Linked-Based Implementation

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Today's Plan

Announcements

A quick review of pointers

Linked-Based Implementation

Pointers Review

Pointer Variables

A typed variable whose value is the address of another variable of same type

```
int x = 5;
int y = 8;
int *p, *q = nullptr;  //declares two int pointers


. . .
```

Make sure you do this if not assigning a value!

Run-time Stack

Type	Name	Address	Data
...	...	...	...
int	x	0x12345670	5
int	y	0x12345674	8
int pointer	p	0x12345678	`nullptr`
int pointer	q	0x1234567C	`nullptr`
...	...	...	...

```
int x = 5;
int y = 8;
int *p, *q = nullptr;  //declares two int pointers


. . .
p = &x;       // sets p to the address of x
q = &y;       // sets q address of y
```

Make sure you do this if not assigning a value!

Run-time Stack

Type	Name	Address	Data
...	...	...	...
int	x	0x12345670	5
int	y	0x12345674	8
int pointer	p	0x12345678	0x12345670
int pointer	q	0x1234567C	0x12345674
...	...	...	...

```
int x = 5;
int y = 8;
int *p, *q = nullptr;  //declares two int pointers


. . .
p = &x;       // sets p to the address of x
q = &y;       // sets q address of y
```

Make sure you do this if not assigning a value!

We won't do much of this

Run-time Stack

Type	Name	Address	Data
...	...	...	...
int	x	0x12345670	5
int	y	0x12345674	8
int pointer	p	0x12345678	0x12345670
int pointer	q	0x1234567C	0x12345674
...	...	...	...

Dynamic Variables

Created at runtime in the free store or memory heap
using operator **new**

Nameless typed variables accessed through pointers

```
// create a nameless variable of type dataType on the
//application heap and stores its address in p
dataType *p = new dataType;
```

Run-time Stack

Type	Name	Address	Data
...	...	...	...
dataType ptr	p	0x12345678	0x100436f20
...	...	...	...

Free Store (application heap)

Type	Address	Data
...	...	...
dataType	0x100436f20	
...	...	...

Accessing members

```
dataType some_object;
dataType *p = new dataType;
// initialize and do stuff with instantiated objects

. . .

string my_string = some_object.getName();
string another_string = p->getName();
```

To access member functions in place of . operator

Deallocating Memory

```
delete p;
p = nullptr;
```

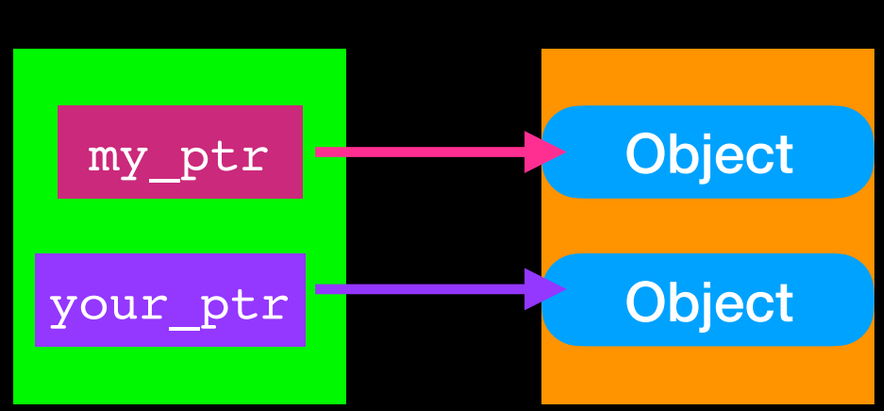
Deletes **the object** pointed to by p

Must do this!!!

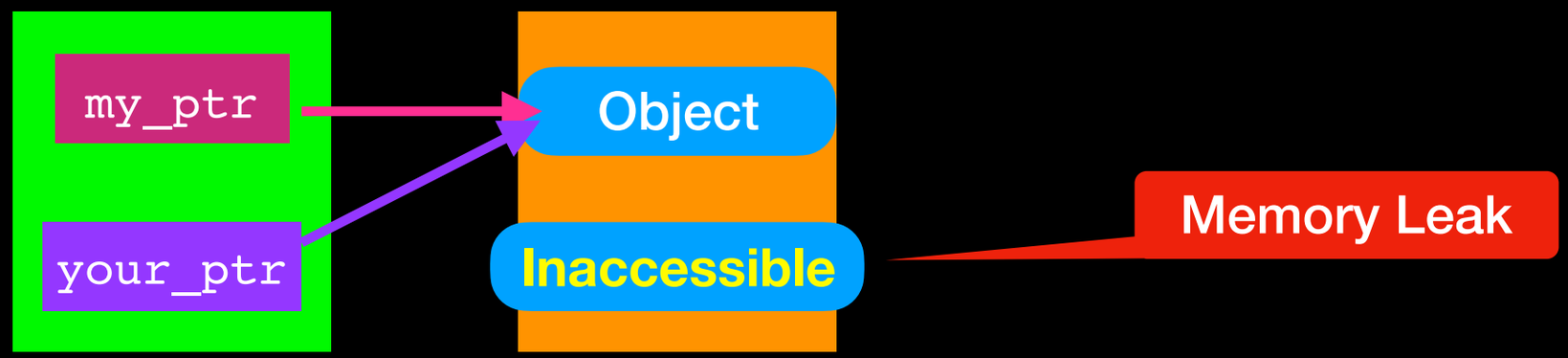
Avoid Memory Leaks (1)

Occurs when object is created in free store but program no longer has access to it

```
dataType *my_ptr = new dataType;
dataType *your_ptr = new dataType;
// do stuff with my_ptr and your_ptr
```



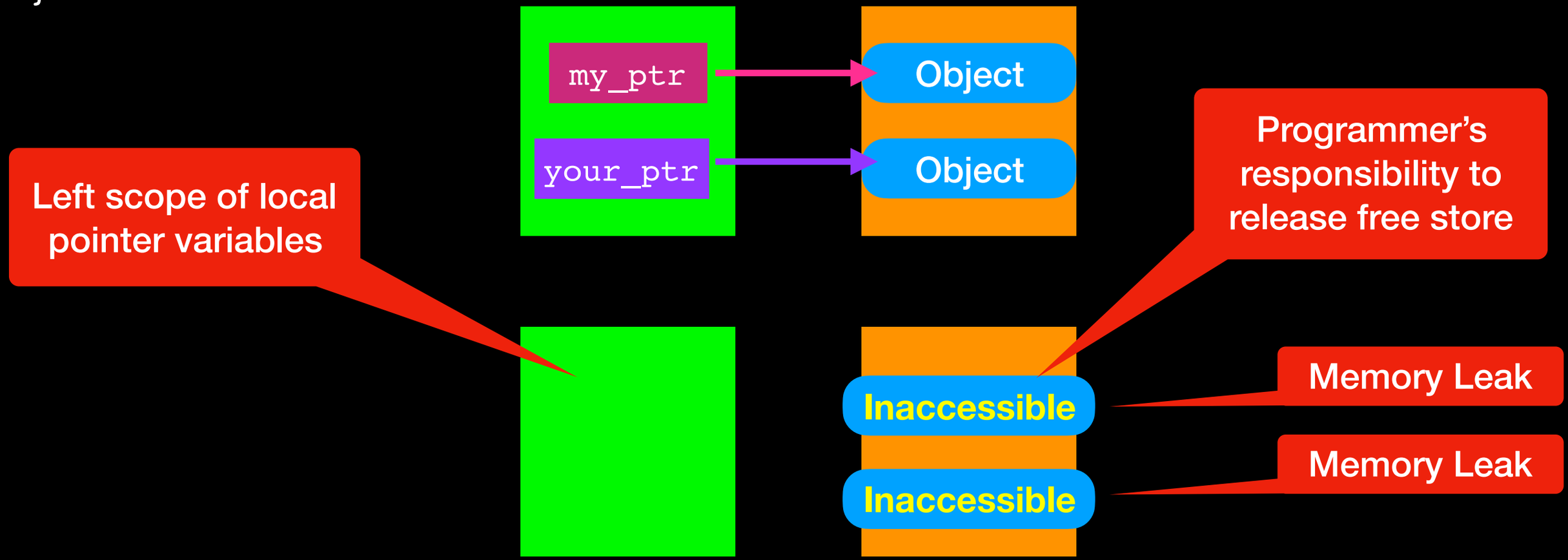

```
your_ptr = my_ptr;
```



Avoid Memory Leaks (2)

Occurs when object is created in free store but program no longer has access to it

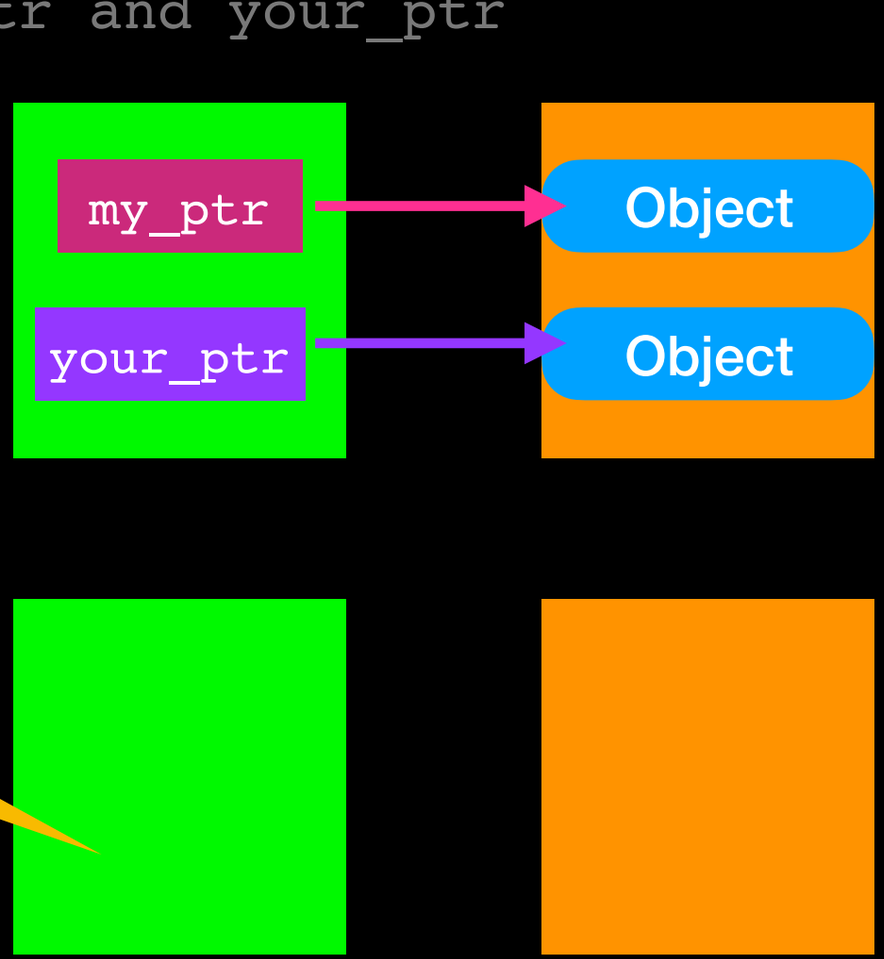
```
void leakyFunction(){
dataType *my_ptr = new dataType;
dataType *your_ptr = new dataType;
// do stuff with my_ptr and your_ptr
}
```



Avoid Memory Leaks (2)

Occurs when object is created in free store but program no longer has access to it

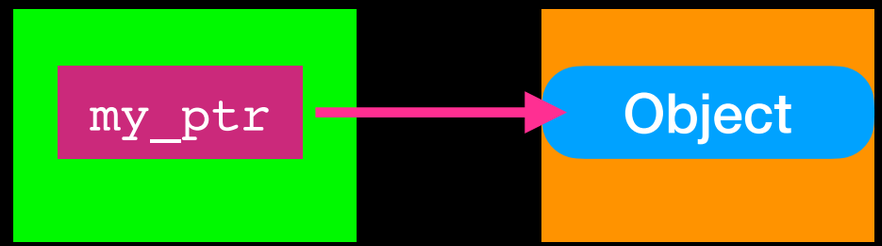
```
void leakyFunction(){
dataType *my_ptr = new dataType;
dataType *your_ptr = new dataType;
// do stuff with my_ptr and your_ptr
delete my_ptr;
delete your_ptr;
}
```



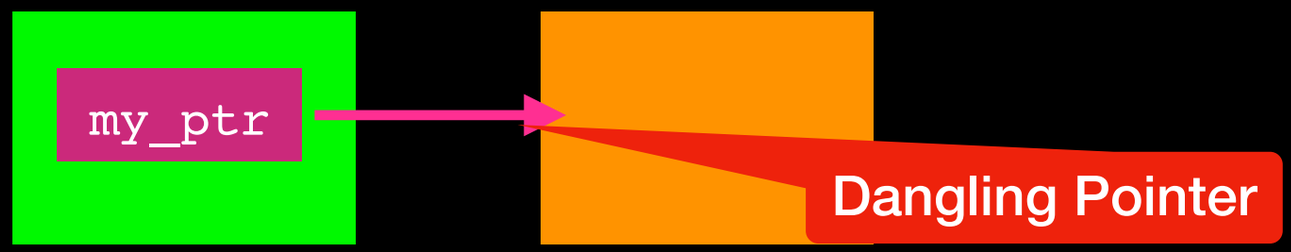
Left scope of local pointer variables but deleted dynamic objects first

Avoid Dangling Pointers

Pointer variable that no longer references a valid object



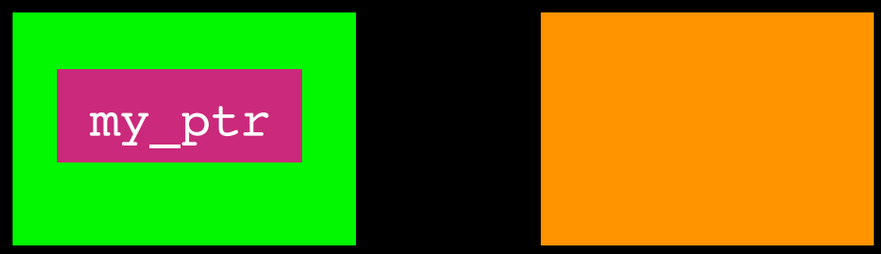

```
delete my_ptr;
```



Fix

```
delete my_ptr;
my_ptr = nullptr;
```

Must do this!!!



Avoid Dangling Pointers

Pointer variable that no longer references a valid object

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delete my_ptr;
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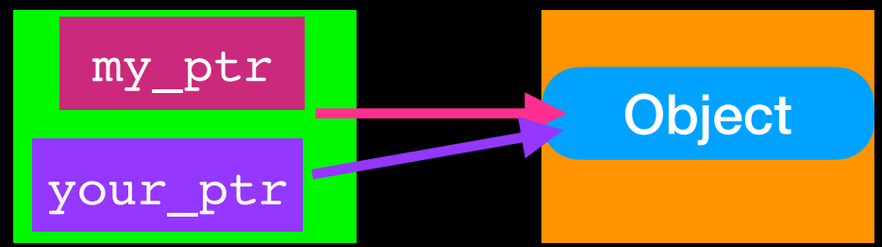
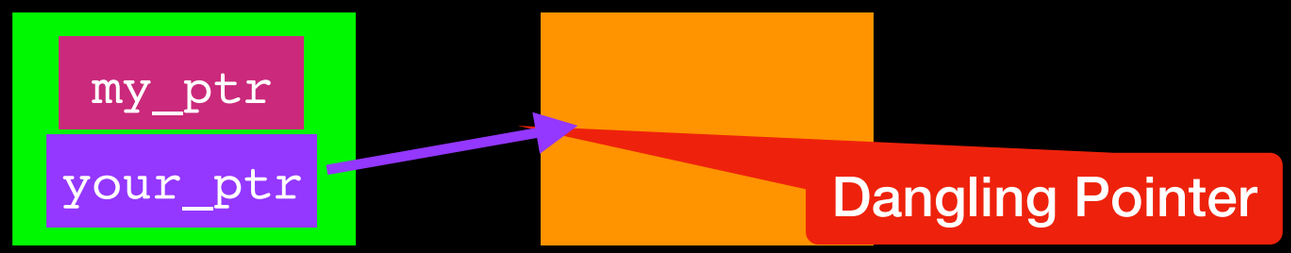
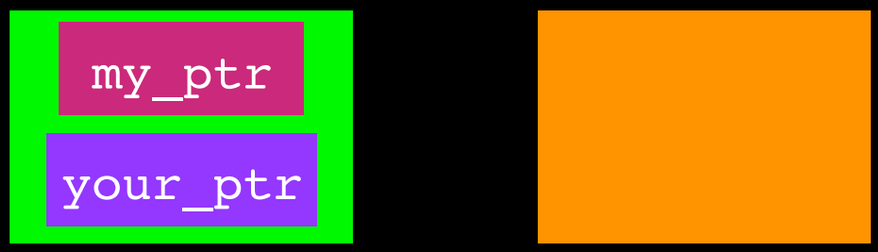
```





Fix

```
delete my_ptr;
my_ptr = nullptr;
your_ptr = nullptr;
```



Must set all pointers to `nullptr`!!!

What is wrong with the following code?

```
void someFunction()
{
   int* p = new int[5];
   int* q = new int[10];

   p[2] = 9;
   q[2] = p[2]+5;
   p[0] = 8;
   q[7] = 15;

   std::cout<< p[2] << " " <<  q[2] << std::endl;
   q = p;
   std::cout<< p[0]  << " " << q[7] << std::endl;

}
```

What is wrong with the following code?

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void someFunction()
{
   int* p = new int[5];
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   q[7] = 15;

   std::cout<< p[2] << " " <<  q[2] << std::endl;
   q = p;
   std::cout<< p[0]  << " " << q[7] << std::endl;

}
```

MEMORY LEAK:
`int[10]` **lost on heap**

SEGMENTATION FAULT
`int[5]` **index out of range**

MEMORY LEAK:
Did not delete `int[5]`
before exiting function

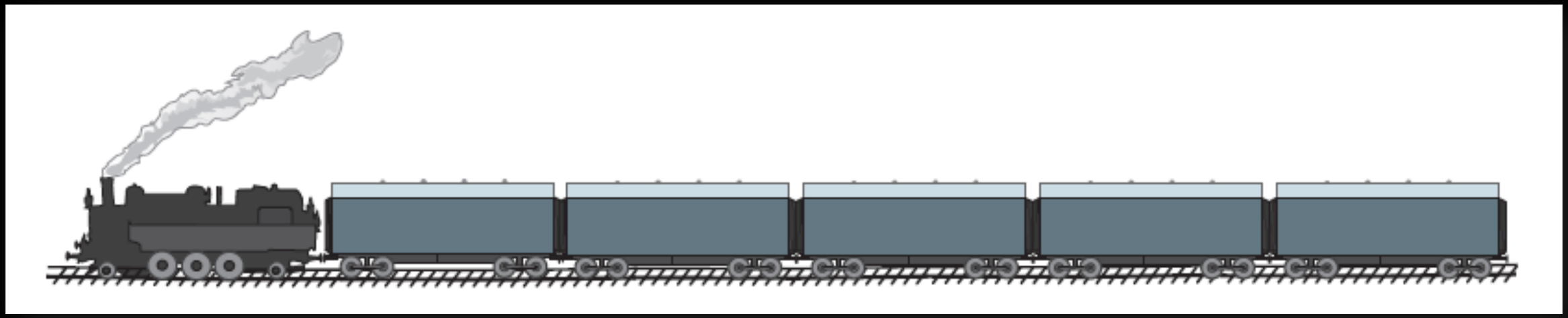
Let’s try a different implementation for Bag

Link-Based Implementation

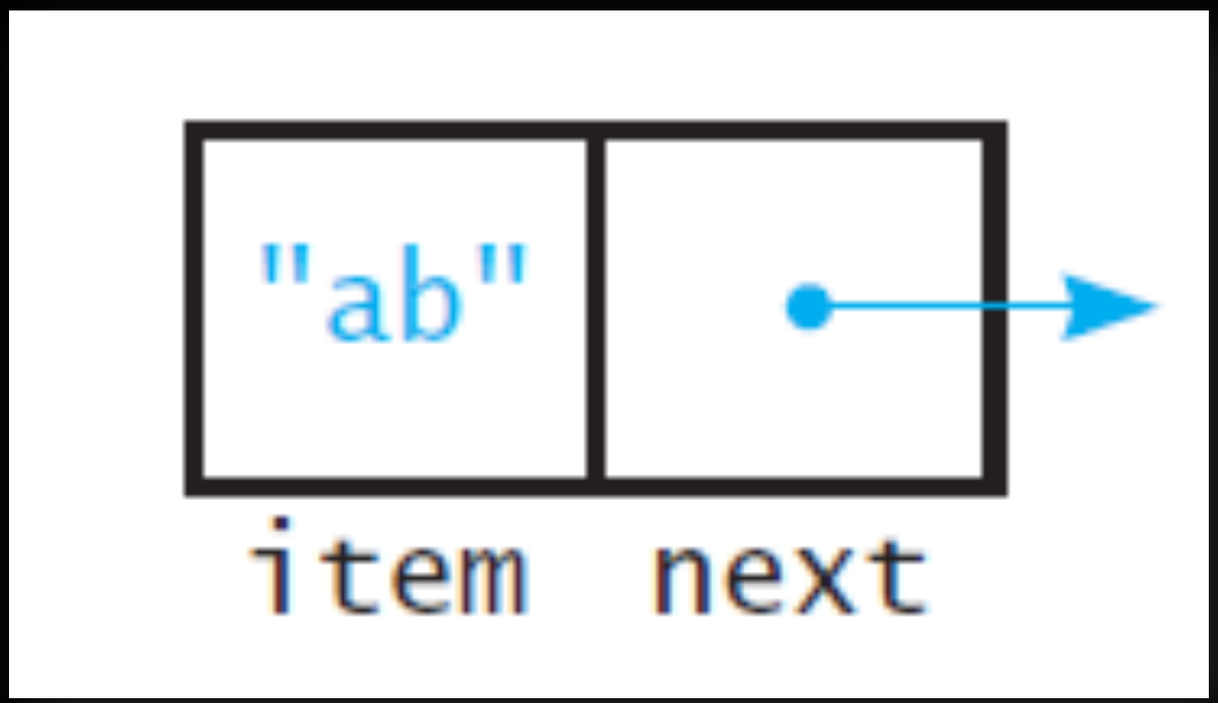
Data Organization

Place data within a Node object

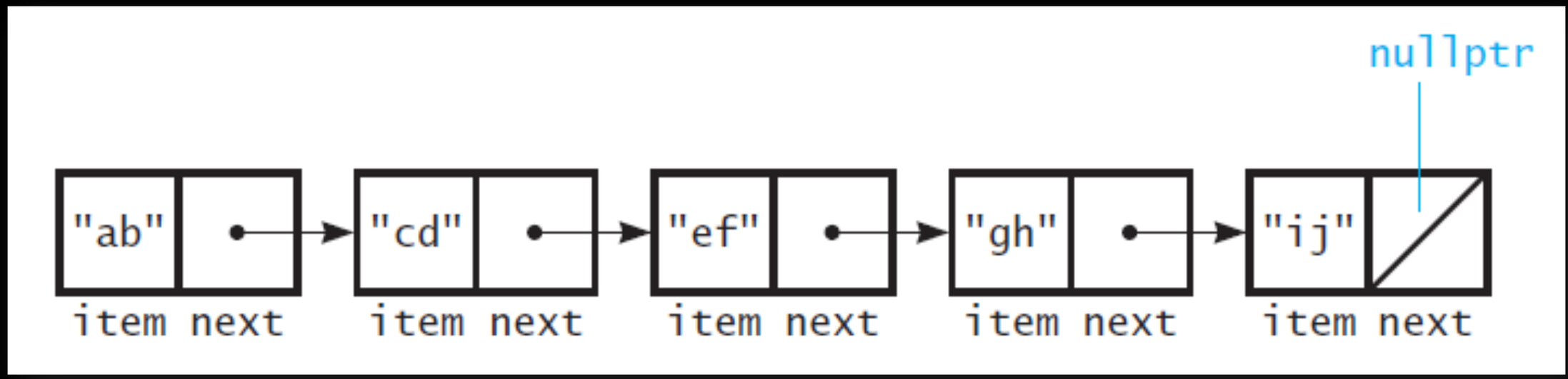
Link nodes into a chain



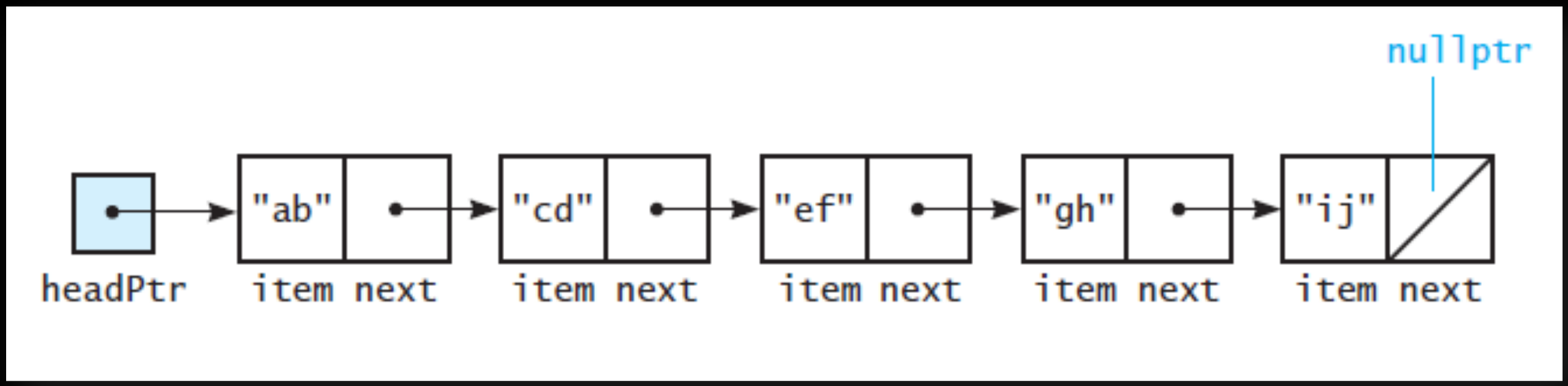
Node



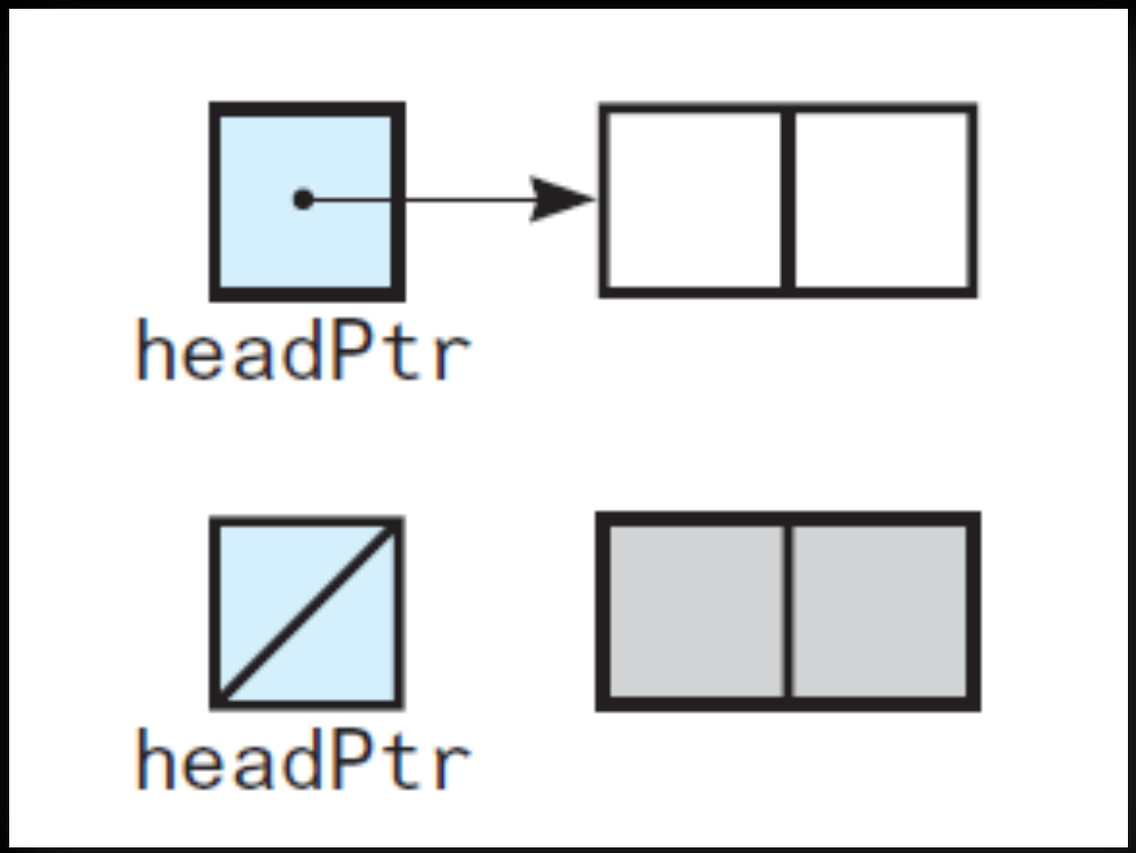
Chain


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

Entering the Chain

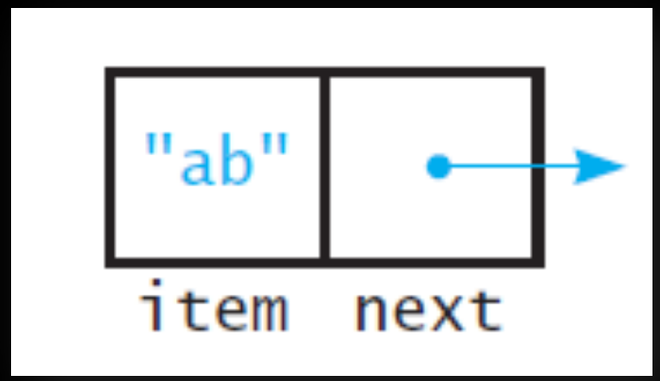


The Empty Chain



The Class Node

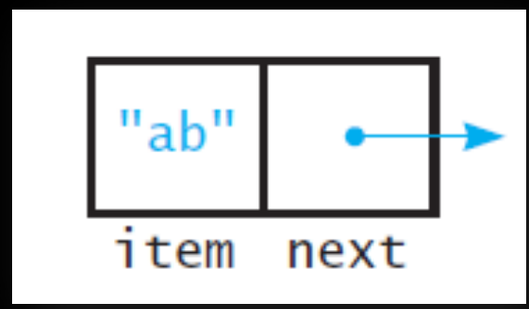
```
#ifndef NODE_H_
#define NODE_H_

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

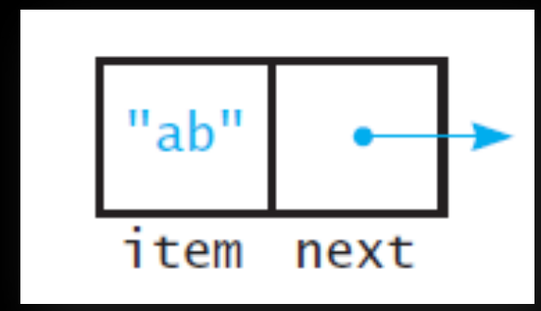
The Constructors

```
#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

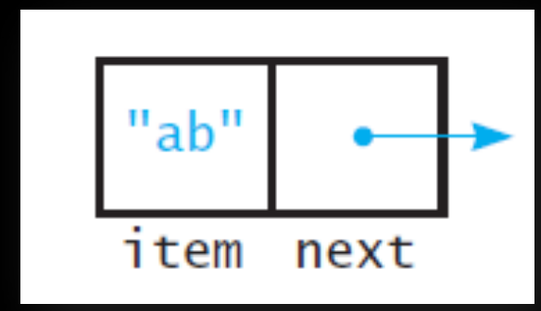
The "*setData*" members




```
#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
```

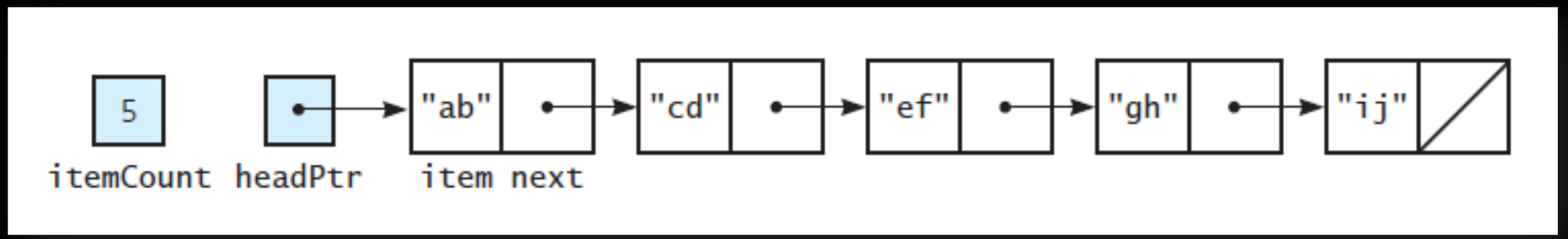
Node Implementation

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 "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:

 ???

}; // 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"

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class LinkedBag
{
public:
   LinkedBag();
   LinkedBag(const LinkedBag<T>& a_bag); // Copy constructor
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   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

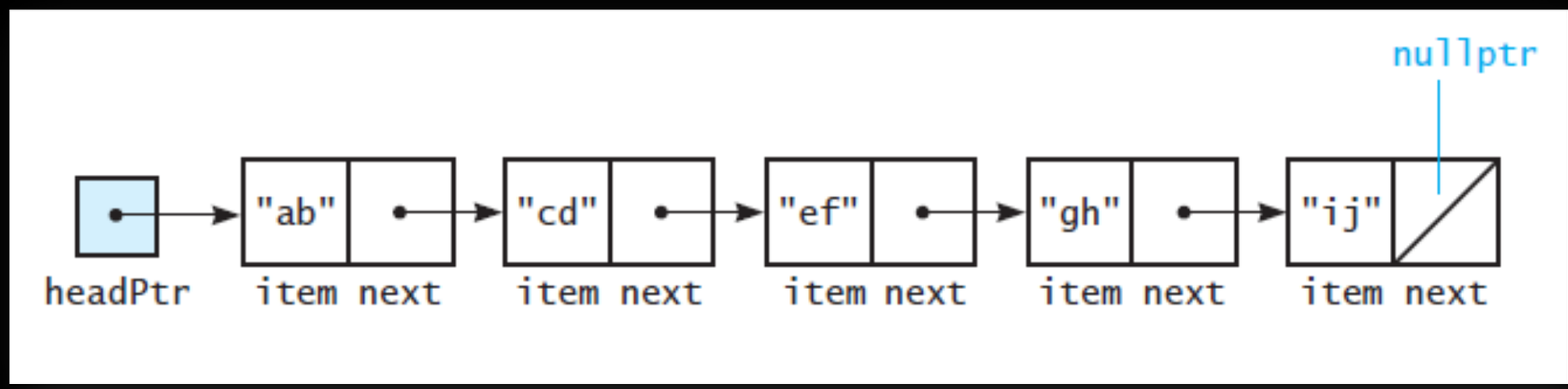
```
#include “LinkedBag.hpp”



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

}  // end default constructor
```

The default constructor

Private data member initialization

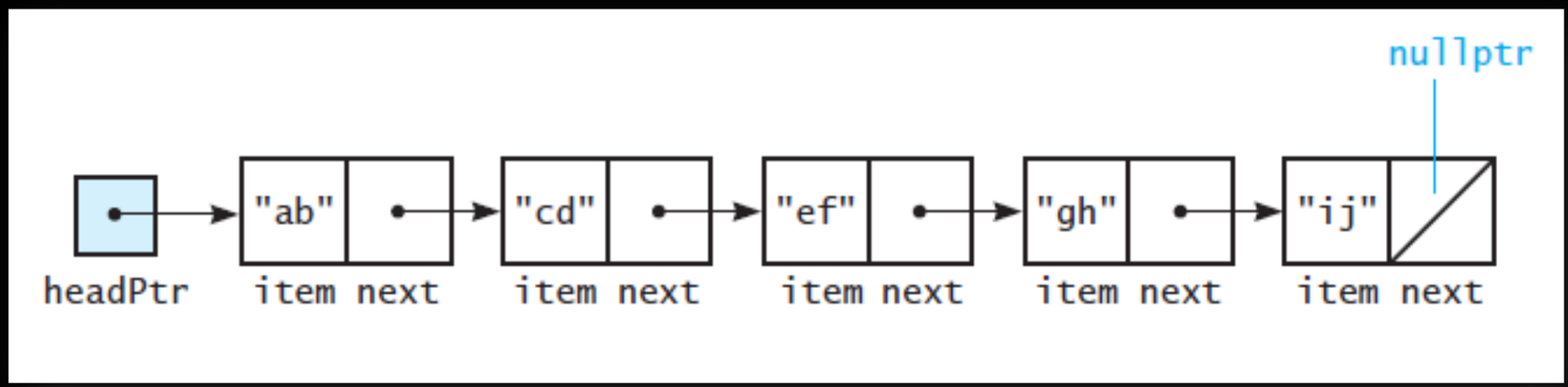
```
add(const T& new_entry)
```

Where should we add?

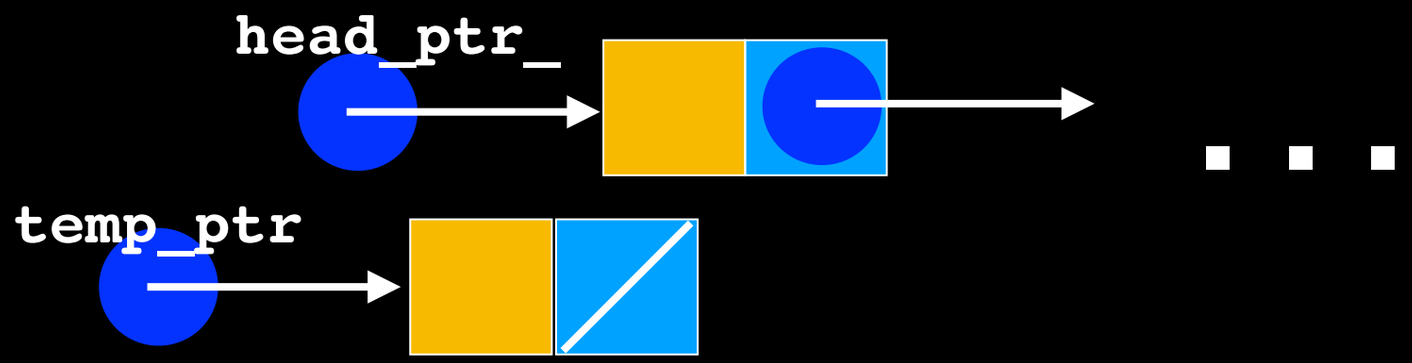


Lecture Activity

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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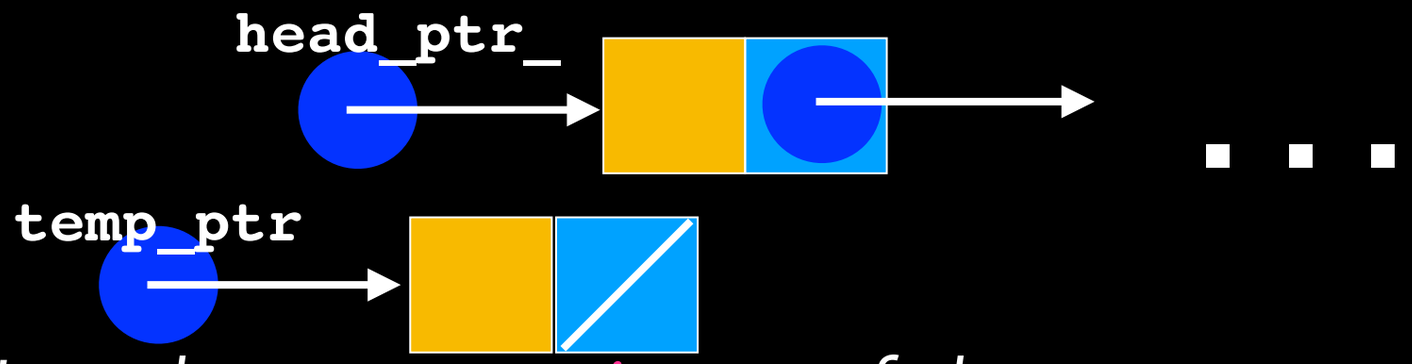
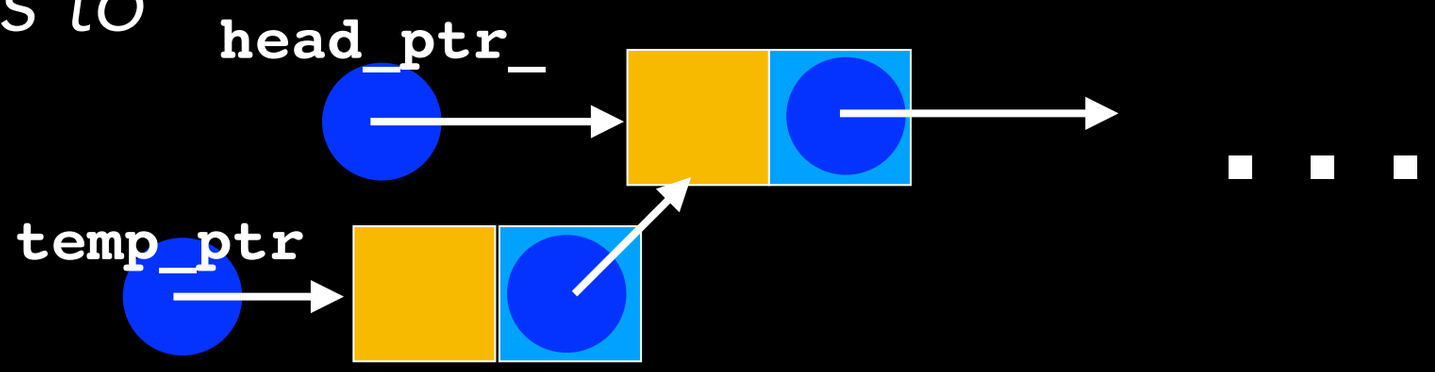


Let the next pointer of the new node point to the same node head_ptr_ points to



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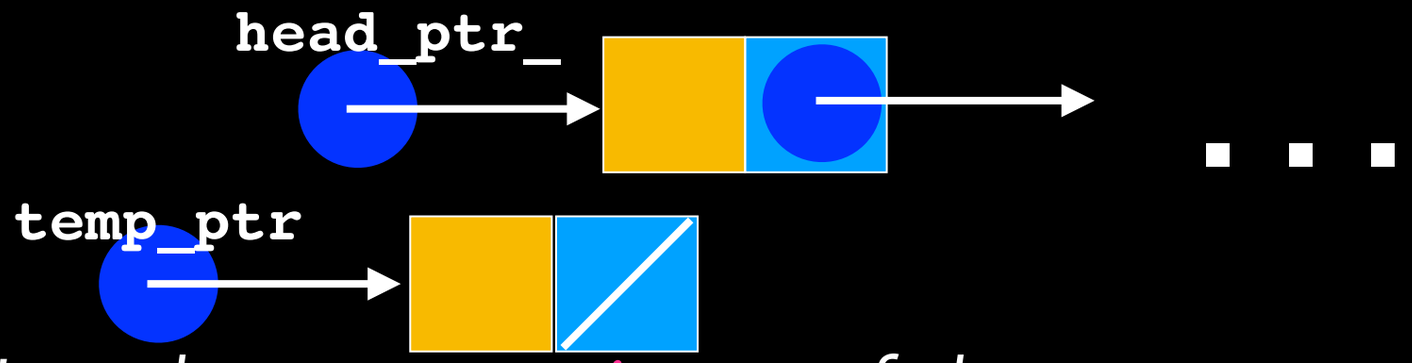

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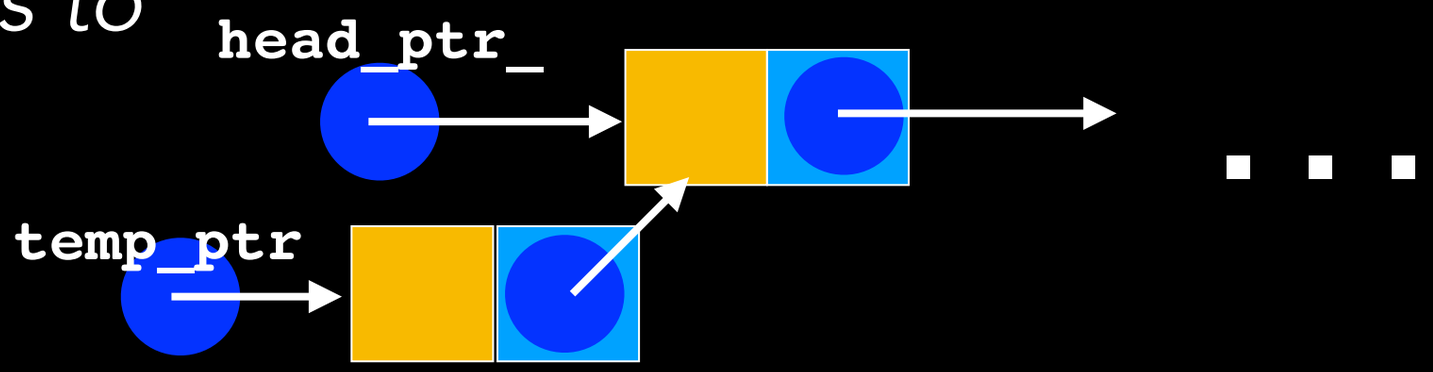
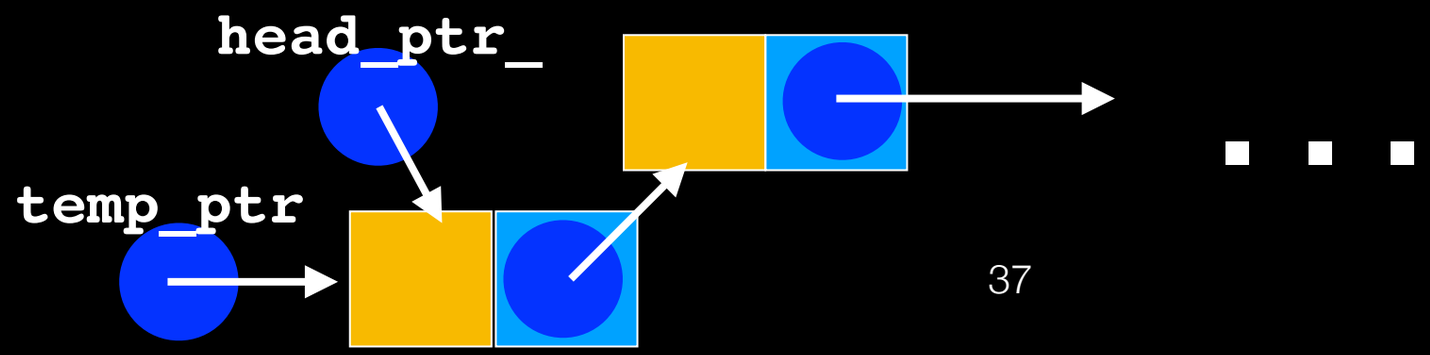


Let head_ptr_ point to the new node



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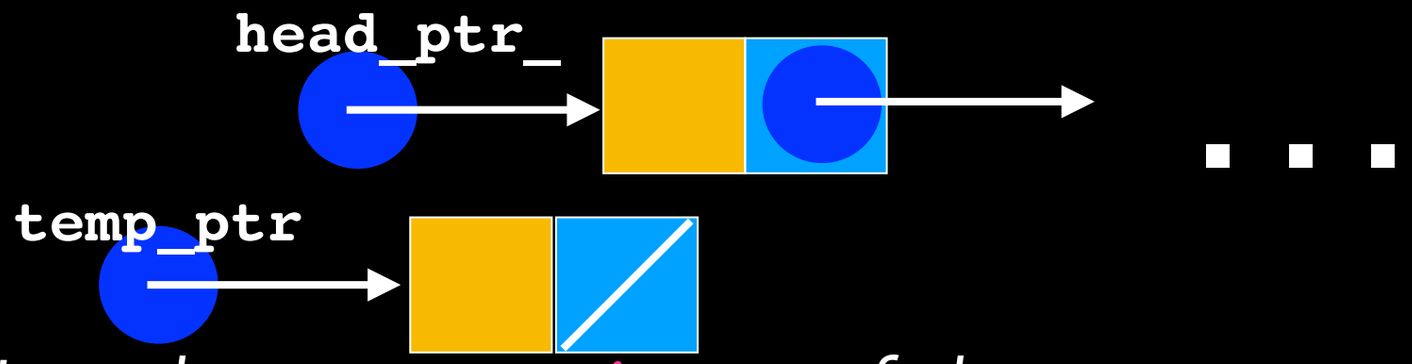

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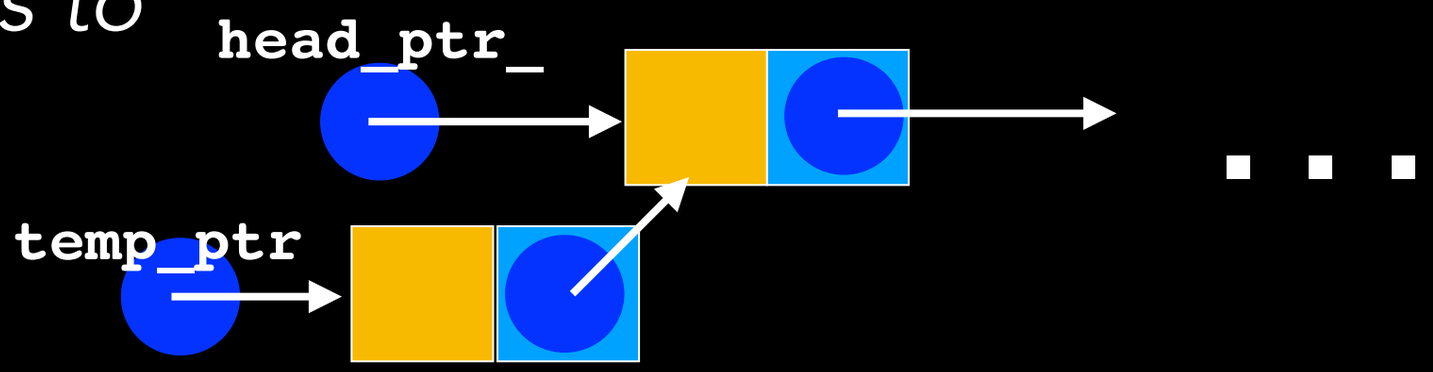
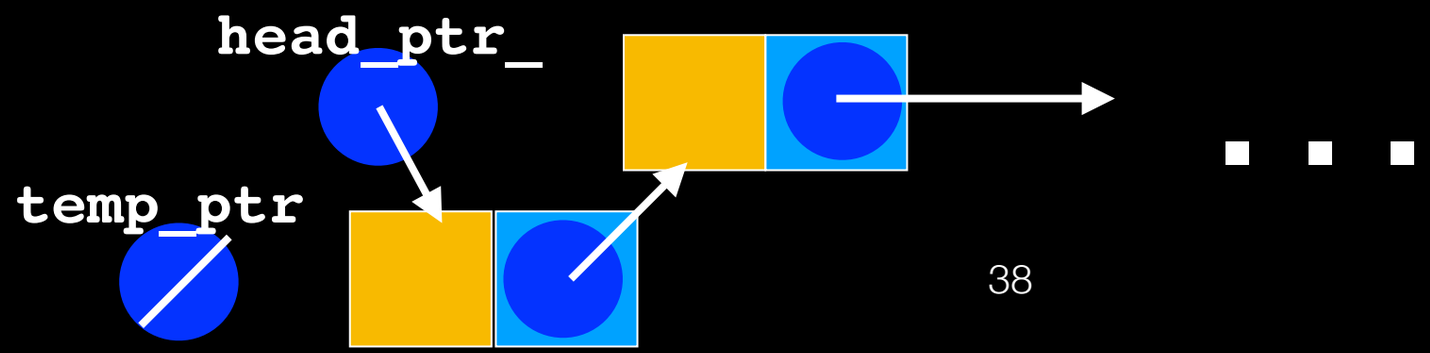


Let head_ptr_ point to the new node



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)

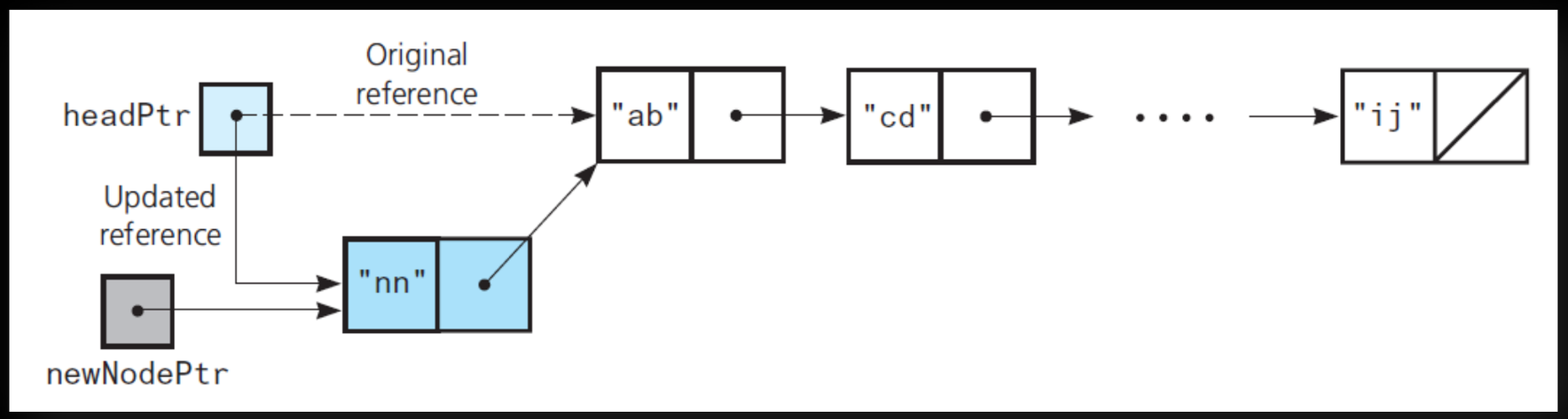
```
temp_ptr = new node
temp_ptr->next = head_ptr_
head_ptr = temp_ptr
temp_ptr = nullptr
```

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!

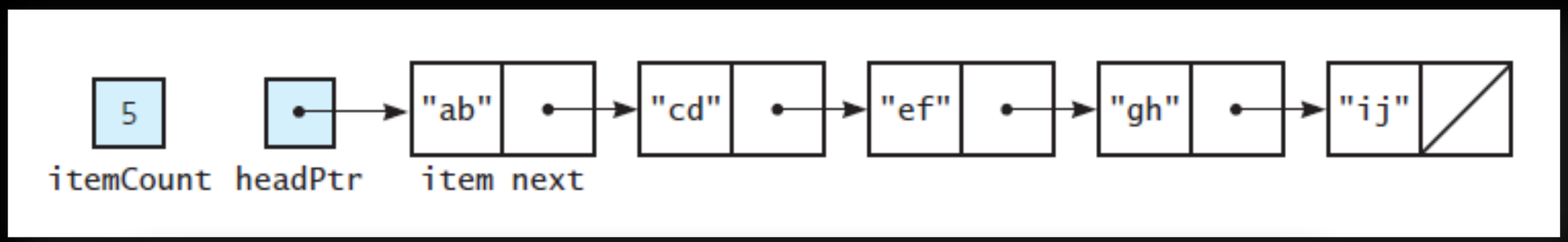


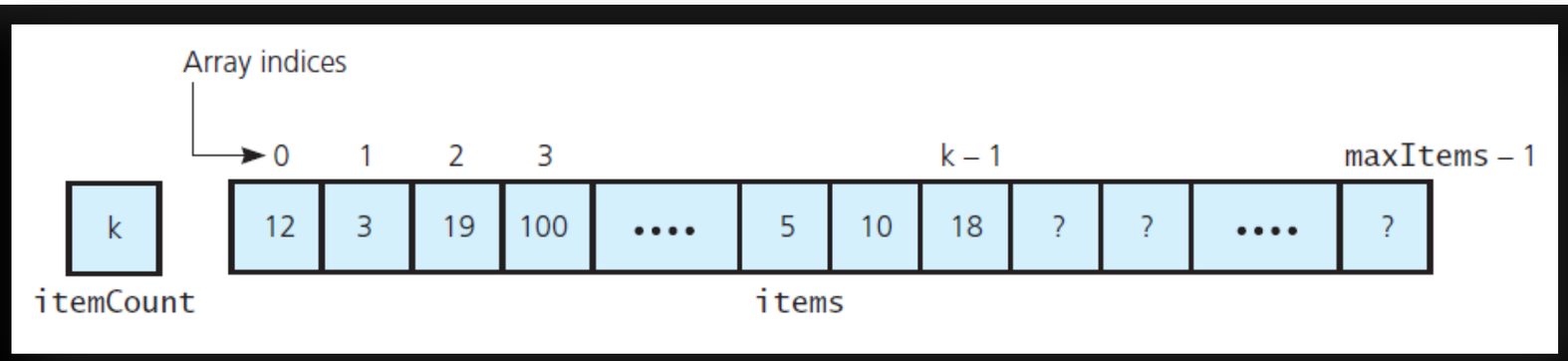
Efficiency

Create a new node and assign two pointers

What about adding to end of chain?

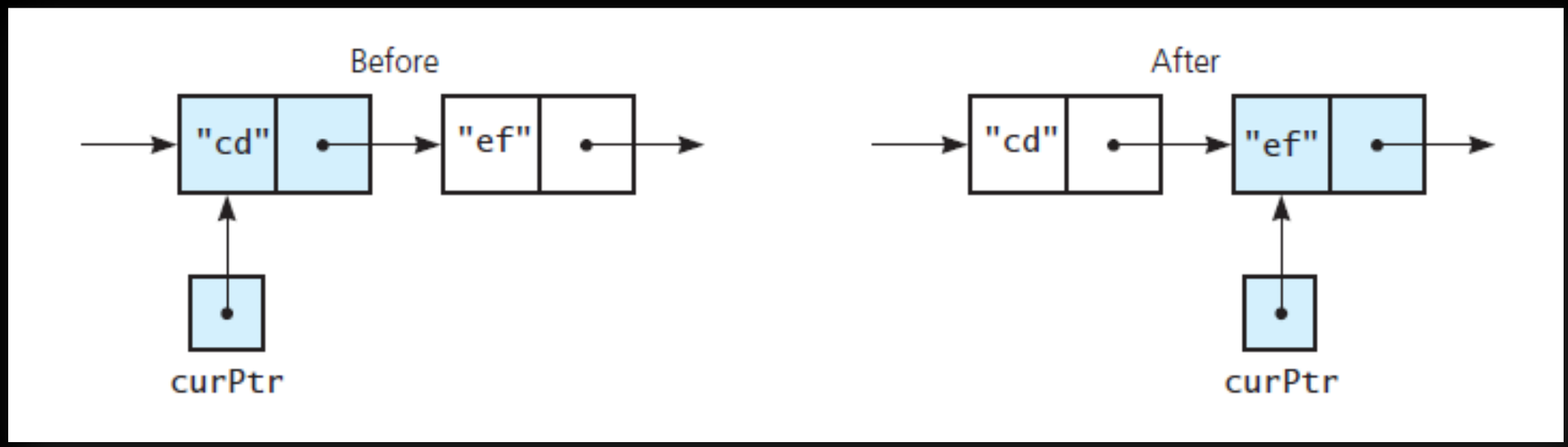
What about adding to front of array?





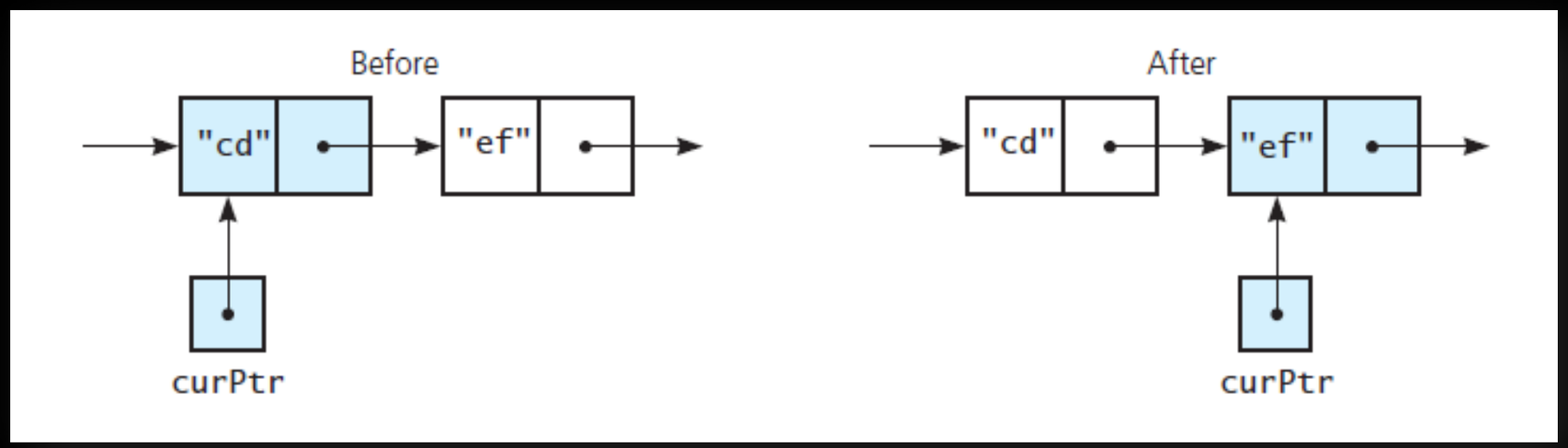
Lecture Activity

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
}
```

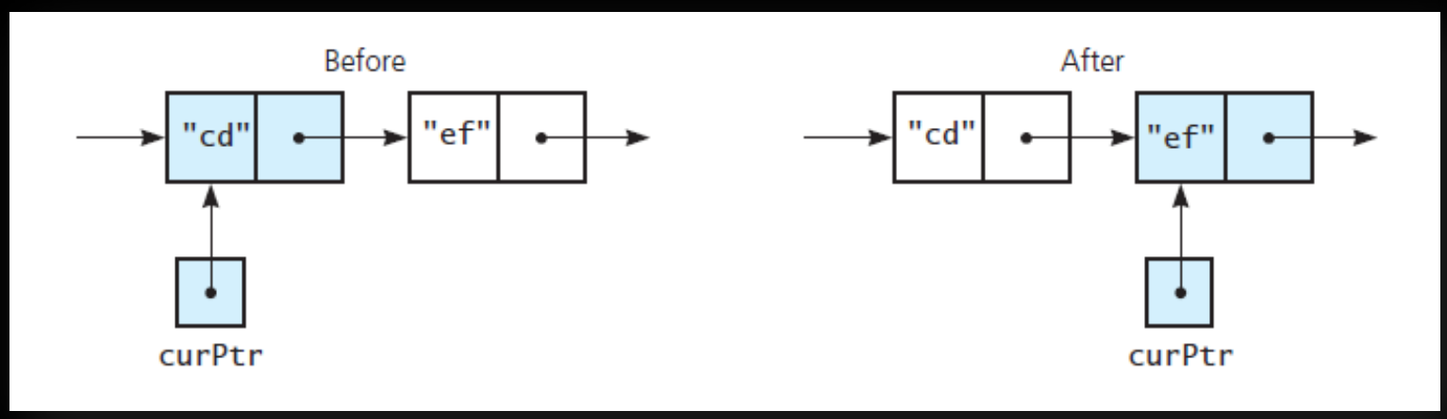


LinkedBag Implementation

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

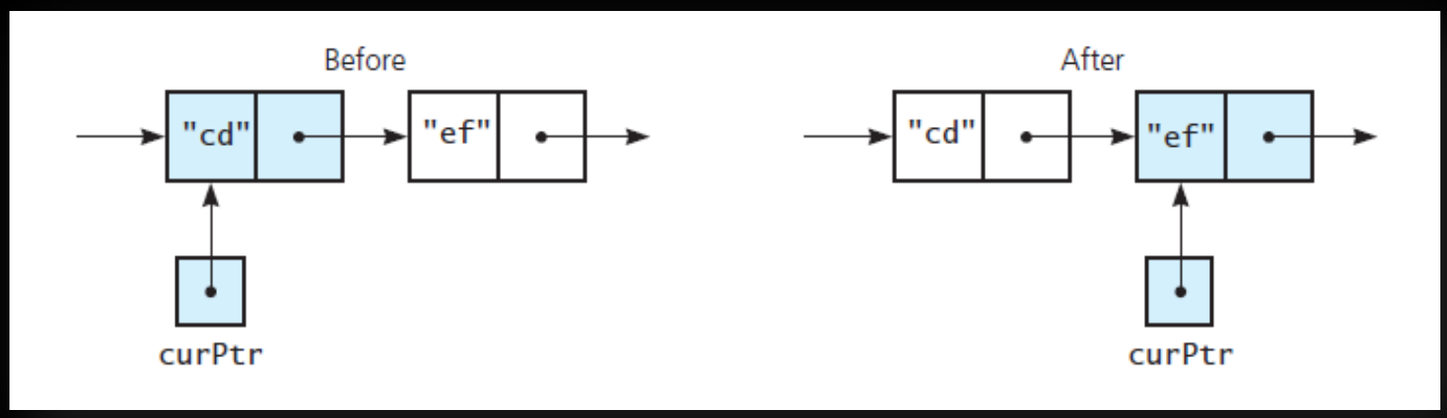
count frequency of (count each) `an_entry`

LinkedBag Implementation

The `getPointerTo` method

```
#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
```

Traversing:
visit each node
if found what looking for
return



Efficiency

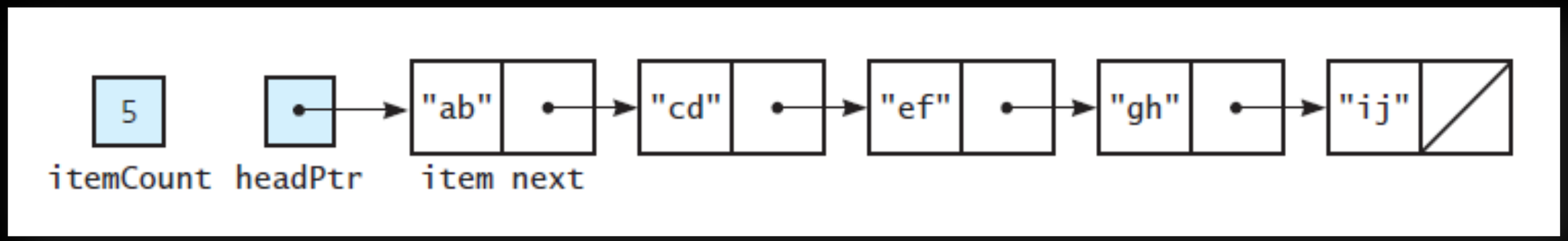
No fixed number of steps

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)
- approximately n/2 on average if random?

Purposely vague
Some fixed amount of work

What should we do to remove?



LinkedBag Implementation

```
#include "LinkedBag.hpp"


template<class T>
bool LinkedBag<T>::remove(const T& an_entry)
{
   Node<T>* entry_ptr = getPointerTo(an_entry);
   bool can_remove = !isEmpty() && (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
```

The `remove` method

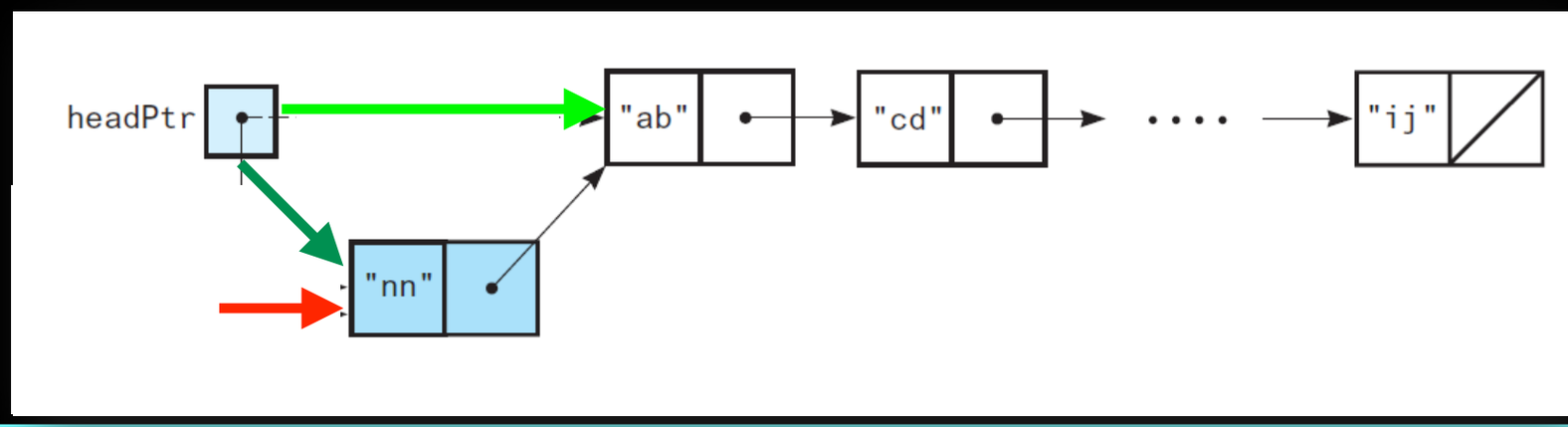
Find

Deleting first node is easy

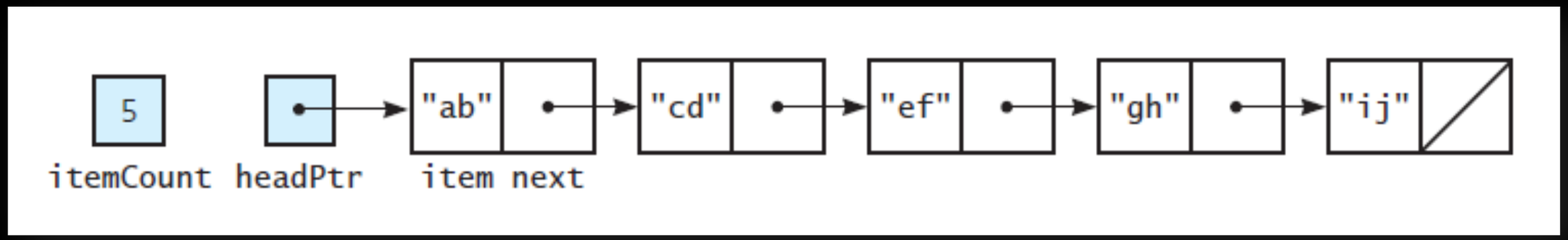
Copy data from first node to node to delete

Delete first node

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



How do we clear the bag?



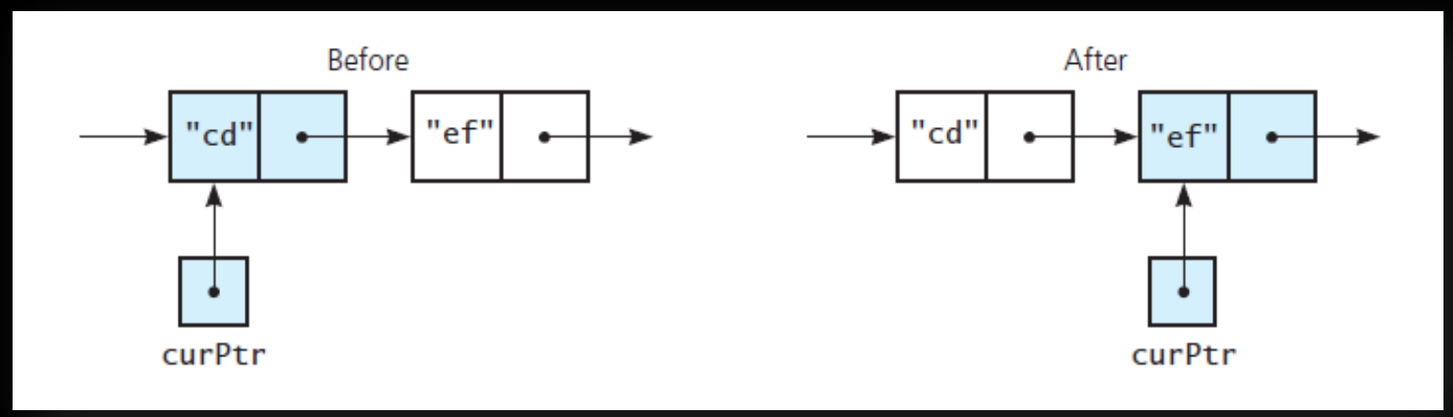
LinkedBag Implementation

```
#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
```

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!!!!

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!!!

Copy Constructor

1. Initialize one object from another of the same type

```
MyClass one;
MyClass two = one;
```

More explicitly

```
MyClass one;
MyClass two(one); // Identical to above.
```

Creates a **new object** as a copy of another one

Compiler will provide one but may not appropriate for complex objects

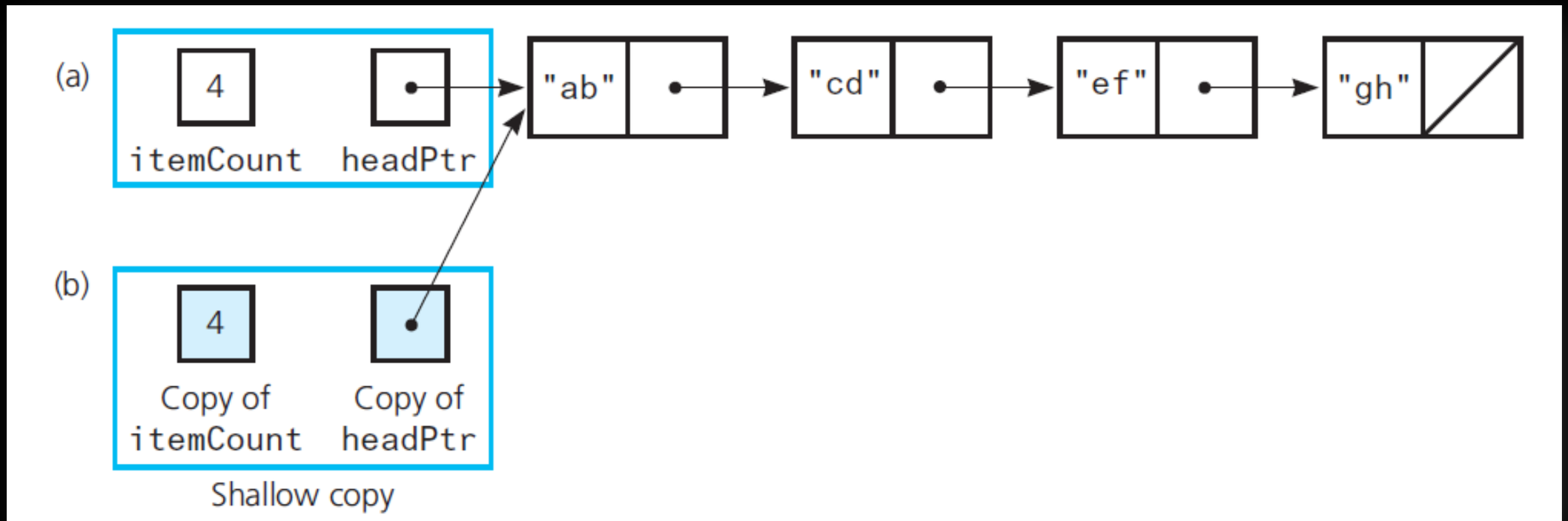
2. Copy an object to **pass by value** as an argument to a function

```
void MyFunction(MyClass arg) {
        /* ... */
}
```

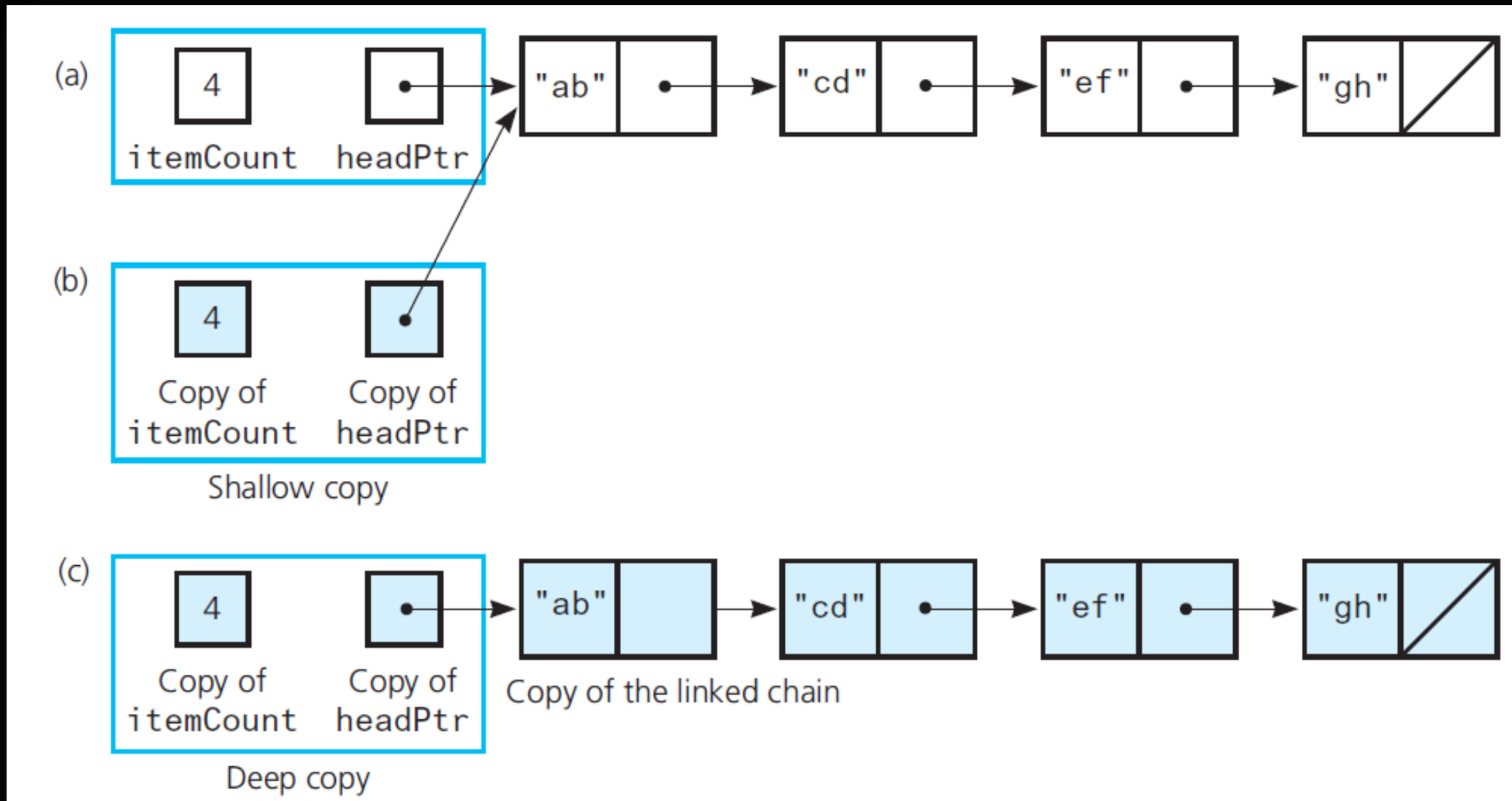
3. Copy an object to be **returned** by a function

```
MyClass MyFunction() {
   MyClass mc;
   return mc;
}
```

Deep vs Shallow Copy



Deep vs Shallow Copy



Overloaded operator=

```
MyClass one;
//Stuff here
MyClass two = one;
```

Instantiation: copy constructor is called

IS DIFFERENT FROM

```
MyClass one, two;
//Stuff here
two = one;
```

Assignment, NOT instantiation: no constructor is called, must overload `operator=` to avoid shallow copy

LinkedBag Implementation

```
#include "LinkedBag.hpp"
template<class T>
LinkedBag<T>::LinkedBag(const LinkedBag<T>& a_bag)
{
   item_count_ = a_bag.item_count_;
   Node<T>* orig_chain_ptr = a_bag.head_ptr_;  // Points to nodes in original chain
   if (orig_chain_ptr == nullptr)
      head_ptr_ = nullptr;  // Original bag is empty
   else
   {
      // Copy first node
      head_ptr_ = new Node<T>();
      head_ptr_->setItem(orig_chain_ptr->getItem());

      // Copy remaining nodes
      Node<T>* new_chain_ptr = head_ptr_;      // Points to last node in new chain
      orig_chain_ptr = orig_chain_ptr->getNext();     // Advance original-chain pointe
      while (orig_chain_ptr != nullptr)
      {
         // Get next item from original chain
         T next_item = orig_chain_ptr->getItem();
         // Create a new node containing the next item
         Node<T>* new_node_ptr = new Node<T>(next_item);
         // Link new node to end of new chain
         new_chain_ptr->setNext(new_node_ptr);

         // Advance pointer to new last node
         new_chain_ptr = new_chain_ptr->getNext();
         // Advance original-chain pointer
         orig_chain_ptr = orig_chain_ptr->getNext();
      }  // end while
      new_chain_ptr->setNext(nullptr);  // Flag end of chain
   }  // end if
}  // end copy constructor
```

The `copy constructor`
A constructor whose parameter is an object of the same class

Called when object is initialized with a copy of another object, e.g.
`LinkedBag<string> my_bag = your_bag;`

Copy first node

Two traversing pointers
One to new chain, one to original chain

`while`

Copy item from current node

Create new node with item

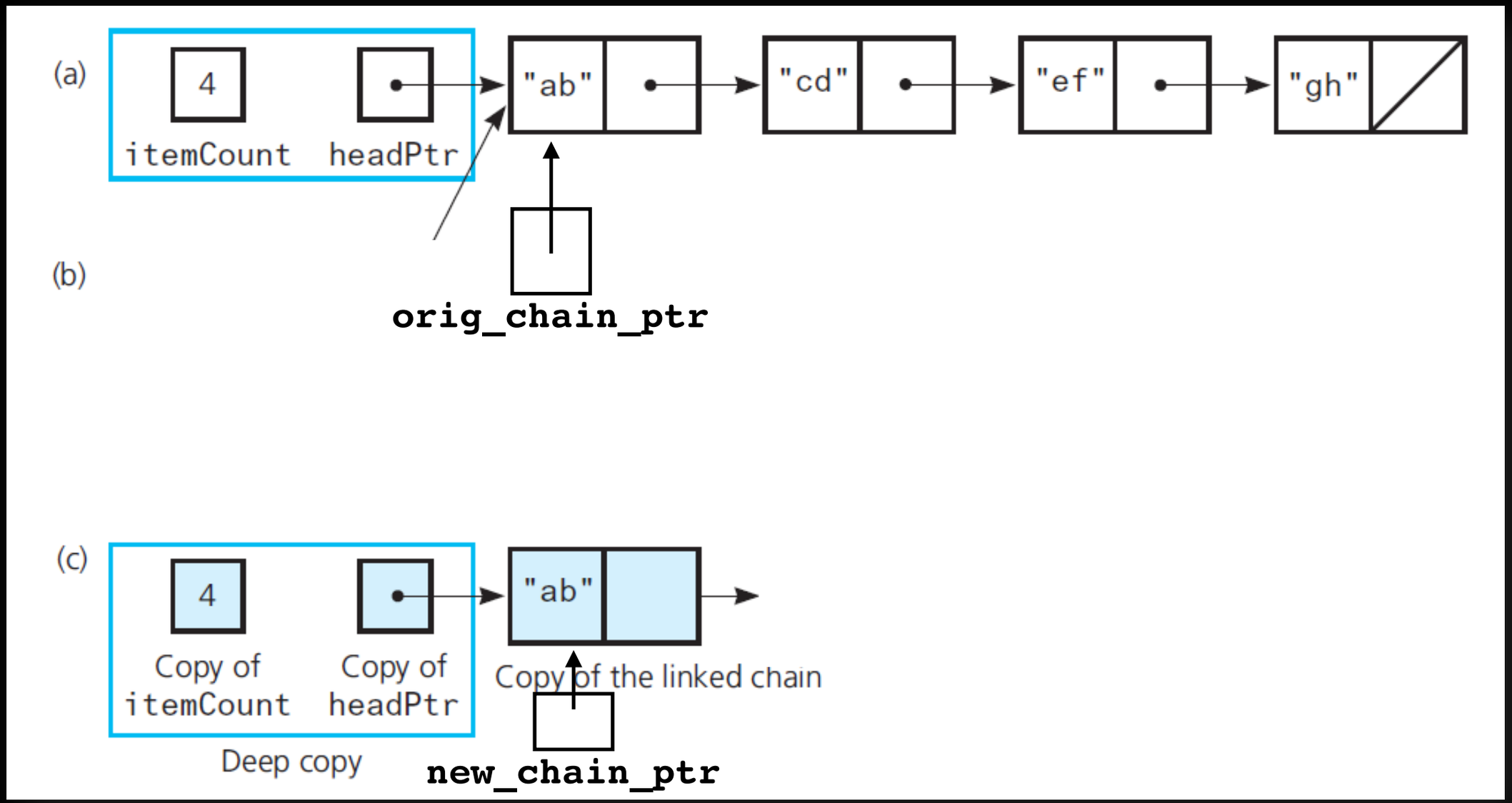
Connect new node to new chain

Advance pointer traversing new chain

Advance pointer traversing original chain

Signal last node

Deep vs Shallow Copy



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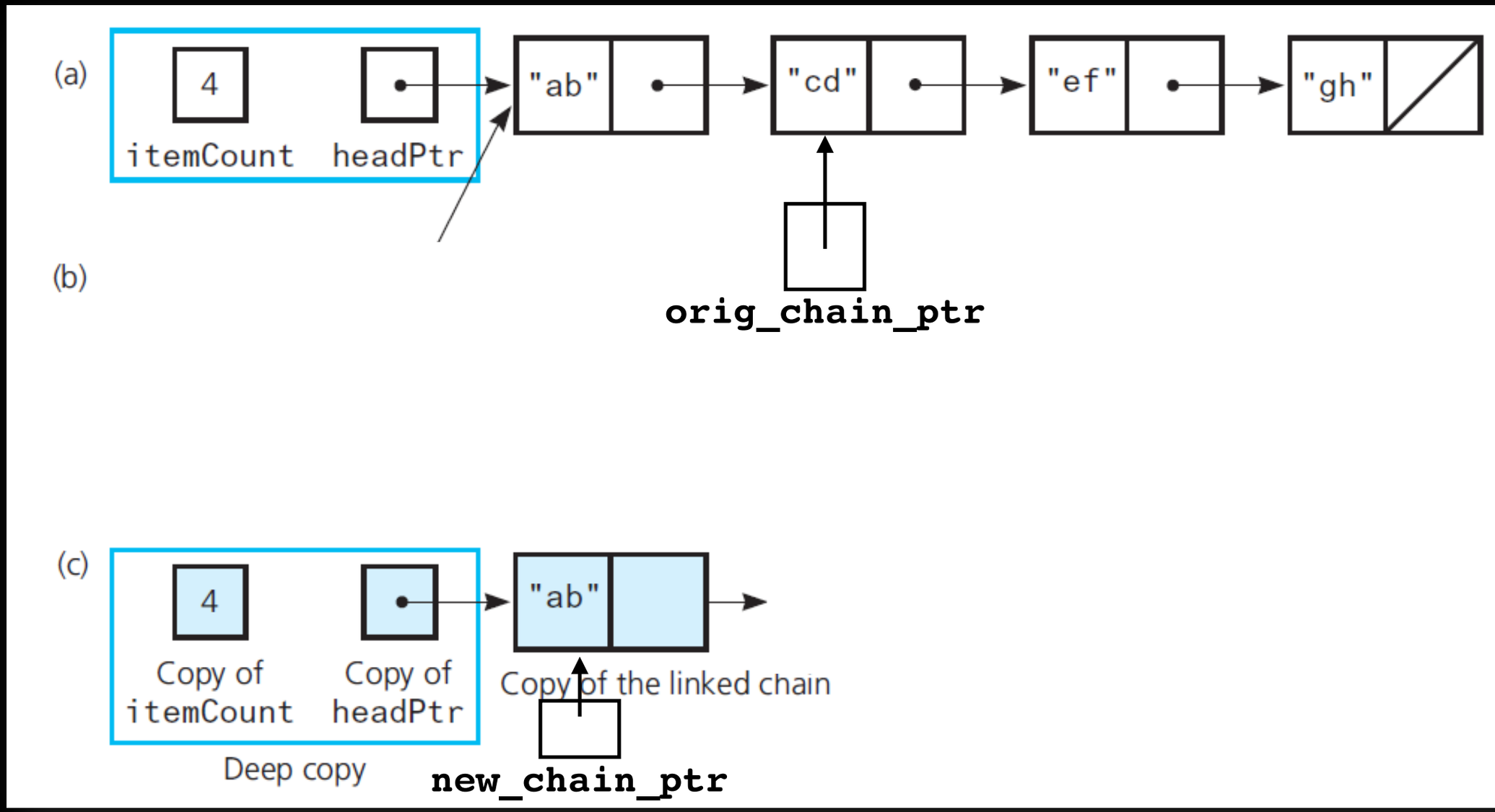
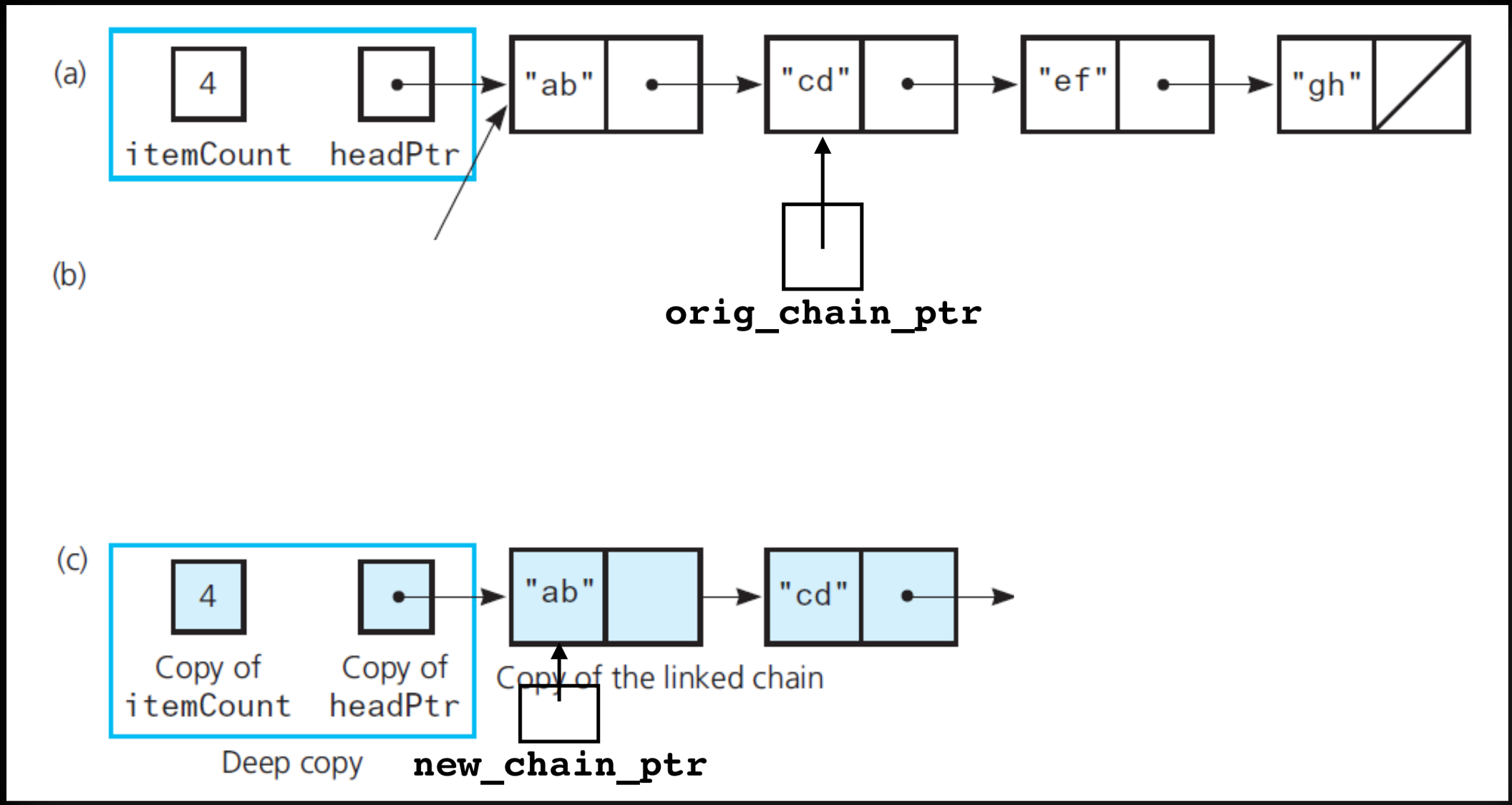


Deep vs Shallow Copy



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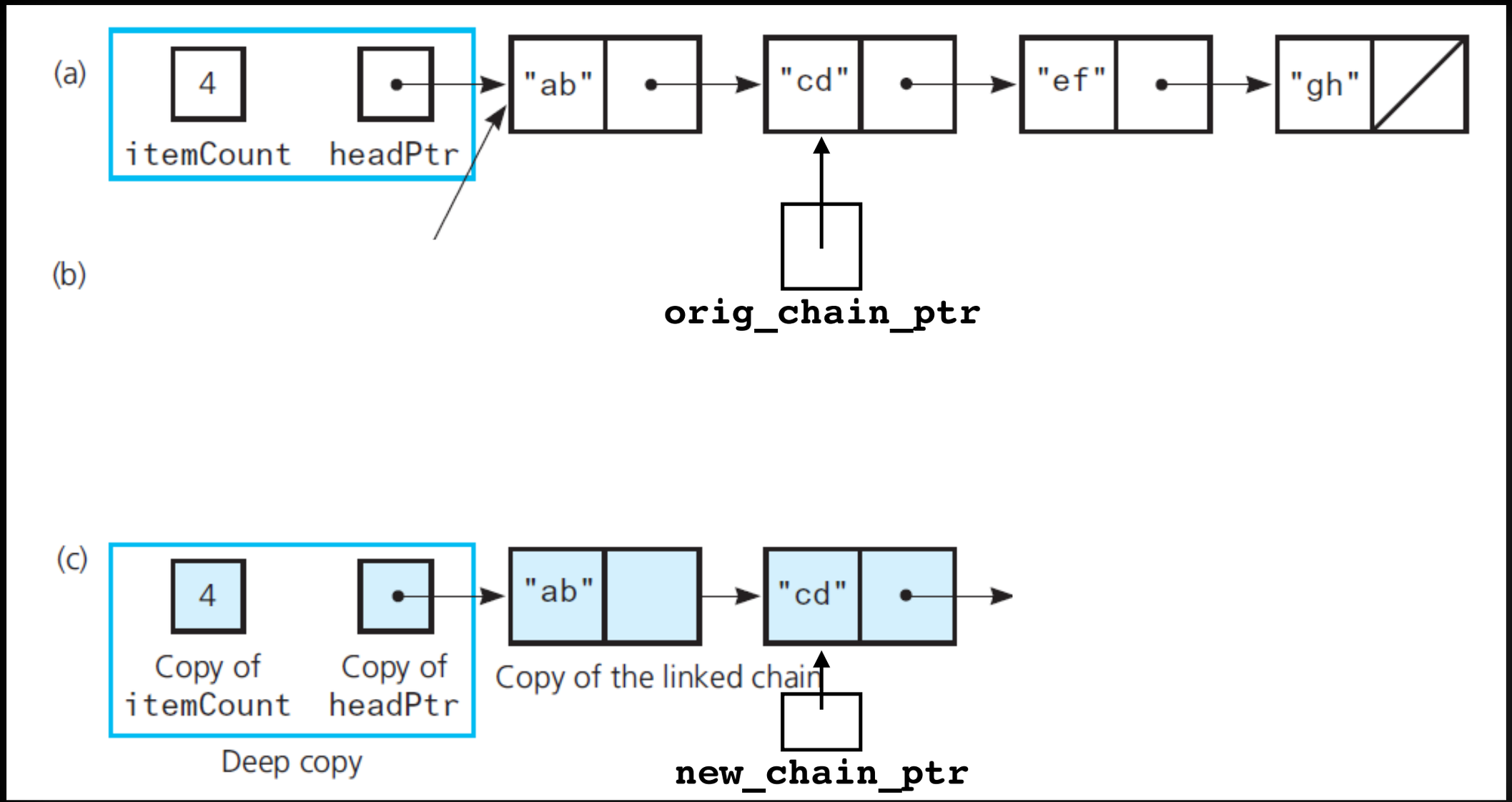
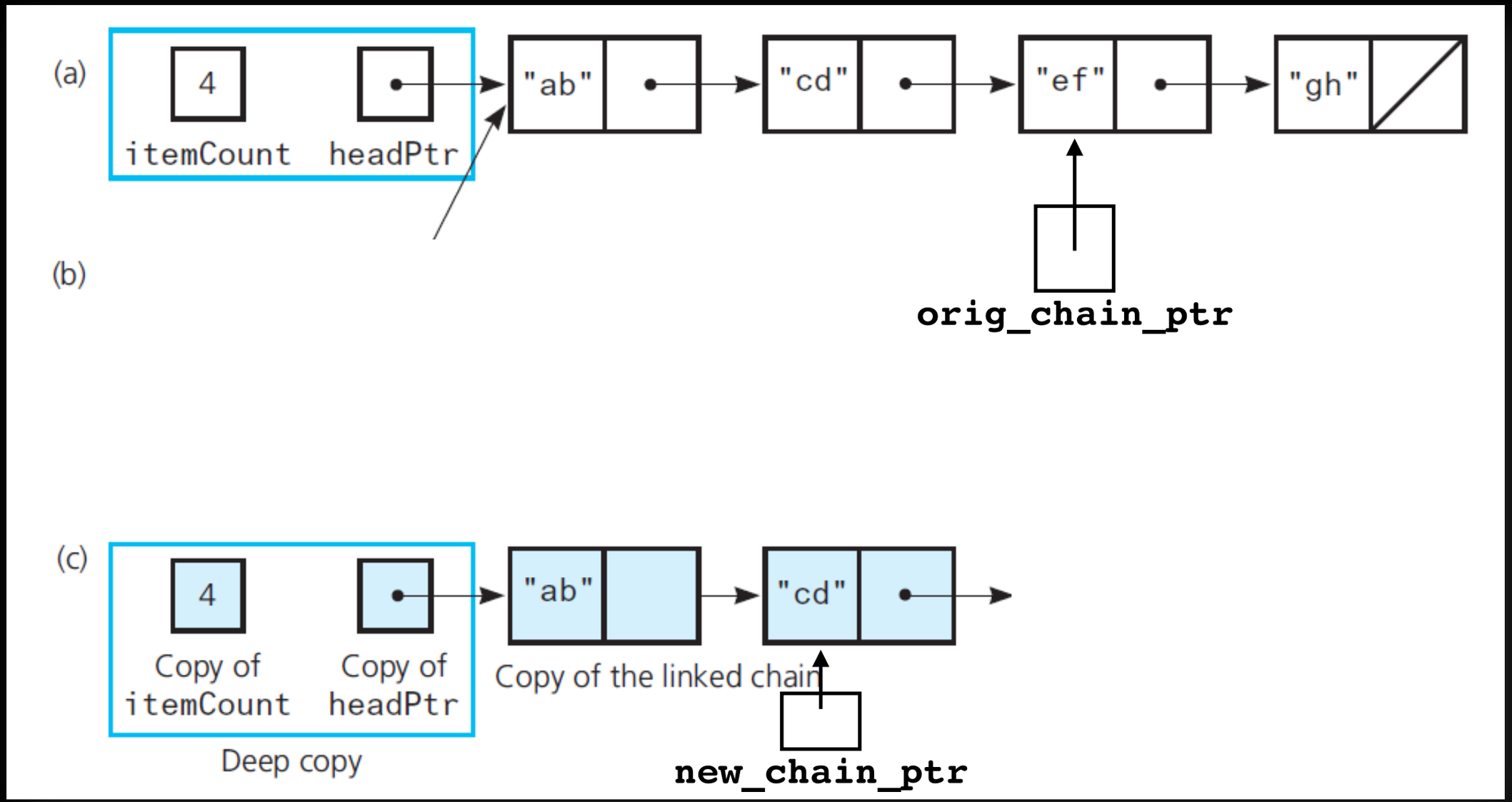
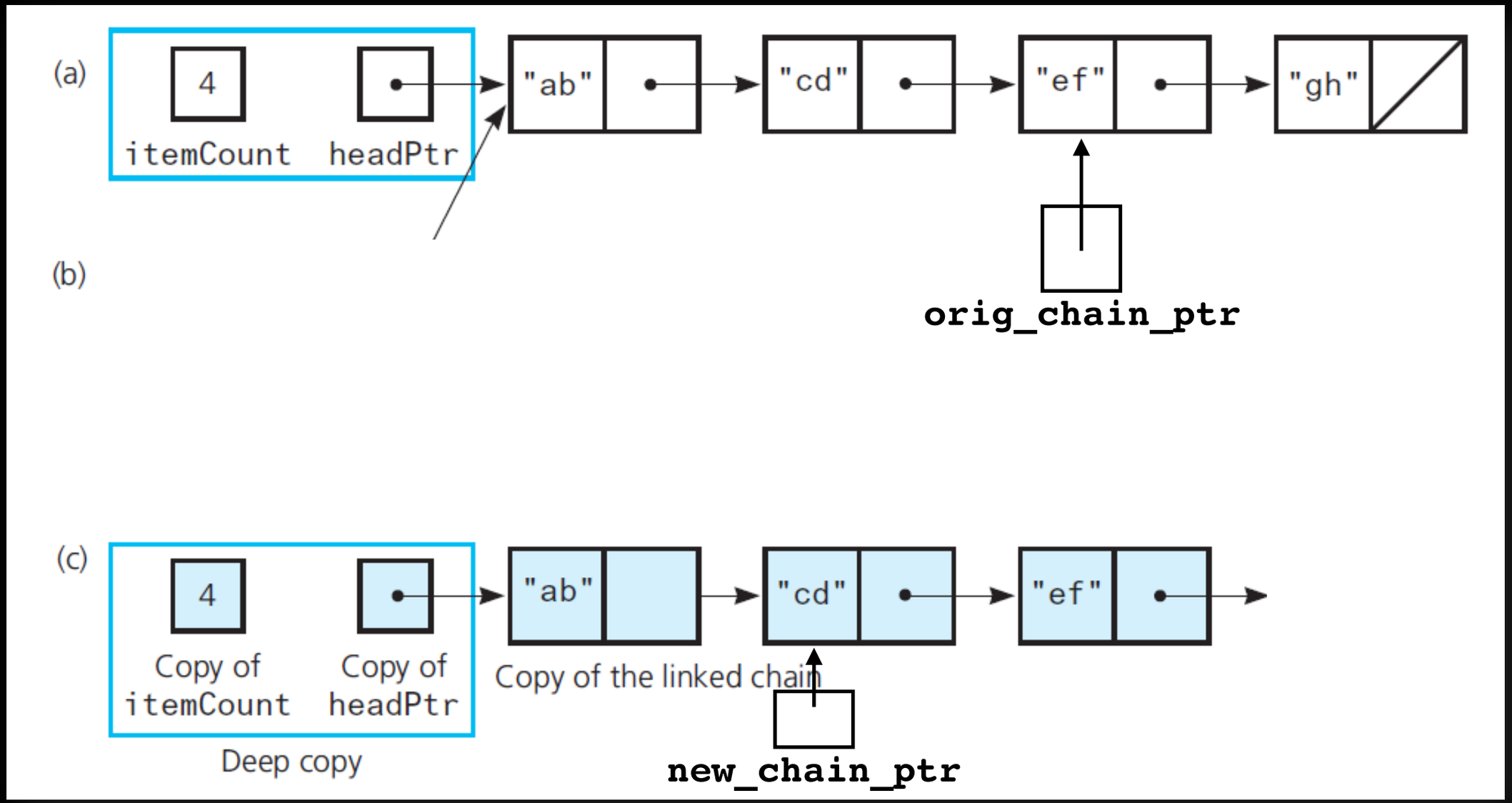


Deep vs Shallow Copy



Deep vs Shallow Copy



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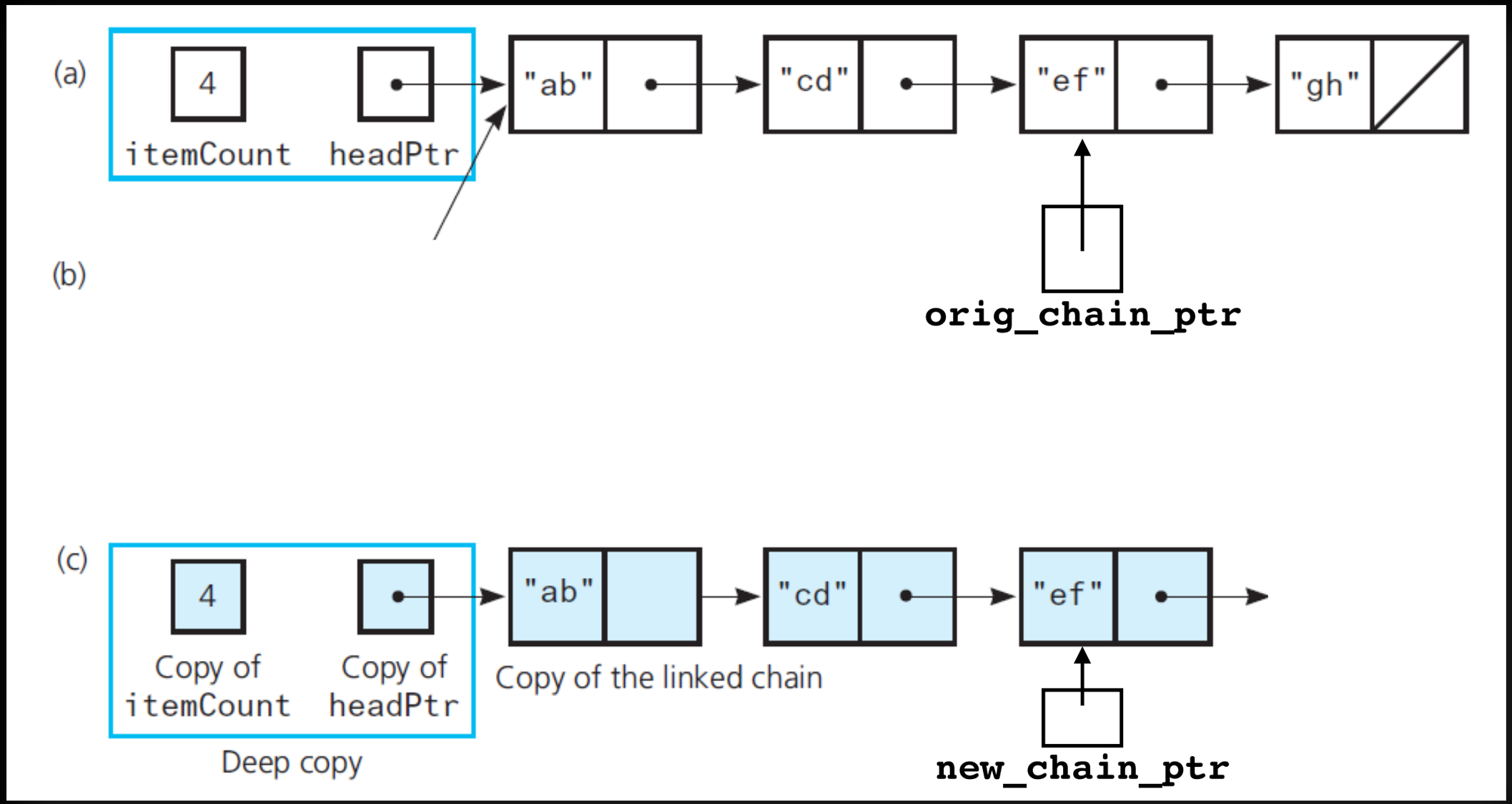
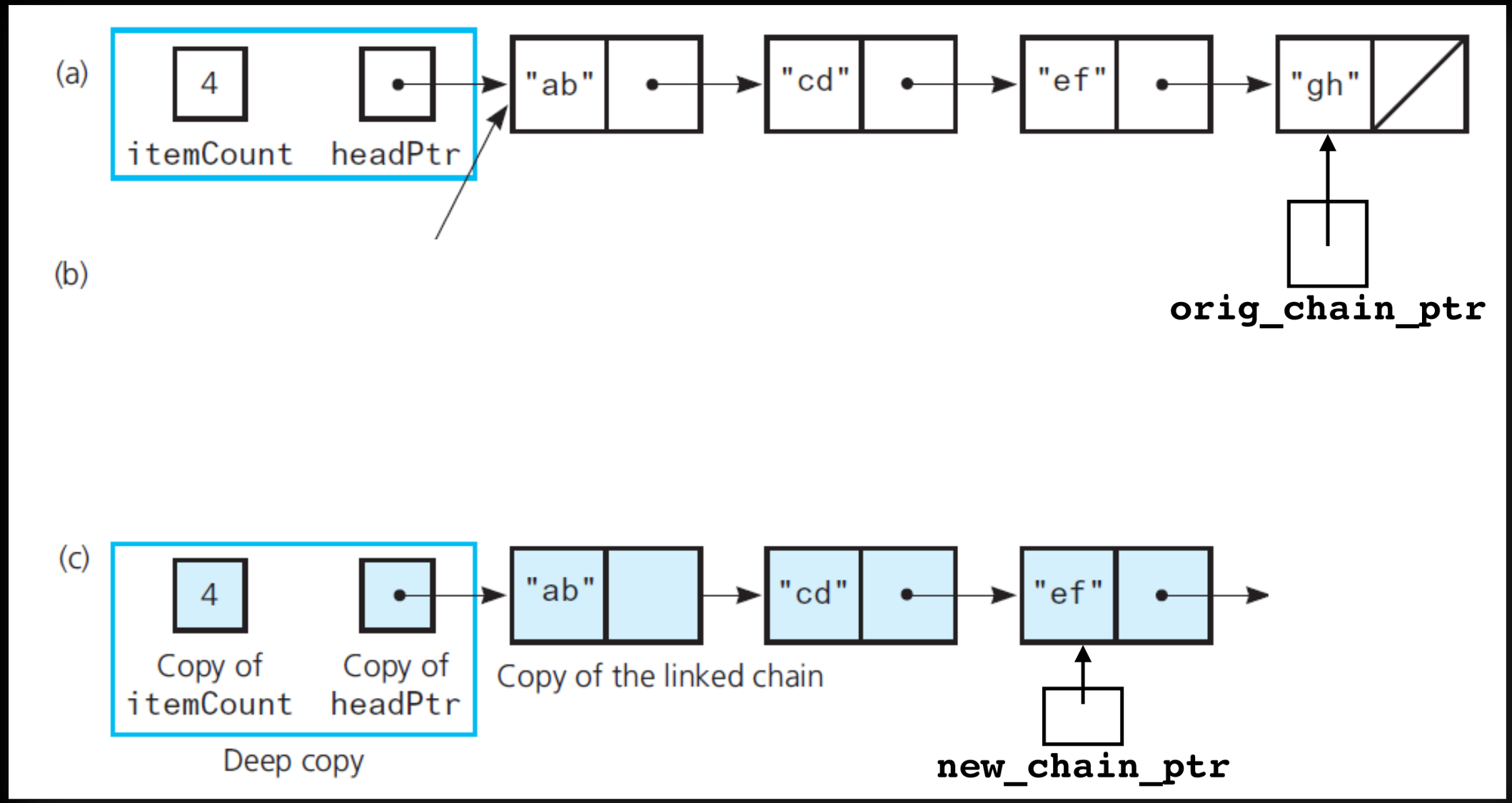


Deep vs Shallow Copy



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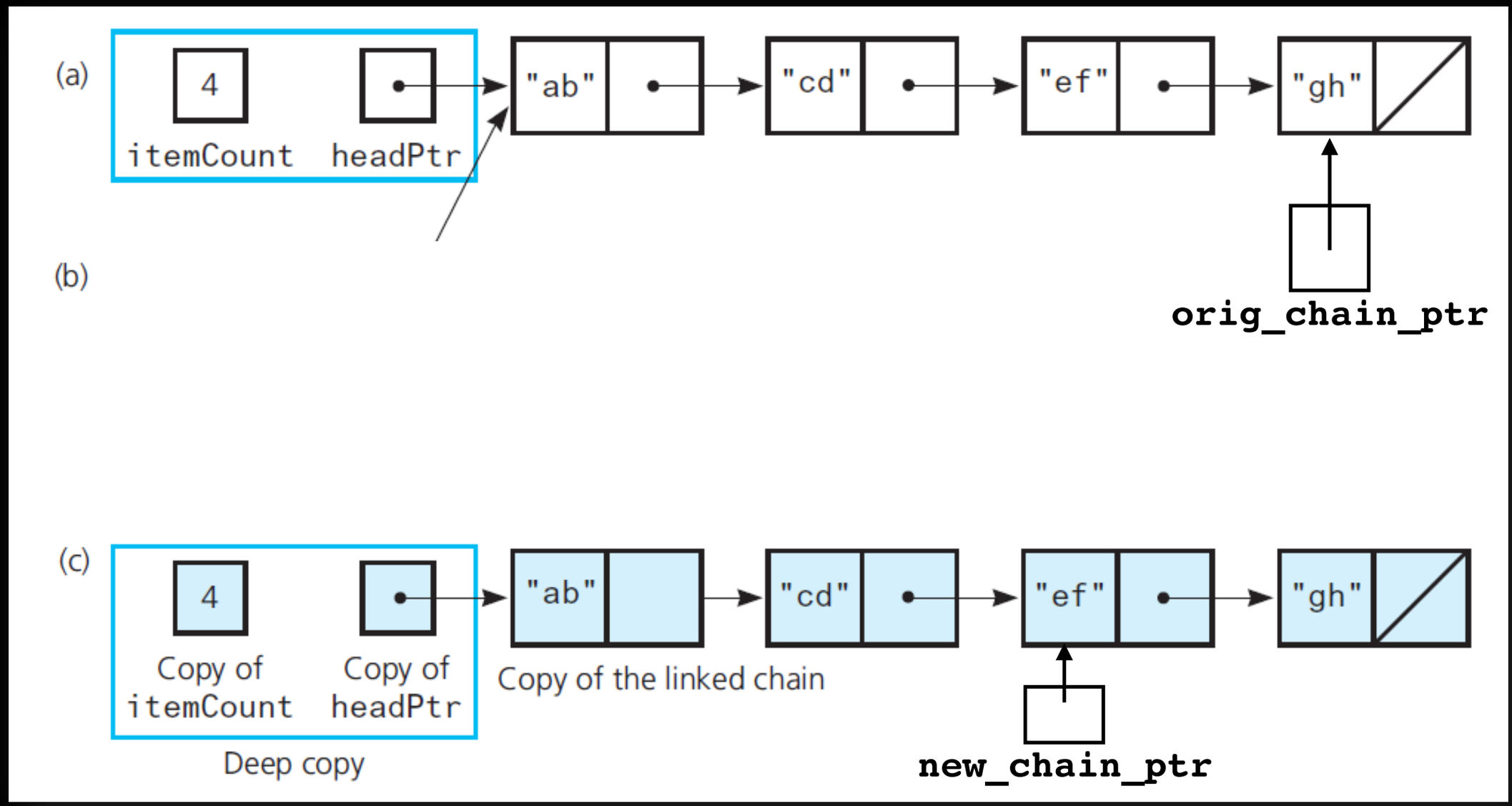

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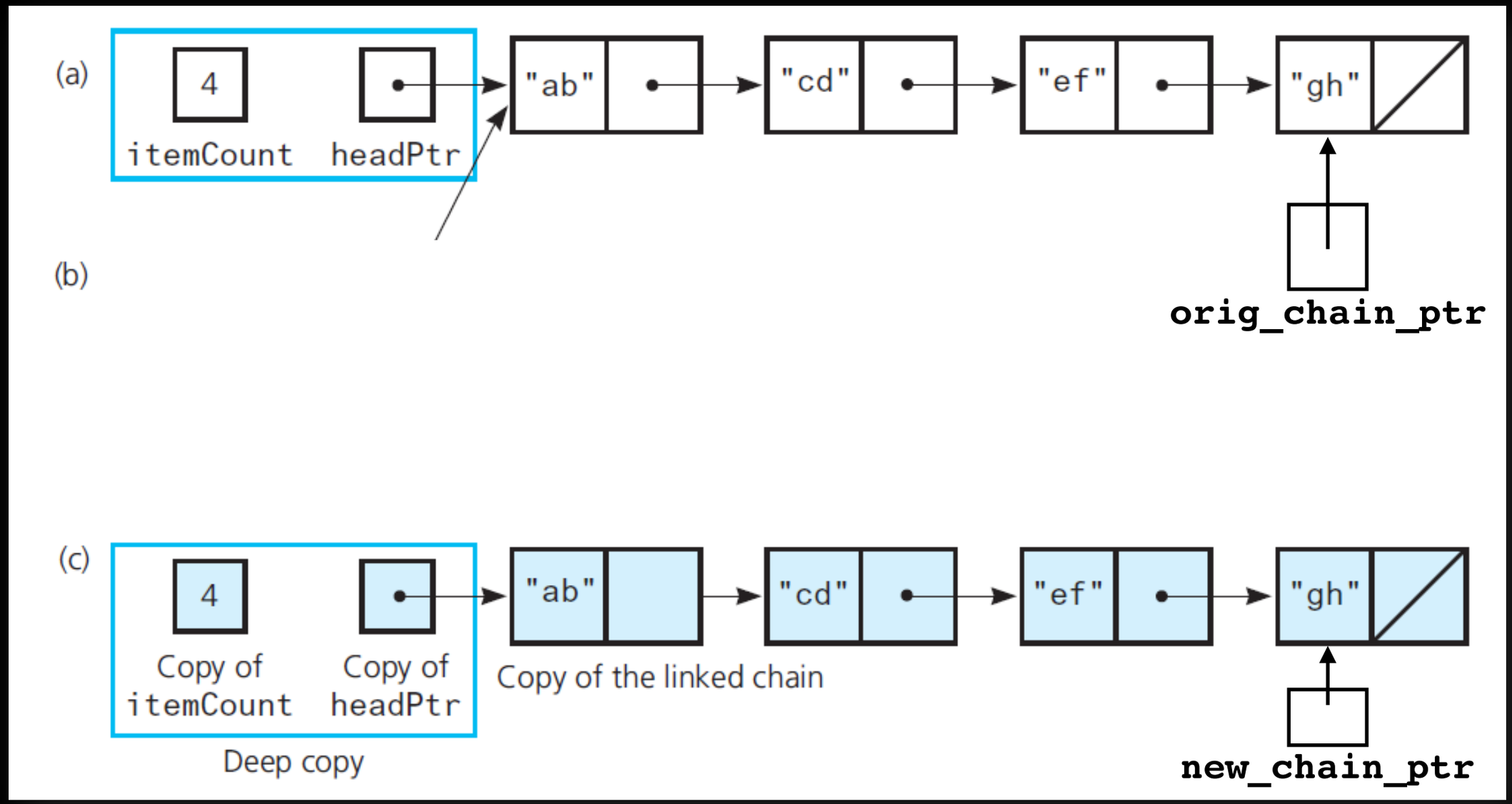

Efficiency Considerations

Every time you pass or return an object by value:

- Call copy constructor
- Call destructor

For linked chain:

- Traverse entire chain to copy (n *“steps”*)
- Traverse entire chain to destroy (n *“steps”*)

Preferred:

```
myFunction(const MyClass& object);
```

The Class LinkedBag

```
#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_
```

Efficient

Expensive

THINK
WORST CASE

The Class LinkedBag

```
#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_
```

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