InvertedIndexReport

December 17, 2016

1 INVERTED INDEX SEARCH ENGIN

source code at my github repo

2 1. Report

2.1 Early Plan

first, I was trying to write the whole project in python3.5 and with the aid of the Wiley book, Algorithm and > Data structure in python, and I read the book up to end of chapter 8: trees, and I have built my code on that book basic, many expertise of python programming like annotation and decorator which supports in python3.5.2 had been used in this period and code developed practical, clean, designed, but snails, which takes about 2 weeks to complete, and are stored in my github repo: DataStructure_Python, in implementing TST and TrieST I have used the another famous book, Algorithm.4ed published by Addison-Wesley, which was written java friendly, I used its algorithm to developed my code.

2.2 Middle Plan

in middle of the project I decided to write the whole project in Jupyter notebook, it was challenging and also fun. but if you (like me) don't have a relible memory for remembering all of the methods for a class or variables, interacting with Jupyter gets hard.

2.3 Final Product

after the backend of the project completed, I should begin to implement the Graphical user interface (GUI), first I started to learn basic of Tkinter layout manager, but after a day or two, I gave up and search for something like swing in python, so I found Jython (an extinct project !!!!!) unfortunately Jython just support python2.7, but that was not a bad news because python2.7 was my first programming language that I learned. I translate all of my code in python2.7 and start coding in Jython with Jython compiler. after a while a faced with some frightening exception like "instance error" or "null pointer exception" or "java.lang.Runnable exception". But fortunately I overcame them finally and the whole project survive.

2.3.1 dependencies:

```
to run the project you need jython compiler, you can install this via this command:

'sudo apt-get install Jython'


to open jupyter notebook you should donwload this packages:
```

'sudo apt-get install anaconda3'

'sudo apt-get install ipython-notebook'

'sudo apt-get install jupyter'

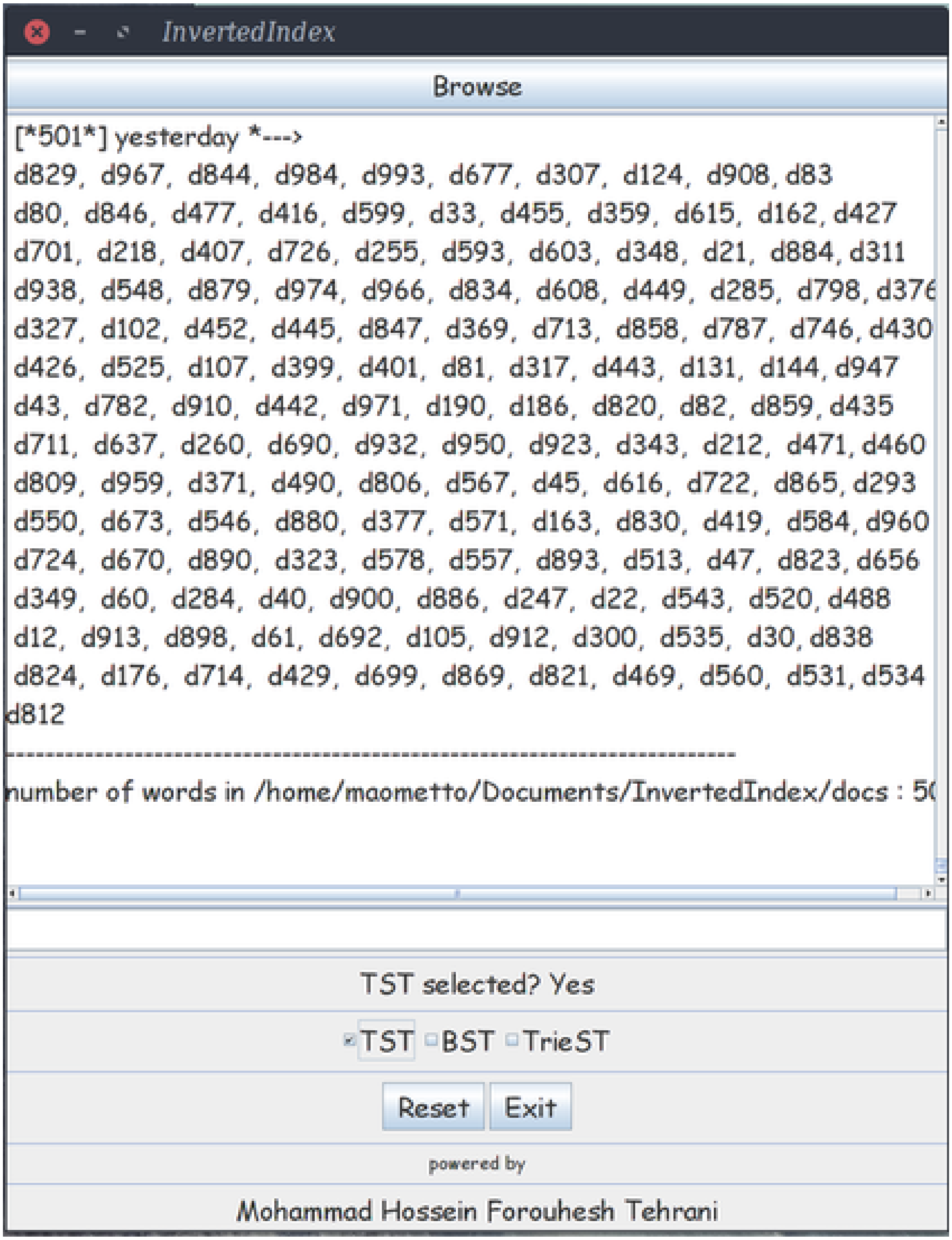
2.4 here are some screenshoots of the project:

describtion:

this window will open when you run the program.

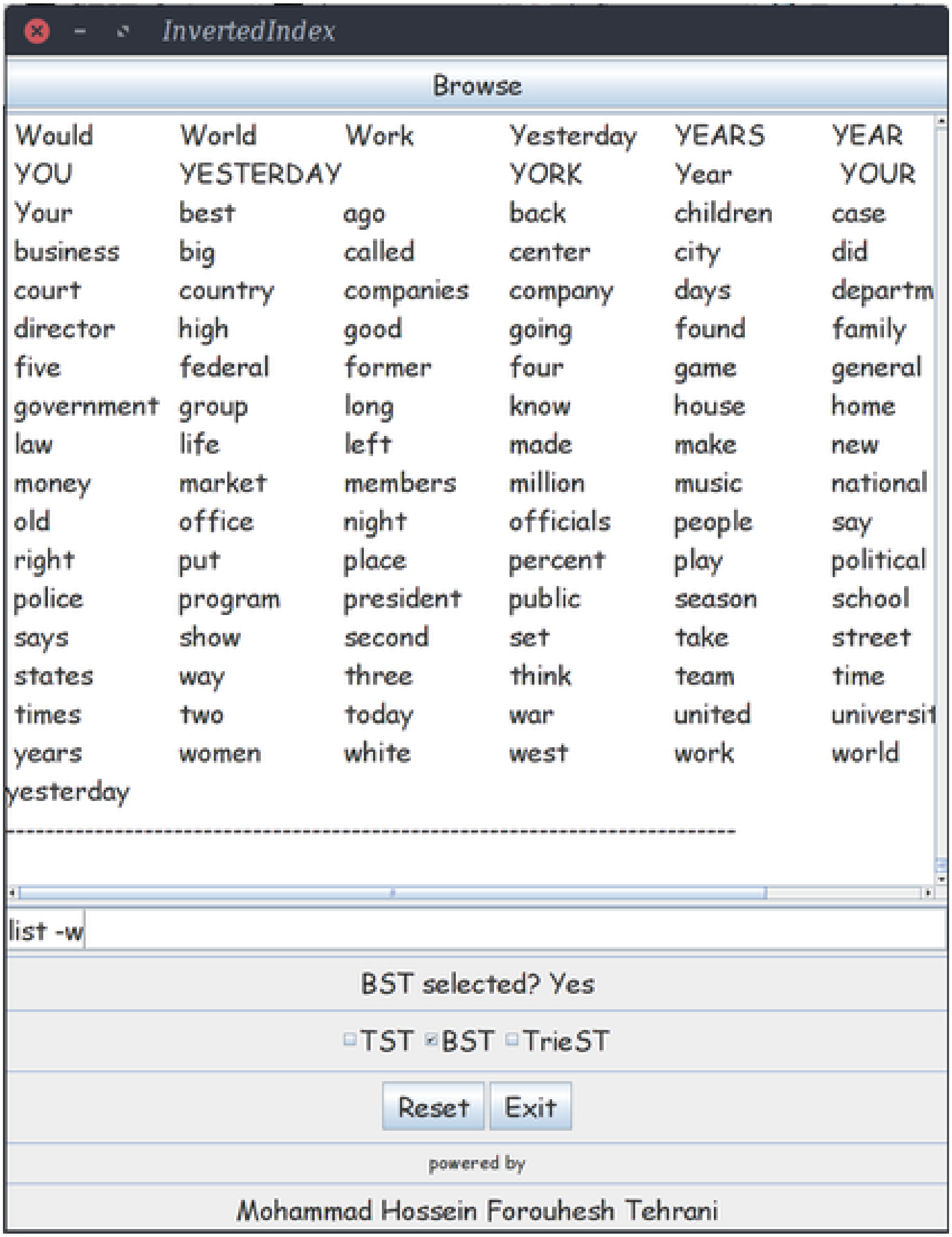
describtion:

`when you hit the TST checkbox after a while, this will be shown to you.`



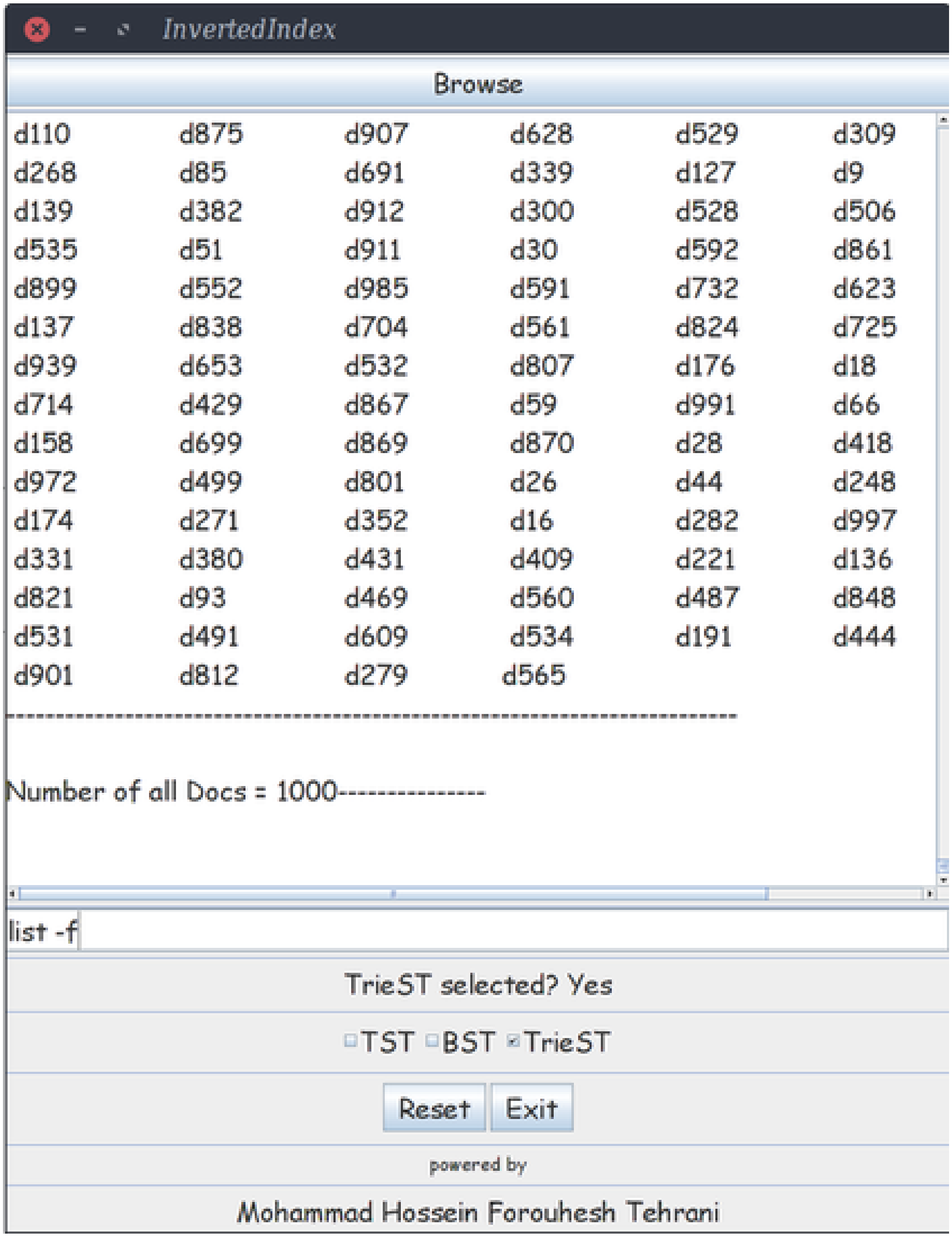
describtion:

`you may want just your words.`



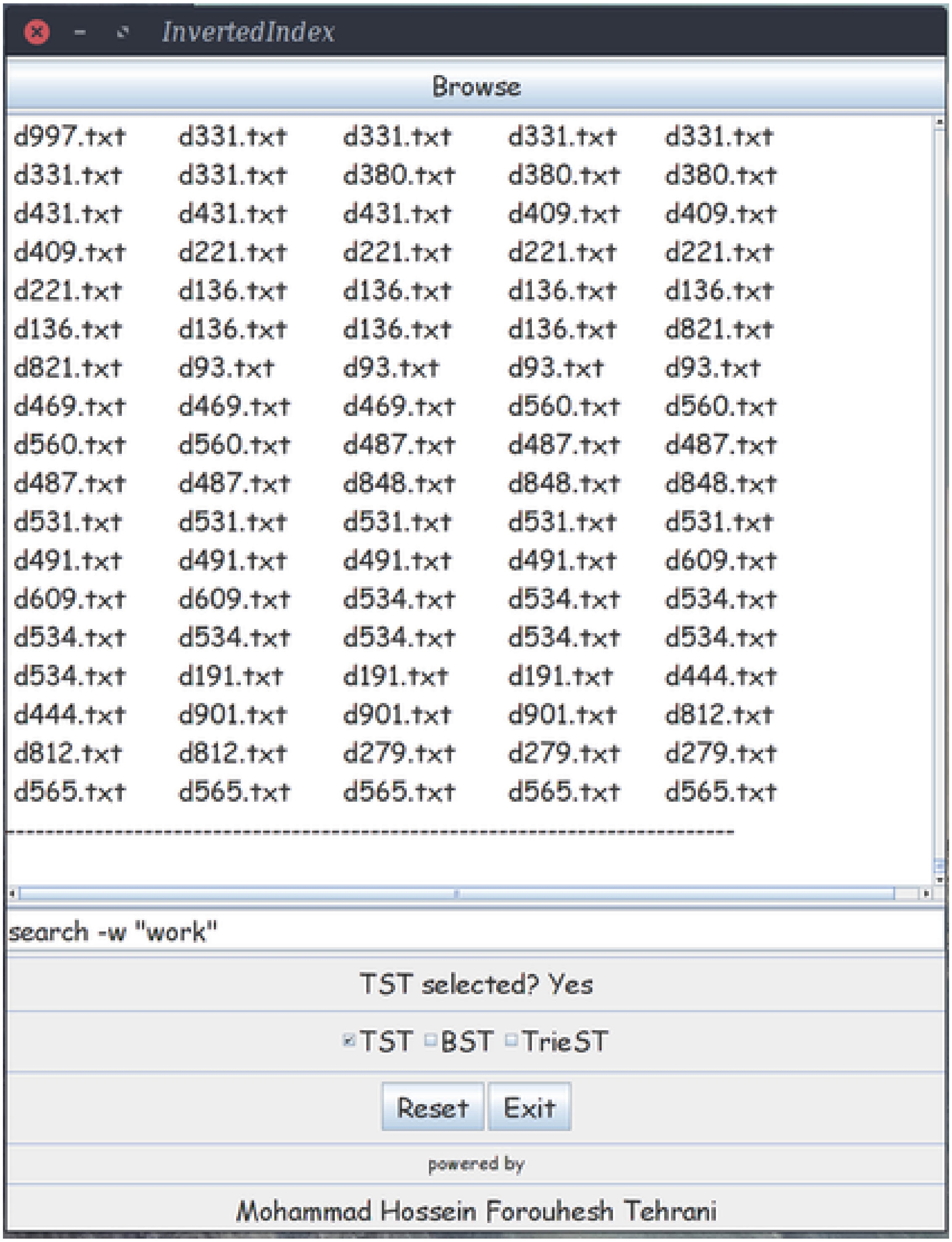
describtion:

`with this command you can see the files in the directory.`



describtion:

`you can search the words.`



3 2. Here is a short describtion of the data structure code:

3.1 DynamicArray

3.1.1 preview :

`dynamic cpython array instead of python list`

In [1]:
```python
import ctypes


class DynamicArray:
    """
    dynamic python array instead of python list
    """
    def __init__(self):
        """
        create an empty array
        """
        self._number_of_actual_elements = 0
        self._capacity = 1
        self._low_level_array = self._make_array(self._capacity)

    def __len__(self) -> int:
        """

        :return: the length of array
        """
        return self._number_of_actual_elements

    def  __getitem__(self, index: int) -> object:
        """

        :type index: int
        :param index: the index of desired item in the array.
        :return: return the item.
        """
        if not 0 <= index < self._number_of_actual_elements:
            raise IndexError("index out of range")
        return self._low_level_array[index]

    def is_empty(self):
        if self._number_of_actual_elements == 0:
            return True
        return False

    def pop(self):
        if self.is_empty():
            raise Exception("empty array")
        var = self._low_level_array[self._number_of_actual_elements - 1]
        self._number_of_actual_elements -= 1
        return var

    def append(self, item: object):
        """
        add object to the end of array
        :param item: desired object
        """
        if self._number_of_actual_elements == self._capacity:
            self._resize(2 * self._capacity)
        self._low_level_array[self._number_of_actual_elements] = item
        self._number_of_actual_elements += 1
```

```
    def _resize(self, new_size: int):
        """
        resize the internal array to capacity new_size
        :param new_size: desired capacity
        """
        new_array = self._make_array(new_size)
        for k in range(self._number_of_actual_elements):
            new_array[k] = self._low_level_array[k]
        self._low_level_array = new_array
        self._capacity = new_size

    def _make_array(self, capacity: int) -> object:
        """
        return new array with fixed capacity.
        :param capacity: the desired capacity
        :return: return ctypes array
        """
        return (capacity * ctypes.py_object)()
```

3.2 LinkedList

3.2.1 preview:

this is my linked list class which supports many feature like adding first and last and between, it

```
In [2]: class LinkedList:
            class Node:
                """
                Lightweight, nonpublic class for storing a doubly linked node.
                """
                __slots__ = 'element', 'prev', 'after', 'upside_arrow', 'downside_arrow'  # streamline

                def __init__(self, element, prev, after):  # initialize node's fields
                    self.element = element  # user's element
                    self.prev = prev  # previous node reference
                    self.after = after

            def __init__(self):
                """
                Create an empty list.
                """
                self.header = self.Node(None, None, None)
                self.trailer = self.Node(None, None, None)
                self.header.after = self.trailer  # trailer is after header
                self.trailer.prev = self.header  # header is before trailer
                self.size = 0

            def __len__(self):
                return self.size

            def __iter__(self):
                if self.is_empty():
                    yield self.Node(None, None, None)
                current = self.header
```

```python
    while current is not None:
        yield current
        current = current.after

def is_empty(self) -> bool:
    return self.size == 0

def insert_between(self, element, predecessor: Node, successor: Node) -> Node:
    newest = self.Node(element, predecessor, successor)  # linked to neighbors
    predecessor.after = newest
    successor.prev = newest
    self.size += 1
    return newest

def delete_node(self, node: Node) -> type(Node.element):
    predecessor = node.prev
    successor = node.after
    predecessor.after = successor
    successor.prev = predecessor
    self.size -= 1
    element = node.element  # record deleted element
    node.prev = node.after = node.element = None  # deprecate node
    return element

# ------------------------------------------------------------------------------------------

def add_first(self, element: type(Node.element)) -> Node:
    return self.insert_between(element, self.header, self.header.after)

def add_last(self, element: type(Node.element)) -> Node:
    return self.insert_between(element, self.trailer.prev, self.trailer)

def add_before(self, prevElement: type(Node.element), element: type(Node.element)) -> Node:
    original = self.search(prevElement)
    return self.insert_between(element, original.prev, original)

def add_after(self, nextElement: type(Node.element), element: type(Node.element)) -> Node:
    original = self.search(nextElement)
    return self.insert_between(element, original, original.after)

# ------------------------------------------------------------------------------------------

def delete(self, undesireElement) -> type(Node.element):
    original = self.search(undesireElement)
    if original is None:
        return
    return self.delete_node(original)

def search(self, desireElement: type(Node.element)) -> Node:
    head = self.header
    while head.after is not None:
        head = head.after
        if head.element == desireElement:
            return head
```

```
        return None
```

3.3 LinkedStack

```
In [3]: class LinkedStack():

            # ------------------------------------- Nested Class ------------------------------------
            class Node:

                __slots__ = 'element', 'next'  # streamline memory usage

                def __init__(self, element, next):  # initialize node field
                    self.element = element  # reference to current element
                    self.next = next  # reference to the next node

            # ------------------------------------- Stack Methods -----------------------------------
            def __init__(self):
                self.head = self.Node(None, None)  # head is a kind of node
                self.size = 0

            def __len__(self) -> int:
                return self.size

            def __iter__(self):
                if self.is_empty():
                    yield
                current = self.head
                while current is not None:
                    yield current
                    current = current.next

            def is_empty(self) -> bool:
                return self.size == 0

            def push(self, element: type(Node.element)):
                self.head = self.Node(element, self.head)  # created and linked a new node
                self.size += 1  # size is incremented

            def top(self) -> type(Node.element):
                if self.is_empty():
                    raise Exception("stack is empty")
                return self.head.element

            def pop(self) -> Node:
                if self.is_empty():
                    raise Exception("stack is empty")
                answer = self.head.element
                self.head = self.head.next  # bypass the former node :)
                self.size -= 1  # size decremented
                return answer

            def querry(self):
                """
                for TTD and debuging.
```

```
        """
        for k in self:
            print(k.element)
```

3.4 LinkedQueue

```
In [4]: class LinkedQueue:
            """
            FIFO implementation of queue with using linked list as internal storage
            """

            # ---------------------------------- Nested Class ------------------------------
            class Node:
                "light weight class for storing liked node"
                __slots__ = 'element', 'next'                       # streamline memory usage

                def __init__(self, element, next):                  # initialize node field
                    self.element = element                          # reference to current element
                    self.next = next                                # reference to the next node

            # ---------------------------------- Stack Methods ------------------------------
            def __init__(self):
                self._head = self.Node(None, None)
                self._tail = self.Node(None, None)
                self._size = 0

            def __len__(self) -> int:
                """
                return the number of elements in the linked list
                :return: integer
                """
                return self._size

            def __iter__(self):
                """
                iterate thorough the linked list
                """
                if self.is_empty():
                    yield
                current = self._head
                while current is not None:
                    yield current
                    current = current.next

            def is_empty(self) -> bool:
                """

                :return: bool True if list is empty and False otherwise
                """
                return self._size == 0

            def first(self):
                """
                just Return the first element in the queue
```

```
        """
        if self.is_empty():
            raise Exception("empty Error")
        return self._head.element

    def dequeue(self):
        """
        remove and return the first element
        """
        if self.is_empty():
            raise Exception("empty Error")
        var = self._head.element
        self._head = self._head.next
        self._size -= 1
        if self.is_empty():
            self._tail = None
        return var

    def enqueue(self, element):
        newest = self.Node(element, None)
        if self.is_empty():
            self._head = newest
        else:
            self._tail.next = newest
        self._tail = newest
        self._size += 1

    def querry(self):
        """
        for TTD and debuging.
        """
        for k in self:
            print(k.element)
```

3.5 Binary Search Tree

3.5.1 preview:

```
my BST class is implemented with aim of inner node class and an abstract meta class which provide th
```

In [5]:
```
from abc import ABCMeta, abstractmethod
import os
import re


class ABCNode(metaclass=ABCMeta):
    @abstractmethod
    def insert(self, key, NodeType):
        pass

    @abstractmethod
    def find(self, key):
        pass

    @abstractmethod
```

```python
    def minimum(self):
        pass

    @abstractmethod
    def successor(self):
        pass

    @abstractmethod
    def delete(self):
        pass


class BST(object):
    class Node(ABCNode):
        __slots__ = "key", "parent", "left", "right", "size", "repetition"

        # ----------------------------------------------------------------------------------

        def __init__(self, parent, key):
            """Create a new leaf with key t."""
            self.key = key
            self.parent = parent
            self.left = None
            self.right = None
            self.size = 1
            self.repetition = 1

        # ----------------------------------------------------------------------------------

        def update_stats(self):
            """Updates this node's size based on its children's sizes."""
            self.size = (0 if self.left is None else self.left.size) \
                        + (0 if self.right is None else self.right.size)

        # ----------------------------------------------------------------------------------

        def insert(self, key, NodeType) -> ABCNode:
            self.size += 1
            if key < self.key:
                if self.left is None:
                    self.left = NodeType(self, key)
                    return self.left
                else:
                    return self.left.insert(key, NodeType)
            elif key == self.key:
                self.repetition += 1
                return
            else:
                if self.right is None:
                    self.right = NodeType(self, key)
                    return self.right
                else:
                    return self.right.insert(key, NodeType)
```

```python
# ----------------------------------------------------------------------------

def find(self, key) -> ABCNode:
    """Return the node for key if it is in this tree, or None otherwise."""
    if key == self.key:
        return self
    elif key < self.key:
        if self.left is None:
            return None
        else:
            return self.left.find(key)
    else:
        if self.right is None:
            return None
        else:
            return self.right.find(key)

# ----------------------------------------------------------------------------

def rank(self, key) -> int:
    """Return the number of keys <= key in the subtree rooted at this node."""
    left_size = 0 if self.left is None else self.left.size
    if key == self.key:
        return left_size + 1
    elif key < self.key:
        if self.left is None:
            return 0
        else:
            return self.left.rank(key)
    else:
        if self.right is None:
            return left_size + 1
        else:
            return self.right.rank(key) + left_size + 1

def minimum(self) -> ABCNode:
    """Returns the node with the smallest key in the subtree rooted by this node."""
    current = self
    while current.left is not None:
        current = current.left
    return current

def successor(self) -> ABCNode:
    """
    Returns the node with the smallest key larger than this node's key,
    or None if this has the largest key in the tree.
    """
    if self.right is not None:
        return self.right.minimum()
    current = self
    while current.parent is not None and current.parent.right is current:
        current = current.parent
    return current.parent
```

```
        # ----------------------------------------------------------------------------------------

        def delete(self) -> ABCNode:
            """"Delete this node from the tree."""
            if self.left is None or self.right is None:
                if self is self.parent.left:
                    self.parent.left = self.left or self.right
                    if self.parent.left is not None:
                        self.parent.left.parent = self.parent
                else:
                    self.parent.right = self.left or self.right
                    if self.parent.right is not None:
                        self.parent.right.parent = self.parent
                current = self.parent
                while current.key is not None:
                    current.update_stats()
                    current = current.parent
                return self
            else:
                s = self.successor()
                self.key, s.key = s.key, self.key
                return s.delete()

        # ---------------------------------------------check for error------------------------

        def check(self, lower_key, higher_key):
            """
            Checks that the subtree rooted at key is a valid BST
            and all keys are between (lower_key, higher_key).
            """
            if lower_key is not None and self.key <= lower_key:
                raise Exception("BST RI violation")
            if higher_key is not None and self.key >= higher_key:
                raise Exception("BST RI violation")
            if self.left is not None:
                if self.left.parent is not self:
                    raise Exception("BST RI violation")
                self.left.check(lower_key, self.key)
            if self.right is not None:
                if self.right.parent is not self:
                    raise Exception("BST RI violation")
                self.right.check(self.key, higher_key)
            if self.size != 1 + (0 if self.left is None else self.left.size) + (
                    0 if self.right is None else self.right.size):
                raise Exception("BST RI violation")

        def __repr__(self) -> str:
            return "<BST Node, key:" + str(self.key) + ">"

    def __init__(self, NodeType=Node):
        self.root = None
        self.NodeType = NodeType
        self.psroot = self.NodeType(None, None)
```

```python
        self.content = DynamicArray()
        self.docs = DynamicArray()

    # ---------------------------------------------------------------------------------
    def reroot(self):
        self.root = self.psroot.left

    def insert(self, key) -> Node:
        """Insert key into this BST, modifying it in-place."""
        if self.root is None:
            self.psroot.left = self.NodeType(self.psroot, key)
            self.reroot()
            self.root.update_stats()
            return self.root
        else:
            return self.root.insert(key, self.NodeType)

    def add_doc(self, doc_name: str):
        self.docs.append(doc_name)

    # ---------------------------------------------------------------------------------

    def find(self, key) -> Node:
        """Return the node for key if is in the tree, or None otherwise."""
        if self.root is None:
            return None
        else:
            return self.root.find(key)

    def rank(self, key) -> int:
        """The number of keys <= key in the tree."""
        if self.root is None:
            return 0
        else:
            return self.root.rank(key)

    def traverse(self, node: Node = None) -> list:
        if node is None:
            node = self.root

        self.content.append(node)
        if node.left is not None:
            self.traverse(node=node.left)
        if node.right is not None:
            self.traverse(node=node.right)

    def delete(self, key) -> Node:
        node = self.find(key)
        if node is None:
            raise Exception("nadari in klid ro")
        deleted = node.delete()
        self.reroot()
        return deleted
```

```
    # ------------------------------------------------------------------------------------------

    def check(self):
        if self.root is not None:
            self.root.check(None, None)  # check in the Node class

    def __str__(self) -> str:
        if self.root is None:
            return '<empty tree>'

        def recurse(node):
            if node is None: return [], 0, 0
            label = str(node.key)
            left_lines, left_pos, left_width = recurse(node.left)
            right_lines, right_pos, right_width = recurse(node.right)
            middle = max(right_pos + left_width - left_pos + 1, len(label), 2)
            pos = left_pos + middle // 2
            width = left_pos + middle + right_width - right_pos
            while len(left_lines) < len(right_lines):
                left_lines.append(' ' * left_width)
            while len(right_lines) < len(left_lines):
                right_lines.append(' ' * right_width)
            if (middle - len(label)) % 2 == 1 and node.parent is not None and \
                            node is node.parent.left and len(label) < middle:
                label += '.'
            label = label.center(middle, '.')
            if label[0] == '.': label = ' ' + label[1:]
            if label[-1] == '.': label = label[:-1] + ' '
            lines = [' ' * left_pos + label + ' ' * (right_width - right_pos),
                     ' ' * left_pos + '/' + ' ' * (middle - 2) +
                     '\\' + ' ' * (right_width - right_pos)] + \
                    [left_line + ' ' * (width - left_width - right_width) + right_line

                     for left_line, right_line in zip(left_lines, right_lines)]
            return lines, pos, width

        return '\n'.join(recurse(self.root)[0])
```

3.6 Ternary Search Tree

3.6.1 preview :

based on string searching method and functionality.

```
In [6]: class TST:
            __slots__ = 'size', 'root', 'valid_words', 'docs'

            # ------------------------------ inner class ------------------------------

            class Node:
                __slots__ = 'key_char', 'left', 'mid', 'right', 'value'

                def __init__(self, key_char: str):
                    self.key_char = key_char
                    self.left = None
```

```python
            self.mid = None
            self.right = None
            self.value = str()

    # ------------------ --------- end of inner class ------------------------

    def __init__(self):
        self.root = TST.Node(" ")
        self.size = 0
        self.valid_words = LinkedQueue()
        self.docs = DynamicArray()

    def __sizeof__(self) -> int:
        return self.size

    def __contains__(self, item: str) -> bool:
        if item is None:
            raise Exception("nothing to be contained!!!")
        return self.__getitem__(item) is not None

    def __getitem__(self, item: str) -> str:
        if item is None:
            raise Exception("call __getitem__ with None argument")
        if len(item) == 0:
            raise Exception("item must have length >= 1")
        x = self.get(self.root, item, 0)
        if x is None:
            return None
        return x.value

    def intable(self, stream: object) -> tuple:
        try:
            integer = int(stream)
            return True, integer
        except Exception as err:
            return False, err

    def get(self, x: Node, item: str, d: int) -> Node:
        """
        return sub-trie corresponding to given key
        """
        if x is None:
            return None
        if len(item) == 0:
            raise Exception("item must have length >= 1")
        char = item[d]
        if char < x.key_char:
            return self.get(x.left, item, d)
        elif char > x.key_char:
            return self.get(x.right, item, d)
        elif d < len(item) - 1:
            return self.get(x.mid, item, d + 1)
        else:
            return x
```

```python
def put(self, item: str, value: int) -> None:
    """
    Inserts the key-value pair into the symbol table
    """
    if item is None:
        raise Exception("call __setitem__ with None argument")
    else:
        self.size += 1
    self.root = self.set(self.root, item, value, 0)


def set(self, x: Node, item: str, value: int, d: int) -> Node:
    char = item[d]
    if x is None:
        x = TST.Node(char)
        # self.size += 1
    if char < x.key_char:
        x.left = self.set(x.left, item, value, d)
    elif char > x.key_char:
        x.right = self.set(x.right, item, value, d)
    elif d < len(item) - 1:
        x.mid = self.set(x.mid, item, value, d + 1)
    else:
        x.value = value
    return x

def longestPrefixOf(self, query: str) -> str:
    if query is None:
        raise Exception("call longestPrefixOf() with None argument")
    if len(query) == 0:
        return None
    length = int(0)
    x = self.root
    i = 0
    while x is not None and i < len(query):
        char = query[i]
        if char < x.key_char:
            x = x.left
        elif char > x.key_char:
            x = x.right
        else:
            i += 1
            if x.value is not None:
                length = i
            x = x.mid

    return query[0:length]          # testing required

def keys(self) -> LinkedQueue:
    queue = LinkedQueue()
    self.collect(self.root, str(), queue)
    return queue                    # queue is iterable?
```

```
def keysWithPrefix(self, prefix: str) -> LinkedQueue:

    if prefix is None:
        raise Exception("call keysWithPrefix() with None argument")
    queue = LinkedQueue()
    x = self.root
    x = self.get(x, prefix, 0)
    if x is None:
        return queue
    if x.value is not None:
        queue.enqueue(prefix)
    self.collect(x.mid, str(prefix), queue)
    return queue

def collect(self, x: Node, prefix: str, queue: LinkedQueue) -> None:
    if x is None:
        return None
    self.collect(x.left, prefix, queue)
    if x.value is not None:
        queue.enqueue(str(prefix) + x.key_char)
    # self.collect(x.mid, str(prefix) + str(x.key_char), queue)
    prefix = prefix[:-1]
    self.collect(x.right, prefix, queue)

def keysThatMatch(self, pattern: str) -> LinkedQueue:
    queue = LinkedQueue()
    self.patternMatching(self.root, str(), 0, pattern, queue)
    return queue

def patternMatching(self, x: Node, prefix: str, i: int, pattern: str, queue: LinkedQueue):
    """
    some kind of collector
    """
    if x is None:
        return
    char = pattern[i]
    if char == '.' or char < x.key_char:
        self.patternMatching(x.left, prefix, i, pattern, queue)
    if char == '.' or char == x.key_char:
        if i == len(pattern) - 1 and x.value is not None:
            queue.enqueue(str(prefix) + str(x.key_char))
        if i < len(pattern) - 1:
            self.patternMatching(x.mid, str(prefix) + str(x.key_char), i + 1, pattern, queu
            prefix = prefix[:-1]

    if char == '.' or char > x.key_char:
        self.patternMatching(x.right, prefix, i, pattern, queue)


def add_doc(self, doc_name: str):
    self.docs.append(doc_name)

def traverse(self):
    if self.size == 0:
```

```
            raise Exception("empty tst can't be traversed")
        for q in self.keys():
            if self[q.element] is not None and self[q.element] is not "":
                yield q.element

    def validation(self):
        for v in self.traverse():

            self.valid_words.enqueue(v)
```

3.7 TrieST

3.7.1 previwe :

this class is based on a light weight inner Node class, it can supports all 256 ascii character :))

In [7]:
```
class TrieST:
    R = 256
    __slots__ = 'root', 'number_of_keys', 'valid_words', 'docs'

    # ---------------------------------------------------------------------------------
    class Node:
        __slots__ = 'value', 'next'

        def __init__(self):
            self.value = str()
            self.next = [None] * TrieST.R

    def __init__(self):
        self.root = self.Node()
        self.number_of_keys = 0
        self.valid_words = LinkedQueue()
        self.docs = DynamicArray()


    def __sizeof__(self) -> int:
        return self.number_of_keys

    def __len__(self) -> int:
        return self.__sizeof__()

    def is_empty(self) -> bool:
        return self.__sizeof__() == 0

    def __getitem__(self, key: str) -> str:
        x = self.get(self.root, key, 0)
        if x is None:
            return None
        return str(x.value)

    def __contains__(self, key: str) -> bool:
        return self.__getitem__(key) is not None

    def get(self, x: Node, key: str, d: int) -> Node:
        if x is None:
```

```
            return None
        if d == len(key):
            return x
        char = key[d]
        return self.get(x.next[int(ord(char))], key, d + 1)

    def put(self, key: str, value: int):
        if value is None:
            del key
        else:
            self.root = self.set(self.root, key, value, 0)

    def set(self, x: Node, key: str, value: int, d: int) -> Node:
        if x is None:
            x = self.Node()
        if d == len(key):
            if x.value is None:
                self.number_of_keys += 1
            x.value = value
            return x
        char = key[d]
        x.next[int(ord(char))] = self.set(x.next[int(ord(char))], key, value, d + 1)
        return x

    def keys(self) -> LinkedQueue:
        return self.keysWithPrefix("")

    def keysWithPrefix(self, prefix: str) -> LinkedQueue:
        result = LinkedQueue()
        x = self.get(self.root, prefix, 0)
        self.collect(x, str(prefix), result)
        return result

    def collect(self, x: Node, prefix: str, result: LinkedQueue) -> None:
        if x is None:
            return
        if x.value is not None:
            result.enqueue(str(prefix))
        for i in range(self.R):
            prefix += chr(i)
            self.collect(x.next[i], prefix, result)
            prefix = prefix[:-1]

    def keysThatMatch(self, pattern: str) -> LinkedQueue:
        result = LinkedQueue()
        self.patternMatching(self.root, str(), pattern, result)
        return result

    def patternMatching(self, x: Node, prefix: str, pattern: str, result: LinkedQueue) -> None:
        if x is None:
            return
        d = len(prefix)
        if d == len(pattern) and x.value is not None:
            result.enqueue(str(prefix))
```

```python
        if d == len(pattern):
            return

        char = pattern[d]
        if char == '.':
            for i in range(self.R):
                prefix += str(i)
                self.patternMatching(x.next[i], prefix, pattern, result)
                prefix = prefix[:-1]
        else:
            prefix += str(char)
            self.patternMatching(x.next[int(ord(char))], prefix, pattern, result)
            prefix = prefix[:-1]

    def longestPrefix(self, query: str) -> str:
        length = self.longestPrefixOf(self.root, query, 0, -1)
        if length == -1:
            return None
        else:
            return query[:length]

    def longestPrefixOf(self, x: Node, query: str, d: int, length: int) -> int:
        if x is None:
            return length
        if x.value is not None:
            length = d
        if d == len(query):
            return length
        char = query[d]
        return self.longestPrefixOf(x.next[int(ord(char))], query, d + 1, length)

    def add_doc(self, doc_name: str):
        self.docs.append(doc_name)

    def traverse(self):
        query = self.keys()
        for q in query:
            if self[q.element] is not "":
                yield(q.element)

    def validation(self):
        for v in self.traverse():
            self.valid_words.enqueue(v)

    def delete(self, key: str, x: Node=None, d: int=None) -> Node:
        if x is None and d is None:
            self.root = self.delete(key, x=self.root, d=0)
        if x is None:
            return None
        if d == len(key):
            if x.value is not None:
                self.number_of_keys -= 1
            x.value = None
        else:
```

```python
    char = key[d]
    x.next[int(ord(char))] = self.delete(x.next[int(ord(char))], key, d + 1)

# remove subtrie rooted at x if it is completely empty
if x.value is not None:
    return x
for i in range(self.R):
    if x.next[i] is not None:
        return x
return None
```