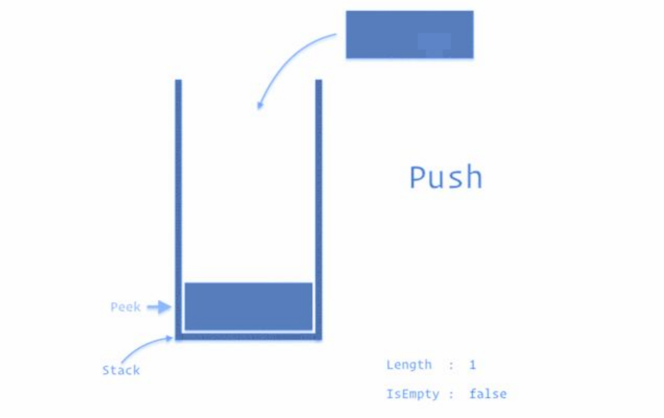
Stacks, Queues and Monotonicity

Pre-requisites

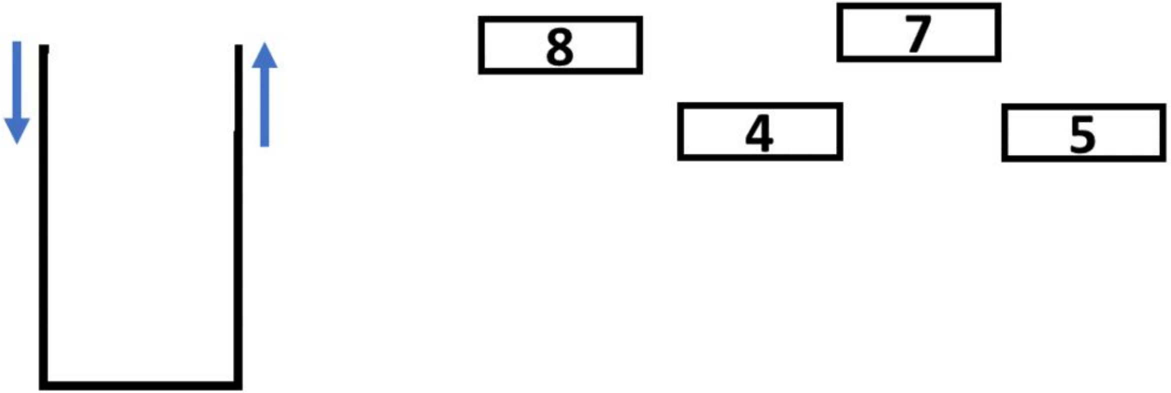
- Linear data structures array/list
- Linked List

Stacks



Introduction To Stack

Stack data structure is a linear data structure that accompanies a principle known as **LIFO** (Last In First Out) or FILO (First In Last Out).



Real Life Example

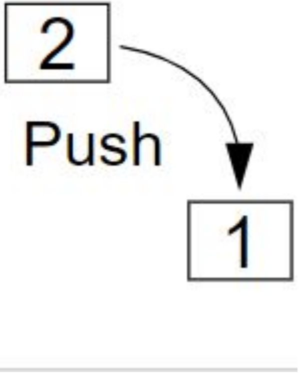
Stack of plates

Stack of books

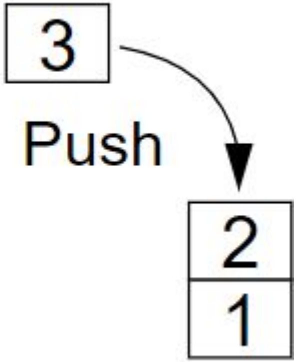
Stack Operations

Push operation

- Add an element to the top of the stack



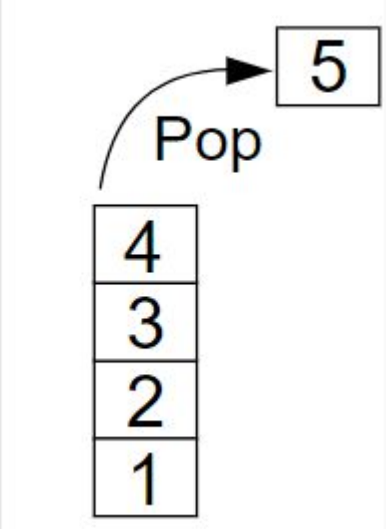
Stack Operations



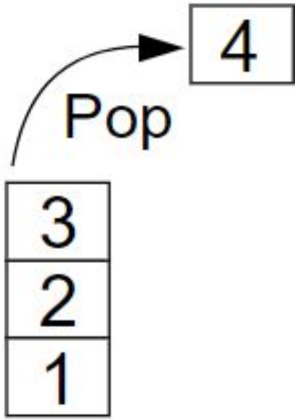
Stack Operations

Pop operation

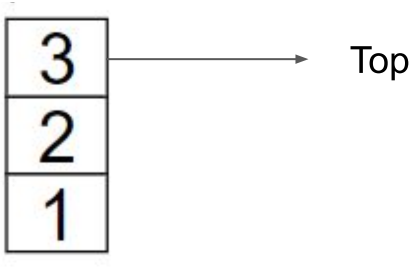
- Remove element from the top of the stack



Stack Operations



Stack Operations



Peek operation

- returning the top element of a stack.

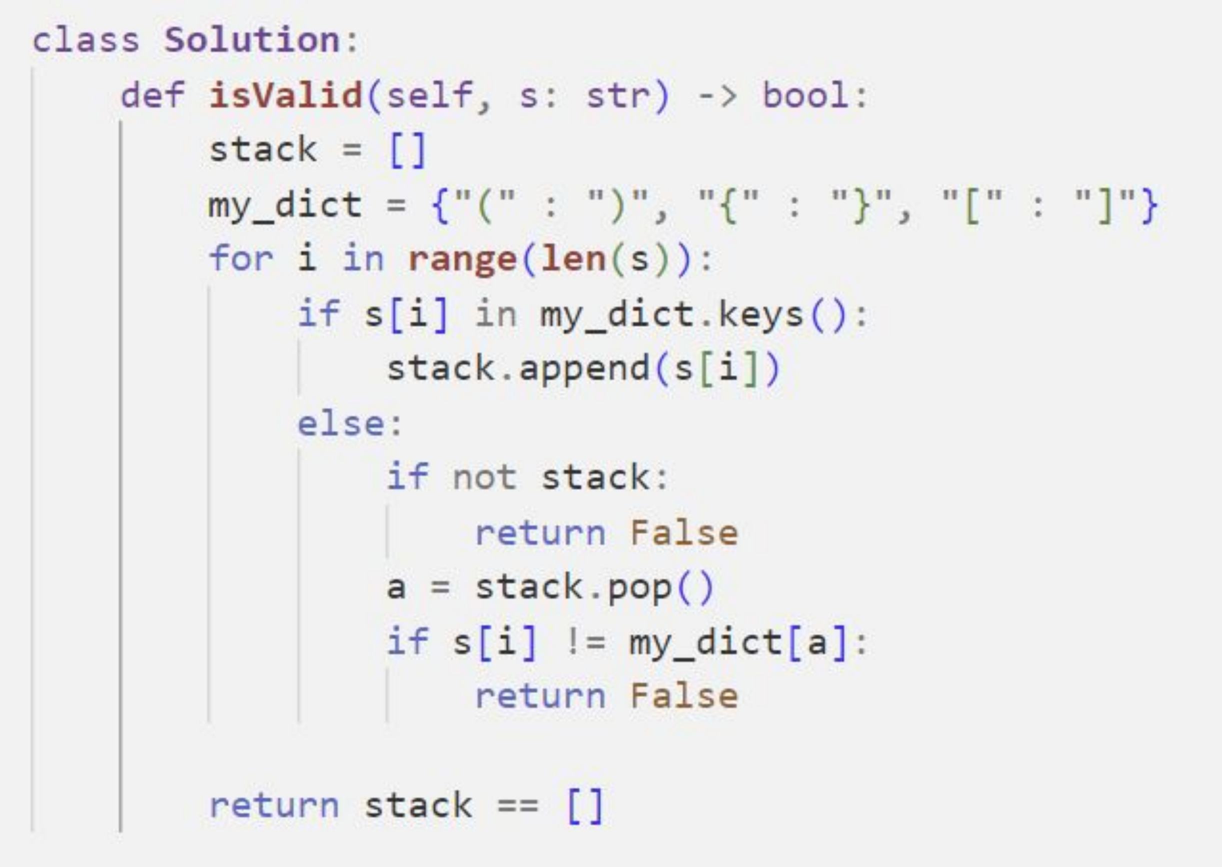
Is empty()

- Check if the list is empty or not.
- If it’s empty return True else False.

Practice

Problem

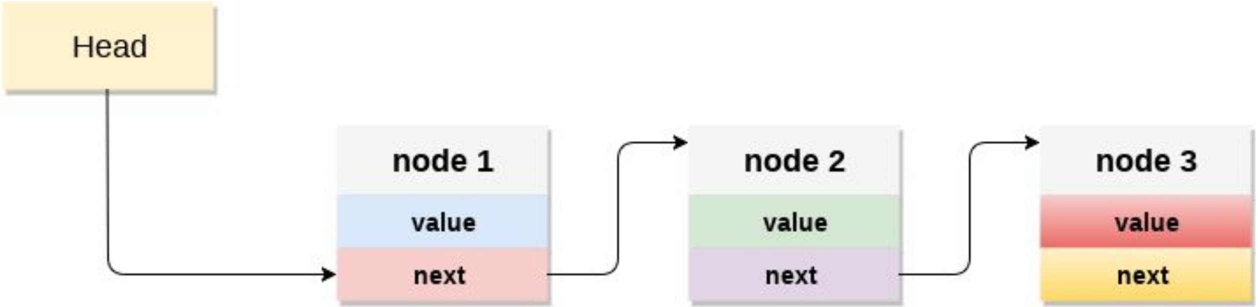
Solution



```python
class Solution:
    def isValid(self, s: str) -> bool:
        stack = []
        my_dict = {"(" : ")", "{" : "}", "[" : "]"}
        for i in range(len(s)):
            if s[i] in my_dict.keys():
                stack.append(s[i])
            else:
                if not stack:
                    return False
                a = stack.pop()
                if s[i] != my_dict[a]:
                    return False

        return stack == []
```

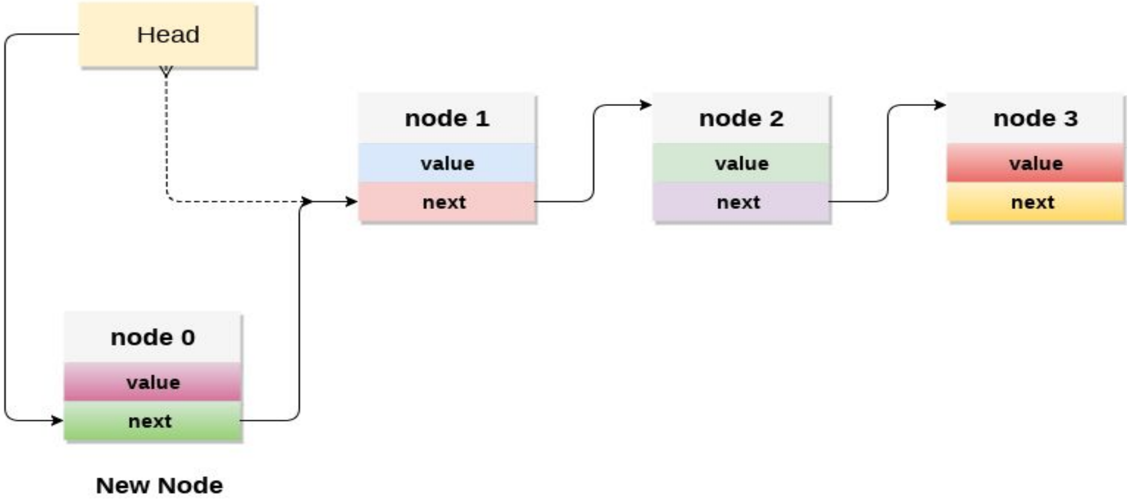
How can we implement Stack?

Implementing stack using linked list



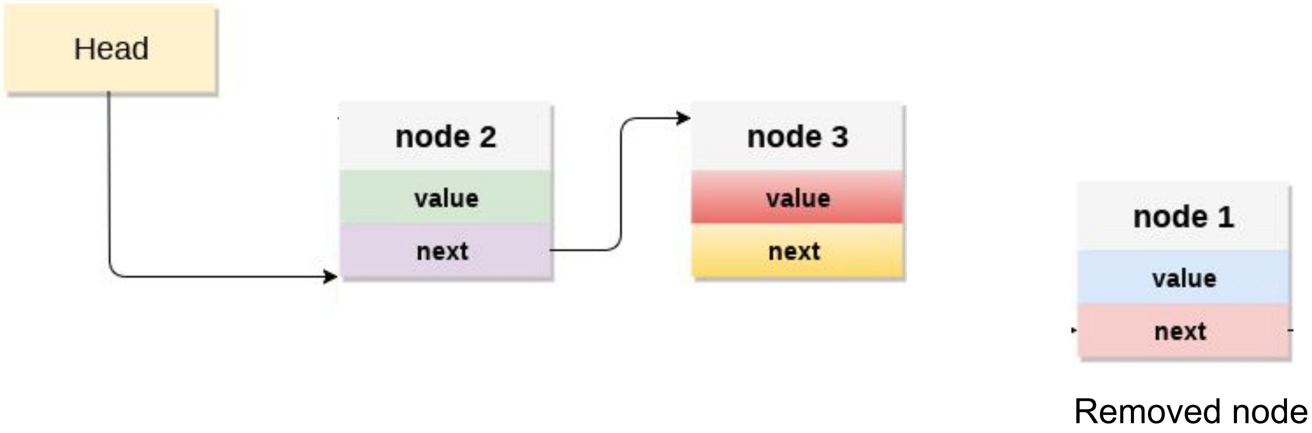
Push operation

- Initialise a node
- Update the value of that node by data i.e. node.value = data
- Now link this node to the top of the linked list i.e. node.next = head
- And update top pointer to the current node i.e. head = node



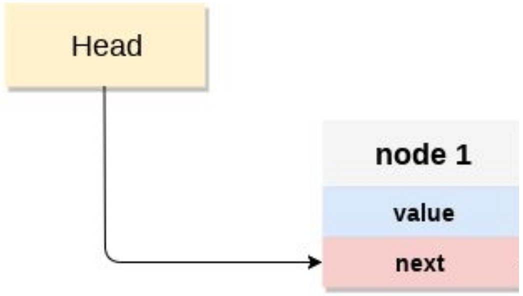
POP operation

- First Check whether there is any node present in the linked list or not, if not then return
- Otherwise make pointer let say temp to the top node and move forward the top node by 1 step
- Now free this temp node



Top operation

- Check if there is any node present or not, if not then return.
- Otherwise return the value of top node of the linked list which is the node at **Head**



Implementation

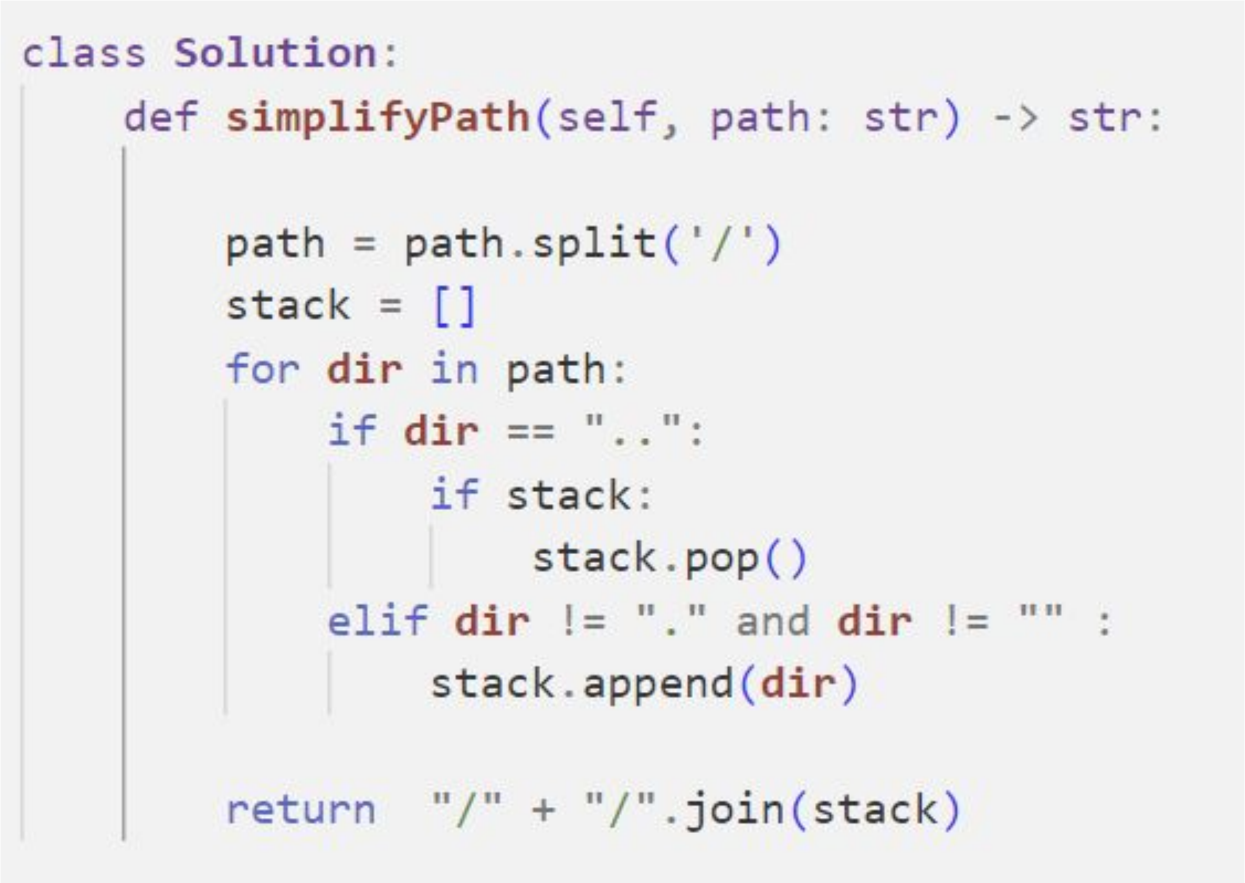
```python
class Node:
    def __init__(self, data):
        self.data = data
        self.next = None

class Stack:
    def __init__(self):
        self.head = None

    def isempty(self):
        if self.head == None:
            return True
        else:
            return False

    def peek(self):
        if self.isempty():
            return None
        else:
            return self.head.data
```

```python
def push(self, data):

    if self.head == None:
        self.head = Node(data)
    else:
        new_node = Node(data)
        new_node.next = self.head
        self.head = new_node

def pop(self):

    if self.isempty():
        return None
    else:
        popped_node = self.head
        self.head = self.head.next
        popped_node.next = None
        return popped_node.data
```

Pair Programming

Problem

Solution



```python
class Solution:
    def simplifyPath(self, path: str) -> str:

        path = path.split('/')
        stack = []
        for dir in path:
            if dir == "..":
                if stack:
                    stack.pop()
            elif dir != "." and dir != "" :
                stack.append(dir)

        return  "/" + "/".join(stack)
```

Time and space complexity

- Push
  - Time complexity - ___?
- Pop
  - Time complexity - ___?
- Peek
  - Time complexity - ___?
- isEmpty()
  - Time complexity - ___?

Time and space complexity

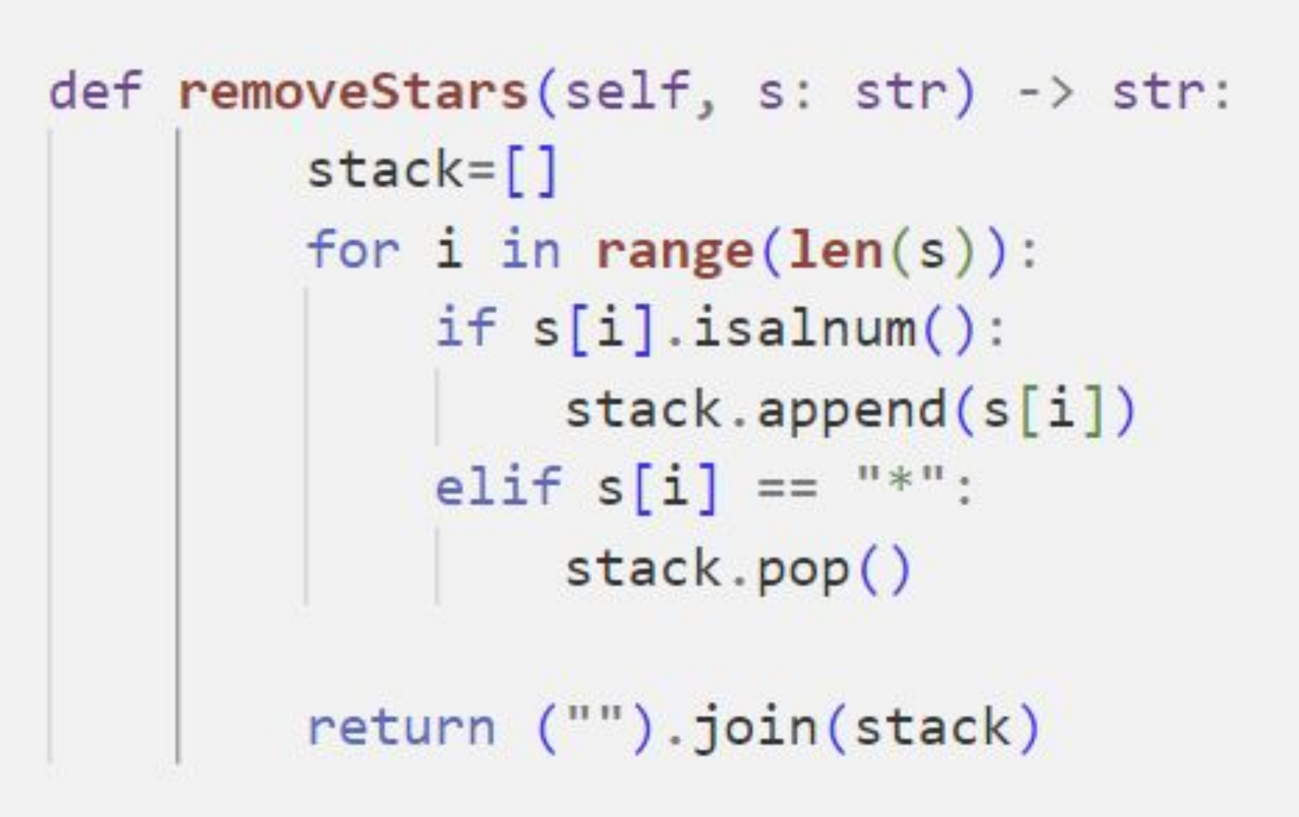
- Push
  - Time complexity - O(1)
- Pop
  - Time complexity - O(1)
- Peek
  - Time complexity - O(1)
- isEmpty()
  - Time complexity - O(1)

Applications of Stack

Practice

Problem

Solution



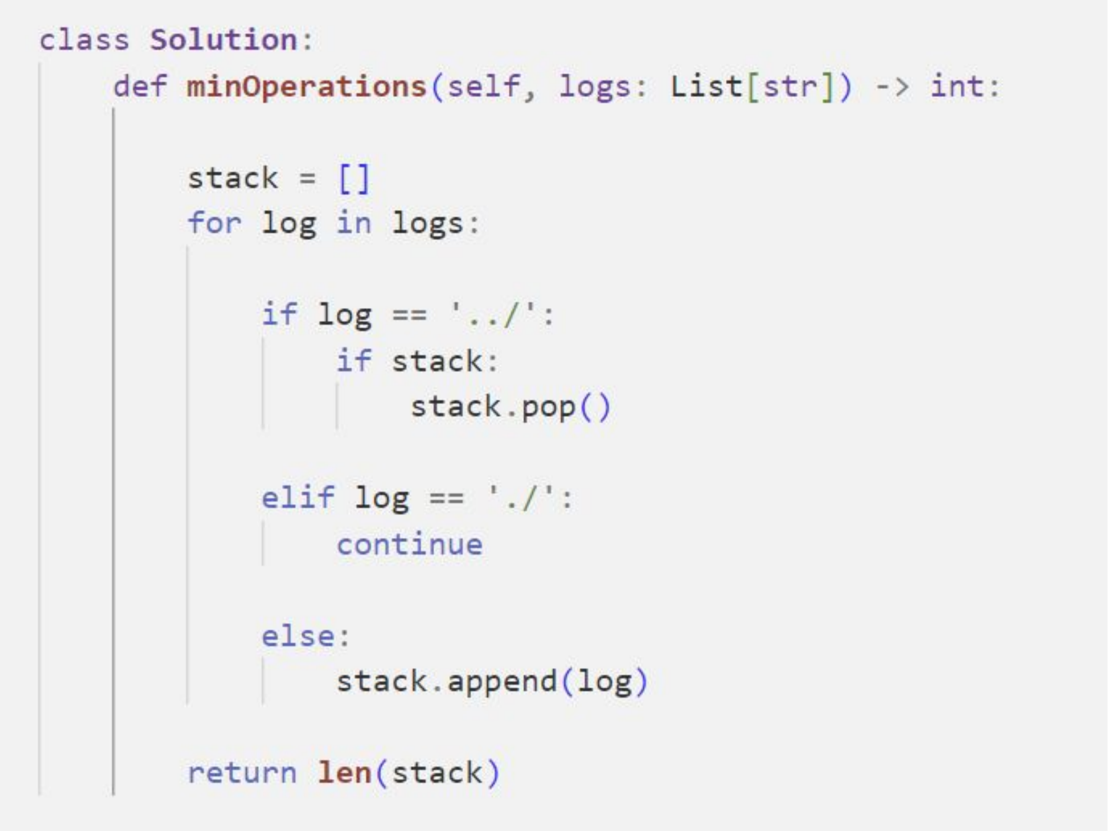
```python
def removeStars(self, s: str) -> str:
        stack=[]
        for i in range(len(s)):
            if s[i].isalnum():
                stack.append(s[i])
            elif s[i] == "*":
                stack.pop()

        return ("").join(stack)
```

Reflection: Stack can help you simulate deletion of elements in the middle in O(1) time complexity

Pair Programming

Problem

Solution



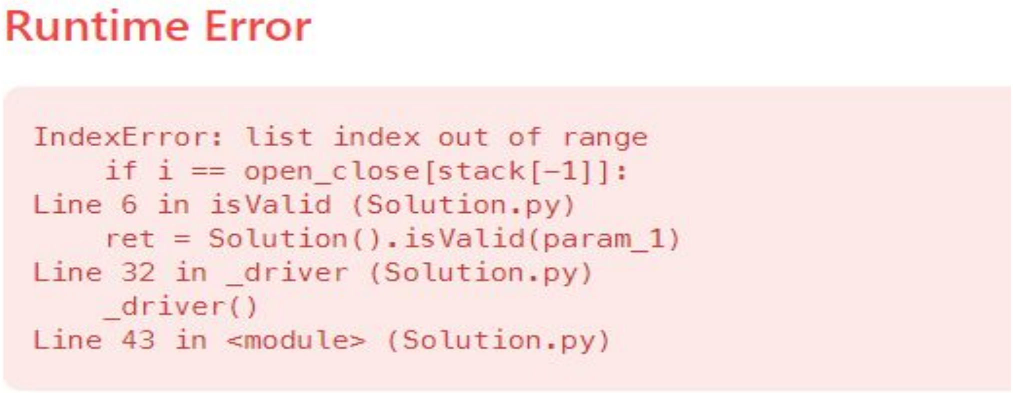
```
class Solution:
    def minOperations(self, logs: List[str]) -> int:

        stack = []
        for log in logs:

            if log == '../':
                if stack:
                    stack.pop()

            elif log == './':
                continue

            else:
                stack.append(log)

        return len(stack)
```

Reflection: stack can help you defer decision until some tasks are finished.

The bottom of the stack waits on the top of stack until they are processed

Common PitFalls

- Popping from empty list
  - This will throw index out of range error
- Null pointer exception if we are using linked list



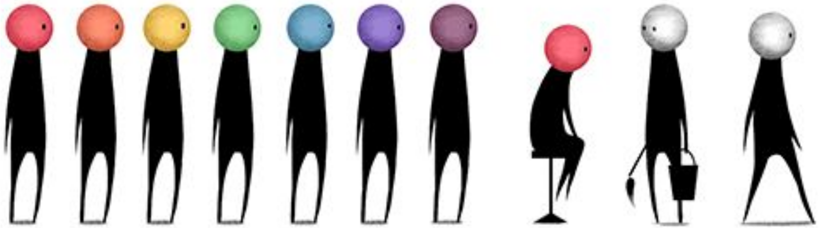
Runtime Error

```
IndexError: list index out of range
    if i == open_close[stack[-1]]:
Line 6 in isValid (Solution.py)
    ret = Solution().isValid(param_1)
Line 32 in _driver (Solution.py)
    _driver()
Line 43 in <module> (Solution.py)
```

Common PitFalls

- Stack overflow
  - May be not in python but In other programming language
  - Pushing to a full stack

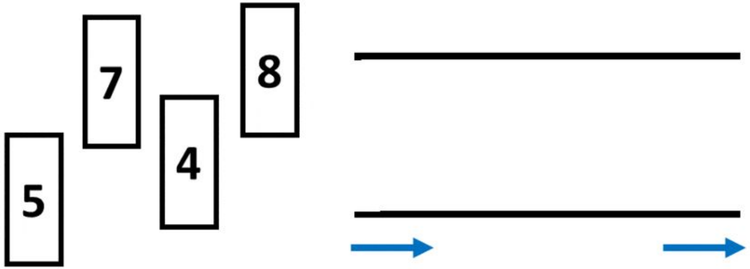
Queues



Introduction

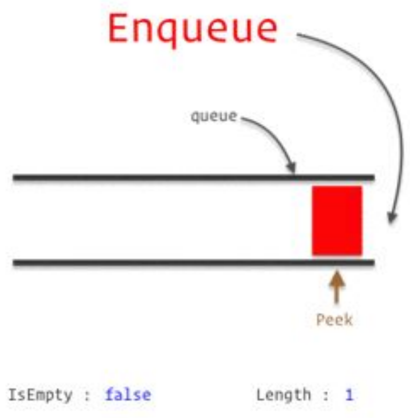
A collection whose elements are added at one end (the **rear**) and removed from the other end (the **front**)

- Uses **FIFO** data handling



Real Life Example

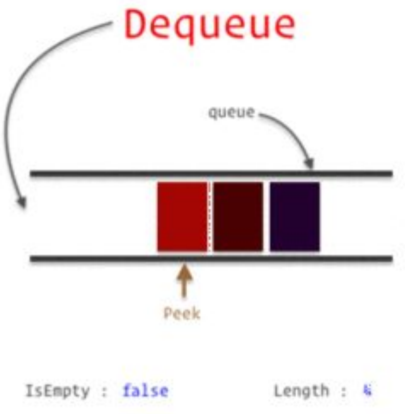
Queue Operations



Enqueue (Append)

- Add an element to the tail of a queue
- **F**irst **I**n

Queue Operations



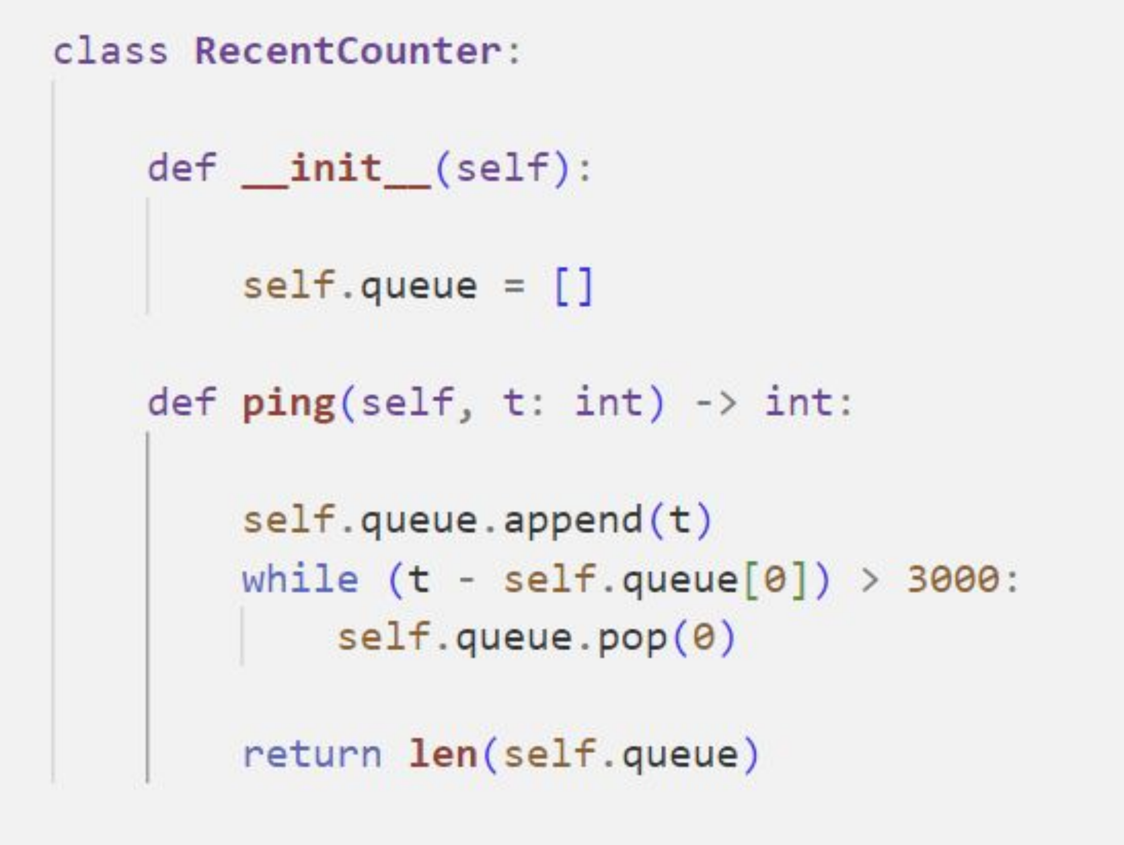
Dequeue (Popleft)

- Remove an element from the head of the queue
- **F**irst **O**ut

Practice

[Problem]

Solution



```python
class RecentCounter:

    def __init__(self):

        self.queue = []

    def ping(self, t: int) -> int:

        self.queue.append(t)
        while (t - self.queue[0]) > 3000:
            self.queue.pop(0)

        return len(self.queue)
```

Implementing Queue

Using an array to implement a queue is significantly harder than using an array to implement a stack. **Why**?

What would the time complexity be?

Implementing Queue with List

```
def __init__(self):
   self.queue = []
   self.headIndex = 0

def append(self, value: int):
   self.queue.append(value)

def pop(self) -> int:
   if self.headIndex < len(self.queue):
       val = self.queue[self.headIndex]
       self.headIndex += 1
       return val
```

Implementing Queue

- Either linked list or list can be used with careful considerations
- In practice, prefer to use built-in or library implementations like `deque()`
- Internally, `deque()` is implemented as a linked list of nodes

```
.pop()

.append()

.popleft()

.appendleft()
```

Implementation (built-in)

```python
from collections import deque

# Initializing a queue

queue = deque()

# Adding elements to a queue

queue.append('a')

queue.append('b')

# Removing elements from a queue

print(queue.popleft())

print(queue.popleft())

# Uncommenting queue.popleft()

# will raise an IndexError

# as queue is now empty
```

We can also use it the other way around by using;

- `.appendleft()`
- `.pop()`

Time and space complexity

- Append
  - Time complexity - ____?
- Popleft
  - Time complexity - ____?
- Peek
  - Time complexity - ____?
- isEmpty()
  - Time complexity - ____?

Time and space complexity

- Append
  - Time complexity - O(1)

- Popleft
  - Time complexity - O(1)

- Peek
  - Time complexity - O(1)

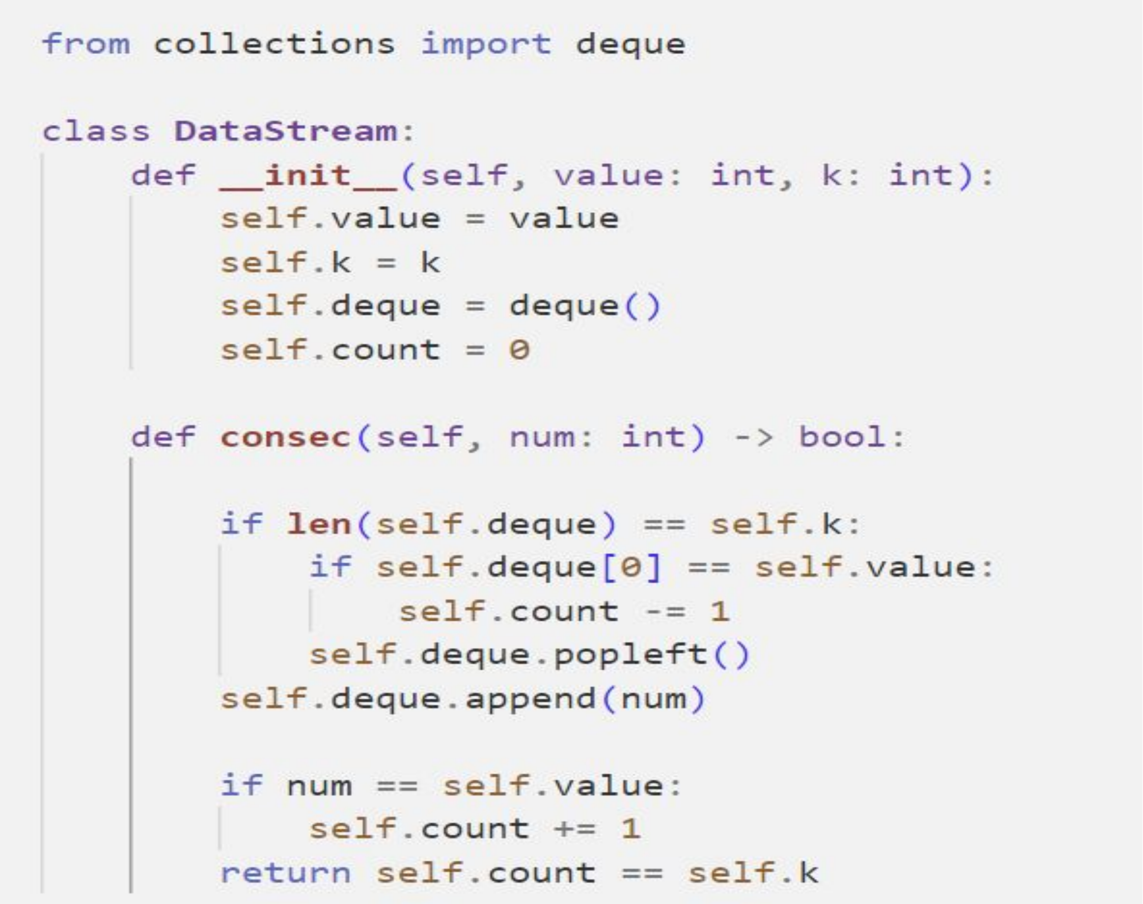
- isEmpty()
  - Time complexity - O(1)

Applications of Queue

Practice

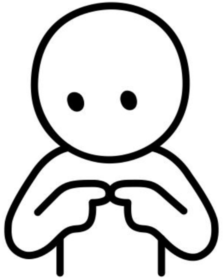
[Problem](#)

Solution



```python
from collections import deque

class DataStream:
    def __init__(self, value: int, k: int):
        self.value = value
        self.k = k
        self.deque = deque()
        self.count = 0

    def consec(self, num: int) -> bool:

        if len(self.deque) == self.k:
            if self.deque[0] == self.value:
                self.count -= 1
            self.deque.popleft()
        self.deque.append(num)

        if num == self.value:
            self.count += 1
        return self.count == self.k
```

Reflection: Queue helps solve problems that need access to the “first something”



Common Pitfalls

A2SV

Africa To Silicon Valley

Not handling edge cases

- Popping from an empty queue

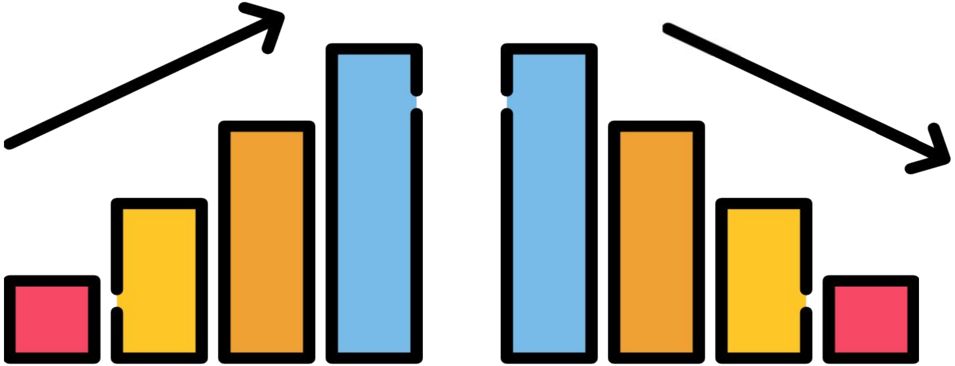
```
if queue:
    queue.popleft()
```

- Appending to a full queue

```
if len(queue) < capacity:
    queue.append(val)
```

Check point

Monotonicity



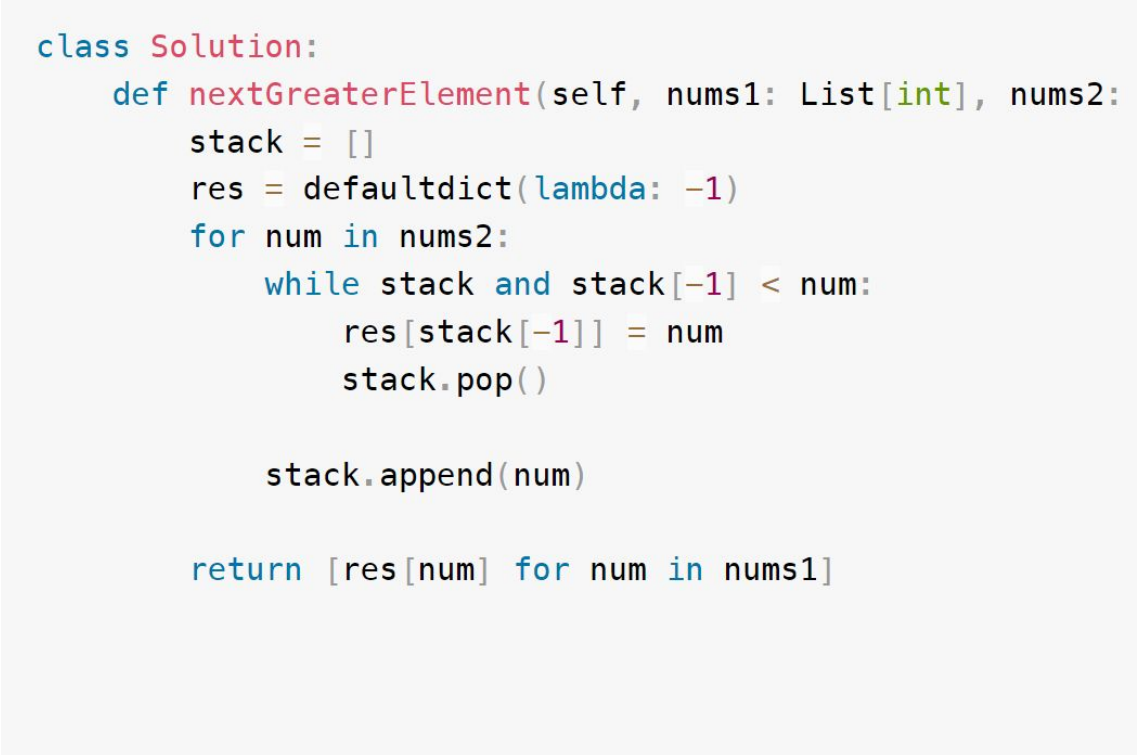
Practice

Problem

Basic Concepts

- A stack whose elements are **monotonically** increasing or decreasing.
- Useful when we're looking for the next larger/smaller element
- For a mono-decreasing stack:
    - we need to pop smaller elements before pushing.
    - it keeps tightening the result as lexicographically greater as possible. (Because we keep popping smaller elements out and keep greater elements).

Solution

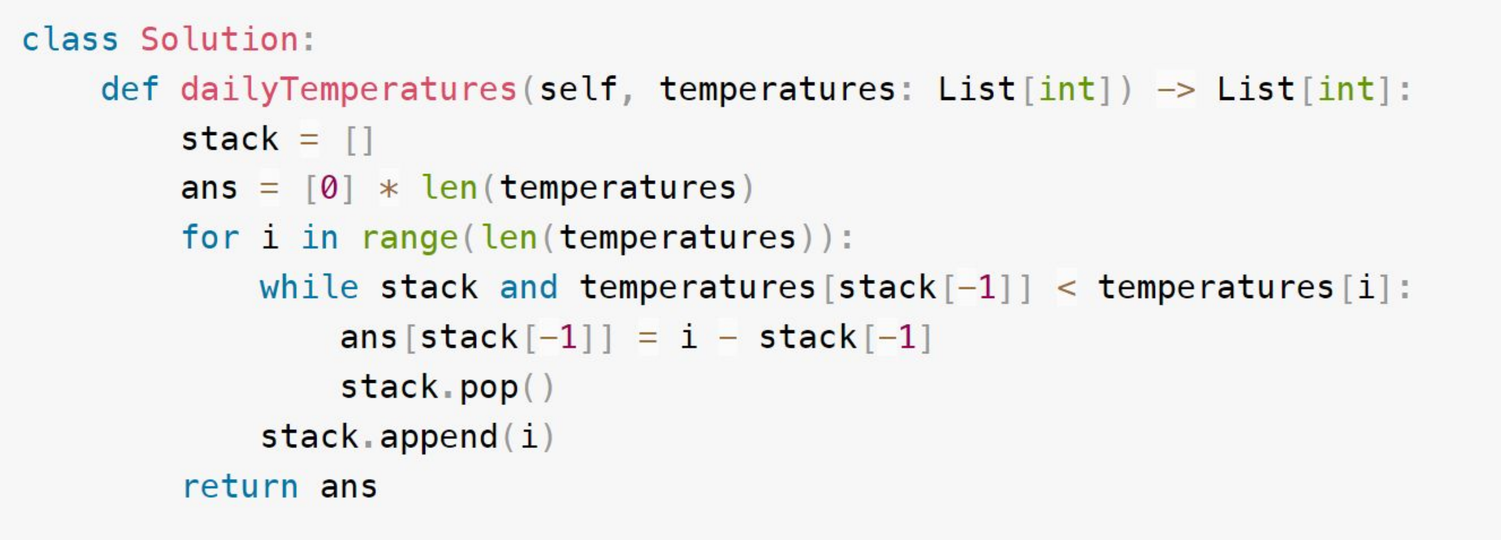


```
class Solution:
    def nextGreaterElement(self, nums1: List[int], nums2:
        stack = []
        res = defaultdict(lambda: -1)
        for num in nums2:
            while stack and stack[-1] < num:
                res[stack[-1]] = num
                stack.pop()

            stack.append(num)

        return [res[num] for num in nums1]
```

Practice

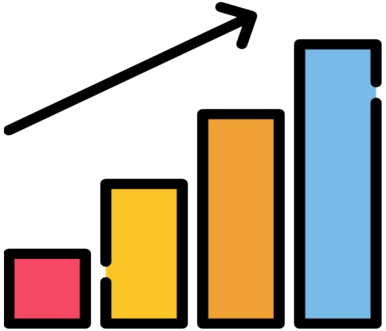
Problem

Solution



```python
class Solution:
    def dailyTemperatures(self, temperatures: List[int]) -> List[int]:
        stack = []
        ans = [0] * len(temperatures)
        for i in range(len(temperatures)):
            while stack and temperatures[stack[-1]] < temperatures[i]:
                ans[stack[-1]] = i - stack[-1]
                stack.pop()
            stack.append(i)
        return ans
```

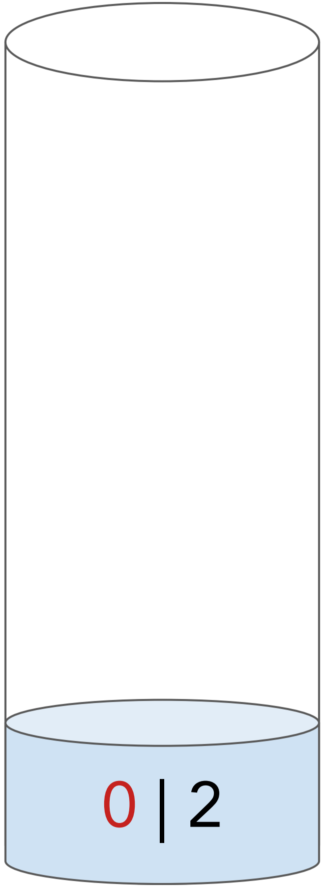
Monotonic Stack Application



- It gives you how far a value spans as a **maximum** or **minimum** in the given array.

[2, 1, 3, 5, 6, 1]

0 1 2 3 4 5

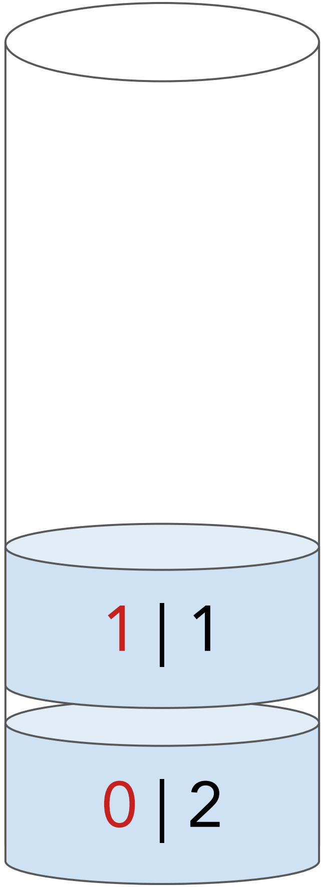


Monotonically decreasing stack

[2, 1, 3, 5, 6, 1]

0 1 2 3 4 5

Monotonically decreasing stack



[2, 1, 3, 5, 6, 1]

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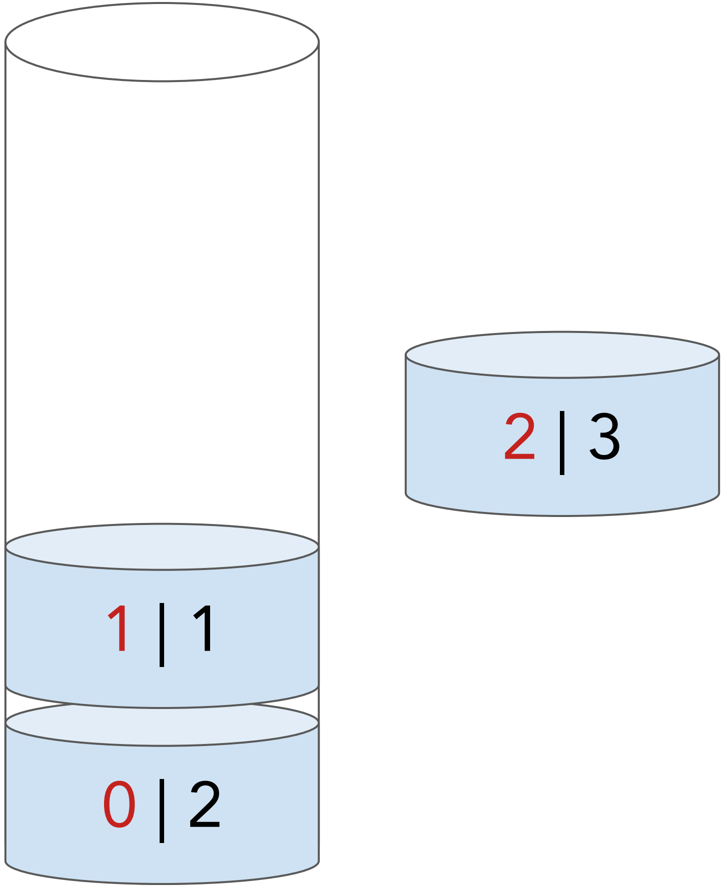
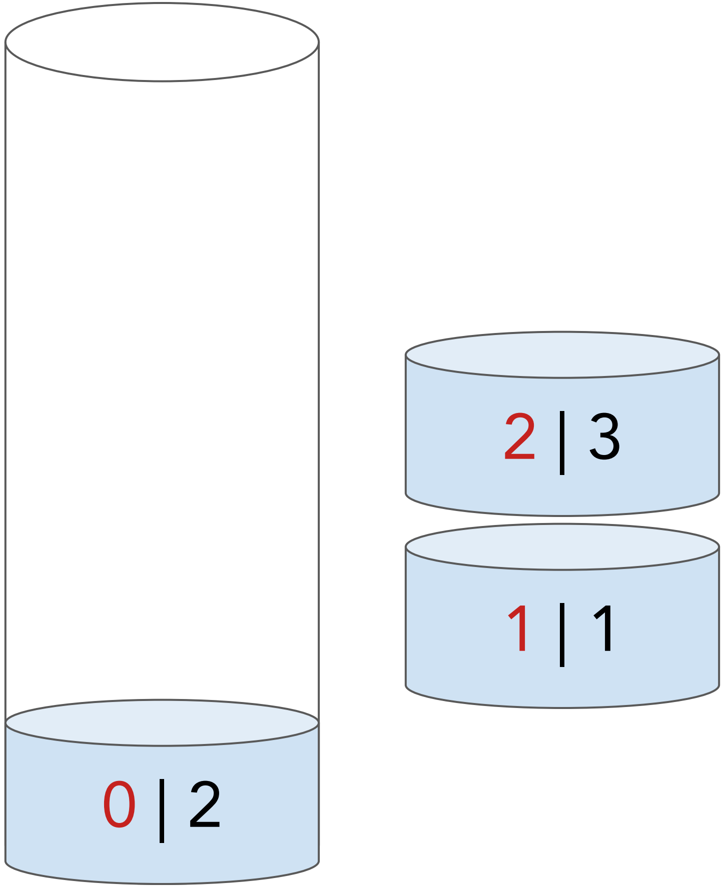


Monotonically decreasing stack

[2, 1, 3, 5, 6, 1]
0 1 2 3 4 5

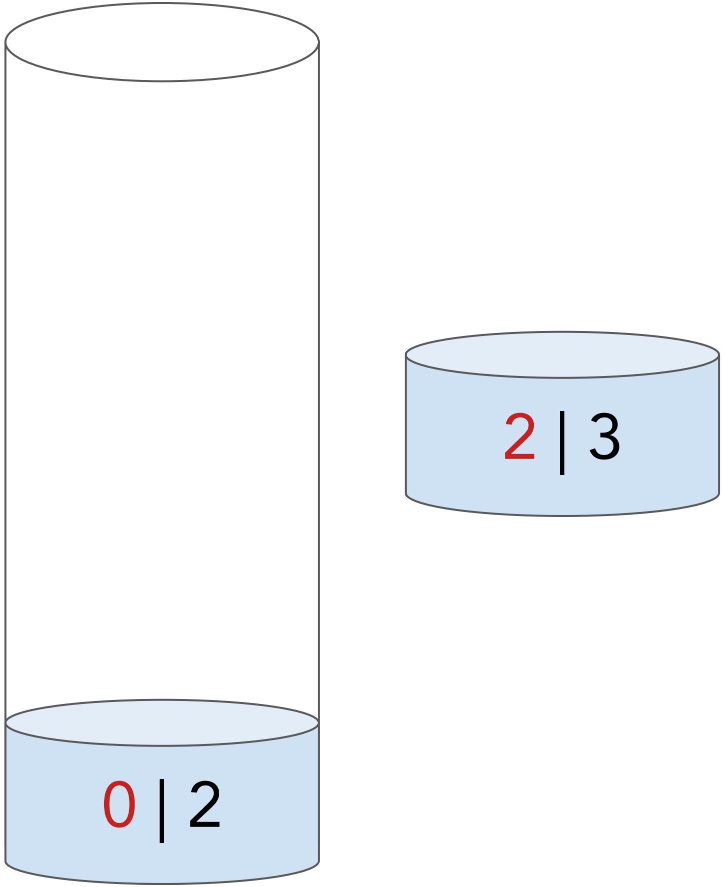
Monotonically decreasing stack



[2, 1, 3, 5, 6, 1]

0 1 2 3 4 5

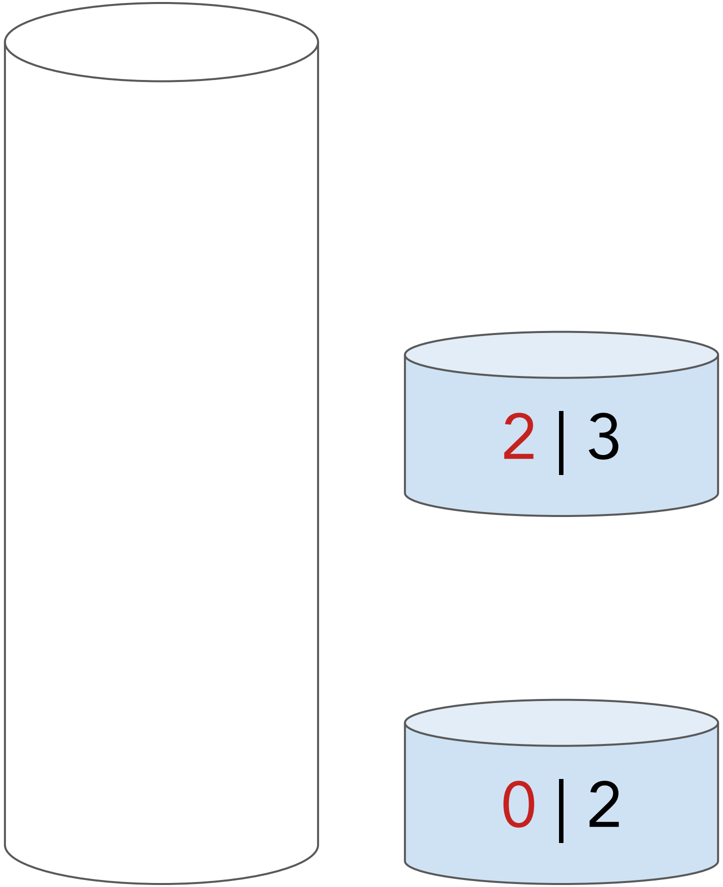
Monotonically decreasing stack



[2, 1, 3, 5, 6, 1]

0 1 2 3 4 5

Monotonically decreasing stack

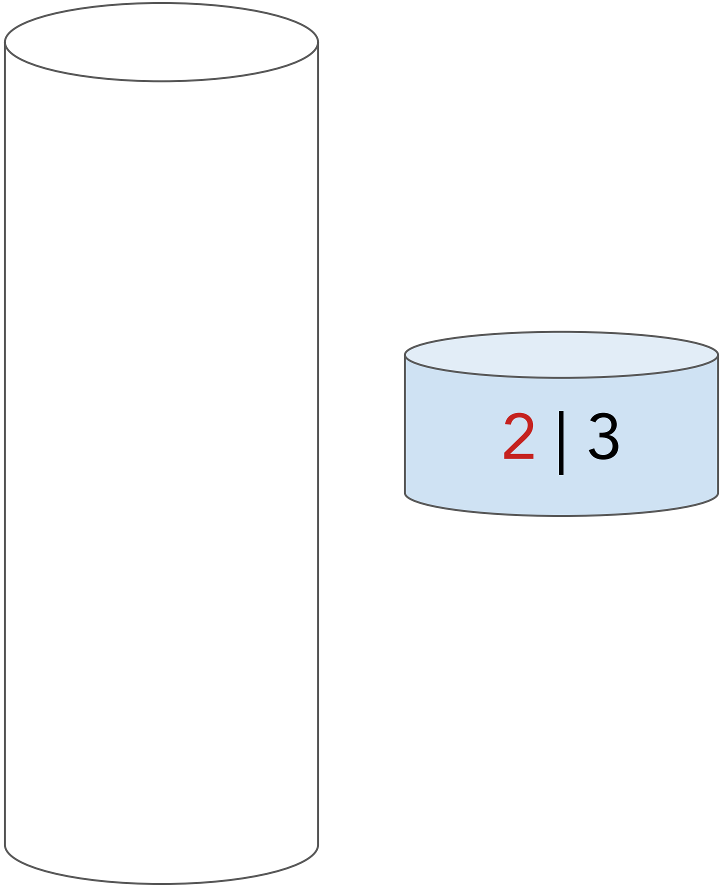


2 | 3

0 | 2

[2, 1, 3, 5, 6, 1]

0 1 2 3 4 5

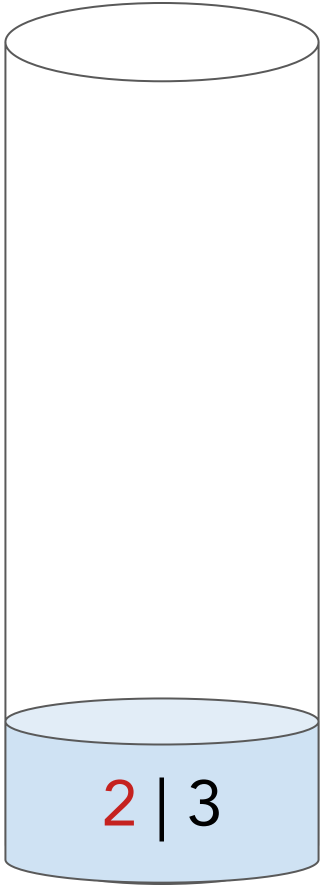


Monotonically decreasing stack

[2, 1, 3, 5, 6, 1]

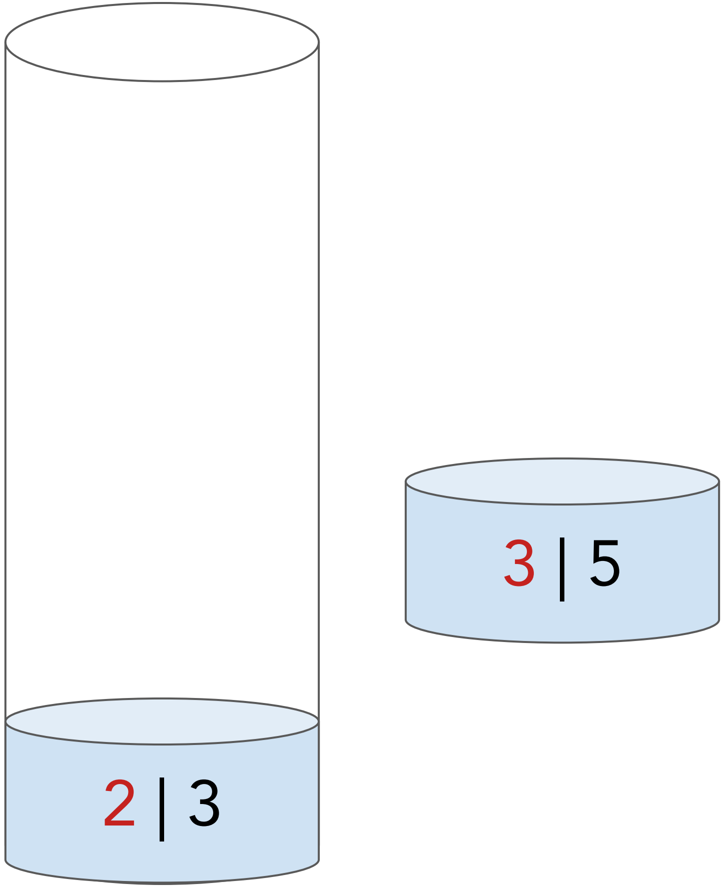
0 1 2 3 4 5

Monotonically decreasing stack



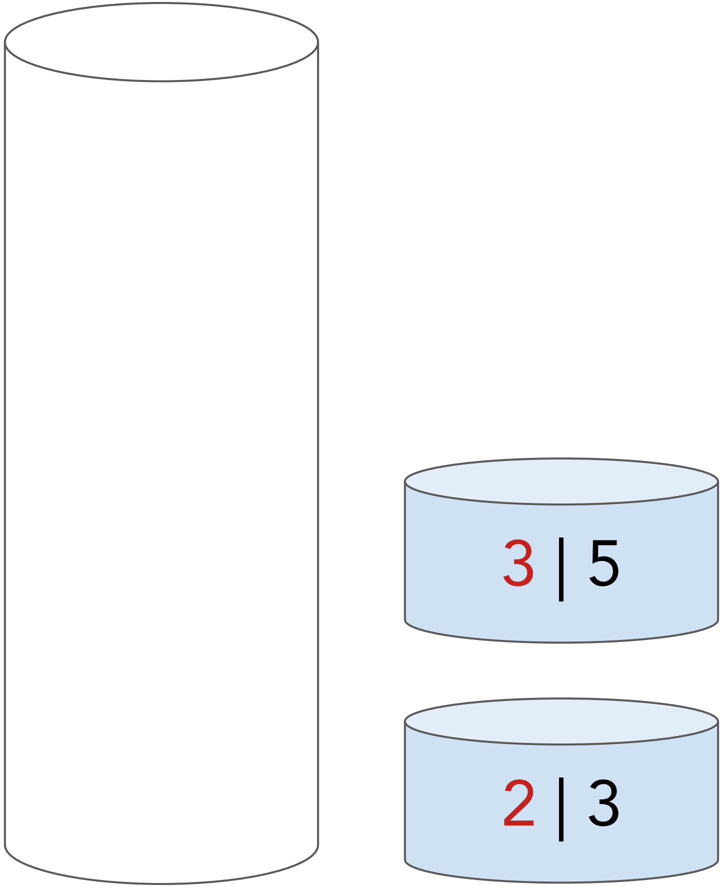
[2, 1, 3, 5, 6, 1]
0 1 2 3 4 5

Monotonically decreasing stack



[2, 1, 3, 5, 6, 1]
0 1 2 3 4 5

Monotonically decreasing stack



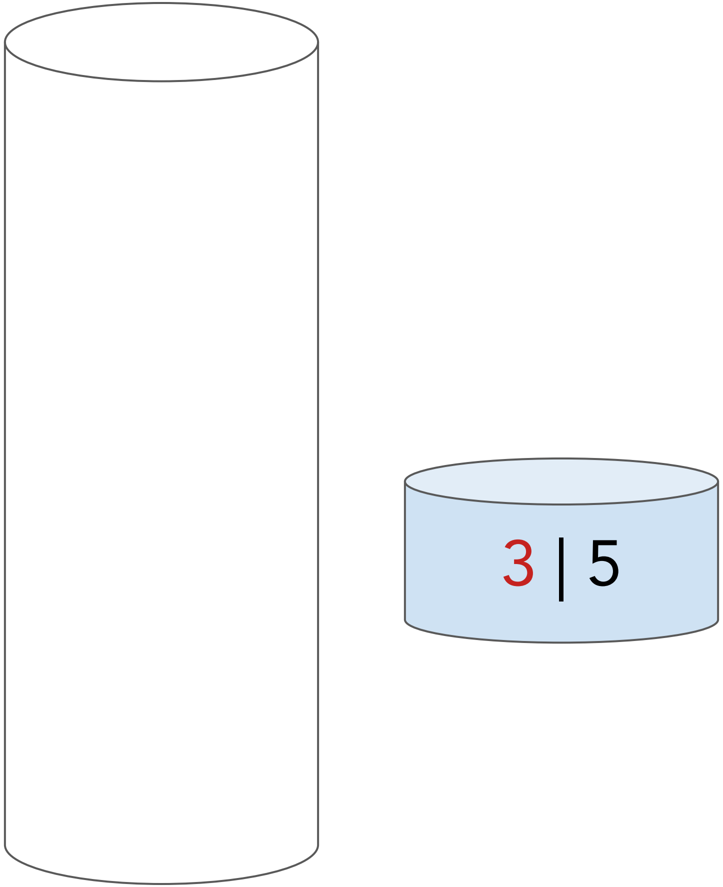
3 | 5

2 | 3

[2, 1, 3, 5, 6, 1]

0 1 2 3 4 5

Monotonically decreasing stack

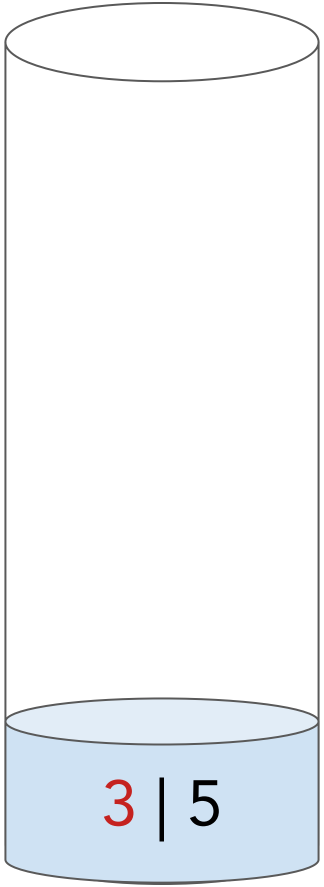


3 | 5

[2, 1, 3, 5, 6, 1]

0 1 2 3 4 5

Monotonically decreasing stack



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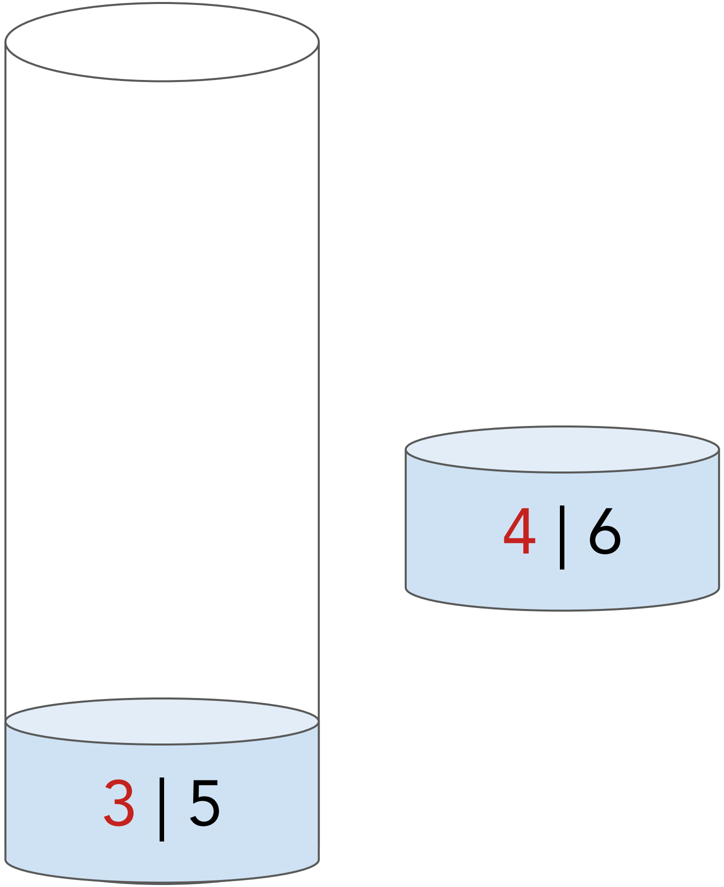
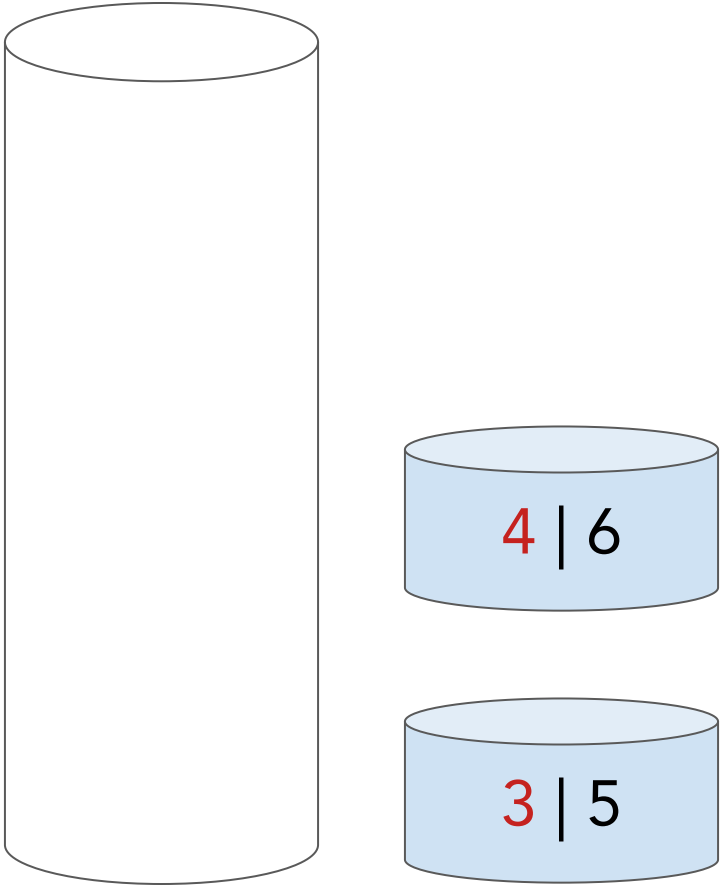


Monotonically decreasing stack

[2, 1, 3, 5, 6, 1]

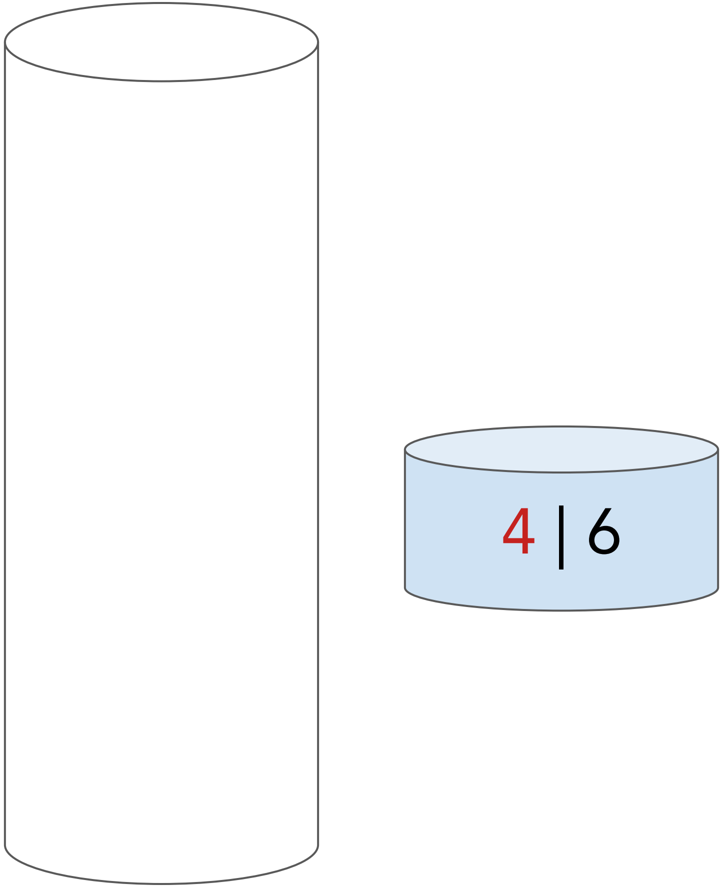
0 1 2 3 4 5

Monotonically decreasing stack



[2, 1, 3, 5, 6, 1]

0 1 2 3 4 5

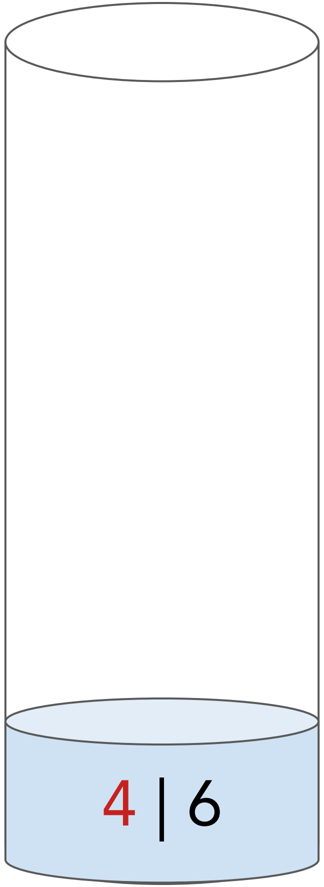


Monotonically decreasing stack

[2, 1, 3, 5, 6, 1]

0 1 2 3 4 5

Monotonically decreasing stack



[2, 1, 3, 5, 6, 1]

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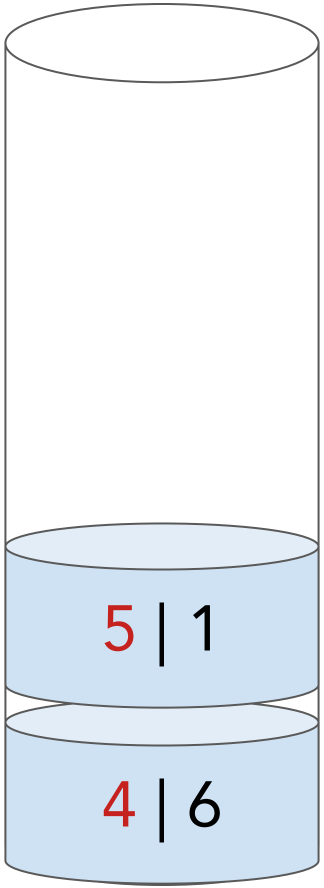
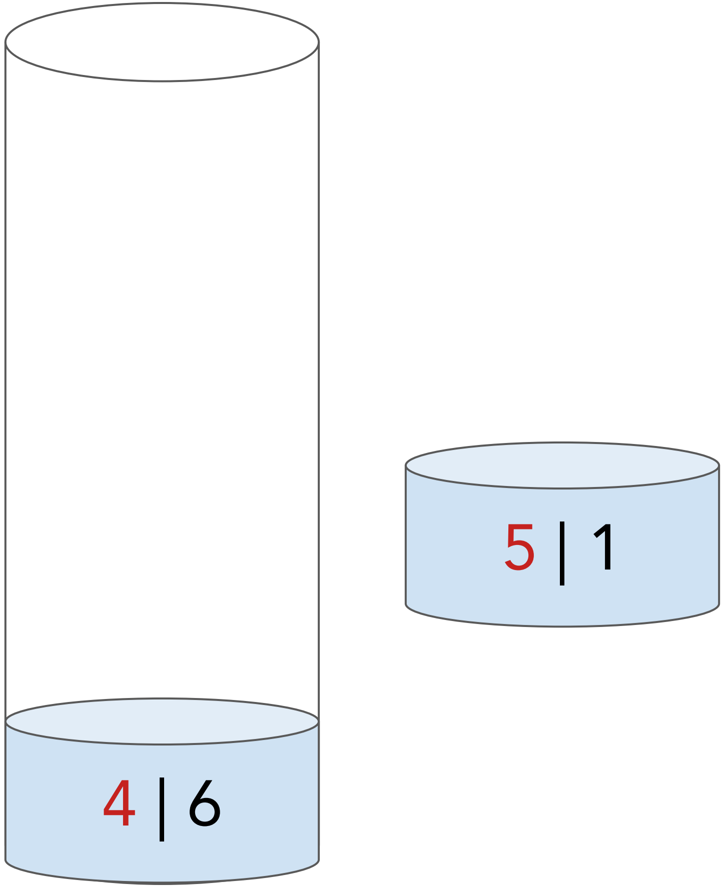
Monotonically decreasing stack



[2, 1, 3, 5, 6, 1]

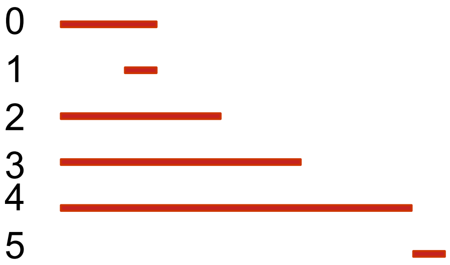
0 1 2 3 4 5

Monotonically decreasing stack



[2, 1, 3, 5, 6, 1]

0 1 2 3 4 5



Index Spans:

1: 1 <= ... < 2

0: 0 <= ... < 2

2: 0 <= ... < 3

3: 0 <= ... < 4

5: 4 <= ... < 5

Monotonic Queue

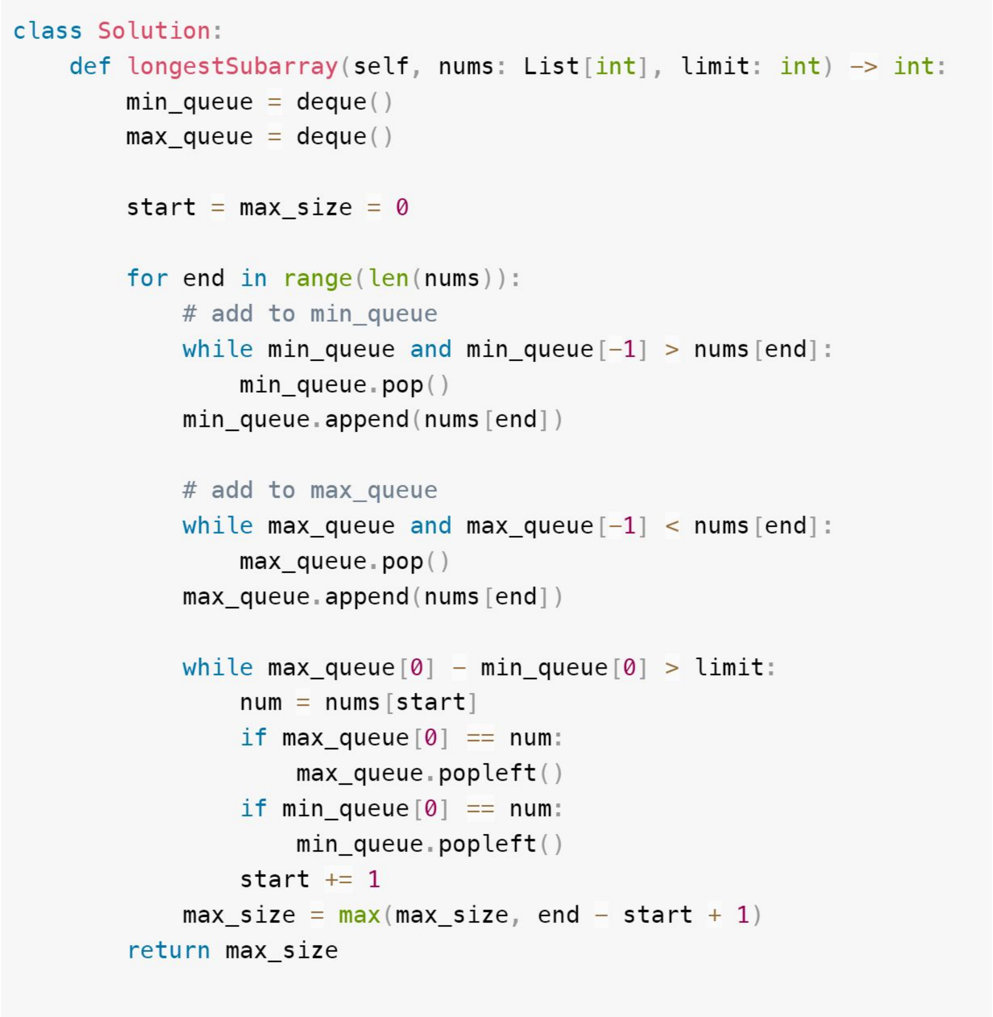
- A queue whose elements are monotonically increasing or decreasing.
- For a mono-decreasing Queue:
  - To push an element e, starts from the rear element, we pop out elements less than e.

Pair Programming

Problem

Solution

- Create a min queue to track the minimum element in our window.
- Create a max queue to track the maximum element in our window.
- If max - min is greater than limit, shrink the window
    - If number about to be popped is in either of the queues, pop it.



```
class Solution:
    def longestSubarray(self, nums: List[int], limit: int) -> int:
        min_queue = deque()
        max_queue = deque()

        start = max_size = 0

        for end in range(len(nums)):
            # add to min_queue
            while min_queue and min_queue[-1] > nums[end]:
                min_queue.pop()
            min_queue.append(nums[end])

            # add to max_queue
            while max_queue and max_queue[-1] < nums[end]:
                max_queue.pop()
            max_queue.append(nums[end])

            while max_queue[0] - min_queue[0] > limit:
                num = nums[start]
                if max_queue[0] == num:
                    max_queue.popleft()
                if min_queue[0] == num:
                    min_queue.popleft()
                start += 1
            max_size = max(max_size, end - start + 1)
        return max_size
```

Time and Space Complexity

- The time and space complexity for monotonic stack and queue operations are the same as stack and queue operations.
  - **Why**?

Pitfalls & Opportunities

- Be careful of how to handle equality
    - Should we pop elements in the monotonic stack/queue that are equal?
- Check if stack/queue is empty before accessing/removing
- For greater problems, usually use a monotonically increasing stack
- For smaller problems, usually use a monotonically decreasing stack
- For problems with a circular list, iterate through the list twice.

Practice Questions

Stacks

- Valid Parentheses
- Simplify Path
- Evaluate Reverse Polish Notation
- Score of parenthesis
- Backspace String Compare

Queues

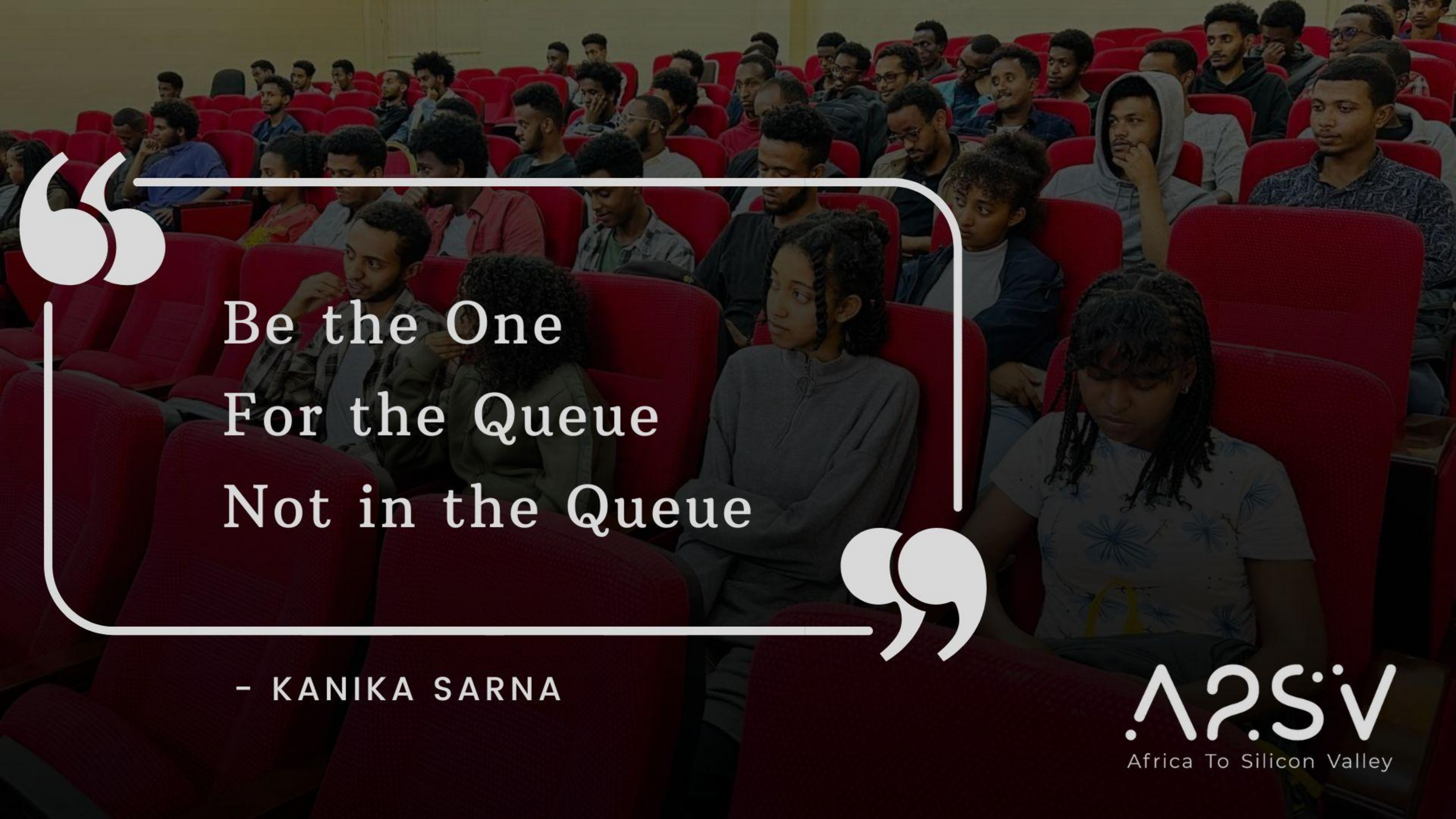
- Number of recent calls
- Find consecutive integers
- Design Circular Deque
- Implement Queue using Stack
- Shortest subarray with sum at least K

Monotonic

- Car Fleet
- Remove duplicates
- Sum of subarray minimum
- Remove k digits
- 132 Pattern

Resources

A comprehensive guide and template for monotonic stack based problems



> Be the One
> For the Queue
> Not in the Queue

- KANIKA SARNA

A2SV

Africa To Silicon Valley