Lecture #4

- Resource Management, Part 2
  - Assignment Operators
- Basic Linked Lists
  - Insertion, deletion, destruction, traversals, etc.
- Advanced Linked Lists
  - Tail Pointers
  - Doubly-linked Lists

Assignment Operators

Assignment Operators…
Why should you care?

Assignment Operators are required in all nontrivial C++ programs.

If you fail to use them properly, it can result in nasty bugs and crashes.

So pay attention!

The Assignment Operator

```
int main()
{
    Circ  x(1,2,3);

    Circ  y = x;

}
```

New variable

Existing variable

Last time we learned how to construct a new variable using the value of an existing variable (via the copy constructor).

Now lets learn how to *change* the value of an existing variable to the value of an another variable.

```
int main()
{
    Circ  foo(1,2,3);

    Circ  bar(4,5,6);

    bar = foo;
}
```

Existing variable

Existing variable

In this example, both foo and bar have been constructed.

Both have had their member variables initialized.

Then we set bar equal to foo.

The Assignment Operator

In this case, the copy constructor is NOT used to copy values from foo to bar.

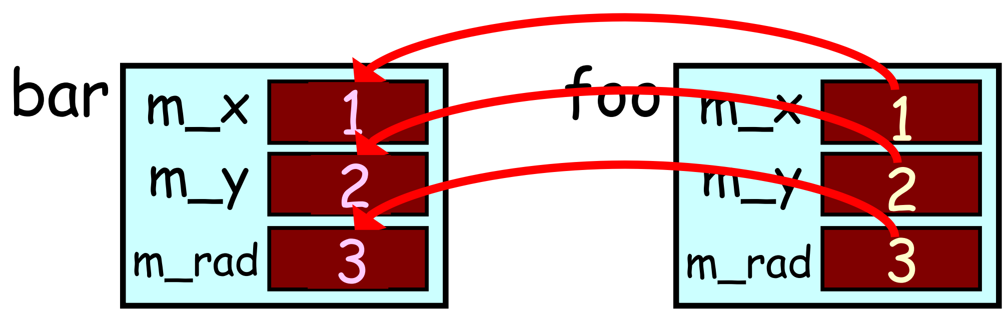
Instead, a special member function called an assignment operator is used to copy foo's values into bar.

Why isn't bar's copy constructor called? Because bar was already constructed on the line above! The bar variable already exists and is already initialized, so it doesn't make any sense to re-construct it!

```
int main()
{
   Circ  foo(1,2,3);

   Circ  bar(4,5,6);

   bar = foo;
}
```

If you don't define your own assignment operator...

Then C++ provides a default version that just copies each of the members.



Lets see how to define our own assignment operator.

The Assignment Operator

foo

Hmmm.. This looks familiar, doesn't it?

What does it remind you of?

```
class Cir
{
public:
  Circ(fl                              t)
  {
    m_x = x     _y = y; m_rad = r;
  }
  void setMeEqualTo(const Circ &src)
  {
    m_x = src.m_x;
    m_y = src.m_y;
    m_rad = src.m_rad;
  }
  float GetArea(void)
  {
    return(3.14159*m_rad*m_rad);
  }
private:
  float m_x, m_y, m_rad;
};
```

The syntax for an assignment operator is a bit confusing.

So lets define a simpler version first…

Here's how we'd use our new function.

```
int main()
{
  Circ  foo(1,2,3);

  Circ  bar(4,5,6);

  bar.setMeEqualTo(foo);
}  // same as bar = foo;
```

The Assignment Operator

Now lets see what a real assignment operator

The const keyword guarantees that the source object (src) is not modified during the copy.

You MUST pass a *reference* to the source object. This means you have to have the & here!!!

```
p
  Circ(float x   loat y, float r)
  {
    m_x = x; m_y =  y; m_rad = r
  }
  Circ &operator=  (const Circ &src)
  {
    m_x = src.m_x;
    m_y = src.m_y;
    m_rad = src.m_rad;
    return(*this);
  }
  float GetArea(void)
  {
    return(3.14159*m_rad*m_rad);
  }
private:
  float m_x, m_y, m_rad;
};
```

1. The function name is operator=
2. The function return type is a reference to the class.
3. The function returns *this when its done.

I'll explain this more in a bit...

The Assignment Operator

foo

```
class Circ
{
 ...
 Circ &operator=(const Circ &src)
 {
   m_x = src.m_x;
   m_y = src.m_y;
   m_rad = src.m_rad;
   return(*this);
 }
 ...
private:
  m_x 1  m_y 2  m_rad 3
}
```

```
class Ci
{
public:
  Circ(fl
  {
     m_x
  }
  Circ &
```

```
int main()
{
   Circ  foo(1,2,3);

   Circ  bar(4,5,6);

   bar = foo;
}
```

So, to summarize…

If you've defined an operator= function in a class…

Then any time you use the equal sign to set an existing variable equal to another…

C++ will call the operator= function of your target variable and pass in the source variable!

bar

;

```
class Circ
{
 ...
 Circ &operator=(const Circ &src)
 {
   m_x = src.m_x;
   m_y = src.m_y;
   m_rad = src.m_rad;
   return(*this);
 }
 ...
private:
  m_x 4  m_y 5  m_rad 6
}
```

The Assignment Operator

```
class PiNerd
{
public:
   PiNerd(int n) {
     m_n = n;
     m_pi = new int[n];
     for (int j=0;j<n;j++)
       m_pi[j] = getPiDigit(j);
   }

   ~PiNerd(){delete []m_pi;}

   void showOff()
   {
     for (int j=0;j<n;j++)
       cout << m_pi[j] << endl;
    }
private:
    int *m_pi, m_n;
};
```

Ok - so when would we ever need to write our own Assignment Operator?

After all, C++ copies all of the fields for us automatically if we don't write our own!

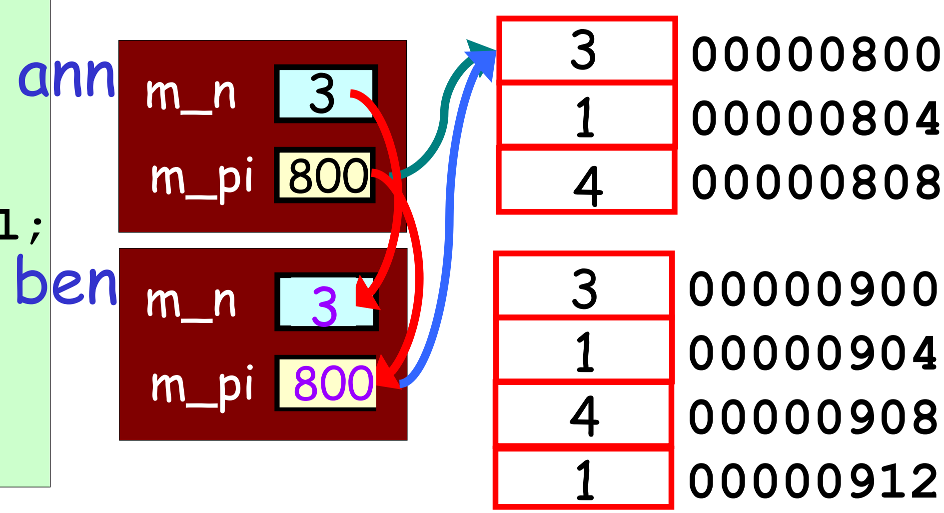
Well, remember our PiNerd class...

Lets see what happens if we use the default assignment operator with it...

The Assignment Operator

```
class PiNerd
{
public:
   PiNerd(int n) {
     m_n = n;
     m_pi = new int[n];
     for (int j=0;j<n;j++)
       m_pi[j] = getPiDigit(j);
   }

   ~PiNerd(){delete []m_pi;}

   void showOff()
   {
     for (int j=0;j<n;j++)
       cout << m_pi[j] << endl;
    }
private:
    int *m_pi, m_n;
};
```

```
int main()
{
    PiNerd  ann(3);

    PiNerd  ben(4);

    ben = ann;
}
```



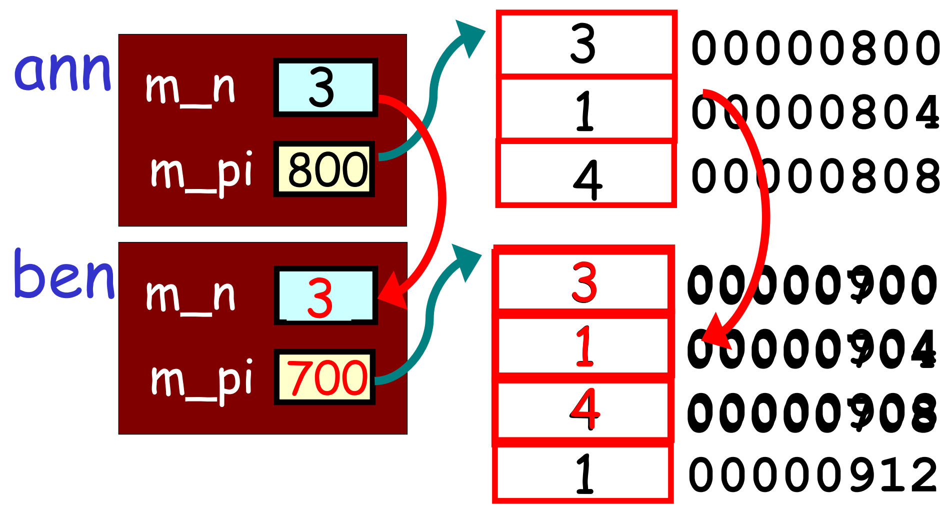
Assignment Operator

For such classes, you **must** define your own *asignment operator!*

Here's how it works for

ben = ann;

1. Free any memory currently held by the target variable (ben).
2. Determine how much memory is used by the source variable (ann).
3. Allocate the same amount of memory in the target variable.
4. Copy the contents of the source variable to the target variable.
5. Return a reference to the target variable.



The Assignment Operator

```
class P
{
public:
   PiNerd(     n) { … }
   ~PiNerd     delete[]m_pi; }

   // assignment operator:
   PiNerd &operator=(const PiNerd &src)
   {
     delete [] m_pi;
     m_n = src.m_n;
     m_pi = new int[m_n];
     for (int j=0;j<m_n;j++)
        m_pi[j] = src.m_pi[j];
     return(*this);
   }
   void showOff() { ... }

private:
   int *m_pi, m_n;
};
```

```
int main()
{
  PiNerd ann(3);
  PiNerd ben(4);
```

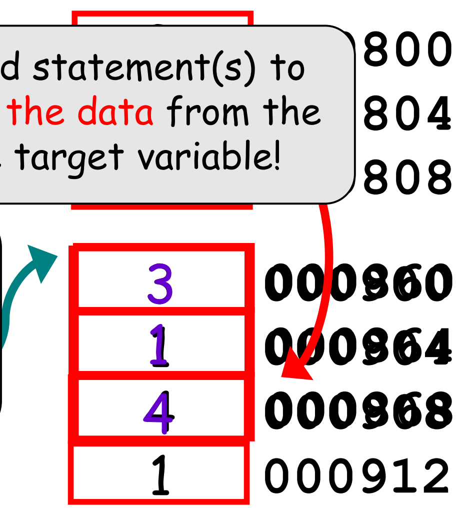
OK, first let's add a line to free the memory used by the target object.

Next let's determine how much memory is required to hold the source object's data.

Next we'll add a statement to allocate enough storage so the target can hold a copy of the source's data.

Now we can add statement(s) to copy over all of the data from the source to the target variable!

Finally, we'll add a statement so the function returns a reference to itself when it's done.
(Don't worry, I'll explain soon)

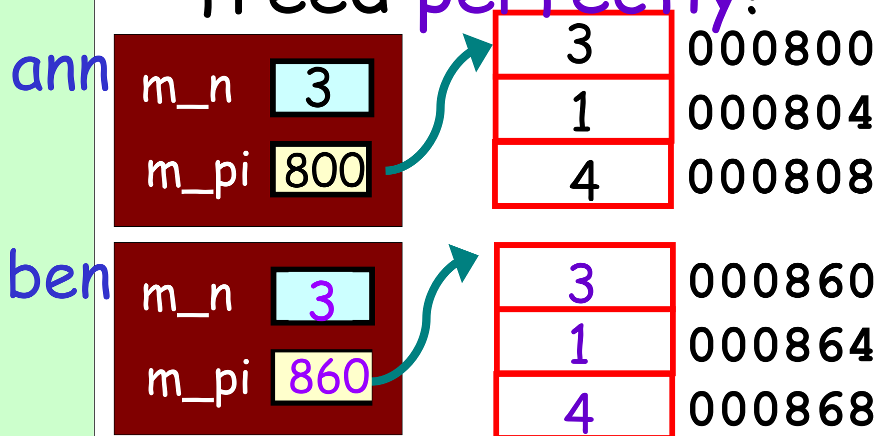


The Assignment Operator

```
class PiNerd
{
public:
   PiNerd(int n) { … }
   ~PiNerd(){ delete[]m_pi; }

   // assignment operator:
   PiNerd &operator=(const PiNerd &src)
   {
     delete [] m_pi;
     m_n = src.m_n;
     m_pi = new int[m_n];
     for (int j=0;j<m_n;j++)
        m_pi[j] = src.m_pi[j];
     return(*this);
   }
   void showOff() { ... }

private:
    int *m_pi, m_n;
};
```

```
int main()
{
   PiNerd ann(3);
   PiNerd ben(4);

   ben = ann;

}// ann's d'tor called, then ben's
```

… and everything is freed perfectly!



The Assignment Operator

Question: Why do we have return(*this) at the end of the assignment operator function?

Answer: So we can do multiple assignments in the same statement, like this…

tim
```
class Gassy
{
  Gassy &operator= (const Gassy &src)
  {
    m_age = src.m_age;
    m_ateBeans = src.m_ateBeans;
    return(*this);
  }
  m_age [5]   m_ateBeans [false]
};
```

ted
```
class Gassy
{
  Gassy &operator= (const Gass
  {
    m_age = src.m_age;
    m_ateBeans = src
    return(*this);
  }
  m_age [5]   m_
};
```

sam
```
class Gassy
{
                                    c)
         = src.m_ateBeans;
        s);
     m_ateBeans [false]
```

"this" is a special C++ pointer variable that holds the address of the current object (i.e., ted's address in RAM)

So if "this" is a pointer to ted, then "*this" refers to the whole ted variable.

So this line returns the ted variable itself! Strange huh? A member function of a variable can return the variable itself!?!?

So the statement: "ted = sam" is just replaced by the ted variable!

So, to sum up… The assignment operator returns "*this" so that there's always a variable on the right hand side of the = for the next assignment.

```
  Gassy sam(5,false);
  Gassy ted(10,false);
  Gassy tim(3,true);

  tim = ted = sam;
}
```

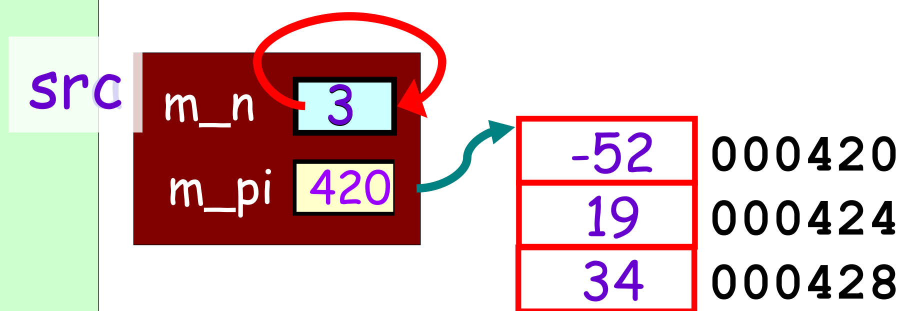
Operator

"*Aliasing*" is when we use two different references/pointers to refer to the same variable. It can cause unintended problems!

Our assignment operator has one more problem with it… Can anyone guess what it is?

```
class PiNerd
{
public:
   ...

   PiNerd &operator=(const PiNerd &src)
   {
     delete [] m_pi;
     m_n = src.m_n;
     m_pi = new int[m_n];
     for (int j=0;j<m_n;j++)
        m_pi[j] = src.m_pi[j];
     return(*this);
   }

private:
    int *m_pi, m_n;
};
```

```
void f(PiNerd &x,PiNerd &y)
{
   ...
   x = y;  // really ann = ann;  !!!
}

int main()
{
   PiNerd ann(3);
   f(ann,ann);
}
```



Hmm… What happens if we set a to itself?

So now we copy the random values over themselves!

The Assignment Operator

The fix:

Our assignment operator function must check to see if a variable is being assigned to itself, and if so, do nothing…

If the right-hand variable's address…

Is the same as the left-hand variable's address…

```
   ...
  PiNerd &operator=(const PiNerd &src)
  {
    if (&src == this)
      return(*this); // do nothing
    delete [] m_pi;
    m_n = src.m_n;
    m_pi = new int[m_n];
    for (int j=0;j<m_n;j++)
       m_pi[j] = src.m_pi[j];
    return(*this);
  }
  ...
};
```

Then they're the same variable!

We simply return a reference to the variable and do nothing else!

And we're done!

Copy Constructor/ Assignment Review

Question: which of the following use the copy constructor and which use the assignment operator?

```
int main()        // #1
{
  PiNerd  a(4), b(3);
  b = a;
}
```

```
int main()        // #2
{
  PiNerd c(5), d(c);
  PiNerd e = d;
}
```

```
// #3
PiNerd func(void)
{
  PiNerd g(15);
  return(g);
}

int main()
{
  PiNerd   f = func();
}
```

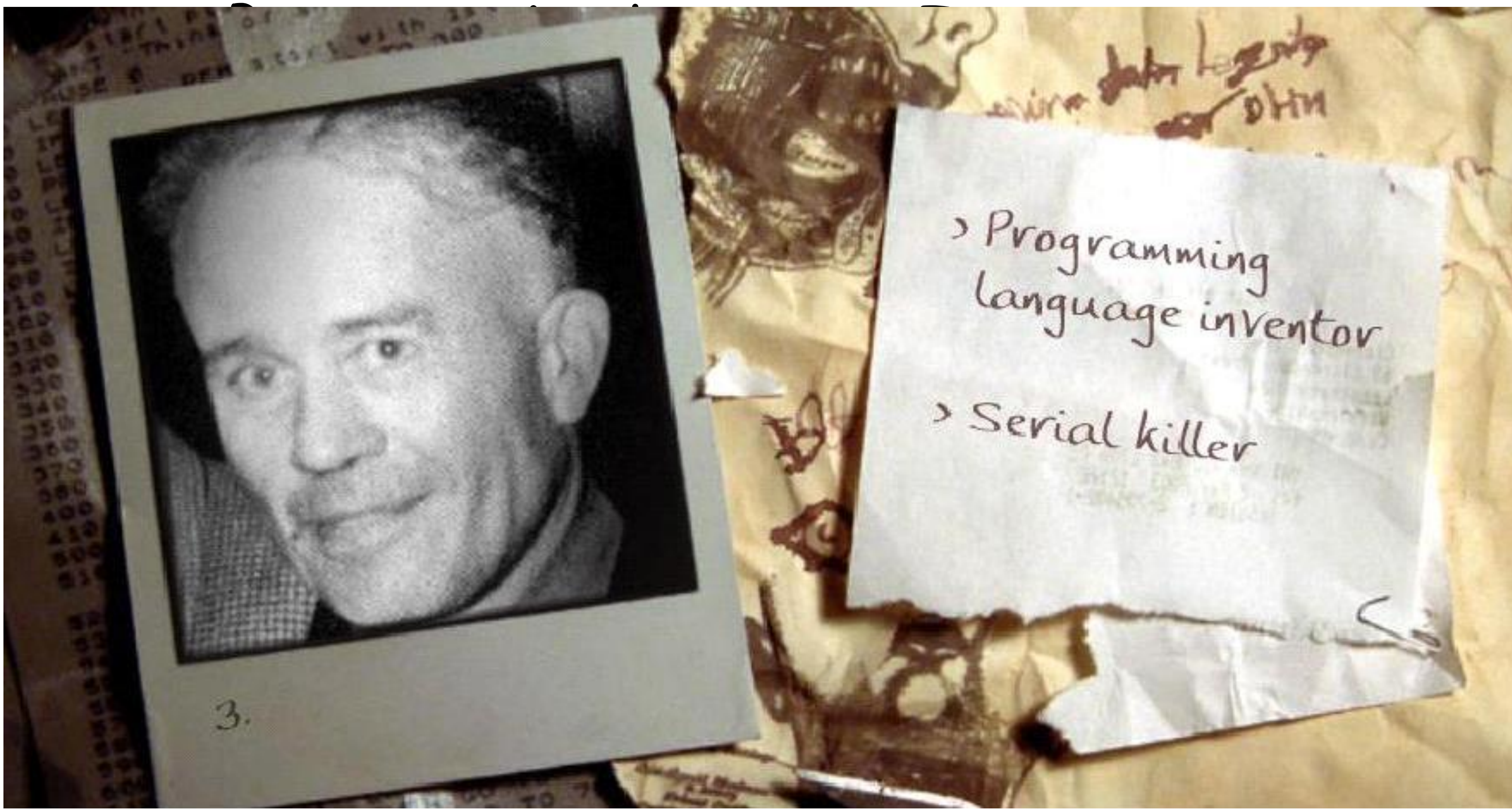
Challenge

Write an assignment operator for our CSNerd Class:

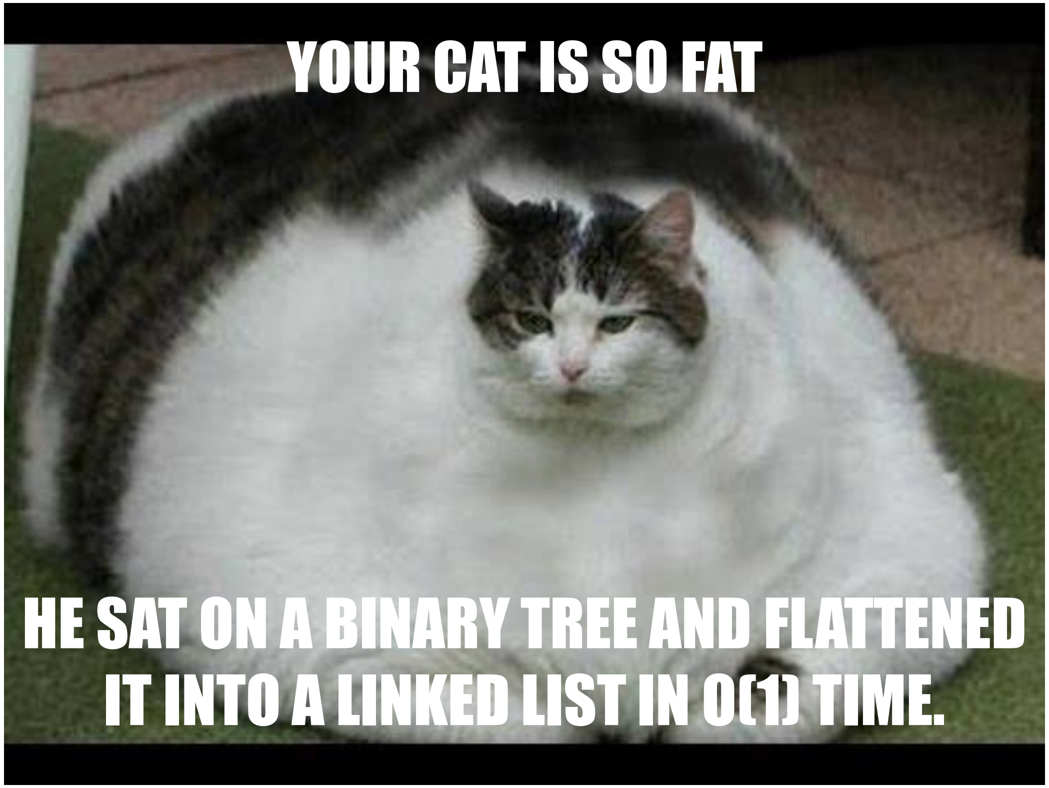
```
struct Book
{
   string title;
   string author;
};
```

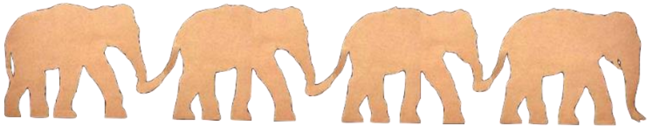
```
class CSNerd
{
public:
   CSNerd(string name) {
     m_myBook = nullptr;
     m_myName = name;
   }
   void giveBook(string t, string a) {
     m_myBook = new Book;
     m_myBook->title = t;
     m_myBook->author = a;
   }
   ~CSNerd() {
     delete m_myBook;
   }
private:
   Book *m_myBook;
   string m_myName;
};
```

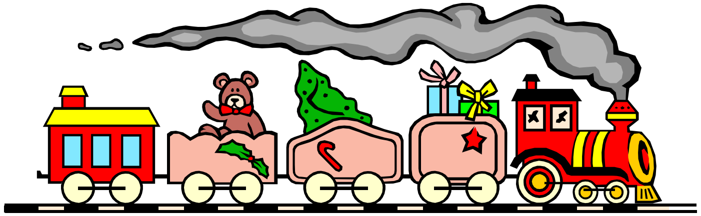
Time for your favorite game!



Linked Lists







Linked Lists…
Why should you care?

Linked Lists are used in everything from video games to search engines.

Any time you don't know how many items you'll need to store ahead of time, you use 'em.

And virtually every job interview will grill you on them.

So pay attention!

Arrays are great… But…

Arrays are great when you need to store a fixed number of items…

```
int main()
{
   int array[100];
   …
}
```

```
int main()
{
   // might have 10 items or 1M
   int array[1000000];
   …
}
```

But what if you don't know how many items you'll have ahead of time?

Then you have to reserve enough slots for the largest possible case.

Even new/delete don't really help!

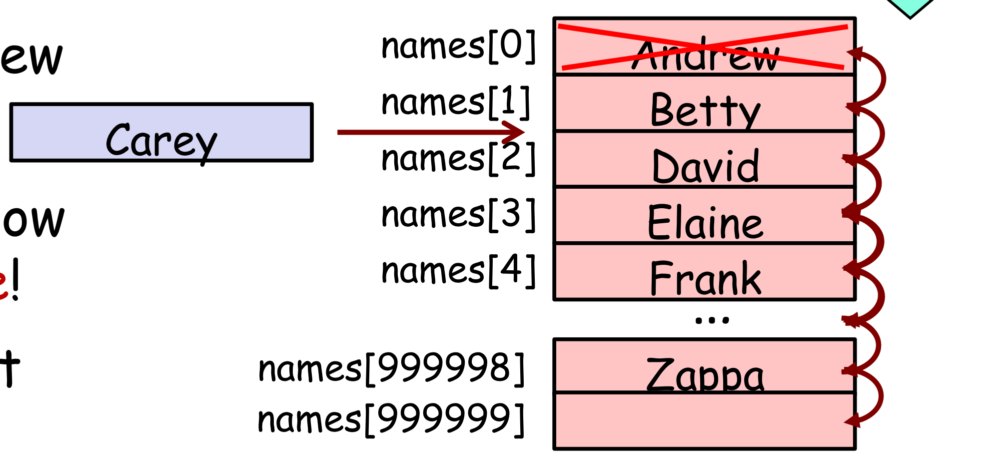
```
int main()
{
  int numItems, *ptr;

  cin >> numItems;
  ptr = new int[numItems];
}
```

It takes nearly 1M steps to add a new item!

And what if you need to insert a new item in the middle of an array?

We have to move every item below the insertion spot down by one!

And it's just as slow if we want to delete an item! Yuck!



So Arrays Aren't Always Great

Hmm… Can we think of an approach from "real life" that works better than a fixed-sized array?

How about organizing the items as we would in a Scavenger Hunt?

What can we think of that:

allows you to store an arbitrary number of items

makes it fast to insert a new item in the middle

makes it fast to delete an item from the middle

Using this approach we can store an arbitrary number of items!

There's no fixed limit to the number of chests and clues we can have!

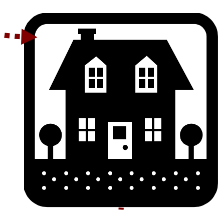
The hunt starts with a clue to the location of the first chest…

Clue:

The first item is by the tree

Clue:

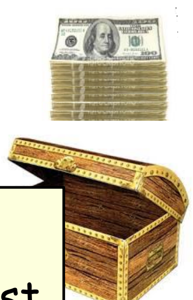
The next item is by the house

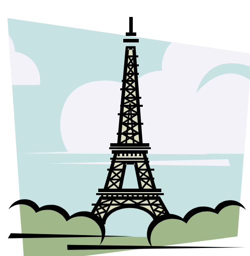


Clue:

The next item is by the tower

Then each chest holds an item and a clue to the location of the next chest.





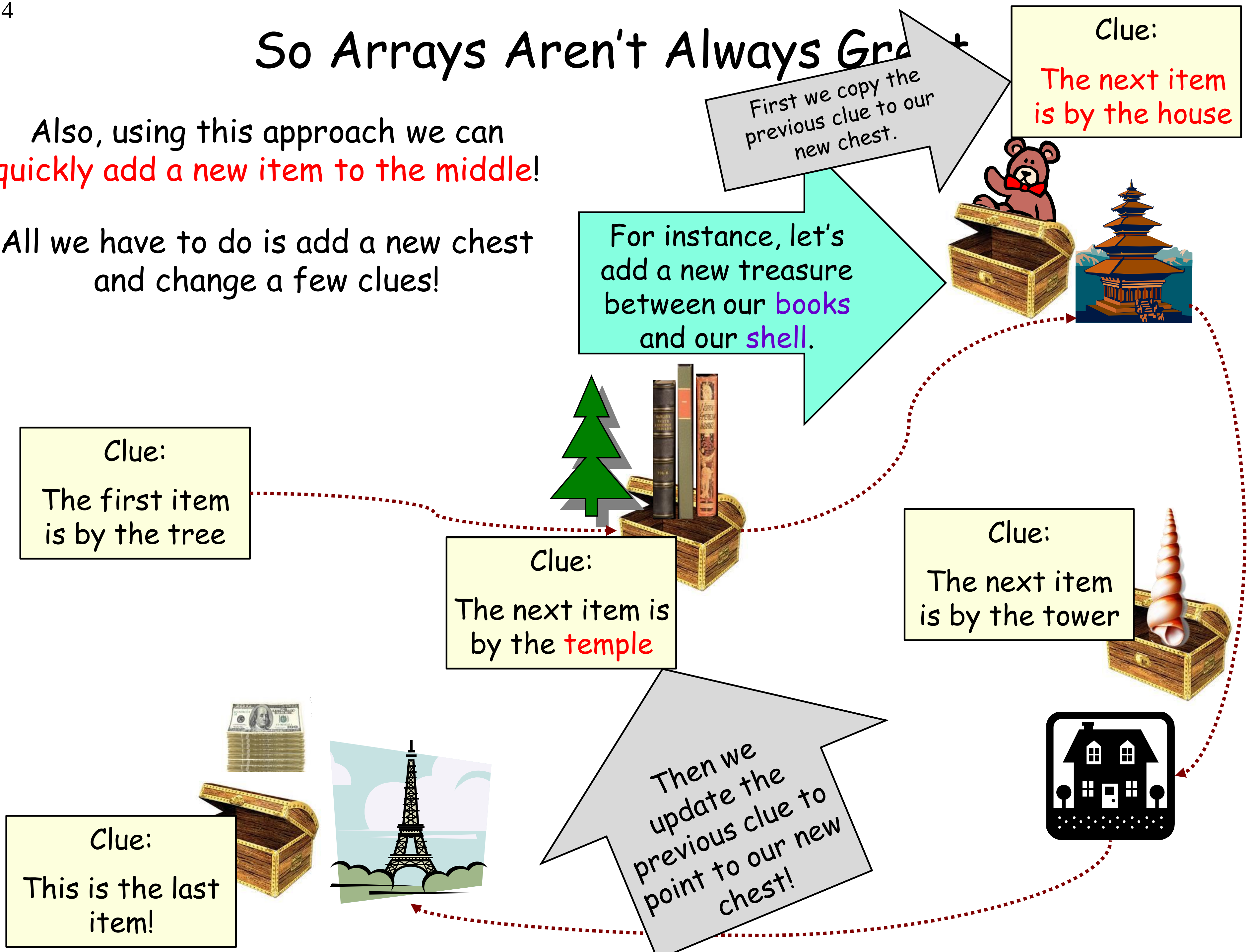
Clue:

This is the last item!

So Arrays Aren't Always Great

Also, using this approach we can quickly add a new item to the middle!

All we have to do is add a new chest and change a few clues!



So Arrays Aren't Always Great

Finally, using this approach we can quickly remove an item from the middle!

All we have to do is remove the target chest and change a single clue!

Clue:

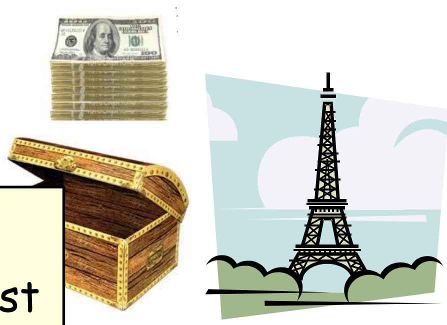
The next item is by the tower

Clue:

The first item is by the tree

Clue:

The next item is by the temple



Clue:

This is the last item!

A C++ Scavenger Hunt?

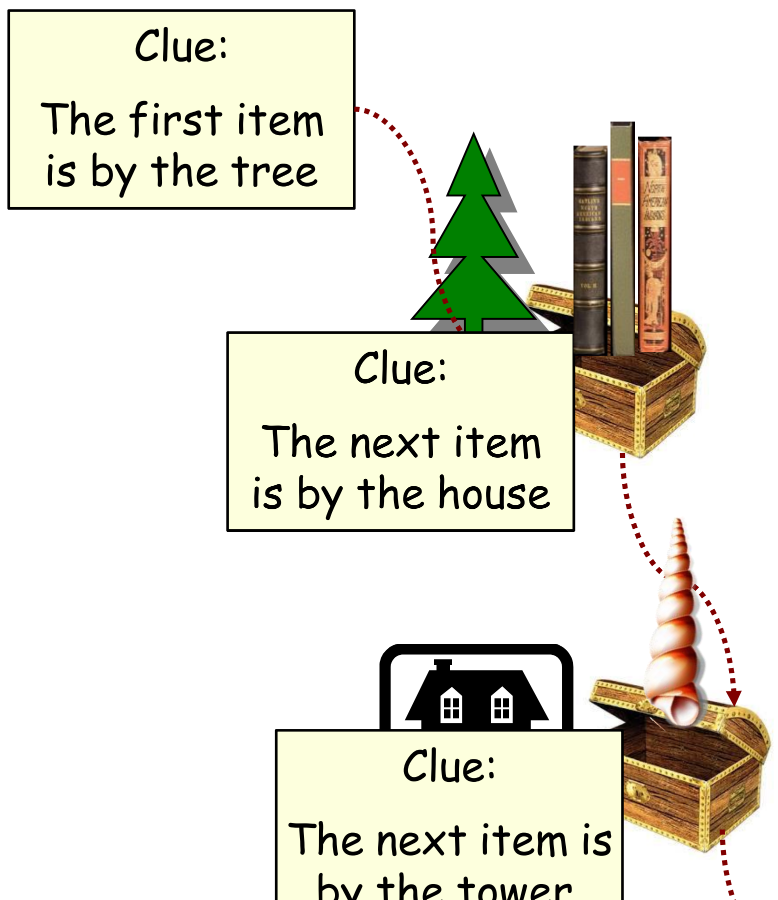
Ok, so in our Scavenger Hunt, we had:

A clue that leads us to our first treasure chest.

Each chest then holds an item (e.g., books) and a clue that leads us to the next chest.

So here's the question… can we simulate a Scavenger Hunt with a C++ data structure?

Why not? Let's see how.



A C++ Scavenger Hunt?

Well, we can use a C++ struct to represent a Chest.

As we know, each Chest holds two things:

A treasure – let's use a string variable to hold our treasure, e.g., "shells".

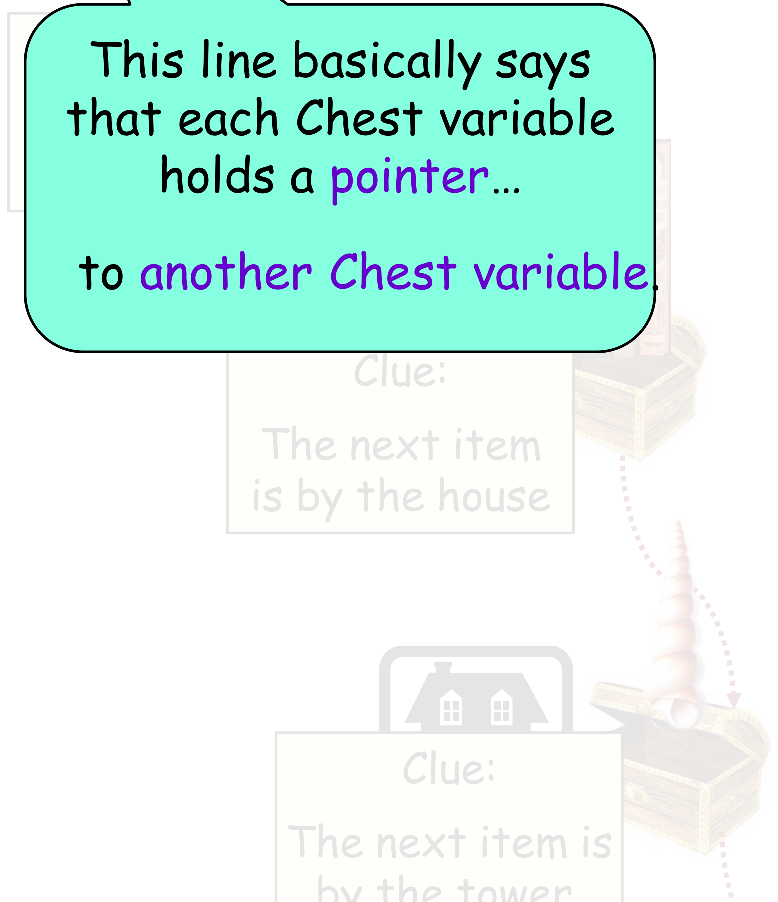
The location of the next chest – let's represent that with a pointer variable.

We can now define a Chest variable for each of the items in our scavenger hunt!

```
struct Chest
{
    string treasure;
    Chest * nextChest;
};
```

This line basically says that each Chest variable holds a pointer…

to another Chest variable.



A C++ Scavenger Hunt?

Well, we can use a C++ struct to represent a Chest.

```
struct Chest
{
    string treasure;
    Chest * nextChest;
};
```

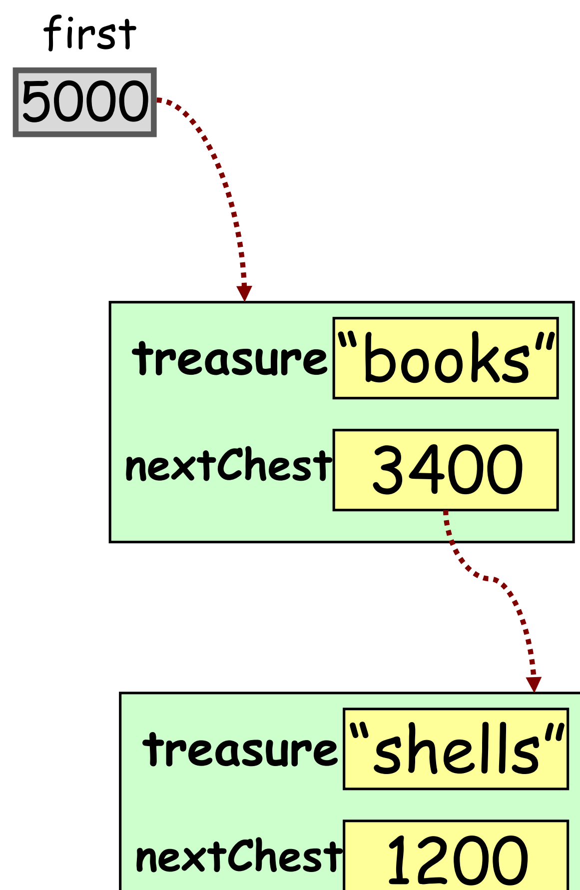
OK, let's see the C++ version of a simplified scavenger hunt data structure!

represent that with a pointer variable.

We can now define a Chest variable for each of the items in our scavenger hunt!

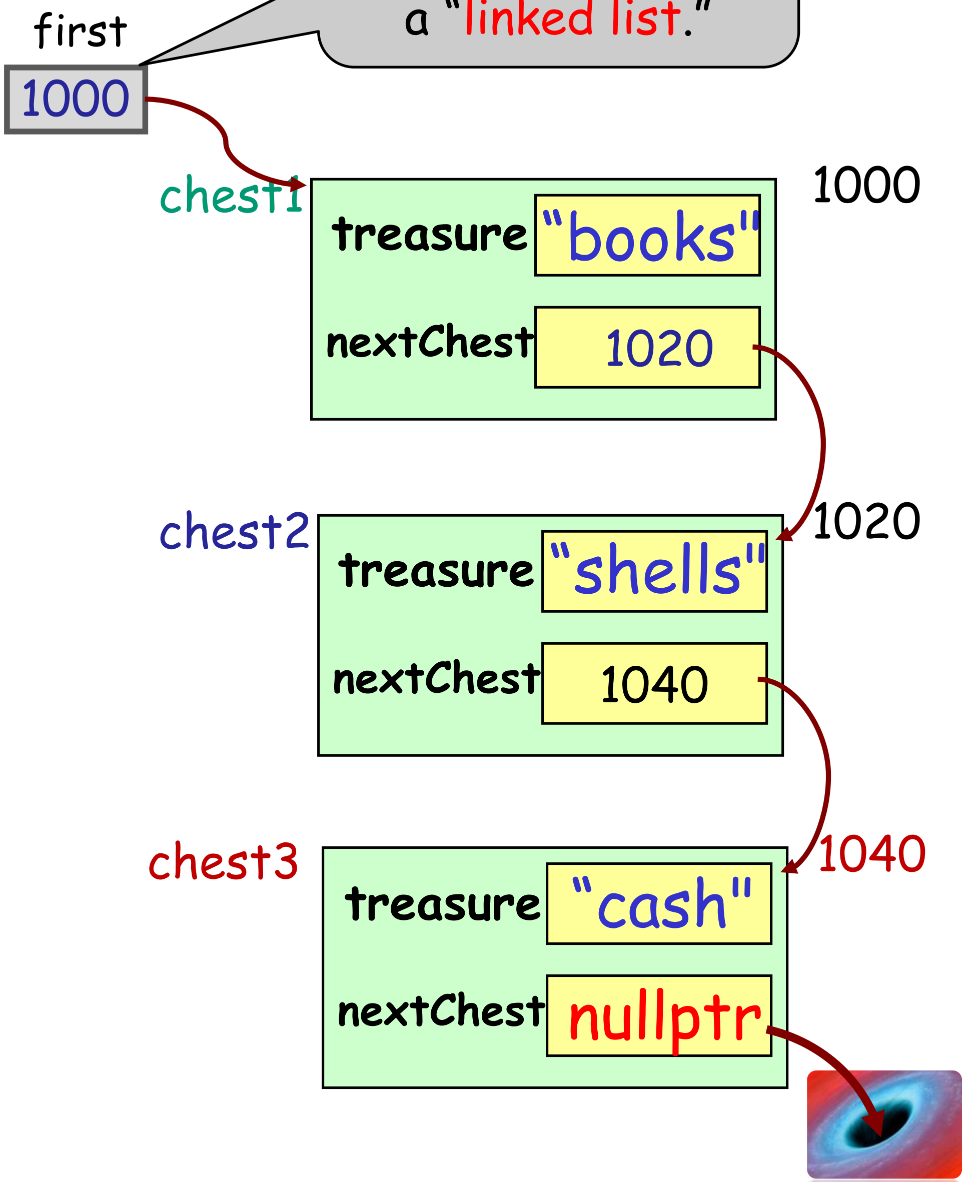
And we can define a pointer to point to the very first chest – our first clue!

Chest *first; // pointer to our 1st chest



A C++ Sc ... nt?

This data structure is called a "linked list."

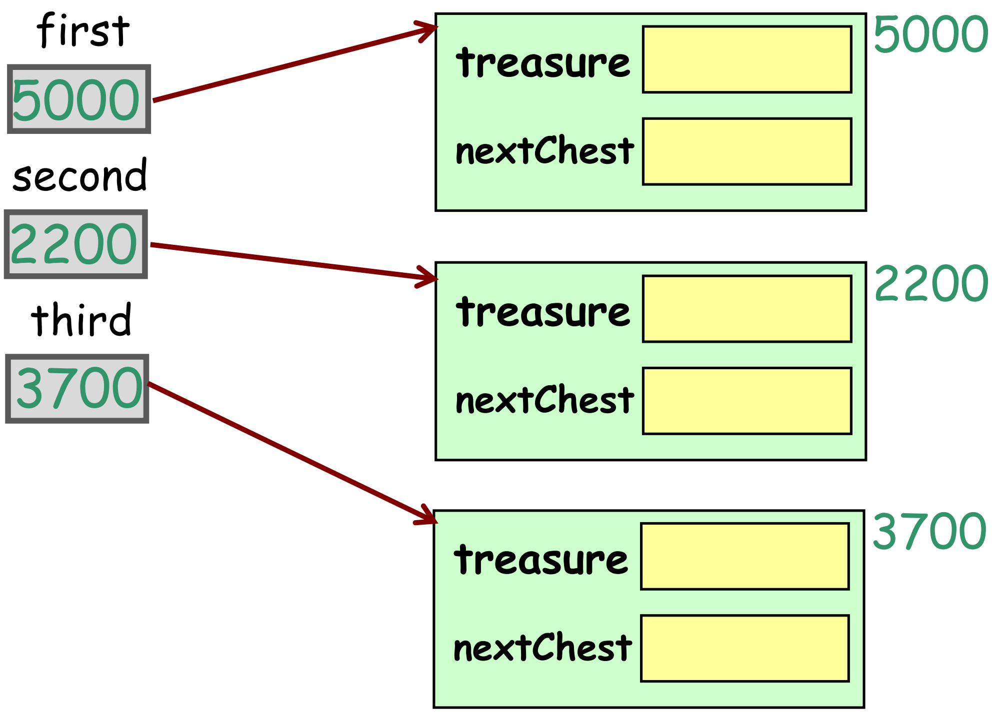



```
struct Chest
{
    string treasure;
    Chest * nextChest;
};

int main(void)
{
  Chest *first;
  Chest  chest1, chest2, chest3;

  first = &chest1;

  chest1.treasure = "books";
  chest1.nextChest = &chest2;

  chest2.treasure = "shells";
  chest2.nextChest = &chest3;

  chest3.treasure = "cash";
  chest3.nextChest = nullptr;

}
```

Linked Lists

Normally, we don't use local variables to create our linked list.

Instead we use dynamically-allocated variables (and pointers!).




```
struct Chest
{
   string treasure;
   Chest * nextChest;
};

int main(void)
{
  Chest *first, *second, *third;

  first = new Chest;
  second = new Chest;
  third = new Chest;

}
```

The pointer to the top item in the linked list is traditionally called the "head pointer."

OK, now let's add cargo and link 'em up!

Given just the head pointer, you can reach every element in the list…

without using your other external pointers!

head

5000

second

2200

third

3700

5000		
treasure	"books"	
nextChest	2200	

2200		
treasure	"shells"	
nextChest		

3700		
treasure	"cash"	
nextChest	nullptr	

Again, in our last node, we'll set its nextChest pointer to nullptr. This indicates that it's the last item in the list.

```
struct Chest
{
    string treasure;
    Chest * nextChest;
};

int main(void)
{
  Chest *head, *second, *third;

  head = new Chest;
  second = new Chest;
  third = new Chest;

  first->treasure = "books";
  first->nextChest = second;

  second->treasure = "shells";
  second->nextChest = third;

  third->treasure = "cash";
  third->nextChest = nullptr;

  delete head;
  delete second;
  delete third;
}
```

Linked Lists

Ok, it's time to start using the right Computer Science terms.

Instead of calling them "chests", let's call each item in the linked list a "Node".

And instead of calling the value held in a node treasure, let's call it "value".

And, instead of calling the linking pointer nextChest, let's call it "next".

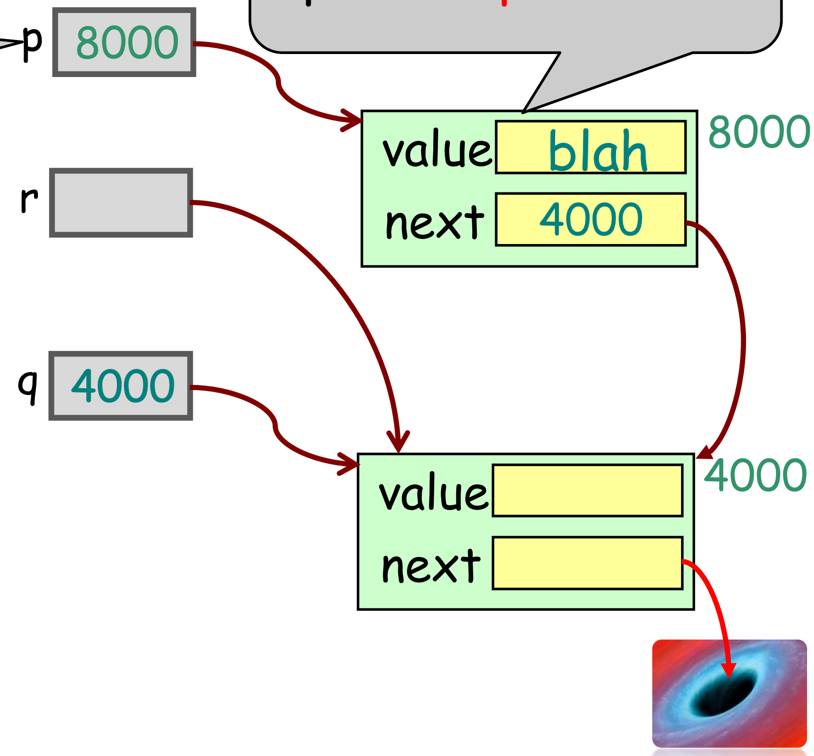
Finally, there's no reason a Node only needs to hold a single value!

```
struct Node // student node
{
    int studentID;
    string name;
    int phoneNumber;
    float gpa;

    Node *next;
};
```

```
struct Node
{
    string value;
    Node * next;
};

int main(void)
{
  Node *head, *second, *third;

  head = new Node;
  second = new Node;
  third = new Node;

  head->value = "books";
  head->next = second;

  second->value = "shells";
  second->next = third;

  third->value = "cash";
  third->next = nullptr;

  delete head;
  delete second;
  delete third;
}
```

Note: The delete command doesn't kill the pointer…

it kills what the pointer points to!



To allocate new nodes:

```
Node *p = new Node;
Node *q = new Node;
```

To change/access a node p's value:

```
p->value = "blah";
cout << p->value;
```

To make node p link to another node that's at address q:

```
p->next = q;
```

To get the address of the node after p:

```
Node *r = p->next;
```

To make node q a "terminal" node:

```
q->next = nullptr;
```

To free your nodes:

```
delete p;
delete q;
```

Before we continue, here's a short recap on what we've learned:

Linked Lists

Normally, we don't create our linked list all at once in a single function.

After all, some linked lists hold millions of items! That wouldn't fit!

Instead, we create a dedicated class (an ADT) to hold our linked list…

And then add a bunch of member functions to add new items (one at a time), process the items, delete items, etc.

OK, so let's see our new class.

```
struct Node
{
    string value;
    Node * next;
};

int main(void)
{
  Node *head, *second, *third;

  head = new Node;
  second = new Node;
  third = new Node;

  head->value = "books";
  head->next = second;

  second->value = "shells";
  second->next = third;

  third->value = "cash";
  third->next = nullptr;

  delete head;
  delete second;
  delete third;
}
```

A Linked List Class!

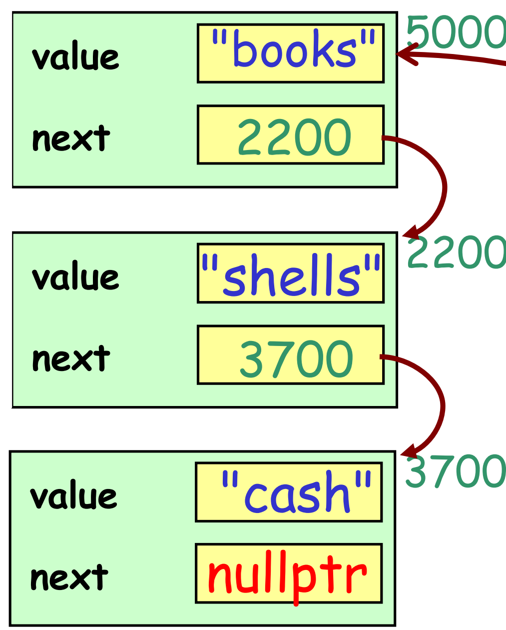
First, in the simplest type of linked list class, the only member variable we need is a head pointer.

Why? Given just the head pointer, we can follow the links to every node in the list.

And since we can find all the nodes, we can also link in new ones, delete them, etc..

```
struct Node
{
   string value;
class LinkedList
{
public:




private:
  Node *head;  5000
};
```

Ok, so let's add a head pointer to our class.



A Linked List Class!

Alright, now what methods should our linked list class have?

We need a constructor to create an empty list…

And methods to add new items…

And a method to delete items…

And a method to find if an item is in the list…

And a method to print all the items…

And finally, we need a destructor to free all of our nodes!

Let's consider these one at a time!

```
struct Node
{
   string  value;
   Node   *next;
};
class LinkedList
{
public:
   LinkedList() { … }
   void addToFront(string v) { … }
   void addToRear(string v) { … }
   void deleteItem(string v) { … }
   bool findItem(string v) { … }
   void printItems() { … }
   ~LinkedList() { … }

private:
  Node *head;
};
```

Linked List Constructor

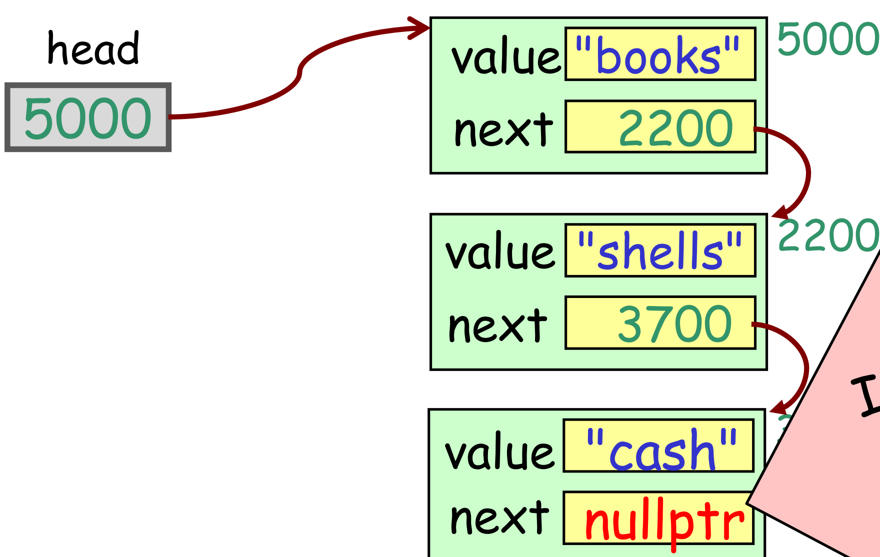
OK, so what should our constructor do?

Well, we'll want it to create an "empty" linked list – one with no items.

But how do we create an empty list?

Well, earlier I showed you how we marked the last node in a linked list…

We set its next value to nullptr.



Indicates that there aren't any nodes following this one…

```
struct Node
{
    string  value;
    Node  *next;
};
```

```
class LinkedList
{
public:
   LinkedList()
   {


   }

   …

   ode *head;
};
```

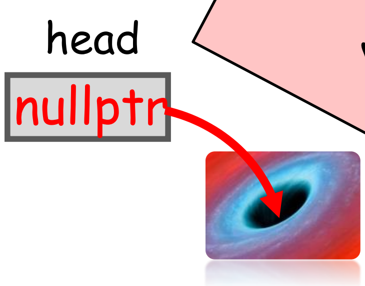
Linked List Constructor

So, following this logic…

We can create an empty linked list by setting our head pointer to nullptr!

OK, next let's learn how to print the items in our list!

A head pointer with a value of nullptr means "empty list"!



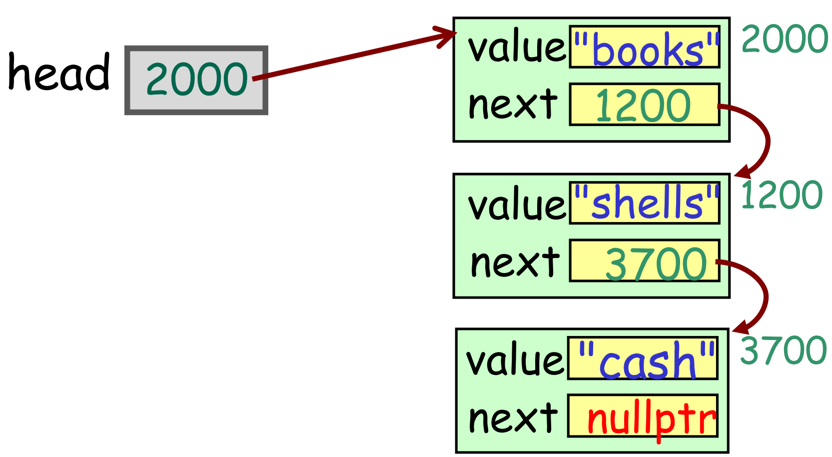

```
struct Node
{
   string  value;
   Node   *next;
};
class LinkedList
{
public:
   LinkedList()
   {
      head = nullptr;
   }

   …

private:
  Node *head;
};
```

Printing the Items in a Linked List

So let's assume we've used our class to create a linked list and add some items…

How do we go about printing the items in the list?

```
int main()
{
    LinkedList myList;

    // code to add nodes

    myList.printItems();
}
```



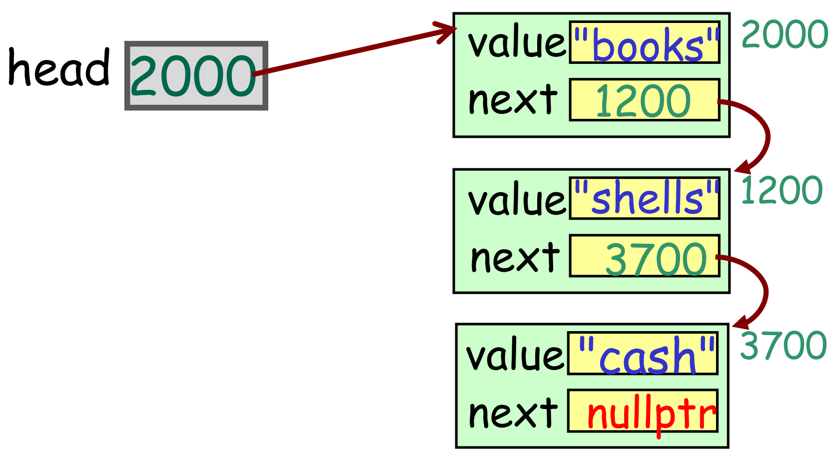

```
struct Node
{
    string  value;
    Node   *next;
};
class LinkedList
{
public:
    LinkedList() { … }
    void addToFront(string v) { … }
    void addToRear(string v) { … }
    void deleteItem(string v) { … }
    bool findItem(string v) { … }
    void printItems() { … }
    ~LinkedList() { … }

private:
  Node *head;
};
```

Printing the Items in a Linked List

So let's assume we've used our class to create a linked list and add some items…

How do we go about printing the items in the list?

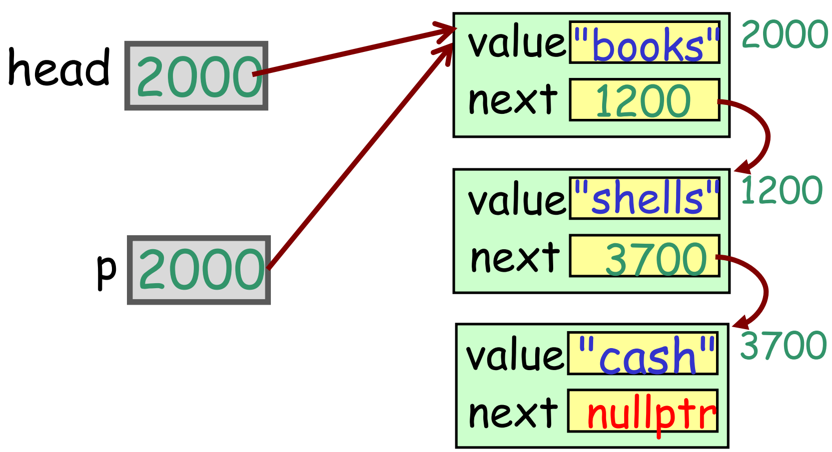
```
int main()
{
    LinkedList myList;

    // code to add nodes

    myList.printItems();
}
```




```
struct Node
{
    string value;
    Node *next;
};
class LinkedList
{
public:
    void printItems()
    {




    }

private:
    Node *head;
};
```

Printing the Items in a Linked List

OK, so our goal is to loop through each of the nodes and print out their values, starting with the node pointed to by "head"…




```
struct Node
{
    string  value;
    Node   *next;
};

class LinkedList
{
public:
   void printItems()
   {
      Node *p;
      p = head; // p points to 1st node
      while ( p points to a valid node )
      {
         print the value in the node

         p = address of the next node
      }
   }

private:
   Node *head;
};
```

Printing the Items in a Linked List

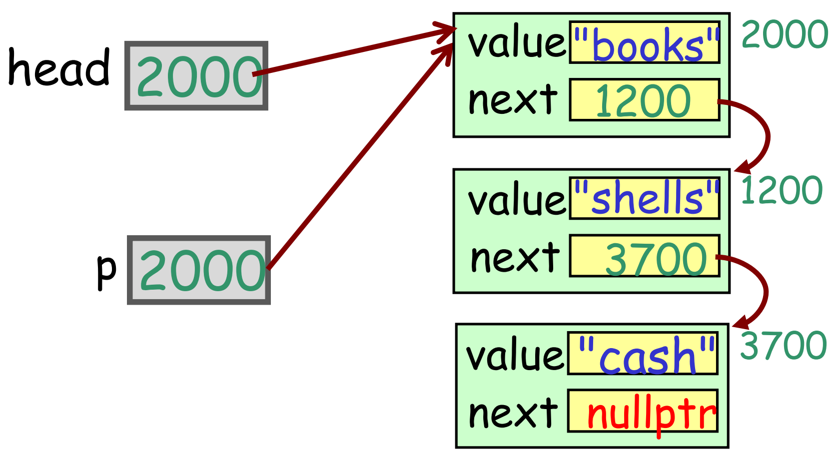
OK, so our goal is to loop through each of the nodes and print out their values, starting with the node pointed to by "head"...

Be careful!

You can't use p++ to move forward in a linked list!

You <u>must</u> use the next pointer!

```
struct Node
{
    string  value;
    Node   *next;
};

class LinkedList
{
public:

  void printItems()
  {
    Node *p;
    p = head; // p points to 1st node
    while ( p points to a valid node )
    {
      cout << p->value << endl;

      p = p->next;
    }
  }

private:
  Node *head;
};
```



Printing the Items in a Linked List

And there's our complete printing loop!

So this answers our question!

If p's value is nullptr, it does NOT point to a valid node. Otherwise it does.

When we use the condition:

while (p != nullptr) { … }

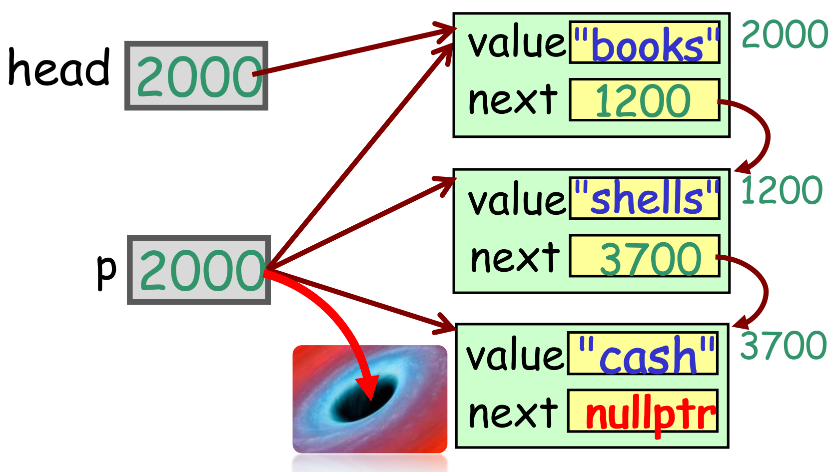
the loop will process EVERY node in the list and only stop once it's gone PAST the end of the list.

Any time we iterate through one or more nodes like this, it's called a "traversal".

Alright, now let's learn how to add nodes to our list!

This is a linked list traversal!

```
void p...ems()
{
   Node *p...
   p = head;  // p points to 1st node

   while ( p != nullptr )
   {
      cout << p->value << endl;
      p = p->next;
   }
}

private:
   Node *head;
};
```



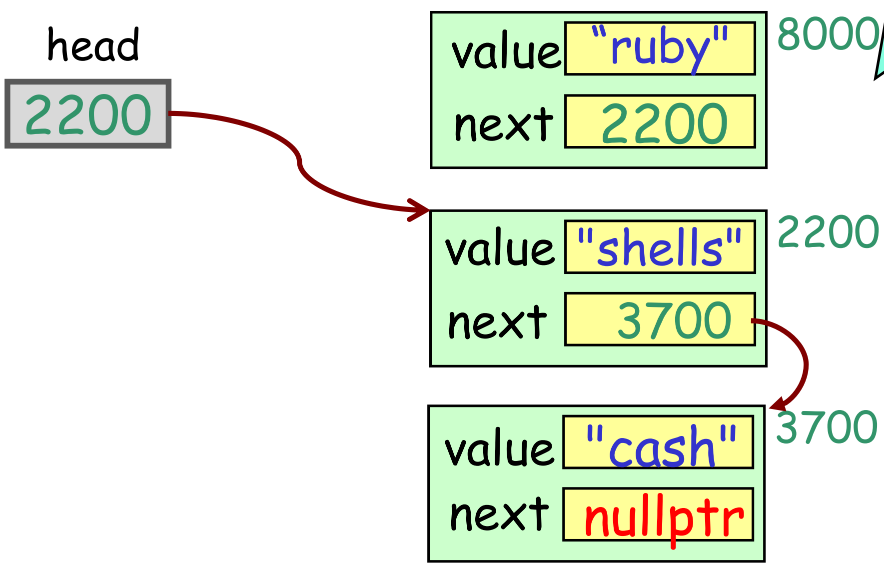
Adding an Item to a Linked List

There are three places you can insert a new item into a linked list:

at the top of the list
at the end of the list
somewhere in the middle

The algorithm to insert at the top is the easiest to code and also runs the fastest.

Let's see this one first, and add a "ruby" to the top of our list!



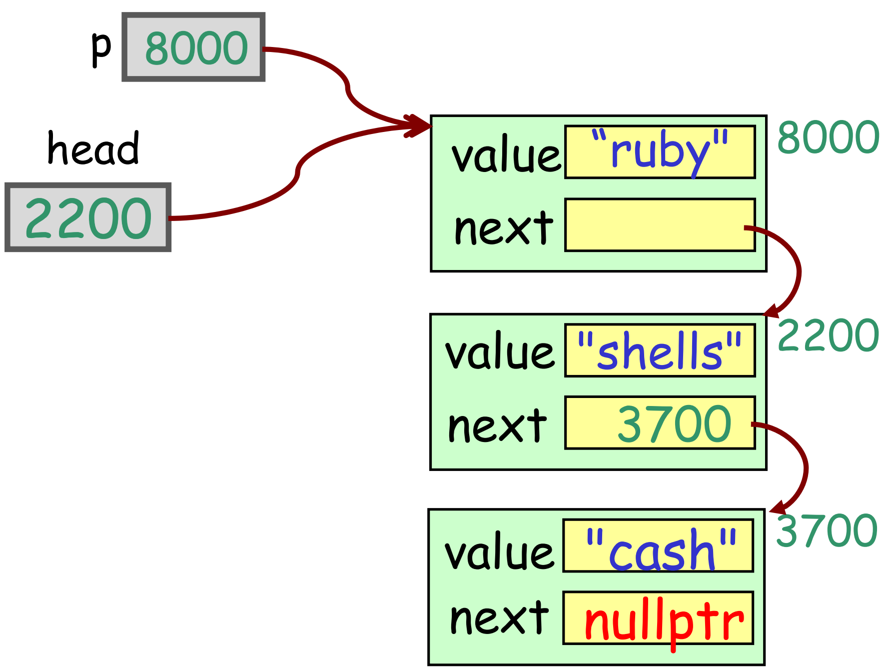
These two steps must be in this order!

```
struct Node
{
    string  value;
    Node  *next;
};

class LinkedList
{
public:
    void addToFront(string v)
    {
        Allocate a new node

        Put value v in the node

        Link the new node to the
        old top node
        Link the head pointer to
        our new top node
    }

    ...

private:
    Node *head;
};
```

Adding an Item to the Front

OK, now let's replace our psuedo-code with valid C++ code.

And as you can see, our new node has been added at the top!



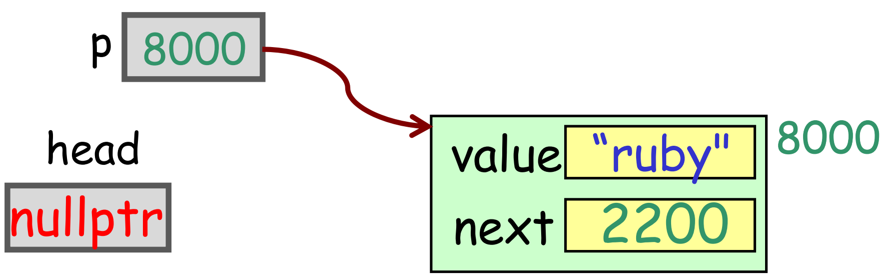

```
struct Node
{
   string  value;
   Node   *next;
};
class LinkedList
{
public:
   void addToFront(string v)
   {
      Node *p;
      p = new Node;
      p->value = v; // put v in node

      p->next =  head;

      head = p;

   }

   ...

private:
  Node *head;
};
```

Adding an Item to the Front

OK, but will this same algorithm work if the Linked List is empty?

Let's see!

Pretty cool – the same algorithm works whether the list is empty or not!



Alright, now let's see how to add a node to the rear of a list!

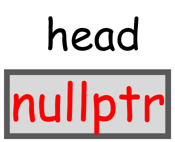
```
struct Node
{
    string  value;
    Node   *next;
};
class LinkedList
{
public:
   void addToFront(string v)
   {
      Node *p;
      p = new Node;
      p->value = v; // put v in node

      p->next =  head;

      head = p;

   }

   ...

private:
  Node *head;
};
```

Adding an Item to the Rear

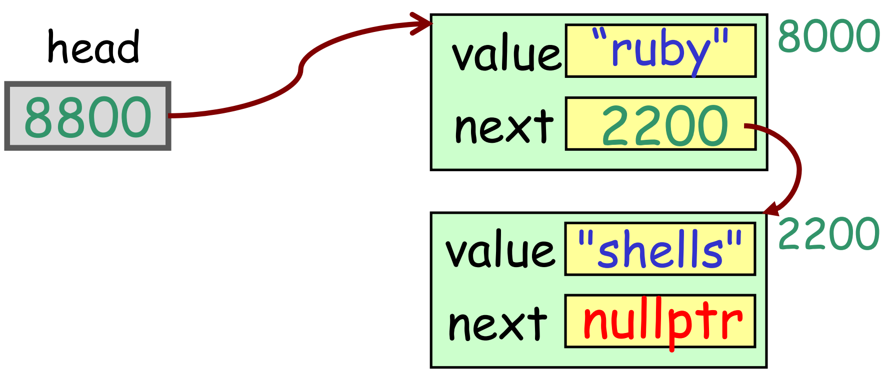
Alright, next let's look at how to append an item at the end of a list…

There are actually two cases to consider:

Case #1:
The existing list is totally empty!



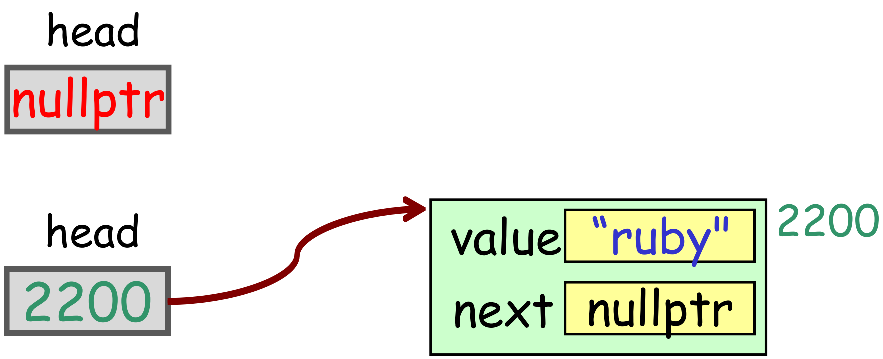
Case #2:
The existing list has one or more nodes…




```
struct Node
{
    string  value;
    Node  *next;
};
class LinkedList
{
public:
    void addToRear(string v)
    {


    }
    …
};
```

Adding an Item to the Rear

Alright, let's consider Case #1 first…
It's much easier!



So how do you add a new node to the end of an empty linked list?

In fact, it's the same as adding a new node to the front of an empty linked list.

Which we just learned two minutes ago!

After all, in both cases we're adding a node right at the top of the linked list.

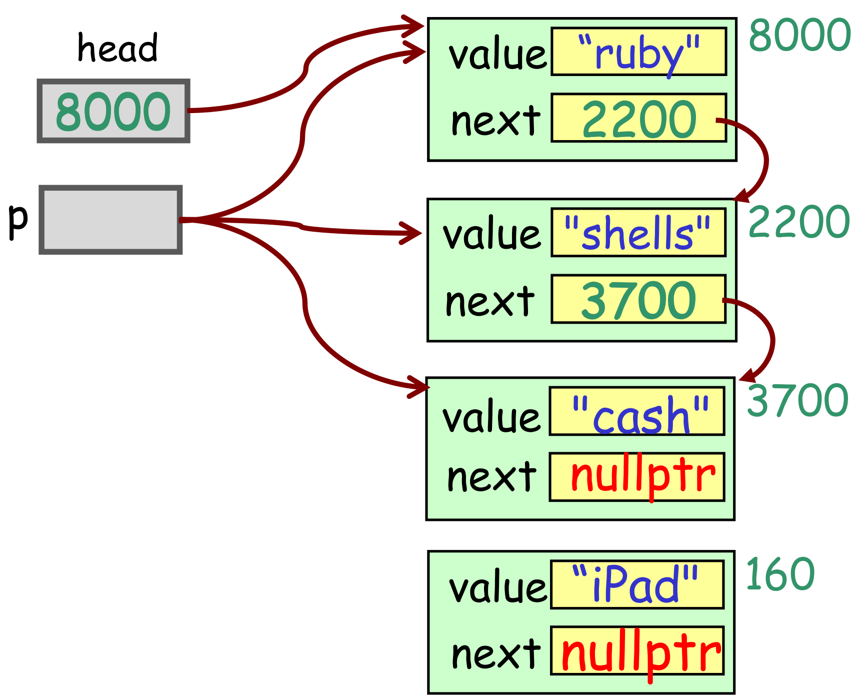
```
struct Node
{
    string  value;
    Node  *next;
};
class LinkedList
{
public:
    void addToRear(string v)
    {
       if (head == nullptr)
          addToFront(v); // easy!!!




    }
    …
};
```

Adding an Item to the Rear

Alright, let's consider Case #2 next:
It's more complex…

Here we want to add an item to the end of a linked list that already has nodes.

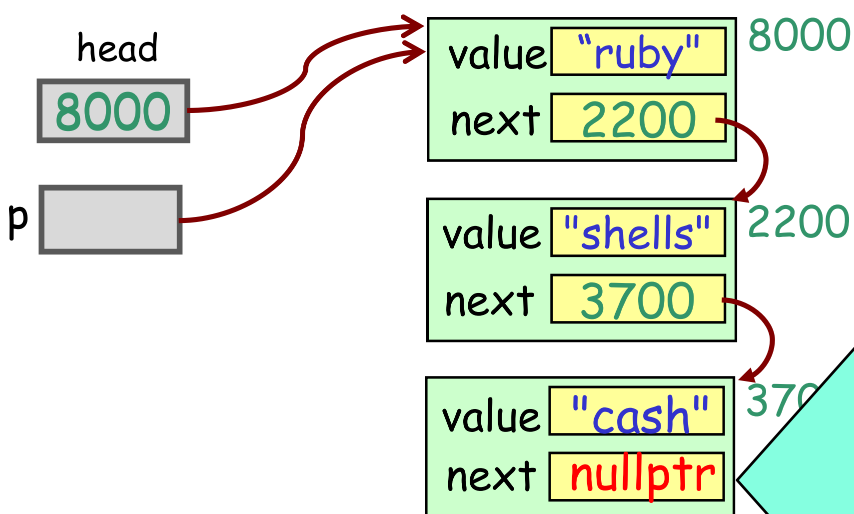
Well that doesn't look too bad… Let's add an "iPad" to our list.




```
struct Node
{
    string  value;
    Node   *next;
};
class LinkedList
{
public:
    void addToRear(string v)
    {
       if (head == nullptr)
          addToFront(v); // easy!!!
       else
       {
          Use a temp variable to
          traverse to the current
          last node of the list

          Allocate a new node
          Put value v in the node
          Link the current last node
          to our new node
          Link the last node to nullptr
       }
    }
    ...
};
```

Adding an Item to the Rear

OK, let's see the C++ code now!



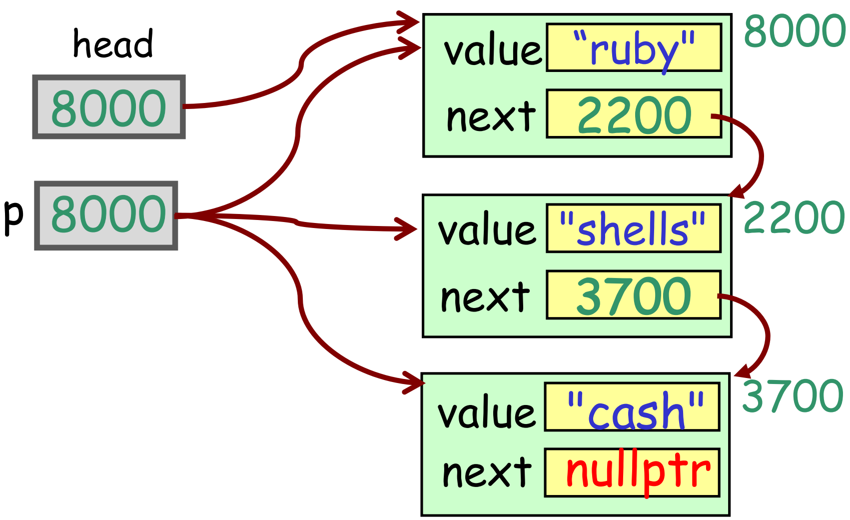
We want to stop looping when p points at this node

```
struct Node
{
    string  value;
    Node   *next;
};
class LinkedList
{
public:
    void addToRear(string v)
    {
       if (head == nullptr)
          addToFront(v); // easy!!!
       else
       {
         Node *p;
         p = head; // start at top node
         while( p->next != nullptr )
            p = p->next;

          Allocate a new node
          Put value v in the node
          Link the current last node
          to our new node
          Link the last node to nullptr
       }
    }
    ...
};
```

Adding an Item to the Rear

OK, let's see the C++ code now!

Alright, let's finish up our function!




```
struct Node
{
    string  value;
    Node  *next;
};
class LinkedList
{
public:
    void addToRear(string v)
    {
        if (head == nullptr)
            addToFront(v); // easy!!!
        else
        {
            Node *p;
            p = head; // start at top node
            while( p->next != nullptr )
                p = p->next;

            Allocate a new node
            Put value v in the node
            Link the current last node
            to our new node
            Link the last node to nullptr
        }
    }
    ...
};
```

Adding an Item to the Rear

OK, let's see the C++ code now!

Alright, let's finish up our function!

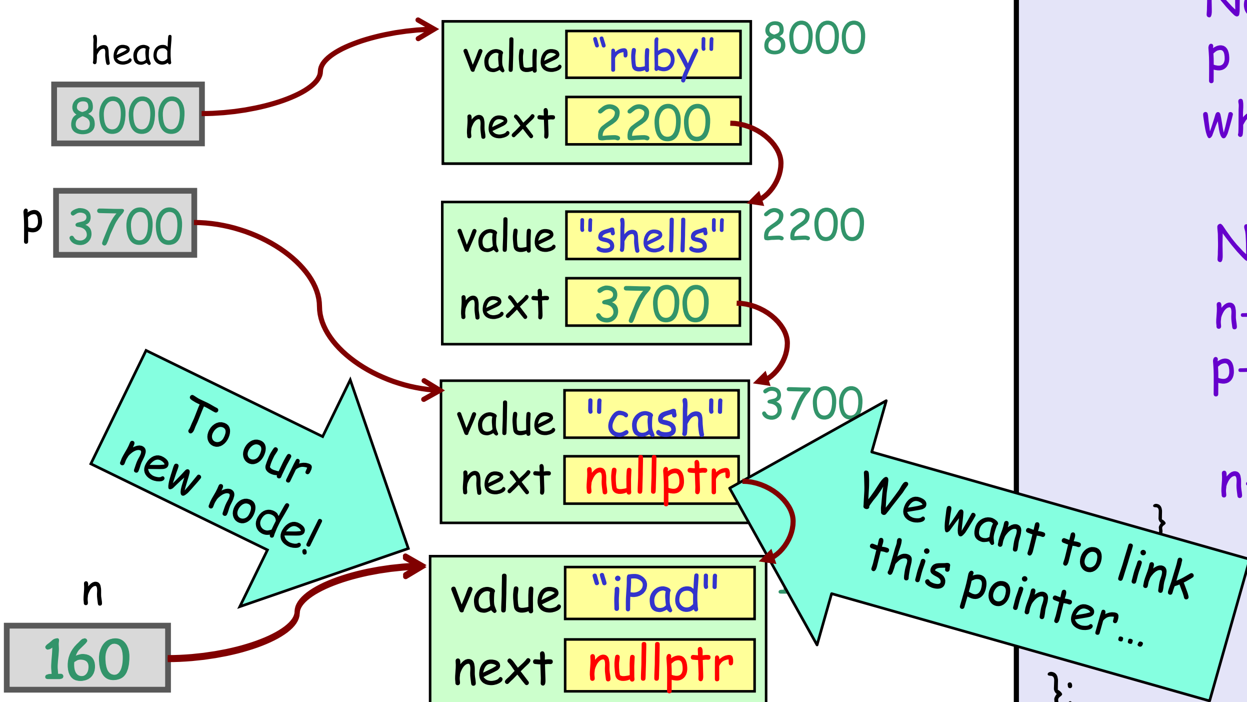
```
struct Node
{
    string  value;
    Node   *next;
};
```

When we use the condition:

while (p->next != nullptr) { … }

the loop continues until p points at the very last node of the list.

```
      front(v); // easy!!!
  else
  {
     Node
     p = head // start at top node
     while( p->next != nullptr )
        p = p->next;
     Node *n = new Node;
     n->value = v;
     p->next = n;

     n->next = nullptr;
  }
};
```



Not at the top, not at the bottom…

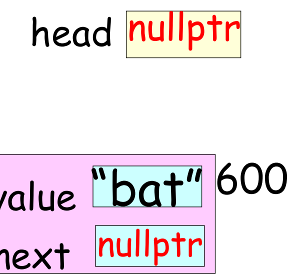
In some cases, we won't always want to just add our node to the top or bottom of the list… Why?

Well, what if we have to maintain an alphabetized linked list, or we want to allow the user to pick the spot to put each item?

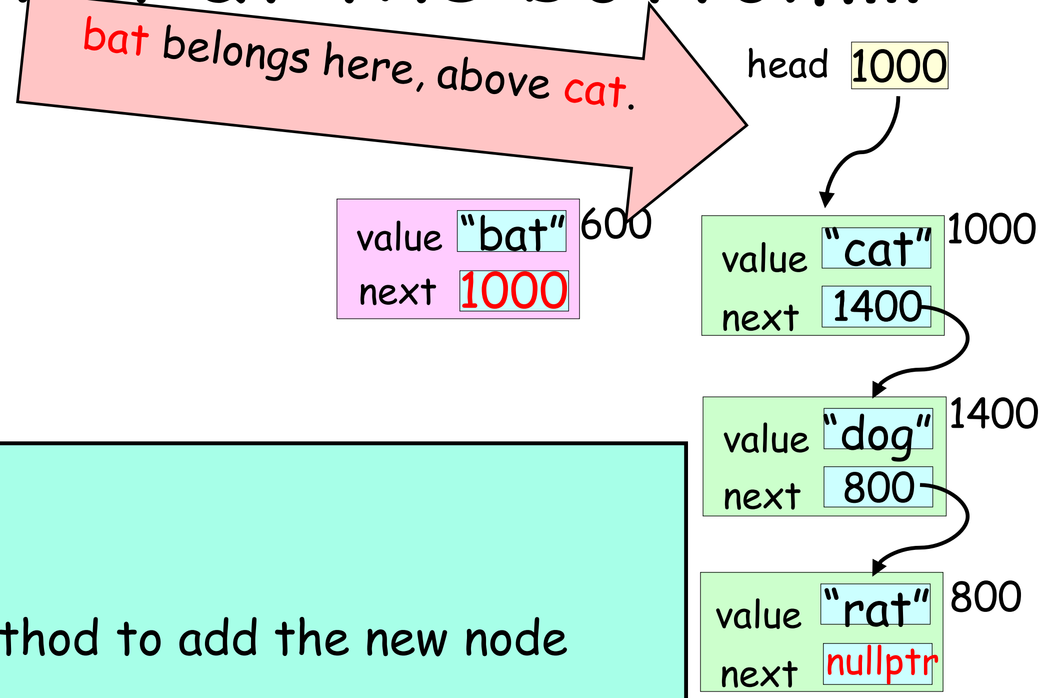
In these cases, we can't just add new items at the top or bottom…

Here's the basic algorithm:

```
void AddItem(string newItem)
{
    if (our list is totally empty)
        Just use our addToFront() method to add the new node

}
```



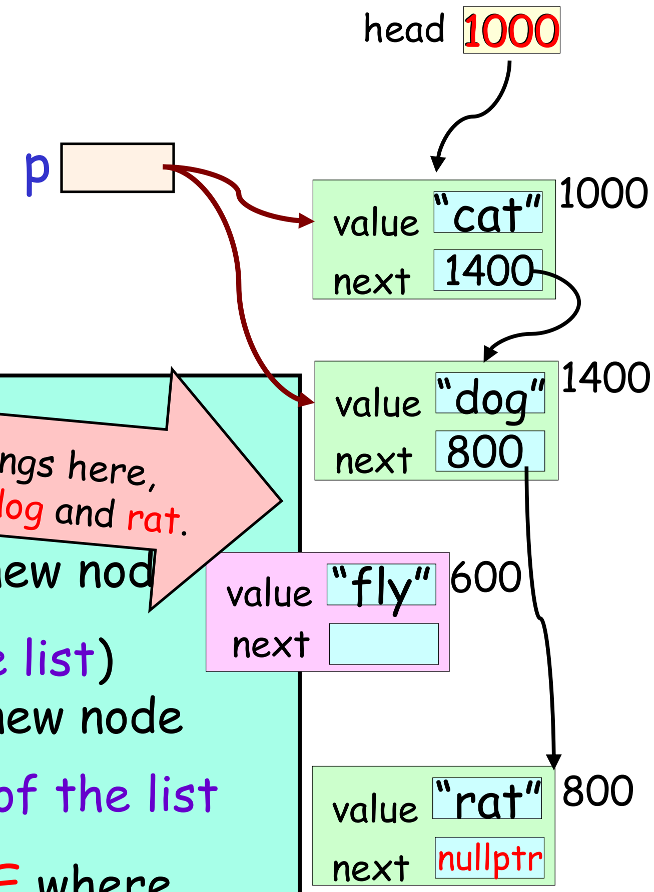
Not at the top, not at the bottom…



Here's the basic algorithm:

```
void AddItem(string newItem)
{
    if (our list is totally empty)
        Just use our addToFront() method to add the new node

    else if (our new node belongs at the very top of the list)
        Just use our addToFront() method to add the new node









}
```

Not at the top, not at the bottom…

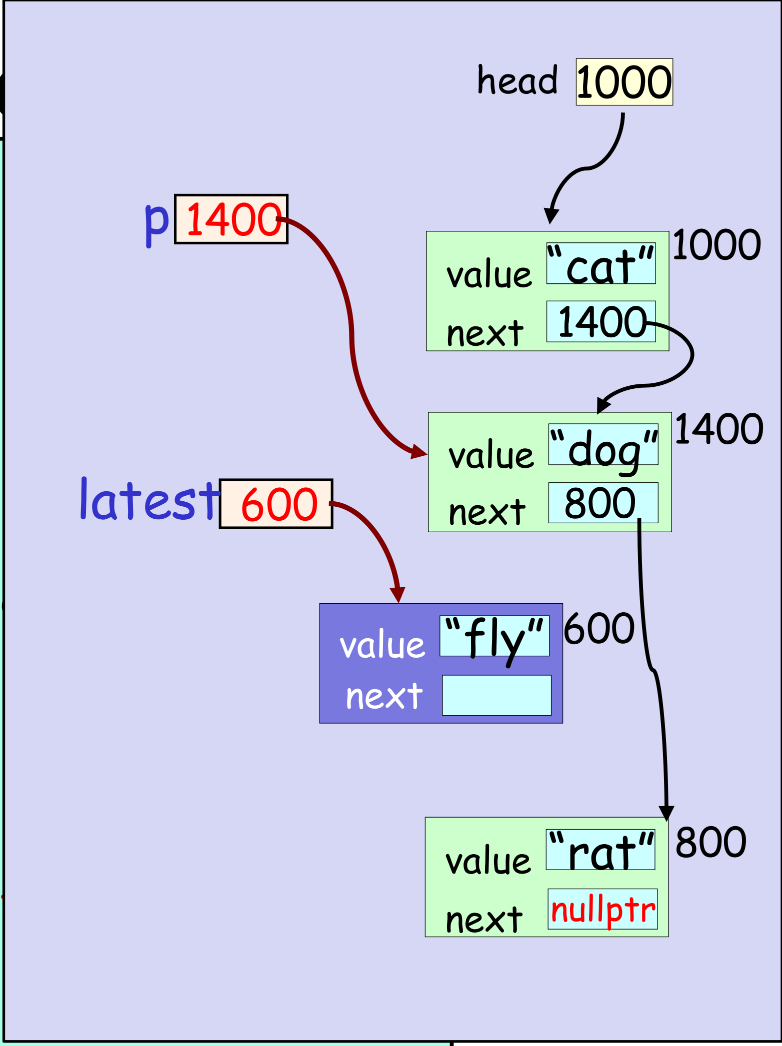


Here's the basic algorithm:

```
void AddItem(string newItem)
{
    if (our list is totally empty)
        Just use our addToFront() method to add the new nod

    else if (our new node belongs at the very top of the list)
        Just use our addToFront() method to add the new node

    else // new node belongs somewhere in the middle of the list
    {
        Use a traversal loop to find the node just ABOVE where
        you want to insert our new item

        Allocate and fill our new node with the item

        Link the new node into the list right after the ABOVE node
}   }
```

Let's Convert it t

```
void AddItem(string newItem)
{
   if (head == nullptr)
      AddToFront(newItem);

   else if ( /* decide if the new item belongs at the top */ )
      AddToFront(newItem);

   else // new node belongs somewhere in the mi
   {
      Node *p = head;   // start with top node
      while (p->next != nullptr)
      {
         if (/* p points just above where I want to in
               break;   // break out of the loop!

         p = p->next;     // move down one node
      }
      Node *latest = new Node;    // alloc and fill our new node
      latest->value = newItem;
      latest->next = p->next;   // link new node to the node below
      p->next =  latest;          // link node above to our new node
   }
}
```



These two lines **must** be in this order!

Let's Convert i

Finally, let's fill in the blanks to convert our function into one that adds items in alphabetical order!

```
void AddItem(string newItem)
{
   if (head == nullptr)
      AddToFront(newItem);

   else if (  newItem < head->value )
      AddToFront(newItem);

   else // new node belongs somewhere in the middle of the list
   {
      Node *p = head;   // start with first node
      while (p->next != nullptr)
      {
         if ( newItem >= p->value && newItem <= p->next->value  )
            break;

         p = p->next;     // move down one node
      }
      Node *latest = new Node;     // alloc and fill our new node
      latest->value = newItem;
      latest->next = p->next;   // link new node to node below
      p->next = latest;         // link above node to our new node
   }
}
```

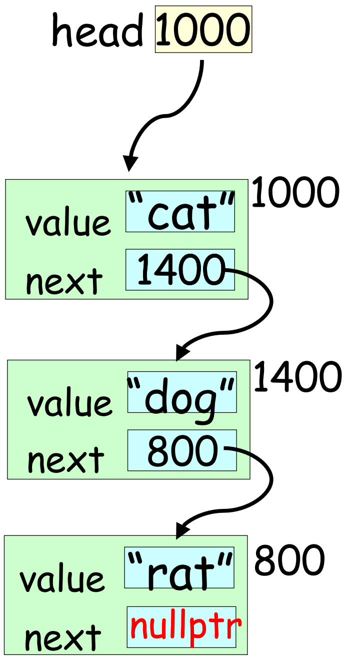
Deleting an Item in a Linked List

When deleting an item from a linked list, there are two different cases to consider:

Case #1: You're deleting the first node.

Case #2: You're deleting an interior node or the last node.

Let's consider Case #1 first…

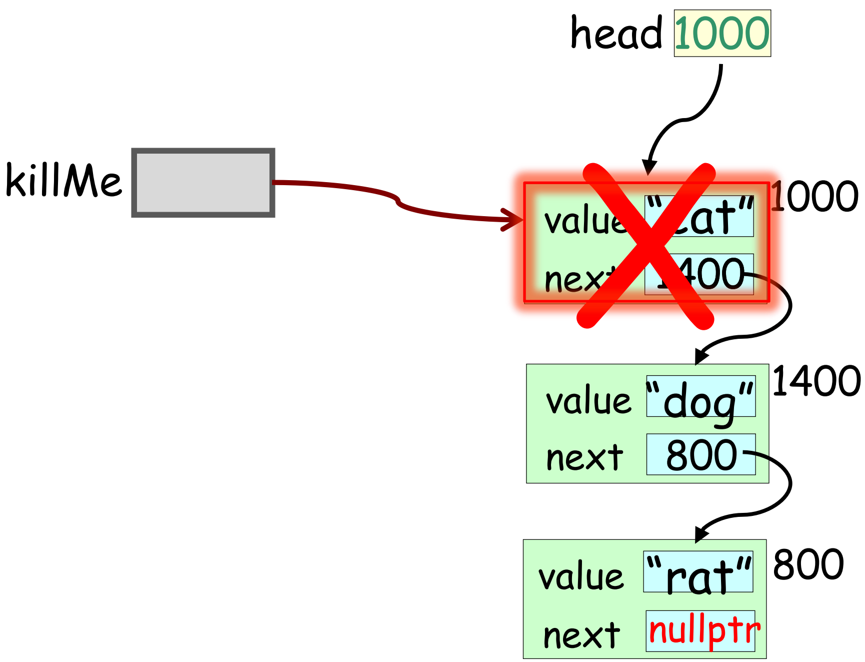



```
struct Node
{
    string  value;
    Node   *next;
};

class LinkedList
{
public:
    void deleteItem(string v)
    {

    }
    ...
};
```

Deleting an Item in a Linked List

Ok, let's consider Case #1…
deleting the top item in a list.

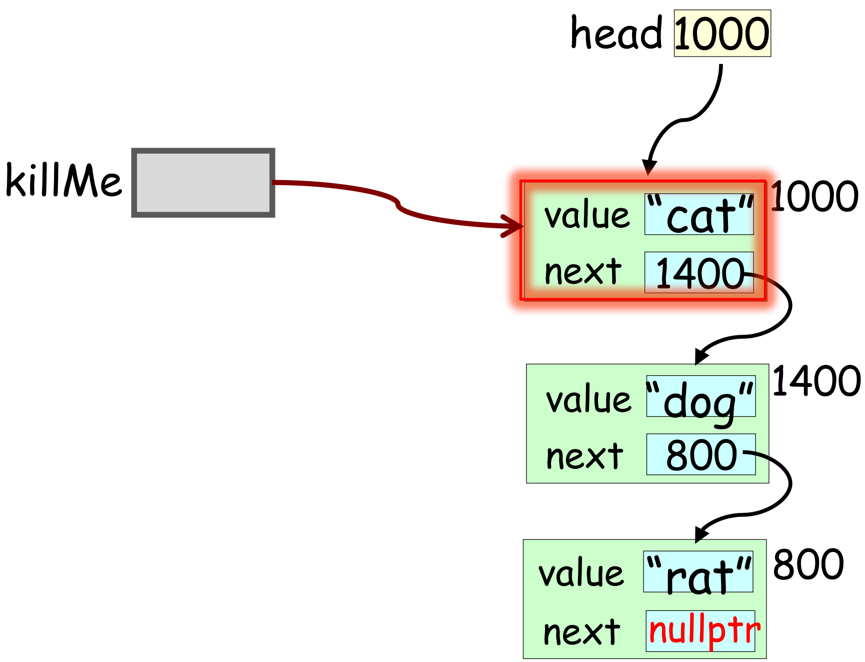
Let's kill our cat.




```
struct Node
{
    string  value;
    Node   *next;
};
class LinkedList
{
public:
   void deleteItem(string v)
   {
     If the list's empty then return
     If the first node holds the
      item we wish to delete then
      {
       killMe = address of top node
       Update head to point to the
       second node in the list
       Delete our target node
       Return – we're done
      }

   }
   …
};
```

Deleting an Item in a Linked List

OK, let's see the C++ code now!

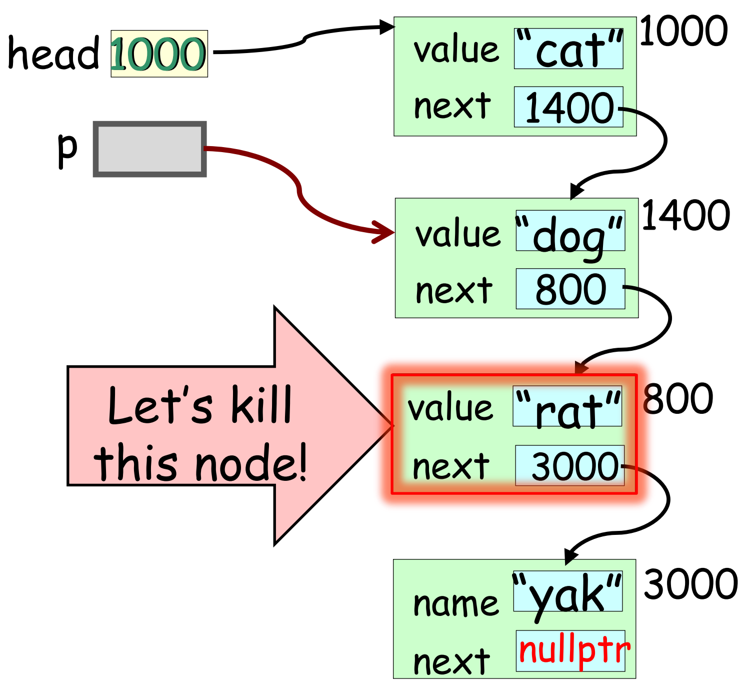



```
struct Node
{
    string  value;
    Node   *next;
};
class LinkedList
{
public:                              "cat"
   void deleteItem(string v)
   {
     if (head == nullptr) return;

     if (head->value == v)

       Node *killMe = head;

       head = killMe->next;

       delete killMe;

       return;



   }
   ...
};
```

Deleting an Item in a Linked List

Alright, let's consider Case #2 next – unfortunately it's more complex…

Let's kill our "rat" node!

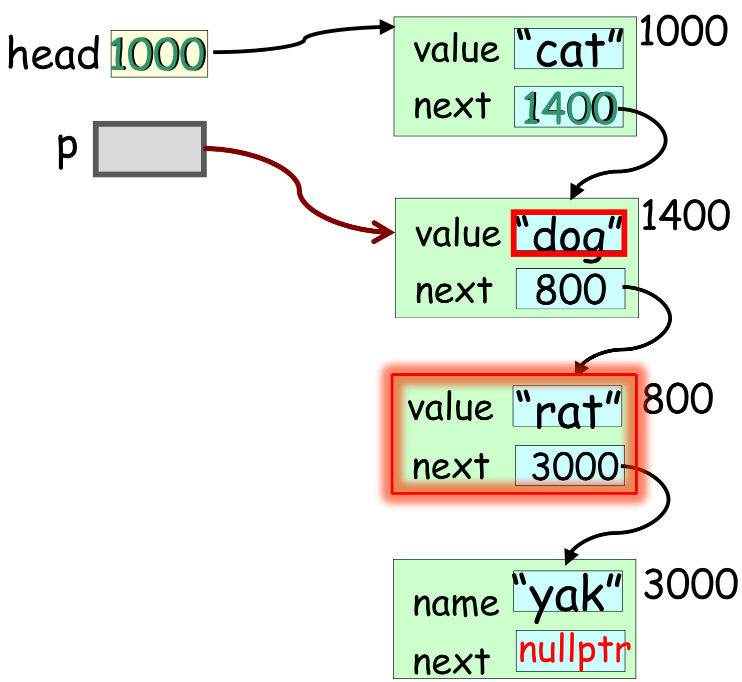



```
struct Node
{
    string  value;
    Node   *next;
};
```

```
class LinkedList
{
public:
                                   "rat"
   void deleteItem(string v)
   {
     … // the code we just wrote
     Use a temp pointer to traverse
     down to the node above the
     one we want to delete…

     If we found our target node
     {
       killMe = addr of target node
       Link the node above to
       the node below
       Delete our target node
     }
   }
   …
};
```

Deleting an Item in a Linked List

OK, let's see the C++ code now!

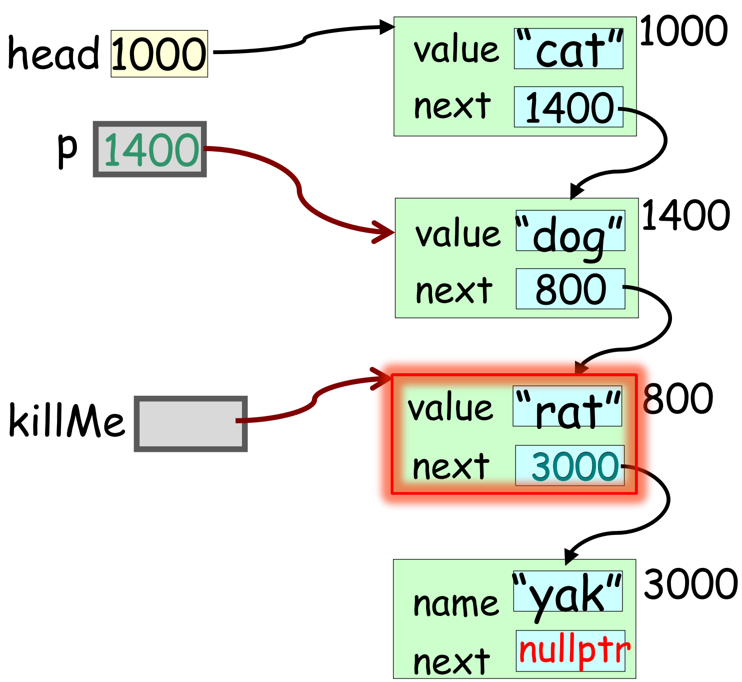



```
struct Node
{
    string  value;
    Node   *next;
};
class LinkedList
{
public:                                "rat"
   void deleteItem(string v)
   {
     ... // the code we just wrote
     Node *p = head;
     while (p != nullptr)
     {
        if ( p->next != nullptr   &&
             p->next->value == v )
           break;  // p pts to node above
        p = p->next;
     }
     If we found our target node
     {
        killMe = addr of target node
        Link the node above to
        the node below
        Delete our target node
     }
   }
   ...
};
```

Deleting an Item in a Linked List

OK, let's see the C++ code now!

And believe it or not, this same code works when the target node is the last one in the list!




```
struct Node
{
    string  value;
    Node   *next;
};

class LinkedList
{
public:
                                  "rat"
   void deleteItem(string v)
   {
     ... // the code we just wrote
     Node *p = head;
     while (p != nullptr)
     {
        if ( p->next != nullptr   &&
             p->next->value == v )
           break;  // p pts to node above
        p = p->next;
     }
     if (p != nullptr) // found our value!
     {
        Node *killMe = p->next;

        p->next =  killMe->next;

        delete killMe;

     }
   ...

};
```

Linked List Challenge

Now it's your turn!

How would you write the findItem() method?

It should return true if it can find the passed-in item, and false otherwise.

```
int main()
{
    Linked List myFriends;

    myFriends.addToFront("David");
    …

    if (myFriends.findItem("Carey") == true)
        cout << "I'm so lucky!\n";
}
```

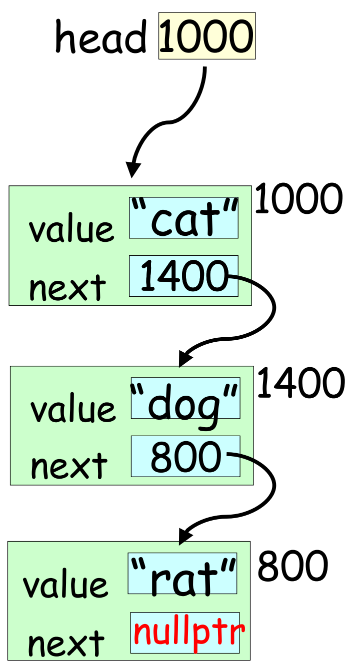
```
struct Node
{
    string  value;
    Node   *next;
};

class LinkedList
{
public:
    bool findItem(string v)
    {



    }
    …



private:
  Node *head;
};
```

Destructing a Linked List

OK, so how do we completely destruct a linked list once we're done with it?

Well, perhaps we can use something like our existing printItems() code?

Let's see what happens!



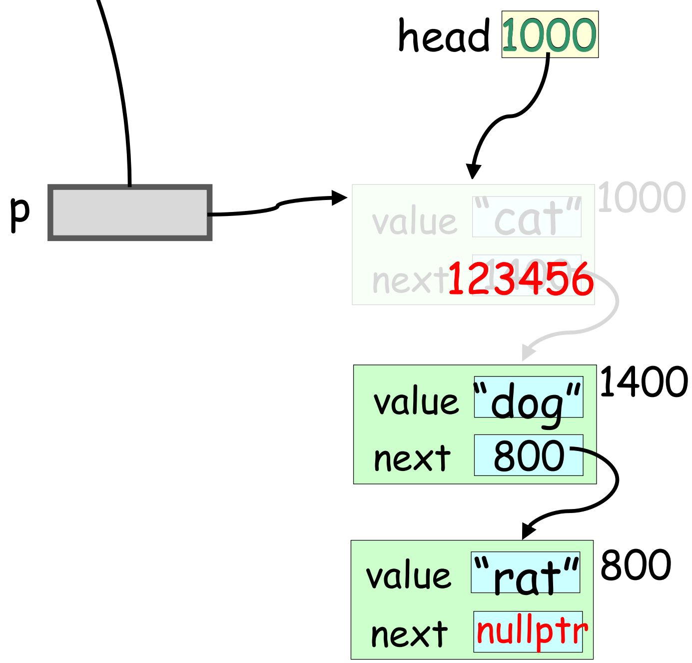

```
struct Node
{
    string  value;
    Node   *next;
};

class LinkedList
{
public:
    ~LinkedList()
    {
        Node *p;
        p = head;
        while (p != nullptr)
        {
            delete p;
            p = p->next;
        }
    }
    ...

private:
  Node *head;
};
```

a Linked List

e completely destruct a
e we're done with it?

Well, perhaps we can use something like our existing printItems() code?

Let's see what happens!

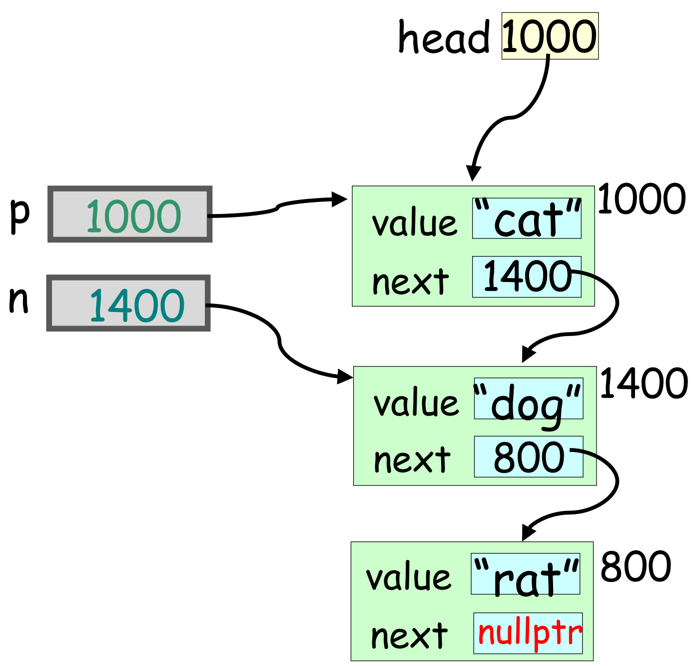



```
struct Node
{
    string  value;
    Node   *next;
};
class LinkedList
{
public:
   ~LinkedLis
   {
      Node *p
      p = head;
      while (p !=        ptr)
      {
         delete p;
         p = p->next;
      }
   }
   ...

  Node *head;
};
```

Houston… We have a problem!

Destructing a Linked List

OK, let's fix it.




```
struct Node
{
    string  value;
    Node   *next;
};
class LinkedList
{
public:
    ~LinkedList()
    {
        Node *p;
        p = head;
        while (p != nullptr)
        {
            Node *n = p->next;
            delete p;
        }   p = n;
    }
    ...

private:
  Node *head;
};
```

Linked Lists Aren't Perfect!

As you can already tell, linked lists aren't perfect either!

First of all, they're much more complex than arrays!!!

Second, to access the k^{th} item, I have to traverse down k-1 times from the head first! No instant access!!!

And to add an item at the end of the list… I have to traverse through all N existing nodes first!

Well, as it turns out, we can fix this last problem… Let's see how!

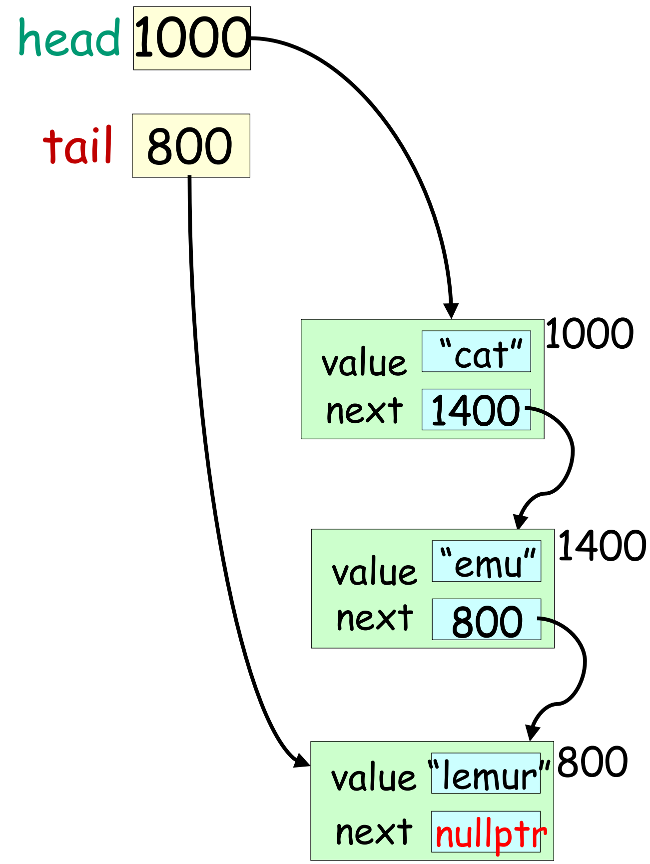
Linked Lists and Tail Pointers

Since we have a head pointer…

Why not maintain a "tail" pointer too?

A tail pointer is a pointer that always points to the last node of the list!

```
class LinkedList
{
public:
   LinkedList() {…}
   void addToFront(string v) {…}
   …

private:
  Node  *head;
  Node  *tail;
};
```

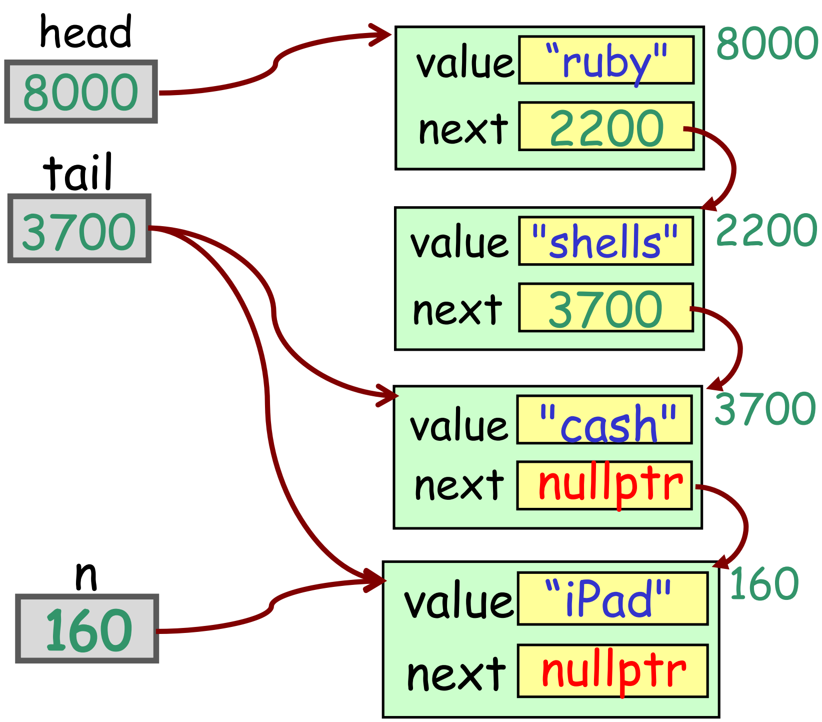


Using the tail pointer, we can add new items to the end of our list without traversing!

Adding an Item to the Rear… With a Tail Pointer

Let's see how to update our addToRear() function once our class has a tail pointer.

WARNING: You have to update all of your other methods to use the tail pointer (e.g., constructor, addToFront()) as well!




```
class LinkedList
{
public:
   void addToRear(string v)
   {
      if (head == nullptr)
         addToFront(v);
      else
      {
         Node *n = new Node;
         n->value = v;
         tail->next = n;
         n->next = nullptr;
         tail = n;
      }
   }
   ...
private:
   Node *head;
   Node *tail;
};
```

Doubly-linked Lists

One of the downsides with our simple linked list is that we can only travel in one direction... down!

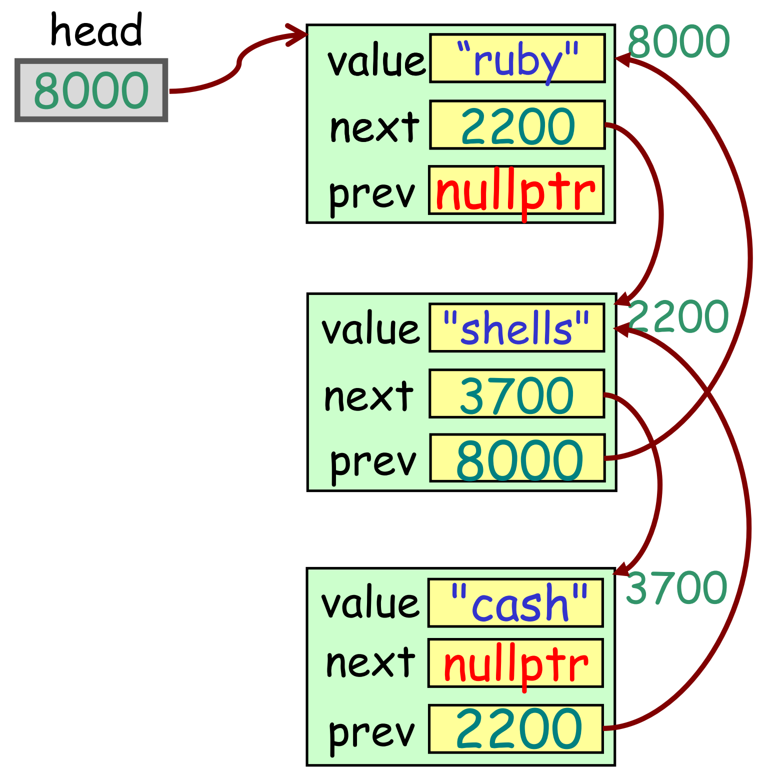
Given a pointer to a node, I can only find nodes below it!

Wouldn't it be nice if we could move both directions in a linked list?

We can! With a doubly-linked list!

A doubly-linked list has both *next* and *previous* pointers in every node:

```
struct Node
{
    string   value;

    Node *   next;
    Node *   prev;
};
```



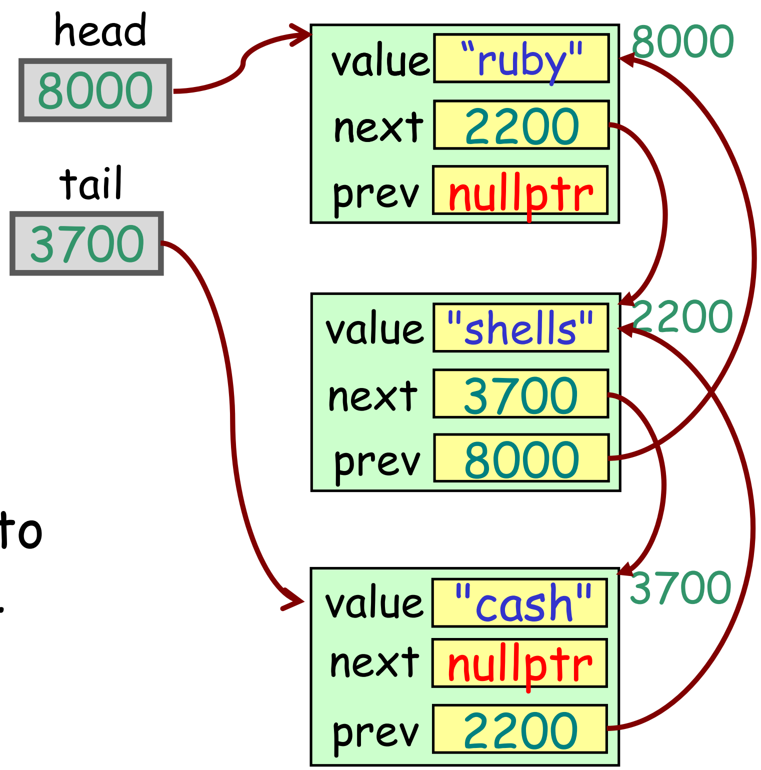
Doubly-linked Lists

And, if I like, I can have a tail pointer too!

Now I can traverse in both directions!

```
Node *p;

p = head;
while (p != nullptr)
{
    cout << p->value;
    p = p->next;
}
```

```
Node *p;

p = tail;
while (p != nullptr)
{
    cout << p->value;
    p = p->prev;
}
```



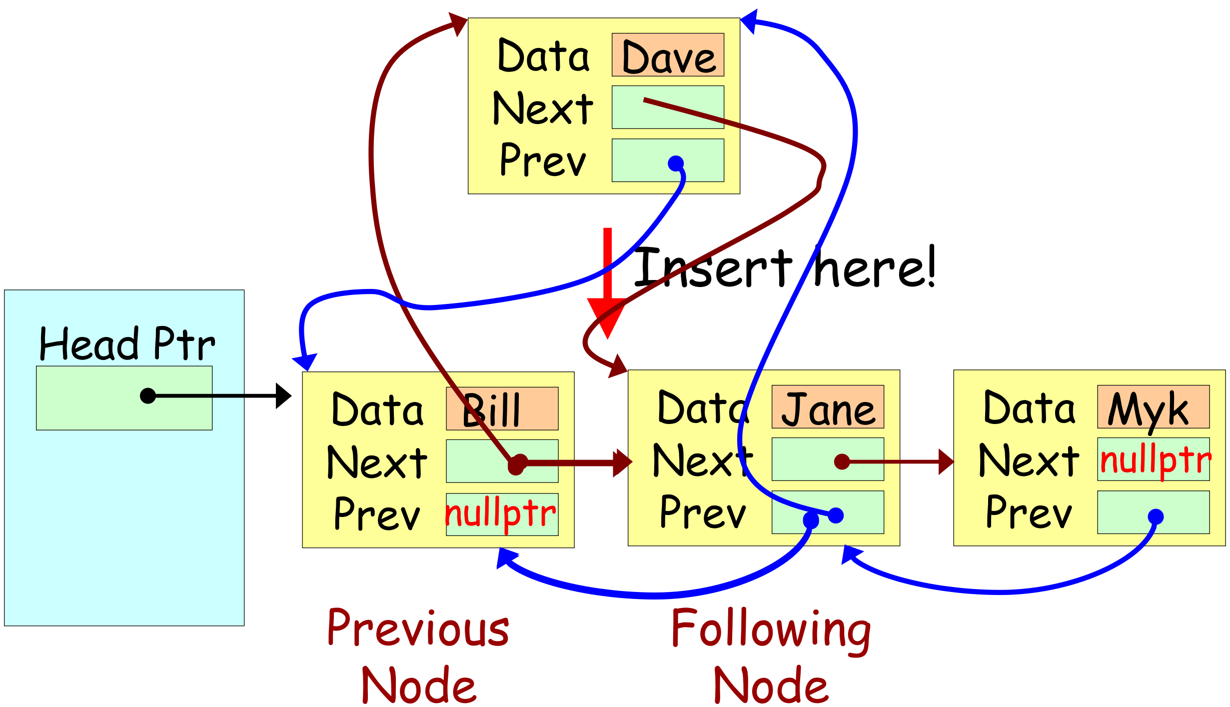
Of course, now we're going to have to link up lots of additional pointers…

But nothing comes free in life! ☺

Doubly-linked Lists: What Changes?

Every time we insert a new node or delete an existing node, we must update *three* sets of pointers:

1. The new node's next and previous pointers.
2. The previous node's next pointer.
3. The following node's previous pointer.



And of course, we still have special cases if we insert or delete nodes at the top or the bottom of the list.

Linked List Cheat Sheet

```
struct Node
{
    string value;

    Node *next;
    Node  *prev;
};
```

Given a pointer to a node: Node *ptr;

NEVER access a node's data until validating its pointer:

```
if (ptr != nullptr)
    cout << ptr->value;
```

To advance ptr to the next node/end of the list:

```
if (ptr != nullptr)
    ptr = ptr->next;
```

To see if ptr points to the last node in a list:

```
if (ptr != nullptr && ptr->next == nullptr)
    then-ptr-points-to-last-node;
```

To get to the next node's data:

```
if (ptr != nullptr && ptr->next != nullptr)
    cout << ptr->next->value;
```

To get the head node's data:

```
if (head != nullptr)
    cout << head->value;
```

To check if a list is empty:

```
if (head == nullptr)
    cout << "List is empty";
```

Does our traversal meet this requirement?

```
NODE *ptr = head;
while (ptr != nullptr)
{
   cout << ptr->value;
   ptr = ptr->next;
}
```

To check if a pointer points to the first node in a list:

```
if (ptr == head)
    cout << "ptr is first node";
```

Linked Lists vs. Arrays

Which is Faster?

Getting to the 753rd item in a linked list or an array?

Which is Faster?

Inserting a new item at the front of a linked list or at the front of an array?

Which is faster?

Removing an item from the middle of a linked list or the middle of an array?

Which is easier to program?

Which data structure will take less time to program and debug?

Class Challenge

Write a function called insert that accepts two NODE pointers as arguments:

b4node: points to a node in a doubly-linked list
newnode: points to a new node you want to insert

When your function is called, it should insert newnode *after* b4node in the list, properly linking all nodes.

(You may assume that a valid node follows b4node prior to insertion.)

```
struct NODE
{
  string data;
  NODE *next, *prev;
};
```