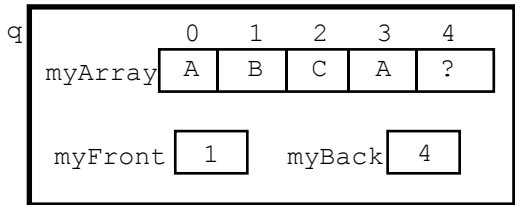
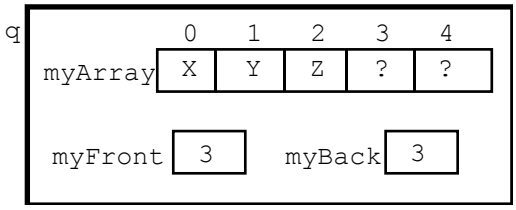
Chapter 8: Queues

Exercises 8.2

1.

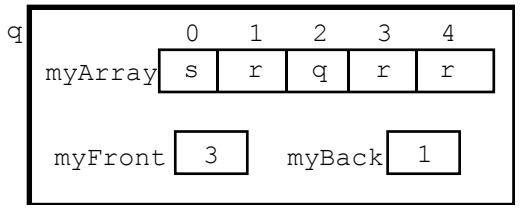


2.

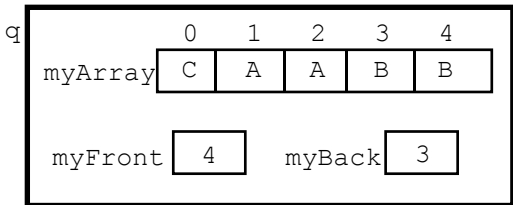


Queue is now empty

3.



4.



Error occurs when i = 4. After `ch` = 'A' is inserted in location 2, `myBack` is 3 and `myFront` is 4, which means the queue is full, so the next `enqueue()` operation fails.

5.

```
/*-- DQueue.h -----------------------------------------------------

  This header file defines a Queue data type.
  Basic operations:
    constructor:      Constructs an empty queue
    copy constructor: Constructs a copy of a queue
    =:                Assignment operator
    destructor:       Destroys a queue
    empty:            Checks if a queue is empty
    enqueue:          Modifies a queue by adding a value at the back
    front:            Accesses the top stack value; leaves queue
                       unchanged
    dequeue:          Modifies queue by removing the value at the
                       front
    display:           Displays all the queue elements
-----------------------------------------------------------------*/

#include <iostream>

#ifndef DQUEUE
#define DQUEUE

typedef int QueueElement;
```

```
class Queue
{
 public:
  /***** Function members *****/
  /***** Constructors *****/

  Queue(int numElements = 128);
  /*-------------------------------------------------------------
    Construct a Queue object.

    Precondition:  None.
    Postcondition: An empty Queue object has been constructed
        (myFront and myBack are initialized to 0 and myArray
        is an array with numElements (default 128) elements
        of type QueueElement).
  -------------------------------------------------------------*/

  Queue (const Queue & original);
  /*-------------------------------------------------------------
    Copy Constructor

    Precondition:  original is the queue to be copied and
        is received as a const reference parameter.
    Postcondition: A copy of original has been constructed.
  -------------------------------------------------------------*/

 /***** Destructor *****/
  ~Queue();
  /*-------------------------------------------------------------
    Class destructor

    Precondition:  None
    Postcondition: The dynamic array in the queue has been
      deallocated.
  -------------------------------------------------------------*/


  /***** Assignment *****/
  const Queue & operator= (const Queue & rightHandSide);
  /*-------------------------------------------------------------
    Assignment Operator

   Precondition:  original is the queue to be assigned and
       is received as a const reference parameter.
   Postcondition: The current queue becomes a copy of
       original and a const reference to it is returned.
  -------------------------------------------------------------*/

  bool empty() const;
  /*-------------------------------------------------------------
    Check if queue is empty.
    Precondition: None
    Postcondition: Returns true if queue is empty and
        false otherwise.
   -------------------------------------------------------------*/
```

```
  void enqueue(const QueueElement & value);
  /*-------------------------------------------------------
    Add a value to a queue.

    Precondition:  value is to be added to this queue
    Postcondition: value is added at back of queue provided
        there is space; otherwise, a queue-full message is
        displayed and execution is terminated.
   -------------------------------------------------------*/

  void display(ostream & out) const;
  /*-------------------------------------------------------
    Display values stored in the queue.

    Precondition:  ostream out is open.
    Postcondition: Queue's contents, from front to back, have
        been output to out.
   -------------------------------------------------------*/

  QueueElement front() const;
  /*-------------------------------------------------------
    Retrieve value at front of queue (if any).

    Precondition:  Queue is nonempty
    Postcondition: Value at front of queue is returned, unless
        the queue is empty; in that case, an error message is
        displayed and a "garbage value" is returned.
   -------------------------------------------------------*/

  void dequeue();
  /*-------------------------------------------------------
    Remove value at front of queue (if any).

    Precondition:  Queue is nonempty.
    Postcondition: Value at front of queue has been removed,
        unless the queue is empty; in that case, an error
        message is displayed and execution allowed to proceed.
   -------------------------------------------------------*/

 private:
  /***** Data members *****/
  int myFront,              // front
      myBack;               //   and back of queue
  int myCapacity;           // capacity of queue
  QueueElement * myArray;   // dynamic array to store elements;
                            //  empty slot used to distinguish
                            //  between empty and full
}; // end of class declaration

#endif



/*-- DQueue.cpp----------------------------------------------------------
   This file implements Stack member functions.
   Empty slot used to distinguish between empty and full
-----------------------------------------------------------------------*/
```

```
#include <iostream>
#include <cassert>
#include <new>
using namespace std;

#include "DQueue.h"

//--- Definition of Queue constructor
Queue::Queue(int numElements)
{
   assert (numElements > 0);  // check precondition
   myCapacity = numElements;  // set queue capacity
                              // allocate array of this capacity
   myArray = new(nothrow) QueueElement[myCapacity];
   if (myArray != 0)          // memory available
      myFront = myBack = 0;
   else
   {
      cerr << "Inadequate memory to allocate queue \n"
              " -- terminating execution\n";
      exit(1);
   }                          // or assert(myArray != 0);
}

//--- Definition of Queue copy constructor
Queue::Queue(const Queue & original)
: myCapacity(original.myCapacity),
  myFront(original.myFront), myBack(original.myBack)
{
   //--- Get new array for copy
   myArray = new(nothrow) QueueElement[myCapacity];
   if (myArray != 0)                 // check if memory available
      // copy original's array member into this new array
      for (int i = myFront; i!= myBack; i = (i + 1)%myCapacity)
         myArray[i] = original.myArray[i];
   else
   {
      cerr << "*Inadequate memory to allocate queue ***\n";
      exit(1);
   }
}

//--- Definition of Queue destructor
Queue::~Queue()
{
   delete [] myArray;
}

//--- Definition of assignment operator
const Queue & Queue::operator=(const Queue & rightHandSide)
{
   if (this != &rightHandSide)               // check that not st = st
   {
      //-- Allocate a new array if necessary
      if (myCapacity != rightHandSide.myCapacity)
      {
         delete[] myArray;                      // destroy previous array
         myCapacity = rightHandSide.myCapacity; // copy myCapacity
```

```
         myArray = new QueueElement[myCapacity];
         if (myArray == 0)                    // check if memory available
         {
            cerr << "*** Inadequate memory ***\n";
            exit(1);
         }
        }

       myFront = rightHandSide.myFront;        // copy myFront member
       myBack = rightHandSide.myBack;          // copy myBack member
                                               // copy queue elements
      for (int i = myFront; i!= myBack; i= (i + 1)%myCapacity)
          myArray[i] = rightHandSide.myArray[i];
    }

    return *this;
}

//--- Definition of empty()
inline bool Queue::empty() const
{
  return myFront == myBack;
}

//--- Definition of enqueue()
void Queue::enqueue(const QueueElement & item)
{
  if ((myBack +1)% myCapacity == myFront)
    cerr << "Queue is full: cannot add to queue.  Error!! " << endl;
  else
  {
    myArray[myBack] = item;
    myBack = (myBack+ 1) % myCapacity;
  }
}

//--- Definition of front()
QueueElement Queue::front() const
{
  if (myFront == myBack)
  {
    cerr <<"Queue is empty: error!  Returning garbage value\n";
    QueueElement garbage;
    return garbage;
  }
  else
    return myArray[myFront];
}

//--- Definition of dequeue()
void Queue::dequeue()
{
  if (myFront == myBack)
    cerr <<"Queue is empty: cannot remove from queue: error!\n";
  else
    myFront= (myFront + 1) % myCapacity;
}
```

```
void Queue::display(ostream & out) const
{
  for (int i = myFront; i != myBack; i = (i + 1) % myCapacity)
    cout << myArray[i] << " ";
  cout << endl;
}
```

6.

```
// Prototype:
bool full() const;
/*-------------------------------------------------------------------
  Check if queue is full.

  Precondition: None
  Postcondition: Returns true if queue is full and false otherwise.
 -------------------------------------------------------------------*/

// Definition:
bool Queue::full()
{
  return myFront == (myBack + 1)% QUEUE_CAPACITY;
}

// Definition:
bool Queue::full()
{
  return myFront == (myBack + 1)% myCapacity;
}
```

7.

```
// Prototype:
int size() const;
/*-------------------------------------------------------------------
  Find number of elements in the queue.
  Precondition:  None
  Postcondition: Number of queue elements is returned.
 -------------------------------------------------------------------*

// Definition:
int Queue::size() const
{
  if (myFront == myBack)
    return 0;
  else if (myFront > myBack)
    return myBack - myFront + QUEUE_CAPACITY;
  else
    return myBack - myFront;
}
```

8.

```
// Prototype
int size(Queue q);
/*-------------------------------------------------------------------
  Find number of elements in a queue received as a value parameter.
  Precondition:  None
  Postcondition: Number of queue elements is returned.
 -------------------------------------------------------------------*
```

```
// Definition
int size(Queue q)
{
  int count = 0;
  while (!q.empty())
  {
    q.removeQ();
    count++;
  }
  return count;
}

/* Here is a version that preserves the parameter q. */
int size(Queue q)
{
  Queue temp;
  int count = 0;

  while (!q.Empty())
  {
    temp.addQ(q.front());
    q.removeQ();
    count++;
  }
  while (!temp.empty())
  {
    q.addQ(temp.front());
    temp.removeQ();
  }
  return count;
}
```

9.

```
// Prototype:
QueueElement back() const;
/*-------------------------------------------------------------------------
  Retrieve the back element of this queue.
  Precondition:  None
  Postcondition: Back element of the queue is returned, unless there
      was none, in which case a queue-empty message is displayed.
 -------------------------------------------------------------------------*

// Definition:
QueueElement Queue::back() const
{
  if (myFront == myBack)
    {
      cerr <<"Error: queue is empty -- returning garbage value\n";
      QueueElement garbage;
      return garbage;
    }
  //else
  if (myBack == 0)
    return myArray[QUEUE_CAPACITY - 1];
  //else
  return myArray[myBack - 1];
}
```

10.

```
// Prototype:
QueueElement back();
/*-------------------------------------------------------------------------
  Retrieve the back element of a queue received as a value parameter.
  Precondition:  None
  Postcondition: Back element of the queue is returned, unless there
      was none, in which case a queue-empty message is displayed.
 -------------------------------------------------------------------------*

// Definition:
QueueElement back(Queue q)
{
  if (q.empty())
  {
    cerr <<"Error: queue is empty -- returning garbage value\n";
    QueueElement garbage;
    return garbage;
  }
  //else
  QueueElement last;
  while (!q.empty())
  {
    last = q.front();
    q.dequeue();
  }
  return last;
}

//-- Non-destructive version (preserves parameter q)
QueueElement back(Queue q) const
{
  if (q.empty())
  {
    cerr <<"Error: queue is empty -- returning garbage value\n";
    QueueElement garbage;
    return garbage;
  }
  //else
  Queue temp;
  QueueElement last;
  while (!q.empty())
  {
    last = q.front();
    temp.addQ(last);
    q.removeQ();
  }
  while (!temp.empty())
  {
    q.addQ(temp.front());
    temp.removeQ();
  }
  return last;
}
```

11.

```
// Prototype:
QueueElement nthElement(int n);
/*-------------------------------------------------------------------------
  Retrieve the n-th element of a queue.
  Precondition:  1 <= n <= number of queue elements
  Postcondition: n-th element of the queue is returned, unless queue
      has fewer than n elements, in which case an error message is
      displayed.  Also, the elements preceding the n-th element are
      removed from the queue.
 -------------------------------------------------------------------------*

// Definition:
QueueElement Queue::nthElement(int n)
{
  QueueElement elem;
  while( n > 0 && !empty())
  {
    elem = front();
    removeQ();
    n--;
  }
  if (n > 0)
  {
    cerr << "Error: insufficient number of elements in the queue\n";
            "-- returning garbage value\n";
    QueueElement garbage;
    return garbage;
  }
  //else
  return elem;
}
```

12.

```
// Prototype:
QueueElement nthElement(int n) const;
/*-------------------------------------------------------------------------
  Retrieve the n-th element of a queue.
  Precondition:  1 <= n <= number of queue elements
  Postcondition: n-th element of the queue is returned, unless queue
      has fewer than n elements, in which case an error message is
      displayed..
 -------------------------------------------------------------------------*

// Definition:
QueueElement Queue::nthElement(int n) const
{
  if (myFront < myBack && myBack - myFront < n
      || myFront > myBack && QUEUE_CAPACITY - (myFront - myBack) < n)
    {
      cerr << "Error: insufficient number of elements in the queue\n";
      "-- returning garbage value\n";
      QueueElement garbage;
      return garbage;
    }
```

```
    //else
    int index_n = (myFront + n - 1) % QUEUE_CAPACITY;
    return myArray[index_n];
  }
```

13. The algorithm is as follows:
    1. Create a stack.
    2. While the queue is not empty, do the following:
        a. Remove an item from the queue.
        b. Push this item onto the stack.
    3. While the stack is not empty, do the following:
        a. Pop an item from the stack.
        b. Add this item to the queue.

14.

(a) For n = 3:

Possible Permutations	*Impossible Permutations*
123 132 213 231 312	321

==========

(b) For n = 4:

Possible Permutations	*Impossible Permutations*
1234 1324 1342 1423	1243
2134 2143 2314 2341 2413	2431
3124 3142 3412	3214 3241 3421
4123	4132 4312 4321 4213 4231

==========

(c) For n = 5:

Possible Permutations	*Impossible Permutations*
12345 12354 12435 12453 12534	12543
13245 13254 13425 13452 13524	13542
14235 14253 14523	14325 14352 14532
15234	15243 15324 15342 15423 15432
21345 21354 21435 21453 21534	21543
23145 23154 23415 23451 23514	23541
24135 24153 24513	24315 24351 24531
25134	25143 25314 25341 25413 25431
31245 31254 31425 31452 31524	31542
	32145 32154 32415 32451 32514 32541
34125 34152 34512	34215 34251 34521
35124	35142 35214 35241 35412 35421

41235 41253 41523	41325 41352 41532
	42135 42153 42315 42351 42513 42531
	43125 43152 43215 43251 43512 43521
45123	45132 45213 45231 45312 45321
51234	51243 51324 51342 51423 51432
	52134 52143 52314 52341 52413 52431
	53124 53142 53214 53241 53412 53421
	54123 54132 54213 54231 54312 54321

==========

(d) The rule is: for each digit *d* in the number, the digits to the right of *d* that are less than *d* MUST be in ascending order.

15.

```
/* Implementation of Queue class.
   Count of elements used to distinguish between empty and full

   Add a data member:   int myCount;  to the private section of
   the Queue class declaration.
 */

#include <iostream>
using namespace std;

Queue::Queue()
: myFront(0), myBack(0), myCount(0)
}

bool Queue::empty() const
{
  return myCount == 0;
}

void Queue::enqueue(const QueueElement & value)
{
  if (myCount < QUEUE_CAPACITY)
   {
      myArray[myBack] = value;
      myBack = (myBack + 1) % QUEUE_CAPACITY;
      myCount++;
   }
   else
   {
      cerr << "*** Queue full -- can't add new value ***\n"
              "Must increase value of QUEUE_CAPACITY in Queue.h\n";
      exit(1);
   }
}

QueueElement Queue::front()
{
  if (myCount > 0)
    return myArray[myFront];
  else
  {
```

```
    cerr << "*** Queue is empty -- returning garbage value ***\n";
    QueueElement garbage;
    return garbage;
  }
}

void Queue::dequeue()
{
  if (myCount > 0)
  {
    myFront = (myFront + 1) % QUEUE_CAPACITY;
    myCount--;
  }
  else
    cerr << "*** Queue is empty -- can't remove a value ***\n";
}
```

16.

```
/* Implementation of Queue class.
   Count of elements used to distinguish between empty and full.
   No data member myBack is used.

   Add a data member:   int myCount;  to the private section of
   the Queue class declaration and remove:  int myBack;
 */

#include <iostream>
using namespace std;

Queue::Queue()
: myFront(0), myCount(0)
}

bool Queue::empty() const
{
  return myCount == 0;
}

void Queue::enqueue(const QueueElement & value)
{
  if (myCount < QUEUE_CAPACITY)
   {
      int back = (myFront + myCount) % QUEUE_CAPACITY;
      myArray[back] = value;
      myCount++;
   }
   else
   {
      cerr << "*** Queue full -- can't add new value ***\n"
              "Must increase value of QUEUE_CAPACITY in Queue.h\n";
      exit(1);
   }
}

QueueElement Queue::front()
{
  if (myCount > 0)
    return myArray[myFront];
```

```
  else
  {
    cerr << "*** Queue is empty -- returning garbage value ***\n";
    QueueElement garbage;
    return garbage;
  }
}

void Queue::dequeue()
{
  if (myCount > 0)
  {
    myFront = (myFront + 1) % QUEUE_CAPACITY;
    myCount--;
  }
  else
    cerr << "*** Queue is empty -- can't remove a value ***\n";
}
```

17.

```
/* Implementation of Queue class.
   Full data member used to distinguish between empty and full

   Add a data member:   bool iAmFull;  to the private section of
   the Queue class declaration.
 */

#include <iostream>
using namespace std;

Queue::Queue()
: myFront(0), myCount(0), iAmFull(false)
{}

bool Queue::empty() const
{
  return (myBack == myFront && !iAmFull);
}

void Queue::enqueue(const QueueElement & item)
{
  if (!iAmFull)
  {
    myArray[myBack] = item;
    myBack = (myBack+ 1) % QUEUE_CAPACITY;
    iAmFull = (myBack == myFront);
  }
  else
  {
    cerr << "*** Queue full -- can't add new value ***\n"
            "Must increase value of QUEUE_CAPACITY in Queue.h\n";
    exit(1);
  }
}
```

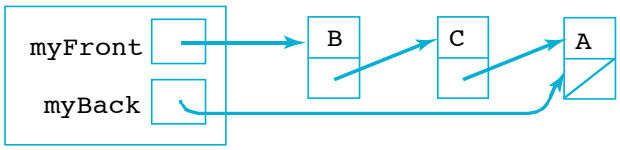
```
QueueElement Queue::front()
{
  if (!empty())
  {
    return myArray[myFront];
  }
  else
  {
    cerr << "*** Queue is empty -- returning garbage value ***\n";
    QueueElement garbage;
    return garbage;
  }
}

void Queue::dequeue()
{
  if (!empty())
  {
    myFront= (myFront + 1) % QUEUE_CAPACITY;
    iAmFull = false;
  }
  else
    cerr <<"Queue is empty: cannot remove from queue.  Error!!" << endl;
}
```

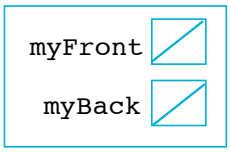
18. This is similar to the use of one buffer for two stacks (Exer. 12 in §7.2): If two queues were to be stored in one array with the front of each being at the ends of the array, then the queues could grow until the backs met in the middle. Then, one of the queues would have to be shifted back to its end. If each queue size is fixed, wraparound within each queue could be employed to avoid shifting elements.

Exercises 8.3

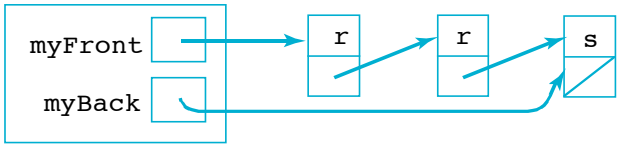
1.



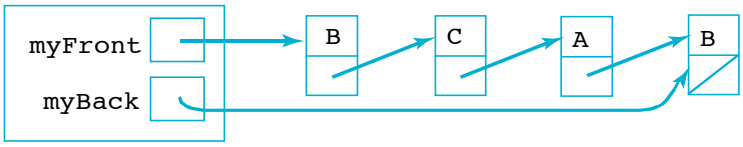
2.



3.



4.



5.

```
// Prototype:
QueueElement back() const;
/*-------------------------------------------------------------------------
  Retrieve the back element of this queue.
  Precondition:  None
  Postcondition: Back element of the queue is returned, unless there
      was none, in which case a queue-empty message is displayed.
 -------------------------------------------------------------------------*

// Definition:
QueueElement Queue::back() const
{
  if (myBack != 0)
    return * myArray;
  //else
    cerr <<"Error: queue is empty -- returning garbage value\n";
    QueueElement garbage;
    return garbage;
}
```

6.

```
// Prototype:
QueueElement nthElement(int n);
/*-------------------------------------------------------------------------
  Retrieve the n-th element of a queue.
  Precondition:  1 <= n <= number of queue elements
  Postcondition: n-th element of the queue is returned, unless queue
      has fewer than n elements, in which case an error message is
      displayed.  Also, the elements preceding the n-th element are
      removed from the queue.
 -------------------------------------------------------------------------*

// Definition:
QueueElement Queue::nthElement(int n)
{
  QueueElement elem;
  while( n > 0 && !empty())
  {
    elem = front();
    removeQ();
    n--;
  }
  if (n > 0)
  {
    cerr << "Error: insufficient number of elements in the queue\n";
            "-- returning garbage value\n";
    QueueElement garbage;
    return garbage;
  }
```

```
  //else
  return elem;
}
```

7.

```
// Prototype:
QueueElement nthElement(int n) const;
/*-------------------------------------------------------------------------
  Retrieve the n-th element of a queue.
  Precondition:  1 <= n <= number of queue elements
  Postcondition: n-th element of the queue is returned, unless queue
      has fewer than n elements, in which case an error message is
      displayed..
 -------------------------------------------------------------------------*

// Definition:
QueueElement Queue::nthElement(int n) const
{
  int count = 0;
  Queue::NodePonter ptr = myFront;

  for (int count = 0; count < n && ptr != 0; count++)
    ptr = ptr->next;

  if (ptr != 0)
    return *ptr;
  //else
  cerr << "Error: insufficient number of elements in the queue\n";
          "-- returning garbage value\n";
  QueueElement garbage;
  return garbage;
}
```

8.

```
/*-- CLQueue.h ----------------------------------------------------

  This header file defines a Queue data type.
  Basic operations:
    constructor:      Constructs an empty queue
    copy constructor: Constructs a copy of a queue
    =:                Assignment operator
    destructor:       Destroys a queue
    empty:            Checks if a queue is empty
    enqueue:          Modifies a queue by adding a value at the back
    front:            Accesses the top stack value; leaves queue
                       unchanged
    dequeue:          Modifies queue by removing the value at the
                       front
    display:           Displays all the queue elements

  A circular linked list is used to store the queue elements.
-------------------------------------------------------------------*/
```

```
#ifndef CLQUEUE
#define CLQUEUE

#include <iostream>

typedef int QueueElement;
class Queue
{
 private:
  class Node
  {
   public:
    //------ DATA MEMBERS OF Node
    QueueElement data;
    Node * next;

    //------ Node OPERATIONS

    /* --- The Node default class constructor initializes a Node's
           next member.

      Precondition:  None
      Postcondition: The next member has been set to 0.
    ------------------------------------------------------------------*/
    Node()
    : next(0)
    {}

   /* --- The Node class constructor initializes a Node's data members.

      Precondition:  None
      Postcondition: The data and next members have been set to
                     dataValue and 0, respectively.
    ------------------------------------------------------------------*/
    Node(DequeElement dataValue)
    : data(dataValue), next(0)
    {}
  }; //--- end of Node class

  typedef Node * NodePointer;

 public:
  /***** Function members *****/
  /***** Constructors *****/

  Queue();
  /*-----------------------------------------------------------
    Construct a Queue object.

    Precondition:  None.
    Postcondition: An empty Queue object has been constructed
        (myBack is initialized to 0).
  -----------------------------------------------------------*/
```

```
Queue (const Queue & original);
 /*-------------------------------------------------------
   Copy Constructor

   Precondition:  original is the queue to be copied and
       is received as a const reference parameter.
   Postcondition: A copy of original has been constructed.
 -------------------------------------------------------*/

 /***** Destructor *****/
 ~Queue();
 /*-------------------------------------------------------
   Class destructor

   Precondition:  None
   Postcondition: The linked list in the queue has been
     destroyed.
 -------------------------------------------------------*/

 /***** Assignment *****/
 const Queue & operator=(const Queue & rightHandSide);
 /*-------------------------------------------------------
   Assignment Operator

  Precondition:  original is the queue to be assigned and
      is received as a const reference parameter.
  Postcondition: The current queue becomes a copy of
      original and a const reference to it is returned.
 -------------------------------------------------------*/

 bool empty() const;
 /*-------------------------------------------------------
   Check if queue is empty.
   Precondition: None
   Postcondition: Returns true if queue is empty and
       false otherwise.
  -------------------------------------------------------*/

 void enqueue(const QueueElement & value);
 /*-------------------------------------------------------
   Add a value to a queue.

   Precondition:  value is to be added to this queue
   Postcondition: value is added at back of queue provided
       memory is available otherwise, a memory-error message
       is displayed and execution is terminated.
  -------------------------------------------------------*/

 QueueElement front() const;
 /*-------------------------------------------------------
   Retrieve value at front of queue (if any).

   Precondition:  Queue is nonempty
   Postcondition: Value at front of queue is returned, unless
       the queue is empty; in that case, an error message is
       displayed and a "garbage value" is returned.
  -------------------------------------------------------*/
```

```
  void dequeue();
  /*-------------------------------------------------------------
    Remove value at front of queue (if any).

    Precondition:  Queue is nonempty.
    Postcondition: Value at front of queue has been removed,
        unless the queue is empty; in that case, an error
        message is displayed and execution allowed to proceed.
   -------------------------------------------------------------*/

  void display(ostream & out) const;
  /*-------------------------------------------------------------
    Display values stored in the queue.

    Precondition:  ostream out is open.
    Postcondition: Queue's contents, from front to back, have
        been output to out.
   -------------------------------------------------------------*/

 private:
  /***** Data member *****/
   NodePointer myBack;

}; //--- end of Queue class

#endif



/*-- CLQueue.cpp-----------------------------------------------------------
   This file implements Stack member functions.
   A circular linked list with pointer to last node is used to
   store the queue elements.
-------------------------------------------------------------------------*/

#include <iostream>
using namespace std;

#include "CLQueue.h"

// Definition of constructor
Queue::Queue()
: myBack(0)
{ }

// Definition of empty()
bool Queue::empty() const
{  return myBack == 0; }

// Definition of enqueue()
void Queue::enqueue(const QueueElement & dataVal)
{
  Queue::NodePointer newPtr = new(nothrow) Node(dataVal);
  if (newPtr == 0)
  { cerr << "Out of memory\n";  exit(1); }

  if (myBack == 0)
    newPtr->next = newPtr;
```

```
  else
  {
    newPtr->next = myBack->next;
    myBack->next = newPtr;
  }
  myBack = newPtr;
}


// Definition of front()
QueueElement Queue::front() const
{
  if (myBack == 0)
  {
    cerr <<"Queue is empty: error!  Returning garbage value\n";
    QueueElement garbage;
    return garbage;
  }
  // else
  return myBack->next->data;
}

// Definition of dequeue()
void Queue::dequeue()
{
  if (myBack == 0)
    cerr <<"Queue is empty: cannot remove from queue: error!\n";
  else
  {
    Queue::NodePointer ptr = myBack->next;
    if (ptr->next == ptr)      // one-element queue becomes empty
      myBack = 0;
    else
      myBack->next = ptr->next;
    delete ptr;
  }
}


// Definition of the destructor
Queue::~Queue()
{
  if (myBack != 0)
  {
    Queue::NodePointer ptr,
                       prev = myBack->next;
    while (prev != myBack)
    {
      ptr = prev->next;
      delete prev;
      prev = ptr;
    }
    delete myBack;
  }
}
```

```
// Definition of the copy constructor
Queue::Queue(const Queue & original)
{
  myBack = 0;
  if (!original.empty())
  {
    Queue::NodePointer origPtr = original.myBack->next,
                               frontPtr, lastPtr;

    frontPtr = new Node(origPtr->data);
    if (frontPtr == 0)
    { cerr << "Out of memory\n";  exit(1); }

    lastPtr = frontPtr;
    while (origPtr != original.myBack)
    {
      origPtr = origPtr->next;
      lastPtr->next = new Node(origPtr->data);
      if (lastPtr == 0)
        { cerr << "Out of memory\n";  exit(1); }

      lastPtr = lastPtr->next;
    }
    lastPtr->next = frontPtr;
    myBack = lastPtr;
  }
}

// Definition of the assignment operator
const Queue &  Queue::operator=(const Queue & original)
{
  myBack = 0;
  if (this != &original)
    {
      delete myBack;
      Queue::NodePointer origPtr = original.myBack->next,
                                   frontPtr, lastPtr;

      frontPtr = new Node(origPtr->data);
      if (frontPtr == 0)
      { cerr << "Out of memory\n";  exit(1); }

      lastPtr = frontPtr;
      while (origPtr != original.myBack)
        {
          origPtr = origPtr->next;
          lastPtr->next = new Node(origPtr->data);
          if (lastPtr == 0)
          { cerr << "Out of memory\n";  exit(1); }

          lastPtr = lastPtr->next;
        }
      lastPtr->next = frontPtr;
      myBack = lastPtr;
    }
  return *this;
}
```

```
// Definition of the output operators
void Queue::display(ostream & out) const
{
  if (empty()) return;

  Queue::NodePointer ptr = myBack;
  do
  {
    ptr = ptr->next;
    out << ptr->data << "  ";
  }
  while (ptr != myBack);

}

inline ostream & operator<<(ostream & out, const Queue & aQueue)
{
  aQueue.display(out);
  return out;
}

// See Programmming Problem 18 for a driver
```

Exercises 8.4

1.

```
/*----- Deque.h -------------------------------------------------------
  A deque (double-ended queue) is similar to a queue but additions
  and deletions may be performed on either end.  Each store/retrieve
  operation must specify at which end the operation is to be performed.

  Basic operations:
     Constructor: Constructs an empty deque
     empty:       Checks if a deque is empty
     add:         Modifies a deque by adding a value at one end
     retrieve:    Retrieve the value at one end; leaves deque unchanged
     remove:      Modifies a deque by removing the value at one end
     display:     Displays the deque elements
  Class Invariant:
      1. The deque elements (if any) are stored in consecutive positions
         in myArray, beginning at position myFront.
      2. 0 <= myFront, myBack < DEQUE_CAPACITY
      3. Deque's size < DEQUE_CAPACITY
 ---------------------------------------------------------------------*/

#include <iostream>

#ifndef DEQUE
#define DEQUE

const int DEQUE_CAPACITY = 128;
typedef int DequeElement;
enum End {FRONT, BACK};
```

```
class Deque
{
 /***** Function Members *****/
 public:
  Deque();
  /*-------------------------------------------------------------------
    Construct a Deque object.

    Precondition:  None.
    Postcondition: An empty Deque object has been constructed; myFront
        and myBack are initialized to -1 and myArray is an array with
        DEQUE_CAPACITY elements of type DequeElement.
   -------------------------------------------------------------------*/

  bool empty() const;
  /*-------------------------------------------------------------------
    Check if deque is empty.

    Precondition:  None.
    Postcondition: True is returned if the deque is empty and false is
        returned otherwise.
   -------------------------------------------------------------------*/

  void add(const DequeElement & value, End where);
  /*-------------------------------------------------------------------
    Add a value to a deque.

    Precondition:  where is FRONT (0) or BACK (1).
    Postcondition: value is added at end of deque specified by where,
        provided there is space; otherwise, a deque-full message is
        displayed and execution is terminated.
   -------------------------------------------------------------------*/

  DequeElement retrieve(End where) const;
  /*-------------------------------------------------------------------
    Retrieve value at one end of deque (if any).

    Precondition:  Deque is nonempty; where is FRONT (0) or BACK (1).
    Postcondition: Value at at end of deque specified by where is
        returned, unless deque is empty; in that case, an error message
        is displayed and a "garbage value" is returned.
   -------------------------------------------------------------------*/

  void remove(End where);
  /*-------------------------------------------------------------------
    Remove value at one end of deque (if any).

    Precondition:  Deque is nonempty; where is FRONT (0) or BACK (1).
    Postcondition: Value at at end of deque specified by where is
        removed, unless deque is empty; in that case, an error message
        is displayed.
   -------------------------------------------------------------------*/
```

```
  // --- display
  void display(ostream & out) const;
  /*-------------------------------------------------------------------
    Output the values stored in the deque.

    Precondition:  ostream out is open.
    Postcondition: Deque's contents have been output to out.
   -------------------------------------------------------------------*/

/***** Data Members *****/
private:
  DequeElement myArray[DEQUE_CAPACITY];
  int myFront,
      myBack;

}; // end of class declaration

#endif



//----- Deque.cpp -----
#include <iostream>
#include <cassert>
using namespace std;

#include "Deque.h"

//-- Definition of constructor
Deque:: Deque ()
: myFront(0), myBack(0)
{}


//-- Definition of empty()
bool Deque::empty() const
{
  return myFront == myBack;
}


//-- Definition of add()
void Deque::add(const DequeElement & value, End where)
{
  assert (where == FRONT || where == BACK);
  int newBack = (myBack + 1) % DEQUE_CAPACITY;
  if (newBack == myFront)
  {
    cerr << "Deque is full: cannot add to deque.  Error!! " << endl;
    exit(1);
  }

  //else
  if (where == BACK)
  {
    myArray[myBack] = value;
    myBack = newBack;
  }
```

```
  else
  {
    int beforeFront = (myFront > 0 ? myFront - 1 : DEQUE_CAPACITY - 1);
    myFront = beforeFront;
    myArray[myFront] = value;
  }
}

//-- Definition of retrieve()
DequeElement Deque::retrieve(End where) const
{
  assert (where == FRONT || where == BACK);
  if (myFront == myBack)
  {
    cerr <<"Deque is empty:Error!!" << endl;
    return myArray[myBack];// some invalid data item;
  }
  else if (where == FRONT)
    return myArray[myFront];
  else
    return myArray[myBack > 0 ? myBack - 1 : DEQUE_CAPACITY - 1];
}

//-- Definition of remove()
void Deque::remove(End where)
{
  assert (where == FRONT || where == BACK);
  if (myFront == myBack)
  {
    cerr <<"Deque empty: Cannot remove an element. Error!!"
         << endl;
    return;
  }
  else if (where == FRONT)
    myFront= (myFront + 1) % DEQUE_CAPACITY;
     else
       myBack = (myBack > 0 ? myBack - 1 : DEQUE_CAPACITY - 1);
  // Result of (myBack - 1) % DEQUE_CAPACITY is implementation-
  // dependent if first operand of % is negative.
}

//-- Definition of display()
void Deque::display(ostream & out) const
{
  cout << "front: " << myFront << "  back: " << myBack << endl;
  for (int i = myFront; i != myBack; i = (i + 1) % DEQUE_CAPACITY)
    cout << myArray[i] << " ";
  cout << endl;
}

//-- See Programming Problem 20 for a driver program.
```

2. Implementing a scroll is an easy restriction of the deque class in Exercise 1 — simply restrict the add operation to the front and remove to the back.