CS32 Discussion
Week 3

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Outline

- Doubly Linked List
- Sorted Linked List
- Reverse a Linked List

Doubly Linked List

- A linked list where each node has two pointers:
  - Next – pointing to the next node
  - Prev – pointing to the previous node

- struct Node {

  int value;

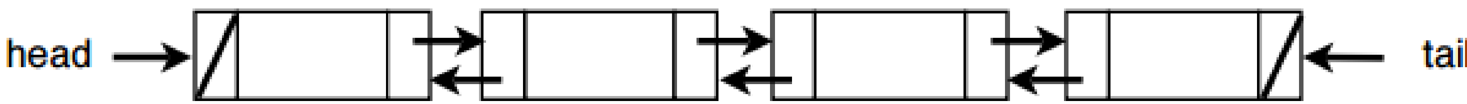
  Node *Next;

  Node *Prev;

- };

Doubly Linked List

- That's how it looks like:



doubly-linked list with 4 nodes

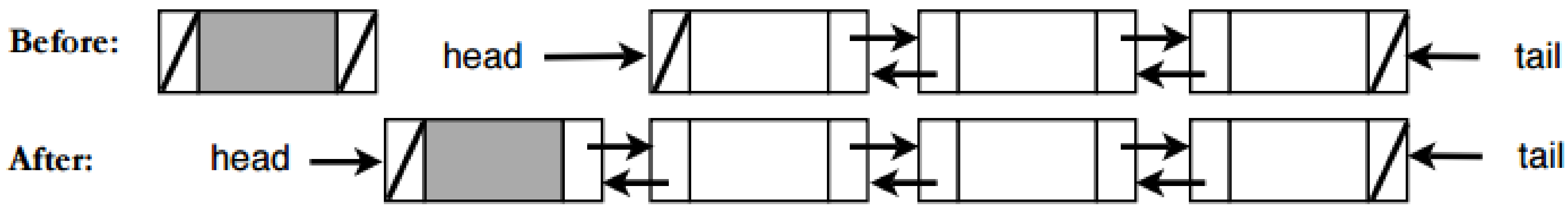
- Features to capture a DLL:
  - Two pointers: *head, tail*
  - head -> prev = NULL
  - tail -> next = NULL
  - head == tail == NULL when list is empty

Insertion

Four different conditions to insert a new node *P*

1. Insert before the head;
2. Insert after the tail;
3. Insert somewhere in the middle
4. When list is empty;

Insertion (Before head)



- 1) Set the *prev* of *head* to the new node *p*
  - head -> prev = p;
- 2) Set the *next* of *p* to *head*
  - p -> next = head;
- 3) *p* becomes the new *head*
  - head = p;
- 4) *head -> prev = NULL;*

Insertion (after tail)

- Quite the same as insertion before head:

```
tail -> next = p;
p -> prev = tail;
tail = p;
p -> next = NULL;
```

Insertion in the middle (*after node q*)

- 1) Fix the next node of *q* first:
  - Node *r = q -> next;
- 2) Point both *next of q* and *prev of r* to *p*
  - q -> next = r -> prev = p;
- 3) Point both sides of *p* to *q* and *r* respectively:
  - p -> prev = q;
  - p -> next = r;

Insertion in the middle (*after node q*)

- Or do it without r:
  - p -> prev = q;
  - p -> next = q->next;
  - q -> next = q -> next -> prev = p;

Insertion (to an empty list)

- How do we represent an empty list?
  - head == NULL (Or tail == NULL; Or head == tail == NULL)

- 1) Insertion, just set *p* as *head* (as well as *tail)*:
  - head = tail = p;
- 2) Don’t forget to set NULL on both sides:
  - p->next = p->prev = NULL;

Search

- Just like the singly linked list.

```
Node* Search(int key, Node* head){
   Node *q = head;
   while(q != NULL) {
        if(q -> value == key) return q;
        else q = q -> next; //iterate to the next node
   }
   return NULL;
}
```

```
Node* Search(int key, Node* tail){
   Node *q = tail;
   while(q != NULL) {
        if(q -> value == key) return q;
        else q = q -> prev; //iterate to the previous node
   }
   return NULL;
}
```

Removal

- More complex than singly linked list.
  - Check if the node ***p*** is the head **(p == head)**. Let this boolean be **A**.
  - Check if the node is the tail **(p == tail)**. Let this boolean be **B**.

Removal

- Four cases:
  - **Case 1 (A, but not B)**: *P* is the head of the list, and there is more than one node.
  - **Case 2 (B, but not A)**: *P* is the tail of the list, and there is more than one node.
  - **Case 3 (A and B)**: *P* is the only node.
  - **Case 4 (not A and not B)**: *P* is in the middle of the list.

Removal Case 1 (*P* is head)

- 1) Update *head*
  - head = head -> next;
- 2) delete *p*
  - delete p;
- 3) Set the *prev* of *head* to NULL
  - head -> prev = NULL;

Removal Case 2 (*P* is tail)

- 1) Update *tail*
  - tail = tail -> prev;
- 2) delete *p*
- 3) Set the *next* of *tail* to NULL
  - tail -> next = NULL;

Removal Case 3 (*P* is the only node)

- 1) Empty the linked list:
  - head = tail = NULL;
- 2) delete p:

Removal Case 4 (*P* is in the middle)

- 1) Fix the *prev* and *next* of *p*:
  - Node *q = p -> prev;
  - Node *r = p -> next;
- 2) Concatenate *q* and *r*:
  - q -> next = r;
  - r -> prev = q;
- 3) Delete *p*

Removal Case 4 (Equivalent implementation)

- If we do not fix with *q* and *r*:
  - p -> prev -> next = p -> next;
  - p -> next -> prev = p -> prev;
  - delete p;

Removal summary

```
void removeNodeInDLL(Node *p, Node& *head, Node& *tail) {
   if (p == head && p == tail) //case 3
        head = tail = NULL;
   else if (p == head) { //case 1
        head = head -> next;
        head -> prev = NULL;
   }
   else if (p == tail) { //case 2
       tail = tail -> prev;
       tail -> next = NULL;
   }
   else {//case 4
       p -> prev -> next = p -> next;
       p -> next -> prev = p -> prev;
  }
  delete p;
}
```

Copying a doubly linked list

- 1) Create *head* and *tail* for the new list
- 2) Iterate through the old list. For each node, **copy its value to a new node**.
- 3) Insert the new node to the tail of the new list.
- 4) Repeat 3 until we have iterated the entire old list. Set NULL before *head* and next of *tail*.

Copy a Doubly Linked List

```
void copyDDL(Node *head_o, Node *tail_o, Node& *head_n, Node& *tail_n) {
    if (tail_o == NULL) { //the original list is empty
        head_n = tail_n = NULL; return;
    }
    Node *q = head_o;  //iterator
    Node *p = new Node();
    p -> value = q -> value;
    head_n = tail_n = p;
    q = q -> next;
    while (q) {
        p = new Node();
        p -> value = q -> value;
        tail_n -> next = p;
        p -> prev = tail_n;
        tail_n = tail_n -> next;
        q = q -> next;
    }
    head_n -> prev = tail_n -> next = NULL
}
```

insertion for the first node is different

Copy value to the new node

Append the new node to the tail of the new list, and update tail.

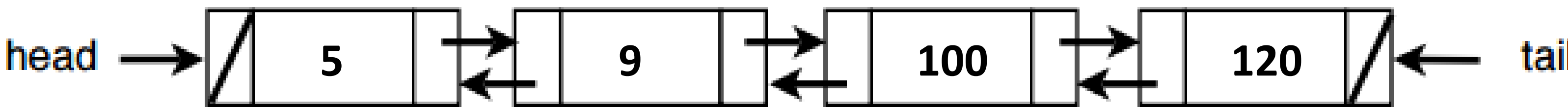
Cautions about coding with a linked list

- To draw diagrams of nodes will be extremely helpful.
- When copying a linked list, only copy stored values to new nodes. Do not copy pointers.

Sorted linked list

Do we need to search the entire linked?

- Consider an ascending sorted (doubly linked) list:



- Do we need to search through all the nodes when we're searching for:
  - 8
  - 50

- A way to optimize the search: sorted list and early stop

How to implement an ascending sorted (doubly linked) list?

- Change the insertion. Find the node *q* whose value is the *greatest lower bound* to the new node *p*.

- 1) Check if *head*'s value is larger than *p*'s. If so, insert *p* as head.

```
if (p -> value < head -> value) {
        p -> next = head;
        head -> prev = p;
        p -> prev = NULL;
        head = p;
}
```

How to implement an ascending sorted (doubly linked) list?

- 2) if not, iterate through the list until we find the node *q* whose value is the *greatest lower bound to p*.
  - Note: q->next can either have a value larger than *q*, or is NULL.

```
Node *q = head -> next;
while (q && q -> value < p -> value) {
    if (q-> next == NULL || q -> next -> value > p -> value) break;
    q = q -> next;
}
```

How to implement an ascending sorted (doubly linked) list?

- 3) Insert *p* after *q*:

```
if (q -> next != NULL)
    q -> next -> prev = p;
p -> next = q -> next; /* if q is the last node then its next is
already NULL */
p -> prev = q;
q -> next = p;
```

Insert into an ascending doubly linked list

```
void insert(Node *p, Node *head) {
    if (p -> value < head -> value) {
            p -> next = head;
            head -> prev = p;
            p -> prev = NULL;
            head = p;
            return;
    }
    Node *q = head -> next;
    while (q -> value < p -> value) {
        if (q-> next == NULL || q -> next -> value > p -> value) break;
        q = q -> next;
    }
    if (q -> next != NULL)
        q -> next -> prev = p;
    p -> next = q -> next;
    p -> prev = q;
    q -> next = p;
}
```

Early stop in searching a sorted linked list

We stop the iteration once we see a node which stores a value that is larger than key.

```
Node* Search(int key, Node* head){
    Node *q = head;
    while(q != NULL && q -> value <= key) {
        if(q -> value == key) return q;
        else q = q -> next; //iterate to the next node
    }
    return NULL;
}
```

What about removal and update?

Why *early stop* technique saves cost

- Spare cost from search to insertion and update
- However, search is called massively, but insertion and updates are not.
- O(n/2) cost is saved for each search (assuming the data complies with a uniform distribution)

Reverse Linked List (Leetcode #206, easy)

Given a **singly** linked list, reverse every node of it (i.e. each next points to the previous node).

Node* reverseList(Node* head)

Solution

```
Node* reverseList(struct ListNode* head) {
      Node *prev=NULL,*cur=head,*next;
      while(cur) {
           next = cur->next;
           cur->next = prev;
           prev = cur;
           cur = next; }
     return prev;
}
```

Bugs in your software are actually special features :)