CSC212
Data Structure

COMPUTER SCIENCE
CITY COLLEGE OF NEW YORK

Lecture 7
Linked Lists

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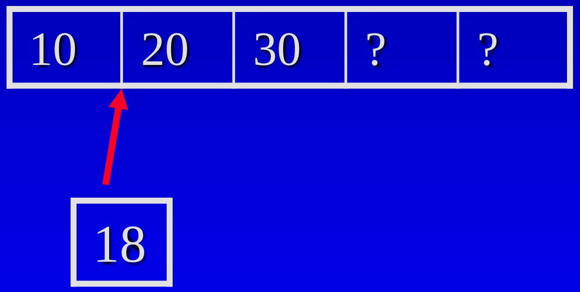
Motivation

- In a sequence using an array, inserting a new item needs to move others back...



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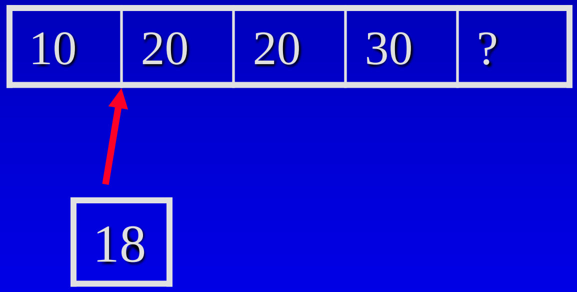


Motivation

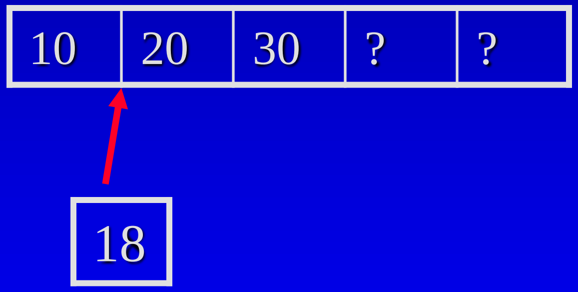
- In a sequence using an array, inserting a new item needs to move others back...

10	18	20	30	?

- So the Big-O of the insert is O(n)

Motivation

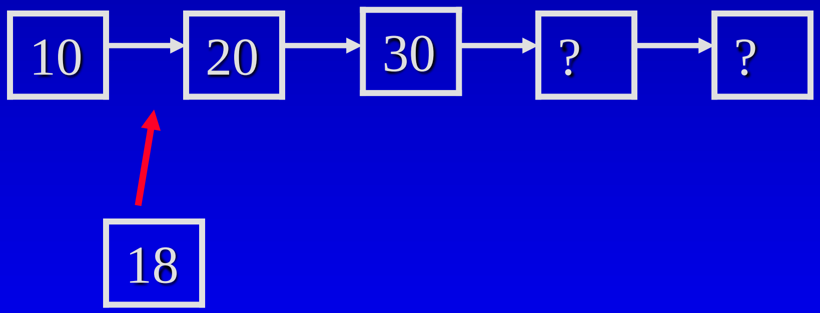
- How can we insert a new item without moving others ?



We need a new data structure

Motivation

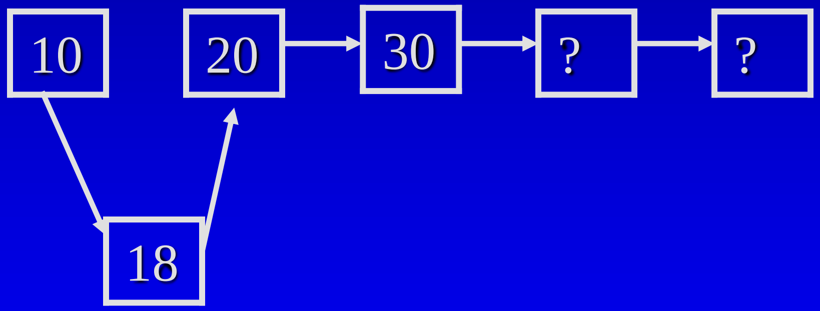
- How can we insert a new item without moving others ?



break an array into a linked chain...

Motivation

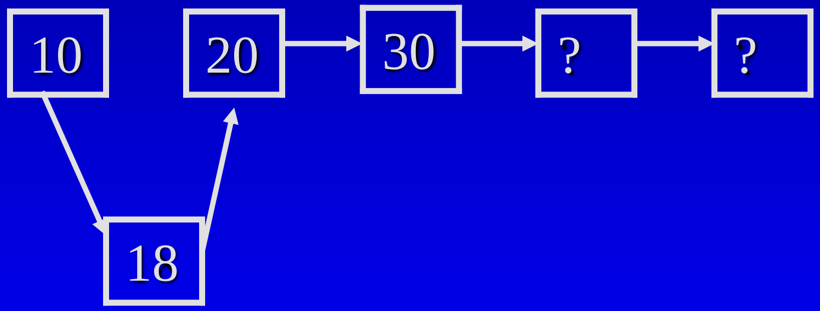
- How can we insert a new item without moving others ?



and then put the new item into the chain

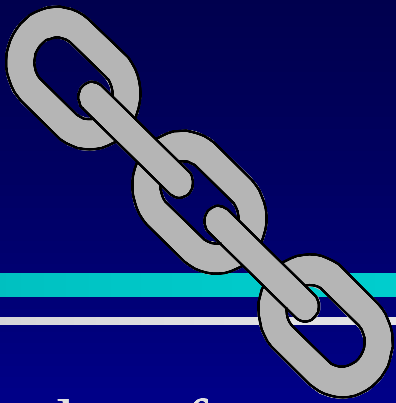
Motivation

- How can we insert a new item without moving others ?

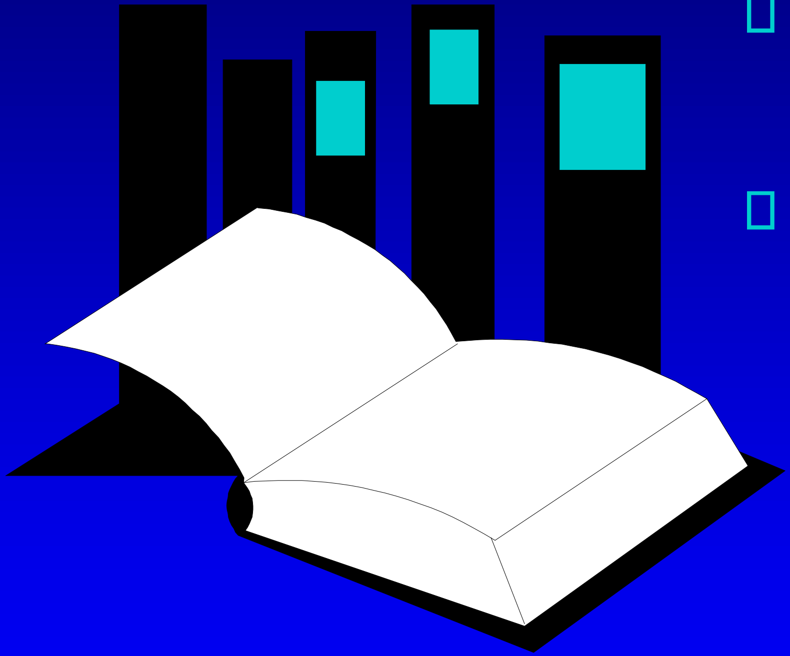


But the links (->) need some way to build up

Linked Lists in Action



- Chapter 5 introduces the often-used data structure of linked lists.
- This presentation shows how to implement the most common operations on linked lists.



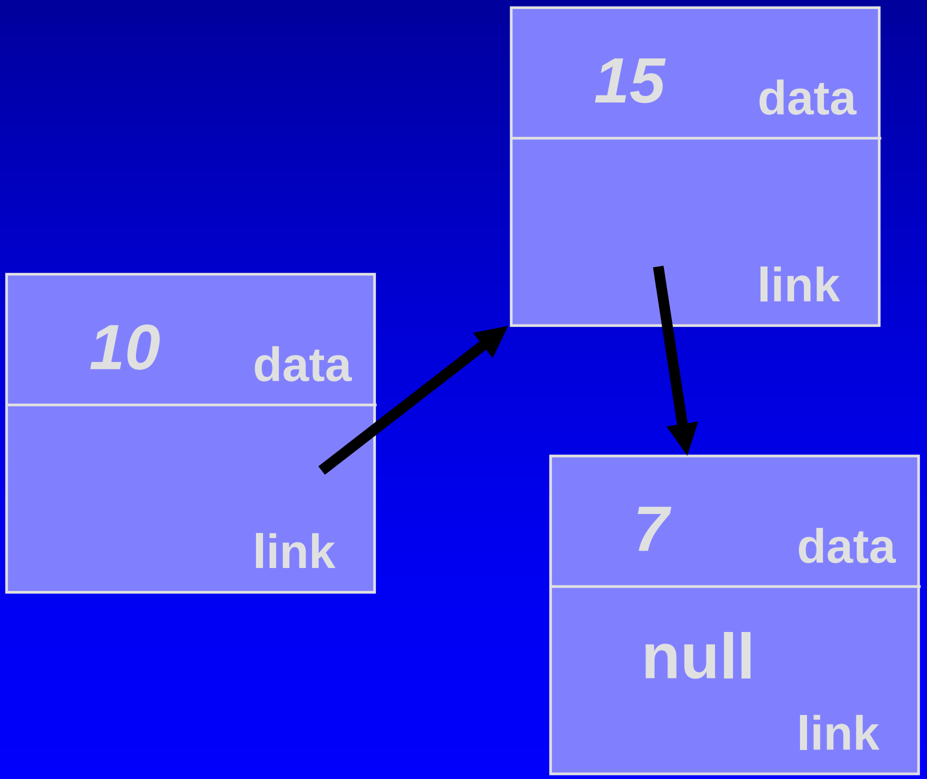
CHAPTER 5

Data Structures and Other Objects

Declarations for Linked Lists

- Each node in the linked list is a class, as shown here.

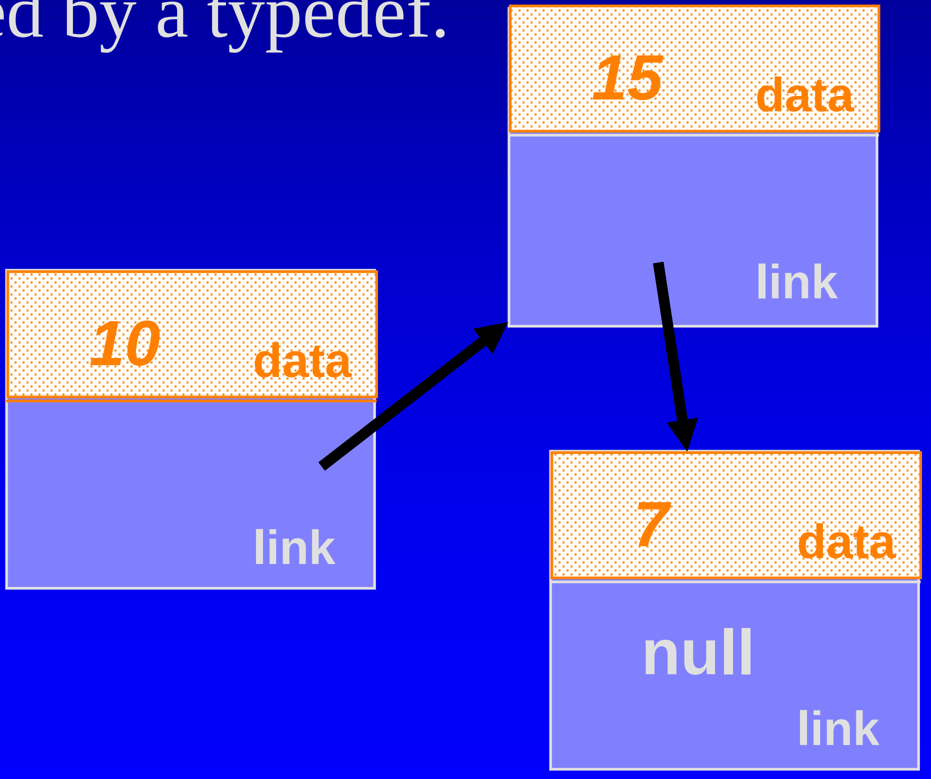
```
class node
{
public:
    typedef int value_type;
    ...
private:
    value_type data;
    node *link;
};
```



Declarations for Linked Lists

- The data portion of each node is a type called **value_type**, defined by a typedef.

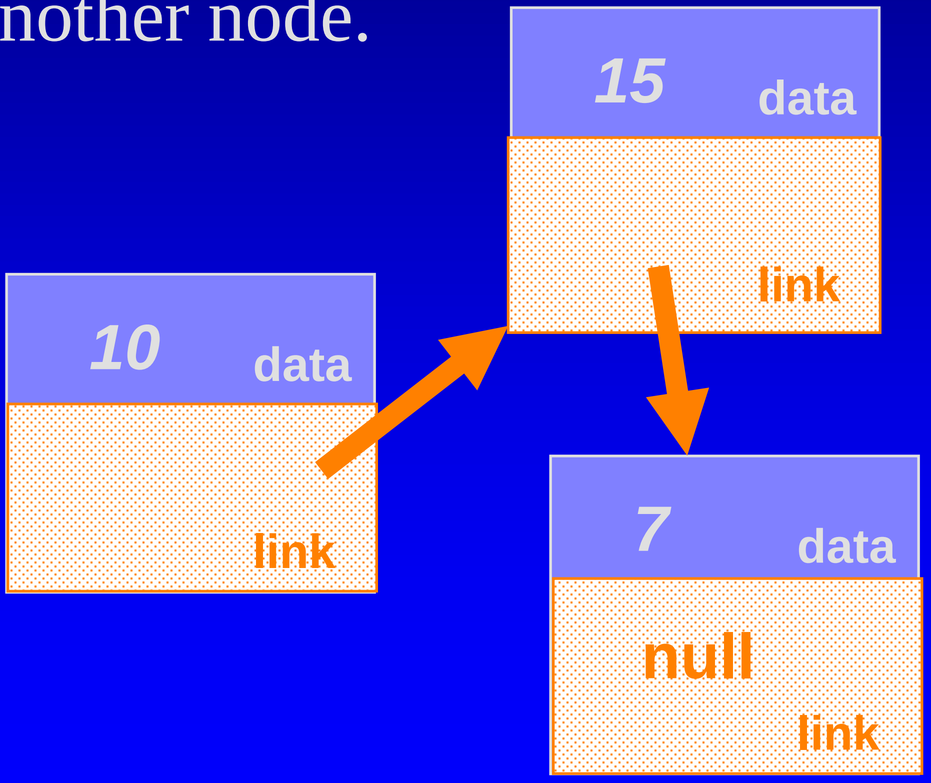
```
class node
{
public:
    typedef int value_type;
    ...
private:
    value_type data;
    node *link;
};
```



Declarations for Linked Lists

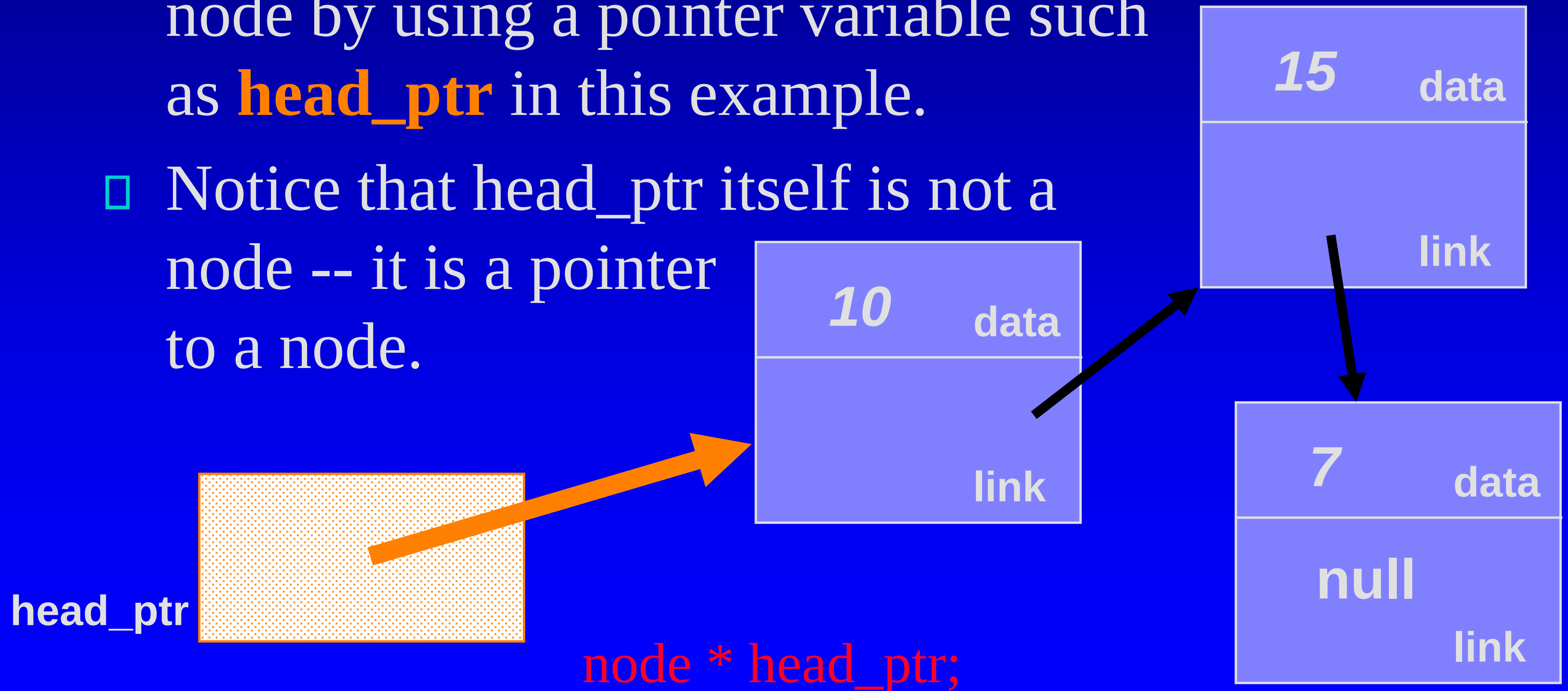
- Each node also contains a link field which is a pointer to another node.

```
class node
{
public:
    typedef int value_type;
    ...
private:
    value_type data;
    node *link;
};
```



Declarations for Linked Lists

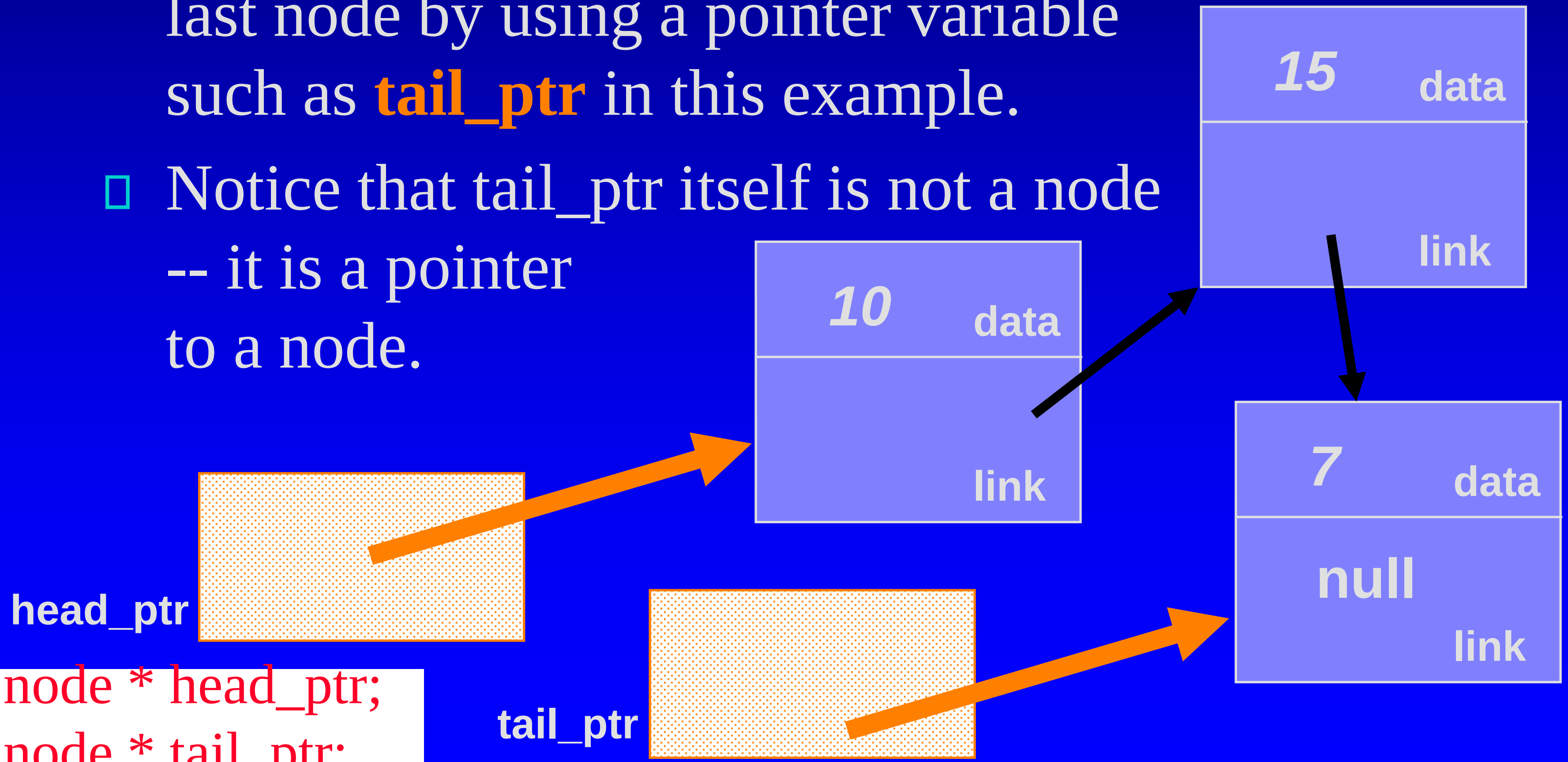
- A program can keep track of the first node by using a pointer variable such as **head_ptr** in this example.
- Notice that head_ptr itself is not a node -- it is a pointer to a node.



node * head_ptr;

Declarations for Linked Lists

- A program can also keep track of the last node by using a pointer variable such as **tail_ptr** in this example.
- Notice that tail_ptr itself is not a node -- it is a pointer to a node.




```
node * head_ptr;
node * tail_ptr;
```

Declarations for Linked Lists

- A program can keep track of the first and the last nodes by using pointer variables such as **head_ptr, tail_ptr**.
- Notice that neither head_ptr nor tail_ptr is a node -- it is a pointer to a node.
- For an empty list, **null** ***is stored*** in both the head and the tail pointers.

```
node * head_ptr;
node * tail_ptr;
head_ptr = NULL;
tail_ptr = NULL;
// NULL can be
used for any
pointers!
```

head_ptr null

tail_ptr null

The Complete node Class Definition

- The node class is fundamental to linked lists
- The private member variables
  - data: a value_type variable
  - link: a pointer to the next node
- The member functions include:
  - A constructor
  - Set data and set link
  - Retrieve data and retrieve link

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- The n
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  - dat
  - link
- The n
  - A c
  - Set
  - Ret

```
class node
  {
  public:
          // TYPEDEF
          typedef double value_type;

          // CONSTRUCTOR
          node(
             const value_type& init_data = value_type( ),
             node* init_link = NULL
          )
          { data = init_data; link = init_link; }

          // Member functions to set the data and link fields:
          void set_data(const value_type& new_data) { data = new_data; }
          void set_link(node* new_link)          { link = new_link; }

          // Constant member function to retrieve the current data:
          value_type data( ) const { return data; }

          // Two slightly different member functions to retrieve
          // the current link:
          const node* link( ) const { return link; }
          node* link( )           { return link;}

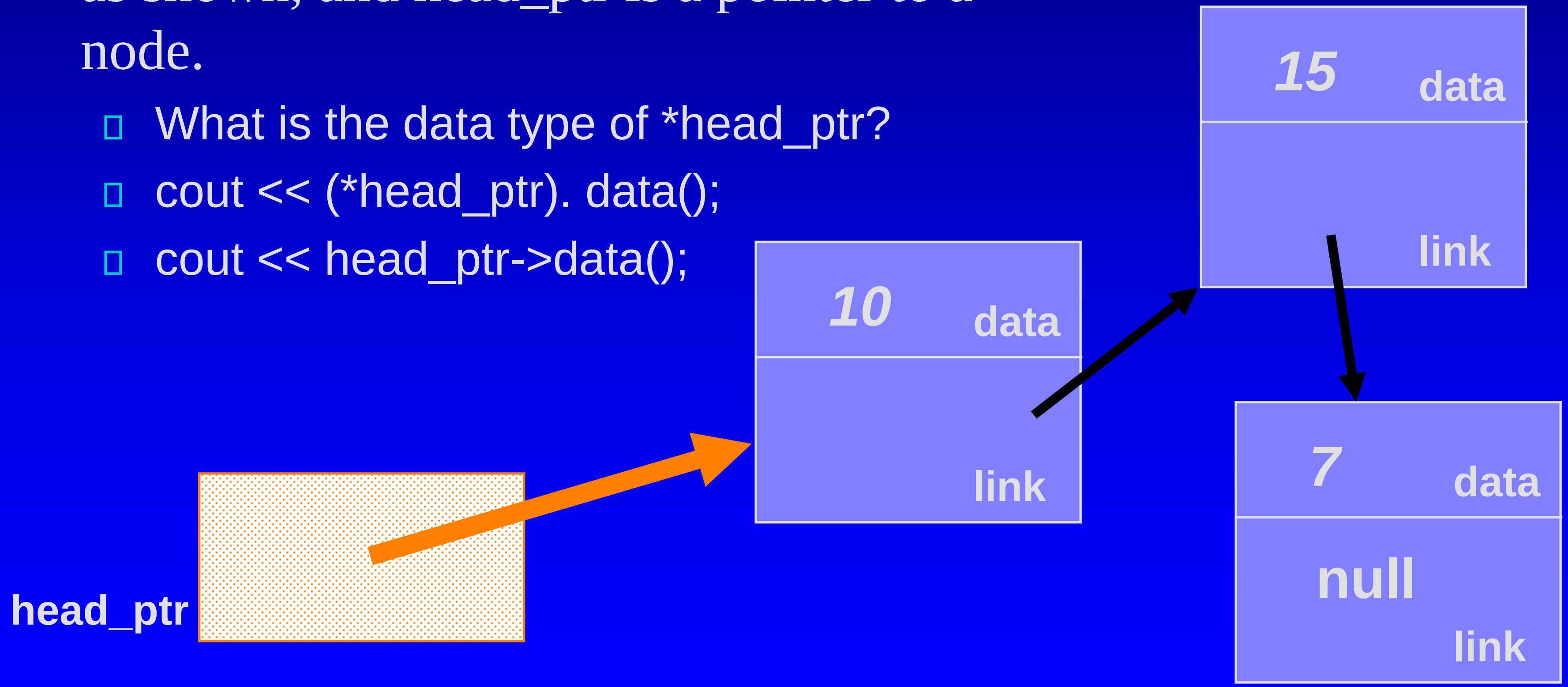
  private:
          value_type data;
          node* link;
  };
```

default argument given by the value_type default constructor

Why TWO? p. 213-4

A Small Quiz -

- Suppose a program has built the linked list as shown, and head_ptr is a pointer to a node.
  - What is the data type of *head_ptr?
  - cout << (*head_ptr). data();
  - cout << head_ptr->data();



Linked List Toolkit

- Design Container Classes using Linked Lists
  - The use of a linked list is similar to our previous use of an array in a container class
  - But storing and retrieving needs more work since we do not have that handy indexing
- => Linked List Toolbox
  - using node class

The Workings of four functions

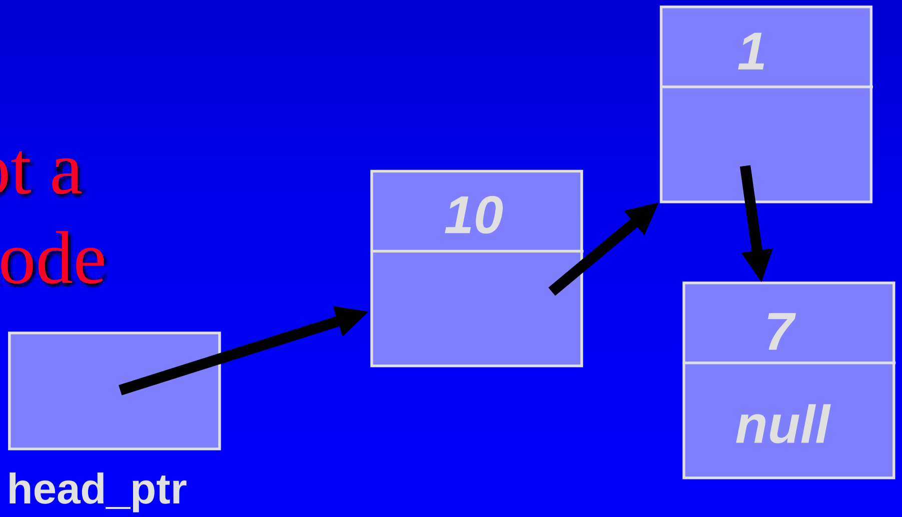
- This lecture will show four functions:
  - Compute the length of a linked list (code)
  - Insert a new node at the head (code)
  - Insert a node at any location (pseudo-code)
  - Delete a node from the head (pseudo-code)
- Read Section 5.2 for other functions in the Toolbox
  - will be used in container classes bag and sequence

Length of a Linked List

```
size_t list_length(const node* head_ptr);
```

We simply want to compute the **length** of the linked list, for example the one shown here.

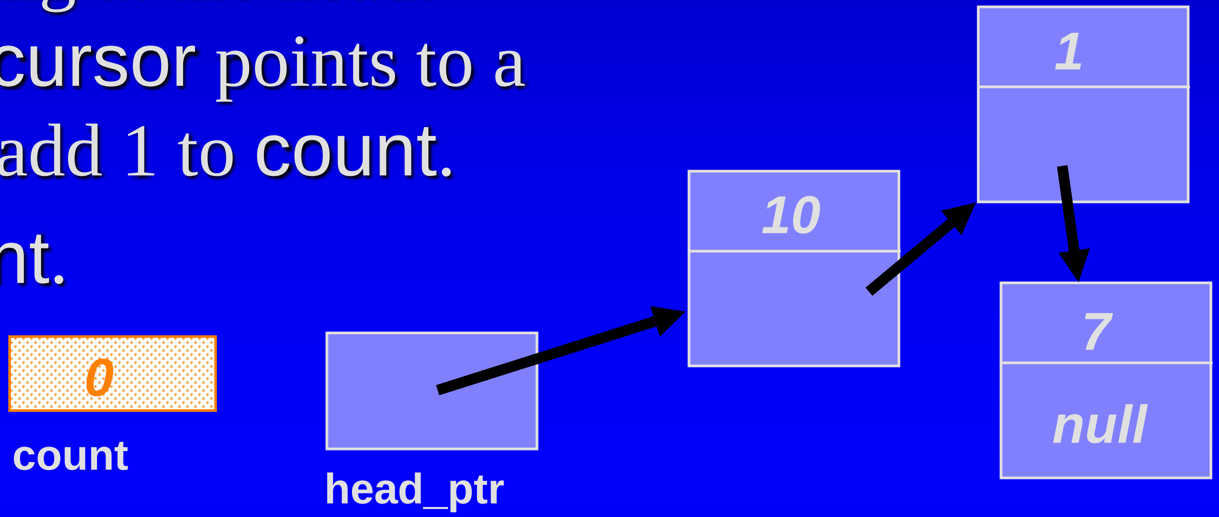
Note that list_length is not a member function of the node class



Pseudo-code of list_length

```
size_t list_length(const node* head_ptr);
```

1. Initialize the count to zero.
2. Make cursor point to each node, starting at the head. Each time cursor points to a new node, add 1 to count.
3. return count.



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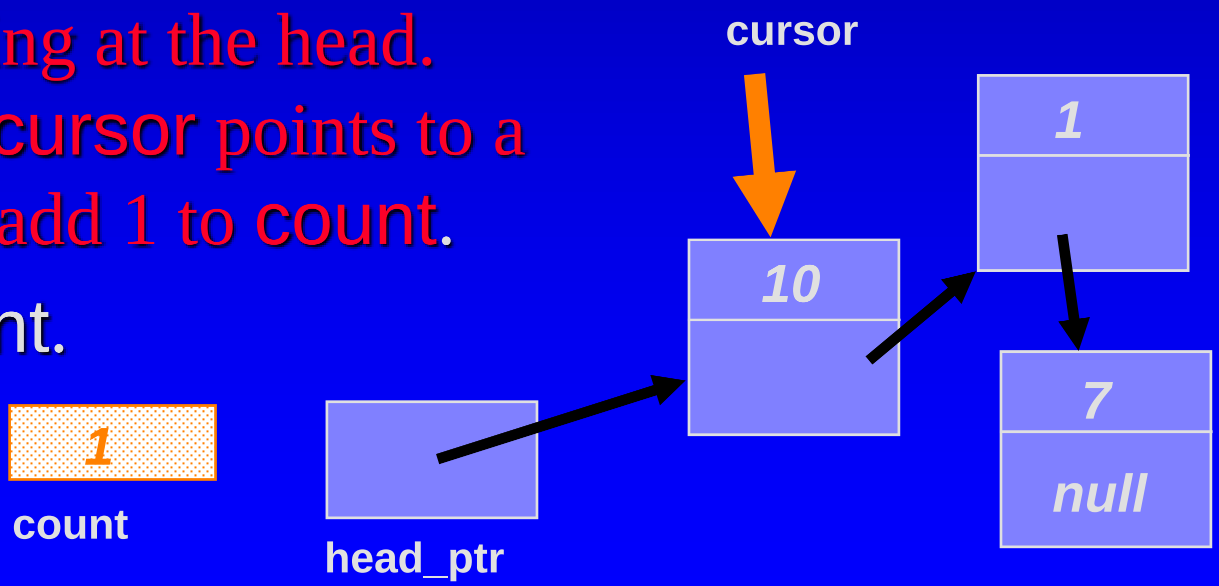

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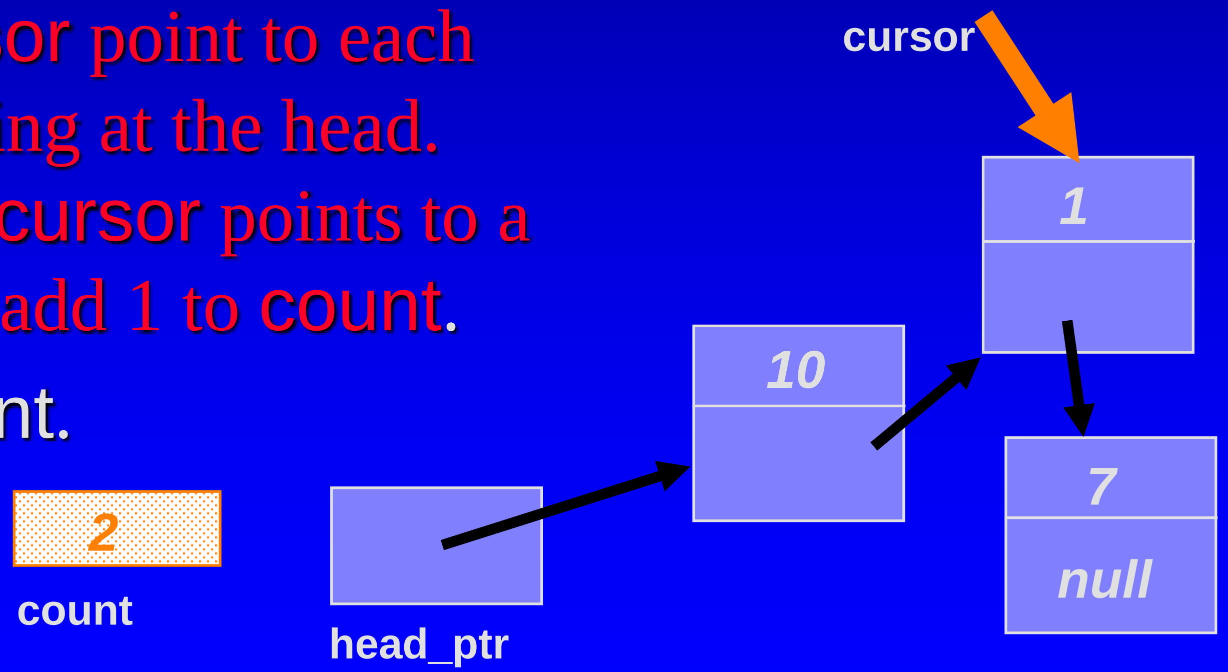

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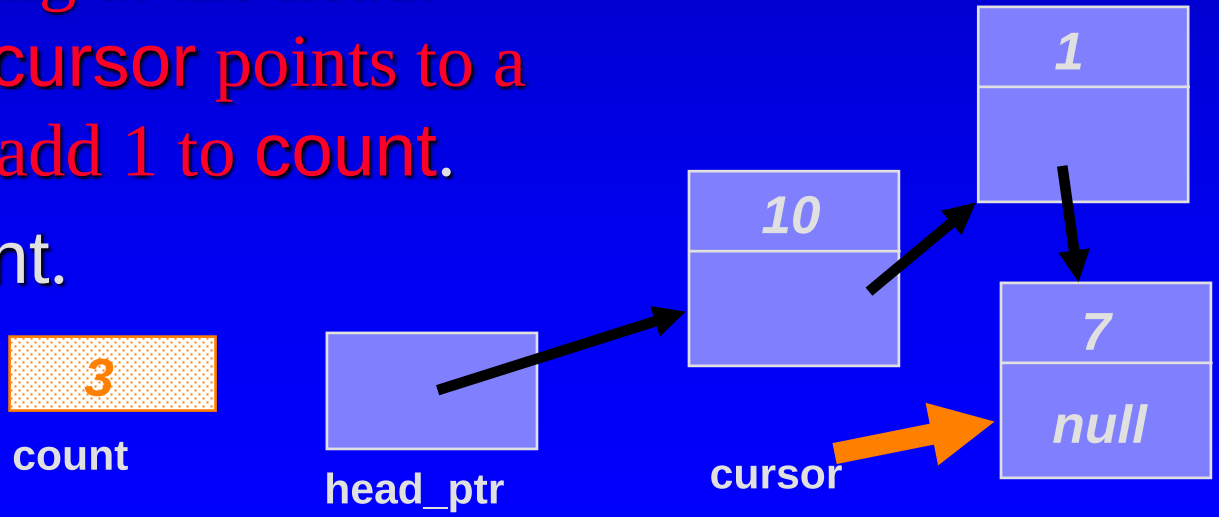

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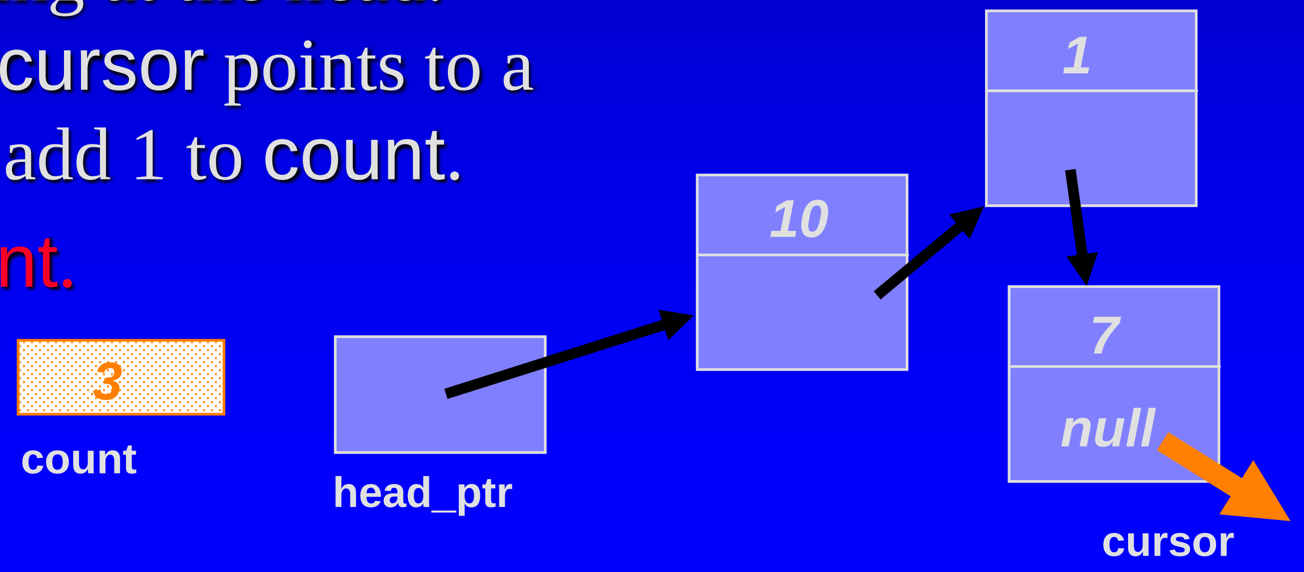

Real code of list_length: List Traverse

```
size_t list_length(const node* head_ptr)
{
    const node *cursor;
    size_t count = 0;  // step 1
    for (cursor = head_ptr; cursor != NULL; cursor = cursor->link())
            count++;   // step 2
    return count;  // step 3
}
```

1. Initialize the count to zero.
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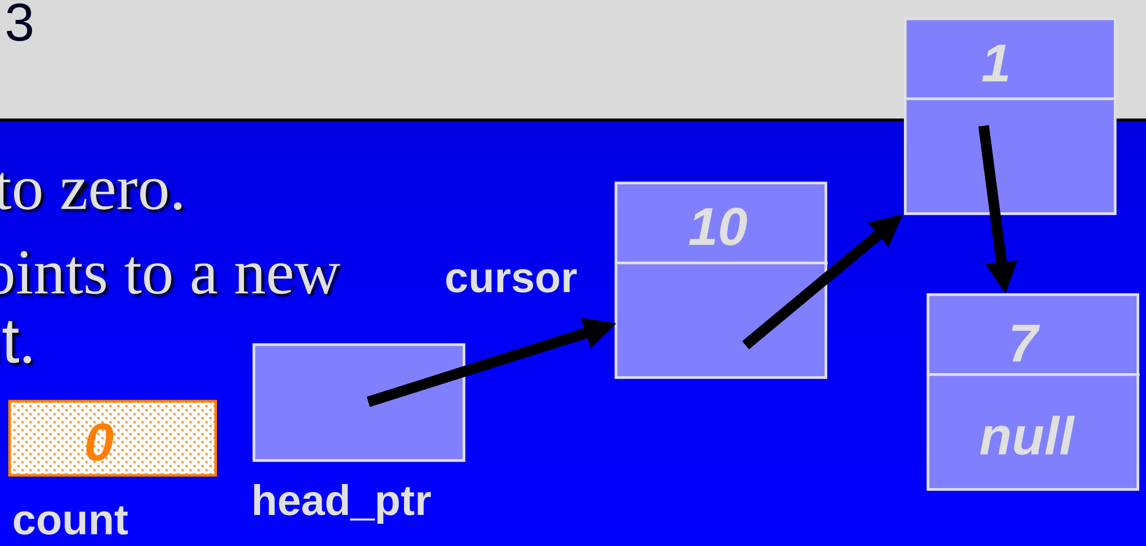

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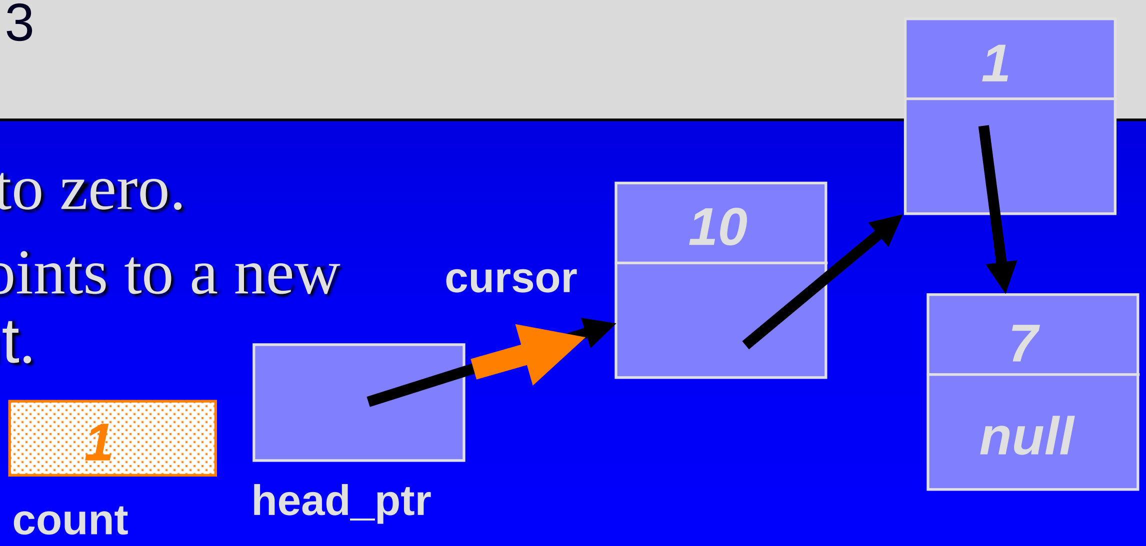

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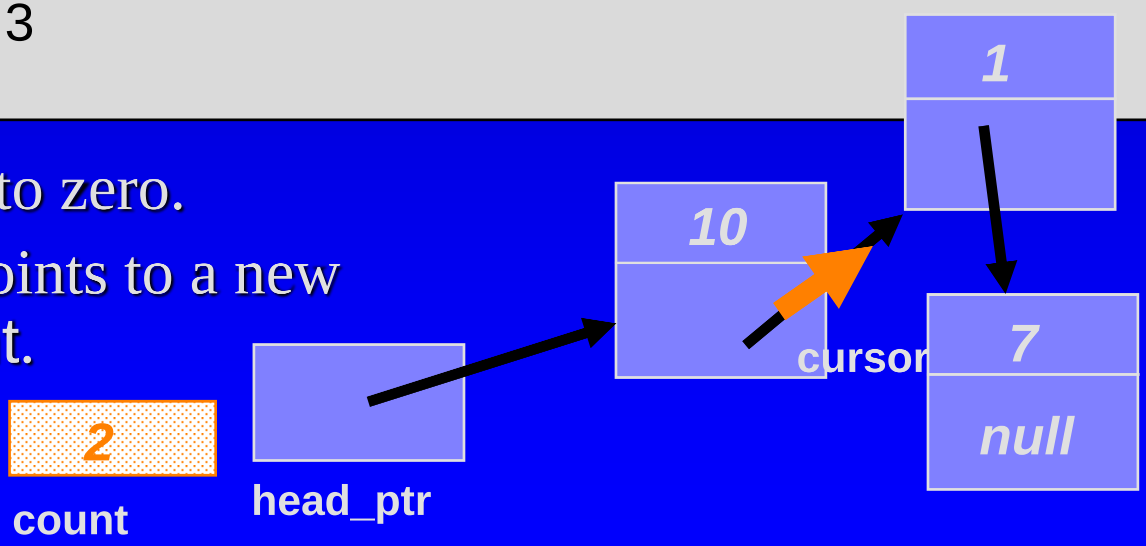

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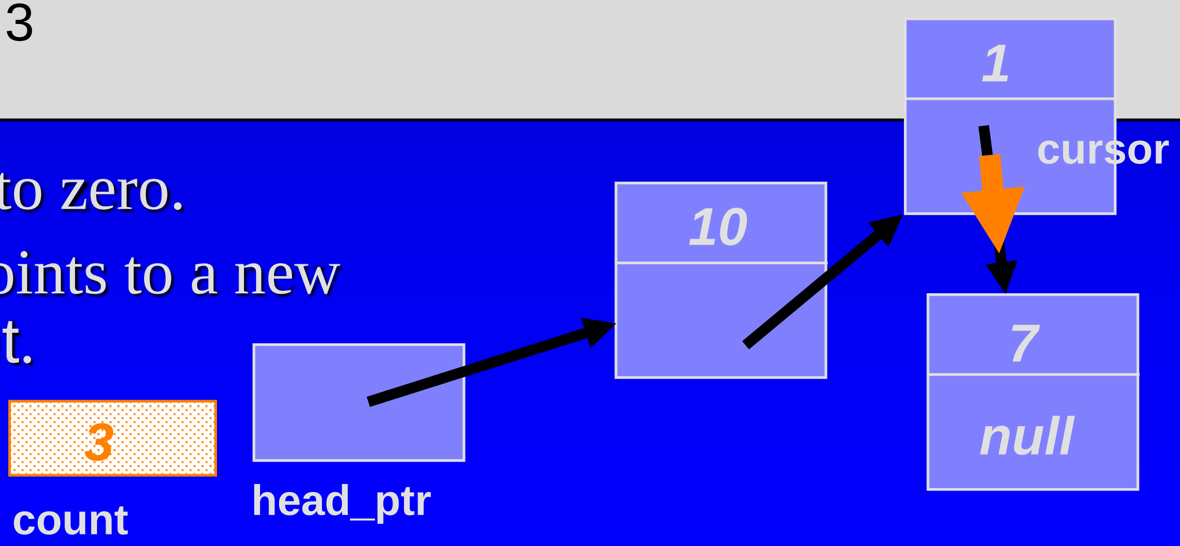
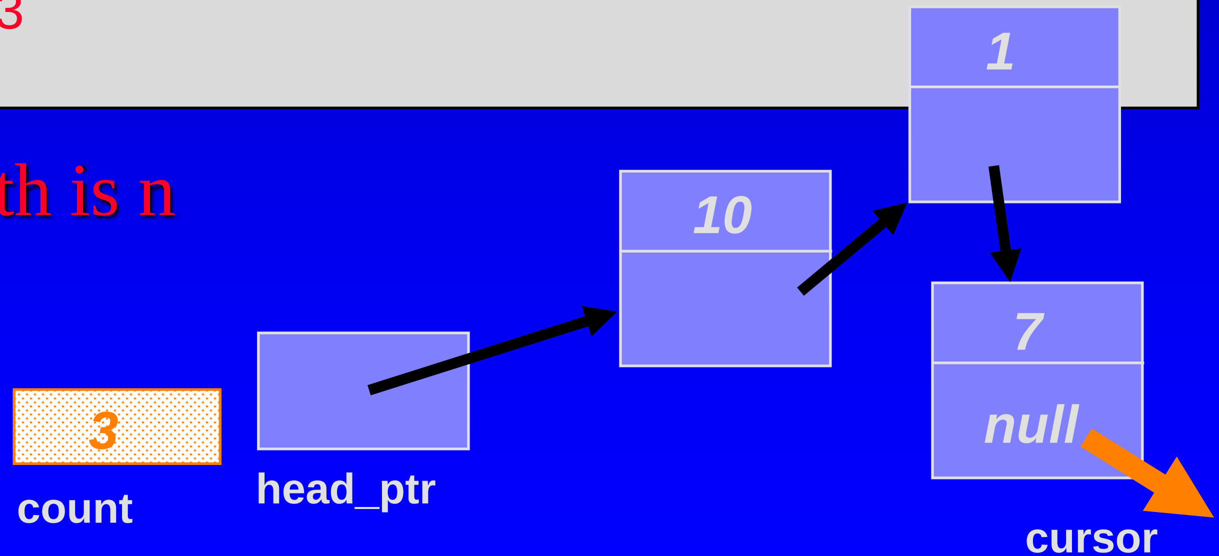


Big-O of list_length

```
size_t list_length(const node* head_ptr)
{
    const node *cursor;
    size_t count = 0;
    for (cursor = head_ptr; cursor != NULL; cursor = cursor->link())
            count++;
    return count; // step 3
}
```

Big-O: O (n) if length is n

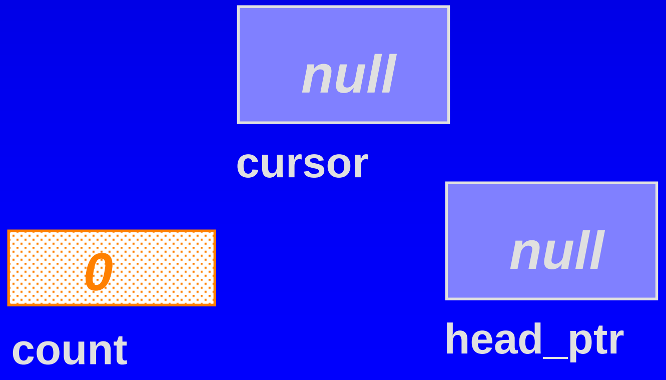


Does list_length work for an empty list?

```
size_t list_length(const node* head_ptr)
{
    const node *cursor;
    size_t count = 0;
    for (cursor = head_ptr; cursor != NULL; cursor = cursor->link())
            count++;
    return count;
}
```

cursor = head_ptr = NULL

count = 0



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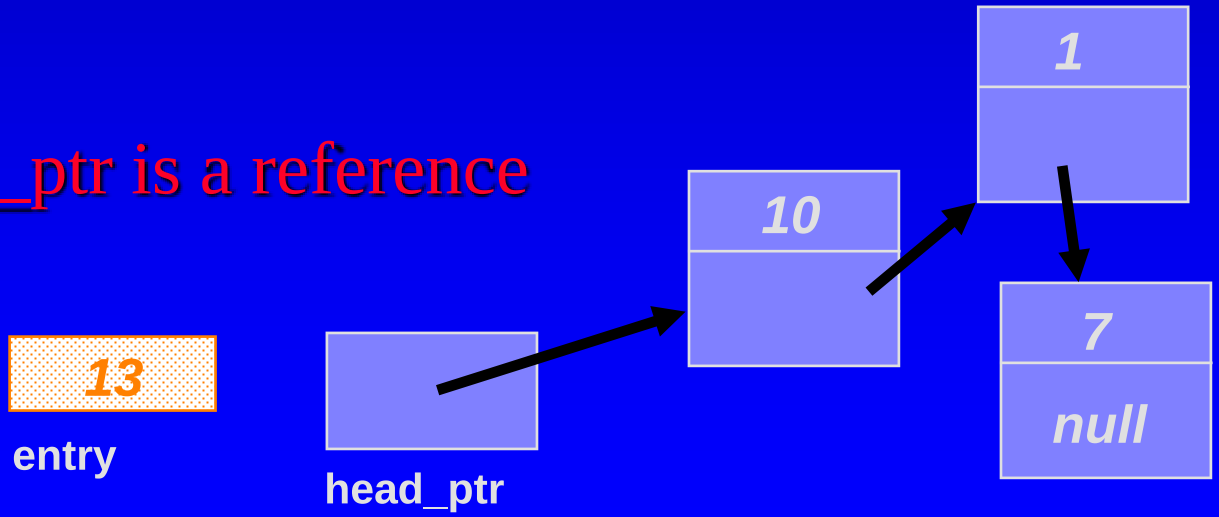
  - will be used in container classes bag and sequence

Inserting a node at the Head

```
void list_head_insert(node*& head_ptr, const node::value_type& entry);
```

We want to add a new entry, 13, to the **head** of the linked list shown here.

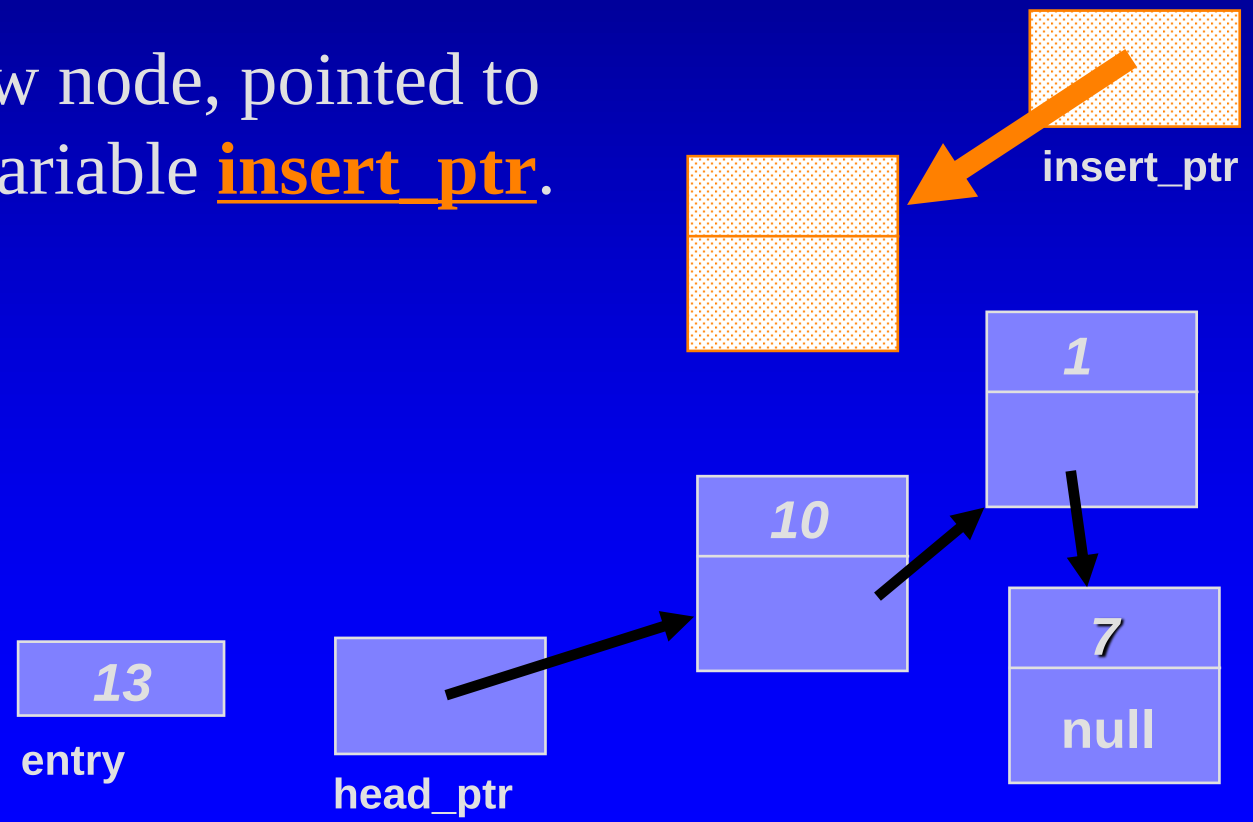
Note that head_ptr is a reference node pointer



Inserting a Node at the Head

```
void list_head_insert(node*& head_ptr, const node::value_type& entry);
```

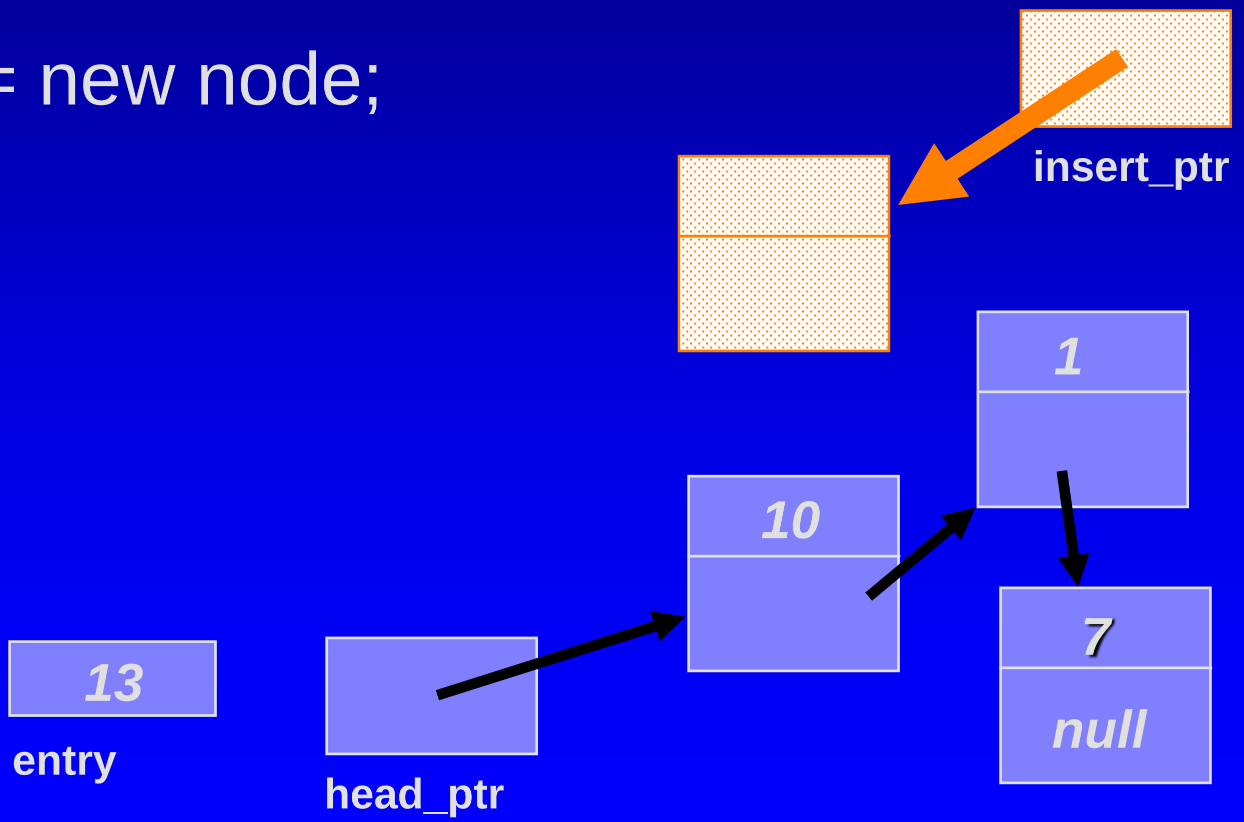
- Create a new node, pointed to by a local variable **insert_ptr**.



Inserting a Node at the Head

```
void list_head_insert(node*& head_ptr, const node::value_type& entry);
```

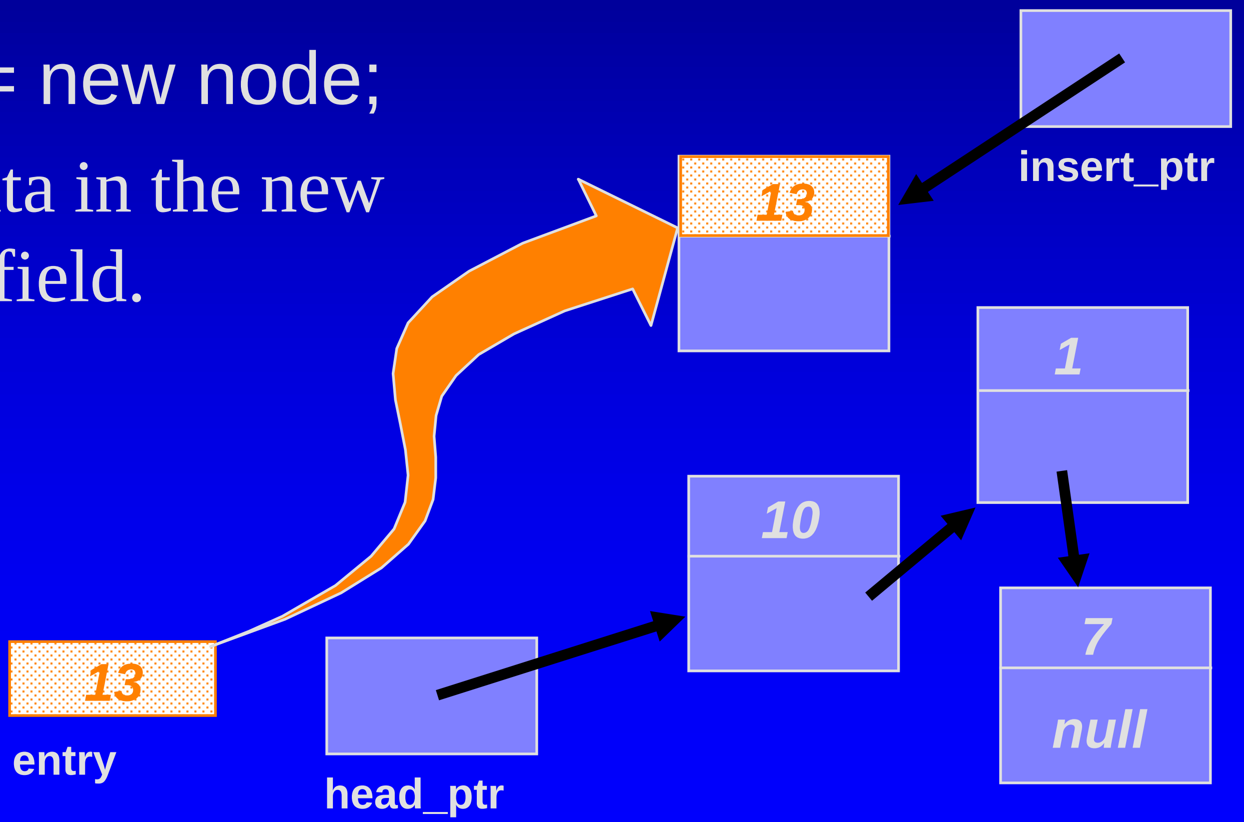
- insert_ptr = new node;



Inserting a Node at the Head

```
void list_head_insert(node*& head_ptr, const node::value_type& entry);
```

- insert_ptr = new node;
- Place the data in the new node's data field.

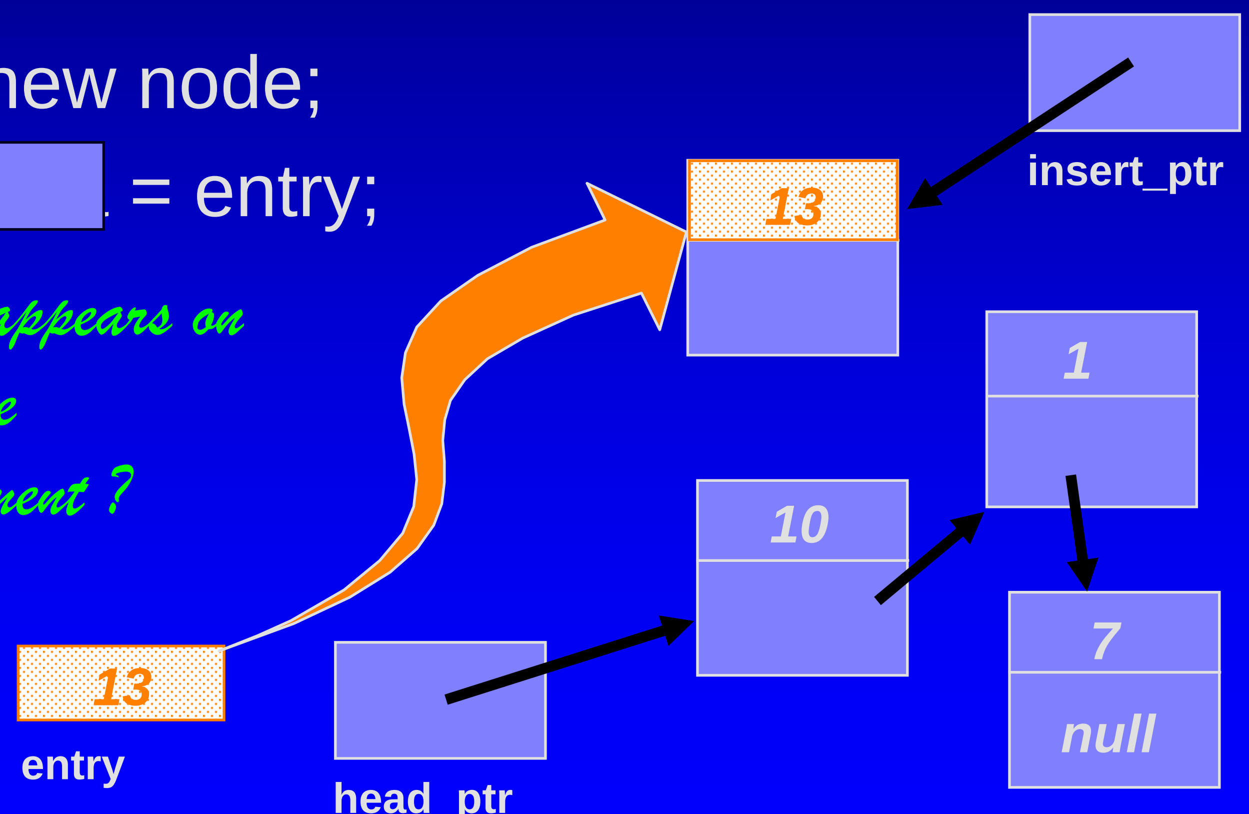


Inserting a Node at the Head

void list_head_insert(node*& head_ptr, const node::value_type& entry);

- insert_ptr = new node;
- ? = entry;

What expression appears on the left side of the assignment statement ?

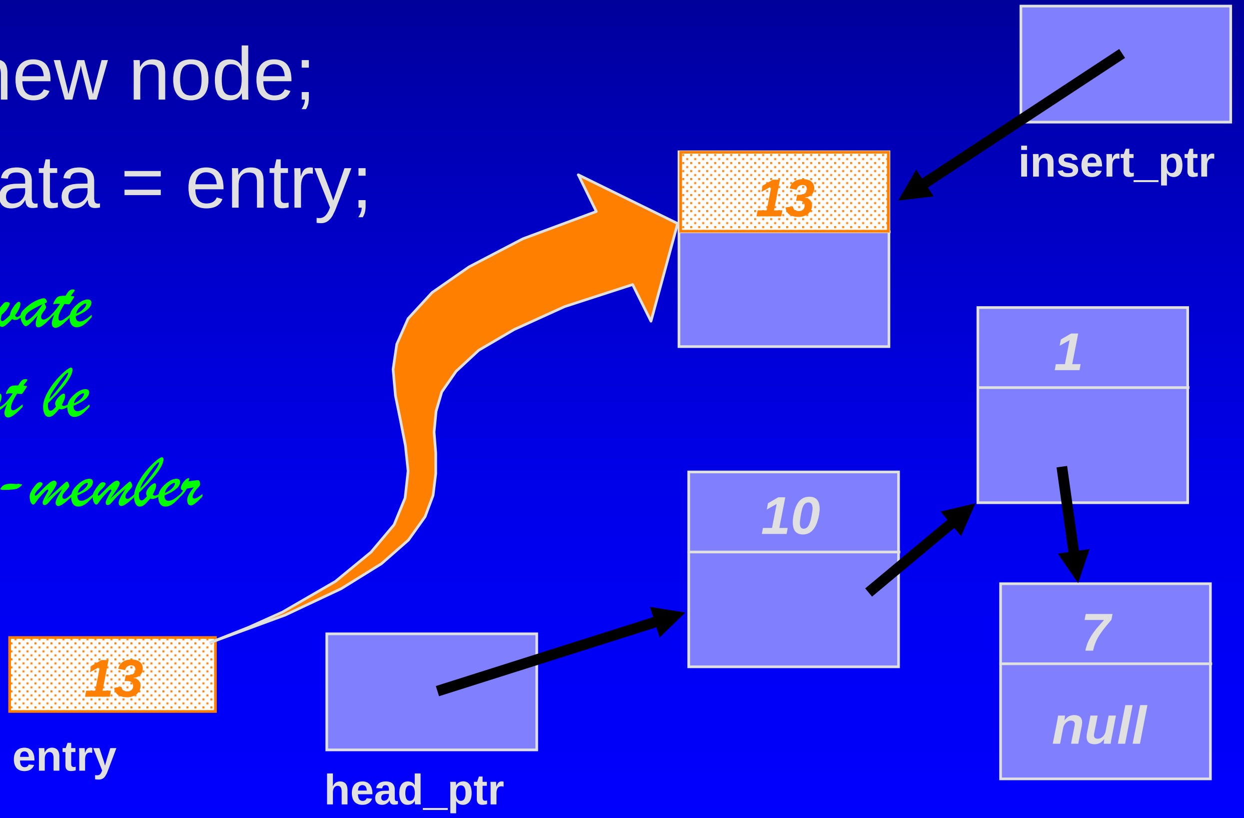


Inserting a Node at the Head

```
void list_head_insert(node*& head_ptr, const node::value_type& entry);
```

- insert_ptr = new node;
- insert_ptr->data = entry;

But data is a private variable, so cannot be accessed by a non-member function



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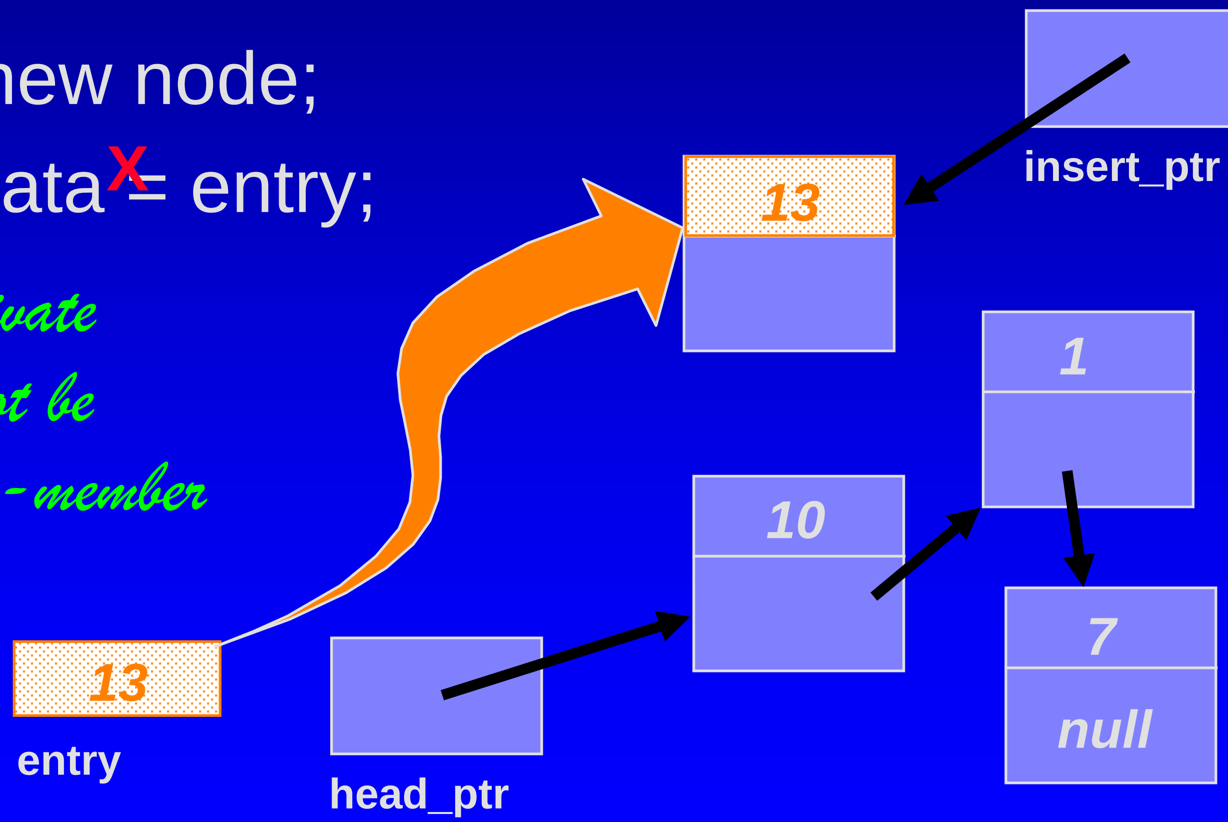
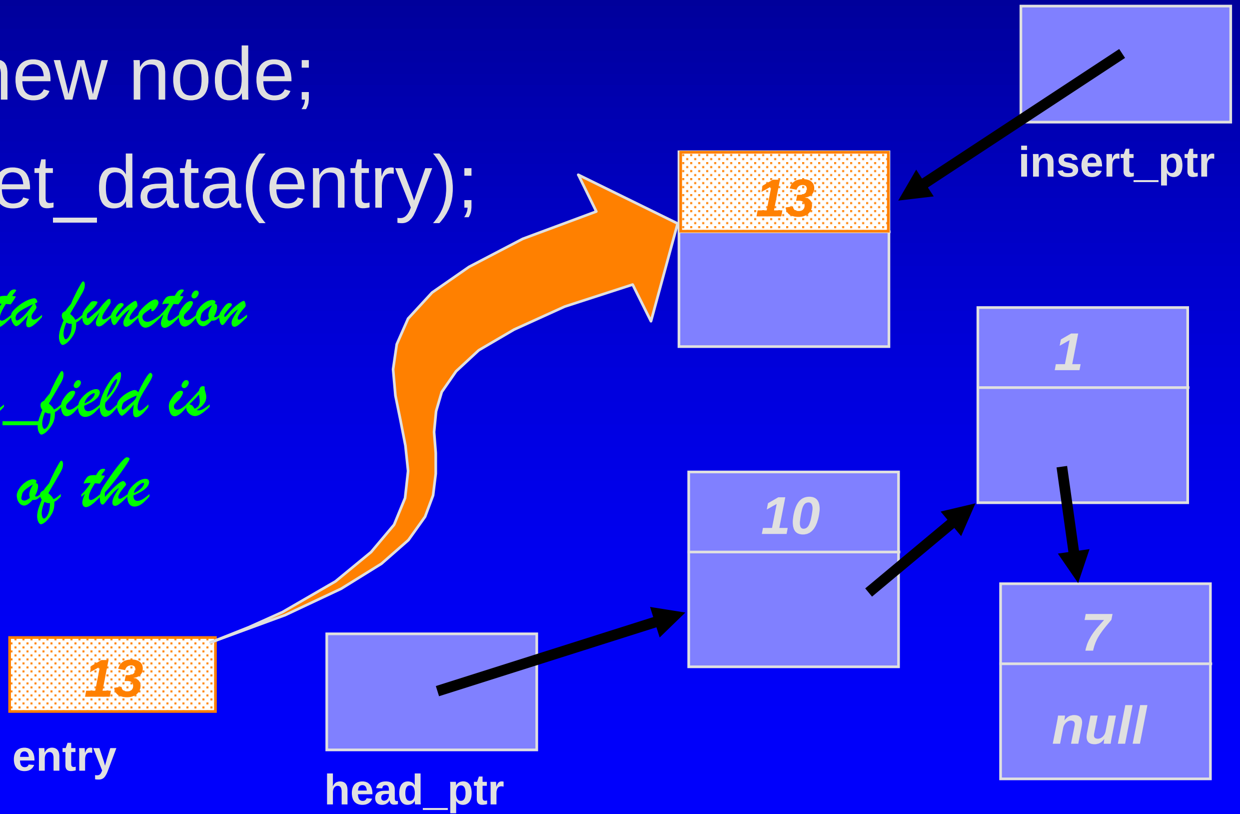


Inserting a Node at the Head

```
void list_head_insert(node*& head_ptr, const node::value_type& entry);
```

- insert_ptr = new node;
- insert_ptr->set_data(entry);

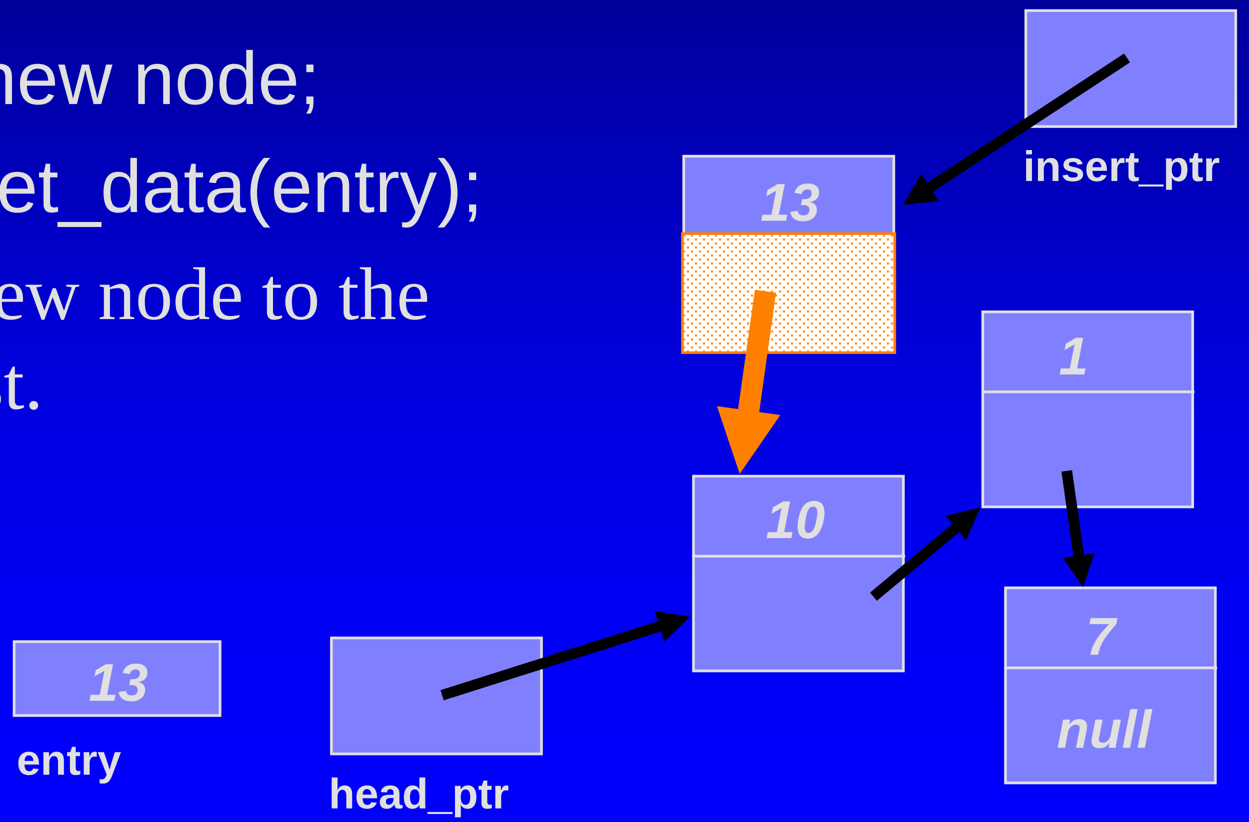
Instead, Set_data function is used since data_field is a private variable of the node class



Inserting a Node at the Head

```
void list_head_insert(node*& head_ptr, const node::value_type& entry);
```

- insert_ptr = new node;
- insert_ptr->set_data(entry);
- Connect the new node to the front of the list.

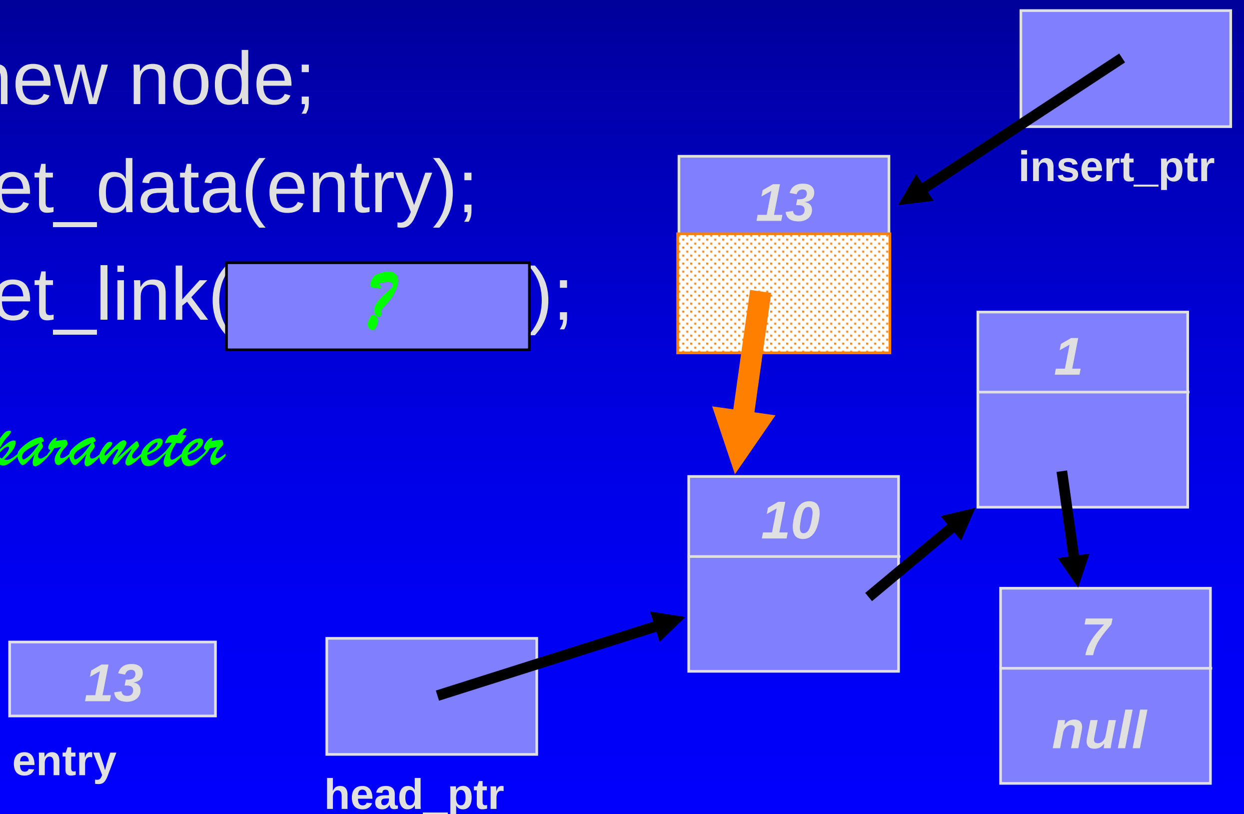


Inserting a Node at the Head

```
void list_head_insert(node*& head_ptr, const node::value_type& entry);
```

- insert_ptr = new node;
- insert_ptr->set_data(entry);
- insert_ptr->set_link(?);

What will be the parameter ?

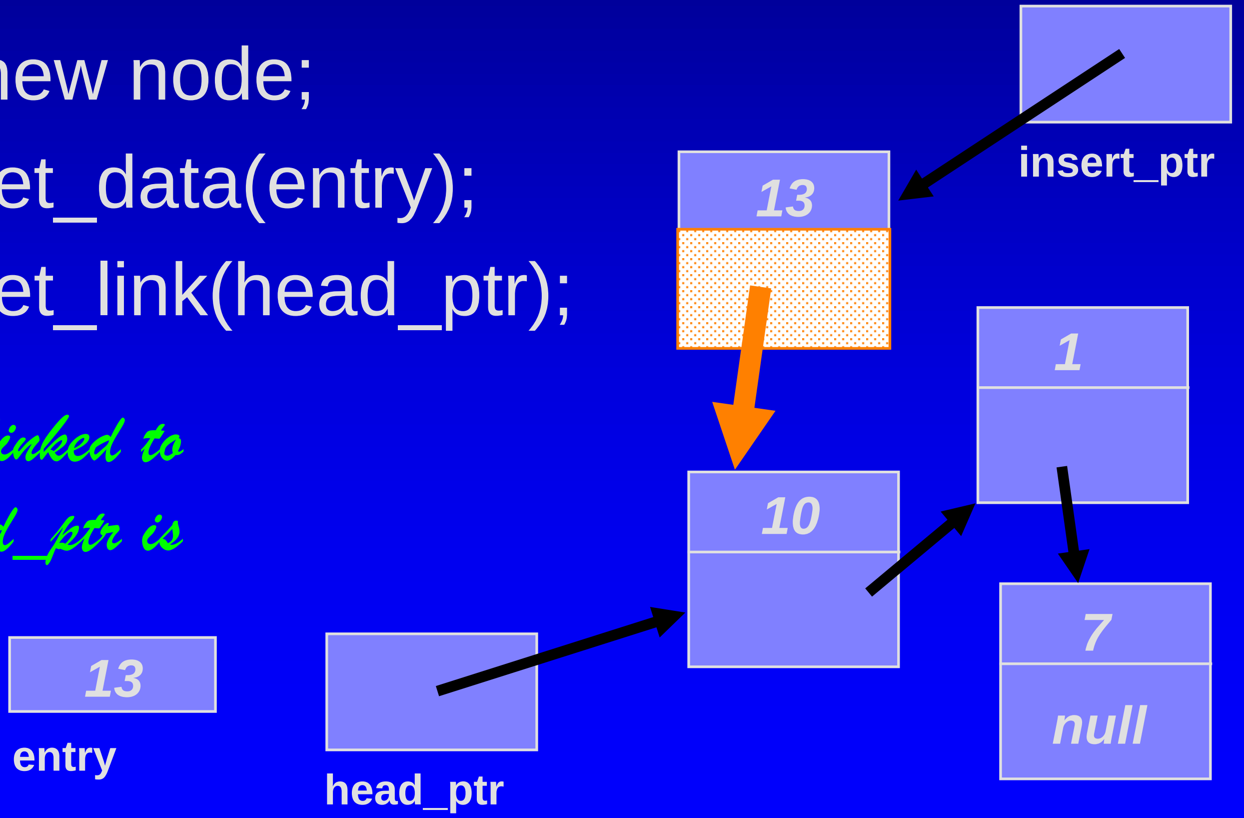


Inserting a Node at the Head

void list_head_insert(node*& head_ptr, const node::value_type& entry);

- insert_ptr = new node;
- insert_ptr->set_data(entry);
- insert_ptr->set_link(head_ptr);

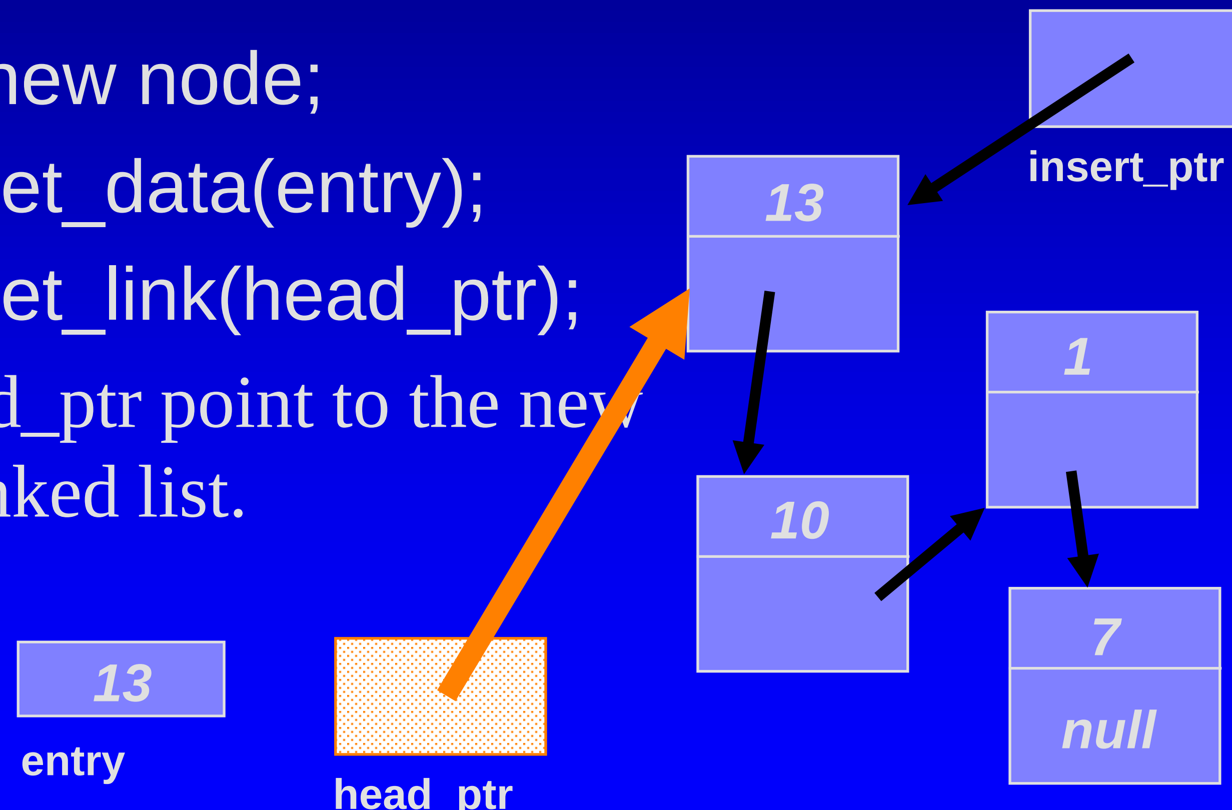
The new node is linked to the node that head_ptr is pointing to.



Inserting a Node at the Head

```
void list_head_insert(node*& head_ptr, const node::value_type& entry);
```

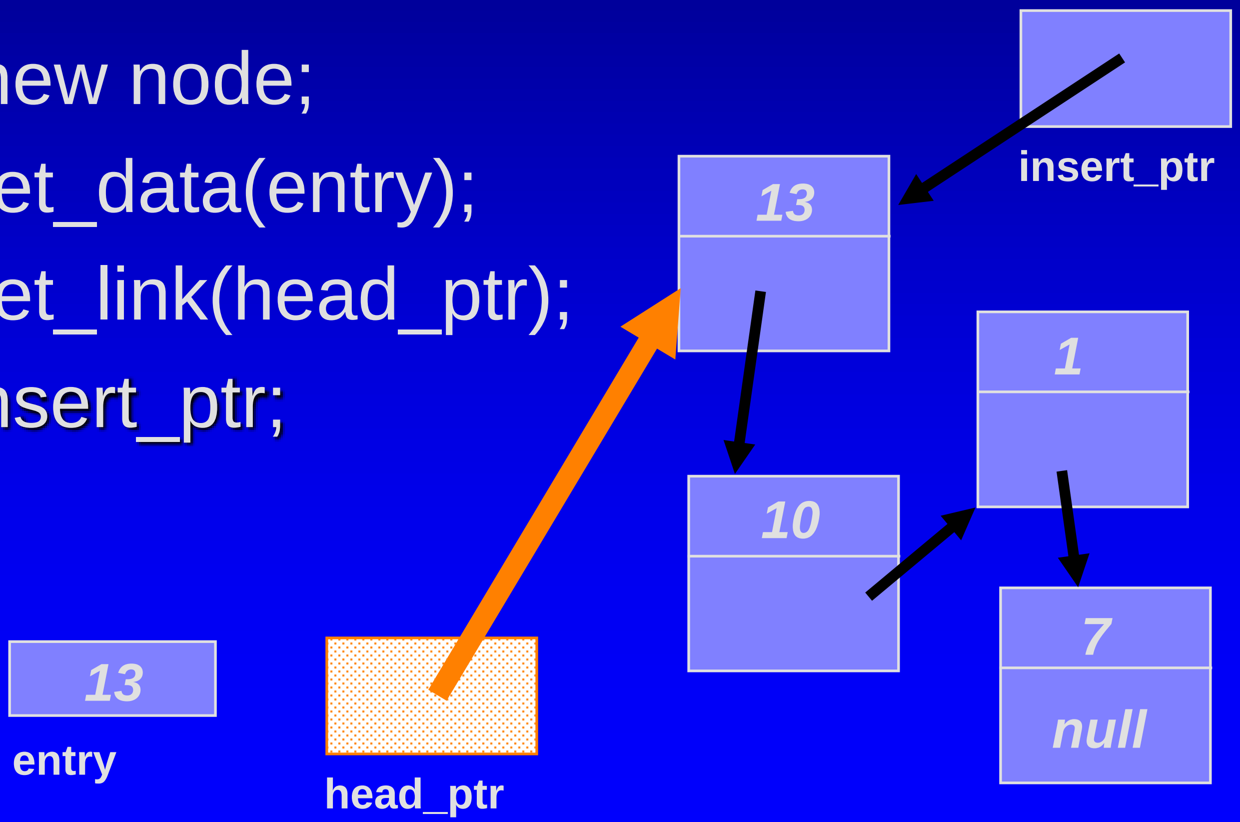
- insert_ptr = new node;
- insert_ptr->set_data(entry);
- insert_ptr->set_link(head_ptr);
- Make the head_ptr point to the new head of the linked list.



Inserting a Node at the Head

```
void list_head_insert(node*& head_ptr, const node::value_type& entry);
```

- insert_ptr = new node;
- insert_ptr->set_data(entry);
- insert_ptr->set_link(head_ptr);
- head_ptr = insert_ptr;



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void list_head_insert(node*& head_ptr, const node::value_type& entry);
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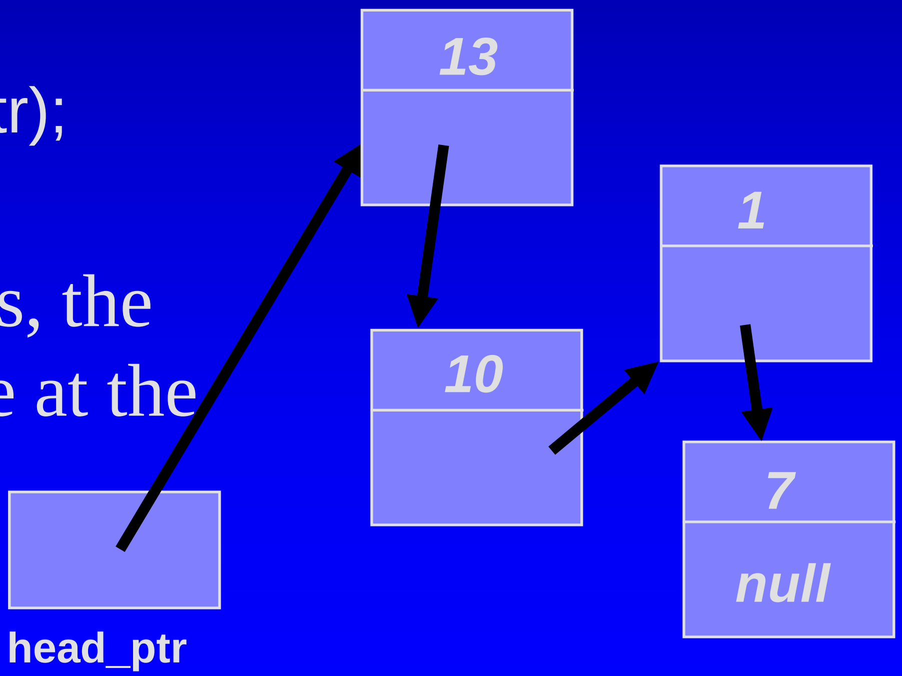
- insert_ptr = new node;
- insert_ptr->set_data(entry);
- insert_ptr->set_link(head_ptr);
- head_ptr = insert_ptr;

When the function returns, the linked list has a new node at the head, containing 13.



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void list_head_insert(node*& head_ptr, const node::value_type& entry)
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    insert_ptr->set_data(entry);
    insert_ptr->set_link(head_ptr);
    head_ptr = insert_ptr;
}
```

What is the Big-O of

the head_insert function?

Linked List: O(1)

- cmp: Array: O(n)

Inserting a Node at the Head

```
void list_head_insert(node*& head_ptr, const node::value_type& entry)
{
    node *insert_ptr;

    insert_ptr = new node;
    insert_ptr->set_data(entry);
    insert_ptr->set_link(head_ptr);
    head_ptr = insert_ptr;
}
```

Does the function work correctly for the empty list ?

Inserting a Node at the Head

```
void list_head_insert(node*& head_ptr, const node::value_type& entry)
{
    node *insert_ptr;

    insert_ptr = new node;
    insert_ptr->set_data(entry);
    insert_ptr->set_link(head_ptr);
    head_ptr = insert_ptr;
}
```

Does the function work correctly for the empty list ?

13

entry

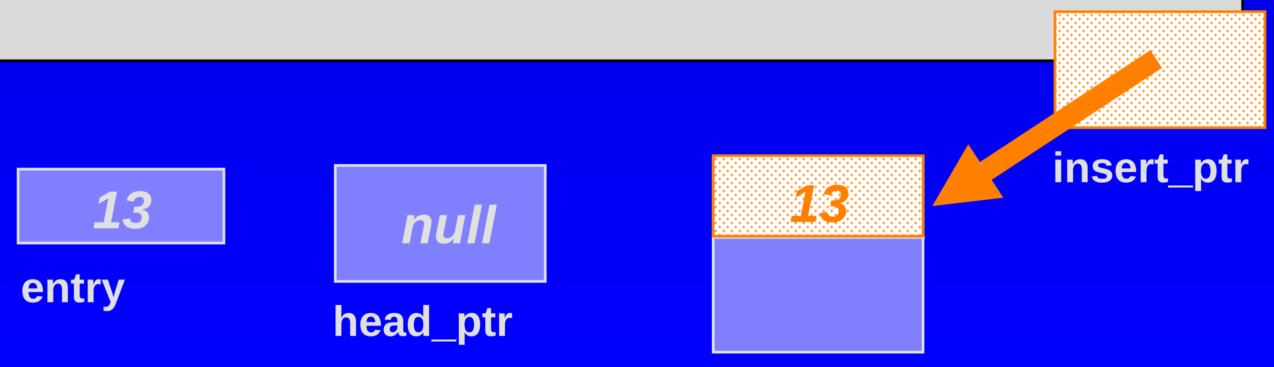
null

head_ptr

Inserting a Node at the Front

```
void list_head_insert(node*& head_ptr, const node::value_type& entry)
{
    node *insert_ptr;

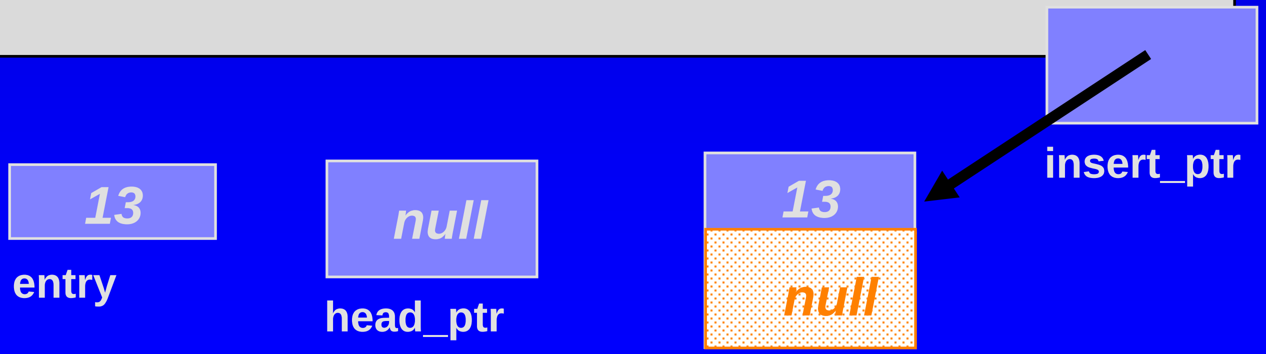
    insert_ptr = new node;
    insert_ptr->set_data(entry);
    insert_ptr->set_link(head_ptr);
    head_ptr = insert_ptr;
}
```



Inserting a Node at the Head

```
void list_head_insert(node*& head_ptr, const node::value_type& entry)
{
    node *insert_ptr;

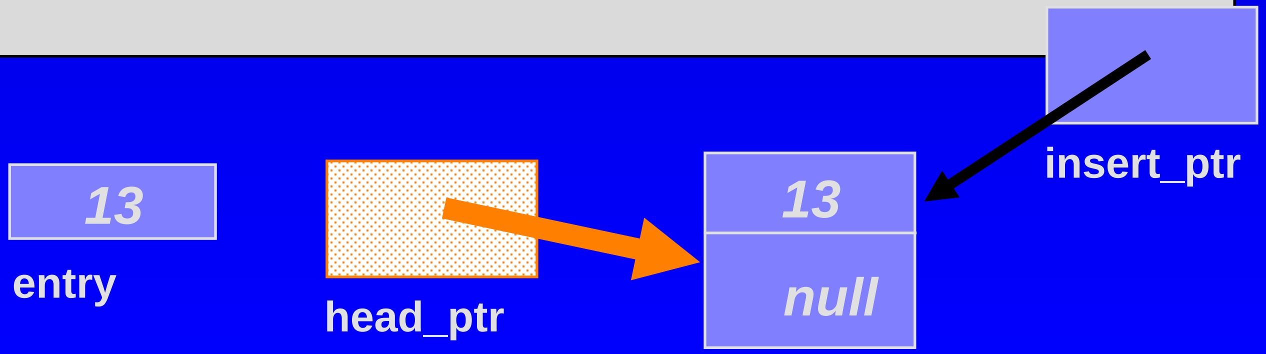
    insert_ptr = new node;
    insert_ptr->set_data(entry);
    insert_ptr->set_link(head_ptr);
    head_ptr = insert_ptr;
}
```



Inserting a Node at the Head

```
void list_head_insert(node*& head_ptr, const node::value_type& entry)
{
    node *insert_ptr;

    insert_ptr = new node;
    insert_ptr->set_data(entry);
    insert_ptr->set_link(head_ptr);
    head_ptr = insert_ptr;
}
```

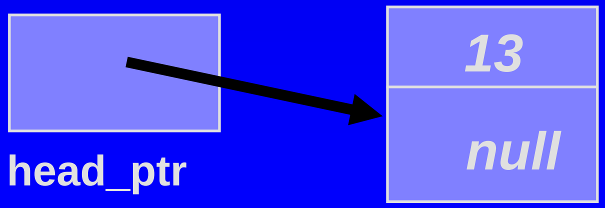


Inserting a Node at the Head

```
void list_head_insert(node*& head_ptr, const node::value_type& entry)
{
   node *insert_ptr;

   insert_ptr = new node;
   insert_ptr->set_data(entry);
   insert_ptr->set_link(head_ptr);
   head_ptr = insert_ptr;
}
```

When the function returns, the linked list has one node, containing 13.



Caution!

- Always make sure that your linked list functions work correctly with an empty list.

Inserting a Node at the Head

```
void list_head_insert(node*& head_ptr, const node::value_type& entry)
{
    node *insert_ptr;

    insert_ptr = new node;
    insert_ptr->set_data(entry);
    insert_ptr->set_link(head_ptr);
    head_ptr = insert_ptr;
}
```

Q: Can you give an implementation with ONLY a single statement?

Inserting a Node at the Head

```
void list_head_insert(node*& head_ptr, const node::value_type& entry)
{
    node *insert_ptr;

    insert_ptr = new node(entry, head_ptr);



    head_ptr = insert_ptr;
}
```

YES, we can use the constructor with parameters!

Inserting a Node at the Head

```
void list_head_insert(node*& head_ptr, const node::value_type& entry)
{


    head_ptr = new node(entry, head_ptr);



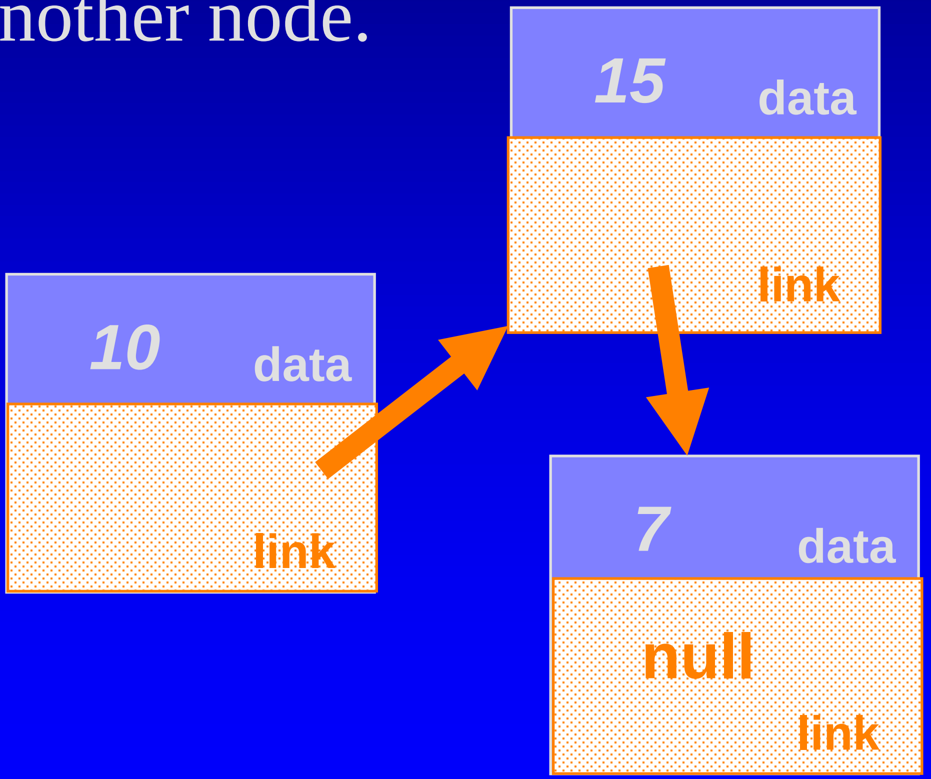

}
```

and assign the return pointer of new directly to the head pointer !

Declarations for Linked Lists

- Each node also contains a link field which is a pointer to another node.

```
class node
{
public:
    typedef int value_type;
    ...
private:
    value_type data;
    node *link;
};
```



The Co

- The n
- The p
  - dat
  - link
- The n
  - A c
  - Set
  - Ret

```
class node
  {
  public:
         // TYPEDEF
         typedef double value_type;

         // CONSTRUCTOR
         node(
            const value_type& init_data = value_type( ),
            node* init_link = NULL
         )
         { data = init_data; link = init_link; }

         // Member functions to set the data and link fields:
         void set_data(const value_type& new_data) { data = new_data; }
         void set_link(node* new_link)           { link = new_link; }

         // Constant member function to retrieve the current data:
         value_type data( ) const { return data; }

         // Two slightly different member functions to retrieve
         // the current link:
         const node* link( ) const { return link; }
         node* link( )          { return link;}

  private:
         value_type data;
         node* link;
  };
```

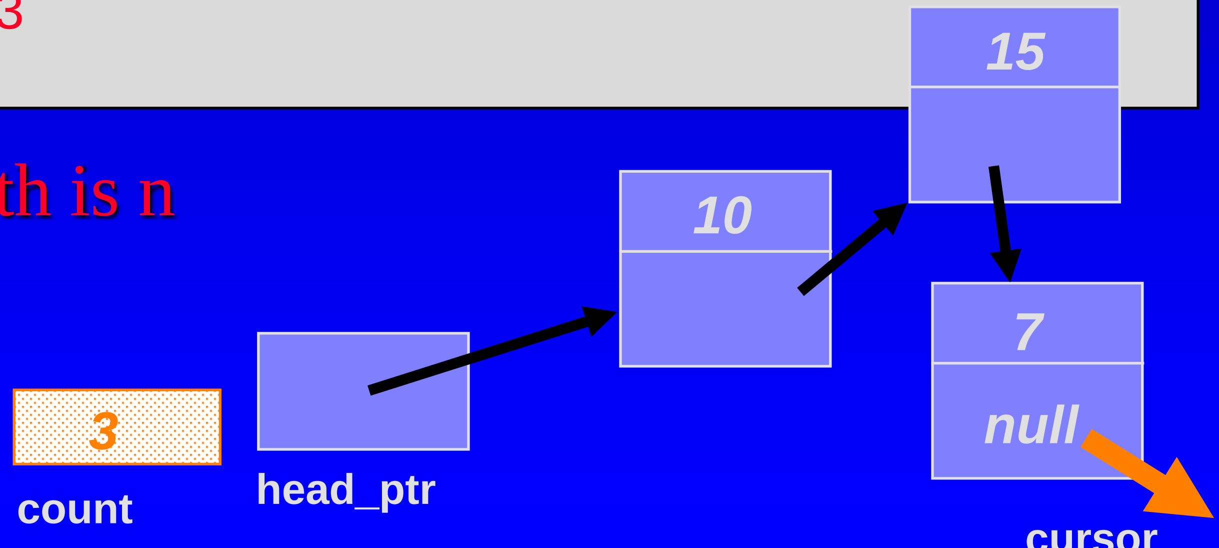
default argument given by the value_type default constructor

Why TWO? p. 213-4

Big-O of list_length

```
size_t list_length(const node* head_ptr)
{
    const node *cursor;
    size_t count = 0;
    for (cursor = head_ptr; cursor != NULL; cursor = cursor->link())
            count++;
    return count; // step 3
}
```

Big-O: O (n) if length is n



The Workings of four functions

- This lecture will show four functions:
  - Compute the length of a linked list (code)
  - Insert a new node at the head (code)
  - Insert a node at any location (pseudo-code)
  - Delete a node from the head (pseudo-code)
- Read Section 5.2 for other functions in the Toolbox
  - will be used in container classes bag and sequence

Pseudocode for Inserting Nodes

- Nodes are often inserted at places other than the front of a linked list.
- There is a general pseudocode that you can follow for any insertion function. . .

Pseudocode for Inserting Nodes

- Determine whether the new node will be the first node in the linked list. If so, then there is only one step:

```
list_head_insert(head_ptr, entry);
```

Pseudocode for Inserting Nodes

- Determine whether the new node will be the first node in the linked list. If so, then there is only one step:

```
list_head_insert(head_ptr, entry);
```

The function we already wrote

Pseudocode for Inserting Nodes

- Determine whether the new node will be the first node in the linked list. If so, then there is only one step:

```
list_head_insert(head_ptr, entry);
```

A pointer to the head of the list

Pseudocode for Inserting Nodes

- Determine whether the new node will be the first node in the linked list. If so, then there is only one step:

```
list_head_insert(head_ptr, entry);
```

The data to put in the new node

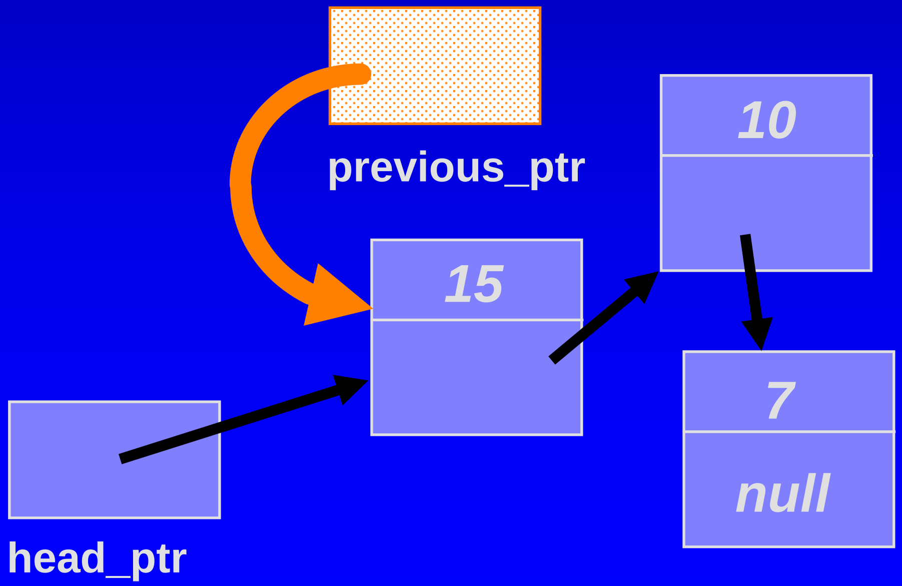
Pseudocode for Inserting Nodes

- Otherwise (if the new node will not be first):
  - Start by setting a pointer named **previous_ptr** to point to the node which is just **before** the new node's position.

Pseudocode for Inserting Nodes

- Otherwise (if the new node will not be first):
  - Start by setting a pointer named **previous_ptr** to point to the node which is just **before** the new node's position.

In this example, the new node will be the second node

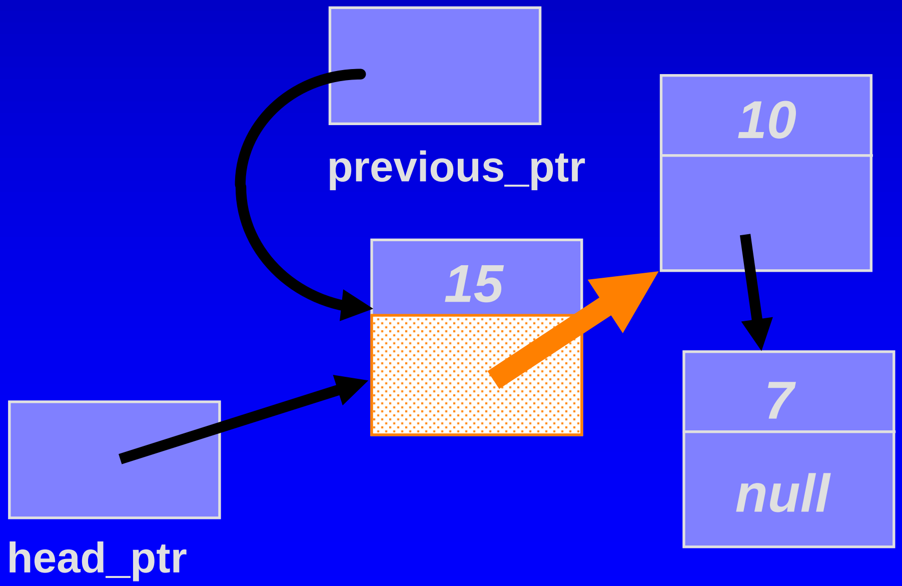


Pseudocode for Inserting Nodes

- Otherwise (if the new node will not be first):
  - Start by setting a pointer named previous_ptr to point to the node which is just before the new node's position

Look at the pointer which is **in the node** *previous_ptr

What is the name of this pointer ?

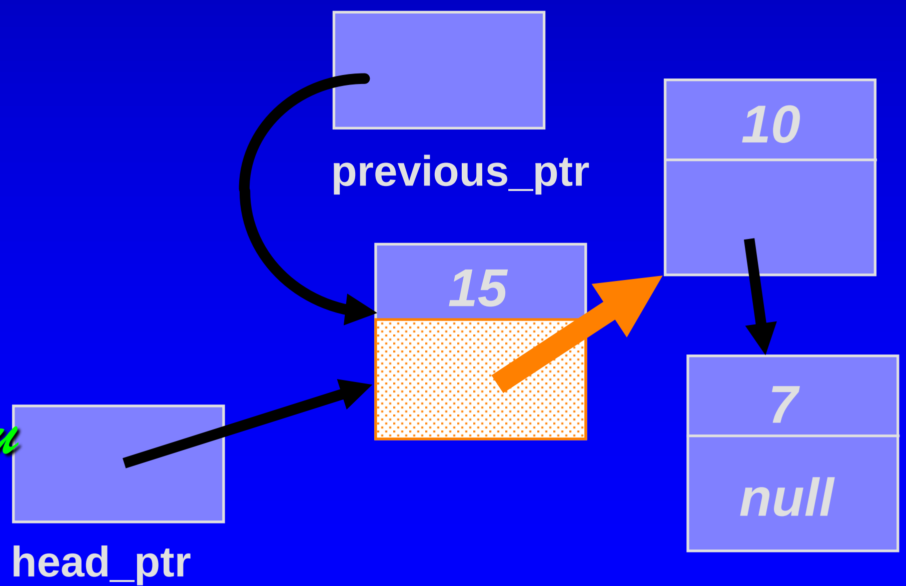


Pseudocode for Inserting Nodes

- Otherwise (if the new node will not be first):
  - Start by setting a pointer named previous_ptr to point to the node which is just before the new node's position

This pointer is called
previous_ptr->link

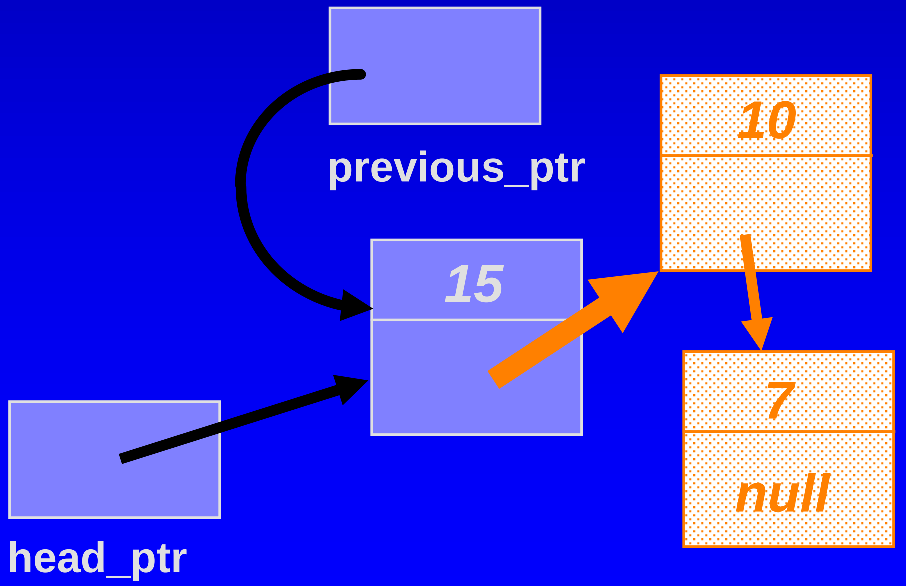
Always remember how can you access link



Pseudocode for Inserting Nodes

- Otherwise (if the new node will not be first):
  - Start by setting a pointer named previous_ptr to point to the node which is just before the new node's position

previous_ptr->link points to the head of a smaller linked list, with 10 and 7

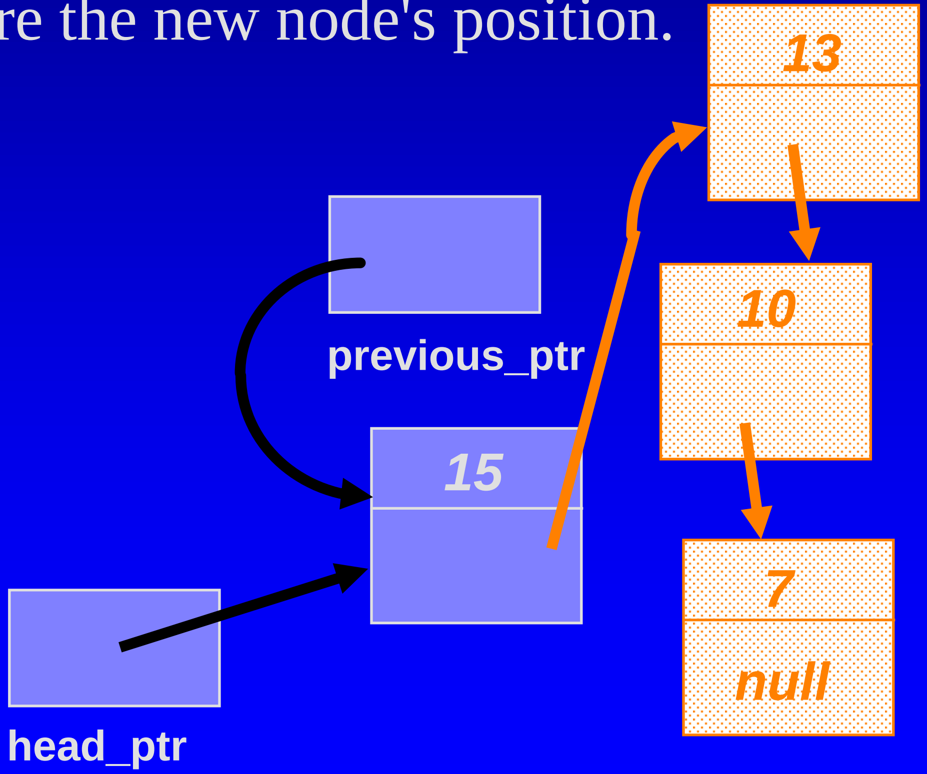


Pseudocode for Inserting Nodes

- Otherwise (if the new node will not be first):
  - Start by setting a pointer named previous_ptr to point to the node which is just before the new node's position.

The new node must be inserted at the head of this small linked list.

Write one C++ statement which will do the insertion.



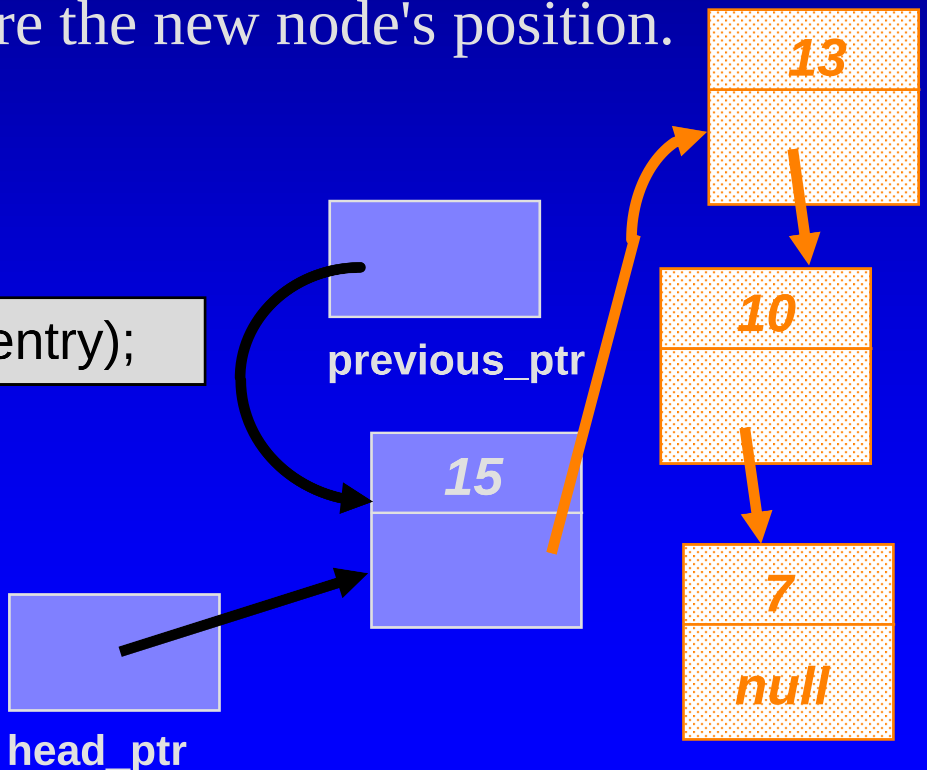
Pseudocode for Inserting Nodes

- Otherwise (if the new node will not be first):
  - Start by setting a pointer named previous_ptr to point to the node which is just before the new node's position.

X

```
list_head_insert(previous_ptr->link, entry);
```

Write one C ... ment
which wil ... nsertion.

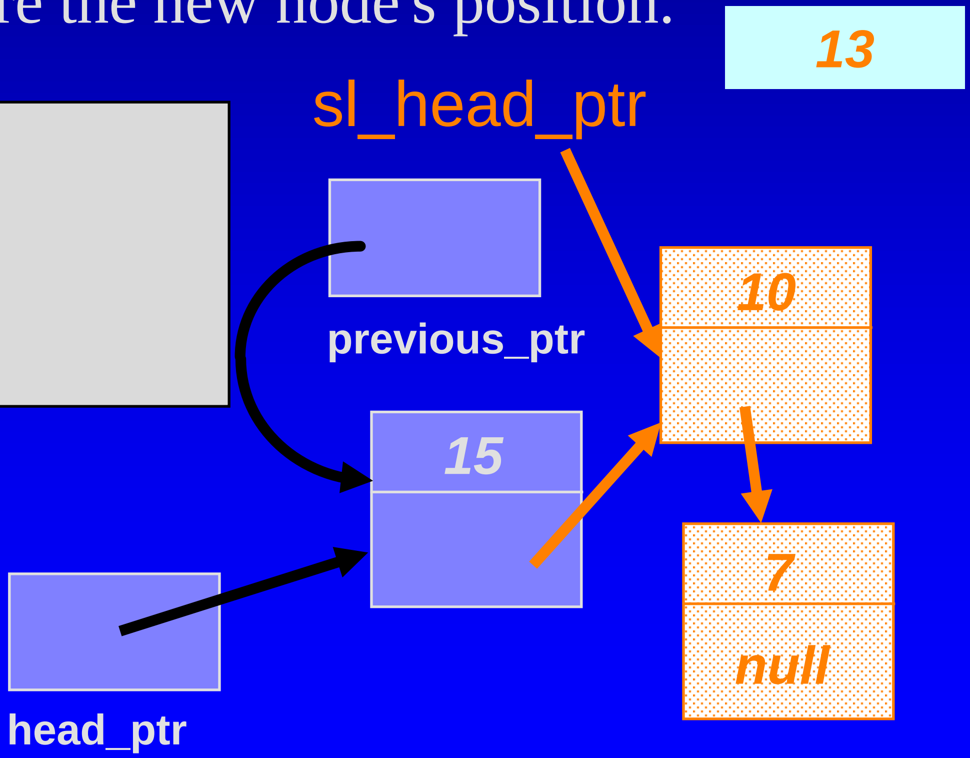


Pseudocode for Inserting Nodes

- Otherwise (if the new node will not be first):
  - Start by setting a pointer named previous_ptr to point to the node which is just before the new node's position.

```
node *sl_head_ptr;
sl_head_ptr = previous_ptr->link();
list_head_insert(sl_head_ptr, entry);
previous_ptr->set_link(sl_head_ptr);
```

More precisely, you need to use member function link() , and have three lines of code



Pseudocode for Inserting Nodes

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  - Start by setting a pointer named previous_ptr to point to the node which is just before the new node's position.

```
node *sl_head_ptr;
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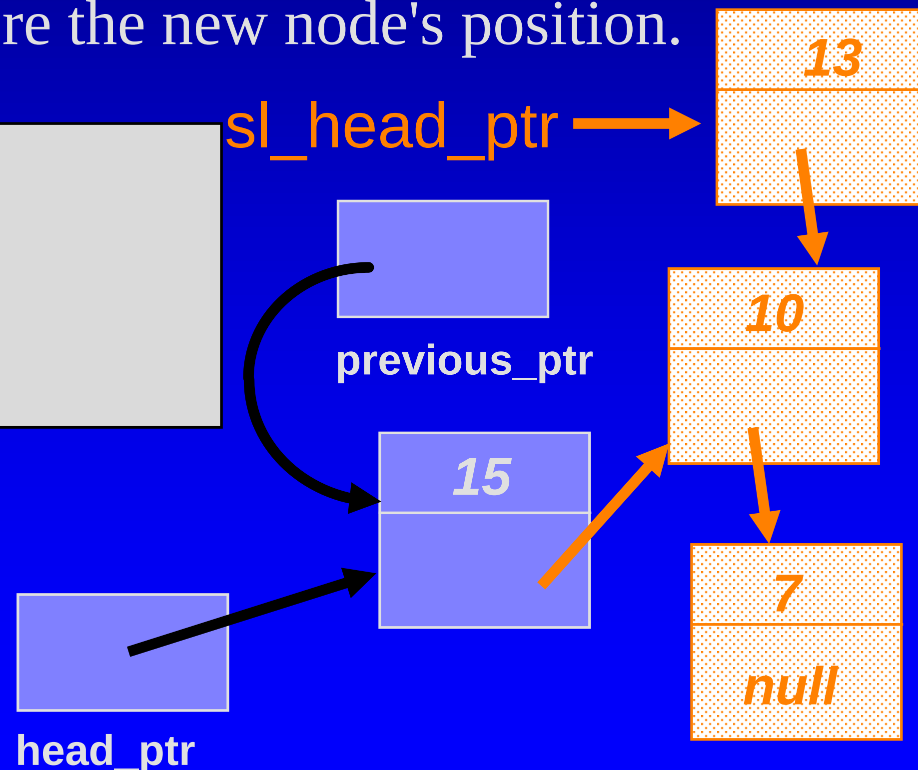
list_head_insert(sl_head_ptr, entry);
previous_ptr->set_link(sl_head_ptr);
```

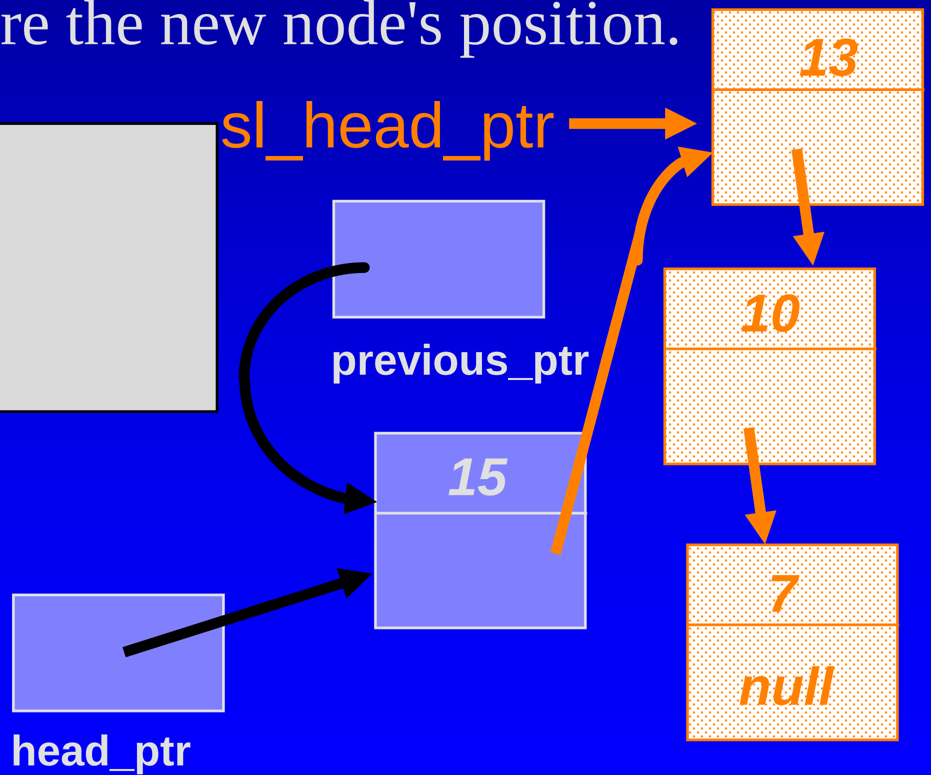
More precisely, you need to use member function link() , and have three lines of code



Pseudocode for Inserting Nodes

- Otherwise (if the new node will not be first):
  - Start by setting a pointer named previous_ptr to point to the node which is just before the new node's position.

```
node *sl_head_ptr;
sl_head_ptr = previous_ptr->link();
list_head_insert(sl_head_ptr, entry);
previous_ptr->set_link(sl_head_ptr);
```



More precisely, you need to use member function link() , and have three lines of code

Pseudocode for Inserting Nodes

- Determine whether the new node will be the first node in the linked list. If so, then there is only one step:

```
list_head_insert(head_ptr, entry);
```

- Otherwise (if the new node will not be first):
  - Set a pointer named previous_ptr to point to the node which is just before the new node's position.
  - Do the following :

```
node *sl_head_ptr;
sl_head_ptr = previous_ptr->link();
list_head_insert(sl_head_ptr, entry);
previous_ptr->set_link(sl_head_ptr);
```

Pseudocode for Inserting Nodes

- The process of adding a new node in the middle of a list (only the step after previous_ptr has been set) can also be incorporated as a separate function. This function is called list_insert in the linked list toolkit of Section 5.2.
- Challenge yourself:
  - The textbook actually gives you a different implementation (p 235, 4 lines of code)
  - Can you implement list_insert with just one line of code?
    - Don’t use list_head_insert
    - See Self-Test Ex 16

The Workings of four functions

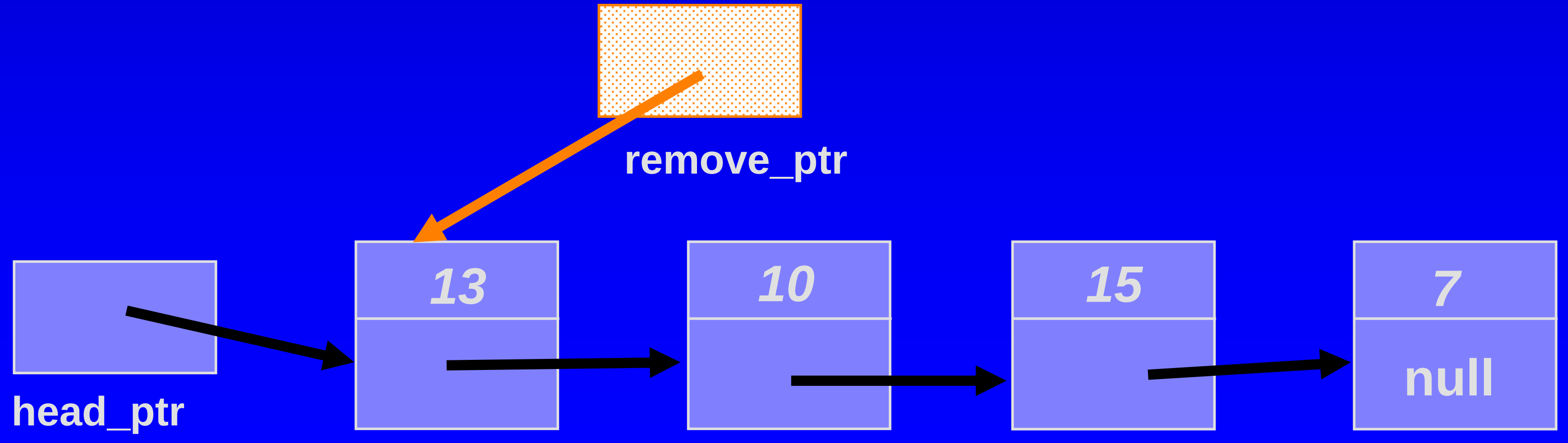
- This lecture will show four functions:
  - Compute the length of a linked list (code)
  - Insert a new node at the head (code)
  - Insert a node at any location (pseudo-code)
  - Delete a node from the head (pseudo-code)
- Read Section 5.2 for other functions in the Toolbox
  - will be used in container classes bag and sequence

Pseudocode for Removing Nodes

- Nodes often need to be removed from a linked list.
- As with insertion, there is a technique for removing a node from the front of a list, and a technique for removing a node from elsewhere.
- We’ll look at the pseudocode for removing a node from the head of a linked list.

Removing the Head Node

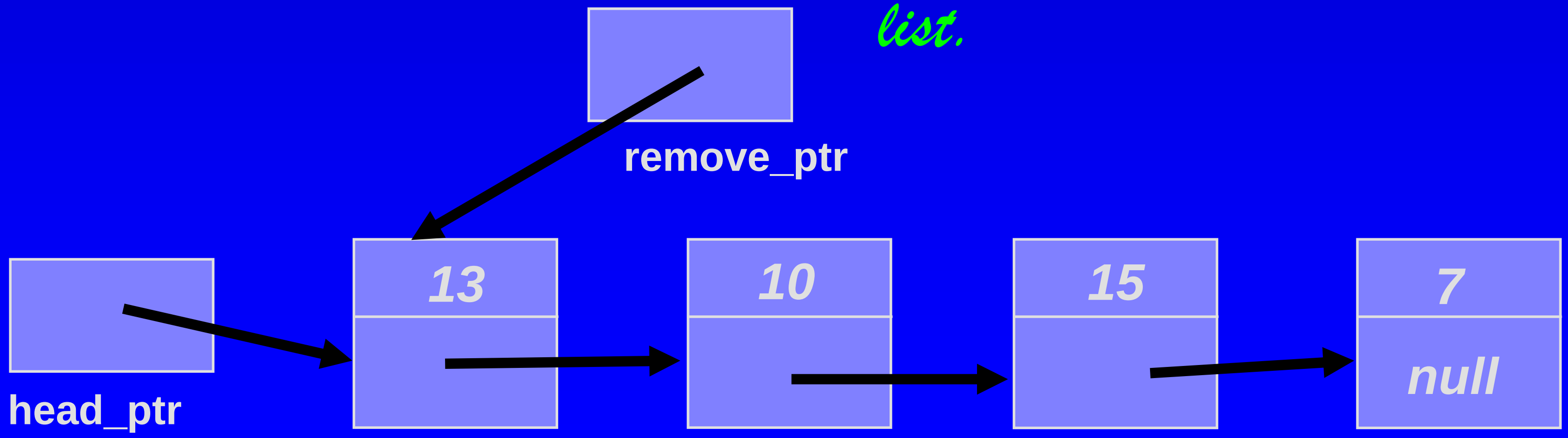
- Start by setting up a temporary pointer named **remove_ptr** to the head node.



Removing the Head Node

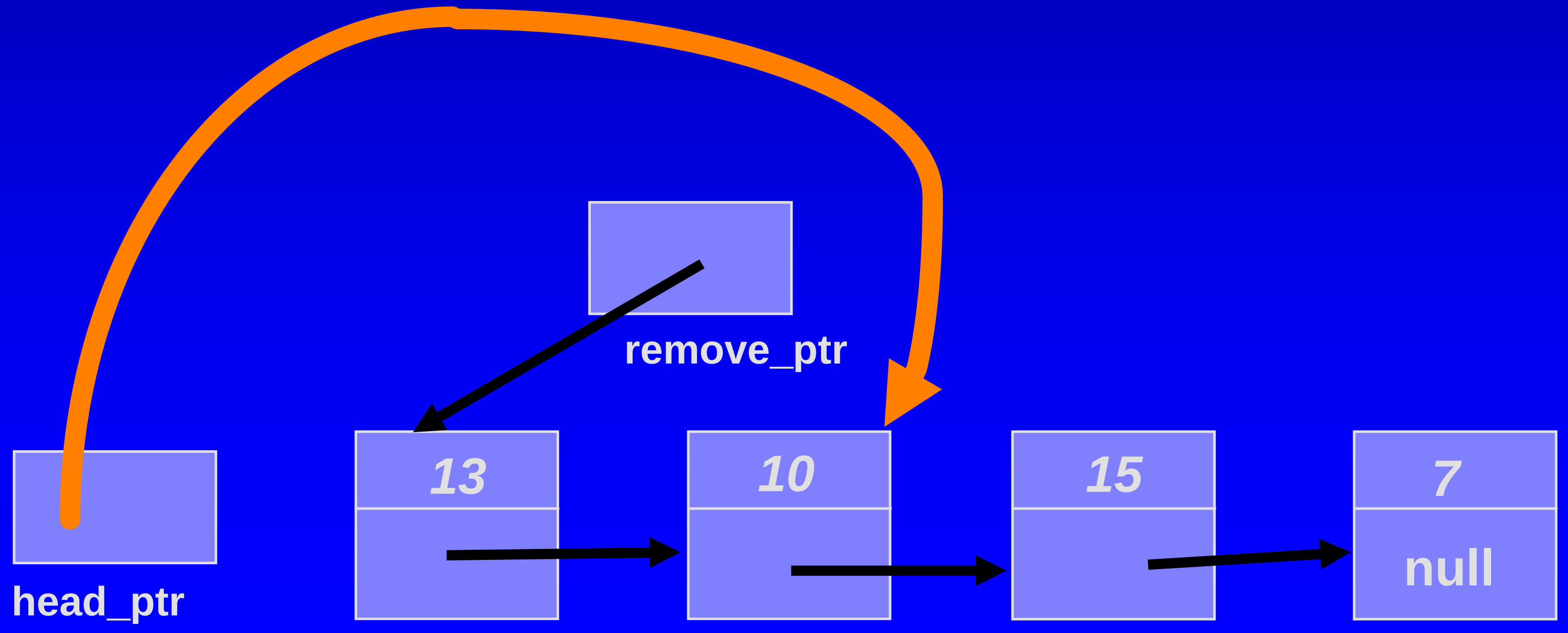
- Set up remove_ptr.
- head_ptr = remove_ptr->link();

Draw the change that this statement will make to the linked list.



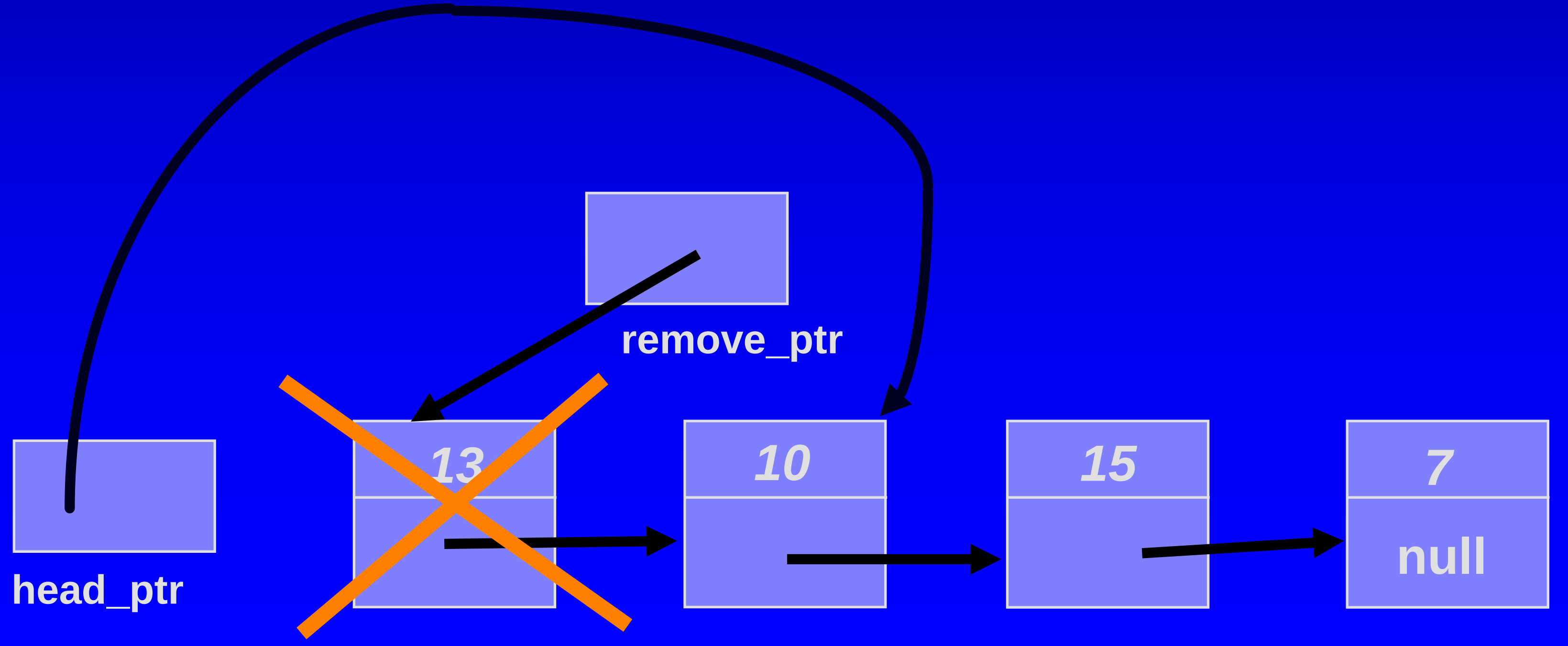
Removing the Head Node

- Set up remove_ptr.
- head_ptr = remove_ptr->link();



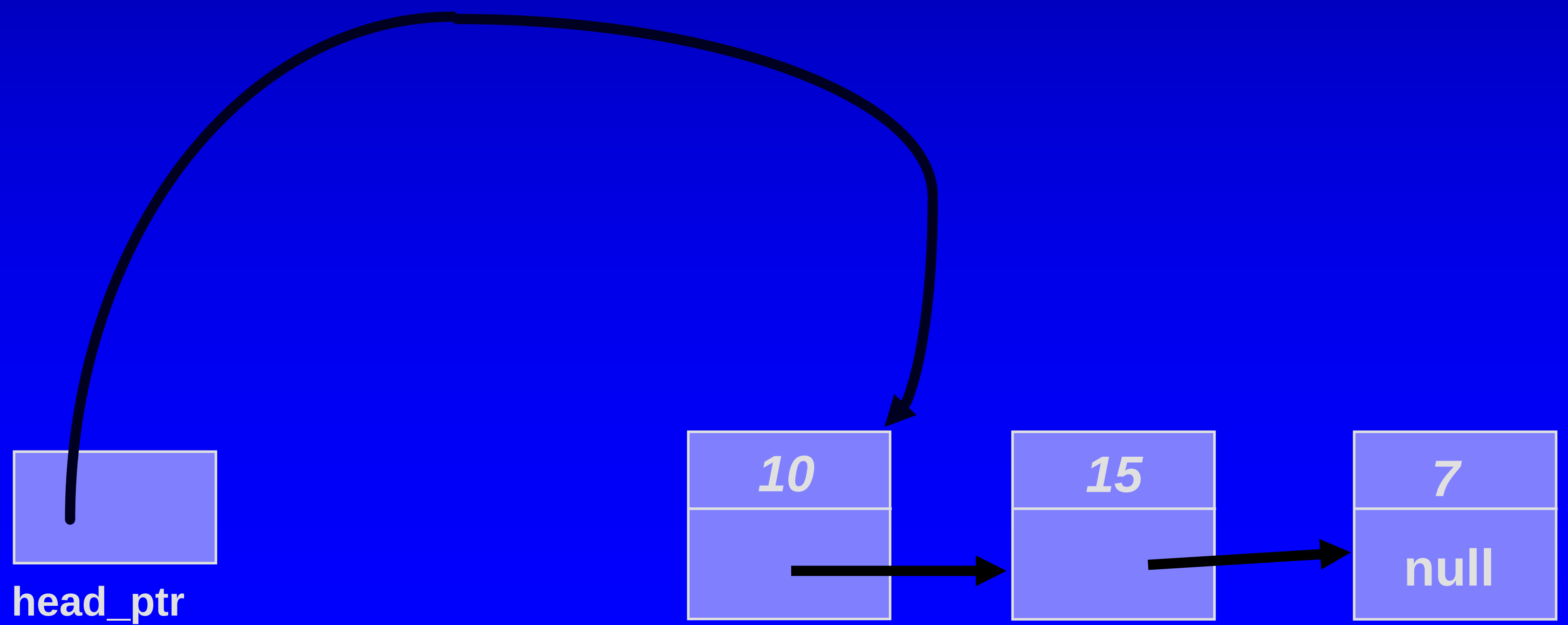
Removing the Head Node

- Set up remove_ptr.
- head_ptr = remove_ptr->link;
- delete remove_ptr; // Return the node's memory to heap.



Removing the Head Node

Here's what the linked list looks like after the removal finishes.



Summary

- It is easy to insert a node at the front of a list.
- The linked list toolkit also provides a function for inserting a new node elsewhere
- It is easy to remove a node at the front of a list.
- The linked list toolkit also provides a function for removing a node elsewhere--you should read about this function and the other functions of the toolkit.

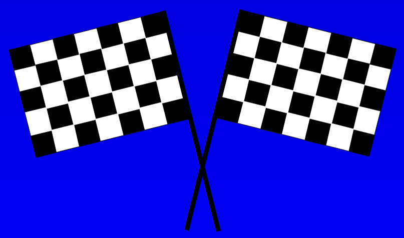
Key points you need to know

Toolkit Code

- Linked List Toolkit uses the node class which has
  - set and retrieve functions
- The functions in the Toolkit are not member functions of the node class
  - length, insert(2), remove(2), search, locate, copy,...
  - compare their Big-Os with similar functions for an array
- They can be used in various container classes, such as bag, sequence, etc.

Homework...

- Self-Test Exercises (node)
  - 1-12
- Read after class
  - Linked List ToolKit (Section 5.2)
  - Do Self-Test Ex 13 -25
- Read before the next lecture
  - Section 5.3- 5.4
- Programming Assignment 4
  - Detailed guidelines online!



THE END