Module 07: Programming in C++

Reference & Pointer

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Module Objectives

- Understand References in C++
- Compare and contrast References and Pointers

Module Outline

- Reference variable or Alias
  - Basic Notion
  - Call-by-reference in C++
- Example: Swapping two number in C
  - Using Call-by-value
  - Using Call-by-address
- Call-by-reference in C++ in contrast to Call-by-value in C
- Use of `const` in Alias / Reference
- Return-by-reference in C++ in contrast to Return-by-value in C
- Differences between References and Pointers

Module 07: Lecture 10

- Reference variable or Alias
  - Basic Notion
  - Call-by-reference in C++
- Example: Swapping two number in C
  - Using Call-by-value
  - Using Call-by-address
- Call-by-reference in C++ in contrast to Call-by-value in C

Reference

- A reference is an alias / synonym for an existing variable

```
int i = 15;  // i is a variable
int &j = i;  // j is a reference to i
```

i	← variable
15	← memory content
200	← address
j	← alias or reference

Program 07.01: Behavior of Reference


```
#include <iostream>
using namespace std;

int main() {
    int a = 10, &b = a; // b is reference of a

    // a and b have the same memory
    cout << "a = " << a << ", b = " << b << endl;
    cout << "&a = " << &a << ", &b = " << &b << endl;

    ++a; // Changing a appears as change in b
    cout << "a = " << a << ", b = " << b << endl;

    ++b; // Changing b also changes a
    cout << "a = " << a << ", b = " << b << endl;

    return 0;
}
```

```
a = 10, b = 10
&a = 002BF944, &b = 002BF944
a = 11, b = 11
a = 12, b = 12
```

- a and b have the same memory location and hence the same value
- Changing one changes the other and vice-versa

Pitfalls in Reference

Wrong declaration	Reason	Correct declaration
`int& i;`	no variable to refer to – must be initialized	`int& i = j;`
`int& j = 5;`	no address to refer to as 5 is a constant	`const int& j = 5;`
`int& i = j + k;`	only temporary address (result of `j + k`) to refer to	`const int& i = j + k;`

C++ Program 07.02: Call-by-reference


```
#include <iostream>
using namespace std;

void Function_under_param_test(// Function prototype
    int &b, // Reference parameter
    int c); // Value parameter

int main() {
    int a = 20;
    cout << "a = " << a << ", &a = " << &a << endl << endl;
    Function_under_param_test(a, a); // Function call

    return 0;
}

void Function_under_param_test(int &b, int c) {  // Function definition
    cout << "b = " << b << ", &b = " << &b << endl << endl;
    cout << "c = " << c << ", &c = " << &c << endl << endl;
}
------- Output -------
a = 20, &a = 0023FA30
b = 20, &b = 0023FA30
c = 20, &c = 0023F95C
```

- Param b is call-by-reference while param c is call-by-value
- Actual param a and formal param b get the same value in called function
- Actual param a and formal param c get the same value in called function
- Actual param a and formal param b get the same value in called function
- However, actual param a and formal param c have *different* addresses in called function

C Program 07.03: Swap in C

Call-by-value	Call-by-address

`#include <stdio.h>`
 	
`void swap(int, int); // Call-by-value`
`int main() {`
`  int a = 10, b = 15;`
`  printf("a= %d & b= %d to swap\n", a, b);`
`  swap(a, b);`
`  printf("a= %d & b= %d on swap\n", a, b);`
`  return 0;`
`}`
 	
`void swap(int c, int d){`
`  int t;`
`  t = c;`
`  c = d;`
`  d = t;`
`}`
	`#include <stdio.h>`
	
	`void swap(int *, int *); // Call-by-address`
	`int main() {`
	`  int a=10, b=15;`
	`  printf("a= %d & b= %d to swap\n", a, b);`
	`  swap(&a, &b);`
	`  printf("a= %d & b= %d on swap\n", a, b);`
	`  return 0;`
	`}`
	
	`void swap(int *x, int *y){`
	`  int t;`
	`  t = *x;`
	`  *x = *y;`
	`  *y = t;`
	`}`

• a= 10 & b= 15 to swap • a= 10 & b= 15 on swap	• a= 10 & b= 15 to swap • a= 15 & b= 10 on swap
• Passing values of a=10 & b=15 • In callee; c = 10 & d = 15 • Swapping the values of c & d • No change for the values of a & b in caller • Swapping the value of c & d instead of a & b	• Passing Address of a & b • In callee x = Addr(a) & y = Addr(b) • Values at the addresses is swapped • Changes for the values of a & b in caller • It is correct, but C++ has a better way out

Program 07.04: Swap in C & C++

C Program: Call-by-value – wrong	C++ Program: Call-by-reference – right

`#include <stdio.h>`
 	
`void swap(int, int); // Call-by-value`
`int main() {`
`  int a = 10, b = 15;`
`  printf("a= %d & b= %d to swap\n",a,b);`
`  swap(a, b);`
`  printf("a= %d & b= %d on swap\n",a,b);`
`  return 0;`
`}`
 	
`void swap(int c, int d) {`
`  int t ;`
`  t = c ;`
`  c = d ;`
`  d = t ;`
`}`
	`#include <iostream>`
	`using namespace std;`
	`void swap(int&, int&); // Call-by-reference`
	`int main() {`
	`  int a = 10, b = 15;`
	`  cout<<"a= "<<a<<" & b= "<<b<<"to swap"<<endl;`
	`  swap(a, b);`
	`  cout<<"a= "<<a<<" & b= "<<b<<"on swap"<<endl;`
	`  return 0;`
	`}`
	
	`void swap(int &x, int &y) {`
	`  int t ;`
	`  t = x ;`
	`  x = y ;`
	`  y = t ;`
	`}`

• a= 10 & b= 15 to swap • a= 10 & b= 15 on swap	• a= 10 & b= 15 to swap • a= 15 & b= 10 on swap
• Passing values of a=10 & b=15 • In callee; c=10 & d=15 • Swapping the values of c & d • No change for the values of a & b • Here c & d do not share address with a & b	• Passing values of a = 10 & b = 15 • In callee x = 10 & y = 15 • Swapping the value x & y • Changes the values of a & b • x & y having same address as a & b respectively

Module 07: End Of Lecture 10

- Reference variable or Alias
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  - Using Call-by-address
- Call-by-reference in C++ in contrast to Call-by-value in C

Module 07: Lecture 11

- Use of `const` in Alias / Reference
- Return-by-reference in C++ in contrast to Return-by-value in C
- Differences between References and Pointers

Program 07.05: Reference Parameter as const

- A reference parameter may get changed in the called function
- Use const to stop reference parameter being changed

const reference – bad

```
#include <iostream>
using namespace std;

int Ref_const(const int &x) {
    ++x;          // Not allowed
    return (x);
}

int main() {
    int a = 10, b;
    b = Ref_const(a);
    cout << "a = " << a <<" and"
         << " b = " << b;
    return 0;
}
```

- Error:Increment of read only Reference 'x'

- Compilation Error: Value of x can't be changed
- Implies, 'a' can't be changed through 'x'

const reference – good

```
#include <iostream>
using namespace std;

int Ref_const(const int &x) {

    return (x + 1);
}

int main() {
    int a = 10, b;
    b = Ref_const(a);
    cout << "a = " << a << " and"
         << " b = " << b;
    return 0;
}
```

a = 10 and b = 11

- No violation.

Program 07.06: Return-by-reference

- A function can return a value by reference
- C uses Return-by-value

Return-by-value

```
#include <iostream>
using namespace std;

int Function_Return_By_Val(int &x) {
    cout <<"x = "<<x<<" &x = "<<&x<<endl;
    return (x);
}
int main() {
    int a = 10;
    cout <<"a = "<<a<<" &a = "<<&a<<endl;

    const int& b = // const needed. Why?
        Function_Return_By_Val(a);

    cout <<"b = "<<b<<" &b = "<<&b<<endl;
    return 0;
}
```

```
a = 10 &a = 00DCFD18
x = 10 &x = 00DCFD18
b = 10 &b = 00DCFD00
```

- Returned variable is temporary
- Has a different address

Return-by-reference

```
#include <iostream>
using namespace std;

int& Function_Return_By_Ref(int &x) {
    cout <<"x = "<<x<<" &x = "<<&x<<endl;
    return (x);
}
int main() {
    int a = 10;
    cout <<"a = "<<a<<" &a = "<<&a<<endl;

    const int& b = // const optional
        Function_Return_By_Ref(a);

    cout <<"b = "<<b<<" &b = "<<&b<<endl;
    return 0;
}
```

```
a = 10 &a = 00A7F8FC
x = 10 &x = 00A7F8FC
b = 10 &b = 00A7F8FC
```

- Returned variable is an alias of a
- Has the same address

Program 07.07: Return-by-reference can get tricky

Return-by-reference

```
#include <iostream>
using namespace std;
int& Return_ref(int &x) {


    return (x);
}

int main() {
    int a = 10, b;
    b = Return_ref(a);
    cout << "a = " << a << " and b = "
         << b << endl;

    Return_ref(a) = 3; // Changes
                       // reference
    cout << "a = " << a;

    return 0;
}
```

a = 10 and b = 10
a = 3

- Note how a value is assigned to function call
- This can change a local variable

Return-by-reference – Risky!

```
#include <iostream>
using namespace std;
int& Return_ref(int &x) {
    int t = x;
    t++;
    return (t);
}

int main() {
    int a = 10, b;
    b = Return_ref(a);
    cout << "a = " << a << " and b = "
         << b << endl;

    Return_ref(a) = 3;

    cout << "a = " << a;

    return 0;
}
```

a = 10 and b = 11
a = 10

- We expect a to be 3, but it has not changed
- It returns reference to local. This is risky

I/O of a Function

- In C++ we can changes values with a function as follows:

Orifice	Purpose	Mechanism
Value Parameter	Input	Call-by-value
Reference Parameter	In-Out	Call-by-reference
`const` Reference Parameter	Input	Call-by-reference
Return Value	Output	Return-by-value Return-by-reference

Recommended Mechanisms

- Call
  - Pass parameters of built-in types by value
    - Recall: Array parameters are passed by reference in C
  - Pass parameters of user-defined types by reference
    - Make a reference parameter `const` if it is not used for output
- Return
  - Return built-in types by value
  - Return user-defined types by reference
    - Return value is not copied back
    - May be faster than returning a value
    - Beware: Calling function can change returned object
    - Never return a local variables by reference

Difference between Reference and Pointer

Pointers	References
• Refers to an address	• Refers to an address
• Pointers can point to NULL. int *p = NULL; // p is not pointing	• References cannot be NULL int &j ; //wrong

• Pointers can point to different variables at different times
 	
`int a, b, *p;`
`p = &a; // p points to a`
`...`
`p = &b // p points to b`
	• For a reference, its referent is fixed
	
	`int a, c, &b = a; // Okay`
	`.....`
	`&b = c // Error`

• NULL checking is required	• Makes code faster Does not require NULL checking
• Allows users to operate on the address – diff pointers, increment, etc.	• Does not allow users to operate on the address. All operations are interpreted for the referent
• Array of pointers can be defined	• Array of references not allowed

Module Summary

- Introduced reference in C++
- Studied the difference between call-by-value and call-by-reference
- Studied the difference between return-by-value and return-by-reference
- Discussed the difference between References and Pointers

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