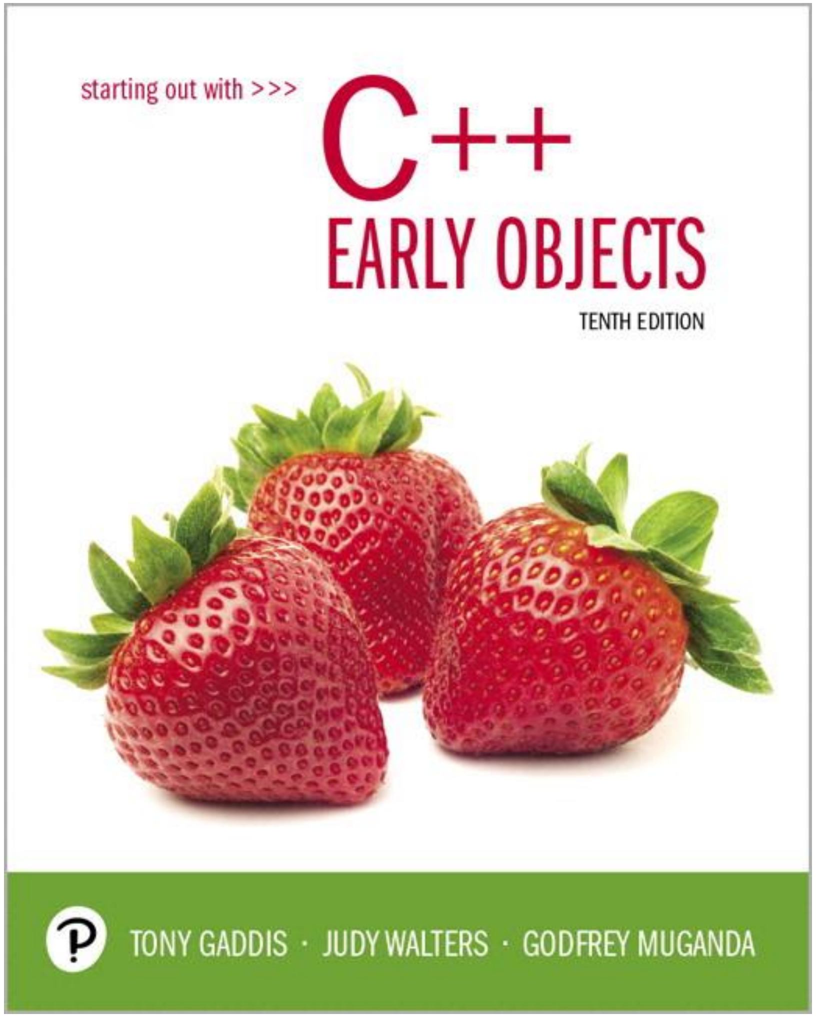
Starting Out with C++ Early Objects

Tenth Edition



Chapter 10

Pointers

Topics 1 of 2

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10.2 Pointer Variables

10.3 The Relationship Between Arrays and Pointers

10.4 Pointer Arithmetic

10.5 Initializing Pointers

10.6 Comparing Pointers

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10.9 Dynamic Memory Allocation

10.10 Returning Pointers from Functions

10.11 Pointers to Class Objects and Structures

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10.1 Pointers and the Address Operator

- Each variable in a program is stored at a unique location in memory that has an address
- Use the address operator **&** to get the address of a variable:

```
int num = -23;
cout << &num; // prints address
              // in hexadecimal
```

- The address of a memory location is a pointer

Graphic 10-1

- Pg. 660

Hands-On Pg. 660

- Listing 10-1

10.2 Pointer Variables 1 of 3

- Pointer variable (pointer): a variable that holds an address
- Pointers provide an alternate way to access memory locations

Pointer Variables 2 of 3

- Definition:

```
int  *intptr;
```

- Read as:

  "**intptr** can hold the address of an int" or
  "**intptr** is a pointer to an int"

- The spacing in the definition does not matter:

```
int * intptr;
int*  intptr;
```

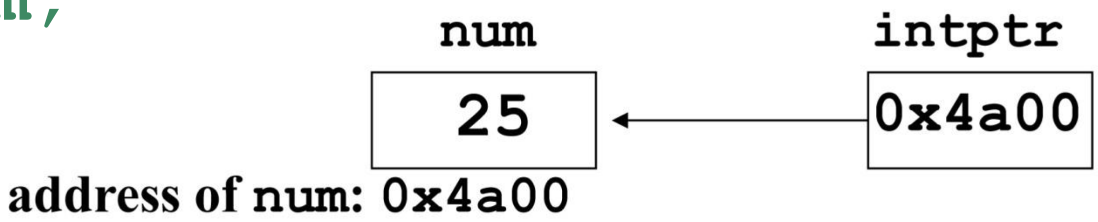
- ***** is called the indirection operator

Pointer Variables 3 of 3

- Definition and assignment:

```
int num = 25;
int *intptr;
intptr = &num;
```

- Memory layout:



- You can access **num** using **intptr** and indirection operator *****:

```
cout << intptr;  // prints 0x4a00
cout << *intptr; // prints 25
*intptr = 20;    // puts 20 in num
```

Hands-On Pg. 662

- Listing 662

Hands-On Pg. 663

- Listing 10-3

Hands-On Pg. 664

- Listing 10-4

10.3 The Relationship Between Arrays and Pointers 1 of 2

An array name is the starting address of the array

```
int vals[] = {4, 7, 11};
```

4	7	11

starting address of `vals`: `0x4a00`

```
cout << vals;     // displays 0x4a00
cout << vals[0];  // displays 4
```

The Relationship Between Arrays and Pointers 2 of 2

- An array name can be used as a pointer constant

```
int vals[] = {4, 7, 11};
cout << *vals;     // displays 4
```

- A pointer can be used as an array name

```
int *valptr = vals;
cout << valptr[1]; // displays 7
```

Hands-On Pg. 665

- Listing 10-5 (and graphic)

Pointers in Expressions

- Given:

```
int vals[]={4,7,11};
int *valptr = vals;
```

- What is **`valptr + 1`**?
- It means (address in **`valptr`**) + (1 * size of an **`int`**)

```
cout << *(valptr+1); // displays 7
cout << *(valptr+2); // displays 11
```

- Must use **`( )`** in expression

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Array Access 1 of 2

Array elements can be accessed in many ways

Array access method	Example
array name and `[ ]`	`vals[2] = 17;`
pointer to array and `[ ]`	`valptr[2] = 17;`
array name and subscript arithmetic	`*(vals+2) = 17;`
pointer to array and subscript arithmetic	`*(valptr+2) = 17;`

Array Access 2 of 2

- Array notation

```
vals[i]
```

is equivalent to the pointer notation

```
*(vals + i)
```

- Remember that no bounds checking is performed on array access. This applies to using a pointer for access as well as using the array name and a subscript.

Hands-On Pg. 666

- Listing 10-6

Hands-On Pg. 667

- Listing 10-7

Hands-On Pg. 668

- Listing 10-8

10.4 Pointer Arithmetic 1 of 5

Some arithmetic operators can be used with pointers:

- Increment and decrement operators **++**, **--**
- Integers can be added to or subtracted from pointers using the operators **+**, **-**, **+=**, and **-=**
- One pointer can be subtracted from another by using the subtraction operator **-**

Pointer Arithmetic 2 of 5

Assume the variable definitions

```
int vals[]={4,7,11};
int *valptr = vals;
```

Examples of use of **++** and **--**

```
valptr++; // points at 7
valptr--; // now points at 4
```

Pointer Arithmetic 3 of 5

Assume the variable definitions:

```
int vals[]={4,7,11};
int *valptr = vals;
```

Example of the use of **+** to add an int to a pointer:

```
cout << *(valptr + 2)
```

This statement will print 11

Pointer Arithmetic 4 of 5

Assume the variable definitions:

```
int vals[]={4,7,11};
int *valptr = vals;
```

Example of use of +=:

```
valptr = vals; // points at 4
valptr += 2;   // points at 11
```

Pointer Arithmetic 5 of 5

Assume the variable definitions

```
int vals[] = {4,7,11};
int *valptr = vals;
```

Example of pointer subtraction

```
valptr += 2;
cout << valptr - val;
```

This statement prints **2**: the number of **ints** between **valptr** and **val**

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- Listing 10-9

10.5 Initializing Pointers

- You can initialize to NULL or 0 (zero)

```
int *ptr = NULL;
```

- You can initialize to addresses of other variables

```
int num, *numPtr = &num;
int val[ISIZE], *valptr = val;
```

- The initial value must have the correct type

```
float cost;
int *ptr = &cost; // won't work
```

Initializing Values in C++ 11

- In C++ 11, putting empty { } after a variable definition indicates that the variable should be initialized to its default value
- C++ 11 also has the the key word **`nullptr`** to indicate that a pointer variable does not contain a valid memory location
- You can use

```
int *ptr = nullptr;
```

- or

```
int *ptr{ };
```

10.6 Comparing Pointers

- Relational operators can be used to compare the addresses in pointers
- Comparing addresses in pointers is not the same as comparing contents pointed at by pointers:

```
if (ptr1 == ptr2)    // compares
                     // addresses
if (*ptr1 == *ptr2) // compares
                    // contents
```

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- Listing 10-10

10.7 Pointers as Function Parameters 1 of 3

- A pointer can be a parameter
- It works like a reference parameter to allow changes to argument from within a function
- A pointer parameter must be explicitly dereferenced to access the contents at that address

Pointers as Function Parameters 2 of 3

Requires:

1) asterisk * on parameter in prototype and header

```
void getNum(int *ptr);
```

2) asterisk * in body to dereference the pointer

```
cin >> *ptr;
```

3) address as argument to the function in the call

```
getNum(&num);
```

Pointers as Function Parameters 3 of 3

```
void swap(int *x, int *y)
{
    int temp;
    temp = *x;
    *x = *y;
    *y = temp;
}
int num1 = 2, num2 = -3;
swap(&num1, &num2);  //call
```

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- Listing 10-11

Passing an Array Via a Pointer Parameter

- A pointer parameter receives an address when a function is called
- The address could be for a single variable, or it could be the address of the first element of an array.
- You can use either subscript notation or pointer arithmetic to access the elements of the array.

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- Listing 10-12

10.8 Pointers to Constants and Constant Pointers

- A pointer to a constant: you cannot change the value that is pointed at
- A constant pointer: the address in the pointer cannot be changed after the pointer is initialized

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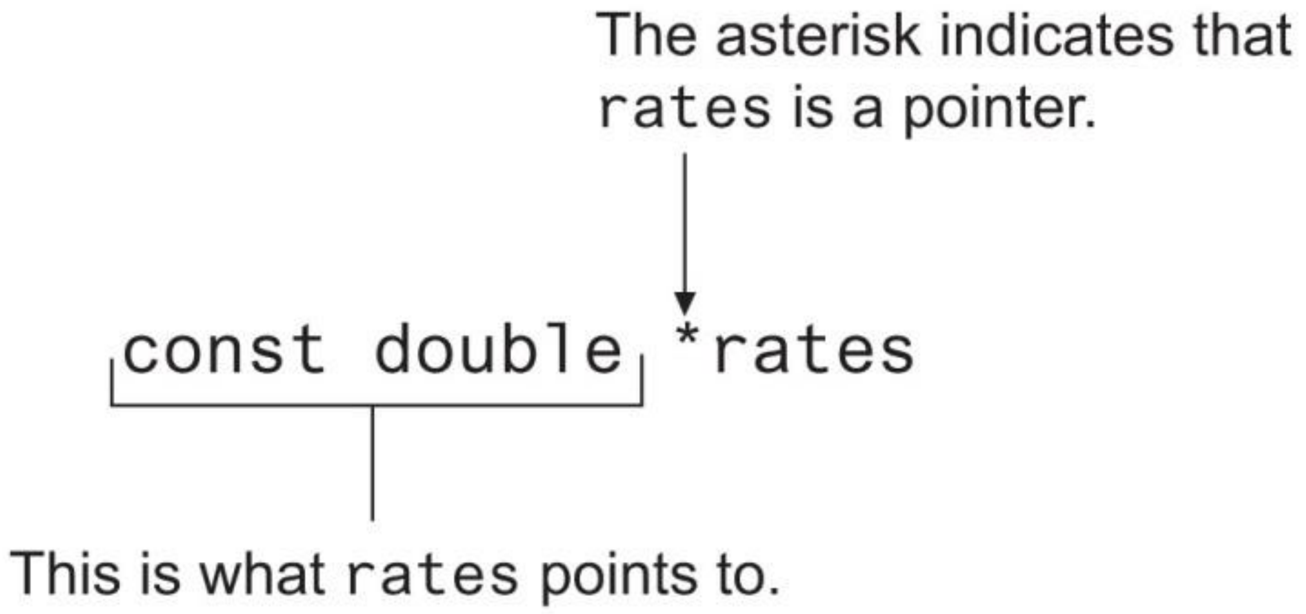
Pointers to Constants

- Must use the **`const`** keyword in the pointer definition:

```
const double taxRates[] =
                    {0.65, 0.8, 0.75};
const double *ratePtr;
```

- Use the **`const`** keyword for pointer parameters in function headers to protect data from modification in the function, as well as to pass addresses of **`const`** arguments

Pointer to Constant – What does the Definition Mean?



Read as: “rates is a pointer to a constant that is a double.”

Constant Pointers

- A constant pointer is a pointer whose data (the address in the pointer) cannot change
- Defined with the **`const`** keyword next to the variable name:

```
int classSize = 24;
int * const classPtr = &classSize;
```

- It must be initialized when defined
- No initialization needed if used as a function parameter
  - Initialized by the argument when function is called
  - Arguments can differ on on different function calls
- While the address in the pointer cannot change, the data at that address may be changed

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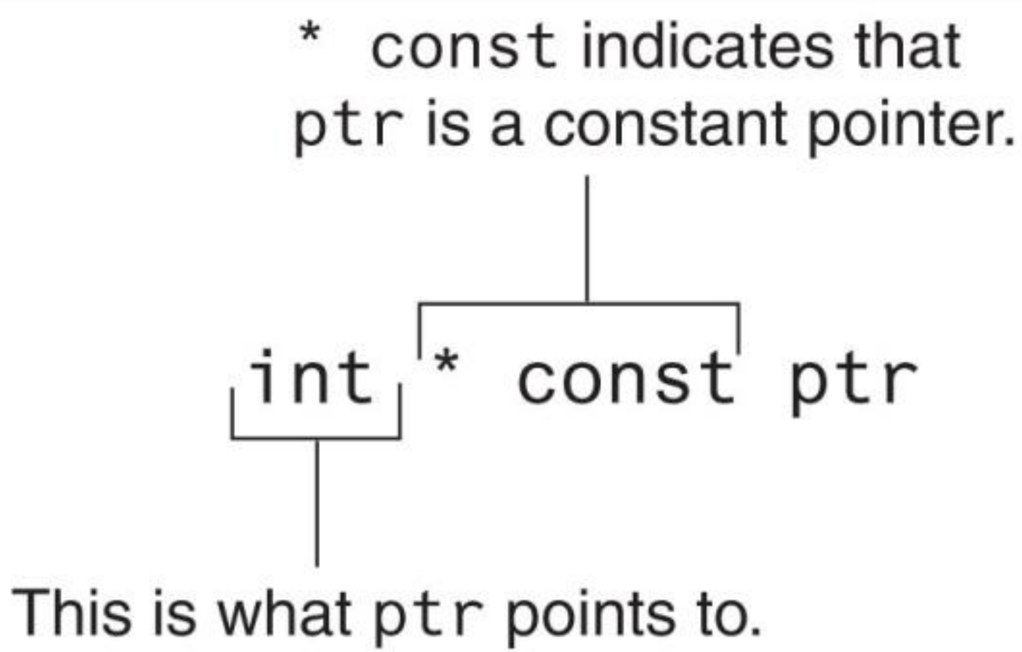
Constant Pointer – What does the Definition Mean?



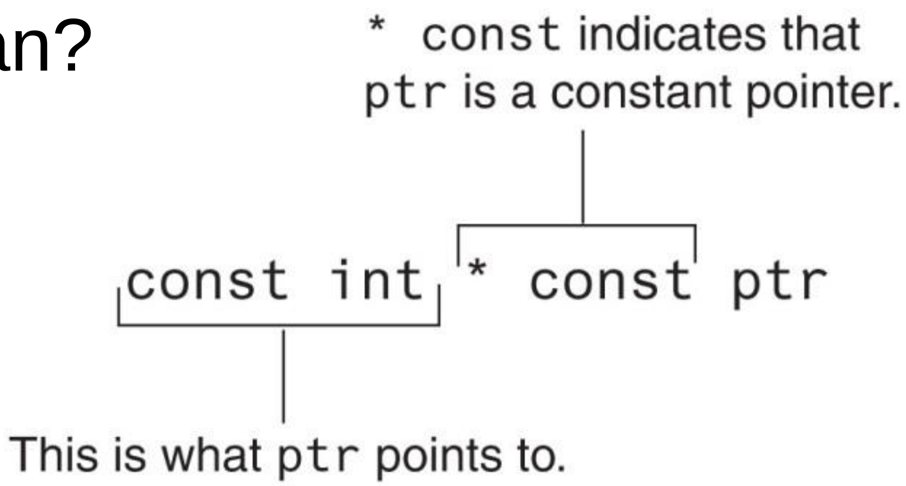
Read as: “ptr is a constant pointer to an int.”

Constant Pointer to Constant

- You can combine pointers to constants and constant pointers:

```
int size = 10;
const int * const ptr = &size;
```

- What does it mean?



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- Listing 10-13

10.9 Dynamic Memory Allocation 1 of 2

- You can allocate storage for a variable while a program is running
- Use the **`new`** operator to allocate memory

```
double *dptr;
dptr = new double;
```

- **`new`** returns address of a memory location
- The data type of the variable is indicated after **`new`**

Dynamic Memory Allocation 2 of 2

- You can also use **`new`** to allocate an array

```
arrayPtr = new double[25];
```

  - The program may terminate if there is not sufficient memory

- You can then use **`[ ]`** or pointer arithmetic to access the array

Dynamic Memory Example

```
int *count, *arrayptr;
count = new int;
cout <<"How many students? ";
cin >> *count;
arrayptr = new int[*count];

for (int i=0; i<*count; i++)
{
  cout << "Enter score " << i << ": ";
  cin >> arrayptr[i];
}
```

Releasing Dynamic Memory

- Use **`delete`** to free dynamic memory

```
delete count;
```

- Use **`delete []`** to free dynamic array memory

```
delete [] arrayptr;
```

- Only use **`delete`** with dynamic memory!

Dangling Pointers and Memory Leaks

- A pointer is dangling if it contains the address of memory that has been freed by a call to **`delete`**.
  - Solution: set such pointers to NULL (or **`nullptr`** in C++ 11) as soon as the memory is freed.
- A memory leak occurs if no-longer-needed dynamic memory is not freed. The memory is unavailable for reuse within the program.
  - Solution: free up dynamic memory after use

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- Listing 10-14

10.10 Returning Pointers from Functions

- A pointer can be the return type of function

```
int* newNum();
```

- The function must not return a pointer to a local variable in the function
- The function should only return a pointer
  - to data that was passed to the function as an argument
  - to dynamically allocated memory

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- Listing 10-15

More on Memory Leaks

General guidelines to avoid memory leaks:

- If a function allocates memory via **`new`**, it should, whenever possible, also deallocate the memory using **`delete`**
- If a class needs dynamic memory, it should
  - allocate it using **`new`** in the constructor
  - deallocate it using **`delete`** in the destructor

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- Listing 10-16

10.11 Pointers to Class Objects and Structures

- You can create pointers to objects and structure variables

```
struct Student {…};
class Square {…};
Student stu1;
Student *stuPtr = &stu1;
Square sq1[4];
Square *squarePtr = &sq1[0];
```

- You need to use `()` when using `*` and `.` operators

```
(*stuPtr).studentID = 12204;
```

Structure Pointer Operator ->

- Simpler notation than **`(*ptr).member`**
- Use the form **`ptr->member`**

```
stuPtr->studentID = 12204;
squarePtr->setSide(14);
```

in place of the form **`(*ptr).member`**

```
(*stuPtr).studentID = 12204;
(*squarePtr).setSide(14);
```

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Dynamic Memory with Objects

- You can allocate dynamic structure variables and objects using pointers:

```
stuPtr = new Student;
```

- You can pass values to the object's constructor:

```
squarePtr = new Square(17);
```

- **`delete`** causes destructor to be invoked:

```
delete squarePtr;
```

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- Listing 10-17

Structure/Object Pointers as Function Parameters

- Pointers to structures or objects can be passed as parameters to functions
- Such pointers provide a pass-by-reference parameter mechanism
- Pointers must be dereferenced in the function to access the member fields

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- Listing 10-18

10.12 Selecting Members of Objects 1 of 2

Situation: A structure/object contains a pointer as a member. There is also a pointer *to* the structure/ object.

Problem: How do we access the pointer member via the structure/object pointer?

```
struct GradeList
  { string courseNum;
    int * grades;
  }
GradeList test1, *testPtr = &test1;
```

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Selecting Members of Objects 2 of 2

Expression	Meaning
`testPtr->grades`	Access the grades pointer in **`test1`**. This is the same as **`(*testPtr).grades`**
`*testPtr->grades`	Access the value pointed at by **`testPtr->grades`**. This is the same as **`*(*testPtr).grades`**
`*test1.grades`	Access the value pointed at by **`test1.grades`**

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10.13 Smart Pointers

- Introduced in C++ 11
- They can be used to solve the following problems in a large software project
  - dangling pointers – pointers whose memory is deleted while the pointer is still being used
  - memory leaks – allocated memory that is no longer needed but is not deleted
  - double-deletion – two different pointers de-allocating the same memory

Smart Pointers

- Smart pointers are objects that work like pointers.
- Unlike regular (raw) pointers, smart pointers can automatically delete dynamic memory that is no longer being used.
- There are three types of smart pointers:
  - unique pointers (**`unique_ptr`**)
  - shared pointers (**`shared_ptr`**)
  - weak pointers (**`weak_ptr`**)

Unique Pointers

- A smart pointer owns (or manages) the object that it points to.
- A unique pointer points to a dynamically allocated object that has a single owner.
- Ownership can be transferred to another unique pointer.
- Memory for the object is deallocated when the owning unique pointer goes out of scope, or if the unique pointer takes ownership of a different object.

Unique Pointer Examples

- Requires the `<memory>` header file
- Create a unique pointer that points to an int:

```
unique_ptr<int> uptr(new int);
```

- Assign the value 5 to it and print it:

```
*uptr = 5;
cout << *uptr;
```

- Transfer ownership to unique pointer ptr2:

```
unique_ptr<int> uptr2;
uptr2 = move(uptr);
```

Unique Pointers and Ownership Transfers – the `move()` function

- In a statement such as:

```
uptr2 = move(uptr);
```

  - Any object owned by **`uptr2`** is deallocated
  - **`uptr2`** takes ownership of the object previously owned by **`uptr`**
  - **`uptr`** becomes empty

The `move()` Function and Unique Pointers as Parameters

- The **`move()`** function is required on the argument when passing a unique pointer by value.
- The **`move()`** function is not required for pass by reference
- A unique pointer can be returned from a function, as the compiler automatically uses **`move()`** in this case.

Manually Clearing a Unique Pointer

- Unique pointers deallocate the memory for their objects when they go out of scope.
- To manually deallocate memory, use

```
uptr = nullptr;
```

or

```
uptr.reset();
```

Unique Pointers and Arrays

- Use array notation when using a unique pointer to allocate memory for an array

```
unique_ptr<int[]>uptr3(new int[5]);
```

- Doing so ensures that the proper deallocation (**`delete[]`** instead of **`delete`**) will be used.

Shared Pointers

- A smart pointer owns (or manages) the object that it points to.
- A shared pointer points to a dynamically allocated object that may have multiple owners.
- A control block manages the reference count of the number of shared owners and also possibly the raw pointer if one exists.

Creating Shared Pointers

- Create a shared pointer to point to an existing dynamic object declared with a raw pointer:

```
int * rawPtr = new int;
shared_ptr<int> uptr4(rawPtr);
```

- Create a second shared pointer initialized to the same object:

```
shared_ptr<int>uptr5 = uptr4;
```

- **`rawPtr`**, **`uptr4`**, and **`uptr5`** are all tracked in the control block.

How Many Control Blocks?

- Be careful that all references to a dynamic object are tracked in the same control block
- In the code below:

```
int * rawPtr = new int;
shared_ptr<int> uptr4(rawPtr);
shared_ptr<int> uptr5(rawPtr);
```

- Two control blocks are created. This can cause a dangling pointer.

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- Listing 10-19

Memory Management Tip

- Creating a shared pointer involves memory for the object and memory for the control block.
- These memory allocations can be combined by using the **`make_shared`** function:

```
shared_ptr<int> uptr6 = make_shared<int>();
```

- You can also pass parameters to a constructor using an overloaded version of **`make_shared`**.

Hands-On Pg. 709, 710

- Listing 10-20
- Listing 10-22

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