
# Linked Lists

## Atomic Operations

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# Linked list: Definition

**Definition of a C structure**

```
typedef struct list_s {
  int key;
  ...
  list_t *next;
} list_t;
```

Key and data fields

Auto-referencing pointer

```
typedef struct list_s list_t;
struct list_s {
  int key;
  ...
  list_t *next;
};
```

# Allocation of a new node

**Memory allocation**

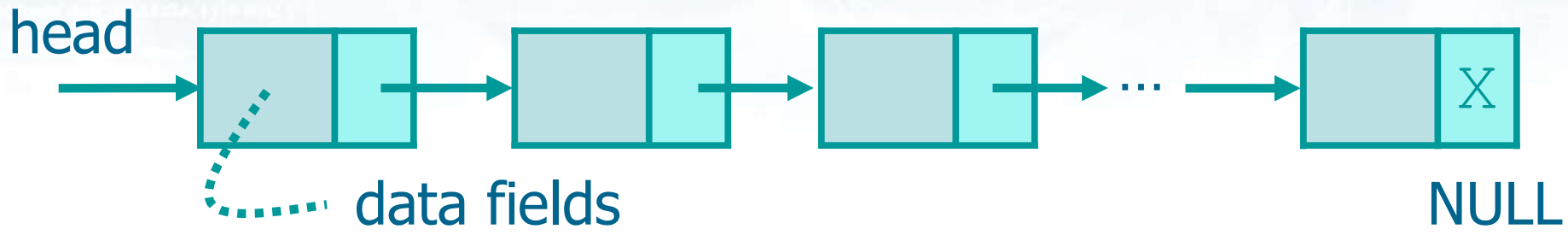
```
list_t *new_element ( ) {
  list_t *e_ptr;
  e_ptr = (list_t *) malloc (sizeof (list_t));
  if (e_ptr==NULL) {
    fprintf (stderr, "Memory allocation error.\n");
    exit (FAILURE);
  }
  return (e_ptr);
}
```

**Function call**

```
list_t *head, *new;
...
head = NULL;
...
new = new_element();
```

Initially the list is empty, thus, **head** must be initially set to NULL

# Visit



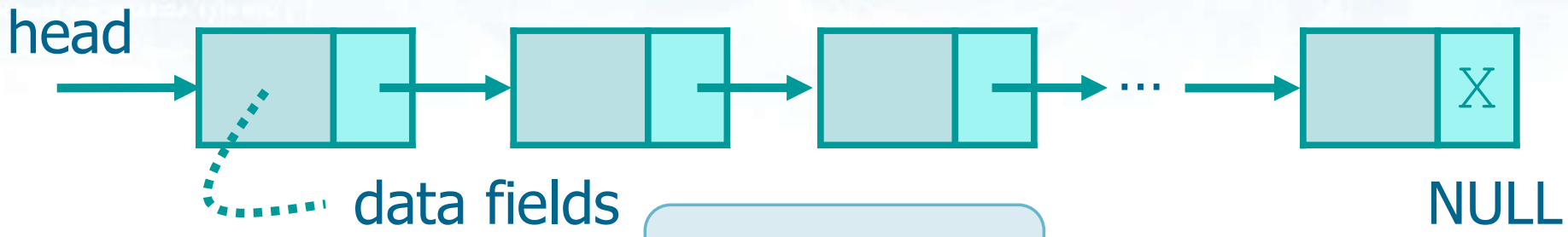

```
list_t *p;
...
p = head;
while (p != NULL) {
   ...
   p = p->next;
}
```

We check up-front, thus the algorithm works even for empty lists

Visit the element p, i.e., p->key and all data fields

Move to the next element

# Search 1



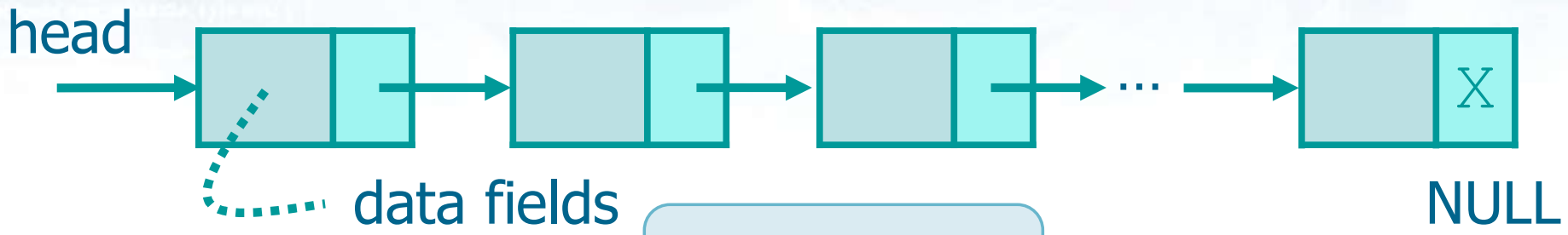

Looking for a specific **value**

```
list_t *p;
...
p = head;
while (p!=NULL) {
  if (value==p->key) {
    ...
  } else {
    p = p->next;
  }
}
```

Element found

Need to break out of the while loop once done

# Search 2



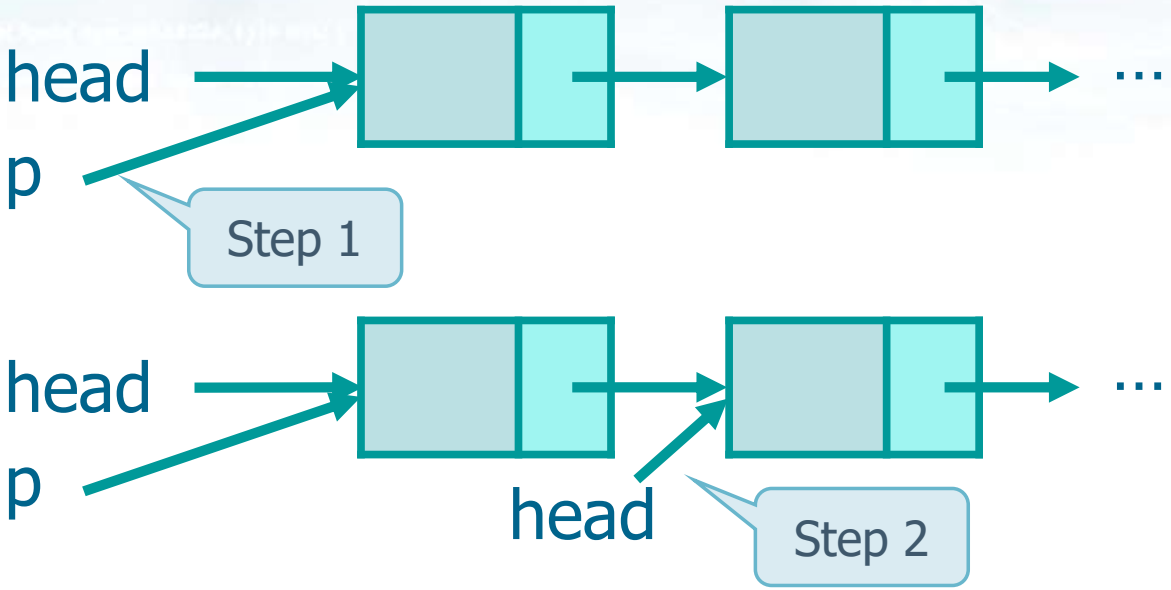

Looking for a specific **value**

```
list_t *p;
...
p = head;
while ((p!=NULL) && (p->key!=value)) {
  p = p->next;
}
if (p!=NULL) {
  ...
}
```

Element found

The order **matter**
`((p!=NULL) && (p->key!=value))`
**is buggy**

# Head extraction

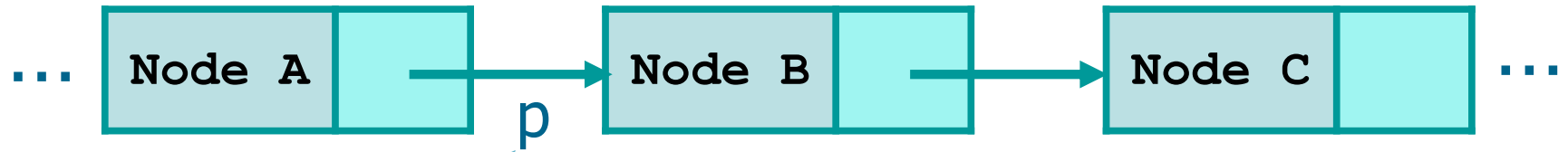



```
        if (head!=NULL) {
Step 1    p = head;
Step 2    head = head->next;
          ...
        }
```

Deal with the element p, i.e., p->key and all data fields. Finally, free it

# In-order extraction

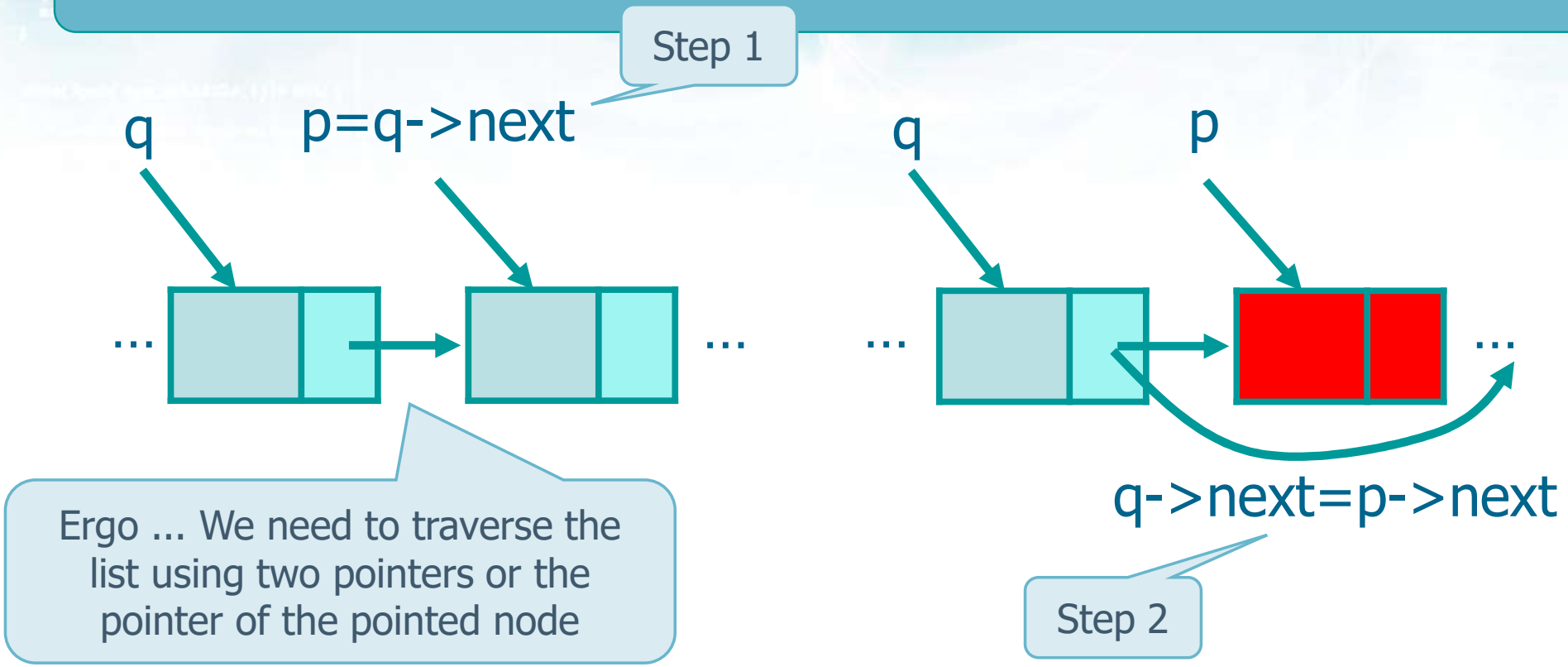
- The extraction of a given element is possible only if we have access to the element placed before it
  - To extract an element we need its pointer
    - This pointer is stored in the element placed in the list before the element
  - For now, we suppose we need to extract the successor of an element
    - We will analyze how to reach it in the next section




With pointer p, we can extract node C not node B

If we visit the list looking for the node to erase, we may be to late to perform the operation

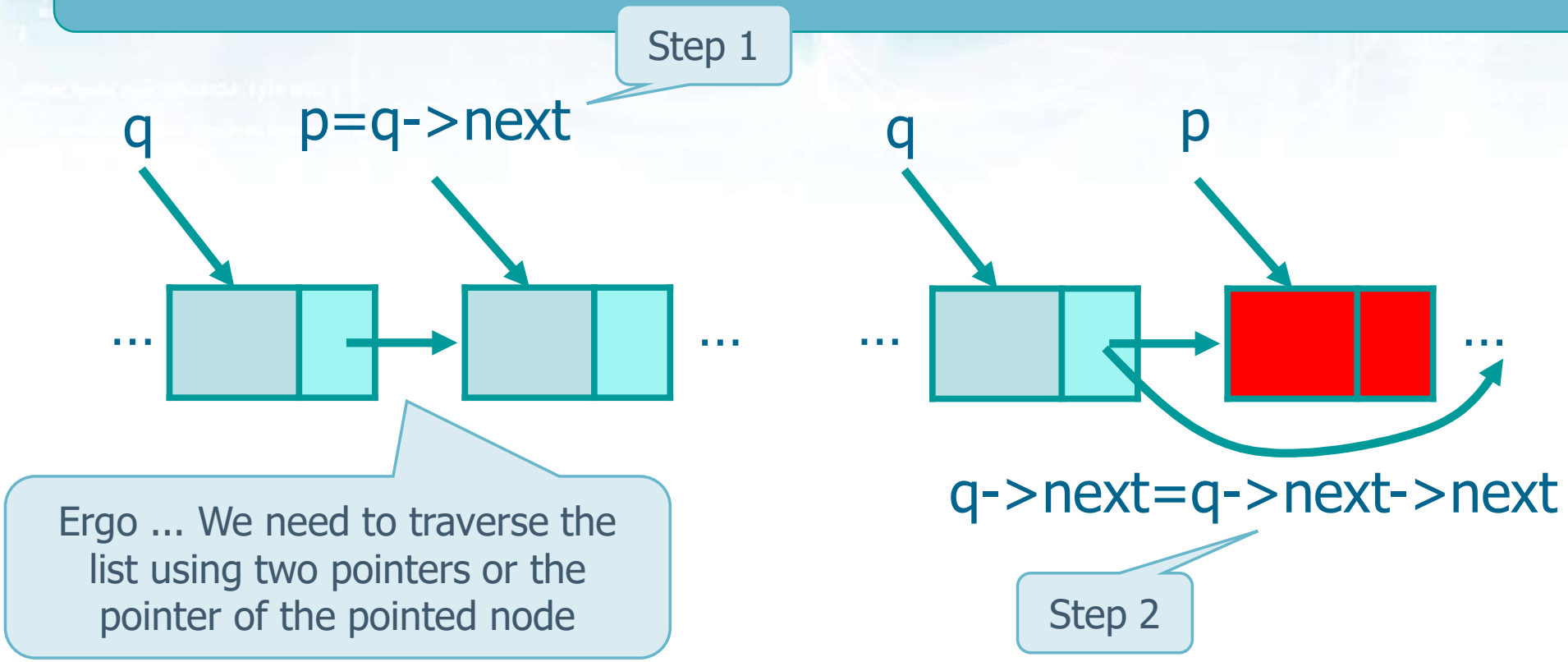
# In-order extraction 1




```
Step 1  p = q->next;
Step 2  q->next = p->next;
        ...
```

Deal with the element p, i.e., p->key and all data fields. Finally, free it

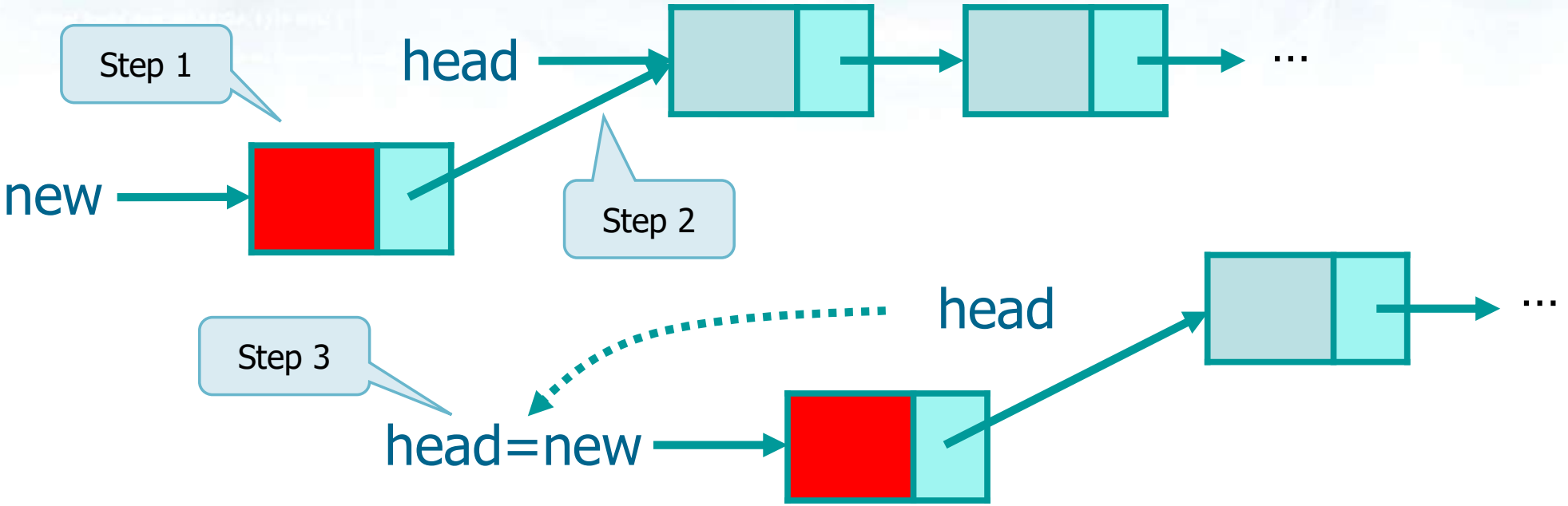
# In-order extraction 2




```
Step 1  p = q->next;
Step 2  q->next = q->next->next;
        ...
```

p is required only to deal with the extracted element

# Head insertion



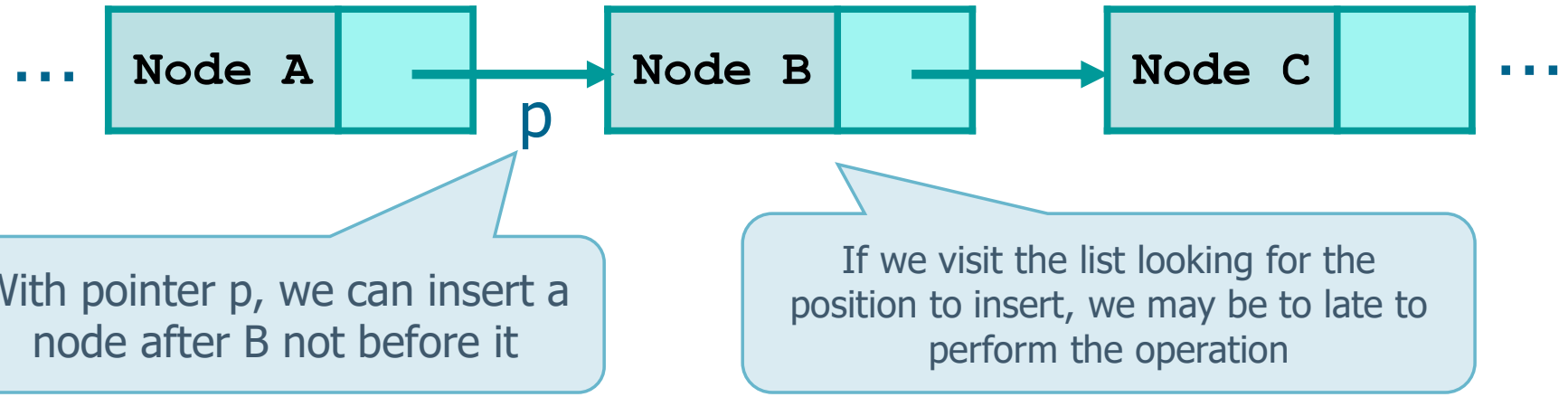

```
Step 1  new = new_element();
        ...
Step 2  new->next = head;
Step 3  head = new;
```

Set key and data fields
(possibly using strcpy, strcat, etc.)

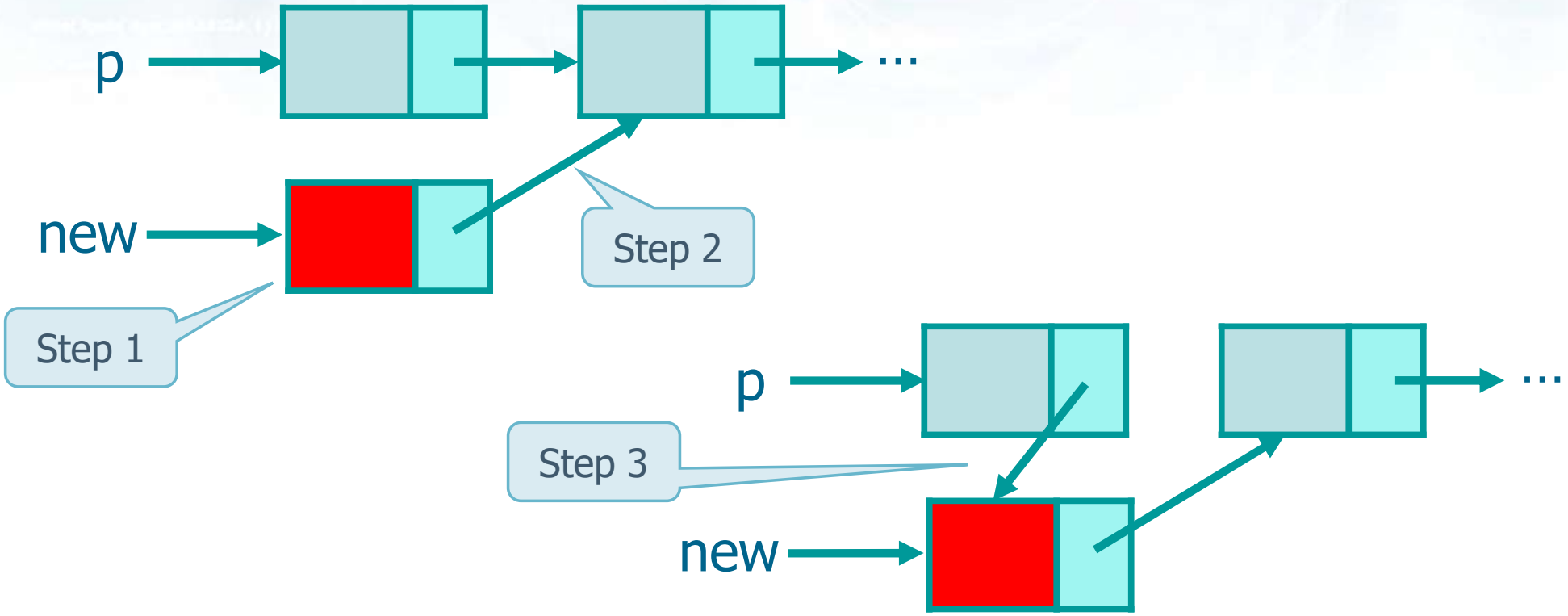
Does it work if the lists is empty?
Yes, it does ...
If the list is empty head=NULL,
then p->next will be NULL

# In-order insertion

- Similarly to the extraction case, to insert a new element before a given element p, it is necessary to access the pointer field within the element coming before p
- Thus, we focus on the insertion of a new element after (not before) an existing element p
  - We will analyze how to reach it in the next section



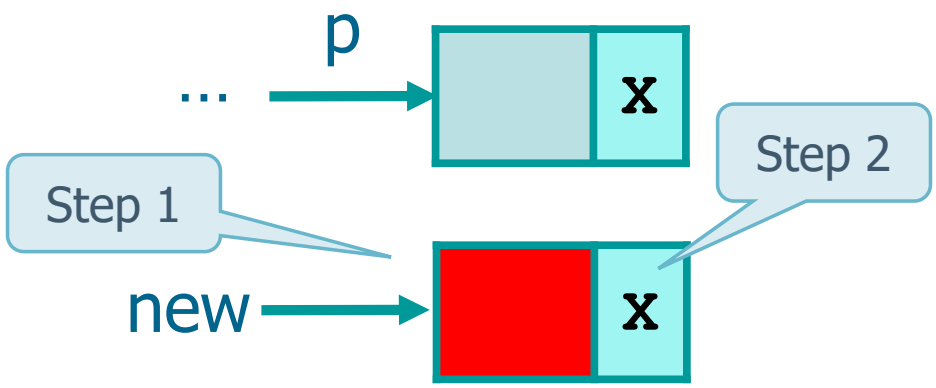
# In-order insertion

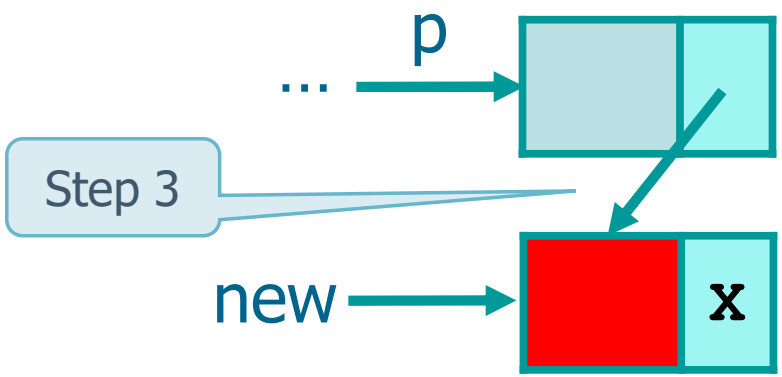



```
Step 1  new = new_element();
        ...
Step 2  new->next = p->next;
Step 3  p->next = new;
```

# Tail insertion

- If it is necessary insert an element into the list tail, i.e., as a last element
  - Just use the previous code after making **p** referring to the last element of the list

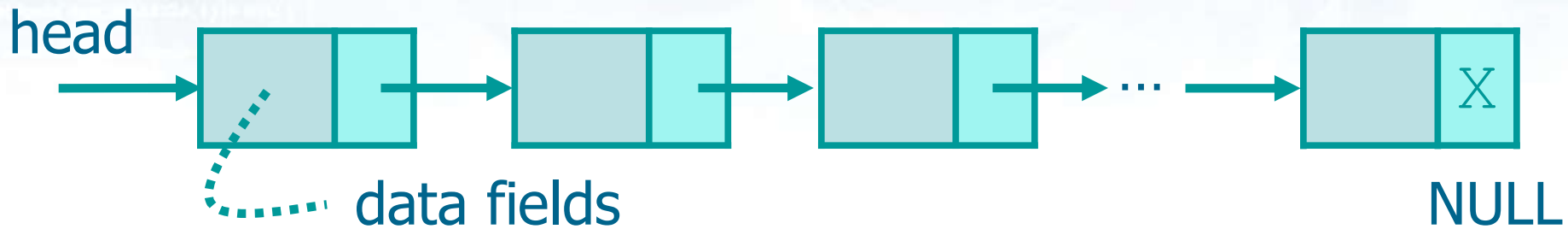



```
Step 1  new = new_element();
        ...
Step 2  new->next = p->next;
Step 3  p->next = new;
```

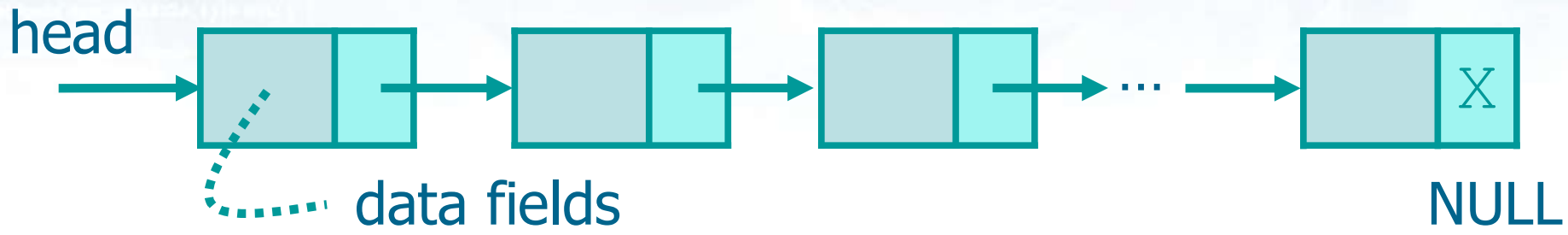
The only difference is that p->next is NULL

# Dispose a list




- Lists must be freed when they are no longer necessary
  - To free a list, we must visit it and free its elements one by one

# Dispose a list

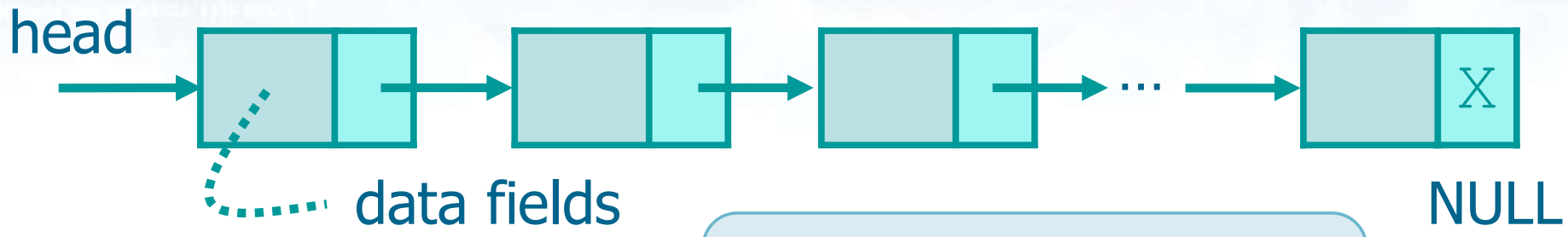



```
p = head;
while (p != NULL) {
   ...
   free (p);
   p = p->next;
}
head = NULL;
```

First, free inner fields
Then free the element itself

Buggy code
With **p = p->next**, we make an access to the **next** field of a freed element

# Dispose a list




We can use **head** directly to visit the list and p can be dedicated to extracted elements

```
while (head != NULL) {
  p = head;
  head = head->next;
  ...
  free (p);
}
```

First, free inner fields
Then free the element itself

# Lists with special elements

- Several operations on lists can be simplified using the so called **sentinels**
  - A sentinel (also called signal value, or dummy value, or flag value) is often used to indicate the **end** or the **beginning** of the list
  - There are at least three type of extensions using sentinels, as sentinels can be used on
    - The head of the list
    - The tail
    - On both the head and tail

# Example

List search

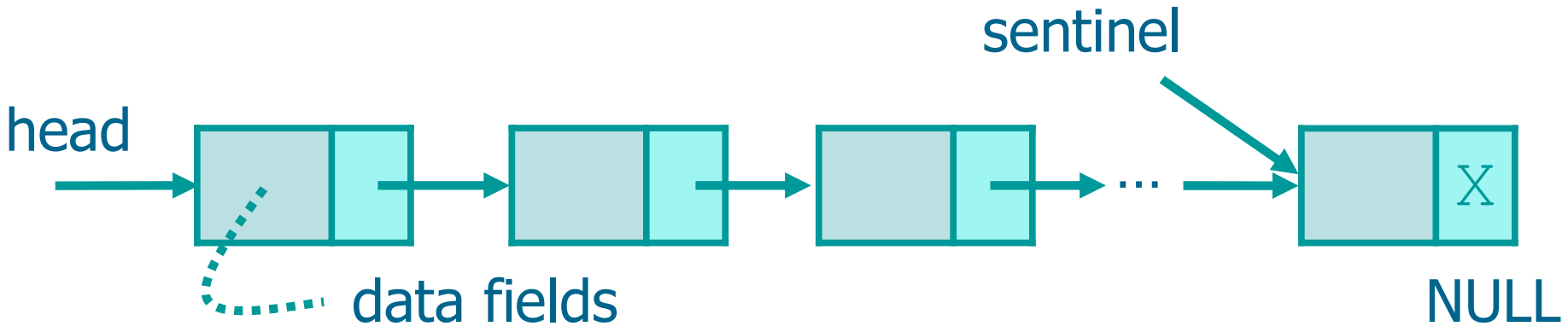
```
p = head;
while ((p!=NULL) && (p->key!=value)) {
  p = p->next;
}
if (p!=NULL) {
  ...
}
```

The **value** has been found

- Searching for an element implies checking 2 conditions
  - p does not have to be NULL **and** it does not have to refer to the node storing value
  - Checking the logical AND of two conditions is more expensive than checking only one condition

# Lists with special elements

- We insert a sentinel element at the end of the list
  - We always have at least one element in the list, i.e., the sentinel
    - We waste a small chunk of memory
  - We can use the extra element to store the value we are looking for
  - Thus, we can simplify the search condition



- We need to maintain sentinel in all cases fromthe list initialization on

# Lists with special elements

```
sentinel->key = value;
p = head;
while (value!=p->key) {
  p = p->next;
}
if (p!=sentinel) {
  ...
} else {
  ...
}
```

At the very beginning, we insert the value in the sentinel

Thus, **value** is always in the list and we can simplify the condition

value found

value **not** found

- We need to maintain the sentinel in all cases from the list initialization on