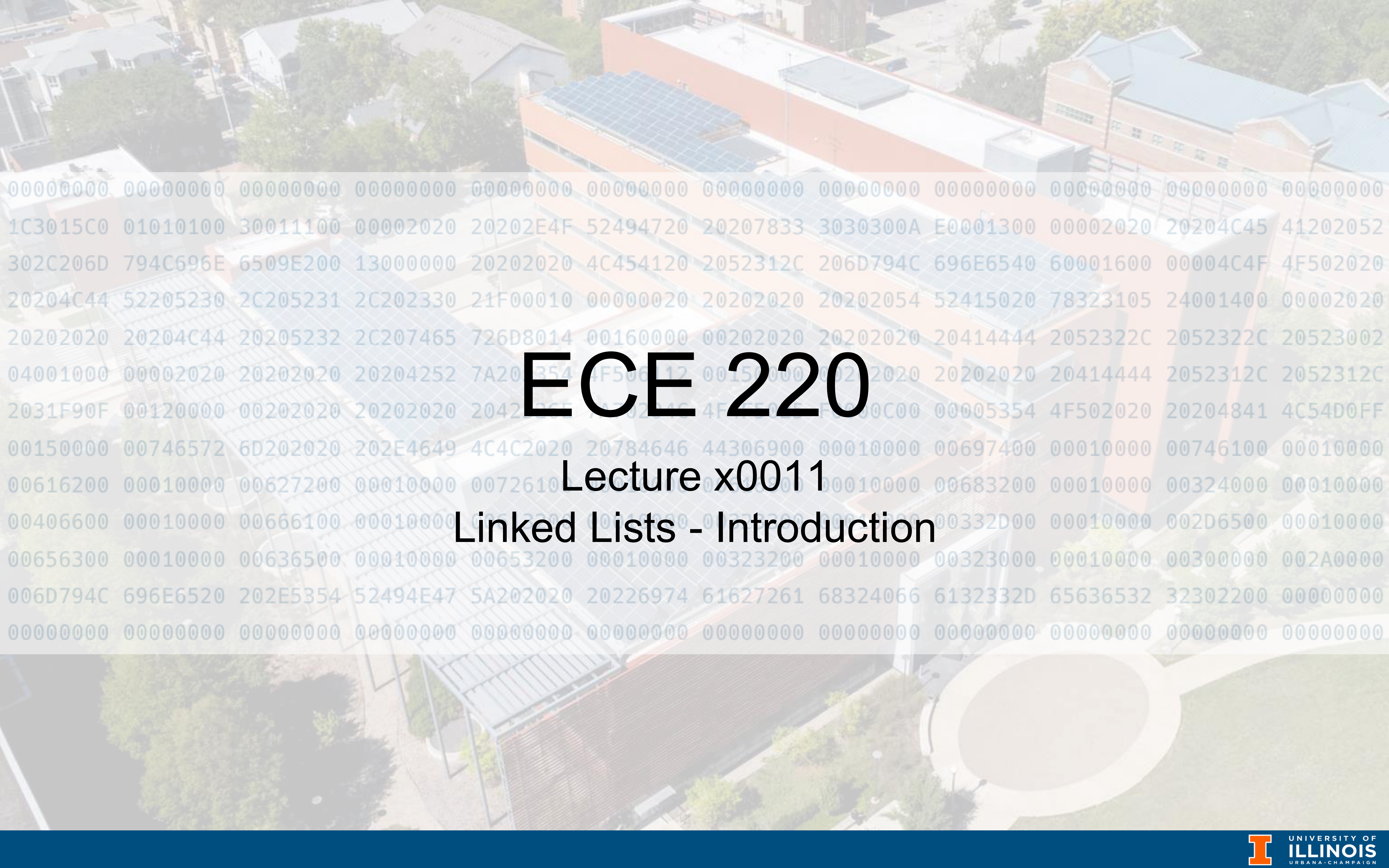

ECE 220
Lecture x0011
Linked Lists - Introduction
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Recap

- 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.

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Lesson objectives

- Define and describe the structure and components of a linked list, including nodes, head, and tail pointers.
- Compare and contrast arrays and linked lists with respect to memory allocation, data access, and efficiency of insertion and deletion operations.
- Implement and test fundamental linked list operations in C, including inserting, traversing, and deleting nodes.
- 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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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.
- An **array** is an *indexed* list; i.e. can access elements by their index.

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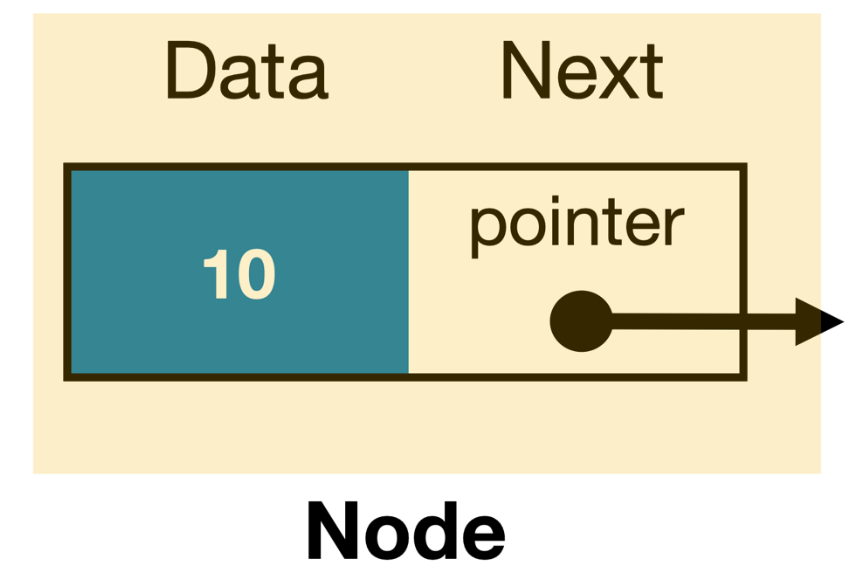
Linked list

- 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.



Node

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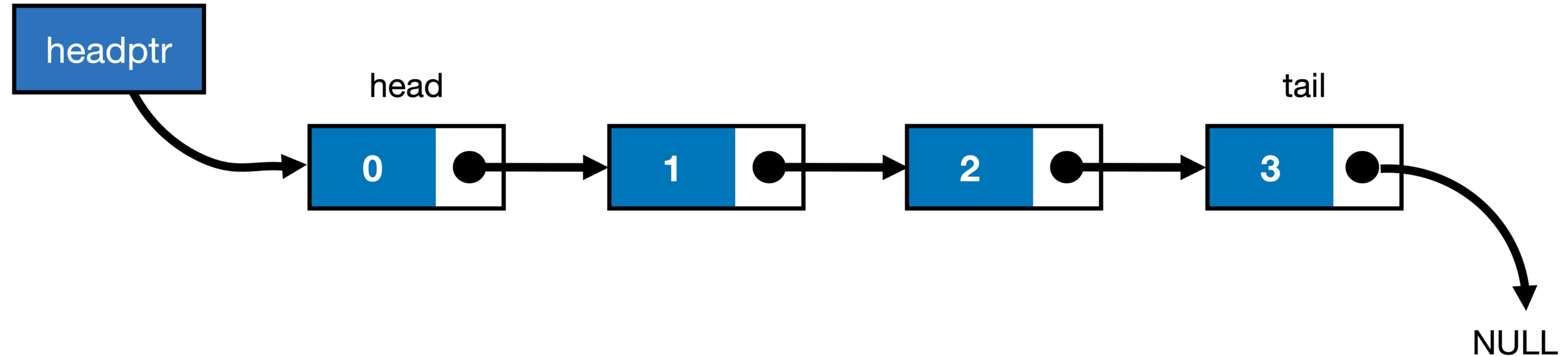
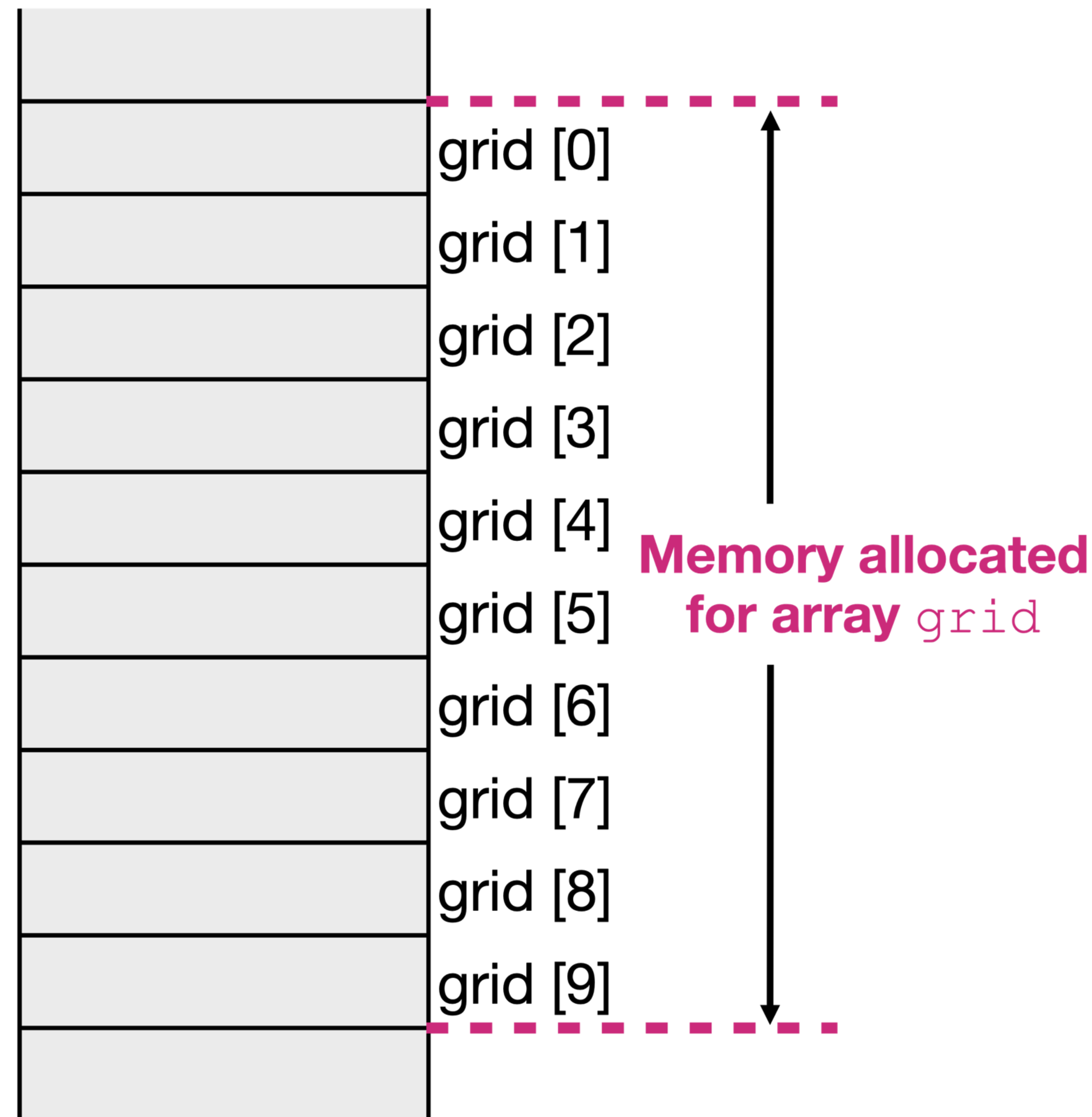
Linked list – head pointer

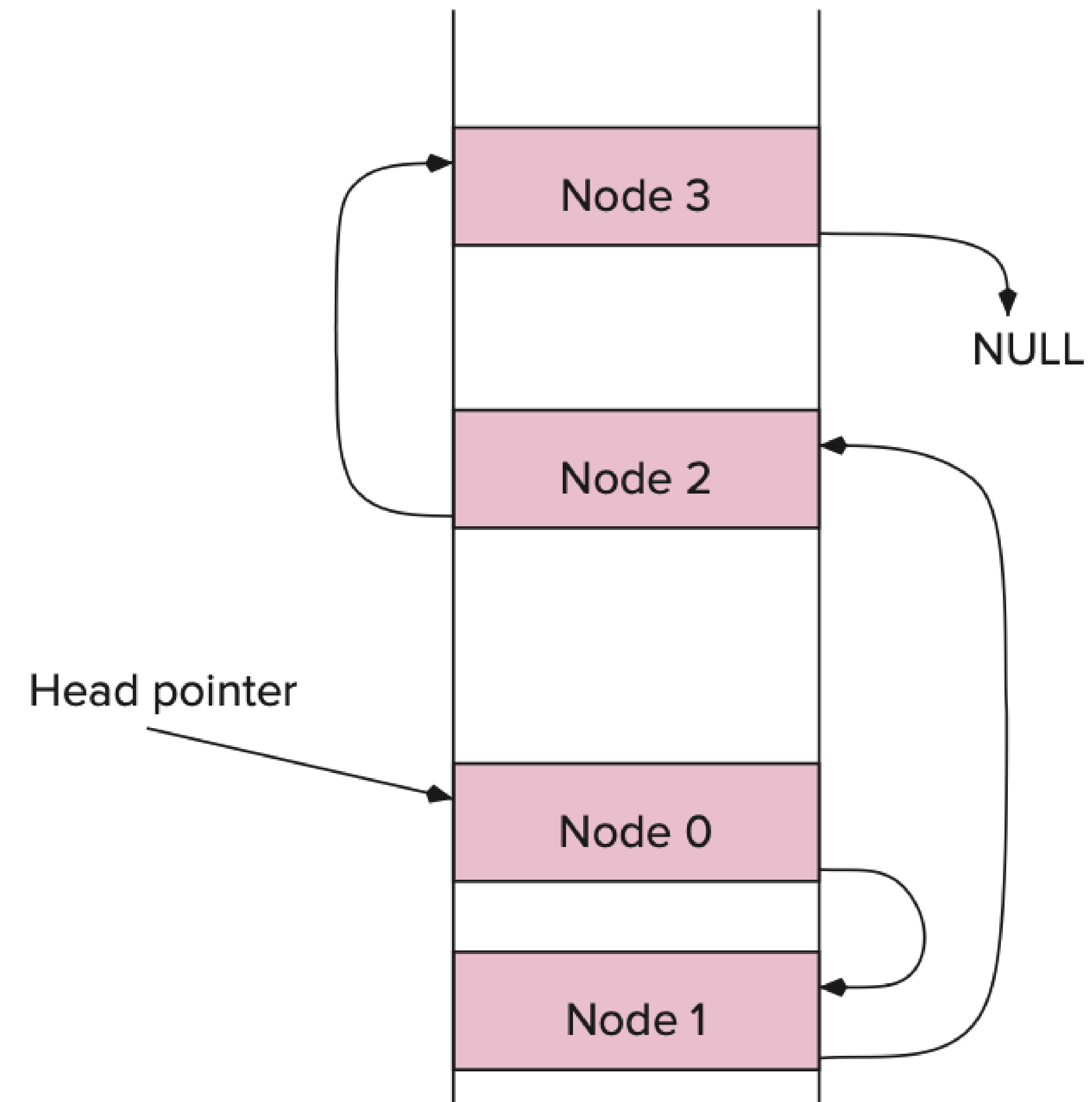


- The first node in the list is called the *head*
    - Accessed using a pointer called ***head pointer***
    - Used as the starting reference to *traverse* the list
- The last node in the list is called the *tail*.
    - The tail may contain data, but it always points to NULL value

Array vs. linked list in memory



Array
(can be automatic or dynamic)



Linked list
(dynamic only)

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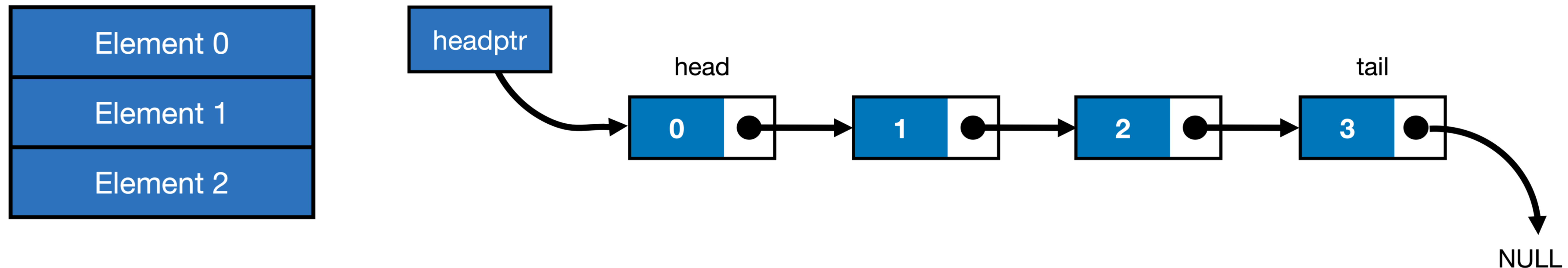
Array vs. linked list



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

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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 *by key*.

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Linked list vs. struct

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

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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

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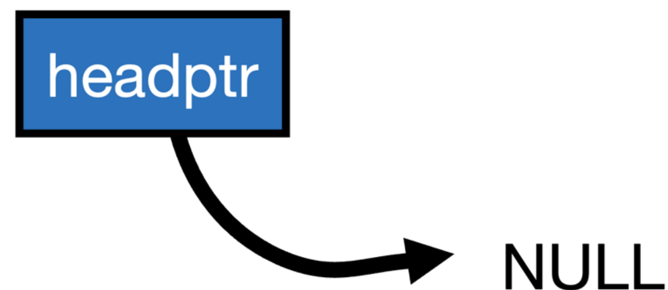
```
typedef struct person{
    char *name;
    unsigned int byear;
    struct person *next;
}node;
```

Linked list basics – empty list

- What should be the empty list?




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

node* headptr = NULL;
```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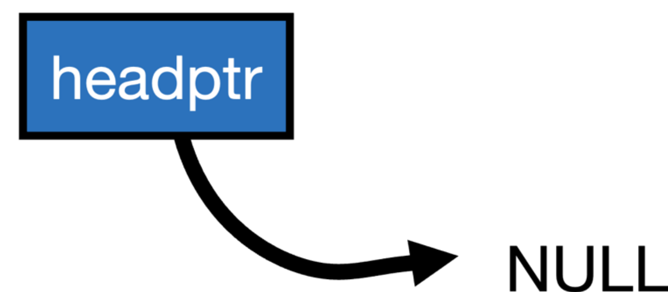
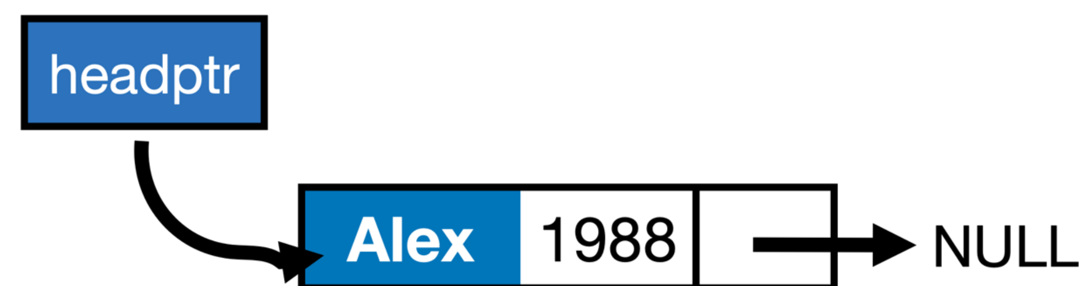
Linked list basics – singleton

- 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;
```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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.

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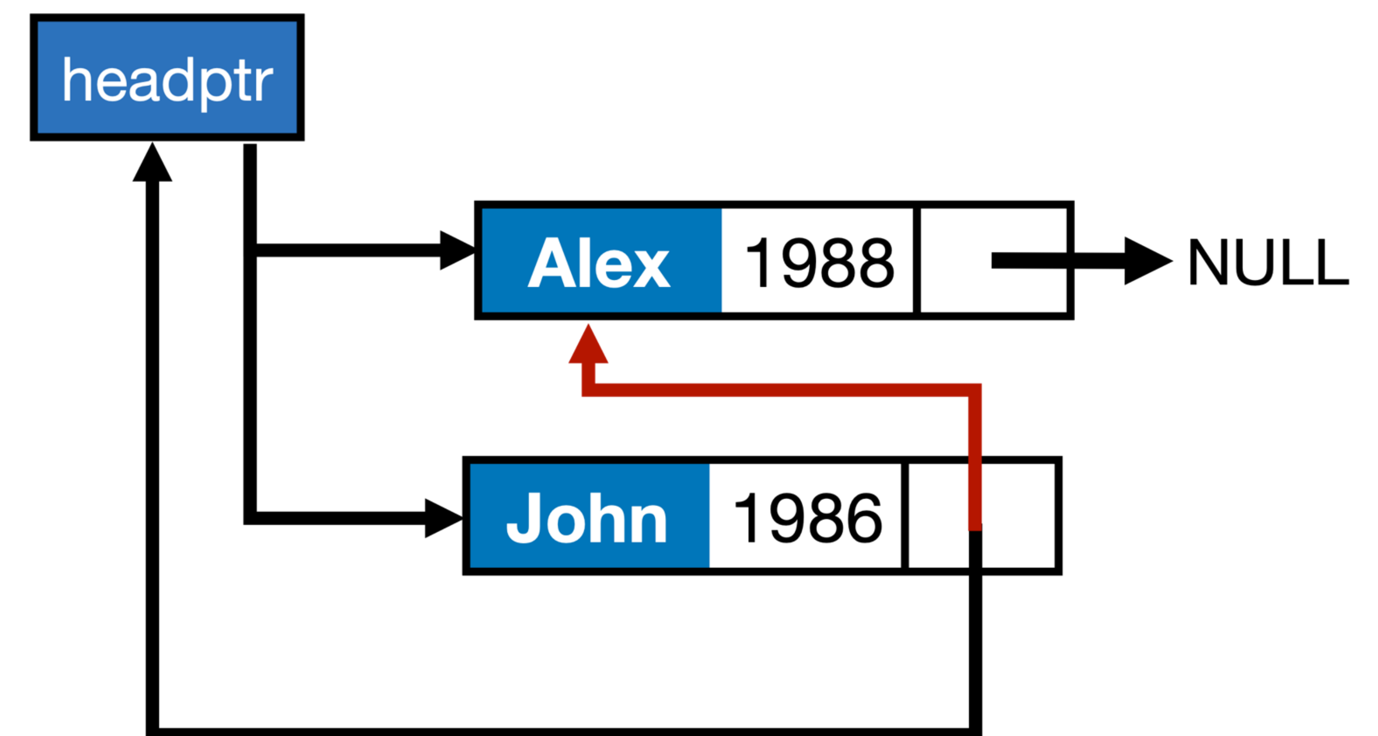
Linked lists – new nodes

- 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.

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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

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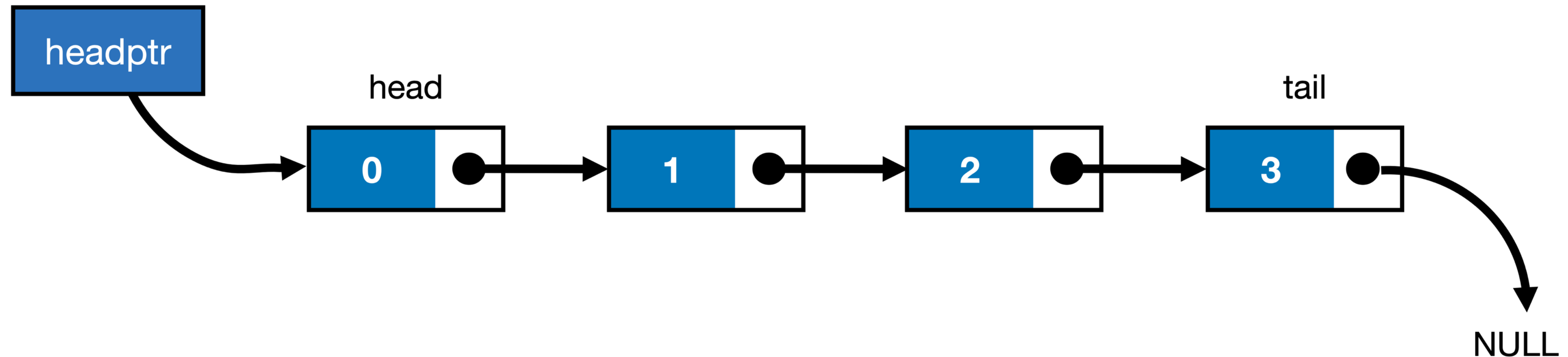
Traversing a linked list



- 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.

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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);
  }
}
```

- 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.

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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.

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Code so far …

```
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);
  }
}
```

```
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;
  else{
    temp->next = cursor;
    cursor = temp;
  }
}
```

What happened?

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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?)**

A 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

- 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 later in semester)

- 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.

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Adding at tail position

- 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!

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Adding at tail – different way

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){
  if (*headptr == NULL)
    add_at_head(headptr, new);
  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.

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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
- 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.

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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?
  - Call `free` on `second_last` elements next.
  - Set `second_last`'s `next` to `NULL`.
  - What if list empty?
  - What if singleton list?

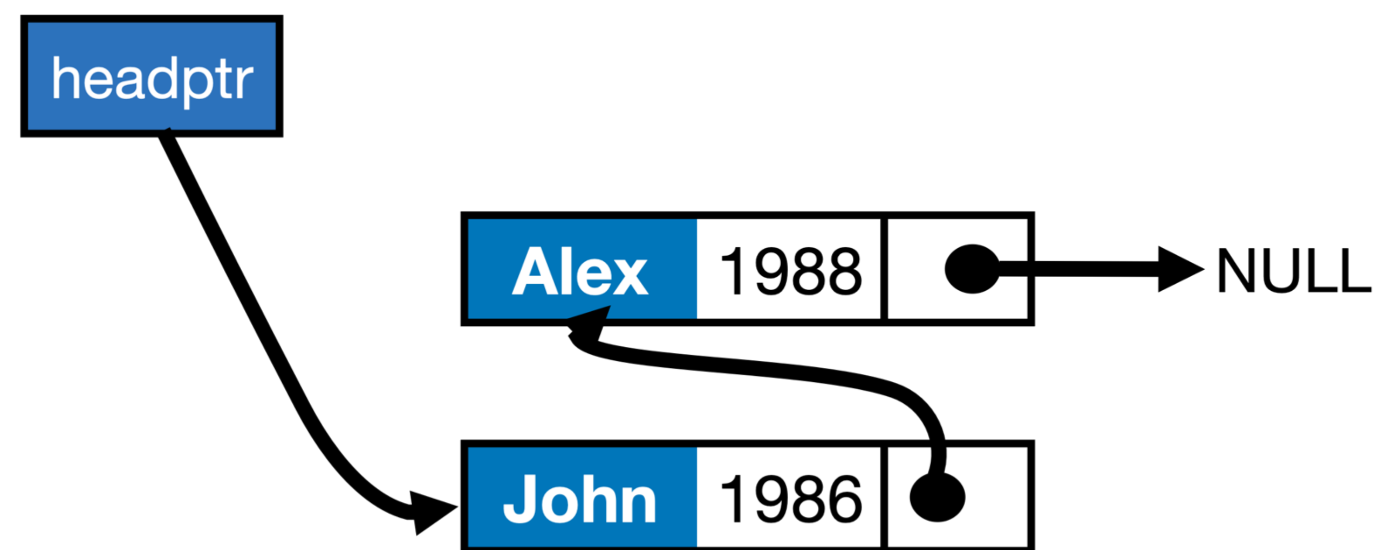
```
void del_tail(node **cursor){
  if (*cursor==NULL)
    return;
  if ((*cursor)->next==NULL){
    free(*cursor);
    *cursor=NULL;
    return;
  }
  node * second_last = *cursor;
  while (second_last->next->next != NULL)
    second_last=second_last->next;
  free(second_last->next);
  second_last->next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

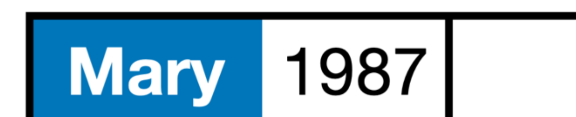
Insertion in a sorted linked list

- 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.

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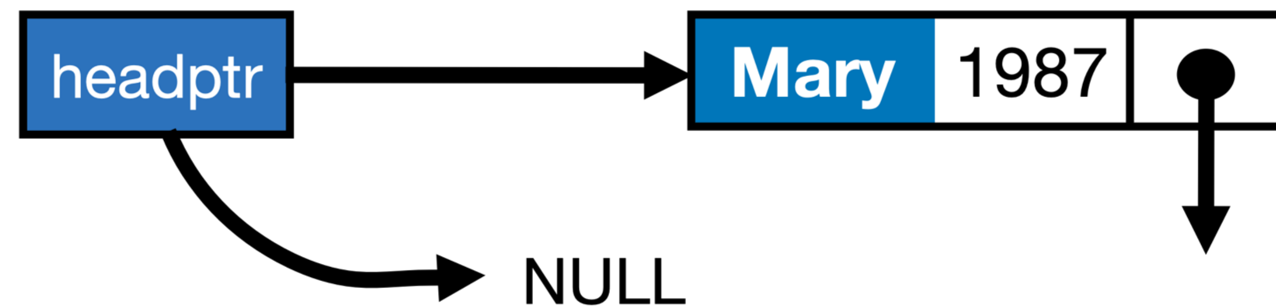
Insert into beginning of sorted list

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

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



If empty list, add at head.

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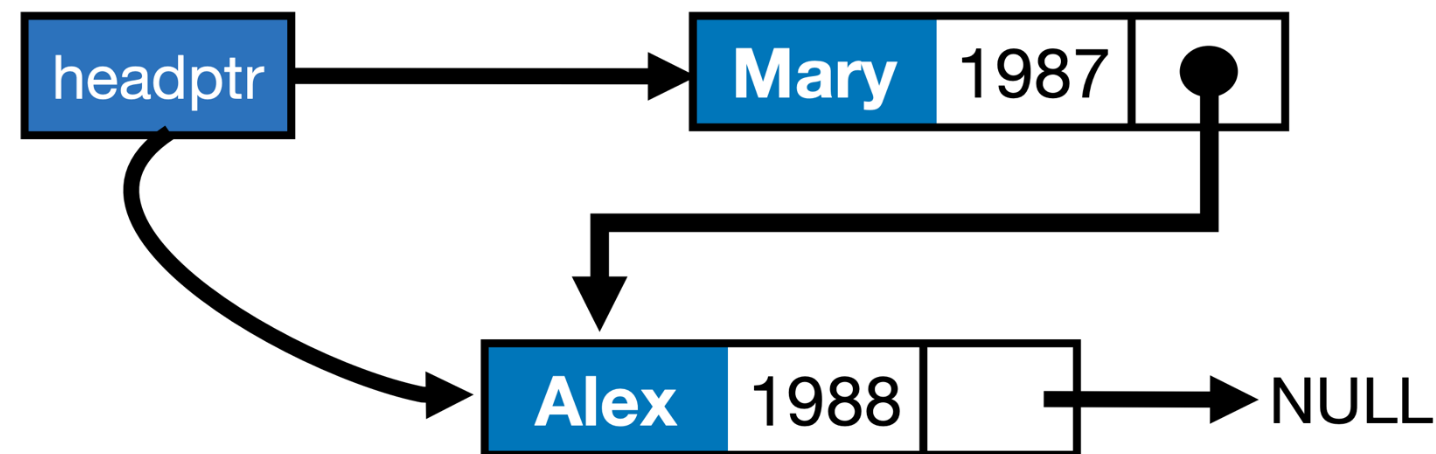
Sorted linked list insertion - middle

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

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



What if not empty?

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

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

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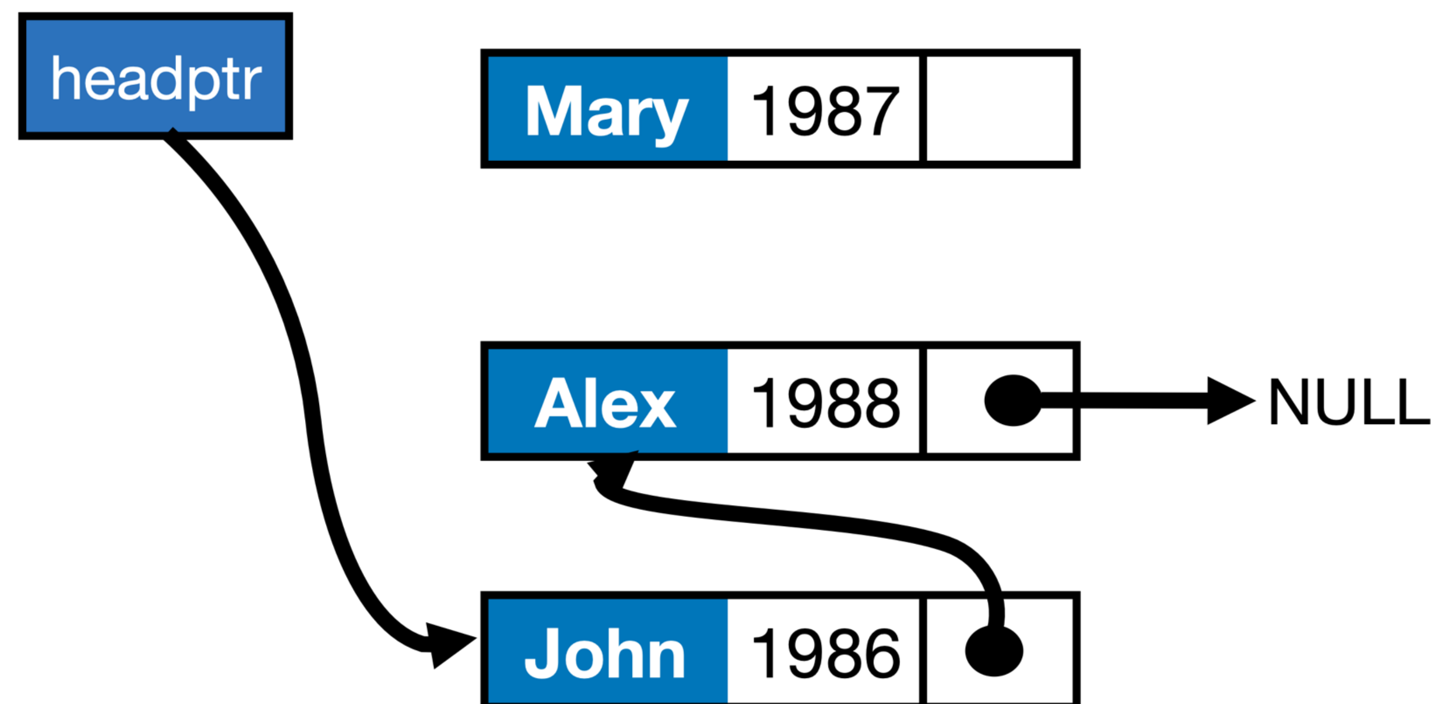
Insertion sorted list

- 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!

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- ~~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
  - 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

- 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?

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Next week

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

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