Copy and Move

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Today's Plan

Copy operations

Move operations

Recap

```
LinkedBag();
~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;
```

What if we need a copy of the bag?

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

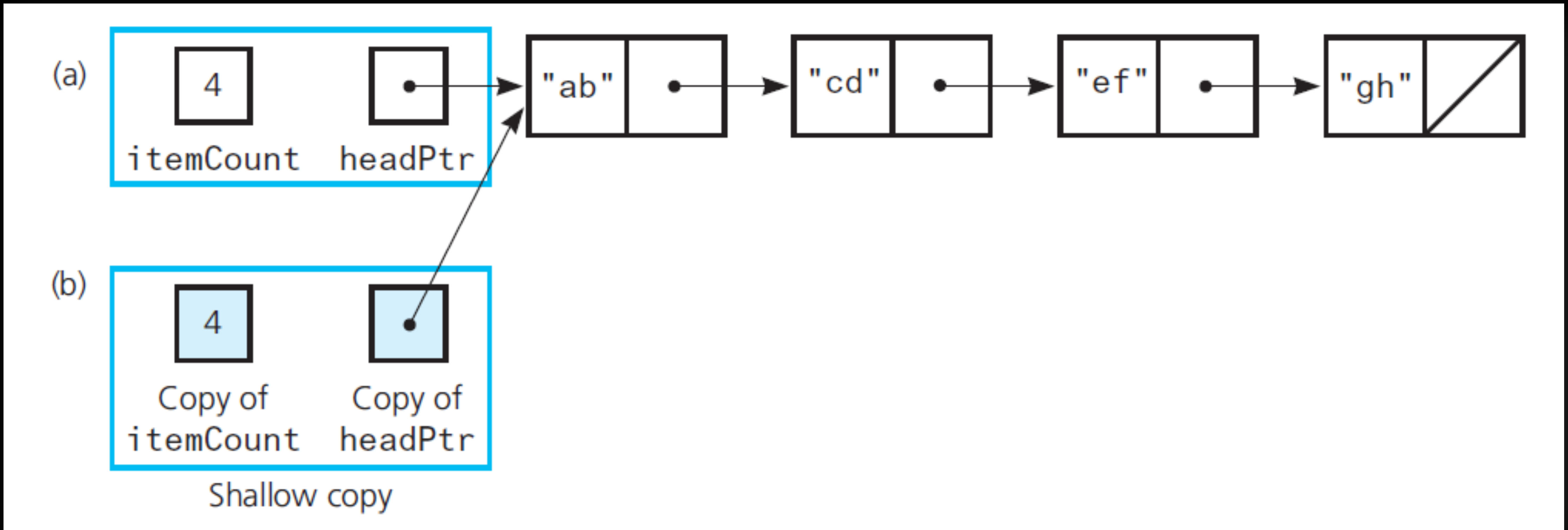
2. Copy an object to **pass by value** as an argument to a function

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

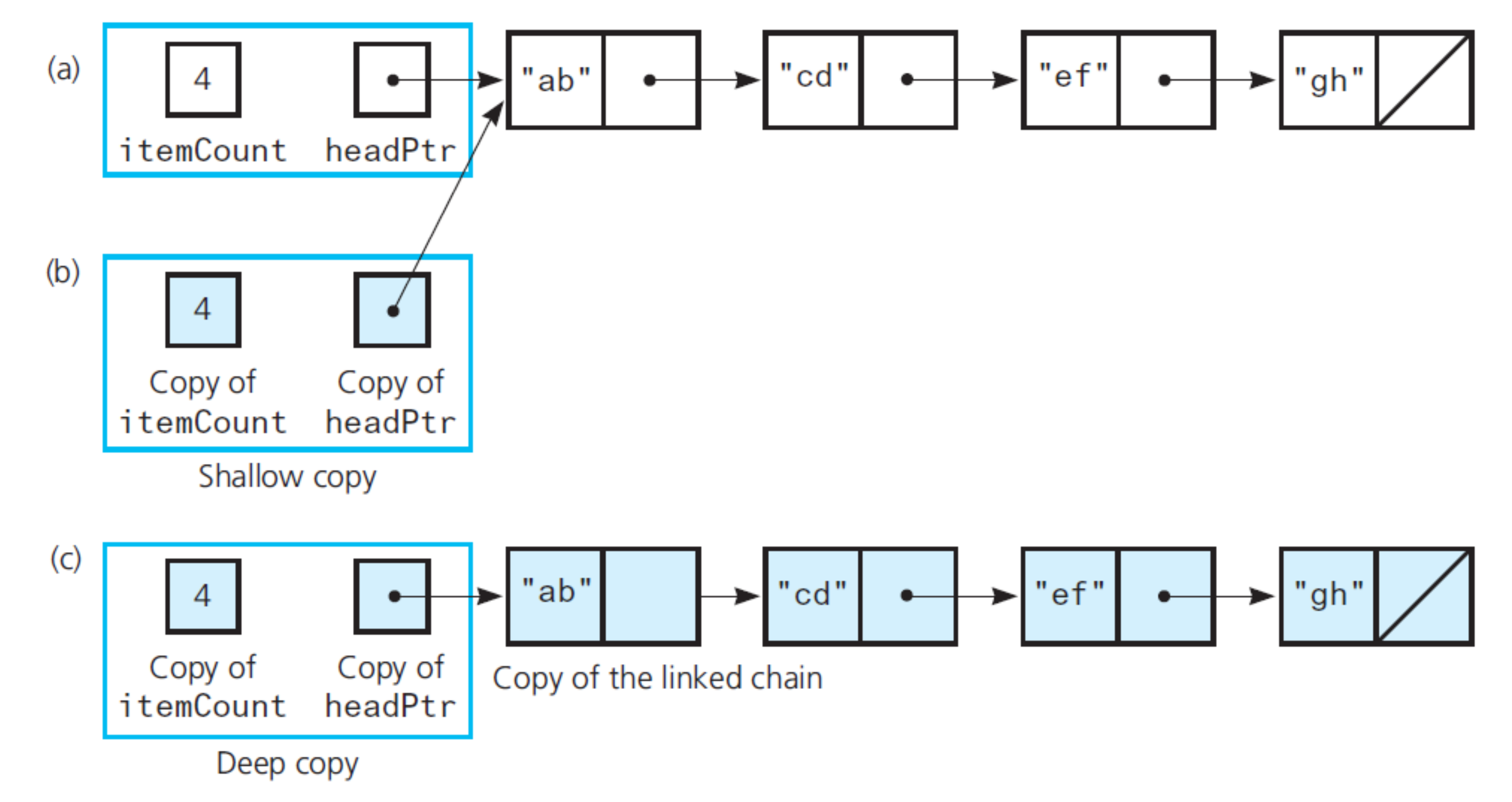
3. Copy an object to be **returned** by a function

```
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

Different functions/call same implementation

Class must explicitly define deep copy behavior when memory is dynamically allocated

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

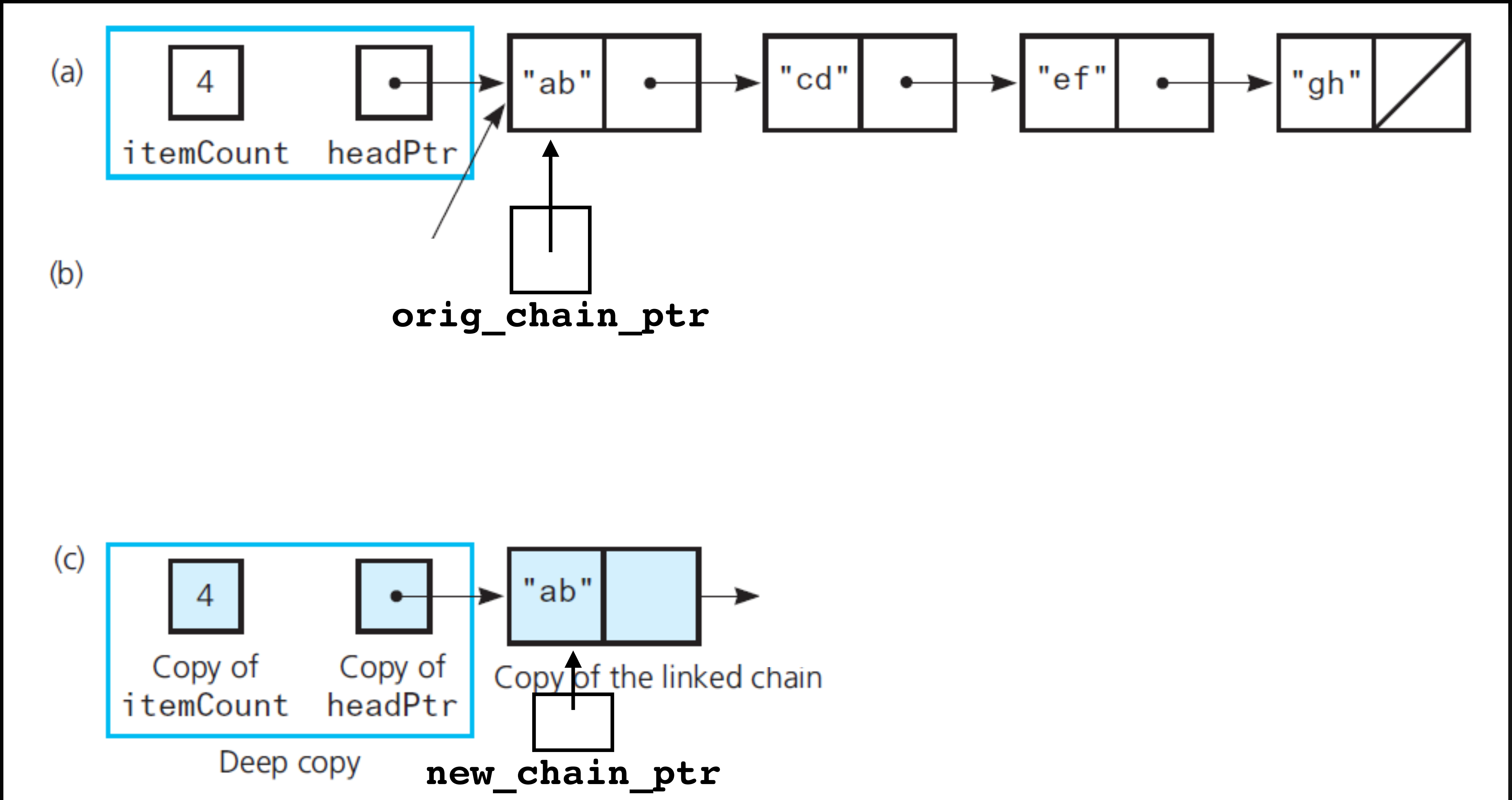
Advance pointer traversing original chain

Signal last node

Deep vs Shallow Copy

```
// 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();
```



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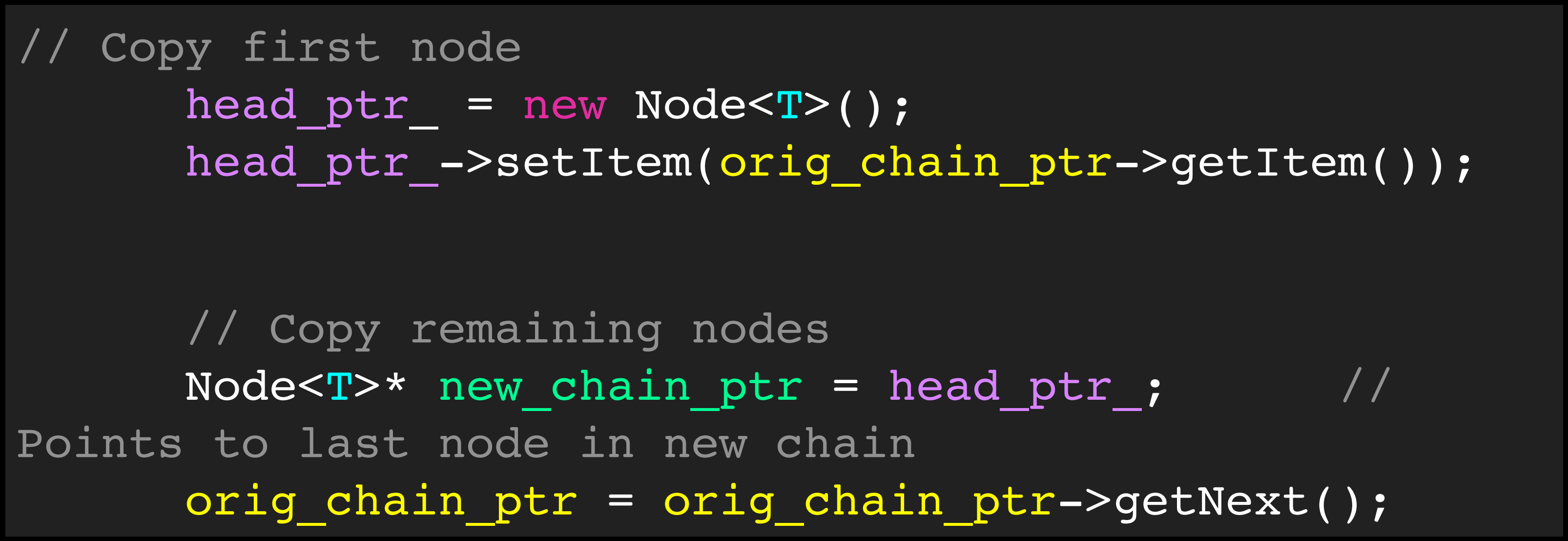

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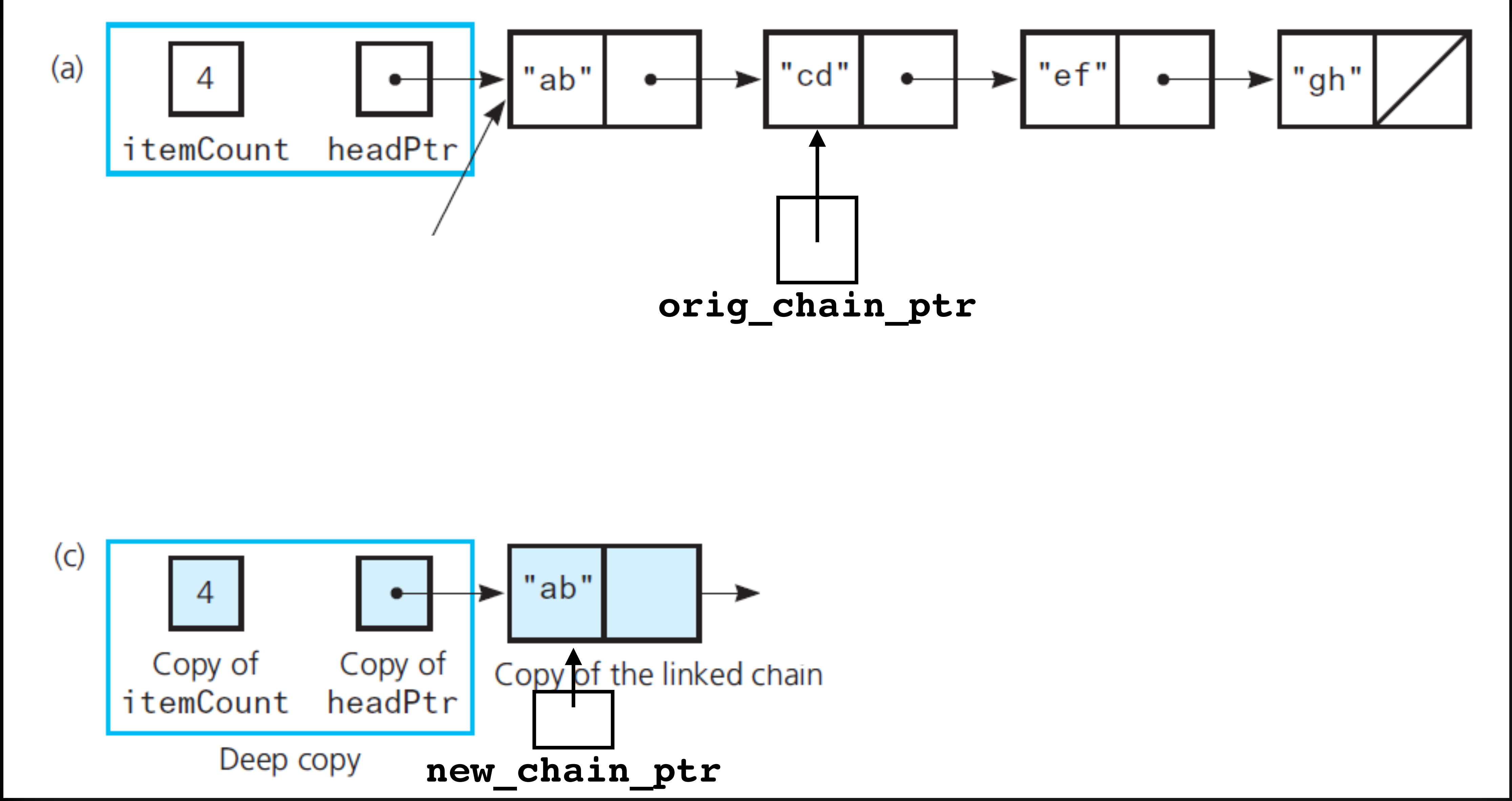

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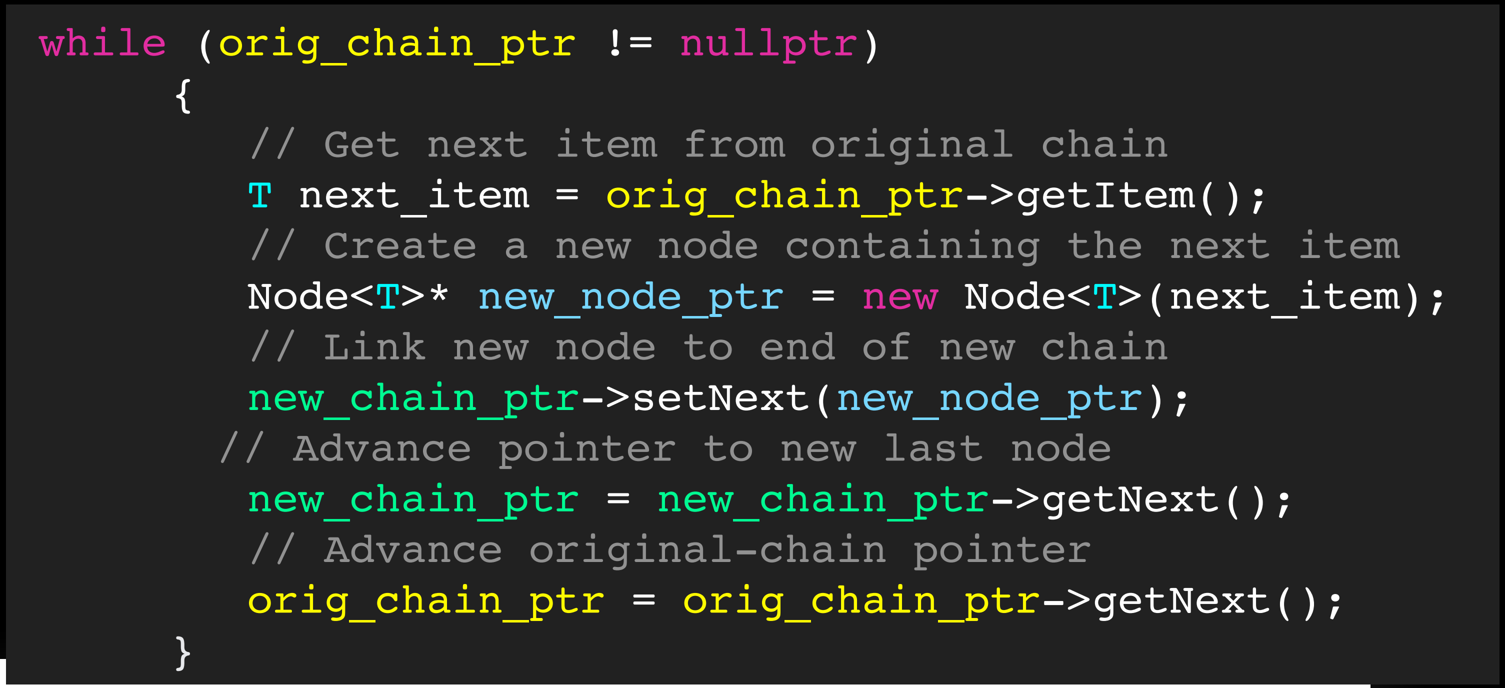

```
while (orig_chain_ptr != nullptr)
     {
        // Get next item from original chain
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        // Create a new node containing the next item
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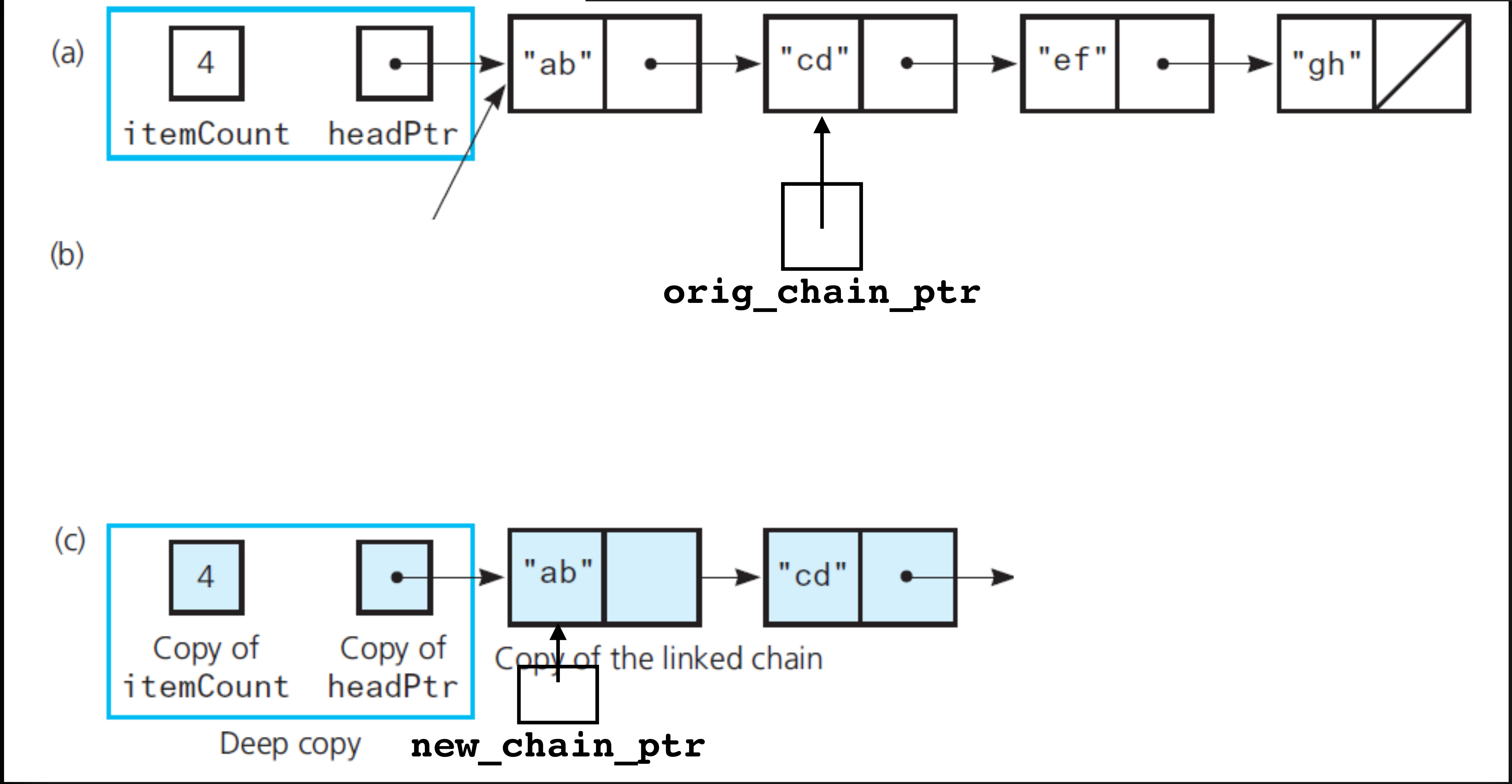
     }
```



Deep vs Shallow Copy

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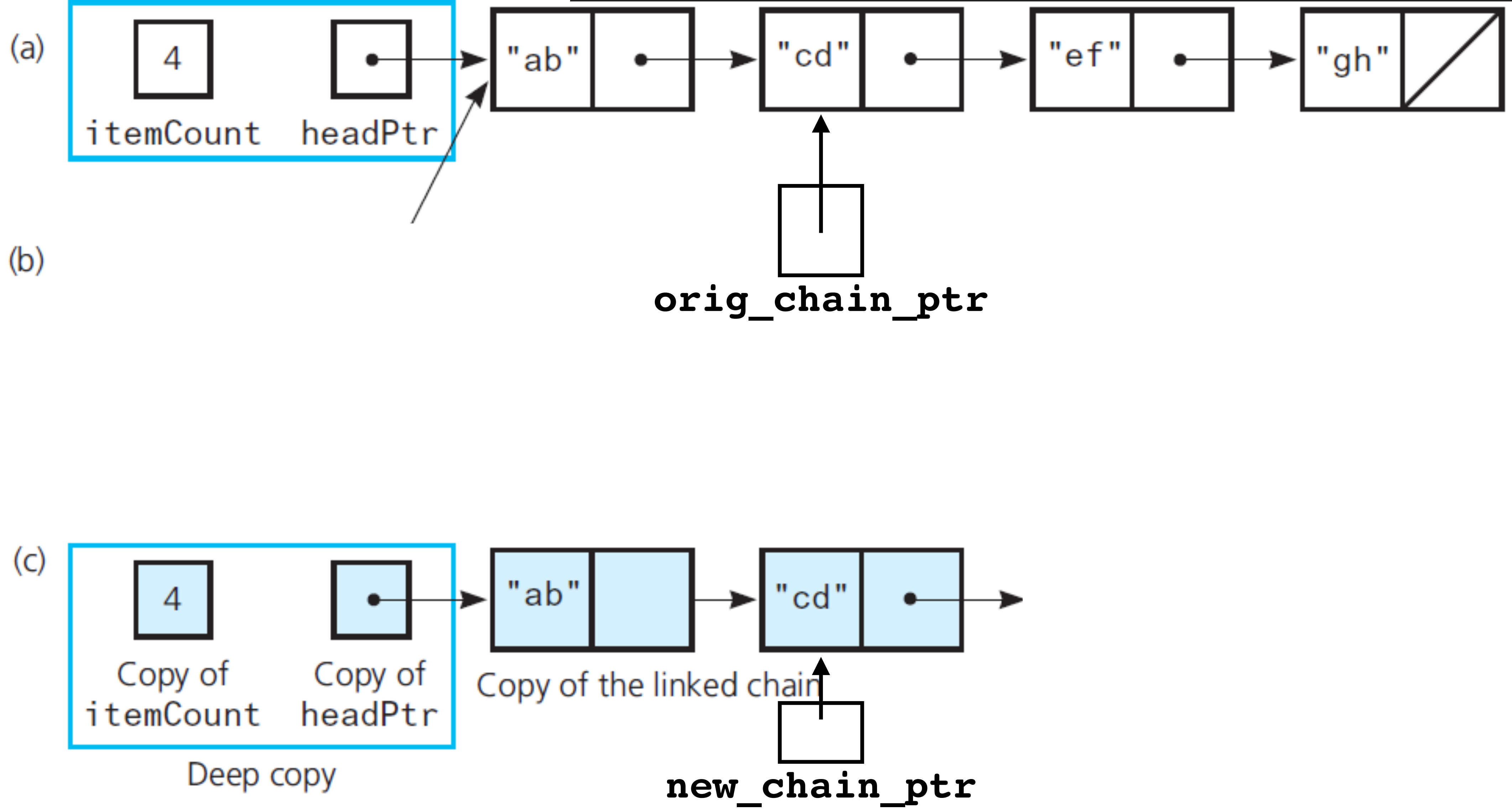

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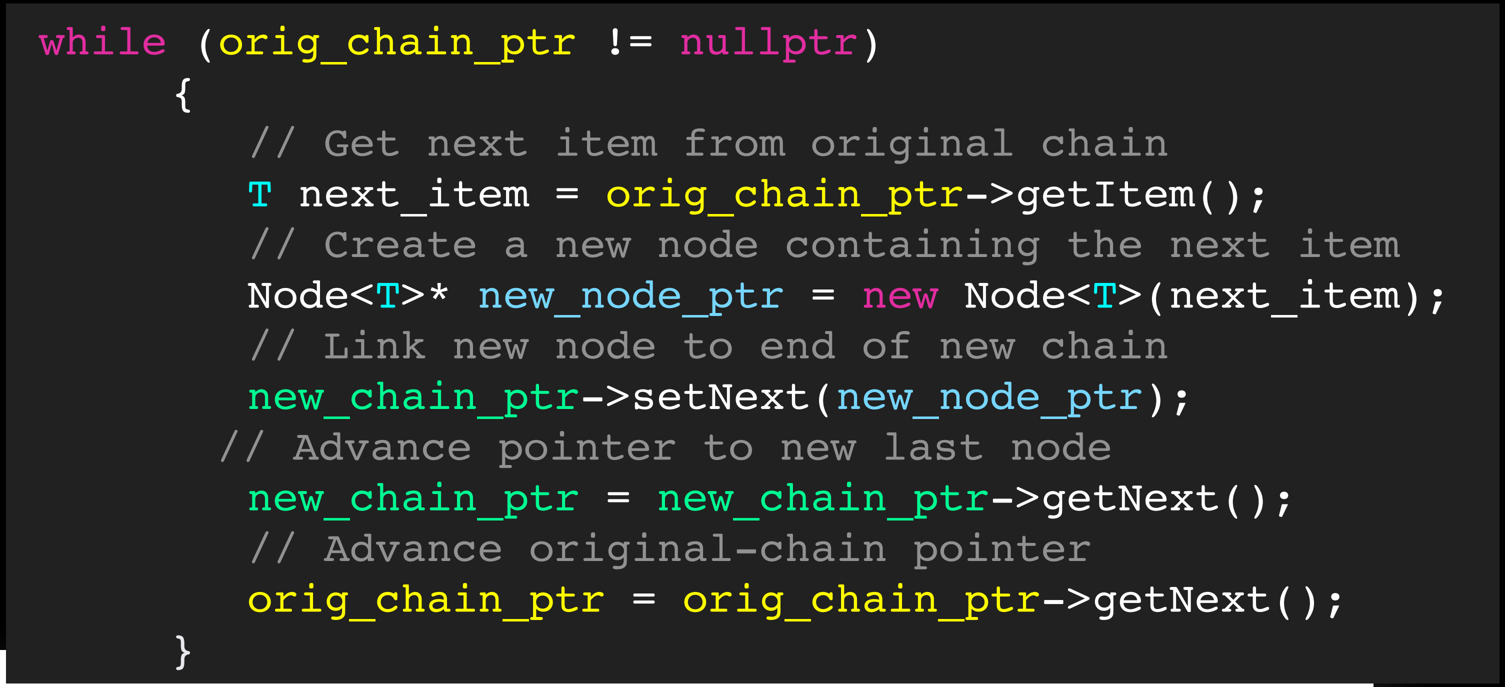

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     }
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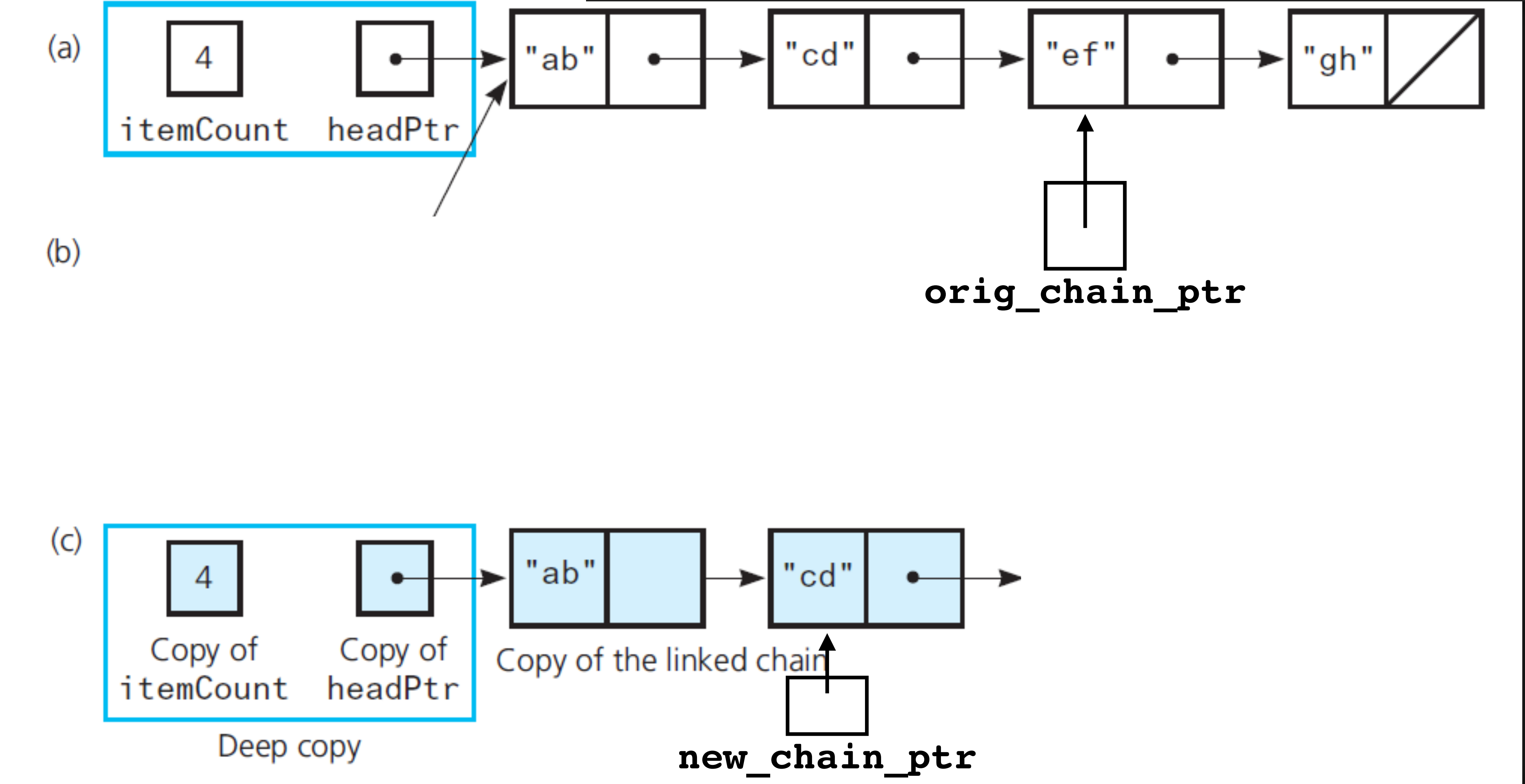

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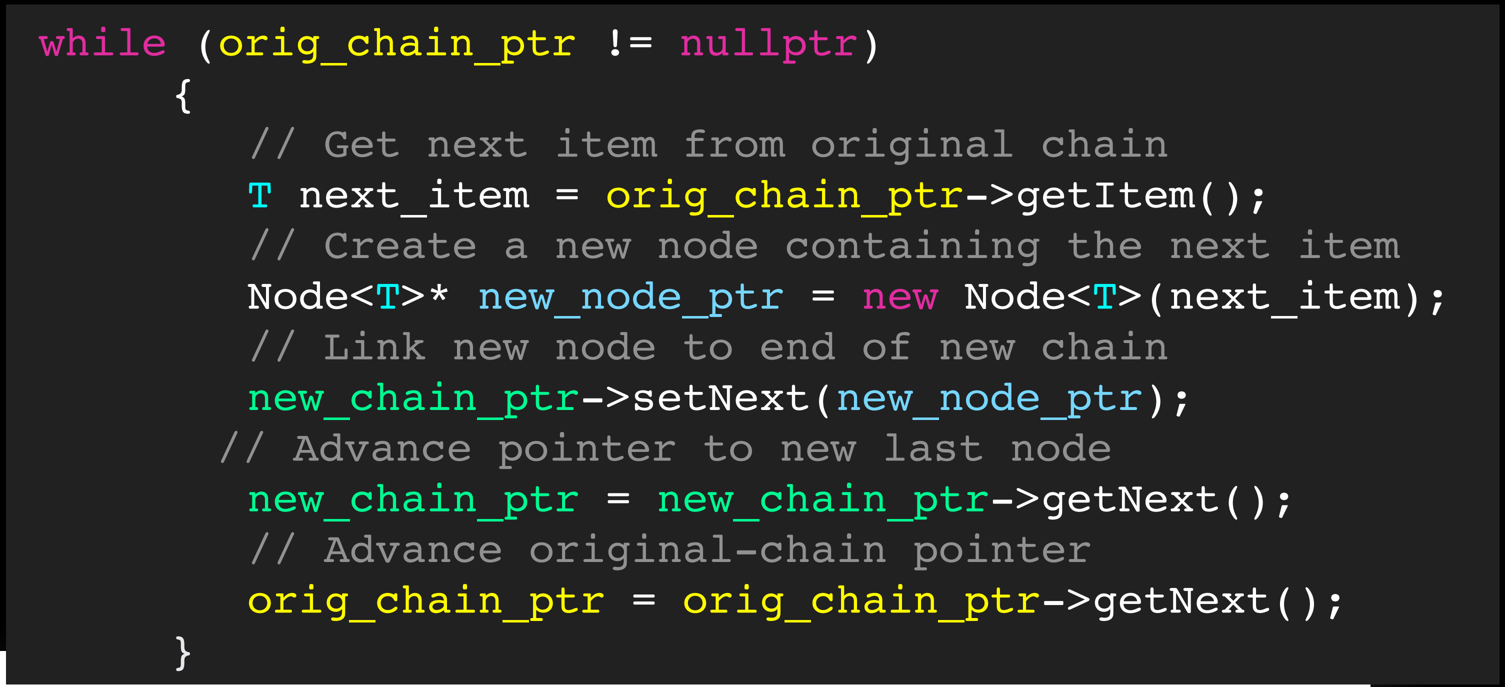

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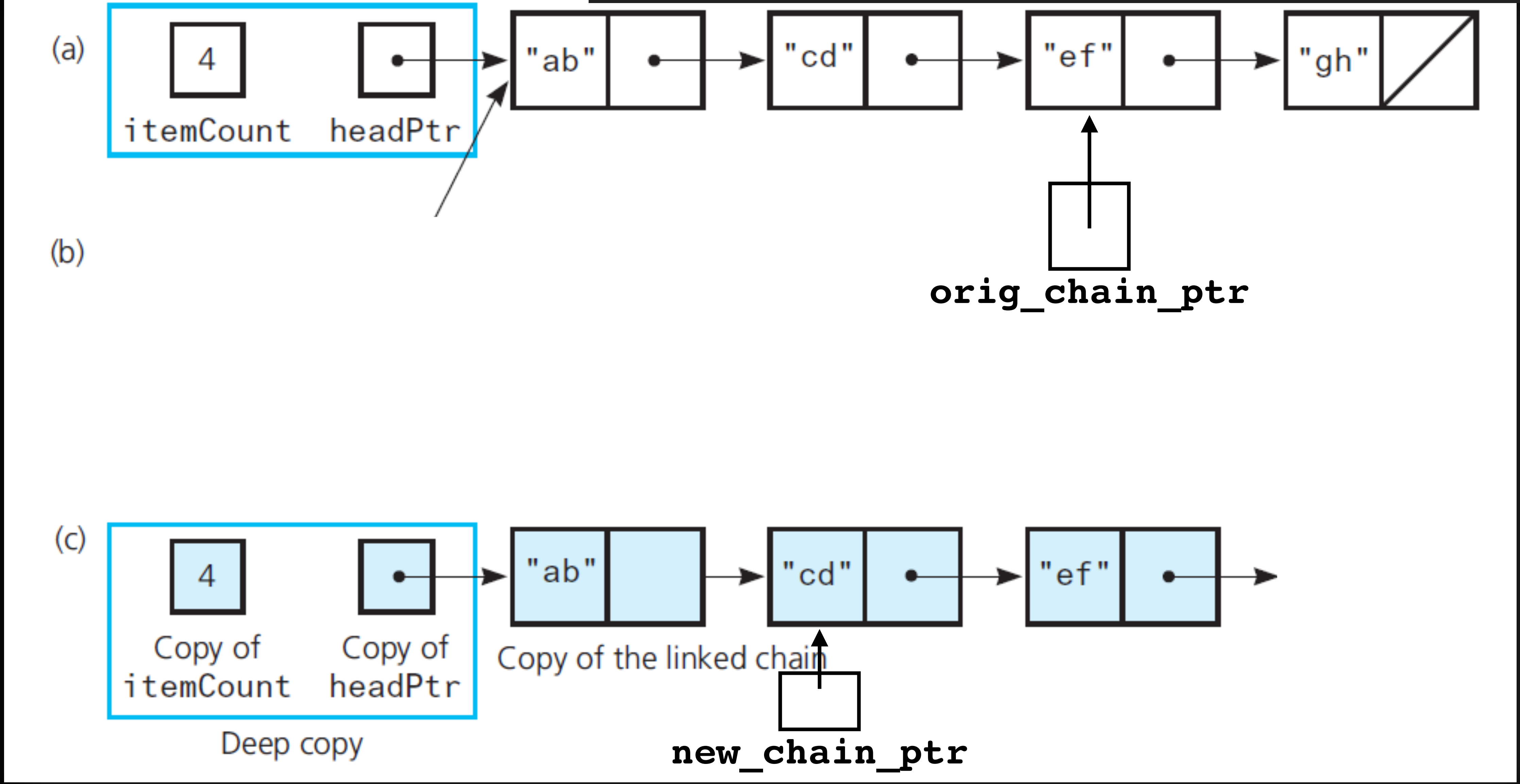
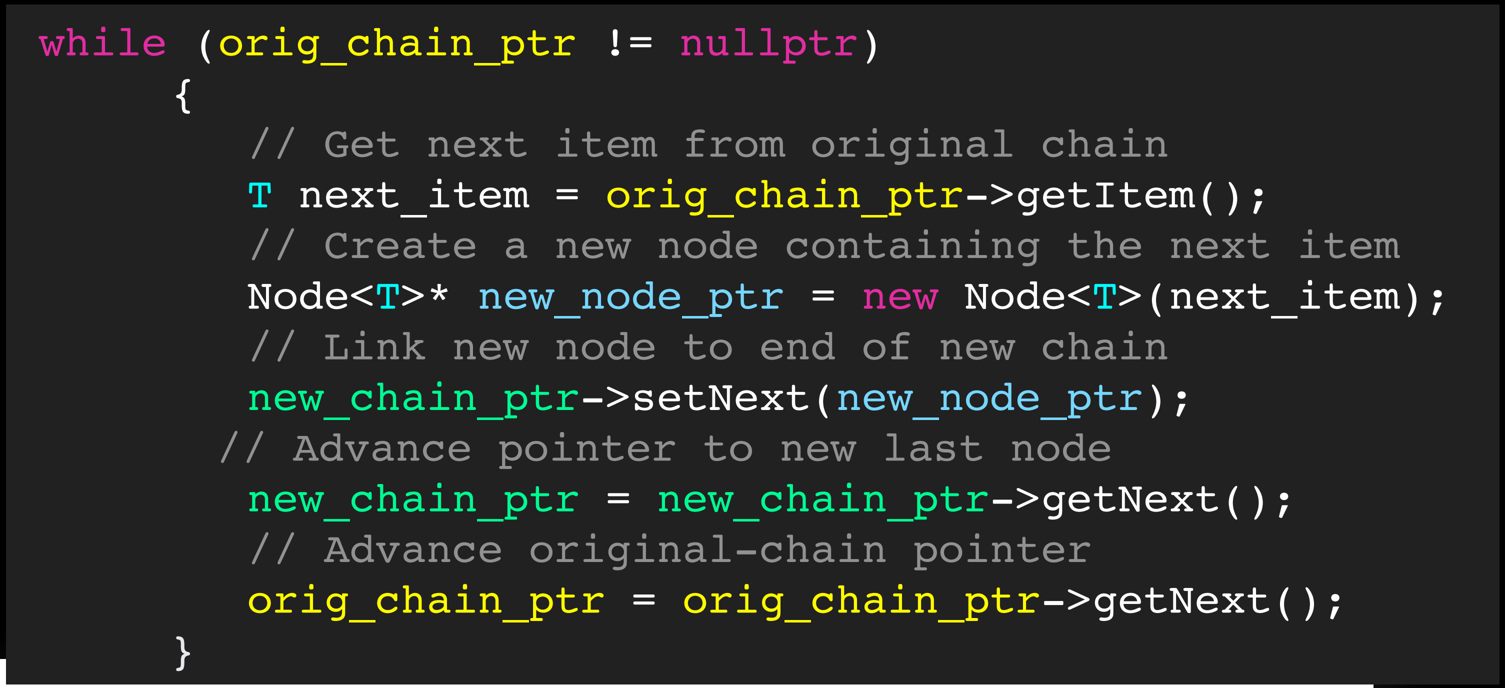


Deep vs Shallow Copy



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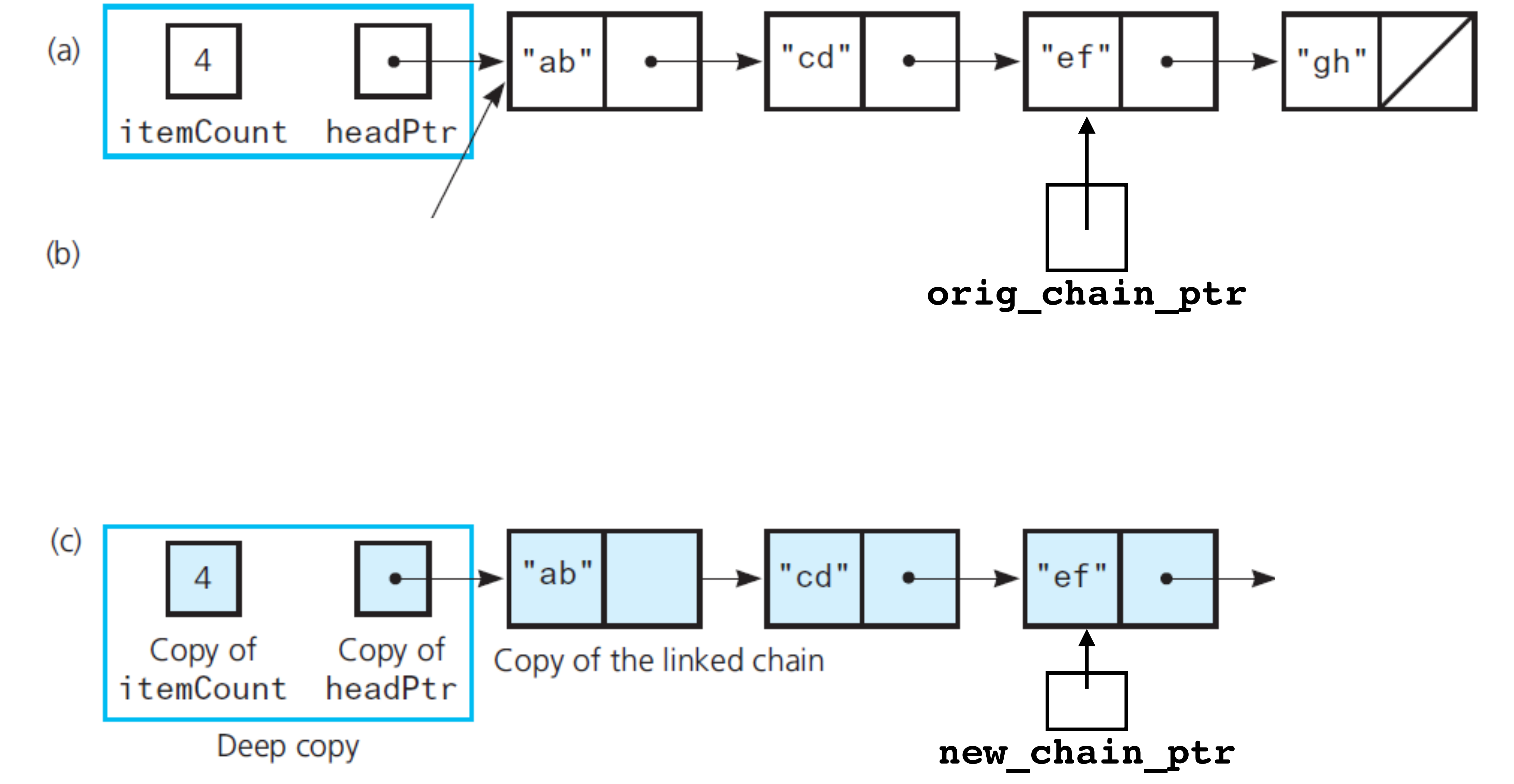
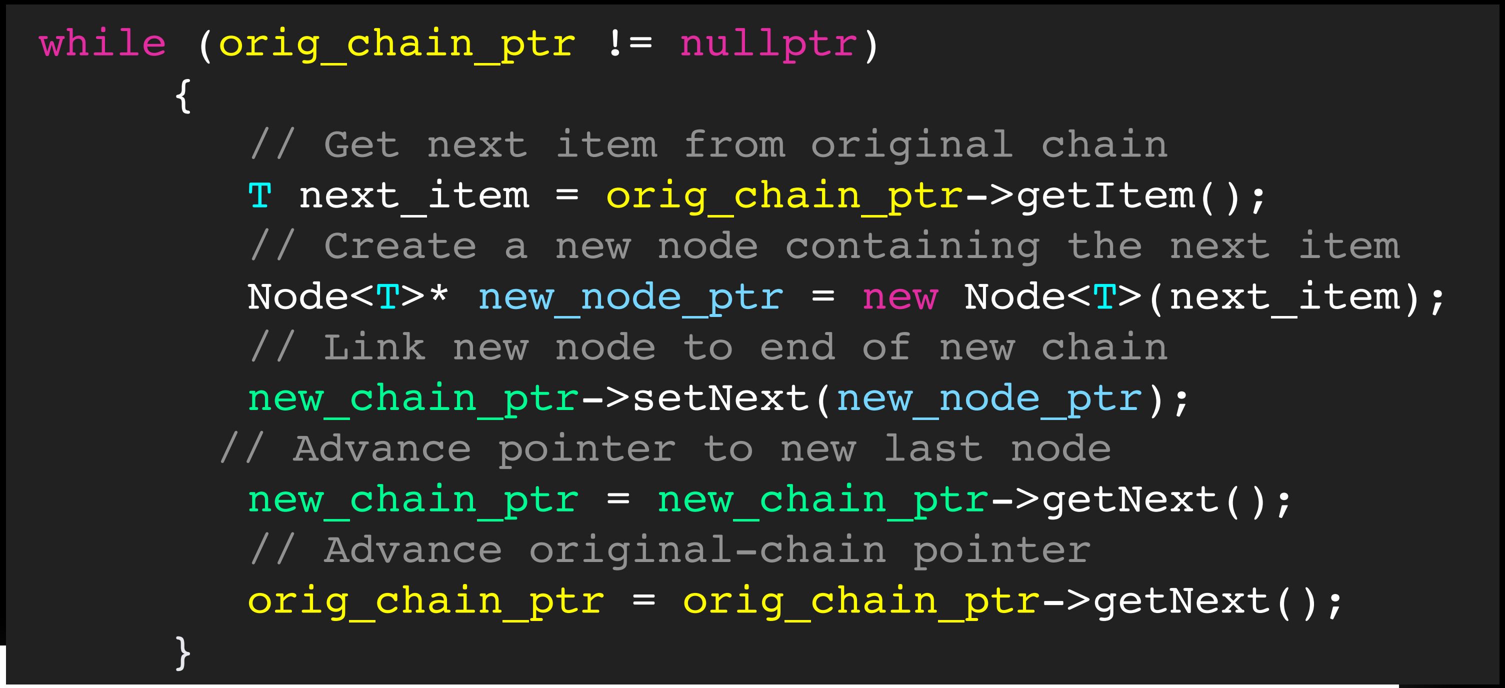


Deep copy

Deep vs Shallow Copy



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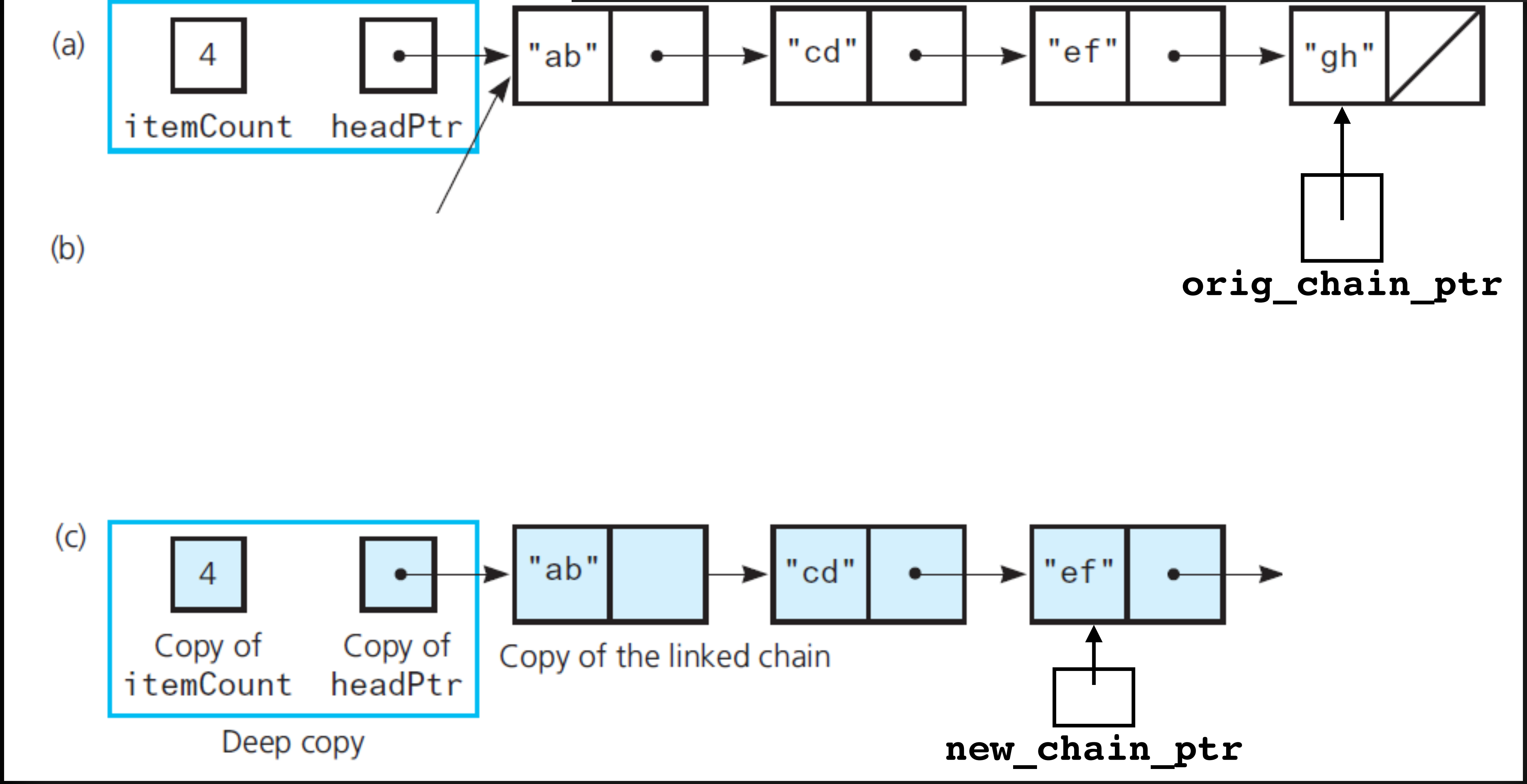
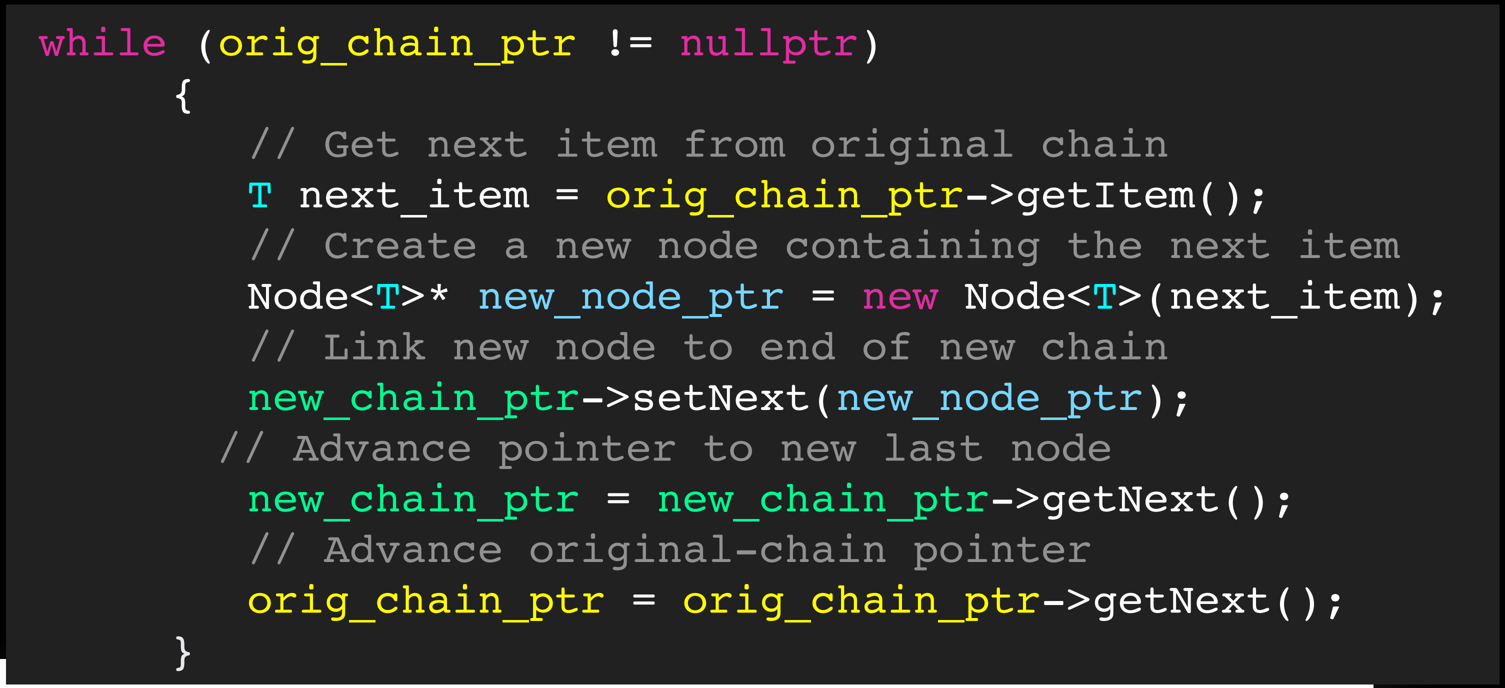


Deep vs Shallow Copy



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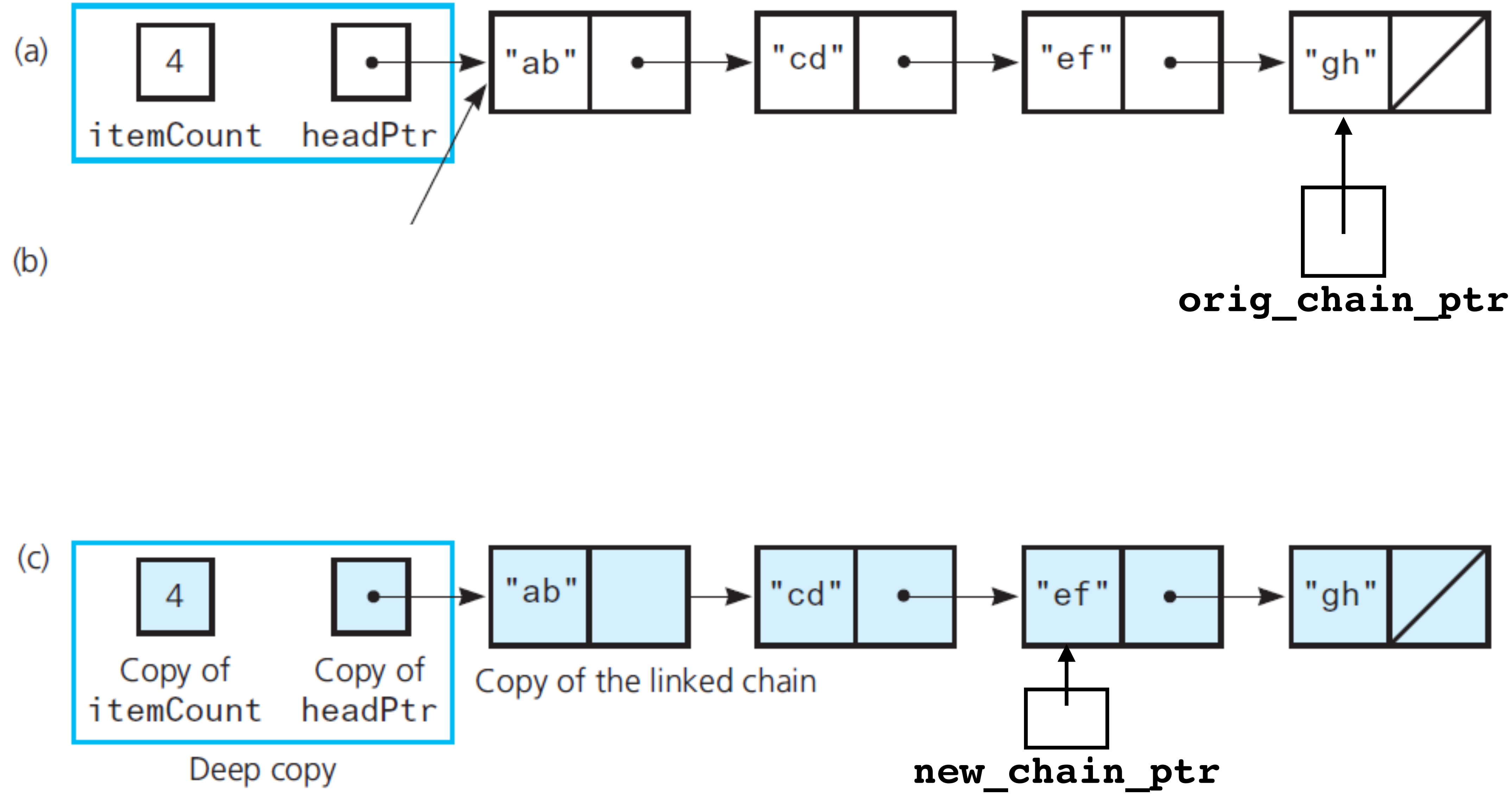

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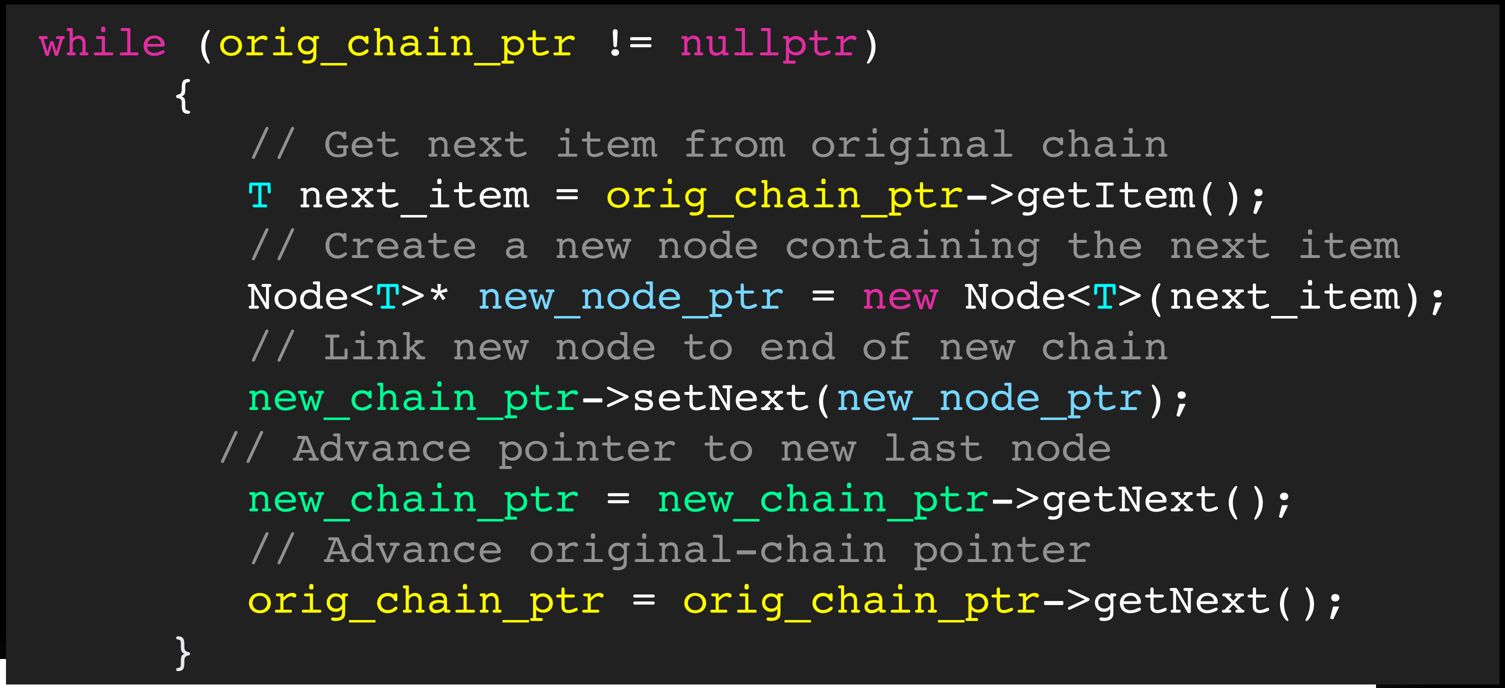

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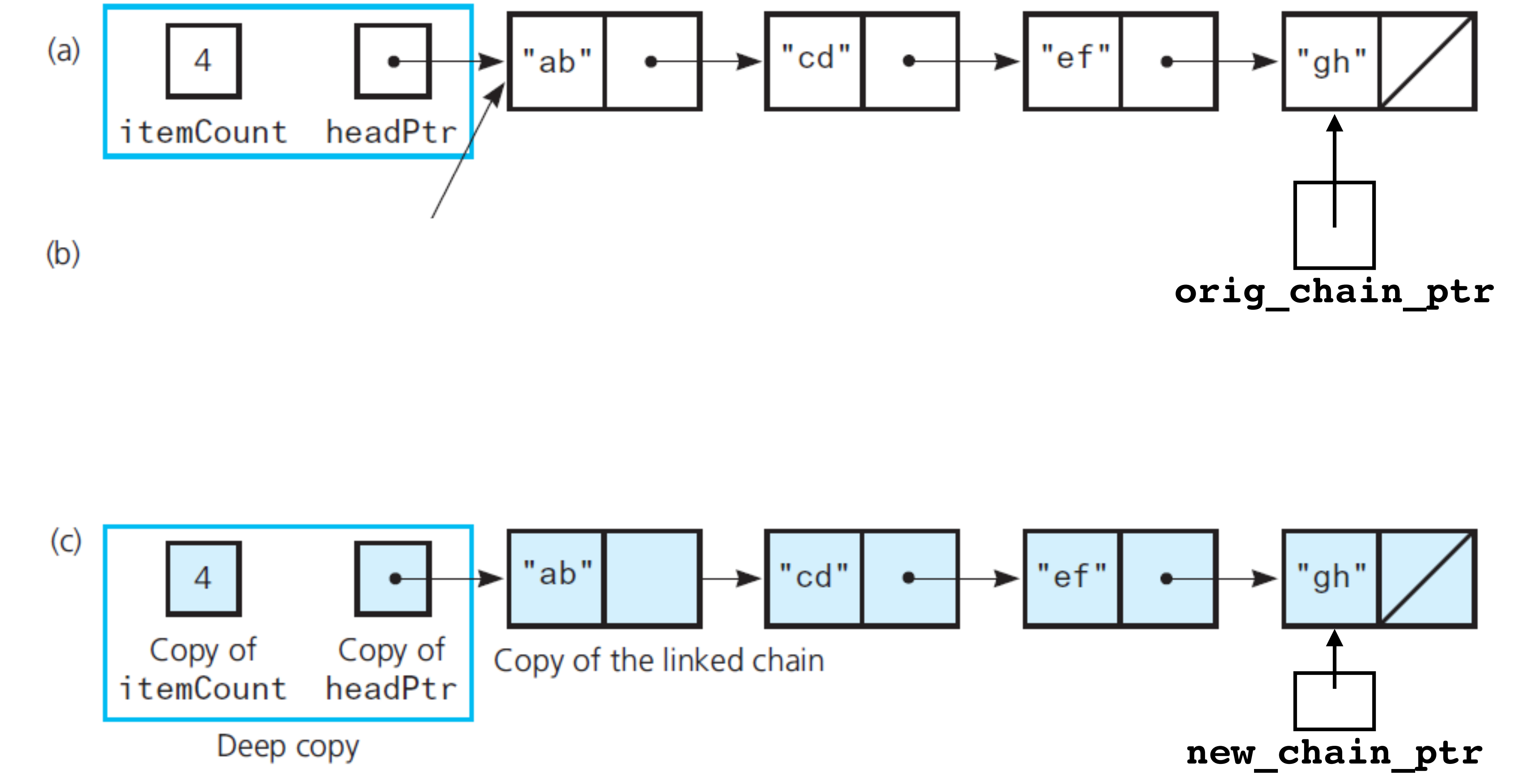


Efficiency Considerations

Every time you pass or return an object by value:

- Call copy constructor
- Call destructor

O(n)

For linked chain: O(n)

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

Preferred call by const reference:

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

Move Semantics

Copying can be time/space consuming, especially if large amount of data

Copying often involves making copy and destroying original (e.g, pass by value, return by value, old-school swap with intermediate): inefficient

More efficient to **transfer ownership** of resources to another object

lvalues and *rvalues*

lvalue = rvalue

Examples:

```
int x = 2;
int y = x+1;
x = y;
x = y + z;
string msg = “hello”;
bool pass = computeGrades(student);
```

The return value, not the function

Lvalues can be referred to by name, pointer or lvalue reference: i.e. they have an address

Rvalues are literals or temporary objects that are the result of evaluating expressions, or are copied into or returned by functions, they don’t have an address and cannot have a value assigned to it

Can have lvalue and rvalue of same type.

Move Semantics

Since
C++ 11

Rvalues are eligible for **move operations**

After object x is moved into object y:

- y is equivalent to the former value of x
- x is in a special state called the *moved-from state*
- Object in moved-from state can only be reassigned or destructed (becomes an rvalue)
- rvalue is semantically temporary, thus it is more likely to be put in temporary memory or optimized

std::move()

A type-cast

Converts an lvalue to an rvalue

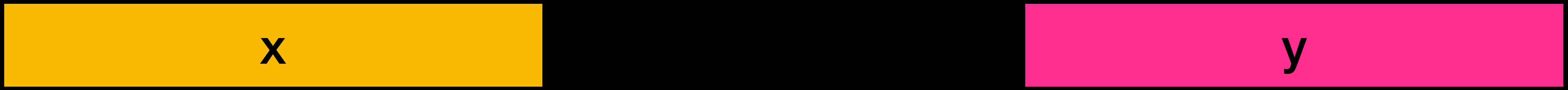
Allows the **efficient transfer of resources** from the moved object to another

```
y =   std::move(x);
```

x is now treated as an rvalue

Old-school swap

```
void swap(vector<string>& x, vector<string>& y)
{
      vector<string> temp{x};
      x = y;
      y = temp;
}
```



Old-school swap

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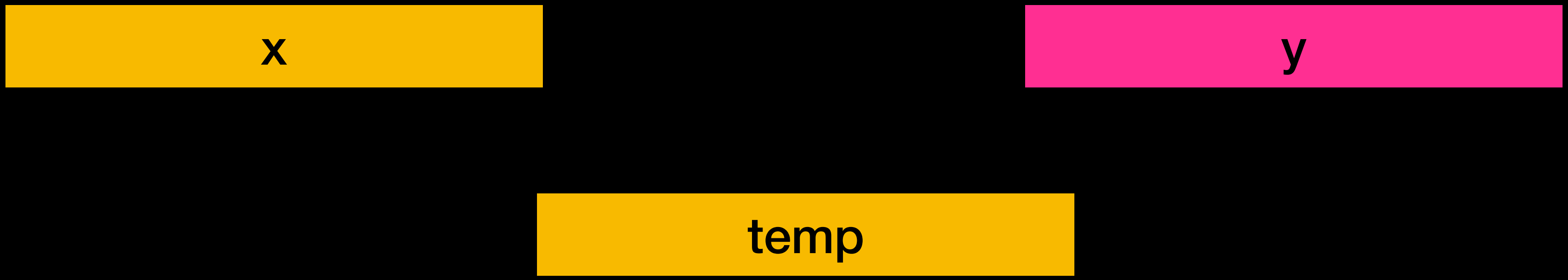

x

y

temp

Old-school swap

```
void swap(vector<string>& x, vector<string>& y)
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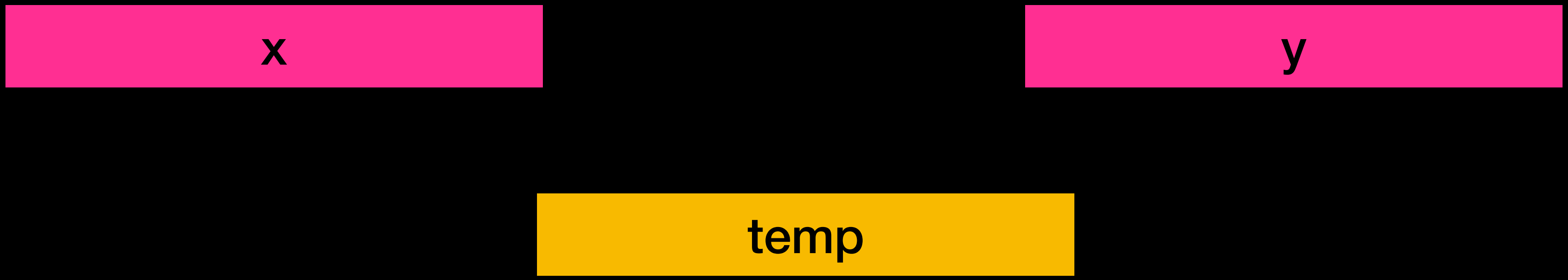
```



x

y

temp

Old-school swap

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void swap(vector<string>& x, vector<string>& y)
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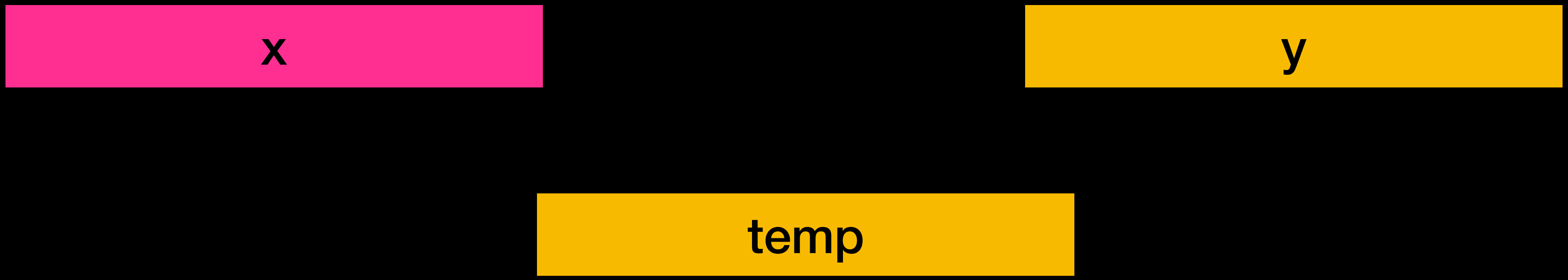

Old-school swap

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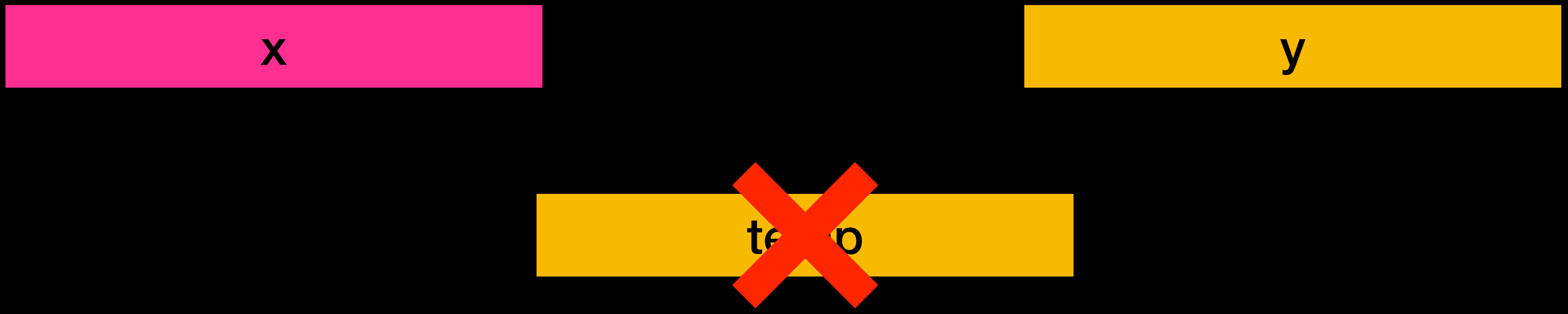
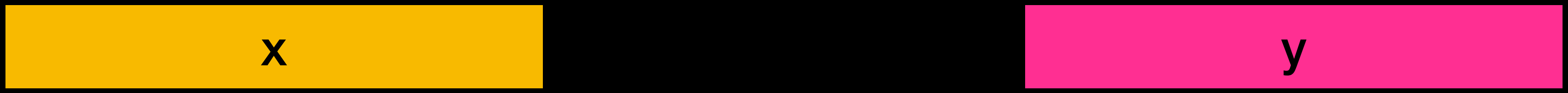


std::swap

```
void swap(vector<string>& x, vector<string>& y)
{
      vector<string> temp{std::move(x)};
      x = std::move(y);
      y = std::move(temp);
}
```



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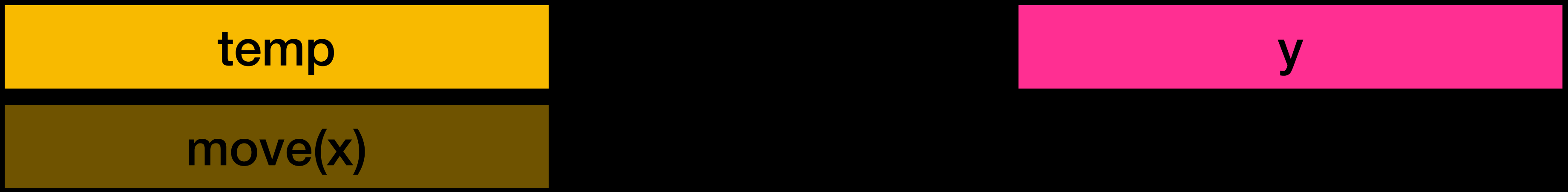

temp

move(x)

y

std::swap

```
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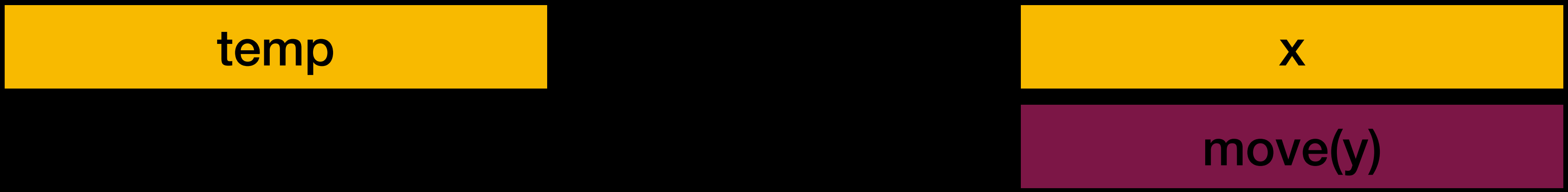
```



temp

x

move(y)

std::swap

```
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{
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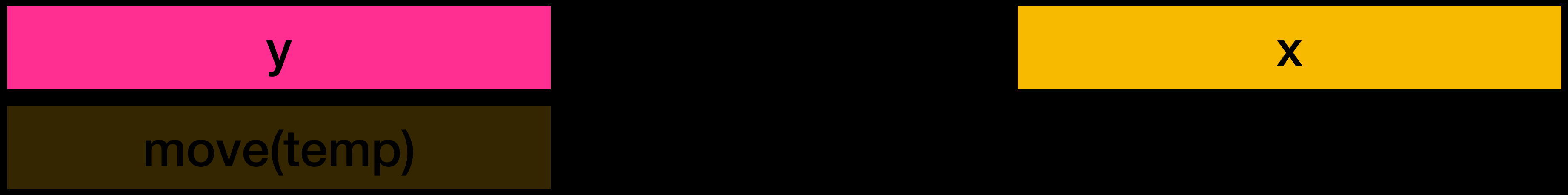

std::swap

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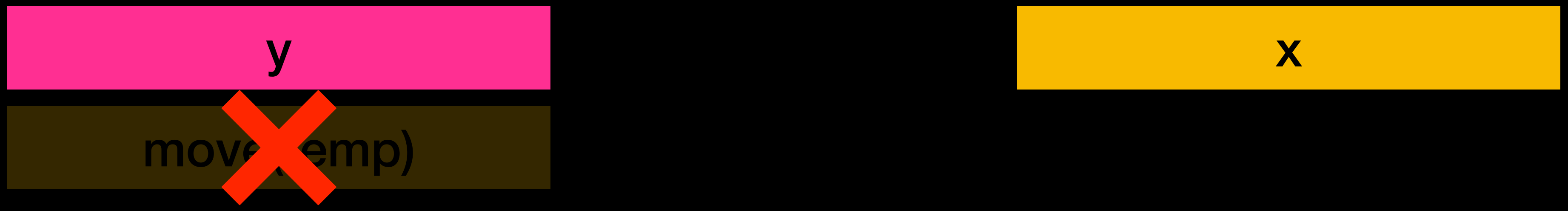

std::swap

Now part of the STL

Can use for any STL type

Example:

```
vector<string> x;
vector<string> y;
//do stuff …

std::swap(x,y);
```

Move Constructor and Assignment

Triggered similarly to copy constructor and assignment operator, but right hand side is rvalue

Explicitly implement move semantics for the class

When defining one should probably define all 5 (Copy constructor, Move constructor, Assignment operator, Move-assignment operator, Destructor)

More in CSci 335

Move Constructor

Implements move semantics instead of copy when:

1. Initialize one object from rvalue

```
MyClass one = rvalue;
```

2. Pass by rvalue reference

rvalue reference

```
void myFunction(MyClass&& arg) {
        /* ... */
}
```

Performs member-wise moves on non-static members of the class

Compiler will NOT generate move constructor if any copy operation is explicitly defined

LinkedBag Implementation

The `move constructor`

A constructor whose parameter is an **rvalue** reference of the same class

rvalue reference

```
#include “LinkedBag.hpp”
template<class T>
LinkedBag<T>::LinkedBag(LinkedBag<T>&& a_bag):
item_count_{a_bag.item_count_},
head_ptr_{a_bag.head_ptr_}
{
   a_bag.item_count_ = 0;
   a_bag.head_ptr_ = nullptr;

}  // end move constructor
```

Move nodes to this bag

No longer points to moved bag

O(1)

```
MyClass one = rvalue;

one = rvalue;
```

LinkedBag Implementation

The `move assignment operator` std::swap is an O(1) operation, swap with **rvalue** which is about to be destructed by the system anyway

rvalue reference

```
#include “LinkedBag.hpp”
template<class T>
void LinkedBag<T>::operator=(LinkedBag<T>&& rhs)
{
   std::swap(item_count_, rhs.item_count_);
   std::swap(head_ptr_, rhs.head_ptr_);

}  // end move assignment operator
```

Swap bags

O(1)

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(LinkedBag<T>&& a_bag);        // Move 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_
```