ECE 220

Lecture x0011 - 10/24/24

Linked Lists - Introduction

Announcements

- Same as last class
  - Exam next week
  - HKN review session
  - Conflict exam request deadline

Recap

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- Last time we discussed:

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  - Automatic vs. dynamic memory allocation

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  - Allocating 2D arrays
  - Memory leak vs. seg-faults
  - `valgrind` to detect memory leaks.

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  - A **list** is collection of *elements/items* which can be accessed sequentially.
  - Entertains the concept of ***order***; first, second, last.
  - Note: An empty list is still a list.
- An **array** is an *indexed* list; i.e. can access elements by their index.

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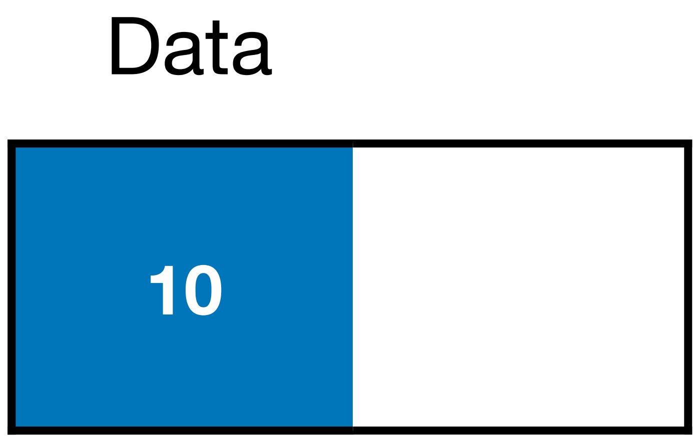
    - A ***data*** part that stores the actual element



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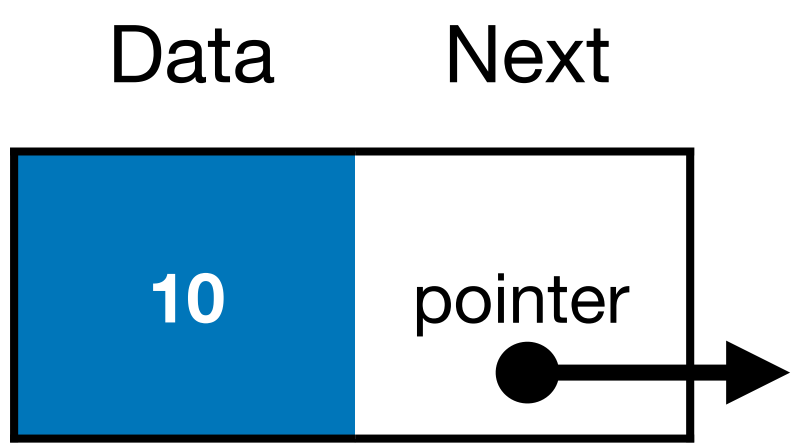

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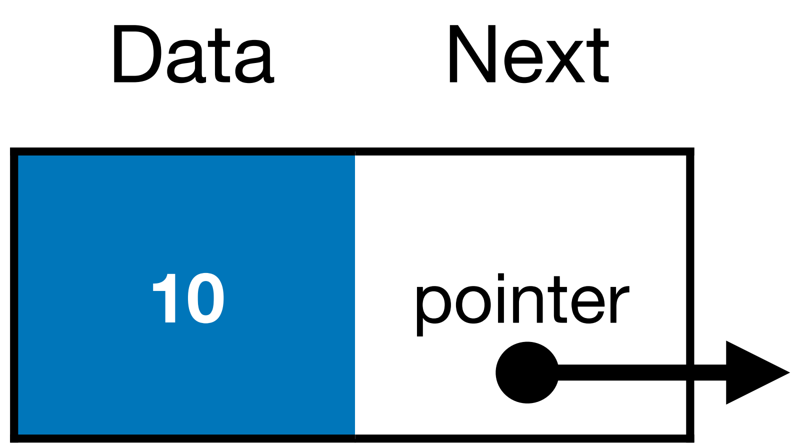
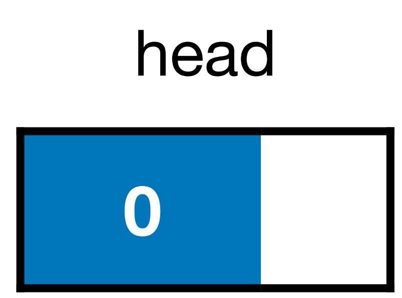


Node

Linked list

Linked list



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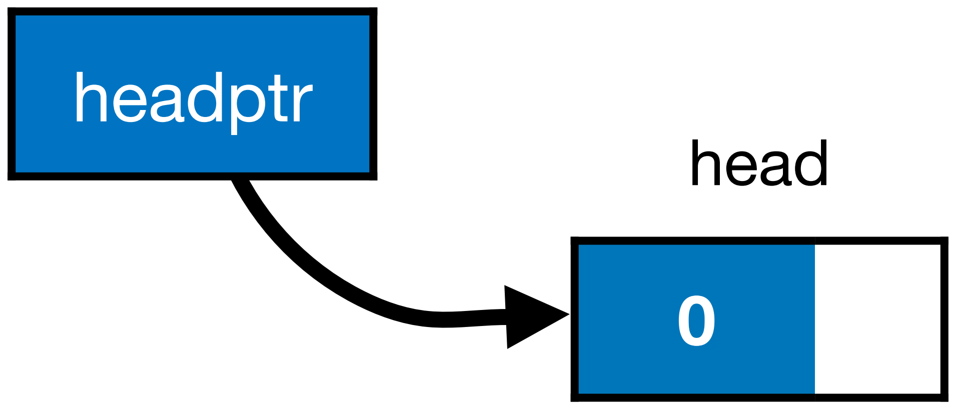
Linked list



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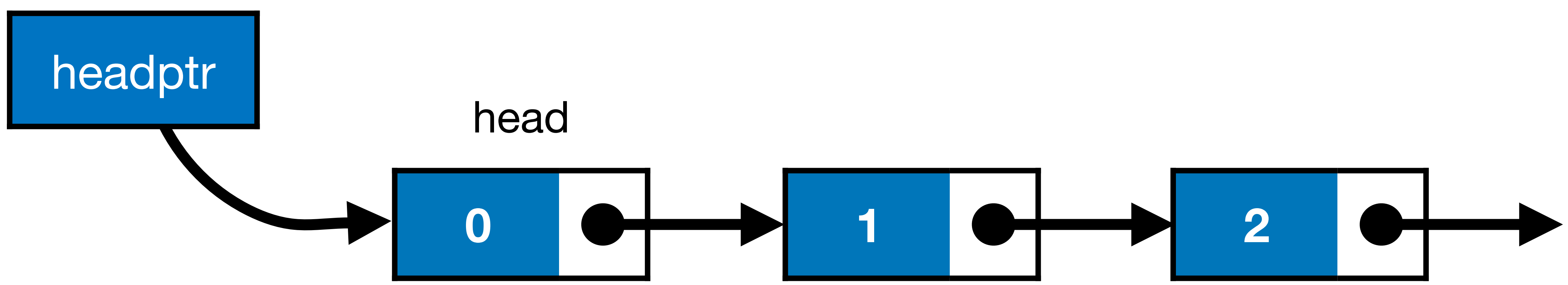

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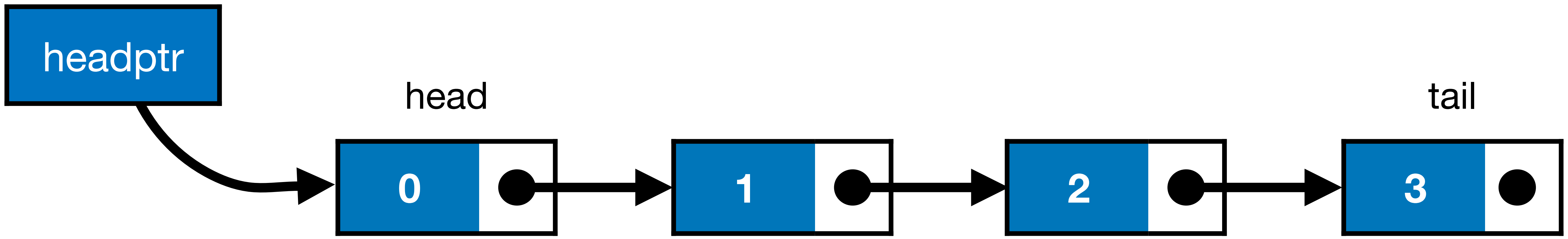

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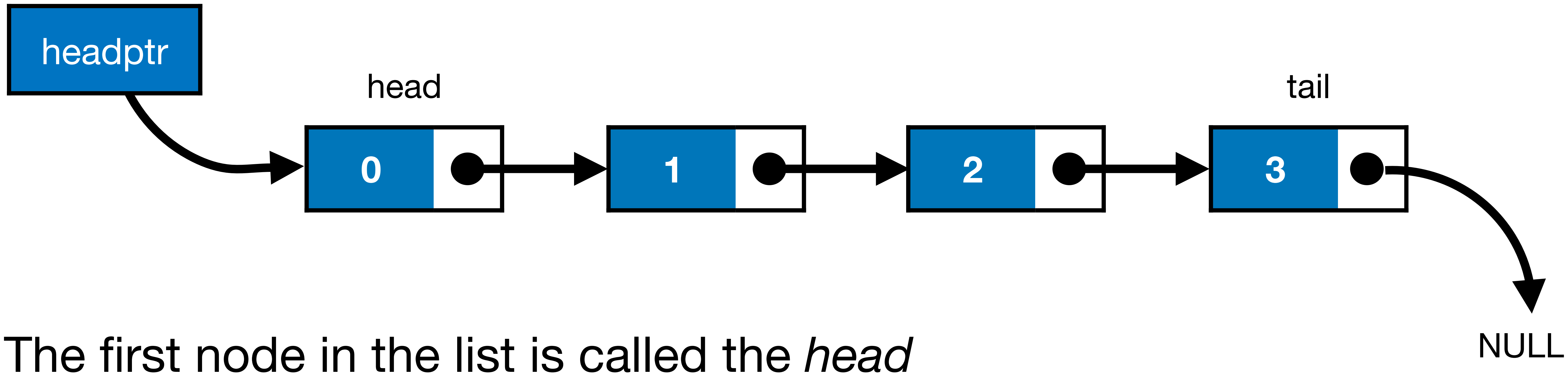

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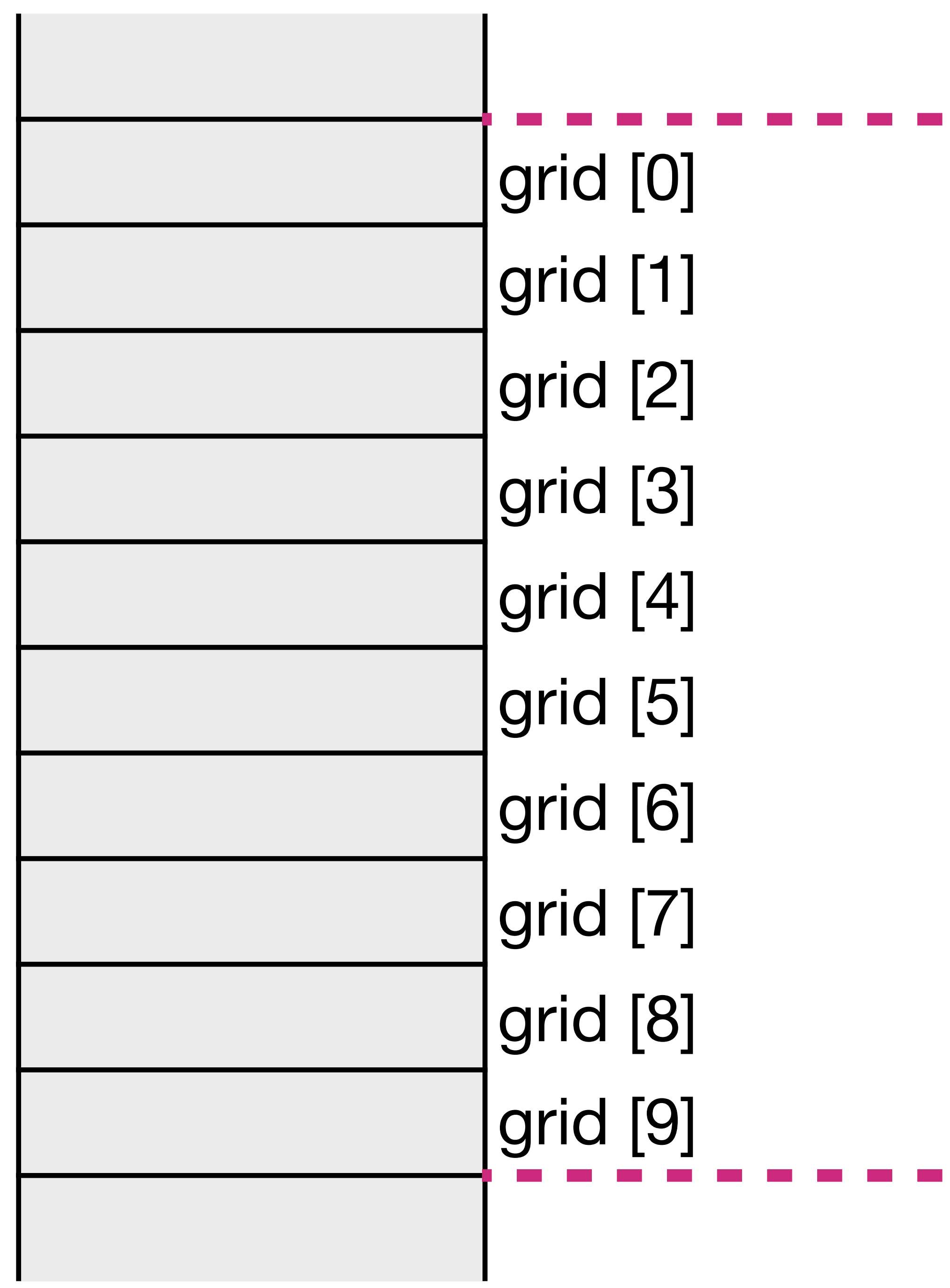
    - Accessed using pointer called ***head pointer***
    - Used as the starting reference to *traverse* the list
- The last node in the list is called the *tail*.
    - The tail may contain data, but it always points to NULL value

Array vs. linked list

Array vs. linked list

Array
(can be automatic or dynamic)

Array vs. linked list



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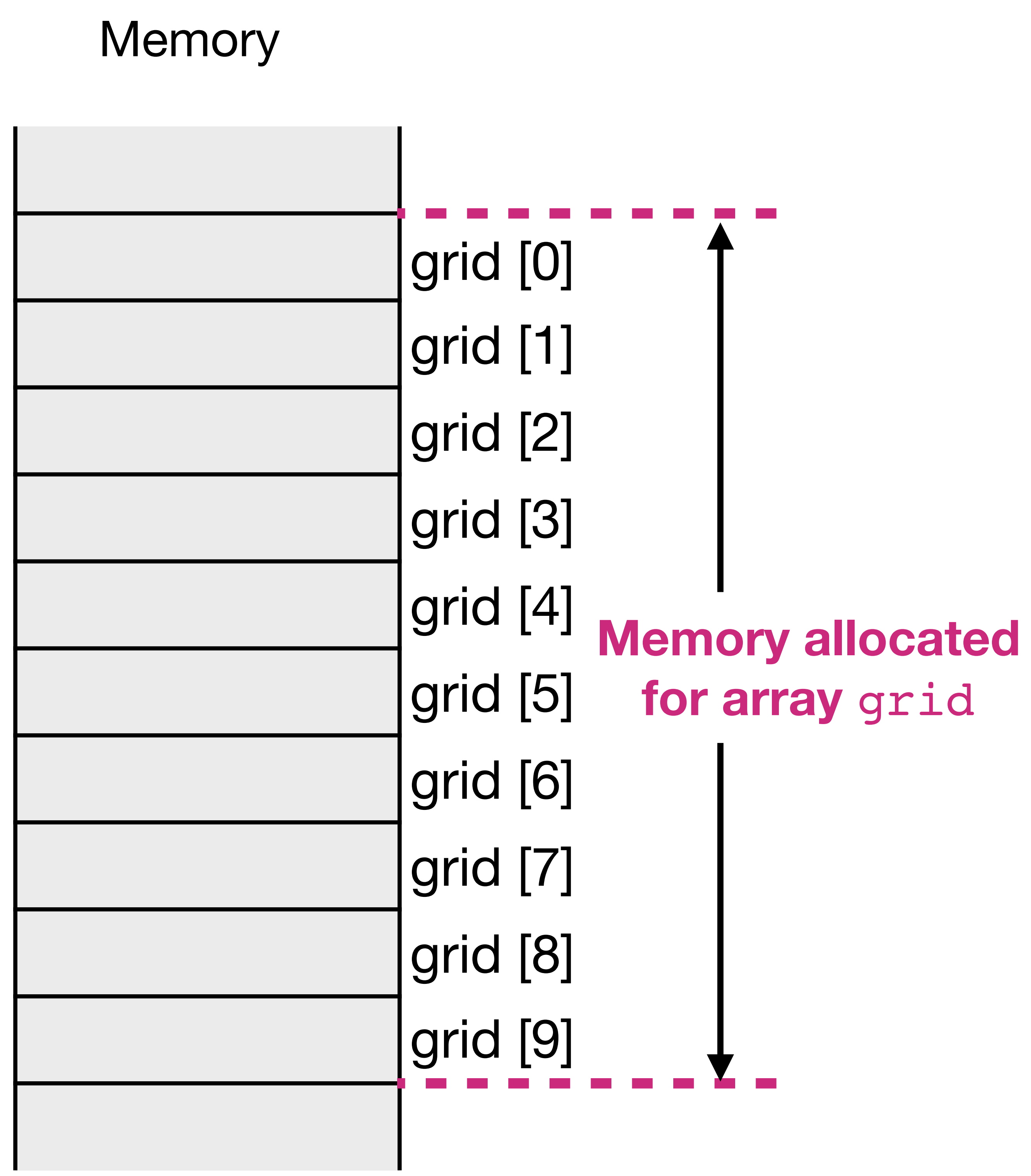

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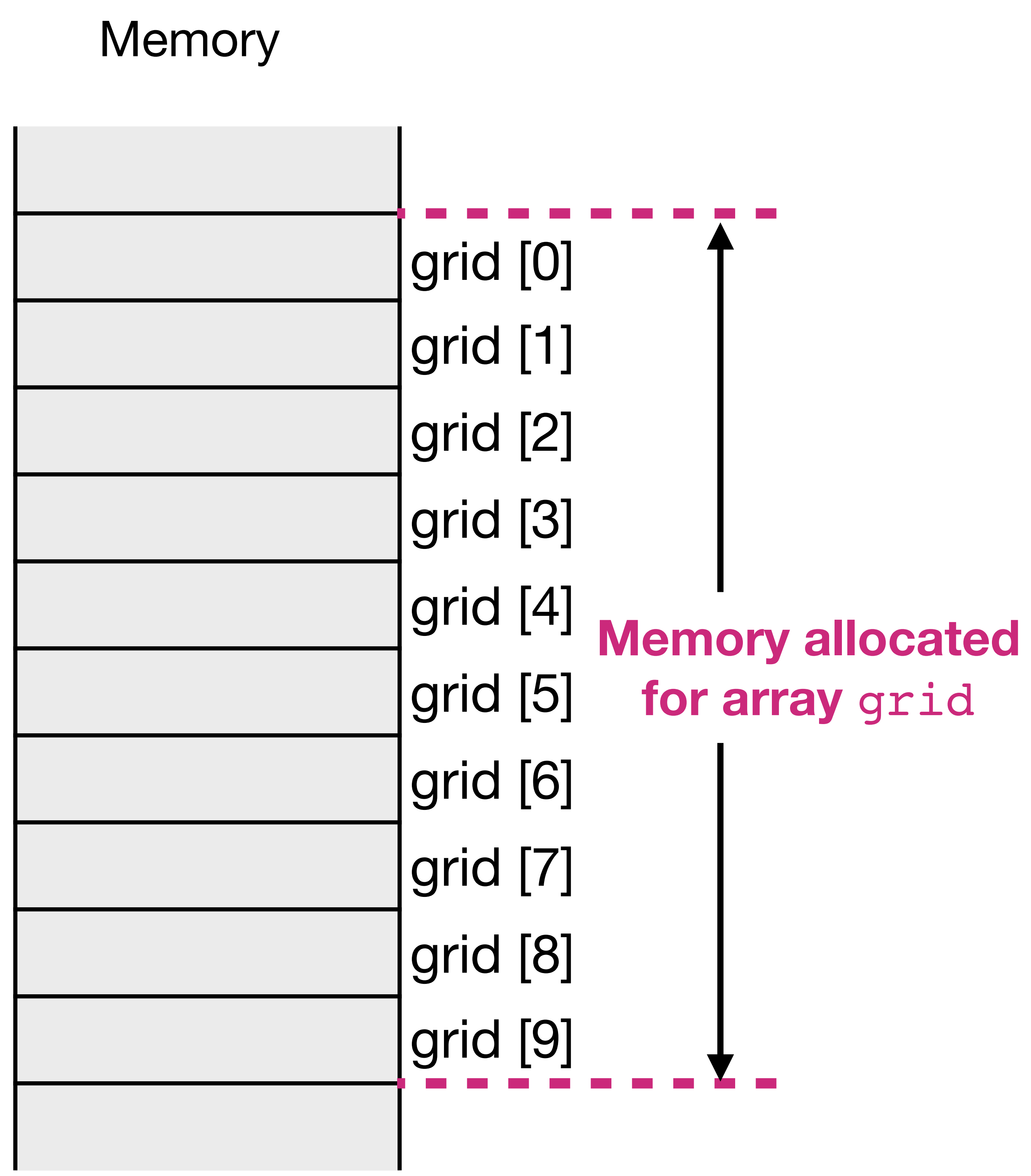

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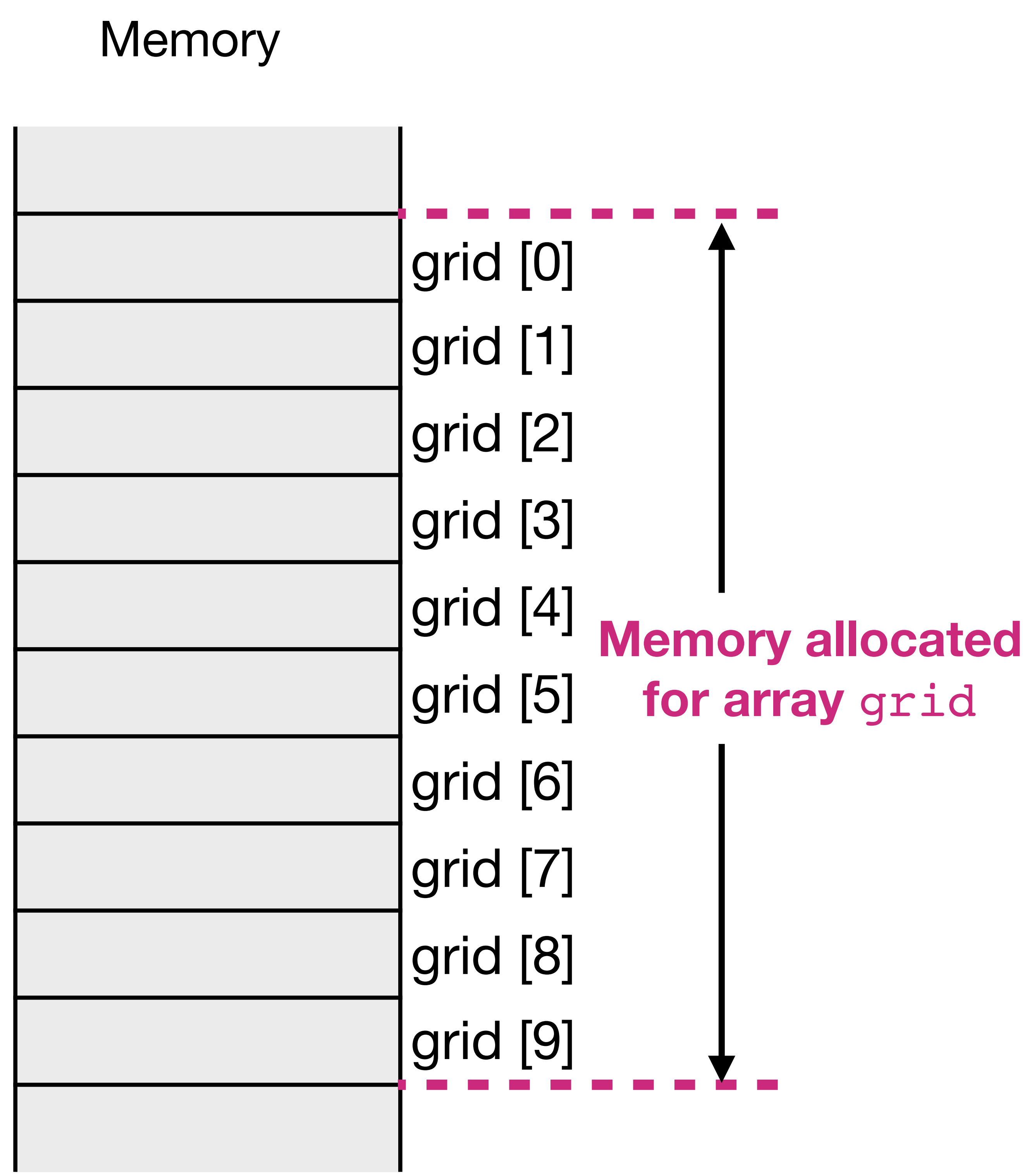

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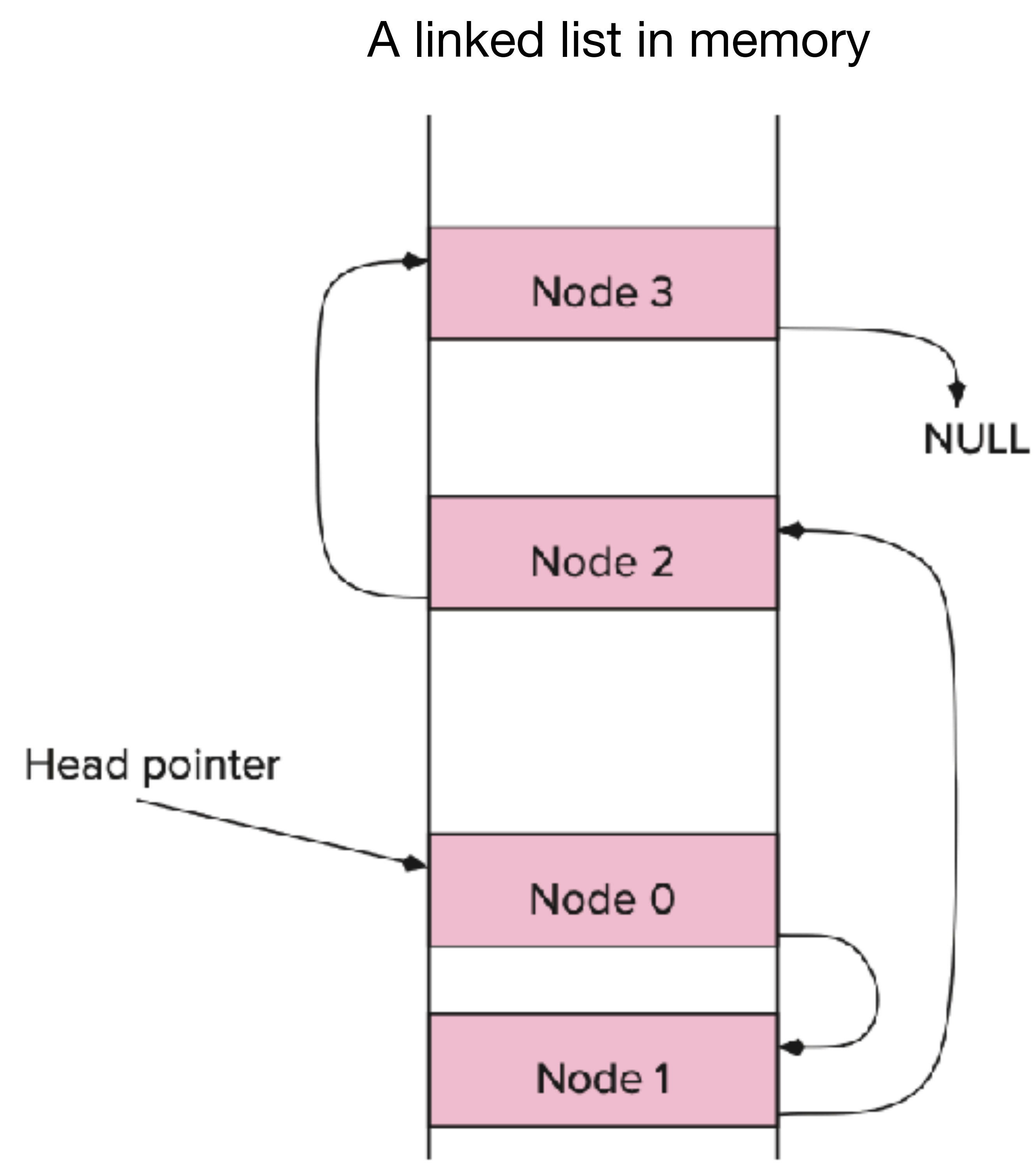

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Memory Allocation	**Automatic / Dynamic**	**Dynamic**

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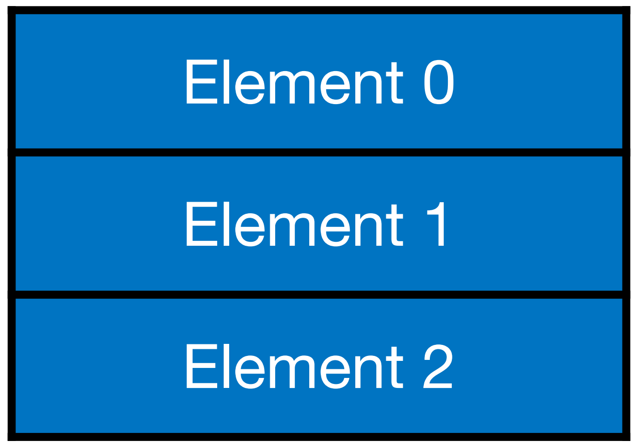

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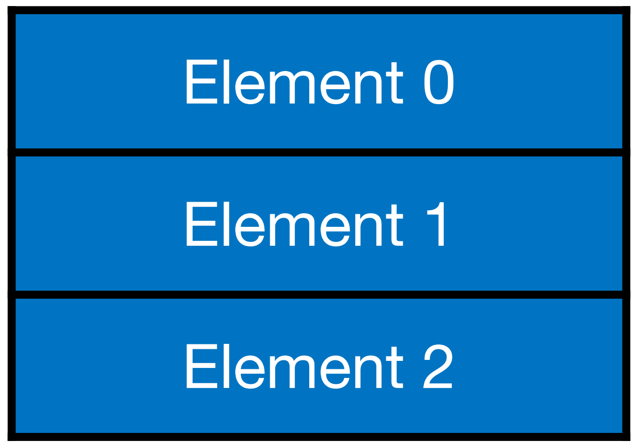

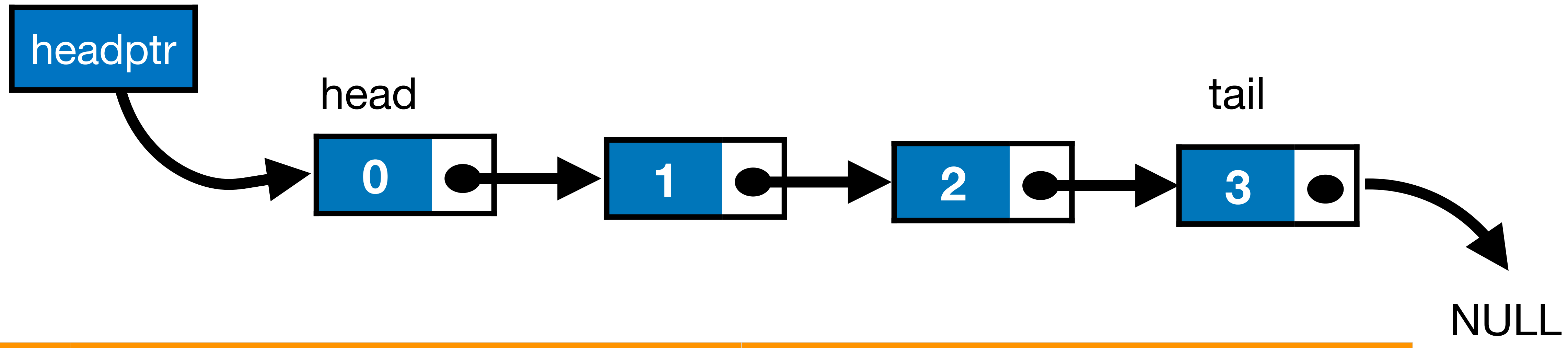

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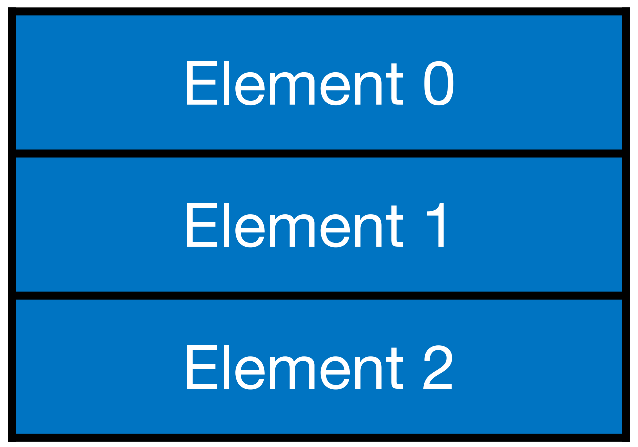

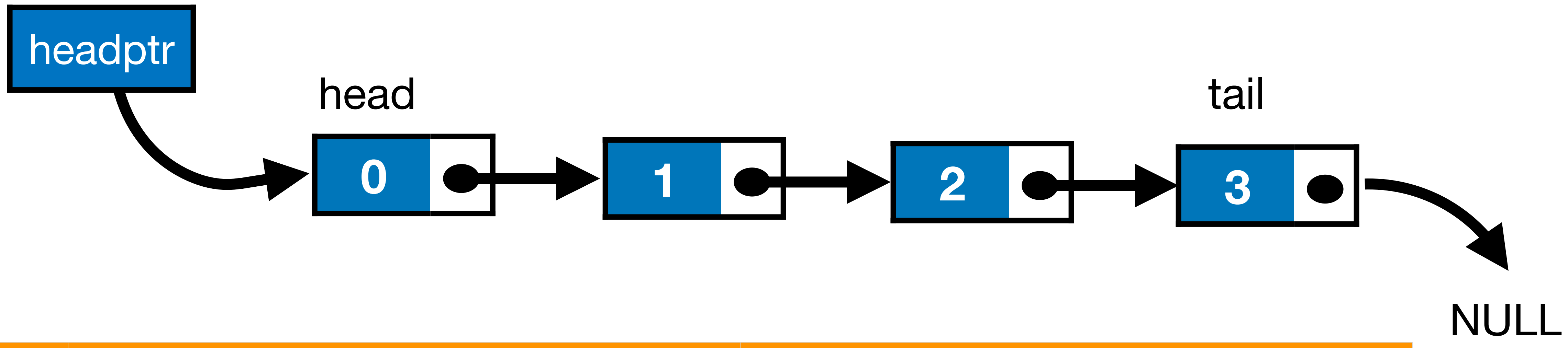

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Memory Allocation	**Automatic / Dynamic**	**Dynamic**
Memory Structure	**Contiguous**	**Not necessary consecutive**

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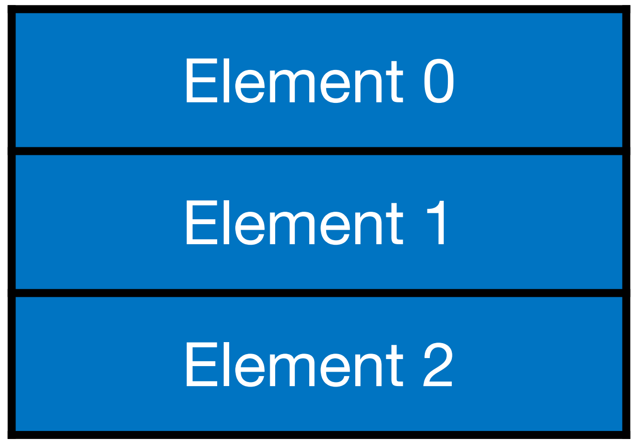

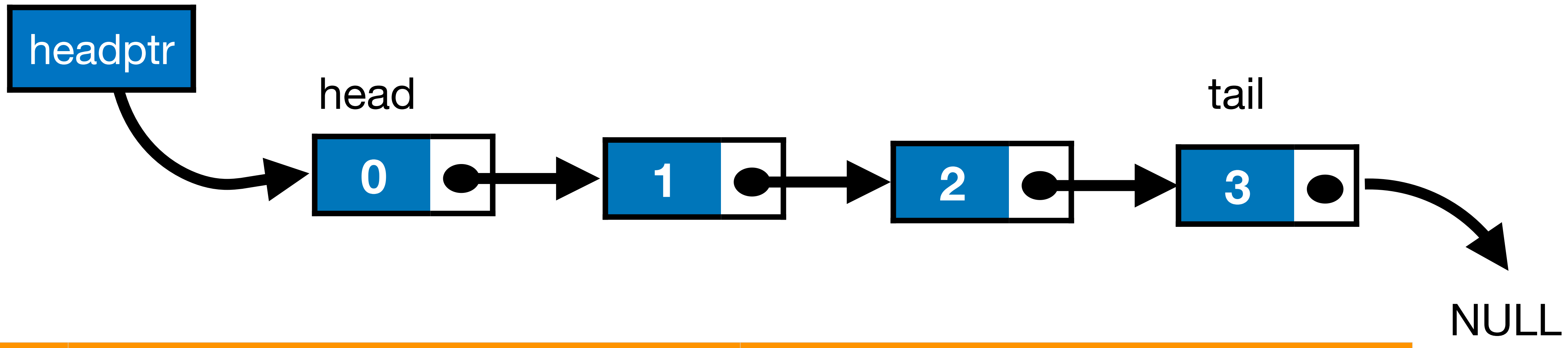

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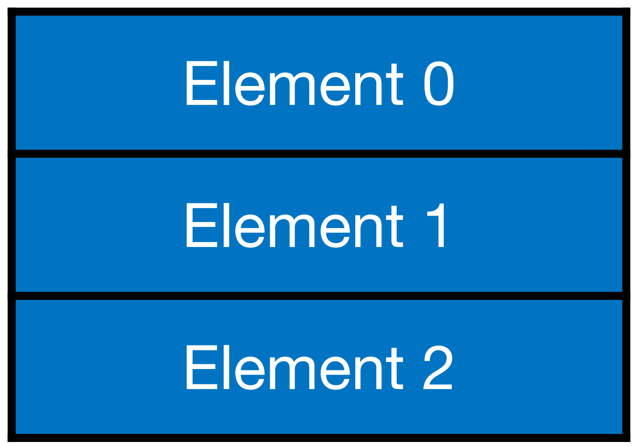

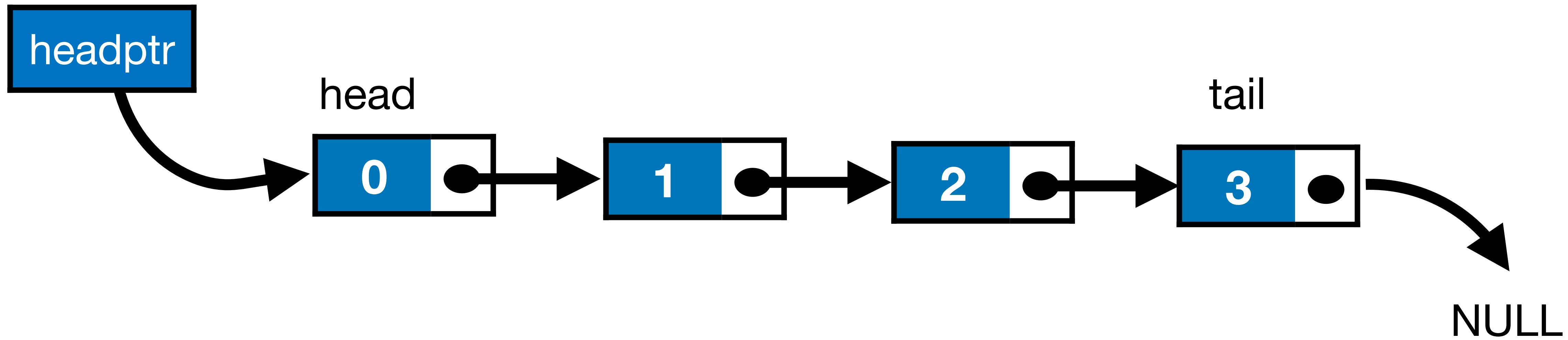

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Memory Allocation	Automatic / Dynamic	Dynamic
Memory Structure	Contiguous	Not necessary consecutive
Order of Access	Random	Sequential
Insertion / Deletion	Create/delete space, then shift all successive elements	Change pointer address

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    float GPA;
    struct StudentStruct *next;
}node;
```

Using linked lists

Declaring a linked list

Example: A person

```
typedef struct person{
    char *name;
    unsigned int birthyear;
}Person;
```

```
typedef struct person{
    char *name;
    unsigned int byear;
    struct person *next;
}node;
```

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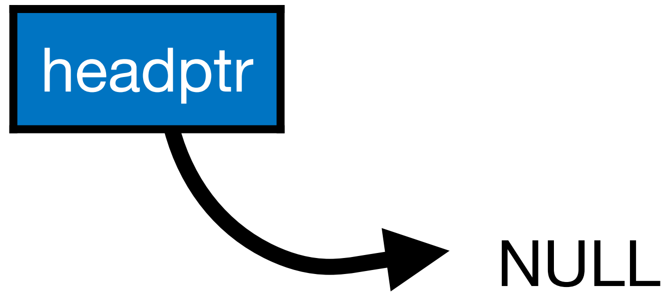

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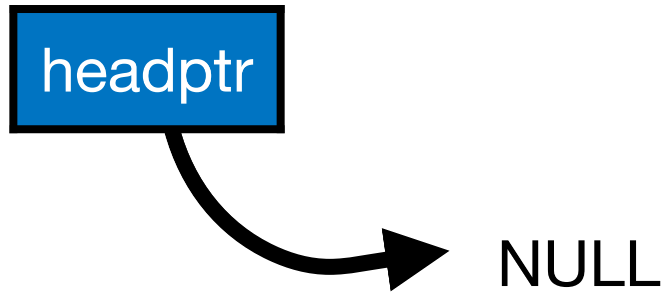


```
typedef struct person{
    char *name;
    unsigned int byear;
    struct person *next;
}node;

node* headptr = NULL;
```

Declaring a linked list

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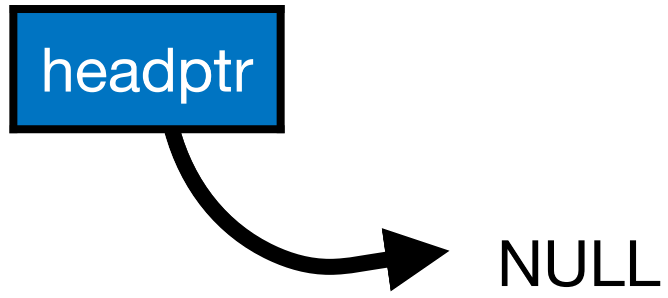

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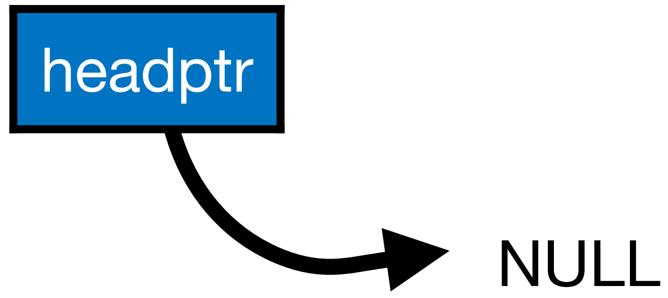

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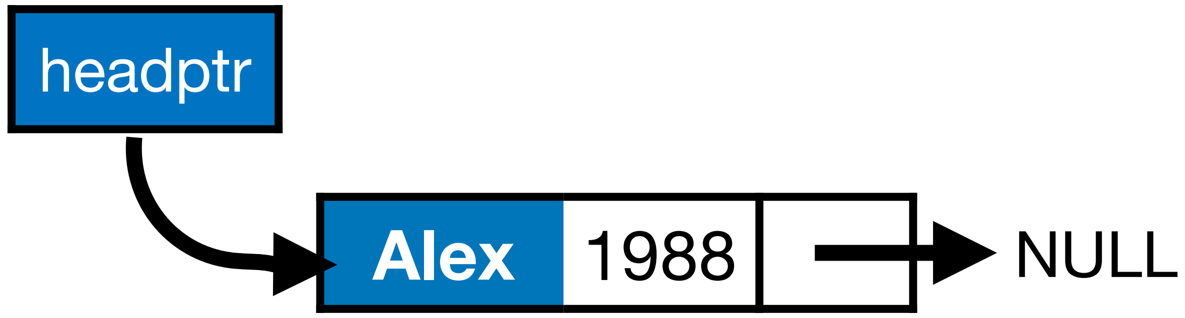


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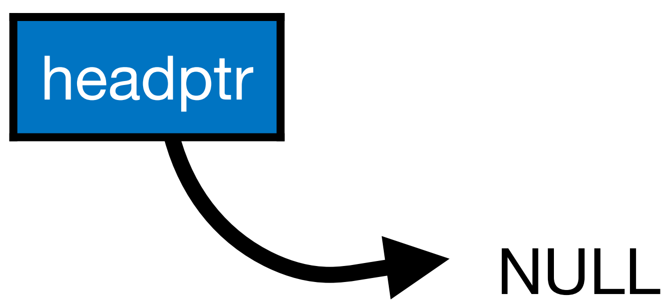

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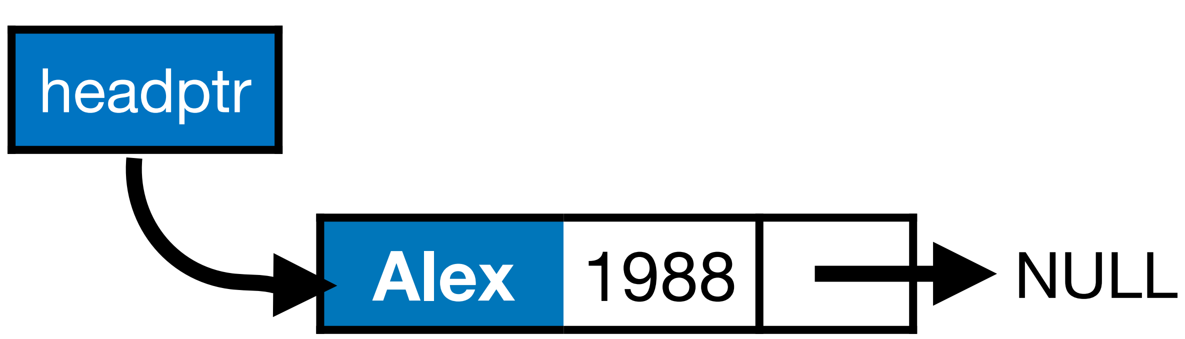


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typedef struct person{
    char *name;
    unsigned int byear;
    struct person *next;
}node;

node* headptr;
node* temp=(node*) malloc(sizeof(node));
temp->name="Alex"
temp->byear=1988;
temp->next=NULL;
headptr = temp;
```

Linked lists - more elements

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  - Unsorted list: Can insert at *head* or at *tail*
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- Deleting an item from the list
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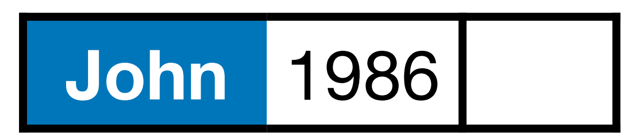

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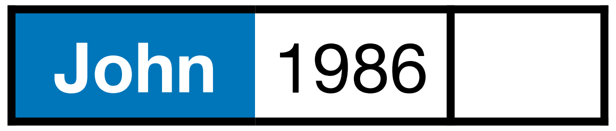

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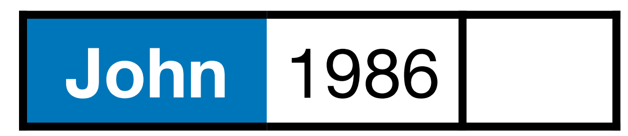

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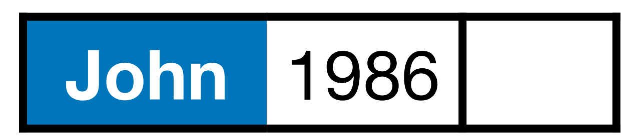

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    - For plain linked lists, we get to choose.

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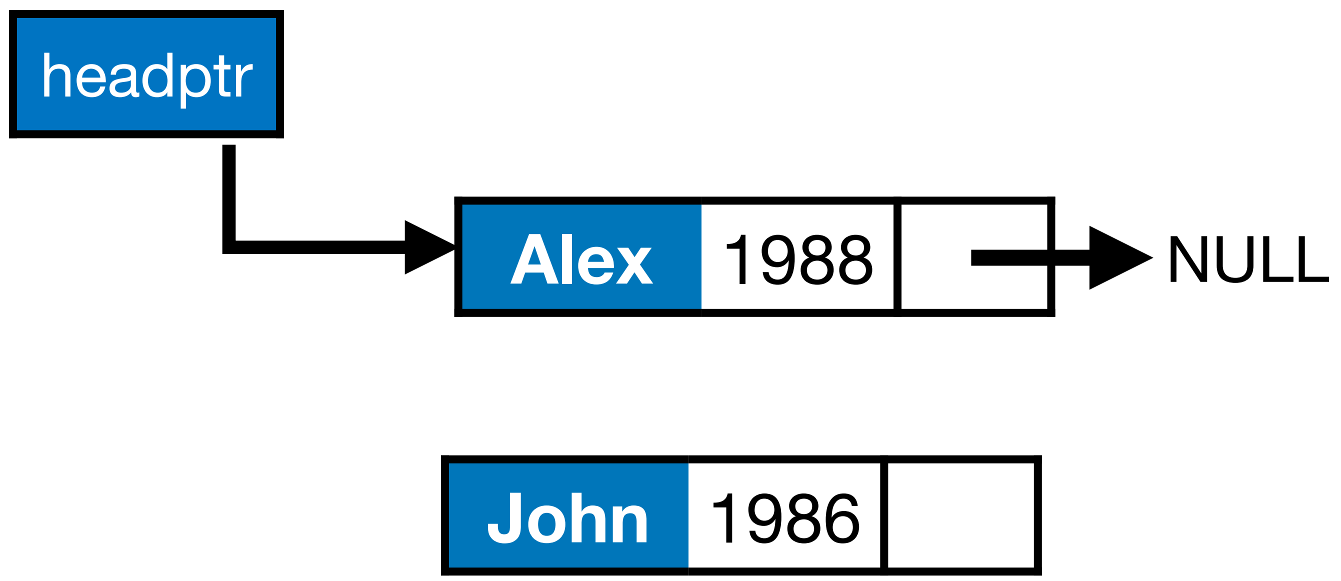

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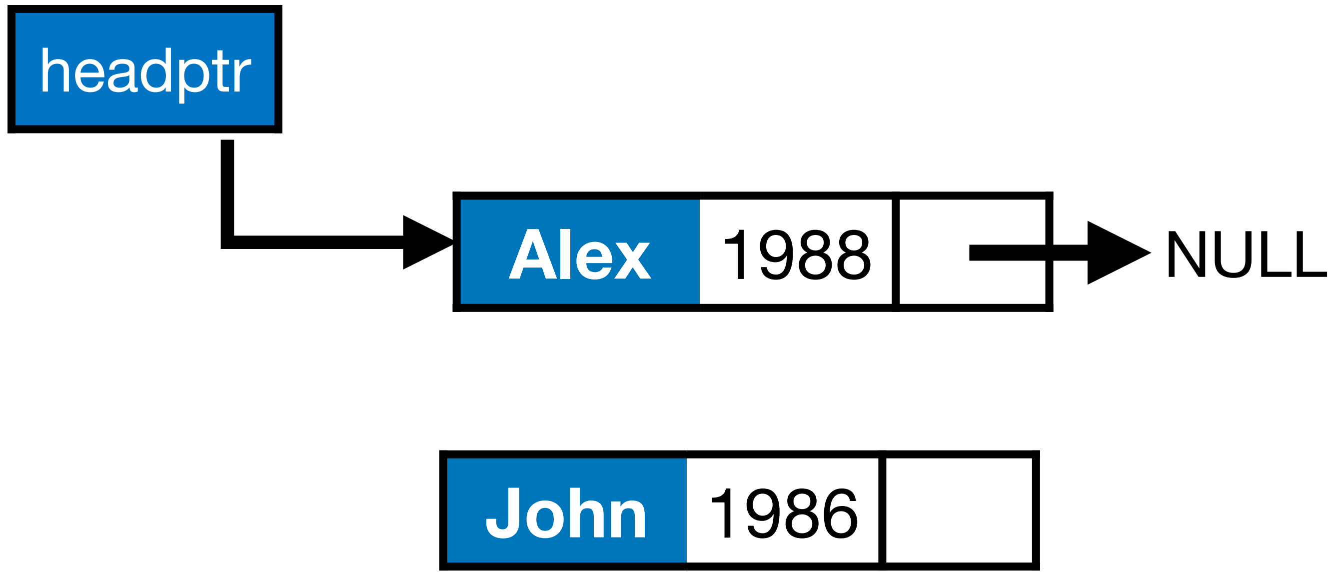

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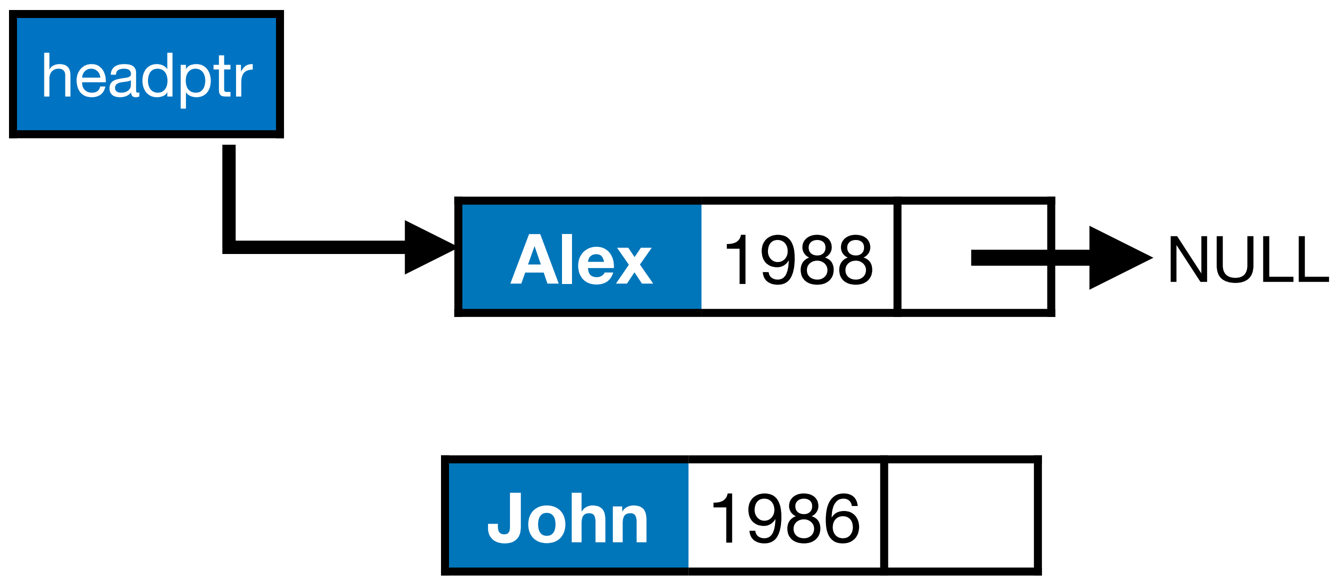

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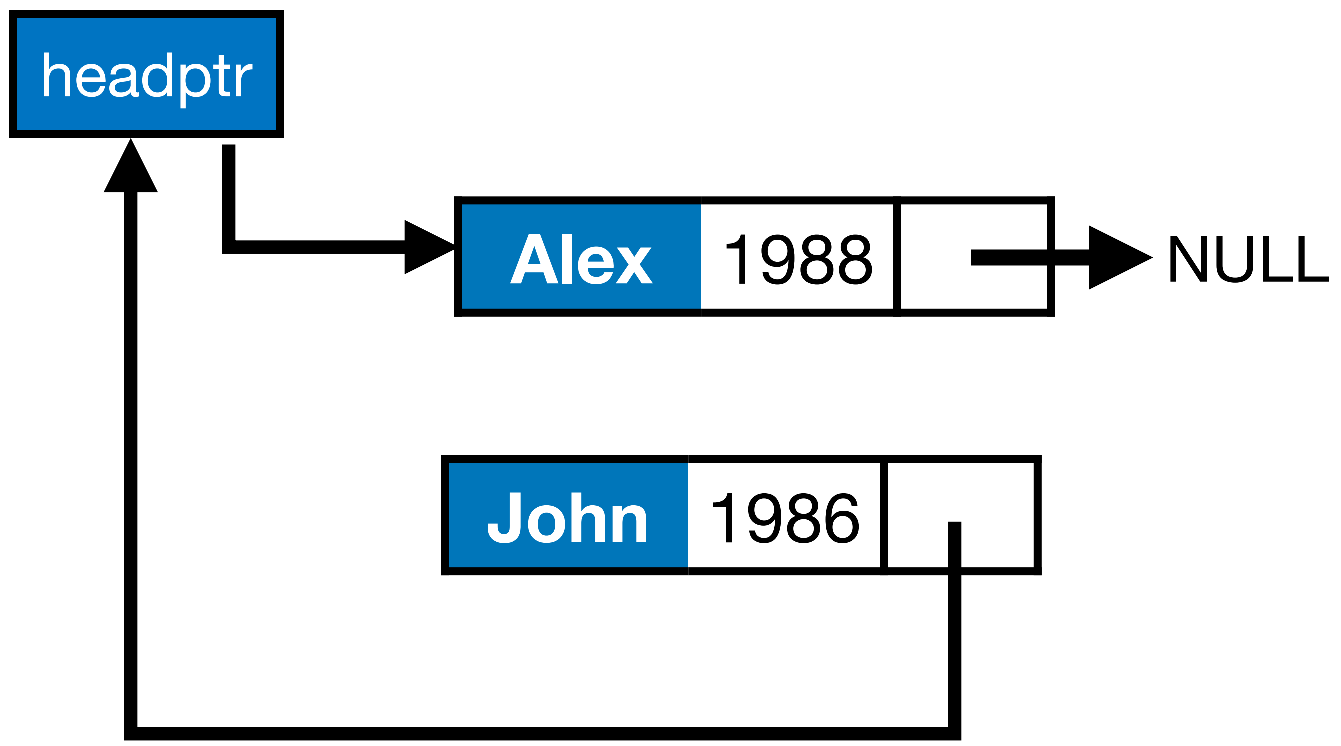

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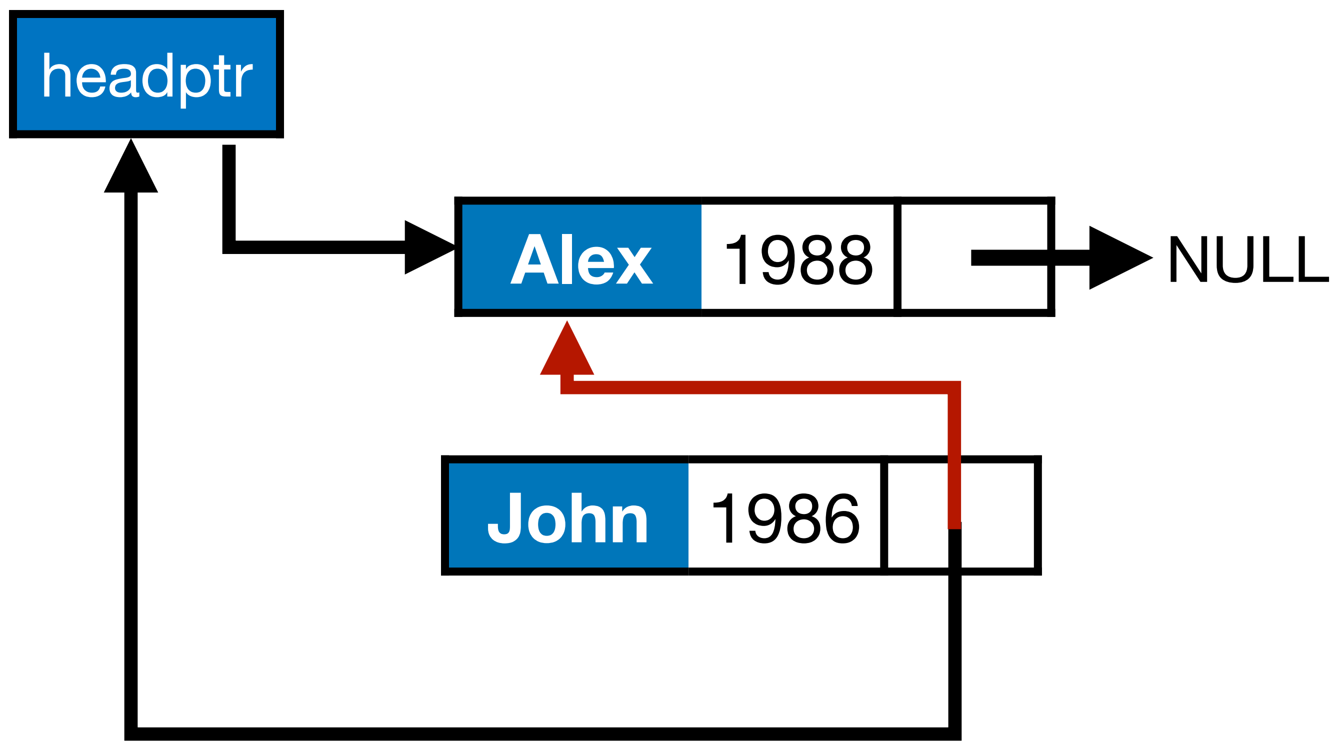

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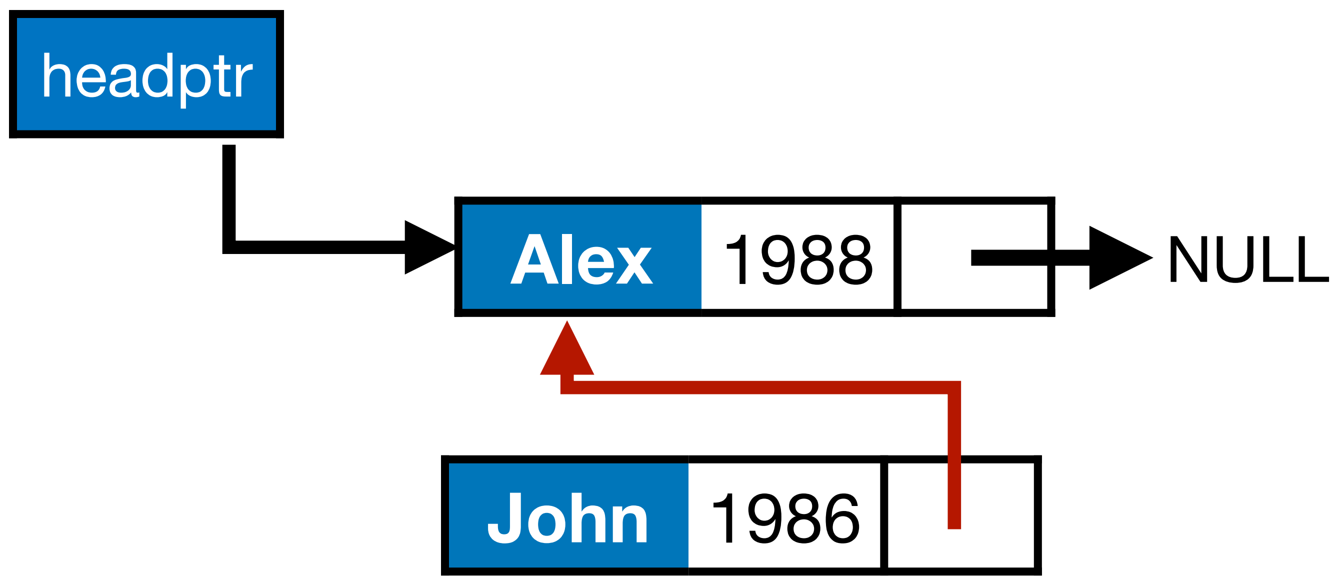

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  - Delete from head, tail or middle.

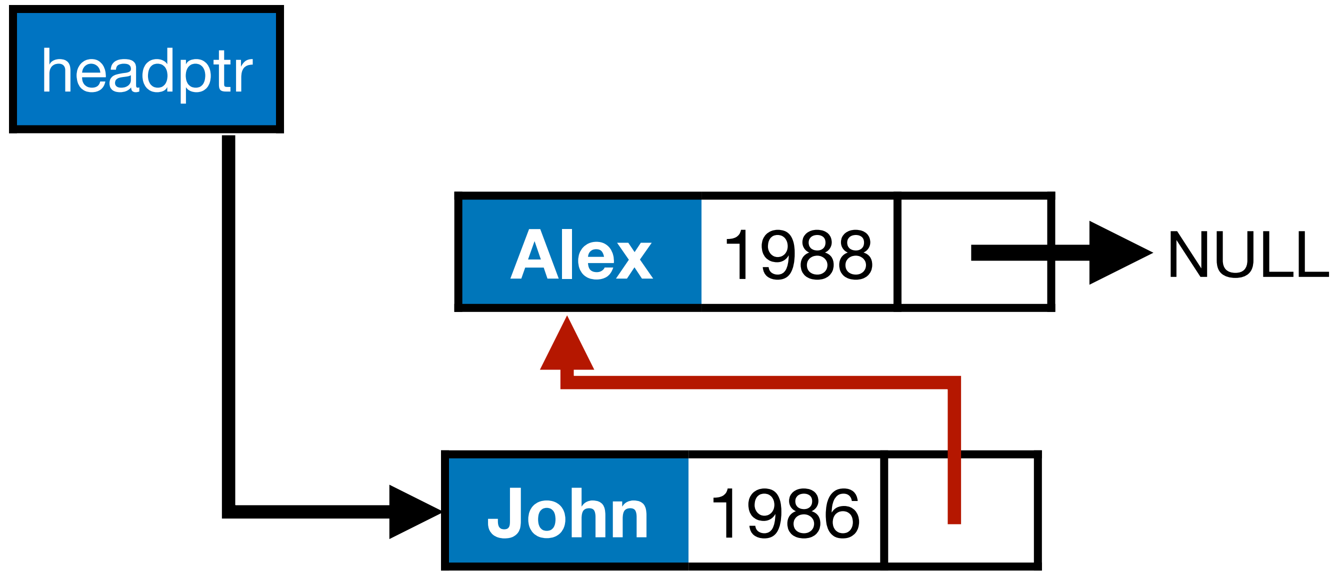
Linked lists - adding a node

- Suppose we want to **add at head.**

- What needs to be done?

  - New node should point to current head.

  - Current head should be updated to new node.



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node* temp=(node*) malloc(sizeof(node));
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…
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```

In our code, cursor will stand for the node currently being examined; in this example the head pointer

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  - New node should point to *current* head.
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…
```

In our code, cursor will stand for the node currently being examined; in this example the head pointer

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temp->next = cursor;
cursor = temp;
```

Linked lists - adding a node

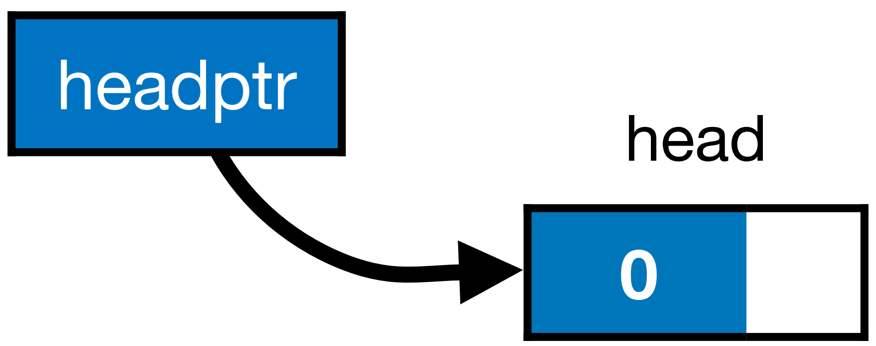
- What needs to be done?
  - New node should point to *current* head.
  - Current head should be updated to new node.
  - Deal with case of empty list

```
node* temp=(node*) malloc(sizeof(node));
…
…
if (cursor == NULL)
    cursor = temp;
else{
    temp->next = cursor;
    cursor = temp;
}
```

In our code, cursor will stand for the node currently being examined; in this example the head pointer

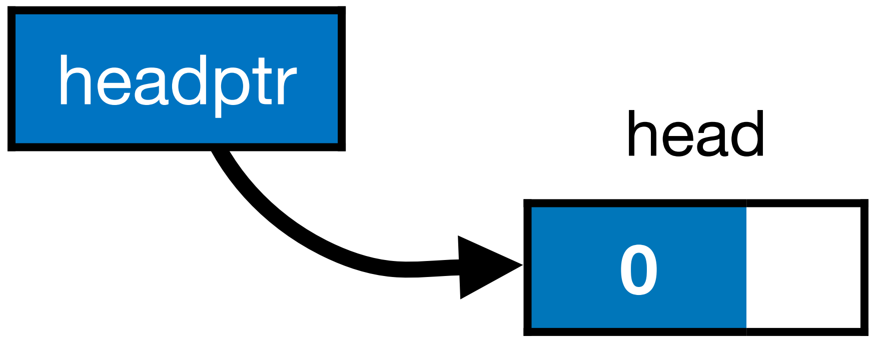
Traversing a linked list

Traversing a linked list



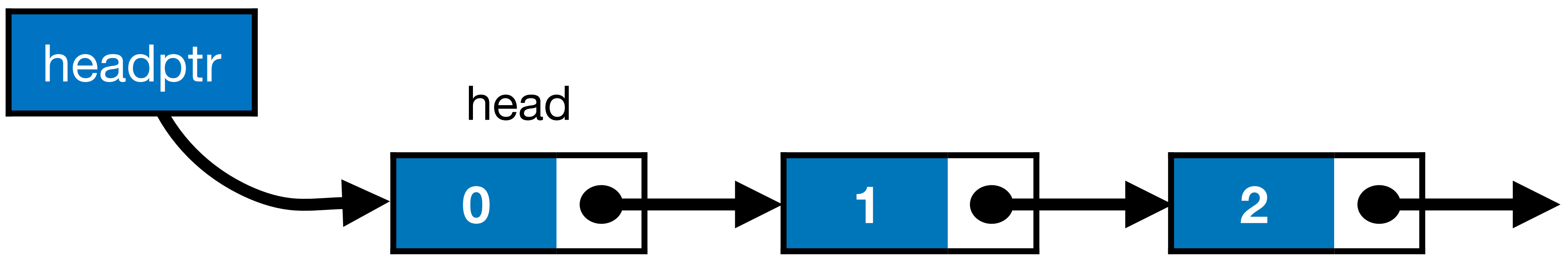
- Head pointer points to the first node of the list.

Traversing a linked list



- Head pointer points to the first node of the list.
- To traverse the list we do the following

Traversing a linked list



- Head pointer points to the first node of the list.
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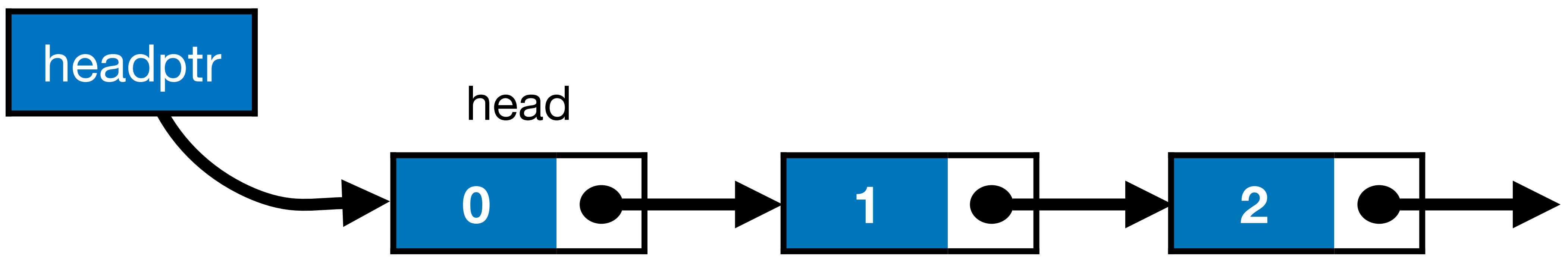

- Head pointer points to the first node of the list.
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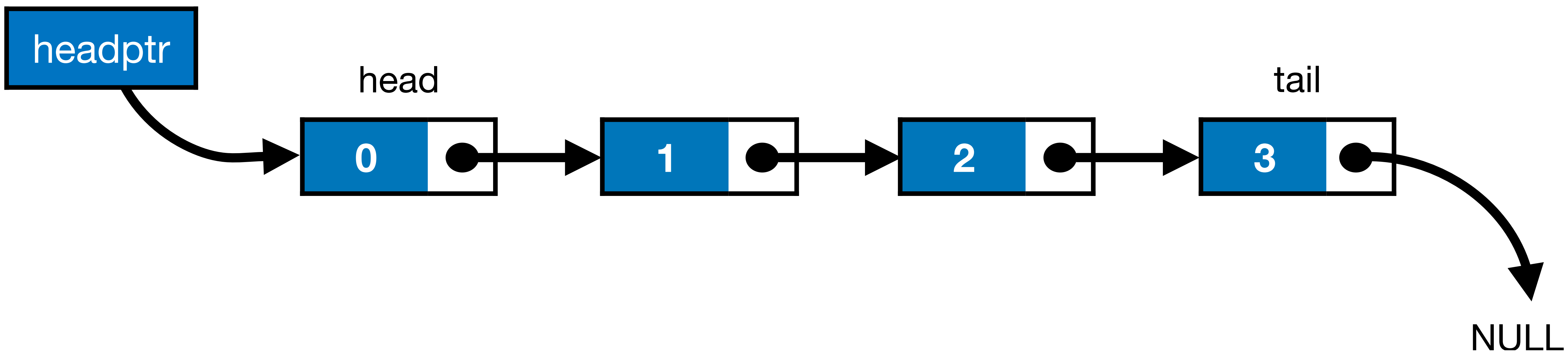

- Head pointer points to the first node of the list.
- To traverse the list we do the following
    - Follow the pointers.
    - Display the contents of the nodes as they are traversed.
    - Stop when the next pointer points to NULL.

Linked lists - traversing

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    - ~~Unsorted list: Can insert at *head*~~ or at *tail*
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- Recall that linked lists are defined *recursively.* So to traverse and *print.*

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Linked lists - traversing

- Recall that linked lists are defined *recursively.* So to traverse and *print.*
  - If the list is empty do nothing,

```
void print_list(node *cursor){
  if (cursor==NULL)
    return;
```

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void print_list(node *cursor){
  if (cursor==NULL)
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    printf("%s was born in %d\n",
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Linked lists - traversing

- Recall that linked lists are defined *recursively.* So to traverse and *print.*
  - If the list is empty do nothing,
  - otherwise, print current element &
  - recurse on the rest!

```
void print_list(node *cursor){
  if (cursor==NULL)
    return;
  else{
    printf("%s was born in %d\n",
           cursor->name,
           cursor->byear);
    print_list(cursor->next);
  }
}
```

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- Functions to write (a) `print_list` to traverse node and (b) `add_at_head` to add to head.

Code so far ...

```
void print_list(node *cursor){
  if (cursor==NULL)
    return;
  else{
    printf("%s was born in %d\n",
           cursor->name,
           cursor->byear);
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```

```
void add_at_head(node *cursor, node *new){
  node *temp = malloc(sizeof(node));

  temp->name = new->name;
  temp->byear = new->byear;

  if (cursor == NULL)
    cursor = temp;
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    temp->next = cursor;
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```

Code so far ...

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void add_at_head(node **cursor, node *new){

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    temp->next = *cursor;
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```

`headptr` **is a single pointer that should always point to start of list. Since we are relying on a function to make an update, we need to** ***pass-by-reference*** **(remember the defective swap function?)**

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`headptr` is a single pointer that should always point to start of list. Since we are relying on a function to make an update, we need to *pass-by-reference* (remember the defective swap function?)

An pointer to `new` is passed to `add_at_head`. We copy that onto the heap so that the calling function can/may reuse the parameter it passed in.

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An pointer to `new` is passed to `add_at_head`. We copy that onto the heap so that the calling function can/may reuse the parameter it passed in.

Since we are passing in a double pointer the code from slide #20 had to be carefully updated to make the types match as done above.

```
if (cursor == NULL)
    cursor = temp;
else{
    temp->next = cursor;
    cursor = temp;
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```

Adding a node - add at tail

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Adding a node - add at tail

- A pure implementation of a ***singly*** linked-list is <u>completely</u> defined by its head pointer.
    - <u>Aside:</u> A ***doubly*** linked lists has a pointer to the next element as well as the *previous* element (… tune in next week)
- To add an item at the *tail* position, we need to first **find the tail**. **How**: The only element in the list whose next is NULL is the tail element.

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Adding at tail

- Just like `print_list`, keep traversing/recursing till tail element is found. Then add the new node there.

```
void add_at_tail(node **cursor, node *new){
  if (*cursor == NULL)
    add_at_head(cursor, new);
  else
    add_at_tail(&(*cursor)->next, new);
}
```

Adding at tail

- Just like `print_list`, keep traversing/recursing till tail element is found. Then add the new node there.

```
void add_at_tail(node **cursor, node *new){
  if (*cursor == NULL)
    add_at_head(cursor, new);
  else
    add_at_tail(&(*cursor)->next, new);
}
```

Note: We don't keep adding large blocks on the stack in this version because we are passing around a *pointer* to `new`. **This is important!**

If we did not do that, then recursion could overflow available space on the stack very quickly!

Deleting a node from head

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- To delete a node from the **head** is simple.

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    - Make a copy of the head pointer

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node *old_head = *headptr;
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- To delete a node from the **head** is simple.
  - Make a copy of the head pointer
  - Shift the head pointer to its next item

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node *old_head = *headptr;
*headptr = (*headptr)->next;
```

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Deleting a node from head

- To delete a node from the **head** is simple.
    - Make a copy of the head pointer
    - Shift the head pointer to its next item
    - Call `free` on a copy of the head pointer

```
node *old_head = *headptr;
*headptr = (*headptr)->next;
free(old_head);
```

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- To delete a node from the **head** is simple.
  - Make a copy of the head pointer
  - Shift the head pointer to its next item
  - Call `free` on a copy of the head pointer
- What if list empty?

```
void del_head(node **headptr){
  if (*headptr==NULL)
    return;
  else{
    node *old_head = *headptr;
    *headptr = (*headptr)->next;
    free(old_head);
  }
}
```

- ~~Inserting an item in the list~~
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  if (*headptr==NULL)
    return;
  else{
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    *headptr = (*headptr)->next;
    free(old_head);
  }
}
```

Exercise: Can we delete the entire linked list with just this function?

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Deleting the tail node

```
void del_tail(node **cursor){
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Deleting the tail node

- To delete a node from the **tail** is more involved.

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- To delete a node from the **tail** is more involved.
  - First find the second to last node - how?

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- To delete a node from the **tail** is more involved.
    - First find the second to last node - how?

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void del_tail(node **cursor){
```

```
  node * second_last = *cursor;
  while (second_last->next->next != NULL)
    second_last=second_last->next;
```

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Deleting the tail node

- To delete a node from the **tail** is more involved.
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  - Call `free` on `second_last` elements next.

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void del_tail(node **cursor){

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    while (second_last->next->next != NULL)
      second_last=second_last->next;
    free(second_last->next);
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- To delete a node from the **tail** is more involved.
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  - First find the second to last node - how?
  - Call `free` on `second_last` elements next.
  - Set `second_last`'s `next` to `NULL`.
  - What if list empty?
  - What if singleton list?

```
void del_tail(node **cursor){
  if (*cursor==NULL)
    return;
  if ((*cursor)->next==NULL){
    free(*cursor);
    *cursor=NULL;
    return;
  }
  node * second_last = *cursor;
  while (second_last->next->next != NULL)
    second_last=second_last->next;
  free(second_last->next);
  second_last->next = NULL;
}
```

- ~~Traversing the list~~
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Insertion in a sorted linked list

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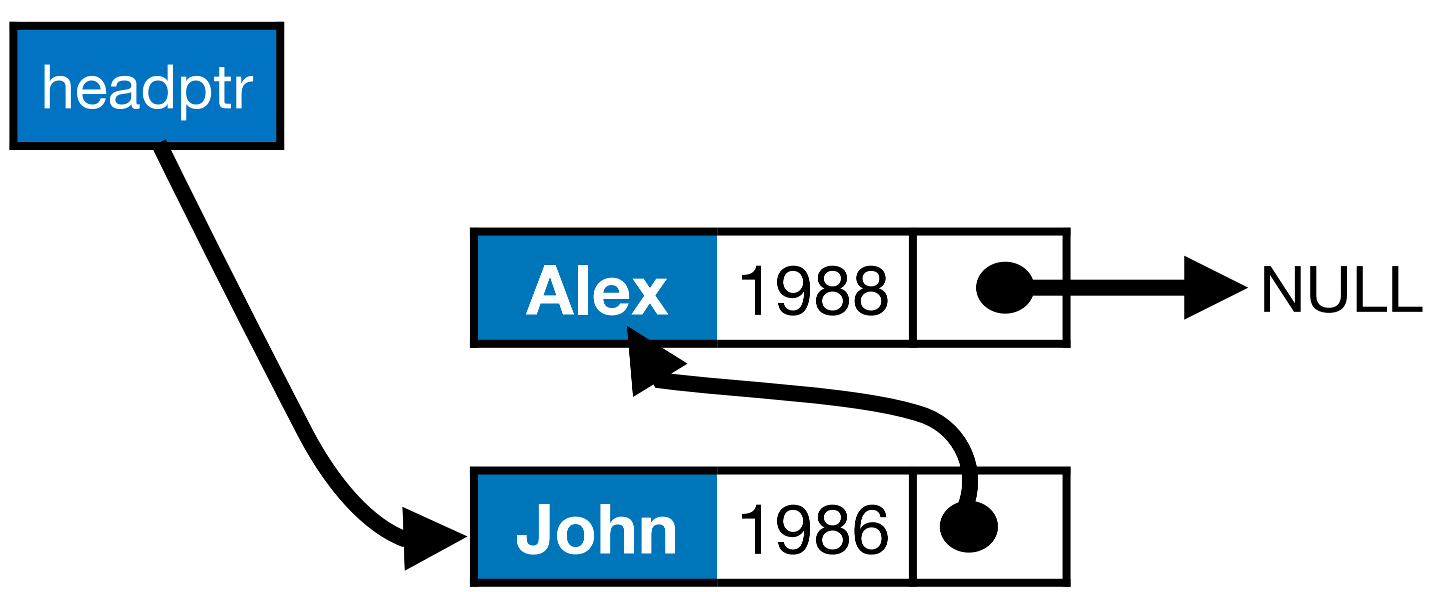
Insertion in a sorted linked list

- Suppose our linked list is already sorted by birth year.



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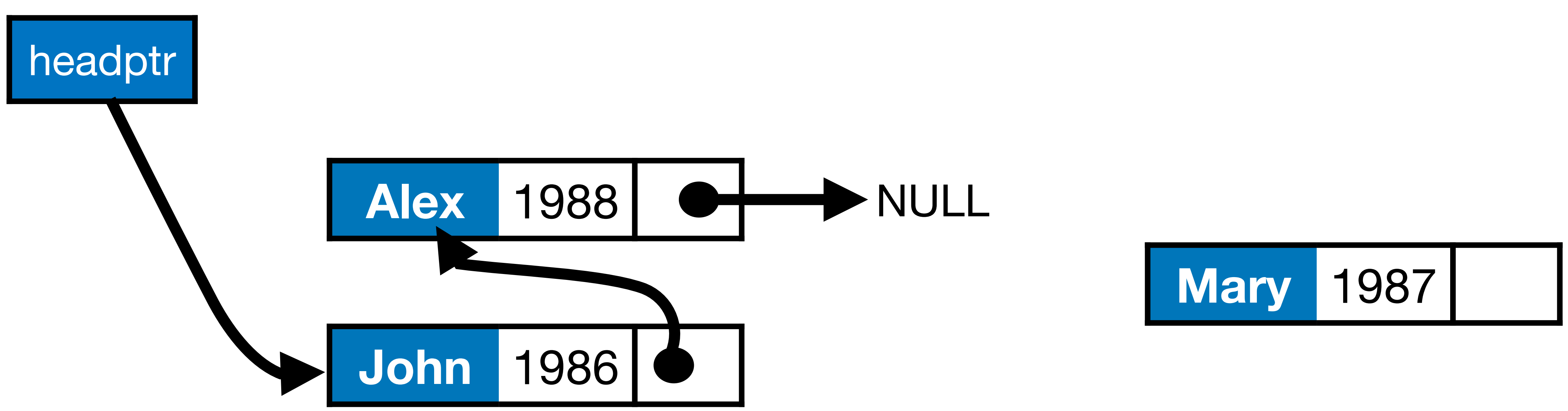

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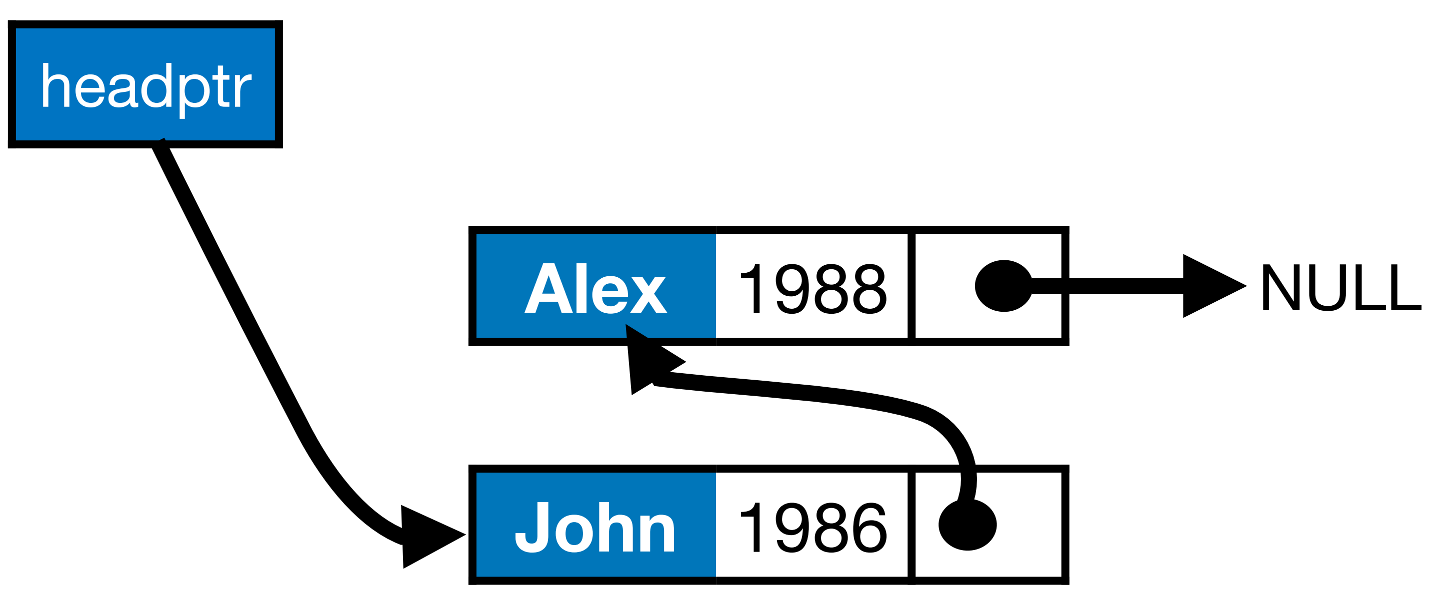
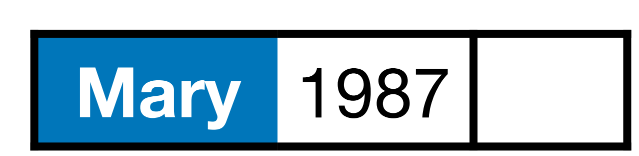
Let us start from basics!





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void insert(node **cursor, node *new){
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Give a new node, how to find the its insertion point?

If empty list, add at head.

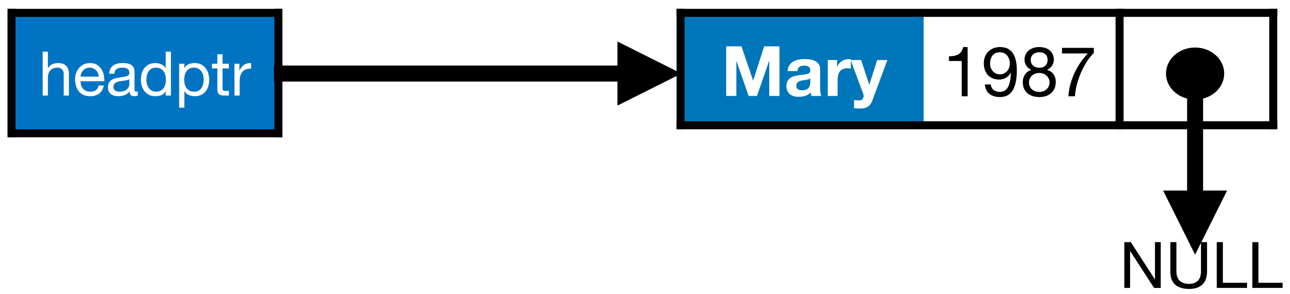
Insertion in a sorted linked list

- Suppose our linked list is already sorted by birth year.

Give a new node, how to find the its insertion point?

```
void insert(node **cursor, node *new){
  if ((*cursor == NULL) ||

    add_at_head(cursor, new);
    return;
  }
```



If empty list, add at head.

Insertion in a sorted linked list

- Suppose our linked list is already sorted by birth year.

Give a new node, how to find the its insertion point?

```
void insert(node **cursor, node *new){
  if ((*cursor == NULL) ||

     add_at_head(cursor, new);
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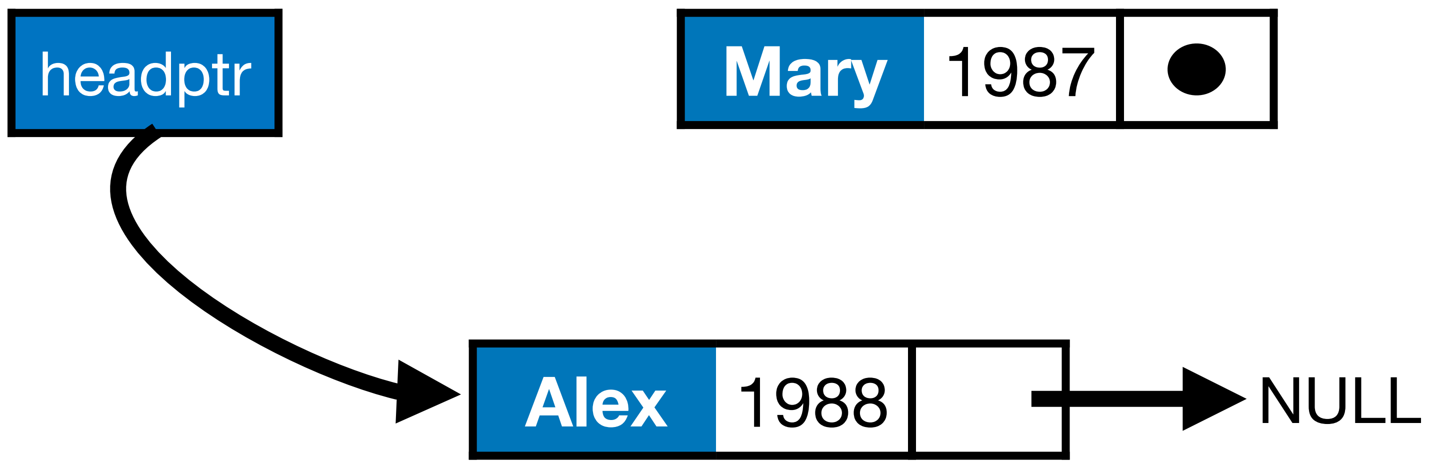

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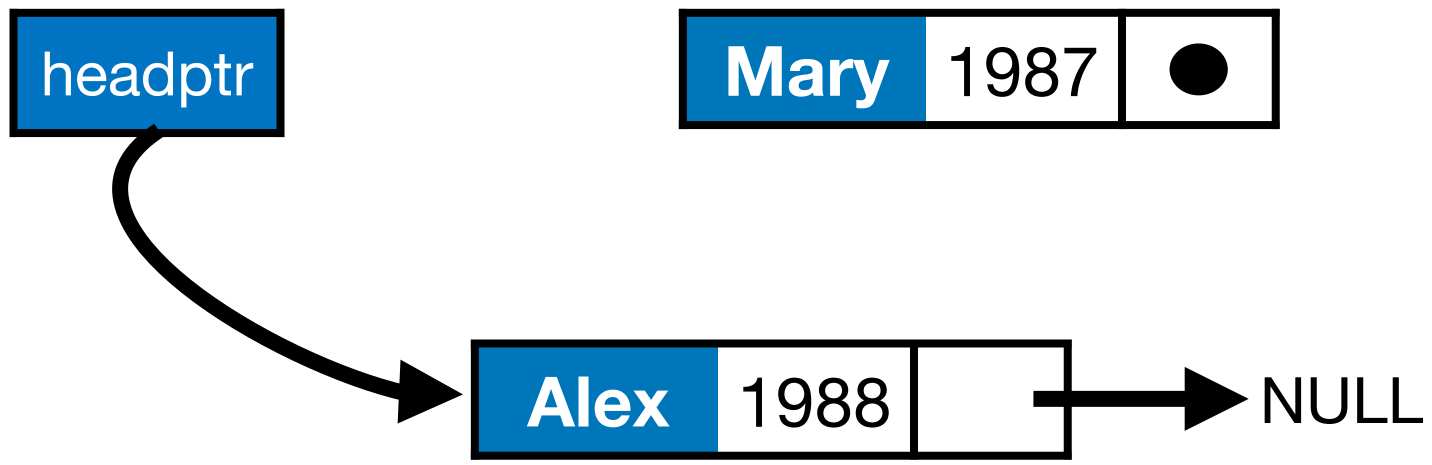

What if not empty?

If first item is bigger than new node still add at head!

Insertion in a sorted linked list

- Suppose our linked list is already sorted by birth year.

Give a new node, how to find the its insertion point?

```
void insert(node **cursor, node *new){
  if ((*cursor == NULL) ||
        (*cursor)->byear>=new->byear){
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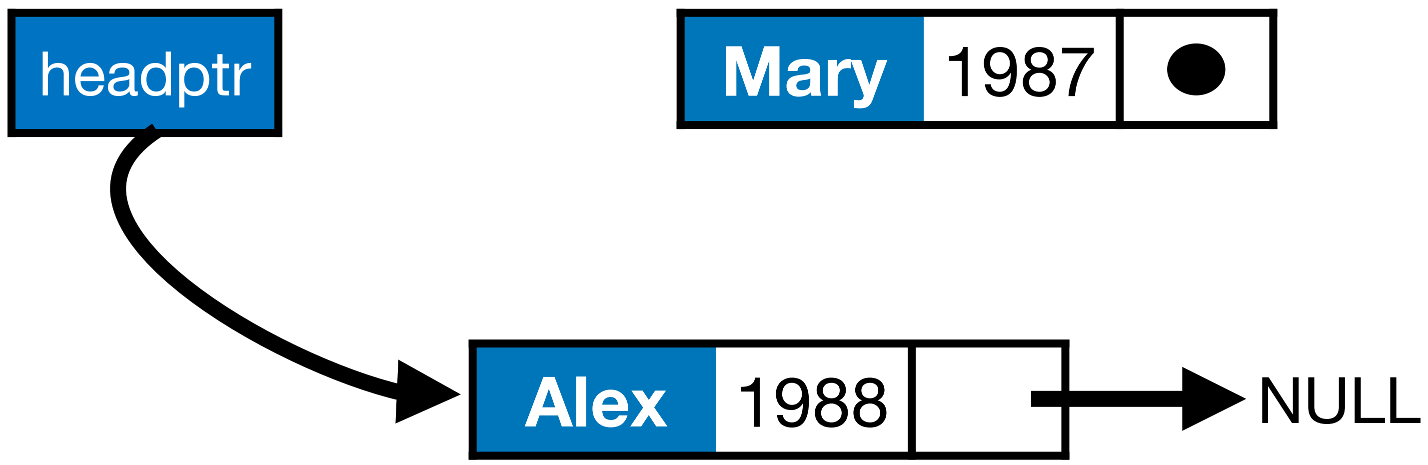

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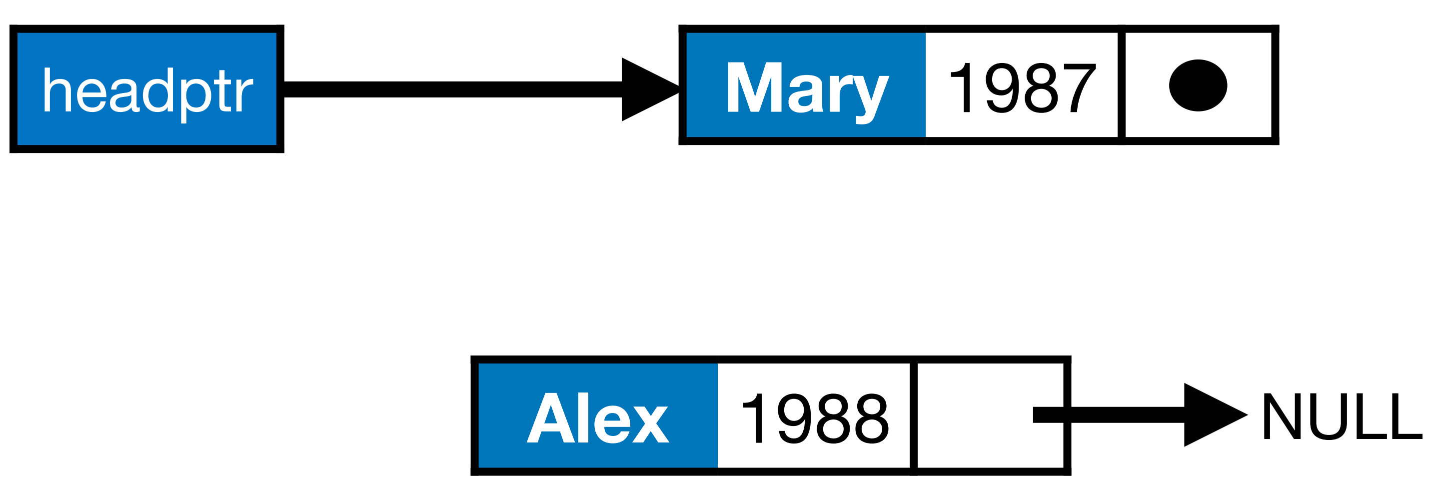

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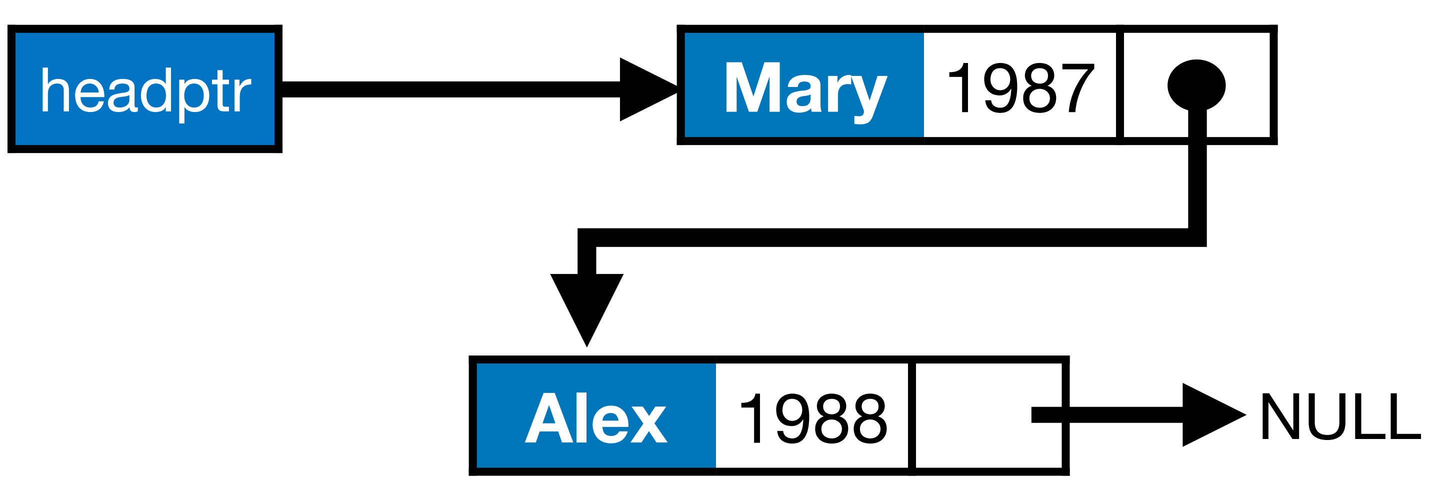

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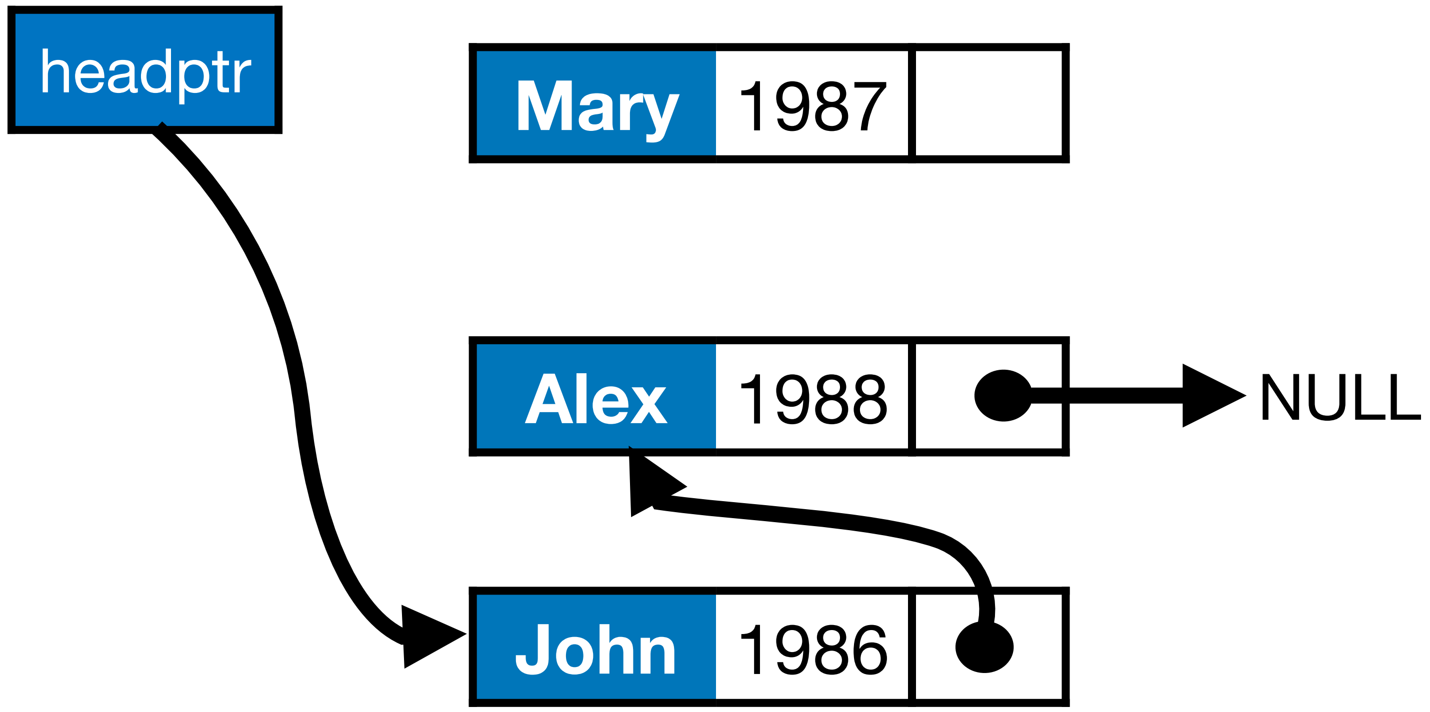

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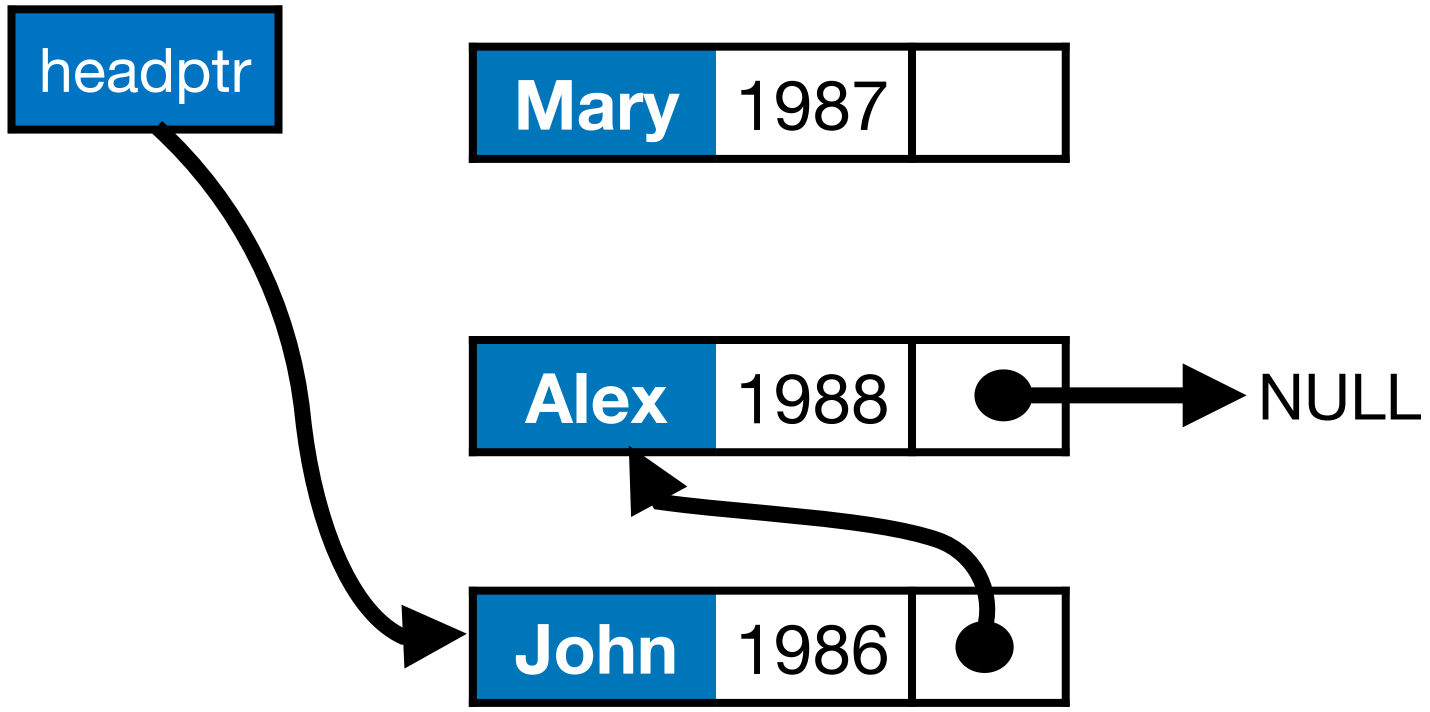


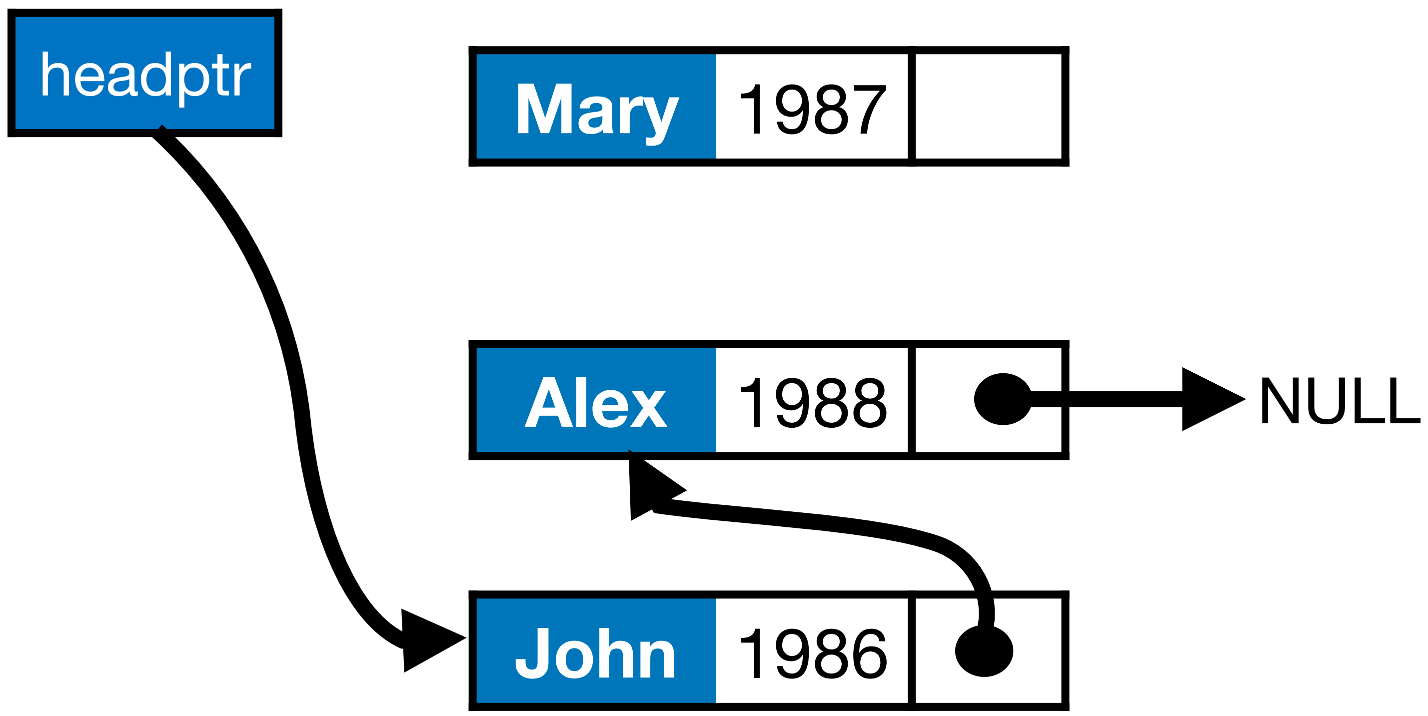
General case: if list is not empty and first item is smaller than new, update pointer & recurse!

Insertion in a sorted linked list

- Suppose our linked list is already sorted by birth year.

Give a new node, how to find the its insertion point?

```
void insert(node **cursor, node *new){
   if ((*cursor == NULL) ||
         (*cursor)->byear>=new->byear){
      add_at_head(cursor, new);
      return;
   }
   else{
      insert(&(*cursor)->next, new);
   }
}
```



General case: if list is not empty and first item is smaller than new, update pointer & recurse!

- ~~Inserting an item in the list~~
    - ~~Unsorted list: Can insert at *head* or at *tail*~~
    - ~~Sorted list: Insert so as to maintain sorted property~~
- ~~Traversing the list~~
- ~~Deleting an item from the list~~
    - Delete from head, tail **or middle.**

Deletion

- ~~Inserting an item in the list~~
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Deletion

- To delete a node we have to specify it by some identifying quantity.

```
int delete_node(node **headptr, char *name){
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    - Delete from head, tail **or middle.**

Deletion

- To delete a node we have to specify it by some identifying quantity.
- Then we traverse/search through the list. Cases are:

```
int delete_node(node **headptr, char *name){
    node *prev;
    node *current = *headptr;

    while (current!=NULL){
      if (strcmp(current->name, name)==0)
        break;
      prev = current;
      current = current->next;
    }
```

- ~~Inserting an item in the list~~
  - ~~Unsorted list: Can insert at *head* or at *tail*~~
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- To delete a node we have to specify it by some identifying quantity.

- Then we traverse/search through the list. Cases are:

  - Item not found

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int delete_node(node **headptr, char *name){
    node *prev;
    node *current = *headptr;

    while (current!=NULL){
      if (strcmp(current->name, name)==0)
        break;
      prev = current;
      current = current->next;
    }
    if (current==NULL)
      return -1;
```

- ~~Inserting an item in the list~~
    - ~~Unsorted list: Can insert at *head* or at *tail*~~
    - ~~Sorted list: Insert so as to maintain sorted property~~
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Deletion

- To delete a node we have to specify it by some identifying quantity.
- Then we traverse/search through the list. Cases are:
    - Item not found
    - Item found at head

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int delete_node(node **headptr, char *name){
    node *prev;
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    while (current!=NULL){
      if (strcmp(current->name, name)==0)
        break;
      prev = current;
      current = current->next;
    }
    if (current==NULL)
      return -1;

    if (current == *headptr)
      *headptr = current->next;
    else
```

Deletion

- To delete a node we have to specify it by some identifying quantity.
- Then we traverse/search through the list. Cases are:
  - Item not found
  - Item found at head
  - Item found elsewhere

```
int delete_node(node **headptr, char *name){
    node *prev;
    node *current = *headptr;

    while (current!=NULL){
      if (strcmp(current->name, name)==0)
        break;
      prev = current;
      current = current->next;
    }
    if (current==NULL)
      return -1;

    if (current == *headptr)
      *headptr = current->next;
    else
      prev->next=current->next;
    free(current);
    return 0;
}
```

Search

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- Left as an exercise … should be easy enough now that you have seen how to look for, find and then delete a node!

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Search

- Left as an exercise … should be easy enough now that you have seen how to look for, find and then delete a node!
  - **Note**: When an element is found, there is no index to return; so what should the search function do?
  - What to return when element is not found in list?