

C++ DATA TYPES, FUNCTIONS AND OVERLOADING

7TH WEEK 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
<code>ceil(x)</code>	rounds x to the smallest integer not less than x	<code>ceil(9.2)</code> is 10.0 <code>ceil(-9.8)</code> is -9.0
<code>cos(x)</code>	trigonometric cosine of x (x in radians)	<code>cos(0.0)</code> is 1.0
<code>exp(x)</code>	exponential function e^x	<code>exp(1.0)</code> is 2.71828 <code>exp(2.0)</code> is 7.38906
<code>fabs(x)</code>	absolute value of x	<code>fabs(5.1)</code> is 5.1 <code>fabs(0.0)</code> is 0.0 <code>fabs(-8.76)</code> is 8.76
<code>floor(x)</code>	rounds x to the largest integer not greater than x	<code>floor(9.2)</code> is 9.0 <code>floor(-9.8)</code> is -10.0
<code>fmod(x, y)</code>	remainder of x/y as a floating-point number	<code>fmod(2.6, 1.2)</code> is 0.2
<code>log(x)</code>	natural logarithm of x (base e)	<code>log(2.718282)</code> is 1.0 <code>log(7.389056)</code> is 2.0
<code>log10(x)</code>	logarithm of x (base 10)	<code>log10(10.0)</code> is 1.0 <code>log10(100.0)</code> is 2.0
<code>pow(x, y)</code>	x raised to power y (x^y)	<code>pow(2, 7)</code> is 128 <code>pow(9, .5)</code> is 3
<code>sin(x)</code>	trigonometric sine of x (x in radians)	<code>sin(0.0)</code> is 0
<code>sqrt(x)</code>	square root of x (where x is a nonnegative value)	<code>sqrt(9.0)</code> is 3.0
<code>tan(x)</code>	trigonometric tangent of x (x in radians)	<code>tan(0.0)</code> 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

Function Prototypes and Argument Coercion Cont'd

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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

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.

```
enum Animal
{
    ANIMAL_CAT = -3,
    ANIMAL_DOG, // assigned -2
    ANIMAL_PIG, // assigned -1
    ANIMAL_HORSE = 5,
    ANIMAL_GIRAFFE = 5, // shares same value as ANIMAL_HORSE
    ANIMAL_CHICKEN // assigned 6
};
```

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

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 Tip1

- 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.

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

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.

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.

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.

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

```
1 // Fig. 6.12: fig06_12.cpp
2 // A scoping example.
3 #include <iostream>
4 using std::cout;
5 using std::endl;
6
7 void useLocal( void ); // function prototype
8 void useStaticLocal( void ); // function prototype
9 void useGlobal( void ); // function prototype
10
11 int x = 1; // global variable
12
13 int main()
14 {
15     int x = 5; // local variable to main
16
17     cout << "local x in main's outer scope is " << x << endl;
18
19     { // start new scope
20         int x = 7; // hides x in outer scope
21
22         cout << "local x in main's inner scope " << x << endl;
23     } // end new scope
24
25     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

Scoping Example Cont'd

```
26
27 useLocal(); // useLocal has local x
28 useStaticLocal(); // useStaticLocal has static local x
29 useGlobal(); // useGlobal uses global x
30 useLocal(); // useLocal reinitializes its local x
31 useStaticLocal(); // static local x retains its prior value
32 useGlobal(); // global x also retains its value
33
34 cout << "\nlocal x is " << x << " on entering useLocal" << endl;
35 return 0; // indicates successful termination
36 } // end main
37
38 // useLocal reinitializes local variable x during each call
39 void useLocal( void )
40 {
41     int x = 25; // initialized each time useLocal is called
42
43     cout << "\nlocal x is " << x << " on entering useLocal" << endl;
44     x++;
45     cout << "local x is " << x << " on exiting useLocal" << endl;
46 } // end function useLocal
```

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

Scoping Example Cont'd

```
47
48 // useStaticLocal initializes static local variable that gets initialized only once
49 // first time the function is called; value of x is saved
50 // between calls to this function
51 void useStaticLocal( void )
52 {
53     static int x = 50; // initialized first time useStaticLocal is called
54
55     cout << "\nlocal static x is " << x << " on entering useStaticLocal"
56         << endl;
57     x++;
58     cout << "local static x is " << x << " on exiting useStaticLocal"
59         << endl;
60 } // end function useStaticLocal
61
62 // useGlobal modifies global variable x during each call
63 void useGlobal( void )
64 {
65     cout << "\nglobal x is " << x << " on entering useGlobal" << endl;
66     x *= 10;
67     cout << "global x is " << x << " on exiting useGlobal" << endl;
68 } // 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)

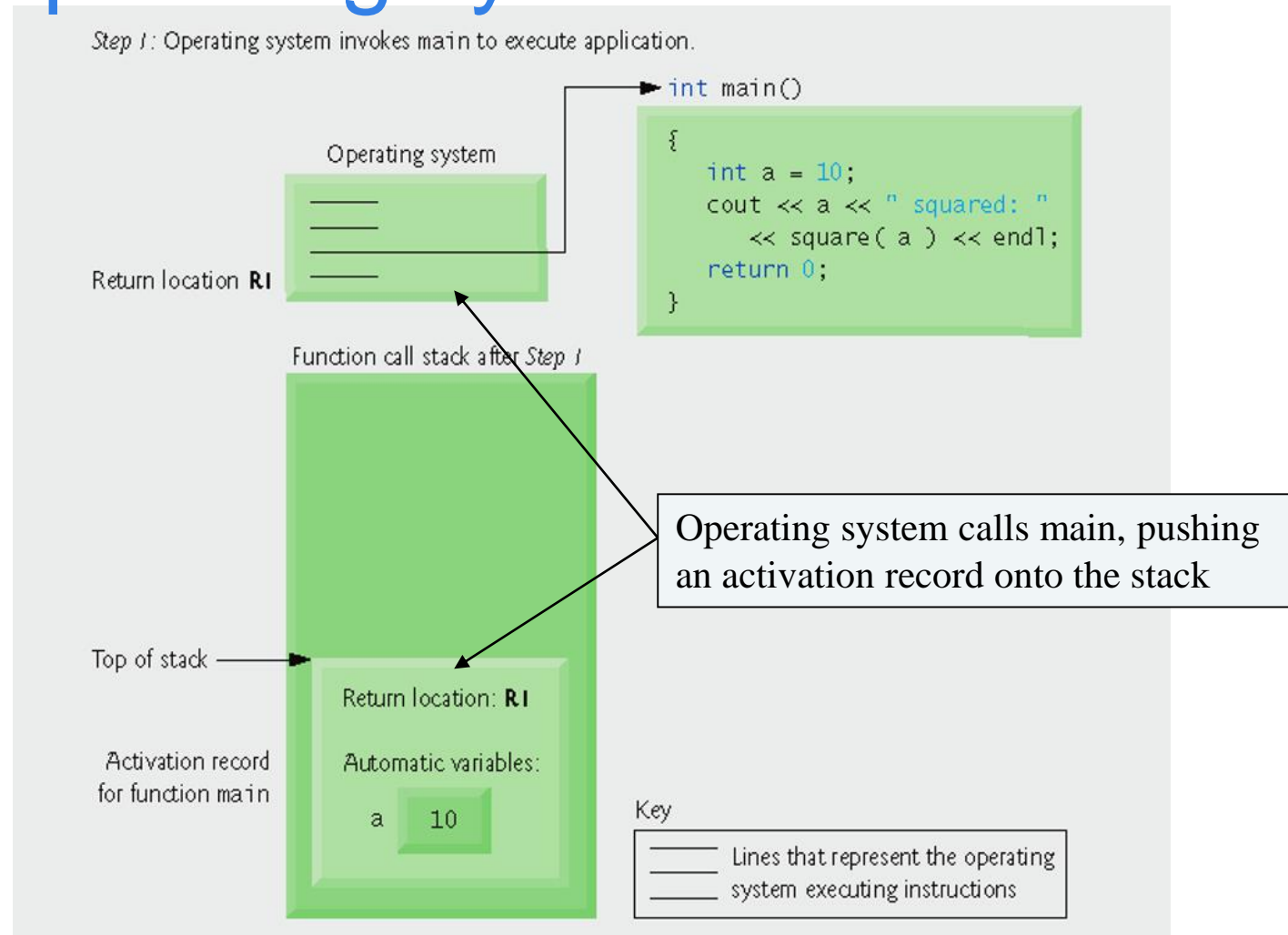
```
1 // Fig. 6.13: fig06_13.cpp
2 // square function used to demonstrate the function
3 // call stack and activation records.
4 #include <iostream>
5 using std::cin;
6 using std::cout;
7 using std::endl;
8
9 int square( int ); // prototype for function square
10
11 int main()
12 {
13     int a = 10; // value to square (local automatic variable in main)
14
15     cout << a << " squared: " << square(a) << endl; // display a squared
16     return 0; // indicate successful termination
17 } // end main
18
19 // returns the square of an integer
20 int square( int x ) // x is a local variable
21 {
22     return x * x; // calculate square and return result
23 } // end function square
```

Calling function **square**



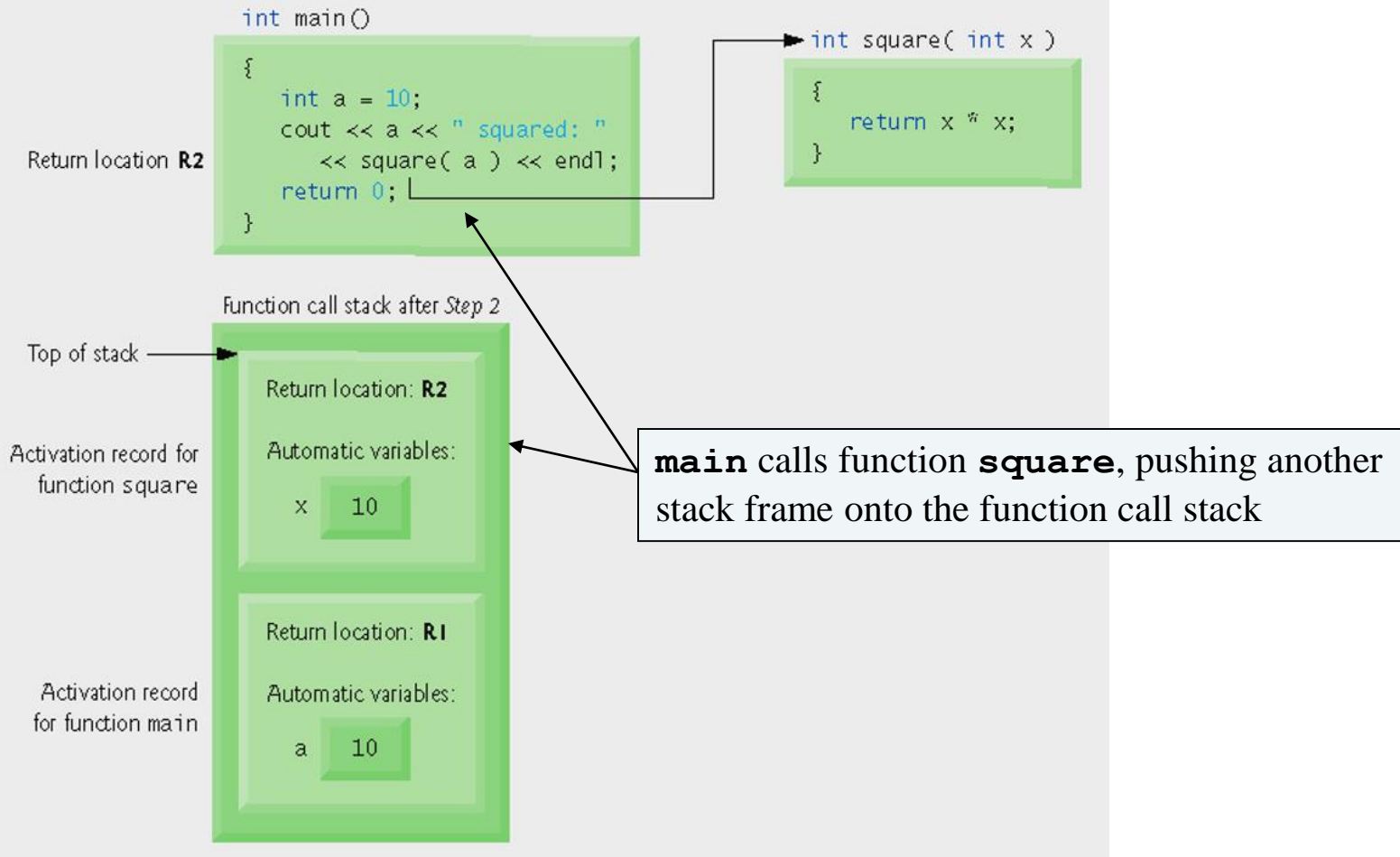
10 squared: 100

Function call stack after the operating system invokes main

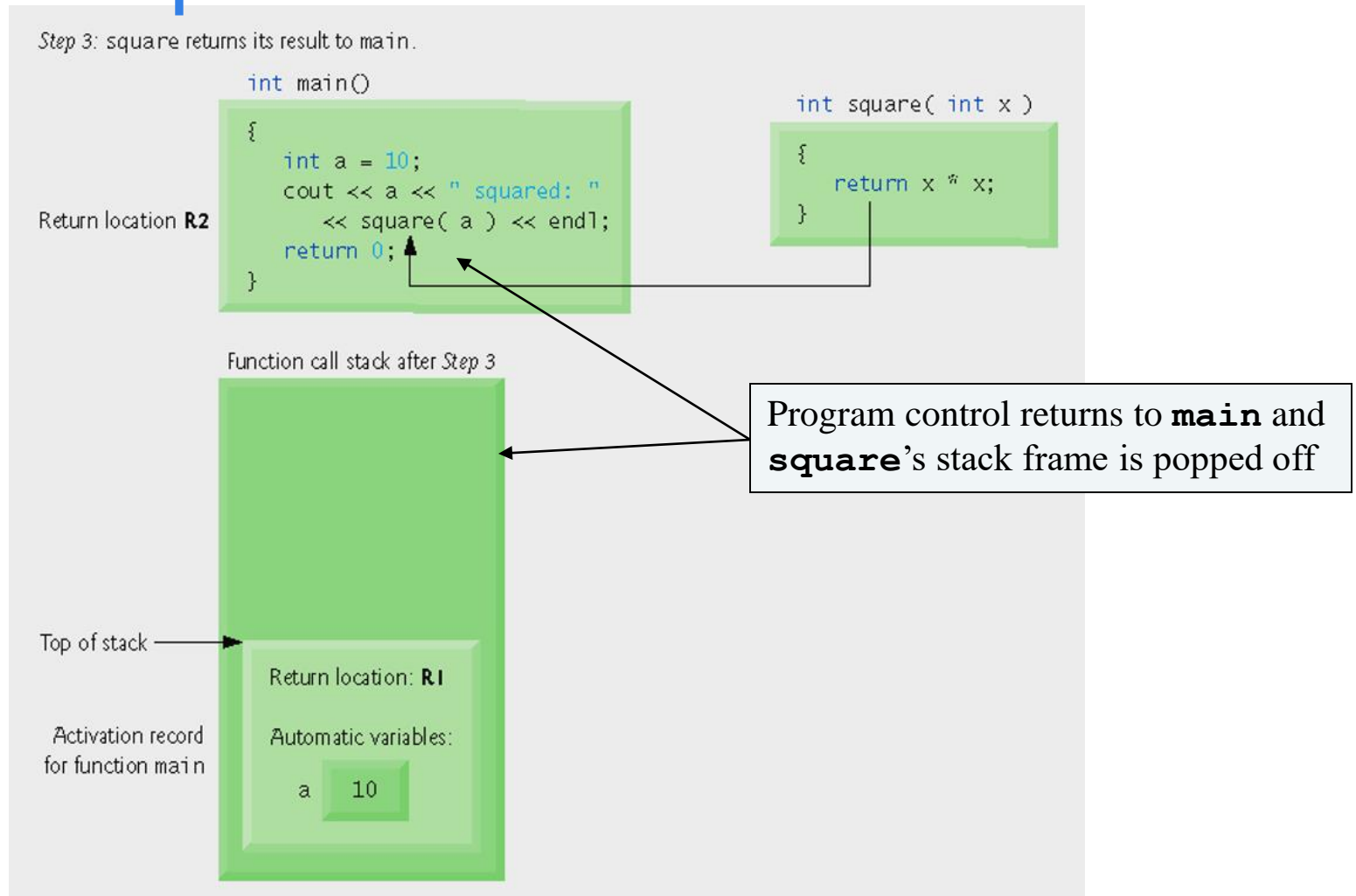


Function call stack after main invokes function square

Step 2: main invokes function square to perform calculation.



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.

```

1 // Fig. 6.18: fig06_18.cpp
2 // Using an inline function to calculate the volume of a cube.
3 #include <iostream>
4 using std::cout;
5 using std::cin;
6 using std::endl;
7
8 // Definition of inline function cube. Definition of function appears
9 // before function is called, so a function prototype is not required.
10 // First line of function definition acts as the prototype.
11 inline double cube( const double side )
12 {
13     r side; // calculate cube
14 } // end function cube
15
16 int main()
17 {
18     double sideValue; // stores value entered by user
19     cout << "Enter the side length of your cube: ";
20     cin >> sideValue; // read value from user
21
22     // calculate cube of sideValue and display result
23     cout << "Volume of cube with side "
24         << sideValue << " is " << cube( sideValue ) << endl;
25     return 0; // indicates successful termination
26 } // end main

```

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

```
1 // Fig. 6.19: fig06_19.cpp
2 // Comparing pass-by-value and pass-by-reference with references.
3 #include <iostream>
4 using std::cout;
5 using std::endl;
6
7 int squareByValue( int ); // function prototype (value pass)
8 void squareByReference( int & ); // function prototype (reference pass)
9
10 int main()
11 {
12     int x = 2; // value to square using squareByValue
13     int z = 4; // value to square using squareByReference
14
15     // demonstrate squareByValue
16     cout << "x = " << x << " before squareByValue\n";
17     cout << "Value returned by squareByValue: "
18         << squareByValue( x ) << endl;
19     cout << "x = " << x << " after squareByValue\n" << endl;
20
21     // demonstrate squareByReference
22     cout << "z = " << z << " before squareByReference" << endl;
23     squareByReference( z );
24     cout << "z = " << z << " after squareByReference" << endl;
25     return 0; // indicates successful termination
26 } // end main
27
```

Function illustrating pass-by-value

Function illustrating pass-by-reference

Variable is simply mentioned by name in both function calls

Parameter Passing Cont'd

```
28 // squareByValue multiplies number by itself, stores the
29 // result in number and returns the new value of number
30 int squareByValue( int number )
31 {
32     return number *= number; // caller's argument not modified
33 } // end function squareByValue
34
35 // squareByReference multiplies numberRef by itself and stores the result
36 // in the variable to which numberRef refers in function main
37 void squareByReference( int &numberRef )
38 {
39     numberRef *= numberRef; // caller's argument modified
40 } // end function squareByReference
```

Receives copy of argument in main

Receives reference to argument in main

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

z = 4 before squareByReference
z = 16 after squareByReference

Modifies variable in main

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.