

□ One Way to Look at Templates...

Until now, we have used variables:

- The type of a variable is fixed when you write code.
- The value of a variable isn't fixed when you write code.

With templates, type isn't fixed when you write code!

With templates, you use a type more or less as a variable!

Example: Queue of some type Foo

```
template <class Foo> class QueueT {
```

C++ keywords

Name of template

Parameter,
can be any type

```
private:  
    Foo Buffer[100];  
    int Head, Tail, Count;  
  
public:  
    QueueT();  
    void Enqueue(const Foo& item);  
    Foo Dequeue();  
    ~QueueT();  
};
```

The header of a templated class declaration specifies one or more type names which are then used within the template declaration.

These type names are typically NOT standard or user-defined types, but merely placeholder names that serve as formal parameters.

Definition of “template”:

Parameterized class with formal parameters that denote unknown types.

Usage:

In situations where the same algorithms and/or data structures need to be applied to different data types.

Declaration syntax:

```
template <class Foo> class Queue {  
// template member declarations go here  
};
```

□ What can a type parameter be used for?

To specify the type specifying of data which will be local to objects of the class:

```
private:  
    Foo Buffer[100];
```

To specify the type of a parameter to a class member function:

```
void Enqueue(const Foo& item);
```

To specify the return type of a class member function:

```
Foo Dequeue();
```

Instantiating a Template

Given the template declaration:

```
template <class Foo> class QueueT {...};
```

Instantiate QueueT of objects in two ways:

```
QueueT<Location> LocationQueue;
```

```
typedef QueueT<int> IntegerQueue;  
IntegerQueue intQueue;
```

Each of these defines an **object** which is derived from the template QueueT.

Note how an actual type (Location or int) is substituted for the formal template parameter (Foo) in the object declaration.

Once created, the template object is used like any other object:

```
intQueue.Enqueue(100);    // add 100 to the queue
intQueue.Enqueue(200);    // add 200
```

The parameter type for the member function `Enqueue()` was specified as `Foo` in the template declaration and mapped to `int` in the declaration of the object `intQueue`. When calling `Enqueue()` we supply an `int` value.

```
int x = intQueue.Dequeue(); // remove 100
intQueue.Enqueue(300);      // queue now
                             // has (200,300)
int Sz = intQueue.Size();   // size is 2
```

The compiler macro expands the template code:

- You write `QueueT<int> intQueue`.
- Compiler emits new copy of a class named, say, "QueueTint" and substitutes "int" for "Foo" throughout.
- Therefore, the compiler must have access to the parameterized implementation of the template member functions in order to carry out the substitution.
- Therefore, the template implementation CANNOT be pre-compiled.
- Most commonly, all template code goes in the header file with the template declaration.

The compiler "maps" the declaration:

```
private:  
    Foo Buffer[100];
```

to the declaration:

```
private:  
    int Buffer[100];
```

The compiler "mangles" the template name with the actual parameter (type name) to produce a unique name for the class.

Implementing Template Class Methods

template and
formal
parameter(s)

Class name and
formal
parameter(s)

Scope resolution
operator and
function name

```
template <class Foo> QueueT<Foo>::QueueT() {  
  
    // ... member function body goes here  
  
}
```

Return type goes here:

```
template <class Foo> void QueueT<Foo>::Enqueue(Foo item) {  
  
    // ... member function body goes here  
  
}
```

A Complete Template Queue Class

```
// QueueT.h
#ifndef QUEUET_H
#define QUEUET_H
#include <cassert>
const int Size = 100;
template <class Foo> class QueueT {
private:
    Foo Buffer[Size];
    int Head, Tail, Count;
public:
    QueueT();
    void Enqueue(const Foo& Item);
    Foo Dequeue();
    int getSize() const;
    bool isEmpty() const;
    bool isFull() const;
    ~QueueT();
};
// . . . template implementation goes here
#endif
```

Using the template parameter: data type, parameter type, return type.

```
// . . . continuing header file QueueT.h

template <class Foo> QueueT<Foo>::QueueT() : Head(0),
                                           Tail(0), Count(0) {
}

template <class Foo> void QueueT<Foo>::Enqueue(Foo Item) {

    assert(Count < Size);    // die if Queue is full!

    Buffer[Tail] = Item;
    Tail = (Tail + 1) % Size; // circular array indexing
    Count++;
}
```

A Complete Template Class

```
// . . . continuing header file QueueT.h

template <class Foo> Foo QueueT<Foo>::Dequeue() {

    assert(Count > 0);           // die if Queue is empty

    int oldHead = Head;         // remember where old Head was
    Head = (Head + 1) % Size;   // reset Head
    Count--;
    return Buffer[oldHead];      // return old Head
}

template <class Foo> int QueueT<Foo>::getSize() const {

    return (Count);
}
```

A Complete Template Class

```
// . . . continuing header file QueueT.h

template <class Foo> bool QueueT<Foo>::isEmpty() const {
    return (Count == 0);
}

template <class Foo> bool QueueT<Foo>::isFull() const {
    return (Count >= Size);
}

template <class Foo> QueueT<Foo>::~~QueueT() {
}

// . . . end template QueueT<Foo> implementation
```

A Driver for the QueueT Template

```
#include <iostream>
#include <iomanip>
using namespace std;
#include "QueueT.h"

void main() {

    const int numVals = 10;
    QueueT<int> intQ;

    for (int i = 0; i < numVals; i++) {
        intQ.Enqueue(i*i);
    }

    int Limit = intQ.getSize();
    for (i = 0; i < Limit; i++) {
        int nextVal = intQ.Dequeue();
        cout << setw(3) << i << setw(5) << nextVal << endl;
    }
}
```

| | |
|---|----|
| 0 | 0 |
| 1 | 1 |
| 2 | 4 |
| 3 | 9 |
| 4 | 16 |
| 5 | 25 |
| 6 | 36 |
| 7 | 49 |
| 8 | 64 |
| 9 | 81 |

Recap

Note that method bodies use the same algorithms for a queue of `ints` or a queue of `doubles` or a queue of `Locations`...

But the compiler still type checks!

It does a macro expansion, so if you declare

```
QueueT<int>      iQueue;  
QueueT<char>    cQueue;  
QueueT<Location> Vertices;
```

the compiler has instantiated three different classes after expansion to use with normal type checking rules.

Declaration of the array of FOOs assumes Foo has a default constructor:

```
template <class Foo> class QueueT {  
    private:  
        Foo Buffer[Size];  
        ...  
};
```

Assignment of FOOs assumes Foo has appropriately overloaded the assignment operator:

```
template <class Foo> void QueueT<Foo>::Enqueue(Foo item) {  
    ...  
    Buffer[tail] = item;  
    ...  
};
```

Implicit Assumptions in QueueT

The way that `Foo`s are returned by `Dequeue()` method assumes `Foo` has provided an appropriate copy constructor:

```
template <class Foo> Foo QueueT<Foo>::Dequeue() {  
    ...  
    return Buffer[oldHead];  
}
```

Template parameters may be:

type names (we saw this previously)

variables e.g., to specify a size for a data structure

constants useful to define templates for special cases
(not terribly useful)

Queue Template with a Variable Parameter

One weakness of the QueueT template is that the queue array is of a fixed size. We can easily make that user-selectable:

```
template <class Foo, int Size> class QueueT {
private:
    Foo  buffer[Size];
    int  Head,
        Tail;
    int  Count;
public:
    QueueT();
    bool Enqueue(Foo Item);
    bool Dequeue(Foo& Item);
    int  getSize() const;
    bool isEmpty() const;
    bool isFull() const;
    ~QueueT();
};
```

Second template parameter is just an int variable, which falls within the class scope just as a private data member would.

Driver for Revised Queue Template

```
#include <iostream>
#include <iomanip>
using namespace std;
#include "QueueT.h"
void main() {
    const int smallSize = 10;
    const int largeSize = 100;

    QueueT<int, smallSize> smallQ;
    QueueT<int, largeSize> largeQ;

    for (int i = 0; i < smallSize-1; i++)
        smallQ.Enqueue(i);

    for (i = 0; i < largeSize-1; i++) {
        largeQ.Enqueue(i);

        for (i = 0; i < largeSize-1; i++) {
            int nextVal;
            largeQ.Dequeue(nextVal);
            cout << setw(3) << i << setw(5) << nextVal << endl;
        }
    }
}
```

The value specified in the declaration must still be a constant though...

... that could be avoided by redesigning the template to take the array size as a parameter to a constructor...

Template Type-checking

Suppose we have the declarations:

```
QueueT<int, 100>    smallIntegerQueue;  
QueueT<int, 1000>  largeIntegerQueue;  
QueueT<int, 1000>  largeIntegerQueue2;  
QueueT<float, 100> smallRealQueue;  
QueueT<float, 1000> largeRealQueue;
```

Which (if any) of the following are legal assignments:

```
smallIntegerQueue = largeIntegerQueue;  
  
smallIntegerQueue = smallRealQueue;  
  
largeIntegerQueue = largeIntegerQueue2;
```

Linked List Template

```
// LinkListT.h
#ifndef LINKLISTT_H
#define LINKLISTT_H

#include <cassert>
#include "LinkNodeT.h"

template <class Item> class LinkListT {
private:
    LinkNodeT<Item>* Head; // points to head node in list
    LinkNodeT<Item>* Tail; // points to tail node in list
    LinkNodeT<Item>* Curr; // points to "current" node in list
```

These are pointers to template objects so any template parameters must be specified explicitly.

```
public:
    LinkListT();
    LinkListT(const LinkListT<Item>& Source);
    ~LinkListT();
```

Function parameter is a template object, so...

```
// . . .
```

Linked List Template

```
// . . .
    bool isEmpty() const;
    bool atEnd() const;
    bool PrefixNode(Item newData);
    bool AppendNode(Item newData);
    bool InsertAfterCurr(Item newData);
    bool Advance();
    void gotoHead();
    void gotoTail();
    bool MakeEmpty();
    bool DeleteCurrentNode();
    bool DeleteValue(Item Target);
    Item getCurrentData() const;
    void PrintList(ostream& Out);
    LinkListT<Item>& operator=(const LinkListT<Item>&
                               Source);
};

#include "LinkListT.cpp"

#endif
```

Operator return type is a template object, so...



Linked List Node Template

```
// LinkNodeT.h
#ifndef LINKNODET_H
#define LINKNODET_H


template <class Item> class LinkNodeT {
private:
    Item Data;
    LinkNodeT<Item>* Next;

public:
    LinkNodeT();
    LinkNodeT(Item newData);
    void setData(Item newData);
    void setNext(LinkNodeT<Item>* newNext);
    Item getData() const;
    LinkNodeT<Item>* getNext() const;
};

#include "LinkNodeT.cpp"

#endif
```

Function return type is a pointer to a template object, so...



A Node Template Constructor

```
////////////////////////////////////  
// Constructor for LinkNode objects with assigned  
// Data field.  
//  
// Parameters:  
//   newData   Data element to be stored in node  
// Pre:        none  
// Post:       new LinkNode has been created with  
//             given Data field and NULL  
//             pointer  
//  
template <class Item>  
LinkNodeT<Item>::LinkNodeT(Item newData) {  
    Data = newData;  
    Next = NULL;  
}
```

```
////////////////////////////////////  
// Sets new value for Data element of object.  
//  
// Parameters:  
//   newData   Data element to be stored in node  
// Pre:        none  
// Post:       Data field of object has been  
//             modified to hold newData  
//  
template <class Item>  
void LinkNodeT<Item>::setData(Item newData) {  
  
    Data = newData;  
}  
  
////////////////////////////////////  
// Suppressed to save space.  
//  
template <class Item>  
void LinkNodeT<Item>::setNext(LinkNodeT<Item>* newNext) {  
  
    Next = newNext;  
}
```

```
////////////////////////////////////  
// Returns value of Data element of object.  
//  
// Parameters: none  
// Pre:      object has been initialized  
// Post:     Data field of object has been  
//           returned  
//  
template <class Item>  
Item LinkNodeT<Item>::getData() const {  
  
    return Data;  
}  
  
////////////////////////////////////  
// Suppressed to save space.  
//  
template <class Item>  
LinkNodeT<Item>* LinkNodeT<Item>::getNext() const {  
  
    return Next;  
}
```

```
////////////////////////////////////  
// Destructor for LinkListT objects.  
//  
// Parameters: none  
// Pre:      LinkListT object has been constructed  
// Post:     LinkListT object has been destructed;  
//           all dynamically-allocated nodes  
//           have been deallocated.  
//  
template <class Item> LinkListT<Item>::~~LinkListT() {  
  
    LinkNodeT<Item>* toKill = Head;  
  
    while ( toKill != NULL) {  
        Head = Head->getNext();  
        delete toKill;  
        toKill = Head;  
    }  
}
```

Linked List Template Prefix Function

```
////////////////////////////////////  
// Inserts a new LinkNodeT at the front of the list.  
//  
template <class Item> bool LinkListT<Item>::PrefixNode(Item  
newData) {  
  
    LinkNodeT<Item>* newNode =  
                                new LinkNodeT<Item>(newData);  
  
    if (newNode == NULL) return false;  
  
    if ( isEmpty() ) {  
        newNode->setNext(NULL);  
        Head = Tail = Curr = newNode;  
        return true;  
    }  
    newNode->setNext(Head);  
    Head = newNode;  
  
    return true;  
}
```

```
////////////////////////////////////  
// Deep copy assignment operator for LinkListT objects.  
//  
template <class Item>  
LinkListT<Item>& LinkListT<Item>::  
operator=(const LinkListT<Item>& Source) {  
  
    if (this != &Source) {  
  
        MakeEmpty();                // delete target's list, if any  
  
        LinkNodeT<Item>* myCurr = Source.Head; // copy list  
  
        while (myCurr != NULL) {  
            Item xferData = myCurr->getData();  
            AppendNode(xferData);  
            myCurr = myCurr->getNext();  
        }  
    }  
    return *this;  
}
```

Linked List Template Copy Constructor

```
////////////////////////////////////  
// Deep copy constructor for LinkListT objects.  
//  
template <class Item>  
LinkListT<Item>::LinkListT(const LinkListT<Item>& Source) {  
  
    Head = Tail = Curr = NULL;  
  
    LinkNodeT<Item>* myCurr = Source.Head;    // copy list  
  
    while (myCurr != NULL) {  
        Item xferData = myCurr->getData();  
        AppendNode(xferData);  
        myCurr = myCurr->getNext();  
    }  
}
```

The template mechanism may also be used with non-member functions:

```
template <class Foo> Swap(Foo& First, Foo& Second) {  
    Foo tmpFoo = First;  
    First      = Second;  
    Second    = tmpFoo;  
}
```

Given the template function above, we may swap the value of two variables of ANY type, provided that a correct assignment operation and copy constructor are available.

However, the two actual parameters **MUST** be of **EXACTLY** the same type:

```
double X = 3.14159;  
int    a = 5;  
Swap(a, X);           // error at compile time
```

```
template <class Foo> void InsertionSort(Foo* const A, int Size) {  
  
    int Begin, Look;  
    Foo Item;  
  
    for (Begin = 1; Begin < Size; Begin++) {  
        Look = Begin - 1;  
        Item = A[Begin];  
        while ( Look >= 0 && A[Look] > Item) {  
            A[Look + 1] = A[Look];  
            Look--;  
        }  
        A[Look + 1] = Item;  
    }  
}
```

This will use the insertion sort algorithm to sort an array holding ANY type of data, provided that there are > and deep = operators for that type (if a deep assignment is logically necessary).