Unit 3 (ch7, ch9)

Pointers, Arrays and Dynamic Memory

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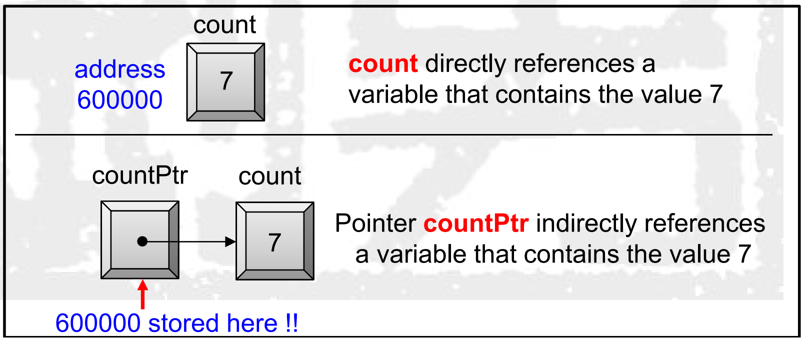
Outline

- *3.1 Pointers*
- 3.2 Dynamic Memory Allocation
- 3.3 Pointer and Array

Pointers

- A pointer is the memory address of a variable
  - Pointers "point" to a variable by telling where the variable is located
- Memory addresses can be used to access variables indirectly
  - When a variable is used as a call-by-reference argument, its address is passed



Declaring Pointers

- Pointer variables must be declared to have a type
  - Define how to explain the data retrieved from memory
  - Ex: declare a pointer variable p that "point" to a double:

    double *p;
  - The asterisk(*) identifies p as a pointer variable
- To declare multiple pointers in a statement, use the asterisk before each pointer variable
  - Pointer and non-pointer variables can be put together
  - Ex: int *p1, *p2, v1, v2;

    p1 and p2 point to variables of type *int*
    v1 and v2 are variables of type *int*

Operators on Pointer Variables

- The & operator can be used to obtain the address of a variable
  - Ex: p1 = &v1;

    p1 is now a pointer to v1

    v1 can be called v1 or
    "the variable pointed to by p1"
- "The variable pointed to by p" is denoted as *p in C++
  - C++ uses the * operator in several different ways
  - With pointers, the * is dereferencing operator here
    - p is said to be dereferenced
    - p is the address, *p is the data

Example of Pointer Operations

- v1 = 0;
  p1 = &v1;
  *p1 = 42;
  cout << "v1 = " << v1 << endl;
  cout << "*p1 = " << *p1 << endl;

  v1 and *p1 now refer to the same variable

  output:

  v1 = 42
  *p1 = 42

Pointer Assignment

- The assignment operator = is used to assign the value of one pointer to another
  - Ex: If p1 still points to v1 (previous slide), then

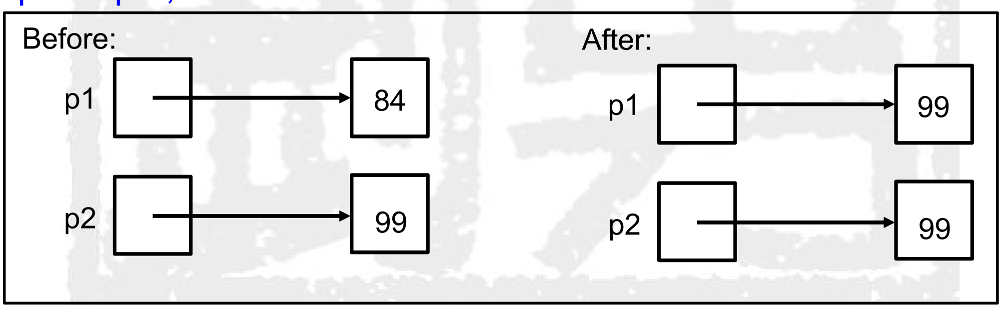
    p2 = p1;

    causes *p2, *p1, and v1 be the same variable
- Some care is required making assignments to pointer variables
  - p1= p3; // changes the location that p1 "points" to
  - *p1 = *p3; // changes the value at the location that // p1 "points" to

Uses of the Assignment Operator

p1 = p2 ;

*p1 = *p2 ;



Pass-by-Reference with Pointers

- In C++, we use reference parameters to pass arguments to a function by reference
- In old C, we implement pass-by-reference with pointer arguments
  - When calling a function with an argument that should be modified, the address of that argument is passed
  - Passing pointers to large data objects avoids the overhead of being passed by value
- Given the address of a variable, the dereferencing operator (*) form a synonym for it in the function
  - Used to modify the variable's value at that location in the caller's memory

Ex: Pass-by-Reference with Pointers

- In this example, the first function *cubeByValue* demonstrates typical pass-by-value mechanism
  - The local change has no affect on the original variable
- Another function *cubeByReference* passes the number by using pass-by-reference with a pointer
  - The address of that number is passed to the function
- The function dereferences the pointer and cubes the value to which nPtr points
  - This directly changes the value of *number* in main
- Graphical analysis for the execution of the programs is provided respectively

Comparison of Pass-by-Pointer

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

int cubeByValue( int );

int main( )
{
    int number = 5;
    cout << "The original value of number is "
          << number;
    // pass number by value
    number = cubeByValue(number);
    cout << "\nThe new value of number is "
          << number << endl;
}   // end main

int cubeByValue ( int n )
{
    return n * n * n;
}
```

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

void cubeByReference( int * );

int main( )
{
    int number = 5;
    cout << "The original value of number is "
          << number;
    // pass the address of number
    cubeByReference(&number);
    cout << "\nThe new value of number is "
          << number << endl;
}   // end main

void cubeByReference ( int *nPtr )
{
    *nPtr = *nPtr * *nPtr * *nPtr;
}
```


Pass-by-Value Analysis (1/2)

Step 1: Before **main** calls **cubeByValue**:

```
int main()
{
    int number = 5;
    number = cubeByValue( number );
}
```

number: 5

```
int cubeByValue( int n )
{
    return n * n * n;
}
```

n: undefined

Step 2: After **cubeByValue** receives the call:

```
int main()
{
    int number = 5;
    number = cubeByValue( number );
}
```

number: 5

```
int cubeByValue( int n )
{
    return n * n * n;
}
```

n: 5

Pass-by-Value Analysis (2/2)

Step 3: After **cubeByValue** cubes parameter **n** and before **cubeByValue** returns to **main**:

```
int main()                                  number
{                                           [ 5 ]
    int number = 5;
    number = cubeByValue( number );
}
```

```
int cubeByValue( int n )
{
    return [n * n * n;]
}        [125]                 n
                             [ 5 ]
```

Step 4: After **cubeByValue** returns to **main** and before assigning the result to **number**:

```
int main()                                  number
{                                           [ 5 ]
    int number = 5;          [125]
    number = [cubeByValue( number );]
}
```

```
int cubeByValue( int n )
{
    return n * n * n;
}                              n
                         [undefined]
```

Step 5: After **main** completes the assignment to **number**:

```
int main()                                  number
{                                           [125]
    int number = 5;          [125]
  [number =  cubeByValue( number );]
}  [125]
```

```
int cubeByValue( int n )
{
    return n * n * n;
}                              n
                         [undefined]
```


Pass-by-Reference Analysis

Step I: Before **main** calls **cubeByReference**:

```
Int main()                          number
{
    [int number = 5;]               [ 5 ]

    cubeByReference( &number );
}
```

```
void cubeByReference(int *nPtr)
{
    *nPtr = *nPtr * *nPtr * *nPtr
}
                              nPtr
                          [undefined]
```

Step II: After **cubeByReference** receives the call and before ***nPtr** is cubed:

```
Int main()                          number
{
    int number = 5;                 [ 5 ]

    cubeByReference( &number );
}
```

```
void cubeByReference( [int *nPtr] )
{
    *nPtr = *nPtr * *nPtr * *nPtr
}
                                   nPtr
Call establishes this pointer    [      ]
```

Using const with Pointers

- There are 4 ways to pass a pointer to a function
- A nonconstant pointer to nonconstant data
  ex: int *myPtr = &x;
  - Both the address and the data can be changed
- A nonconstant pointer to constant data
  ex: const int *myPtr = &x;
  - Modifiable pointer to a ***const int*** (data are not modifiable)
- A constant pointer to nonconstant data
  ex: int *const myPtr = &x;
  - Constant pointer to an ***int*** (data can be changed, but the address cannot)
- A constant pointer to constant data
  ex: const int *const Ptr = &x;
  - Both the address and the data are not modifiable

Nonconstant Pointer to Constant Data

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

void f( const int * );

int main( )
{
    int y;
    // f attempts illegal modification
    f( &y );
}   // end main
```

```
// xPtr cannot modify the value of constant variable
// to which it points
void f( const int *xPtr )
{
    *xPtr = 100;
}   // end function f
```

Microsoft Visual C++ compiler error message:

```
c:\cpphtp7_examples\ch07\Fig07_10\fig07_10.cpp(17) :
   error C3892: 'xPtr' : you cannot assign to a variable that is const
```

GNU C++ compiler error message:

```
fig07_10.cpp: In function `void f(const int*)':
fig07_10.cpp:17: error: assignment of read-only location
```

Constant Pointer to Nonconstant Data

```
int main( )
{
   int x, y;

   // The integer can be modified through ptr
   // But ptr always points to the same location
   int * const ptr = &x;

   *ptr = 7;   // allowed: *ptr is not a constant
   ptr = &y;  // error: ptr is a constant, cannot assign it a new address
}  // end main
```

Microsoft Visual C++ compiler error message:

```
c:\cpphtp7_examples\ch07\Fig07_11\fig07_11.cpp(14) : error C3892: 'ptr' :
   you cannot assign to a variable that is const
```

GNU C++ compiler error message:

```
fig07_11.cpp: In function `int main()':
fig07_11.cpp:14: error: assignment of read-only variable `ptr'
```


Outline

- 3.1 Pointers
- *3.2 Dynamic Memory Allocation*
- 3.3 Pointer and Array

Dynamic Variables -- new Operator

- Sometimes you need a flexible array or data structure to support dynamic requests
  - Traditional array requires a fixed size at compile time
  - Variables created using the *new* operator are called dynamic variables
  - Created and destroyed while the program is running
- Using pointers, variables can be manipulated even if there is no identifier for them
  - Ex: create a pointer to a "nameless" *int* variable
    - int *p1 = new int;
  - The new variable is referred to as *p1
  - *p1 can be used anyplace an integer variable can
    - Ex: cin >> *p1; *p1 = *p1 + 7;

Example: Pointer Manipulations (1/2)

```
//DISPLAY 9.2 Basic Pointer Manipulations
//Demonstrate pointers and dynamic variables.
#include <iostream>
using namespace std;

int main( )
{
   int *p1, *p2;

   p1 = new int;
   *p1 = 42;
   p2 = p1;
   cout << "*p1 == " << *p1 << endl;
   cout << "*p2 == " << *p2 << endl;

   *p2 = 53;
   cout << "*p1 == " << *p1 << endl;
   cout << "*p2 == " << *p2 << endl;

   p1 = new int;
   *p1 = 88;
   cout << "*p1 == " << *p1 << endl;
   cout << "*p2 == " << *p2 << endl;
   cout << "Hope you got the point of this example!\n";

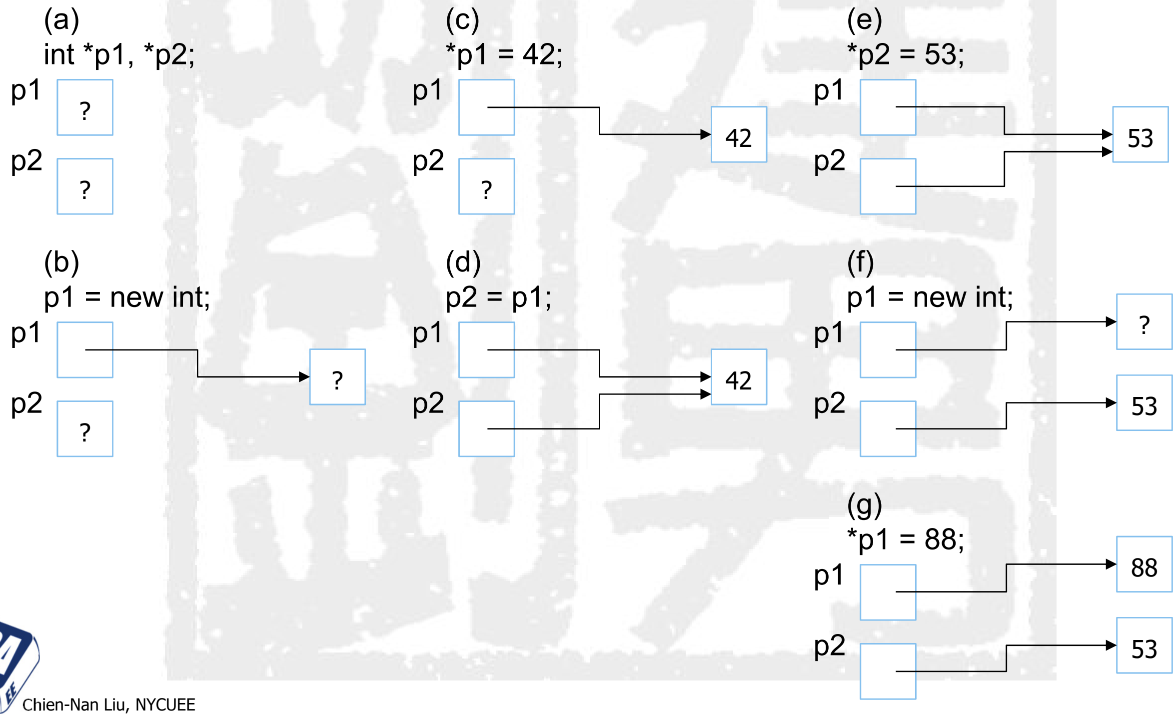
   return 0;
}
```

Sample Dialogue

```
*p1 == 42
*p2 == 42
*p1 == 53
*p2 == 53
*p1 == 88
*p2 == 53
Hope you got the point of this example!
```

Example: Pointer Manipulations (2/2)

Explanation of Display 9.2



Memory Management -- delete Operator

- An area of memory called the freestore or the heap is reserved for dynamic variables
  - New dynamic variables use memory in the freestore
  - If all of the freestore is used, calls to *new* will fail
- Unneeded memory can be recycled
  - When dynamic variables are no longer needed, they can be deleted to return the memory they occupied
  - Only dynamic memory obtained through *new* operator can be recycled !!
- The *delete* operator returns the used memory
  - Ex: delete p;
  - The value of p is now undefined and the memory that p pointed to is back in the freestore (may be used later)

Dangling Pointers

- Using *delete* on a pointer variable destroys the dynamic variable pointed to
  - That memory location doesn't belong to you anymore
- If another pointer variable was pointing to the dynamic variable, that variable is also undefined
- Undefined pointer variables are called dangling pointers
  - Dereferencing a dangling pointer (*p) is usually a disaster
  - That address may be used by other variable → illegal change
  - Such runtime error is difficult to be caught

Automatic Variable v.s. Dynamic Variable

- Variables declared in a function are destroyed when the function ends
  - The creation and destruction of these automatic variables is controlled automatically
- Variable declared outside any function definition are global variables
  - Global variables are available all the time
- The programmer should manually control the creation and destruction of dynamic variables
  - Unless you delete the variable, that memory space is occupied even though you leave the function already

Type Definitions

- A name can be assigned to a type definition, then used to declare variables
  - Keyword *typedef* is used to define new type names
  - Syntax:
    - typedef Known_Type_Definition New_Type_Name;
    - Known_Type_Definition can be any type
- To avoid confusing between pointer variable and typical variable, define a pointer type name
  - Example: typedef int* IntPtr;
    - Defines a new type, IntPtr, for pointer variables containing pointers to *int* variables
  - IntPtr p; is equivalent to int *p;

Confusing Pointer Declaration

- Type definition helps to prevent declaration error
  - int *P1, P2;   // Only P1 is a pointer variable
  - IntPtr P1, P2; // P1 and P2 are pointer variables
- A second advantage in using typedef to define a pointer type is seen in parameter lists
  - Example: void sampleFunction(IntPtr& pointerVar);

    is less confusing than

    void sampleFunction(int*& pointerVar);

Creating Dynamic Arrays

- Dynamic arrays are created using the new operator
  - Ex: create an array of 10 elements of type double

```
typedef double* DoublePtr;
DoublePtr d;
d = new double[10];
```

This could be an integer variable!

  - d can now be used as if it were an ordinary array!

Deleting Dynamic Arrays

- Pointer variable d is a pointer to a dynamic array
- When finished with the array, it should be deleted to return memory to the freestore
  - Syntax: delete [ ] d;
  - The brackets tell C++ a dynamic array is being deleted → need to know how many elements to remove
- Forgetting the brackets while deleting a dynamic array is not legal
  - It tells the computer to remove only one variable (first array element)

Example of a Dynamic Array

```
//Sorts a list of numbers entered at the keyboard.
#include <iostream>
#include <cstdlib>
#include <cstddef>

typedef int* IntArrayPtr;
void fill_array(int a[], int size);
void sort(int a[], int size);   // ascending order

int main( )
{
    using namespace std;
    cout << "This program sorts numbers
                    from lowest to highest.\n";

    int array_size;
    cout << "How many numbers will be sorted? ";
    cin >> array_size;

    IntArrayPtr a;
    a = new int[array_size];

    fill_array(a, array_size);
    sort(a, array_size);

    cout << "In sorted order the numbers are:\n";
    for (int index = 0; index < array_size; index++)
        cout << a[index] << " ";
    cout << endl;

    delete [] a;

    return 0;
}

void fill_array(int a[], int size)
{
    using namespace std;
    cout << "Enter " << size << " integers.\n";
    for (int index = 0; index < size; index++)
        cin >> a[index];
}

void sort(int a[], int size)
//Any implementation of sort may be used.
```


Dynamic Memory Allocation in C

- The functions to obtain and release memory during execution are put in library <stdlib.h>
- `malloc`
  - Takes number of bytes to allocate
    - Use *`sizeof`* to determine the size of an object
  - Returns pointer of type `void *`
    - A `void *` pointer may be assigned to any pointer
    - If no memory available, returns `NULL`
  - Example:

    ```
    newPtr = malloc( n*sizeof(int) ); //n-element array
    ```
- When using *malloc*, test the return value for the NULL pointer
  - Give an error message if the memory allocation is failed

The sizeof Operator

- The unary operator *sizeof* determines the total size of a variable in bytes at compilation time
  - Can also be applied on an array, a constant, or a data type name
  - When applied to the name of an array, the *sizeof* operator returns the memory size of total elements
- When applied to a pointer parameter, the *sizeof* operator returns the size of the pointer in bytes
  - If it cannot recognize the array, only a single pointer variable is counted
- The number of elements in an array also can be determined using two sizeof operations
  - sizeof realArray / sizeof(realArray[0])

Return Dynamic Memory in C

- `free`
  - Deallocates memory allocated by `malloc`
  - Takes a pointer as an argument
  - `free ( newPtr );`
- Freeing memory not allocated dynamically with `malloc` is an error
  - In C, manage memory by malloc ←→ free
  - In C++, manage memory by new ←→ delete
  - You cannot mix the two systems (ex: malloc + delete)
- Referring to memory that has been freed is a runtime error
  - You don't know whether the memory content is modified

Common Programming Error

- Not returning dynamically allocated memory when it is no longer needed can cause the system to run out of memory
  - This is sometimes called a "memory leak"

→ **When memory that was dynamically allocated is no longer needed, use `free` to return the memory to the system immediately**

Error-Prevention Tip

- After deleting dynamically allocated memory, set the pointer that referred to that memory to 0
  - This disconnects the pointer from the previously allocated space on the free store
- By setting the pointer to 0, the program loses any access to that free-store space
  - This space in memory could still contain information, despite having been deleted
- In fact, that space could have already been reallocated for a different purpose
  - If you didn't set the pointer to 0, your code could inadvertently access this new information
  - Cause extremely subtle, nonrepeatable logic errors

Outline

- 3.1 Pointers
- 3.2 Dynamic Memory Allocation
- *3.3 Pointer and Array*

Introduction to Arrays

- An array is used to process a collection of data of the same type
  - Examples: A list of names
A list of temperatures
- Why do we need arrays?
  - Imagine keeping track of 5 test scores, or 100, or 1000 in memory
    - How would you name all the variables?
    - How would you process each of the variables?

Declaring an Array

- An array, named score, containing five variables of type *int* can be declared as
  int score[5];
- This is like declaring 5 variables of type int:
  score[0], score[1], … , score[4]
- The value in brackets is called a subscript or an index
  - The index starts from 0, not 1 …
- The variables making up the array are referred to as
  - Indexed variables or elements of the array
- The number of indexed variables in an array is the size of the array
  - The largest index is one less than the size
  - The first index value is zero

Using [ ] With Arrays

- In an array declaration, [ ]'s enclose the size of the array
  - Ex: for an array of 5 integers → int score [5];
- When referring to one indexed variable, the [ ]'s enclose a number identifying the indexed variable
  - Ex: score[3] is one of the indexed variables
  - The value in the [ ]'s can be any expression that evaluates to one of the integers 0 to (size -1)
- To assign a value to an indexed variable, use the assignment operator:

```
int n = 2;
score[n + 1] = 99;
```

→ variable score[3] is assigned 99

Loops And Arrays

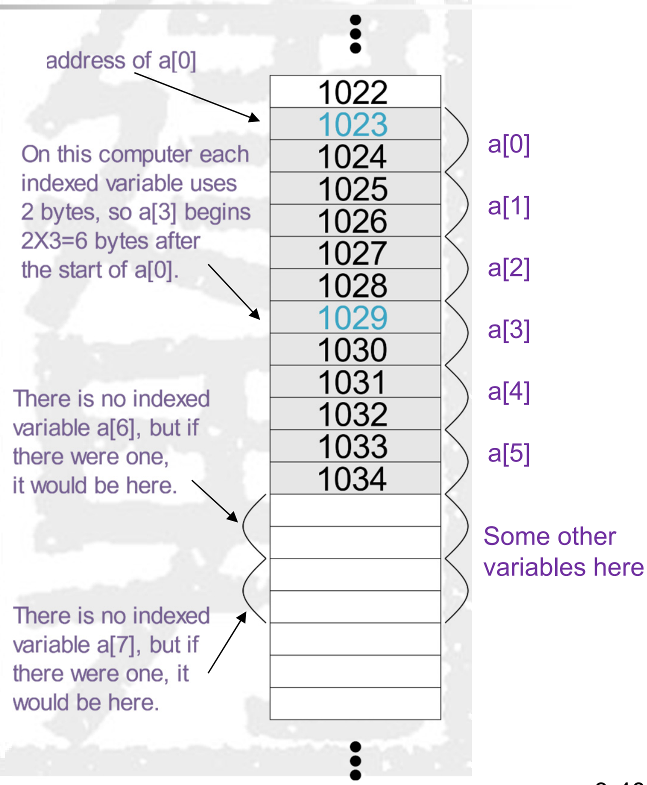
- for-loops are commonly used to step through arrays

  First index is 0 **Last index is (size – 1)**

  - Example:
    ```
    for (i = 0; i < 5; i++)
    {
        cout << score[i] << " off by "
         << (max – score[i]) << endl;
    }
    ```
    could display the difference between each score and the maximum score stored in an array
- Enumeration can help to think about the behavior
  - i = 0 → cout << score[0] << " off by " << max – score[0]
  - i = 1 → cout << score[1] << " off by " << max – score[1]
  - ……

Arrays and Memory

- Declaring the array int a[6]
  - Reserves memory for six variables of type *int*
  - The variables are stored one after another (consecutive locations)
  - Only the address of a[0] is remembered
  - To determine the address of a[3]
    - Start at a[0]
    - Count the memory for three integers
    - Past enough memory to find a[3]



Out of Range Problems

- A common error is using a nonexistent index
  - Index values for int a[6] are the values 0 through 5, not 1 to 6
  - An index value not allowed by the array declaration is out of range, ex: using a[7] ??
- Using an out of range index value does not produce an error message!!
  - However, this address could be where some other variable is stored
  - May cause some unpredictable errors!!

Array and Pointer Variables

- In C/C++, only the first element of an array is remembered
  - Actually, array variables are pointer variables that point to the first indexed variable (ex: a[0])
  - Example:

```
int  a[10];
typedef int* IntPtr;
IntPtr p;
```

    - Variables a and p are the same kind of variable
    - a is a pointer variable that points to a[0]
- p = a; causes p to point to the same location as a → point to a[0]
  - Using a and p has the same effects

Pointer Variables as Array Variables

- In previous example, pointer variable *p* can be used as if it were an array variable
  - Example: p[0], p[1], …p[9]
    are all legal ways to use *p*
- Variable *a* can also be used as a constant pointer variable
  - But the pointer value in *a* cannot be changed
  - This is not legal:

```
IntPtr p2;
…          // p2 is assigned a value
a = p2;  // attempt to change a
```


Example: Arrays and Pointers (1/2)

```
//Program to demonstrate that an array variable is a kind of pointer variable.
#include <iostream>
using namespace std;

typedef int* IntPtr;

int main( )
{
   IntPtr p;
   int a[10];
   int index;

   for (index = 0; index < 10; index++)
      a[index] = index;

   p = a;

   for (index = 0; index < 10; index++)
      cout << p[index] << " ";
   cout << endl;

   for (index = 0; index < 10; index++)
      p[index] = p[index] + 1;

   for (index = 0; index < 10; index++)
      cout << a[index] << " ";
   cout << endl;

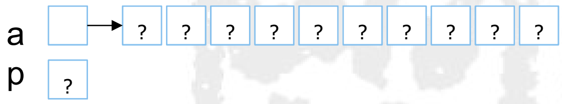
   return 0;
}
```

Output

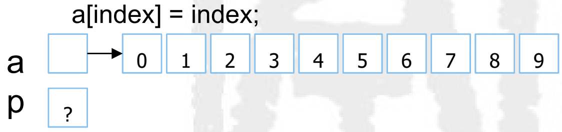
```
0 1 2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9 10
```

Example: Arrays and Pointers (2/2)

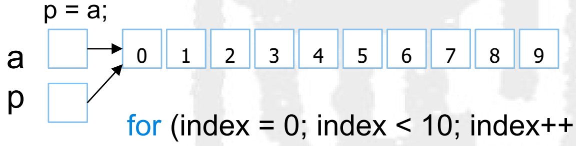
(a)
```
IntPtr p;
int a[10];
```



(b)
```
for (index = 0; index < 10; index++)
   a[index] = index;
```



(c)
```
p = a;
```

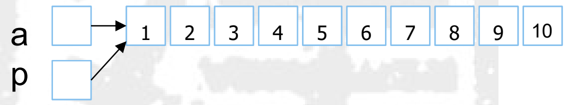



```
for (index = 0; index < 10; index++)
   cout << p[index] << " ";
```

Iterating through p is the same as iterating through a

Output 0 1 2 3 4 5 6 7 8 9

(d)
```
for (index = 0; index < 10; index++)
   p[index] = p[index] + 1;
```



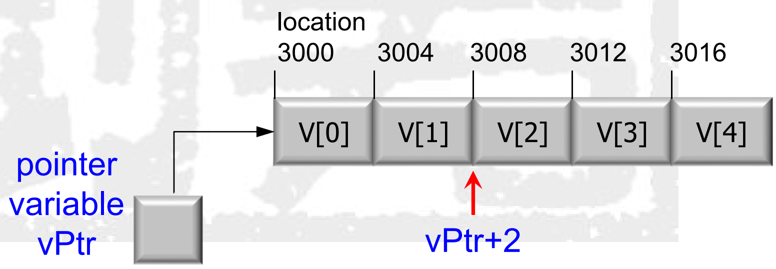

```
for (index = 0; index < 10; index++)
   cout << a[index] << " ";
```

Output 1 2 3 4 5 6 7 8 9 10

Iterating through a is the same as iterating through p

Pointer Arithmetic

- Arithmetic can be performed on the addresses contained in pointers
  - Given a dynamic array of integers, v, as shown below
  - If int *vptr = v, vptr points to v[0]
  - The expression vptr+2 evaluates to the address of v[2]
    - Adding one adds enough bytes for one element in the array
  - This is NOT the arithmetic on the memory address !!
    - If vPtr = 3000, vptr+2 = 3008, not 3002 …



Pointer Arithmetic Operations

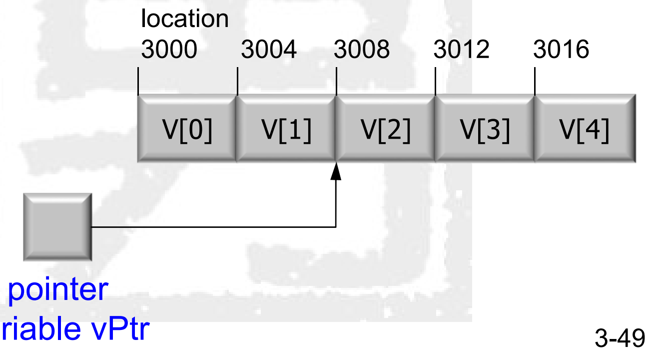
- You can add and subtract with pointers
  - The ++ and - - operators can be used
  - Two pointers of the same type can be subtracted to obtain the number of indexed variables between
    - The pointers should be in the same array!
    - Ex: If vPtr contains the address 3000 and v2Ptr contains the address 3008, v2Ptr – vPtr = 2 in previous example
- Pointers can be compared using equality and relational operators
  - Relational operators apply on the pointers in the same array
  - Using equality operators, the pointers can be compared with the addresses stored in pointers
    - Ex: compare with NULL pointer → it points to nothing !!

Relationship Between Pointers and Arrays

- The array name (without a subscript) is a **constant** pointer to the first element of the array.
  - This pointer cannot be modified as a normal variable
- Pointers can do operations involving array indexing
- Assume the following declarations:
  - int b[5]; // create 5-element int array b
    int *bPtr; // create int pointer bPtr
- We can set bPtr to the address of the first element in array b with the statement
  - bPtr = b; // assign address of array b to bPtr
- This is equivalent to
  - bPtr = &b[0]; // also assigns address of array b to bPtr

Relationship Between Pointers and Arrays

- Array element b[2] can alternatively be referenced with the pointer expression
  - *(bPtr + 2)
- The 2 in the preceding expression is the offset to the pointer
- This notation is referred to as pointer/offset notation.
  - The parentheses are necessary, because the precedence of * is higher than that of +



Relationship Between Pointers and Arrays

- The address &b[3] can be written with the pointer expression bPtr + 3
  - Array elements can also be referenced with pointers
- The array name (which is implicitly const) can be treated as a pointer and used in pointer arithmetic
- For example, the expression *(b + 3) also refers to the array element b[3]
- In general, all subscripted array expressions can be written with a pointer and an offset
  - For clarity, use array notation instead of pointer operation when manipulating arrays

Relationship Between Pointers and Arrays

- Pointers can be subscripted exactly as arrays can
- For example, the expression bPtr[1] refers to the array element b[1]; this expression uses pointer/ subscript notation
- In summary, four notations are discussed for referring to array elements:
  - Array subscript notation,
  - Pointer/offset notation with the array name as a pointer,
  - Pointer subscript notation, and
  - Pointer/offset notation with a pointer

Code: Using Array Names and Pointers

```
//Using subscripting and pointer notations with arrays.
#include <iostream>
using namespace std;

int main()
{
        int b[] = { 10, 20, 30, 40 }; //create 4-element array b
        int *bPtr = b; // set bPtr to point to array bPtr

        // output array b using array subscript notation
        cout << "Array b printed with:\n\nArray subscript notation\n";

        for( int i = 0; i < 4; i++)
                cout << "b[" << i << "]" << b[i] << "\n";

        //output array b using the array name and pointer/offset notation
        cout << "\nPointer/offset notation where "
                << "the pointer is the array name\n";

        for( int offset1 = 0; offset1 < 4; offset1++)
                cout << "*(b+ " << offset1 << ") = " << *( b + offset1) << "\n";
```

Code: Using Array Names and Pointers

```
    //output array b using bPtr and array subscript notation
    cout << "\nPointer subscript notation\n";

    for ( int j = 0; j < 4; j++)
        cout << "bPtr[" << j << "]" << bPtr[j] << "\n";

    cout << "\nPointer/offset notation\n";

    //output array b using bPtr and pointer/offset notation
    for ( int offset2 = 0; offset2 < 4; offset2++)
        cout << "*(bPtr+ " << offset2 << ") = "
            << *( bPtr + offset2) << "\n";
} // end main
```

```
Array b printed with:

Array subscript notation
b[0] = 10
b[1] = 20
b[2] = 30
b[3] = 40
```


Program Results

```
Pointer/offset notation where the pointer is the array name
*(b + 0) = 10
*(b + 1) = 20
*(b + 2) = 30
*(b + 3) = 40

Pointer subscript notation
bPtr[0] = 10
bPtr[1] = 20
bPtr[2] = 30
bPtr[3] = 40

Pointer/offset notation
*(bPtr + 0) = 10
*(bPtr + 1) = 20
*(bPtr + 2) = 30
*(bPtr + 3) = 40
```

Multi-Dimensional Arrays

- C++ allows arrays with multiple index values
  - char page [30] [100];
    declares an array of characters named page
    - This array has two index values:
      The first ranges from 0 to 29
      The second ranges from 0 to 99
  - Each index is enclosed in its own brackets
  - Page can be visualized as an array of 30 rows and 100 columns
- C++ supports two dimensions only
  - For more dimensions, use index transformation
  - Ex: 2D transformation
    - x, y: reference addr.
    - real index = y*4 + x

	x=0	x=1	x=2	x=3
y=0	0	1	2	3
y=1	4	5	6	7
y=2	8	9	10	11

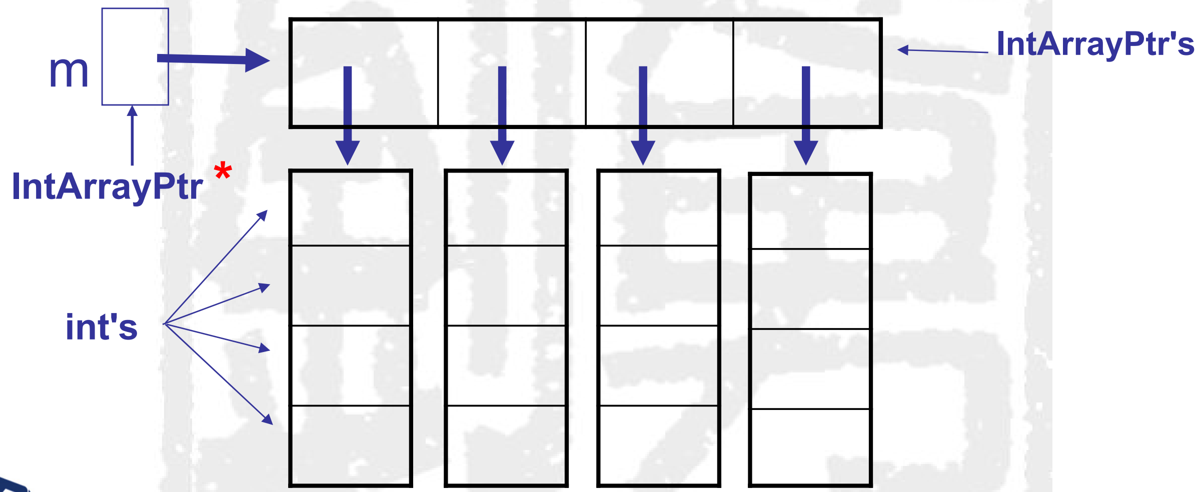
Multidimensional Dynamic Arrays

- Multidimensional arrays are arrays of arrays
  - In other words, they are actually arrays of pointers
- To create a 3x4 multidimensional dynamic array
  - First create a one-dimensional dynamic array
    - Start with a new definition:
      `typedef int* IntArrayPtr;`
    - Now create a dynamic array of pointers named m:
      `IntArrayPtr *m = new IntArrayPtr[3];`
  - For each pointer in m, create a dynamic array of int's
    - ```
      for (int i = 0; i<3; i++)
          m[i] = new int[4];
      ```

return a pointer to the dynamic array
      ```

A Multidimensional Dynamic Array

- The dynamic array created on the previous slide could be visualized like this:



Deleting Multidimensional Arrays

- To delete a multidimensional dynamic array
  - Each call to new that created an array must have a corresponding call to delete[ ]
  - Example: To delete the dynamic array created on a previous slide:

```
for ( i = 0; i < 3; i++)
        delete [ ] m[i]; //delete the arrays of 4 int’s
delete [ ] m; // delete the array of IntArrayPtr's
```

Example of 2-D Dynamic Array

```
#include <iostream>
using namespace std;
typedef int* IntArrayPtr;

int main( )
{
    int d1, d2;
    cout << "Enter the row and column
              dimensions of the array:\n";
    cin >> d1 >> d2;

    IntArrayPtr *m = new IntArrayPtr[d1];
    int i, j;
    for (i = 0; i < d1; i++)
        m[i] = new int[d2];
    //m is now a d1 by d2 array.

    cout << "Enter " << d1 << " rows of "
         << d2 << " integers each:\n";

    for (i = 0; i < d1; i++)
        for (j = 0; j < d2; j++)
            cin >> m[i][j];

    cout << "Echoing the two-dimensional array:\n";
    for (i = 0; i < d1; i++)
    {
        for (j = 0; j < d2; j++)
            cout << m[i][j] << " ";
        cout << endl;
    }
    for (i = 0; i < d1; i++)
        delete[] m[i];
    delete[] m;

    return 0;
}
```

Sample Dialogue

```
Enter the row and column dimensions of the array:
3 4
Enter 3 rows of 4 integers each:
1 2 3 4
5 6 7 8
9 0 1 2
Echoing the two-dimensional array:
1 2 3 4
5 6 7 8
9 0 1 2
```


Demo Dynamic Array of Strings in C

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
typedef char* StringPtr;

int main( void )
{
    int i, d1, d2, idx;
    char temp[80];
    printf("Enter the number of strings: ");
    scanf("%d", &d1);

    StringPtr *m = malloc(d1 * sizeof(StringPtr));
    for (i = 0; i < d1; i++)
    {
        printf("Enter string %d: ", i+1);
        scanf("%s", temp);
        d2 = strlen(temp);
        m[i] = malloc( (d2+1) * sizeof(char));
        strcpy(m[i], temp);
    }
    //m is now an array with d1 strings.

    printf("\nRandomly show 10 strings:\n");
    for (i = 0; i < 10; i++)
    {
        idx = rand()%d1;
        printf("%s\n", m[idx]);
    }
    for (i = 0; i < d1; i++)
        free( m[i] );
    free(m);

    return 0;
}
```

```
Enter the number of strings: 3
Enter string 1: test1
Enter string 2: test2
Enter string 3: test3

Randomly show 10 strings:
test2
test3
......
```