Linked List Classes

Slides

Linked List Example

This chapter presents a sample implementation of a linked list, encapsulated in a C++ class.

The primary goals of this implementation are:

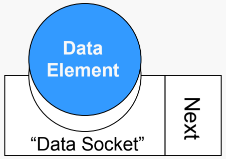
- to provide a proper separation of functionality.
- to design the list to serve as a container; i.e., the list should be able to store data elements of any type.

First, a `LinkNode` class is used to encapsulate the low-level pointer operations.

Second, a `LinkList` class is used to encapsulate a list of `LinkNode` objects.

Third, an `Item` class is used to encapsulate the data and separate it from the pointers that define the list structure.

The basic view is that each list node provides a data "socket" that is capable of accepting any type of data element:



Warning: the LinkList class given in this chapter is intended for instructional purposes. The given implementation contains a number of **known** flaws, and perhaps some **unknown** flaws as well. Caveat emptor.

Node Class

LinkNode class is used to encapsulate pointer operations:

```
// LinkNode.h
//
// The LinkNode class provides a simple
// implementation
// for nodes of a singly-linked list structure.
//
// The user must provide a declaration and
// implementation of a class named Item in
// order for the given implementation of LinkNode
// to be valid.
//
#ifndef LINKNODE
#define LINKNODE
#include "Item.h"  // for Item type declaration

class LinkNode {
private:
   Item      Data; // data "capsule"
   LinkNode* Next; // pointer to next node

public:
   LinkNode();
   LinkNode(const Item& newData);
   void setData(const Item& newData);
   void setNext(LinkNode* const newNext);
   Item getData() const;
   LinkNode* getNext() const;
};

#endif
```

const for protection

Why does LinkNode not contain a destructor?

```
// to define a LinkNode pointer type
class LinkNode; // Forward declaration
typedef LinkNode* NodePtr;
```

The LinkNode class neither knows nor cares what an Item variable is — a LinkNode is a container.

Node Class Constructors

LinkNode constructor implementations:

```
// LinkNode.cpp
//
#include "LinkNode.h"  // for class declaration

///////////////////////////////////////////////////
// Default constructor for LinkNode objects.
//
// Parameters: none
// Pre:        none
// Post:       new LinkNode has been created with
//                 default Data field and NULL
//                 pointer
//
LinkNode::LinkNode() {
   //explicit initialization of
   //Data member unnecessary
   Next = NULL;
}

///////////////////////////////////////////////////
// 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
//
LinkNode::LinkNode(const Item& newData) {
   Data = newData;
   Next = NULL;
}
```

Uses default construction for Item objects.

Uses default (or overloaded) assignment for Item objects.

We are assuming that Item is a class. (Do you see where?)

Node Class Mutators

LinkNode mutator implementations :

```
////////////////////////////////////////////////////
// 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
//
void LinkNode::setData(const Item& newData) {

   Data = newData;
}

////////////////////////////////////////////////////
// Sets new value for Next pointer of object.
//
// Parameters:
//   newNext   new value for pointer field
// Pre:        none
// Post:       Next field of object has been
//                 modified to hold newNext
//
void LinkNode::setNext(LinkNode* const newNext) {

   Next = newNext;
}
```

Why is the parameter to setNext not passed as:

`const LinkNode* const newNext`

Node Class Reporters

LinkNode reporter implementations :

```
////////////////////////////////////////////////////
// Returns value of Data element of object.
//
// Parameters: none
// Pre:        object has been initialized
// Post:       Data field of object has been
//                 returned
//
Item LinkNode::getData() const {

   return Data;
}

////////////////////////////////////////////////////
// Returns value of Next pointer of object.
//
// Parameters: none
// Pre:        object has been initialized
// Post:       Next field of object has been
//                 returned
//
LinkNode* LinkNode::getNext() const {

   return Next;
}
```

Uses const to guarantee no modification occurs.

Linked List Class

LinkList class is used to encapsulate all high-level list operations:

```
// LinkList.h
// The LinkList class provides an implementation for a
// singly-linked list consisting of ListNode objects.
//
// User must provide a declaration and implementation
// of a class named Item with a default constructor and
// an overloaded == operator in order for the given
// implementation of LinkNode to be valid.

#ifndef LINKLIST_H
#define LINKLIST_H

#include <cassert>

#include "LinkNode.h"   // for node declaration
//#include "Item.h" // must be included by user

class LinkList {
private:
   LinkNode* Head;    // points to head node in list
   LinkNode* Tail;    // points to tail node in list
   LinkNode* Curr;    // points to "current" node
public:
   LinkList(); //constructor
   ~LinkList();//destructor
   bool isEmpty() const;
   bool inList() const;
   bool PrefixNode(const Item& newData);
   bool Insert(const Item& newData);
   bool Advance();
   void gotoHead();
   void gotoTail();
   bool DeleteCurrentNode();
   bool DeleteValue(const Item& Target);
   Item getCurrentData() const;
   void setCurrentData(const Item& newData);
// missing: copy constructor, assignment overload FNs
};
#endif
```

One line Fns could be "inline" for efficiency.

consts for protection

See Copying Objects notes for missing functions.

LinkList Constructor

Code

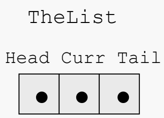
```
// LinkList.cpp
//
#include "LinkList.h"


//////////////////////////////////////////////////
// Default constructor for LinkList objects.
//
// Parameters: none
// Pre:        none
// Post:       new empty LinkList has been created
//
LinkList::LinkList() {
   Head = Tail = Curr = NULL;
}
```

The object definition:

```
LinkList TheList;
```

Results in the following state:



LinkList Destructor

Code

```
//////////////////////////////////////////////////
// Default destructor for LinkList objects.
//
// Parameters: none
// Pre:        LinkList object has been constructed
// Post:       LinkList object has been destructed;
//                 all dynamically-allocated nodes
//                 have been deallocated.
//
LinkList::~LinkList() {

   LinkNode* toKill = Head;

   while ( toKill != NULL) {
      Head = Head->getNext();
      delete toKill;
      toKill = Head;
   }
   Head = Tail = Curr = NULL;
}
```

Compiler generates calls to the destructor automatically whenever a LinkList object goes out of scope (i.e. its lifetime ends: at the end of the function/block in which the objects are defined, when a dynamically allocated object is destroyed with delete(), when an object containing a member object is destroyed).

A class destructor's names is always the tilde followed by the name of the class. It has no parameters or return type and cannot be overloaded.

LinkList needs a destructor in order to properly return the dynamically-allocated nodes to the system heap.

LinkList Reporters

Code

```
//////////////////////////////////////////////////
// Indicates whether LinkList is empty.
//
// Parameters: none
// Pre:        LinkList object has been constructed
// Post:       returns true if object contains an
//                  empty list, and false otherwise
//
bool LinkList::isEmpty() const {

   return (Head == NULL);
}

//////////////////////////////////////////////////
// Indicates whether the current pointer for the
// LinkList object has a target.
//
// Parameters: none
// Pre:        LinkList object has been constructed
// Post:       returns true if current pointer has
//                 a target, and false otherwise
//
bool LinkList::inList() const {

   return (Curr != NULL);
}
```

LinkList uses a pointer (Curr) to keep a sense of the current position in the list as operations are performed.

This isn't absolutely necessary (especially if the list is to be kept sorted in some order), but it is useful for general lists.

LinkList PrefixMutator

Code: inserting at the head of the list

```
//////////////////////////////////////////////////
// Inserts a new LinkNode at the front of the
// list.
//
// Parameters:
//    newData  Data element to be inserted
// Pre:        LinkList object has been constructed
// Post:       LinkNode containing newData has been
//                 constructed and inserted at the
//                 beginning of the list, if
//                 possible.
//
// Returns:    true if operation succeeds
//             false otherwise
//
bool LinkList::PrefixNode(const Item& newData) {

   LinkNode* newNode = new(nothrow) LinkNode(newData);

   if (newNode == NULL) return false;

   if ( isEmpty() ) {
      newNode->setNext(NULL);
      Head = Tail = Curr = newNode;
      return true;
   }

   newNode->setNext(Head);
   Head = newNode;

   return true;
}
```

Pointer dereference. This is a very good place to blow up at runtime if you don't verify newNode is not NULL prior to this statement.

Is this statement necessary? (Included as a precaution?)

Uses LinkNode member functions to modify node pointers — this gives a separation between the "high" level list functions the user sees and the "massaging" of the pointers.

LinkList Insert Mutator

Code: inserting after the current position

```
//////////////////////////////////////////////////
// Inserts a new LinkNode immediately after the
// current position in the list.
//
// Parameters:
//    newData  Data element to be inserted
// Pre:        LinkList object has been constructed
// Post:       LinkNode containing newData has been
//                 constructed and inserted after
//                 the current position, if possible.
//
// Returns:    true if operation succeeds
//             false otherwise
//
bool LinkList::Insert(const Item& newData) {

   if (Curr == NULL) return false;

   LinkNode* newNode = new(nothrow) LinkNode(newData);

   if (newNode == NULL) return false;

   if ( isEmpty() )
      return false;

   newNode->setNext(Curr->getNext());
   Curr->setNext(newNode);
   if (Curr == Tail)
      Tail = newNode;

   return true;
}
```

Why should this case never occur?

Note test for valid current position.

LinkList Position Mutators

Code: changing the current position

```
////////////////////////////////////////////////////////
// Resets the current position to the head of the list.
//
void LinkList::gotoHead() {

   Curr = Head;
}

////////////////////////////////////////////////////////
// Resets the current position to the tail of the list.
//
void LinkList::gotoTail() {

   Curr = Tail;
}

///////////////////////////////////////////////////
// Advances the current position to the next node
// in the list, if there is one; leaves the
// current position unchanged otherwise.
//
// Parameters: none
// Pre:        LinkList object has been constructed
// Post:       Current position advanced to the
//                 next node, if possible.
//
// Returns:    true if operation succeeds
//             false otherwise
//
bool LinkList::Advance() {

   if (Curr != NULL) {
      Curr = Curr->getNext();
      return true;
   }
   else
      return false;
}
```

Note test for valid current position.

LinkList Delete Curr Mutator

Code: deleting the current node

```
/////////////////////////////////////////////////////////
// Deletes the node at the current position, if possible.
//
// Returns:    true if operation succeeds false otherwise
//
bool LinkList::DeleteCurrentNode() {

   LinkNode* delThis;

   if (Curr == NULL) return false;

   if (Curr == Head) { //delete Head node
      delThis = Curr;
      Head = Head->getNext();
      Curr = Head;
      if (Tail == delThis) Tail = Curr;
      delThis->setNext(NULL);
      delete delThis;
      return true;
   }

   //locate Curr's previous node
   LinkNode* prevNode = Head;
   while (prevNode != NULL &&
          prevNode->getNext() != Curr)
      prevNode = prevNode->getNext();

   //check for valid Curr pointer
   if (prevNode == NULL) return false;

   //previous found bypass and delete Curr
   delThis = Curr;
   prevNode->setNext(Curr->getNext());
   Curr->setNext(NULL);
   Curr = prevNode->getNext();
   if (Tail == delThis) Tail = prevNode;
   delete delThis;
   return true;
}
```

Test for valid current position.

Handle deletion of head node.

Find previous node.

If not found, error.

Handle deletion of node in middle or at tail of list.

LinkList Delete Value Mutator

Code: deleting a list value

```
//////////////////////////////////////////////////
// Deletes the (first) node in the list that
// contains the specified Data element.
//
// Parameters:
//    Target    Data value to be deleted
// Pre:         LinkList object has been constructed
//              Equality oper. overloaded for Item
// Post:        First node in the list that contains
//                  the specified data value has
//                  been deleted.
//
// Returns:     true if operation succeeds
//              false otherwise
//
bool LinkList::DeleteValue(const Item& Target) {

   LinkNode* myCurr    = Head;
   LinkNode* myTrailer = NULL;

   while ( (myCurr != NULL) &&
           !(myCurr->getData() == Target) ) {
      myTrailer = myCurr;
      myCurr = myCurr->getNext();
   }
   if (myCurr == NULL) return false;

   if (myTrailer == NULL)
      Head = Head->getNext();
   else
      myTrailer->setNext(myCurr->getNext());

   if (Curr == myCurr) Curr = myTrailer;
   if (Tail == myCurr) Tail = myTrailer;
   myCurr->setNext(NULL);
   delete myCurr;
   return true;
}
```

Look for matching node.

If not found, error.

Handle case target is the head node.

Handle deletion of node in middle or at tail of list.

LinkList Set Curr Mutators

Code: changing the Data in the current node

```
//////////////////////////////////////////////////
// Replaces the Data element of the current node,
// if possible; assert() failure will kill program
// if not, so test with inList() before calling.
//
// Parameters:
//    newData   Data element used for updating
// Pre:         LinkList object has been constructed
// Post:        Data element of current node has
//                  been updated, if possible.
//
void LinkList:: setCurrentData(const Item& newData) {

   assert (Curr != NULL);

   Curr->setData(newData);
}
```

If no current position, die. 

This implementation places a burden on the user of the class. If the current position is undefined (e.g., if the list is empty), then the call to `assert()` will cause the program to terminate rather gracelessly. A better design would alert the user/client:

```
bool LinkList:: setCurrentData(const ItemType& newData)
{

   if (!Curr) return false;

   Curr->setData(newData);
   return true;
}
```

LinkList Reporter

Code: returning the Data in the current node

```
//////////////////////////////////////////////////
// Returns the Data element of the current node,
// if possible; assert() failure will kill program
// if not, so test with inList() before calling.
//
// Parameters: none
// Pre:        LinkList object has been constructed
// Post:       Data element of current node has
//                 been returned, if possible.
//
Item LinkList::getCurrentData() const {

   assert (Curr != NULL);

   return (Curr->getData());
}
```

If no current position, die.

This possible premature termination due to an undefined current position could be eliminated by having the function return a pointer to a copy of the data element, or by having the function use a reference parameter to communicate a copy of the data value to the caller, and also return true/false to indicate success.

Better design: maintain an internal error state in the class. (E.g., similar to the stream status in <iostream>).

Note: a pointer to an object in a list (i.e. `Item*`) or a reference to an object in a list (i.e. `Item&`) should NOT be returned by a member function. Why?

Data Element Class

The user must `typedef` Item to match the data class that he/she really wishes to use. Recall the Inventory Class:

```
// *********** INVENTORY CLASS DECLARATION ************

class InvItem {
  private:
   string SKU;            //StocK Unit #: KEY FIELD
   string Description;    //Item Details
   int    Retail;         //Selling Price
   int    Cost;           //Store Purchase Price
   int    Floor;          //Number of Items on display
   int    Warehouse;      //Number of Items in stock

  public:
   InvItem();             //default constructor
   InvItem(const string& iSKU, //parameter constructor
           const string& iDescription,
                 int    iRetail,
                 int    iCost,
                 int    iFloor,
                 int    iWarehouse);

   //Reporter Member Functions
   // . . . Unchanged from previous declaration

   //Mutator Member Functions
   // . . . Unchanged from previous declaration

   //Operator Overloads
   bool operator==(const InvItem& anItem);

}; // class InvItem

typedef InvItem Item;
```

Required type name equivalency definition

Data Class Equality Operator

Inventory class equality operator:

```
//-------------- Operator Overload Functions ---------

////////////////////////////////////////////////////////
// Operator == Fn for InvItem Class
//
// Parameters:   an Item to compare
// Pre:          members have been initialized
// Post: T/F comparison of SKUs returned
//
bool InvItem::operator==(const InvItem& anItem){

        return (SKU == anItem.getSKU());
}
```

This simple operator overload function is required for the correct use of the LinkList class. The `DeleteValue()` function assumes that two Item objects can be compared for equality, (but not inequality).

By only testing the SKU members for equality the code is reflecting a design decision that the SKU numbers of all Inventory items must be unique.

//OK?

```
return (SKU == anItem.SKU);
```


LinkList Search

Sequential search function for LinkList:

```
//////////////////////////////////////////////////////
// Search function for LinkList Item objects.
//
// Parameters:
//    List      a LinkList object
//    Item      a Item object
// Pre:         LinkList object has been constructed
//              Equality oper. overloaded for Item
// Post:        returns true if anItem is found in List
//              and false otherwise
//
bool   Search(LinkList& List, const Item& anItem) {

   if (List.isEmpty())
         return false;
   else {
         List.gotoHead();
         while( (List.inList()) &&
               !((List.getCurrentData() == anItem)) )
            List.Advance();

         return (List.inList());
   }
} // Search
```

Note: this function is "external" to the LinkList class. The inclusion of the function as a LinkList class member function is left as an exercise.

Why is the second condition in the while boolean expression not stated:

`(anItem != (List.getCurrentData())`

Even more subtle, why can it not also be stated:

`!(anItem == (List.getCurrentData()))`

Alternate Implementation

Alternate PrefixNode() Implementation:

```
////////////////////////////////////////////////////
// Inserts a new LinkNode at the front of the
// list.
//
// Parameters:
//    newData  Data element to be inserted
// Pre:        LinkList object has been constructed
// Post:       LinkNode containing newData has been
//                 constructed and inserted at the
//                 beginning of the list, if
//                 possible.
//
// Returns:    true if operation succeeds
//             false otherwise
//
bool LinkList::PrefixNode(const Item& newData) {

   LinkNode newNode(newData);

   if ( isEmpty() ) {
      newNode.setNext(NULL);
      Head = Tail = Curr = &newNode;
      return true;
   }

   newNode.setNext(Head);
   Head = &newNode;

   return true;
}
```

Is the above implementation superior or inferior to the original implementation of PrefixNode(), see slide 7.11?

Merge Lists (preservation)

```
/* Given 2 ascending ordered single linked-lists,
   return a new ordered list which contains all of
   the elements of both lists, (the original lists
   must NOT be destroyed by the merging). */

LinkList MergeLists(LinkList L1, LinkList L2){
  Item TmpData;
  LinkList merge;

  L1.gotoHead();
  while (L1.inList()) {
     TmpData = L1.getCurrentData();
     insertion(merge, TmpData);
     L1.Advance();
  }

  L2.gotoHead();
  while (L2.inList()) {
     TmpData = L2.getCurrentData();
     insertion(merge, TmpData);
     L2.Advance();
  }

  return merge;
}
```

AddList(merge, L1) ;

AddList(merge, L2) ;

//No preservation
L1.~LinkList();
L2.~LinkList();

```
void AddList(LinkList& target, LinkList source)
{
  Item TmpData;

  source.gotoHead();
  while (source.inList()) {
     TmpData = source.getCurrentData();
     insertion(target, TmpData);
     source.Advance();
  }
}
```

insertion(performs an ordered insert)

WARNING: untested code!

Ordered Insertion

Non-class, (non-member), function to perform an ordered LinkList insertion.

```
// Insert the Item in the ascending ordered LinkList

bool insertion(LinkList& list, const Item & newData){

  list.gotoHead();

  while ( (list.inList()) &&
          (list.getCurrentData() < newData ) )
     list.Advance();

  if (list.isEmpty())
     return(list.PrefixNode(newData));
  else if (!list.inList()) { //newData > tail
          list.gotoTail();   //append to tail
          return(list.Insert(newData));
       }
  else { //insert before Current list element
         Item tmpData = list.getCurrentData();
         list.setCurrentData(newData);
         return(list.Insert(tmpData));
       }
}
```

Sets current node to contain newData item and inserts old node data item after current node.

WARNING: untested code!

Merge Lists (no preservation) *in situ*

```
/* Given 2 ascending ordered single linked-lists, merge
all of the elements of both lists together returned
through the first list, (the second list is destroyed by
the merging). */

void LinkList::Mergelists(LinkList& L2) {

   LinkNode* MergeHead;
   LinkNode* trail1;
   LinkNode* trail2;
   Item i1, i2;

   if (Head == NULL) { //this empty return L2 List
      Head = L2.Head; L2.Head = NULL;
      Curr = L2.Curr; L2.Curr = NULL;
      Tail = L2.Tail; L2.Tail = NULL;
      return;
   }//if
   if (L2.Head == NULL) //return this List
      return;

   // set merge list head to smaller first item
   MergeHead = (Head->getData() < L2.Head->getData())
                    ? Head : L2.Head;

   while ( (Head != NULL) && (L2.Head != NULL) ) {
      i1 = Head->getData();
      i2 = L2.Head->getData();

      if ( i1 == i2 ){//equal current merge items
         trail2 = L2.Head->getNext();//advance L2.Head
         L2.Head->setNext(Head);      //due to initial/curr
         L2.Head = trail2;            //equal elements
      }//if
```

Assumes elements within list are unique.

while conditions rely upon Boolean short-circuiting.

Problem: if List2 contains multiple items equal to head of list1?

WARNING: untested code!

Merge Lists *in situ* (cont)

```
          else
         if ( i1 < i2 ) {             //advance this list
            while ( (Head != NULL) && //until end of list
                  (Head->getData() < i2) ) { //or smaller
               trail1 = Head;         // item is found
               Head = Head->getNext();
            } //while
            trail1->setNext(L2.Head);
         } //if
         else { //i2 < i1               //advance L2 list
            while ( (L2.Head != NULL)  &&//until end list
                  (L2.Head->getData() < i1) ) { //or
               trail2 = L2.Head;        //smaller item is
               L2.Head = L2.Head->getNext(); //found
            } //while
            trail2->setNext(Head);
         } //else

   } //while

   if ( Head == NULL )//L2 is longer list
      Tail = L2.Tail; //update Tail

   L2.Head = L2.Tail = L2.Curr = NULL;
   Head = MergeHead;
}
```

Duplicated code should be eliminated.

WARNING: untested code!