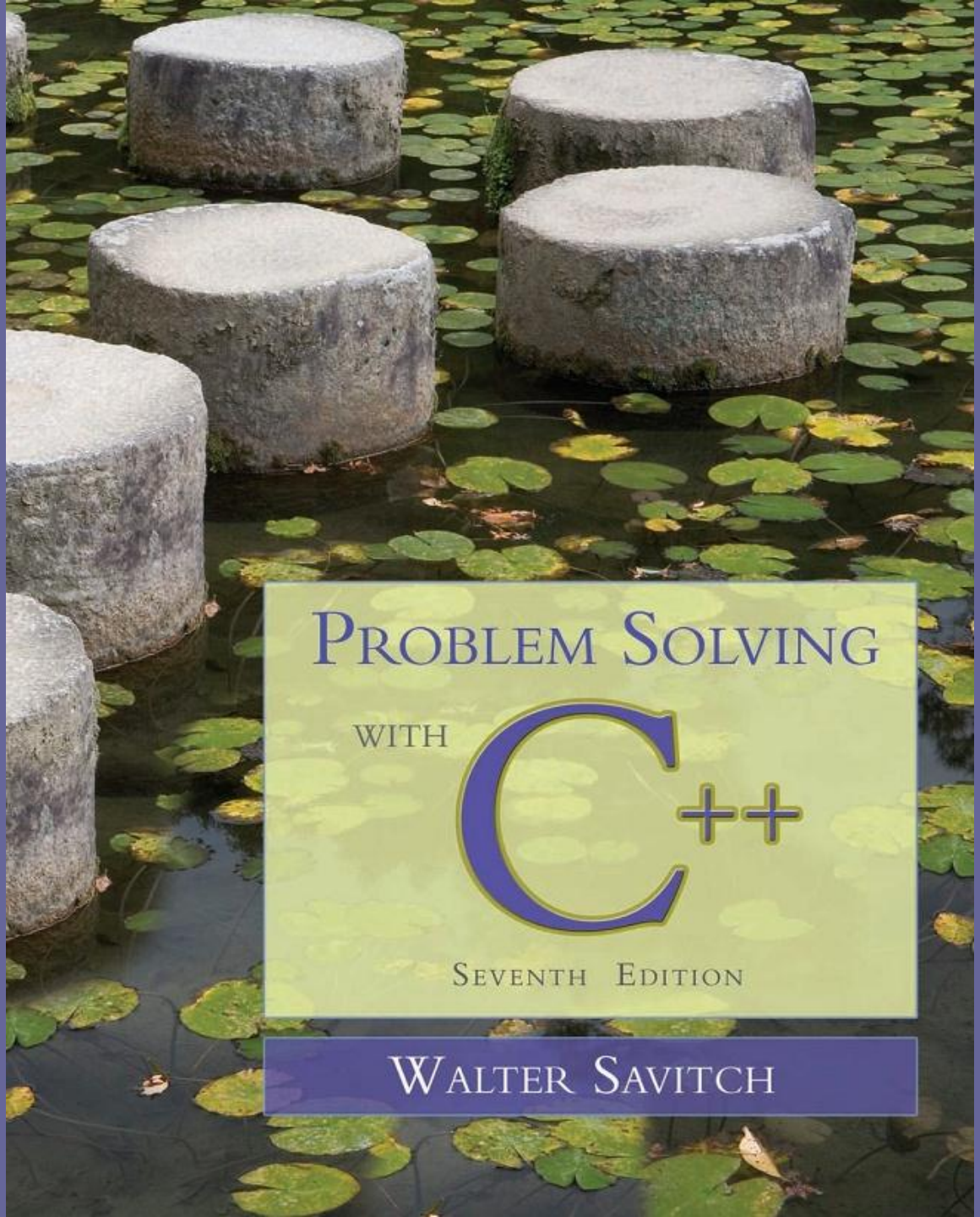
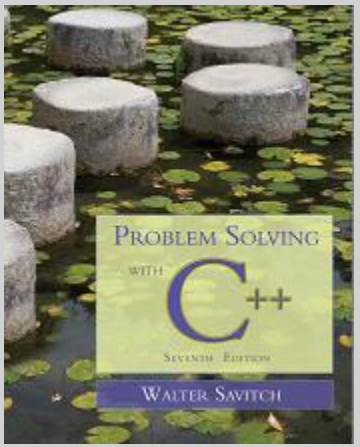

PROBLEM SOLVING
WITH
C++
SEVENTH EDITION
WALTER SAVITCH

Chapter 9

Pointers and Dynamic Arrays



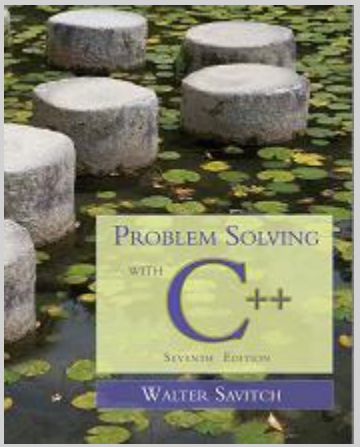
Overview

9.1 Pointers

9.2 Dynamic Arrays

9.1

Pointers



Pointers

- A pointer is the memory address of a variable
- Memory addresses can be used as names for variables
  - If a variable is stored in three memory locations, the address of the first can be used as a name for the variable.
  - When a variable is used as a call-by-reference argument, its address is passed

Pointers Tell Where To Find A Variable

- An address used to tell where a variable is stored in memory is a pointer
  - Pointers "point" to a variable by telling where the variable is located

Declaring Pointers

- Pointer variables must be declared to have a pointer type
  - Example: To declare a pointer variable p that can "point" to a variable of type double:

```
double  *p;
```

  - The asterisk identifies p as a pointer variable

Multiple Pointer Declarations

- To declare multiple pointers in a statement, use the asterisk before each pointer variable
  - Example:

```
int *p1, *p2, v1, v2;
```

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

The address of Operator

- The & operator can be used to determine the address of a variable which can be assigned to a pointer variable
  - Example: p1 = &v1;

    p1 is now a pointer to v1
    v1 can be called v1 or "the variable pointed to by p1"

The Dereferencing Operator

- C++ uses the * operator in yet another way with pointers
  - The phrase "The variable pointed to by p" is translated into C++ as *p
  - Here the * is the dereferencing operator
    - p is said to be dereferenced

A Pointer Example

```
v1 = 0;
p1 = &v1;
*p1 = 42;
cout << v1 << endl;
cout << *p1 << endl;
```

v1 and *p1 now refer to the same variable

output:

```
42
42
```

Pointer Assignment

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

```
p2 = p1;
```

causes *p2, *p1, and v1 all to name the same variable

Caution! Pointer Assignments

- 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

Display 9.1

The new Operator

- Using pointers, variables can be manipulated even if there is no identifier for them
  - To create a pointer to a new "nameless" variable of type int:

```
p1 = new int;
```

  - The new variable is referred to as *p1
  - *p1 can be used anyplace an integer variable can

```
cin >> *p1;
*p1 = *p1 + 7;
```

Dynamic Variables

- Variables created using the new operator are called dynamic variables
  - Dynamic variables are created and destroyed while the program is running
  - Additional examples of pointers and dynamic variables are shown in **Display 9.2**

    An illustration of the code in Display 9.2 is seen in **Display 9.3**

new and Class Types

- Using operator new with class types calls a constructor as well as allocating memory
  - If MyType is a class type, then

```
MyType *myPtr; // creates a pointer to a
                        // variable of type MyType
myPtr = new MyType;
                // calls the default constructor

myPtr  = new MyType (32.0, 17);
                 // calls  Mytype(double, int);
```

Basic Memory Management

- An area of memory called the freestore 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 variables are no longer needed, they can be deleted and the memory they used is returned to the freestore

The delete Operator

- When dynamic variables are no longer needed, delete them to return memory to the freestore
  - Example:

```
delete p;
```

The value of p is now undefined and the memory used by the variable that p pointed to is back in the freestore

Dangling Pointers

- Using delete on a pointer variable destroys the dynamic variable pointed to
- 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 disasterous

Automatic Variables

- Variables declared in a function are created by C++ and destroyed when the function ends
  - These are called automatic variables because their creation and destruction is controlled automatically
- The programmer manually controls creation and destruction of pointer variables with operators new and delete

Global Variables

- Variables declared outside any function definition are global variables
  - Global variables are available to all parts of a program
  - Global variables are not generally used

Type Definitions

- A name can be assigned to a type definition, then used to declare variables
- The keyword typedef is used to define new type names
  - Syntax:

    typedef Known_Type_Definition New_Type_Name;

    - Known_Type_Definition can be any type

Defining Pointer Types

- To avoid mistakes using pointers, 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;

Multiple Declarations Again

- Using our new pointer type defined as

  typedef int* IntPtr;

  - Prevent this error in pointer declaration:

    int *P1, P2; // Only P1 is a pointer variable

- with

  IntPtr P1, P2; // P1 and P2 are pointer
  // variables

Pointer Reference Parameters

- A second advantage in using typedef to define a pointer type is seen in parameter lists
  - Example: void sample_function(IntPtr& pointer_var);

    is less confusing than

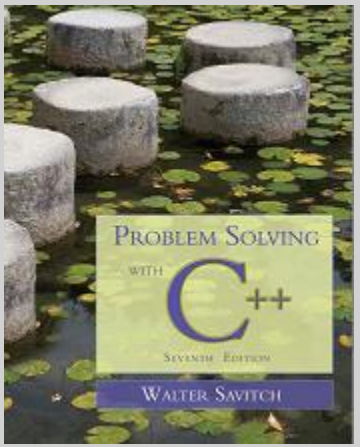
    void sample_function(int*& pointer_var);

Section 9.1 Conclusion

- Can you
  - Declare a pointer variable?
  - Assign a value to a pointer variable?
  - Use the new operator to create a new variable in the freestore?
  - Write a definition for a type called NumberPtr to be a type for pointers to dynamic variables of type int?
  - Use the NumberPtr type to declare a pointer variable called my_point?

9.2

Dynamic Arrays



Dynamic Arrays

- A dynamic array is an array whose size is determined when the program is running, not when you write the program

Pointer Variables and Array Variables

- Array variables are actually pointer variables that point to the first indexed variable
  - Example:

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

    - Variables a and p are the same kind of variable
- Since a is a pointer variable that points to a[0],

```
p = a;
```

causes p to point to the same location as a

Pointer Variables As Array Variables

- Continuing the previous example: Pointer variable p can be used as if it were an array variable

Display 9.4

- Example: p[0], p[1], …p[9] are all legal ways to use p
- Variable a can be used as a pointer variable except 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
```

Creating Dynamic Arrays

- Normal arrays require that the programmer determine the size of the array when the program is written
  - What if the programmer estimates too large?
    - Memory is wasted
  - What if the programmer estimates too small?
    - The program may not work in some situations
- Dynamic arrays can be created with just the right size while the program is running

Creating Dynamic Arrays

- Dynamic arrays are created using the new operator
  - Example: To 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!

Dynamic Arrays (cont.)

- Pointer variable d is a pointer to d[0]
- When finished with the array, it should be deleted to return memory to the freestore
  - Example: delete [ ] d;
    - The brackets tell C++ a dynamic array is being deleted so it must check the size to know how many indexed variables to remove
    - Forgetting the brackets, is not legal, but would tell the computer to remove only one variable

Display 9.5 (1)

Display 9.5 (2)

Pointer Arithmetic (Optional)

- Arithmetic can be performed on the addresses contained in pointers
  - Using the dynamic array of doubles, d, declared previously, recall that d points to d[0]
  - The expression d+1 evaluates to the address of d[1] and d+2 evaluates to the address of d[2]
    - Notice that adding one adds enough bytes for one variable of the type stored in the array

Pointer Arthmetic 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!
  - This code shows one way to use pointer arithmetic:

```
for (int i = 0; i < array_size; i++)
   cout << *(d + i) << "  " ;
   // same as cout << d[i] << "  " ;
```

Multidimensional Dynamic Arrays

- To create a 3x4 multidimensional dynamic array
  - View multidimensional arrays as arrays of arrays
  - First create a one-dimensional dynamic array
    - Start with a new definition:

      ```
      typedef int* IntArrayPtr;
      ```

    - Now create a dynamic array of pointers named m:

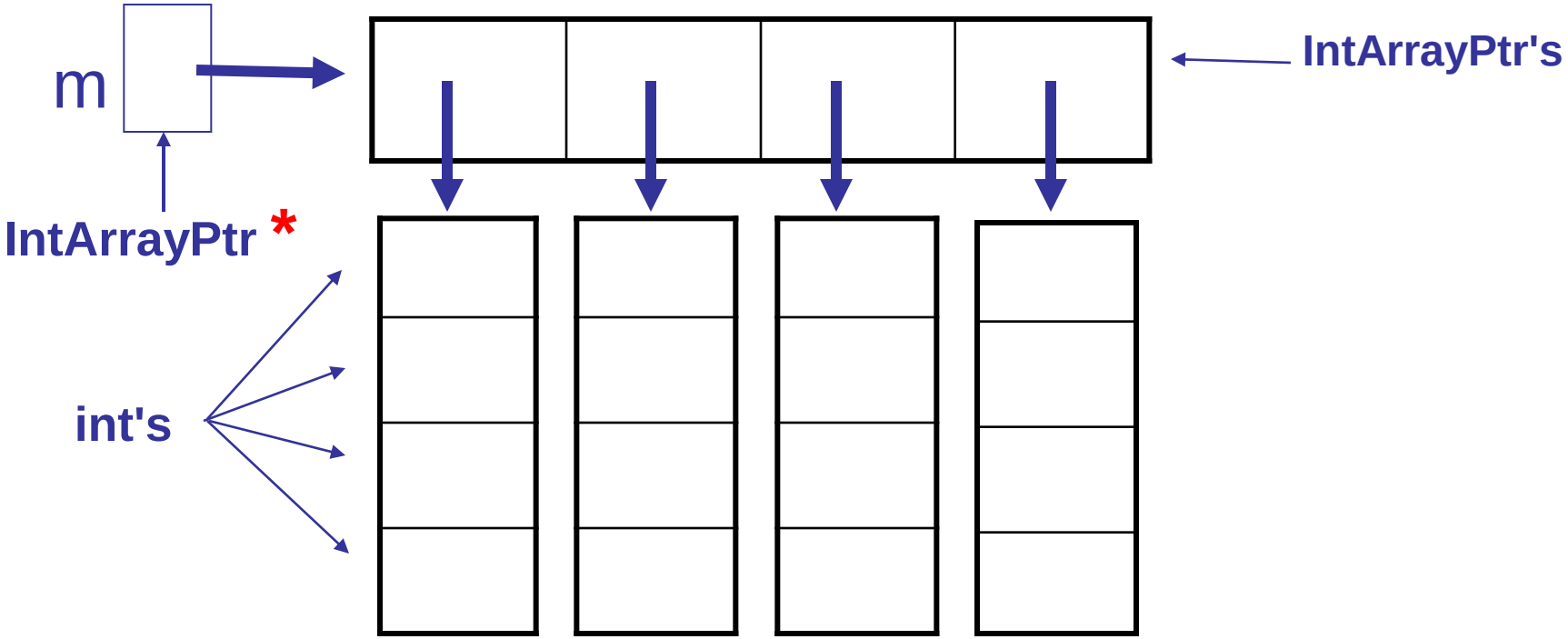
      ```
      IntArrayPtr *m = new IntArrayPtr[3];
      ```

  - For each pointer in m, create a dynamic array of int's
    -

      ```
      for (int i = 0; i<3; i++)
          m[i] = new int[4];
      ```

A Multidimensial 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
```

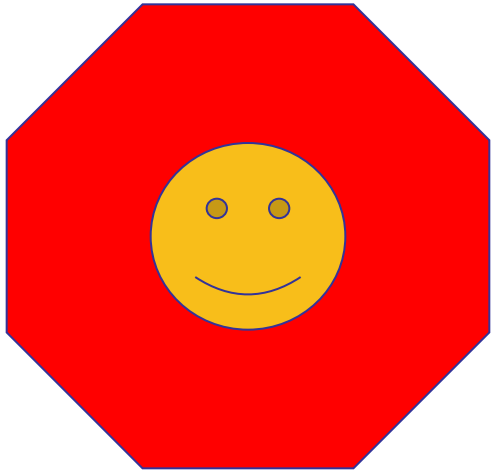
Display 9.6 (1) **Display 9.6 (2)**

Section 9.2 Conclusion

- Can you
  - Write a definition for pointer variables that will be used to point to dynamic arrays? The array elements are of type char. Call the type CharArray.
  - Write code to fill array "entry" with 10 numbers typed at the keyboard?

```
int * entry;
entry = new int[10];
```

Chapter 9 -- End



Display 9.1

Uses of the Assignment Operator

```
p1 = p2;
```


```
*p1 = *p2;
```

Display 9.2

Back Next

Basic Pointer Manipulations

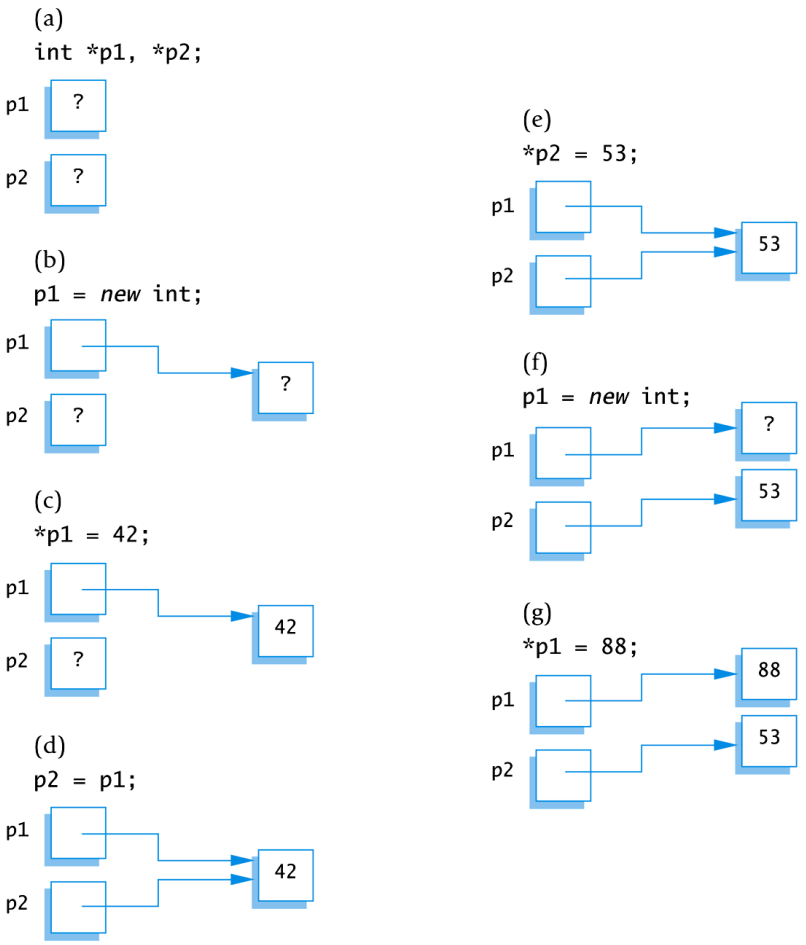
```
//Program to demonstrate pointers and dynamic variables.
#include <iostream>
using namespace std;

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!
```

Display 9.3

DISPLAY 9.3 Explanation of Display 9.2



```
//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;
}
```

Note that changes to the array p *are also changes to the array* a.

Output

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

Display 9.5 (1/2)

DISPLAY 9.5 **A Dynamic Array** *(part 1 of 2)*

```
1  //Sorts a list of numbers entered at the keyboard.
2  #include <iostream>
3  #include <cstdlib>
4  #include <cstddef>
5
6  typedef int* IntArrayPtr;
7
8  void fill_array(int a[], int size);
9  //Precondition: size is the size of the array a.
10 //Postcondition: a[0] through a[size-1] have been
11 //filled with values read from the keyboard.
12
13 void sort(int a[], int size);
14 //Precondition: size is the size of the array a.
15 //The array elements a[0] through a[size-1] have values.
16 //Postcondition: The values of a[0] through a[size-1] have been rearranged
17 //so that a[0] <= a[1] <= ... <= a[size-1].
18
19 int main( )
20 {
21     using namespace std;
22     cout << "This program sorts numbers from lowest to highest.\n";
23
24     int array_size;
25     cout << "How many numbers will be sorted? ";
26     cin >> array_size;
27
28     IntArrayPtr a;
29     a = new int[array_size];
30
31     fill_array(a, array_size);
32     sort(a, array_size);
33
34     cout << "In sorted order the numbers are:\n";
35     for (int index = 0; index < array_size; index++)
36         cout << a[index] << " ";
37     cout << endl;
38
39     delete [] a;
40
41     return 0;
42 }
43
```

Ordinary array parameters

The dynamic array a *is used like an ordinary array.*

(continued)

Display 9.5 (2/2)

DISPLAY 9.5 A Dynamic Array *(part 2 of 2)*

```
44   //Uses the library iostream:
45   void fill_array(int a[], int size)
46   {
47        using namespace std;
48       cout << "Enter " << size << " integers.\n";
49       for (int index = 0; index < size; index++)
50           cin >> a[index];
51   }
52
53   void sort(int a[], int size)
```

<Any implementation of `sort` may be used. This may or may not require some additional function definitions. The implementation need not even know that `sort` will be called with a dynamic array. For example, you can use the implementation in Display 7.12 (with suitable adjustments to parameter names).>

Display 9.6 (1/2)

A Two-Dimensional Dynamic Array (*part 1 of 2*)

```
#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;
    }
```

Display 9.6 (2/2)

A Two-Dimensional Dynamic Array (*part 2 of 2*)

```
    for (i = 0; i < d1; i++)
        delete[] m[i];
    delete[] m;

    return 0;
}
```

Note that there must be one call to `delete []` for each call to `new` that created an array. (These calls to `delete []` are not really needed since the program is ending, but in another context it could be important to include them.)

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
```