CS32 Discussion
Week 6

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Outline

- Recursion
- Template Classes
- STL Containers

Recursion

- Function-writing technique where the function refers to itself.
- Recall the following function:

```
int factorial(int n)
{
    if (n <= 1)
        return 1;

    return n * factorial(n - 1);
}
```

- Let us talk about how to come up with such a function.

Decomposition of the problem

- You're all used to the following technique.

```
int factorial(int n)
{
    int temp = 1;
    for (int i = 1; i <= n; i++)
        temp *= i;
    return temp;
}
```

- n! = 1 * 2 * 3 * … * (n-1) * n
  = factorial(n-1)!

Power of Belief

- **BELIEVE factorial(n - 1) will do the right thing.**

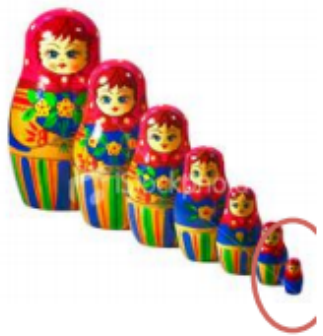
```
int factorial(int n)
{
    int temp = factorial(n - 1) * n;


    return temp;
}
```

- factorial(n) will believe that factorial(n-1) will return the right value.
- factorial(n-1) will believe that factorial(n-2) will return the right value.
- …
- factorial(2) will believe that factorial(1) will return the right value.

Base Case

- **BELIEVE factorial(n - 1) will do the right thing.**

```
int factorial(int n)
{
    if (n <= 1)
        return 1;
    int temp = factorial(n - 1) * n;
    return temp;
}
```



- factorial(n) will believe that factorial(n-1) will return the right value.
- factorial(n-1) will believe that factorial(n-2) will return the right value.
- …
- factorial(2) will believe that factorial(1) will return the right value.
- **AND MAKE factorial(1) return the right value!**

Pattern

- How to Write a Recursive Function for Dummies
  1. Find the base case(s).
     - What are the trivial cases? e.g. empty string, empty array, etc.
     - When should the recursion stop?
  2. Decompose the problem.
     - Example: Tail recursion
       - Take the first (or last) of the n items of information.
       - Make a recursive call to the rest of n-1 items, believing the recursive call will give you the correct result.
       - Given this result and the information you have on the first (or last) item, conclude about the n items.
  3. Just solve this subproblem!

Quicksort

```
void split(double a[], int n, double splitter, int& firstNotGreater, int& firstLess);

void order(double a[], int n)
{
  if (n <= 1) return;
  int pivot = a[0], ng, less;
  split(a, n, pivot, ng, less);
  order(a, ng);
  order(a + less, ng – less);
  return;
}
```

Practice helps

- Recursion is somewhat counter-intuitive when confronted for the first time.
- Just do a lot of practice and you will see some patterns.
- Try finding more examples by googling.

- Again, the key to recursion is to "believe"! Do not try to track the call stack down and see what happens until you really have to.

Problem: Permutation

- Print out the permutations of a given vector.

- E.g.
- [1,2,3] have the following permutations:
- [1,2,3], [1,3,2], [2,1,3], [2,3,1], [3,1,2], and [3,2,1].

- void permutation(vector<int>& nums, int start);

Permutation

```
void permutation(vector<int>& nums, int start) {
      if (start == nums.size() - 1) {
           for(int i=0; i<nums.size(); ++i)
                cout << nums[i] << ' ,';    cout << endl;
      }
      permutation(nums, start + 1);
      for (int i=start+1; i<nums.size(); ++i) {
         swap(nums[start], nums[i]);
         permutation(nums, start + 1);
         swap(nums[start], nums[i]);
      }
   }
```

Template

Template Classes

```
class Pair {
    public:
       Pair();
       Pair(int firstValue,
            int secondValue);
       void setFirst(int newValue);
       void setSecond(int newValue);
       int getFirst() const;
       int getSecond() const;
    private:
       int m_first;
       int m_second;
};
```

- This class works only with integers.
- Can we make a "generic" Pair class? (Note that typedef does not do the job for us.)

Template Classes

```
template<typename T>
class Pair {
    public:
       Pair();
       Pair(T firstValue,
            T secondValue);
       void setFirst(T newValue);
       void setSecond(T newValue);
       T getFirst() const;
       T getSecond() const;
    private:
       T m_first;
       T m_second;
};
```

- Here we go.

```
Pair<int> p1;
Pair<char> p2;
```

Template Classes

```
template<typename T, U>
class Pair {
    public:
       Pair();
       Pair(T firstValue,
            U secondValue);
       void setFirst(T newValue);
       void setSecond(U newValue);
       T getFirst() const;
       U getSecond() const;
    private:
       T m_first;
       U m_second;
};
```

- More than one type:

```
Pair<int, int> p1;
Pair<string, int> p2;
```

Template Classes

```
template<typename T>
void Pair<T>::setFirst(T newValue)
{
    m_first = newValue;
}
```

- Member functions should be edited as well.

Template Specialization

- What if sometimes, we want a template class with certain data type to have its exclusive behaviors?
- E.g., define member function uppercase()
  - pair<int> p1;
  - pair<char> p2;
  - We want to allow p2.uppercase();
  - We don’t want to allow p1.uppercase();

Template Specialization

```
template<>
class Pair<char> {
    public:
       Pair();
       Pair(char firstValue,
            char secondValue);
       void setFirst(char newValue);
       void setSecond(char newValue);
       char getFirst() const;
       char getSecond() const;
       void uppercase();
    private:
       char m_first;
       char m_second;
};
```

- Make an exception.

```
Pair<char> p1;
Pair<int> p2;

p1.uppercase(); (O)
P2.uppercase(); (X)
```

Template Functions

```
template<typename T>
void swap(T& x, T& y)
{
   T temp = x;
   x = y;
   y = temp;
}
```

- Pretty much the same trick.
- Call the function without <>. The types are automatically detected.

```
int x = 2, y = 3;
swap(x, y);

char j = 'c', k = 'm';
swap(j, k);
```

Note

```
// From Prof. Smallberg's slide
template<typename T>
T minimum(const T& a, const T& b)
{
    if (a < b)
        return a;
    else
        return b;
}
```

Pass by value for ADTs are slow

- When you are not changing the values of the parameters, make them const references to avoid potential computational cost.

STL Containers

STL

- **S**tandard **T**emplate **L**ibrary
  - Library of commonly used data structures.
    - `vector` (array)
    - `set` (binary search tree – will learn it soon)
    - `list` (doubly linked list)
    - `map`
    - `stack`
    - `queue`

STL

- A few common functions:
  - `.size()` `.empty()`
- For a container that is neither stack nor queue:
  - `.insert()` `.erase()` `.swap()` `.clear()`
- For list/vector:
  - `.push_back()` `.pop_back()`
- For set/map:
  - `.find()` `.count()`
- ... and you've seen stacks and queues.

STL Example

```
#include <list>
using namespace std;
int main()
{
    list<int> a;
    for (int i = 0; i < 10; i++)
        a.push_back(i);
    cout << a.size() << endl;  // prints 10
}
```

STL Example

```
#include <vector>
using namespace std;
int main()
{
    vector<int> a;
    for (int i = 0; i < 10; i++)
        a.push_back(i);
    cout << a.size() << endl;  // prints 10
}
```

STL Iterators

- Suppose I want to iterate through elements in a container:
- For an array, you would do:

```
int arr[100];
...
for (int i = 0; i < 100; i++)
{
    cout << arr[i] << endl;
}
```

- But how do we do this for a list or a set?

STL Iterators

- "abstract" way of traversing through elements
- `structure<data type>::iterator` -- pointer to an element in a container
- `.begin()` gives you the "first" element in the container
- .end() indicates that the iteration is complete

```
list<int> l;
for (list<int>::iterator it = l.begin(); it != l.end(); it++)
{
   cout << *it << " ";    // Note that '*'!!
}
```

STL Iterators

- Use **const_iterator** when the container is constant!

```
void func(const list<int> &l)
{
  for (list<int>::const_iterator it = l.begin(); it != l.end(); it++)
  {
     cout << *it << " ";
  }
}
```

begin(), end(), and back()

- begin(): return an iterator that points to the first element.
- end(): return an iterator that points to the ***past-the-last*** element
  - *past-the-last: a* theoretical element to represent the place after the last element.
- back(): return an iterator that points to the ***last*** element.

STL Iterators

- If you need to iterate in the reverse direction, you can optionally use **rbegin()** and **rend()**:

```
void func(const list<int> &l)
{
  for (list<int>::const_iterator it = l.rbegin(); it != l.rend(); it++)
  {
      cout << *it;       // Note that '*'!!
  }
}
```

- Note that you're still using it++ to "advance" the iterator.

STL Iterators

- Iterators are used to call some important functions like insert() and erase():

```
list<int> myList;
myList.push_back(0);    // 0
myList.push_back(1);    // 0 1

list<int>::iterator it = myList.begin();
it++;
myList.insert(it, 30); // 0 30 1, it still points to 1.
myList.erase(it);      // 0 30
```

Quick Note on erase()

- Suppose you're given a structure and would like to remove all elements that satisfy a certain condition:

```
for (list<int>::iterator it = l.begin(); it != l.end(); it++)
{
  if (*it == 10)
  {
     l.erase(it);   // remove the element pointed by it
  }
}
```

- What is the problem here?

Quick Note on erase()

- Suppose you're given a structure and would like to remove all elements that satisfy a certain condition:

```
for (list<int>::iterator it = l.begin(); it != l.end();)
{
  if (*it == 10)
  {
     it = l.erase(it);   // remove the element pointed by it
  }
  else
     it++;
}
```

- erase() returns an iterator for the next element.

Insight: List

- How list is implemented: *doubly linked list.*

- No [] allowed to access elements in List.
- Using iterator to traverse a list is always *Safe*.
- And: >, >=, <, and <= comparisons are NOT VALID for list iterators!

Insight: Vector

- How vector is implemented: *dynamic array.*

- We can use [] to access elements in a vector.
- >, >=, <, and <= comparisons are VALID for vector iterators.

- But there might be dangerous behaviors on vector iterators each time we have performed insertion/deletion (incl. push_back()).

Dangerous Behavior of Vector Iterator

```
int main () {
    vector<int> v;
    v.push_back(50);
    v.push_back(22);
    v.push_back(10);

    vector<int>::iterator b = v.begin();
    vector<int>::iterator e = v.end();
    for (int i = 0; i < 100; i++) {
       v.push_back(i);
    }
    while (b != e) {
       cout << *b++ << endl;
    }
 }
```

Dangerous Behavior of Vector Iterator

- Insertions and deletions on *vectors*, will possibly INVALIDATE any iterators defined on that vector !!!

Dangerous Behavior of Vector Iterator

- Dynamic arrays resize themselves as needed.
- Whenever this happens, the old array is deleted in favor of a new one, but the old iterators are not also updated, and so they refer to deallocated memory.
- Insertion at certain point cause the array of vector to expand (new array is created).
- Deletion at certain point cause it to shrink (also create new array).

Dangerous Behavior of Vector Iterator

- Reinitialize iterators of a vector whenever its size has been changed.
- *(We don't need to do that for List)*

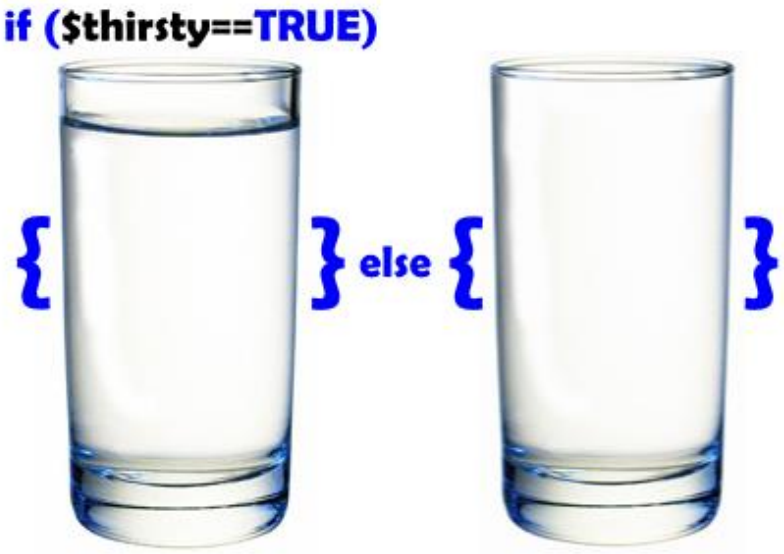
Differences between Vectors and Lists

	Vector	List
[]	Allowed	Not allowed
Compare iterators (<, >, =, etc)	Allowed	Not allowed
Use iterators after modifying contents	Not safe. Iterators need to be reinitialize	Safe
Body container	Dynamic Array	Doubly Linked List

STL

- You don't have to memorize names of member functions for each – you can just look things up when you need to.

  e.g. http://www.cplusplus.com/reference/stl/
- But **do** remember:
  - what data structure each container implements
  - how to use iterators



Bugs in your software are actually special features :)