function of the same name that contains all default arguments results in an error when an attempt is made to use that function name in a call passing no arguments. The compiler does not know which function to choose.

Function Templates

- Function templates
  - More compact and convenient form of overloading
    - Identical program logic and operations for each data type
  - Function template definition
    - Defines a whole family of overloaded functions
    - Begins with the **template** keyword
    - Contains template parameter list of formal type parameters for the function template enclosed in angle brackets (<>)
    - Formal type parameters
      - Preceded by keyword **typename** or keyword **class**

Function Templates Cont'd

- Function-template specializations
  - Generated automatically by the compiler to handle each type of call to the function template
  - Example for function template **max** with type parameter **T** called with **int** arguments
    - Compiler detects a **max** invocation in the program code
    - **int** is substituted for **T** throughout the template definition
    - This produces function-template specialization **max< int >**

Function Templates Example

```cpp
// Fig. 6.26: maximum.h
// Definition of function template maximum.

template < class T >  // or template< typename T >
T maximum( T value1, T value2, T value3 )
{
   T maximumValue = value1; // assume value1 is maximum

   // determine whether value2 is greater than maximumValue
   if ( value2 > maximumValue )
      maximumValue = value2;

   // determine whether value3 is greater than maximumValue
   if ( value3 > maximumValue )
      maximumValue = value3;

   return maximumValue;
} // end function template maximum
```

Using formal type parameter **T** in place of data type

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```cpp
// Fig. 6.27: fig06_27.cpp
// Function template maximum test program.
#include <iostream>
using std::cout;
using std::cin;
using std::endl;

#include "maximum.h" // include definition of function template maximum

int main()
{
   // demonstrate maximum with int values
   int int1, int2, int3;

   cout << "Input three integer values: ";
   cin >> int1 >> int2 >> int3;

   // invoke int version of maximum
   cout << "The maximum integer value is: "
      << maximum( int1, int2, int3 );

   // demonstrate maximum with double values
   double double1, double2, double3;

   cout << "\n\nInput three double values: ";
   cin >> double1 >> double2 >> double3;

   // invoke double version of maximum
   cout << "The maximum double value is: "
      << maximum( double1, double2, double3 );
```

Invoking **maximum** with **int** arguments

Invoking **maximum** with **double** arguments

Function Templates Example Cont'd

```
   // demonstrate maximum with char values
   char char1, char2, char3;

   cout << "\n\nInput three characters: ";
   cin >> char1 >> char2 >> char3;

   // invoke char version of maximum
   cout << "The maximum character value is: "
      << maximum( char1, char2, char3 ) << endl;
   return 0; // indicates successful termination
} // end main
```

Invoking **maximum** with **char** arguments

```
Input three integer values: 1 2 3
The maximum integer value is: 3

Input three double values: 3.3 2.2 1.1
The maximum double value is: 3.3

Input three characters: A C B
The maximum character value is: C
```

Recursion

- Factorial
  - The factorial of a nonnegative integer *n*, written *n*! (and pronounced "*n* factorial"), is the product
    - $n \cdot (n-1) \cdot (n-2) \cdot \cdots \cdot 1$
  - Recursive definition of the factorial function
    - $n! = n \cdot (n-1)!$
    - Example
      - $5! = 5 \cdot 4 \cdot 3 \cdot 2 \cdot 1$
        $5! = 5 \cdot (4 \cdot 3 \cdot 2 \cdot 1)$
        $5! = 5 \cdot (4!)$

Recursive Factorial Function

```cpp
// Fig. 6.29: fig06_29.cpp
// Testing the recursive factorial function.
#include <iostream>
using std::cout;
using std::endl;

#include <iomanip>
using std::setw;

unsigned long factorial( unsigned long ); // function prototype

int main()
{
   // calculate the factorials of 0 through 10
   for ( int counter = 0; counter <= 10; counter++ )
      cout << setw( 2 ) << counter << "! = " << factorial( counter )
         << endl;

   return 0; // indicates successful termination
} // end main
```

First call to **`factorial`** function

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Recursive Factorial Function Cont'd

```
// recursive definition of function factorial
unsigned long factorial( unsigned long number )
{
   if ( number <= 1 ) // test for base case
      return 1; // base cases: 0! = 1 and 1! = 1
   else // recursion step
      return number * factorial( number - 1 );
} // end function factorial
```

```
 0! = 1
 1! = 1
 2! = 2
 3! = 6
 4! = 24
 5! = 120
 6! = 720
 7! = 5040
 8! = 40320
 9! = 362880
10! = 3628800
```

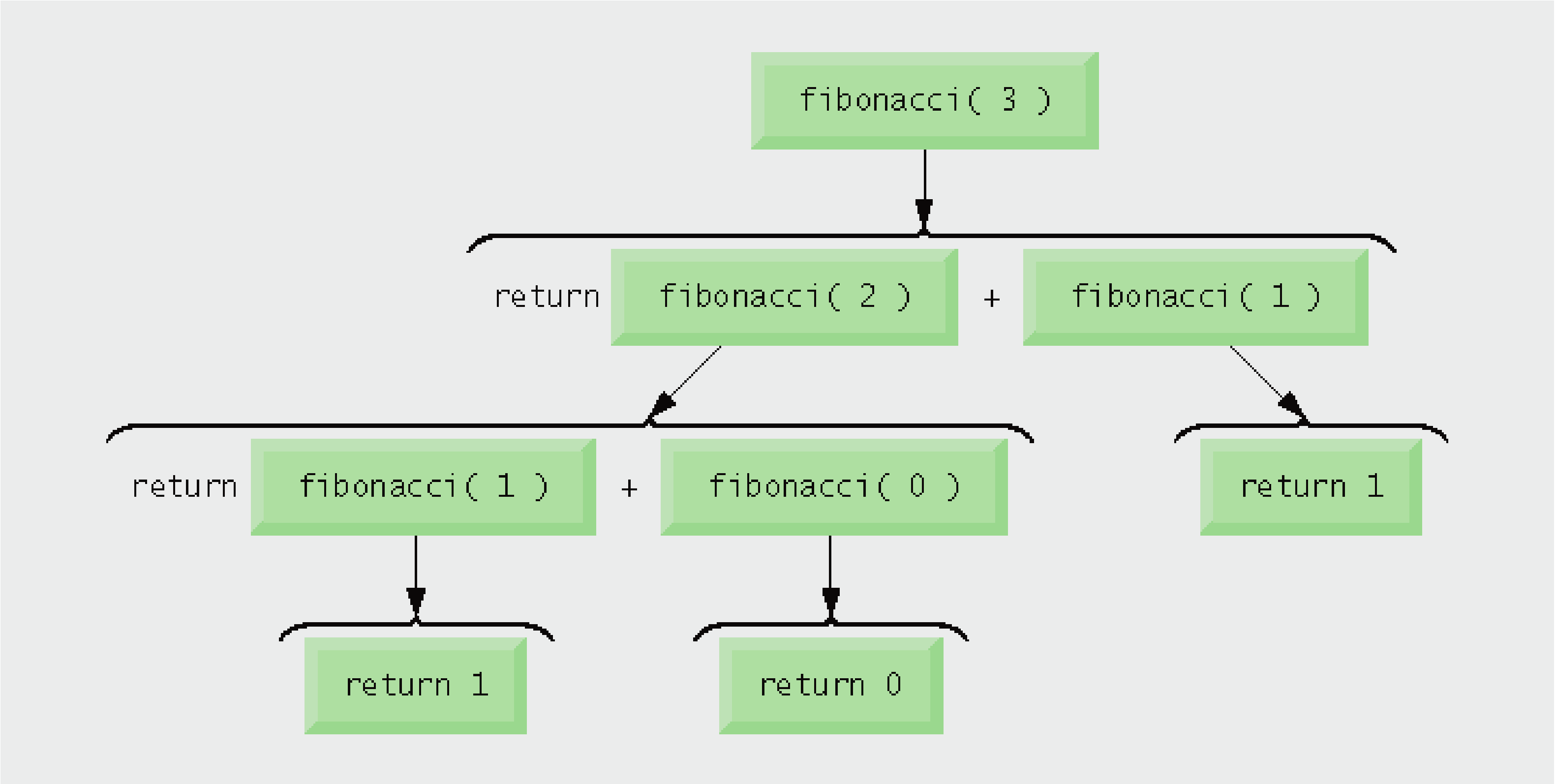
Base cases simply **`return 1`**

Recursive call to **`factorial`** function with a slightly smaller problem

Example Using Recursion: Fibonacci Series

- The Fibonacci series
  - 0, 1, 1, 2, 3, 5, 8, 13, 21, …
  - Begins with 0 and 1
  - Each subsequent Fibonacci number is the sum of the previous two Fibonacci numbers
  - can be defined recursively as follows:
    - fibonacci(0) = 0
    - fibonacci(1) = 1
    - fibonacci(n) = fibonacci(n – 1) + fibonacci(n – 2)

Set of recursive calls to function fibonacci



Iterative Factorial Function

```
// Fig. 6.32: fig06_32.cpp
// Testing the iterative factorial function.
#include <iostream>
using std::cout;
using std::endl;

#include <iomanip>
using std::setw;

unsigned long factorial( unsigned long ); // function prototype

int main()
{
   // calculate the factorials of 0 through 10
   for ( int counter = 0; counter <= 10; counter++ )
      cout << setw( 2 ) << counter << "! = " << factorial( counter )
         << endl;

   return 0;
} // end main

// iterative function factorial
unsigned long factorial( unsigned long number )
{
   unsigned long result = 1;
```

Iterative Factorial Function Cont'd

```

   // iterative declaration of function factorial
   for ( unsigned long i = number; i >= 1; i-- )
      result *= i;

   return result;
} // end function factorial
```

Iterative approach to finding a factorial

```
0! = 1
1! = 1
2! = 2
3! = 6
4! = 24
5! = 120
6! = 720
7! = 5040
8! = 40320
9! = 362880
10! = 3628800
```

Recursion vs Iteration

- Negatives of recursion
  - Overhead of repeated function calls
    - Can be expensive in both processor time and memory space
  - Each recursive call causes another copy of the function (actually only the function's variables) to be created
    - Can consume considerable memory
- Iteration
  - Normally occurs within a function
  - Overhead of repeated function calls and extra memory assignment is omitted

Software Engineering Observation 6

Any problem that can be solved recursively can also be solved iteratively (nonrecursively). A recursive approach is normally chosen in preference to an iterative approach when the recursive approach more naturally mirrors the problem and results in a program that is easier to understand and debug. Another reason to choose a recursive solution is that an iterative solution is not apparent.