Chapter 9

Pointers

9.1

Getting the Address of a Variable

Getting the Address of a Variable

- Each variable in program is stored at a unique address
- Use address operator `&` to get address of a variable:

```
int num = -99;
cout << &num; // prints address
              // in hexadecimal
```

9.2

Pointer Variables

Pointer Variables

- Pointer variable : Often just called a pointer, it's a variable that holds an address

- Because a pointer variable holds the address of another piece of data, it "points" to the data

Something Like Pointers: Arrays

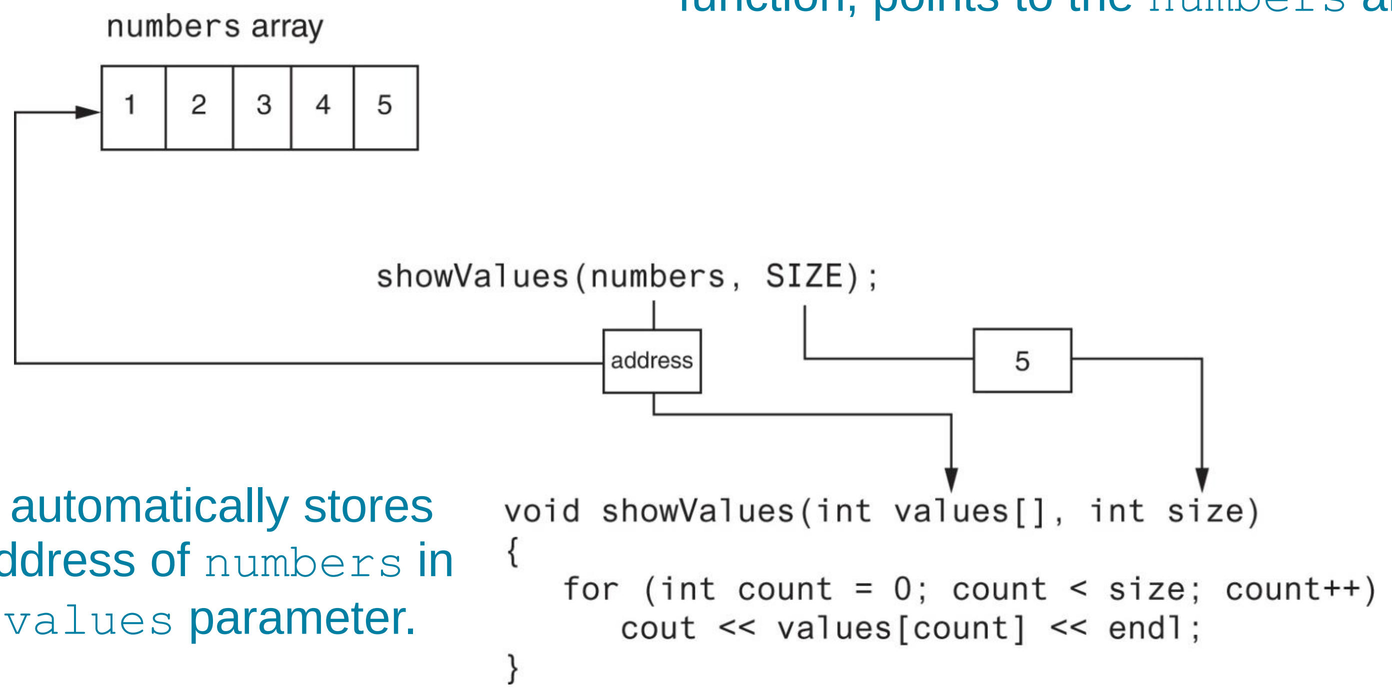
- We have already worked with something similar to pointers, when we learned to pass arrays as arguments to functions.

- For example, suppose we use this statement to pass the array `numbers` to the `showValues` function:

```
showValues(numbers, SIZE);
```

Something Like Pointers : Arrays

The `values` parameter, in the `showValues` function, points to the `numbers` array.



C++ automatically stores the address of `numbers` in the `values` parameter.

Something Like Pointers: Reference Variables

- We have also worked with something like pointers when we learned to use reference variables. Suppose we have this function:

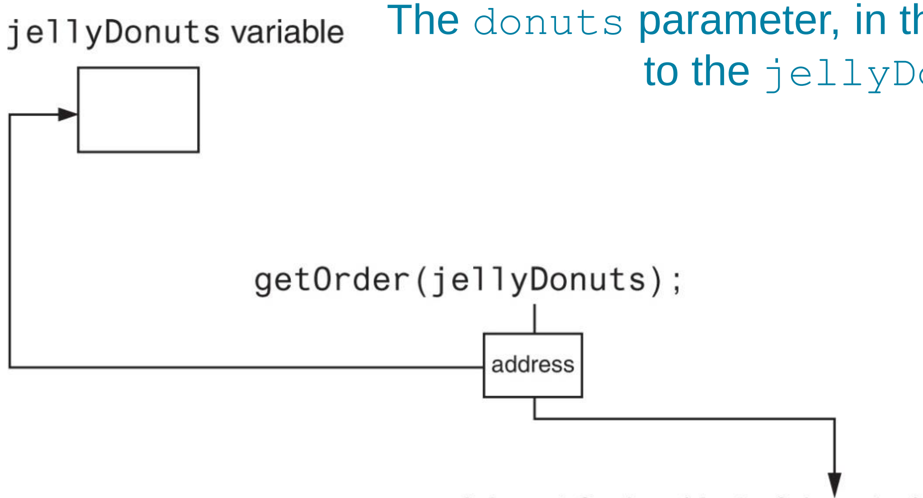
```
void getOrder(int &donuts)
{
   cout << "How many doughnuts do you want? ";
   cin >> donuts;
}
```

- And we call it with this code:

```
int jellyDonuts;
getOrder(jellyDonuts);
```

Something Like Pointers: Reference Variables

The donuts parameter, in the getOrder function, points to the jellyDonuts variable.




```
void getOrder(int &donuts)
{
    cout << "How many doughnuts do you want? ";
    cin >> donuts;
}
```

C++ automatically stores the address of jellyDonuts in the donuts parameter.

Pointer Variables

- Pointer variables are yet another way using a memory address to work with a piece of data.

- Pointers are more "low-level" than arrays and reference variables.

- This means you are responsible for finding the address you want to store in the pointer and correctly using it.

Pointer Variables

- Definition:

```
int  *intptr;
```

- Read as:

  "`intptr` can hold the address of an int"

- Spacing in definition does not matter:

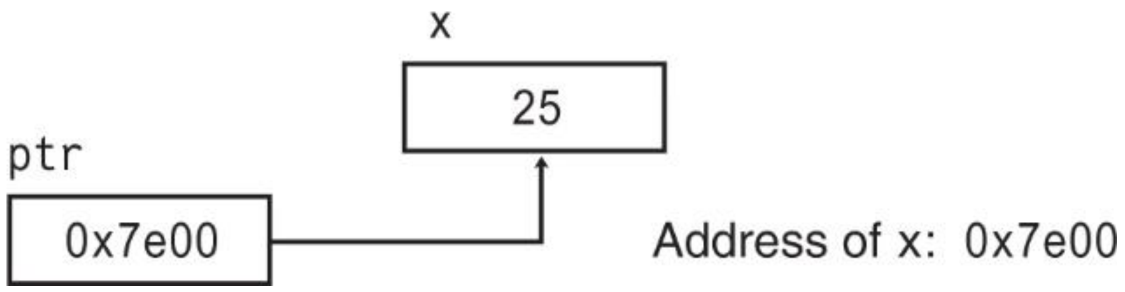
```
int * intptr;  // same as above
int*  intptr;  // same as above
```

Pointer Variables

- Assigning an address to a pointer variable:

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

- Memory layout:



Pointer Variables

- Initialize pointer variables with the special value `nullptr`.
- In C++ 11, the `nullptr` key word was introduced to represent the address `0`.
- Here is an example of how you define a pointer variable and initialize it with the value `nullptr`:

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

A Pointer Variable in Program 9-2

Program 9-2

```
// This program stores the address of a variable in a pointer.
#include <iostream>
using namespace std;

int main()
{
    int x = 25;           // int variable
    int *ptr = nullptr;   // Pointer variable, can point to an int

    ptr = &x;             // Store the address of x in ptr
    cout << "The value in x is " << x << endl;
    cout << "The address of x is " << ptr << endl;
    return 0;
}
```

Program Output

```
The value in x is 25
The address of x is 0x7e00
```

The Indirection Operator

- The indirection operator (`*`) dereferences a pointer.
- It allows you to access the item that the pointer points to.

```
int x = 25;
int *intptr = &x;
cout << *intptr << endl;
```

This prints 25.

The Indirection Operator in Program 9-3

Program 9-3

```
// This program demonstrates the use of the indirection operator.
#include <iostream>
using namespace std;

int main()
{
    int x = 25;            // int variable
    int *ptr = nullptr;    // Pointer variable, can point to an int

    ptr = &x;              // Store the address of x in ptr

    // Use both x and ptr to display the value in x.
    cout << "Here is the value in x, printed twice:\n";
    cout << x << endl;     // Displays the contents of x
    cout << *ptr << endl;  // Displays the contents of x

    // Assign 100 to the location pointed to by ptr. This
    // will actually assign 100 to x.
    *ptr = 100;
```

(program continues)

The Indirection Operator in Program 9-3

Program 9-3 *(continued)*

```
    // Use both x and ptr to display the value in x.
    cout << "Once again, here is the value in x:\n";
    cout << x << endl;    // Displays the contents of x
    cout << *ptr << endl; // Displays the contents of x
    return 0;
}
```

Program Output

```
Here is the value in x, printed twice:
25
25
Once again, here is the value in x:
100
100
```

9.3

The Relationship Between Arrays and Pointers

The Relationship Between Arrays and Pointers

- Array name is starting address of 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

- Array name can be used as a pointer constant:

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

- Pointer can be used as an array name:

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

The Array Name Being Dereferenced in Program 9-5

Program 9-5

```
// This program shows an array name being dereferenced with the *
// operator.
#include <iostream>
using namespace std;

int main()
{
   short numbers[] = {10, 20, 30, 40, 50};

   cout << "The first element of the array is ";
   cout << *numbers << endl;
   return 0;
}
```

Program Output

```
The first element of the array is 10
```

Pointers in Expressions

Given:

```
int vals[]={4,7,11}, *valptr;
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 `( )` as shown in the expressions

Array Access

- 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

- Conversion: `vals[i]` is equivalent to `*(vals + i)`
- No bounds checking performed on array access, whether using array name or a pointer

From Program 9-7

```
const int NUM_COINS = 5;
double coins[NUM_COINS] = {0.05, 0.1, 0.25, 0.5, 1.0};
double *doublePtr;    // Pointer to a double
int count;            // Array index

// Assign the address of the coins array to doublePtr.
doublePtr = coins;

// Display the contents of the coins array. Use subscripts
// with the pointer!
cout << "Here are the values in the coins array:\n";
for (count = 0; count < NUM_COINS; count++)
   cout << doublePtr[count] << " ";

// Display the contents of the array again, but this time
// use pointer notation with the array name!
cout << "\nAnd here they are again:\n";
for (count = 0; count < NUM_COINS; count++)
   cout << *(coins + count) << " ";
cout << endl;
```

Program Output

```
Here are the values in the coins array:
0.05 0.1 0.25 0.5 1
And here they are again:
0.05 0.1 0.25 0.5 1
```

9.4

Pointer Arithmetic

Pointer Arithmetic

- Operations on pointer variables:

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

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

`+, -` (pointer and `int`)	`cout << *(valptr + 2); // 11`

`+=, -=` (pointer and `int`)	`valptr = vals; // points at 4`
	`valptr += 2;   // points at 11`

`-` (pointer from pointer)	`cout << valptr-val; // difference`
	`//(number of ints) between valptr`
	`// and val`

From Program 9-9

```
    const int SIZE = 8;
    int set[SIZE] = {5, 10, 15, 20, 25, 30, 35, 40};
    int *numPtr = nullptr;  // Pointer
    int count;              // Counter variable for loops

    // Make numPtr point to the set array.
    numPtr = set;

    // Use the pointer to display the array contents.
    cout << "The numbers in set are:\n";
    for (count = 0; count < SIZE; count++)
    {
        cout << *numPtr << " ";
        numPtr++;
    }

    // Display the array contents in reverse order.
    cout << "\nThe numbers in set backward are:\n";
    for (count = 0; count < SIZE; count++)
    {
        numPtr--;
        cout << *numPtr << " ";
    }
    return 0;
}
```

Program Output

```
The numbers in set are:
5 10 15 20 25 30 35 40
The numbers in set backward are:
40 35 30 25 20 15 10 5
```

9.5

Initializing Pointers

Initializing Pointers

- Can initialize at definition time:

```
int num, *numptr = &num;
int val[3], *valptr = val;
```

- Cannot mix data types:

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

- Can test for an invalid address for `ptr` with:

```
if (!ptr) ...
```

9.6

Comparing Pointers

Comparing Pointers

- Relational operators (<, >=, etc.) can be used to compare addresses in pointers
- Comparing addresses <u>in</u> pointers is not the same as comparing contents <u>pointed at by</u> pointers:

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

9.7

Pointers as Function Parameters

Pointers as Function Parameters

- A pointer can be a parameter
- Works like reference variable to allow change to argument from within function
- Requires:
  1) asterisk * on parameter in prototype and heading

  ```
  void getNum(int *ptr); // ptr is pointer to an int
  ```

  2) asterisk ***** in body to dereference the pointer

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

  3) address as argument to the function

  ```
  getNum(&num);      // pass address of num to getNum
  ```

Example

```
void swap(int *x, int *y)
{     int temp;
      temp = *x;
      *x = *y;
      *y = temp;
}

int num1 = 2, num2 = -3;
swap(&num1, &num2);
```

Pointers as Function Parameters in Program 9-11

Program 9-11

```
// This program uses two functions that accept addresses of
// variables as arguments.
#include <iostream>
using namespace std;

// Function prototypes
void getNumber(int *);
void doubleValue(int *);

int main()
{
   int number;

   // Call getNumber and pass the address of number.
   getNumber(&number);

   // Call doubleValue and pass the address of number.
   doubleValue(&number);

   // Display the value in number.
   cout << "That value doubled is " << number << endl;
   return 0;
}

```

(Program Continues)

Pointers as Function Parameters in Program 9-11

Program 9-11 *(continued)*

```
//****************************************************************
// Definition of getNumber. The parameter, input, is a pointer. *
// This function asks the user for a number. The value entered  *
// is stored in the variable pointed to by input.               *
//****************************************************************

void getNumber(int *input)
{
   cout << "Enter an integer number: ";
   cin >> *input;
}

//****************************************************************
// Definition of doubleValue. The parameter, val, is a pointer. *
// This function multiplies the variable pointed to by val by   *
// two.                                                         *
//****************************************************************

void doubleValue(int *val)
{
   *val *= 2;
}
```

Program Output with Example Input Shown in Bold

```
Enter an integer number: 10 [Enter]
That value doubled is 20
```

Pointers to Constants

- If we want to store the address of a constant in a pointer, then we need to store it in a pointer-to-const.

Pointers to Constants

- Example: Suppose we have the following definitions:

```
const int SIZE = 6;
const double payRates[SIZE] =
     { 18.55, 17.45, 12.85,
       14.97, 10.35, 18.89 };
```

- In this code, `payRates` is an array of constant doubles.

Pointers to Constants

- Suppose we wish to pass the `payRates` array to a function? Here's an example of how we can do it.

```
void displayPayRates(const double *rates, int size)
{
   for (int count = 0; count < size; count++)
   {
      cout << "Pay rate for employee " << (count + 1)
           << " is $" << *(rates + count) << endl;
   }
}
```

The parameter, rates, is a pointer to `const double`.

Declaration of a Pointer to Constant

The asterisk indicates that `rates` is a pointer.

```
const double *rates
```

This is what `rates` points to.

Constant Pointers

- A constant pointer is a pointer that is initialized with an address, and cannot point to anything else.

- Example

```
int value = 22;
int * const ptr = &value;
```

Constant Pointers

* `const` indicates that `ptr` is a constant pointer.

```
int * const ptr
```

This is what `ptr` points to.

Constant Pointers to Constants

- A constant pointer to a constant is:
  - a pointer that points to a constant
  - a pointer that cannot point to anything except what it is pointing to

- Example:

```
int value = 22;
const int * const ptr = &value;
```

Constant Pointers to Constants

* `const` indicates that `ptr` is a constant pointer.

```
const int * const ptr
```

This is what `ptr` points to.

9.8

Dynamic Memory Allocation

Dynamic Memory Allocation

- Can allocate storage for a variable while program is running
- Computer returns address of newly allocated variable
- Uses `new` operator to allocate memory:

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

- `new` returns address of memory location

Dynamic Memory Allocation

- Can also use `new` to allocate array:

```
const int SIZE = 25;
arrayPtr = new double[SIZE];
```

- Can then use `[]` or pointer arithmetic to access array:

```
  for(i = 0; i < SIZE; i++)
      *arrayptr[i] = i * i;
```

 or

```
  for(i = 0; i < SIZE; i++)
      *(arrayptr + i) = i * i;
```

- Program will terminate if not enough memory available to allocate

Releasing Dynamic Memory

- Use `delete` to free dynamic memory:

```
delete fptr;
```

- Use `[]` to free dynamic array:

```
delete [] arrayptr;
```

- Only use `delete` with dynamic memory!

Dynamic Memory Allocation in Program 9-14

Program 9-14

```
// This program totals and averages the sales figures for any
// number of days. The figures are stored in a dynamically
// allocated array.
#include <iostream>
#include <iomanip>
using namespace std;

int main()
{
    double *sales = nullptr, // To dynamically allocate an array
           total = 0.0,      // Accumulator
           average;          // To hold average sales
    int numDays,             // To hold the number of days of sales
        count;               // Counter variable

    // Get the number of days of sales.
    cout << "How many days of sales figures do you wish ";
    cout << "to process? ";
    cin >> numDays;
```

Dynamic Memory Allocation in Program 9-14

```
        // Dynamically allocate an array large enough to hold
        // that many days of sales amounts.
        sales = new double[numDays];

        // Get the sales figures for each day.
        cout << "Enter the sales figures below.\n";
        for (count = 0; count < numDays; count++)
        {
            cout << "Day " << (count + 1) << ": ";
            cin >> sales[count];
        }

        // Calculate the total sales
        for (count = 0; count < numDays; count++)
        {
            total += sales[count];
        }

        // Calculate the average sales per day
        average = total / numDays;

        // Display the results
        cout << fixed << showpoint << setprecision(2);
        cout << "\n\nTotal Sales: $" << total << endl;
        cout << "Average Sales: $" << average << endl;
```

Program 9-14 (Continued)

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Dynamic Memory Allocation in Program 9-14

Program 9-14 (Continued)

```
46
47         // Free dynamically allocated memory
48         delete [] sales;
49         sales = nullptr;     // Make sales a null pointer.
50
51         return 0;
52     }
```

Program Output with Example Input Shown in Bold

```
How many days of sales figures do you wish to process? 5 [Enter]
Enter the sales figures below.
Day 1: 898.63 [Enter]
Day 2: 652.32 [Enter]
Day 3: 741.85 [Enter]
Day 4: 852.96 [Enter]
Day 5: 921.37 [Enter]

Total Sales: $4067.13
Average Sales: $813.43
```

Notice that in line 49 `nullptr` *is assigned to the* `sales` *pointer. The* `delete` *operator is designed to have no effect when used on a null pointer.*

9.9

Returning Pointers from Functions

Returning Pointers from Functions

- Pointer can be the return type of a function:

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

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

From Program 9-15

```
int *getRandomNumbers(int num)
{
     int *arr = nullptr;  // Array to hold the numbers

     // Return a null pointer if num is zero or negative.
     if (num <= 0)
          return nullptr;

     // Dynamically allocate the array.
     arr = new int[num];

     // Seed the random number generator by passing
     // the return value of time(0) to srand.
     srand( time(0) );

     // Populate the array with random numbers.
     for (int count = 0; count < num; count++)
          arr[count] = rand();

     // Return a pointer to the array.
     return arr;
}
```

9.10

Using Smart Pointers to Avoid Memory Leaks

Using Smart Pointers to Avoid Memory Leaks

- In C++ 11, you can use *smart pointers* to dynamically allocate memory and not worry about deleting the memory when you are finished using it.
- Three types of smart pointer:

```
unique_ptr
shared_ptr
weak_ptr
```

- Must `#include` the memory header file:

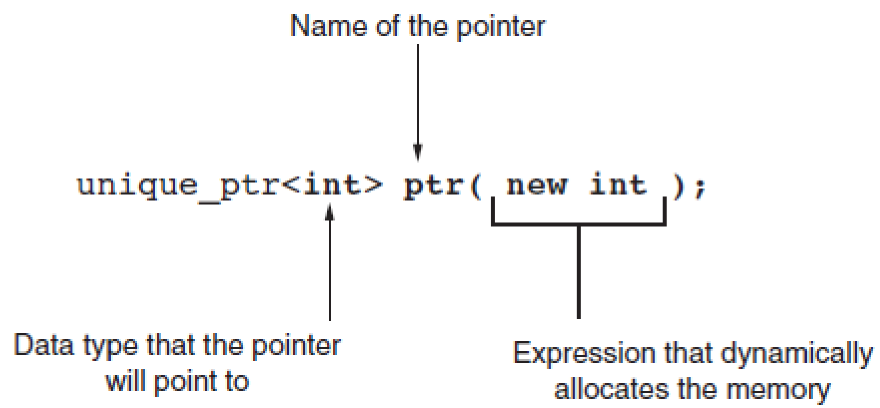
```
#include <memory>
```

- In this book, we introduce `unique_ptr`:

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

Using Smart Pointers to Avoid Memory Leaks

Figure 9-12



- The notation <int> indicates that the pointer can point to an int .
- The name of the pointer is ptr .
- The expression new int allocates a chunk of memory to hold an int.
- The address of the chunk of memory will be assigned to ptr.

Using Smart Pointers in Program 9-17

Program 9-17

```
// This program demonstrates a unique_ptr.
#include <iostream>
#include <memory>
using namespace std;

int main()
{
    // Define a unique_ptr smart pointer, pointing
    // to a dynamically allocated int.
    unique_ptr<int> ptr( new int );

    // Assign 99 to the dynamically allocated int.
    *ptr = 99;

    // Display the value of the dynamically allocated int.
    cout << *ptr << endl;
    return 0;
}
```

Program Output

```
99
```

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