Chapter 5

Arrays

Learning Objectives

- Introduction to Arrays
  - Declaring and referencing arrays
  - For-loops and arrays
  - Arrays in memory
- Arrays in Functions
  - Arrays as function arguments, return values
- Programming with Arrays
  - Partially Filled Arrays, searching, sorting
- Multidimensional Arrays

Introduction to Arrays

- Array definition:
  - A collection of data of same type
- First "aggregate" data type
  - Means "grouping"
  - int, float, double, char are simple data types
- Used for lists of like items
  - Test scores, temperatures, names, etc.
  - Avoids declaring multiple simple variables
  - Can manipulate "list" as one entity

Declaring Arrays

- Declare the array → allocates memory
  int score[5];
  - Declares array of 5 integers named "score"
  - Similar to declaring five variables:
    int score[0], score[1], score[2], score[3], score[4]
- Individual parts called many things:
  - Indexed or subscripted variables
  - "Elements" of the array
  - Value in brackets called index or subscript
    - Numbered from 0 to size - 1

Accessing Arrays

- Access using index/subscript
  - cout << score[3];
- Note two uses of brackets:
  - In declaration, specifies SIZE of array
  - Anywhere else, specifies a subscript
- Size, subscript need not be literal
  - int score[MAX_SCORES];
  - score[n+1] = 99;
    - If n is 2, identical to: score[3]

Array Usage

- Powerful storage mechanism
- Can issue command like:
  - "Do this to i^{th} indexed variable"
    where i is computed by program
  - "Display all elements of array score"
  - "Fill elements of array score from user input"
  - "Find highest value in array score"
  - "Find lowest value in array score"

Array Program Example:
Display 5.1 Program Using an Array (1 of 2)

Display 5.1 Program Using an Array

```
1  //Reads in five scores and shows how much each
2  //score differs from the highest score.
3  #include <iostream>
4  using namespace std;
5  int main( )
6  {
7      int i, score[5], max;
8      cout << "Enter 5 scores:\n";
9      cin >> score[0];
10     max = score[0];
11     for (i = 1; i < 5; i++)
12     {
13         cin >> score[i];
14         if (score[i] > max)
15             max = score[i];
16         //max is the largest of the values score[0],..., score[i].
17     }
```

Array Program Example:
Display 5.1 Program Using an Array (2 of 2)

```
18        cout << "The highest score is " << max << endl
19             << "The scores and their\n"
20             << "differences from the highest are:\n";
21        for (i = 0; i < 5; i++)
22            cout << score[i] << " off by "
23                 << (max - score[i]) << endl;
24        return 0;
25    }
```

SAMPLE DIALOGUE

Enter 5 scores:
5 9 2 10 6
The highest score is 10
The scores and their
differences from the highest are:
5 off by 5
9 off by 1
2 off by 8
10 off by 0
6 off by 4

for-loops with Arrays

- Natural counting loop
  - Naturally works well "counting through" elements of an array
- Example:

```
for (idx = 0; idx<5; idx++)
{
      cout << score[idx] << "off by "
                  << max – score[idx] << endl;
}
```

  - Loop control variable (idx) counts from 0 – 5

Major Array Pitfall

- Array indexes always start with zero!
- Zero is "first" number to computer scientists
- C++ will "let" you go beyond range
  - Unpredictable results
  - Compiler will not detect these errors!
- Up to programmer to "stay in range"

Major Array Pitfall Example

- Indexes range from 0 to (array_size – 1)
  - Example:
    double temperature[24]; // 24 is array size
    // Declares array of 24 double values called temperature
    - They are indexed as:
      temperature[0], temperature[1] … temperature[23]
  - Common mistake:
    temperature[24] = 5;
    - Index 24 is "out of range"!
    - No warning, possibly disastrous results

Defined Constant as Array Size

- Always use defined/named constant for array size
- Example:
  const int NUMBER_OF_STUDENTS = 5;
  int score[NUMBER_OF_STUDENTS];
- Improves readability
- Improves versatility
- Improves maintainability

Uses of Defined Constant

- Use everywhere size of array is needed
  - In for-loop for traversal:

```
for (idx = 0; idx < NUMBER_OF_STUDENTS; idx++)
{
    // Manipulate array
}
```

  - In calculations involving size:
    lastIndex = (NUMBER_OF_STUDENTS – 1);
  - When passing array to functions (later)
- If size changes → requires only ONE change in program!

Ranged-Based For Loop

- The C++11 ranged-based for loop makes it easy to iterate over each element in a loop
- Format

```
for (datatype varname : array)
{
     //  varname is set to each successive
     //  element in the array
}
```

- Example

```
int arr[] = {20, 30, 40, 50};
for (int x : arr)
   cout << x << " ";
cout << endl;
```

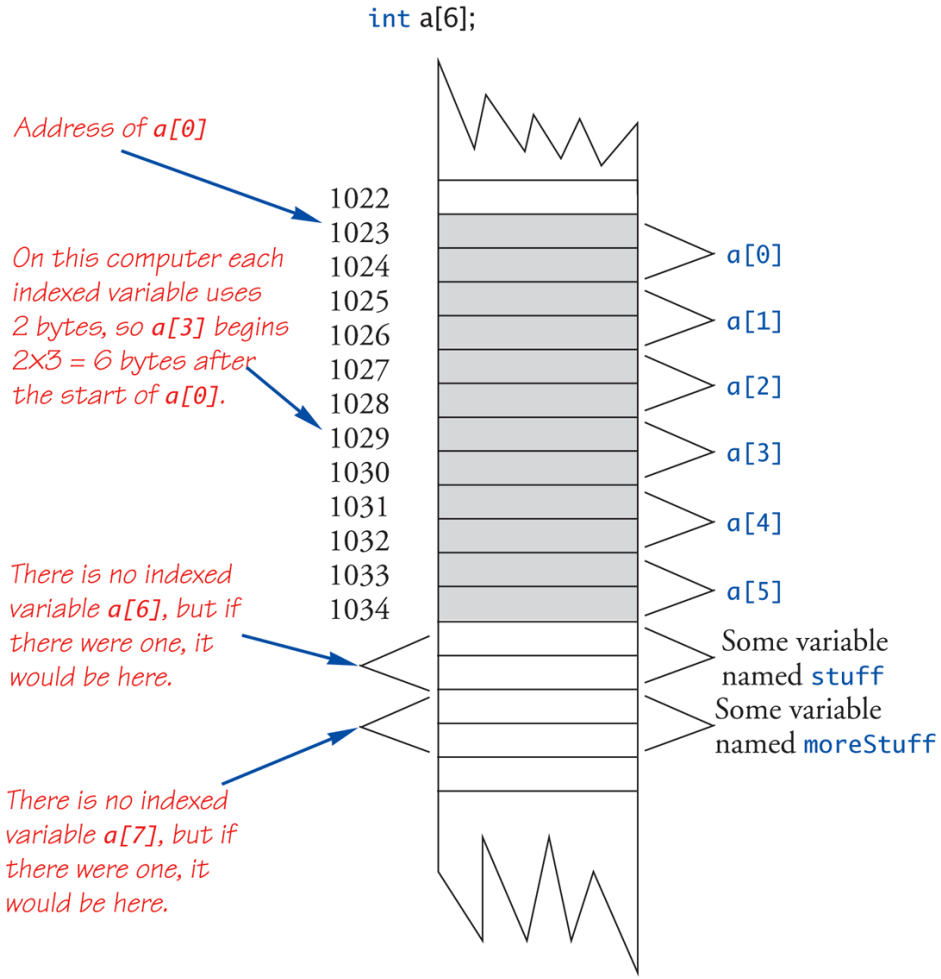
Output: 20 30 40 50

Arrays in Memory

- Recall simple variables:
  - Allocated memory in an "address"
- Array declarations allocate memory for entire array
- Sequentially-allocated
  - Means addresses allocated "back-to-back"
  - Allows indexing calculations
    - Simple "addition" from array beginning (index 0)

An Array in Memory

Display 5.2 An Array in Memory



Initializing Arrays

- As simple variables can be initialized at declaration:
  int price = 0; // 0 is initial value
- Arrays can as well:
  int children[3] = {2, 12, 1};
  - Equivalent to following:
    int children[3];
    children[0] = 2;
    children[1] = 12;
    children[2] = 1;

Auto-Initializing Arrays

- If fewer values than size supplied:
  - Fills from beginning
  - Fills "rest" with zero of array base type
- If array-size is left out
  - Declares array with size required based on number of initialization values
  - Example:
    int b[] = {5, 12, 11};
    - Allocates array b to size 3

Arrays in Functions

- As arguments to functions
  - Indexed variables
    - An individual "element" of an array can be function parameter
  - Entire arrays
    - All array elements can be passed as "one entity"
- As return value from function
  - Can be done → chapter 10

Indexed Variables as Arguments

- Indexed variable handled same as simple variable of array base type
- Given this function declaration:
  void myFunction(double par1);
- And these declarations:
  int i; double n, a[10];
- Can make these function calls:
  myFunction(i); // i is converted to double
  myFunction(a[3]); // a[3] is double
  myFunction(n); // n is double

Subtlety of Indexing

- Consider:
  myFunction(a[i]);
  - Value of i is determined first
    - It determines which indexed variable is sent
  - myFunction(a[i*5]);
  - Perfectly legal, from compiler's view
  - Programmer responsible for staying "in-bounds" of array

Entire Arrays as Arguments

- Formal parameter can be entire array
  - Argument then passed in function call is array name
  - Called "array parameter"
- Send size of array as well
  - Typically done as second parameter
  - Simple int type formal parameter

Entire Array as Argument Example: **Display 5.3** Function with an Array Parameter

Display 5.3 Function with an Array Parameter

SAMPLE DIALOGUEFUNCTION DECLARATION

```
void fillUp(int a[], int size);
//Precondition: size is the declared size of the array a.
//The user will type in size integers.
//Postcondition: The array a is filled with size integers
//from the keyboard.
```

SAMPLE DIALOGUEFUNCTION DEFINITION

```
void fillUp(int a[], int size)
{
    cout << "Enter " << size << " numbers:\n";
    for (int i = 0; i < size; i++)
        cin >> a[i];
    cout << "The last array index used is " << (size - 1) << endl;
}
```

Entire Array as Argument Example

- Given previous example:
- In some main() function definition, consider this calls:

```
int score[5], numberOfScores = 5;
fillup(score, numberOfScores);
```

  - 1st argument is entire array
  - 2nd argument is integer value
- Note no brackets in array argument!

Array as Argument: How?

- What's really passed?
- Think of array as 3 "pieces"
  - Address of first indexed variable (arrName[0])
  - Array base type
  - Size of array
- Only 1st piece is passed!
  - Just the beginning address of array
  - Very similar to "pass-by-reference"

Array Parameters

- May seem strange
  - No brackets in array argument
  - Must send size separately
- One nice property:
  - Can use SAME function to fill any size array!
  - Exemplifies "re-use" properties of functions
  - Example:
    int score[5], time[10];
    fillUp(score, 5);
    fillUp(time, 10);

The const Parameter Modifier

- Recall: array parameter actually passes address of 1st element
  - Similar to pass-by-reference
- Function can then modify array!
  - Often desirable, sometimes not!
- Protect array contents from modification
  - Use "const" modifier before array parameter
    - Called "constant array parameter"
    - Tells compiler to "not allow" modifications

Functions that Return an Array

- Functions cannot return arrays same way simple types are returned
- Requires use of a "pointer"
- Will be discussed in chapter 10…

Programming with Arrays

- Plenty of uses
  - Partially-filled arrays
    - Must be declared some "max size"
  - Sorting
  - Searching

Partially-filled Arrays

- Difficult to know exact array size needed
- Must declare to be largest possible size
  - Must then keep "track" of valid data in array
  - Additional "tracking" variable needed
    - int numberUsed;
    - Tracks current number of elements in array

Partially-filled Arrays Example: **Display 5.5** Partially Filled Array (1 of 5)

Display 5.5 Partially Filled Array

```
1   //Shows the difference between each of a list of golf scores and their average.
2   #include <iostream>
3   using namespace std;
4   const int MAX_NUMBER_SCORES = 10;

5   void fillArray(int a[], int size, int& numberUsed);
6   //Precondition: size is the declared size of the array a.
7   //Postcondition: numberUsed is the number of values stored in a.
8   //a[0] through a[numberUsed-1] have been filled with
9   //nonnegative integers read from the keyboard.

10  double computeAverage(const int a[], int numberUsed);
11  //Precondition: a[0] through a[numberUsed-1] have values; numberUsed > 0.
12  //Returns the average of numbers a[0] through a[numberUsed-1].

13  void showDifference(const int a[], int numberUsed);
14  //Precondition: The first numberUsed indexed variables of a have values.
15  //Postcondition: Gives screen output showing how much each of the first
16  //numberUsed elements of the array a differs from their average.
```

(continued)

Partially-filled Arrays Example: **Display 5.5** Partially Filled Array (2 of 5)

Display 5.5 Partially Filled Array

```
17   int main( )
18   {
19       int score[MAX_NUMBER_SCORES], numberUsed;

20       cout << "This program reads golf scores and shows\n"
21            << "how much each differs from the average.\n";

22       cout << "Enter golf scores:\n";
23      fillArray(score, MAX_NUMBER_SCORES, numberUsed);
24       showDifference(score, numberUsed);

25       return 0;
26   }
```

Partially-filled Arrays Example:
Display 5.5 Partially Filled Array (3 of 5)

```
27  void fillArray(int a[], int size, int& numberUsed)
28  {
29      cout << "Enter up to " << size << " nonnegative whole numbers.\n"
30           << "Mark the end of the list with a negative number.\n";
31      int next, index = 0;
32      cin >> next;
33      while ((next >= 0) && (index < size))
34      {
35          a[index] = next;
36          index++;
37          cin >> next;
38      }
39      numberUsed = index;
40  }
```

Partially-filled Arrays Example: **Display 5.5** Partially Filled Array (4 of 5)

```
41  double computeAverage(const int a[], int numberUsed)
42  {
43      double total = 0;
44      for (int index = 0; index < numberUsed; index++)
45          total = total + a[index];
46      if (numberUsed > 0)
47      {
48          return (total/numberUsed);
49      }
50      else
51      {
52          cout << "ERROR: number of elements is 0 in computeAverage.\n"
53               << "computeAverage returns 0.\n";
54          return 0;
55      }
56  }
```

Partially-filled Arrays Example: **Display 5.5** Partially Filled Array (5 of 5)

Display 5.5 Partially Filled Array

```
57  void showDifference(const int a[], int numberUsed)
58  {
59      double average = computeAverage(a, numberUsed);
60      cout << "Average of the " << numberUsed
61           << " scores = " << average << endl
62           << "The scores are:\n";
63      for (int index = 0; index < numberUsed; index++)
64      cout << a[index] << " differs from average by "
65           << (a[index] - average) << endl;
66  }
```

SAMPLE DIALOGUE

```
This program reads golf scores and shows
how much each differs from the average.
Enter golf scores:
Enter up to 10 nonnegative whole numbers.
Mark the end of the list with a negative number.
69 74 68 -1
Average of the 3 scores = 70.3333
The scores are:
69 differs from average by -1.33333
74 differs from average by 3.66667
68 differs from average by -2.33333
```

Global Constants vs. Parameters

- Constants typically made "global"
  - Declared above main()
- Functions then have scope to array size constant
  - No need to send as parameter then?
    - Technically yes
  - Why should we anyway?
    - Function definition might be in separate file
    - Function might be used by other programs!

Searching an Array

- Very typical use of arrays
- Display 5.6 next slide

Display 5.6
Searching an Array (1 of 4)

Display 5.6 Searching an Array

```
1  //Searches a partially filled array of nonnegative integers.
2  #include <iostream>
3  using namespace std;
4  const int DECLARED_SIZE = 20;

5  void fillArray(int a[], int size, int& numberUsed);
6  //Precondition: size is the declared size of the array a.
7  //Postcondition: numberUsed is the number of values stored in a.
8  //a[0] through a[numberUsed-1] have been filled with
9  //nonnegative integers read from the keyboard.

10 int search(const int a[], int numberUsed, int target);
11 //Precondition: numberUsed is <= the declared size of a.
12 //Also, a[0] through a[numberUsed -1] have values.
13 //Returns the first index such that a[index] == target,
14 //provided there is such an index; otherwise, returns -1.
```

Display 5.6
Searching an Array (2 of 4)

```
15  int main( )
16  {
17      int arr[DECLARED_SIZE], listSize, target;

18      fillArray(arr, DECLARED_SIZE, listSize);

19      char ans;
20      int result;
21      do
22      {
23          cout << "Enter a number to search for: ";
24          cin >> target;

25          result = search(arr, listSize, target);
26          if (result == -1)
27              cout << target << " is not on the list.\n";
28          else
29              cout << target << " is stored in array position "
30                   << result << endl
31                   << "(Remember: The first position is 0.)\n";
```

Display 5.6
Searching an Array (3 of 4)

Display 5.6 Searching an Array

```
32          cout << "Search again?(y/n followed by Return): ";
33          cin >> ans;
34      } while ((ans != 'n') && (ans != 'N'));
35      cout << "End of program.\n";
36      return 0;
37  }

38  void fillArray(int a[], int size, int& numberUsed)
39  <The rest of the definition of fillArray is given in Display 5.5>
40  int search(const int a[], int numberUsed, int target)
41  {
42      int index = 0;
43      bool found = false;
44      while ((!found) && (index < numberUsed))
45      if (target == a[index])
46          found = true;
47      else
48          index++;
```

Display 5.6
Searching an Array (4 of 4)

```
49        if (found)
50            return index;
51        else
52            return -1;
53    }
```

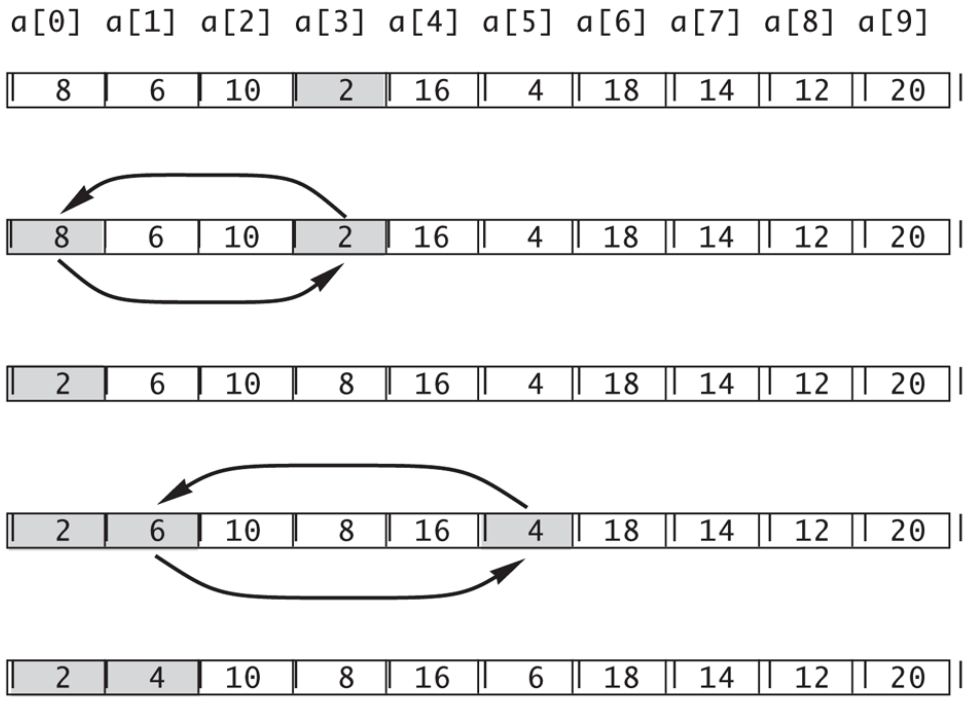
SAMPLE DIALOGUE

```
Enter up to 20 nonnegative whole numbers.
Mark the end of the list with a negative number.
10 20 30 40 50 60 70 80 -1
Enter a number to search for: 10
10 is stored in array position 0
(Remember: The first position is 0.)
Search again?(y/n followed by Return): y
Enter a number to search for: 40
40 is stored in array position 3
(Remember: The first position is 0.)
Search again?(y/n followed by Return): y
Enter a number to search for: 42
42 is not on the list.
Search again?(y/n followed by Return): n
End of program.
```

Sorting an Array: **Display 5.7** Selection Short

- Selection Sort Algorithm

Display 5.7 Selection Sort



Sorting an Array Example:
Display 5.8 Sorting an Array (1 of 4)

Display 5.8 Sorting an Array

```
1   //Tests the procedure sort.
2   #include <iostream>
3   using namespace std;

4   void fillArray(int a[], int size, int& numberUsed);
5   //Precondition: size is the declared size of the array a.
6   //Postcondition: numberUsed is the number of values stored in a.
7   //a[0] through a[numberUsed - 1] have been filled with
8   //nonnegative integers read from the keyboard.
9   void sort(int a[], int numberUsed);
10  //Precondition: numberUsed <= declared size of the array a.
```

(continued)

Sorting an Array Example: **Display 5.8** Sorting an Array (2 of 4)

Display 5.8 Sorting an Array

```
11  //The array elements a[0] through a[numberUsed - 1] have values.
12  //Postcondition: The values of a[0] through a[numberUsed - 1] have
13  //been rearranged so that a[0] <= a[1] <= ... <= a[numberUsed - 1].

14  void swapValues(int& v1, int& v2);
15  //Interchanges the values of v1 and v2.

16  int indexOfSmallest(const int a[], int startIndex, int numberUsed);
17  //Precondition: 0 <= startIndex < numberUsed. Reference array elements
18  //have values. Returns the index i such that a[i] is the smallest of the
19  //values a[startIndex], a[startIndex + 1], ..., a[numberUsed - 1].

20  int main( )
21  {
22      cout << "This program sorts numbers from lowest to highest.\n";

23      int sampleArray[10], numberUsed;
24      fillArray(sampleArray, 10, numberUsed);
25      sort(sampleArray, numberUsed);

26      cout << "In sorted order the numbers are:\n";
27      for (int index = 0; index < numberUsed; index++)
28          cout << sampleArray[index] << " ";
29      cout << endl;

30      return 0;
31  }
```

Sorting an Array Example: **Display 5.8** Sorting an Array (3 of 4)

```
32  void fillArray(int a[], int size, int& numberUsed)
33            <The rest of the definition of fillArray is given in Display 5.5.>

34  void sort(int a[], int numberUsed)
35  {
36      int indexOfNextSmallest;
37      for (int index = 0; index < numberUsed - 1; index++)
38      {//Place the correct value in a[index]:
39          indexOfNextSmallest =
40                          indexOfSmallest(a, index, numberUsed);
41          swapValues(a[index], a[indexOfNextSmallest]);
42          //a[0] <= a[1] <=...<= a[index] are the smallest of the original array
43          //elements. The rest of the elements are in the remaining positions.
44      }
45  }

46  void swapValues(int& v1, int& v2)
47  {
48      int temp;
49      temp = v1;
50      v1 = v2;
```

Sorting an Array Example:
Display 5.8 Sorting an Array (4 of 4)

Display 5.8 Sorting an Array

```
51      v2 = temp;
52  }
53
54  int indexOfSmallest(const int a[], int startIndex, int numberUsed)
55  {
56      int min = a[startIndex],
57          indexOfMin = startIndex;
58      for (int index = startIndex + 1; index < numberUsed; index++)
59          if (a[index] < min)
60          {
61              min = a[index];
62              indexOfMin = index;
63              //min is the smallest of a[startIndex] through a[index]
64          }
65      return indexOfMin;
66  }
```

SAMPLE DIALOGUE

```
This program sorts numbers from lowest to highest.
Enter up to 10 nonnegative whole numbers.
Mark the end of the list with a negative number.
80 30 50 70 60 90 20 30 40 -1
In sorted order the numbers are:
20 30 30 40 50 60 70 80 90
```

Multidimensional Arrays

- Arrays with more than one index
  - char page[30][100];
    - Two indexes: An "array of arrays"
    - Visualize as:
      page[0][0], page[0][1], …, page[0][99]
      page[1][0], page[1][1], …, page[1][99]
      …
      page[29][0], page[29][1], …, page[29][99]
- C++ allows any number of indexes
  - Typically no more than two

Multidimensional Array Parameters

- Similar to one-dimensional array
  - 1st dimension size not given
    - Provided as second parameter
  - 2nd dimension size IS given
- Example:

```
void DisplayPage(const char p[][100], int sizeDimension1)
{
        for (int index1=0; index1<sizeDimension1; index1++)
        {
                for (int index2=0; index2 < 100; index2++)
                        cout << p[index1][index2];
                cout << endl;
        }
}
```

Summary 1

- Array is collection of "same type" data
- Indexed variables of array used just like any other simple variables
- for-loop "natural" way to traverse arrays
- Programmer responsible for staying "in bounds" of array
- Array parameter is "new" kind
  - Similar to call-by-reference

Summary 2

- Array elements stored sequentially
  - "Contiguous" portion of memory
  - Only address of 1st element is passed to functions
- Partially-filled arrays → more tracking
- Constant array parameters
  - Prevent modification of array contents
- Multidimensional arrays
  - Create "array of arrays"