IS 0020

Program Design and Software Tools

Introduction to C++ Programming

Lecture 2

Functions

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Program Components in C++

- Modules: *functions* and *classes*
- Programs use new and "prepackaged" modules
  - New: programmer-defined functions, classes
  - Prepackaged: from the standard library
- Functions invoked by function call
  - Function name and information (arguments) it needs
- Function definitions
  - Only written once
  - Hidden from other functions

Functions

- Functions
  - Modularize a program
  - Software reusability
    - Call function multiple times
- Local variables
  - Known only in the function in which they are defined
  - All variables declared in function definitions are local variables
- Parameters
  - Local variables passed to function when called
  - Provide outside information

Math Library Functions

- Perform common mathematical calculations
  - Include the header file **`<cmath>`**
- Functions called by writing
  - *functionName* (*argument*); or
  - *functionName* (*argument1*, *argument2*, …);
- Example

```
cout << sqrt( 900.0 );
```

  - All functions in math library return a **`double`**
- Function arguments can be
  - Constants: **`sqrt( 4 );`**
  - Variables: **`sqrt( x );`**
  - Expressions:
    - **`sqrt( sqrt( x ) ) ;`**
    - **`sqrt( 3 - 6x );`**
- Other functions
  - **`ceil(x), floor(x), log10(x), etc.`**

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Function Definitions

- Function prototype
  - `int square( int );`
- Calling/invoking a function
  - `square(x);`
- Format for function definition

  return-value-type function-name **(** *parameter-list* **)**
  {
  declarations and statements
  }
- Prototype must match function definition
  - Function prototype

    ```
    double maximum( double, double, double );
    ```
  - Definition

    ```
    double maximum( double x, double y, double z )
    {
     …
    }
    ```


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Function Definitions

- Example function

  ```
  int square( int y )
  {
    return y * y;
  }
  ```
- **`return`** keyword
  - Returns data, and control goes to function's caller
    - If no data to return, use `return;`
  - Function ends when reaches right brace
    - Control goes to caller
- Functions cannot be defined inside other functions

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Function Prototypes

- Function signature
  - Part of prototype with name and parameters
    - `double maximum( double, double, double );`

$\underbrace{\texttt{maximum(double, double, double)}}_{\text{Function signature}}$

- Argument Coercion
  - Force arguments to be of proper type
    - Converting **`int`** (4) to **`double`** (4.0)

```
cout << sqrt(4)
```

  - Conversion rules
    - Arguments usually converted automatically
    - Changing from **`double`** to **`int`** can truncate data
      - 3.4 to 3
  - Mixed type goes to highest type (promotion)

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Function Prototypes

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`	(`false` becomes 0, `true` becomes 1)

Fig. 3.5 Promotion hierarchy for built-in data types.

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Header Files

- Header files contain
  - Function prototypes
  - Definitions of data types and constants
- Header files ending with .h
  - Programmer-defined header files

```
#include “myheader.h”
```

- Library header files

```
#include <cmath>
```


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Enumeration: enum

- Enumeration
  - Set of integers with identifiers

  enum *typeName* **{***constant1*, *constant2*…**};**
  - Constants start at 0 (default), incremented by 1
  - Constants need unique names
  - Cannot assign integer to enumeration variable
    - Must use a previously defined enumeration type
- Example

```
enum Status {CONTINUE, WON, LOST};
Status enumVar;
enumVar = WON; // cannot do enumVar = 1
```

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Storage Classes

- Variables have attributes
  - Have seen name, type, size, value
  - Storage class
    - How long variable exists in memory
  - Scope
    - Where variable can be referenced in program
  - Linkage
    - For multiple-file program which files can use it

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Storage Classes

- Automatic storage class
  - Variable created when program enters its block
  - Variable destroyed when program leaves block
  - Only local variables of functions can be automatic
    - Automatic by default
    - keyword **`auto`** explicitly declares automatic
  - **`register`** keyword
    - Hint to place variable in high-speed register
    - Good for often-used items (loop counters)
    - Often unnecessary, compiler optimizes
  - Specify either **`register`** or **`auto`**, not both
    - **`register int counter = 1;`**

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Storage Classes

- Static storage class
  - Variables exist for entire program
    - For functions, name exists for entire program
  - May not be accessible, scope rules still apply
- **`auto`** and **`register`** keyword
  - local variables in function
  - **`register`** variables are kept in CPU registers
- **`static`** keyword
  - Local variables in function
  - Keeps value between function calls
  - Only known in own function
- **`extern`** keyword
  - Default for global variables/functions
    - Globals: defined outside of a function block
  - Known in any function that comes after it

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Scope Rules

- Scope
  - Portion of program where identifier can be used
- File scope
  - Defined outside a function, known in all functions
  - Global variables, function definitions and prototypes
- Function scope
  - Can only be referenced inside defining function
  - Only labels, e.g., identifiers with a colon (**`case:`**)

Scope Rules

- Block scope
  - Begins at declaration, ends at right brace **}**
    - Can only be referenced in this range
  - Local variables, function parameters
  - Local **`static`** variables still have block scope
    - Storage class separate from scope
- Function-prototype scope
  - Parameter list of prototype
  - Names in prototype optional
    - Compiler ignores
  - In a single prototype, name can be used once


```
// Fig. 3.12: fig03_12.cpp
// A scoping example.
#include <iostream>

using std::cout;
using std::endl;

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

int x = 1;      // global vari

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

   cout << "local x in main's ou

   { // start new scope

      int x = 7;

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

   } // end new scope
```

Local/global? Scope?

Local/global? Scope?

Local/global? Scope?

Outline

fig03_12.cpp
(1 of 5)

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

   cout << endl << "local x i
        << " on entering useLocal" << endl;
   ++x;
   cout << "local x is " << x
        << " on exiting useLocal" << endl;

} // end function useLocal

```

Local/global? Scope?

fig03_12.cpp
(3 of 5)


```
// 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 )
{
   // initialized only first time useStaticLocal is called
   static int x = 50;

   cout << endl << "local static x is " << x
        << " on entering useStaticLocal" << endl;
   ++x;
   cout << "local static x is " <<
        << " on exiting useStaticLocal" << endl;

} // end function useStaticLocal

```

Local/global? Scope?

fig03_12.cpp
(4 of 5)

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Recursion

- Recursive functions
  - Functions that call themselves
  - Can only solve a base case
- If not base case
  - Break problem into smaller problem(s)
  - Launch new copy of function to work on the smaller problem (recursive call/recursive step)
    - Slowly converges towards base case
    - Function makes call to itself inside the return statement
  - Eventually base case gets solved
    - Answer works way back up, solves entire problem

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Recursion

- Example: factorial

  $n! = n * (n – 1) * (n – 2) * … * 1$
  - Recursive relationship (n! = n * (n – 1)!)

    $5! = 5 * 4!$

    $4! = 4 * 3!…$
  - Base case (1! = 0! = 1)

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Example Using Recursion: Fibonacci Series

- Fibonacci series: 0, 1, 1, 2, 3, 5, 8...
  - Each number sum of two previous ones
  - Example of a recursive formula:
    - *fib(n) = fib(n-1) + fib(n-2)*
- C++ code for Fibonacci function

```
long fibonacci( long n )
{
  if ???? // base case
      return ???;
  else
      ???
}
```


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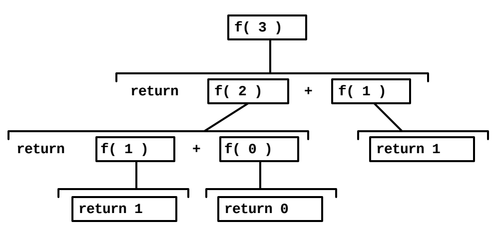
Example Using Recursion: Fibonacci Series



- Order of operations
  - `return fibonacci( n - 1 ) + fibonacci( n - 2 );`
- Recursive function calls
  - Each level of recursion doubles the number of function calls
    - 30th number = 2^30 ~ 4 billion function calls
  - Exponential complexity

Recursion vs. Iteration

- Repetition
  - Iteration: explicit loop
  - Recursion: repeated function calls
- Termination
  - Iteration: loop condition fails
  - Recursion: base case recognized
- Both can have infinite loops
- Balance between performance (iteration) and good software engineering (recursion)

Inline Functions

- Inline functions
  - Keyword **`inline`** before function
  - Asks the compiler to copy code into program instead of making function call
    - Reduce function-call overhead
    - Compiler can ignore **`inline`**
  - Good for small, often-used functions
- Example

```
inline double cube( const double s )
   { return s * s * s; }
```

  - **`const`** tells compiler that function does not modify **`s`**

References and Reference Parameters

- Call by value
  - Copy of data passed to function
  - Changes to copy do not change original
  - Prevent unwanted side effects
- Call by reference
  - Function can directly access data
  - Changes affect original
- Reference parameter
  - Alias for argument in function call
    - Passes parameter by reference
  - Use **`&`** after data type in prototype
    - **`void myFunction( int &data )`**
    - Read "**`data`** is a reference to an **`int`**"
  - Function call format the same
    - However, original can now be changed

References and Reference Parameters

- Pointers
  - Another way to pass-by-refernce
- References as aliases to other variables
  - Refer to same variable
  - Can be used within a function

```
int count = 1;     // declare integer variable count
int &cRef = count; // create cRef as an alias for count
++cRef; // increment count (using its alias)
```

- References must be initialized when declared
  - Otherwise, compiler error
  - Dangling reference
    - Reference to undefined variable

Default Arguments

- Function call with omitted parameters
  - If not enough parameters, rightmost go to their defaults
  - Default values
    - Can be constants, global variables, or function calls
- Set defaults in function prototype

  `int myFunction( int x = 1, int y = 2, int z = 3 );`
  - `myFunction(3)`
    - `x = 3`, `y` and `z` get defaults (rightmost)
  - `myFunction(3, 5)`
    - `x = 3`, `y = 5` and `z` gets default

Unitary Scope Resolution Operator

- Unary scope resolution operator (`::`)
  - Access global variable if local variable has same name
  - Not needed if names are different
  - Use `::variable`
    - `y = ::x + 3;`
  - Good to avoid using same names for locals and globals

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Function Overloading

- Function overloading
  - Functions with same name and different parameters
  - Should perform similar tasks
    - i.e., function to square **int**s and function to square **float**s

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

- Overloaded functions distinguished by signature
  - Based on name and parameter types (order matters)
  - Name mangling
    - Encode function identifier with no. and types of parameters
  - Type-safe linkage
    - Ensures proper overloaded function called

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Function Templates

- Compact way to make overloaded functions
  - Generate separate function for different data types
- Format
  - Begin with keyword **template**
  - Formal type parameters in brackets **<>**
    - Every type parameter preceded by **typename** or **class** (synonyms)
    - Placeholders for built-in types (i.e., **int**) or user-defined types
    - Specify arguments types, return types, declare variables
  - Function definition like normal, except formal types used

Function Templates

- Example

```
template < class T > // or template< typename T >
T square( T value1 )
{
   return value1 * value1;
}
```

  - **`T`** is a formal type, used as parameter type
    - Above function returns variable of same type as parameter
  - In function call, T replaced by real type
    - If **`int`**, all **`T`**'s become **`int`**s

```
int x;
int y = square(x);
```


fig03_27.cpp
(1 of 3)

```
// Fig. 3.27: fig03_27.cpp
// Using a function template.
#include <iostream>

using std::cout;
using std::cin;
using std::endl;

// definition of function template maximum
template < class T >  // or template < typename T >
T maximum( T value1, T value2, T value3 )
{
   T max = value1;

   if ( value2 > max )
      max = value2;

   if ( value3 > max )
      max = value3;

   return max;

} // end function template maximum

```

Formal type parameter **`T`** placeholder for type of data to be tested by **`maximum`**.

`maximum` expects all parameters to be of the same type.

fig03_27.cpp
(2 of 3)

```
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 );

```

`maximum` called with various data types.

fig03_27.cpp
(3 of 3)

fig03_27.cpp
output (1 of 1)

```
   // 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
```

```
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
```