Lecture 4 - Array and Vector

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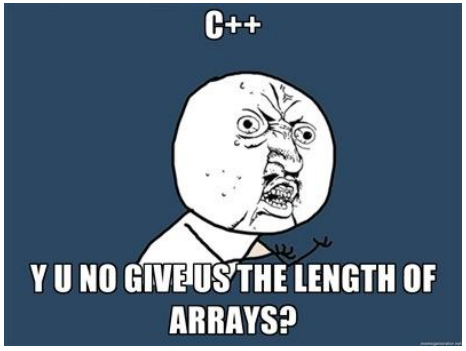
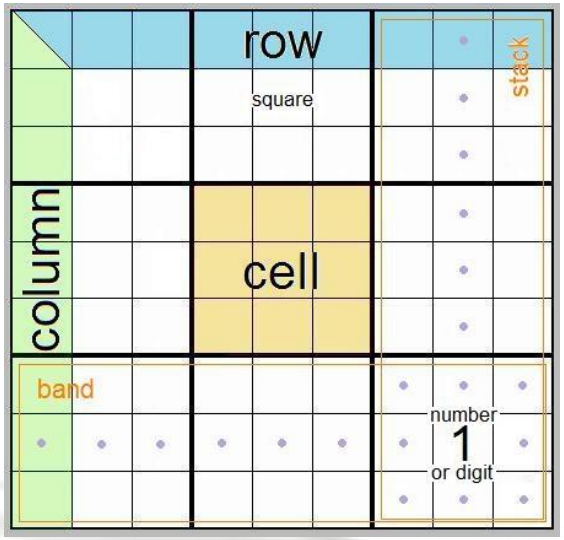


Sudoku Validator

- A Sudoku validator reads a Sudoku answer from a file, and then checks if the answer is valid or not.
- A Sudoku answer is a 9×9 grid filled with digits so that **each column**, **each row**, and **each of the nine 3×3 sub-grids (called cells)** that compose the grid contains all of the digits from 1 to 9.



8	4	3	5	6	7	2	9	1
5	6	7	1	9	2	4	8	3
2	9	1	4	8	3	7	6	5
1	3	2	9	7	8	6	5	4
9	7	6	3	4	5	8	1	2
4	5	8	6	2	1	3	7	9
7	8	5	2	3	9	1	4	6
3	1	4	7	5	6	9	2	8
6	2	9	8	1	4	5	3	7

Sudoku.h

```
 1  #include <iostream>
 2  class Sudoku {
 3  public:
 4      Sudoku();
 5      Sudoku(const int init_map[]);
 6      void setMap(const int  set_map[]);
 7      int getElement(int index);
 8      bool isCorrect();
 9      static const int sudokuSize = 81;
10
11  private:
12      bool checkUnity(int arr[]);
13      int map[sudokuSize];
14  };
```

Sudoku.cpp

```
 1  #include "Sudoku.h"
 2  using namespace std;
 3
 4  Sudoku::Sudoku()
 5  {
 6      for(int i=0; i<sudokuSize; ++i)
 7          map[i] = 0;
 8  }
 9  Sudoku::Sudoku(const int init_map[])
10  {
11      for(int i=0; i<sudokuSize; ++i)
12          map[i] = init_map[i];
13  }
14
15  void Sudoku::setMap(const int set_map[])
16  {
17      for(int i=0; i<sudokuSize; ++i)
18          map[i] = set_map[i];
19  }
20  int Sudoku::getElement(int index)
21  {
22      return map[index];
23  }
24
25  bool Sudoku::checkUnity(int arr[])
26  {
27      int arr_unity[9];   // counters
28
29      for(int i=0; i<9; ++i)
30          arr_unity[i] = 0;    // initialize
31      for(int i=0; i<9; ++i)
32          ++arr_unity[arr[i]-1];    // count
33      for(int i=0; i<9; ++i)
34          if(arr_unity[i] != 1)   // all element
35              return false;          // must be 1
36      return true;
37  }
38
```

Sudoku.cpp (cont.)

```
39 bool Sudoku::isCorrect()
40 {
41     bool check_result;
42     int check_arr[9];
43     int location;
44     for(int i=0; i<81; i+=9)    // check rows
45     {
46         for(int j=0; j<9; ++j)
47             check_arr[j] = map[i+j];
48         check_result = checkUnity(check_arr);
49         if(check_result == false)
50             return false;
51     }
52     for(int i=0; i<9; ++i)   // check columns
53     {
54         for(int j=0; j<9; ++j)
55             check_arr[j] = map[i+9*j];
56         check_result = checkUnity(check_arr);
57         if(check_result == false)
58             return false;
59     }
60     for(int i=0; i<9; ++i)   // check cells
61     {
62         for(int j=0; j<9; ++j)
63         {
64             location = 27*(i/3) + 3*(i%3)
                          +9*(j/3) + (j%3);
65             check_arr[j] = map[location];
66         }
67         check_result =
                  checkUnity(check_arr);
68         if(check_result == false)
69             return false;
70     }
71     return true;
72 }
```

public static const Data Member

- Note that the size of the array is specified as a *public static const* data member.
  - *public* so that it's accessible to the clients of the class.
  - *const* so that this data member is constant.
  - *static* so that the data member is shared by all objects of the class
- *static* data members are also known as class variables.
- When objects of a class containing *static* data members are created, all the objects share one copy of the class's *static* data members.

Error: Initialization of *const* Data Member


```
> cat -n const1.cpp
     1  class Cls {
     2  public:
     3          Cls(){ x = 3;}
     4          const int x;
     5  };
     6  int main() { return 0; }
> g++ -o const1 const1.cpp
const1.cpp: In constructor `Cls::Cls()':
const1.cpp:3: error: uninitialized member `Cls::x' with `const' type `const int'
const1.cpp:3: error: assignment of read-only data-member `Cls::x'
```

Initialization of *const* Data Member (cont.)

```
> cat -n const2.cpp
     1  class Cls {
     2  public:   const int x = 3;
     3  };
     4  int main() { return 0; }
> g++ -o const2 const2.cpp
const2.cpp:2:23: warning: in-class initialization of non-static data member is a
      C++11 extension [-Wc++11-extensions]
public:   const int x = 3;
                  ^
1 warning generated.
```


```
> cat -n const3.cpp
     1  class Cls {
     2  public:   Cls():x(3) {}
     3            const int x;
     4  };
     5  int main()  {  return 0; }
> g++ -o const3 const3.cpp
>
```

Initialization of *static const* Data Member

static_const1.cpp

```
1  class Cls {
2  public:   Cls():x(3) {}
3          static const int x;
4  };
5  int main()  {  return 0;  }
```


```
> g++ -o static_const1
static_const1.cpp
 static_const1.cpp: In constructor
`Cls::Cls()':
 static_const1.cpp:2: error: `const int
Cls::x' is a static data member; it can
only be initialized at its definition
```

static_const2.cpp

```
1  class Cls {
2  public:   Cls(){}
3          static const int x = 3;
4  };
5  int main()  {  return 0;  }
```


```
> g++ -o static_const2
static_const2.cpp
>
```

Size of Object with *static const* and *const* Data Members

```
 1  #include <iostream>
 2  using namespace std;
 3  class Cls {
 4  public:   Cls():y(4){}
 5            static const int x = 3;
 6            const int y;
 7  };
 8  int main()
 9  {
10        Cls obj;
11        cout << "sizeof(Cls) = " << sizeof(Cls) << endl;
12        cout << "sizeof(obj) = " << sizeof(obj) << endl;
13        return 0;
14  }
```

```
Output:
sizeof(Cls) = 4
sizeof(obj) = 4
```

static Data Member

```
 1  #include <iostream>
 2  using namespace std;
 3
 4  class Cls {
 5  public:      Cls(){  NumObject++;  }
 6      static int NumObject;
 7  };
 8  int Cls::NumObject = 0;
 9  int main()
10  {
11      cout << Cls::NumObject << endl;
12      Cls obj1;
13      cout << Cls::NumObject << endl;
14      Cls obj2;
15      cout << obj1.NumObject << endl;
16      cout << obj2.NumObject << endl;
17      return 0;
18  }
```

Just Declaration

Definition (Do not use "static" here.)

Output:
0
1
2
2

static Data Member (cont.)

- A *static* data member can be accessed within the class definition and the member-function definitions like any other data member.
- A *public static* data member can also be accessed outside of the class, even when no objects of the class exist, using the class name followed by the binary scope resolution operator (::) and the name of the data member.

Sample Input and Sample Output

Number of cases

Map of case #1

Map of case #2

```
> cat su_infile
2
1 2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9
8 6 5 3 2 9 4 1 7
2 4 3 1 7 5 8 6 9
1 9 7 6 8 4 5 2 3
3 1 9 2 5 8 6 7 4
4 2 6 7 9 1 3 5 8
5 7 8 4 3 6 1 9 2
7 5 4 9 1 3 2 8 6
6 8 2 5 4 7 9 3 1
9 3 1 8 6 2 7 4 5
```

```
> ./sudoku_validate
1 2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9
INCORRECT
8 6 5 3 2 9 4 1 7
2 4 3 1 7 5 8 6 9
1 9 7 6 8 4 5 2 3
3 1 9 2 5 8 6 7 4
4 2 6 7 9 1 3 5 8
5 7 8 4 3 6 1 9 2
7 5 4 9 1 3 2 8 6
6 8 2 5 4 7 9 3 1
9 3 1 8 6 2 7 4 5
CORRECT
```

Validation Result

sudoku_validate.cpp

```
 1  #include <cstdlib>
 2  #include <iostream>
 3  #include <fstream>
 4  #include "Sudoku.h"
 5  #define MAX_CASE    100
 6  using namespace std;
 7  int main()
 8  {
 9      int sudoku_in[Sudoku::sudokuSize];
10      Sudoku su[MAX_CASE];
11      ifstream in("su_infile",ios::in);
12      int num_case;
13      in >> num_case;
14      for(int j=0; j<num_case; ++j)
15      {
16          for(int i=0; i<Sudoku::sudokuSize; ++i)
17              in >> sudoku_in[i];     // read in map
18          su[j].setMap(sudoku_in);  // set map
19      }
20      for(int j=0; j<num_case; ++j)
21      {         // print out the maps
22          for(int i=0; i<Sudoku::sudokuSize; ++i)
23          {
24              cout << su[j].getElement(i) << " ";
25              if(i % 9 == 8 )
26                  cout << endl;
27          }
28          if(su[j].isCorrect()) // validation results
29              cout << "CORRECT\n";
30          else
31              cout << "INCORRECT\n";
32      }
33      return 0;
34  }
```

Replacing Array with *vector*

```
 1  #include <vector>
 2  #include <cstdlib>
 3  #include <iostream>
 4  #include <fstream>
 5  #include "Sudoku.h"
 6  using namespace std;
 7  int main()
 8  {
 9      int sudoku_in[Sudoku::sudokuSize];
10      Sudoku su_tmp;
11      vector<Sudoku> su;
12      ifstream in("su_infile",ios::in);
13     int num_element, num_case;
14     in >> num_case;
    // num_case is not used in this program
15      cout << "size = " <<
                    su.size() << endl;
16      num_element = 0;
17      while(in >> sudoku_in[num_element++])
18      {                    // read in map
19          if(num_element >=
                    Sudoku::sudokuSize) {
20              su_tmp.setMap(sudoku_in);
21              num_element = 0;
22              su.push_back(su_tmp);
23          }
24      }
25      cout << "size = " << su.size() << endl;
26      cout << su[0].isCorrect() << endl;
27      for(int i = 1; i<su.size(); ++i)
28          cout << su.at(i).isCorrect() << endl;
29
30      return 0;
31  }
```

```
> ./sudoku_validate2
size = 0
size = 2
0
1
```

C++ Standard Library
Class Template *vector*

- C-style pointer-based arrays have great potential for errors and are not flexible
  - A program can easily "walk off" either end of an array, because C++ does not check whether subscripts fall outside the range of an array.

```
arr[-1]
```

  - Two arrays cannot be meaningfully compared with equality operators or relational operators.

```
if(arr1 == arr2)
```

  - When an array is passed to a general-purpose function designed to handle arrays of any size, the size of the array must be passed as an additional argument.

```
func(arr, size)
```

  - One array cannot be assigned to another with the assignment operator(s).

```
arr1 = arr2
```

C++ Standard Library
Class Template *vector* (cont.)

- C++ Standard Library class template *vector* represents a more robust type of array featuring many additional capabilities.
- Standard class template *vector* is defined in header <*vector*> and belongs to namespace *std*.
- By default, all the elements of a *vector* object are set to *0*.
- *vector*s can be defined to store any data type.

```
vector<int> v1;
vector<Sudoku> v2;
```

- *vector* member function *size* obtain the number of elements in the *vector*.

```
cout << v.size();
```

- *vector* objects can be compared with one another using the equality operators.

```
if(v1 == v2)
```

C++ Standard Library
Class Template *vector* (cont.)

- You can create a new *vector* object that is initialized with the contents of an existing *vector* by using its copy constructor.

```
vector<Sudoku> v2(v1);
```

- You can use the assignment (=) operator with *vector* objects.

```
v1 = v2;
```

- You can use square brackets, *[]*, to access the elements in a *vector*. As with C-style pointer-based arrays, C++ does not perform any bounds checking when *vector* elements are accessed with square brackets.

```
v[1];
```

- Standard class template *vector* provides bounds checking in its member function *at*, which "throws an exception" if its argument is an invalid subscript.

```
v.at(1);
```

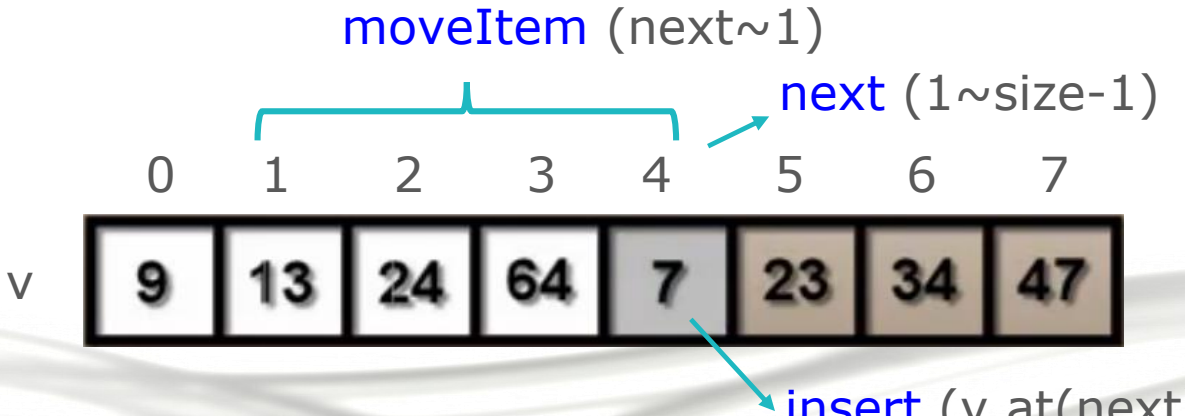
Sorting a Vector with Insertion Sort

```
 1  #include <vector>
 2  #include <iomanip>
 3  #include <iostream>
 4  using namespace std;
 5
 6  int main()
 7  {
 8      const int size = 8;
 9      int init_array[size] =
                {64, 24, 13, 9, 7, 23, 34, 47};
10      vector<int> v(size);
11      int insert, moveItem;
12
13      cout << "Unsorted array:\n";
14      for(int i=0; i<size; ++i)
15      {
16          v.at(i) = init_array[i];
17          cout << setw(4) << v.at(i);
18      }
19      cout << endl;
20
21      cout << "Step-by-step:\n";
22      for(int next=1;next<size;++next)
23      {
24          insert = v.at(next);
25          moveItem = next;
26          while((moveItem>0) &&
                    (v.at(moveItem-1) > insert))
27          {
28              v.at(moveItem) = v.at(moveItem-1);
29              --moveItem;
30          }
31          v.at(moveItem) = insert;
32          for(int i=0; i<size; ++i)
33              cout << setw(4) << v.at(i);
34          cout << endl;
35      }
36
37      return 0;
38  }
```

Sorting a Vector with Insertion Sort (cont.)

```
22    for(int next=1;next<size;++next)
23    {
24        insert = v.at(next);
25        moveItem = next;
26        while((moveItem>0) &&
                  (v.at(moveItem-1) > insert))
27        {
28            v.at(moveItem) = v.at(moveItem-1);
29            --moveItem;
30        }
31        v.at(moveItem) = insert;
      …
35    }
```

```
Output:
Unsorted array:
 64  24  13   9   7  23  34  47
Step-by-step:
 24  64  13   9   7  23  34  47
 13  24  64   9   7  23  34  47
  9  13  24  64   7  23  34  47
  7   9  13  24  64  23  34  47
  7   9  13  23  24  64  34  47
  7   9  13  23  24  34  64  47
  7   9  13  23  24  34  47  64
```



Using *sort()* in C++ Standard Library

```
 1 #include <vector>
 2 #include <algorithm>
 3 #include <iostream>
 4 #include <cstdlib>
 5 #include "Clock.h"
 6 using namespace std;
 7 void insertion_sort(vector<int> & v)
 8 {
 9     int insert, moveItem;
10     for(int next=1;next<v.size();++next)
11     {
12         insert = v.at(next);
13         moveItem = next;
14         while((moveItem>0) &&
               (v.at(moveItem-1) > insert))
15         {
16             v.at(moveItem) = v.at(moveItem-1);
17             --moveItem;
18         }
19         v.at(moveItem) = insert;
20     }
21 }
```

```
23 int main()
24 {
25     Clock clk;
26     const int size = 100000;
27     vector<int> v1(size),v2;
28     srandom(time(NULL));
29     for(int i=0; i<size; ++i)
30         v1.at(i) = random();
31     v2 = v1;    clk.start();
32     sort(v1.begin(), v1.end());
33     cout << "sort(): " <<
         clk.getElapsedTime() << " seconds\n";
34     cout << "v1/v2 are "<<
         ((v1==v2)?"the same.\n":"different.\n");
35     clk.start();
36     insertion_sort(v2);
37     cout << "insertion_sort(): " <<
         clk.getElapsedTime() << " seconds\n";
38     cout << "v1/v2 are "<<
         ((v1==v2)?"the same.\n":"different.\n");
39     return 0;
40 }
```

```
sort(): 0.0547 seconds
v1 and v2 are different.
insertion_sort(): 154.26 seconds
v1 and v2 are the same.
```

Clock.h and Clock.cpp

Clock.h

```
 1  #include <ctime>
 2  using namespace std;
 3  class Clock {
 4      public:
 5          Clock();
 6          Clock(clock_t s);
 7          void start();
 8          void setStart(clock_t start_ts);
 9          clock_t getStart();
10          double getElapsedTime();
11      private:
12          clock_t start_ts;
13  };
```

Clock.cpp

```
 1  #include "Clock.h"
 2  Clock::Clock() { setStart(0); }
 3  Clock::Clock(clock_t s) {
 4      setStart(s);
 5  }
 6  void Clock::start() {
 7      setStart(clock());
 8  }
 9  void Clock::setStart(clock_t ts) {
10      start_ts = (ts>0)?ts:clock();
11  }
12  clock_t Clock::getStart() {
13      return start_ts;
14  }
15  double Clock::getElapsedTime() {
16      return static_cast<double>(clock()-getStart())
                        / CLOCKS_PER_SEC ;
17  }
```

Reference

- *Insertion Sort Concept, http://www.youtube.com/watch?v=Fr0SmtN0IJM&t=126*
- *Insertion Sort Example, http://www.youtube.com/watch?v=c4BRHC7kTaQ&t=75*
- *Insertion Sort with Romanian Folk Dance, http://www.youtube.com/watch?v=ROalU379l3U*