COMPSCI 105 S1 2017
Principles of Computer Science

19 Linked List(3)

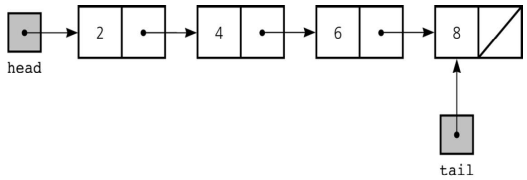
Agenda & Readings

- Agenda
  - Variations of Linked Lists
    - Singly Linked Lists with Head and Tail
    - Doubly Linked Lists with Dummy head node
- Reference:
  - Textbook:
    - Problem Solving with Algorithms and Data Structures
      - Chapter 3 – Lists
      - Chapter 3 – The UnorderedList Abstract Data Type
  - Extra Reading:
    - http://en.literateprograms.org/Singly_linked_list_(Python)

19.1 Singly Linked Lists

Singly Linked List with Head and Tail

- In some singly linked list implementations, it is handy to have a reference to the last node of the list
  - Allow more efficient access (i.e. insertion) at the end of Linked List
  - Useful for queue-like structure, e.g. a waiting list



19.1 Singly Linked Lists

Singly Linked List with Head and Tail

- Cases:
  - Insertion
    - General case:
      - Insert a new node to the beginning of a list
      - Insert a new node to the end of a list
      - Insert a new node to the middle of a list
    - An empty list:
      - Insert a new node to an empty list

Singly Linked List with Head and Tail

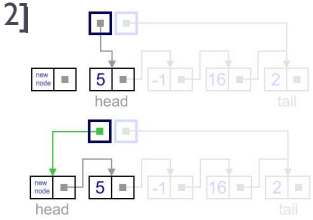
- Cases:
  - Deletion
    - General case:
      - Remove a node at the beginning of a list
      - Remove a node at the end of a list
      - Remove a node from the middle of a list
    - Only one node left in the list:
      - Remove the only one node from a list

Singly Linked List with Head and Tail

- Case 1:
  - Add to head Original linked list: [5, -1, 16, 2]

```
my_list.add_to_head(100)
for num in my_list:
    print(num, end=" ")
```

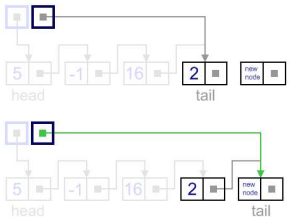
```
100 5 -1 16 2
```



- Case 2:
  - Add to tail Original linked list: [5, -1, 16, 2]

```
my_list.add_to_tail(200)
for num in my_list:
    print(num, end=" ")
```

```
5 -1 16 2 200
```

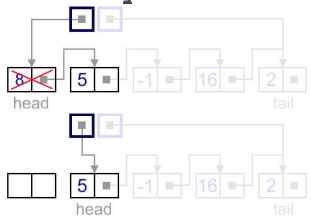


Singly Linked List with Head and Tail

- Case 3:
  - Remove from head Original linked list: [8, 5, -1, 16, 2]

```
my_list.remove_from_head()
for num in my_list:
    print(num, end=" ")
```

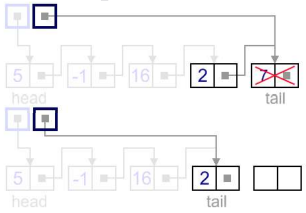
```
5 -1 16 2
```



- Case 4:
  - Remove from tail Original linked list: [5, -1, 16, 2, 7]

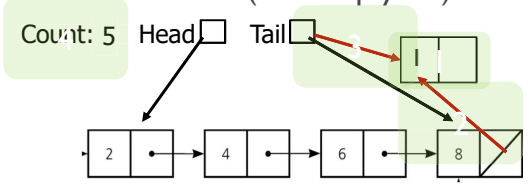
```
my_list.remove_from_tail
for num in my_list:
    print(num, end=" ")
```

```
5 -1 16 2
```



Inserting a Node

- Add an item to the end of the Linked List:
  - General case: (non-empty list)

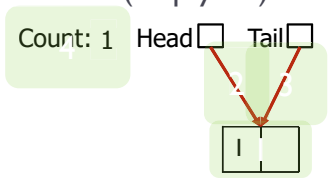



```
new_node = Node(item)
self.tail.set_next(new_node)
self.tail = new_node
self.count += 1
```

  - Steps:
    - Create a new node and place the item as its data
    - Change the next reference of the old last node of the list to refer to the new node
    - Modify the tail to refer to the new node
    - Increase the count

Inserting a Node

- Add an item to an empty Linked List:
  - Special case: (empty list)

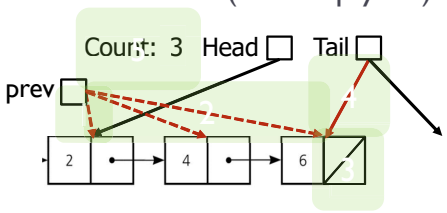



```
new_node = Node(item)
self.head = new_node
if self.tail == None:
    self.tail = new_node
self.count += 1
```

  - Steps:
    - Create a new node and place the item as its data
    - Change both the head and tail to refer to the new node
    - Increase the count

Deleting a Node

- Remove an item from the end of the Linked List:
  - General case (non-empty list):

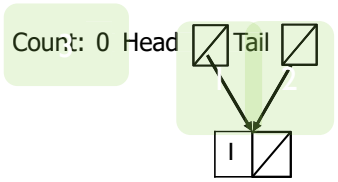



```
prev = self.head
while (prev.get_next() != self.tail):
    prev = prev.get_next()
prev.set_next(None)
self.tail = prev
self.count -= 1
```

  - Steps:
    - Locate the previous node
    - Modify the next of the pervious node to None
    - Modify the tail to refer to the previous node
    - Decrease the count

Deleting a Node

- Remove a node from a list with one element




```
self.head = self.head.get_next()
if self.head == None:
    self.tail = None
self.count -= 1
```

  - Steps:
    - Modify the head and tail to refer to None
    - Decrease the count

Time Complexity

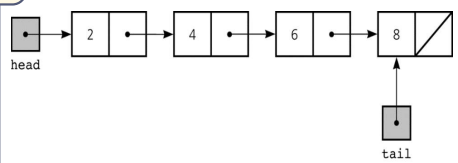
- Summary

	Python List	Singly Linked List
is_empty	***O(1)** : if len(my_list) == 0*	***O(1)***
size	***O(1)** : len(my_list)*	***O(1)** with count variable* ***O(n)** with count variable*
addTohead	***O(n)** : insert(0, item)*	***O(1)***
addToTail	***O(1)** : append*	***O(1)** with tail reference* ***O(n)** without tail*
add	***O(n)** : insert(index, item)*	***O(n)***
removeFromHead	***O(n)** : pop(0)*	***O(1)***
removeFromTail	***O(1)** : pop()*	***O(n)** even with tail*
remove	***O(n)** : pop(n)*	***O(n)***

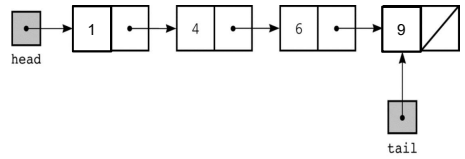
Examples

- A singly linked list with head and tail references:

```
my_list = LinkedList()
my_list.add_to_head(8)
my_list.add_to_head(6)
my_list.add_to_head(4)
my_list.add_to_head(2)
```




```
my_list.remove_from_tail()
my_list.add_to_tail(9)
my_list.remove_from_head()
my_list.add_to_head(1)
```



Exercise 1

- What is the output of the following program?

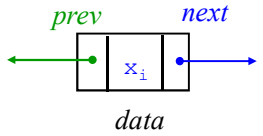
```
my_list = LinkedList()
for x in [9, 2, 22, 40]:
    my_list.add_to_head(x)
my_list.remove_from_tail()
my_list.add_to_tail(32)
my_list.remove_from_head()
my_list.remove_from_head()
my_list.add_to_head(100)
for num in my_list:
    print(num, end=" ")
```


Doubly Linked List

- A common variation on linked lists is to have two pointers to other nodes within each node:
  - One to the next node on the list
  - One to the previous node
- Doubly-linked lists make some operations, such as deleting a tail node, more efficient
- Double-linked lists can have iterators for efficient forward and backward traversals

Doubly Linked List

- Each **NodeDLL** references both its predecessor and its successor




```
class NodeDLL:
    def __init__(self, init_data, next_node=None, prev_node=None):
    …
```

- Each object in a doubly linked list will contain three member variables:
  - data: value stored in this node
  - next: refers to the next node in the list
  - prev: refers to the previous node in the list

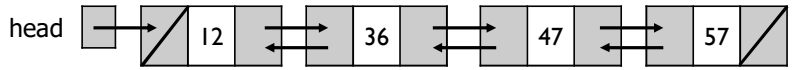
NodeDLL Class

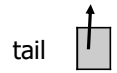
- Code:

```
class NodeDLL:
    def __init__(self, init_data, next_node=None, prev_node=None):
        ...
    def get_data(self):
        return self.data
    def get_prev(self):
        return self.prev
    def get_next(self):
        return self.next
    def set_data(self, new_data):
        self.data = new_data
    def set_next(self, new_next):
        self.next = new_next
    def set_prev(self, new_prev):
        self.prev = new_prev
    ...
```


Doubly Linked List

- Doubly Linked List
  - A head reference is used to reference the first node in the list
  - A tail reference points to the last node.
  - Examples:
    - A doubly linked list with 4 nodes:

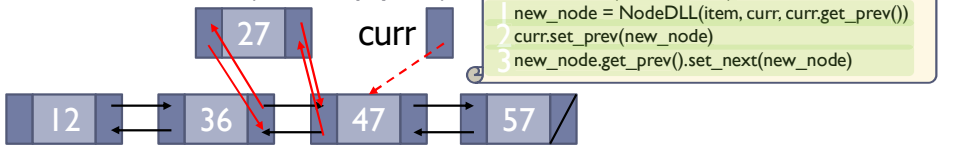




    - An Empty list:

Inserting a Node

- Add an item to the middle of the Linked List:
  - General case: (non-empty list)

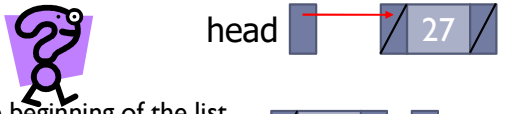



```
def add_before(self, item, curr):
    new_node = NodeDLL(item, curr, curr.get_prev())
    curr.set_prev(new_node)
    new_node.get_prev().set_next(new_node)
```

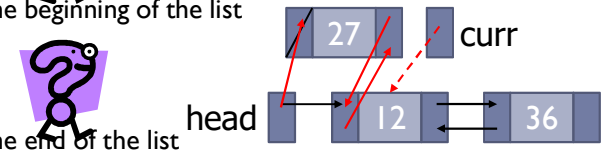
  - Steps:
    - Create a new node and place the item as its data
      - Set the next of the new node to refer to the curr
      - Set the prev of the new node to refer to the previous node of curr
    - Modify the prev of the curr node to refer to the new node
    - Modify the next of the node that is to precede the new node to refer to the new node

Inserting a Node

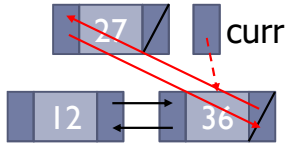
- Add an item to the Linked List:
  - However, we still need to handle insertion in different cases:
    - Case 1: an empty list



    - Case 2: at the beginning of the list

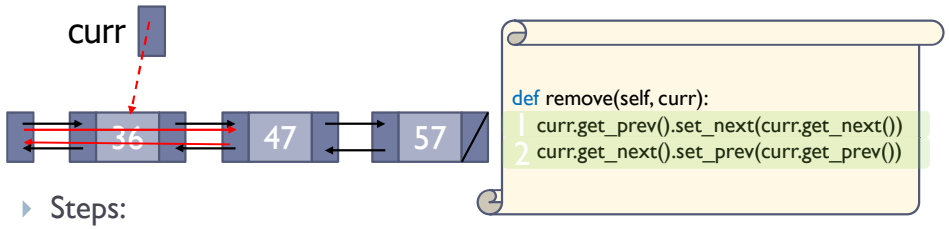


    - Case 3: at the end of the list



Deleting a Node

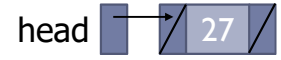
- Remove an item from the middle of the Linked List:
  - General case: (non-empty list)



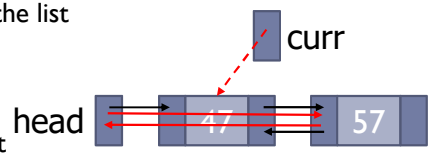
  - Steps:
    - Modify the next of the node that precede curr so that it refers to the node that follows curr
    - Modify the prev of the node that follows curr so that it refers to the node that precedes curr

Deleting a Node

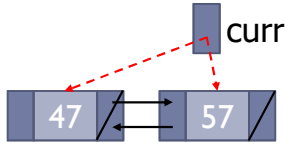
- Remove an item from the the Linked List
  - However, we still need to handle insertion in different cases:
    - Case 1: One element



    - Case 2: at the beginning of the list

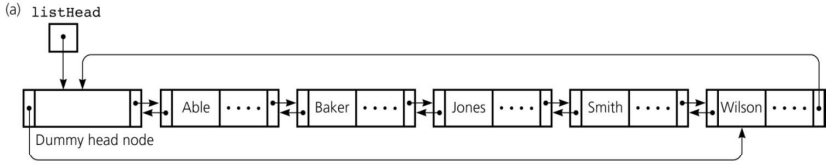


    - Case 3: at the end of the list

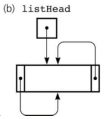


Circular + Dummy Head Node

- How can we simplify the implementation?
  - Use Circular doubly linked list with a dummy head node
    - The prev of the dummy head node refers to the last node
    - The next of the last node refers to the dummy head node

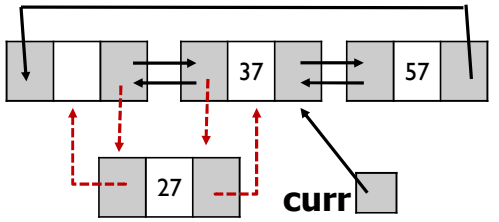


  - Eliminates special cases for insertions and deletions
  - Dummy head node is always present, even when the linked list is empty

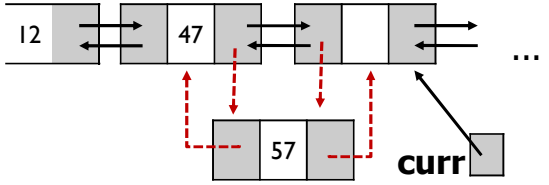


Circular + Dummy Head Node

- Inserting a Node
  - At the beginning:

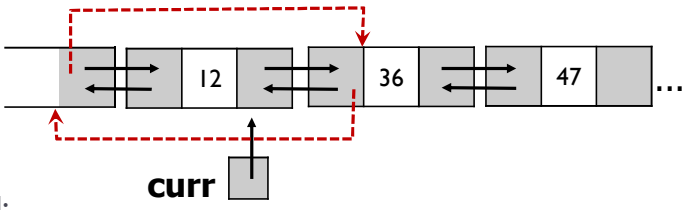


  - At the end:

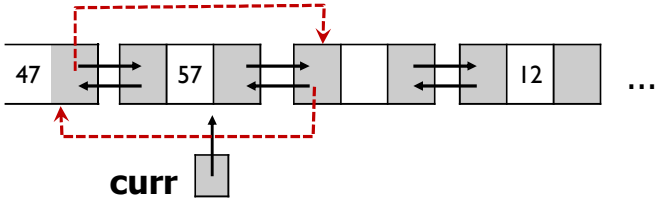


Circular + Dummy Head Node

- Deleting a Node
  - At the beginning:



  - At the end:



Time Complexity

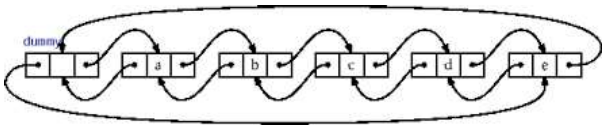
- Summary

	Python List	Singly Linked List	Circular Doubly with a dummy head
is_empty	***O(1)***	***O(1)***	***O(1)***
size	***O(1)***	***O(1)*** *with count*	***O(1)*** *with count*
addTohead	***O(n)***	***O(1)***	***O(1)***
addToTail	***O(1)***	***O(1)*** *with tail* ***O(n)*** *without*	***O(1)***
add	***O(n)***	***O(n)***	***O(n)***

Exercise 2

- Consider the following code fragment

```
from LinkedListDLL import LinkedListDLL
def Test_DoublyLinkedlist():
    my_list.add_to_tail('b')
    my_list.add_to_tail('c')
    my_list.add_to_head('a')
    my_list.add_to_tail('d')
    my_list.add_to_tail('e')
```



Exercise 2

- Consider the following code fragment

```
from LinkedListDLL import LinkedListDLL
def Test_DoublyLinkedlist():
    my_list.add_to_tail(2)
    my_list.add_to_tail(4)
    my_list.add_to_head(6)
    my_list.add_to_tail(8)
```

- Draw the resulting doubly linked list in the space provided

Summary

- Understand and learn how to implement the singly linked-list
- Understand and learn how to implement the doubly linked-list