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 nothing (NULL)

```
head
```

Node Organization

- Each node contains:
  - data field – may be a structure, an object, etc.
  - a pointer – that can point to another node

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

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

Defining the Linked List variable

- Define a pointer for the head of the list:
  ```
  ListNode *head = NULL;  //NULL specifies end of list
  ```
- Now we have an empty linked list:
  ```
  head
  ```
- NULL is equivalent to address 0
- to test a pointer for NULL (these are equivalent):
  ```
  while (p) ...  <=>  while (p != NULL) ...
  if (!p) ...  <=>  if (p == NULL) ...
  ```

```
Note: If you try to dereference a pointer whose value is NULL, you will get a runtime error. For example: head->next. Check before you do this.
```
Linked List operations

- **create** a new, empty list
- **append** a node to the end of the list
- **insert** a node within the list
- **delete** a node
- **display** the linked list
- **delete/destroy** the list

### Operation: `append` node to end of list

- **appendNode**: adds new node to end of list
- **Algorithm**:
  
  Create a new node and store the data in it
  
  If the list has no nodes (it’s empty)
  
  Make head point to the new node.
  
  Else
  
  Find the last node in the list
  
  Make the last node point to the new node

### Linked List class declaration

```cpp
#include <cstdlib> // for NULL
using namespace std;

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() = { head = NULL; } //create empty list
  ~NumberList();
  void appendNode(double);
  void insertNode(double);
  void deleteNode(double);
  void displayList();
};
```

### appendNode: find last elem

- How to find the last node in the list?
- **Algorithm**:

  Make a pointer p point to the first element
  
  while the node that p points to has a NEXT node
  
  make p point to that node (the NEXT node of
  
  the node p currently points to)

### In C++:

```cpp
ListNode *p = head;
while ((*p).next != NULL)  
  p = (*p).next;
```
Traversing a Linked List

- Visit each node in a linked list, to
  - display contents, sum data, test data, etc.
- Basic process:
  
  set a pointer to point to what head points to
  while 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

```cpp
void NumberList::displayList() {
    ListNode *p; // ptr to traverse the list
    // start p at the head of the list
    p = head;
    // while p pts to something (not NULL), continue
    while (p) {
        // Display the value in the current node
        cout << p->value << " ";
        //Move to the next node
        p = p->next;
    }
    cout << endl;
}
```

Or the short version:

```cpp
void NumberList::displayList() {
    for (ListNode *p = head; p; p = p->next)
        cout << p->value << " ";
    cout << endl;
}
```

Destroying a Linked List: destructor

- The destructor must “delete” (deallocate) all nodes used in the list
- To do this, use list traversal to visit each node:
  - save the address of the next node in a pointer
  - delete the node

```cpp
NumberList::~NumberList() {
    ListNode *p; // traversal ptr
    ListNode *n; // saves the next node
    p = head; // start at head of list
    while (p) {
        n = p->next; // save the next
        delete p; // delete current
        p = n; // advance ptr
    }
}
```
**Operation:**

**delete a node from the list**

- deleteNode: removes node from list, and deletes (deallocates) the removed node.
-Requires two extra pointers:
  - one to point to the node to be deleted
  - one to point to the node before the node to be deleted.

```
void deleteNode(double num) {
  ListNode *p = head;   // to traverse the list
  ListNode *n;          // trailing node pointer (previous)
  // 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 is found, set links + delete
  if (p) {
    if (p==head) {   // p points to the first elem, n is garb
      head = p->next;
      delete p;
    } else {        // n points to the predecessor
      n->next = p->next;
      delete p;
    }
  } else: . . . p is NULL, not found do nothing
}
```
Operation:
**insert** a node into a linked list

- Inserts a new node into the middle of a list.
- Uses two extra pointers:
  - one to point to node before the insertion point
  - one to point to the node after the insertion point

**Inserting a Node into a Linked List**

- Insertion completed:

```
null
      n
    p
```

```
5 - 13 - 19 - null
head
newNode
```

**Insert Node Algorithm**

- Insert node in a certain position

Create the new node, store the data in it
Use pointer p to traverse the list,
until it points to: node after insertion point or NULL
--as p is advancing, make n point to the node before
if p points to first node (p is head, n was not set)
make head point to new node
make new node point to p’s node
else
make n’s node point to new node
make new node point to p’s node

Note: we will assume our list is sorted, so the insertion point is immediately before the first node that is larger than the number being inserted.

```
void NumberList::insertNode(double num) {
    ListNode *newNode;   // ptr to new node
    ListNode *p;         // ptr to traverse list
    ListNode *n;         // node previous to p

    //allocate new node
    newNode = new ListNode;
    newNode->value = num;

    // skip all nodes less than num
    p = head;
    while (p && p->value < num) {
        n = p;        // save
        p = p->next;  // advance
    }

    if (p == head) { //insert before first, or empty list
        head = newNode;
        newNode->next = p;
    } else {            //insert after n
        n->next = newNode;
        newNode->next = p;
    }
}
```
Linked List variations

- **Doubly linked list**
  - each node has two pointers, one to the next node and one to the previous node
  - head points to first element, tail points to last.

```cpp
private:
  // Structure for nodes
  struct Node {
    int value;       // Value in the node
    Node *prev;     // Pointer to the previous node
    Node *next;     // Pointer to the next node
  };
  Node *head;       // Pointer to the first element
  Node *tail;        // Pointer to the last element
```

- **Circular linked list**
  - last cell’s next pointer points to the first element.
  - no null pointers
  - every node has a successor

```
```

Linked lists vs Arrays (pros and cons)

- A **linked list** can easily grow or shrink in size.
  - No maximum capacity required
  - No need to resize+copy when list reaches max size.
- When a value is inserted into or deleted from a **linked list**, no other nodes have to be moved.
- **Arrays** allow random access to elements: array[i] (linked lists require traversal to get i’th element).
- **Arrays** do not require extra storage for “links” (linked lists are impractical when the pointer value is bigger than data value).