ECE 220

Lecture x0011 - 03/21/24

Linked Lists - Introduction

Announcements

- Same as last class
  - Exam next week, HKN review session, conflict exam request deadline
  - TA nomination deadline is tomorrow

Recap

Recap

- Last time we discussed:

Recap

- Last time we discussed:
  - Automatic vs. dynamic memory allocation

Recap

- Last time we discussed:
  - Automatic vs. dynamic memory allocation
  - `malloc` family of functions

Recap

- Last time we discussed:
  - Automatic vs. dynamic memory allocation
  - `malloc` family of functions
    - `calloc`

Recap

- Last time we discussed:
  - Automatic vs. dynamic memory allocation
  - `malloc` family of functions
    - `calloc`
    - `realloc`

Recap

- Last time we discussed:
  - Automatic vs. dynamic memory allocation
  - `malloc` family of functions
    - `calloc`
    - `realloc`
- Calling `free` to release memory

Recap

- Last time we discussed:
  - Automatic vs. dynamic memory allocation
  - `malloc` family of functions
    - `calloc`
    - `realloc`
  - Calling `free` to release memory
  - Allocating 2D arrays

Recap

- Last time we discussed:
  - Automatic vs. dynamic memory allocation
  - `malloc` family of functions
    - `calloc`
    - `realloc`
- Calling `free` to release memory
- Allocating 2D arrays
- Memory leak vs. seg-faults

Recap

- Last time we discussed:
  - Automatic vs. dynamic memory allocation
  - `malloc` family of functions
    - `calloc`
    - `realloc`
- Calling `free` to release memory
- Allocating 2D arrays
- Memory leak vs. seg-faults
- `valgrind` to detect memory leaks.

Today - linked list

Today - linked list

- What is a list … really?

Today - linked list

- What is a list … really?
    - A **list** is collection of *elements/items* which can be accessed sequentially.

Today - linked list

- What is a list … really?
    - A **list** is collection of *elements/items* which can be accessed sequentially.
    - Entertains the concept of ***order***; first, second, last.

Today - linked list

- What is a list … really?
    - 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.

Today - linked list

- What is a list … really?
    - A **list** is collection of *elements/items* which can be accessed sequentially.
    - Entertains the concept of ***order***; first, second, last.
    - <u>Note</u>: An empty list is still a list.

- An **array** is an *indexed* list; i.e. can access elements by their index.

Linked list

Linked list

- A linked list is an *ordered* collection of items (often called *nodes*), each of which contains some data, connected using *pointers* (hence the link part).

Linked list

- A linked list is an *ordered* collection of items (often called *nodes*), each of which contains some data, connected using *pointers* (hence the link part).

- A node is a collection of two sub-elements or parts.

Linked list

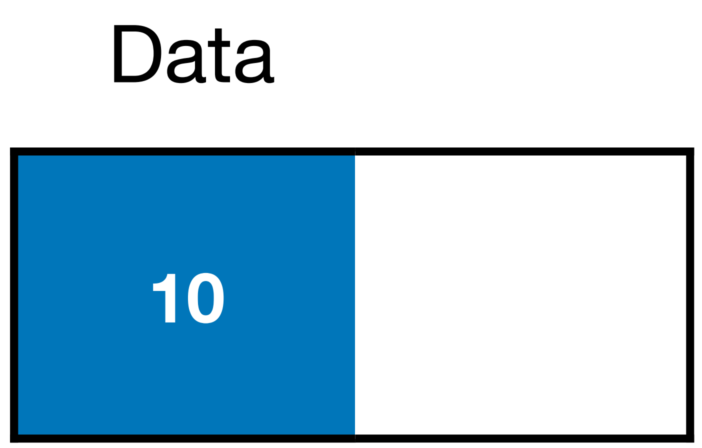
- A linked list is an *ordered* collection of items (often called *nodes*), each of which contains some data, connected using *pointers* (hence the link part).

- A node is a collection of two sub-elements or parts.

Linked list

- A <u>linked list</u> is an *ordered* collection of items (often called *nodes*), each of which contains some data, connected using *pointers* (hence the link part).

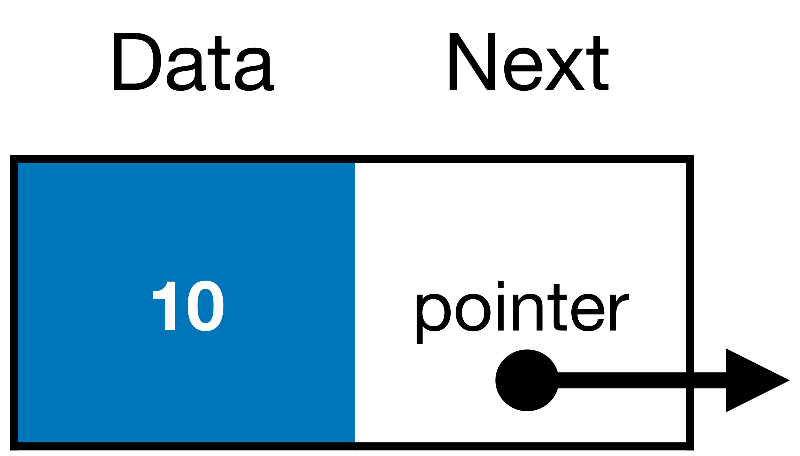
- A node is a collection of two sub-elements or parts.
    - A ***data*** part that stores the actual element



Linked list

- A <u>linked list</u> is an *ordered* collection of items (often called *nodes*), each of which contains some data, connected using *pointers* (hence the link part).

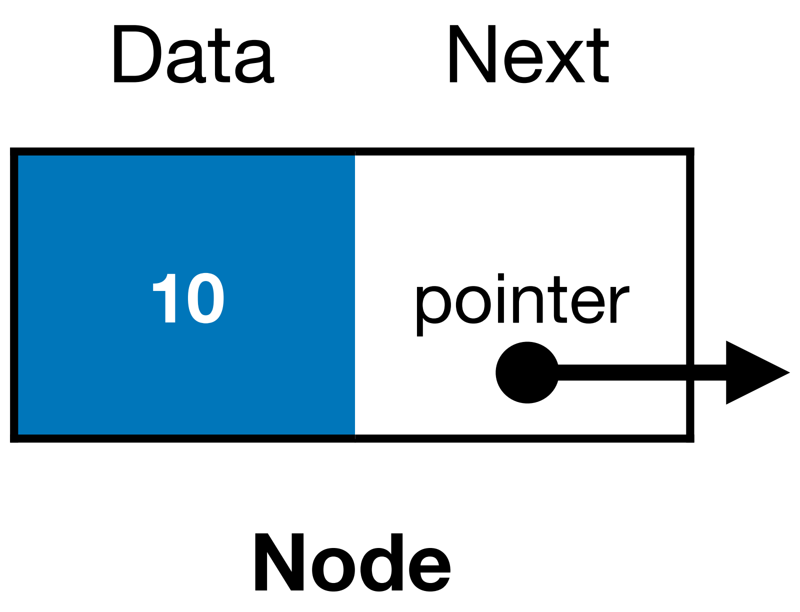
- A node is a collection of two sub-elements or parts.
  - A ***data*** part that stores the actual element
  - And a ***next*** part (pointer) that stores the address of the next node.



Linked list

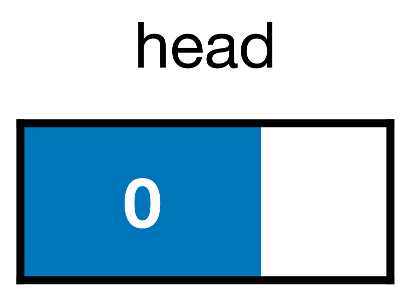
- A linked list is an *ordered* collection of items (often called *nodes*), each of which contains some data, connected using *pointers* (hence the link part).

- A node is a collection of two sub-elements or parts.
    - A ***data*** part that stores the actual element
    - And a ***next*** part (pointer) that stores the address of the next node.



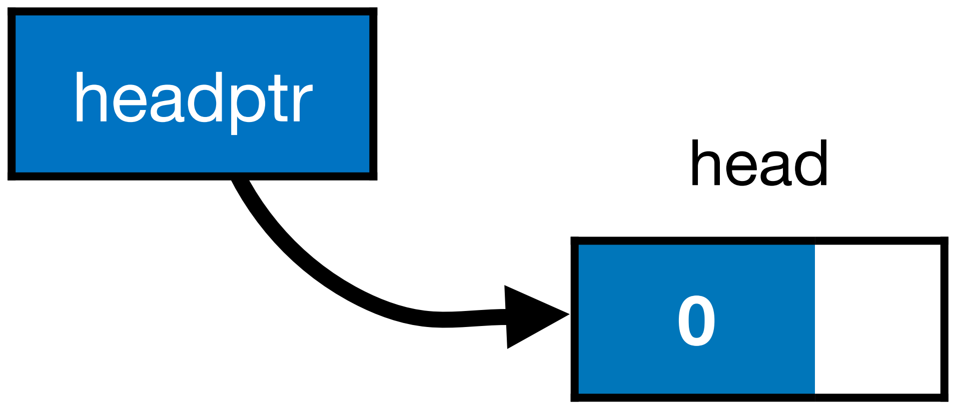
Linked list

Linked list



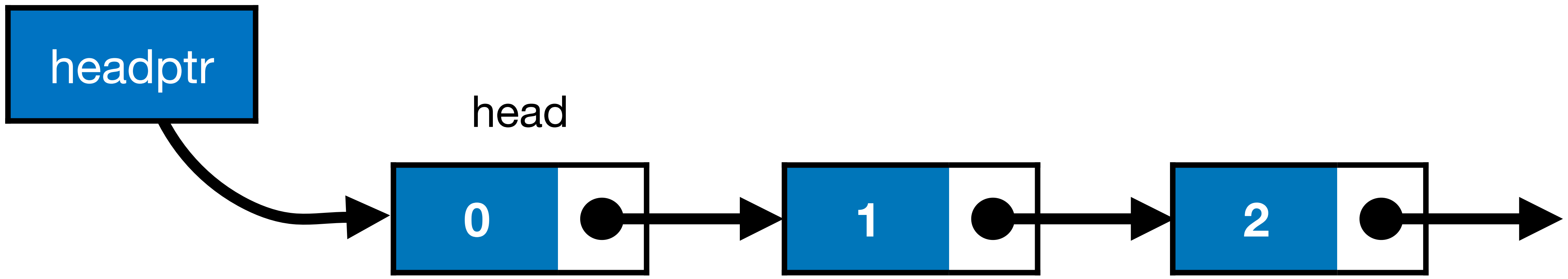
- The first node in the list is called the *head*

Linked list



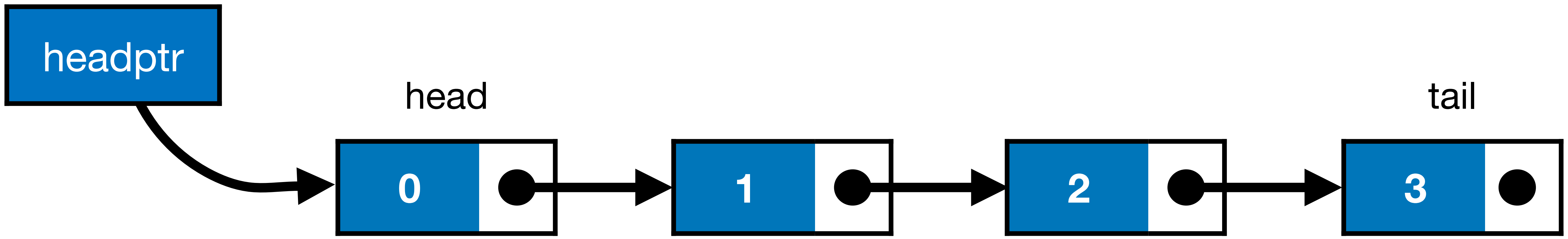
- The first node in the list is called the *head*
    - Accessed using pointer called ***head pointer***

Linked list



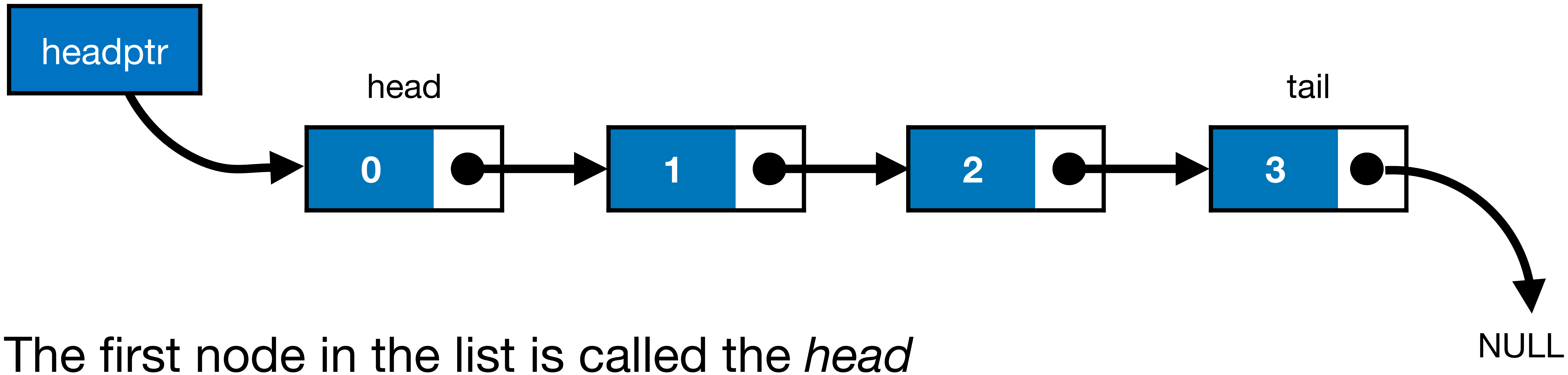
- The first node in the list is called the *head*
    - Accessed using pointer called ***head pointer***
    - Used as the starting reference to *traverse* the list

Linked list



- The first node in the list is called the *head*
  - 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*.

Linked list



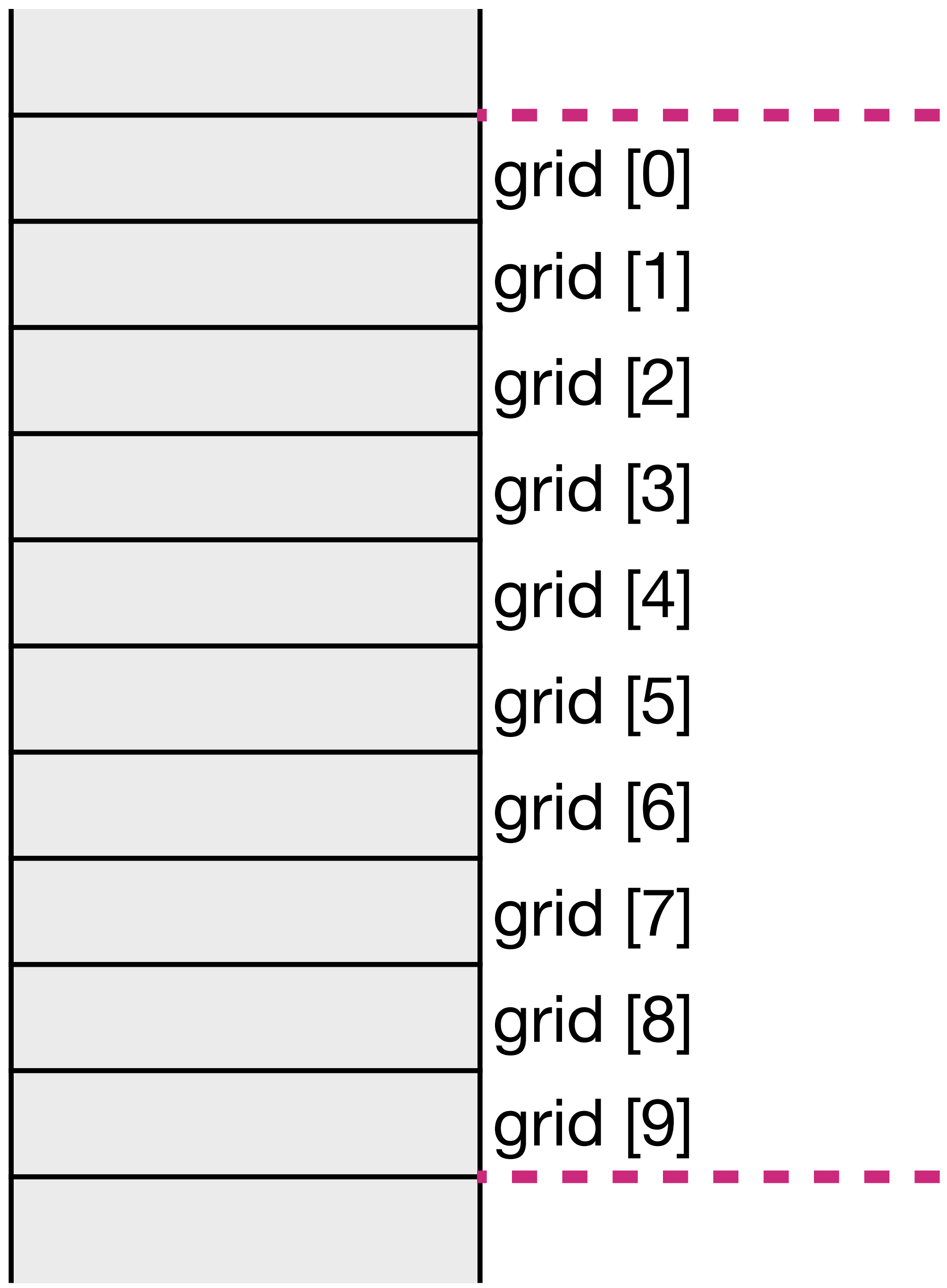
- The first node in the list is called the *head*
    - Accessed using pointer called ***head pointer***
    - Used as the starting reference to *traverse* the list
- The last node in the list is called the *tail*.
    - The tail may contain data, but it always points to NULL value

Array vs. linked list

Array vs. linked list

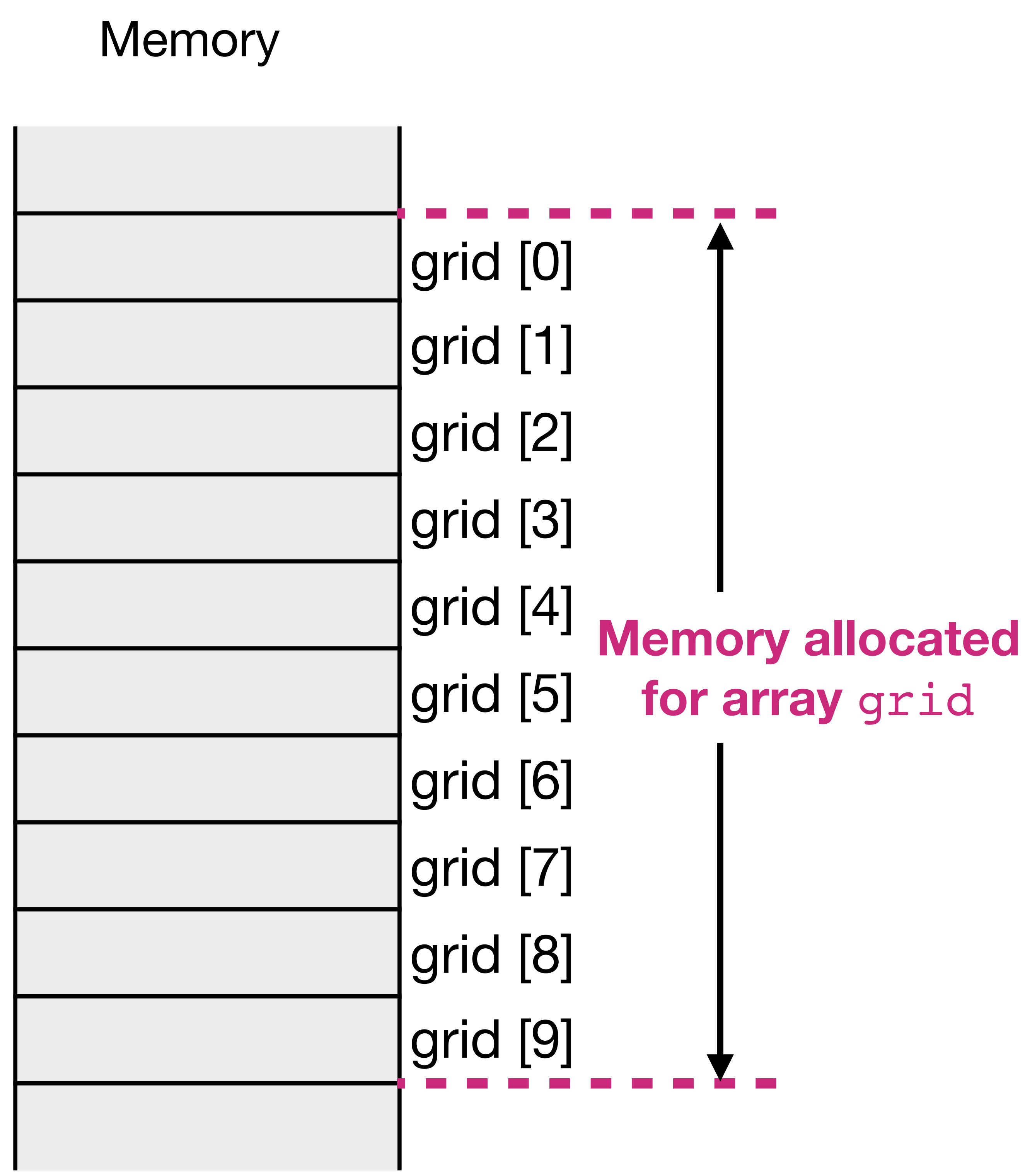
Array
(can be automatic or dynamic)

Array vs. linked list



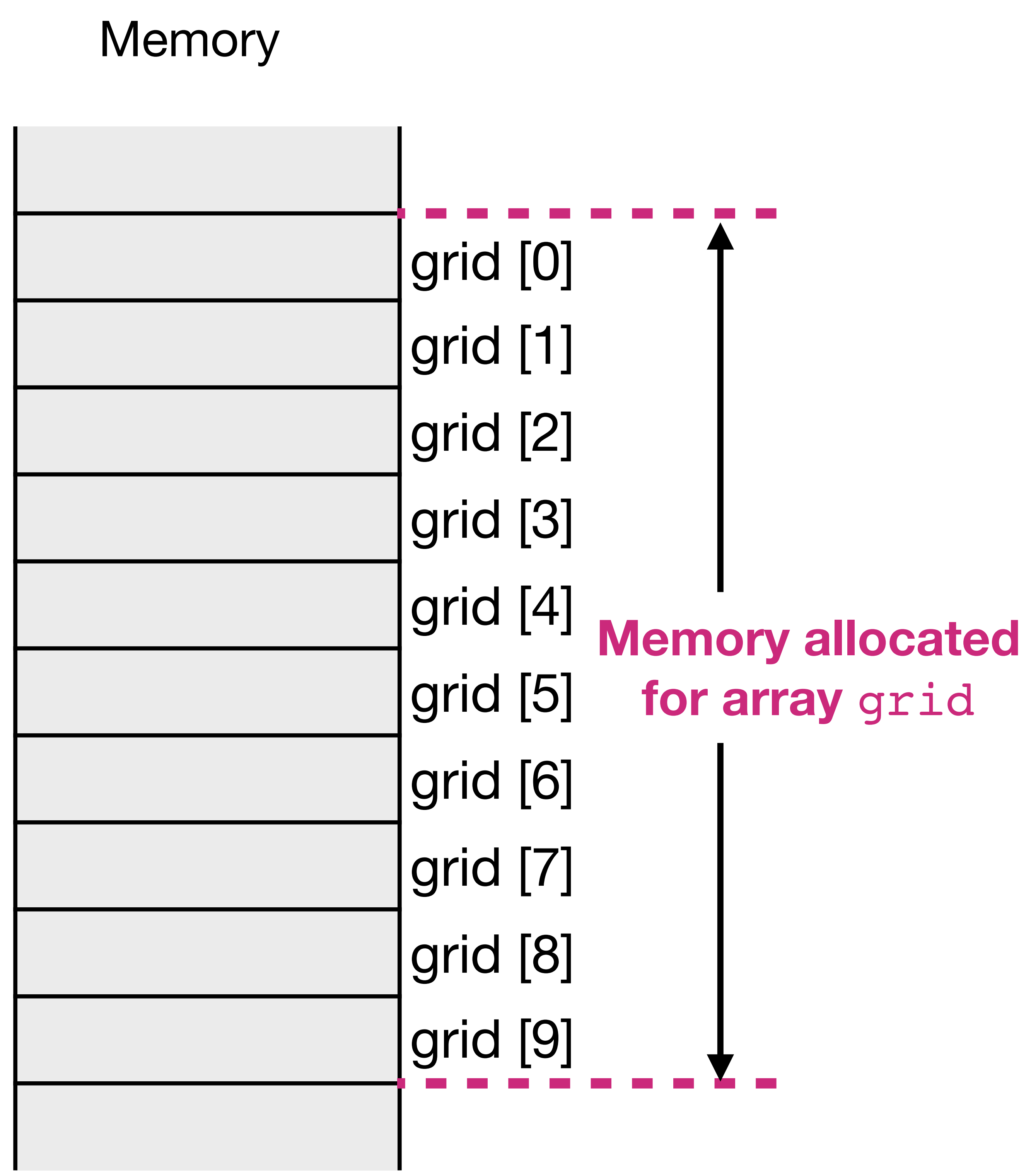
Array
(can be automatic or dynamic)

Array vs. linked list



Array
(can be automatic or dynamic)

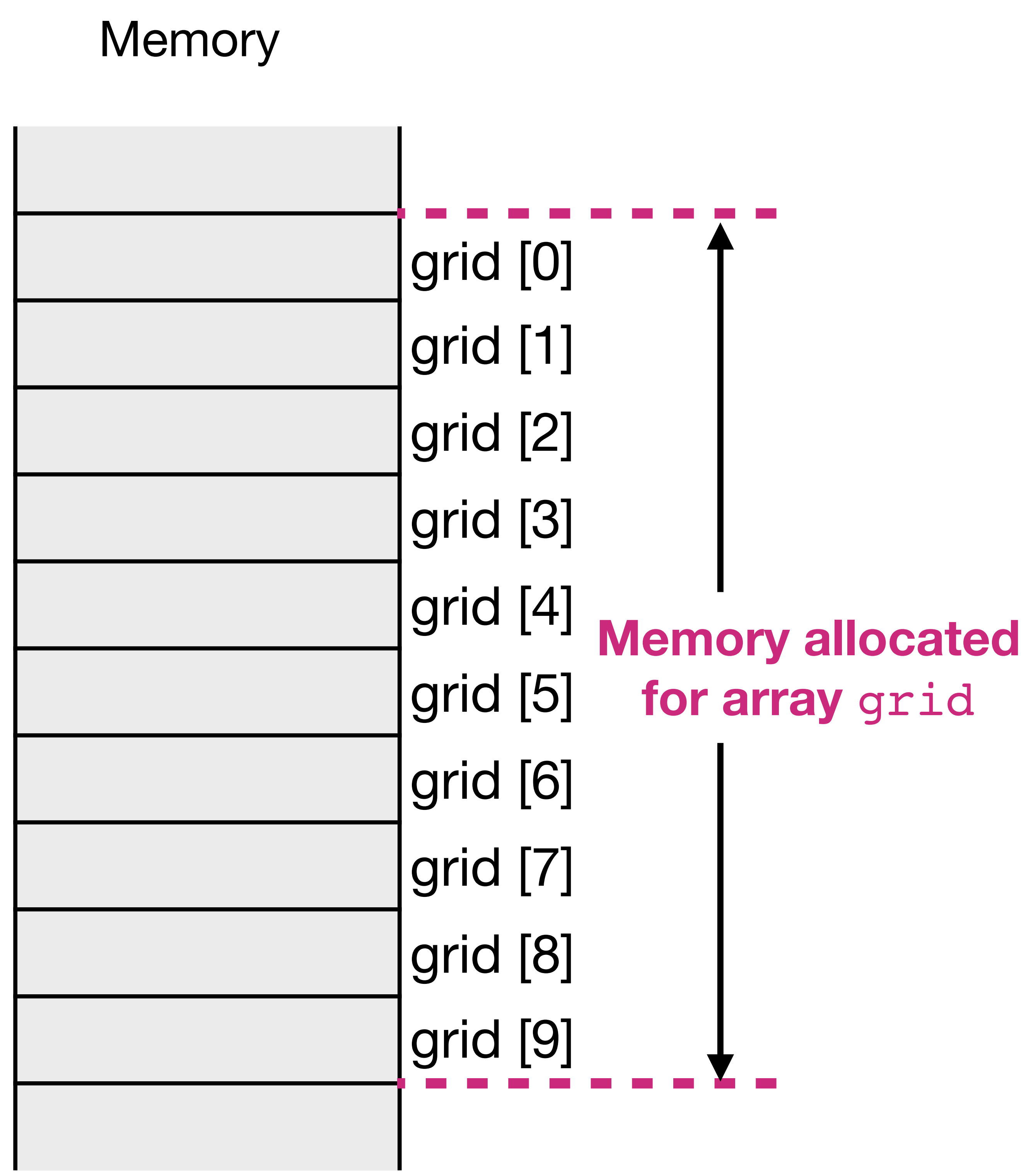
Array vs. linked list



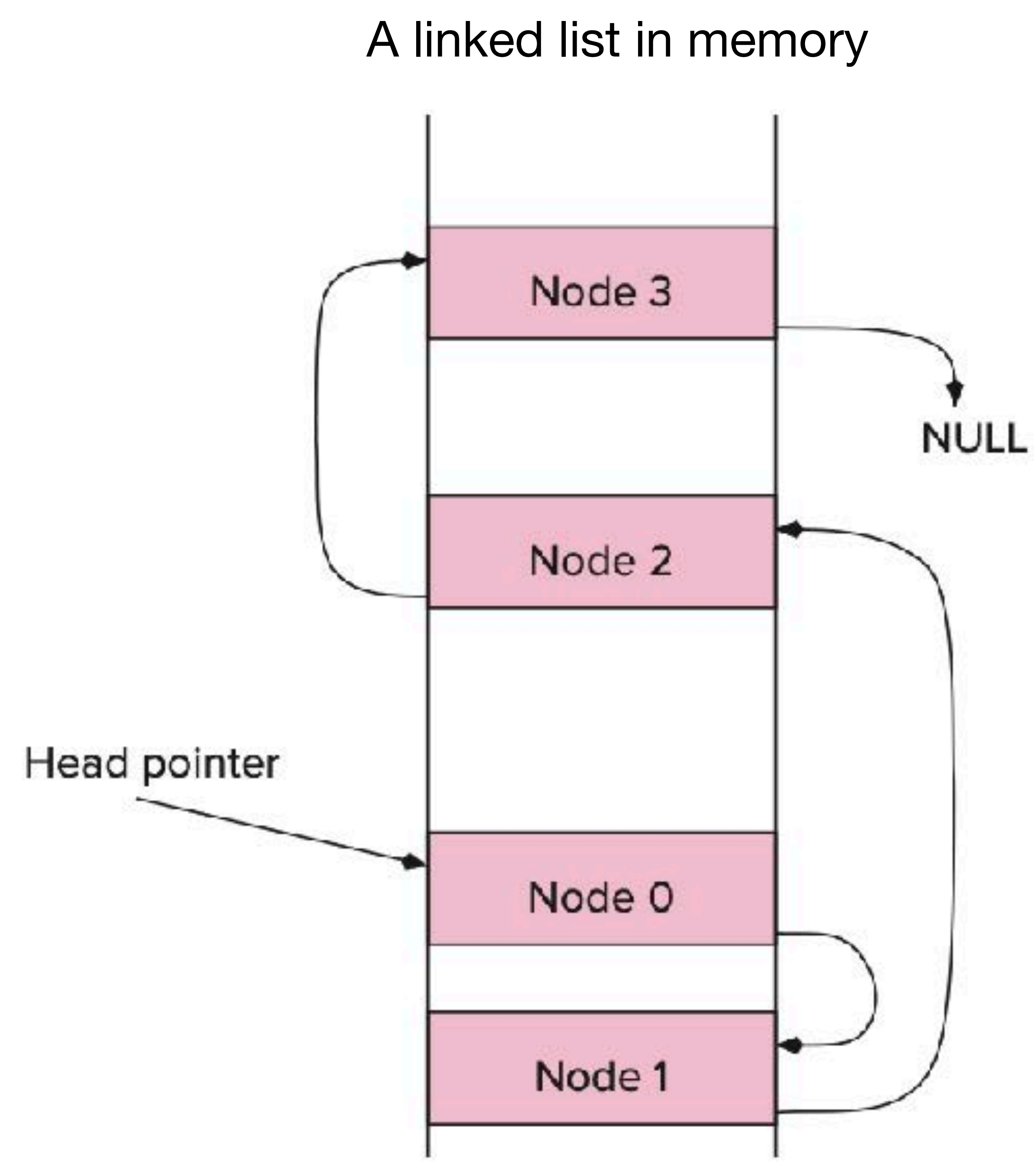
Array
(can be automatic or dynamic)

Linked list
(dynamic only)

Array vs. linked list



Array
(can be automatic or dynamic)



Linked list
(dynamic only)

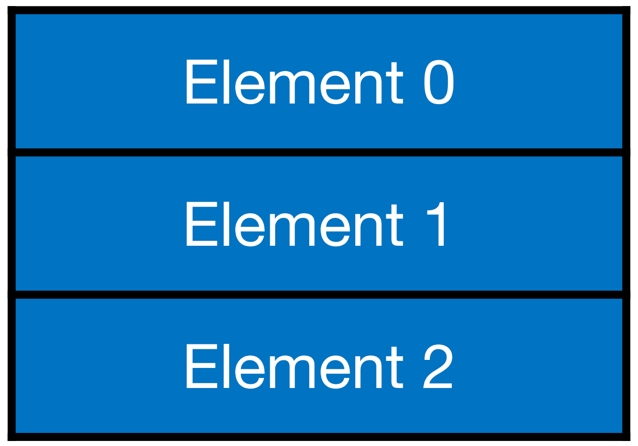
Array vs. linked list

	Array	Linked list

Array vs. linked list

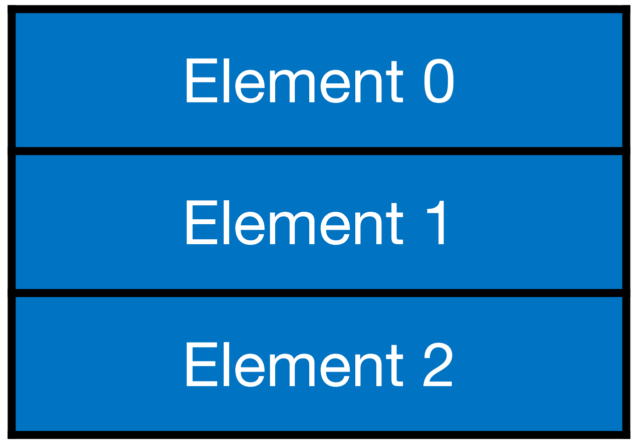
	Array	Linked list
Memory Allocation	**Automatic / Dynamic**	**Dynamic**

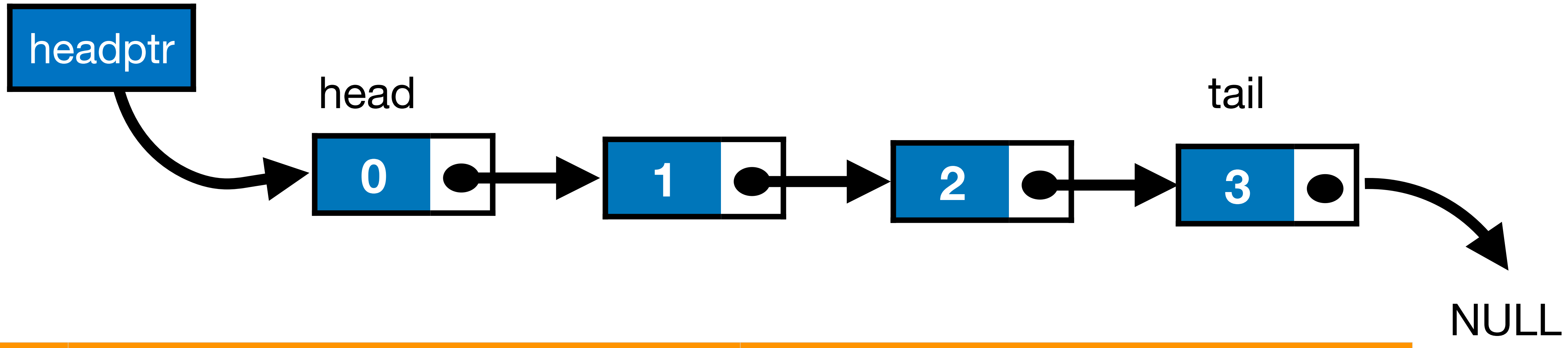
Array vs. linked list



	Array	Linked list
Memory Allocation	**Automatic / Dynamic**	**Dynamic**

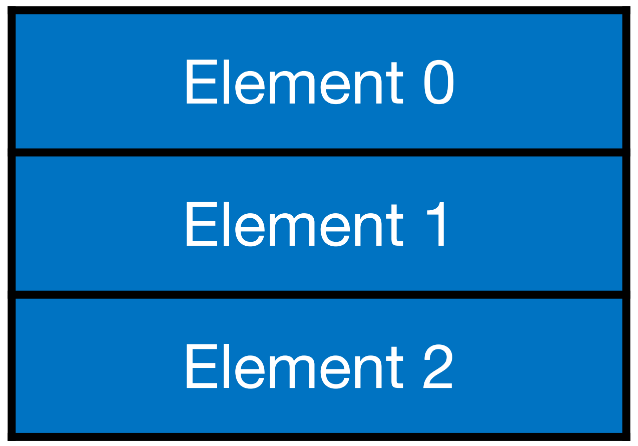
Array vs. linked list

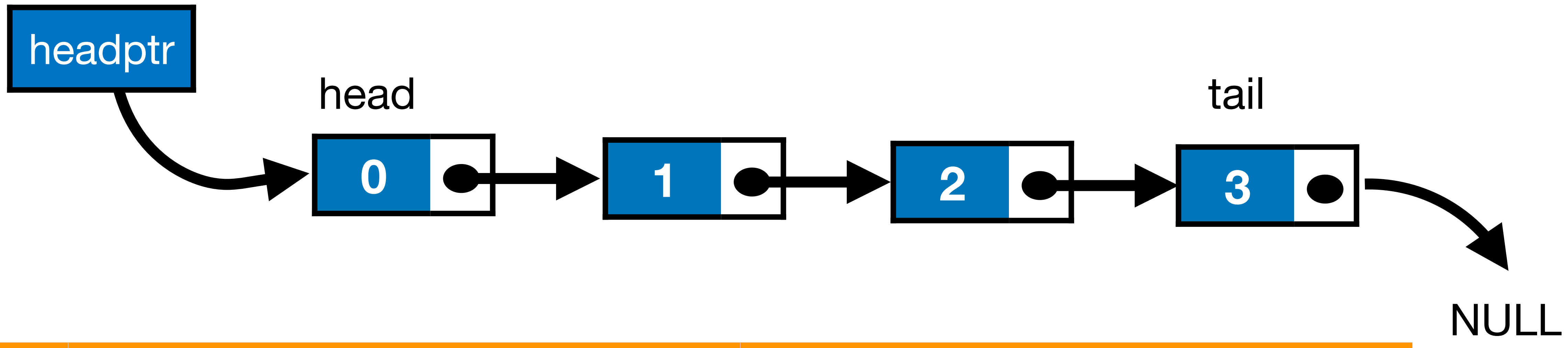




	Array	Linked list
Memory Allocation	**Automatic / Dynamic**	**Dynamic**

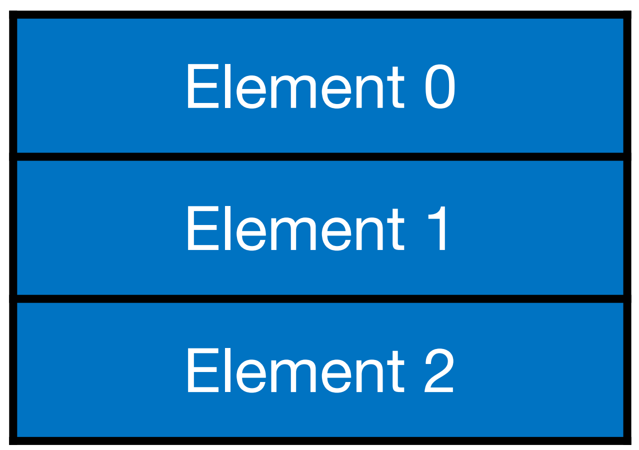
Array vs. linked list

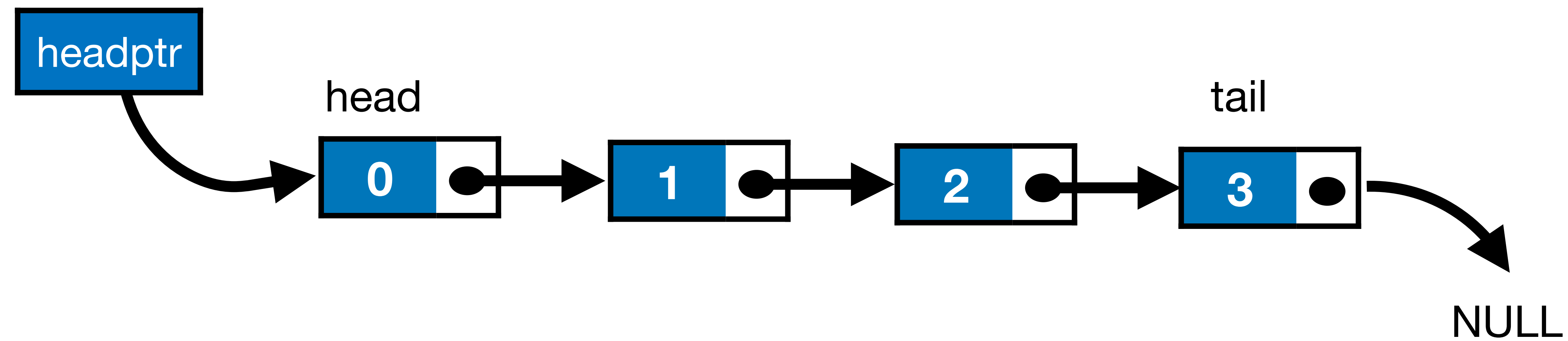




	Array	Linked list
Memory Allocation	**Automatic / Dynamic**	**Dynamic**
Memory Structure	**Contiguous**	**Not necessary consecutive**

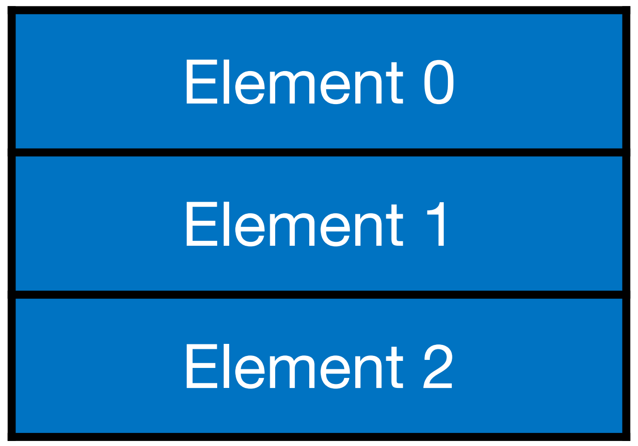
Array vs. linked list

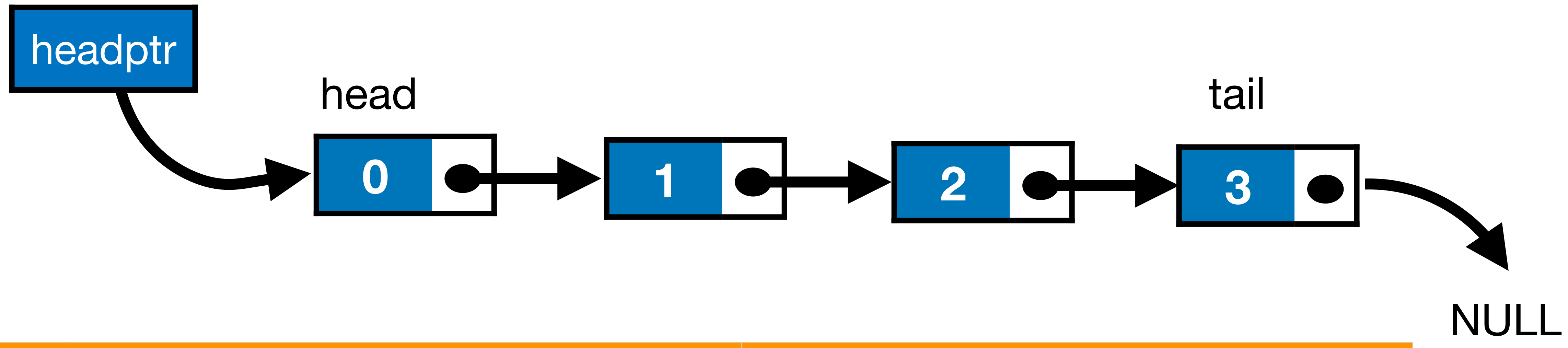




	Array	Linked list
Memory Allocation	**Automatic / Dynamic**	**Dynamic**
Memory Structure	**Contiguous**	**Not necessary consecutive**
Order of Access	**Random**	**Sequential**

Array vs. linked list





	Array	Linked list
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**

Basic operations

Basic operations

- Inserting an item in the list

Basic operations

- Inserting an item in the list
    - Unsorted list: Can insert at *head* or at *tail*

Basic operations

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

Basic operations

- 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

Basic operations

- 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

Basic operations

- 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.

Declaring a linked list

Example: Student record

Declaring a linked list

Example: Student record

```
typedef struct StudentStruct{
    int UIN;
    char *netid;
    float GPA;
}student;
```

Using structs

Declaring a linked list

Example: Student record

```
typedef struct StudentStruct{
    int UIN;
    char *netid;
    float GPA;
}student;
```

Using structs

```
typedef struct StudentStruct{
    int UIN;
    char *netid;
    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;
```

Using linked lists

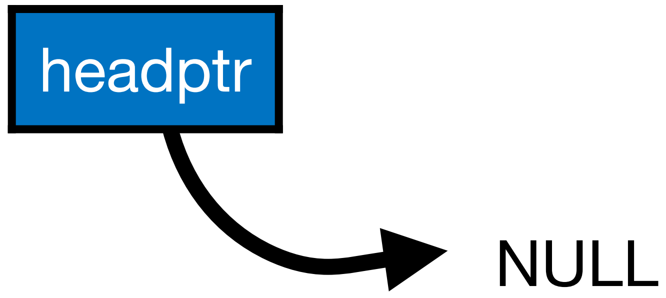
Declaring a linked list

Declaring a linked list

- What should be the empty list?

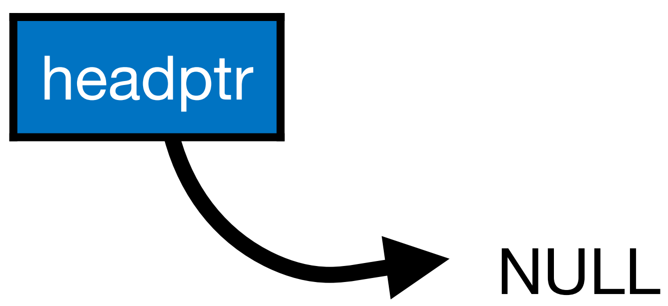
Declaring a linked list

- What should be the empty list?



Declaring a linked list

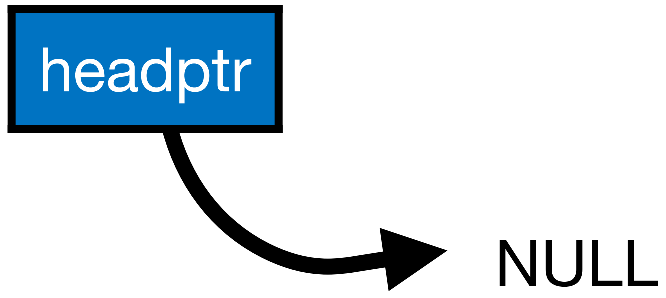
- What should be the empty list?




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

node* headptr = NULL;
```

Declaring a linked list

- What should be the empty list?

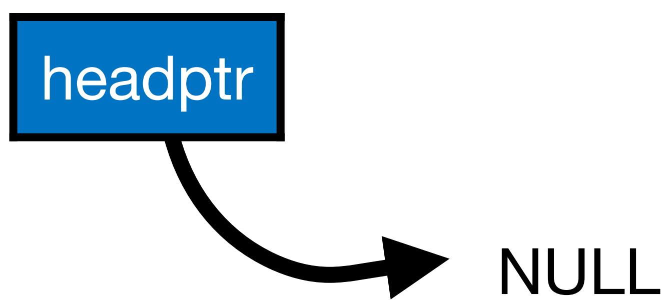


- What should be the singleton list?

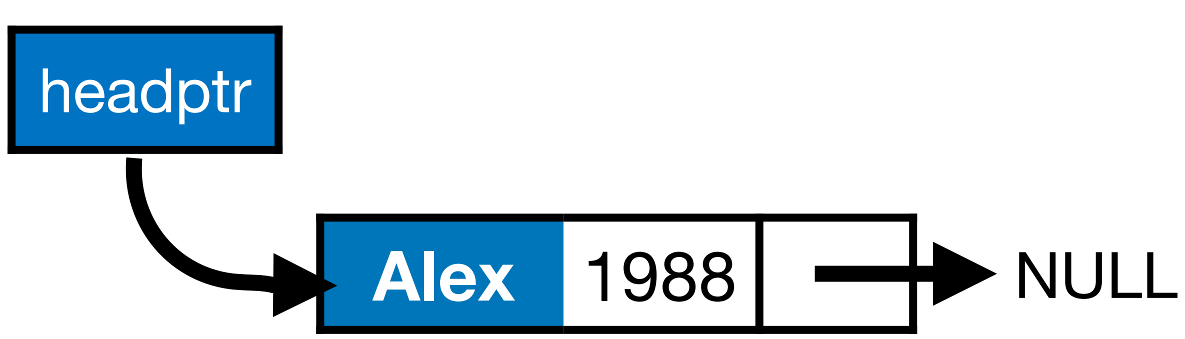
```
typedef struct person{
    char *name;
    unsigned int byear;
    struct person *next;
}node;

node* headptr;
```

Declaring a linked list

- What should be the empty list?



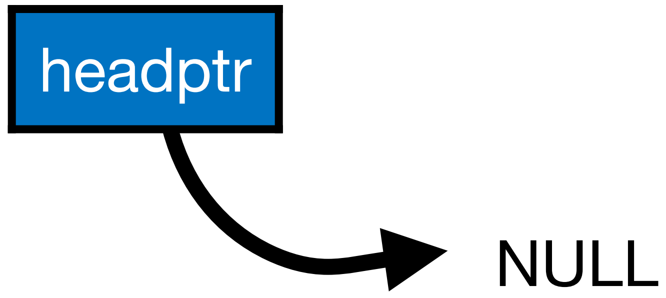
- What should be the singleton list?



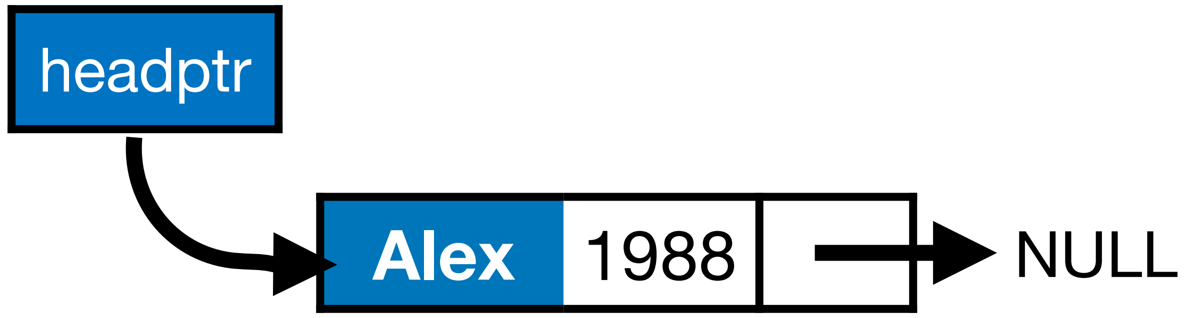

```
typedef struct person{
    char *name;
    unsigned int byear;
    struct person *next;
}node;

node* headptr;
```

Declaring a linked list

- What should be the empty list?



- What should be the singleton list?




```
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

- **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.

Linked lists - more elements

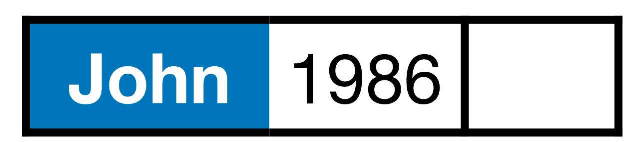
- Suppose we want to add another node

- **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.

Linked lists - more elements

- Suppose we want to add another node

```
{“John”, 1986, }
```

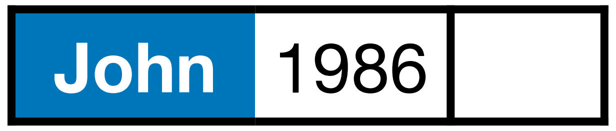


- **Inserting an item in the list**
  - Unsorted list: Can insert at *head* or at *tail*
  - Sorted list: Insert so as to maintain sorted property
- Traversing the list
- Deleting an item from the list
  - Delete from head, tail or middle.

Linked lists - more elements

- Suppose we want to add another node

`{"John", 1986, }`



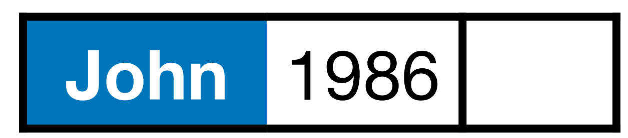
- Should the node be added at the head or tail?

- **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.

Linked lists - more elements

- Suppose we want to add another node

```
{"John", 1986, }
```



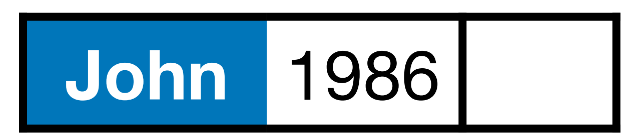
- Should the node be added at the head or tail?
  - For sorted linked lists, this node should go at the head

- **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.

Linked lists - more elements

- Suppose we want to add another node

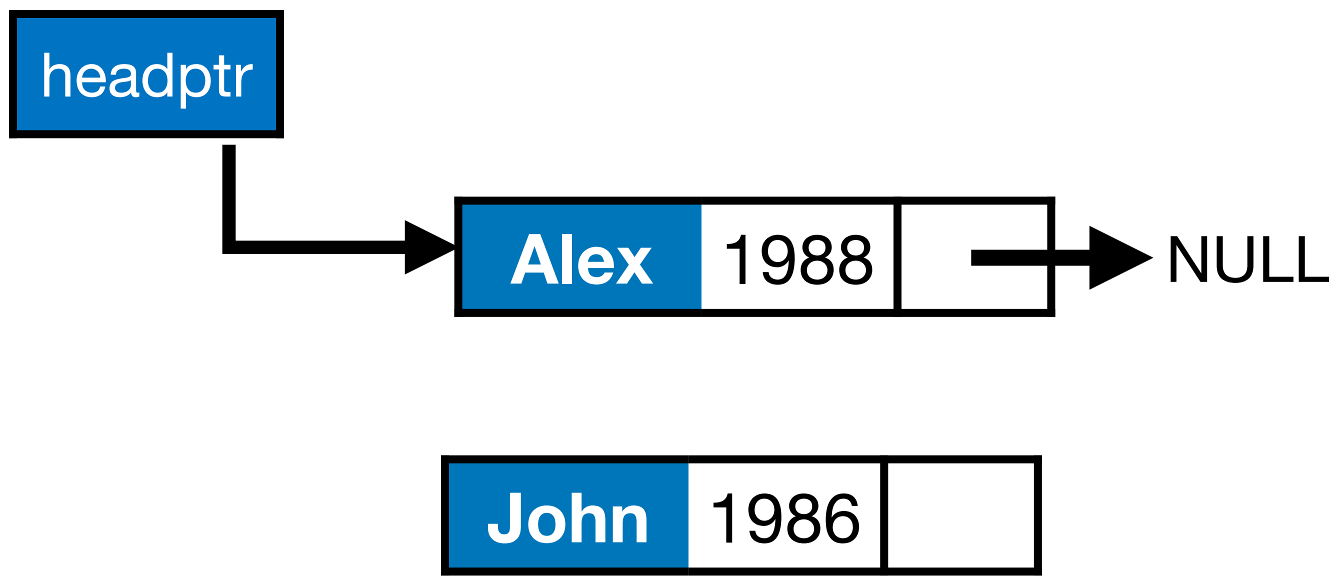
```
{"John", 1986, }
```



- Should the node be added at the head or tail?
  - For sorted linked lists, this node should go at the head
  - For plain linked lists, we get to choose.

- **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.

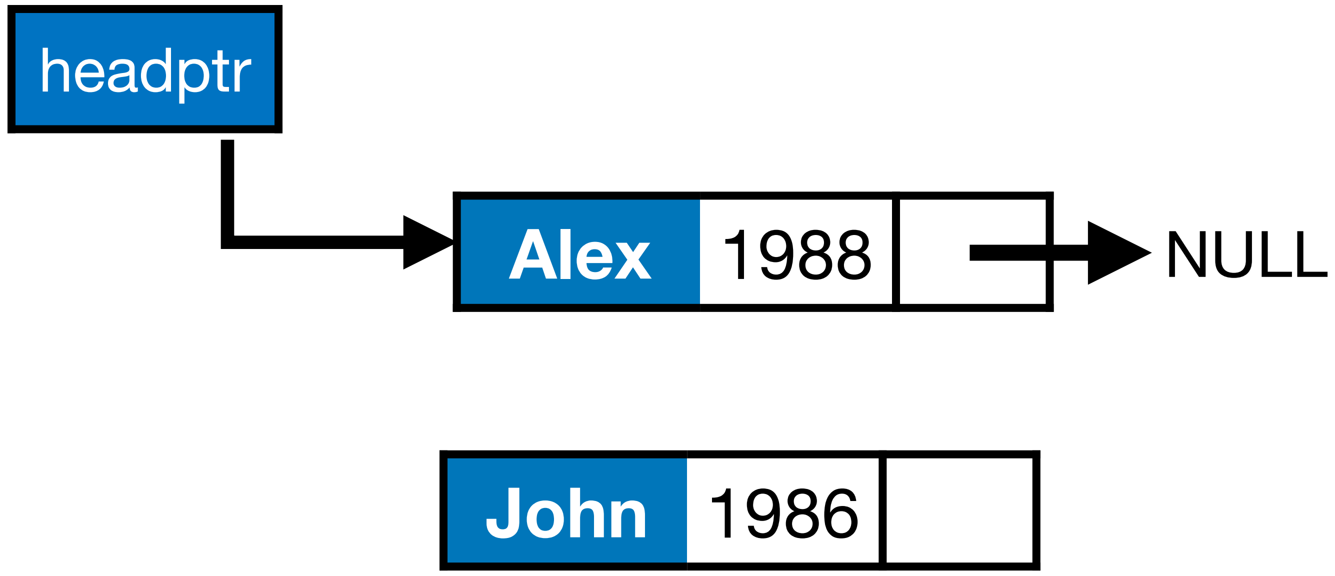
Linked lists - adding a node



- **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.

Linked lists - adding a node

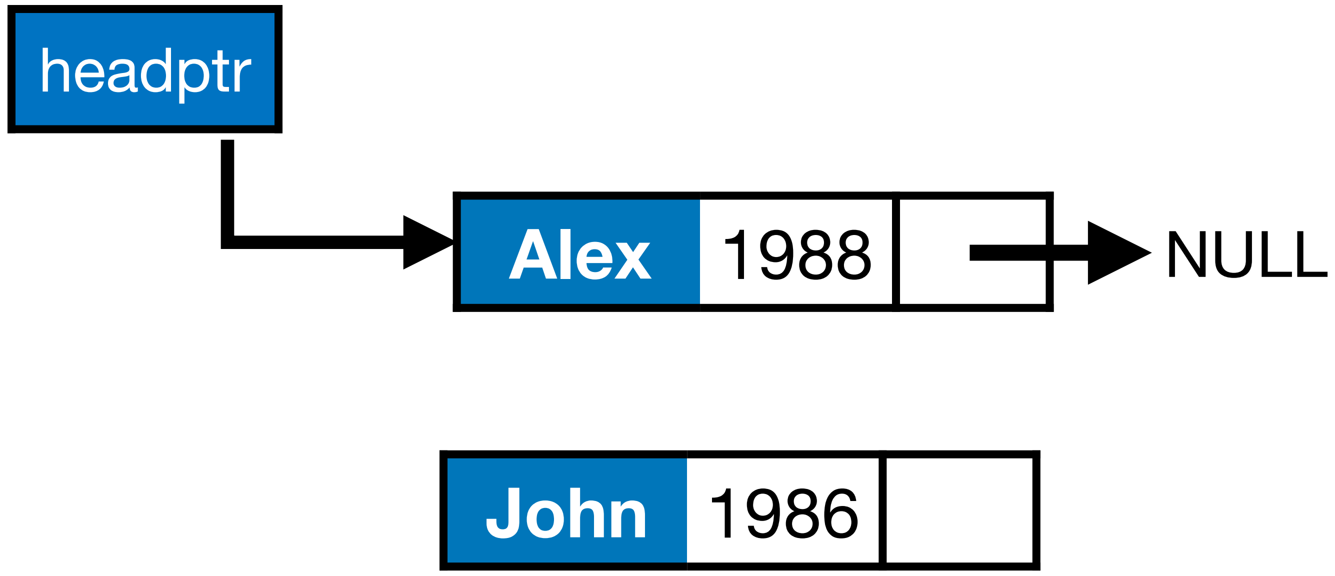
- Suppose we want to **add at head.**



- **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.

Linked lists - adding a node

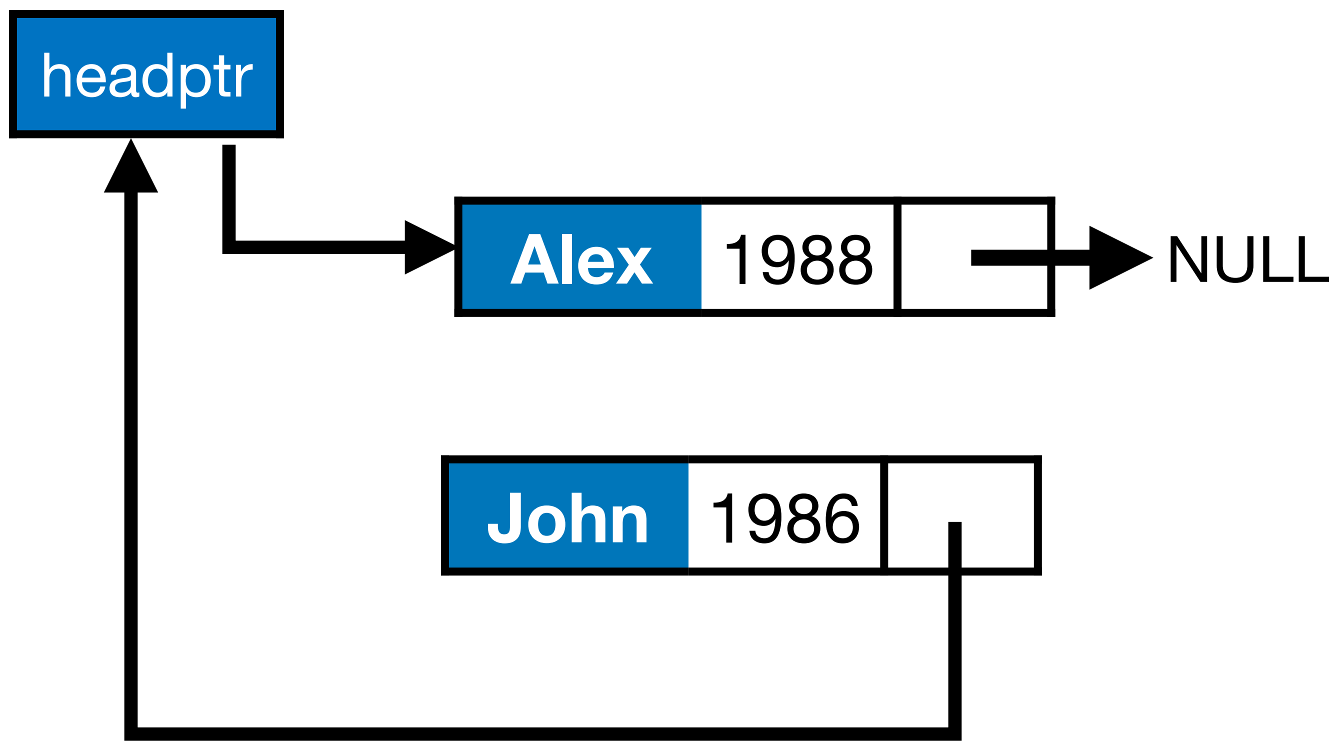
- Suppose we want to **add at head.**
- What needs to be done?



- **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.

Linked lists - adding a node

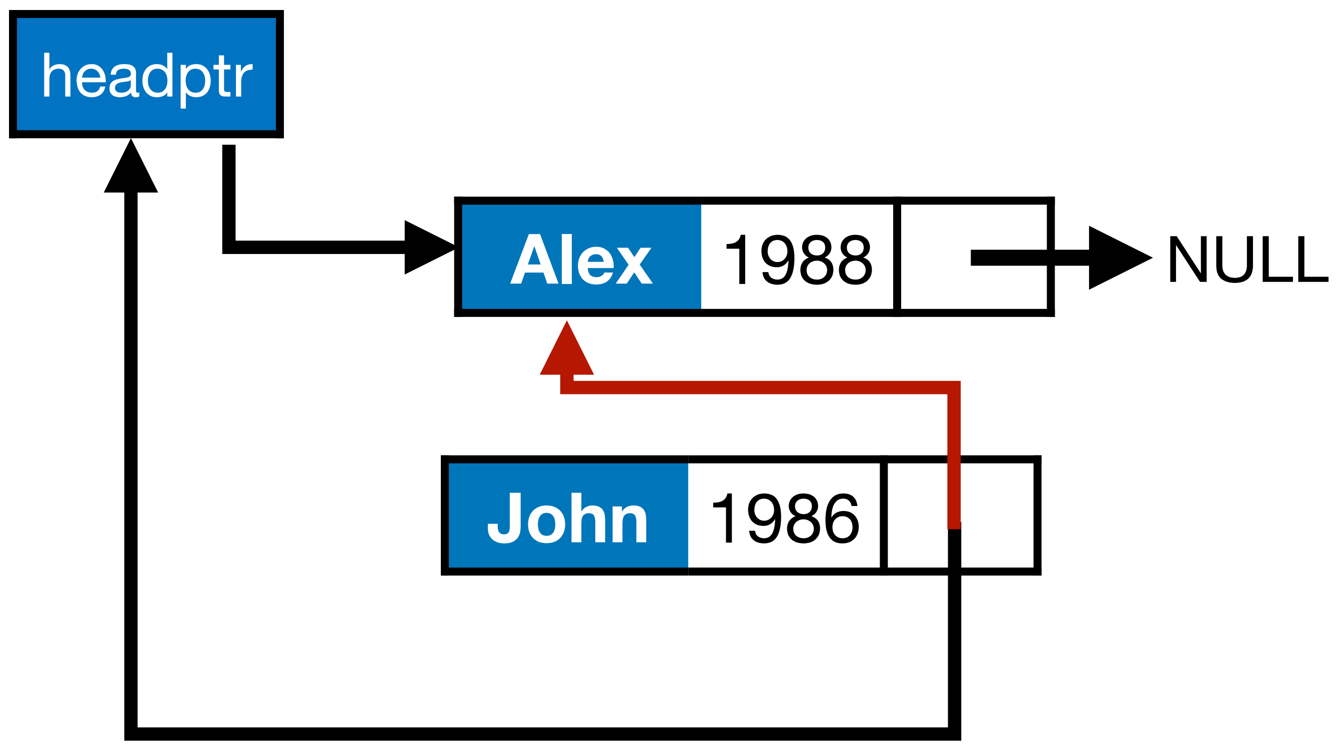
- Suppose we want to **add at head.**
- What needs to be done?
    - New node should point to current head.



- **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.

Linked lists - adding a node

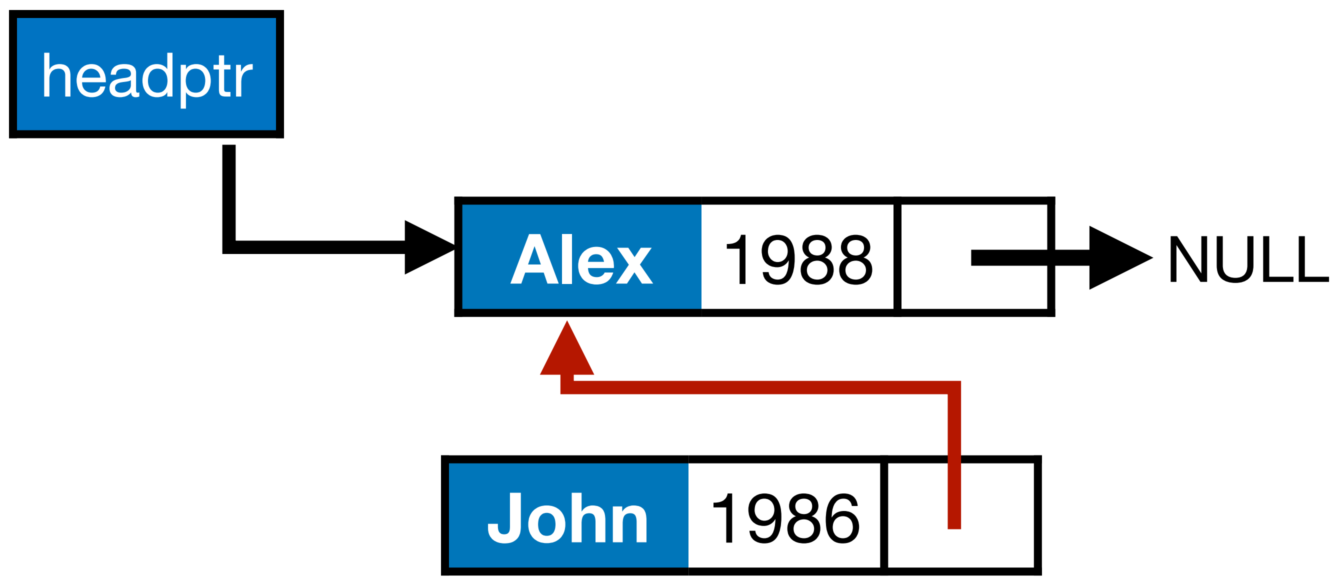
- Suppose we want to **add at head.**
- What needs to be done?
  - New node should point to current head.



- **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.

Linked lists - adding a node

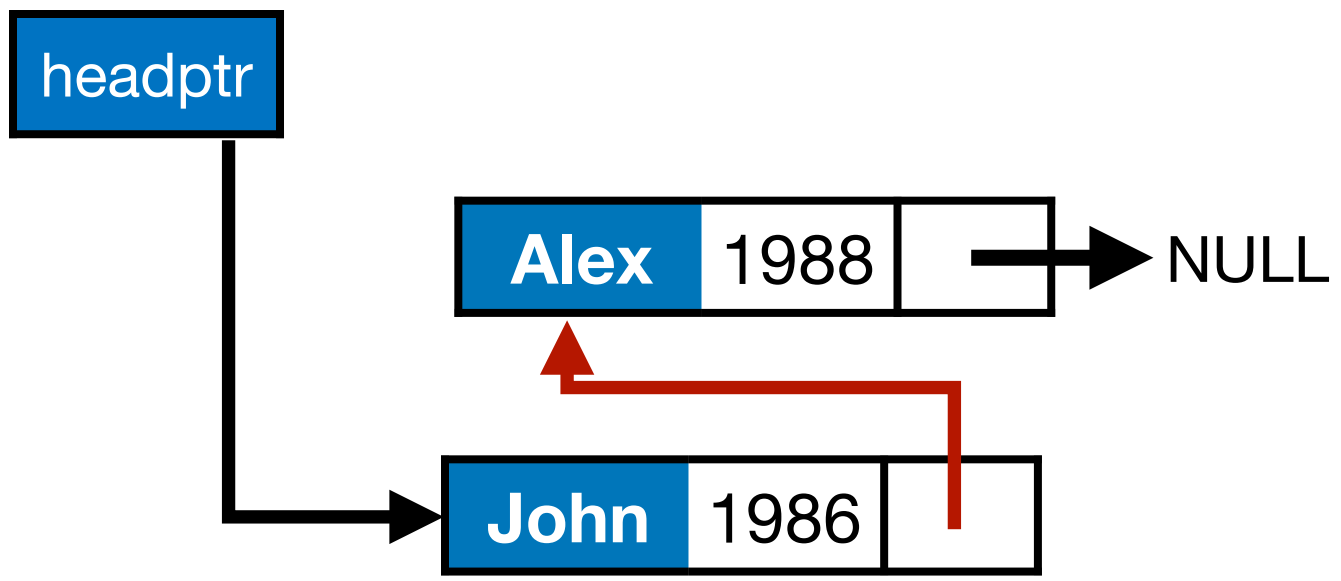
- Suppose we want to **add at head.**
- What needs to be done?
  - New node should point to current head.



- **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.

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.



- **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.

Linked lists - adding a node

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

- What needs to be done?

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

Linked lists - adding a node

- Suppose we want to **add at head.**
- What needs to be done?
  - New node should point to *current* head.

```
node* temp=(node*) malloc(sizeof(node));
…
…
temp->next = cursor;
```

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

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.

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

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

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

Linked lists - adding a node

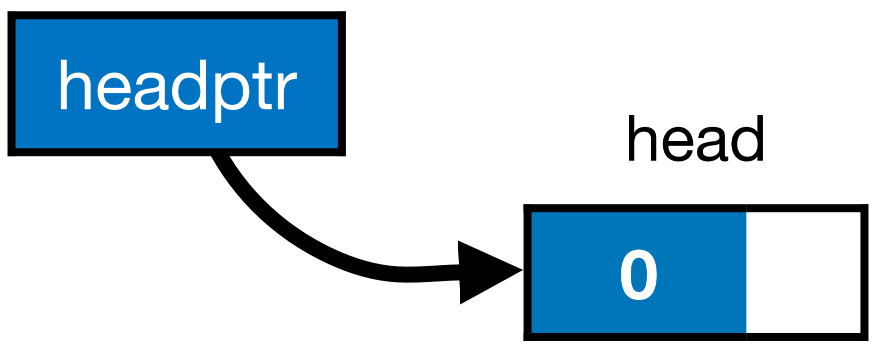
- Suppose we want to **add at head.**
- What needs to be done?
    - New node should point to *current* head.
    - Current head should be updated to new node.
    - Deal with case of empty list

```
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

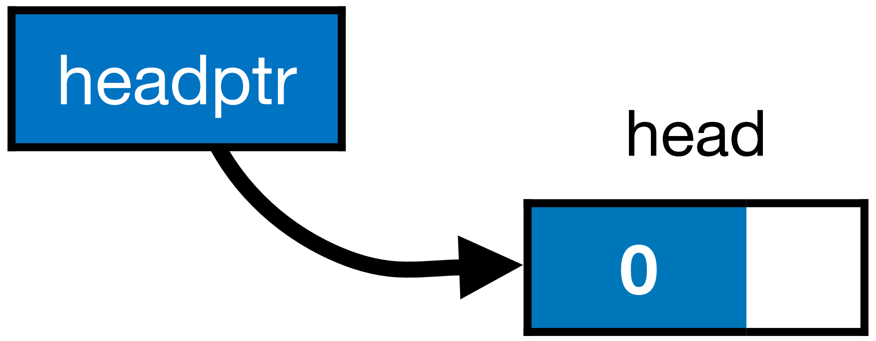
Traversing a linked list

Traversing a linked list



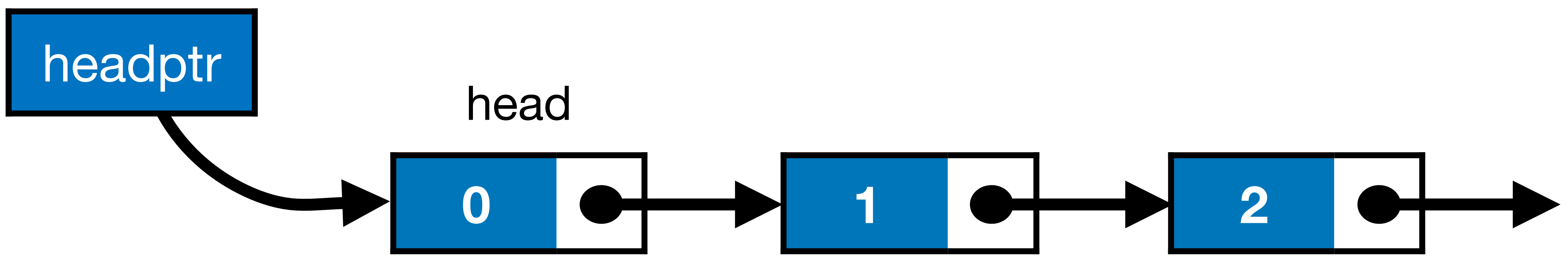
- Head pointer points to the first node of the list.

Traversing a linked list



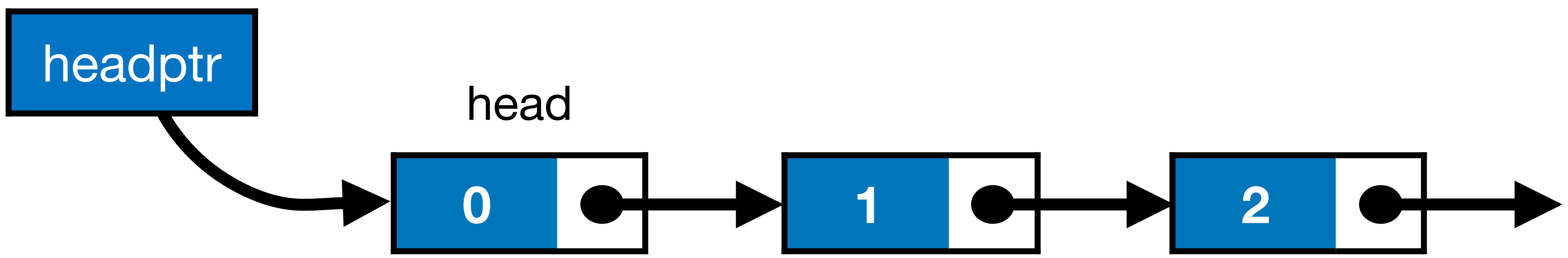
- Head pointer points to the first node of the list.
- To traverse the list we do the following

Traversing a linked list



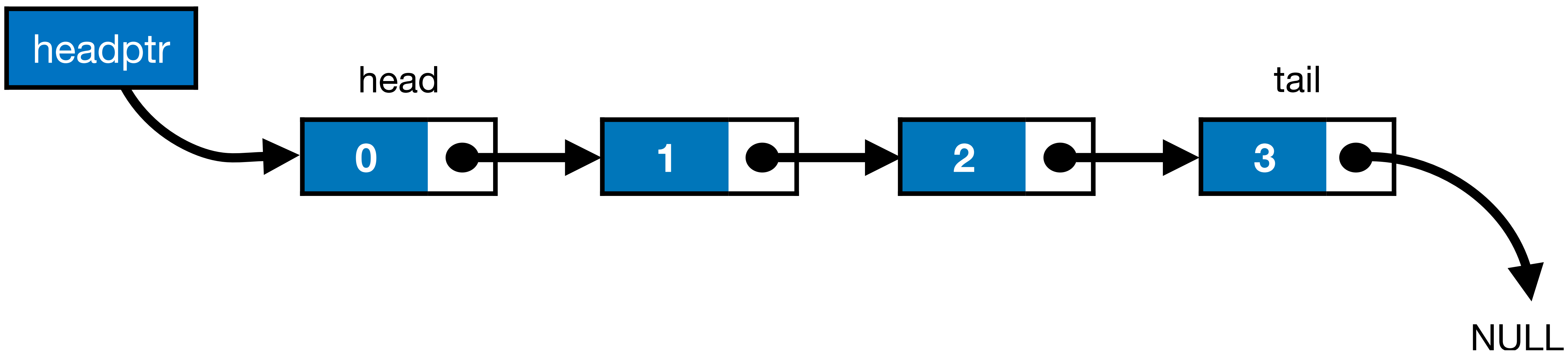
- Head pointer points to the first node of the list.
- To traverse the list we do the following
    - Follow the pointers.

Traversing a linked list



- 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.

Traversing a linked list



- 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

- 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.

Linked lists - traversing

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

- 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.

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;
```

- 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.

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 &

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

- 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.

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);
  }
}
```

- 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.

Exercise

Exercise

- Let us put together whatever we tried so far.
- Add the following nodes successively to the head of an empty list and print the list out.

Exercise

- Let us put together whatever we tried so far.
- Add the following nodes successively to the head of an empty list and print the list out.
    - {Alex, 1988}
    - {John, 1986}
    - {Mary, 1990}
    - {Sue, 1992}

Exercise

- Let us put together whatever we tried so far.

- Add the following nodes successively to the head of an empty list and print the list out.

    - {Alex, 1988}
    - {John, 1986}
    - {Mary, 1990}
    - {Sue, 1992}

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

What happened?

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

  node * temp = (node *) malloc(sizeof(node));
  temp->name = new->name;
  temp->next = new->next;

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

What happened?

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

  node * temp = (node *) malloc(sizeof(node));
  temp->name = new->name;
  temp->next = new->next;

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

`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?)

What happened?

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

  node * temp = (node *) malloc(sizeof(node));
  temp->name = new->name;
  temp->next = new->next;

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

`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.

What happened?

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

  node * temp = (node *) malloc(sizeof(node));
  temp->name = new->name;
  temp->next = new->next;

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

`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.

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

What happened?

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

  node * temp = (node *) malloc(sizeof(node));
  temp->name = new->name;
  temp->next = new->next;

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

`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.

Since we are passing in a double pointer the code on the right (from slide #14) had to be carefully updated to make the types match as done above.

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

Adding a node - add at tail

Adding a node - add at tail

- A pure implementation of a ***singly*** linked-list is completely defined by its head pointer.

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)

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.

Adding a node - add at tail

- A pure implementation of a ***singly*** linked-list is completely defined by its head pointer.

    - Aside: 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.

- **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.

Adding at tail

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

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

Deleting a node from head

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

- ~~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.

Deleting a node from head

- To delete a node from the **head** is simple.
  - Make a copy of the head pointer

```
node *old_head = *headptr;
```

- ~~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.

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

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

- ~~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.

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);
```

- ~~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.

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
- 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~~
  - ~~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.

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
- What if list empty?

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

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

- ~~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.

Deleting the tail node

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

- ~~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.

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

- ~~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?

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

- ~~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?

```
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~~
- ~~**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.
  - Set `second_last`'s `next` to `NULL`.

```
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~~
- ~~**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.
  - 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~~
- ~~**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.
  - 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;
}
```

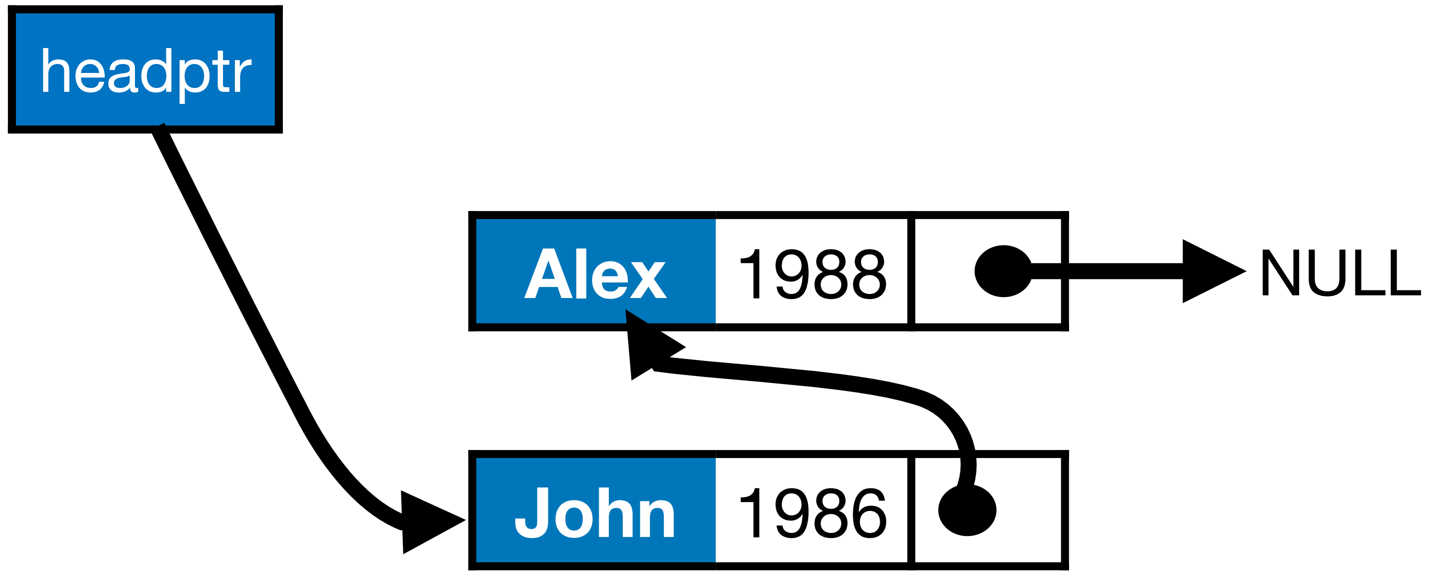
- ~~Traversing the list~~
- ~~**Deleting an item** from the list~~
  - ~~Delete from head~~, **tail** or middle.

Insertion in a sorted linked list

- ~~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.

Insertion in a sorted linked list

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

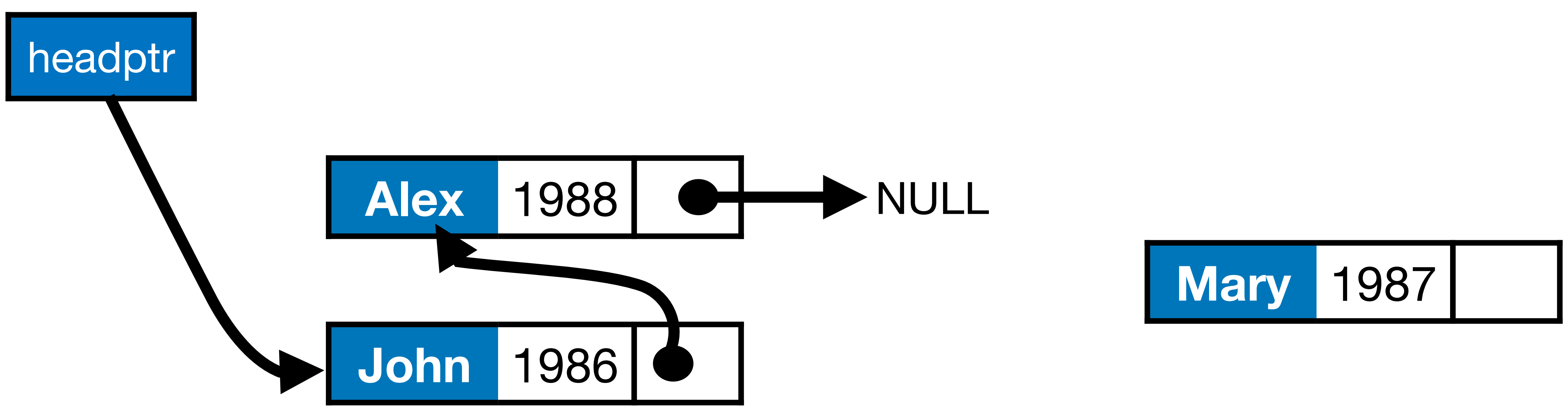


- ~~Inserting an item in the list~~
    - ~~Unsorted list: Can insert at *head* or at *tail*~~
    - **Sorted list: Insert so as to maintain sorted property**
- ~~Traversing the list~~
- ~~Deleting an item from the list~~
    - Delete from head, tail or middle.

Insertion in a sorted linked list

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

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



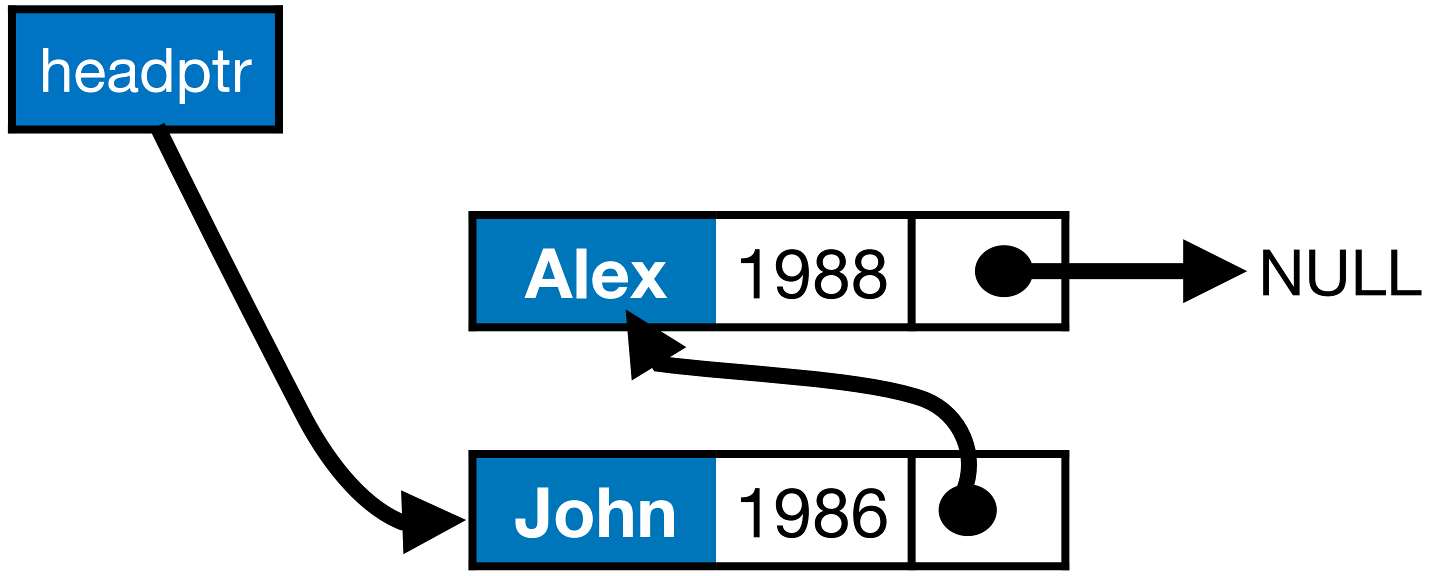
- ~~Inserting an item in the list~~
    - ~~Unsorted list: Can insert at *head* or at *tail*~~
    - **Sorted list: Insert so as to maintain sorted property**
- ~~Traversing the list~~
- ~~Deleting an item from the list~~
    - Delete from head, tail or middle.

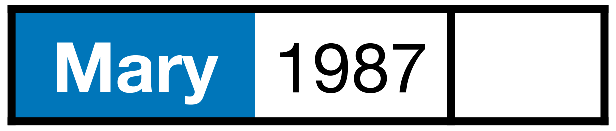
Insertion in a sorted linked list

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

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

Let us start from basics!





- ~~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.

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){
```

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){
```

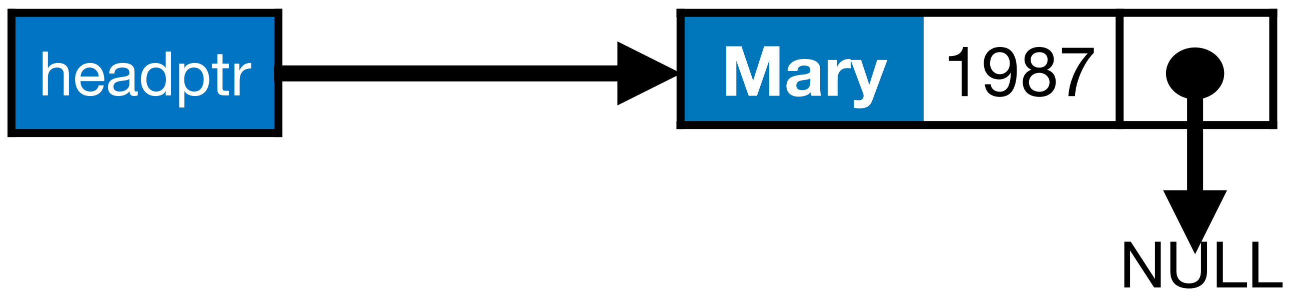
If empty list, add at head.

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;
  }
```



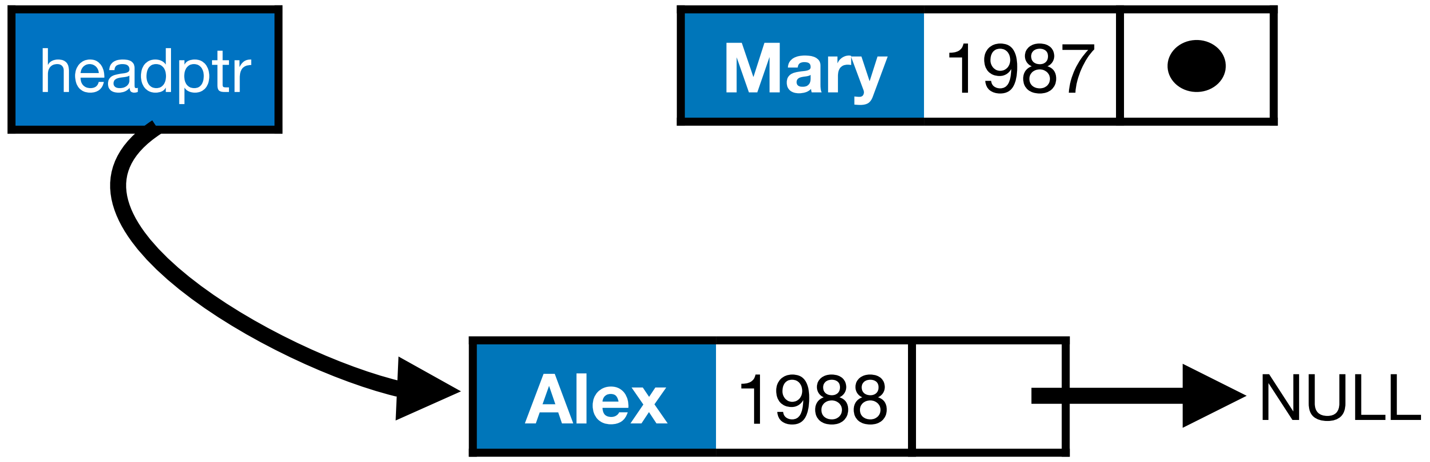
If empty list, add at head.

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);
    return;
  }
```



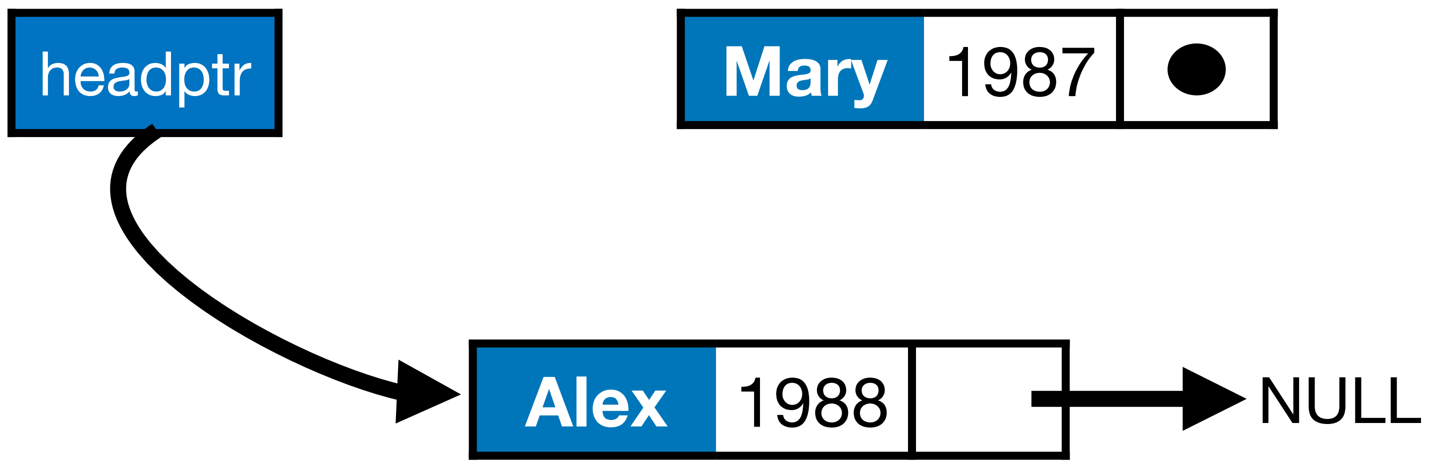
What if not empty?

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;
  }
```



What if not empty?

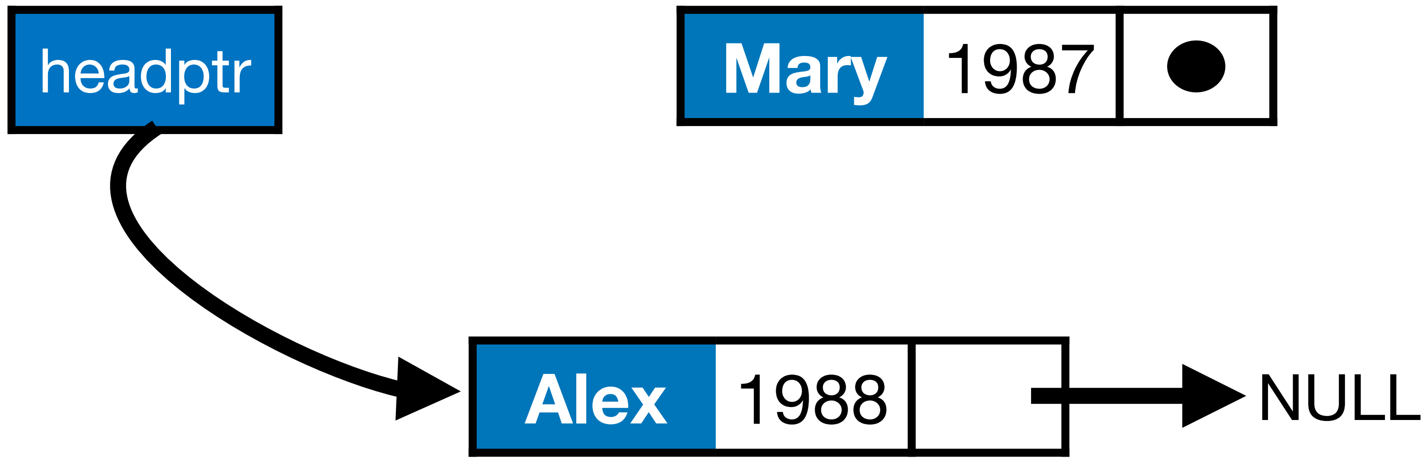
If first item is bigger than new node still add at head!

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



What if not empty?

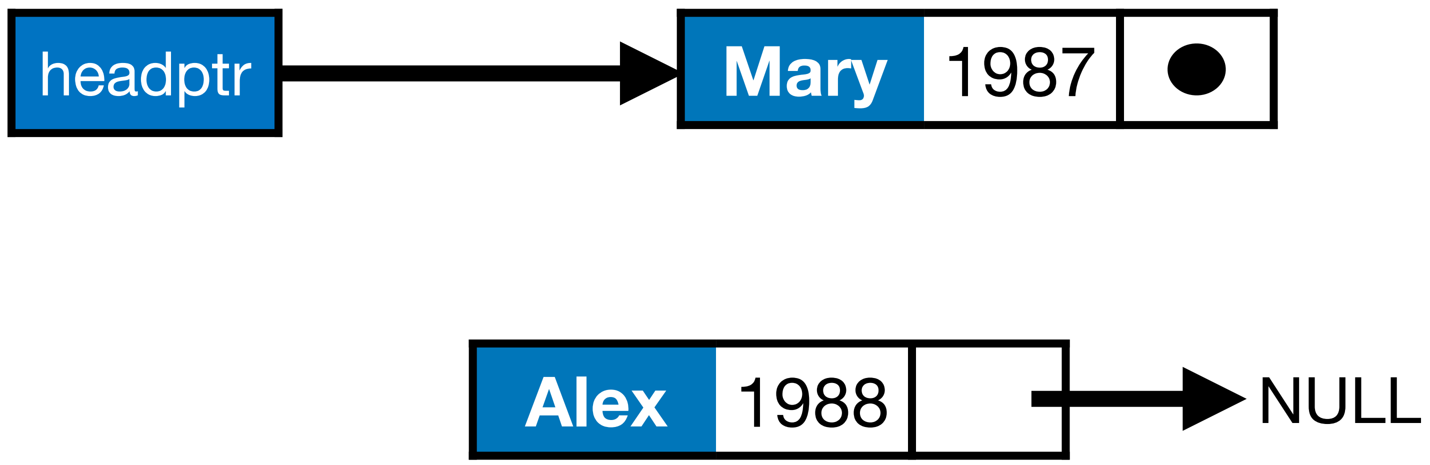
If first item is bigger than new node still add at head!

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



What if not empty?

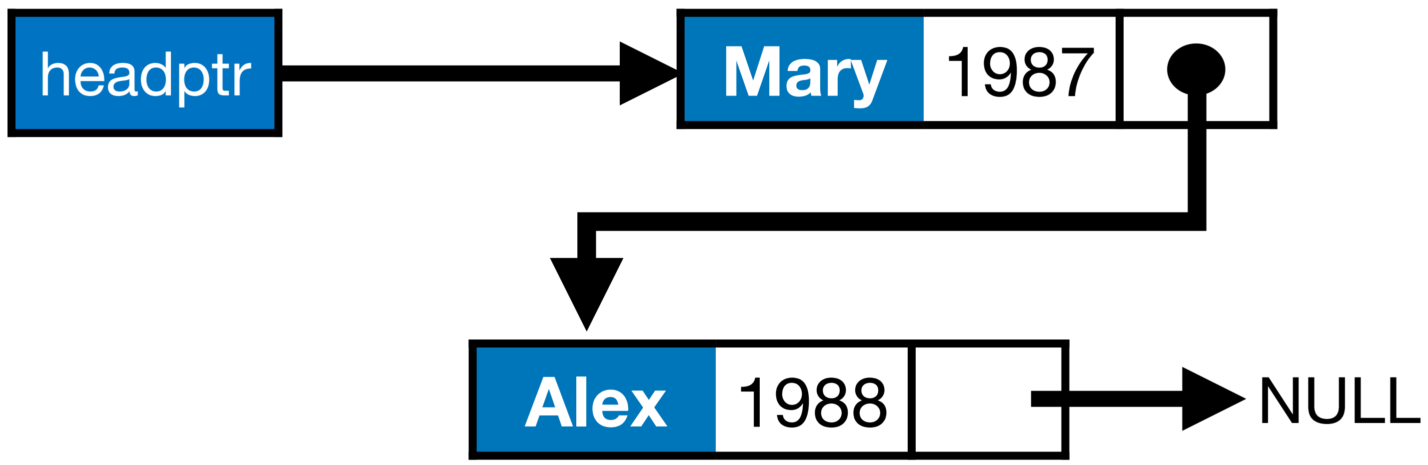
If first item is bigger than new node still add at head!

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



What if not empty?

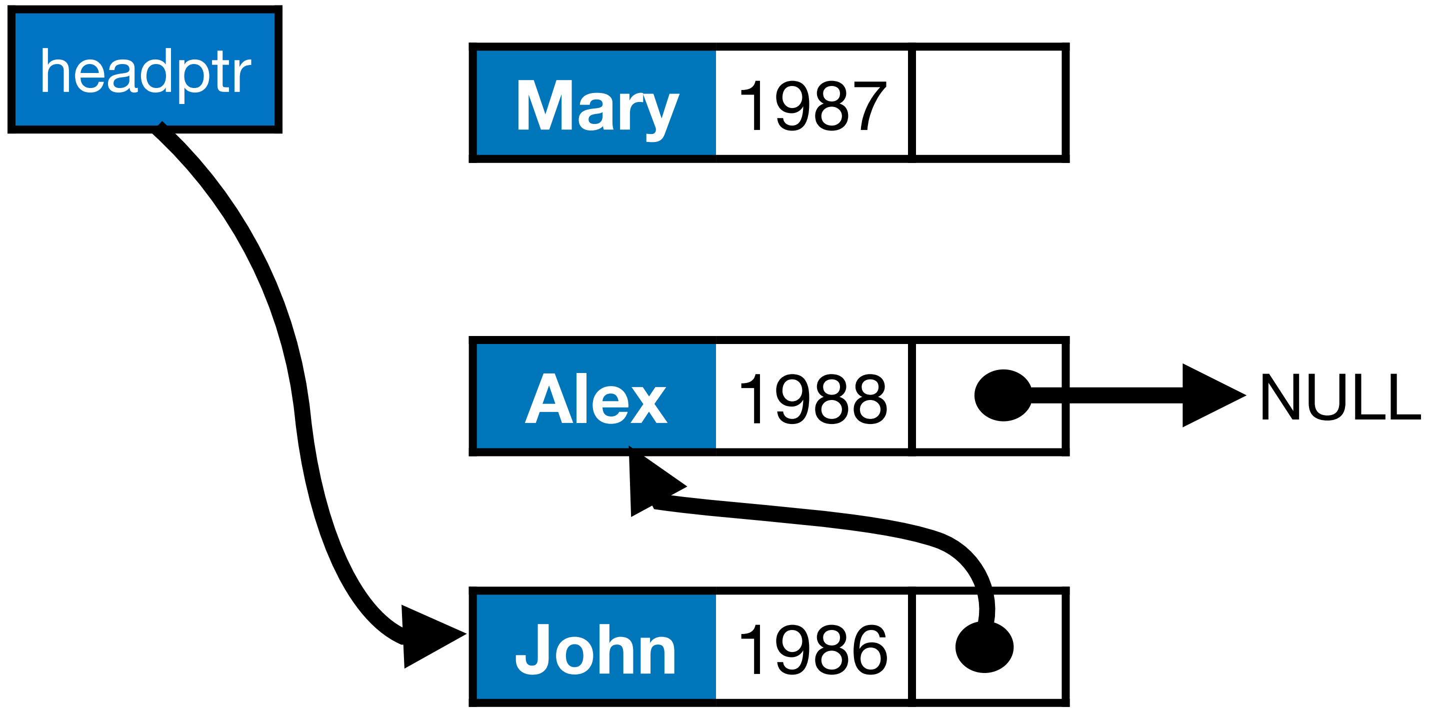
If first item is bigger than new node still add at head!

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

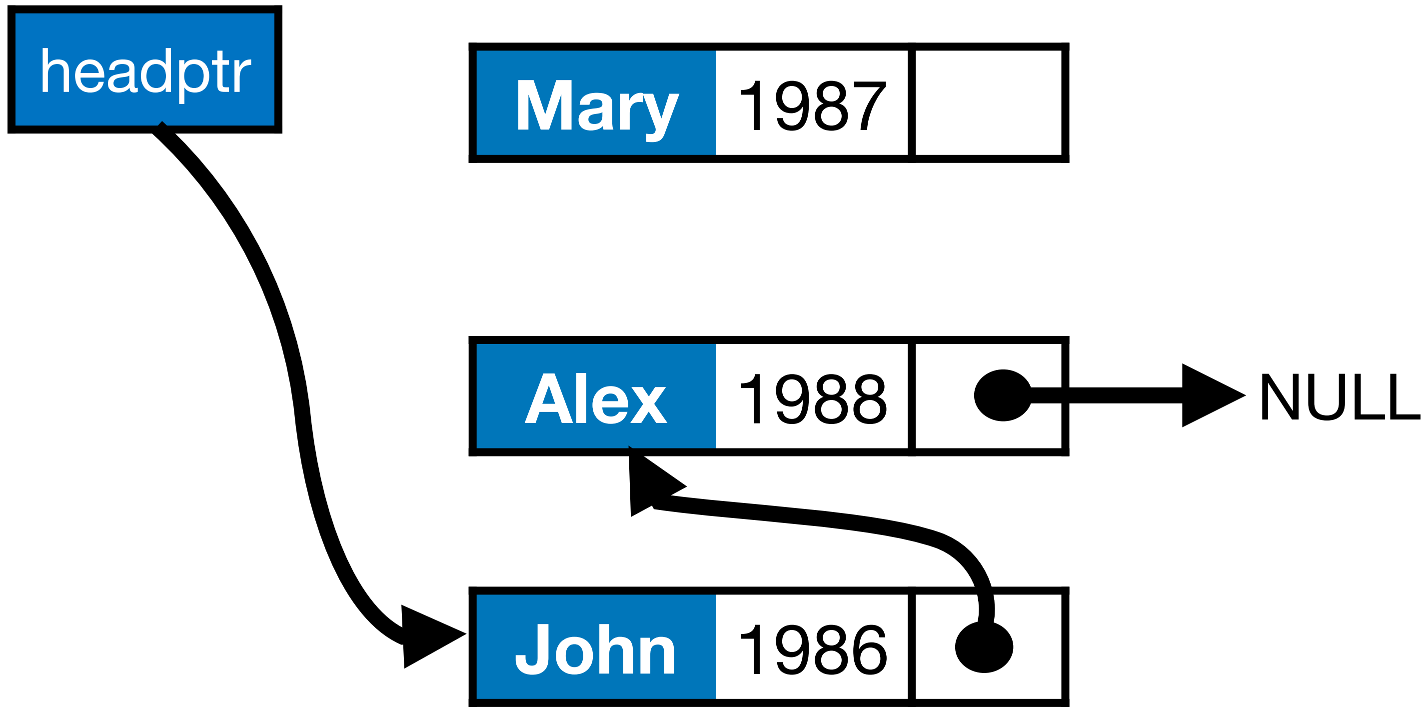


Insertion in a sorted linked list

- 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;
  }
```



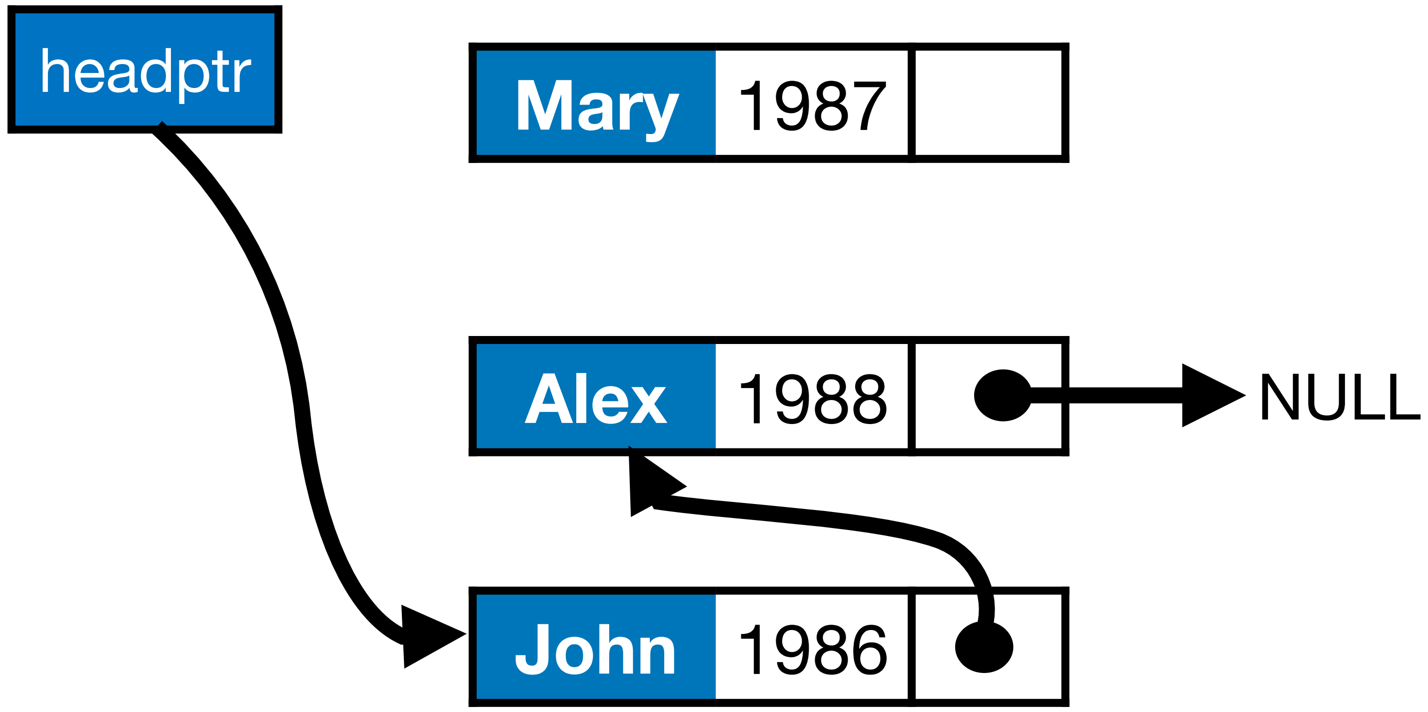
General case: if list is not empty and first item is smaller than new, update pointer & recurse!

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

Deletion

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

```
int delete_node(node **headptr, char *name){
```

- ~~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

- 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*~~
    - ~~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

- 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*~~
    - ~~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

- 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
```

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

Search

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

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?

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?

Well time didn't permit … the next three slides can be skipped. I just think cons cells are cool 🤷🏽‍♂️

Time permitting …

Well time didn't permit … the next three slides can be skipped. I just think cons cells are cool 🤷🏽‍♂️

Time permitting …

- Cons cells - the original take on linked lists

Well time didn’t permit … the next three slides can be skipped. I just think cons cells are cool 🤷🏽‍♂️

Time permitting …

- Cons cells - the original take on linked lists
  - First introduced in 1960 by the Lisp programming language

Well time didn't permit … the next three slides can be skipped. I just think cons cells are cool 🤷🏽‍♂️

Time permitting …

- Cons cells - the original take on linked lists
  - First introduced in 1960 by the Lisp programming language
  - A cons cell, by default, adds items to the beginning of the list:

Well time didn't permit … the next three slides can be skipped. I just think cons cells are cool 🤷🏽‍♂️

Time permitting …

- Cons cells - the original take on linked lists
  - First introduced in 1960 by the Lisp programming language
  - A cons cell, by default, adds items to the beginning of the list:
    - `cons(1, cons(2, (cons 3))` gives `1->2->3`

Well time didn't permit … the next three slides can be skipped. I just think cons cells are cool 🤷🏽‍♂️

Time permitting …

- Cons cells - the original take on linked lists
  - First introduced in 1960 by the Lisp programming language
  - A cons cell, by default, adds items to the beginning of the list:
    - `cons(1, cons(2, (cons 3)))` gives `1->2->3`
    - The function `cons` takes a value and pointer to head of list as input

Well time didn't permit … the next three slides can be skipped. I just think cons cells are cool 🤷🏽‍♂️

Time permitting …

- Cons cells - the original take on linked lists
  - First introduced in 1960 by the Lisp programming language
  - A cons cell, by default, adds items to the beginning of the list:
    - `cons(1, cons(2, (cons 3)))` gives `1->2->3`
    - The function `cons` takes a value and pointer to head of list as input
    - The function `cons` always returns pointer to head of list

Time permitting …

Time permitting …

- Cons cells - the original take on linked lists

Time permitting …

- Cons cells - the original take on linked lists

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

Time permitting …

- Cons cells - the original take on linked lists

- The constructor `cons` takes value and pointer to head of list as input

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

Time permitting ...

- Cons cells - the original take on linked lists
- The constructor `cons` takes value and pointer to head of list as input

```c
typedef struct Cell{
   char *name;
   unsigned int byear;
   struct Cell *next;
}Cell;
```

```c
Cell *cons(char *name, int byear, Cell *rest){
  Cell *cell = malloc(sizeof(Cell));
  cell->name = name;
  cell->byear = byear;
  cell->next = rest;
  return cell;
}
```

Time permitting ...

- Cons cells - the original take on linked lists

- The constructor `cons` takes value and pointer to head of list as input

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

```
Cell *cons(char *name, int byear, Cell *rest){
  Cell *cell = malloc(sizeof(Cell));
  cell->name = name;
  cell->byear = byear;
  cell->next = rest;
  return cell;
}
```

Time permitting ...

- Cons cells - the original take on linked lists
- The constructor `cons` takes value and pointer to head of list as input
- The constructor `cons` always returns pointer to head of list

```c
typedef struct Cell{
   char *name;
   unsigned int byear;
   struct Cell *next;
}Cell;
```

```c
Cell *cons(char *name, int byear, Cell *rest){
  Cell *cell = malloc(sizeof(Cell));
  cell->name = name;
  cell->byear = byear;
  cell->next = rest;
  return cell;
}
```

Time permitting ...

- Cons cells - the original take on linked lists
- The constructor `cons` takes value and pointer to head of list as input
- The constructor `cons` always returns pointer to head of list

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

```
Cell *cons(char *name, int byear, Cell *rest){
  Cell *cell = malloc(sizeof(Cell));
  cell->name = name;
  cell->byear = byear;
  cell->next = rest;
  return cell;
}
```

Time permitting …

- Cons cells - the original take on linked lists

Time permitting …

- Cons cells - the original take on linked lists

- Two special functions:

Time permitting …

- Cons cells - the original take on linked lists

- Two special functions:

    - `first`: Returns value of first item on list (like a peek on stack)

Time permitting ...

- Cons cells - the original take on linked lists

- Two special functions:

    - `first`: Returns value of first item on list (like a peek on stack)

```
Cell *first(Cell **list){
  if (list){
  Cell *cell = malloc(sizeof(Cell));
  cell->name = (*list)->name;
  cell->byear = (*list)->byear;
  // Uncomment to make first into a pop
  // Cell *temp = *list;
  // *list = (*list)->next;
  // free(temp);
  return cell;
  }
  return NULL;
}
```

Time permitting ...

- Cons cells - the original take on linked lists

- Two special functions:

    - `first`: Returns value of first item on list (like a peek on stack)

    - `rest:` Returns pointer to remaining part of the list

Time permitting ...

- Cons cells - the original take on linked lists
- Two special functions:
  - `first`: Returns value of first item on list (like a peek on stack)
  - `rest:` Returns pointer to remaining part of the list

```
Cell *rest(Cell *list){
  if(list){
    return list->next;
  }
  return NULL;
}
```

Time permitting ...

- Cons cells - the original take on linked lists
- Two special functions:
  - `first`: Returns value of first item on list (like a peek on stack)
  - `rest:` Returns pointer to remaining part of the list

```
Cell *first(Cell **list){
  if (list){
  Cell *cell = malloc(sizeof(Cell));
  cell->name = (*list)->name;
  cell->byear = (*list)->byear;
  // Uncomment to make first into a pop
  // Cell *temp = *list;
  // list = &(*list)->next;
  // free(temp);
  return cell;
  }
  return NULL;
}
```

```
Cell *rest(Cell *list){
  if(list){
    return list->next;
  }
  return NULL;
}
```

Next week

- Doubly linked list
- Implementing stack and queues with linked lists
- C to LC3 with linked lists