Data Structures

Link-Based Implementations

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Outline

- **Nodes**.
- Implementations of member functions.
- Constructors and destructor.
- Remarks.

Link-based implementations

- Last time we implemented the ADT bag with arrays.
- There are some drawbacks:
  - Static arrays: The bag size is fixed.
  - Dynamic arrays: Doubling the bag size requires a lot of copy and paste.
- Here we will use pointers to do a **link-based implementation**.
  - Bag items will be put on a "**list**."
  - On the list, each item is "**linked**" to the next item.

Nodes

- The type of an item is **ItemType**.

```
template<typename ItemType>
class BagInterface
{
public:
  virtual bool
    add(const ItemType& newEntry) = 0;
  // all other functions
};
```

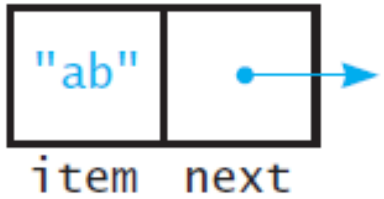

Figure 4-1 (Carrano and Henry, 2015)

- For each item, we will associate a **pointer** pointing to the **next** item-pointer pair.
- The combination of the item and pointer is often called a **node**.
  - The pointer **points to the next node**, not the next item!

List of nodes

- In effect, a **list of nodes** will be created to store items.

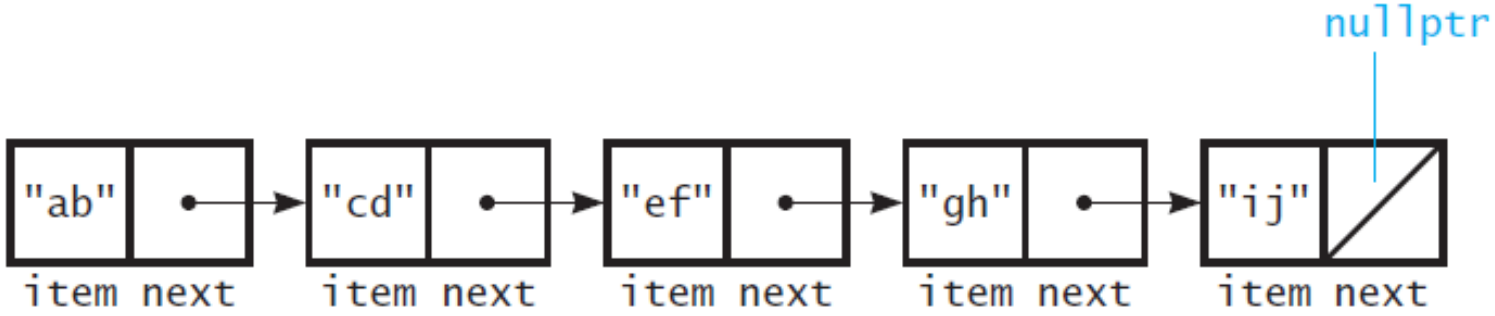

Figure 4-2 (Carrano and Henry, 2015)

- Each node is linked to the next node.
  - The pointer **`next`** points to the next node.

The class Node

```
template<class ItemType>
class Node
{
private:
  ItemType item;
  Node<ItemType>* next;
public:
  Node();
  Node(const ItemType& anItem);
  Node(const ItemType& anItem, Node<ItemType>* nextNodePtr);
  void setItem(const ItemType& anItem);
  void setNext(Node<ItemType>* nextNodePtr);
  ItemType getItem() const ;
  Node<ItemType>* getNext() const ;
};
```

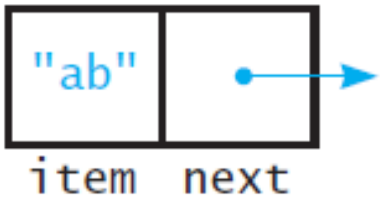

Figure 4-1 (Carrano and Henry, 2015)

The class Node

- Constructors of **Node**:

```
template<class ItemType>
Node<ItemType>::Node() : next(nullptr) {}

template<class ItemType>
Node<ItemType>::Node(const ItemType& anItem)
  : item(anItem), next(nullptr) {}

template<class ItemType>
Node<ItemType>::Node(const ItemType& anItem, Node<ItemType>* nextNodePtr)
  : item(anItem), next(nextNodePtr) {}
```

The class Node

- Getters and setters of **Node**:

```
template<class ItemType>
void Node<ItemType>::setItem(const ItemType& anItem)
{ item = anItem; }

template<class ItemType>
void Node<ItemType>::setNext(Node<ItemType>* nextNodePtr)
{ next = nextNodePtr; }

template<class ItemType>
ItemType Node<ItemType>::getItem() const
{ return item; }

template<class ItemType>
Node<ItemType>* Node<ItemType>::getNext() const
{ return next; }
```

The class `Node`

- The class **`Node`** has **getters** and **setters** for all instance variables.
  - It does **no data hiding** at all.
- Sometimes people implement **`Node`** as a **structure**.
  - Member variables of a structure are by default public.
  - Though they can be set to be private.
- Sometimes a better way is to set **`LinkedBag`** a **friend** of **`Node`**.

Outline

- Nodes.
- **Implementations of member functions**.
- Constructors and destructor.
- Remarks.

The class `LinkedBag`

- What should be contained in the class **`LinkedBag`**?
- Let's look at **`ArrayBag`** again:
  - `itemCount` is still needed.
  - Capacity-related members are not needed.
- Where to store our nodes?
  - The 1st node links to the 2nd.
  - The i^{th} node linkes to the $(i + 1)^{th}$.
- All we need is to store the 1st node, i.e., the **head**.

```
class ArrayBag : public BagInterface
{
private:
  static const int DEFAULT_CAPACITY = 6;
  string items[DEFAULT_CAPACITY];
  int itemCount;
  int maxItems;
  // ...
public:
  // ...
};
```

The head pointer `headPtr`

- An object of **`LinkedBag`** will has an **item counter** **`itemCount`**.
  - Its type is **`int`**.
- An object of **`LinkedBag`** will has a **head pointer** **`headPtr`**.
  - Its type is **`Node<itemType>*`**. It is a pointer, **not a node**.
  - **`headPtr`** is **a static member**; all other nodes are "dynamic members."

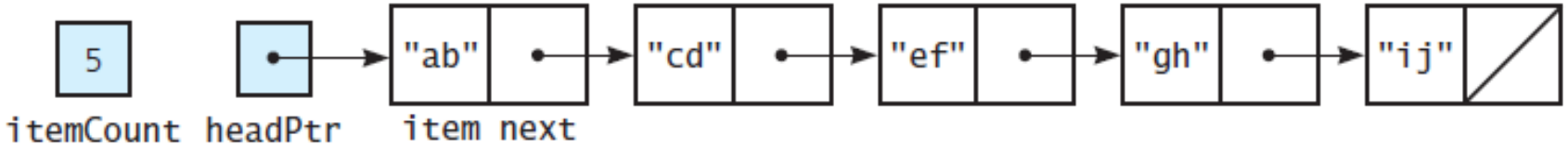

Figure 4-5 (Carrano and Henry, 2015)

The class LinkedBag

- The basic elements of **LinkedBag**:

```
template<class ItemType>
class LinkedBag : public BagInterface<ItemType>
{
private:
  Node<ItemType>* headPtr;
  int itemCount;
  // something else
public:
  // some constructors and destructor
  // functions defined in BagInterface, such as getCurrentSize(),
  // isEmpty(), add(), remove(), etc.
};
```

- Let's implement those functions first.

isEmpty() and getCurrentSize()

- Some member functions are straightforward.

```
template<class ItemType>
bool LinkedBag<ItemType>::isEmpty() const
{
  return itemCount == 0;
}

template<class ItemType>
int LinkedBag<ItemType>::getCurrentSize() const
{
  return itemCount;
}
```

add()

- We define **add()** to add an item at the **beginning** of the list.
  - Why?
  - What if we add it at the end of the list?

```
template<class ItemType>
bool LinkedBag<ItemType>::add(const ItemType& newEntry)
{
  Node<ItemType>* newNodePtr = new Node<ItemType>();
  newNodePtr->setItem(newEntry);
  newNodePtr->setNext(headPtr);
  headPtr = newNodePtr;
  itemCount++;
  return true;
}
```

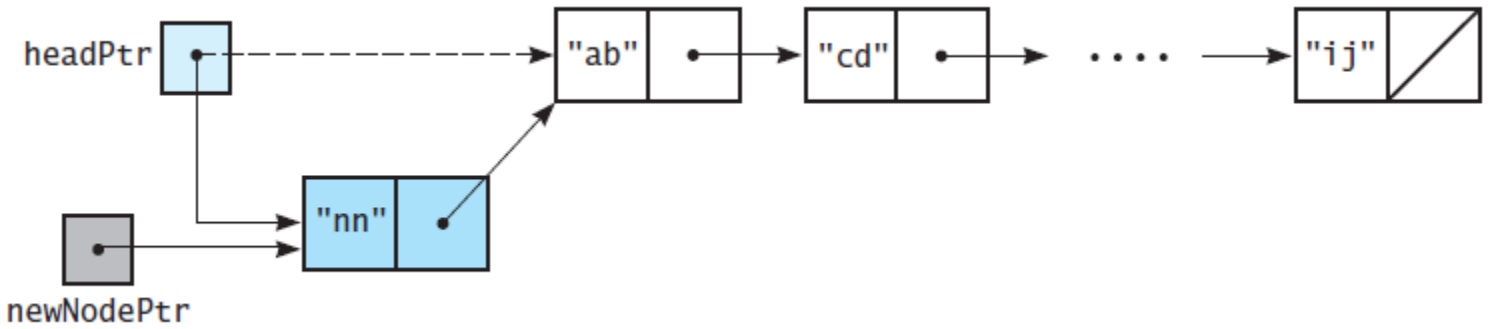

Figure 4-6 (Carrano and Henry, 2015)

`toVector()` and list traversal

- We still want to put all items into a vector. We need to **traverse** the list.
  - With **`headPtr`**, we have the address of the first node.
  - With **`headPtr->getNext()`**, we have the address of the second node.
  - How to proceed?
- We need a **location pointer** **`curPtr`** to store a node address in each iteration.

Let **`curPtr`** point to the first node in the list
while **`curPtr`** is not a null pointer
{
 Assign the **data portion** of the current node to the next element in a vector
 Set **`curPtr`** to the **next pointer portion** of the current node
}

toVector() and list traversal

```
template<class ItemType>
vector<ItemType> LinkedBag<ItemType>::toVector() const
{
  vector<ItemType> bagContents;
  Node<ItemType>* curPtr = headPtr;
  while(curPtr != nullptr)
  {
    bagContents.push_back(curPtr->getItem());
    curPtr = curPtr->getNext();
    // the above line is equivalent to:
    // Node<ItemType>* temp = curPtr->getNext();
    // curPtr = temp
  }
  return bagContents;
}
```

curPtr = curPtr->getNext()

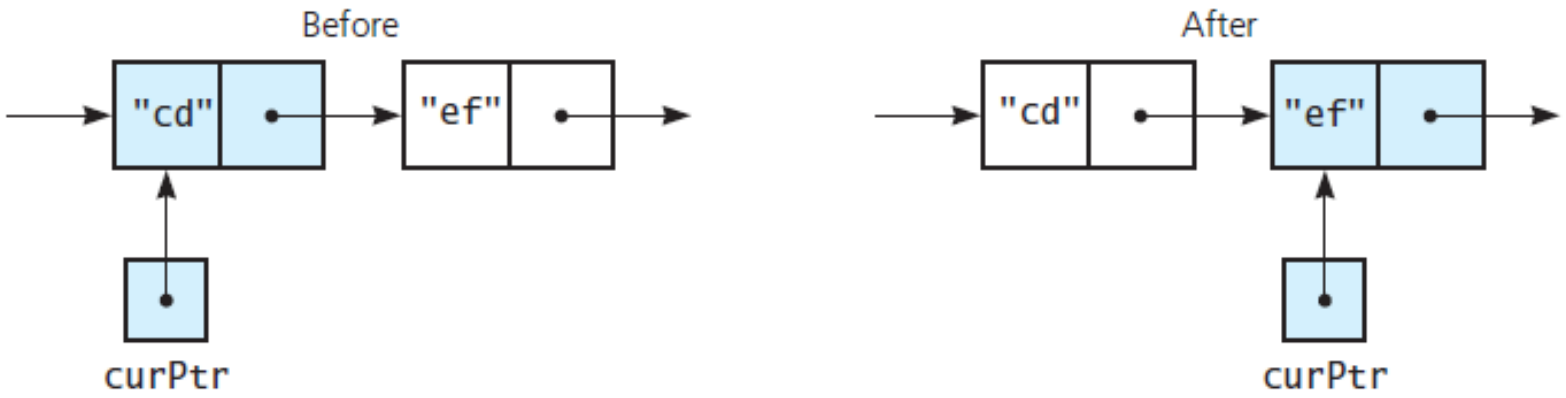

Figure 4-7 (Carrano and Henry, 2015)

remove()

- To remove an item, we will remove **the first copy** (the one closest to the head).
  - First we **locate** that copy (if there is one).
  - Then we **rewrite** the data portion of that node as that of the first node.
  - Finally, we **redirect** **headPtr** to the second node and **release** the first node.

```
Node<ItemType>* nodeToDeletePtr = headPtr;
headPtr = headPtr->getNext(); // redirect
delete nodeToDeletePtr; // release
```

- We will create a private function **getPointerTo()** to do the locating task.
  - Recall that for **ArrayBag**, we have **getIndexOf()**.

remove()

```
template<class ItemType>
bool LinkedBag<ItemType>::remove(const ItemType& anEntry)
{
  Node<ItemType>* entryNodePtr = getPointerTo(anEntry); // step 1
  bool canRemoveItem = !isEmpty() && (entryNodePtr != nullptr);
  if(canRemoveItem)
  {
    entryNodePtr->setItem(headPtr->getItem()); // step 2
    Node<ItemType>* nodeToDeletePtr = headPtr; // step 3
    headPtr = headPtr->getNext();
    delete nodeToDeletePtr;
    nodeToDeletePtr = nullptr;
    itemCount--;
  }
  return canRemoveItem;
}
```

getPointerTo()

- Given an item, we want to find the **location** of the first copy of this item.
  - In **ArrayBag**, the location is represented by an array index.
  - In **LinkedBag**, the location is represented by an **address**.
- We want to define the following private function (why private?):

```
template<class ItemType>
Node<ItemType>* LinkedBag<ItemType>
  ::getPointerTo(const ItemType& anEntry) const
```

  - If the item does not exist, return **nullptr**.
  - Note that returning a pointer is nothing but returning an address.
- The idea: Traverse the list, stop when a node contains the given item, and then return the address.

getPointerTo()

- The implementation:
- If the bag is empty, **curPtr** will be set to **nullptr** at initialization.
- If the item does not exist, **curPtr** will be set to **nullptr** when we assign **curPtr->getNext()** to **curPtr** for the last time.
- In either case, **nullptr** will be returned.

```
template<class ItemType>
Node<ItemType>* LinkedBag<ItemType>
  ::getPointerTo(const ItemType& anEntry) const
{
  bool found = false;
  Node<ItemType>* curPtr = headPtr;
  while(!found && (curPtr != nullptr))
  {
    if(anEntry == curPtr->getItem())
      found = true;
    else
      curPtr = curPtr->getNext();
  }
  return curPtr;
}
```

contains()

- With **getPointerTo()**, **contains()** is easy.

```
template<class ItemType>
bool LinkedBag<ItemType>::contains(const ItemType& anEntry) const
{
  return (getPointerTo(anEntry) != nullptr);
}
```

getFrequencyOf()

- A single traversal determines the frequency of a given item:

```
template<class ItemType>
int LinkedBag<ItemType>::getFrequencyOf(const ItemType& anEntry) const
{
  int frequency = 0;
  Node<ItemType>* curPtr = headPtr;
  while(curPtr != nullptr)
  {
    if(anEntry == curPtr->getItem())
      frequency++;
    curPtr = curPtr->getNext();
  }
  return frequency;
}
```

clear()

- The function **clear()** releases all the **dynamically allocated spaces**:

```
template<class ItemType>
void LinkedBag<ItemType>::clear()
{
  Node<ItemType>* nodeToDeletePtr = headPtr;
  while(headPtr != nullptr)
  {
    headPtr = headPtr->getNext();
    delete nodeToDeletePtr;
    nodeToDeletePtr = headPtr;
  }
  itemCount = 0;
}
```

Outline

- Nodes.
- Implementations of member functions.
- **Constructors and destructor**.
- Remarks.

Constructors and the destructor

- As always, the class **`LinkedBag`** should have some constructors.
  - It should have a **default constructor** (and probably some other constructors with various parameters).
  - It should have a **copy constructor** to do deep copy.
- It should have a **destructor** to deallocate dynamically allocated nodes.

The class LinkedBag

- The basic elements of **LinkedBag**:

```
template<class ItemType>
class LinkedBag : public BagInterface<ItemType>
{
private:
  Node<ItemType>* headPtr;
  int itemCount;
  // ...
public:
  LinkedBag(); // default constructor
  LinkedBag(const LinkedBag<ItemType>& aBag); // copy constructor
  virtual ~LinkedBag(); // destructor
  // ...
};
```

Default constructor and destructor

- The default constructors and destructor of **LinkedBag**:

```
template<class ItemType>
LinkedBag<ItemType>::LinkedBag()
  : headPtr(nullptr), itemCount(0)
{
}

template<class ItemType>
LinkedBag<ItemType>::~LinkedBag()
{
  clear();
}
```

- The destructor is set **virtual**. Why?

Virtual destructor

- Suppose the destructor is not virtual:
  - If **DerivedLB** has its own dynamic contents, it needs to have **its own destructor** to clean them up.
- If we use polymorphism on the **LinkedBag-DerivedLB** relationship:
  - When we **delete b** to "release the space," the behavior is **undefined**.
  - **LinkedBag**'s destructor may be called.
- To ensure the invocation of **DerivedLB**'s destructor, set **LinkedBag**'s destructor to be virtual.

```
class LinkedBag
{
  // ...
  ~LinkedBag() { // some cleaning }
};
class DerivedLB : public LinkedBag
{
  // ...
  ~DerivedLB() { // more cleaning }
}
```

```
LinkedBag* b = new DerivedLB();
// use b to do something
delete b; // What will happen?
```

Copy constructor (shallow copy)

- If we do not define a copy constructor by ourselves, the **default copy constructor** of **`LinkedBag`** will be like:

```
template<class ItemType>
LinkedBag<ItemType>::LinkedBag
   (const LinkedBag<ItemType>& aBag)
{
  itemCount = aBag->itemCount;
  headPtr = aBag->headPtr;
}
```

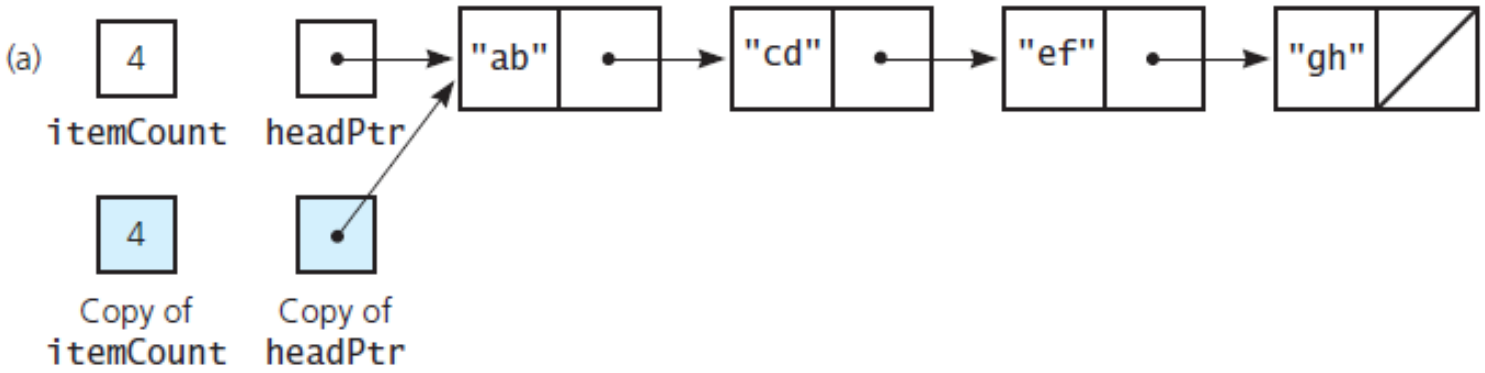

Figure 4-8 (a) (Carrano and Henry, 2015)

Copy constructor (deep copy)

- What we want is **deep copy**: A new list of items should be dynamically created.

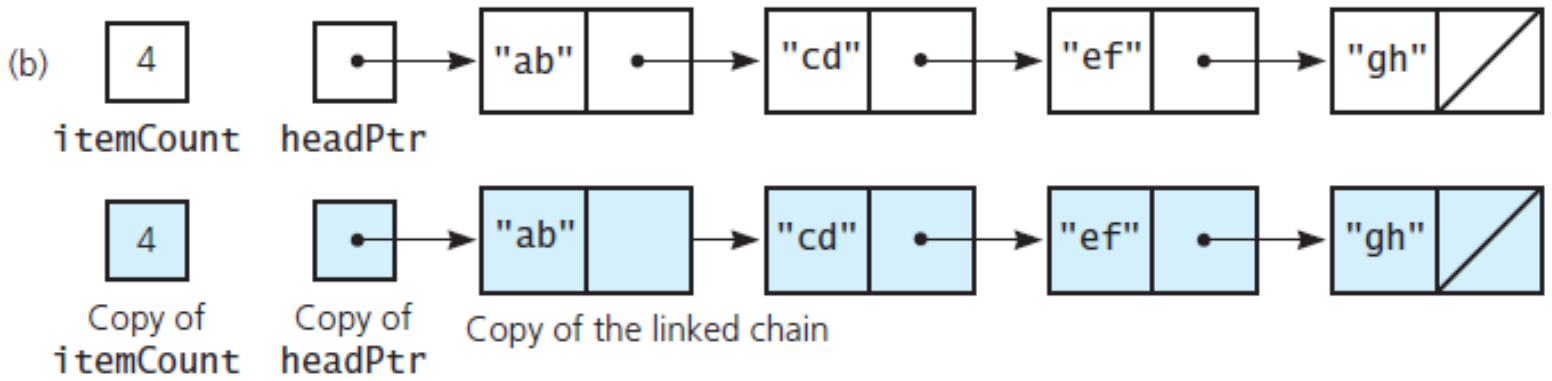

Figure 4-8 (b) (Carrano and Henry, 2015)

- To do so, we need to define our own copy constructor for **`LinkedBag`**:

Copy constructor (deep copy)

- The copy constructor of **LinkedBag**:

```
template<class ItemType>
LinkedBag<ItemType>::LinkedBag(const LinkedBag<ItemType>& aBag)
{
  itemCount = aBag->itemCount;
  Node<ItemType>* origChainPtr = aBag->headPtr;
  if(origChainPtr == nullptr)
    headPtr = nullptr;
  else
  {
    headPtr = new Node<ItemType>();
    headPtr->setItem(origChainPtr->getItem());
    // continue to the next page
```

Copy constructor (deep copy)

- The copy constructor of **LinkedBag**:

```
    // continue from the previous page
    Node<ItemType>* newChainPtr = headPtr;
    while(origChainPtr != nullptr)
    {
      origChainPtr = origChainPtr->getNext();
      ItemType nextItem = origChainPtr->getItem();
      Node<ItemType>* newNodePtr = new Node<ItemType>(nextItem);
      newChainPtr->setNext(newNodePtr);
      newChainPtr = newChainPtr->getNext();
    }
    newChainPtr->setNext(nullptr);
  }
}
```

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Recursion

- **Recursion** can again be applied to implement member functions.
  - E.g., when the function does a list traversal.
- Let's use `getPointerTo()` and `toVector()` to illustrate the idea.
  - Other functions may also be implemented with recursion.

Recursive getPointerTo()

- **getPointerTo()** may be redefined as a recursive function.
  - A new argument is added.

```
template<class ItemType>
Node<ItemType>* LinkedBag<ItemType>
  ::getPointerTo(const ItemType& target,
                 Node<ItemType>* curPtr) const
{ // pass headPtr as the 2nd argument
  // to traverse the whole bag
  Node<ItemType>* result = nullptr;
  if(curPtr != nullptr)
  {
    if(target == curPtr->getItem())
      result = curPtr;
    else
      result = getPointerTo(target, curPtr->getNext());
  }
  return result;
}
```

Recursive `toVector()`

- Similarly, **`toVector()`** can be re-implemented:
  - We add a **recursive member function** **`fillVector()`**.

```
template<class ItemType>
vector<ItemType> LinkedBag<ItemType>
  ::toVector() const
{
  vector<ItemType> bagContents;
  fillVector(bagContents, headPtr);
  return bagContents;
}
```

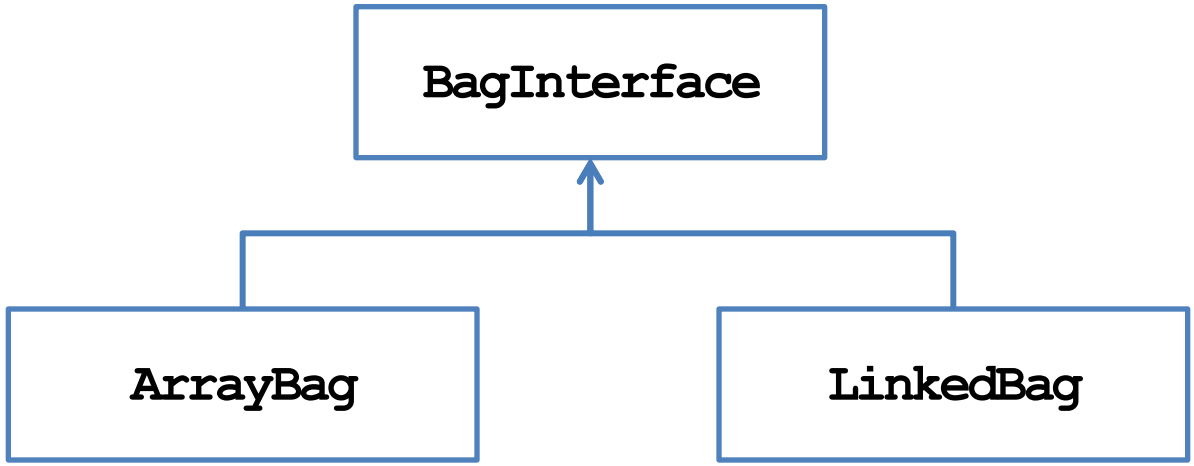
Recursive `toVector()`

```
template<class ItemType>
void LinkedBag<ItemType>
  ::fillVector(vector<ItemType>& bagContents,
               Node<ItemType>* curPtr) const
{
   if (curPtr != nullptr)
   {
      bagContents.push_back(curPtr->getItem());
      fillVector(bagContents, curPtr->getNext());
   }
}
```

- Why do we define **`fillVector()`**? How about **`getPointerTo()`**?
- Should **`fillVector()`** be private, public, or protected?
- Does recursion improve the efficiency of the program?

Polymorphism regarding the ADT bag

- We have defined a pure virtual base class **`BagInterface`**.
- We have implemented two concrete derived classes **`ArrayBag`** and **`LinkedBag`**.



- Thanks to polymorphism, we may now **dynamically** determine which implementation to use at the run time.

Polymorphism regarding the ADT bag

```
int main()
{
  BagInterface<string>* bagPtr = nullptr;
  char userChoice = 0;
  cin >> userChoice;
  if(userChoice == 'A')
    bagPtr = new ArrayBag<string>();
  else
    bagPtr = new LinkedBag<string>();
  bagTester(bagPtr);
  delete bagPtr;
  bagPtr = nullptr;
  return 0;
}
```

```
void bagTester
   (BagInterface<string>* bagPtr)
{
  string items[] = {"aa", "bb", "cc"};
  for(int i = 0; i < 3; i++)
    bagPtr->add(items[i]);
  cout << bagPtr->isEmpty();
  cout << bagPtr->getCurrentSize();
  bagPtr->remove("two");
  cout << bagPtr->isEmpty();
  cout << bagPtr->getCurrentSize();
}
```

Benefits of link-based implementations

Array-based Implementations	Link-based Implementations
A static array has a size limit	Does not have a size limit
A dynamic array requires a lot of time to increase the size	Does not have a size limit
May need to predict the maximum number of items	No need to predict this
May waste space	Use space when you need it

Benefits of array-based implementations

Array-based Implementations	Link-based Implementations
Require less space to store an item	Require more space to store an item
One may directly access any item	A traversal is needed to access an item
Accessing each item requires a constant time	Accessing the *i*th items takes more time for larger *i*
Easier to write the program	Harder to write the program

Comparisons

- Use arrays if:
  - The maximum number of items is fixed and known.
  - The maximum number of items may vary but will be small.
  - Accessing efficiency is critical for you.
- Use links if:
  - The number of items varies a lot.
  - The data portion occupies huge space.