

Lecture Material

Function templates

Class templates

Associative table

Templates

- Frequently we need to write similar function or classes operating on arguments of different types

```
int minimum(int x, int y)
{
    if (x < y)
        return x;
    else
        return y;
}
```

```
double minimum(double x, double y)
{
    if (x < y)
        return x;
    else
        return y;
}
```

- The templates enable us to write the code used for different types just once

```
TYPE minimum(TYPE x, TYPE y)
{
    if (x < y)
        return x;
    else
        return y;
}
```

Templates

```
template <class aType> aType minimum(aType x, aType y)
{
    if(x<y)
        return x;
    else
        return y;
}
```

Keyword

The name of the parameter representing type

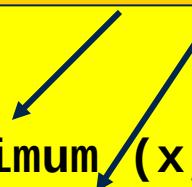
The name of a function template

Word *aType* is a name chosen by the user, not a keyword
aType can be almost any type
The < operation must be defined for *aType*

Templates

```
#include <iostream>
#include <string>
using namespace std;
template < class T > T minimum (T x, T y)
{
    if (x < y)
        return x;    Function template definition
    else
        return y;
}
int main ()
{
    int x = 50, y = 30;
    string a = "hello", b = "goodbye";
    cout << "minimum for ints " << minimum(x, y) << endl;
    cout << "minimum for strings " << minimum (a, b) << endl;
}
```

Template instantiation for given argument type(s)



Templates

Template declaration syntax:

Class template

```
template <class aType> className {  
    // class definition  
};
```

Function template

```
template <class aType> ReturnType  
functionName(arguments)  
{  
    // function definition  
}
```

Object Swap Function

```
#include <iostream>
#include <string>
using namespace std;
template<class T> void swap_value(T& var1, T& var2) {
    T temp;
    temp = var1;
    var1 = var2;
    var2 = temp;
}
int main() {
    int int1 = 1, int2 = 2;
    cout << "original " << int1 << " " << int2 << endl;
    swap_value(int1, int2);
    cout << "after " << int1 << " " << int2 << endl;
    string s1 = "one", s2 = "two";
    cout << "original " << s1 << " " << s2 << endl;
    swap_value(s1, s2);
    cout << "after " << s1 << " " << s2 << endl;
}
```

Works for all classes having operator =

Object Swap Function

```
// using swap_value template as before
class Value {
    private:
        int x;
    public:
        Value(int i = 0) : x(i) {}
        friend ostream& operator<<(ostream& out, Value v);
};

ostream& operator<<(ostream& out, Value v) {
    out << "value(" << v.x << ")";
    return out;
}

int main() {
    Value v1(5), v2(10);
    cout << "original " << v1 << " " << v2 << endl;
    swap_value(v1, v2);
    cout << "after " << v1 << " " << v2 << endl;
}
```

Bubblesort

```
// using swap_value template as before
template < class T >
void bubblesort (T * A, unsigned int size)
{
    for (unsigned int i = 0; i < size-1; i++)
        for (unsigned int j = size - 1; j > i; j--)
            if (A[j] < A[j-1])
                swap_value (A[j], A[j-1]);
}
int main ()
{
    string S[5]={"ula","ala","ola","genowefa","stefania"};
    int I[3]={4,1234,-7};
    bubblesort(S,5);
    bubblesort(I,3);
    for(int i=0;i<5;i++)
        cout<<S[i]<<endl;
    for(int i=0;i<3;i++)
        cout<<I[i]<<endl;
}
```

Works for all classes
having operator <
and operator =

Templates from the Compiler's Point of View

- # During template instantiation the compiler performs similar operations, as macro evaluation
 - # The programmer writes: `minimum(2,3)`
 - # The compiler emits the code for a new copy of a function calling it e.g. `minimum_int` and replaces `T` by `int` in the entire template code
 - # The compiler needs access to the full template code at the moment of instantiation
 - # Usually the entire template code is located in a header file

The *vector* Class Template

```
template<class C> class vector
{
    C *data;
    unsigned int size;
public:
    class index_out_of_range{};
    explicit vector (int s);
    ~vector ();
    C& operator[] (unsigned int pos);
    C operator[] (unsigned int pos) const;
    vector (const vector<C> & s);
    void swap(vector<C>& s);
    vector<C> & operator= (const vector<C> & s);
    friend ostream &
        operator<< (ostream & o, const vector<C> & v);
};
```

Template parameter

Template name

Keywords

Using Template Parameters

We can use the template parameter to:

Define the data type used in class

C *data;

Define the type of member function parameter

void swap(vector<C>& s);

Define the data type returned by member function

C& operator[] (unsigned int pos);

Template Instantiation

- # We have the template definition

```
template<class C> class vector {...};
```

- # *vector* is a class template, to obtain the class name we have to instantiate the template

vector - name of the class template

vector<int> - name of the class, vector of integers

- # The objects are created using the instantiated class template

```
vector<string> a(10);
typedef vector<int> intVector;
intVector b(5);
```

- # The specific type (*string* or *int*) is substituted as a formal template parameter (C) in template definition

Using Class Templates

- # After the template instantiation it is used in the same way, as an ordinary class

```
vector<string> a(5), b(10);  
a.swap(b);
```

- # The parameter to the swap function was given as *vector<C>&* in the template definition
- # Has been mapped to *vector<string>&* in the definition of object *a*
- # Therefore, when calling *a.swap*, we need to give *vector<string>* as an argument

Implementation of Class Template Members

template and formal parameters

```
template<class C> vector<C>::vector (int s)
```

```
{
```

//member function body goes here

```
}
```

scope operator and function name

class name and formal parameters

```
template<class C> void vector<C>::swap(vector<C>& s)
```

```
{
```

//member function body goes here

```
};
```

type of return value

```
template<class C> class vector
```

```
{
```

```
///...
```

```
void swap(vector<C>& s)
```

```
{
```

//member function body goes here

```
}
```

```
///...
```

```
};
```

Definition at the point
of declaration looks
much simpler

Memory Initialization and Default Constructor

- # The rules regarding initialization of memory allocated are presented below
- # *int* represents here any POD (Plain Old Data) type, i.e. a type, whose definition would look exactly the same in C

```
class Object /* ... */;

Object* p1 = new Object;    /* Object::Object() used */
Object* p2 = new Object();  /* Object::Object() used */
int*    p3 = new int;       /* not initialized! */
int*    p4 = new int();     /* initialized to zero */
Object* p5 = new Object[7];/* Object::Object() used 7 times */
int*    p6 = new int[7];    /* not initialized! */
int*    p7 = new int[7]();  /* initialized to zero */
```

Copy Constructor and Exceptions

- # If an exception is thrown in the constructor of class *vector<C>*, destructor of class *vector<C>* will not be invoked
- # Therefore we need to take care of freeing the memory in case of an exception in constructor

```
template<class C> class vector
{
//...
    vector (const vector<C> & s)
    {
        data = new C[s.size];
        size = s.size;
        try {
            for (unsigned i = 0; i < size; i++)
                data[i] = s.data[i];
        }
        catch(...)
        {
            delete [] data;
            throw;
        }
    }
};
```

The Assignment Operator and Exceptions

- To guarantee the proper operation of an assignment operator when an exception is thrown by an assignment operator of type *C*, we implement an assignment operator in terms of copy constructor and the *swap* function

```
template<class C> class vector
{
//...
void swap(vector<C>& s)
{
    C* t1=s.data;
    unsigned int t2=s.size;
    s.data=data;
    s.size=size;
    data=t1;
    size=t2;
}
vector<C> & operator= (const vector<C> & s)
{
    if (this == &s)
        return *this;
    vector<C> n(s);
    swap(n);
    return *this;
}
};
```

The *swap* function never throws an exception

When the exception is thrown in the assignment operator, the state of the object is not changed

Assumptions Regarding the Parameter C

- # Has the default constructor
 - # used in constructors to create an array of objects of type C
- # Has the copy constructor
 - # used in parameter passing in indexing operator
- # Has the assignment operator
 - # used in assignment opeator of template *vector<C>*
- # Has the << operator
 - # used in << operator of template *vector<C>*

Class Templates from the Compiler's Point of View

- # The programmer writes: `vector<int> a;`
- # Compiler emits a new copy of a class definition naming it e.g. `vector_int` and replaces `C` by `int` in the entire template code
- # The compiler needs the access to the full template code at the moment of instantiation
- # Usually entire code of the template is placed in a header file

Class Templates and Type Checking

- # The bodies of member functions use the same algorithms for a vector of integers, reals or character strings
 - # However, the compiler performs typechecking
- # If we write

```
vector<int> a;  
vector<double> b;  
vector<string> c;
```

the compiler will generate three different classes with the normal typechecking rules

```
a[7] = "ala"; //compile-time error
```

Associative Table

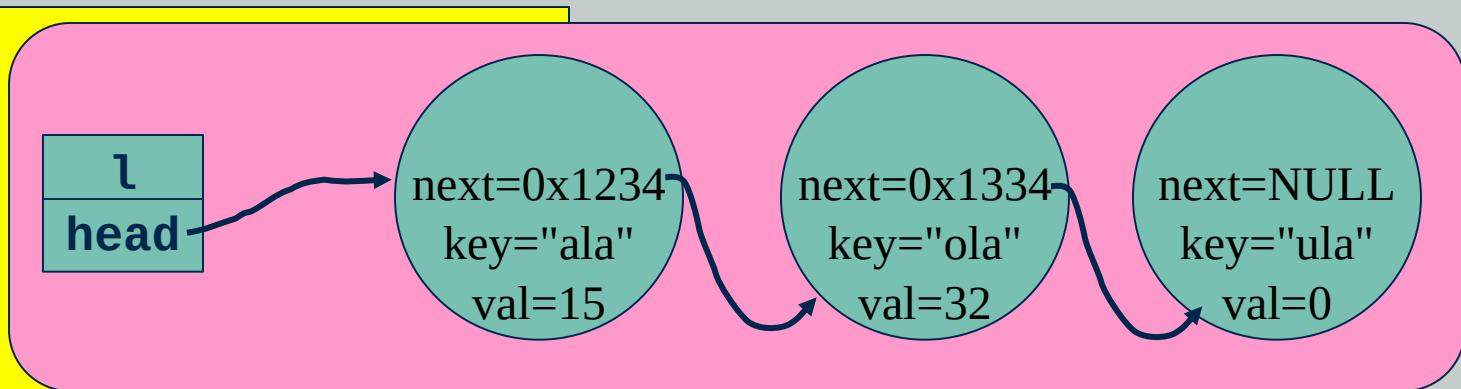
- # An associative table is a data structure containing the set of pairs <key,value>
- # Can be interpreted as a functions mapping the appropriate value to the key
- # It can be e.g. an array of integers indexed by character strings

```
assocTab at;  
at["ala"]=15;  
at["ola"]=32;  
cout << at["ala"]<<at["ola"]<<at["ula"]<<endl;
```

Associative Table

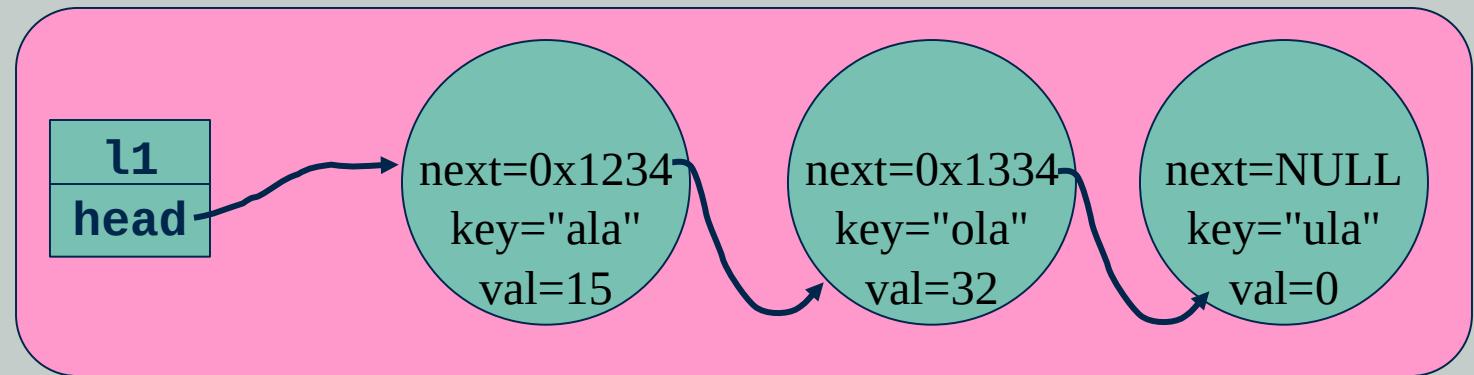
The associative table can be built based on a list structure

```
class assocTab
{
private:
    struct node
    {
        node *next;
        char* key;
        int val;
    };
    node * head;
    void insert (const char *key, int value);
    void clear ();
    node *find (const char *key) const;
    void swap (assocTab & l);
public:
    assocTab ();
    assocTab (const assocTab & l);
    assocTab & operator= (const assocTab & l);
    ~assocTab ();
    int &operator[] (const char *);
};
```



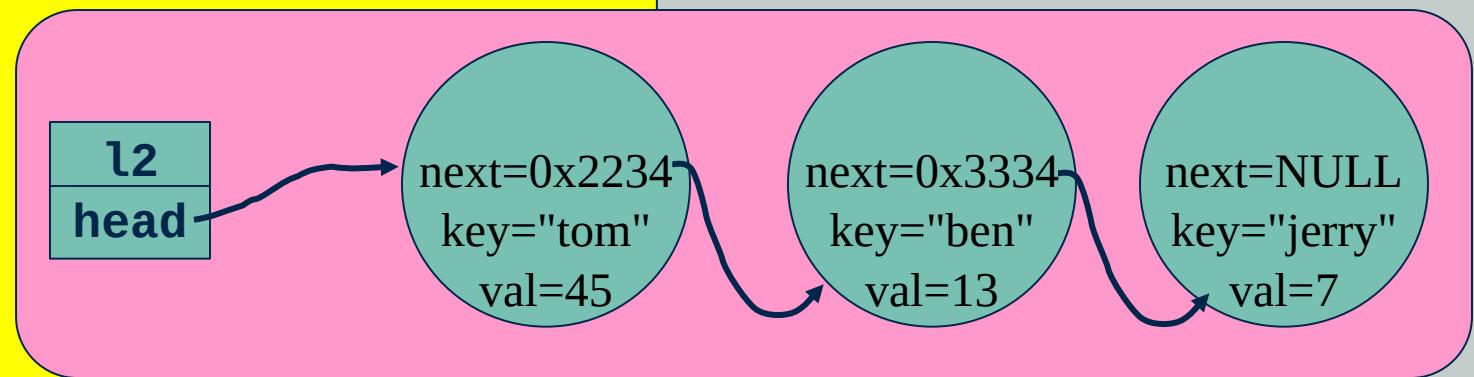
Associative Table - Function *swap*

- To ensure proper operation of an assignment operator, it has been implemented in terms of the copy constructor and the *swap* function



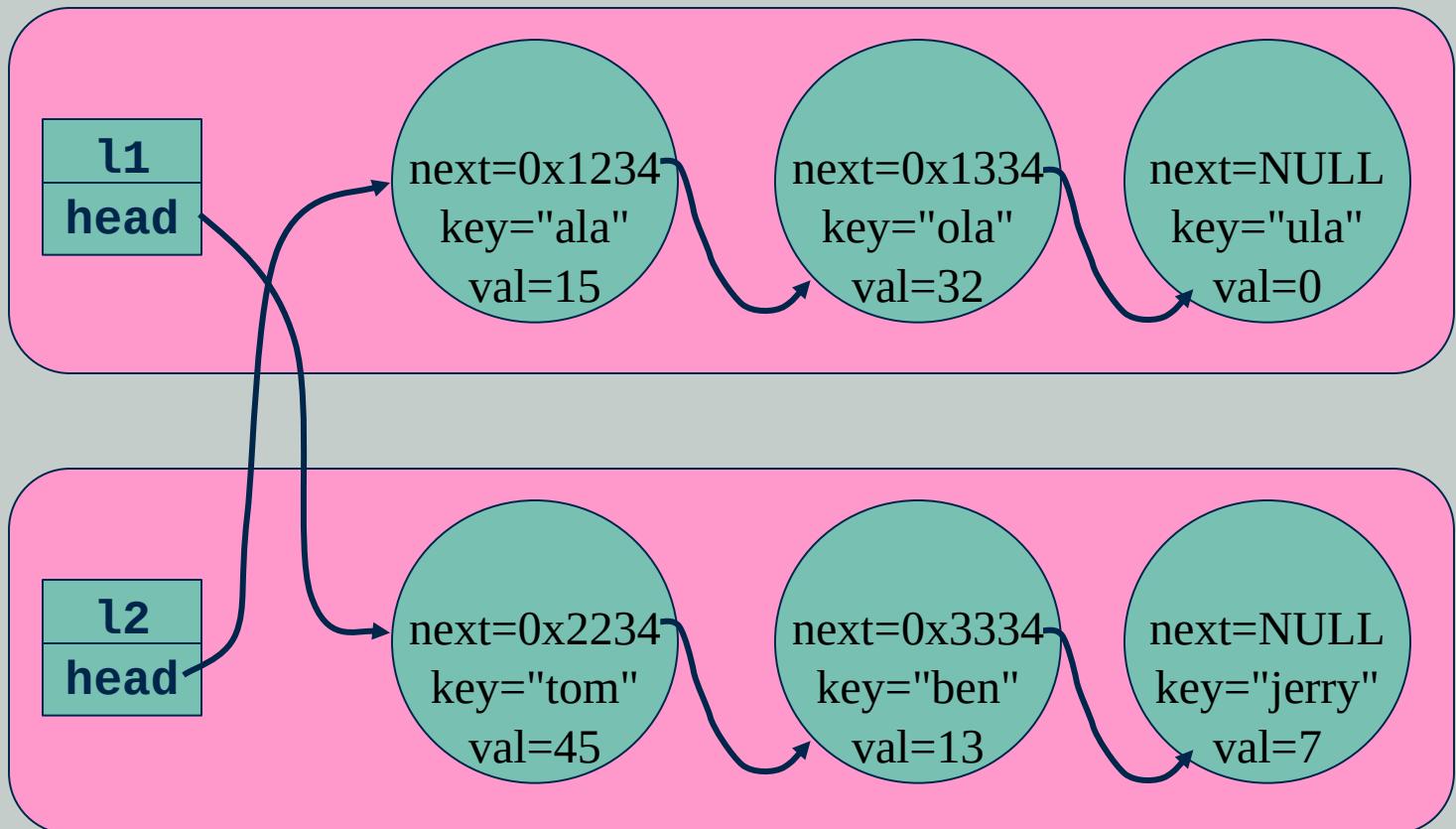
```
assocTab & assocTab::operator= (const assocTab & l)
```

```
{  
    if (&l == this)  
        return *this;  
    assocTab t (l);  
    swap (t);  
    return *this;  
}
```



Associative Table - Function *swap*

The *swap* function swaps only the pointers, so it cannot raise an exception



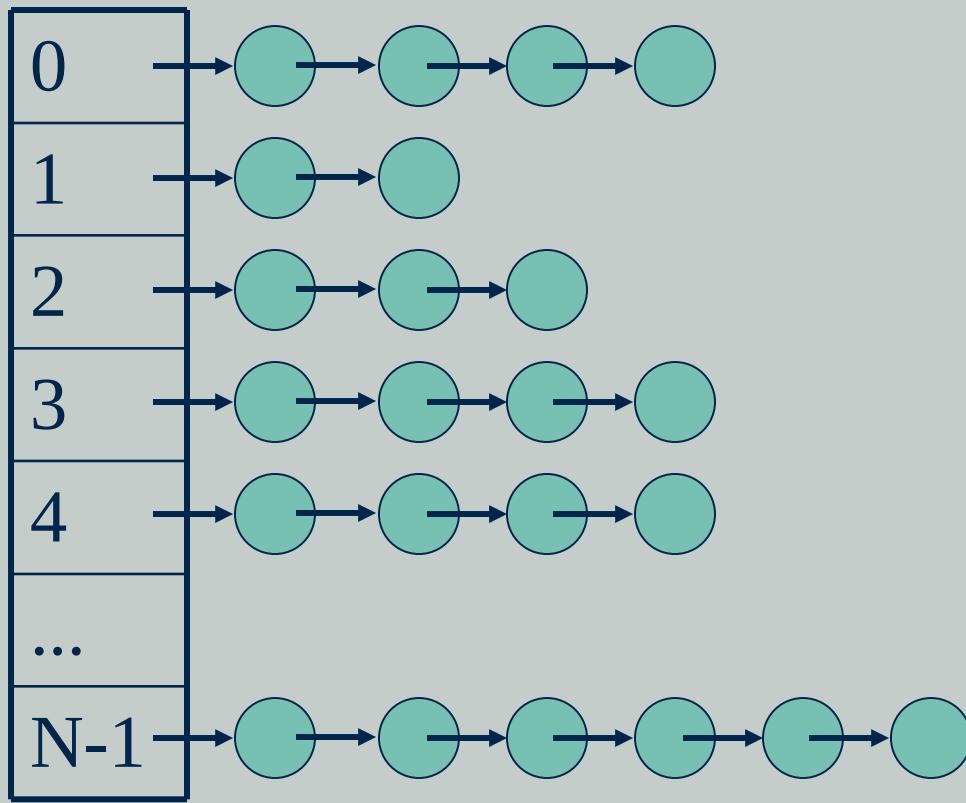
Associative Table - Improved

- # The time of search in the associative table implemented as a list is proportional to the number of elements in a table
- # Frequently used method to reduce the search time is to use a *hash function*
- # Hash function is a function, which maps a character string to the number in range <0...N-1>. The distribution of values should be uniform for all the strings placed in an array
- # The choice of appropriate hash function for the given application domain is an art

```
unsigned int hash(const char*);
```

Associative Table with a Hash Function

- # Instead of one list, we create N lists
- # Every list contains the nodes having the same value of hash function for a key



Ideally, the lengths of all lists are equal and the search time is reduced n times

Associative Table with a Hash Function

Defining the class, we will use the previously defined *vector* template

```
class hashAssocTab
{
    vector<assocTab> v;
    int chains;
public:
    hashAssocTab(unsigned int c): v(c),chains(c){};
    unsigned int hash(const char* s)
    {
        unsigned sum=0;
        while(*s)
        {
            sum+=(unsigned char)(*s);
            s++;
        }
        return sum % chains;
    }
    int& operator[] (const char *s)
    {
        return (v[hash(s)])[s];
    }
    // default constructor, destructor and assignment operator not necessary
};
```