Ch10-Arrays

August 25, 2020

1 Arrays

1.1 Topics

- C-array introduction
- static and dynamic arrays
- array and pointers and similarity
- passing arrays to functions
- aggregate operations on arrays
- C-string - array of characters
- buffer overflow
- sorting data
- 2-d array and tic-tac-toe game

1.2 Array

- range of a particular type of thing
- we've used single variable to store single data/value
- large programs typically deal with a large number of data values that must be stored in memory e.g. sorting data values.
- not practicle to declare a large number of values to store large number of values
- array is a container used to store a large number of same type values under one name
- array we're learning about in this chapter is C-array
- since C++11 standard, C++ provides **array** and **vector** types under STL (standard template libirary)
  - these advanced types are similar to C++ string type
- understanding the C-array helps understand many C++ concepts and data structures that rely on C-array
  - plus, a large no. of legacy C++ codebase and libraries specially developed before C++11 are still using C-array
- C++ vector is a better choice among C++ **array** and C-array, if your comipler supports it
  - vector takes care of all the common operations if your compiler supports
  - similar to C-string (more below) vs C++ string
- array in this notebook refers to C-array
- there are two types of array
  1. static array
  2. dynamic array

1.3 Static array

- the size of the array is determined during compile-time and is fixed
- local static array is stored on stack memory segment
- syntax to declare a static array

```
type arrayName[size];
```

- size tells the compiler how many of similar type of values can be stored in the arrayName
- size must be literal or constant integer
- the following figure depicts what happens in computer memory when an array of int is declared

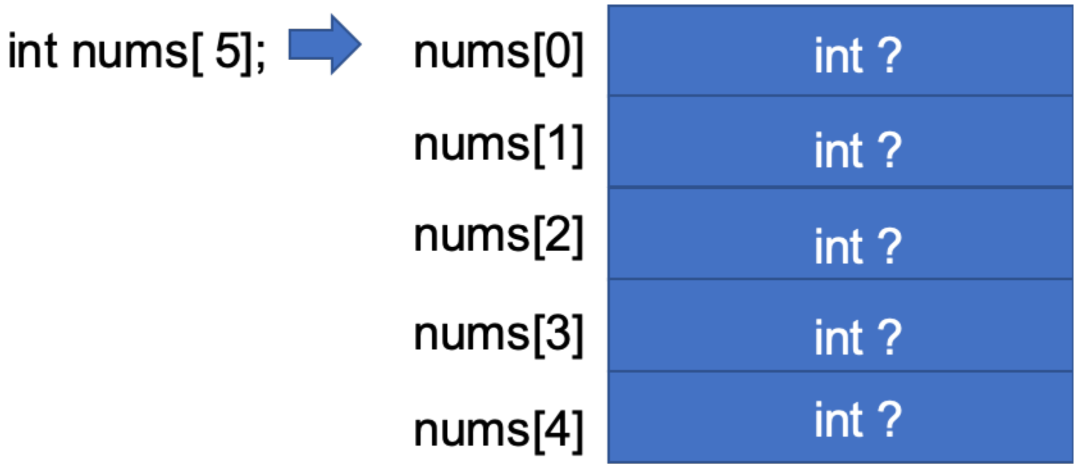


Fig. C++ Array Declaration

- each member of the array is called an element
- each element has same type and name that only differs by its index
- index also called offset starts from 0

1.3.1 visualize array using pythontutor.com

[1]:
```
#include <iostream>
#include <string>

using namespace std;
```

[2]:
```
// nums array to store 5 integers
int nums[5];
```

1.3.2 accessing member elements

- members can be access and used ONLY one element per operation
- no aggregate operation is allowed on the array variable as a whole

– e.g. copy one array into another; printing the whole array, etc.

[3]:
```
// access and store values into each element
nums[0] = 10;
nums[1] = 20;
nums[2] = 30;
nums[3] = 40;
nums[4] = 50;
```

[4]:
```
// access some element
cout << nums[0];
```

```
10
```

[5]:
```
// each element can be used like a single variable
nums[1] = nums[2] + nums[3];
```

[6]:
```
// traverse an array
for(int i=0; i<5; i++) {
    cout << i << " -> " << nums[i] << endl;
}
```

```
0 -> 10
1 -> 70
2 -> 30
3 -> 40
4 -> 50
```

[7]:
```
// declaring and initializing an array
// size is optinal; will be determined with the no. of values it's initialzed␣
 ↪with
float grades[] = {90.5, 34.5, 56, 81, 99, 100, 89.9};
```

[8]:
```
grades
```

[8]:
```
{ 90.5000f, 34.5000f, 56.0000f, 81.0000f, 99.0000f, 100.000f, 89.9000f }
```

1.4 Member functions

- C-array is so primitive that it doesn't come with any useful operations or member functions
- implementing any array operation falls under programmer's responsibility!
- e.g. how can you quickly tell the size or length of an array?

[9]:
```
// finding the size of the array
size_t arr_size = sizeof(grades)/float(sizeof(float));
```

[10]:
```
cout << "array's size or length = " << arr_size;
```

```
array's size or length = 7
```

[11]:
```
cout << "last grade = " << grades[arr_size-1] << endl;
```

```
last grade = 89.9
```

1.4.1 array size is fixed!

- one has to know how many data members will be stored in a given array
- what happens when the array is full?

[12]:
```
// grades doesn't have index 7 as the size is 7
grades[7] = 67;
```

```
input_line_22:3:1: warning: array index 7 is past the

end of the array (which contains 7 elements) [-Warray-bounds]
grades[7] = 67;
^      ~

input_line_14:4:1: note: array 'grades' declared
here
float grades[] = {90.5, 34.5, 56, 81, 99, 100, 89.9};
^
```

1.5 Array and Pointers

- there's a lot of similarity on how array and pointers work!
  - they can be used interchangebly as desired

[13]:
```
int ids[] = {100, 200, 300, 400};
```

[14]:
```
// copy the base address of array
// which is the address of element at index 0; which is &ids[0];
int * ptr = ids;
```

[15]:
```
// print all the memory addresses
cout << ptr << " equals to " << &ids[0] << " equals to " << ids;
```

```
0x10c468f80 equals to 0x10c468f80 equals to 0x10c468f80
```

[16]:
```
// print the data
cout << *ptr << " equals to " << ids[0] << " equals to " << *ids;
```

```
100 equals to 100 equals to 100
```

[17]:
```
// using pointers to traverse array
// point to the second element
```

```
ptr++;
```

[18]:
```
cout << *ptr << endl;
```

```
200
```

[19]:
```
ptr = ids; // copy the base address
for(int i=0; i<4; i++) {
    cout << i << "-> " << *(ptr+i) << " == " << ptr[i] << " == " << ids[i] <<␣
 ↪endl;
}
```

```
0-> 100 == 100 == 100
1-> 200 == 200 == 200
2-> 300 == 300 == 300
3-> 400 == 400 == 400
```

1.6 Dynamic array

- array size can be determined during run time (program execution)
  - once the size is set, it's fixed
- local dynamic array is allocated on the heap memory segment using pointer and **new** operator
- syntax to declare dynamic array:

```
type * arrayName = new type[size];
```

- unlike static array; size can be variable
  - size can be determined or assigned during program execution
- once the dynamic array is declared, using dynamic array is same as using static array
- dynamic memory must be deallocated to prevent from memory leak
- syntax:

```
delete[] arrayName;
```

1.6.1 visualize dynamic array in pythontutor.com

[20]:
```
size_t capacity;
```

[21]:
```
cout << "How many integers would you like to enter? ";
cin >> capacity;
```

```
How many integers would you like to enter? 5
```

[22]:
```
int * some_array = new int[capacity];
```

[23]:
```
// prompt user to store 5 numbers and store them into array
for(int i=0; i<capacity; i++) {
    cout << "Enter a number: ";
    cin >> some_array[i];
}
```

```
Enter a number: 5
Enter a number: 10
Enter a number: 15
Enter a number: 30
Enter a number: 100
```

[25]:
```
// output some values
cout << capacity << " " << some_array[0] << " " << some_array[arr_size-1];
```

```
5 5 1600482421
```

1.7 Aggregate operations on arrays

- some commonly used aggregate operators are (=, math operators (+, *, etc.), comparison operators (>, ==, etc.)
- array doesn't allow any aggregate operations as a whole
  - e.g. copy one array into another; printing the whole array, etc. are arregate operations
  - it doesn't make sense to compare two arrays (compare with what elements' values?)

1.7.1 shallow copy with = operator

- both dynamic and static array CAN'T be assigned to another static array using = operator
- both dynamic and static array can be assigned or copied to another dynamic array
  - however, it doesn't actually copy the data
- copying one array into another by its name copies only the base address
  - thus creating two allias pointing to the same memory location
- if one is modified, the other is modified as well

1.7.2 visualize shallow copy using pythontutor.com

[26]:
```
int * copy_array = new int[arr_size];
```

[27]:
```
// try to copy some_array into copy_array as a whole
copy_array = some_array;
```

[28]:
```
// let's see some values
cout << some_array[0] << " == " << copy_array[0];
```

```
5 == 5
```

[29]:
```
// let's update some_array
some_array[0] = 100;
```

[30]:
```
// now, let's see the value of copy_array[0]
cout << some_array[0] << " == " << copy_array[0];
```

```
100 == 100
```

1.7.3 deep copy

- deep copy refers to the actual copy of the data
- data from one array must be copied to another array element by element
- must write your own function or code to achieve the deep copy
- Note: destination array type must match the source array type
- Note: destination array size must be at least as big as the source array size

[31]:
```
// let's copy some_array created above
// let's create an empty array to deep copy data to
int * deep_copy = new int[capacity];
```

[33]:
```
// let's deep copy
for(int i=0; i<capacity; i++)
    deep_copy[i] = some_array[i];
```

[35]:
```
// if one array is modified it doesn't affect the other array
deep_copy[0] *= 2; // update the first element with twice its value
```

[35]:
```
200
```

[43]:
```
// let's print the copied data side by side
for(int i=0; i<capacity; i++) {
    cout << i << " -> " << deep_copy[i] << " " << some_array[i] << endl;
}
```

```
0 -> 200 100
1 -> 10 10
2 -> 15 15
3 -> 30 30
4 -> 100 100
```

[34]:
```
deep_copy
```

[34]:
```
@0x7ffee79e38d0
```

1.8 Passing array to function

- arrays (both static and dynamic) can be passed to a function
- array provides a very efficient way to pass a larger number of similar values without copying them
  - pass-by reference is by default and the only way!
  - array can't be pass-by value

[35]:
```
// since actual size of the array is not easy to determine,
// size of the array is also passed as an argument
void updateArray(int array[], int size) {
    for(int i = 0; i<size; i++) {
        array[i] *= 2; // simply double the value of each element
    }
}
```

[36]:
```
// print array function; notice passing pointer
void printArray(int * array, int size) {
    cout << "{";
    for(int i=0; i<size; i++)
        cout << array[i] << ", ";
    cout << "}\n";
}
```

[46]:
```
printArray(some_array, arr_size);
```

```
{200, 40, 60, 80, 100, }
```

[44]:
```
updateArray(some_array, arr_size);
```

[45]:
```
printArray(some_array, arr_size);
```

```
{200, 40, 60, 80, 100, }
```

1.9 Returning array from function

- since assignment operator= is not allowed on array, returning a local static array is not possible
- dynamic array is possbile but not the best practice!
  - details as to why it's a bad practice is left for your own research and exploration
  - it has to do with the ownership and memory management (deleting memory, etc.)
- best practice is to pass an empty array (pass-by reference) and get it filled inside the function
  - getting the data/result out of the function without explictly returing it from a function
- quick demo of returning dynamic array can be visualized at pythontutor.com

1.10 C-string

- C language doesn't have a type defiend to work with string like in C++
- now that we understand pointer and C-array, let's revisit C-string
- C-string is array of characters that ends with a NULL character '\0'

[47]:
```
// declare and initialization is easier
// null character is automatically added at the end!
char name[] = "John Smith";
```

[48]:
```
// once declared; working with C-string is pain
// work one character at a time!
char f_name[10];
```

[60]:
```
f_name[0] = 'J';
f_name[1] = 'a';
f_name[2] = 'k';
f_name[3] = 'e';
f_name[4] = '\0';
```

[57]:
```
// C-string must end with null-character '\0'
cout << f_name;
```

```
Jake
```

1.11 Array of strings

- one can declare array of any type (fundamental and advanced)

[1]:
```
#include <iostream>
#include <string>

using namespace std;
```

[2]:
```
// array of C++ string
string names[] = {"John", "Jake", "Dave", "Jenny"};
```

[3]:
```
// first element and first character of first element
cout << names[0] << " first char = " << names[0][0];
```

```
John first char = J
```

1.12 Array of char - *array of C-string (char)*

- similar to array of C++ string conceptually; harder to work with however!
- must use as a parameter for **main(int argc, char* argv[])**

[4]:
```
// create array of char * that stores 4 c-string
char * stuff[4];
```

[5]:
```
char val1[] = "ball";
```

[6]:
```
char val2[] = "test";
char * val3 = "cat";
char * val4 = "dog";
```

```
input_line_13:3:15: warning: ISO C++11 does not allow

conversion from string literal to 'char *' [-Wwritable-strings]
char * val3 = "cat";
```

```
              ^
input_line_13:4:15: warning: ISO C++11 does not
allow conversion from string literal to 'char *' [-Wwritable-strings]
char * val4 = "dog";
              ^
```

[7]:
```
stuff[0] = val1;
stuff[1] = val2;
stuff[2] = val3;
stuff[3] = val4;
```

1.12.1 passing array of char * to function

[8]:
```
// write a function similar to main
int my_main(int argc, char* argv[]) {
    cout << "argc = " << argc << endl;
    for(int i=0; i< argc; i++) {
        cout << argv[i] << " ";
        if (string(argv[i]) == "test")
            cout << " test is found in argv[]\n";
    }
    return 0;
}
```

[9]:
```
my_main(4, stuff);
```

```
argc = 4
ball test  test is found in argv[]
cat dog
```

1.13 Buffer-overflow

- C-string is also called buffer
- if C-string is not used correctly, it'll lead to buffer overflow security flaw
- if data is copied to c-string without checking the bounds, it may overflow!
- one of the most dangerous security flaw that lets hackers completely control the vulnerable program and computer
- going in-depth of buffer-overflow is beyond the scope of the course

1.13.1 demo programs for buffer-overflow

- buffer overflow can be used to overwrite existing data or corrupt memory
  - a simple overflow demo is found at `demo_programs/Ch10/buffer_overflow1.cpp`
- buffer overflow can be used to change the flow of execution; read other part of memory
  - a more intuitive demo is found here: `demo_programs/Ch10/buffer_overflow2.cpp`

1.14 Sorting data

- a very important operation done to solve a large number of problems
- all the data must be stored in memory in order to sort
- e.g. sort student's grades, ids, names, etc.
- there are many algorithms to sort data
  - one of the highly studiedtopics in Algorithm class
- you can learn and write your own algorithm to sort data
- an easy and efficent way to sort data is using library
- **<algorithm>** header library has many commonly used algorithm implemented
  - more: https://en.cppreference.com/w/cpp/header/algorithm
- **sort(begin, end)** function sorts the data given a sequence that has **begin( ) and end( )**
  - by default sorts in ascending order
  - can be used to sort in descending order

[9]:
```
// let's declared an array of float
float stu_grades[] = {100, 99.6, 55, 100, 65, 15.5};
```

[10]:
```
#include <algorithm> // sort()
#include <iterator> // begin() and end()
```

[11]:
```
// sort stu_grades in ascending order
sort(begin(stu_grades), end(stu_grades));
```

[12]:
```
// now let's see the sorted values
stu_grades
```

[12]:
```
{ 15.5000f, 55.0000f, 65.0000f, 99.6000f, 100.000f, 100.000f }
```

[13]:
```
// sort stu_grades in descending order
// pass greater<type> function template that is used to compare the data
// with greater value towards the beginning
sort(begin(stu_grades), end(stu_grades), greater<float>());
```

[29]:
```
stu_grades
```

[29]:
```
{ 100.000f, 100.000f, 99.6000f, 65.0000f, 55.0000f, 15.5000f }
```

[22]:
```
// sort array of strings
string words[] = {"zebra", "yoyo", "x-ray", "ball", "apple"};
```

[24]:
```
// sort in ascending order
sort(begin(words), end(words));
```

[25]:
```
words
```

[25]:
```
{ "apple", "ball", "x-ray", "yoyo", "zebra" }
```

1.15 Bubble sort

- bubble sort repeatedly compares and swaps two adjacent elements if they're not in order
- see animation here: https://en.wikipedia.org/wiki/Bubble_sort
- step through the algorithm here: https://opendsa-server.cs.vt.edu/ODSA/Books/CS3/html/BubbleSort.htm
- one of the worst performing algorithms; but used to demonstrate a quick and easy way to write your own sort algorithm for a small number of elements
  - because of its poor performance, bubble sort should not be used in real-world applications

[2]:
```
#include <iostream>
#include <string>

using namespace std;
```

[2]:
```
template<class T>
void printArray(T * arr, int size) {
    cout << "{";
    for(int i=0; i<size; i++)
        cout << arr[i] << ", ";
    cout << "}\n";
}
```

[3]:
```
template<class T>
void bubbleSort(T * array, int size) {
    bool swapped;
    for(int pass=0; pass<size; pass++) {
        swapped = false;
        // let's print array before every pass
        // TODO: comment out the the following debugging info...
        //cout << "pass # " << pass << ": ";
        //printArray<float>(array, size);
        for(int i=0; i<size-1-pass; i++) {
            // sort in ascending order; check out of order?
            if (array[i] > array[i+1]) {
                swap(array[i], array[i+1]);
                swapped = true;
            }
        }
        // check if the elements are sorted; i.e. not single pair was swapped
        // let's print array after each pass
        //printArray<float>(array, size);
        if (!swapped)
            break;
    }
}
```

[4]:
```
int numbers[] = {100, 99, 55, 100, 65, 15};
```

[6]:
```
bubbleSort<int>(numbers, 6);
```

[7]:
```
numbers
```

[7]:
```
{ 15, 55, 65, 99, 100, 100 }
```

1.16 Two-dimensional array

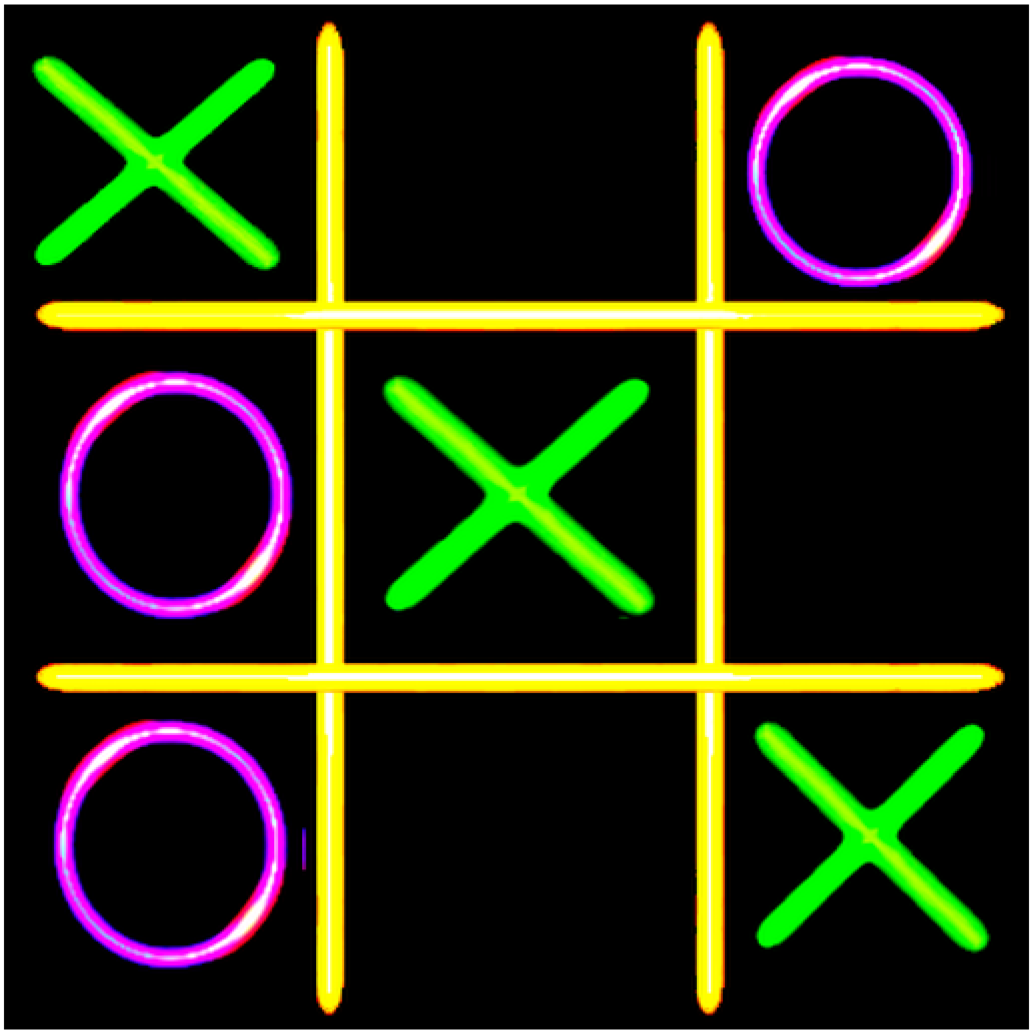
- two dimensional array is a useful construct to store data of 2-d in nature
  - table with row and column (representing 2-d board games), cartesian coordinates, etc.
- 3-d and more is also possible
  - 3-d array is mostly used in video games to store graphics information
- syntax to declare 2-d array:

```
type arrayName[rowSize][colSize];
```

- 2-d array can be both static and dynamic

1.16.1 Tic-tac-toe game

- represent 2-d tic-tac-toe board



[1]:
```
#include <iostream>
#include <iomanip>
#include <string>

using namespace std;
```

[2]:
```
// declare a 2-d tic-tac board;
// tic_tac_toe[0][0] represents top left box
char tic_tac_toe[3][3];
```

[3]:
```
// define a function to initialize empty tic_tac_toe board
// Note: must provide the column_width inside []
void initTicTacToe(char board[][3], int row) {
    for(int i=0; i<row; i++)
        for(int j=0; j<3; j++)
            board[i][j] = ' '; // space represents empty box
}
```

[4]:
```
void printTicTacToe(char board[][3], int row) {
    cout << endl << setfill('-') << setw(14) << " " << endl;
    for(int i=0; i<row; i++) {
        cout << "| ";
        for(int j=0; j<3; j++)
            cout << tic_tac_toe[i][j] << " | ";
        cout << endl << setfill('-') << setw(14) << " " << endl;
    }
}
```

[5]:
```
// let's initialize our board
initTicTacToe(tic_tac_toe, 3);
```

[6]:
```
// let's print the empty board
printTicTacToe(tic_tac_toe, 3);
```

```

-------------
|   |   |   |
-------------
|   |   |   |
-------------
|   |   |   |
-------------
```

[7]:
```
// let's fill Xs and Os as shown in the above figure
// assuming a game play
tic_tac_toe[0][0] = 'X';
tic_tac_toe[0][2] = 'O';
tic_tac_toe[1][0] = 'O';
tic_tac_toe[1][1] = 'X';
tic_tac_toe[2][0] = 'O';
tic_tac_toe[2][2] = 'X';
```

[8]:
```
printTicTacToe(tic_tac_toe, 3);
```

```

-------------
| X |   | O |
-------------
| O | X |   |
-------------
| O |   | X |
-------------
```

[9]:
```
// let's determine winner!
char findWinner(char board[][3], int row) {
    char winner; // is it O or X?
    bool won;
    // check rows
    for(int i=0; i<row; i++) {
        winner = board[i][0]; // whatever symbol is at the first box, that␣
 ↪should continue to win
        won = true;
        // check the rest of the columns
        for(int j=1; j<3; j++) {
            if (winner != board[i][j]) {
                won = false;
                break;
            }
        }
        if (won) // we've a winner
            return winner;
    }
    // #FIXME: check columns FIXME#
    // check diagonals
    // top left to bottom right
    if (board[0][0] == board[1][1] && board[1][1] == board[2][2]) return␣
 ↪board[0][0];
    // #FIXME: check the other diagonal

    return '-'; // return '-' if it's a tie
}
```

[10]:
```
char winner;
```

[11]:
```
winner = findWinner(tic_tac_toe, 3);
```

[13]:
```
if (winner == '-')
    cout << "Oops! it's a tie...\n";
else
    cout << "Congrats " << winner << "! You win!!\n";
```

```
Congrats X! You win!!
```

1.17 Exercises

1. Write a function that takes an array and finds and returns the max value in the array.
    - write at least 3 automated test cases

[15]:
```
#include <cassert>
```

[14]:
```
template<class T>
T max(T * array, int size) {
    assert(size >= 1); // make sure array is not empty!
    T curr_max = array[0];
    for(int i=1; i<size; i++) {
        // if the value at i is larger than curr_max; update it with the new max
        if (curr_max < array[i])
            curr_max = array[i];
    }
    return curr_max;
}
```

[20]:
```
void test_max() {
    assert(max({1, 2, 3} == 3));
    assert(max({10, -5, -30} == 10));
    assert(max({-10, -5, -30, 0, -100} == 0));
    cerr << "all test cases passed for max()\n";
}
```

[21]:
```
test_max();
```

```
all test cases passed for max()
```

2. Write a function that takes an array and finds and returns the min value in the array.
    - write at least 3 automated test cases
3. Write a complete C++ program that computes some statistical values on any given number of numbers
    - prompt user to enter a bunch of numbers
    - find and display the max and min values
    - find and display the average or mean
    - find and print the range (max - min) in the array
    - find and display the mode or modal (the number with largest frequency)
    - program continues to run until the user wants to quit
4. Write a search function that checks if a given value is found in an array.
    - write 3 automated test cases

1.18 Kattis problems

- a large number of difficult problems require to store data in 1 or 2-d arrays and manipulate the data
- solve the following Kattis problems writing at least 3 automated test cases for each function used as part of the solution

1. Falling Apart - https://open.kattis.com/problems/fallingapart

2. Statistics - https://open.kattis.com/problems/statistics

3. Line Them Up - https://open.kattis.com/problems/lineup

1.19 Summary

- learned about array and types of arrays
- passing array to functions

- similarity between array and pointers in terms of using memory addressses
- methods or member functions or lack there of
- array of C++ strings and C-string
- went over a quick intro to buffer overflow security vulnerability
- sorting using <algorithm> and writing our own bubble sort
- 2-d array and it's application on tic-tac-toe game

[ ]:

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