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:

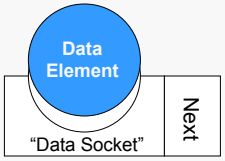
- to provide a proper separation of functionality.
- to design the list to serve as a container; i.e., the list should be able to store data elements of any type.

First, a node class, `SNode` class is used to encapsulate the data and pointers.

Second, a `SList` class is used to encapsulate a list of `SNode` 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 SList 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.

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SNode Class


```
// SNode.h
//
// Singly-linked node class.
//
// Features:
//   - Default SNode contains default Item object and
//     a NULL pointer.
//   - Accessor function getData() returns a reference
//     to the stored data element, allowing user editing
//     of the data object.
//
// Assumptions:
//   - User will supply a header file, Item.h containing
//     a typedef statement mapping some real type to
//     the name Item used in SNode.
//   - That type will provide deep copy support and a
//     destructor, if needed.
//
#ifndef SNODE_H
#define SNODE_H

#include "Item.h"      // for typedef

class SNode {
private:
   Item  Element;
   SNode *Next;

public:
   SNode();
   SNode(const Item& E, SNode* N = NULL);

   Item&  getData();
   void   setData(const Item& E);
   SNode* getNext();
   void   setNext(SNode* N);
};

#endif
```

Why is there no destructor?

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

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SNode Class Constructors

`SNode` constructor implementations:

```
// SNode.cpp
#include <cstdlib>   // for NULL
#include "SNode.h"   // for declaration of type SNode

//////////////////////////////////////////// SNode()
// Constructs an empty node, with default data
// element and NULL pointer.
// Parameters:  none
// Returns:     none
// Calls:       none
// Called by:   client code
//
SNode::SNode() {

   Next = NULL;
}

//////////////////////////////// SNode(Data, Pointer)
// Constructs a node with specified data
// element and pointer.
// Parameters:
//    E     data value to place in node
//    N     pointer to next node
// Returns:     none
// Calls:       none
// Called by:   client code
//
SNode::SNode(const Item& E, SNode *N) {

   Element = E;
   Next    = N;
}
```

Uses default construction for Item objects.

Uses default (or overloaded) assignment for Item objects.

When an object is a data member of another object, the data member is automatically initialized using the default constructor for its type.

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SNode Class Reporters


```
//////////////////////////////////////////// getData()
// Provides user access to stored data element.
// Parameters:  none
// Returns:     reference to node's data element
// Calls:       none
// Called by:   client code
//
Item& SNode::getData() {

   return Element;
}

//////////////////////////////////////////// getNext()
// Provides user access to pointer to next node.
// Parameters:  none
// Returns:     pointer to next node
// Calls:       none
// Called by:   client code
//
SNode* SNode::getNext() const {

   return Next;
}
```

Uses `const` to guarantee no modification occurs.

`getData()` returns a reference to the data member `Element`, not a copy of it.

That allows the user of the `SNode` object to modify the data element it stores, *in situ*.

Some designers would argue this violates information hiding. Others would ask "who owns the data element anyway?"

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SNode Class Mutators


```
//////////////////////////////////////// setData()
// Provides user ability to set data element.
// Parameters:
//    E      data value to be stored
// Returns:      none
// Calls:        none
// Called by:    client code
//
void SNode::setData(const Item& E) {

   Element = E;
}

//////////////////////////////////////// setNext()
// Provides user ability to modify pointer
// to next node.
// Parameters:  value to which pointer will be set
// Returns:      none
// Calls:        none
// Called by:    client code
//
void SNode::setNext(SNode* N) {

    Next = N;
}
```

Why is the parameter to `setNext()` not passed as:

```
const SNode* const N
```

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Linked List Class SList

`SList` is used to encapsulate all high-level list operations.

Goals:

- safe storage of user-supplied data elements
- prevent user from corrupting list structure, but provide user with useful access to data

```
// SList.h
//
// Simple version of singly-linked list.
//
// Features:
//    - "Iterator" to keep track of current position in
//      the list; user can move iterator to head or
//      tail, or advance it one position
//      toward tail of list.
//    - Insert() adds new node after the current
//      position; so, user can
//      insert data elements in any order desired.
//    - Delete() removes node at current position and
//      returns data value from the node.
//    - Get() returns reference to data element of
//      current node, allowing editing actions by user.
//    - Deep copy support and destructor.
//    - Display() writes formatted list contents to any
//      output stream.
//
// Assumptions:
//    - Uses SNode class from SNode.h
//    - User will supply a header file, Item.h
//      containing a typedef statement mapping some
//      known type to the name Item.
//    - Data type Item provides any necessary deep copy
//      support and destructor.
//    - operator<< is supported for type Item.
//
. . .
```

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SList Interface


```
#ifndef SLIST_H
#define SLIST_H
#include <iostream>
using std::ostream;

#include "Item.h"      // for Item declaration
#include "SNode.h"     // for SNode declaration

class SList {
private:
   SNode *Head;
   SNode *Tail;
   SNode *Current;

public:
   SList();                          // make an empty list
   SList(const SList& Source);          // copy constructor
   SList& operator=(const SList& RHS); // assignment
                                        //    overload
   bool  Insert(const Item& E);  // insert value E at
                                 //   current position
   bool  Delete(Item& E);        // delete value at
                                 //   current position
   Item& Get() const;            // get reference to
                                 //   current data
                                 //   element
   bool  Advance();              // move current
                                 // position toward tail
   void  goToHead();             // move current position
                                 //   to head
   void  goToTail();             // move current position
                                 //   to tail
   bool  atEnd() const;          // true if current
                                 //   position is NULL

   bool  isEmpty() const;        // true if list is empty
   void  Display(ostream& Out) const;  // print list
                                       //   contents
   ~SList();                     // deallocate nodes
};

#endif
```

One line functions could be "inline" for efficiency.

consts for safety

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SList Constructor

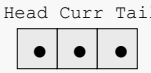

```
//////////////////////////////////////////// SList()
// Constructs an empty linked list.
// Parameters:  none
// Returns:     none
// Calls:       none
// Called by:   client code
//
SList::SList() {

   Head = Tail = Current = NULL;
}
```

The object definition: `SList L;`

L

Results in the following state:



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SList Destructor

The destructor must deallocate all the `SNode` objects that were allocated by the `SList` object.

```
//////////////////////////////////////////// ~SList
// Deallocates SNode objects instantiated by SList
// object.
// Parameters:  none
// Returns:     none
// Calls:       none
// Called by:   client code
//
SList::~SList() {

   SNode *toKill = Head;

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

The destructor is called automatically whenever the lifetime of an `SList` object ends (i.e. 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.

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

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SList Insert Mutator

`SList` implements insertion to add a new node to the list immediately following the target of the `Current` pointer, if that is defined.

What limitation does this impose on the client?

```
//////////////////////////////////////////// Insert()
// Inserts a data value into a new node following
// the Current list position.
// Parameters:  data value to be stored
// Returns:     true if insertion succeeds,
//              false otherwise
// Calls:       SNode constructor
//              SNode.getNext()
//              SNode.setNext()
// Called by:   client code
//
bool SList::Insert(const Item& E) {

   if ( Head == NULL ) {   // inserting in empty list
      SNode *Temp = new SNode(E, NULL);   // make node
      Head = Tail = Temp;                 // hook it in
      Current = Head;                  // make head node
                                       //    current
      return true;
   }

   if ( Current == NULL ) {       // no current position
      return false;
   }

   // inserting node in middle or at end
   SNode *Temp = new SNode(E, NULL);   // make new node
   Temp->setNext(Current->getNext());  // hook it in
   Current->setNext(Temp);
   return true;
}
```

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The Current Position

`SList` maintains a sense of a "current position" by storing a private pointer that can be moved by the client; this allows the client to use the list in a flexible, natural manner.

```
//////////////////////////////////////////// Advance()
// Moves current position to next node, if any.
// Parameters:  none
// Returns:     true if position advanced,
//              false otherwise
// Calls:       SNode.getNext()
// Called by:   client code
//
bool SList::Advance() {

   if ( Current == NULL ) return false;   // no current
                                          //   position
                                          //  to advance
   Current = Current->getNext();
   return true;
}
```

The client may also set the current position to the head or tail of the list, and there is a test to see if the current position is valid; the design corresponds to the STL conventions by making "end" mean "at an imaginary invalid location past the last node".

```
bool SList::atEnd() const {

   return ( Current == NULL );
}
```

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Searching an SList

`SList` does not provide the client with a search function. However, it's easy for the client to implement one:

```
bool Locate(const Item& Target, SList& L) {

   if ( L.isEmpty() ) return false;

   L.goToHead();

   while ( !L.atEnd() ) {

      if ( Target == L.Get() )
         return true;

      L.Advance();
   }

   return false;
}
```

The implementation assumes that there is an equality comparison for the data type `Item`, but search would not make much sense otherwise.

Question: will this code terminate properly if the `SList` doesn't contain a value matching `Target`?

Question: why isn't the `SList` object passed to the function by `const` reference?

Question: could this be a member function of `SList`?

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Client Access to the Data

`SList` provides the client with an accessor function to the data element in the current list node:

```
//////////////////////////////////////////////// Get()
// Provides user access to data element in current list
// node.
// Parameters:  none
// Returns:     reference to current data element
// Calls:       SNode.getData()
// Called by:   client code
//
Item& SList::Get() const {

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

Note how `SList::Get()` and `SNode::getData()` are designed to work together to give the client a reference to the stored data element.

That allows the client to modify the data element *in situ*:

```
SList L;
. . .
L.Get() = 1;
```

```
SList L;
. . .
Item& Temp = L.Get();
Temp = 2;
```

Note also that `Get()` doesn't deal well with being called when `Current` is `NULL`. The reason for this design is that there's no good return value for the reference when `Current` is `NULL`.

This can be handled by making the return value `Item*` instead.

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Design Discussion

Does the fact that `SList::Get()` returns a reference to a member of the node violate information hiding?

No. To be picky, the nodes are NOT members of the `SList` object. But that's an artificial defense, and misses important points.

First of all, the data elements belong to the client, not to the container. Granted, the container is responsible for organizing the data elements, but it is also responsible for providing the client with flexible, efficient access to the data.

Note that the design here is NOT the same as returning a reference or pointer to a node; that would clearly be unsafe since the client could then interact directly with the node interface, and perhaps even deallocate the node, wreaking havoc with the physical structure of the list.

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SList Delete Mutator

`SList` deletion removes the current node (if there is one), and returns the data element it contained to the client:

```
bool SList::Delete(Item& E) {

   if ( Current == NULL ) return false;

   if ( Current == Head) {       // deleting first node
      Head = Head->getNext();    //    reset head pointer
                                 //    "around" target
      E = Current->getData();    //    save data element
      delete Current;            //    deallocate node
      Current = Head;
      return true;
   }

   // find preceding node
   SNode *Previous = Head;       // start at head node

   while ( Previous->getNext() != Current)
      Previous = Previous->getNext();

   // make preceding node point to successor
   Previous->setNext(Current->getNext());

   E = Current->getData();       // save data element
   delete Current;               // deallocate node
   Current = Previous->getNext();

   return true;
}
```

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Deep Copy for SList

`SList` must also provide deep copy support:

```
////////////////////////////////////// copy constructor
// Initializes new SList object as a copy of an
// existing SList object.
// Parameters:  SList object to be copied
// Returns:     none
// Calls:       SNode.getData()
//              SNode.getNext()
//              SList.goToTail()
// Called by:   client code
//
SList::SList(const SList& Source) {

   Head = Tail = Current = NULL;

   SNode *toCopy = Source.Head;

   while ( toCopy != NULL ) {

      Insert(toCopy->getData());
      goToTail();
      toCopy = toCopy->getNext();
   }
}
```

Note that the implementation uses member functions of `SList`, rather than re-implementing their logic here.

As usual, the implementation of `SList::operator=` is similar to the copy constructor.

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Utility Functions

`SList` also provides a simple test for an empty list, and display functionality:

```
void SList::Display(ostream& Out) const {

   SNode *Temp = Head;
   int Pos = 0;

   while ( Temp != NULL ) {

      Out << setw(3) << Pos << ":  "
          << Temp->getData() << endl;
      Pos++;
      Temp = Temp->getNext();
   }
}
```

Note that the implementation assumes that operator<< can be applied to the data type `Item`.

This could also easily be written as a non-member function, however the ability to easily display the contents of a container is so useful in testing and debugging that it is common to build that into containers that are under development.

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Sample Data Element Class


```
// CreditCard.h
#ifndef CREDITCARD_H
#define CREDITCARD_H

#include <iostream>
using std::ostream;
#include <string>
using std::string;

class CreditCard {
private:
   string Number;
   double Balance;

public:
   CreditCard(const string& Num = "",
              double Amount = 0.0);
   void   Payment(double Amount);
   void   Charge(double Amount);
   double CardBalance() const;

   bool operator==(const CreditCard& RHS) const;
   bool operator!=(const CreditCard& RHS) const;
   bool operator<(const CreditCard& RHS) const;
   bool operator<=(const CreditCard& RHS) const;
   bool operator>(const CreditCard& RHS) const;
   bool operator>=(const CreditCard& RHS) const;

   friend ostream& operator<<(ostream& Out,
                              const CreditCard& Card);
};

#endif
```

`friend` **operators and functions can access private members as if they were class members themselves.**

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Aside: friends

There are some circumstances in which an operator or function needs to have direct access to private data of a class, but it cannot itself be a class member.

The most common example is an overloaded `operator<<`.

An operator can only be a member of the class that appears as its left operand.

The left operand of `operator<<` is an output stream object.

The problem may be solved by having the (right operand) class declare the operator to be a `friend`.

Friends have privileged access to the private section of a class:

```
ostream& operator<<(ostream& Out, const CreditCard&
Card) {

   Out << fixed << showpoint;
   Out << Card.Number
       << setw(11) << setprecision(2) << Card.Balance;
   return Out;
}
```

Normally, the implementation of a friend operator or function will be placed in the same file as the class implementation.

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Data Comparison Operators

Sometimes the relational operators will consider only some, or one, of the data members of a class:

```
bool CreditCard::operator==(const CreditCard& RHS) const {

   return ( Number == RHS.Number);
}
```

This overloaded operator is required in order for search code to work. The other relational operators, such as `operator<`, may be needed for sorting or other operations.

As a general rule, if you implement `operator==` for a class, you should also supply `operator!=`.

And, if you implement `operator<`, you should also supply the other four comparisons.

The implementation cost is trivial, and it will make the resulting class much more natural to use.

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Non-destructive List Merge

In some applications it is useful to be able to merge two lists into a third list.

The function below does that, making extensive use of the `SList` interface:

```
// Given two SList objects, return a new ordered list
// which contains all of the elements of both lists,
// (the original lists must NOT be destroyed by the
// merging).
//
SList MergeLists(const SList& L1, SList L2){

  Item  toCopy;
  SList Merger = L1;

  L2.goToHead();
  while ( !L2.atEnd() ) {

     toCopy = L2.Get();
     Merger.Insert(toCopy);
     Merger.goToTail();

     L2.Advance();
  }

  return Merger;
}
```

Question: how would you modify the function above to avoid storing duplicates in the merged list?

Question: what would happen if the function returned `SList&`?

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Simplifying the List

The implementation of `SList` can be simplified somewhat by changing the access controls used in the `SNode` class:

```
class SNode {
public:
   Item  Element;
   SNode *Next;

   SNode();
   SNode(const Item& E, SNode* N = NULL);
};
```

The change is that the data element and pointer are now public, rendering all the member functions except the constructors unnecessary.

What about information hiding?

`SNode` objects are designed to be created, used, and destroyed only by a container class, like `SList`, not by client code. So, the usual concerns about clients corrupting class data are absent.

What do we gain?

This is perhaps the ONLY situation in which the use of public data members is acceptable.

The calls that `SList` functions made to the `SNode` accessor and mutator functions are eliminated in favor of direct accesses. That's both faster at runtime and simpler to write.

Would the interface of `SList` need to be changed?

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Ordered List

The implementation of `SList` could be modified to maintain the data elements in ascending (or descending) order:

```
bool SList::Insert(const Item& E) {

   if ( Head == NULL ) {      // inserting to empty list
      SNode *Temp = new SNode(E, NULL);
      Head = Tail = Temp;
      Current = Head;
      return true;
   }

   SNode *Predecessor = NULL;  // find preceding node
   SNode *Look = Head;
   while ( Look != NULL && Look->Element < E ) {
      Predecessor = Look;
      Look = Look->Next;
   }

   if ( Predecessor == NULL ) {
      SNode *Temp = new SNode(E, Head);
      Head = Temp;
      return true;
   }

   // inserting in middle or at end
   SNode *Temp = new SNode(E, Look);
   Predecessor->Next = Temp;
   return true;
}
```

The data type `Item` must provide `operator<`.

There is now some risk associated with `SList::Get()`; if the client uses it to modify a data element in the wrong way then the list ordering would be incorrect.

The data element should be ordered on an immutable key field.

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Other Design Options

The interface of `SList` reflects a particular design philosophy; other developers would make different decisions.

For example, the user-controlled "bookmark" approach could be abandoned in favor of a less open approach. That would require some additional interface changes:

- at least one search function would be necessary.
- if the client is to have any control over the ordering of the data elements, there would have to be at least some variation of the insertion function, such as a prefix and/or a suffix insertion.
- deletion would have to allow the client to specify the data element to be found and removed.

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