ECE 220

Lecture x0011 - 10/23
Linked Lists - Introduction

Recap

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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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- Apply dynamic memory allocation to create and modify linked list structures safely.

- Evaluate and troubleshoot edge cases in linked list programs, such as handling empty or singleton lists.

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    - 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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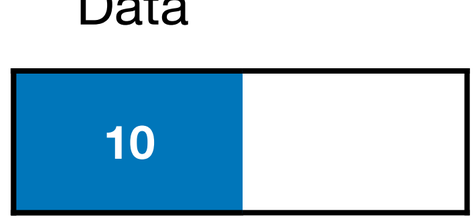

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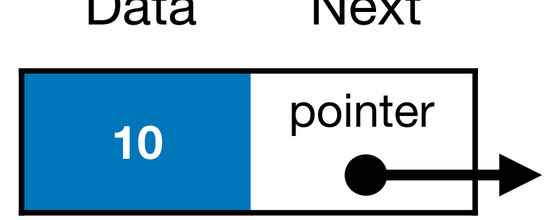

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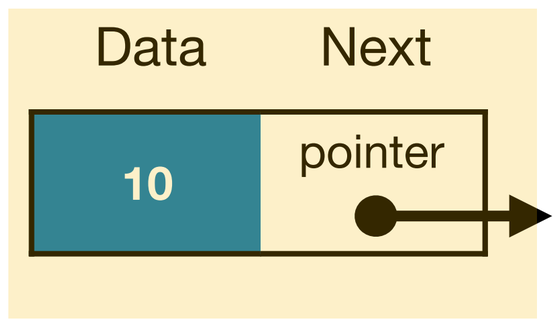

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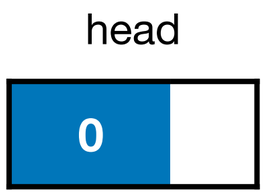

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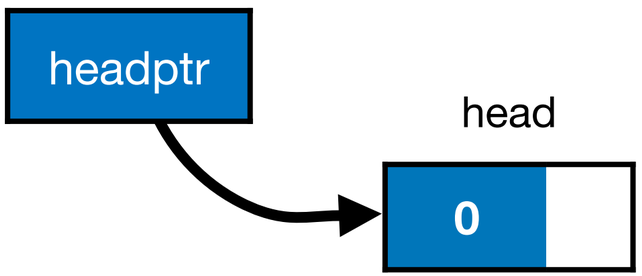
Linked list



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    - Accessed using a pointer called ***head pointer***

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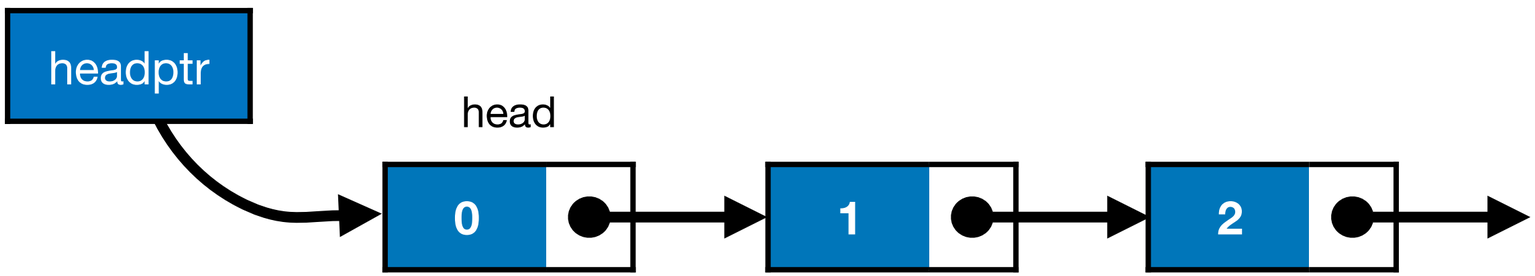

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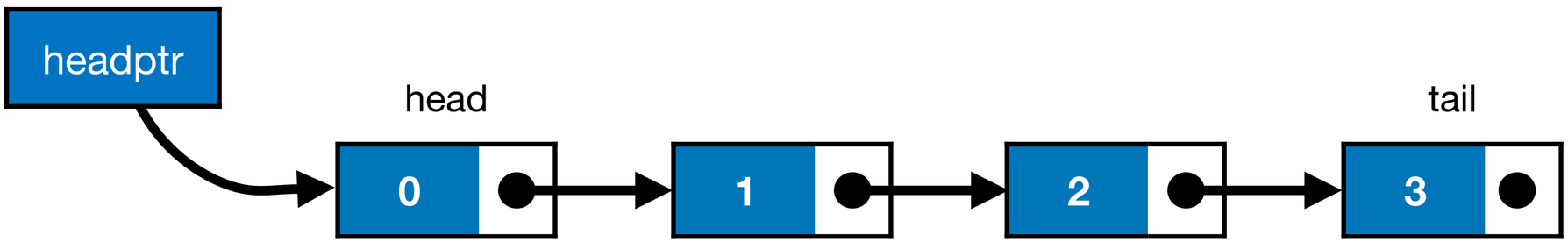

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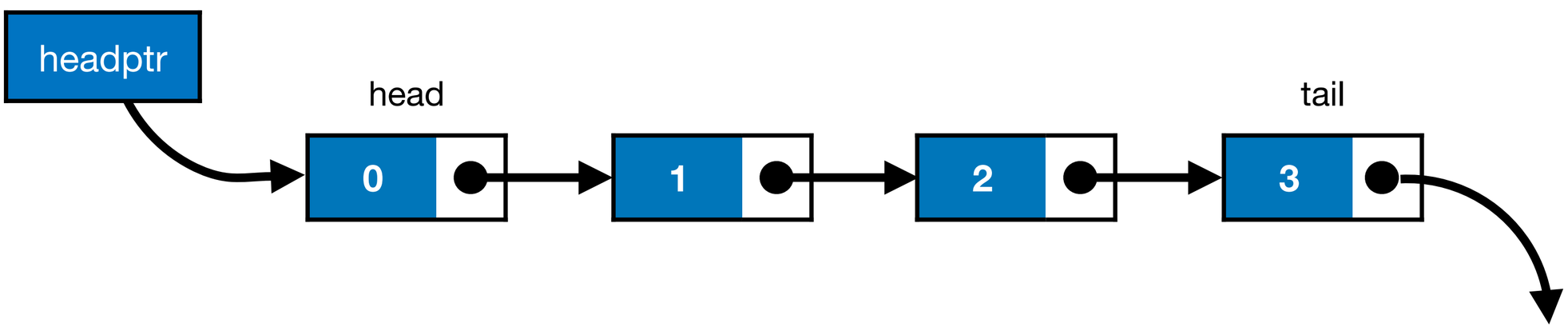

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    - Accessed using a pointer called ***head pointer***
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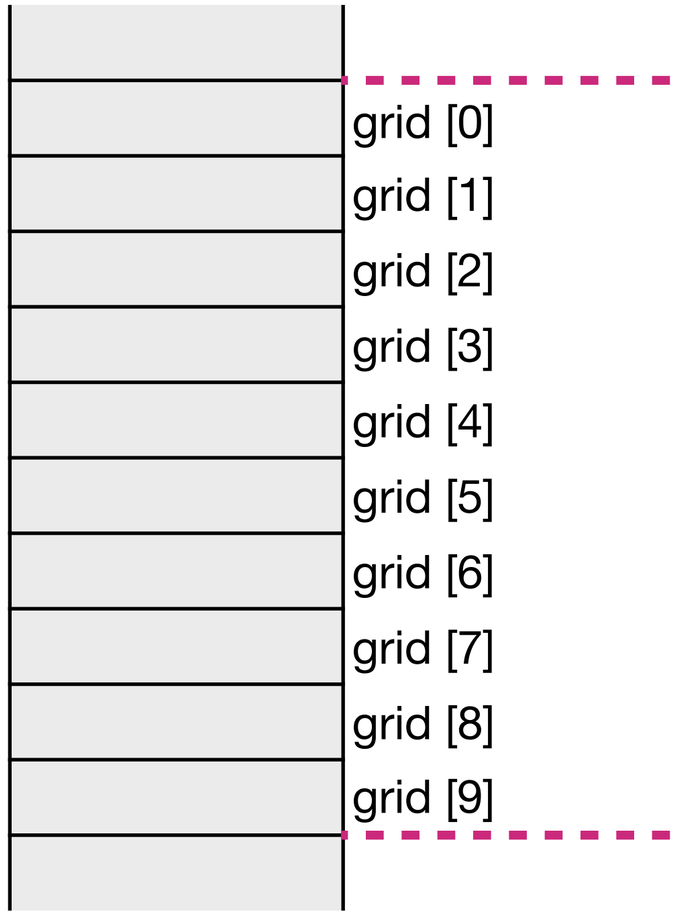
- The last node in the list is called the *tail*.
    - The tail may contain data, but it always points to NULL value

Array vs. linked list

Array vs. linked list

Array
(can be automatic or dynamic)

Array vs. linked list



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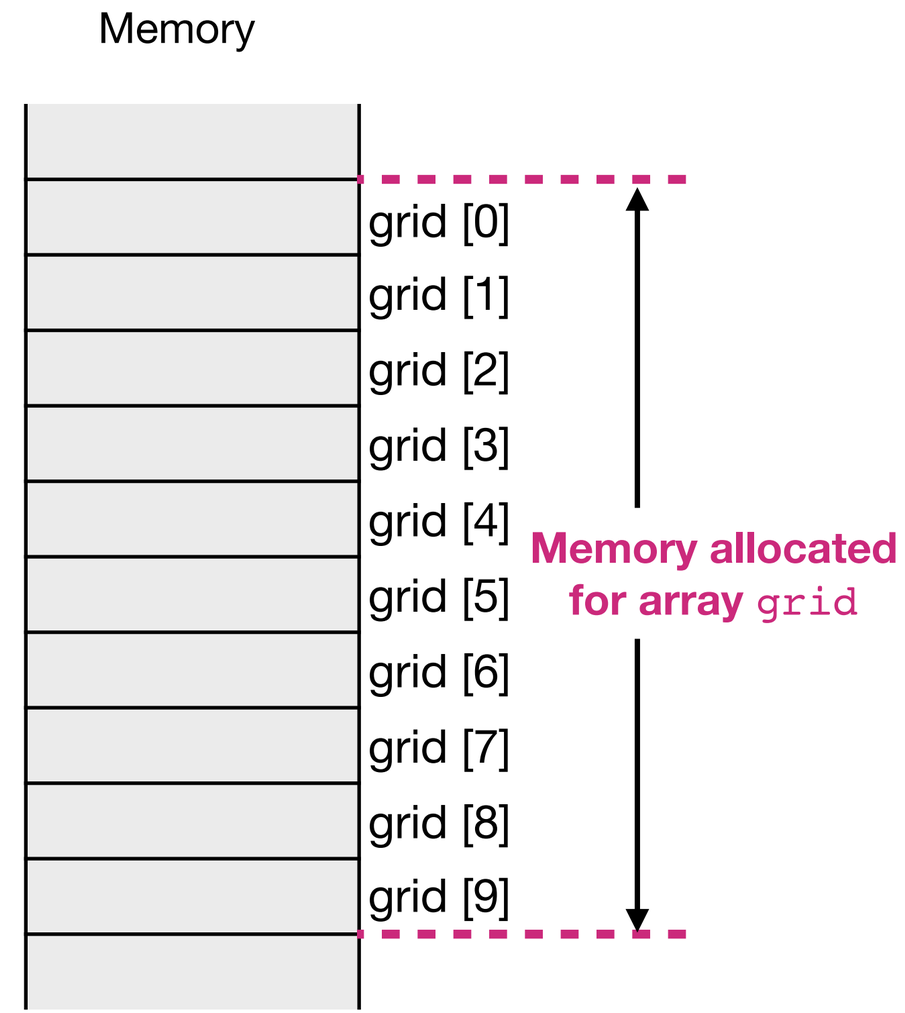

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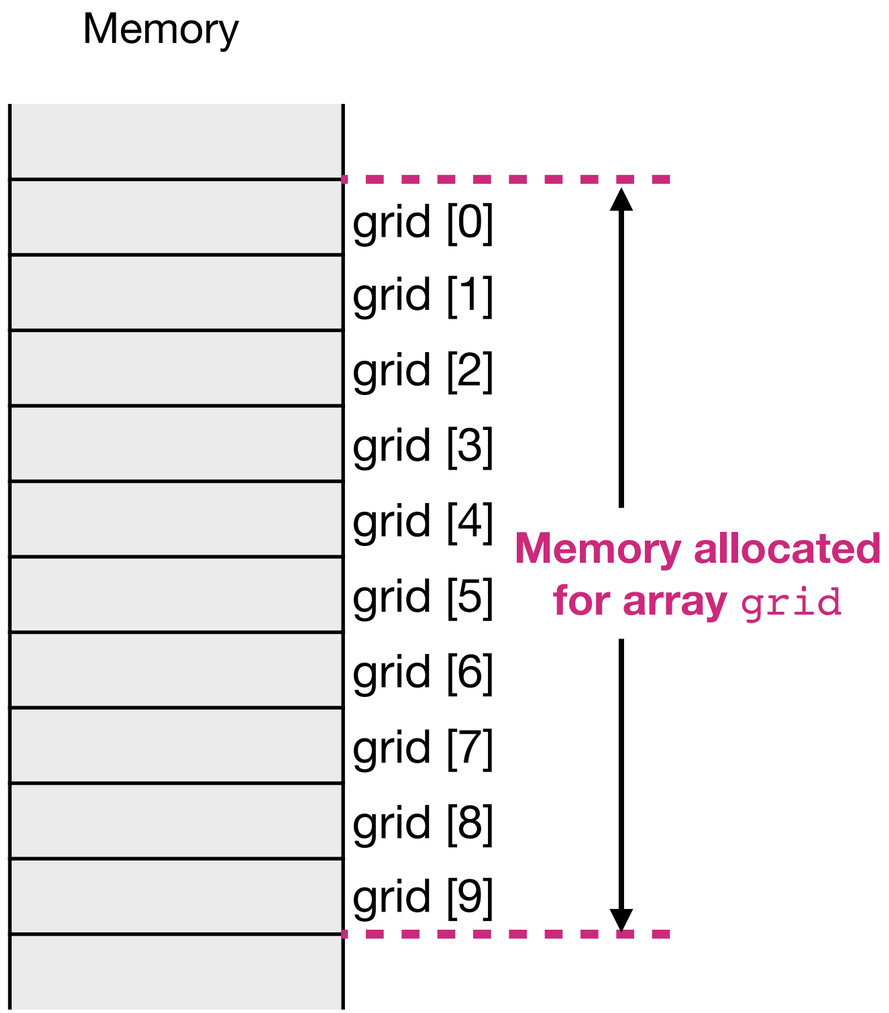

Array
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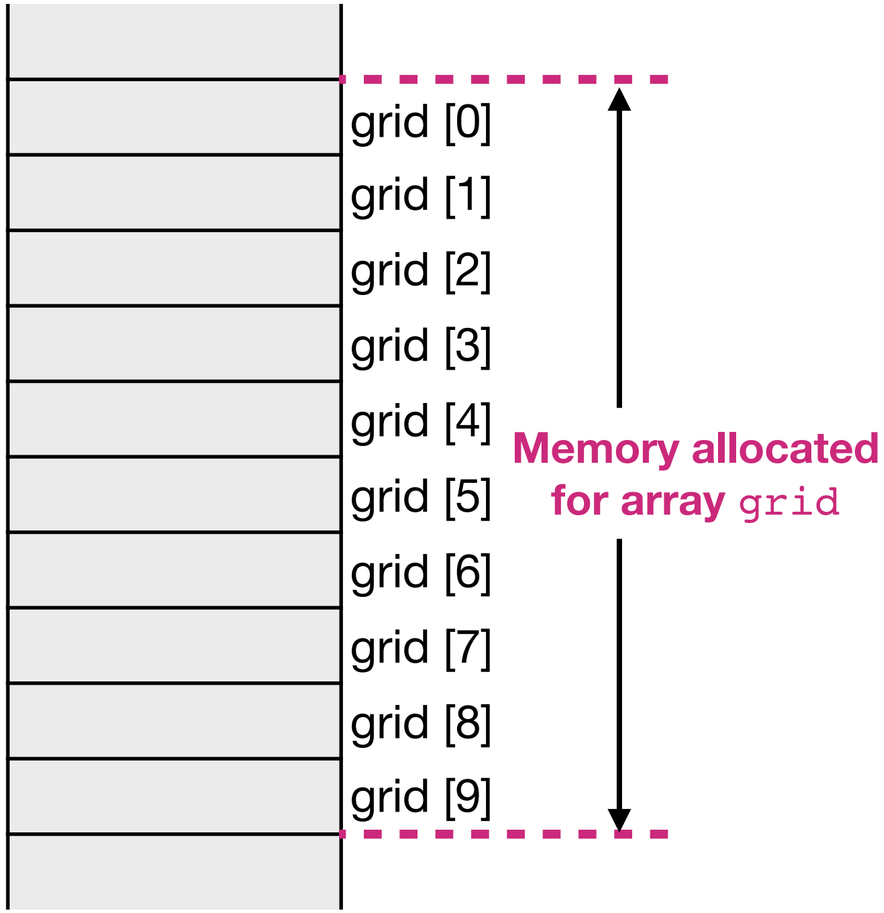
Linked list
(dynamic only)

Array vs. linked list

Memory



Array
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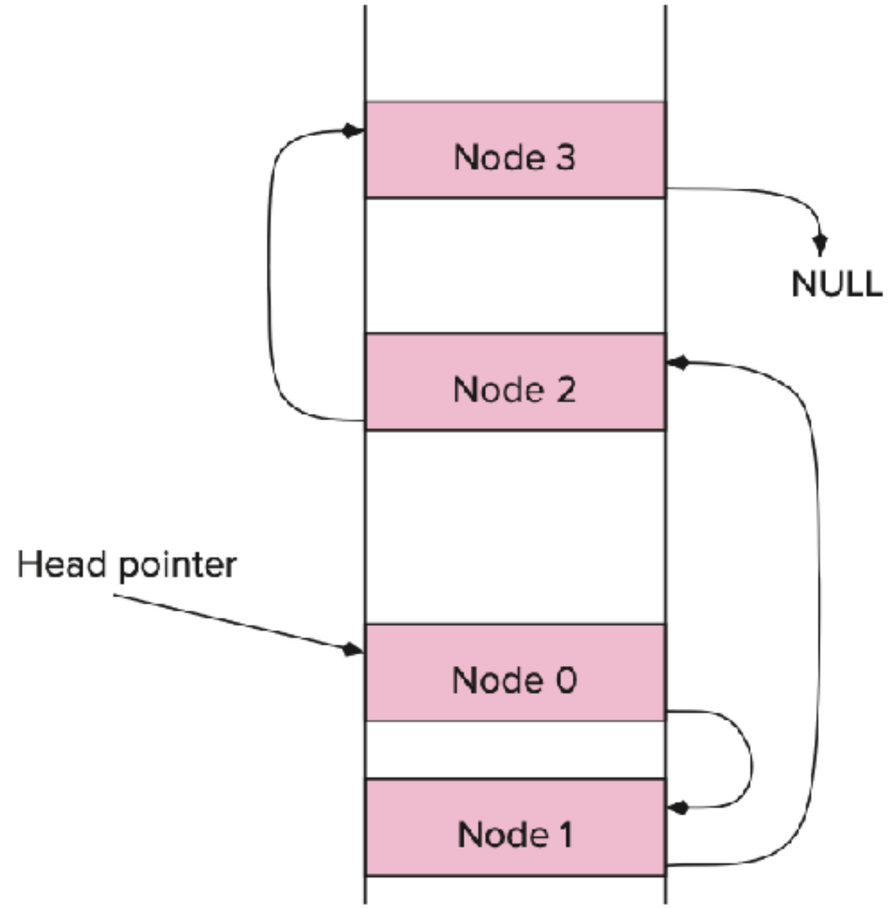
A linked list in memory



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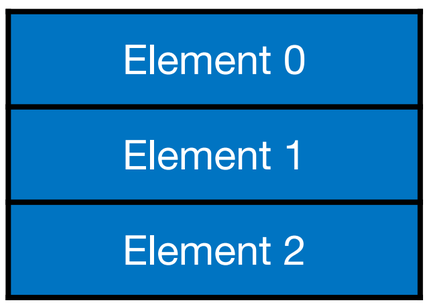

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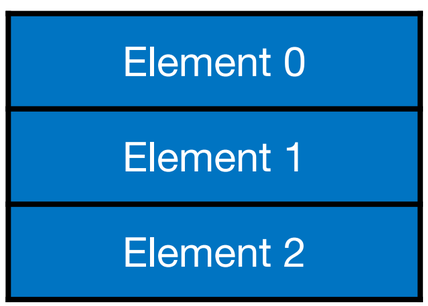

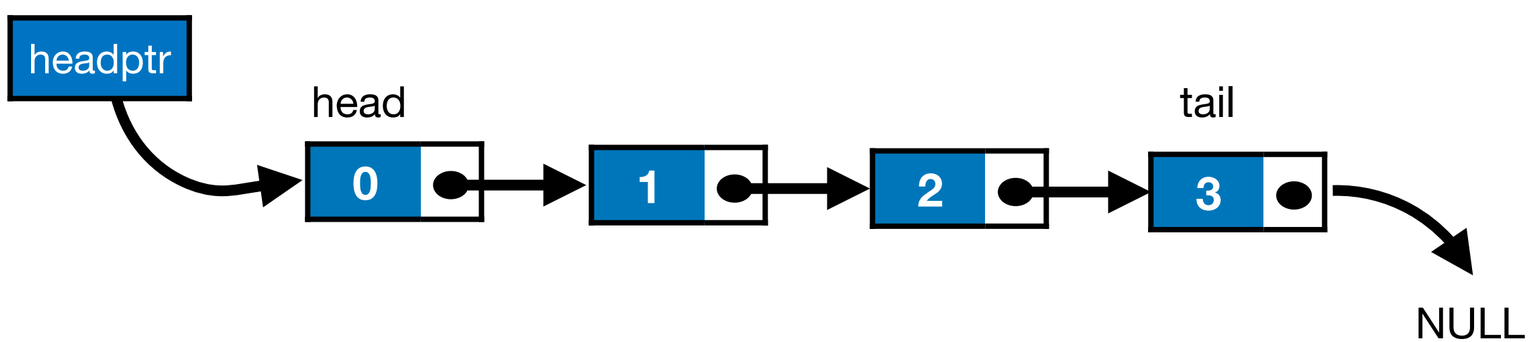

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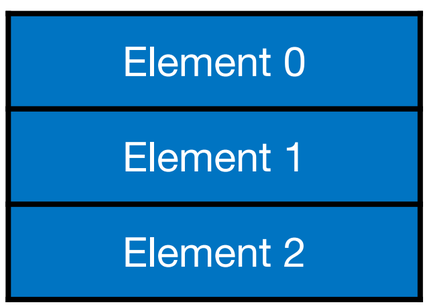

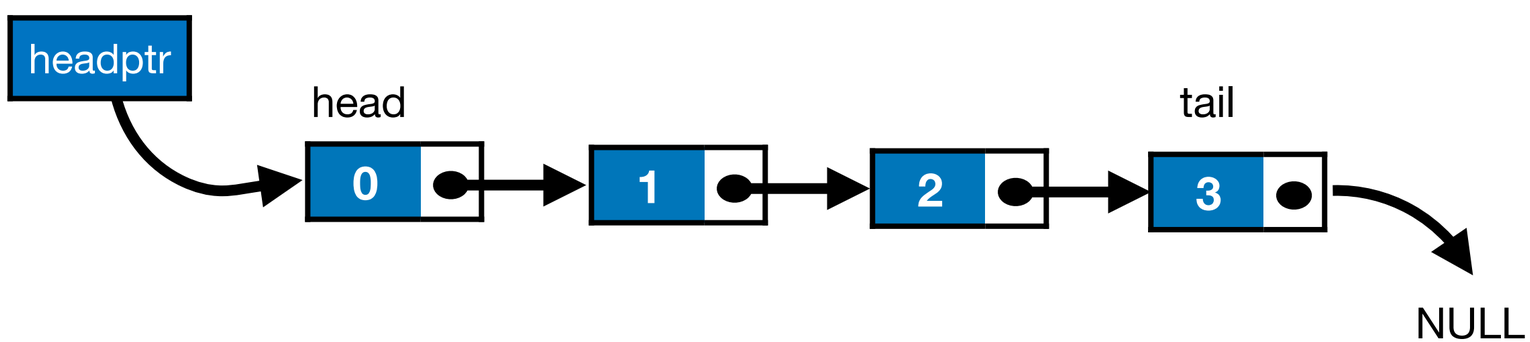

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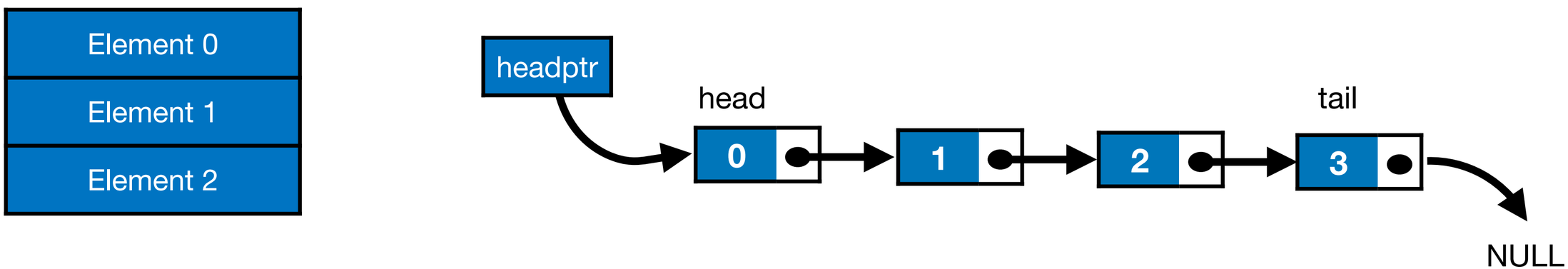

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Memory Allocation	Automatic / Dynamic	Dynamic
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Order of Access	Random	Sequential
Insertion / Deletion	Create/delete space, then shift all successive elements	Change pointer address

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  - Delete from *head*, *tail* or *by key*.

Declaring a linked list

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    int UIN;
    char *netid;
    float GPA;
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Using structs

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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;
```

Using structs

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

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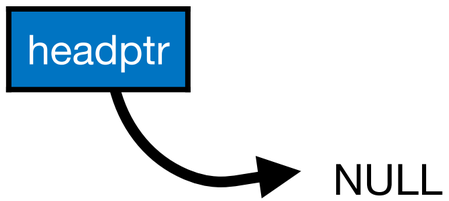

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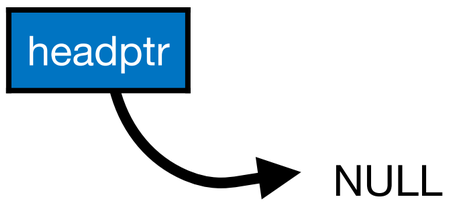


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node* headptr = NULL;
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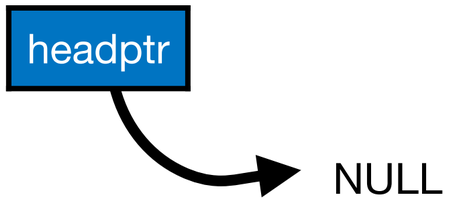

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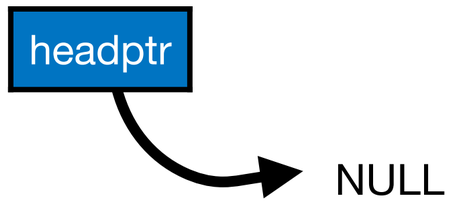

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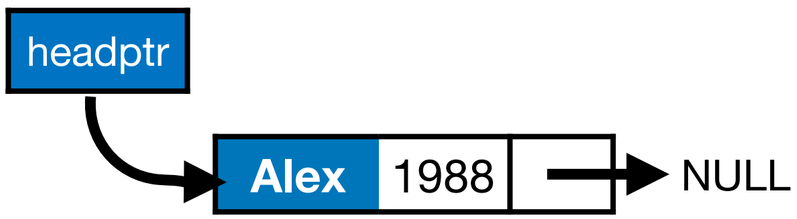


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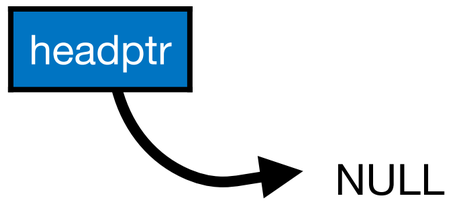

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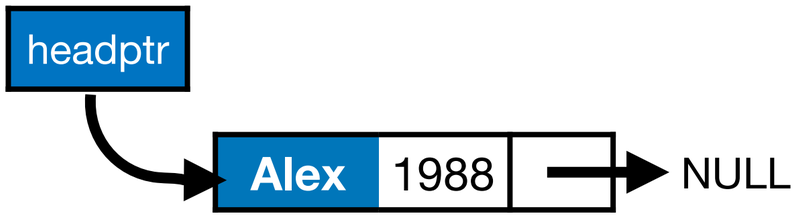


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}node;

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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- Traversing the list
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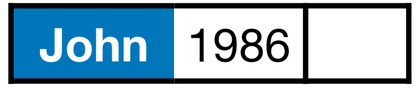

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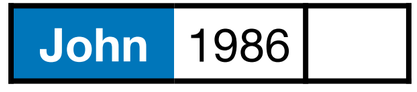

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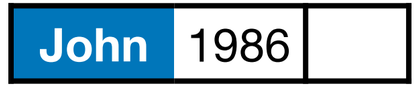

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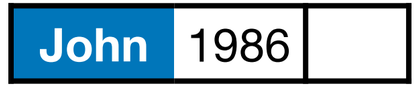

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  - For plain linked lists, we get to choose.

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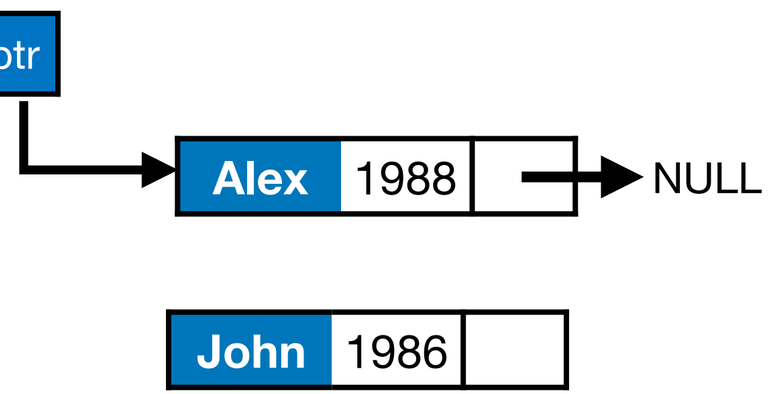
Linked lists - adding a node



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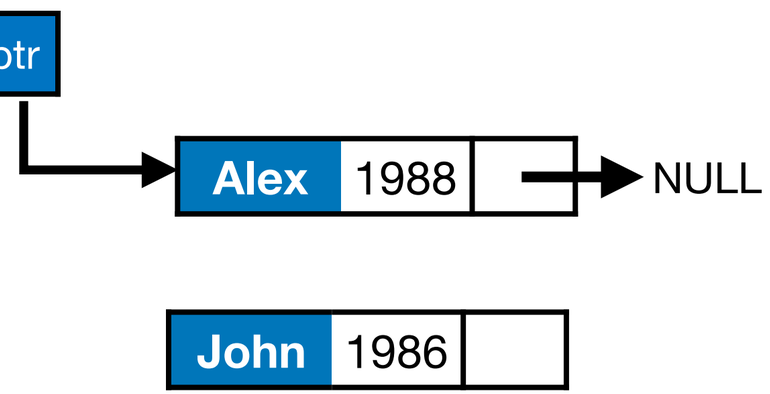

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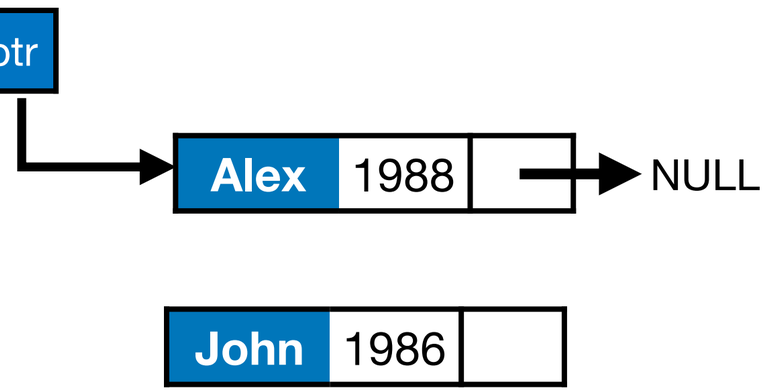

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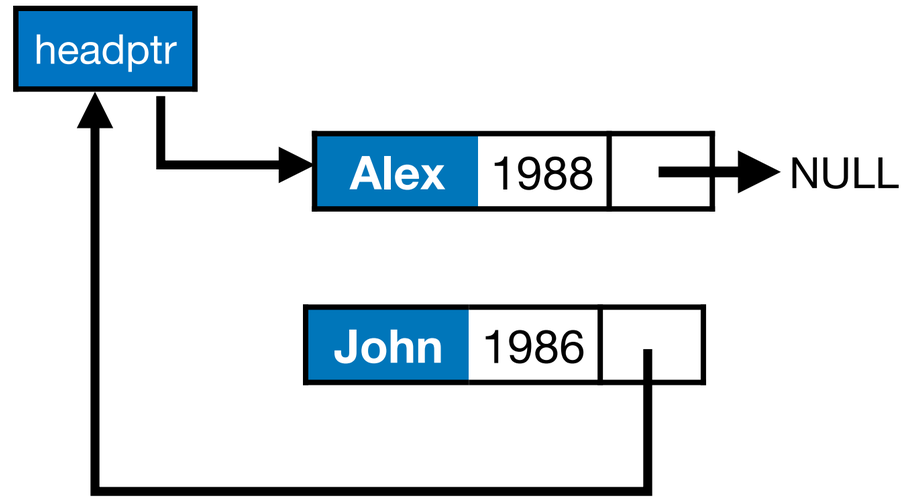

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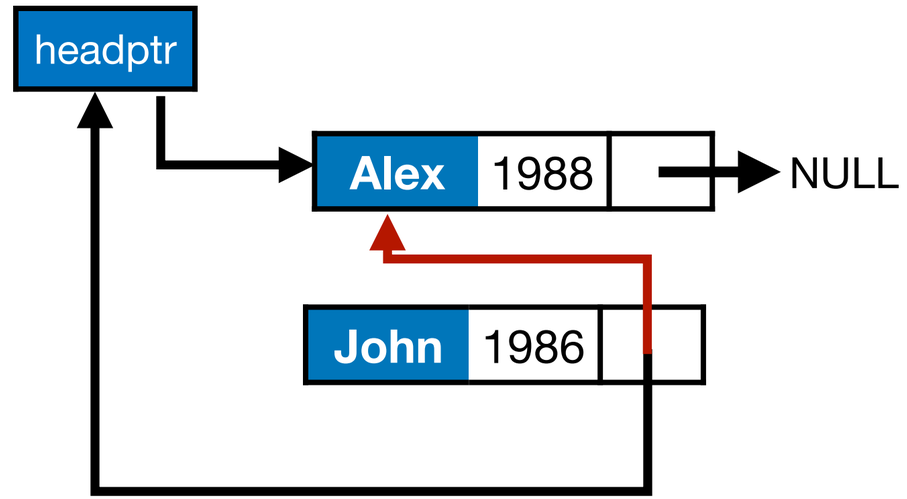

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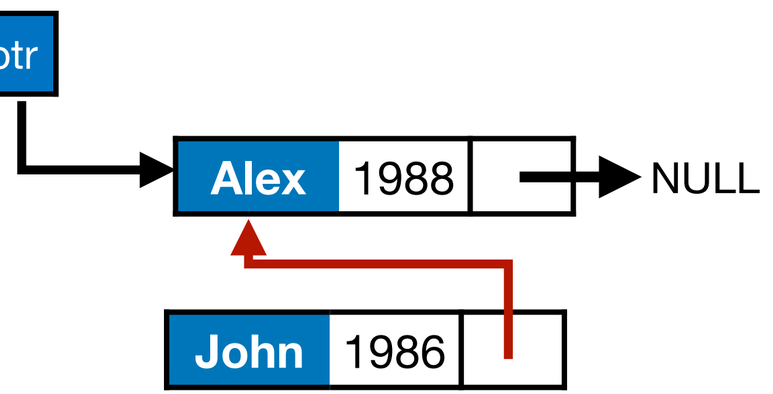

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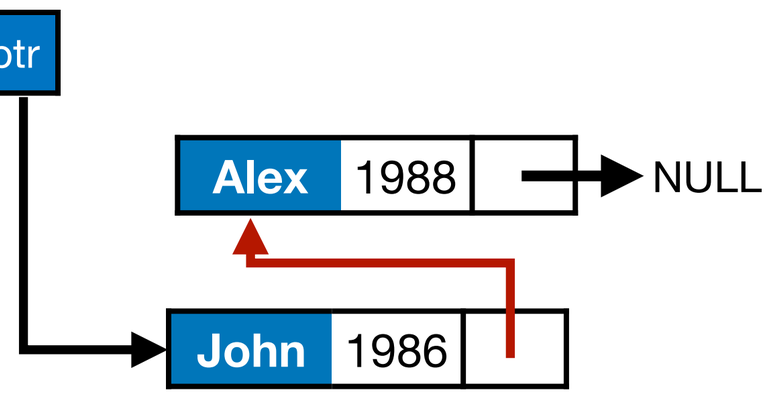

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In our code, cursor will stand for the node *currently* being examined; in this example the ***head*** pointer

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Linked lists - adding a node

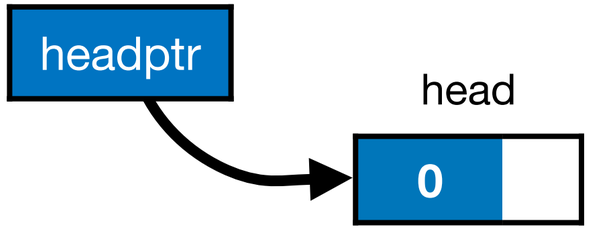
- Suppose we want to **add at head.**
- What needs to be done?
  - New node should point to *current* head.
  - Current head should be updated to new node.
  - Deal with case of empty list

```
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



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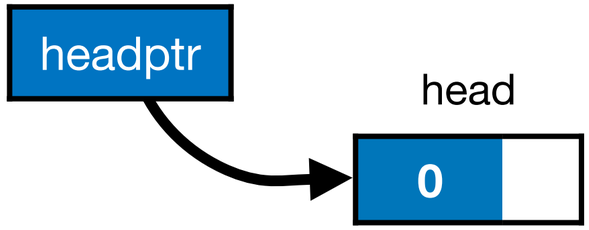

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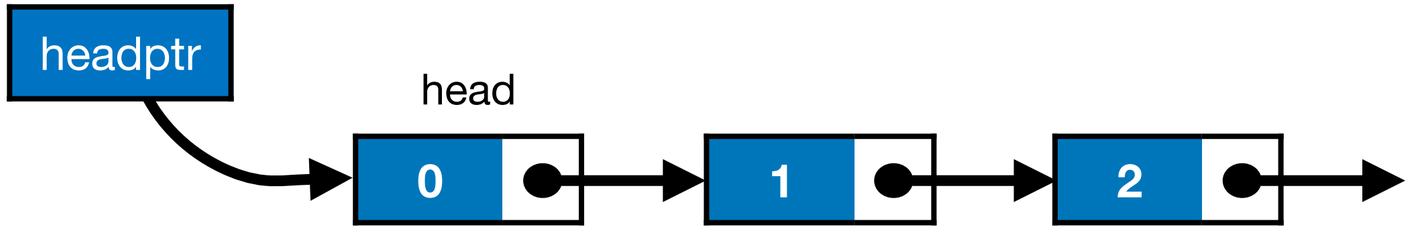

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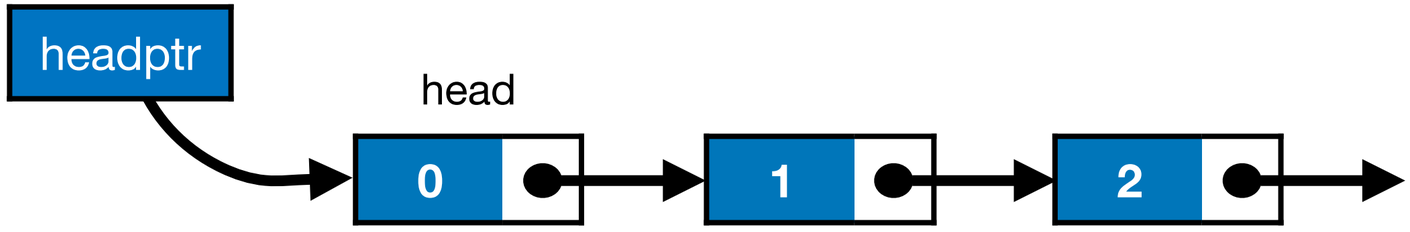

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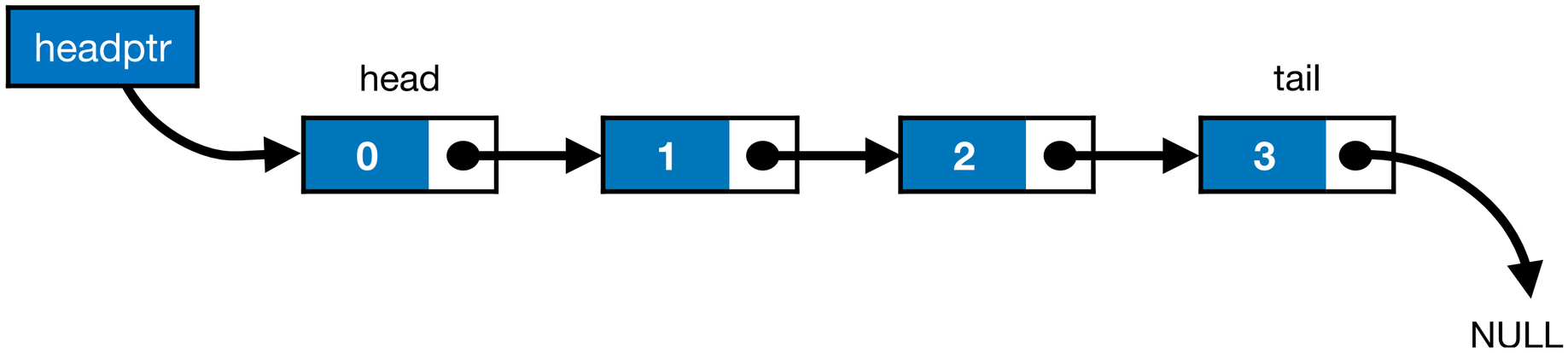

- Head pointer points to the first node of the list.
- To traverse the list we do the following
    - Follow the pointers.
    - Display the contents of the nodes as they are traversed.
    - Stop when the next pointer points to NULL.

Linked lists - traversing

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- Recall that linked lists are defined *recursively.* So to traverse and *print.*

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- 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)
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```

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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!

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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 …

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

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

  if (cursor == NULL)
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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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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.

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  How: The only element in the list whose next is NULL is the tail element.

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- 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);
}
```

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void add_at_tail(node **cursor, node *new){
  if (*cursor == NULL)
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  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!

Adding at tail

Method 2:

- **Exercise at home**: Rewrite the function on the right to be iterative. Hint, you may also have to re-write the `add_at_head` function. Does it take a `new` or a `new` pointer?

```
void add_at_tail(node **headptr, node new){
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  else
    add_at_tail(&(*headptr)->next, new);
}
```

For a lengthy list, we don't keep adding things on on the stack in this version because we are passing around a pointer to `new`. If we did not, then this version would be grossly inefficient.

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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  - Shift the head pointer to its next item
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node *old_head = *headptr;
*headptr = (*headptr)->next;
free(old_head);
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  - 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);
  }
}
```

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    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.
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Deleting the tail node

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

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

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

- ~~Traversing the list~~
- ~~**Deleting an item** from the list~~
  - ~~Delete from head~~, **tail** or middle.

Deleting the tail node

- To delete a node from the **tail** is more involved.
  - First find the second to last node - how?
  - Call `free` on `second_last` elements next.

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

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

- ~~Traversing the list~~
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void del_tail(node **cursor){
  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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  - Set `second_last`'s `next` to `NULL`.
  - What if list empty?

```
void del_tail(node **cursor){
  if (*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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- To delete a node from the **tail** is more involved.
  - First find the second to last node - how?
  - Call `free` on `second_last` elements next.
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  - 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~~
- ~~**Deleting an item** from the list~~
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Insertion in a sorted linked list

- ~~Inserting an item in the list~~
  - ~~Unsorted list: Can insert at *head* or at *tail*~~
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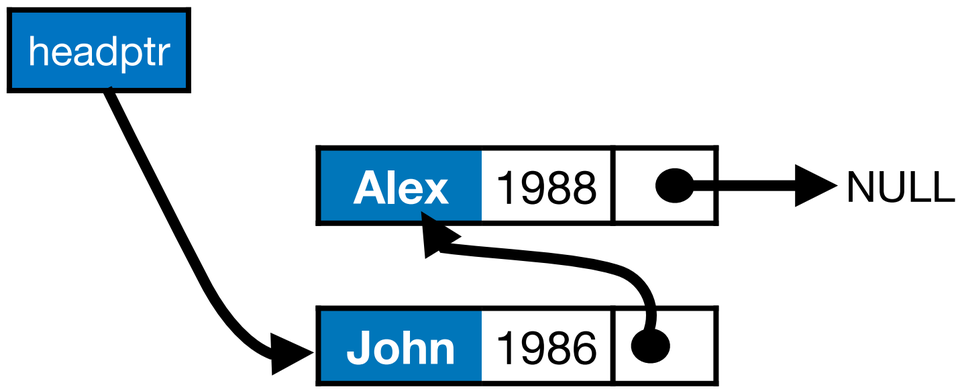
Insertion in a sorted linked list

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



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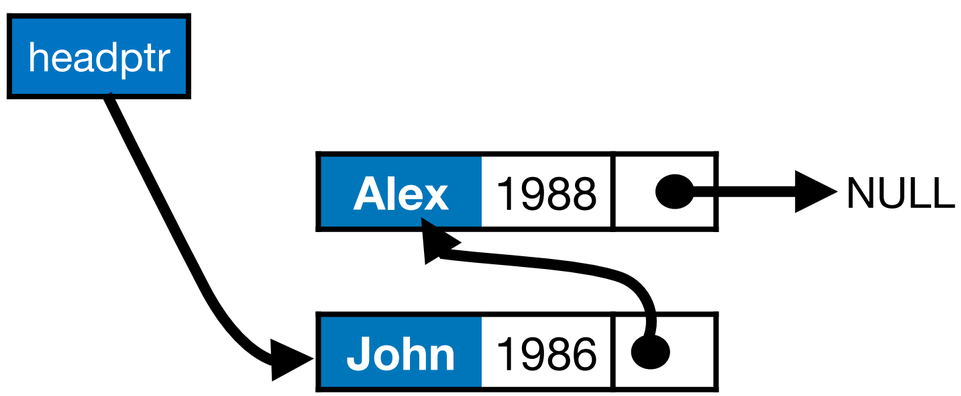

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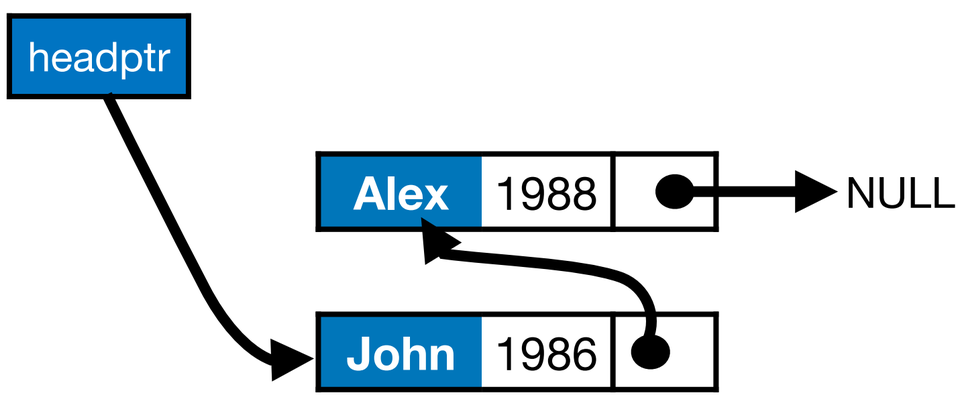

Let us start from basics!

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

    add_at_head(cursor, new);
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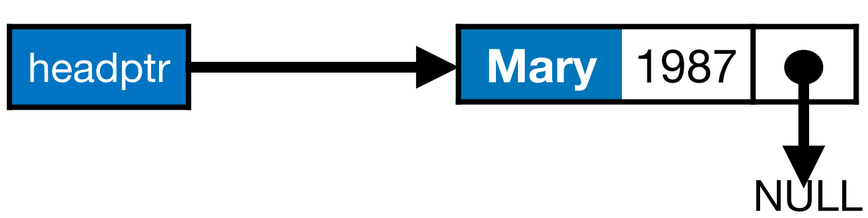

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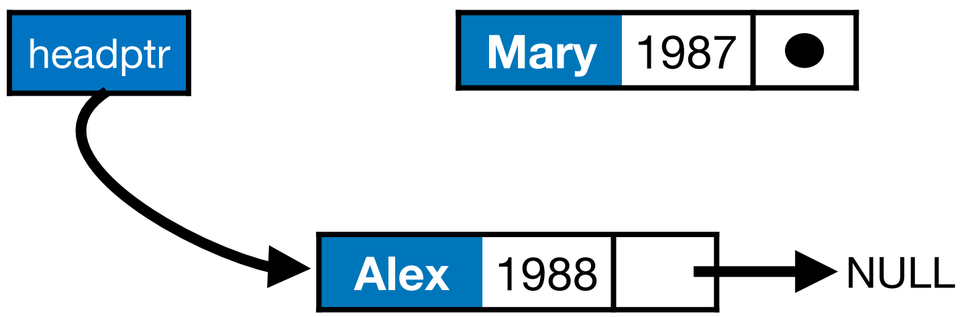

What if not empty?

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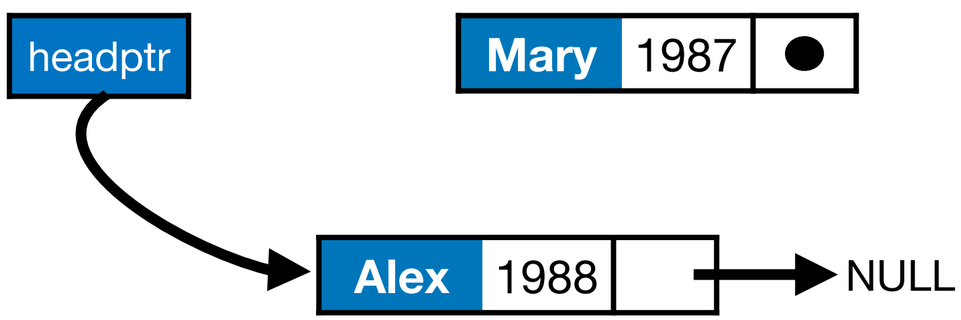

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If first item is bigger than new node still add at head!

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- 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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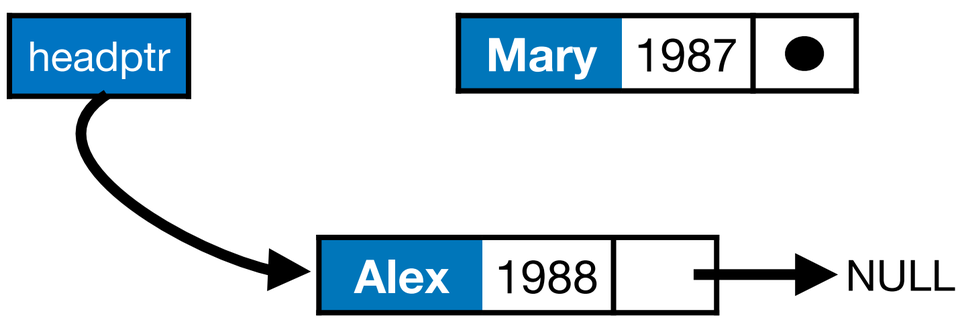

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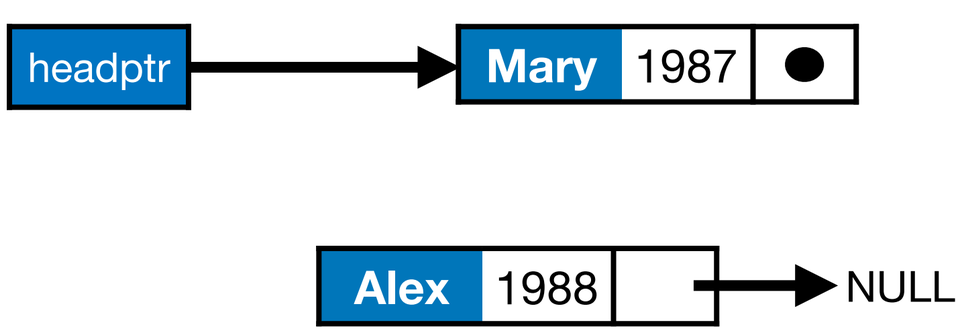

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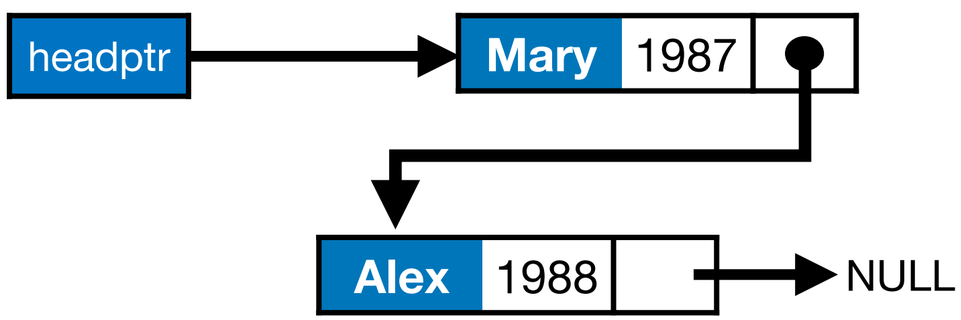

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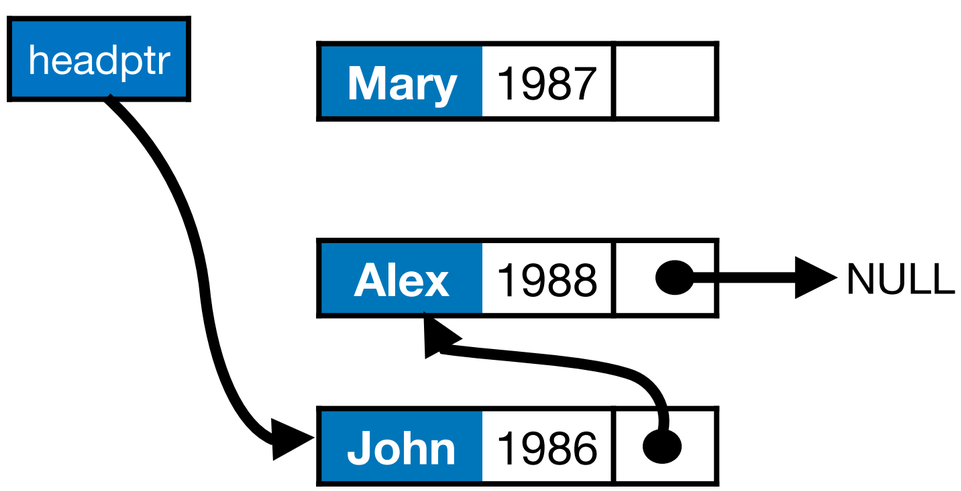

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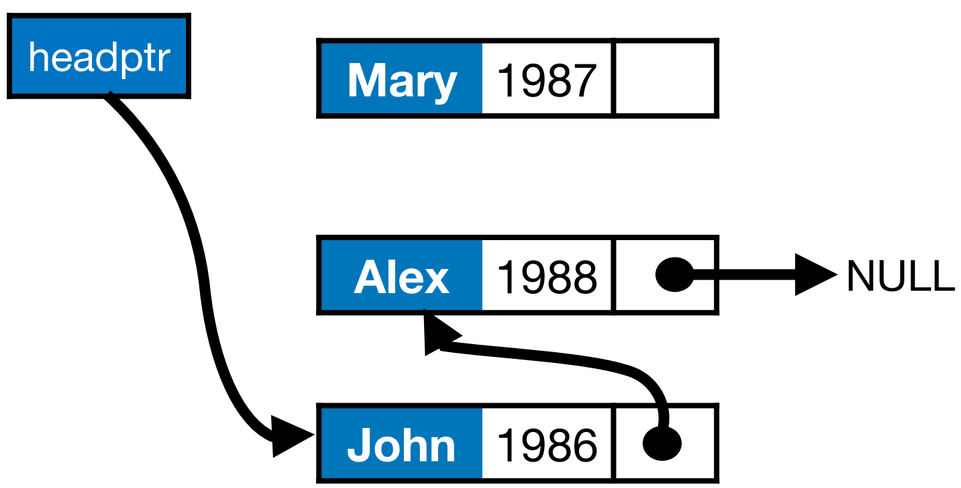
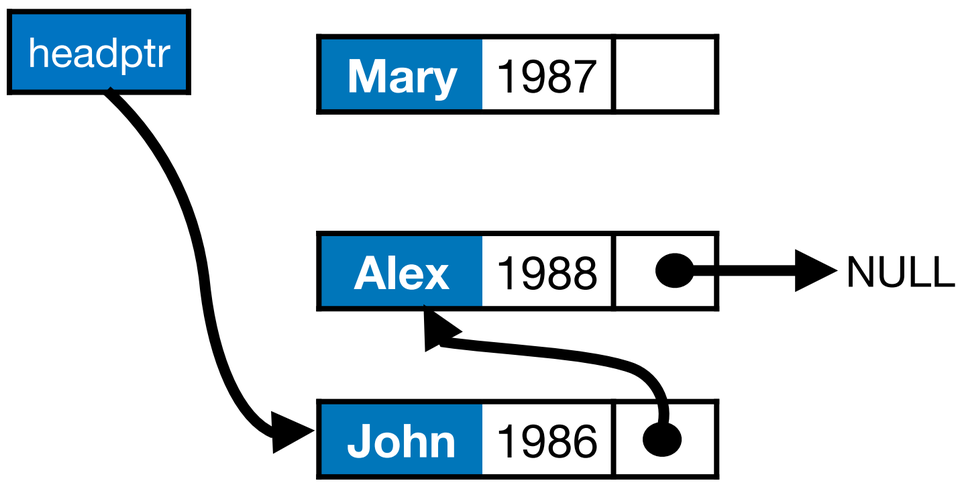


General case: if list is not empty and first item is smaller than new, update pointer & recurse!

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~~
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Deletion

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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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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;
}
```

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  - ~~Unsorted list: Can insert at *head* or at *tail*~~
  - ~~Sorted list: Insert so as to maintain sorted property~~
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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:
  - Item not found

```
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*~~
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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

```
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
```

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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
  - 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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- **Note**: When an element is found, there is no index to return; so what should the search function do?

Search

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- **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?