Algorithms & Data Structures for Big Data

Date 07/08/2023

Algorithm :- Set of clear, unambiguous instructions to solve a problem in finite amount of time.

Conditions :- a) input b) output c) finiteness
d) definiteness e) effectiveness

Data structures :- A systematic scheme of organizing the related data.

Program :- Converting an algorithm to an executable language.

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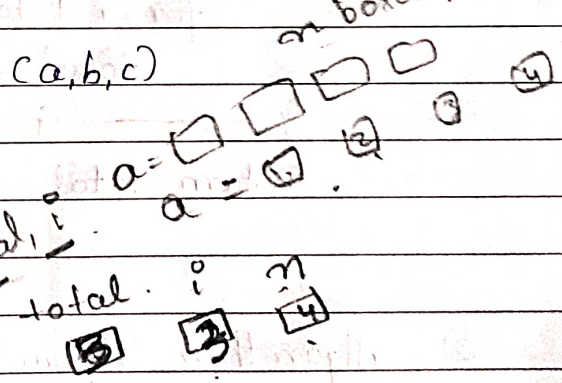
Performance of algorithm :-

Space - Memory required for the computation.
Time - CPU time considered, not the compile time.

Space — Variable → instance size, reference variables, recursion function
Fixed → code, fixed variables, constants.

Total space = Fixed space + variable space.

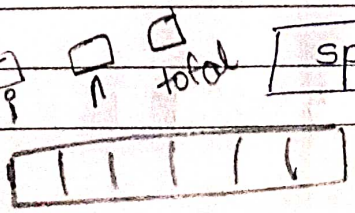
Ex:- 1) Algorithm addElement (a,b,c)
begin
return (a+b+c)
end
→ Only fixed space



2) Algorithm sum (a, n) {
total = 0 — 1
for i = 1 to n { n = 1 i = 1
total = total + a[i] : n
}
return total
}

ans:-
n = 1
total = 1
i = 1
a = variable = n

space ≥ (n+3)

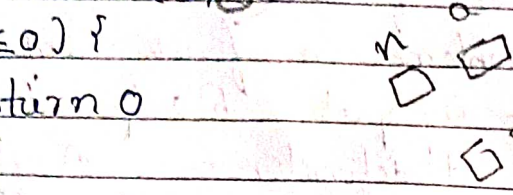


3 (n+1)

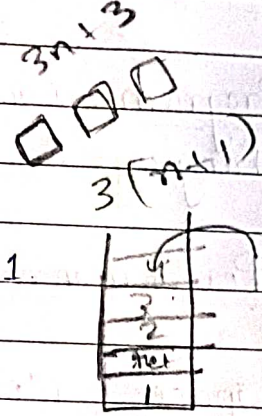
3) Algorithm Rsum (a, n) {
if (n≤0) {
return 0
} else {
return (Rsum (a, n-1) + a[n])
}}

1 return address
3 spaces

Space :-
a = 1 unit (base address)
n = 1
return address = 1.
Total no. of function calls = n+1
Total space ≥ 3n+3



1, 2, 3, 4



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Time complexity :-
Only execute and time is considered. Compile time is excluded.

Ex: 1) Algorithm sum (a, n) { — 0
total = 0. — 1.
for (i = 1 to n) { — n
total = total + a[i] — n
} — 1
return total — 1

Ans
c = 0
c = 1
c = 2
c = 3
c++ / i > n
c++
2n+3

2) Algorithm Rsum (a, n) { a = {1, 2, 3, 4, 5} n = 5
if (n≤0) { — 1
return 0 — 1
} else { — 2
return (Rsum (a, n-1) + a[n])
}}
a = {1, 2, 3, 4} n = 4
Rsum (1, 2, 3, 4) + 4)
Rs

Rsum (1,2,3,4) = Rsum (1,2,3) + 5
Rsum (1,2,3) = Rsum (1,2) + 4
Rsum (1,2) = Rsum (1) + 3
Rsum (1) = Rsum (0) + 2
Rsum (0) = 1

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$T(n) = 2$ when $n \le 0$.

$T(n) = 2 + T(n-1)$ when $n > 0$

$= 2 + 2 + T(n-2)$

$= 2 + 2 + 2 + T(n-3)$

$T(k) = 2*k + T(n-k)$ → Substitution method.

$= 2n + T(n-n)$ — $T(n) = 2$

$= 2n + T(0)$ — $T(0) = 2$.

$T(n) = 2n + 2$ — $n - k = 0$

$n = k$

=

3) Algorithm addMatrix (a, b, m, n, c)

for (i = 1 to m) { — c++ — m

for (j = 1 to n) { — c++ — (n+1)m

c[i,j] = a[i,j] + b[i,j] — c++ — m*n

} }

return c. — c++ — 1.

$mn + m + n + 2$

$2 \quad 2$

a b

$\begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix} \quad \begin{bmatrix} 2 & 3 \\ 1 & 4 \end{bmatrix}$

3) Algorithm addMatrix (a, b, m, n, c) {

for (i = 1 to m) { → c++ = m

for (j = 1 to n) { → c++ = mn

c[i,j] = a[i,j] + b[i,j] → c++ = m*n

} c++ / when j > n = m

} c++ / when i > m = 1

return c. → c++ = 1

}

$2mn + 2m + 2$

if (m == n)

$\Rightarrow 2n^2 + 2n + 2$

$\begin{bmatrix} 1 & 2 \\ 3 & 4 \\ 5 & 6 \end{bmatrix}$

$2 + 2 + 2$.

$3 * 2$

$m * n$

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Asymptotic notation :-

Big oh (O) :- Upper bound time complexity : Worst case value

Omega (Ω) :- Best case value. Time complexity in lower bound value.

Theta (Θ) : Average time complexity.

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General solution for large classes of ~~occur~~ recurrence problems :-

$T(n) = aT(n/b) + d(n)$

n = no. of elements
a = subproblems
n/b = elements in subproblem
$d(n)$ = Time to create subproblem + merge the solution

Homogenous Solution :-

$T(n) = O(n^{\log_b a})$

Particular solution :-

case 1 : when $a > d(b)$

$T(n) = O(n^{\log_b a})$

case 2 : when $a < d(b)$

$T(n) = O(n^{\log_b d(b)})$

case 3 : when $a = d(b)$

$T(n) = O(\log_b n * n^{\log_b d(b)})$

Ex :- 1) $T(n) = 4T(n/2) + n$.

$a = 4 \quad b = 2. \quad d(n) = n \Rightarrow d(b) = b = 2.$

$\therefore a > d(b)$

$O(n^{\log_2 4})$

$T(n) \Rightarrow O(n^2)$ = both homogenous & particular solution

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2. $T(n) = 4T(n/2) + n^2$

$a = 4 \quad b = 2 \quad d(n) = n^2$

$\Rightarrow d(b) = b^2 = 4$

$a = b$

$T(n) = O(\text{Log } n * n^{\log_b d(b)})$

$= O(n^2 \log n)$

$\left(n^{\log_2 4} \quad n^2\right)$

3. ~~$T(n) = 4T(n/2) + 2$~~

$a = 4 \quad b = 2 \quad d(n) = 2 \Rightarrow d(b) = 2$

$a > d(b)$

$T(n) = O(n^{\log_2 4})$

$= O(n^2)$

$\log_4 2$

$2 = 4^{1/2}$

$2 = 4^{(k)}$

$\log_2 8$

$8 = 2^{(k)} = 3$

$\log_4 2$

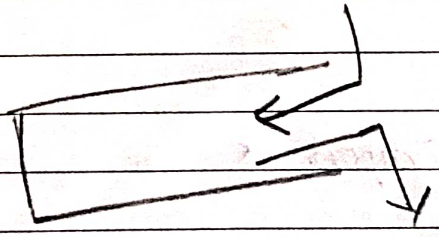
$2 = 4^k \Rightarrow k = 1/2$

Stacks :-

→ LIFO data structure
→ Last in First out
→ Function calls
→ Evaluation expression
→ Conversion of postfix/prefix expression
→ Balancing of symbols
→ Webpages, editors

$2+3*4$

16/8/2023 "self" tells the __init__ is an instance method.
"this" represents the object.



1	2	3	4

3!

1
2
3

$2*3 = 6$

```
class simpleStack :
    def __init__(self):
        self.data = []
        self.count = 0
    def getElementCount(self):
        return self.count
    def isStackEmpty(self):
        return self.count == 0
    def stackPush(self, element):
        self.data.append(ele)
        self.count += 1.
    def stackPop(self):
        if not self.isempty():
            self.count -= 1
            return self.data.pop()
        else:
            return None
    def stackPeek(self):
        if not self.isEmpty():
            return self.data[-1]
        else:
            return None
    def printElements(self):
```

testSimpleStack.py :-

```
from simplestack import *

def testEmptyStack():
    S1 = simpleStack()
    assert(S1.getElementCount() == 0)
    assert(S1.isStackempty() == True)
```

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```
def testPush():
    s2 = simplestack()
    s2.stackPush(10)
    assert(s2.getElementCount()==1)

def testPop():
    s3 = simplestack()
    s3.stackPush(20)
    s3.stackPush(30)
    assert(s3.stackPop()==30)
```

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```
from simplestack import *

def testSymbols(data, stacks):
    lefty = '{[('
    righty = '}])'
    for ch in data:
        if ch in lefty
            stack.stackPush(ch)
        elif ch in righty:
            if stacks.isEmpty():
                return False
            elif righty.index(ch) != lefty.index(stack.stack
                                                 Pop())
                return False
    return (stack.isEmpty())
```

test

```
def testApp():
    stacks = simpleStack()
    f_read = open('','r'). open("","r")
    data = f_read.read()
    f_read.close()
    assert (testSymbols(data, stacks)==True)

testApp()
```

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Queue:

→ First in First out principle (FIFO)

```
Class Queue:
    def __init__(self):
        self.data = []
        self.count = 0          self.front = 0.
    def getElementCount(self):
        return self.count
    def isQueueEmpty(self):
        return self.count == 0
    def enqueue(self, element):
        self.data.append(element)
        self.count += 1
    def deque(self):
        if not self.isEmpty():
            count -= 1          self.count -= 1
            return self.data.remove(front)
            front += 1
            return self.data.pop(0)
        else:
            return None.
```

23/08/23 Time complexity → enqueue - O(1)
dequeue - O(n)

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Dynamic Queue:-

```
class flexiQueue:
    defaultSize = 2
    def __init__(self):
        self.data = [None] * flexiQueue.defaultSize
        self.front = 0
        self.count = 0

    def length(self):
        return self.count
    def isEmpty(self):
        return self.count == 0
    def getFirst(self):
        if not self.isEmpty():
            return self.data[self.front]
        else
            return None
    def enqueue(self, ele):
        if self.count == len(self.data):
            self.reSize(2 * len(self.data))
        idx = (self.front + self.count) % len(self.data)
        self.data[idx] = ele
        self.count += 1
    def dequeue(self):
        if not self.isEmpty():
            elem = self.data[self.front]
            self.count -= 1
            self.data[front] = None
            self.front = (self.front++) % len(self.data)
            if 0 < self.size < len(self.data)//4:
                self.resize(len(self.data)//3
            return size
        else:
            return None
```

```
def resize(self, cap):
    oldData = self.data
    walk = self.front
    self.data = [None] * cap
    for k in range(len(oldData)):
        self.data[k] = oldData[walk]
        walk = (walk+1) % len(oldData)
    self.front = 0
```

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Linked List :-

```
class slist:
    class _Node:
        def __init__(self, ele):
            self.data = elem
            self.next = None
    def __init__(self):
        self.head = None
        self.tail = None
        self.count = 0
    def isempty(self):
        return self.count == 0
    def listCount(self):
        return self.count
    def addAtHead(self, ele):
        # if not self.isempty():
        new_node = self._Node(ele)
        if not self.isEmpty():
            new_node.next = self.head
            self.head = new_node
        else:
            self.head = self.tail = new_node
        self.count += 1
```

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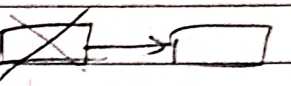
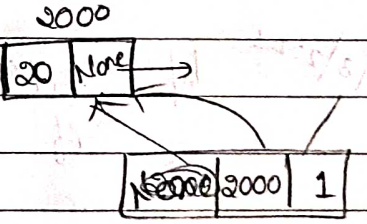
```
def addAtTail(self,ele):
    new_node = self.Node(ele)
    if not self.isEmpty():
        self.tail.next = new_node
        self.tail = new_node
    else:
        self.head = self.tail = new_node
    self.count += 1
```

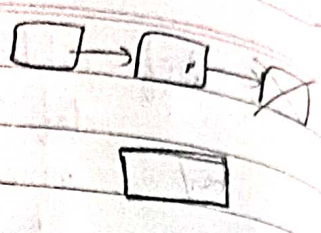


```
def deleteAtHead(self):
    if not self.isEmpty():
        temp = self.head.next
        self.head = temp
    if self.count > 1:
        temp = self.head.next
        del(self.head)
        self.head = temp
        self.count -= 1
    elif self.count == 1:

        self.head = self.tail = None
        self.count = 0
    else:
        return None
```

(partial code)




```
def deleteAtHead(self):
    if not self.isEmpty():
        data = self.head.data
        self.head = self.head.next
        if self.head == None:
            self.tail = None

        self.count -= 1
        return data
    else: return None
```



```
def deleteAtTail(self):
    if not self.isEmpty():
        data = self.tail.data
        self.tail = self.head
        temp = self.head
        while (temp.next != None):
            temp = temp.next
        self.tail = temp
        temp.next = None
```

(partial code)

```
def deleteAtTail(self):
    if not self.isEmpty():
        if self.count != 1:
            last = self.tail
            cur = self.head
            while cur.next != last:
                cur = cur.next
            self.tail = cur
            cur.next = None
        else:
            self.head = self.tail = None
        self.count -= 1
    else:
        return None
```

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```
def isMember(self, key):
    if not self.isEmpty():
        cur = self.head
        while cur != None:
            if cur.data == key:
                break
            else
                cur = cur.next
        return cur != None
    else
        return False
```

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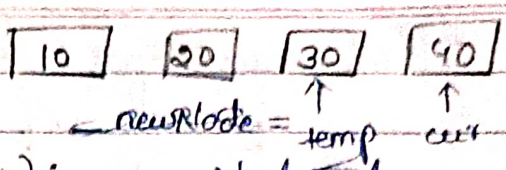
def addGiven




```
def addAfterNode(self, ele, pos):
    if not self.isEmpty():
        temp = self.head
        while(temp.data != pos):
            temp = temp.next
        temp = temp.next
        cur = temp.next
        temp.next = newNode
        newNode.next = cur
        self.count += 1
```

```
def addAfterNode(self, ele, value):
    newNode = self._Node(ele)
    if not self.isEmpty():
        temp = self.head
        while(temp.data != value):
            temp = temp.next
        cur = temp.next
        temp.nex
        if not temp.next == None:
            cur = temp.next
            temp.next = newNode
            newNode.next = cur
        else:
            temp.next = newNode
            self.tail = newNode
        self.count += 1
    else:
        return None
```

```
def addNtpos (self, ele, pos):
    if not self.isEmpty():
        temp = self.head
        while self.iteration = 0
        while (self.iteration < pos):
            temp = temp.next
            self.iteration += 1
        if temp != None:
            cur = temp.next
            newNode = self.__newNode(ele)
            if cur != None:
                temp.next = newNode
                newNode.next = cur
            else:
                temp.next = newNode
                self.tail = newNode
            self.count += 1
        else:
            return None
    else:
        return None
```

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```
def StackUsingQueues(self):
    q1 = Queue()
    q2 = Queue()
    def push(self, ele):
        q1.enqueue(ele)
    def pop():
        while (q1.count > 1):
            q2.enqueue(q1.dequeue), ele = q1.dequeue
        while (q2.count > 0):
            q1.enqueue(q2.dequeue())
        return ele
```

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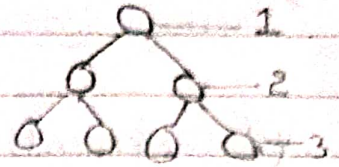
Tree data structure

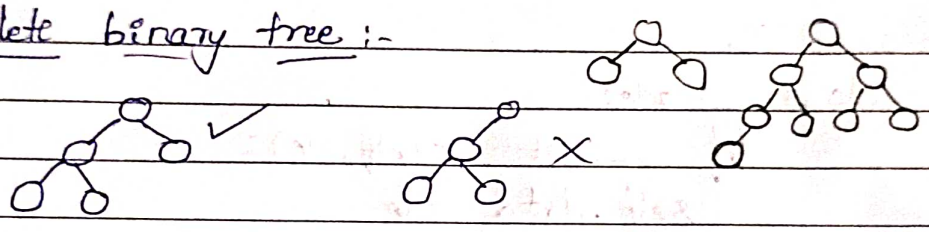


→ Non-linear data structure
→ For file system
→ Root node — Starting node
→ Degree — No. of children nodes for a given node

Binary tree

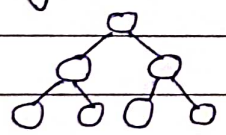
i) No. of nodes at any level $i = 2^{i-1} = 2^{1-1} = 2^0 = 1$
ii) Total No. of nodes at any given depth $k = 2^k - 1$ $2^3 - 1$
7

Complete binary tree :-



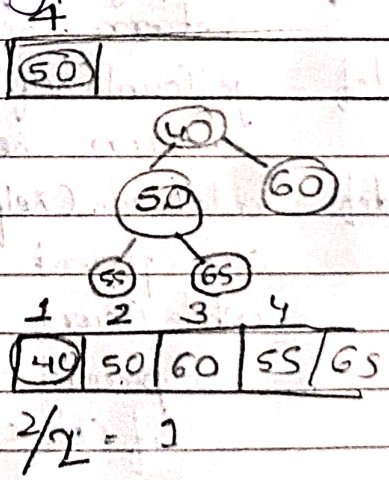
Nodes are filled from left to right then top to bottom

Full binary tree :-



All leaf nodes are filled. There should not be any unfilled slots at any level.

*. node at i
*. parent node at i/2
*. left child at 2i
*. right child at 2i+1



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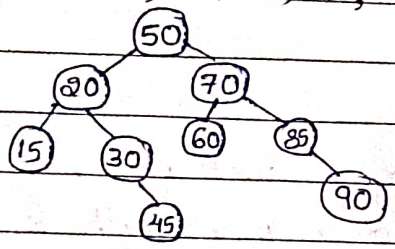
Binary Search Tree :-

1) All elements should be unique
2) Left child should be less than parent
3) Right child should be greater than parent.

Ex:- 50, 20, 70, 30, 60, 85, 45, 15, 90




```
class BST:
    class _Node:
        def __init__(self,ele):
            self.data =ele
            self.left = None
            self.right = None
    def __init__(self):
        self.root= None
        self.count=0
    def isEmpty(self):
        return self.root ==None
    def getCount(self):
        return self.count
    def addNode(self,ele):
        cur = parent = self.root
        while (cur != None and cur.data != ele):
            parent = cur
            if (ele< cur.data):
                cur = cur.left
            else.
                cur= cur.right
        if (cur==None):
            new_node = self._Node(ele)
```

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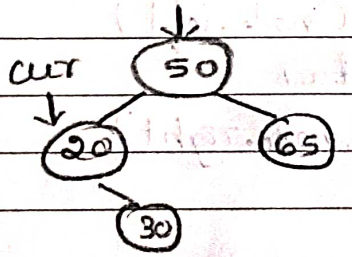
```
if parent = None:
        self.root = new_node
elif    ele < parent.data:
        parent.left = new_node
elif    ele > parent.data :
        parent.right = new_node
self.count += 1
def searchNode (self, key):
    if not self.isEmpty():
        cur = self.root
        while (cur != None):
            if cur.data == key:
                break
            elif:
            else:
                cur = cur.n
            elif (key < cur.data):
                cur = cur.left
            else:
                cur = cur.right
        return cur != None      False      cur == None
    else:
        return None  False
```



key = 20

cur != None → True

cur == 20

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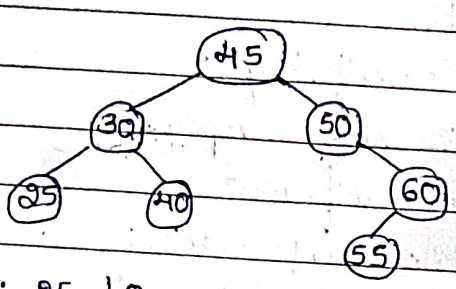
BST Traversals :-

1) Inorder – Left → Parent → Right
2) Preorder – Parent → Left → Right
3) Post order – Left → Right → Parent
4) Level order



Post order : 25, 40, 30, 55, 60, 50, 45
Pre order : 45, 30, 25, 40, 50, 60, 55
Inorder : 25, 30, 40, 45, 50, 55, 60
Levelorder : 45, 30, 50, 25, 40, 60, 55

```
def Inorder(self):
    if not self.isEmpty():
        self._inorder(self.root)

def _inorder(self, node):
    if node != None:
        self._inorder(node.left)
        print(node.data)
        self._inorder(node.right)


def PreOrder(self):
    if not self.isEmpty():
        self._preorder(self.root)
def _preOrder(self, node):
    if node != None:
        print(node.data)
        self._preOrder(node.left)
        self._preorder(node.right)
```

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```
def PostOrder(self):
    if not self.isEmpty():
        self.postOrder(self.root)
def _postOrder(self, node):
    if node != None:
        self._postOrder(node.left)
        self._postOrder(node.right)
        print(node.data)


def LevelOrder(self):
    if not self.isEmpty():
        self.levelOrder(self.root)
def _levelOrder(self, node):
    while(node != None):
        if (node.left != None):
            queue.enqueue(node.left)
        if (node.right != None):
            queue.enqueue(node.right)

        queue.enqueue(node)
        print
        ~~enqueue~~(queue.dequeue())

def _leveOrder(self, node):
    queue.enqueue(node)
    while(node != None):
        ele = queue.dequeue()
        print(ele)
        if(node.left != None):
            queue.enqueue(node.left)
        if(node.right != None):
            queue.enqueue(node.right)
```

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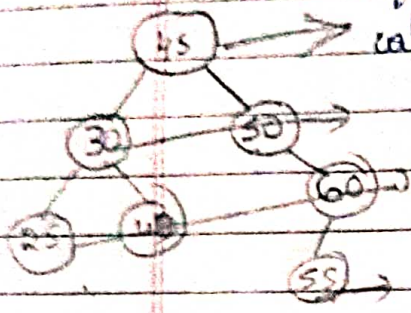
```
def level_order(self):
    if not self.isEmpty():
        q = FlexQueue()
        q.enqueue(self.root)
        while not q.isEmpty():
            node = q.dequeue()
            print(node.data)
            if node.left:
                q.enqueue(node.left)
            if node.right:
                q.enqueue(node.right)
```



45	30	50	25	40	60

45, 30, 50

Q: ~~45~~ ~~30~~ ~~50~~ 25 40 60

node = 45

node = 30

45, 30, 50, 25, 40, 60

→ Implementation of tree traversal using an iterative approach

Delete Node :-

```
def deleteNode(self, key):
    if not self.isEmpty():
        self.root = self._nodeDelete_(self.root, key)
def _nodeDelete_(self, node, key):
    if node == None:
        return None
    elif key < node.data:
        node.left = self._nodeDelete_(node.left, key)
    elif key > node.data:
        node.right = self._nodeDelete_(node.right, key)
    elif node.left and node.right:
        temp = self._findMin_(node.right)
        node.data = temp.data
        node.right = self._nodeDelete_(node.right, temp.data)
    else:
        if node.right == None:
            node = node.left
```

```
        else:
            if node.left == None:
                node = node.right
            self.count -1 = 1
            return node
    def _findMin_(self, node):
        if node.left == None:
            return Node.
        else:
            return (self.findMin_(node.left))
```

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```
    def getLeafCount(self):
        count = 0
        if not self.isEmpty():
            q1 = LinkedQueue()
            q1.enque(self.root)
            while not q1.isEmpty():
                node = q1.dequeue()
                if (node.right = node.left == None):
                    count + = 1
                if node.left:
                    q1.enqueue(node.left)
                if node.right:
                    q1.enqueue(node.right)
            return count.

    def getLeafCount(self):
        if not self.isEmpty():
            return (self._leafCount_(self.root))
        else
            return 0

def _leaf_count(self, node):
    if node:
        if self._isLeafNode(node):
            return 1.
        else:
            return (self._leafCount_(self.left) + self._leafCount(node.right)
```

```
    return 0

def is_leafNode_(node):
    if node.left == None and node.right == None
        return True
    else:
        return False
```

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Bubble sort :-

```
def bubbleSort(input):
    for i in range(len(input)-2,0,-1):
        for j in range(len(input)-1, i, -1):
            if input[j] < input[j-1]:
                input[j], input[j-1] = input[j-1], input[j]
```

Time complexity = $O(n^2)$

Improve bubble sort to reduce the number of sorts.

```
def testSorting(input)
    for idx in range(0, len(input)-1):
        assert(input[idx] <= input[idx+1])

test son testSorting(input)
```

Selection sort:-

Less no. of swapping

```
def selectionSort(input):
    for itr in range(0, len(input)-2):
        pos = itr
```

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```
for idx in range(itr+1, len(input)-1):
    if input[idx] < input[pos]:
        pos = idx
if input[itr], input[pos] = input[pos], input[itr]
```

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Insertion Sort:-

```
def insertionSort(input):
    for itr in range(1, len(input)):
        idx = itr - 1
        key = input[itr]
        while idx >= 0 and key < input[idx]:
            input[idx+1] = input[idx]
            idx -= 1
        input[idx+1] = key
```

Time complexity = $O(n^2)$

no. of comparison is very less.

insertion sort is better than selection & bubble sort

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Quick sort :-

→ Divide & conquer principle

0	1	2	3	4	5	6	7	8	9	10
35	20	45	15	98	9	69	95	16	30	60

pivot = 35

up up up down down

input[up] ≤ pivot

up++;

input[down] > pivot

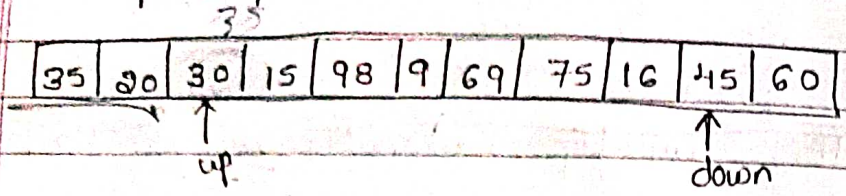
down--;

input[up] = 45 ≰ 35

input[down] ≯ 35

If all elements are not compared & can't increment decrement up & down

Swap up & down



pivot = 35
up = 30
down = 45

Swap pivot with down if all elements are traversed

Depends on the partition, the time complexity will be
→ either $O(n^2)$ or $O(n \log n)$

```
def quickSort(input):
    start = 0
    end = len(input) - 1
    _quicksort_(input, start, end)
    return input

def _quicksort_(input, start, end):
    if start < end: # if start == end, only one element
        mid = _partition_(input, start, end)
        _quicksort_(input, start, mid-1)
        _quicksort_(input, mid+1, end)

def _partition_(input, start, end):
    up = start
    down = end
    pivot = input[start]
    while up <= down:
        while up <= down and input[up] <= pivot:
            up += 1
        while up <= down and input[down] > pivot:
            down -= 1
        input[up], input[down] = input[down], input[up]
    input[start], input[down] = input[down], input[start]
    return down
```

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Balanced partition :- (or best case) :-

$T(n) = 2T(n/2) + O(n)$

partition takes $O(n)$ time, maximum time for number of comparison needed is $n+1$.

$a = 2$ $b = 2$ $d(n) = n$

$d(b) = b = 2$

$a = d(b)$.

Homogenous solution $= O(n^{\log_b a})$

$= O(n)$

Particular solution $= O(n^{\log_b d(b)} . \log n)$

$= O(\log n * n)$

$= O(n \log_2 n)$

Unbalanced partition :- (Worst case)

$T(n) = T(n-1) + O(n)$

$= T(n-1-1) + n-1+n$

$= T(n-1-1) + n-1-1+n-1+n$

$= T(n-2) + (n-2) + (n-1) + n$

$=$ ⋮

$= T(n-n) + (n-n) + \cdots + 1 + 0$

$T(n) = O(n^2)$

$T(n) = T(n-1) + n$

$T(n-1) = T(n-1-1) + (n-1) + n$

$= T(n-2) + n + n-1)$

$= T(n-3) + n + (n-1) + (n-2)$

$=$ ⋮

$= T(n-n) + n + n-1 + n-2 + \cdots + n-n$

$= T(0) + n + n-1 + n-2 + \cdots + 2 + 1 + 0$

$= n + \frac{n(n-1)}{2}$

$= n + \frac{n^2 - n}{2}$

$= O(n^2)$

Merge sort :-

→ Divide & conquer method
→ $T(n) = O(n \log n)$
→ This is not an in-place algorithm. That means we will be using an additional temporary array.

```
def mergeSort(input):
    if len(input) == 0 or len(input) == 1:
        return input
    else:
        mid = len(input)//2
        a = mergeSort(input[:mid])
        b = mergeSort(input[mid:])
        return merge(a,b)

def merge(a,b):
    templist = []
    while len(a) != 0 and len(b) != 0:
        if a[0] < b[0]:
            templist.append(a[0])
            a.pop(0)
        else:
            templist.append(b[0])
            b.pop(0)
    if len(a) == 0:
        templist = templist + b
    else:
        templist = templist + a
    return templist
```

This merge function leads to $O(n^2)$ time complexity

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→ Implement merge function with time complexity O(n log n).

Time complexity.

$T(n) = 2T(n/2) + O(n)$

$a = 2 \quad b = 2 \quad d(b) = 1$

$a = b$

$T(n) = O(n^{\log_2 2} * \log_2 n)$

$T(n) = O(n \log n)$ → Particular solution

Homogenous solution = $O(n)$

Heap:-

→ Complete binary tree

→ Maximum heap: The parent value should always greater or equal to its children.

→ Minimum heap: The parent value should always smaller or equal to its children.

→ Heap sort :- Efficient way of in-place sorting algorithm with time complexity $O(n \log n)$.

→ Works very well even if the dataset is very huge.

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```
class maxHeap:
    def __init__(self, lst=[]):
        self.data = lst
        self._buildHeap_()
    def isEmpty(self):
        return len(self.data) == 0
    def _parent_(self, idx):
        return (idx-1)//2
    def _lchild(self, idx):
        return (2*idx+1)
    def _rchild(self, idx):
        return (2*idx+2)
```

```
def _swap_(self, i, j):
    self.data[i], self.data[j] = self.data[j], self.data[i]

def _buildHeap(self):
    length = len(self.data)
    start = (length-2)//2          # from
    for idx in range(start, -1, -1):   # to
        self._downHeap_(idx, length)
def _downHeap_(self, idx, length):
    if self._lchild(idx) < length:
        left = self._lchild_(idx)
        bigChild = left
        if self._rchild_(idx) < length:
            right = self._rchild_(idx)
            if self.data[right] > self.data[left]:
                bigChild = right
        if self.data[bigChild] >= self.data[idx]:
            self._swap_(bigChild, idx)
            self._downHeap_(bigChild, length)
```

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```
def addElement(self, key):
    self.data.append(key)
    self._upHeap(len(self.data)-1)

def _upHeap(self, j):
    parent = self._parent_(j)
    if j > 0 and self.data[j] > self.data[parent]:
        self._swap_(j, parent)
        self._upHeap_(parent)
```

Time required to move biggest item from lowest level to the highest level (up-heap) = O(log n)

Time required to move smallest item from highest level to the lowest level (down-heap) = O(log n)

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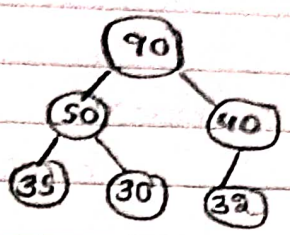
1) Priority queue implementation using normal queue :-
Adding n elements = O(n)
Deleting n elements = $O(n^2)$

2) Sorted queue
$O(n^2)$ — Addition
O(n) — Deletion



90	50	40	35	30	32

3) Heap datastructure
O(n log n) — Addition
O(n log n) — Deletion

32	50	40	35	30	90

50	32	40	35	30	90

Building a heap → O(n log n)

30	32	40	35	50	90

40	32	30	35	50	90

35	32	30	40	50	90

```
def testMaxHeap(self):
    if not self.isEmpty():
        for idx in range(len(self.data)-1, 0, -1):
            assert (self.data[idx] <= self.data[self._parent(idx)])
```

30	32	35	40	50	90

```
def heapSort(self):
    if not self.isEmpty():
        for idx in range(len(self.data)-1, 0, -1):
            self._swap_(0, idx)
            self._downHeap_(0, idx)
```

Time complexity :-

heap sort — for loop = O(n-1) = O(n)
down heap = O(log n)
Total = O(n log n)

Hashing :-

Mechanism which allows insertion/deletion/search operations with constant average time.

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Array based :-

→ Collision is a common process in this
→ To overcome collision, we will do rehashing
Linear probing → $H_R(x) = H(x) + i$, $i = 0, 1, 2, \ldots n-1$
Quadratic probing → $H_R(x) = H(x) + i^2$. This is used to avoid only one particular area being thickly populated
→ Takes constant average time.
→ Searching → Iterate through hashmap and stop if a blank cell is seen in which ~~was never occup~~ no elem-nt was stored before.

Linked list based :-

→ Hashing & compression function is there
→ While adding a node, add at the head. external chaining
→ Efficiency wise it is better than the array based
→ No limit on the no. of elements stored.

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Hash function = hash code generation + compression

Hash code generation :-

1) Bit code method - sum of ascii (tempo1 = t+e+m+p+0+1
2) Polynomial method - $ta^{n-1} + ea^{n-2} + ma^{n-3} + pa^{n-4} + \ldots$ (33, 37, 39,
3) Cyclic Shift method - bit shift

Compression method :-

1) Division method - hashcode % N, table size is prime no.
2) MAD method - Multiplication, Addition, Division method

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Cyclic shift :-

```
def cyclic_shift(input):
    hashcode = 0
    for ch in input:
        hashcode = hashcode << 5
        hashcode = hashcode + ch
```

a = 11011

27 << 5

27 / 2^5

a << 1

11011 / 2

10110

16 + 8 + 1 + 4 + 2 = 30

16 + 4 + 1

MAD method :-

p, a, b

p > N (a prime no.)

a (1, (p-1))

b (0, (p+1))

hashcode = i.

MAD = [(a*i + b) % p] % N.

→ Duplicates are not stored.

→ Dictionaries are implemented using hash map in the backend.

```
class extHash:
    class _node_:
        def __init__(self, id, name):
            self.id = id
            self.name = name
            self.next = None
    tableSize = 11
    def __init__(self):
        self.hashtable = [None] * extHash.tableSize
        self.p = 13
        self.a = np.random.randint(1, self.p-1)
        self.b = np.random.randint(0, self.p+1)
```

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```
def __hashCode__(self, element):
    hashCode = 0
    for ch in element:
        hashcode = hashcode <<5
        hashcode = hashcode + ord(ch)
    return hashcode

def _compression_(self, hcode):
    return(((C.C.hcode * self.a + self.b) % self.p) % exthash.table
                                                        size)

def _hash_(self, element):
    hashCode = _hashcode_(element)
    tableIndex = _compression_(hashcode)
    return tableIndex
```

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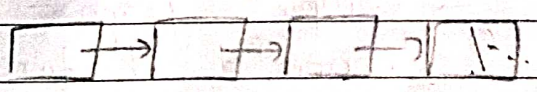
```
def isMember(self, id):
    bIndex = _hash_(id)
    node = self.hashtable[bIndex]
    while node:
        if node.id = id:
            break
        else:
            node = node.next
    return node != None

def addElement(self, id, name):
    if not self.isMember(id):
        bIndex = _hash_(id)
        oldAdd = self.hashtable[bIndex]
        node = self._node_(id, name)
        node.next = oldAdd
        self.hashtable[bIndex] = node

def deleteElement(self, id):
```

```
if self.isMember(id):
    bIndex = __hash_(id)
    node = self.hashtable[bIndex]
    while node: id == id:
        if node.id = id:
prev = None
while node:
    if node.id = id:
        prev.n ele = node.name
        prev. if (prev == None):
            self.hashtable[bIndex] = node.next
        else:
            prev.next = node.next
    else:
        prev = node
        node = node.next
return ele

def dele deleteElement (self, id):
    bIndex = self.__hash__(id)
    if self.hashtable[bIndex]:
        if self.hashtable[bIndex].id == id:
            self.hashtable[bIndex] = self.hashtable
                                     [bIndex].next
    else:
        node = self.hashtable[bIndex]
        while node.next != None:
            if node.next.id == id:
                node.next = (node.next).next
            else:
                node = node.next
```



```
def printHashTable(self):
    for idx in range(0, extHash.tableSize):
        node = self.hashTable[idx]
        while node:
            print(node.id)
            node = node.next
        print("\n")
```

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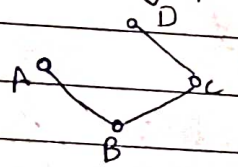
Graphs:-

→ G = (V, E)
→ Set of vertices (nodes) : V = {$V_1, V_2, V_3, \ldots, V_n$}
→ Set of edges : E = {$e_1, e_2, e_3, \ldots, e_m$}

Types of graphs:-

- Undirected graph - pair of vertices in a edge is unordered (A, B) = (B, A)



- Directed graph - each edge is a directed pair of vertices

→ Self edge / loop edge - start & end vertex is same (u, u)
→ We say "a path exists from V_0 to V_n" if there is a list of vertices [$V_0, V_1, V_2, \ldots, V_n$] such that ($V_i, V_{i+1}$) ∈ E for all $0 \le i \le n$

→ A cycle is a path that begins and ends at the same node.

→ Connected graph - An undirected graph is connected if for all pairs of vertices $u \neq v$, there exists a path from u to v.
→ Complete graph - An undirected graph is complete or fully connected, if for all pairs of vertices $u \neq v$ there exists an edge from u to v.

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Representation of graph:-

1) Adjacency matrix:-
→ Let G = (V, E) be a graph with n vertices
→ The adjacency matrix of G is a 2-D n by n array
→ If the edge (vi, vj) is in E(G), adj_mat[i][j] = 1
→ If there is no edge in E(G) for (vi, vj), adj_mat[i][j] = 0
→ Adjacency matrix for an undirected graph is symmetric
→ Adjacency matrix for a digraph need not be symmetric

2) Adjacency List:-
→ Each row in adjacency matrix is represented as list.

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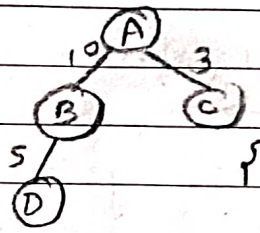
Implementation of adjacency list representation of graph

```
import sys

class Graphs:
    class _vertex_:
        def __init__(self, id):
            self.id = id
            self.adjacentNeighbour = {}
        def _isNeighbour_(self, id):
            return (id in self.adjacentNeighbour)
        def _addNeighbour_(self, id, wt=0):
            if not self._isNeighbour_(id):
                self.adjacentNeighbour[id] = wt
        def _listNeighbours_(self):
            return self.adjacentNeighbour.keys()
        def _edgeCost_(self, id):
            if self._isNeighbour(id):
                return self.adjacentNeighbour[id]
            else:
                return sys.maxsize
```



{A:
{B: 10, C: 3},
B:
{A: 10, D: 5},

→ dictionary keyword

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```
def __init__(self):
    self.vertexCount = 0
    self.adjacencylist = {}
def getVertexCount(self):
    return self.count
def addVertex(self, id):
    if not id in self.adjacencylist:
        newVertex = self.__Vertex(id)
        self.adjacencylist[id] = newVertex
        self.vertexCount += 1
def addEdge(self, from, to, wt=0):
    if not from in self.adjacencylist:
        self.addVertex(from)
    if not to in self.adjacencylist:
        self.addVertex(to)
    self.adjacencylist[from].__addNeighbour__(to, wt)
    self.adjacencylist[to].__addNeighbour__(from, wt)
```

this is only for undirected graph

```
def getEdgeCost(self, from, to):
    if from in self.adjacencylist and to in self.adjacencylist:
        return self.adjacencylist[from].__edgeCost__(to)

def getVertextlast(self):
    return(list(self.adjacencylist.keys()))

def neighborlist(self, id):
    if id in self.adjacencylist:
        return(list(self.adjacencylist[id].__listNeighbours__()))
```

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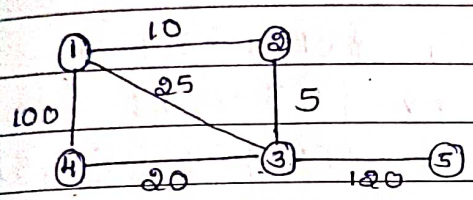
Spanning tree :-

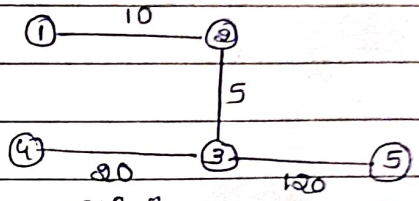
Spanning tree is a acyclic connected subgraph containing all the vertices of a given ~~sub~~graph.
spanning tree should have ~~maximum~~ (n-1) edges, where 'n' is the number of nodes.

Minimum spanning tree :-

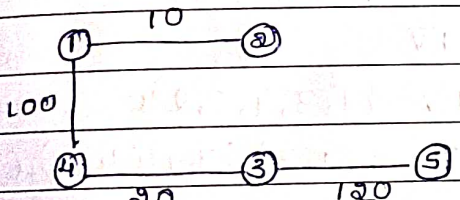
~~Spanning tree is any~~
A spanning tree whose total cost of selected edges is minimum.



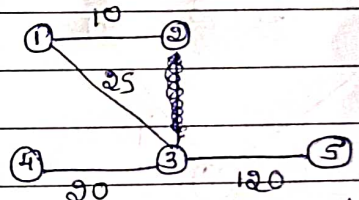
Graph



minimum spanning tree



Spanning tree



Spanning tree

Greedy algorithm :- In later steps, we can't change decision made in previous stages.

Prim's algorithm :-

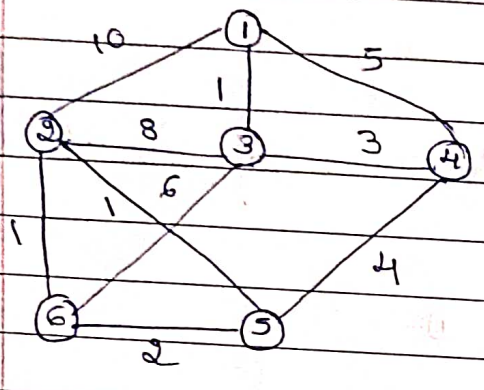
Let TV be set of vertices and T be set of edges
To start with let TV contain an one vertex and T is empty

TV = { any one vertex }
T = { }

while (T contains less than n-1 edges) {
Let (u, v) be least cost edge such that vertex 'u' is

in 'TV' and 'v' is not in 'TV'
add vertex 'v' to TV and edge (u,v) to T
if no such edge break
}

Print (not a minimum spanning tree if T contains less than (n-1) edges)



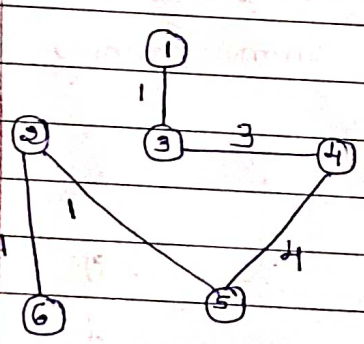
① TV = { 1 }
T = { }

② TV = { 1, 3 }
T = { (1,3) }

③ TV = { 1, 3, 4 }
T = { (1,3) (3,4) }

④ TV = { 1, 3, 4, 5 }
T = { (1,3), (3,4), (4,5) }

⑤ ~~TV = { 1, 3, 4, 5 }~~
~~T = { 1, 3, 4, 5, 2 }~~
TV



MST

⑤ TV = { 1, 3, 4, 5, 2 }
T = { (1,3), (3,4), (4,5), (5,2) }

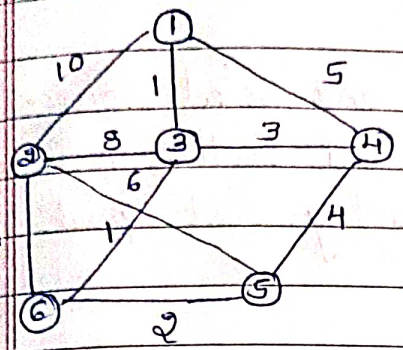
⑥ TV = { 1, 3, 4, 5, 2, 6 }
T = { (1,3), (3,4), (4,5), (5,2), (2,6) }

Kruskal's algorithm :-

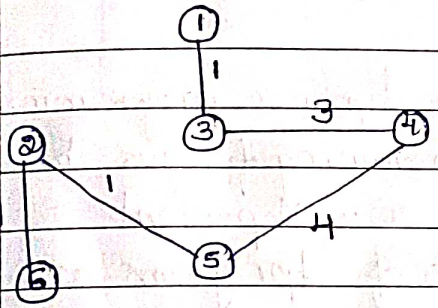
Let T be set edges, E is set representing set of all edges of given graph.
To start with T is empty

T = { }
while (T contains less than n-1 edges and E is not empty){
choose least cost edge (u,v) from E. Remove (u,v) from E
if (u,v) doesn't form cycle in T
Add edge (u,v) to T

else
Discard edge (u, v)
}
print (not a minimum spanning tree if T contains less than (n-1) edges)



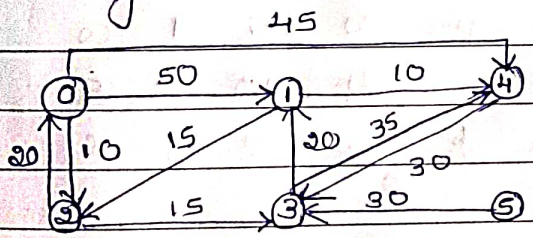
① T = { }
② T = {(1, 3)}
③ T = {(1,3), (2, 5)}
④ T = {(1,3), (2,5), (2,6)}
⑤ T = {(1,3), (2,5), (2,6), (3,4)}
⑥ T = {(1,3), (2,5), (2,6), (3,4), (4,5)}



→ MST.

Dijkstra's algorithm :-

→ Single source all destination
→ Single source shortest path



cost[ ]

	0	1	2	3	4	5
0	0	50	10	1000	45	1000
1	1000	0	15	1000	10	1000
2	20	1000	0	15	1000	1000
3	0	20	1000	0	35	1000
4	1000	1000	1000	30	0	1000
5	1000	1000	1000	30	1000	0

	0	1	2	3	4	5
0	0	50	10	1000	45	1000
0,2	0	50	10	25	45	1000
0,2,3	0	45	10	25	45	1000
0,2,3,4	0	45	10	25	45	1000

1) Initialize distance ~~matrix~~ vector and select source
2) Select the vertex which is nearest to the source
3) If new path cost is less than existing cost update 'Distance vector' with new value

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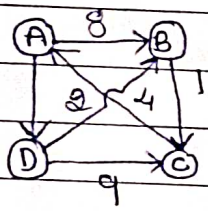
All pair shortest path algorithm :-
(Floyd Warshall algorithm)



→ Example for a dynamic programming
→ Dynamic programming follows bottom up
→ Subprograms are dependent
→ ~~We~~ All results of subprograms are stored.

$cost(i,j) = cost(i,k) + cost(k,j)$

Let intermediate vertex = k = A

	A	B	C	D
A	0	8	∞	1
B	∞	0	1	∞
C	4	∞	0	∞
D	∞	2	9	0

dist =

	A	B	C	D
A	0	8	∞	1
B	∞	0	1	∞
C	4	12	0	5
D	∞	2	9	0

dist(A,A) = dist(A,A) + dist(A,A) = 0+0 = 0
dest (A,B) = dest(A,A) + dist(A,B) = 0+8 = 8
dist (A,C) = dist(A,A) + dist(A,C) = 0+∞ = ∞
dist (A,D) = dist(A,A) + dist(A,D) = 0+1 = 1

dist(B,A) = dist(B,A) + dist(A,A) = ∞+0 = ∞
dest(B,B) = dist(B,A) + dist(A,B) = ∞+8
dist(B,C) = dist(B,A) + dist(A,C) = ∞+∞ = ∞

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dist(B,D) = dist(B,A) + dist(A,D) = ∞ + 1 = ∞

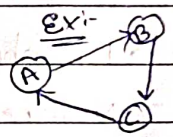
dist(C,A) = dist(C,A) + dist(A,A) = 4 + 0 = 4
dist(C,B) = dist(C,A) + dist(A,B) = 4 + 8 = 12
dist(C,C) = 0
dist(C,D) = dist(C,A) + dist(A,D) = 4 + 1 = 5

dist(D,A) = dist(D,A) + dist(A,A) = ∞
dist(D,B) = dist(D,A) + dist(A,B) = ∞
dist(D,C) = dist(D,A) + dist(A,C) = ∞
dist(D,D) = ∞

Final answer :-

	A	B	C	D
A	0	3	4	1
B	5	0	1	6
C	4	7	0	5
D	7	2	3	0

Ex:-




```
def allpairshortestPath(graph):
    nodes = len(graph)
    dist = graph
    for k in range(nodes):
        for i in range(nodes):
            for j in range(nodes):
                dis[i,j] = min(dist[i,j], dist[i,k] + dist[k,j])
    return dist
```

Time complexity → $O(n^3)$

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Binary Search :-

→ It works on divide & conquer method.
→ Input should be a sorted array.
→ Time complexity → O(log n)

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Brute Force :-

→ Pattern matching
→ It will return the beginning of the first occurance of the text/pattern
→ Time complexity = O(n*m)

Boyer-Moore algorithm :-
→ Number of iteration less.
→ Number of comparison less
→ Requires additional datastructure dictonary where key is the character and value is the index value of it.
→ Time complexity = O(n+m)

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Knuth-Morris-Pratt :-

→ Keeps track how much pattern is matched
→ It works well only if overlap is present