Linked Lists

Unit 5

Sections 11.9 & 18.1-2

CS 2308
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11.9: Pointers to Structures

- Given the following Structure:

```
struct Student {
   string name;       // Student's name
   int idNum;         // Student ID number
   int creditHours;   // Credit hours enrolled
   float gpa;         // Current GPA
};
```

- We can define a pointer to a structure

```
Student s1 = {"Jane Doe", 12345, 15, 3.3};
Student *studentPtr;
studentPtr = &s1;
```

- Now studentPtr points to the s1 structure.

Pointers to Structures

- How to access a member through the pointer?

```
Student s1 = {"Jane Doe", 12345, 15, 3.3};
Student *studentPtr;
studentPtr = &s1;

cout << *studentPtr.name << end;          // ERROR
```

- dot operator has higher precedence than the dereferencing operator, so:

studentPtr is not a structure!

`*studentPtr.name` is equivalent to `*(studentPtr.name)`

- You must dereference the pointer first:

```
cout << (*studentPtr).name << end;       // WORKS
```


structure pointer operator: ->

- Due to the awkwardness of the pointer notation, C provides an operator for dereferencing structure pointers:

`studentPtr->name` is equivalent to `(*studentPtr).name`

- The **structure pointer operator** is the hyphen (-) followed by the greater than (>), like an arrow.
- In summary:

```
s1.name     // a member of structure s1

sptr->name  // a member of the structure sptr points to
```

Structure Pointer: example

- Function to input a student, using a ptr to struct

```
void inputStudent(Student *s) {
   cout << "Enter Student name: ";
   getline(cin,s->name);

   cout << "Enter studentID: ";
   cin >> s->idNum;

   cout << "Enter credit hours: ";
   cin >> s->creditHours;

   cout << "Enter GPA: ";
   cin >> s->gpa;
}
```

Or you could use a reference parameter. I'm using a pointer to give an example of using the -> syntax.

- Call:

```
Student s1;
inputStudent(&s1);
cout << s1.name << endl;
...
```


Dynamically Allocating Structures

- Structures can be dynamically allocated with new:

```
Student *sptr;
sptr = new Student;

sptr->name = "Jane Doe";
sptr->idNum = 12345;
...
delete sptr;
```

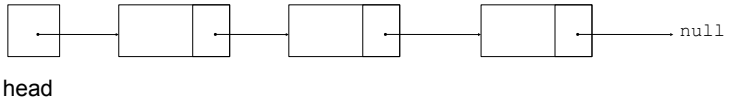
- Arrays of structures can also be dynamically allocated:

```
Student *sptr;
sptr = new Student[100];
sptr[0].name = "John Deer";
...
delete [] sptr;
```

If a pointer points to an array, you can use square brackets with it, as if it were an array. Do not use -> here.

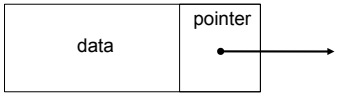
18.1 Introduction to Linked Lists

- A data structure representing a list
- A series of **dynamically allocated** nodes chained together in sequence
  - Each node points to one other node.
- A separate pointer (the head) points to the first item in the list.
- The last element points to null (address 0)



Node Organization

- Each node contains:
  - data members – contain the elements' values.
  - a pointer – that can point to another node



- We use a struct to define the node type:

```
struct ListNode {
   double value;
   ListNode *next;
};
```

- `next` can hold the address of a `ListNode`.
  - it can also be null

Using `nullptr` (or `NULL`)

- Equivalent to address 0
- Used to specify end of the list
- Before C++11 you must use `NULL`
- `NULL` is defined in the cstddef header.
- to test a pointer p for null, these are equivalent:

```
while (p != nullptr) ...  <==>  while (p) ...

if (p == nullptr) ...  <==>  if (!p) ...
```

- Note: Do NOT dereference nullptr!

```
ListNode *p = nullptr;
cout << p->value;    //crash! null pointer exception
```


Linked Lists: Tasks

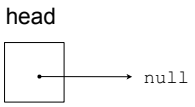
We will implement the following tasks on a linked list:

T1: Create an empty list
T2: Create a new node
T3: Add a new node to front of list (given newNode)
T4: Traverse the list (and output)
T5: Find the last node (of a non-empty list)
T6: Find the node containing a certain value
T7: Find a node AND it's previous neighbor.
T8: Append to the end of a non-empty list
T9: Delete the first node
T10: Delete an element, given p and n
T11: Insert a new element, given p and n

T1:Create an empty list

- let's make the empty list

```
struct ListNode      // the node data type
{
   double value;     // data
   ListNode *next;   // ptr to next node
};

int main() {

   ListNode *head = nullptr;      // the empty list

}
```

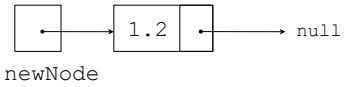


T2:Create a new node:

- let's make a new node:

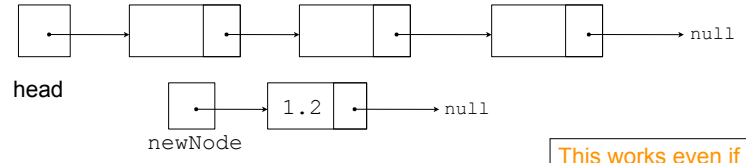
```
ListNode *newNode = new ListNode;
newNode->value = 1.2;
newNode->next = nullptr;
```

- It's not attached to the list yet.



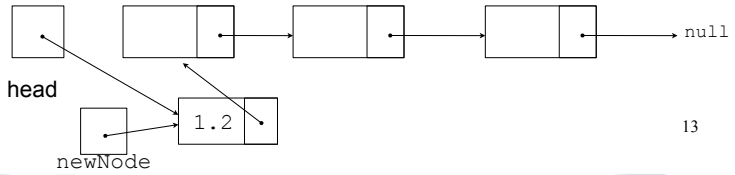
T3:Add new node to front of list:

- make newNode's next point to the first element.
- then make head point to newNode.




```
newNode->next = head;
head = newNode;
```

This works even if head is null, try it.



T4:Traverse the list
(and output all the elements)

- let's output a list of two elements:

```
cout << head->value << " " << head->next->value << endl;
```

- now using a temporary pointer to point to each node:

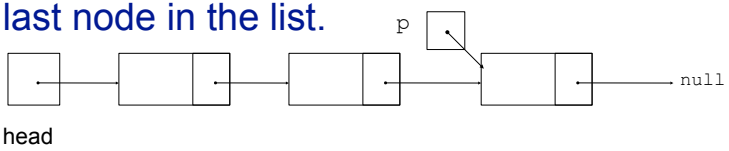
```
ListNode *p;    //temporary pointer (don't use head for this)
p = head;       //p points to the first node
cout << p->value << " ";
p = p->next;    //makes p point to the 2nd node (draw it!)
cout << p->value << endl;
p = p->next;    //what does p point to now?
```

- now let's rewrite that as a loop:

```
ListNode *p;    //temporary pointer (don't use head for this)
p = head;       //p points to the first node

while (p != nullptr) {
  cout << p->value << " ";
  p = p->next;    //makes p point to the next node
}
```


T5:Find the last node
(of a non-empty list)

- Goal: make a temporary pointer, p, point to the last node in the list.

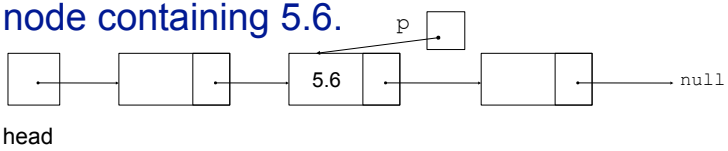


- Make p point to the first node. Then:
  - do p=p->next until p points to the last node.
  - in the last node, next is null.
  - so stop when p->next is null.

```
ListNode *p=head;       //p points to what head points to

while (p->next!=nullptr) {
  p = p->next;          //makes p point to the next node
}
```


T6:Find the node containing a certain value

- Goal: make a temporary pointer, p, point to the node containing 5.6.

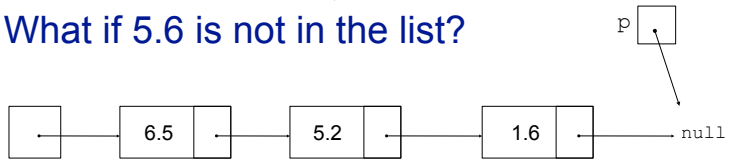


- Make p point to the first node. Then:
  - do p=p->next until p points to the node with 5.6.
  - so stop when p->value is 5.6.

```
ListNode *p=head;       //p points to what head points to

while (p->value!=5.6) {
  p = p->next;          //makes p point to the next node
}
```

Find the node containing a certain value, continued

- What if 5.6 is not in the list?

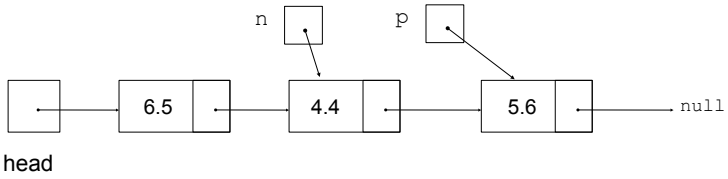


- If 5.6 is not in the list, the loop will not stop. p will eventually be null, and evaluating p->value in the condition will crash.
- So let's make the loop stop if p becomes null.

```
ListNode *p=head;       //p points to what head points to

while (p!=nullptr && p->value!=5.6) {
  p = p->next;          //makes p point to the next node
}
```


T7:Find a node AND it's previous neighbor.

- sometimes we need to track the current **and** the previous node:



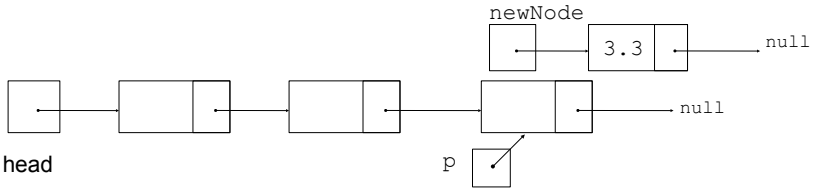

```
ListNode *p = head;      //current node, set to first node
ListNode *n = nullptr;   //previous node, none yet
while (p!=nullptr && p->value!=5.6) {
  n = p;          //save current node address
  p = p->next;    //advance current node to next one
}
```


T8:Append to the end of a non-empty list

- Create a new node, and find the last node:

```
ListNode *newNode = new ListNode;
newNode->value = 3.3;
newNode->next = nullptr;

ListNode *p=head;
while (p->next!=nullptr) {
  p = p->next;
}
```

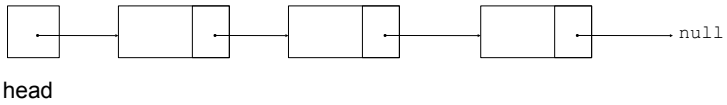
We've done this already.



- Now make the last node's next point to newNode.

```
p->next = newNode;
```


T9:Delete the first node of a non-empty list

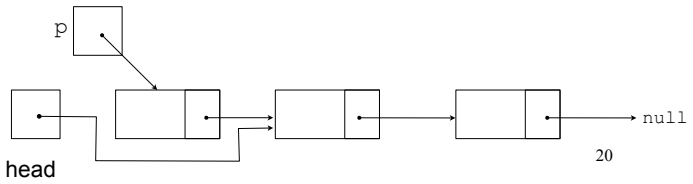


- delete the first element of a non-empty list

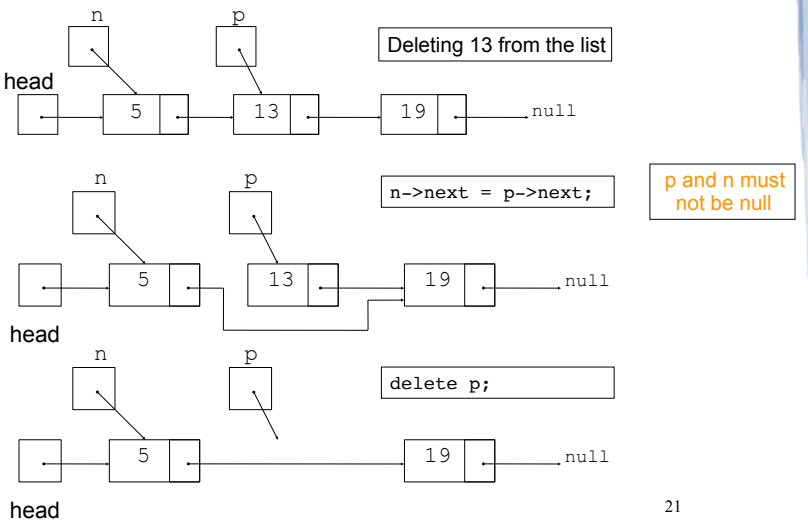
```
head = head->next;
```

- what about deallocating the first node? Oops.

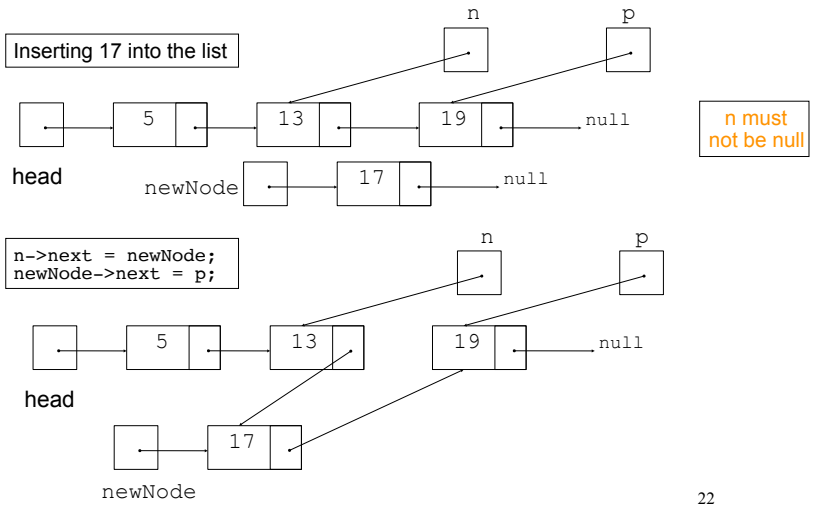
```
ListNode *p = head;
head = head->next;
delete p;
```



T10: Delete an element, given p and n



T11:Insert a new element, given p and n



18.2 List operations

- Consider a list as a sequence of items (regardless of implementation details)
- *Some* basic operations over a list:
  - **create** a new, empty list
  - **append** a value to the end of the list
  - **display** the values in the list
  - **isEmpty** check if the list has any elements in it
  - **insert** a value within the list
  - **delete** a value (remove it from the list)
  - **delete/destroy** the list (if dynamically allocated)

Declaring the List data type

- We will be defining a class called NumberList to represent a List data type.
  - ours will store values of type double, using a linked list.
- The class will implement the basic operations over lists on the previous slide.
- In the private section of the class we will:
  - define a struct data type for the nodes
  - define a pointer variable (head) that points to the first node in the list.

NumberList class declaration

NumberList.h

```
class NumberList
{
   private:
      struct ListNode      // the node data type
      {
         double value;     // data
         ListNode *next;   // ptr to next node
      };
      ListNode *head;      // the list head

   public:
      NumberList();        // creates an empty list
      ~NumberList();

      bool isEmpty();
      void appendNode(double);
      void displayList();
      void deleteNode(double);
      void insertBefore(double, double);
};
```


Operation: **Create** the empty list

- Constructor: sets up empty list (This is T1, create an empty list).

NumberList.cpp

```
#include "NumberList.h"


NumberList::NumberList()
{
   head = nullptr;
}
```


Operation: **isEmpty** test for the empty list

- Test to see if the list has any elements in it.

NumberList.cpp

```
bool NumberList::isEmpty() {

    return (head==nullptr);
}
```


Operation: **append** node to end of list

- appendNode: adds new node to end of list
- Algorithm:

Create a new node (T2)
If the list is empty,
  Make head point to the new node. (T3)
Else (T8)
  Find the last node in the list
  Make the last node point to the new node

in NumberList.cpp

```
void NumberList::appendNode(double num) {

   // Create a new node and store the data in it (T2)
   ListNode *newNode = new ListNode;
   newNode->value = num;
   newNode->next = nullptr;

   // If empty, make head point to new node (T3)
   if (head==nullptr)
      head = newNode;

   else {
      // Append to end of non-empty list (T8)
      ListNode *p = head;  // p points to first element

      // traverse list to find last node
      while (p->next)          //it's not last
         p = p->next;          //make it pt to next

      // now p pts to last node
      // make last node point to newNode
      p->next = newNode;
   }
}
```


Driver to demo NumberList

- ListDriver.cpp version 1 (no output)

ListDriver.cpp

```
#include "NumberList.h"

int main() {

   // Define the list
   NumberList list;

   // Append some values to the list
   list.appendNode(2.5);
   list.appendNode(7.9);
   list.appendNode(12.6);

}
```


Traversing a Linked List

- Visit each node in a linked list, to
  - display contents, sum data, test data, etc.
- Basic process (this is T4):

set a pointer to point to what head points to
while the pointer is not null
  process data of current node
  go to the next node by setting the pointer to
    the next field of the current node
end while

Operation: **display** the list

in NumberList.cpp

```
void NumberList::displayList() {

   ListNode *p = head;  //start p at the head of the list

   // while p pts to something (not null), continue
   while (p)   //or while (p!=nullptr)
   {
      //Display the value in the current node
      cout << p->value << " ";

      //Move to the next node
      p = p->next;
   }
   cout << endl;
}
```

Driver to demo NumberList

- ListDriver.cpp version 2

ListDriver.cpp

```
#include "NumberList.h"

int main() {

   // Define the list
   NumberList list;

   // Append some values to the list
   list.appendNode(2.5);
   list.appendNode(7.9);
   list.appendNode(12.6);

   // Display the values in the list.
   list.displayList();
}
```

Output:
2.5 7.9 12.6

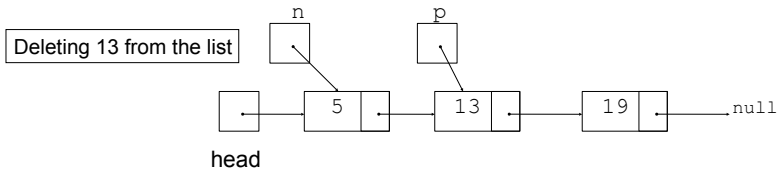
Operation: destroy a List

- The destructor must "delete" (deallocate) all nodes used in the list
- Repeatedly remove the first node, until empty

```
NumberList::~NumberList() {

    ListNode *p;
    while (!isEmpty()) {
        // remove the first node
        p = head;
        head = head->next;
        delete p;
    }

}
```

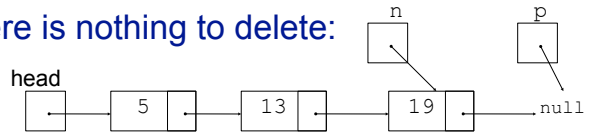

Operation: **delete** a node from the list

- deleteNode: removes node from list, and deletes (deallocates) the removed node.
- This is T7 and T10:
  - T7: Find a node AND it's previous neighbor (p&n)
  - then do T10: Delete an element, given p and n

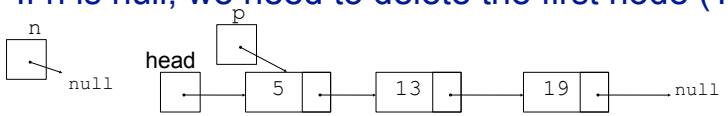


delete: what if p or n are null?

- If p is null, there is nothing to delete:



- If n is null, we need to delete the first node (T9):



- Delete, accounting for p or n being null:

```
if (p!=nullptr) {
  if (n==nullptr)       // delete the first node
     head = head->next;
  else                  // p and n are not null
     n->next = p->next;
  delete p;             // since p wasn't null, deallocate
}          //there is no else, if p was null, nothing to remove
```

deleteNode code

in NumberList.cpp

```
void NumberList::deleteNode(double num) {

    ListNode *p = head;     // to traverse the list
    ListNode *n = nullptr; // trailing node pointer

    // skip nodes not equal to num, stop at last
    while (p && p->value!=num) {
       n = p;          // save it!
       p = p->next;   // advance it
    }

    // p not null: num was found, set links + delete
    if (p) {
        if (n==nullptr) { // p points to the first elem
            head = p->next;
            delete p;
        } else {          // n points to the predecessor
            n->next = p->next;
            delete p;
       }
    }
```


Driver to demo NumberList

in ListDriver.cpp

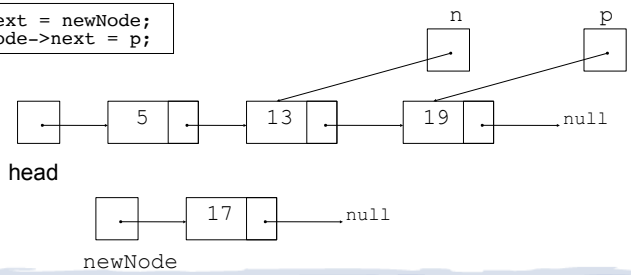
```
// set up the list
NumberList list;
list.appendNode(2.5);
list.appendNode(7.9);
list.appendNode(12.6);
list.displayList();

cout << endl << "remove 7.9:" << endl;
list.deleteNode(7.9);
list.displayList();

cout << endl << "remove 8.9: " << endl;
list.deleteNode(8.9);
list.displayList();

cout << endl << "remove 2.5: " << endl;
list.deleteNode(2.5);
list.displayList();
```

```
Output:
2.5  7.9  12.6

remove 7.9:
2.5  12.6

remove 8.9:
2.5  12.6

remove 2.5:
12.6
```


Operation: **insert** a node into a linked list

- Inserts a new node into a list (any position).
- This is T7 and T11:
  - T7: Find a node AND it's previous neighbor (p&n) (we will make p point to the node containing 19)
  - then do T11: Insert a new element, given p and n

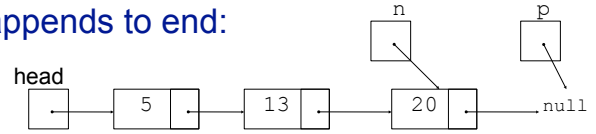
```
n->next = newNode;
newNode->next = p;
```



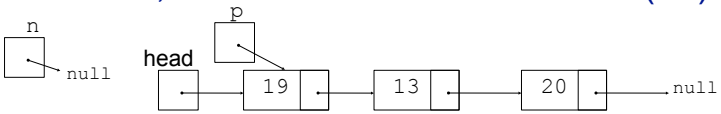
insert: what if p or n are null?

- If p is null, it appends to end:

```
n->next = newNode;
newNode->next = p;
```



- If n is null, we need to add node to front (T3):



- Insert, accounting for n being null:

```
if (n==nullptr) {      // p must be pointing to first node
   head = newNode;
   newNode->next = p;
} else  {              // n is not NULL
   n->next = newNode;
   newNode->next = p;
}
//if p is null, n is pointing to the last node, and it works.
```

insertBefore code

in NumberList.cpp

```
void NumberList::insertBefore(double num, double target) {
   //make new node
   ListNode *newNode = new ListNode;
   newNode->value = num;

   //set up pointers
   ListNode *p = head;
   ListNode *n = nullptr;

   //advance pointers through list to insertion point
   while (p && p->value != target) {
     n = p;         // save
     p = p->next;  // advance
   }

   if (n == nullptr) {      //insert before first
     head = newNode;
     newNode->next = p;
   }
   else {                   //insert after n, before p
     n->next = newNode;
     newNode->next = p;
   }
}
```


Driver to demo NumberList

in ListDriver.cpp

```
int main() {

   // set up the list
   NumberList list;
   list.appendNode(2.5);
   list.appendNode(7.9);
   list.appendNode(12.6);
   list.displayList();

   list.insertBefore (8.5,12.6);
   list.displayList();

   list.insertBefore (1.5,2.5);
   list.displayList();

   list.insertBefore (21.5,25.0);
   list.displayList();

}
```

```
Output:
2.5  7.9  12.6
2.5  7.9  8.5  12.6
1.5  2.5  7.9  8.5  12.6
1.5  2.5  7.9  8.5  12.6  21.5
```