# Introduction to C++

# Linear Linked Lists

## Topic #4

# CS162 - Topic #4

- Lecture: Dynamic Data Structures
  - Review of pointers and the new operator
  - Introduction to Linked Lists
  - Begin walking thru examples of linked lists
  - Insert (beginning, end)
  - Removing (beginning, end)
  - Remove All
  - Insert in Sorted Order

# CS162 - Pointers

- What advantage do pointers give us?
- How can we use pointers and new to allocating memory dynamically
- Why allocating memory dynamically vs. statically?
- Why is it necessary to deallocate this memory when we are done with the memory?

# CS162 - Pointers and Arrays

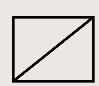
- Are there any disadvantages to a dynamically allocated array?
  - The benefit - of course - is that we get to wait until run time to determine how large our array is.
  - The drawback - however - is that the array is still <u>fixed size</u>.... it is just that we can wait until run time to fix that size.
  - And, at some point prior to using the array we must determine how large it should be.

# CS162 - Linked Lists

- Our solution to this problem is to use **<u>linear linked lists</u>** instead of arrays to maintain a “list”
- With a linear linked list, we can grow and shrink the size of the list as new data is added or as data is removed
- The list is ALWAYS sized exactly appropriately for the size of the list

# CS162 - Linked Lists

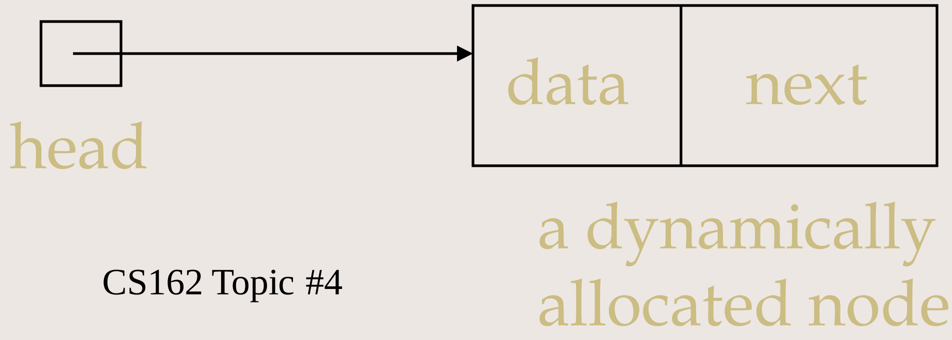
- A linear linked list starts out as empty
  - An empty list is represented by a null pointer
  - We commonly call this the **head** pointer



head

# CS162 - Linked Lists

- As we add the first data item, the list gets one **<u>node</u>** added to it
  - So, **<u>head</u>** points to a **<u>node</u>** instead of being null
  - And, a **<u>node</u>** contains the data to be stored in the list <u>and</u> a **<u>next</u>** pointer (to the next node...if there is one)

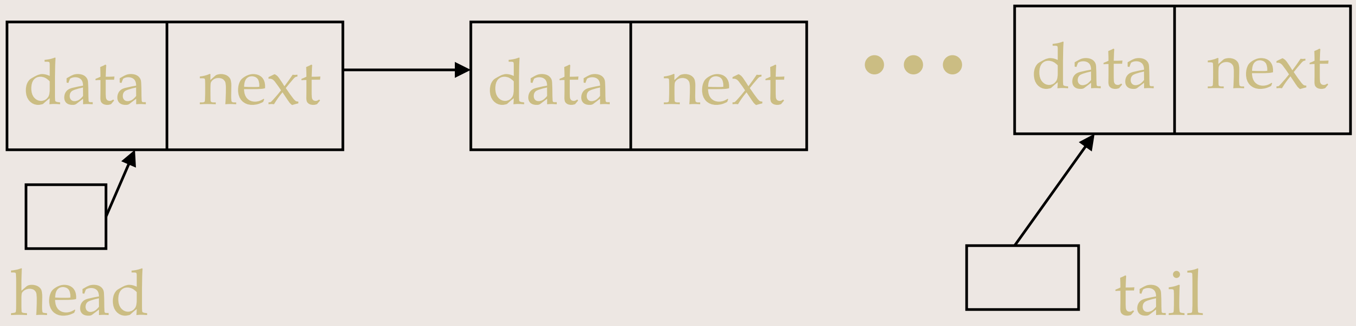


# CS162 - Linked Lists

- To add another data item we must first decide in what order
  - does it get added at the beginning
  - does it get inserted in sorted order
  - does it get added at the end
- This term, we will learn how to add in each of these positions.

# CS162 - Linked Lists

- Ultimately, our lists could look like:




Sometimes we also have a tail pointer. This is another pointer to a node -- but keeps track of the end of the list.
This is useful if you are commonly adding data to the end

# CS162 - Linked Lists

- So, how do linked lists differ than arrays?
  - An array is direct access; we supply an element number and can go directly to that element (through pointer arithmetic)
  - With a linked list, we must either start at the head or the tail pointer and **sequentially traverse** to the desired position in the list

# CS162 - Linked Lists

- In addition, linear linked lists (singly) are connected with just one set of **<u>next</u>** pointers.
  - This means you can go from the first to the second to the third to the forth (etc) nodes
  - But, once you are at the forth you can't go back to the second without starting at the beginning again.....

# CS162 - Linked Lists

- Besides linear linked lists (singly linked)
  – There are other types of lists
    - Circular linked lists
    - Doubly linked lists
    - Non-linear linked lists (CS163)

# CS162 - Linked Lists

- For a linear linked lists (singly linked)
  - We need to define both the head pointer and the node
  - The node can be defined as a struct or a class; for these lectures we will use a struct but on the board we can go through a class definition in addition (if time permits)

# CS162 - Linked Lists

- We’ll start with the following:

```
struct video {                    //our data
    char * title;
    char category[5];
    int quantity;
    };
```

- Then, we define a node structure:

```
struct node {
    video data;   //or, could be a pointer
    node * next;  //a pointer to the next
    };
```

# CS162 - Linked Lists

- Then, our list class changes to be:

```
class list {
  public:
    list();        ~list();   //must have these
    int add (const video &);
    int remove (char title[]);
    int display_all();
  private:
    node * head;        //optionally node * tail;
     };
```

# CS162 - Default Constructor

- Now, what should the constructor do?
  - initialize the data members
  - this means: we want the list to be empty to begin with, so head should be set to NULL

```
list::list() {
        head = NULL;
        }
```

# CS162 - Traversing

- To show how to traverse a linear linked list, let’s spend some time with the display_all function:

```
int list::display_all() {
    node * current = head;
    while (current != NULL) {
      cout <<current->data.title <<‘\t’
              <<current->data.category <<endl;
      current = current->next;
    }
  return 1;
}
```

# CS162 - Traversing

- Let’s examine this step-by-step:
  - Why do we need a “current” pointer?
  - What is “current”?
  - Why couldn’t we have said:

```
while (head != NULL) {
  cout <<head->data.title <<‘\t’
           <<head->data.category <<endl;
  head = head->next;     //NO!!!!!!!
}
```

We would have lost our list!!!!!!

# CS162 - Traversing

– Next, why do we use the NULL stopping condition:

```
while (current != NULL) {
```

– This implies that the very last node’s next pointer must have a **NULL** value

- so that we know when to stop when traversing
- NULL is a #define constant for zero
- So, we could have said:

```
while (current) {
```

# CS162 - Traversing

– Now let’s examine how we access the data’s values:

```
cout <<current->data.title <<‘\t’
        <<current->data.category <<endl;
```

– Since current is a pointer, we use the -> operator (indirect member access operator) to access the “data” and the “next” members of the node structure

– But, since “data” is an object (and not a pointer), we use the . operator to access the title, category, etc.

# CS162 - Linked Lists

– If our node structure had defined data to be a pointer:

```
struct node {
        video * ptr_data;
        node * next;
        };
```

– Then, we would have accessed the members via:

```
cout <<current->ptr_data->title <<'\t'
              <<current->ptr_data->category <<endl;
```

(And, when we insert nodes we would have to remember to allocate memory for a video object in addition to a node object...)

# CS162 - Traversing

- So, if current is initialized to the head of the list, and we display that first node
  - to display the second node we must **traverse**
  - this is done by:

```
current = current->next;
```

  - why couldn't we say:

```
current = head->next;        //NO!!!!!
```

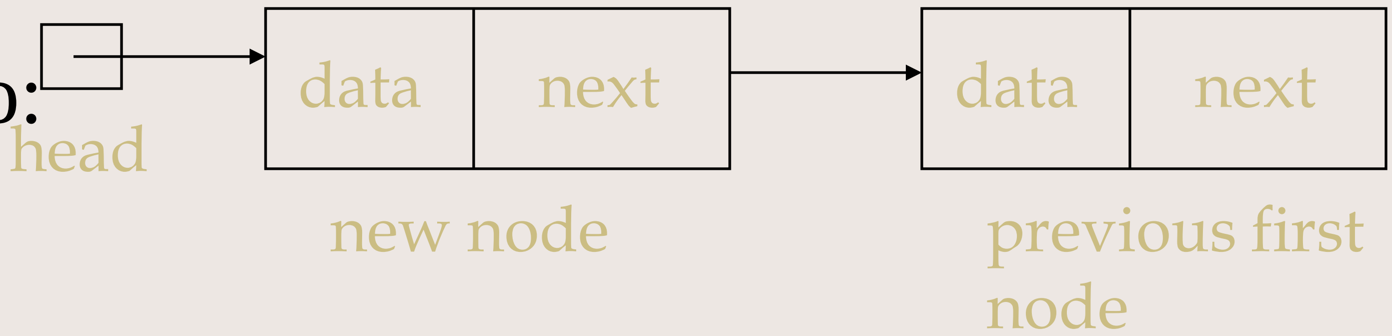
# CS162 - Building

- Well, this is fine for traversal
- But, you should be wondering at this point, how do I create (build) a linked list?
- So, let’s write the algorithm to add a node to the **beginning** of a linked list

# CS162 - Insert at Beginning

- We go from:


- To:




- So, can we say:

head = new node; //why not???

# CS162 - Insert at Beginning

- If we did, we would lose the rest of the list!
- So, we need a temporary pointer to hold onto the previous head of the list

```
node * current = head;
head = new node;
head->data = new video; //if data is a pointer
head->data->title = new char [strlen(newtitle)+1];
strcpy(head->data->title, newtitle);
//etc.
head->next = current;  //reattach the list!!!
```

# CS162 - Inserting at End

- Add a node at the end of a linked list.
  - What is wrong with the following. Correct it in class:

```
node * current = head;
while (current != NULL) {
        current = current->next;
 }
current= new node;
current->data = new video;
current->data = data_to_be_stored;
}
```

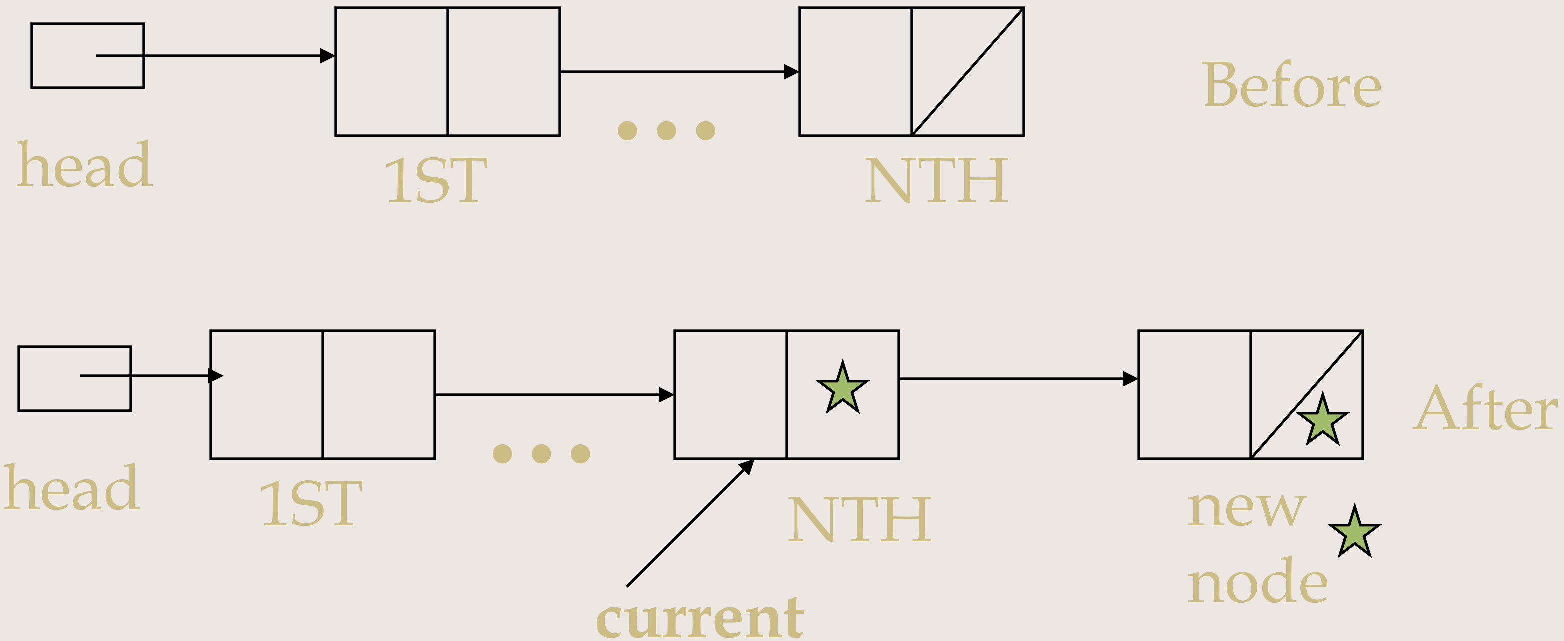
LOOK AT THE BOLD/ITALICS FOR HINTS OF WHAT IS WRONG!

# CS162 - Inserting at End

- We need a temporary pointer because if we use the head pointer
    - we will lose the original head of the list and therefore all of our data
- If our loop's stopping condition is if current is not null -- then what we are saying is loop until current IS null
    - well, if current is null, then dereferencing current will give us a segmentation fault
    - and, we will NOT be pointing to the last node!

# CS162 - Inserting at End

- Instead, think about the "before" and "after" **pointer diagrams:**



# CS162 - Inserting at End

- So, we want to loop until current->next is not NULL!
- But, to do that, we must make sure current isn't NULL
  - This is because if the list is empty, current will be null and we'll get a fault (or should) by dereferencing the pointer

```
if (current)
  while (current->next != NULL) {
        current = current->next;
  }
```

# CS162 - Inserting at End

- Next, we need to connect up the nodes
  - having the last node point to this new node

    current->next = new node;
  - then, traverse to this new node:

    current = current->next;

    current->data = new video;
  - and, set the next pointer of this new last node to null:

    current->next = NULL;

# CS162 - Inserting at End

- Lastly, in our first example for today, it was inappropriate to just copy over the pointers to our data
  - we allocated memory for a video and then immediately lost that memory with the following:

```
current->data = new video;
current->data = data_to_be_stored;
```

  - the correct approach is to allocate the memory for the data members of the video and physically copy each and every one

# CS162 - Removing at Beg.

- Now let's look at the code to remove at node at the beginning of a linear linked list.
- Remember when doing this, we need to deallocate **all** dynamically allocated memory associated with the node.
- Will we need a temporary pointer?
  - Why or why not...

# CS162 - Removing at Beg.

- What is wrong with the following?

```
node * current = head->next;
delete head;
head = current;
```

  – everything? (just about!)

# CS162 - Removing at Beg.

- First, don't dereference the head pointer before making sure head is not NULL

```
if (head) {
   node * current = head->next;
```

  - If head is NULL, then there is nothing to remove!

- Next, we must deallocate all dynamic memory:

```
delete [] head->data->title;
delete head->data;
delete head;
head = current; //this was correct....
```

# CS162 - Removing at End

- Now take what you've learned and write the code to remove a node from the end of a linear linked list
- What is wrong with: (lots!)

```
        node * current = head;
        while (current != NULL) {
                current = current->next;
        }
      delete [] current->data->title;
      delete current->data;
      delete current;
    }
```

# CS162 - Removing at End

- Look at the stopping condition
  - if current is null when the loop ends, how can we dereference current? It isn't pointing to anything
  - therefore, we've gone too far again

```
node * current = head;
if (!head) return 0; //failure mode
while (current->next != NULL) {
        current = current->next;
}
```

  - is there anything else wrong?  (yes)

# CS162 - Removing at End

- So, the deleting is fine....

```
  delete [] current->data->title;
delete current->data;
delete current;
```

  - but, doesn't the previous node to this still point to this deallocated node?
  - when we retraverse the list -- we will still come to this node and access the memory (as if it was still attached).

# CS162 - Removing at End

- When removing the last node, we need to reset the new last node's next pointer to NULL
  - but, to do that, we must keep a pointer to the previous node
  - because we do not want to "retraverse" the list to find the previous node
  - therefore, we will use an additional pointer
    - (we will call it "previous")

# CS162 - Removing at End

- Taking this into account:

```
node * current= head;
node * previous = NULL;
if (!head) return 0;
while (current->next) {
        previous = current;
        current = current->next;
 }
delete [] current->data->title;
delete current->data;
delete current;
previous->next = NULL;  //oops...
}
```

**Can anyone see the remaining problem?**

# CS162 - Removing at End

- Always think about what special cases need to be taken into account.
- What if...
  - there is only ONE item in the list?
  - previous->next won’t be accessing the deallocated node (previous will be NULL)
  - we would need to reset head to NULL, after deallocating the one and only node

# CS162 - Removing at End

- Taking this into account:

```
   …
  if (!previous) //only 1 node
    head = NULL;
  else
    previous->next = NULL;
}
```

**Now, put this all together as an exercise**

# CS162 - Deallocating all

- The purpose of the destructor is to
  - perform any operations necessary to clean up memory and resources used for an object's whose lifetime is over
  - this means that when a linked list is managed by the class that the destructor should deallocate <u>all</u> nodes in the linear linked list
  - delete head won't do it!!!

# CS162 - Deallocating all

- So, what is wrong with the following:

```
list::~list() {
    while (head) {
            delete head;
            head = head->next;
    }
```

  - We want head to be NULL at the end, so that is not one of the problems
  - We are accessing memory that has been deallocated. Poor programming!

# CS162 - Deallocating all

- The answer requires the use of a temporary pointer, to save the pointer to the next node to be deleted prior to deleting the current node:

```
list::~list() {
    node * current;
   while (head) {
            current = head->next;
      delete [] head->data->title;
            delete head->data;
            delete head;
            head = current;
   }
```

# CS162 - Insert in Order

- Next, let's insert nodes in sorted order.
- Like deleting the last node in a LLL,
  - we need to keep a pointer to the previous node in addition to the current node
  - this is necessary to re-attach the nodes to include the inserted node.
- So, what **special cases** need to be considered to insert in sorted order?

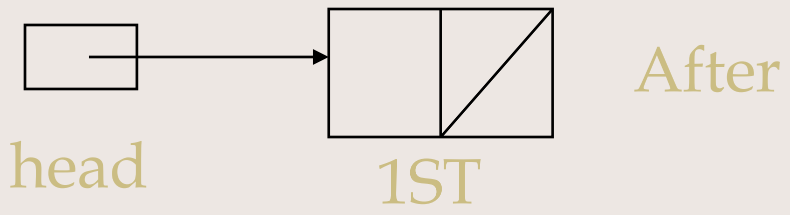
# CS162 - Insert in Order

- Special Cases:
  - Empty List
    - inserting as the head of the list
  - Insert at head
    - data being inserted is less than the previous head of the list
  - Insert elsewhere

# CS162 - Insert in Order

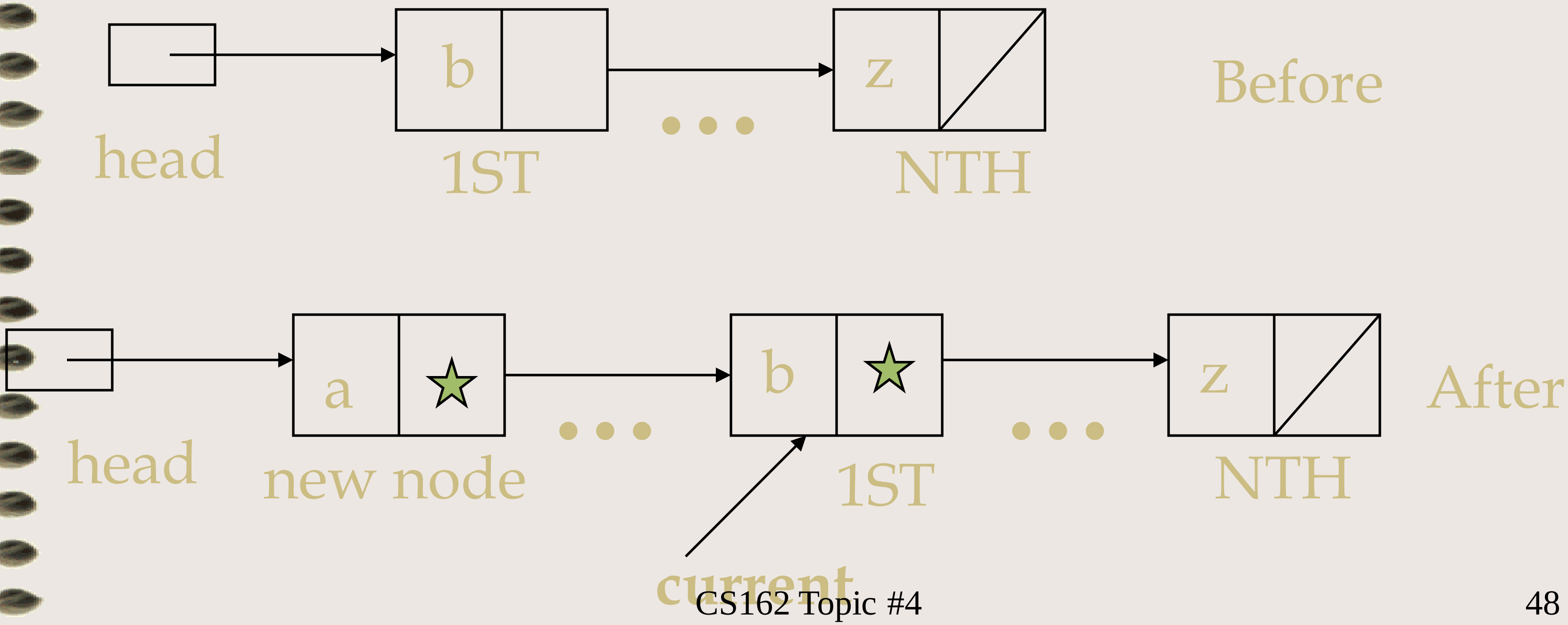
- Empty List
  - if head is null, then we are adding the first node to the list:


```
if (!head) {
  head = new node;
  head->data =...
  head->next = 0;
}
```



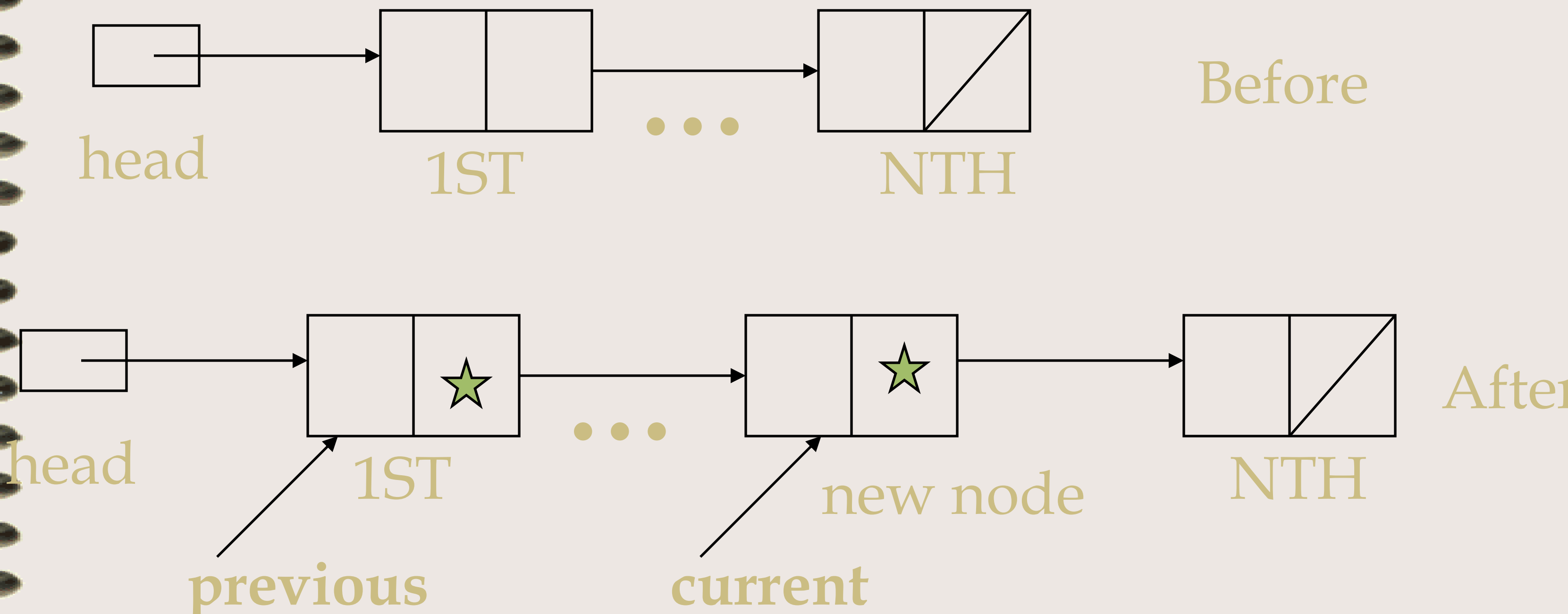
# CS162 - Insert in Order

- Inserting at the Head of the List
  - if head is not null <u>but</u> the data being inserted is <u>less</u> than the first node



# CS162 - Insert in Order

- Here is the “insert elsewhere” case:



# CS162 - Special Cases

- When inserting in the middle
  - can the same algorithm and code be used to add at the end (if the data being added is “larger” than all data existing in the sorted list)?
  - Yes? No?

# CS162 - In Class, Work thru:

- Any questions on how to:
  - insert (at beginning, middle, end)
  - remove (at beginning middle, end)
  - remove all
- Next, let's examine how similar/different this is for
  - circular linked lists
  - doubly linked lists

# CS162 - In Class, Work thru:

- For circular linked lists:
  - insert the very first node into a Circular L L (i.e., into an empty list)
  - insert a node at the <u>end</u> of a Circular L L
  - remove the <u>first</u> node from a Circular L L

  - Walk through the answers in class or as an assignment (depending on time available)

# CS162 - In Class, Work thru:

- For doubly linked lists:
  - write the node definition for a double linked list
  - insert the very first node into a Doubly L L (i.e., into an empty list)
  - insert a node at the end of a Doubly L L
  - remove the first node from a Doubly L L
  - Walk through the answers in class or as an assignment (depending on time available)

# CS162 - What if...

- What if our node structure was a class
  - and that class had a destructor
  - how would this change (or could change) the list class' (or stack or queue class') destructor?

**//Discuss the pros/cons of the following design....**

```
class node {
  public:
    node(); node(const video &); ~node();
  private:
    video * data;   node * next;
};
```

# CS162 - What if...

- OK, so what if the node's destructor was:

```
node::~node() {
  delete [] data->title;
  delete data;
  delete next;
};
list::~list() {
  delete head; //yep, this is not a typo
}
```

  – This is a "recursive" function.... (a preview of our Recursion Lecture; saying delete next causes the destructor to be implicitly invoked. This process ends when the next ptr of the last node is null.)