

Data Structures

Built-in python data structures and relevant notes:

Structure	Python	Relevant Notes
Vector, Stack	list()	append(x) insert(idx, x) extend(iter) pop(idx) remove(x) clear() index(x)
HashMap	dict(), collections.defaultdict(lambda: 0)	d[k]=v d.pop(k)
HashSet	set()	add(x) update(iter) remove(x) clear() union(iter) intersection(iter)
Deque	collections.deque()	rotate(n) append(x) appendleft(x) pop() popleft() extend(iter) extendleft(iter)
Priority Queue	heapq	heapify([]) heappush(hp, x) heappop(hp)

Graph

- collection of vertices (V) and edges (E)
- adjacency matrix representation (good for dense graphs): $V * V$ matrix with distances
- adjacency list representation (good for sparse graphs): list of lists of neighbors
- $E \leq V^2$

Tree

- acyclic graph (root + children)
- given the height of tree as H:
 - $O(H)$ lookup
 - $O(H)$ insert
 - $O(H)$ delete

Binary Tree

- a tree with at most 2 children
- no certainty regarding tree height, hence:
 - $O(H)$ lookup
 - $O(H)$ insert
 - $O(H)$ delete

Binary Search Tree

- a binary tree where $\text{left} < \text{root} < \text{right}$
- no certainty regarding tree height, hence:
 - $O(H)$ lookup
 - $O(H)$ insert
 - $O(H)$ delete

Balanced Binary Search Tree

- a binary search tree where the height difference between subtrees is at most 1
- insertions and deletions possibly make the tree unbalanced, self-balancing trees correct this through rotations (e.g. AVL)
- the height H is balanced, hence with N nodes height is $\log N$, thus:
 - $O(\log N)$ lookup
 - $O(\log N)$ insert
 - $O(\log N)$ delete

Trie

- trees of characters
- terminal nodes (leaves) represent words
- allows caching of current prefix and current node for efficient search
- given the prefix length of K:
 - $O(K)$ lookup
 - $O(K)$ insert
 - $O(K)$ delete

```
class TrieNode:
    def __init__(self):
        self.children = {}
        self.terminal = False

    def insert(self, word):
        cur = self
        for c in word:
            if c not in cur.children:
                cur.children[c] = TrieNode()
            cur = cur.children[c]
        cur.terminal = True

    def remove(self, word):
        cur = self
        for c in word:
            if c not in cur.children:
                return
            cur = cur.children[c]
        cur.terminal = False

    def search(self, word):
        cur = self
        for c in word:
            if c not in cur.children:
                return False
            cur = cur.children[c]
        return cur.terminal
```

Heap (Max)

- balanced binary tree
- root is bigger than children (recursive definition meaning maximum is at the top)
- insertion is done by inserting new element in the last spot and bubbling it up, swapping with parent if needed
- deletion is done by removing element and replacing by the last element added, swapping it down with the max child
- balanced binary tree:
 - $O(1)$ max lookup
 - $O(\log N)$ insert
 - $O(\log N)$ delete

Disjoint Set

- keeps track of multiple sets of elements, disjoint at first
- allows fast check of disjoint sets of elements
- `union(x, y)` should set `x` and `y` to the same set
- `find(x)` should return the set `x` belongs to
- $O(\log N)$ union-find by tracking the size and chaining to the smallest

```
class DisjointSet:
    def __init__(self):
        self.groups = dict()
        self.sizes = dict()

    def find(self, x):
        if x not in self.groups:
            self.groups[x] = x
            self.sizes[x] = 1

        while x != self.groups[x]:
            x = self.groups[x]
        return x

    def union(self, x, y):
        x = self.find(x)
        y = self.find(y)
        if x == y:
            return

        shorter = x if self.sizes[x] < self.sizes[y] else y
        longer = y if self.sizes[x] < self.sizes[y] else x
        self.groups[shorter] = longer
        self.sizes[longer] += self.sizes[shorter]
```

Algorithms

Tree Traversal

Example tree:



Method	Order	Example
Pre (dfs)	root left right	A B D E C F G
In	left root right	D B E A G F C
Post	left right root	D E B G F C A

```
def preorder(root):
    if root == None: return
    print(root)
    preorder(root.left)
    preorder(root.right)

def inorder(root):
    if root == None: return
    inorder(root.left)
    print(root)
    inorder(root.right)

def postorder(root):
    if root == None: return
    postorder(root.left)
    postorder(root.right)
    print(root)
```

Depth-First Search (DFS)

- LIFO approach
- search leftmost first, backtracking when needed

```
# recursive
def dfs(root):
    print(root)
    for child in root.children:
        dfs(child)

# iterative
def dfs(root):
    stack = [root]
    while len(stack) > 0:
        top = stack.pop()
        print(top)
        for child in reversed(top.children):
            stack.append(child)
```

Breadth-First Search (BFS)

- FIFO approach
- explore all nodes in a "level" before going deeper

```
from collections import deque

def bfs(root):
    queue = deque([root])
    while len(queue) > 0:
        front = queue.popleft()
        print(front)
        for child in front.children:
            queue.append(child)
```

Dijkstra

- greedy algorithm to find the shortest path from one node to all others
- no negative weight edges allowed
- $O(E * \log V)$

```
from heapq import heappush, heappop

def dijkstra(graph, src):
    dists = [float("inf")] * len(graph)
    dists[src] = 0

    visited = set()
    pq = [(0, src)]
    while len(pq) > 0:
        (_, cur) = heappop(pq)

        if cur in visited:
            continue
        visited.add(cur)

        # for each neighbor check if the cost of going
        # from current to neighbor is lower than neighbor distance
        for (neighbor, cost) in enumerate(graph[cur]):
            alt = dists[cur] + cost
            if alt < dists[neighbor]:
                dists[neighbor] = alt
                heappush(pq, (dists[neighbor], neighbor))

    return dists
```

Bellman-Ford

- finds the shortest path from one node to all others
- works for negative edges
- relaxes edges $V-1$ times
- can quit early if nothing improves
- can detect negative cycles
- $O(VE)$

```
def bellman_ford(graph, src):
    n_vertices = len(graph)

    dists = [float("inf")] * n_vertices
    dists[src] = 0

    for _ in range(n_vertices - 1):
        # for each neighbor check if the cost of going
        # from current to neighbor is lower than neighbor distance
        for i in range(n_vertices):
            for j in range(n_vertices):
                alt = dists[i] + graph[i][j]
                if alt < dists[j]:
                    dists[j] = alt

    return dists
```


Floyd-Warshall

- shortest path between all nodes
- works for negative edges
- $O(V^3)$

```
def floyd_warshall(graph):
    n_vertices = len(graph)
    dists = [[graph[i][j] for i in range(n_vertices)] for j in
range(n_vertices)]

    for intermediate in range(n_vertices):
        for i in range(n_vertices):
            for j in range(n_vertices):
                alt = dists[i][intermediate] + dists[intermediate][j]
                if alt < dists[i][j]:
                    dists[i][j] = alt

    return dists
```

Kruskal

- find an MST: tree that contains all nodes of the original one with a minimal sum of edge weights
- select minimum cost edges that do not form a cycle
- pop them one by one, using those that do not connect two already used vertices (disjoint set)
- stop when all vertices are connected
- $O(E * \log V)$

```
def kruskal(edges):
    edges.sort()

    mst = []
    disjoint_set = DisjointSet()
    while len(edges) > 0:
        cost, src, dst = edges.pop(0)

        # disjoint set keeps track of connectivity
        if disjoint_set.find(src) != disjoint_set.find(dst):
            disjoint_set.union(src, dst)
            mst.append((cost, src, dst))

    return mst
```

Quick Sort

- recursively sort halves, partitioned by a pivot
- swap left and right elements of the pivot and call quick sort on both halves
- $O(N * \log N)$

```
def quicksort(collection):
    return _quicksort(collection, 0, len(collection) - 1)

def _quicksort(collection, left, right):
    if left >= right:
        return

    pivot = collection[(left + right) // 2]
    split = partition(collection, left, right, pivot)
    _quicksort(collection, left, split - 1)
    _quicksort(collection, split, right)
    return collection

def partition(collection, left, right, pivot):
    while left <= right:
        while collection[left] < pivot:
            left += 1

        while collection[right] > pivot:
            right -= 1

        if left <= right:
            tmp = collection[left]
            collection[left] = collection[right]
            collection[right] = tmp
            left += 1
            right -= 1

    return left
```

Merge Sort

- recursively sort halves, call merge sort on each
- copy elements in order to a new array
- $O(N * \log N)$

```
def mergesort(collection):
    if len(collection) <= 1:
        return collection

    middle = len(collection) // 2
    left = mergesort(collection[:middle])
    right = mergesort(collection[middle:])
    merged = merge(left, right)
    return merged

def merge(left, right):
    merged = []

    l, r = 0, 0
    while l < len(left) and r < len(right):
        if left[l] < right[r]:
            merged.append(left[l])
            l += 1
        else:
            merged.append(right[r])
            r += 1

    while l < len(left):
        merged.append(left[l])
        l += 1

    while r < len(right):
        merged.append(right[r])
        r += 1

    return merged
```

Heap Sort

- build an heap (heapify $O(N)$)
- keep popping the min element into a new array
- $O(N * \log N)$

```
from heapq import heapify, heappush, heappop

def heapsort(collection):
    heapify(collection)
    return [heappop(collection) for _ in range(len(collection))]
```

Binary Search

- cut the search space in half each iteration (logarithmic complexity)
- requires a sorted collection
- $O(\log N)$

```
def bin_search(nums, target):
    lb, ub = 0, len(nums) - 1
    while lb <= ub:
        mid = lb + (ub - lb) // 2
        if nums[mid] < target:
            lb = mid + 1
        elif nums[mid] > target:
            ub = mid - 1
        else:
            return mid
    return -1
```

Cycle Detection

- DFS: check if a node has been visited twice

```
def has_cycle(root):
    visited = set()
    stack = [root]
    while len(stack) > 0:
        top = stack.pop()

        if top in visited:
            return True

        for child in reversed(top.children):
            stack.append(child)

    return False
```

- Disjoint Set: union nodes for each edge and quit if same set is found

```
def has_cycle(edges):
    disjoint_set = DisjointSet()

    for src, dst in edges:
        if disjoint_set.find(src) == disjoint_set.find(dst):
            return True
        disjoint_set.union(src, dst)

    return False
```

- Bellman-Ford: run an extra cycle and if it improves there is a cycle

```
def has_cycle(graph, src):
    n_vertices = len(graph)
    dists = bellman_ford(graph, src)

    # run an extra cycle to see if anything improves
    for i in range(n_vertices):
        for j in range(n_vertices):
            alt = dists[i] + graph[i][j]
            if alt < dists[j]:
                return True

    return False
```

- Tortoise & Hare: if both pointers meet, there is a cycle

```
def has_cycle(root):
    slow, fast = root, root
    while fast and fast.next:
        slow = slow.next
        fast = fast.next.next
        if slow == fast:
            return True
    return False
```

Object Oriented Programming (OOP)

SOLID Principles

Single Responsibility - classes should do one thing and do it well, having one reason to change

Open-Closed - classes should be open for extension and closed for modifications

Liskov Substitution - classes should be substitutable for parent classes or interfaces they implement

Interface Segregation - keep interfaces thin, split big ones into smaller contracts, each client implements what is needed

Dependency Inversion - entities depend on abstractions and not on concretions

Design Patterns

Typical solutions for common software OOP design problems.

Creational - handle object creation

- **Factory** - interface for creating objects, simplifying and centralizing logic

```
class Burger:
    def __init__(self, ingredients):
        self.ingredients = ingredients

class BurgerFactory:
    @classmethod
    def create_cheese_burger(cls):
        return Burger(["bun", "cheese", "beef-patty"])

    @classmethod
    def create_deluxe_burger(cls):
        return Burger(["bun", "cheese", "beef-patty", "tomatoe",
"lettuce"])
```

- **Builder** - construct complex objects step by step

```
class Burger:
    def __init__(self):
        self.buns = None
        self.patty = None

    def set_buns(self, buns):
        self.buns = buns

    def set_patty(self, patty):
        self.patty = patty

class BurgerBuilder:
    def __init__(self):
        self.burger = Burger()

    def build(self):
        return self.burger

    def add_buns(self, buns):
        self.burger.set_buns(buns)
        return self

    def add_patty(self, patty):
        self.burger.set_patty(patty)
        return self
```

- **Singleton** - ensure a single instance of a class

```
class Singleton:
    _instance = None

    @classmethod
    def instance(cls):
        if cls._instance == None:
            cls._instance = cls()
        return cls._instance
```


Behavioral - handle objects' communication and state changes

- **Command** - turns actions into objects (e.g. useful for command queues with delays, undo/redo, event sourcing, ...)

```
class Command:
    def execute(self, program):
        pass

class KillCommand(Command):
    def execute(self, program):
        self.program.kill()

class RestartCommand(Command):
    def execute(self, program):
        self.program.restart()
```

- **Observer** - subscription/notification (pub/sub) of objects to events

```
class Subscriber:
    def notify(self, event):
        pass

class Publisher:
    def __init__(self):
        self.subscribers = []

    def subscribe(self, sub: Subscriber):
        self.subscribers.append(sub)

    def notify(self, event):
        for sub in self.subscribers:
            sub.notify(event)
```

- **Strategy** - define a family of interchangeable algorithms

```
class FilterStrategy:
    def filter(self, val):
        pass

class FilterPositives(FilterStrategy):
    def filter(self, val):
        return val > 0

class FilterNegatives(FilterStrategy):
    def filter(self, val):
        return val < 0

def filter_fn(values, strategy: FilterStrategy):
    return [x for x in values if strategy.filter(x)]
```

Structural - objects' assembly

- **Facade** - a wrapper used to abstract lower-level details

```
class VideoConverter:
    # inner workings and system interactions abstracted
```

- **Adapter** - allow objects with incompatible interfaces to communicate

```
class SquarePeg:
    def __init__(self, width: float):
        self.width = width

class RoundPeg:
    def __init__(self, radius: float):
        self.radius = radius

class RoundHole:
    def __init__(self, radius: float):
        self.radius = radius

    def fits(self, peg: RoundPeg):
        return self.radius >= peg.radius

class SquarePegAdapter(RoundPeg):
    def __init__(self, square_peg: SquarePeg):
        self.square_peg = square_peg
        self.radius = self.square_peg.width * math.sqrt(2) / 2
```

- **Decorator** - wrap objects with additional functionality

```
class Text:
    def __init__(self, text):
        self.text = text

    def render(self):
        return self.text

class UnderlineText(Text):
    def __init__(self, wrapped):
        self.wrapped = wrapped

    def render(self):
        return "<u>" + self.wrapped.render() + "<u>"

class BoldText(Text):
    def __init__(self, wrapped):
        self.wrapped = wrapped

    def render(self):
        return "<b>" + self.wrapped.render() + "<b>"
```