Standard Template Library

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Contents

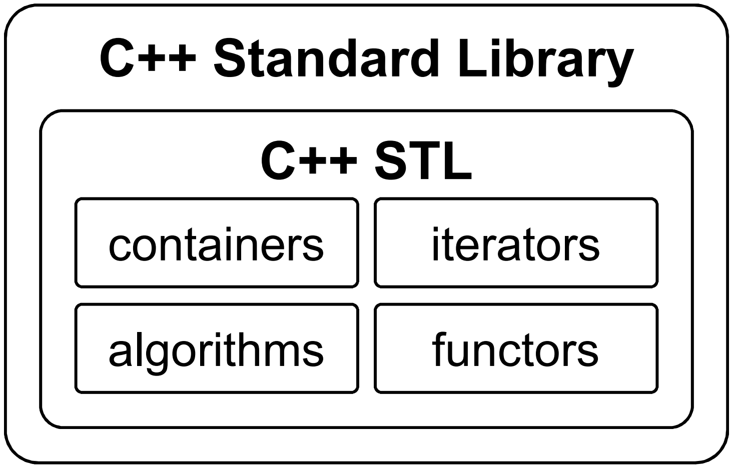
- Overview.
- Containers.
- Algorithms.

Contents

- **Overview.**
- Containers.
- Algorithms.

Overview

- STL origin:
  - Alexander Stepanov, 1994.
  - Main part of C++ Standard Library.
  - Use template extensively.
  - Abstract data types and algorithms.
  - Structure:
    - Containers.
    - Algorithms.
    - Iterators.
    - Functors.



C++ Standard Library

C++ STL

containers

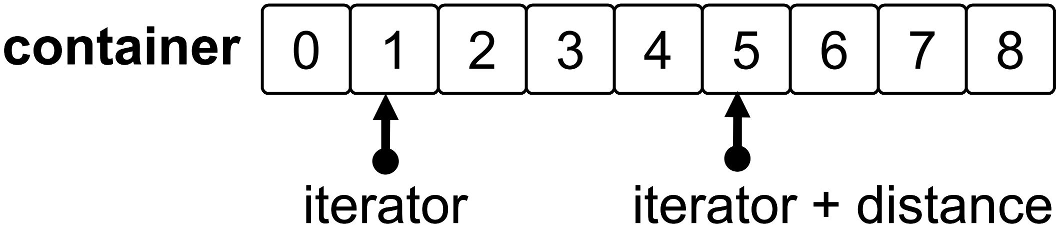
iterators

algorithms

functors

Overview

- Iterator concept:
  - An abstract pointer points to container element.
  - An object to access items in container.
  - Pointer operations:
    - Referencing: <iterator> = **<get position>**.
    - De-referencing: *<iterator>, <iterator>**->**.
    - Jumping: **++/--**<iterator>, <iterator> **+/-** <distance>.
    - Distance: <iterator 1> **-** <iterator 2>.



container 0 1 2 3 4 5 6 7 8

iterator

iterator + distance

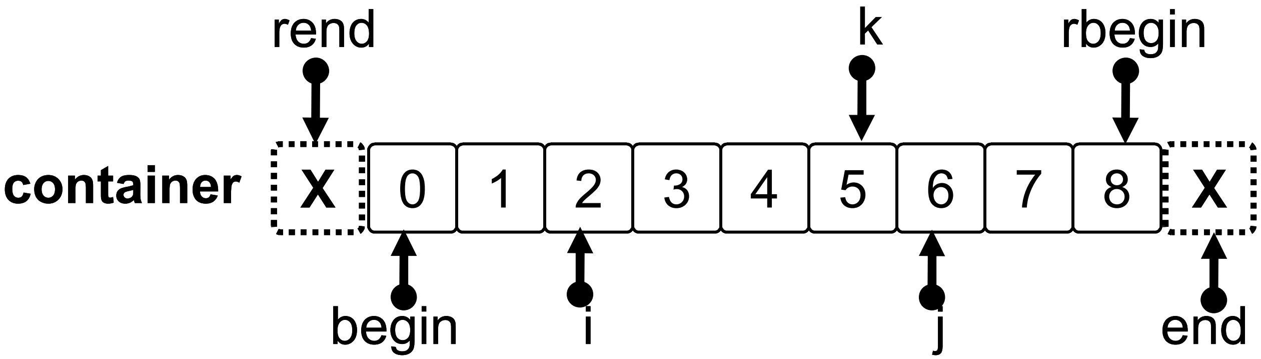
Overview

- Iterator concept:
  - Referencing:

    <container type>::iterator <iterator> = <container position> +/- k.

    <container position>: begin, end, rbegin, rend.

```
std::vector<int>  v  {0, 1, 2, 3, 4, 5, 6, 7, 8};
std::vector<int>::iterator  i = v.begin( ) + 2;
auto  j  = v.end( ) - 3;                // auto type deducing.
auto  k = v.rbegin( ) + 3;              // auto type deducing.
```

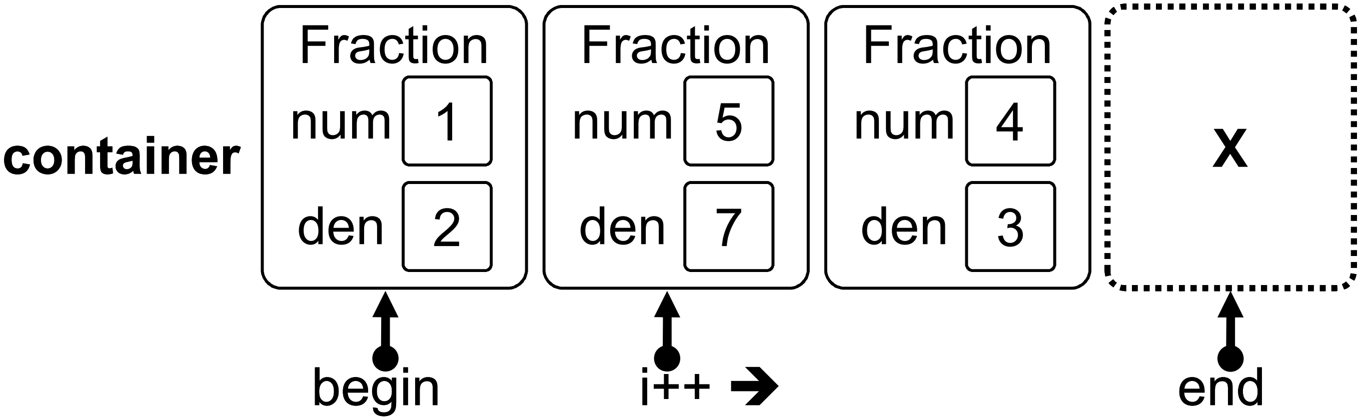


Overview

- Iterator concept:
  - De-referencing and jumping:

```
struct Fraction {
    int  num, den;
};

std::vector<Fraction>  v  { {1, 2}, {5, 7}, {4, 3} };
for (auto i = v.begin( );  i != v.end( );  ++i )
    std::cout << i-> num << ‘/’ << i-> den << ‘\n’;
```



Overview

- Iterator concept:
  - Stream iterator:
    - Treat stream like a container.
    - Read/write stream in STL way.
    - Begin position:

      std::istream_iterator<type>(<stream>).

      std::ostream_iterator<type>(<stream>, <delimeter string>).
    - End position: std::istream_iterator<type>( ).

```
std::ifstream  f(“input.txt”);
auto  f_begin = std::istream_iterator<int>( f );
auto  f_end = std::istream_iterator<int>( );
auto  o = std::ostream_iterator<int>( std::cout, “\n” );
for ( auto i = f_begin;  i != f_end;  ++i )
        *o = *i;     // Read int from f and write to std::cout.
```

Overview

- Iterator concept:
  - Insert iterator:
    - Write value to iterator = insert value to container.
    - Convenient way to insert element.
    - Back insert postion: **std::back_inserter**(<container>).
    - Front insert position: **std::front_inserter**(<container>).
    - Specified position: **std::inserter**(<container>, <iterator pos>).

```
std::ifstream  f(“input.txt”);
auto  f_begin = std::istream_iterator<int>( f );
auto  f_end = std::istream_iterator<int>( );
std::vector<int> v;
auto  o = std::back_inserter( v );
for ( auto i = f_begin;  i != f_end;  ++i )
      *o = *i;   // Read int from f and push_back to v.
```

Overview

- Functor concept:
  - An object can be called like function.
  - By defining operator ( ).

    <return type> <class name>::**operator ( )**(<arguments>).

```
class Power {
private:
   int  m_expo;
public:
   Power( int expo ): m_expo( expo ) { }

   float operator ( )( float base ) {
       float  res = 1;
       for ( int i = 0; i < m_expo; ++i )
           res *= base;
       return res;
   }
};
```

```
int main()
{
   Power  square( 2 );
   float  x = square( 3 );
   float  y = square( 5 );

   Power  cube( 3 );
   float  z = cube( 4 );
   float  t  = cube( 6 );
}
```

Overview

- Functor concept:
  - A functor can store state.

```
class EvenCounter {
private:
    int  m_count;  // Functor state.
public:
    EvenCounter( int start ):
        m_count( start ) {
    }

    int operator ( )( int value ) {
        if ( value % 2 == 0 )
            ++m_count;  // Update each call.
        return m_count;
    }
};
```

```
int main()
{
    std::vector<int>  v {1, 2, 3, 4, 5};

    EvenCounter  count( 0 );
    for ( auto  e: v )
        count( e );

    std::cout << count( 1 );
}
```

Overview

- Functor concept:
  - Pre-defined functors (library <functional>):
    - Arithmetics: std::plus, std::minus.
    - Comparisons: std::greater, std::less, std::equal_to.
    - Not complement: std::not_fn.

```
auto  is_same = std::equal_to( );
bool  r1 = is_same( 1, 1 );        // r1 = true.
bool  r2 = is_same( 1, 2 );        // r2 = false.

auto  is_different = std::not_fn( is_same );
bool  r3 = is_different( 1, 1 );   // r3 = false.
bool  r4 = is_different( 1, 2 );   // r4 = false.
```

Overview

- Functor concept:
  - Lambda expression: (C++11)
    - An anonymous functor.
    - Defined and used in-place.

```
[<captured states>] ( <arguments> ) -> <return type>
{
      // Functor body.
}
```

<capture states>: existing or declared variables.

Overview

- Functor concept:
  - Lambda expression: (C++11)

```
int main()
{   // Anonymous functor having cnt as state.
    auto  countEven = [cnt = 0] ( int value ) {
               if ( value % 2 == 0 )
                   ++cnt;
               return cnt;
    }

    std::vector<int>  v {1, 2, 3, 4, 5};
    for ( auto  e: v )
               countEven( e );
    std::cout << countEven( 1 );
}
```

Contents

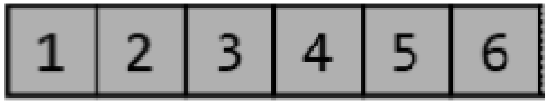
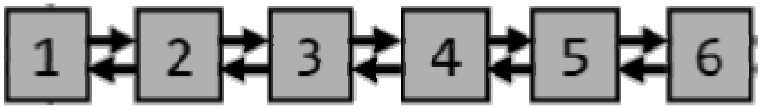
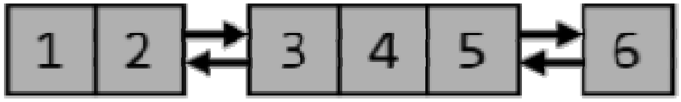
- Overview.
- **Containers.**
- Algorithms.

Containers

- Basic concept:
  - A collections of same type elements.
  - Store elements in specific data structure.
  - Features:
    - Common ways to work with different data structures.
    - General access by iterator.
    - Dynamic memory management.
  - Classifications:
    - Sequence containers.
    - Associative containers.
    - Container adaptors.

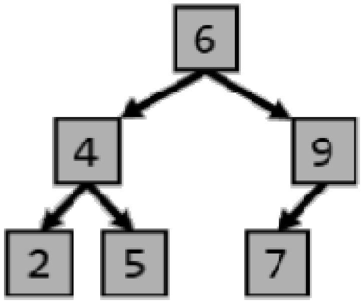
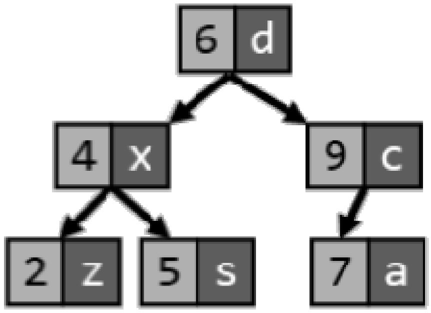
Containers

- Sequence containers:
  - Store elements in linear data structure.
  - Insert orders are maintained.
  - Access element by index.

Containers	Data structures	Features
std::vector		Random access Fast insert/delete end Low memory cost
std::list		Sequential access Very fast insert/delete
std::deque		Random access Fast insert/delete begin, end High memory cost

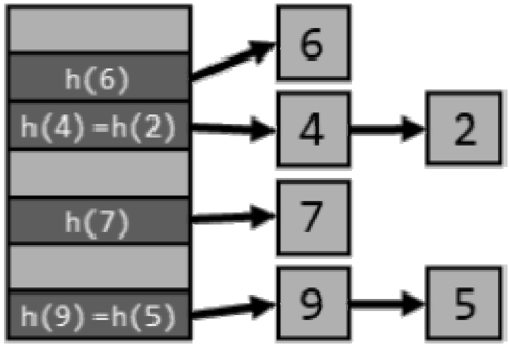
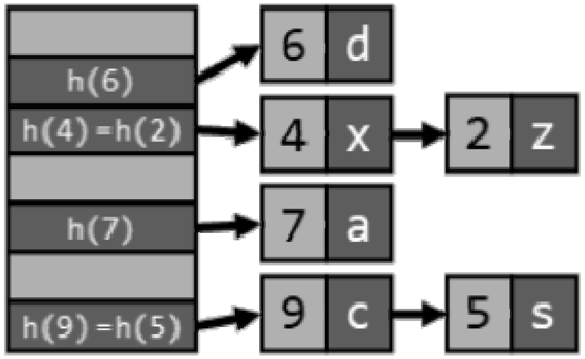
Containers

- Associative containers:
  - Store elements in binary search tree.
  - Insert orders are not maintained.
  - Access element by value.

Containers	Data structures	Use cases
std::set set::multiset		Fast search values Fast insert/delete
std::map std::multimap		Fast search pairs Fast insert/delete .

Containers

- Unordered associative containers:
  - Store elements in hash table.
  - Faster but more memory cost.

Containers	Data structures	Use cases
std::unordered_set set::unordered_multiset	 h(6) h(4) =h(2) h(7) h(9) =h(5) 6 4 2 7 9 5	Very fast search values Very fast insert/delete Very high memory cost
std::unordered_map std::unordered_multimap	 h(6) h(4) =h(2) h(7) h(9) =h(5) 6 d 4 x 2 z 7 a 9 c 5 s	Very fast search pairs Very fast insert/delete Very high memory cost .

Containers

- Container adaptors:
  - Wrapper of sequence container.
  - Provide different API.
  - std::stack: LIFO access (push, pop, top).
  - std::queue: FIFO access (push, pop, front, back).

```
std::stack<Fraction>  s1;                // Stack with std::deque as container.
std::queue<int, std::list<int> > s2; // Queue with std::list as container.
```

Containers

- Construct container:
  - Constructor:
    - <container type> <container>**{ element1, element2, … }**.
    - <container type> <container>**(<iter begin>, <iter end>)**.
  - Assign (sequence container):
    - <container>.assign**({ element1, element2, … })**.
    - <container>.assign**(<iter begin>, <iter end>)**.

```
std::vector <int> v  {1, 2, 3, 4, 5};              // v = {1, 2, 3, 4, 5}
std::list<int>  l ( v.begin( ), v.end( ) );        // l = 1<->2<->3<->4<->5
v.assign( {6, 7, 8, 9} );                          // v = {6, 7, 8, 9}
l.assign( v.begin( ), v.end( ) – 1 );              // l = 6<->7<->8
```

Containers

- Iteration:
  - Use iterator:

```
for (auto i = <container>.begin(); i != <container>.end(); ++i) {
        // Process each element.
}
```

  - Use range-based for (C++11):

```
for (auto &e: <container>) {
        // Process each element.
}
std::vector<int>  v  {2, 2, 1, 3, 1, 3, 5};
for (auto &e: v)
   std::cout << e << ‘ ‘;                    // Print vector: 2 2 1 3 1 3 5
std::cout << ‘\n’;
std::set<int>  s( v.begin( ), v.end( ) );
for (auto &e: s)                             // Print set: 1 2 3 5
   std::cout << e << ‘ ‘;
```

Containers

- Insert/erase elements:
  - <container>.insert:
    - Insert value: **insert**(<iter pos>, <value>).
    - Insert range: **insert**(<iter pos>, <iter begin>, <iter end>).
  - <container>.erase:
    - Erase value: **erase**(<iter pos>).
    - Erase range: **erase**(<iter begin>, <iter end>).

```
std::vector<int>  v  {1, 2, 3, 4};
std::vector<int>  t   {5, 6};
v.insert( v.begin( ) + 2, -1 );                      // v = {1, 2, -1, 3, 4}
v.insert( v.end( ) – 1, t.begin( ), t.end( ) );// v = {1, 2, -1, 3, 5, 6, 4}
v.erase( v.begin( ) + 4, v.end( ) );              // v = {1, 2, -1, 3}
```

Contents

- Overview.
- Containers.
- **Algorithms.**

Algorithms

- Initialize elements:
  - std::fill(<iter begin>, <iter end>, **<value>**).
  - std::generate(<iter begin>, <iter end>,**<gen functor>**).
  - std::generate_n(<iter begin>, n, **<gen functor>**).
  - std::iota(<iter begin>, <iter end>, **<start value>**).
  - Practice:
    - Initialize a list of N random numbers.
    - Initialize a list of N integers from N to 1.

Algorithms

- Compute elements:
  - std::accumulate.
  - std::count.
  - std::count_if.
  - std::inner_product.
  - std::sort.
  - Practice:
    - ➢ Compute distance of two N-D points.
    - ➢ Sort a list of integers in the following order:

      - Even numbers first, then odd numbers.

      - Even numbers in ascending.

      - Odd numbers in descending.

Algorithms

- Copy elements:
    - std::copy.
    - std::copy_if.
    - std::remove_copy_if.
    - Practice:
        - Extract prime numbers from a list of integers.

Algorithms

- Find elements:
  - std::find.
  - std::find_if.
  - std::find_if_not.
  - std::adjacent_find.
  - std::search.
  - Practice:
    - Check if a string contains all numbers or not.
    - Check if a list of integers is an arithmetic sequence.

Algorithms

- Remove elements:
  - std::remove.
  - std::remove_if.
  - std::unique.
  - Remove and erase idom.
  - Practice:
    - Delete all negative numbers in a list of integers.
    - Delete multiple consecutive spaces in a string.

Algorithms

- Transform elements:
  - std::transform.
  - std::replace.
  - std::replace_if.
  - Practice:
    - Square root all perfect numbers in a list.
    - Capitalize first letter of each word in a string.

Summary

- Overview:
  - Generic data types and algorithms.
  - Structure: containers, algorithms, iterators, functors.
  - Iterator:
    - Pointer object pointing to container element.
    - Pointer operations: reference, de-reference, jump, distance.
    - Stream iterator, insert iterator.
  - Functor:
    - Object acting like function, can store states.
    - By overload operator ( ).
    - Lambda: anonymous in-place functor.

Summary

- Containers:
  - Same type elements in specific data structure.
  - Dynamic memory management.
  - Classifications:
    - Sequence: vector, list, deque.
    - Associative: set, multiset, map, multimap.
    - Unordered: unordered_set, unordered_map.
    - Adapter: stack, queue.
  - Operations:
    - Constructor/assign.
    - Iteration: iterator for, range-based for.
    - Insert/erase.

Summary

- Algorithms:
  - Initialize: fill, iota, generate, generate_n.
  - Compute: accumulate, count, count_if, sort.
  - Copy: copy, copy_if, remove_copy_if.
  - Find: find, find_if, find_if_not, adjacent_find, search.
  - Remove: remove, remove_if, unique.
  - Transform: transform, replace, replace_if.

Practice

- Practice 5.1:

  Write C++ functions to do the following initializations:

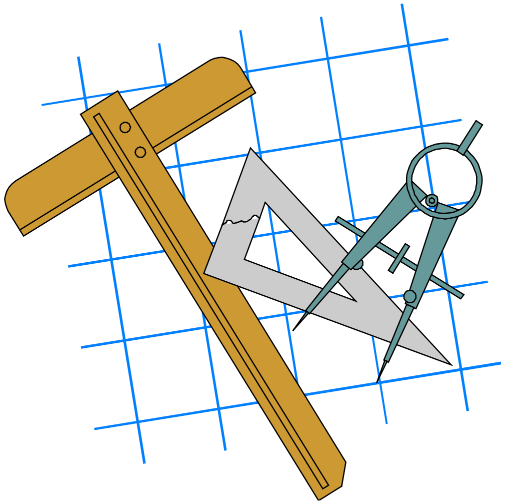
  (use Standard Template Library)

  a) Initialize a list of N integers as follow:

  + Even indexes: [1..(N+1)/2].

  + Odd indexes: random numbers.

  b) Initialize a list of the first N prime numbers.



Practice

- Practice 5.2:

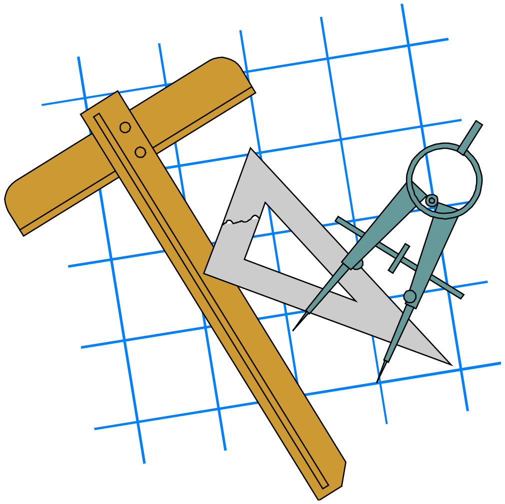
  Write C++ function to check if a string is a palindrome or not.

  (use Standard Template Library)

  Note: a palindrome is string that reads the same backward or forward, spaces and punctuations are not counted.

  Example:

  - “Race car”.
  - “A man, a plan, a canal, Panama!”.



Practice

- Practice 5.3:

Write C++ function to normalize string as follow:

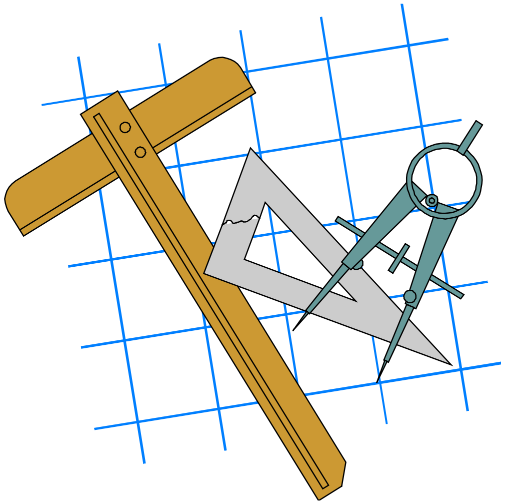
(use Standard Template Library)

- Eliminate leading and trailing spaces.
- Eliminate multiple consecutive spaces or punctuations.
- Capitalize first letter of each words.

Example:

“   [[[the   quick,,, brown   fox   ]]]   “

➔ “[the quick, brown fox]”



Practice

- ## Practice 5.4:

  File “INPUT.TXT” stores integers separated by spaces.

  Write C++ function to filter out prime numbers from “INPUT.TXT” and write the result to file “OUTPUT.TXT” with integers separated by ‘\n’.

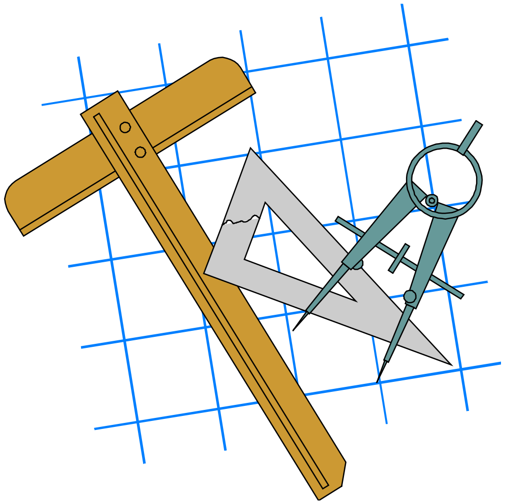
  (use Standard Template Library)

INPUT.TXT

```
1 3 5
2 4
7 13 12
6 9 11
```

OUTPUT.TXT

```
1
2
4
12
6
9
```



Practice

- ## Practice 5.5:

A student has name and GPA.

Given a list of students, write C++ function to print student counts grouped by GPA in descending order of the counts.

(use Standard Template Library)

Student list:

{ {“John”, 7}, {“Eve”, 9}, {“Ander”, 7}, {“Dora”, 8}, {“Tom”, 7}, {“Alex”, 9}

Result list:

GPA 7: 3 students.

GPA 9: 2 students.

GPA 8: 1 students.