Linked list

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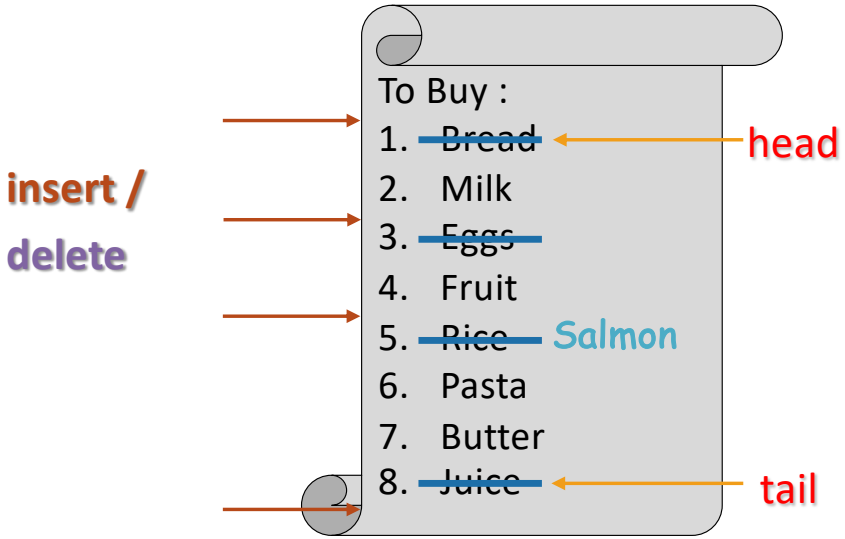
List

http://www.gograph.com/vector-clip-art/queue.html

List



Already bought
Eggs, Rice, Bread, Juice

Oh I forgot
Salmon

Ordered List – Unordered List

To Buy :

1. Bread
2. Milk
3. Eggs
4. Fruit
5. Rice
6. Pasta
7. Butter
8. Juice

Unordered List

Scores :

1. Bruce 2
2. Tom 3
3. Ben 5
4. Max 7
5. Tim 7
6. Marry 8
7. Ron 9
8. Harry 10

Ordered List
Ascending Order

$98n^5 - 4n^4 + n^3 - 8n^2 + 5n + 7$

Ordered List
Decending Order

Logical Abstract Data Type & Implementation

Logical ADT : ขึ้นกับ application

1. Data : ของมีลำดับ มีปลาย หัว head และ/หรือ ท้าย tail

Data Implementation ?

Python List

2. Methods :ขึ้นกับ list เป็น ordered list หรือไม่

Unordered List / Ordered List

- List() สร้าง empty list
- isEmpty() returns boolean ว่า empty list หรือไม่
- size() returns จำนวนของใน list
- search(item) returns ว่ามี item ใน list หรือไม่
- index(item) returns index ของ item กำหนดให้ item อยู่ใน list

unordered list

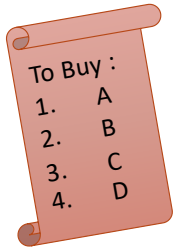
- append(item) adds item ท้าย list ไม่ Returns คิดว่า item ไม่มีอยู่ก่อนใน list
- insert(pos,item) adds item ที่ index pos ไม่ Returns คิดว่า item ไม่มีอยู่ก่อนใน list

ordered list

add(item) adds item เข้า list ตามลำดับ ไม่ Returns

- remove(item) removes & return item คิดว่า item มีอยู่ใน list
- pop() removes & return item ตัวสุดท้าย list _size >= 1
- pop(pos) removes & return item ตัวที่ index = pos list _size >= 1

List Implementation : Sequential (Implicit) Array, Python List



A B C D

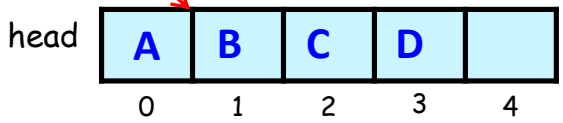
Problem : fix positions

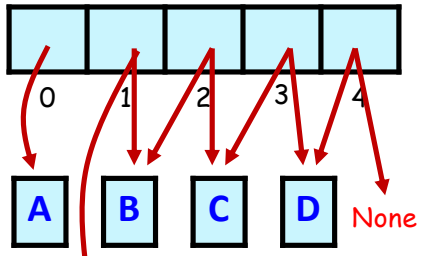
i

Sequential Array

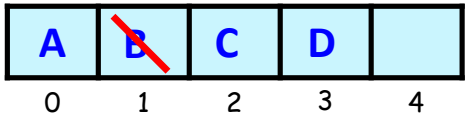
Python : List

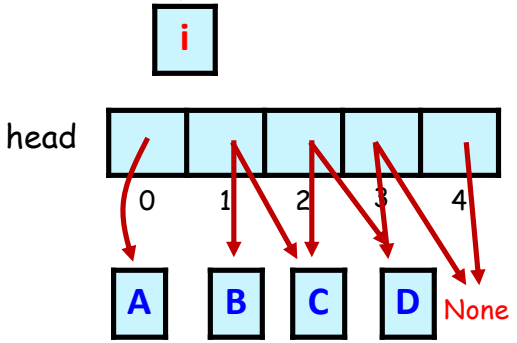
insert i ? : shift out



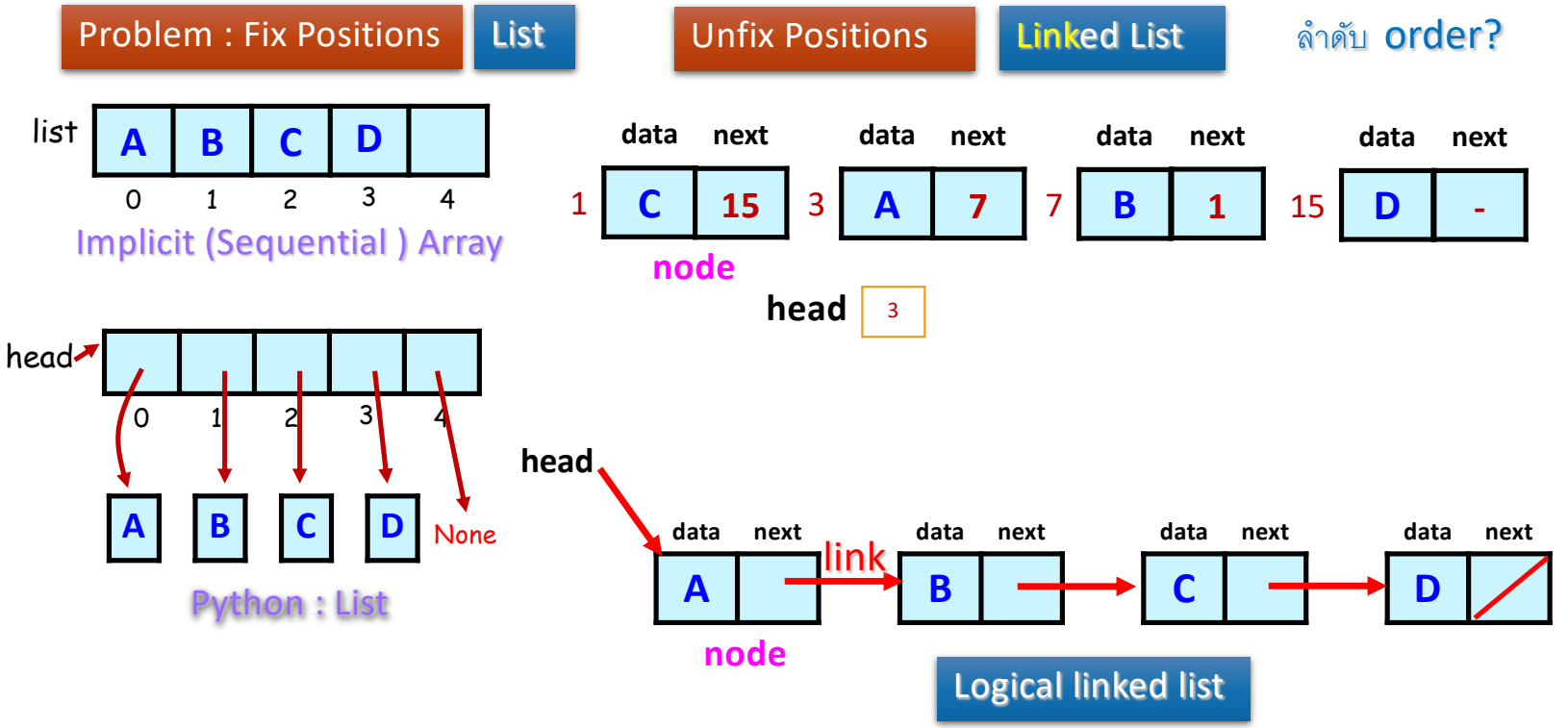


delete : shift in





Linked List



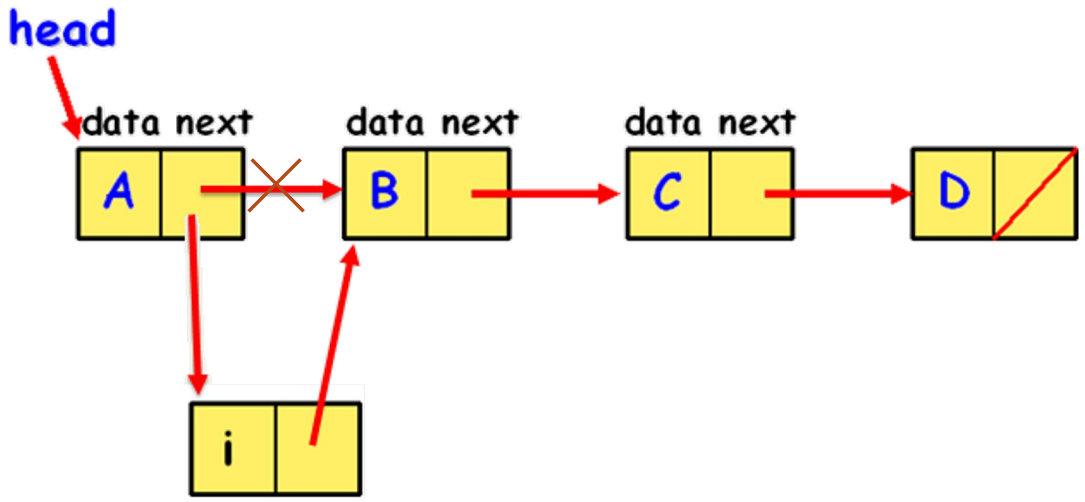
Logical คือในความคิดของเรา

เช่น link แทนด้วยลูกศร แทนการเชื่อมโยงกัน

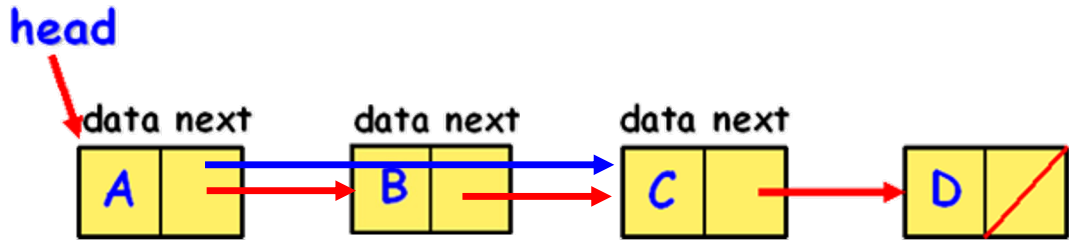
physical (implementation) โครงสร้างที่ใช้ในการสร้างจริง

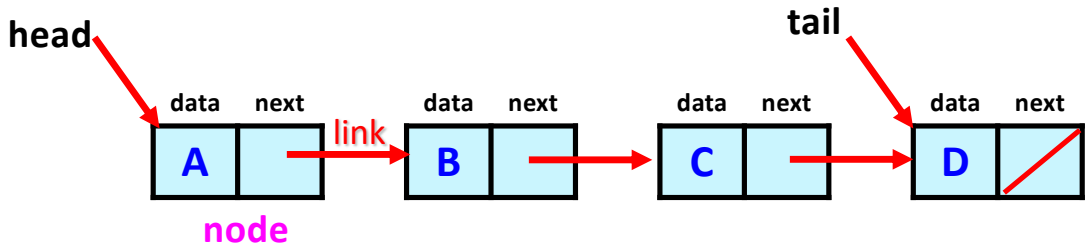
เช่น link อาจใช้ pointer หรือ index ของ array

Solve Inserting Expensive Shifting Problem



Solve Deleting Expensive Shifting Problem





Linked List

Data :

1. data
2. next (link)

} node class

3. head
4. tail ?

} list class

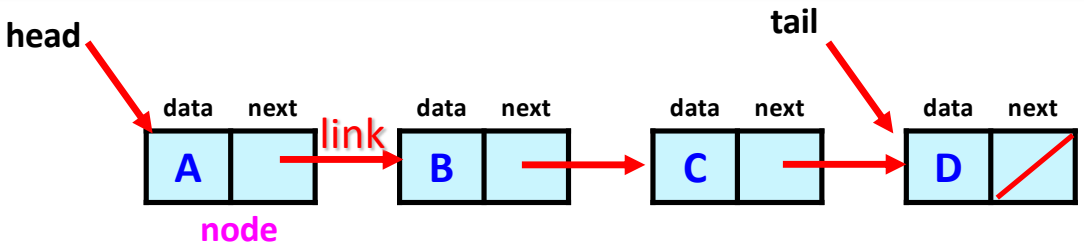
Node Class / List Class

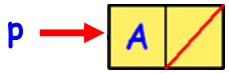
1. Data :

`__init__()` : **constructor** ให้ค่าตั้งต้น

2 underscores 2 underscores

Node Class






```
p =Node('A', None)
```

```
class Node:

    def __init__(self,  data,  next = None):

          self.data = data

          if next is None:
               self.next = None
          else:
               self.next = next


   def __str__(self):
          return str(self.data)
```

List Class

```
class list:
    """ unordered singly linked list
        with head
    """
    def __init__(self):
        self.head = None
```

```
l1 = list()
```

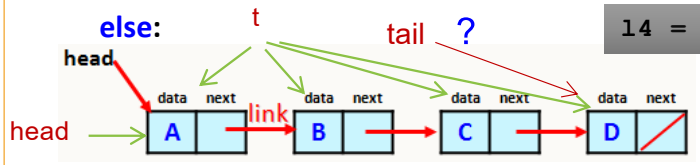
```
    """ unordered singly linked list
        with head & tail
    """
    def __init__(self):
        self.head = self.tail = None
```

```
l2 = list()
```

```
def __init__(self, head = None):
    """ unordered singly linked list
        can set default list
        with head, tail & size
    """
    if head == None:
        self.head = self.tail = None
        self.size = 0
    else:
        self.head = head
        t = self.head
        self.size = 1
        while t.next != None:    # locating tail & find size
            t = t.next
            self.size += 1
        self.tail = t
```

head
tail → None

```
l3 = list()
```

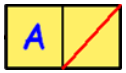



```
l4 = list(head)
```

Methods

1. __init__() : ให้ค่าตั้งต้น
2. **size():**
3. **isEmpty():**
4. **append () : add at the end**
5. **__str__():**
6. **addHead()** : ให้ค่าตั้งต้น
7. **remove(item):**
8. **removeTail():**
9. **removeHead() :**
10. **isIn(item): / search(item)**
11. . . .

Creating a List



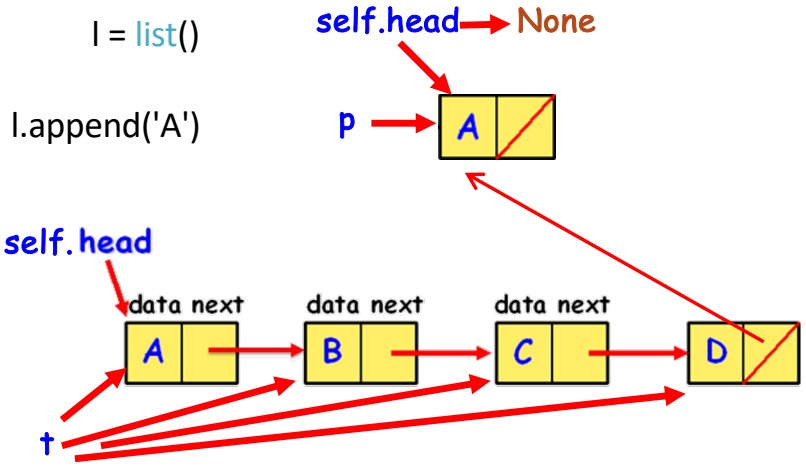
Node('A', None)

```
class Node:
   def __init__(self, data, next = None):
      self.data = data
      if next == None:
         self.next = None
      else:
         self.next = next
```

```
class list:

   """ unordered singly linked list
       with head """
   def __init__(self):
         self.head = None
         self.size = 0

   def append(self, data):

            """ add at the end of list"""
         p = Node(data)
         if self.head == None:  # null list
            self.head = p
         else:
            t = self.head
            while t.next != None :
               t = t.next
            t.next = p
          self.size += 1
```

l = list()

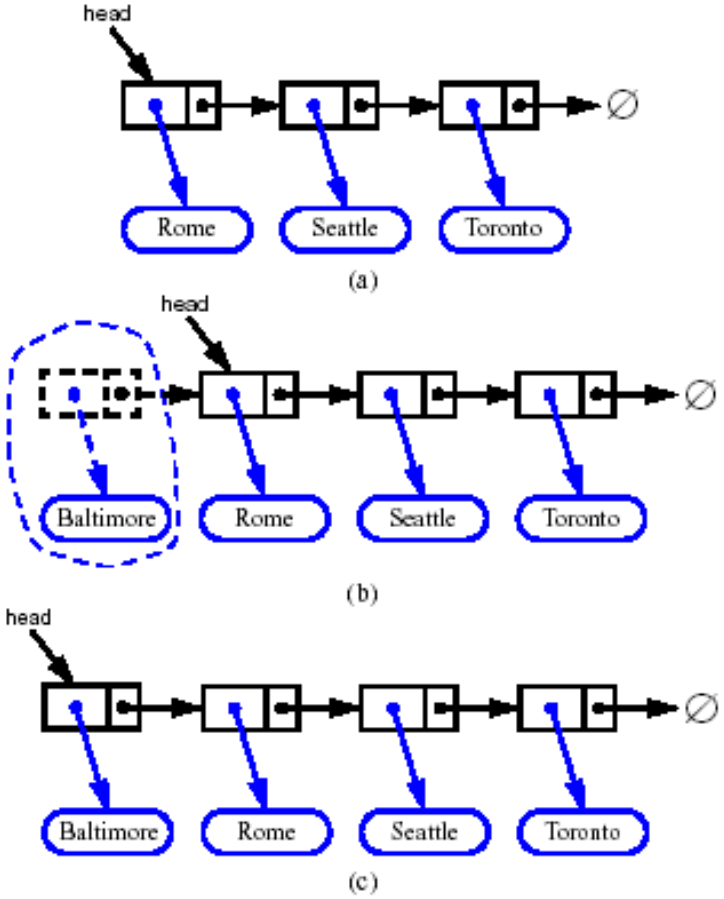
l.append('A')



Inserting at the Head

1. Allocate a new node
2. Insert new element
3. Have new node point to old head
4. Update head to point to new node

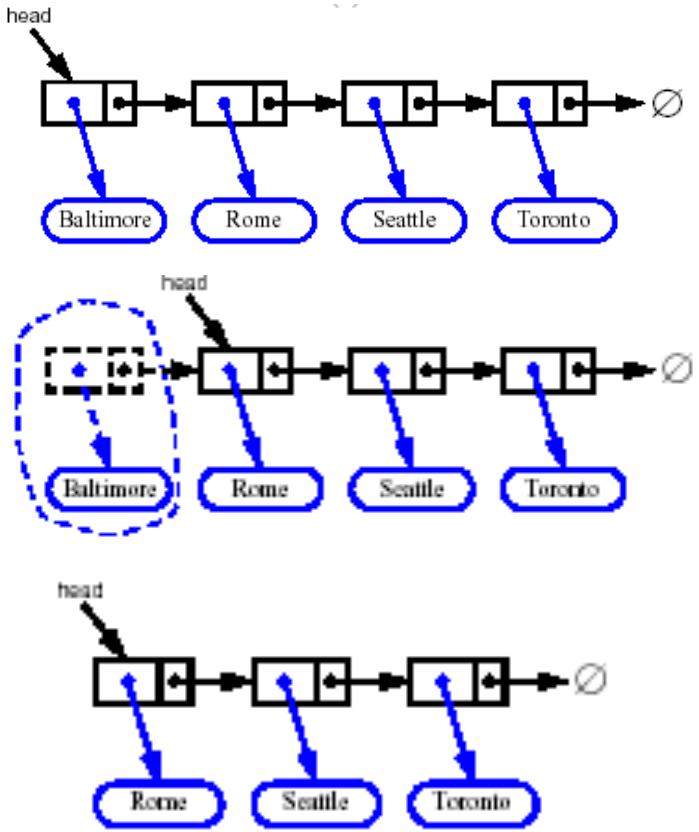
```
class list:
   def  add_head(self, data):
      p = Node(data)
      p.next = self.head
      self.head = p
      self.size += 1
```



Removing at the Head

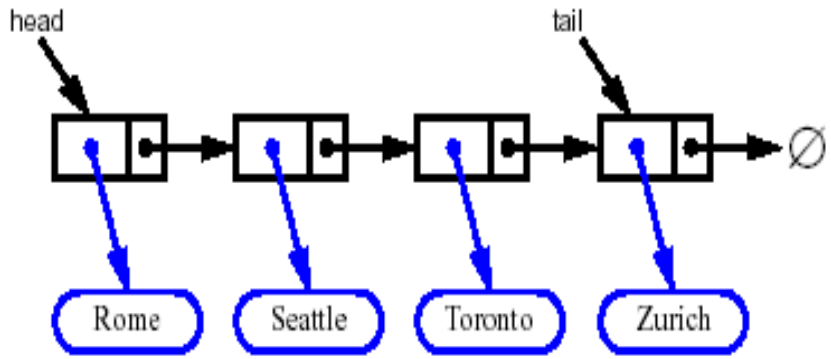
1. Update head to point to next node in the list
2. Allow garbage collector to reclaim the former first node

```
class list:
   def removeHead(self):
      if self.head == None : return
      if self.head.next == None :
            p = self.head
            self.head = None
      else :
            p = self.head
            self.head = self.head.next
      self.size -= 1
      return p.data
```



Removing at the Tail

- Removing at the tail of a singly linked list is not efficient!
- There is no constant-time way to update the tail to point to the previous node

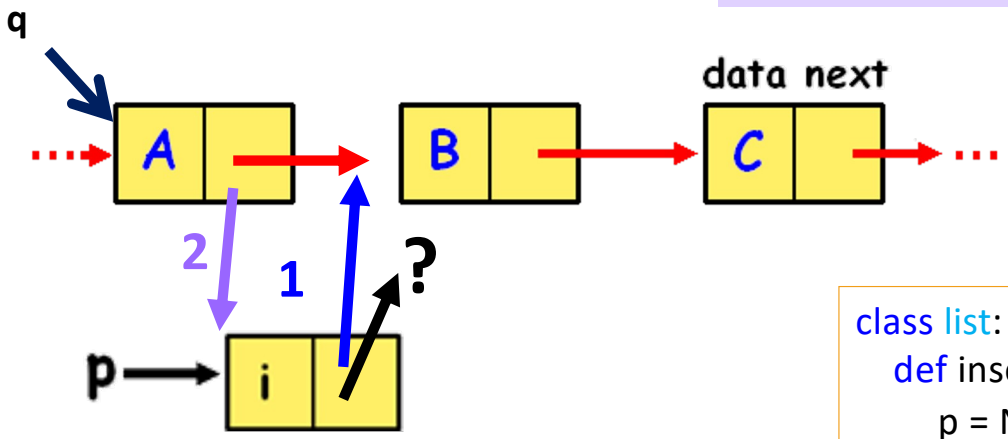



```
class list:
   def removeTail(self):
       if self.head == None : return
       if self.head.next == None :
              self.head = None
              self.size -= 1
              return
       else :
              p = self.head
              while p.next.next != None :
                     p = p.next
              p.next = p.next.next
              self.size -= 1
```

Insert After

`insertAfter(q, 'i')`

insert node data
after a node pointed by q



p = node('i')
p.next = q.next
q.next = p

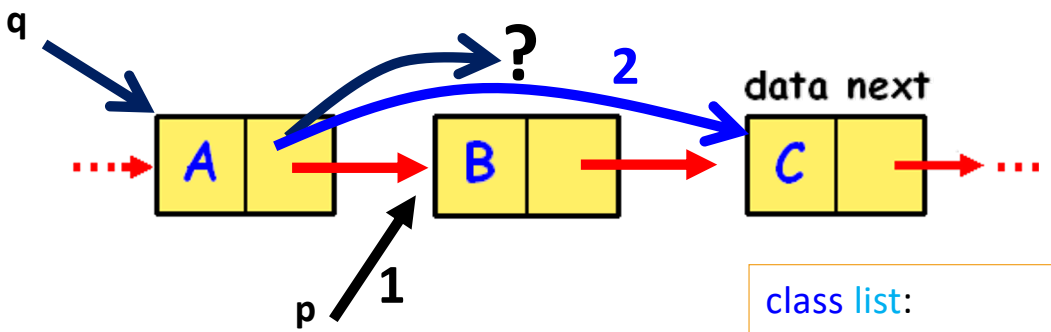
```
class list:
    def insertAfter(self, i, data):
        p = Node(data)
        q = self.head
        count = 0
        while q != None :
            if count == i:
                p.next = q.next
                q.next = p
                return
            q = q.next
            count += 1
```

Why insert after ?
Can you insert before ?

Delete After

`deleteAfter(q)`

delete a node
after a node pointed by q

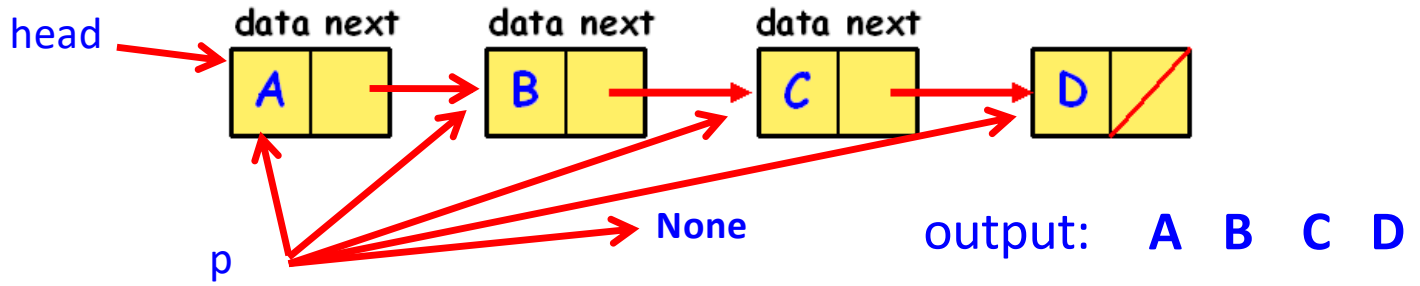


q.next = p.next

```
class list:
    def deleteAfter(self, i):
        q = self.head
        count = 0
        while q != None and q.next != None:
            if count == i:
                p = q.next
                q.next = p.next
                p = None
                self.size -= 1
                return
            q = q.next
            count += 1
```

print list

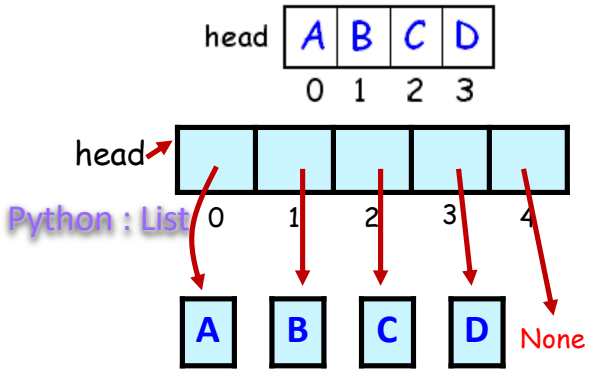
Design how to call.

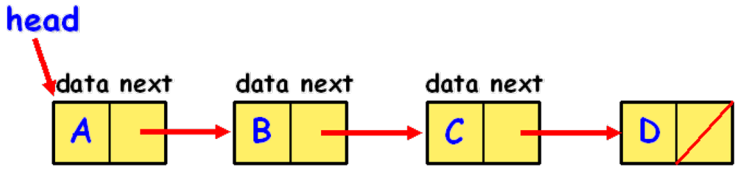



```
p = head
while p != None:
    print(p.data)
    p = p.next
```

```
class list:
    def printList(self):
        p = self.head
        while p != None:
            print(p.data, end=" -> ")
            p = p.next
        print("None")
```

Linked List VS Sequential Array

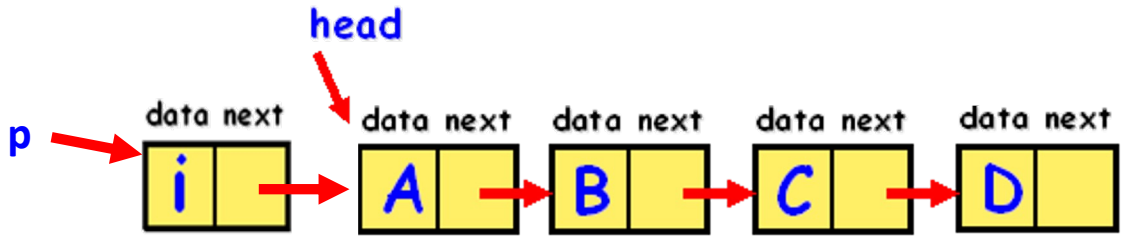




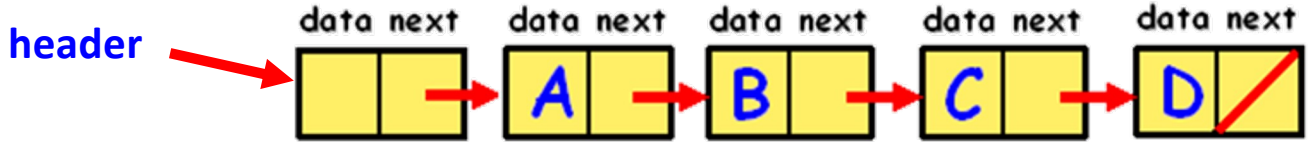
Sequential Array	Linked List
• Insertion / Deletion Shifting Problem. • Random Access. • C array : Automatic Allocation. Python List array : Dynamic Allocation • Lifetime : C-array, Python List • from defined until its scope finishes. • Only keeps data.	• Solved. • Sequential Access. • Node : Dynamic Allocation. • Node Lifetime : from allocated (C : malloc()/new, python: instantiate obj) until C: deallocated by free()/delete, Python : no reference. • Need spaces for linkes.

Header Node

To insert & delete at 1st position change head ie. make special case.



"Header Node" solves the problem.



Empty List has a header node.

Header Node

```
class list:

  """ unordered singly linked list
      with head """
  def __init__(self):
      self.head = None
      self.size = 0

  def append(self, data):

        """ add at the end of list"""
      p = Node(data)
      if self.head == None:  # null list
          self.head = p
      else:
          t = self.head
          while t.next != None :
              t = t.next
          t.next = p
      self.size += 1
```

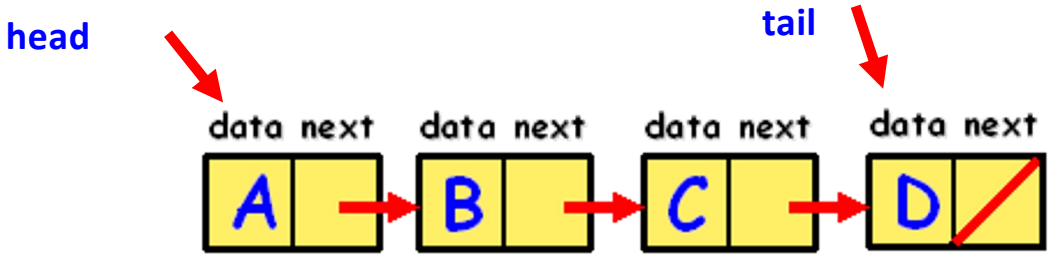
```
class list:

  """ unordered singly linked list
      with head """
      def __init__(self):
          self.header = Node()
          self.size += 1

      def append(self, data):

            """ add at the end of list"""
          p = Node(data)
          t = self.header.next
          while t.next != None :
                t = t.next
          t.next = p
          self.size += 1
```

Header Node

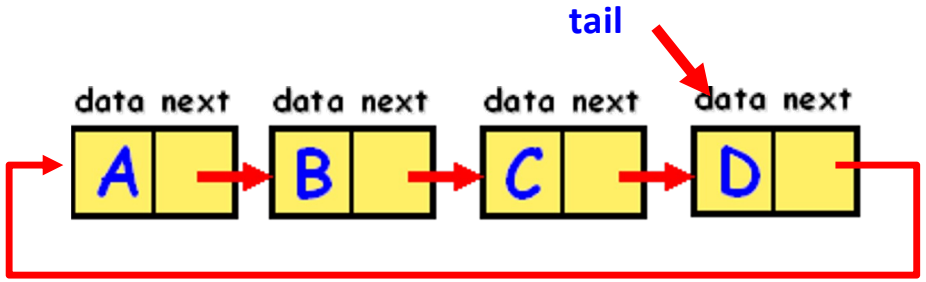
```
class list:
   def removeTail(self):
       if self.head == None : return
       if self.head.next == None :
              self.head = None
              self.size -= 1
              return
       else :
              p = self.head
              while p.next.next != None :
                     p = p.next
              p.next = p.next.next
              self.size -= 1
```

```
class list:
   def removeTail(self):
       if self.head == None : return
       if self.header.next == None :
              self.head = None
              self.size -= 1
              return
       p = self.header.next
       while p.next.next != None :
              p = p.next
       p.next = p.next.next
       self.size -= 1
```

Head & Tail Nodes



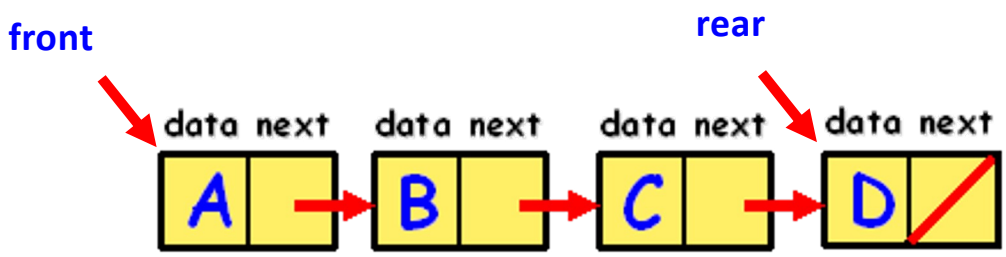
Circular List



Why ptr to tail ? Why not ptr to head?

Linked Stack

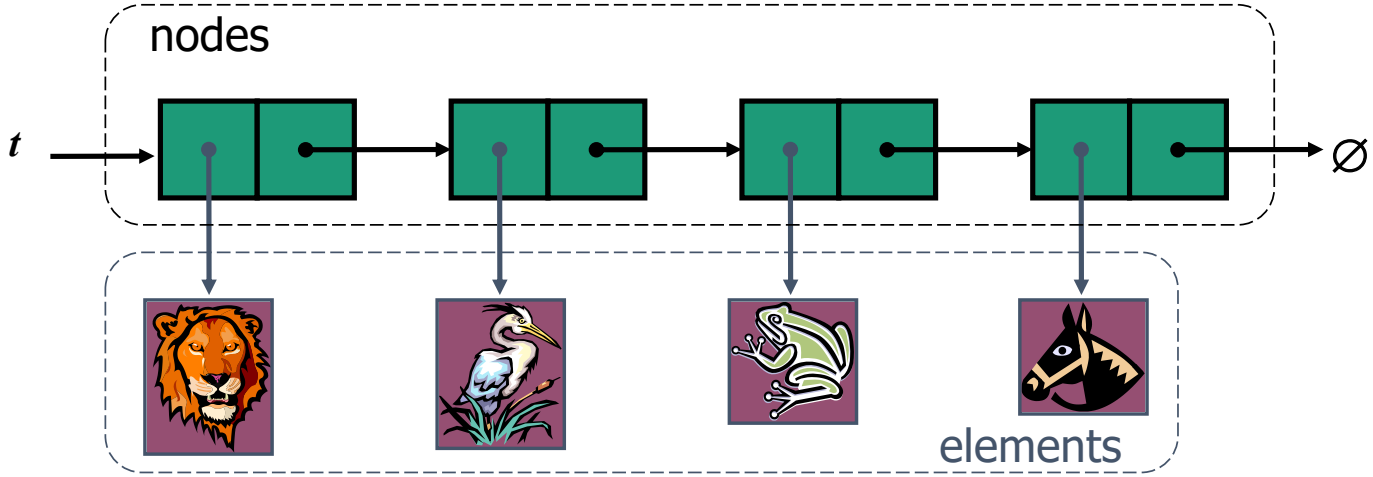
Linked Queue



Can switch front & rear ?

Stack as a Linked List

- We can implement a stack with a singly linked list
- The top element is stored at the first node of the list
- The space used is $O(n)$ and each operation of the Stack ADT takes $O(1)$ time



Linked-List Stack in Python

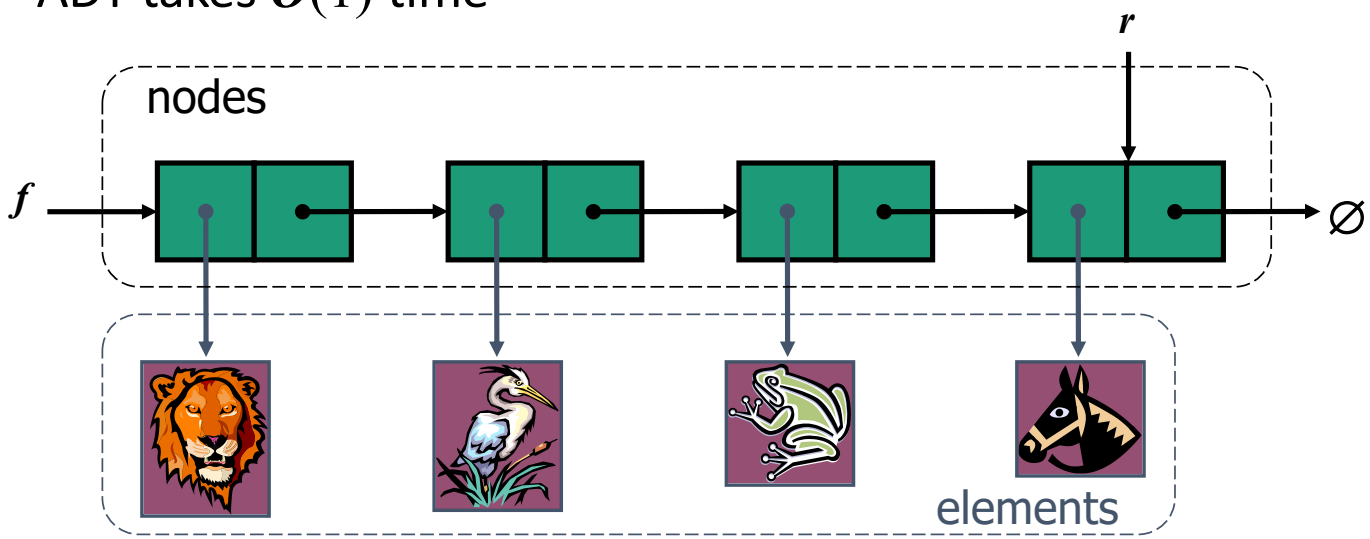
```
1  class LinkedStack:
2    """LIFO Stack implementation using a singly linked list for storage."""
3
4    #---------------------------- nested _Node class ----------------------------
5    class _Node:
6      """Lightweight, nonpublic class for storing a singly linked node."""
7      __slots__ = '_element', '_next'         # streamline memory usage
8
9      def __init__(self, element, next):      # initialize node's fields
10       self._element = element               # reference to user's element
11       self._next = next                     # reference to next node
12
13   #------------------------------ stack methods ------------------------------
14   def __init__(self):
15     """Create an empty stack."""
16     self._head = None                       # reference to the head node
17     self._size = 0                          # number of stack elements
18
19   def __len__(self):
20     """Return the number of elements in the stack."""
21     return self._size
22
```

```
23   def is_empty(self):
24     """Return True if the stack is empty."""
25     return self._size == 0
26
27   def push(self, e):
28     """Add element e to the top of the stack."""
29     self._head = self._Node(e, self._head)     # create and link a new node
30     self._size += 1
31
32   def top(self):
33     """Return (but do not remove) the element at the top of the stack.
34
35     Raise Empty exception if the stack is empty.
36     """
37     if self.is_empty():
38       raise Empty('Stack is empty')
39     return self._head._element                 # top of stack is at head of list
```

```
40   def pop(self):
41     """Remove and return the element from the top of the stack (i.e., LIFO).
42
43     Raise Empty exception if the stack is empty.
44     """
45     if self.is_empty():
46       raise Empty('Stack is empty')
47     answer = self._head._element
48     self._head = self._head._next              # bypass the former top node
49     self._size -= 1
50     return answer
```

Queue as a Linked List

- We can implement a queue with a singly linked list
  - The front element is stored at the first node
  - The rear element is stored at the last node
- The space used is $O(n)$ and each operation of the Queue ADT takes $O(1)$ time



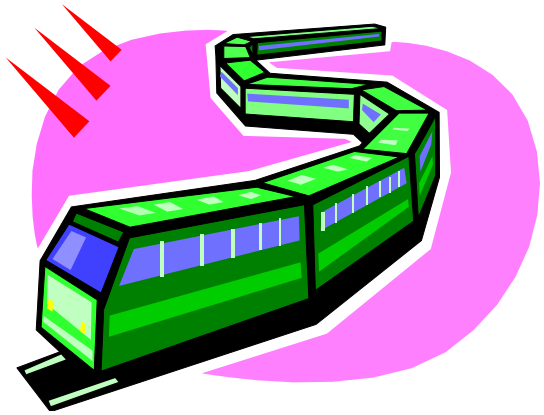
Linked-List Queue in Python

```
1  class LinkedQueue:
2    """FIFO queue implementation using a singly linked list for storage."""
3
4    class _Node:
5      """Lightweight, nonpublic class for storing a singly linked node."""
6      (omitted here; identical to that of LinkedStack._Node)
7
8    def __init__(self):
9      """Create an empty queue."""
10     self._head = None
11     self._tail = None
12     self._size = 0                          # number of queue elements
13
14   def __len__(self):
15     """Return the number of elements in the queue."""
16     return self._size
17
18   def is_empty(self):
19     """Return True if the queue is empty."""
20     return self._size == 0
21
22   def first(self):
23     """Return (but do not remove) the element at the front of the queue."""
24     if self.is_empty():
25       raise Empty('Queue is empty')
26     return self._head._element              # front aligned with head of list
```

Linked-List Queue in Python

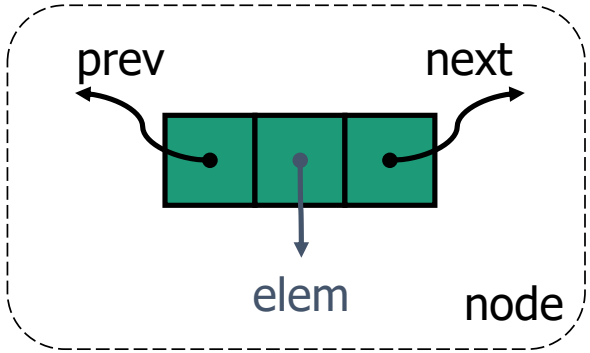
```
27    def dequeue(self):
28      """Remove and return the first element of the queue (i.e., FIFO).
29
30      Raise Empty exception if the queue is empty.
31      """
32      if self.is_empty():
33        raise Empty('Queue is empty')
34      answer = self._head._element
35      self._head = self._head._next
36      self._size -= 1
37      if self.is_empty():                    # special case as queue is empty
38        self._tail = None                    # removed head had been the tail
39      return answer
40
41    def enqueue(self, e):
42      """Add an element to the back of queue."""
43      newest = self._Node(e, None)           # node will be new tail node
44      if self.is_empty():
45        self._head = newest                  # special case: previously empty
46      else:
47        self._tail._next = newest
48      self._tail = newest                    # update reference to tail node
49      self._size += 1
```

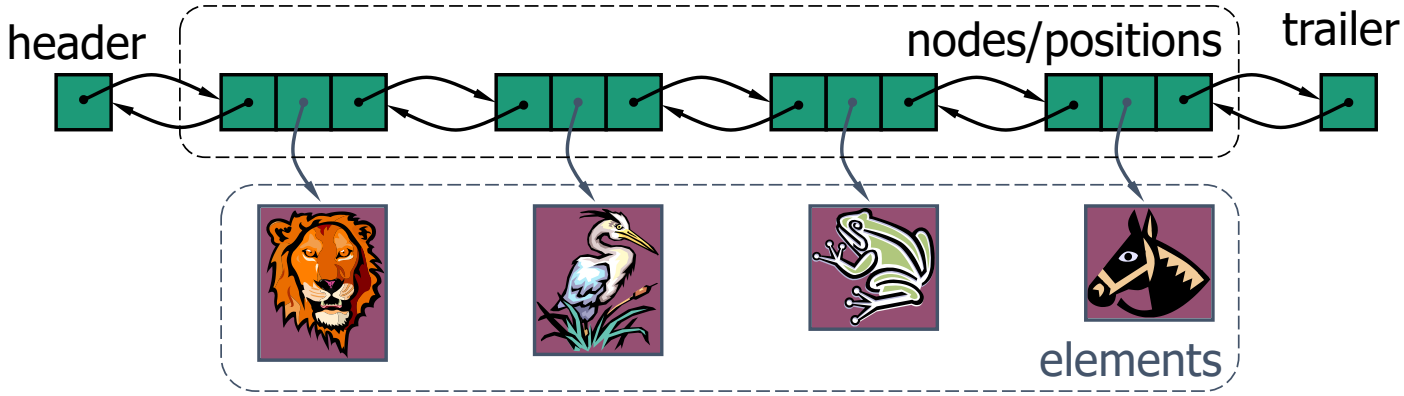
Doubly-Linked Lists



Doubly Linked List

- A doubly linked list provides a natural implementation of the Node List ADT
- Nodes implement Position and store:
  - element
  - link to the previous node
  - link to the next node
- Special trailer and header nodes

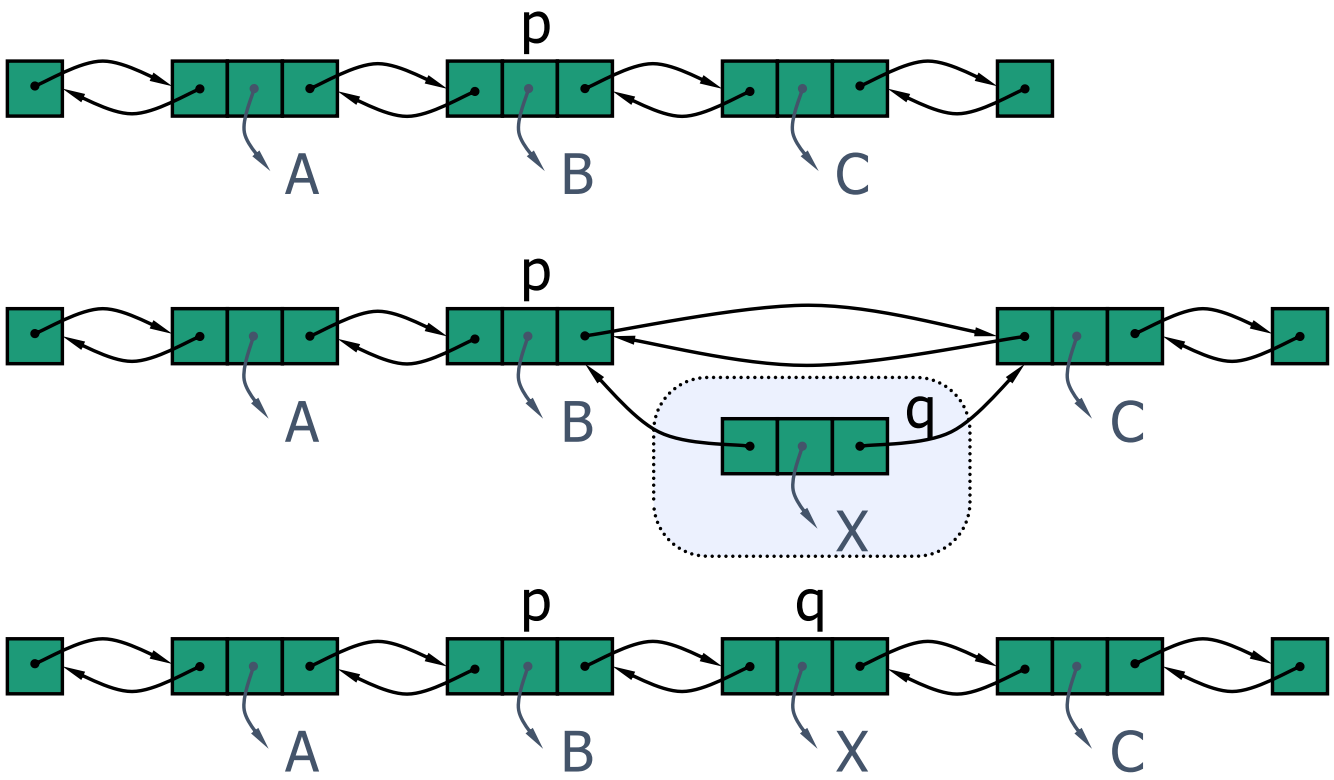




Insertion

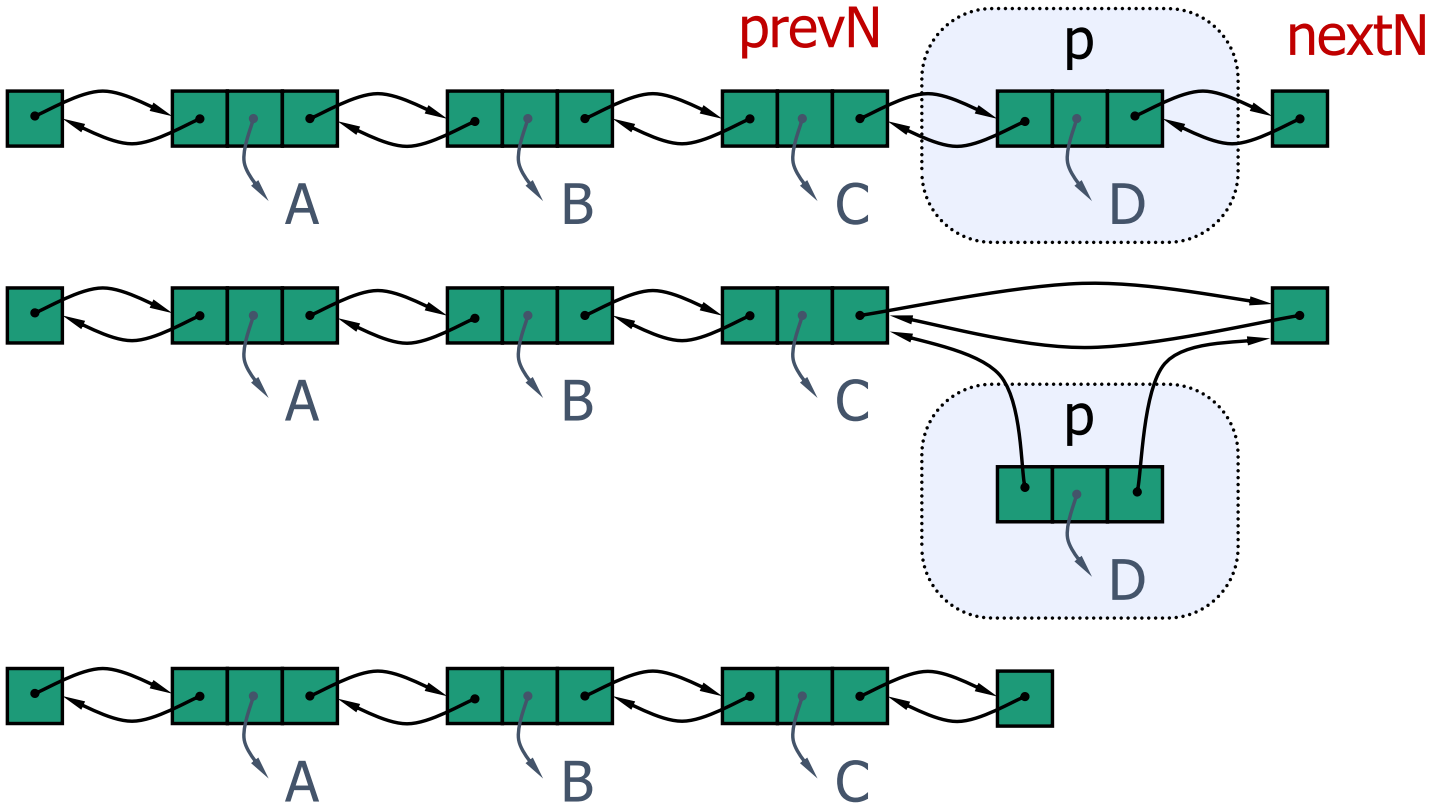
- Insert a new node, q, between p and its successor.

q = node('X')
q.next = p.next
q.prev = p
p.next.prev = q
p.next = q



Deletion

- Remove a node, p, from a doubly-linked list.



prevN = p.prev
nextN = p.next
prevN.next = nextN
nextN.prev = prevN

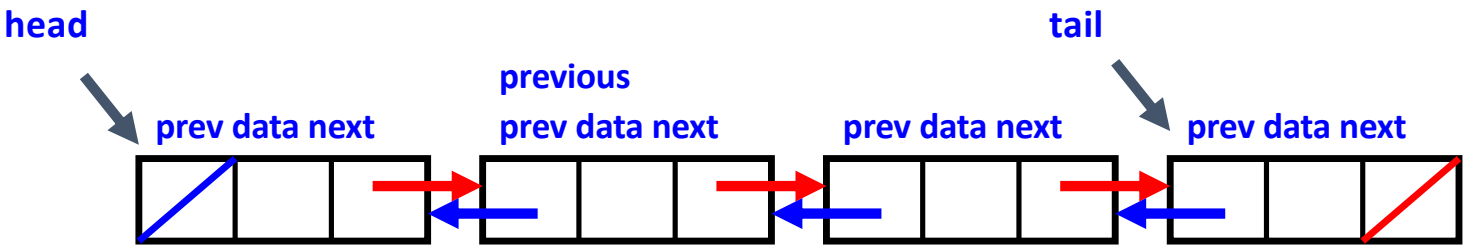
Doubly-Linked List with header node

```
1  class _DoublyLinkedBase:
2    """A base class providing a doubly linked list representation."""
3
4    class _Node:
5      """Lightweight, nonpublic class for storing a doubly linked node."""
6      (omitted here; see previous code fragment)
7
8    def __init__(self):
9      """Create an empty list."""
10     self._header = self._Node(None, None, None)
11     self._trailer = self._Node(None, None, None)
12     self._header._next = self._trailer                # trailer is after header
13     self._trailer._prev = self._header                # header is before trailer
14     self._size = 0                                    # number of elements
15
16   def __len__(self):
17     """Return the number of elements in the list."""
18     return self._size
19
20   def is_empty(self):
21     """Return True if list is empty."""
22     return self._size == 0
23
```

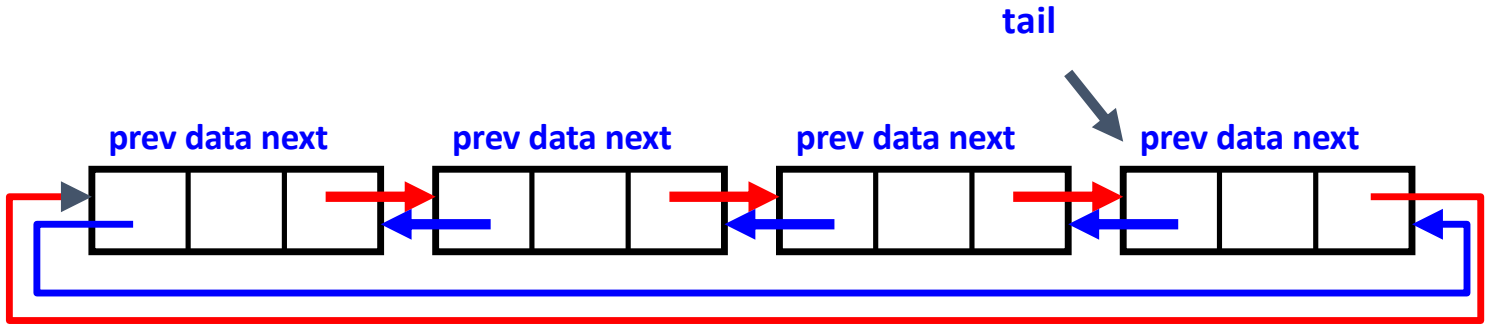
```
class _Node:
  """Lightweight, nonpublic class for storing a doubly linked node."""
  __slots__ = '_element', '_prev', '_next'  # streamline memory

  def __init__(self, element, prev, next):          # initialize node's fields
    self._element = element                         # user's element
    self._prev = prev                               # previous node reference
    self._next = next                               # next node reference
```

```
24   def _insert_between(self, e, predecessor, successor):
25     """Add element e between two existing nodes and return new node."""
26     newest = self._Node(e, predecessor, successor)   # linked to neighbors
27     predecessor._next = newest
28     successor._prev = newest
29     self._size += 1
30     return newest
31
32   def _delete_node(self, node):
33     """Delete nonsentinel node from the list and return its element."""
34     predecessor = node._prev
35     successor = node._next
36     predecessor._next = successor
37     successor._prev = predecessor
38     self._size -= 1
39     element = node._element                          # record deleted element
40     node._prev = node._next = node._element = None   # deprecate node
41     return element                                   # return deleted element
```

Doubly Linked List



Doubly Circular List



Applications

- Polynomial Expression

- Multilists

Polynomial expression

How about ... ?

$A = 5x^3 + 4x^2 - 7x + 10$

$+$

$B = x^3 + 2x - 8$

$C = 6x^3 + 4x^2 - 5x + 2$

$5x^{85} + 7x + 1$

$+$

$x^{76} - 8$

What data structure will you use?

Array?

Array?

Sparse -> Linked List

(has lots of 0 data)

1. class หนึ่งๆ มีใครลงบ้าง 2. นร. คนหนึ่งๆ ลง class ใดบ้าง