ENG 346
Data Structures and Algorithms for Artificial Intelligence
Linked Lists

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https://github.com/mehmetpekmezci/GTU-ENG-346

ENG-346 Teams code is **0uv7jlm**

Agenda

- Singly Linked Lists
- Stacks Revisited
- Queues Revisited
- Doubly Linked Lists

Linked List

- Organize and store a collection of elements, called nodes, in a linear sequence

- Each node in a linked list has
  - Data: Actual value or information to store in the list.
  - Reference(s): Represents the connection(s) between nodes in the sequence.

- Type of linked lists:
  - Singly linked list
  - Doubly linked list
  - Circular linked list

Advantages of Linked Lists

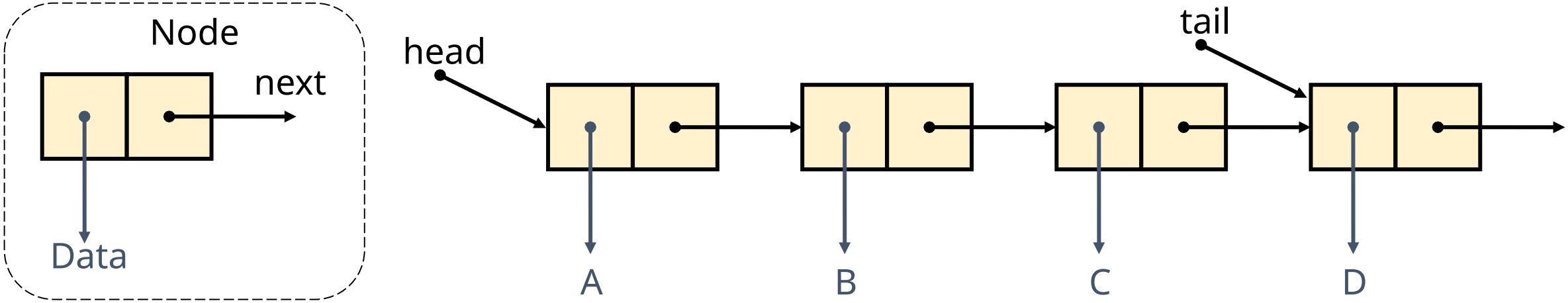
- Dynamic Size: Can easily grow or shrink in size by adding or removing nodes.
- Efficient Insertions and Deletions: Insertions and deletions at the beginning or middle of a linked list can be done in constant time.
- Memory Efficiency: Linked lists use memory more efficiently since they allocate memory for each node as needed.
- No Need for Pre-allocation: Linked lists don't require you to specify the size of the list in advance.
- Constant-Time Insertions at the Head.
- Easy Implementation of Other Data Structures like stacks, queues, and hash tables.

Disadvantages of Linked Lists

- Inefficient Random Access: Accessing an element at a specific index in a linked list can be inefficient, taking O(n) time in the worst case.
- Increased Memory Overhead: Each node in a linked list requires additional memory to store the reference to the next node.
- Slower Traversal: Traversing a linked list can be slower than iterating through an array because it involves following references from one node to the next.

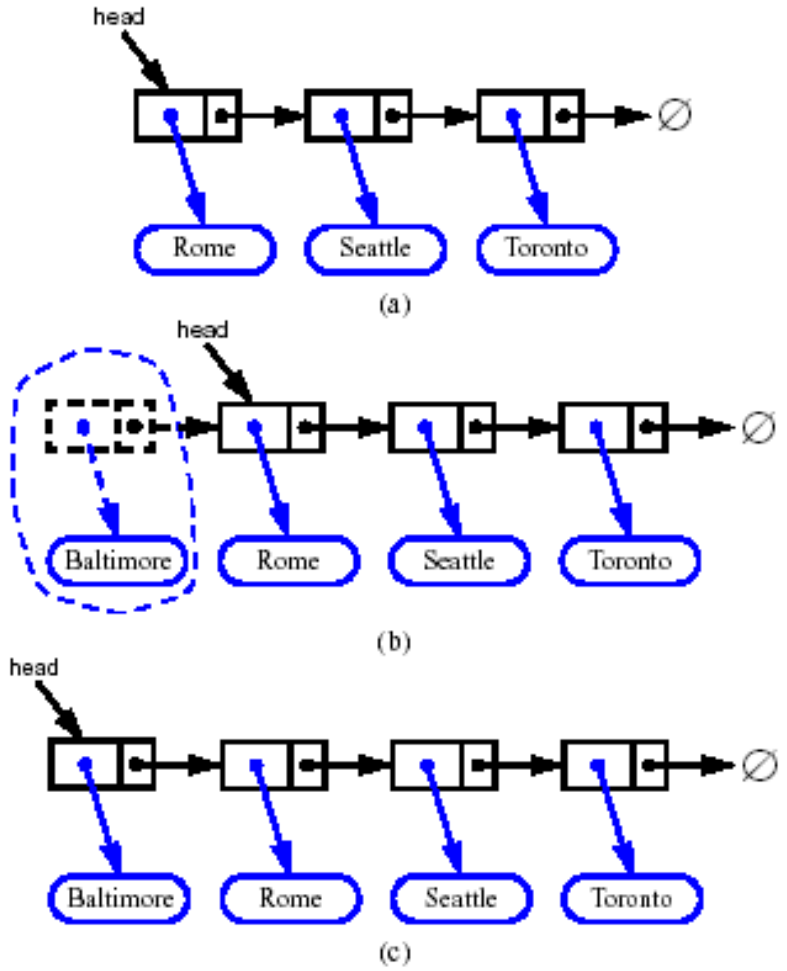
Singly Linked Lists

- A singly linked list is a concrete data structure consisting of a sequence of nodes, starting from a head pointer.
- Each node stores
  - Data
  - Link to the next node



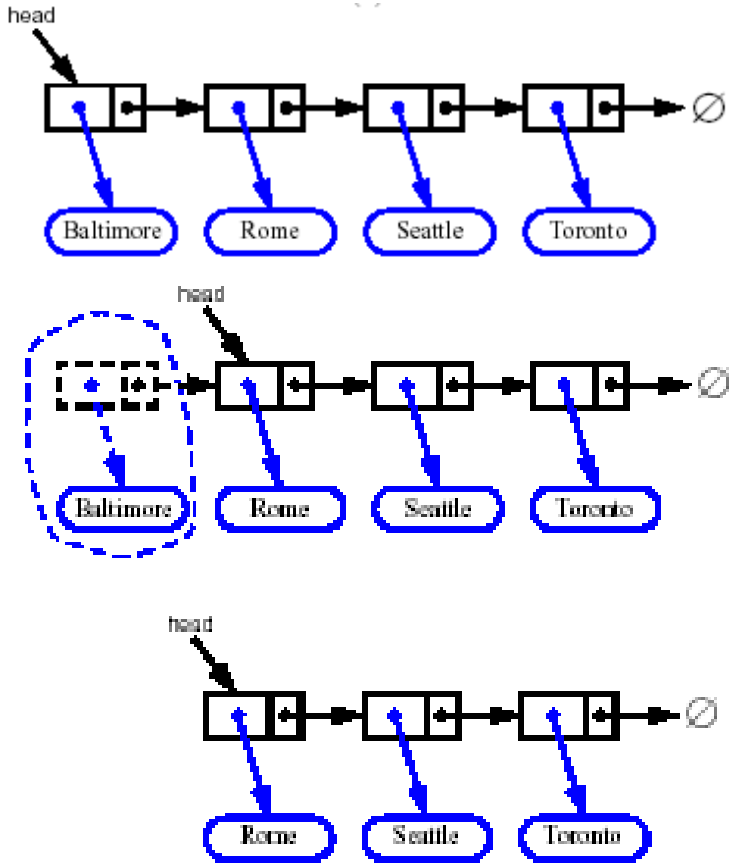
Inserting at the Head

- Allocate a new node
- Insert new element
- Have new node point to old head
- Update head to point to new node



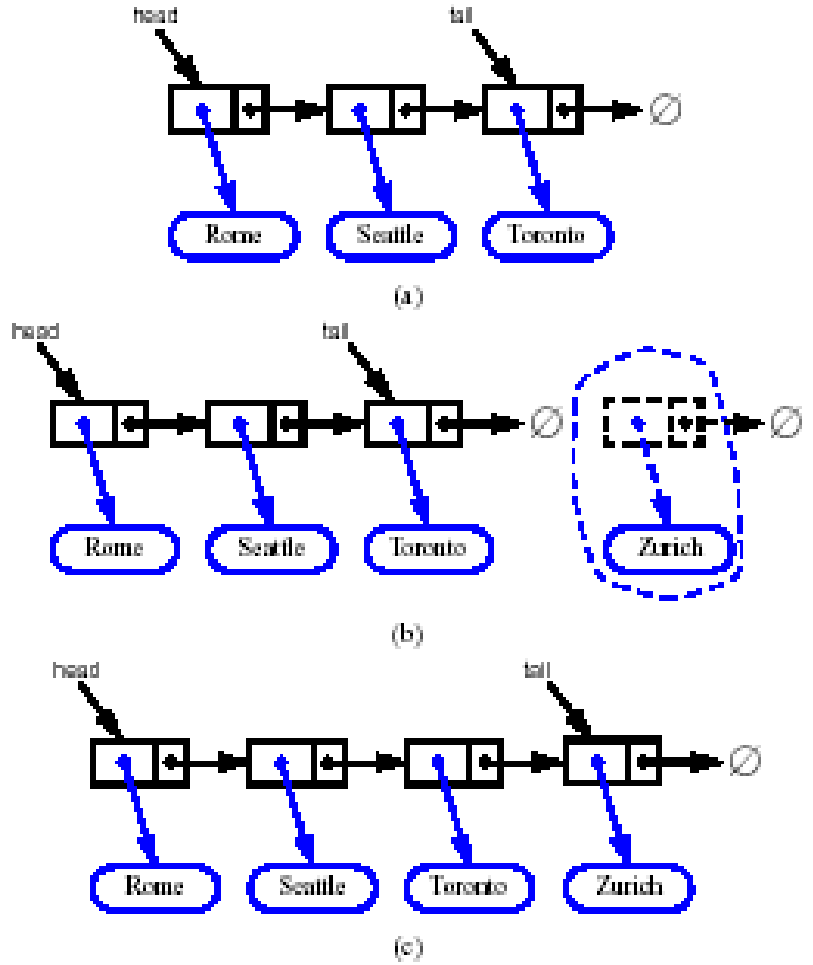
Removing from the Head

- Update head to point to next node in the list
- Allow garbage collector to reclaim the former first node



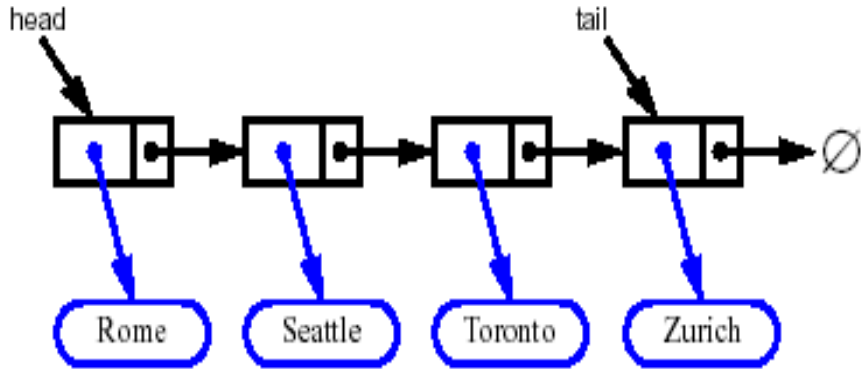
Inserting at the Tail

- Allocate a new node
- Insert new element
- Have new node point to null
- Have old last node point to new node
- Update tail to point to new node



Removing from 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



Stack as a Linked List

- Implement a stack with a singly linked list
- The top element = 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

- Implement a queue with a singly linked list
  - The front element = the first node
  - The rear element = the last node
- The space used is O(n) and each operation of the Queue ADT takes O(1) time

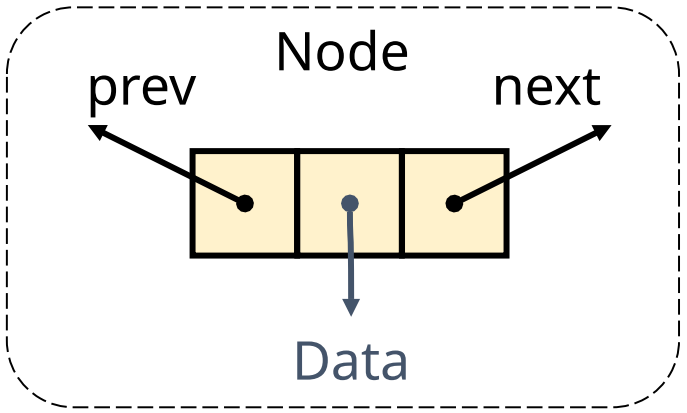
Linked-List Queue in Python

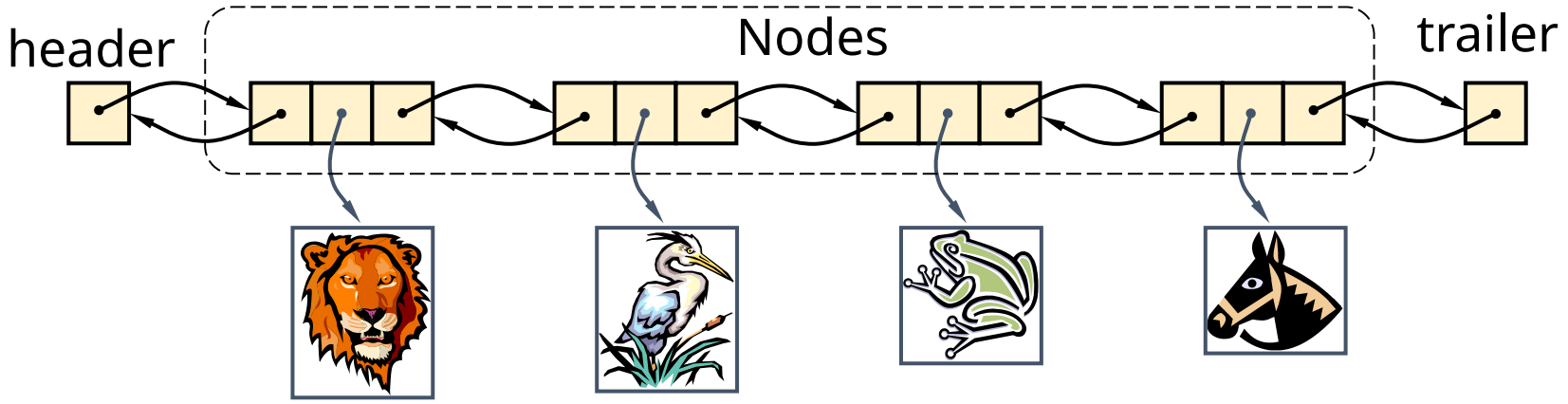
```
1  class LinkedQueue:
2    """FIFO queue implementation using a singly linked list for storage."""
3
4    class _Node:
5      """Lightweight, nonpublic class for storing a singly linked node."""
6      (omitted here; identical to that of LinkedStack._Node)
7
8    def __init__(self):
9      """Create 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
```

```
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 List

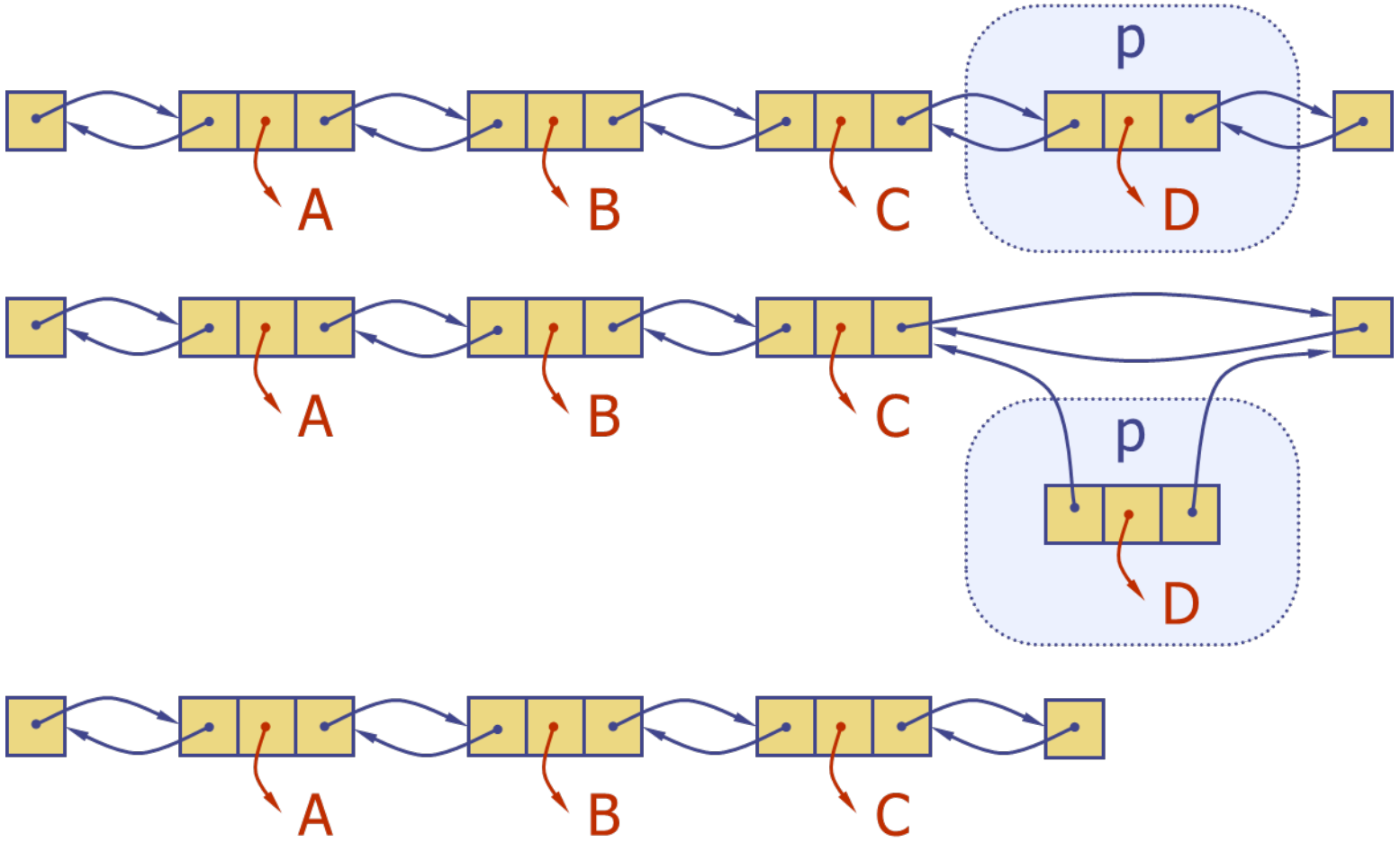
- A linked list which can be traversed in both directions.
- Each Node stores:
  - Data
  - Link to the previous node
  - Link to the next node





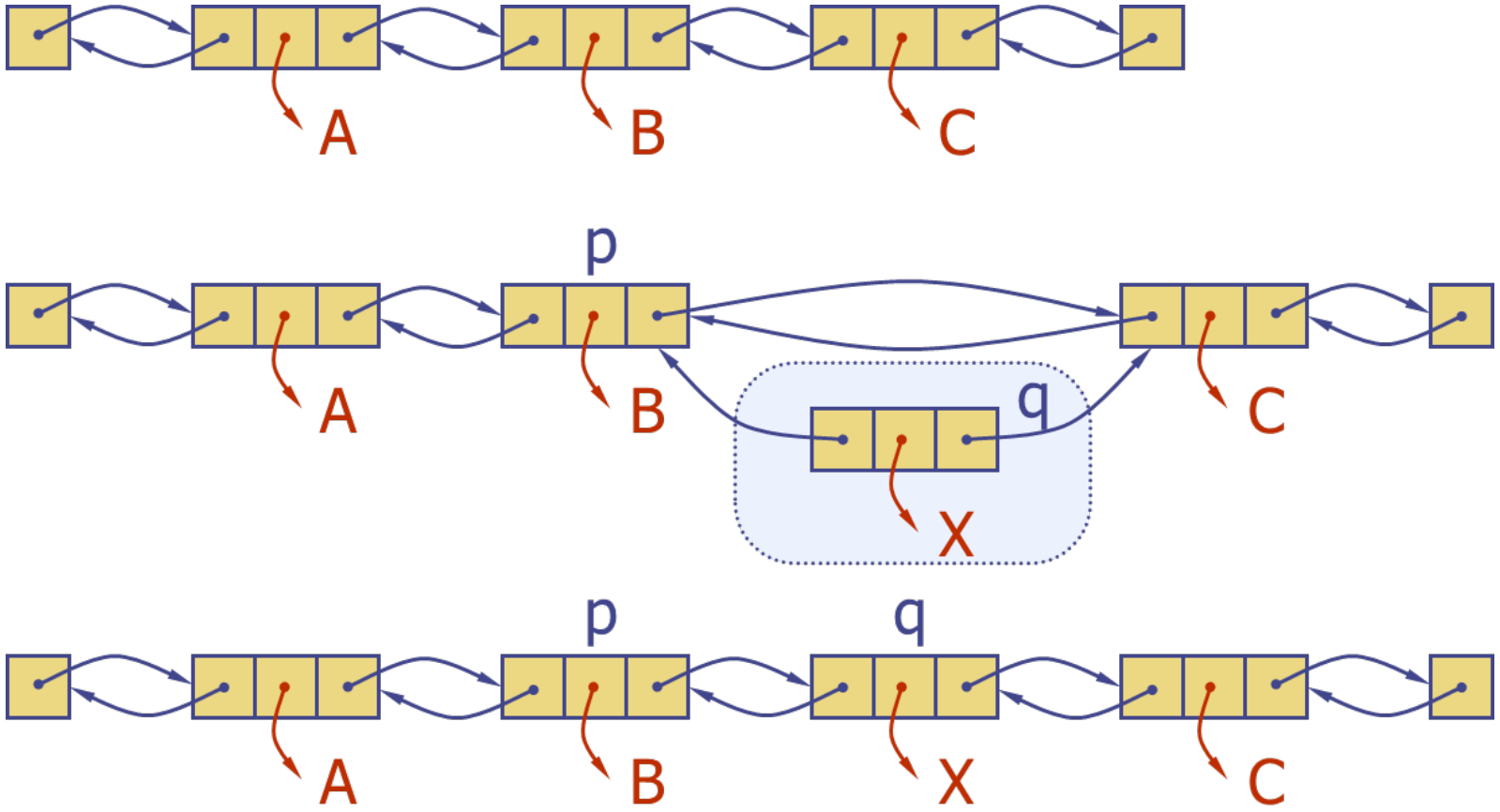
Deletion from Doubly Linked List

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



Insertion to Doubly Linked List

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



Doubly Linked List in Python

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```
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):
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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."""
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```

```
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
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- Efficient Insertions and Deletions: Insertions and deletions at the beginning or middle of a linked list can be done in constant time.
- Memory Efficiency: Linked lists use memory more efficiently since they allocate memory for each node as needed.
- No Need for Pre-allocation: Linked lists don't require you to specify the size of the list in advance.
- Constant-Time Insertions at the Head.
- Easy Implementation of Other Data Structures like stacks, queues, and hash tables.

1. Dynamic Size: Linked lists can easily grow or shrink in size by adding or removing nodes. In contrast, regular lists (arrays) are often allocated a fixed amount of memory, and resizing them can be inefficient and error-prone.
2. Efficient Insertions and Deletions: Insertions and deletions at the beginning or middle of a linked list can be done in constant time (O(1)) if you have a reference to the node where the operation is to be performed. In contrast, adding or removing elements in the middle of a regular list requires shifting elements, which can be O(n) in the worst

Disadvantages of Linked Lists

- Inefficient Random Access: Accessing an element at a specific index in a linked list can be inefficient, taking O(n) time in the worst case.
- Increased Memory Overhead: Each node in a linked list requires additional memory to store the reference to the next node.
- Slower Traversal: Traversing a linked list can be slower than iterating through an array because it involves following references from one node to the next.

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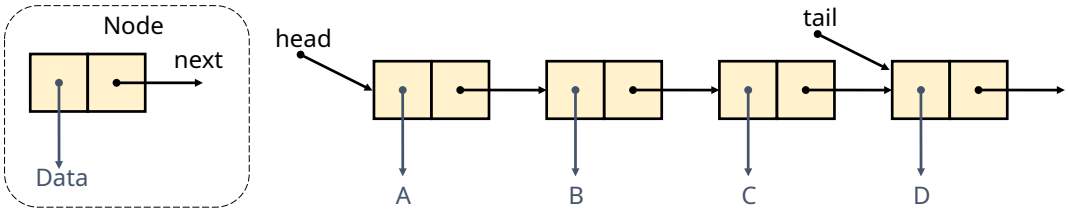

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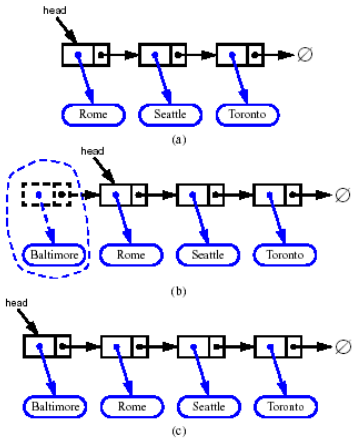

Removing from the Head

- Update head to point to next node in the list
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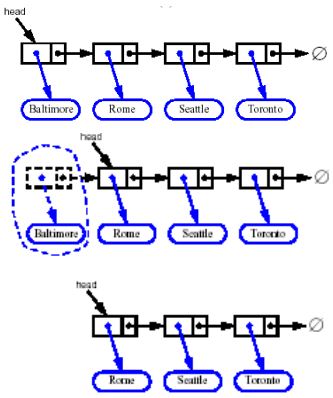

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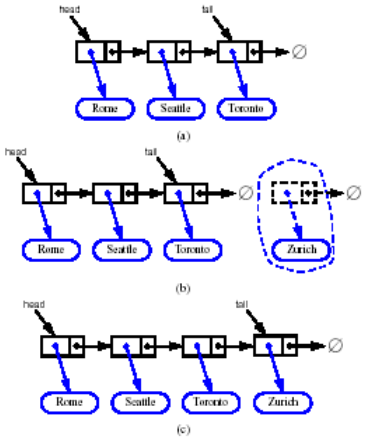
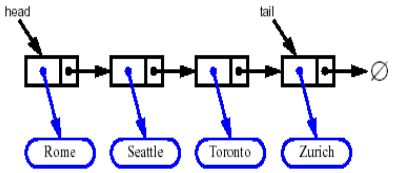


Removing from the Tail

- 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



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```

```
23   def is_empty(self):
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27   def push(self, e):
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```
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.
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45     if self.is_empty():
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Queue as a Linked List

- Implement a queue with a singly linked list
  - The front element = the first node
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  """FIFO queue implementation using a singly linked list for storage."""

  class _Node:
    """Lightweight, nonpublic class for storing a singly linked node."""
    (omitted here; identical to that of LinkedStack._Node)

  def __init__(self):
    """Create an empty queue."""
    self._head = None
    self._tail = None
    self._size = 0                          # number of queue elements

  def __len__(self):
    """Return the number of elements in the queue."""
    return self._size

  def is_empty(self):
    """Return True if the queue is empty."""
    return self._size == 0

  def first(self):
    """Return (but do not remove) the element at the front of the queue."""
    if self.is_empty():
      raise Empty('Queue is empty')
    return self._head._element              # front aligned with head of list
```

```
  def dequeue(self):
    """Remove and return the first element of the queue (i.e., FIFO).

    Raise Empty exception if the queue is empty.
    """
    if self.is_empty():
      raise Empty('Queue is empty')
    answer = self._head._element
    self._head = self._head._next
    self._size -= 1
    if self.is_empty():                     # special case as queue is empty
      self._tail = None                     # removed head had been the tail
    return answer

  def enqueue(self, e):
    """Add an element to the back of queue."""
    newest = self._Node(e, None)            # node will be new tail node
    if self.is_empty():
      self._head = newest                   # special case: previously empty
    else:
      self._tail._next = newest
    self._tail = newest                     # update reference to tail node
    self._size += 1
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- Each Node stores:
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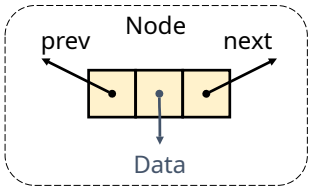
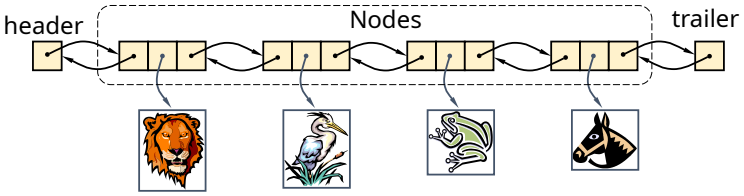
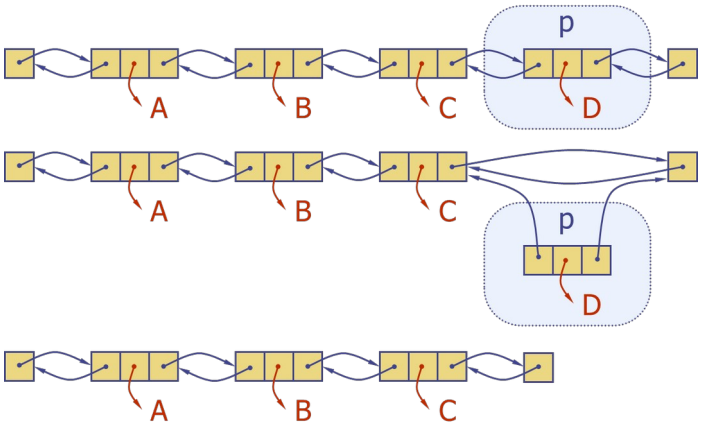




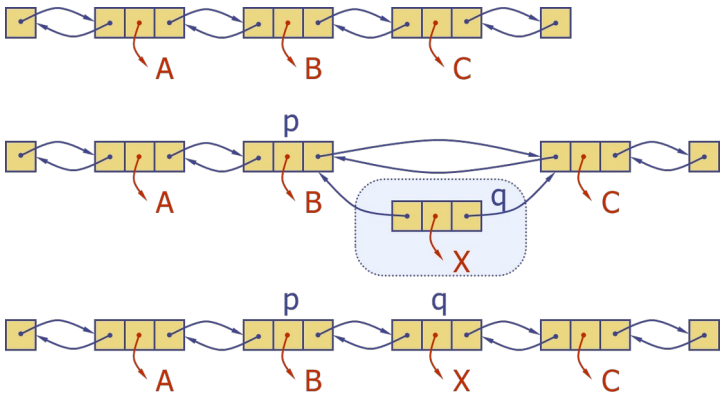
Deletion from Doubly Linked List

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



Insertion to Doubly Linked List

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



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  def __init__(self):
    """Create an empty list."""
    self._header = self._Node(None, None, None)
    self._trailer = self._Node(None, None, None)
    self._header._next = self._trailer                  # trailer is after header
    self._trailer._prev = self._header                  # header is before trailer
    self._size = 0                                      # number of elements

  def __len__(self):
    """Return the number of elements in the list."""
    return self._size

  def is_empty(self):
    """Return True if list is empty."""
    return self._size == 0

```

```
  def _insert_between(self, e, predecessor, successor):
    """Add element e between two existing nodes and return new node."""
    newest = self._Node(e, predecessor, successor)   # linked to neighbors
    predecessor._next = newest
    successor._prev = newest
    self._size += 1
    return newest

  def _delete_node(self, node):
    """Delete nonsentinel node from the list and return its element."""
    predecessor = node._prev
    successor = node._next
    predecessor._next = successor
    successor._prev = predecessor
    self._size -= 1
    element = node._element                          # record deleted element
    node._prev = node._next = node._element = None   # deprecate node
    return element                                   # return deleted element
```