Linked-Based Implementation

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Recap

- Bag ADT : design

- ArrayBag: implementation (first version)

- Pointers
  - Variable that holds address of same type
  - Must be nullptr if not pointing to something
  - Can change what it points to
  - Can access values of what it points to

- Dynamic memory allocation
  - Can dynamically allocate memory on Heap through pointers
  - Use keyword `new` to allocate
  - Use keyword `delete` to deallocate and MUST set pointer to some other value
  - Beware of memory leaks
  - Beware of dangling pointers

Let’s try a different implementation for Bag

Link-Based Implementation

🔗 🔗 🔗 🔗

The Header File

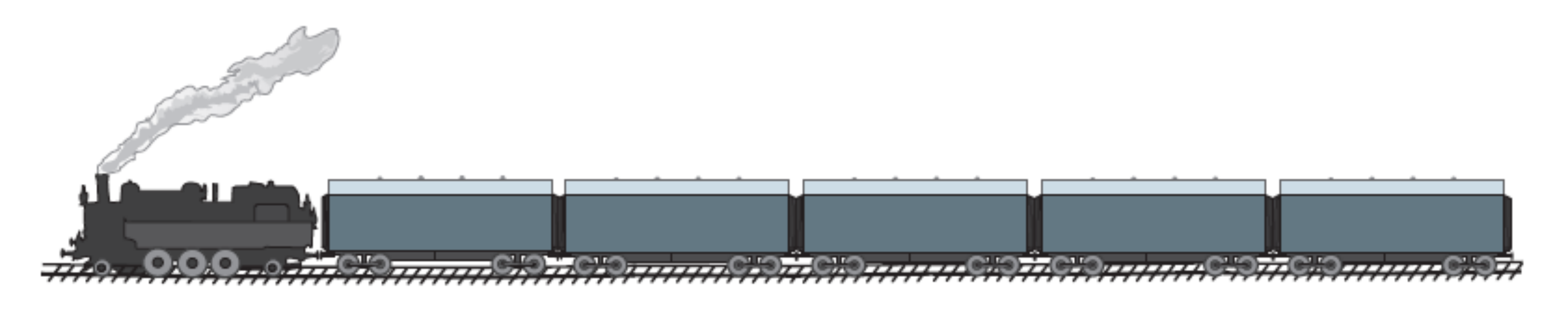
```
#ifndef LINKED_BAG_H_
#define LINKED_BAG_H_


template<class T>
class LinkedBag
{

public:
    LinkedBag();
    int getCurrentSize() const;
    bool isEmpty() const;
    bool add(const T& new_entry);
    bool remove(const T& an_entry);
    void clear();
    bool contains(const T& an_entry) const;
    int getFrequencyOf(const T& an_entry) const;
    std::vector<T> toVector() const;

private:



};     //end LinkedBag

#include "LinkedBag.cpp"
#endif
```

Same interface, different implementation

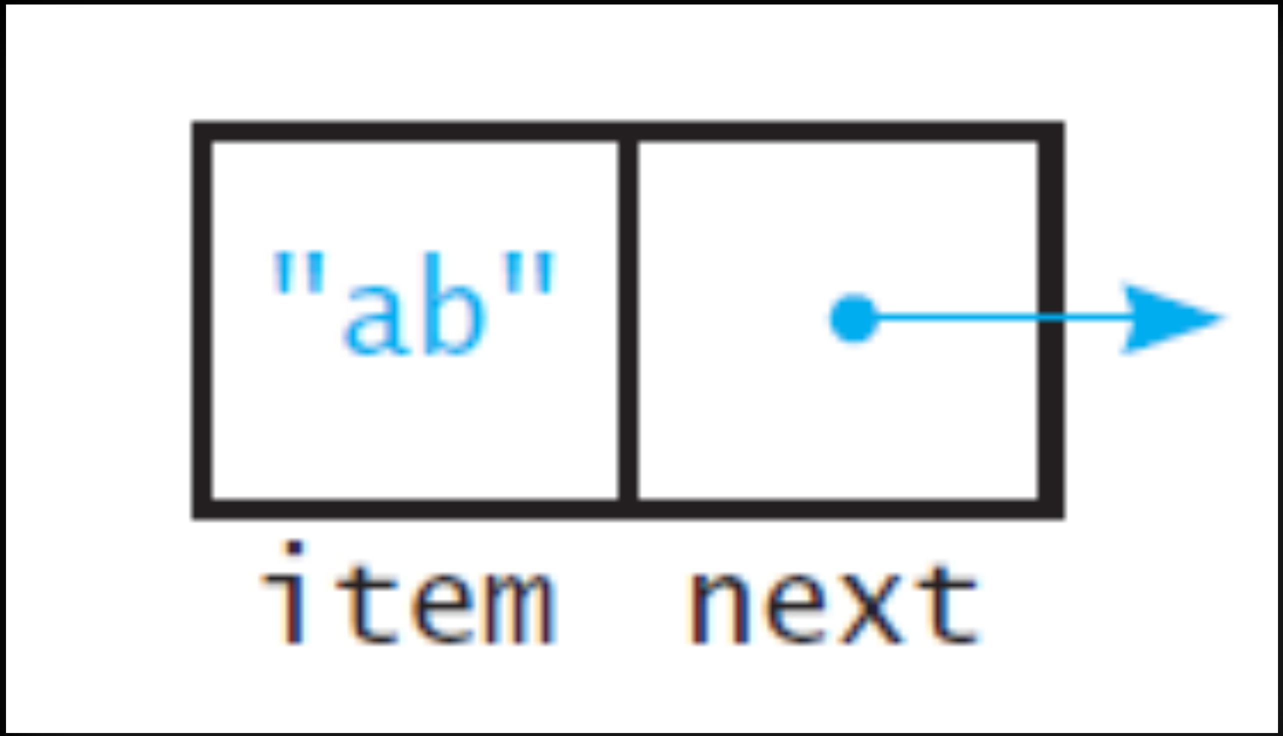
Data Organization

Place data within a Node object

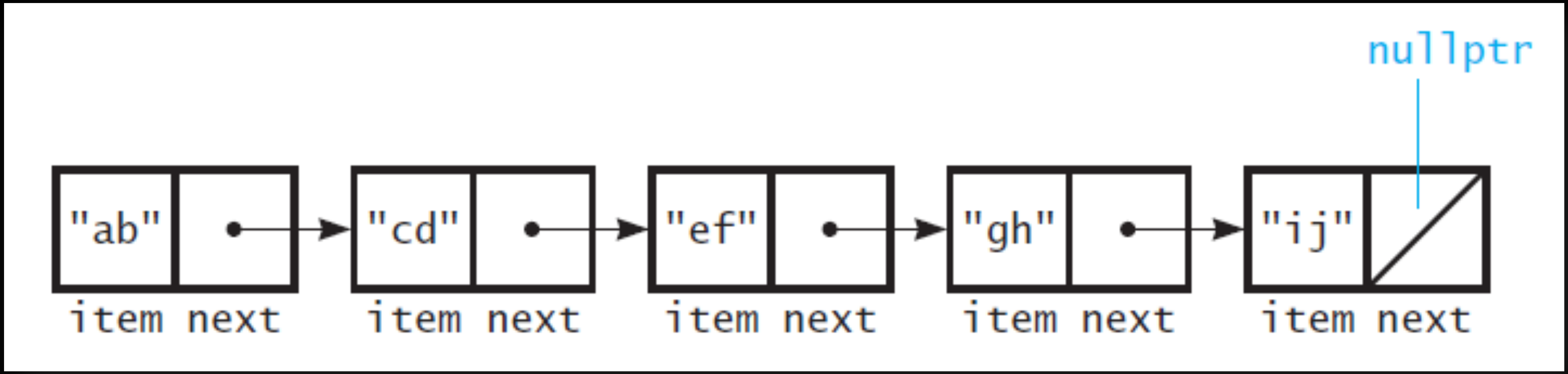
Link nodes into a chain



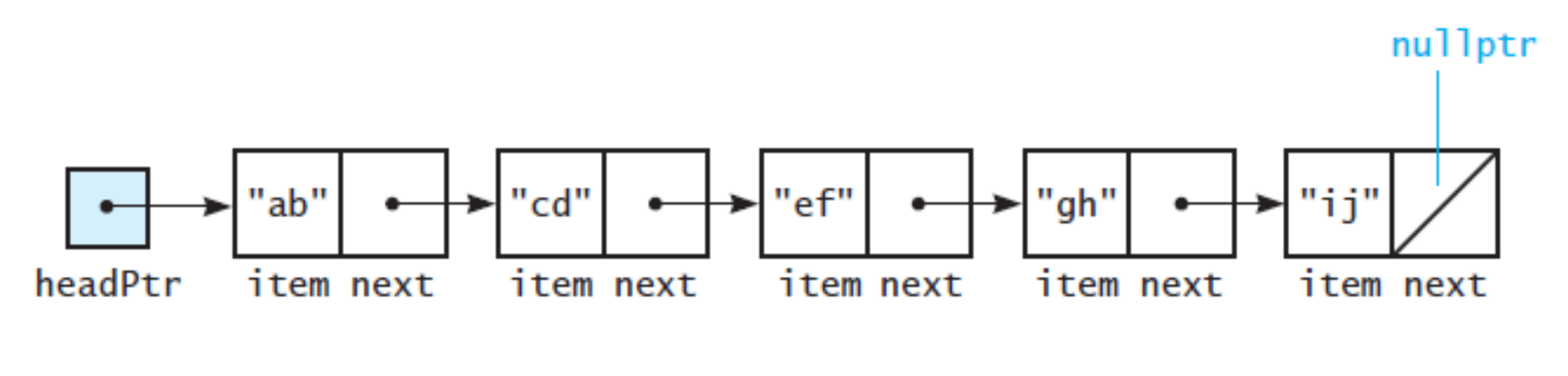
Node



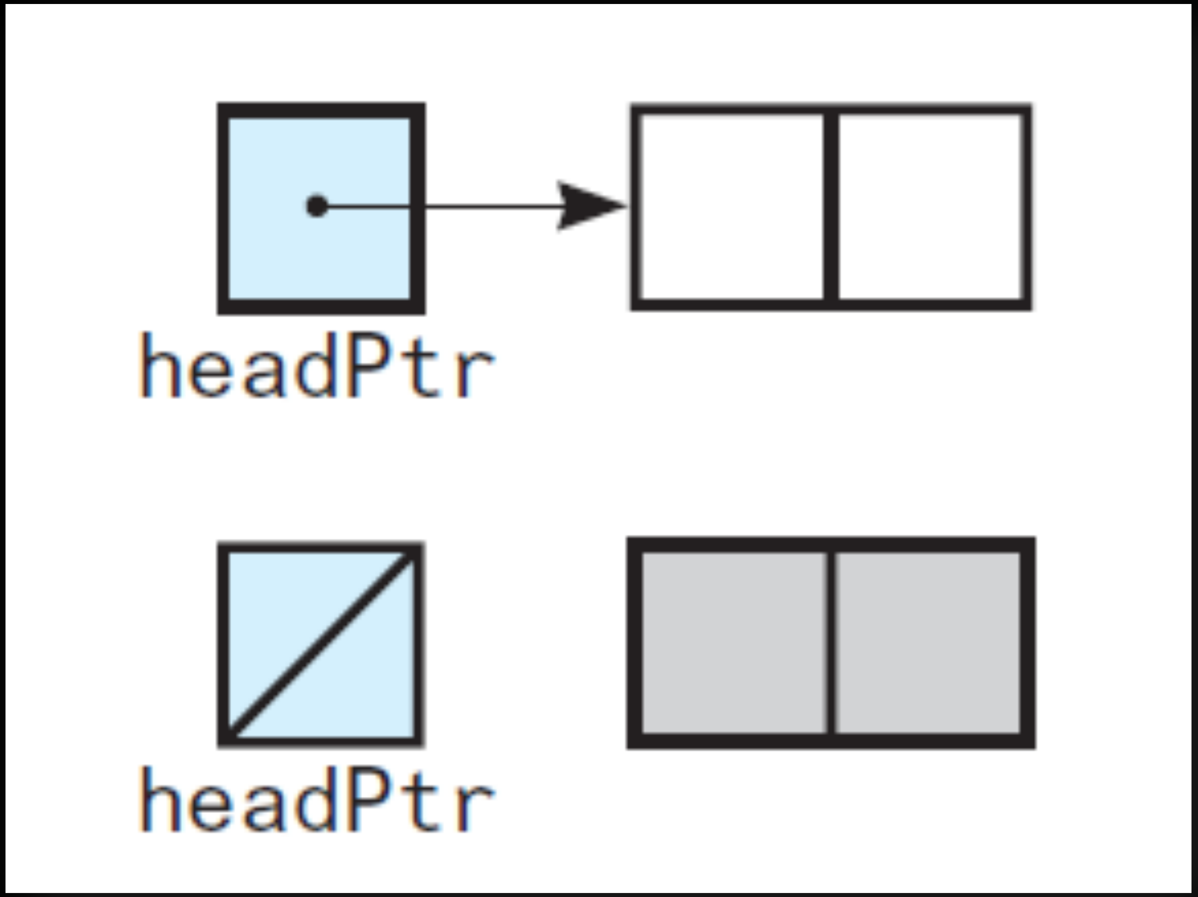
Chain


nullptr
"ab"
"cd"
"ef"
"gh"
"ij"
item next
item next
item next
item next
item next

Entering the Chain

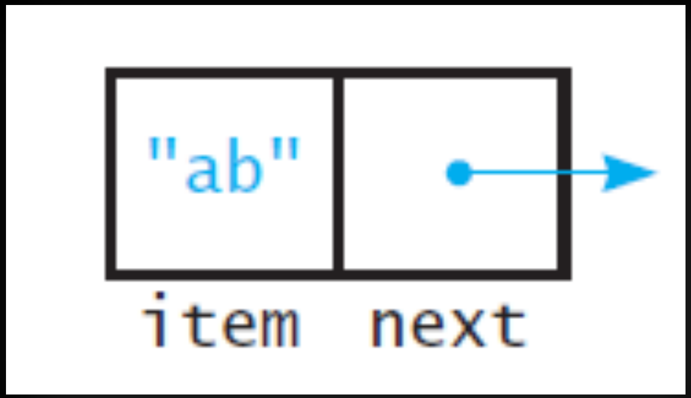


The Empty Chain



The Class Node

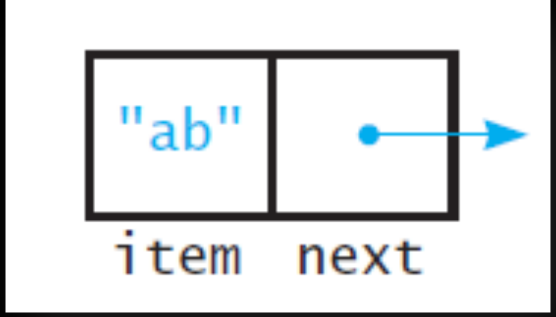
```
#ifndef NODE_H_
#define NODE_H_

template<class T>
class Node
{

public:
    Node();
    Node(const T& an_item);
    Node(const T& an_item, Node<T>* next_node_ptr);
    void setItem(const T& an_item);
    void setNext(Node<T>* next_node_ptr);
    T getItem() const;
    Node<T>* getNext() const;

private:
    T item_;           // A data item
    Node<T>* next_;   // Pointer to next node
}; // end Node



#include "Node.cpp"
#endif // NODE_H_
```



Node Implementation

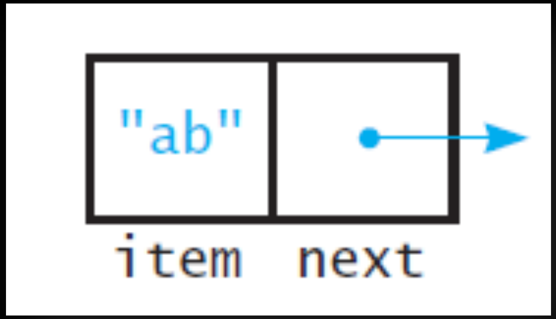
The Constructors

```
#include "Node.hpp"


template<class T>
Node<T>::Node() : next_{nullptr}
{

} // end default constructor


template<class T>
Node<T>::Node(const T& an_item) : item_{an_item}, next_{nullptr}
{

} // end constructor


template<class T>
Node<T>::Node(const T& an_item, Node<T>* next_node_ptr) :
                item_{an_item}, next_{next_node_ptr}
{

} // end constructor
```



Node Implementation

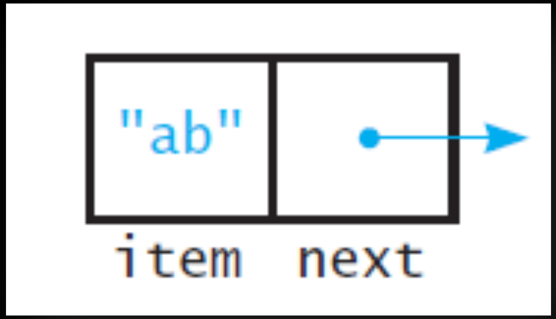
The “*setData*” members



```
#include “Node.hpp”


template<class T>
void Node<T>::setItem(const T& an_item)
{

   item_{an_item};

} // end setItem



template<class T>
void Node<T>::setNext(Node<T>* next_node_ptr)
{

   next_{next_node_ptr};

} // end setNext
```

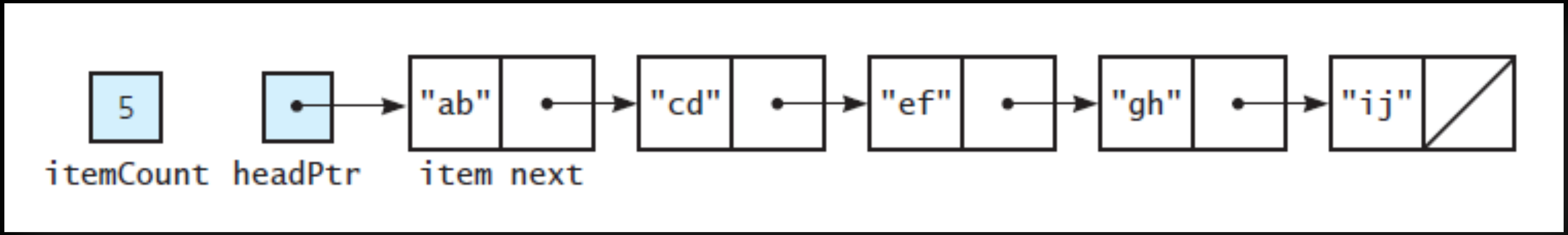
Node Implementation

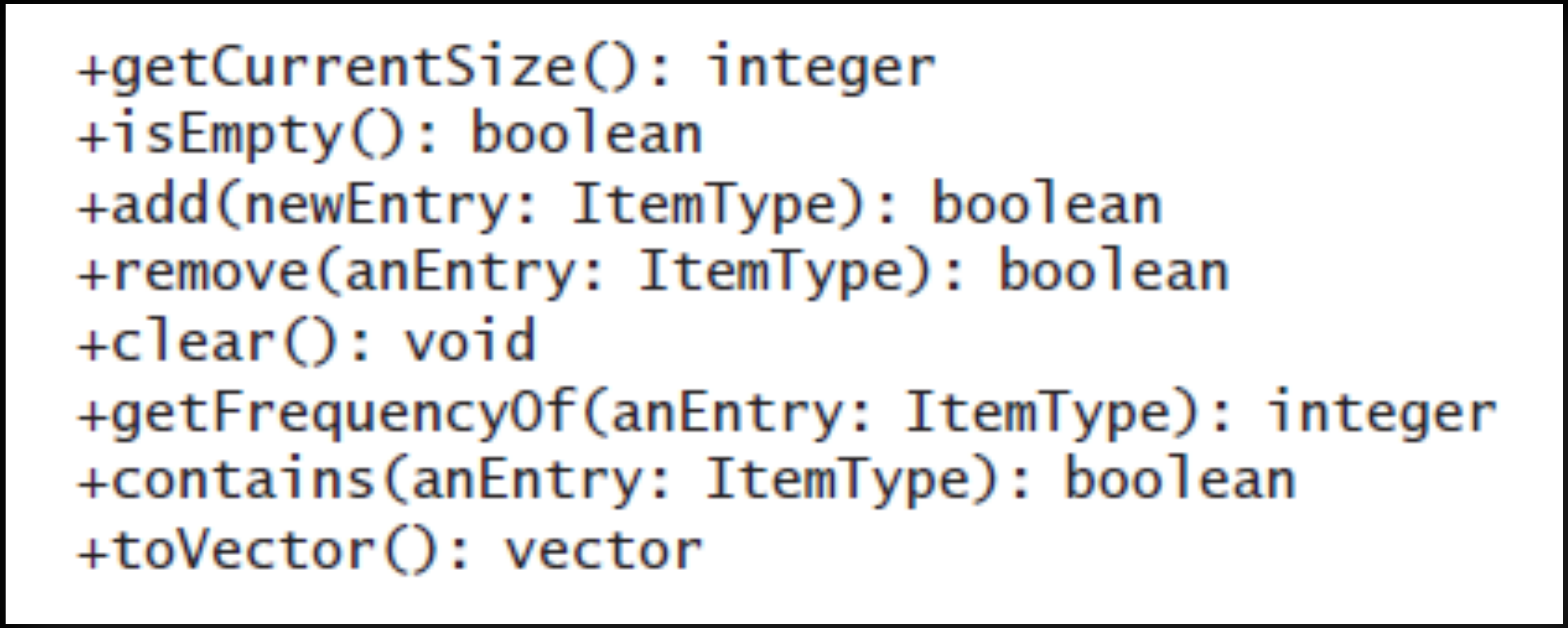
The “get*Data*” members



```
#include “Node.hpp”


template<class T>
T Node<T>::getItem() const
{

   return item_;

} // end getItem



template<class T>
Node<T>* Node<T>::getNext() const
{

   return next_;

} // end getNext
```

A Linked Bag ADT





```
+getCurrentSize(): integer
+isEmpty(): boolean
+add(newEntry: ItemType): boolean
+remove(anEntry: ItemType): boolean
+clear(): void
+getFrequencyOf(anEntry: ItemType): integer
+contains(anEntry: ItemType): boolean
+toVector(): vector
```

The Class LinkedBag

```
#ifndef LINKED_BAG_H_
#define LINKED_BAG_H_


#include “Node.hpp"

template<class T>
class LinkedBag
{
public:
   LinkedBag();
   LinkedBag(const LinkedBag<T>& a_bag); // Copy constructor
   ~LinkedBag();                  // Destructor
   int getCurrentSize() const;
   bool isEmpty() const;
   bool add(const T& new_entry);
   bool remove(const T& an_entry);
   void clear();
   bool contains(const T& an_entry) const;
   int getFrequencyOf(const T& an_entry) const;
   std::vector<T> toVector() const;

private:


 ???
}; // end LinkedBag

#include “LinkedBag.cpp"
#endif //LINKED_BAG_H_
```

Same interface, different implementation

The Class LinkedBag

```
#ifndef LINKED_BAG_H_
#define LINKED_BAG_H_


#include “Node.hpp"

template<class T>
class LinkedBag
{
public:
   LinkedBag();
   LinkedBag(const LinkedBag<T>& a_bag); // Copy constructor
   ~LinkedBag();                // Destructor
   int getCurrentSize() const;
   bool isEmpty() const;
   bool add(const T& new_entry);
   bool remove(const T& an_entry);
   void clear();
   bool contains(const T& an_entry) const;
   int getFrequencyOf(const T& an_entry) const;
   std::vector<T> toVector() const;

private:
   Node<T>* head_ptr_; // Pointer to first node
   int item_count_;           // Current count of bag items

      // Returns either a pointer to the node containing a given entry
     // or the null pointer if the entry is not in the bag.
     Node<T>* getPointerTo(const T& target) const;
}; // end LinkedBag

#include “LinkedBag.cpp"
#endif //LINKED_BAG_H_
```

More than one public method will need to know if there is a pointer to a target so we separate it out into a private helper function (similar to ArrayBag but here we get pointers rather than indices)

LinkedBag Implementation

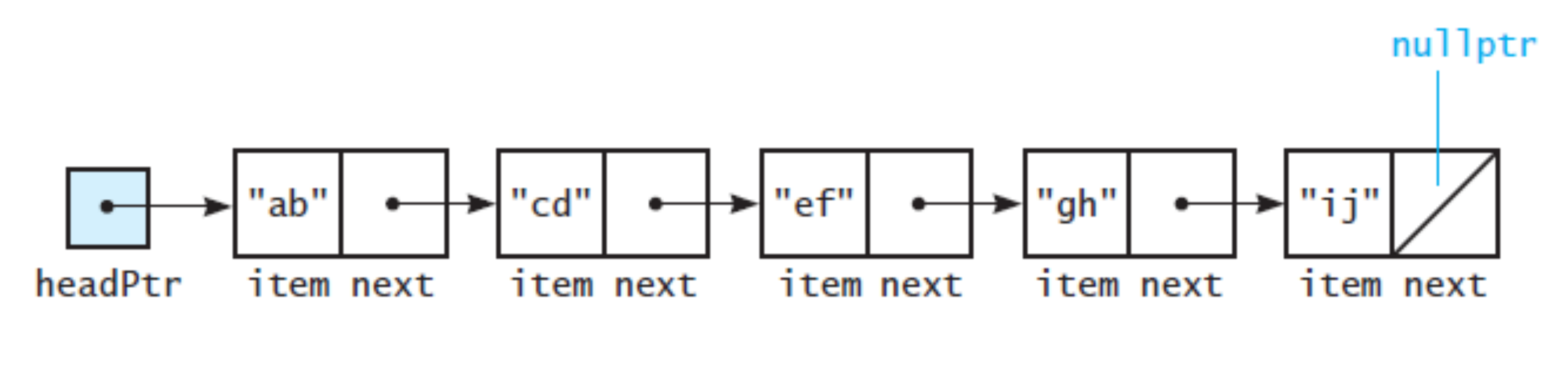
The default constructor

```
#include “LinkedBag.hpp”


template<class T>
LinkedBag<T>::LinkedBag() : head_ptr_{nullptr},
item_count_{0}
{

}  // end default constructor
```

Private data member initialization

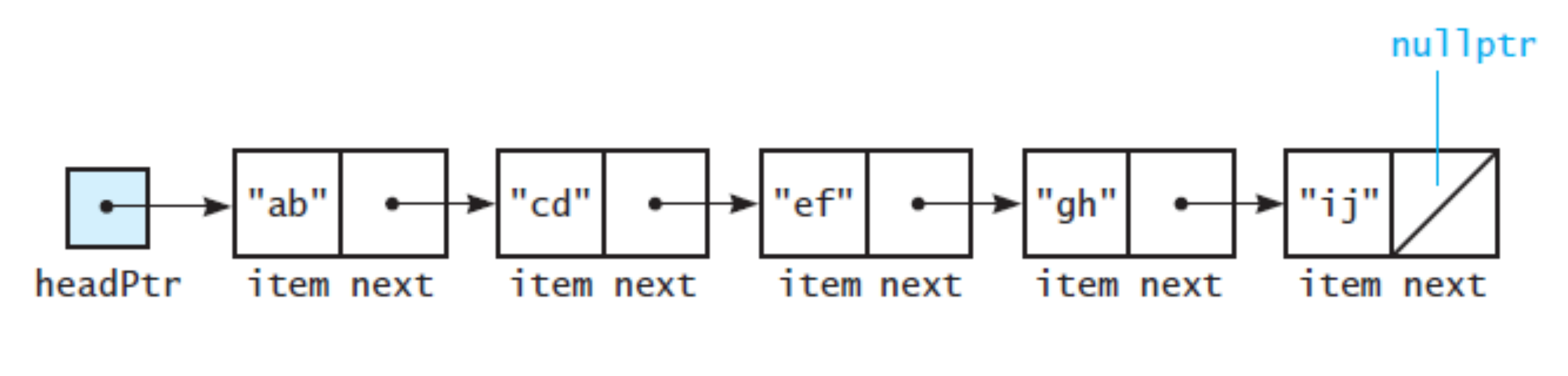
```
add(const T& new_entry)
```

Where should we add?

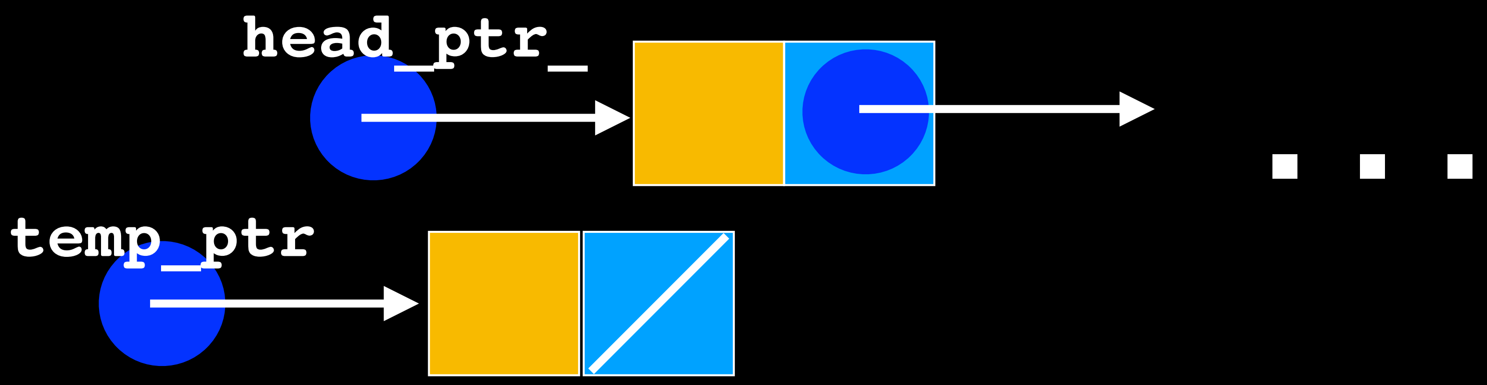


Lecture Activity

Write **pseudocode** for a sequence of steps to add to the **front** of the chain



Instantiate a new node and let a temp pointer point to it



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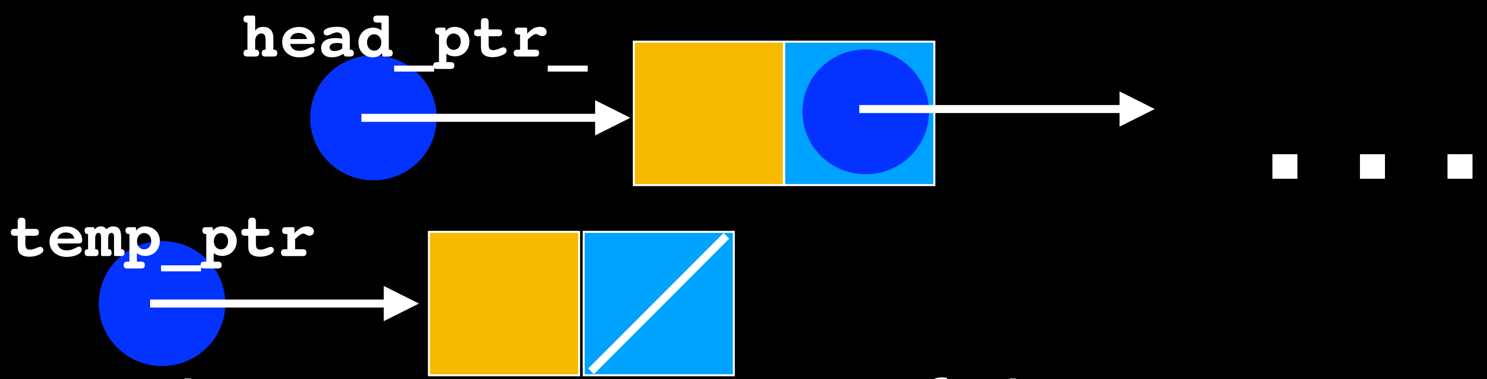
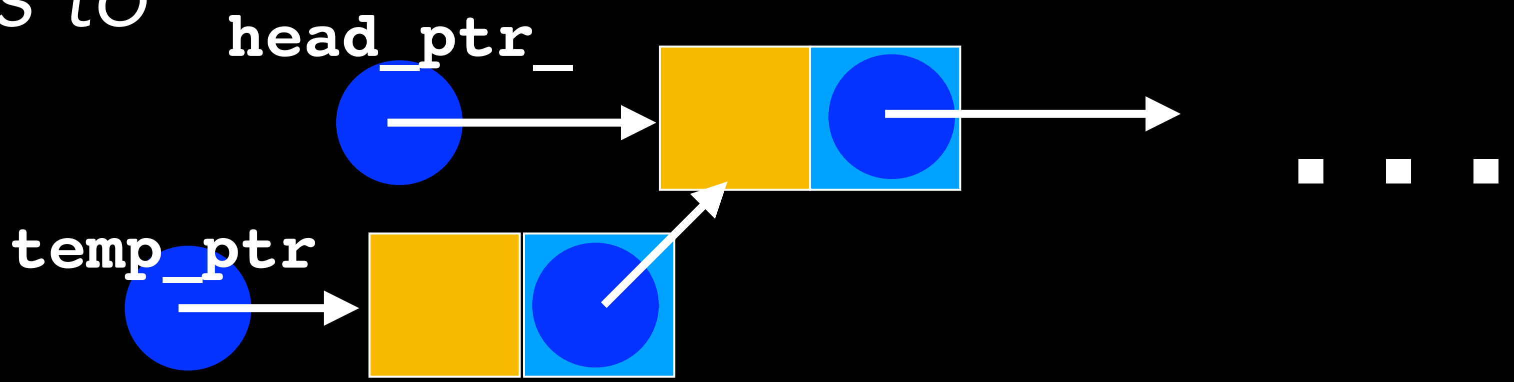


Let the next pointer of the new node point to the same node head_ptr_ points to



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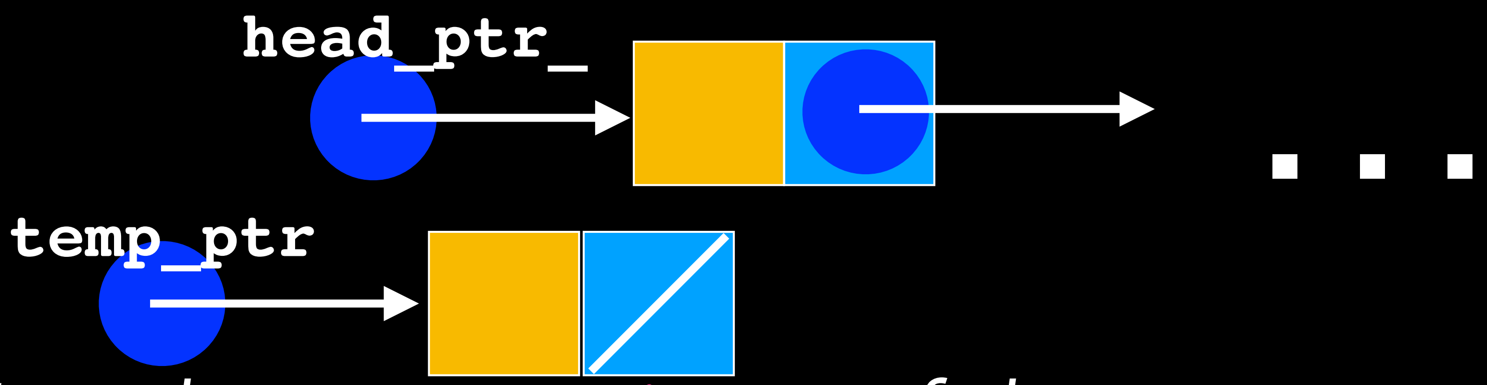

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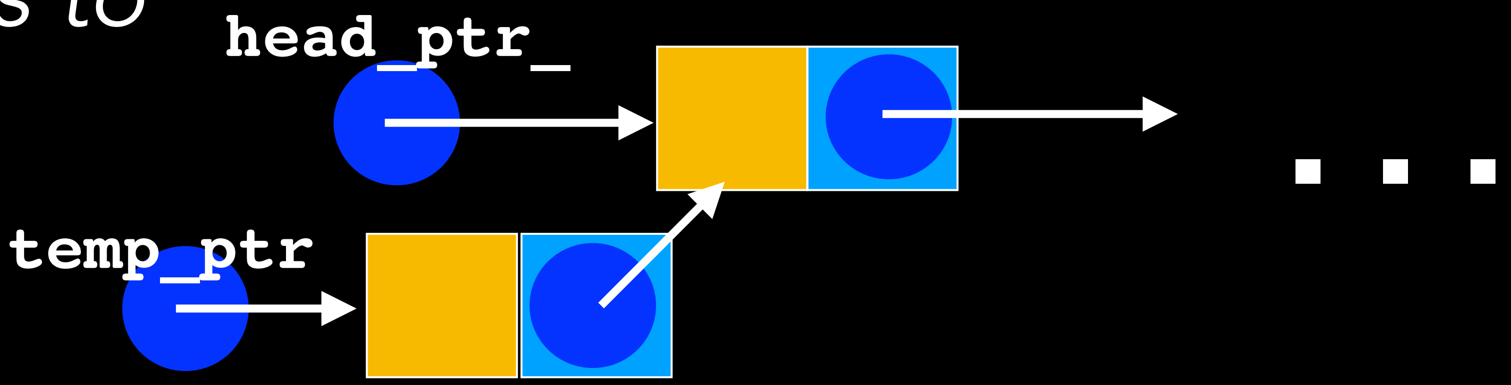
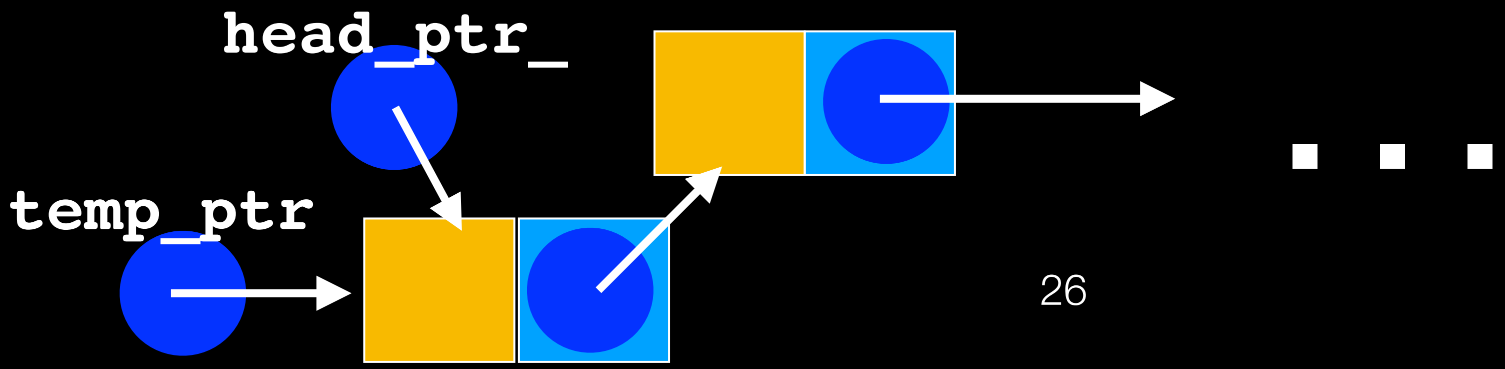
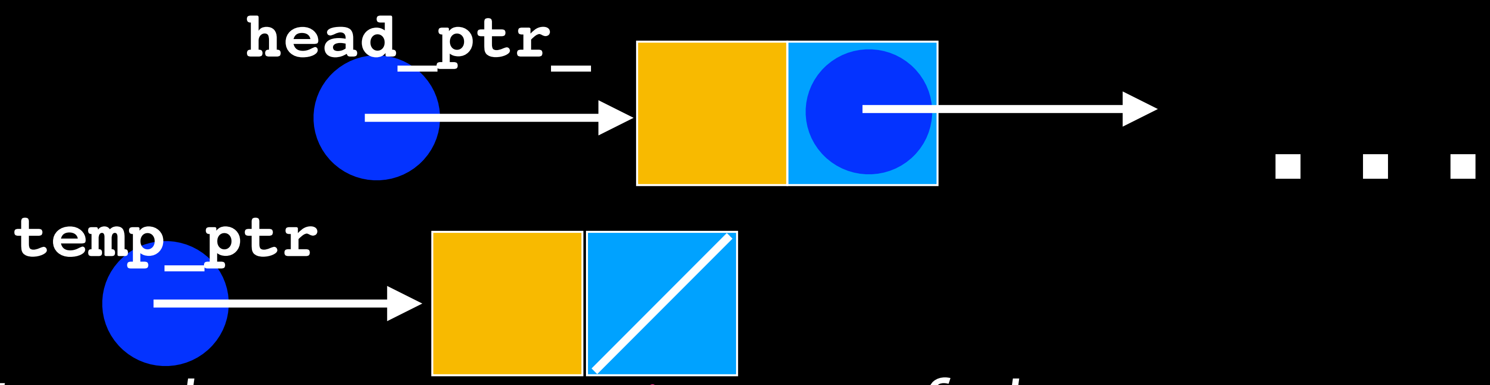


Let head_ptr_ point to the new node



Instantiate a new node and let a temp pointer point to it



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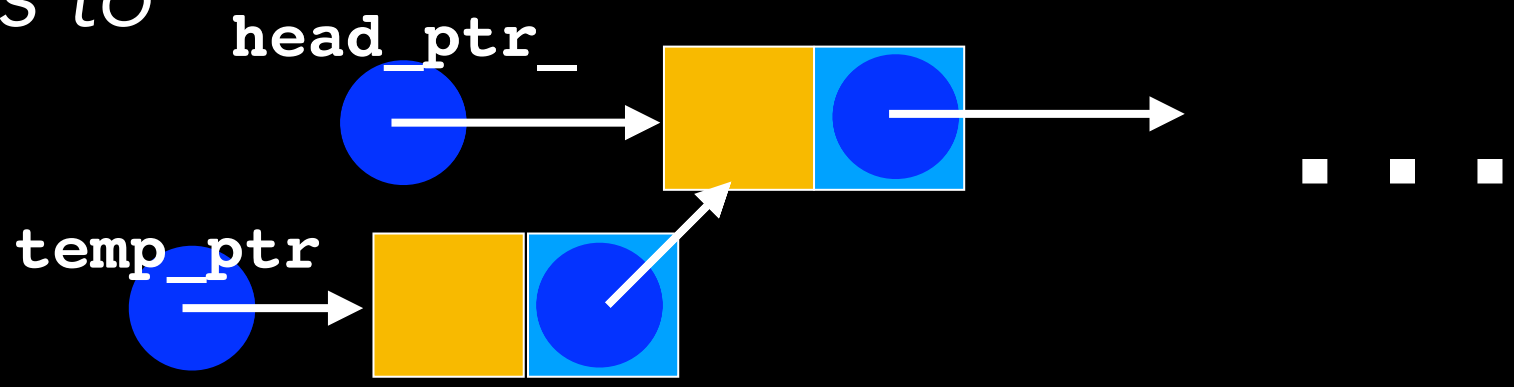
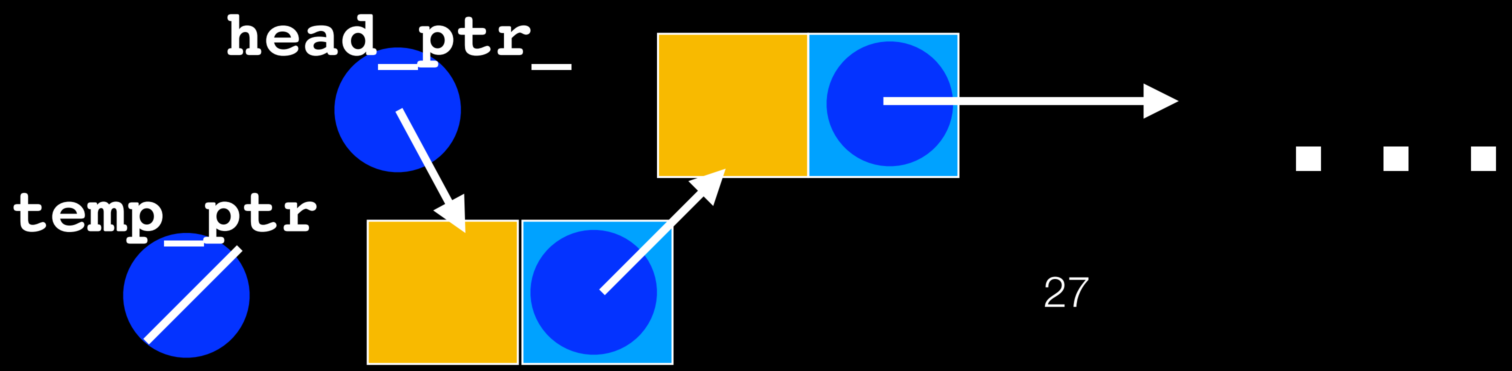


Let head_ptr_ point to the new node



Pseudocode (English-like)

- Instantiate a new node and let `temp_ptr` point to it
- Set `temp_ptr->next` to point to the same node `head_ptr_` points to
- Set `head_ptr` to point to the same node `temp_ptr` points to
- Set `temp_ptr` to `nullptr`

Pseudocode (Code-like)

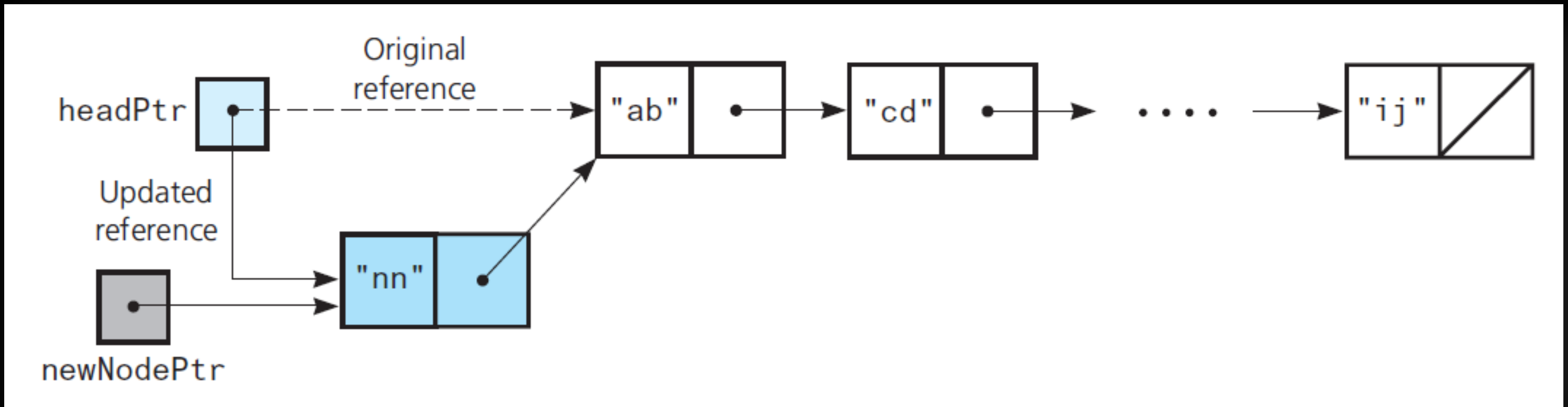
```
temp_ptr = new node
temp_ptr->next = head_ptr_
head_ptr = temp_ptr
temp_ptr = nullptr
```

LinkedBag Implementation

```
#include “LinkedBag.hpp”


template<class T>
bool LinkedBag<T>::add(const T& new_entry)
{
   // Add to beginning of chain: new node references rest of chain;
   // (head_ptr_ is null if chain is empty)
   Node<T>* new_node_ptr = new Node<T>;
   new_node_ptr->setItem(new_entry);
   new_node_ptr->setNext(head_ptr_);   // New node points to chain

   head_ptr_ = new_node_ptr;// New node is now first n
   item_count_++;

   return true;
}  // end add
```

The add method
Add at beginning of chain is easy because we have head_ptr_

Dynamic memory allocation
Adding nodes to the heap!



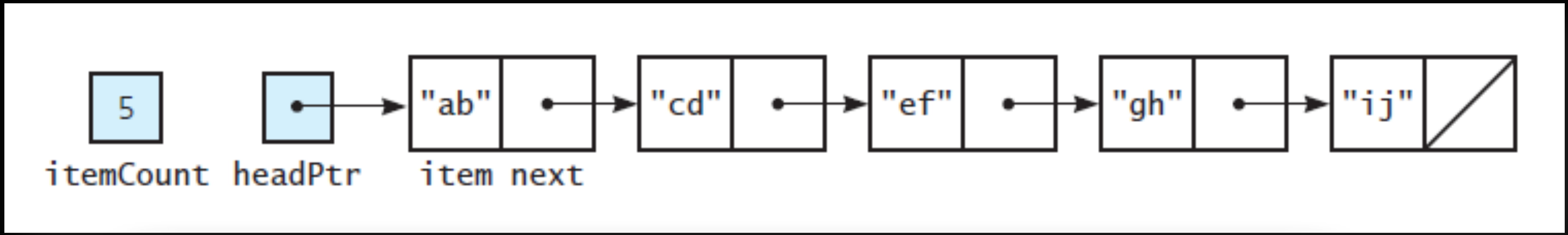
Efficiency

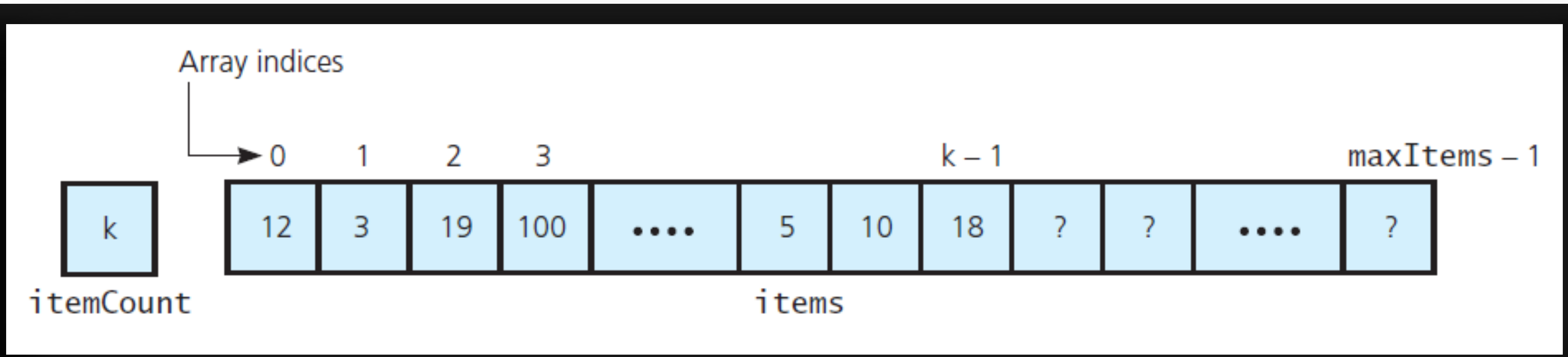
Create a new node and assign two pointers **O(1)**

What about adding to end of chain? **O(n)**

What about adding to front of array? **O(1) or O(n)**

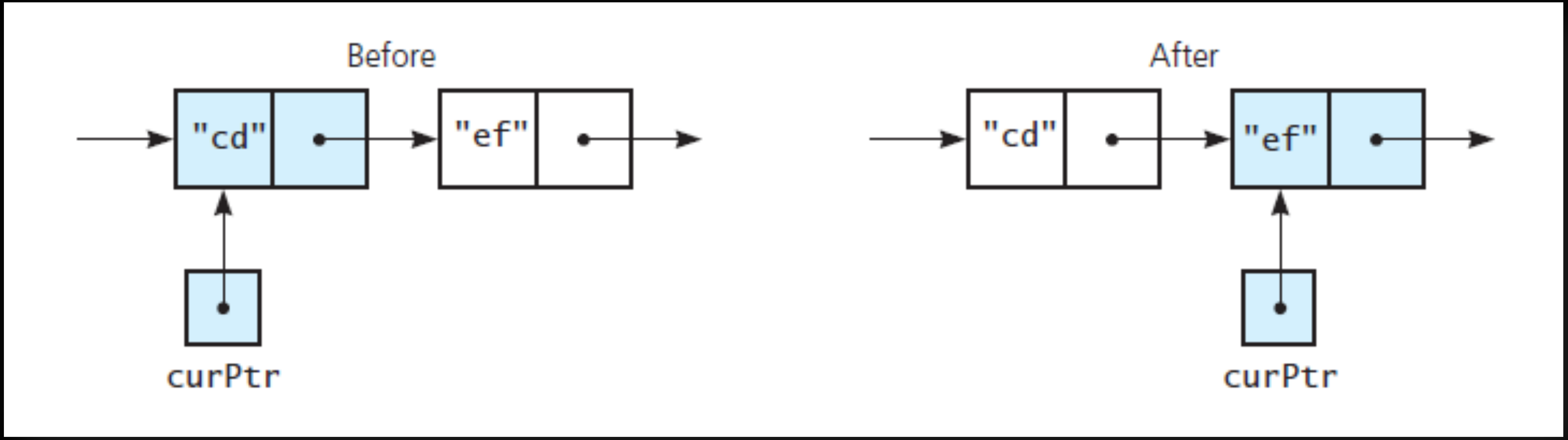
No order **Order**





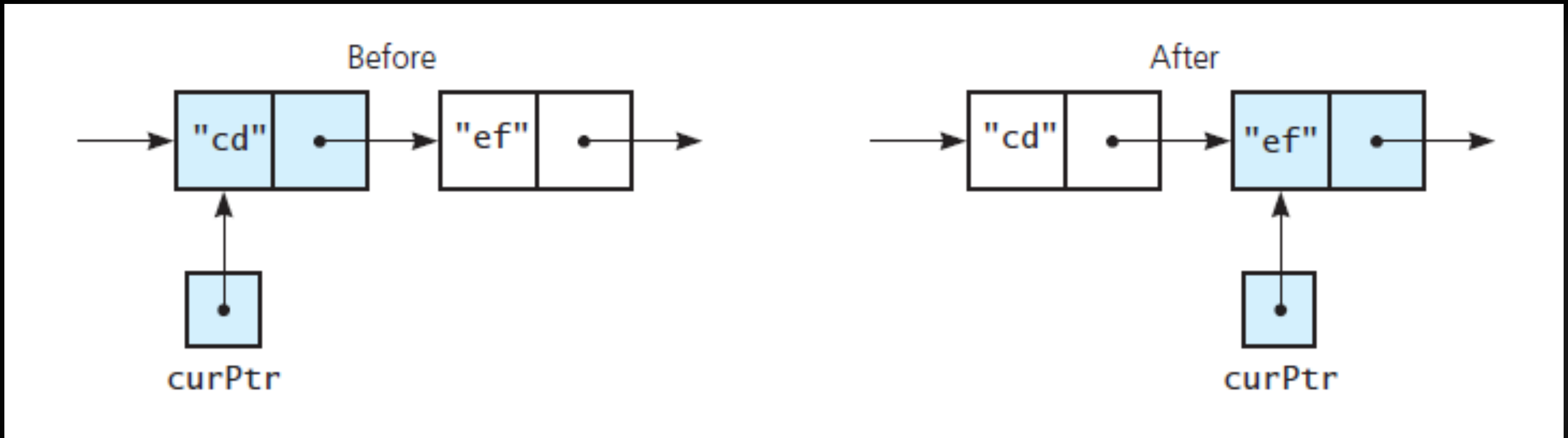
Lecture Activity

Write ***Pseudocode*** to traverse the chain from first node to last



Traversing the chain

```
Let a current pointer point to the first node in the
chain
while(the current pointer is not the null pointer)
{
   "visit" the current node
   set the current pointer to the next pointer of the
         current node
}
```

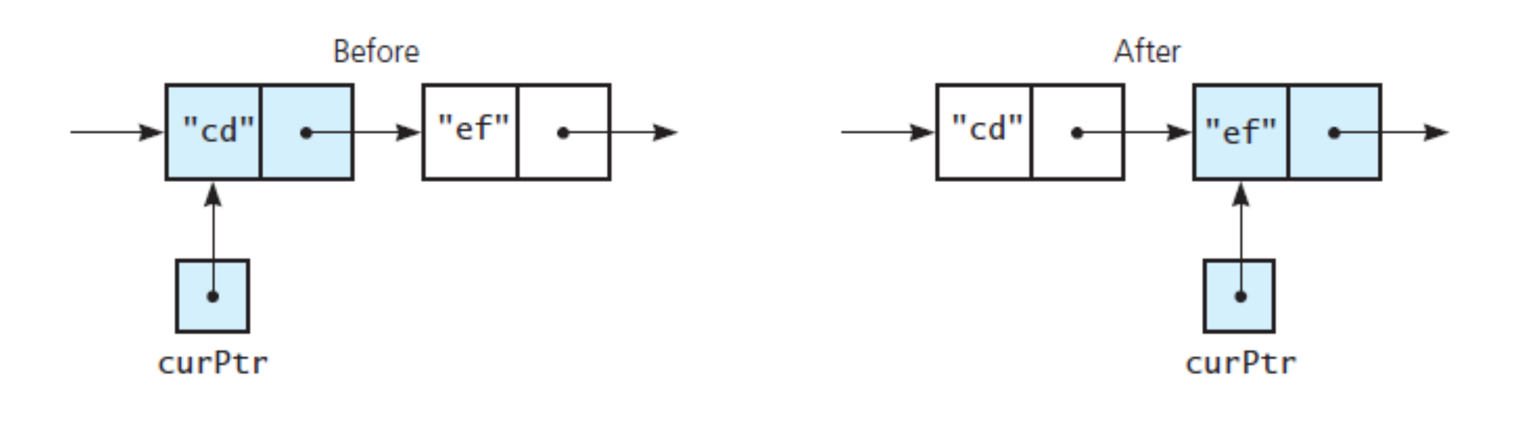


LinkedBag Implementation

The toVector method

```
#include “LinkedBag.hpp”


template<class T>
std::vector<T> LinkedBag<T>::toVector() const
{
   std::vector<T> bag_contents;
   Node<T>* cur_ptr = head_ptr_;

   while ((cur_ptr != nullptr))
   {
     bag_contents.push_back(cur_ptr->getItem());
      cur_ptr = cur_ptr->getNext();
   }  // end while


   return bag_contents;
}  // end toVector
```

Traversing:
- Visit each node
- Copy it



LinkedBag Implementation

Similarly `getFrequencyOf` will:

traverse the chain and

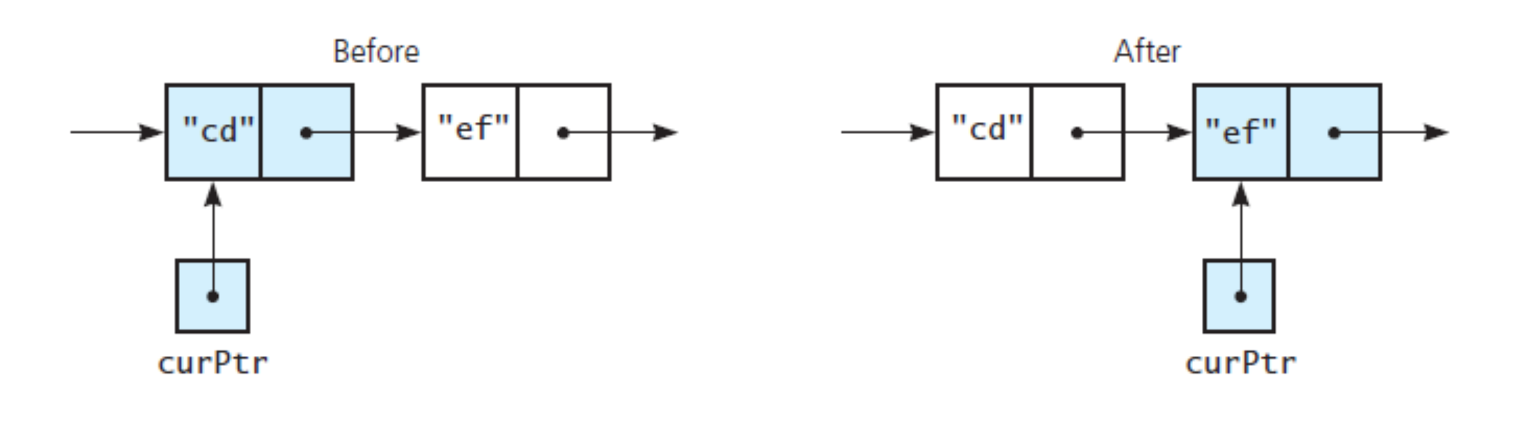
count frequency of (count each) `an_entry`

LinkedBag Implementation

```
#include “LinkedBag.hpp”


template<class T>
Node<T>* LinkedBag<T>::getPointerTo(const T& an_entry) const
{
   bool found = false;
   Node<T>* cur_ptr = head_ptr_;


   while (!found && (cur_ptr != nullptr))
   {
      if (an_entry == cur_ptr->getItem())
         found = true;
      else
         cur_ptr = cur_ptr->getNext();
   } // end while


   return cur_ptr;
} // end getPointerTo
```

The `getPointerTo` method

Traversing:
   visit each node
   if found what looking for
      return



Efficiency

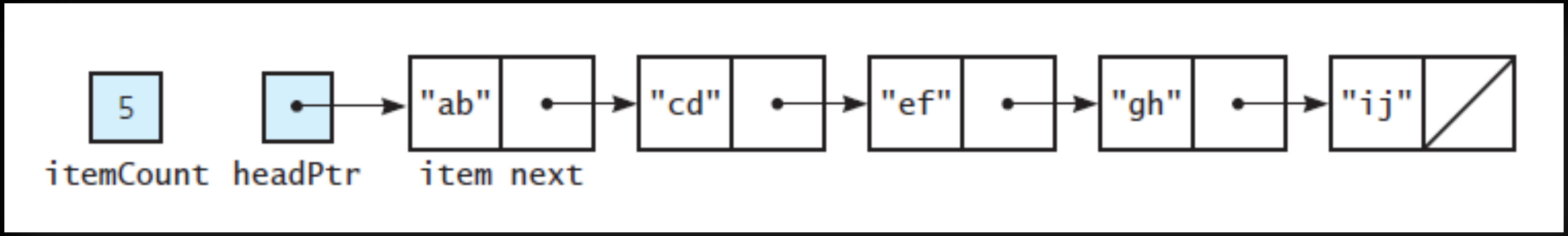
No fixed number of steps

Depends on location of `an_entry`

- 1 “*check*” if it is found at first node (best case)
- n “*checks*” if it is found at last node (worst case)

O(n)

What should we do to remove?



LinkedBag Implementation

O(n)

The `remove` method

```
#include "LinkedBag.hpp"


template<class T>
bool LinkedBag<T>::remove(const T& an_entry)
{
   Node<T>* entry_ptr = getPointerTo(an_entry);
   bool can_remove = (entry_ptr != nullptr);
   if (can_remove)
   {
      // Copy data from first node to located node
      entry_ptr->setItem(head_ptr_->getItem());
      // Delete first node
      Node<T>* node_to_delete_ptr = head_ptr_;
      head_ptr_ = head_ptr_->getNext();
      // Return node to the system
      node_to_delete_ptr->setNext(nullptr);
      delete node_to_delete_ptr;
      node_to_delete_ptr = nullptr;
      item_count_--;
   } // end if

    return can_remove;
}  // end remove
```

Find

O(n)

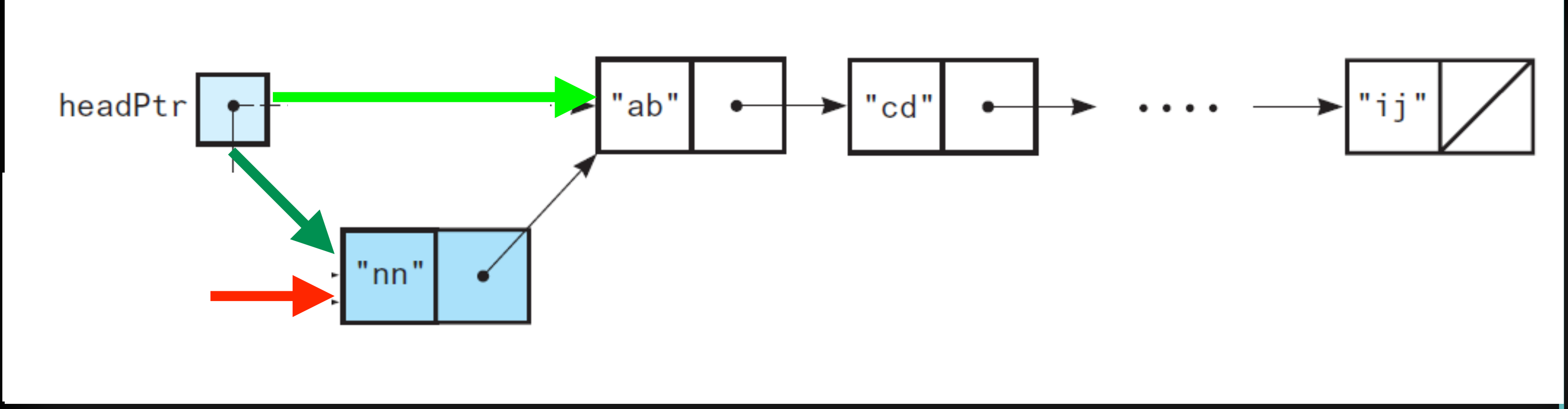
Deleting first node is easy

Copy data from first node to node to delete

Delete first node

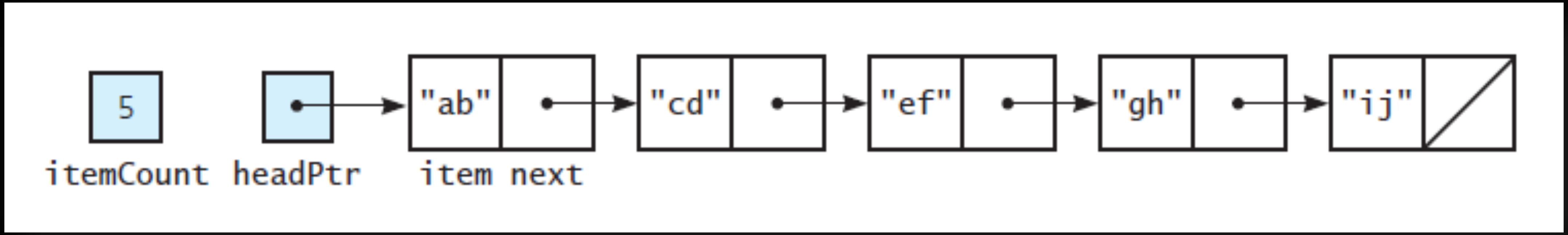
Must do this!!! Avoid memory leaks!!!

O(1)



How do we clear the bag?

Can we do the same thing we did with array?



LinkedBag Implementation

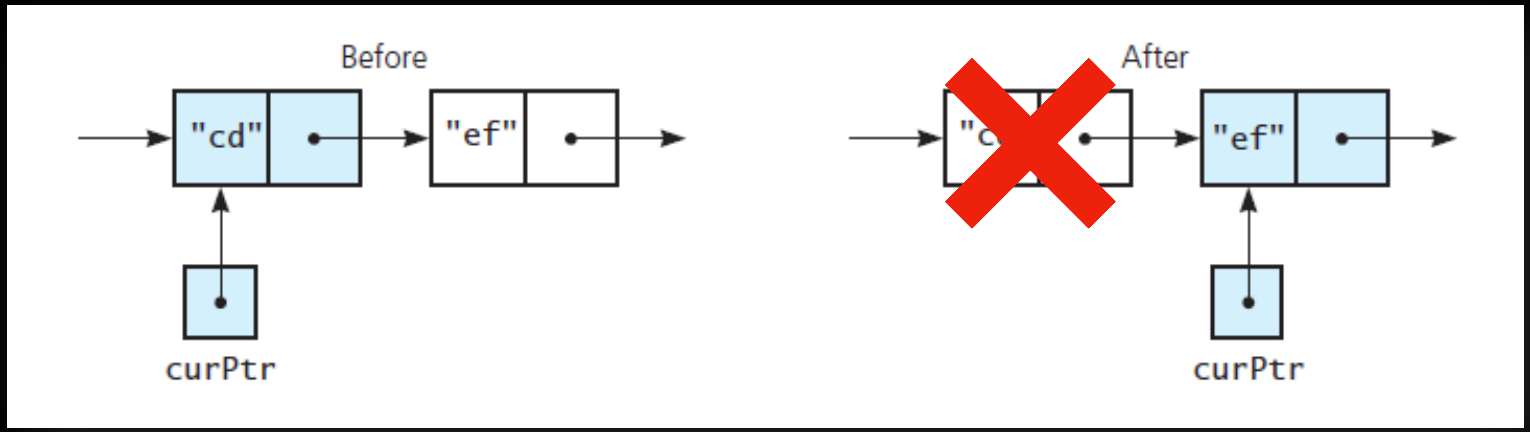
```
#include “LinkedBag.hpp”


template<class T>
void LinkedBag<T>::clear()
{
   Node<T>* node_to_delete_ptr = head_ptr_;
   while (head_ptr_ != nullptr)
   {
      head_ptr_ = head_ptr_->getNext();

      // Return node to the system
      node_to_delete_ptr->setNext(nullptr);
      delete node_to_delete_ptr;

      node_to_delete_ptr = head_ptr_;
   }  // end while
   // head_ptr_ is nullptr; node_to_delete_ptr is nullptr

    item_count_ = 0;
}  // end clear
```

O(n)

The `clear` method

Once again we are traversing:
Visit each node
Delete it

Must do this!!! Avoid memory Leak!!!



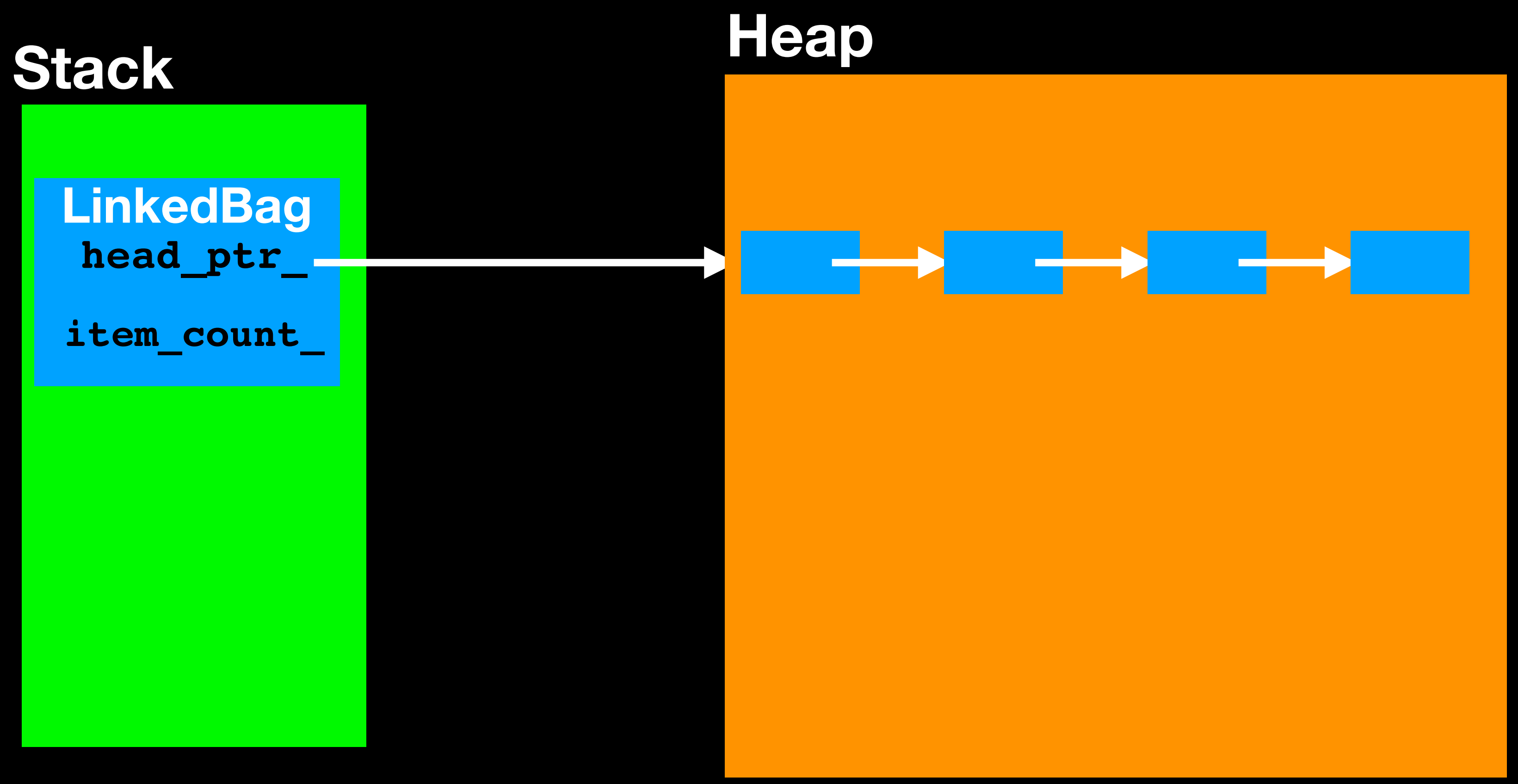
Dynamic Memory Considerations

Each new node added to the chain is allocated dynamically and stored on the heap

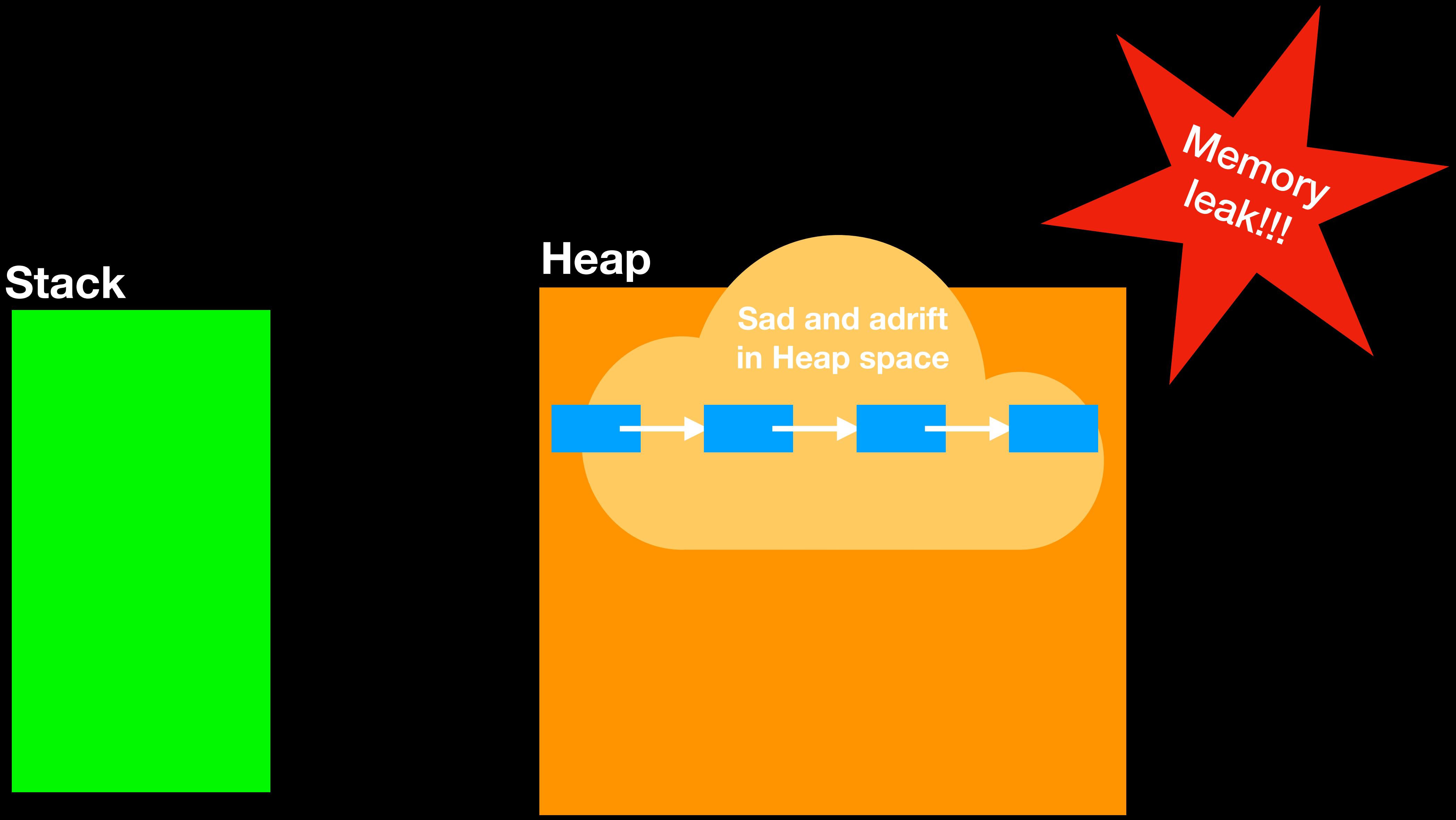
Programmer must ensure this memory is deallocated when object is destroyed!

Avoid memory leaks!!!!

What happens when object goes out of scope?



What happens when object goes out of scope?



LinkedBag Implementation

```
#include “LinkedBag.hpp”


template<class T>
LinkedBag<T>::~LinkedBag()
{

   clear();

}  // end destructor
```

The destructor

Ensure heap space is returned to the system

Must do this!!! Avoid memory leaks!!!

The Class LinkedBag

O(1) ✓

O(n) ✗

```
#ifndef LINKED_BAG_H_
#define LINKED_BAG_H_

#include "BagInterface.hpp"
#include “Node.hpp"

template<class T>
class LinkedBag
{
public:
   LinkedBag();
   LinkedBag(const LinkedBag<T>& a_bag); // Copy constructor
   ~LinkedBag();                         // Destructor
   int getCurrentSize() const;
   bool isEmpty() const;
   bool add(const T& new_entry);
   bool remove(const T& an_entry);
   void clear();
   bool contains(const T& an_entry) const;
   int getFrequencyOf(const T& an_entry) const;
   std::vector<T> toVector() const;

private:
   Node<T>* head_ptr_; // Pointer to first node
   int item_count_;           // Current count of bag items

      // Returns either a pointer to the node containing a given entry
     // or the null pointer if the entry is not in the bag.
     Node<T>* getPointerTo(const T& target) const;
}; // end LinkedBag

#include “LinkedBag.cpp"
#endif //LINKED_BAG_H_
```

The Class LinkedBag

```
#ifndef LINKED_BAG_H_
#define LINKED_BAG_H_

#include "BagInterface.hpp"
#include “Node.hpp"

template<class T>
class LinkedBag
{
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   LinkedBag(const LinkedBag<T>& a_bag); // Copy constructor
 ✗~LinkedBag();                      // Destructor
 ✓int getCurrentSize() const;
 ✓bool isEmpty() const;
 ✓bool add(const T& new_entry);
 ✗bool remove(const T& an_entry);
 ✗void clear();
 ✗bool contains(const T& an_entry) const;
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      // Returns either a pointer to the node containing a given entry
     // or the null pointer if the entry is not in the bag.
 ✗   Node<T>* getPointerTo(const T& target) const;
}; // end LinkedBag

#include “LinkedBag.cpp"
#endif //LINKED_BAG_H_
```

O(1) ✓

O(n) ✗

Next time!