# Linked lists

# Data structures to store a collection of items

- Data structures to store a collection of items are commonly used
  - Typical operations on such data structures: insert, remove, find_max, update, etc

- What are our choices so far to design such a data structure?

# Data structures to store a collection of items

- What are the choices so far?
  - Arrays
    - Limitations
      - fixed capacity, memory may not be fully utilized.
      - Insert and remove can be expensive (a lot of copies) if we don't want to leave holes in the middle of the array.
      - Continuous memory for easy index
  - Dynamic arrays
    - Limitations:
      - Capacity is dynamic, memory still may not be fully utilized, but better than static arrays.
      - Insert and remove can be expensive, especially when the capacity changes.
      - Continuous memory for easy index

# Data structures to store a collection of items

- Linked list is another choice.
  - A true dynamic data structure in that each item in the list is dynamically allocated using a new operator.

  - Capacity is always the same as memory used (with tax)
  - Insert and remove operations are cheap
  - Memory are not continuous
  - Limitations: no (or expensive) [] operator.

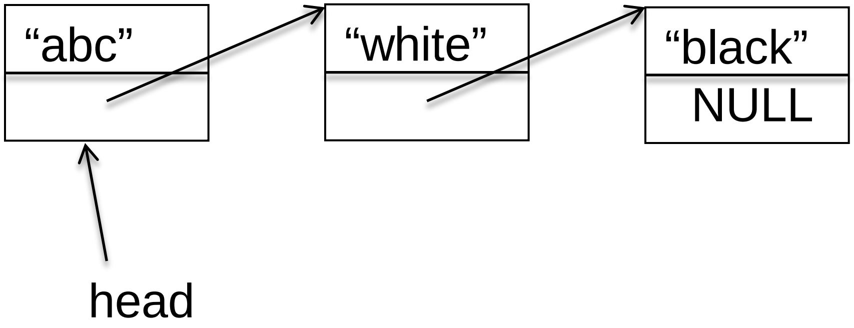
- Linked list is one of the "linked data structures".

# Linked list and array

- An array of string:
  - S[0] = “abc”;
  - S[1]=“white”;
  - S[2] = “black”;
- A linked list of strings
  - Each item has two fields
    - A string field
    - A pointer pointing to the next item.

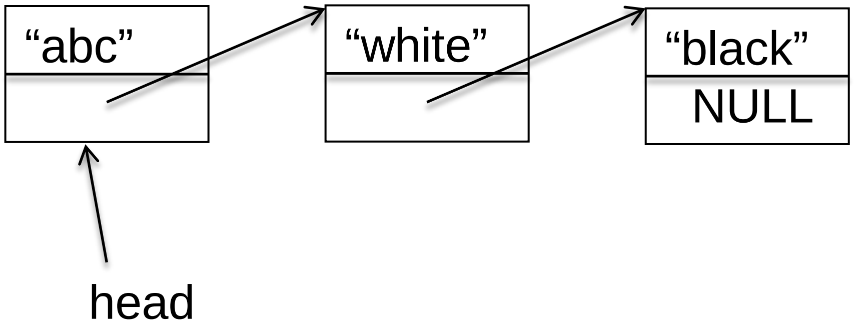
|  |  |
|---|---|
| 0 | “abc” |
| 1 | “white” |
| 2 | “black” |
| 3 |  |
| 4 |  |

```
class listofstring {
public:
    string item;
     listofstring *next;
};
```



# Linked list

- No waste of memory (except for pointers).
- Each box is dynamically allocated by a new operation.
- Several variations
  - Singly linked list
  - Doubly linked lists



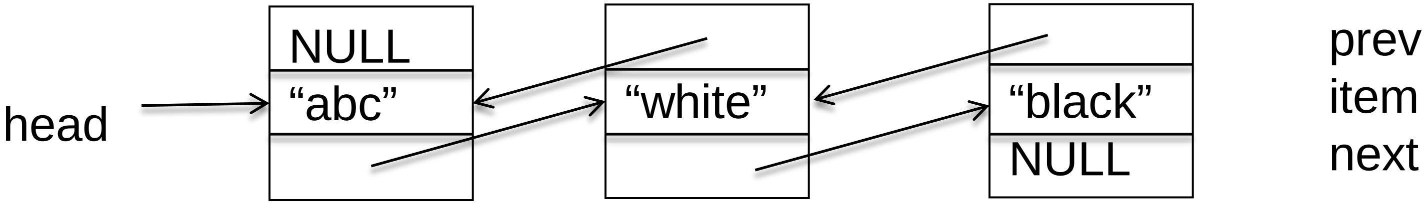
“abc”

“white”

“black”

NULL

head



head

NULL

“abc”

“white”

“black”

NULL

prev

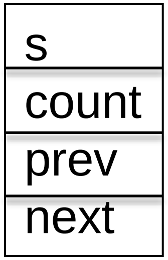
item

next

# A doubly linked list

- Let us assume that we store two data fields in each node: a string and a count. The node data structure is:

```
class listnode
{
public:
   string s;
   int count;
   listnode *next;
   listnode *prev;
   listnode(): s(“”), count(0), next(NULL), prev(NULL) {};
   listnode(const string & ss, const int &c): s(ss), count( c), next(NULL), prev(NULL)
{};
};
```



s

count

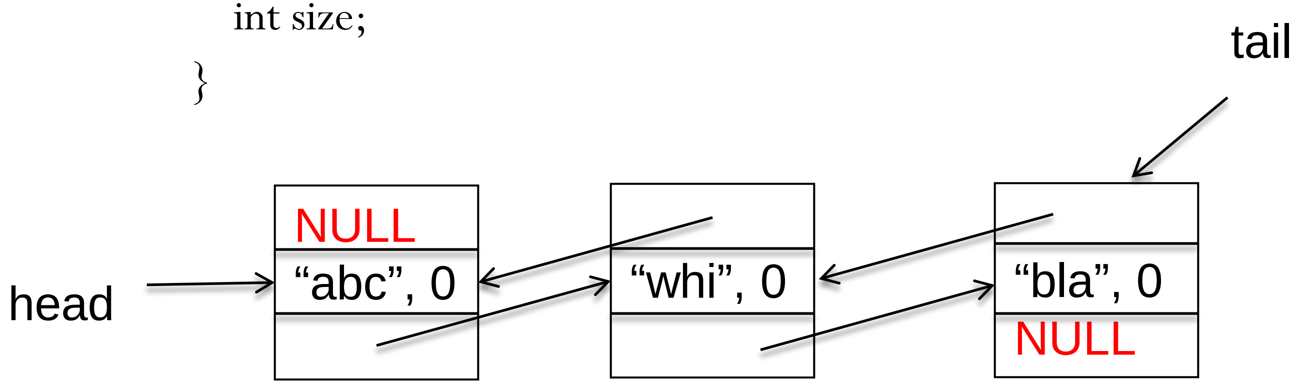
prev

next

# The doubly linked list private data

- Protect data:
  - head: pointer to the head of the list: head->prev == NULL
  - tail: pointer to the tail of the list: tail->next == NULL
  - size: number of nodes in the list

```
class mylist {
 …
Private:
   listnode * head;
   listnode *tail;
   int size;
}
```



# mylist public interface

```
mylist();
  ~mylist();
  void print();
  mylist(const mylist & l);
  mylist& operator=(const mylist  &l);

  void insertfront(const string &s, const int & c);
  void insertback(const string &s, const int & c);
  void insertbefore(listnode *ptr, const string &s, const int &c);
  void insertafter(listnode *ptr, const string &s, const int &c);
  void insertpos(const int & pos, const string &s, const int &c);
```

# mylist public interface

```
void removefront();
void removeback();
void remove(listnode * ptr);
void removepos(const int & pos);

listnode front() const;
listnode back() const;
int length() const;
listnode *search(const string &s);
listnode *findmaxcount();
void removemaxcount();
bool searchandinc (const string &s);
```

# Mylist implementation

- Constructors and destructor
  - Making an empty list (default constructor): head=tail=NULL, size = 0; (See mylist.cpp)
  - Destructor: must use a loop to delete every single node in the list (all nodes are allocated with a new). See mylist.cpp
  - Copy constructor and = operator: Similar logic to destructor: use a loop to walk through each node in the existing list, and insert (just insertback) the same node to the new list.
- The print function (see mylist.cpp)

- The main routines are different versions of insert, remove, and search.

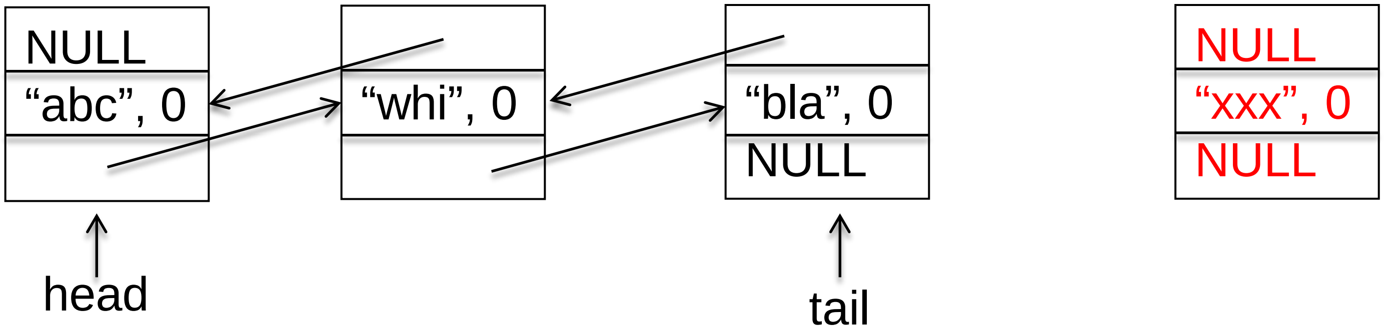
# Insert

- Insertback
  - Two cases:
    - Insert to the empty list
    - Insert to list with items.
  - Insert to empty list
    - Create a new node (prev=NULL, next=NULL), both head and tail should point to the new node.

```
listnode *t = new listnode(s, c);
 if (head == NULL) { // list is currently empty, both head and tail
                    // should point to the new node
   head = t;
   tail = t;
   size++;
}
```

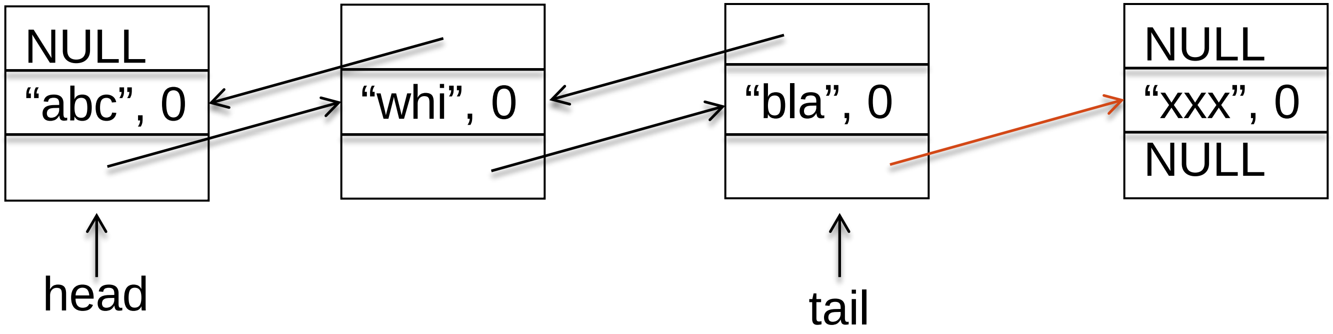
# Insertback

- Insertback to a list with items
  - Step 1: create the new node
    - Listnode *t = new listnode(s, c)



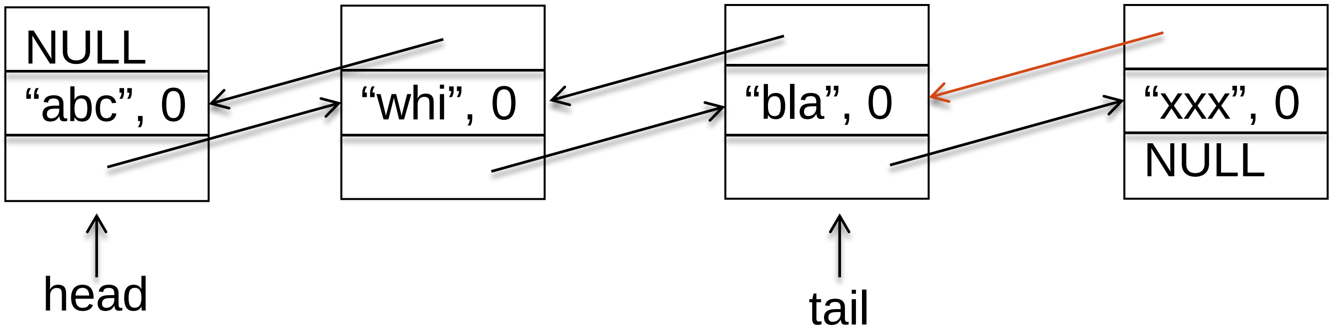
# Insertback

- Insertback to a list with items
  - Step 2: link new node to the tail of the list (next pointer)
    - tail->next = t;



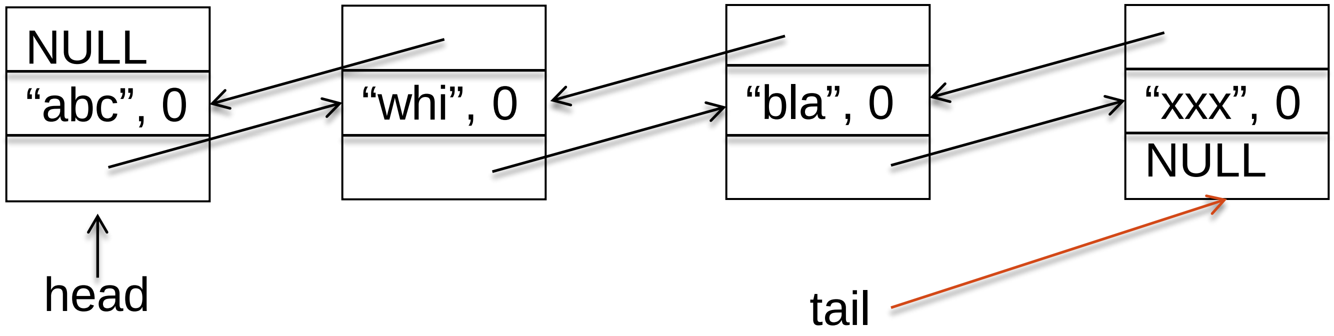
# Insertback

- Insertback to a list with items
  - Step 3: link new node to the list (prev pointer)
    - t->prev = tail;



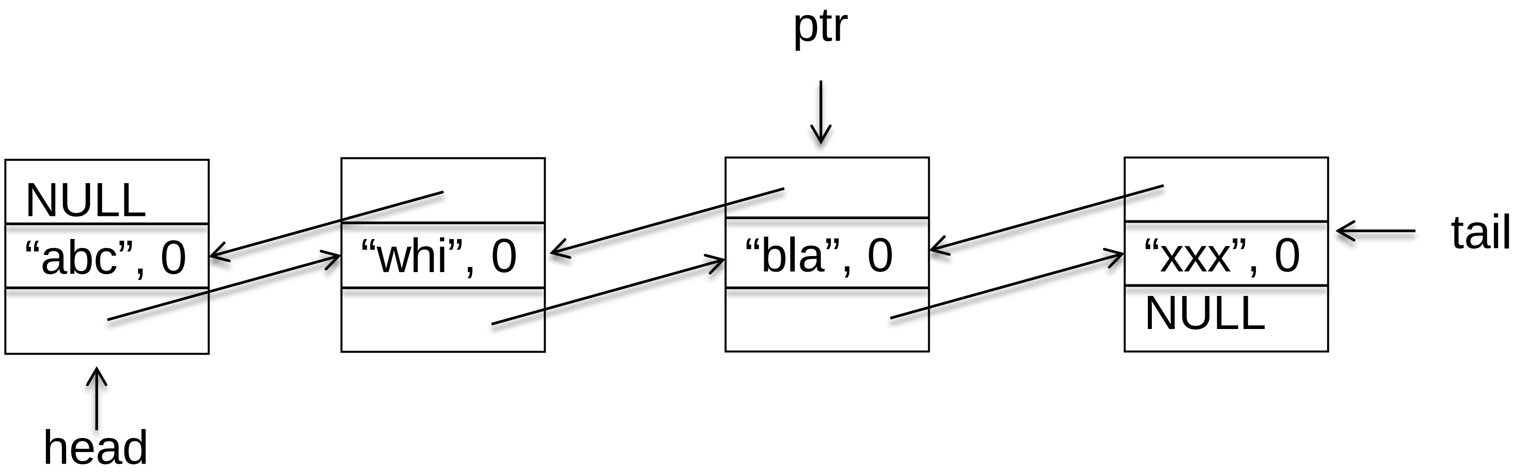
# Insertback

- Insertback to a list with items
  - Step 4: tail point to the new node
    - tail = t
  - See complete code in mylist.cpp



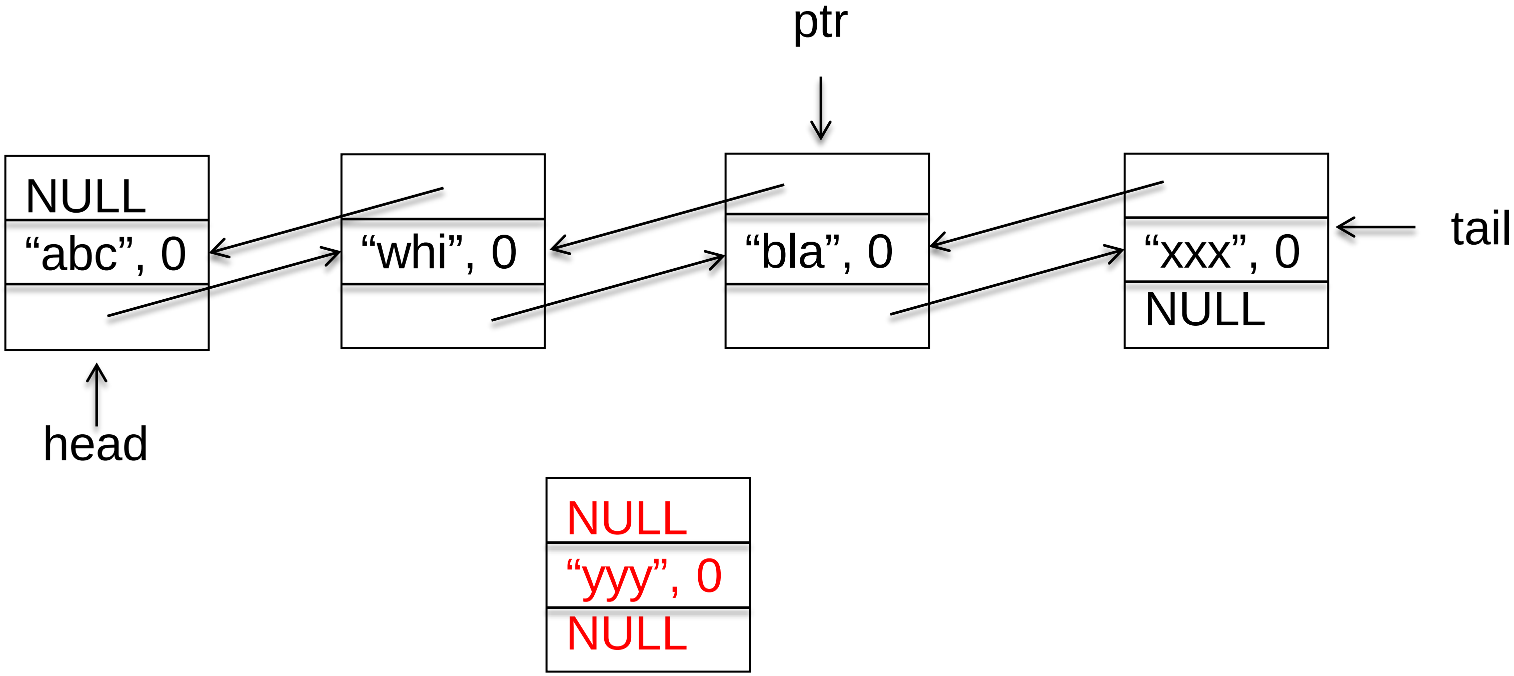
# Insertbefore

- Insert before the head is equal to insertfront, which is similar to insertback
- Insertbefore into the middle of the list before ptr
  - A new node is to be added between ptr->prev, and ptr.



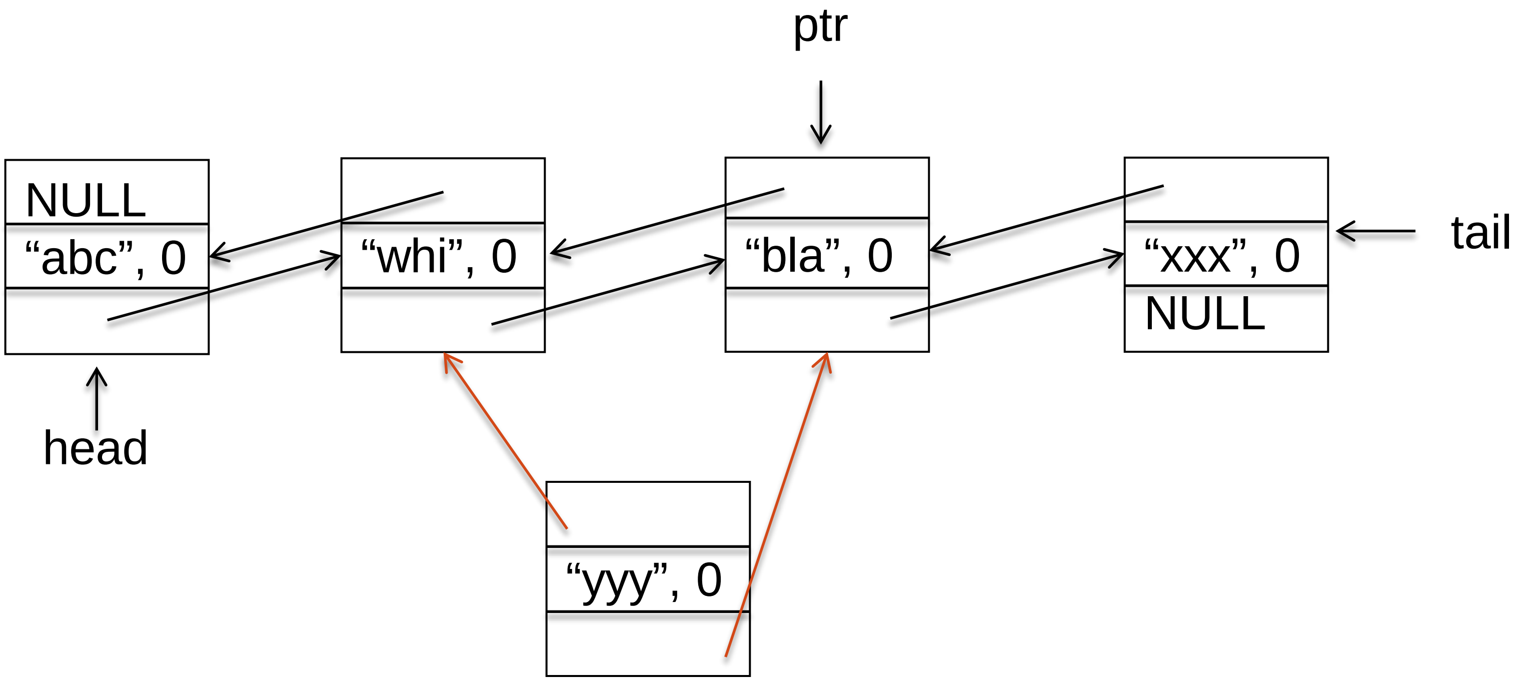
# Insertbefore

- Insertbefore into the middle of the list before ptr
  - A new node is to be added between ptr->prev, and ptr.
- Step 1: create the new node: *listnode* t = new listnode(s,c);*



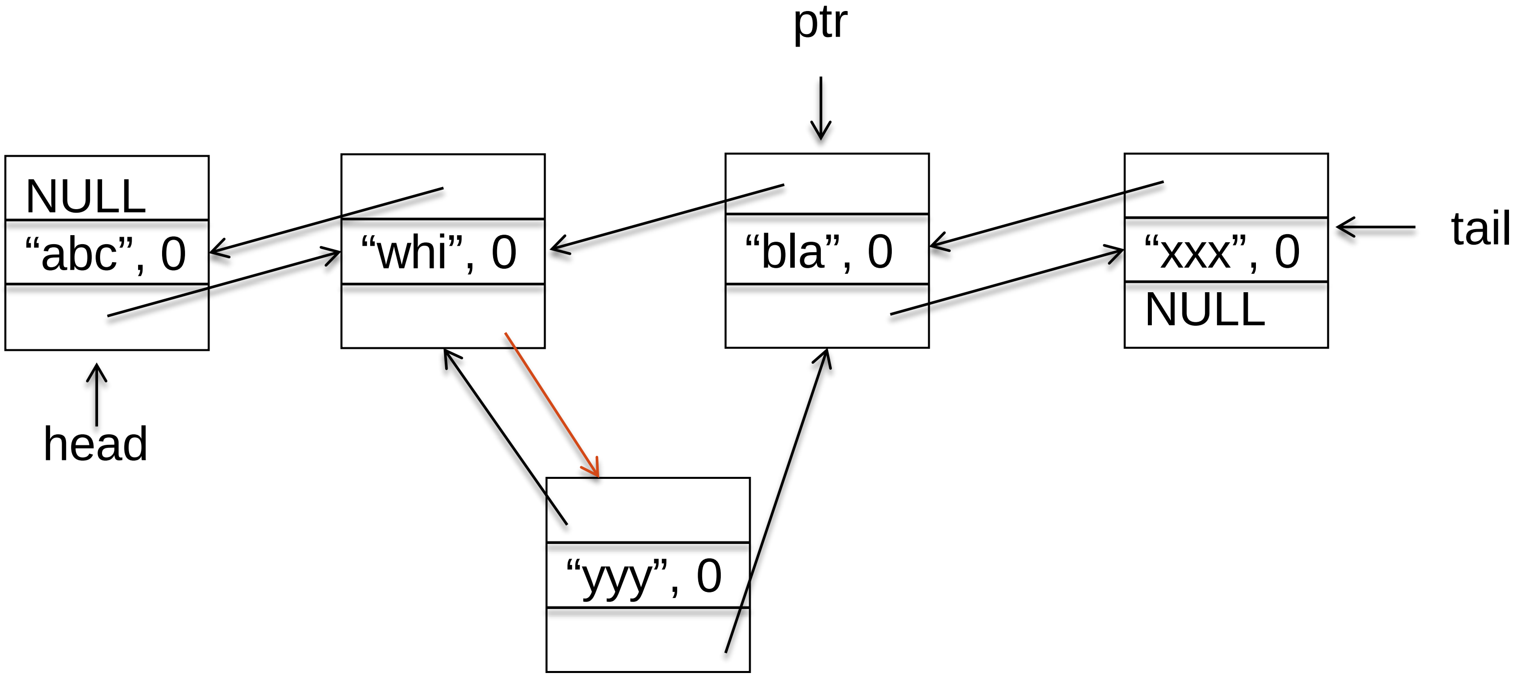
# Insertbefore

- Insertbefore into the middle of the list before ptr
  - A new node is to be added between ptr->prev, and ptr.
- Step 1: try to chain the new node to the list
  - *t->next = ptr; t->prev = ptr->prev;*



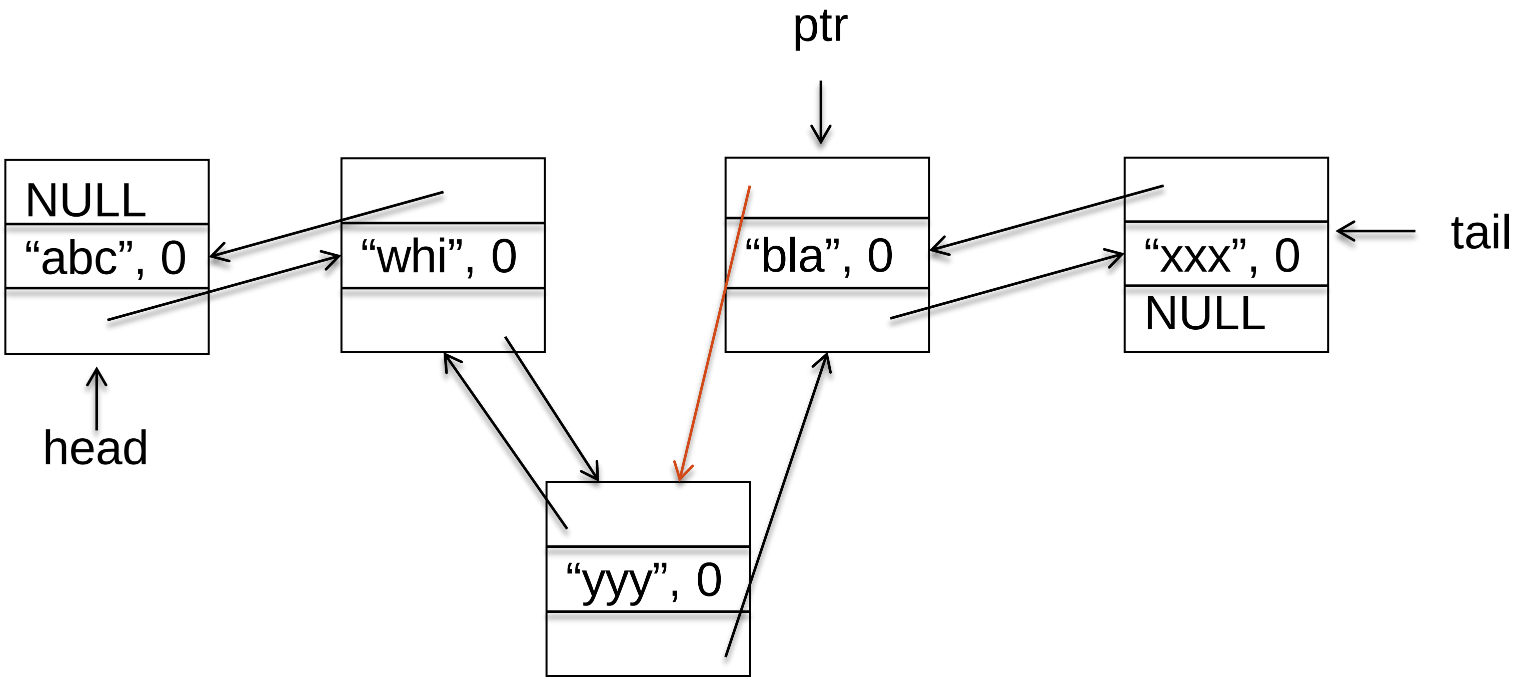
# Insertbefore

- Insertbefore into the middle of the list before ptr
  - A new node is to be added between ptr->prev, and ptr.
- Step 2: change ptr->prev's next pointer
  - *ptr->prev->next = t;*



# Insertbefore

- Insertbefore into the middle of the list before ptr
  - A new node is to be added between ptr->prev, and ptr.
- Step 3: change ptr's prev pointer (see mylist.cpp)
  - *ptr->prev = t;*

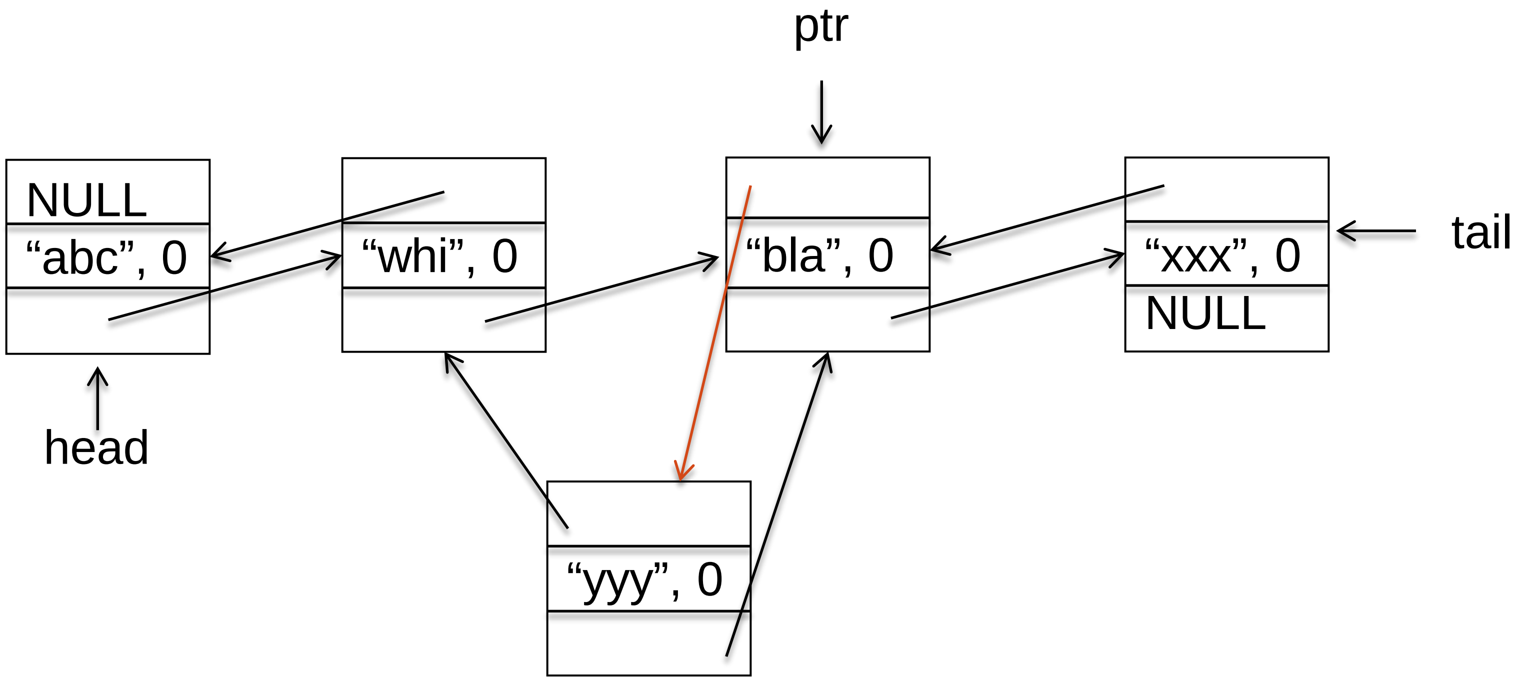


# Insertbefore

- Can step 2 and step 3 change order?

  *ptr->prev = t;*

  *ptr-prev->next = t;*



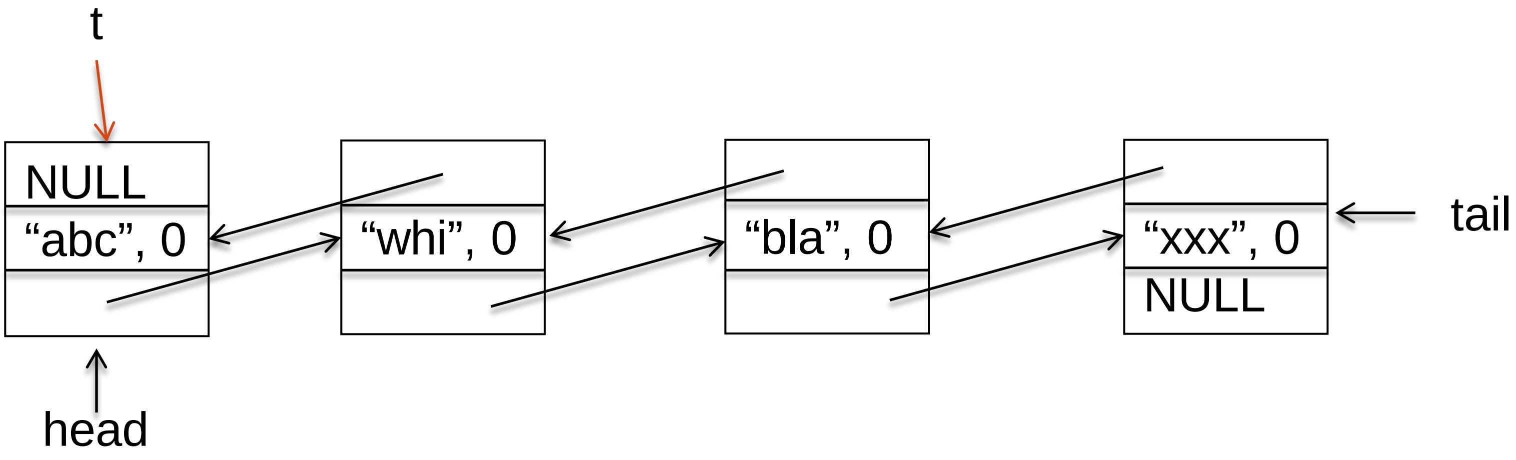
# Remove

- Removefront:
  - Two cases:
    - the list has only one element need to make empty list out of it.

      ```
      delete head;
       head = tail = NULL;
       size = 0;
       return;
      ```
    - The list has more than on elements

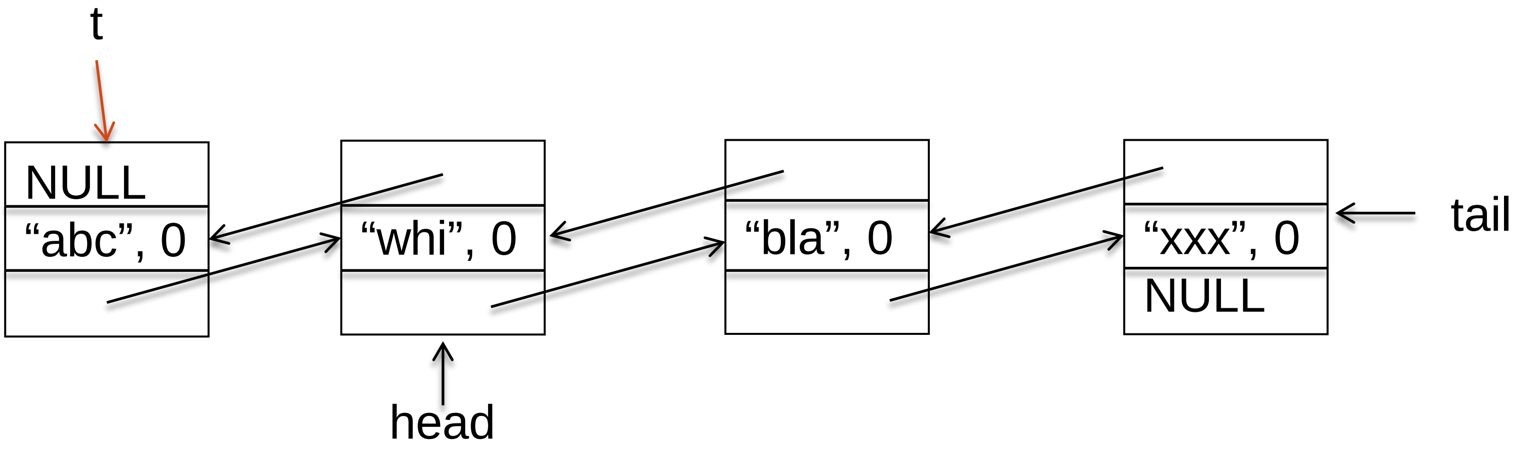
# Remove

- Removefront:
  - The list has more than on elements
    - Step 1: listnode *t = head;



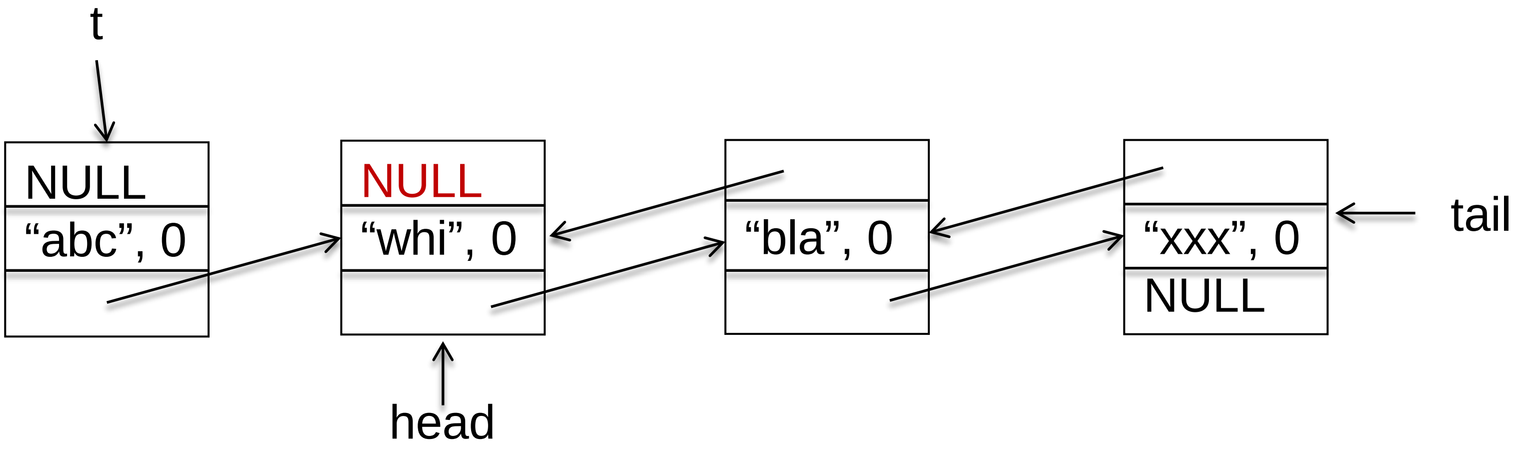
# Remove

- Removefront:
  - The list has more than on elements
    - Step 2: Advance head: head = head->next;



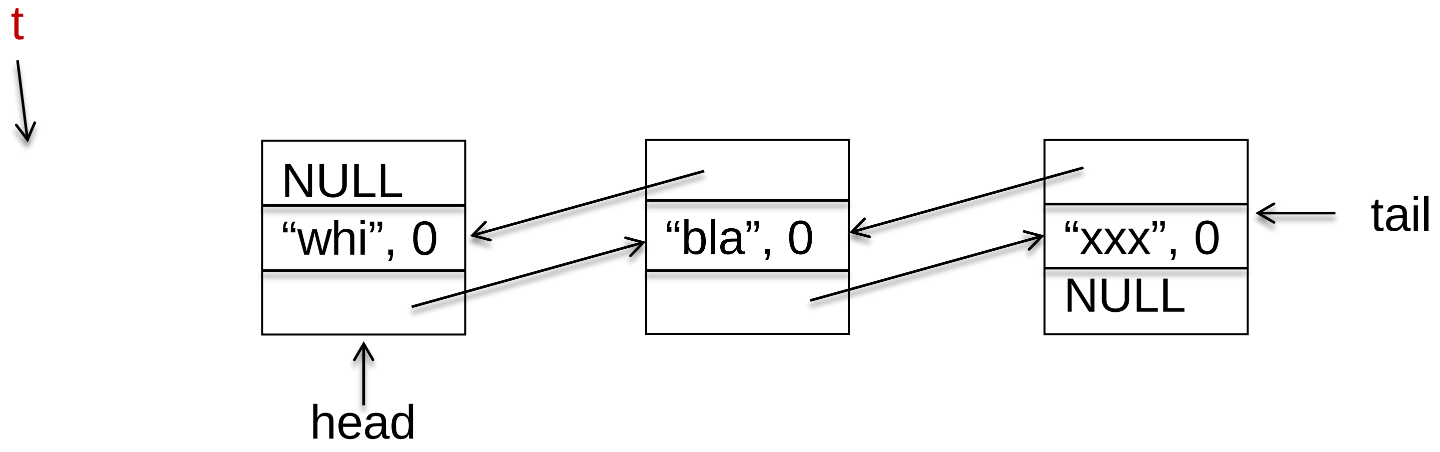
# Remove

- Removefront:
  - The list has more than on elements
    - Step 3: delink the prev of head: head->prev = NULL;



# Remove

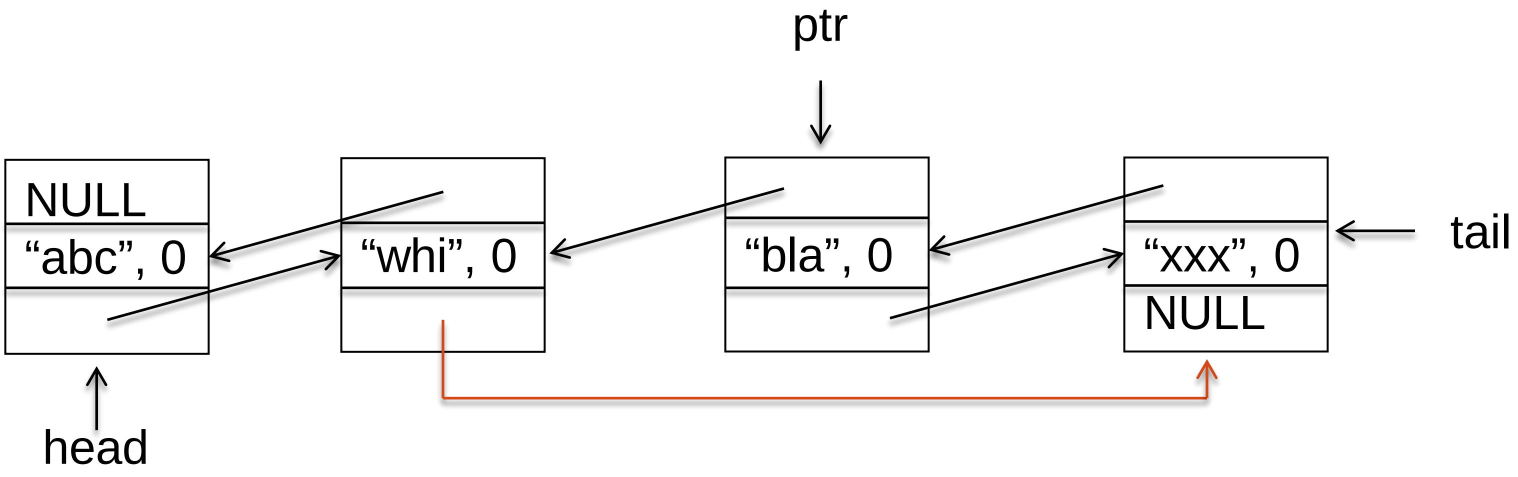
- Removefront:
  - The list has more than on elements (see mylist.cpp)
    - Step 4: delete t;



# Removemiddle

- Remove an item pointed to by ptr
  - Step 1: change ptr->prev's next pointer

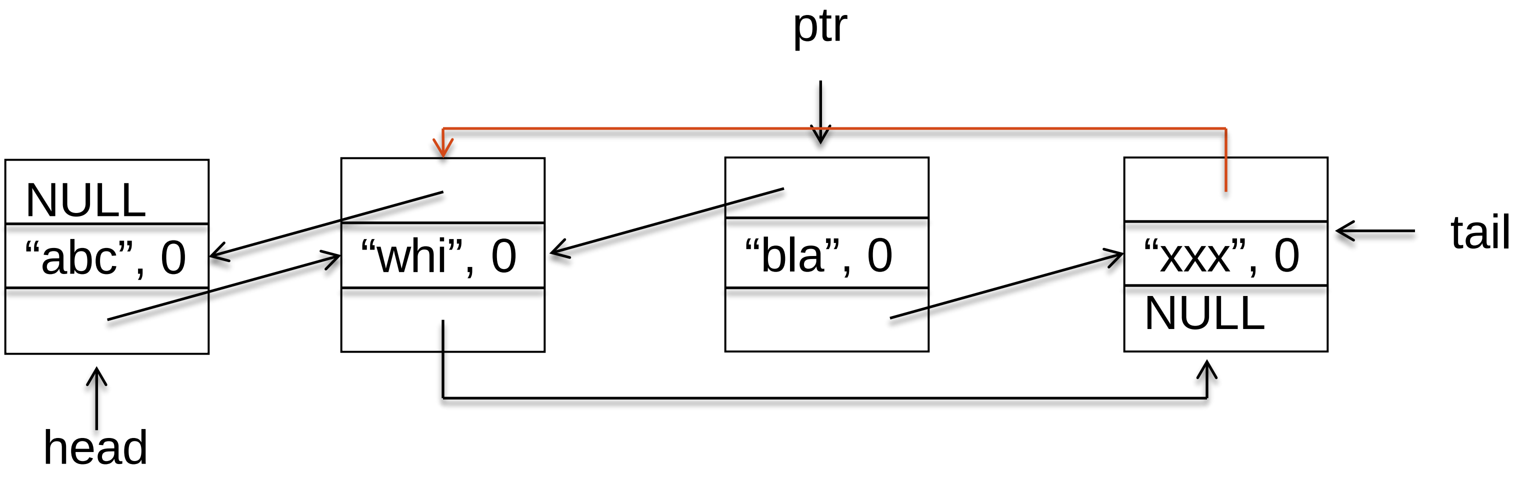
    ptr->prev->next = ptr->next;



# Removemiddle

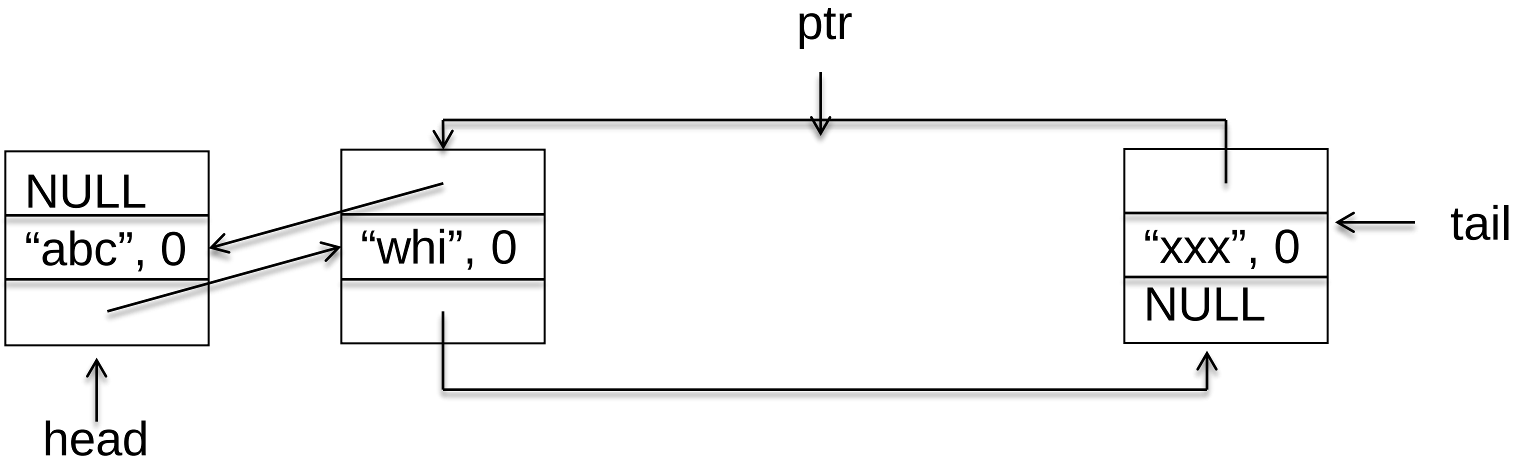
- Remove an item pointed to by ptr
  - Step 2: change ptr->next's prev pointer

    `ptr->next->prev = ptr->prev;`



# Removemiddle

- Remove an item pointed to by ptr
  - Step 3: delete ptr;



# Search

- Use the while loop to walk through every nodes in the list (see mylist.cpp)

```
listnode *t = head;

  while ((t!=NULL) && (t->s != s)) t = t->next;
  return t;
```