Array/Lists And Matrices

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Pre-requisites

- Basic Python Knowledge
- Time and Space Complexity
- Willingness to learn

What are Data Structures?

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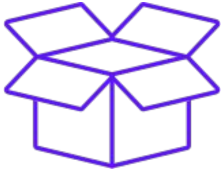
Data Structures

- Particular way of organizing, and storing the data
- Tools to build efficient algorithms
- The right one depends on the task
- Common Data Structures:
    - Arrays
    - Linked Lists
    - Stacks
    - Queues
    - Trees
    - Maps(dictionaries)
    - Sets
    - Tries, etc...



Arrays

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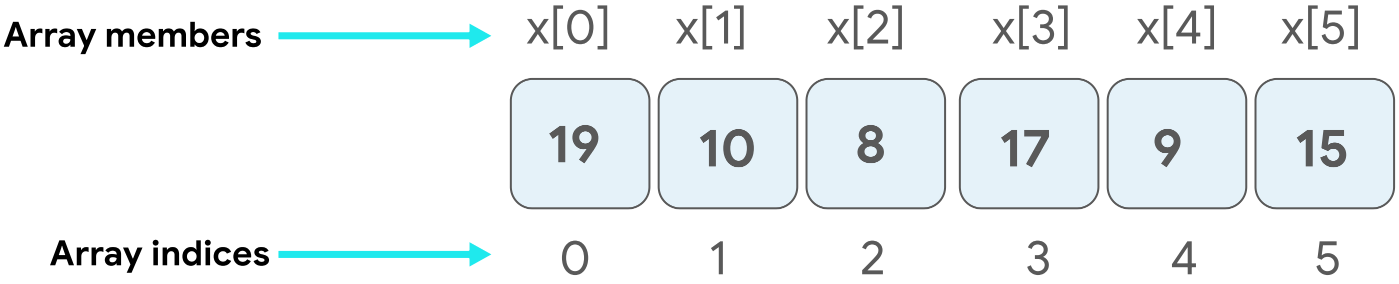
Arrays

- Collection of items stored at contiguous memory locations.
- Storing multiple items of the same type together.
- Easier to calculate the position of each element by simply adding an offset to a base value.



Static Arrays

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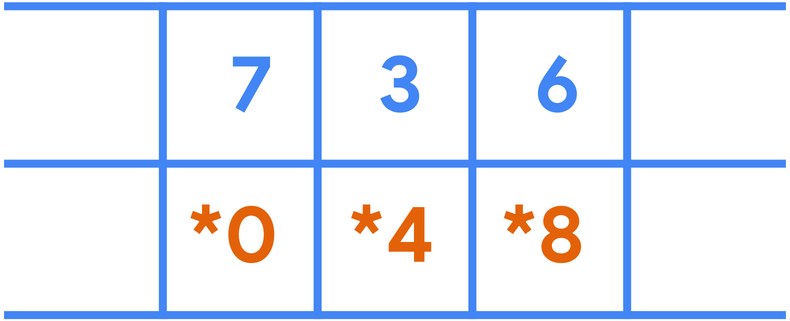
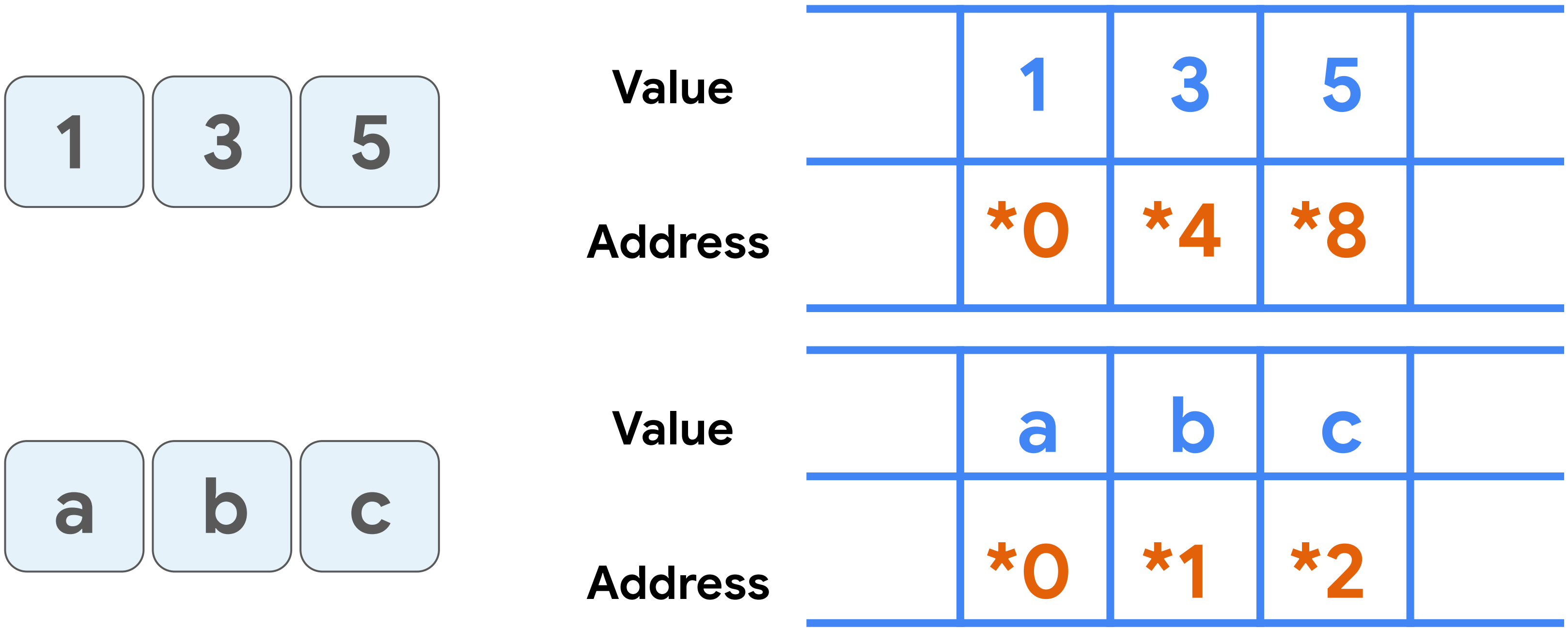
Static Arrays

- A type of array in which the size or length is determined when the array is created and/or allocated.



Static Arrays

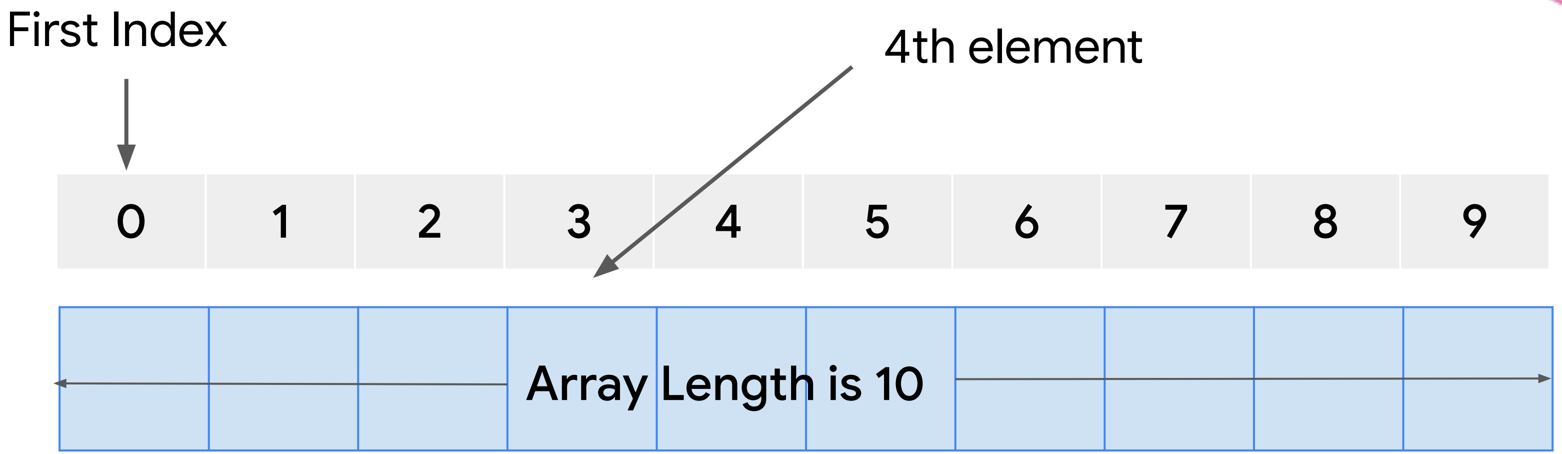


Static Arrays - Reading

- Reading is Very fast : O(1)
- Why?

```
print(my_array[4])
```

Static Arrays - Reading



Each integer occupies 4 bytes, so let us say the 0th index is at memory location 1400

$$1400 + (3 * 4) = 1412$$

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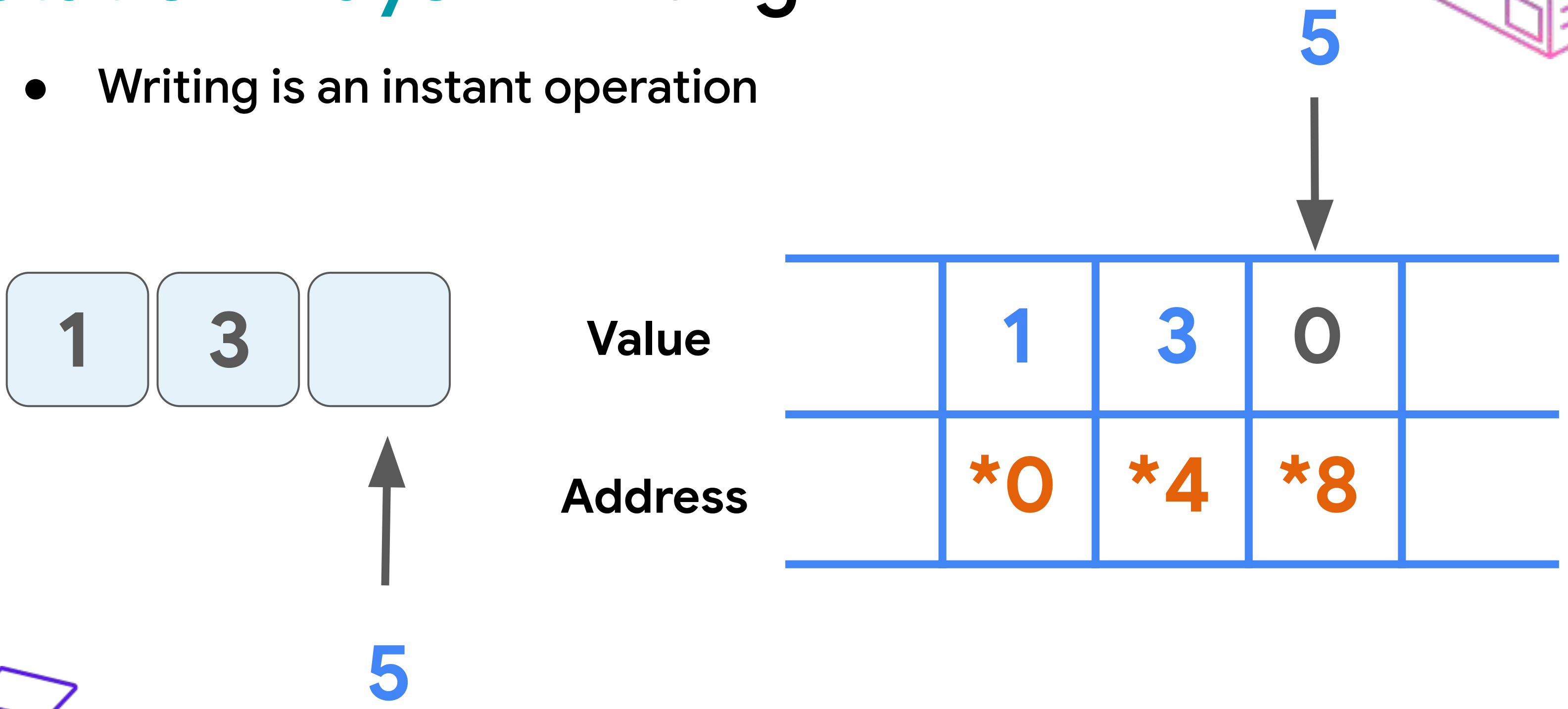
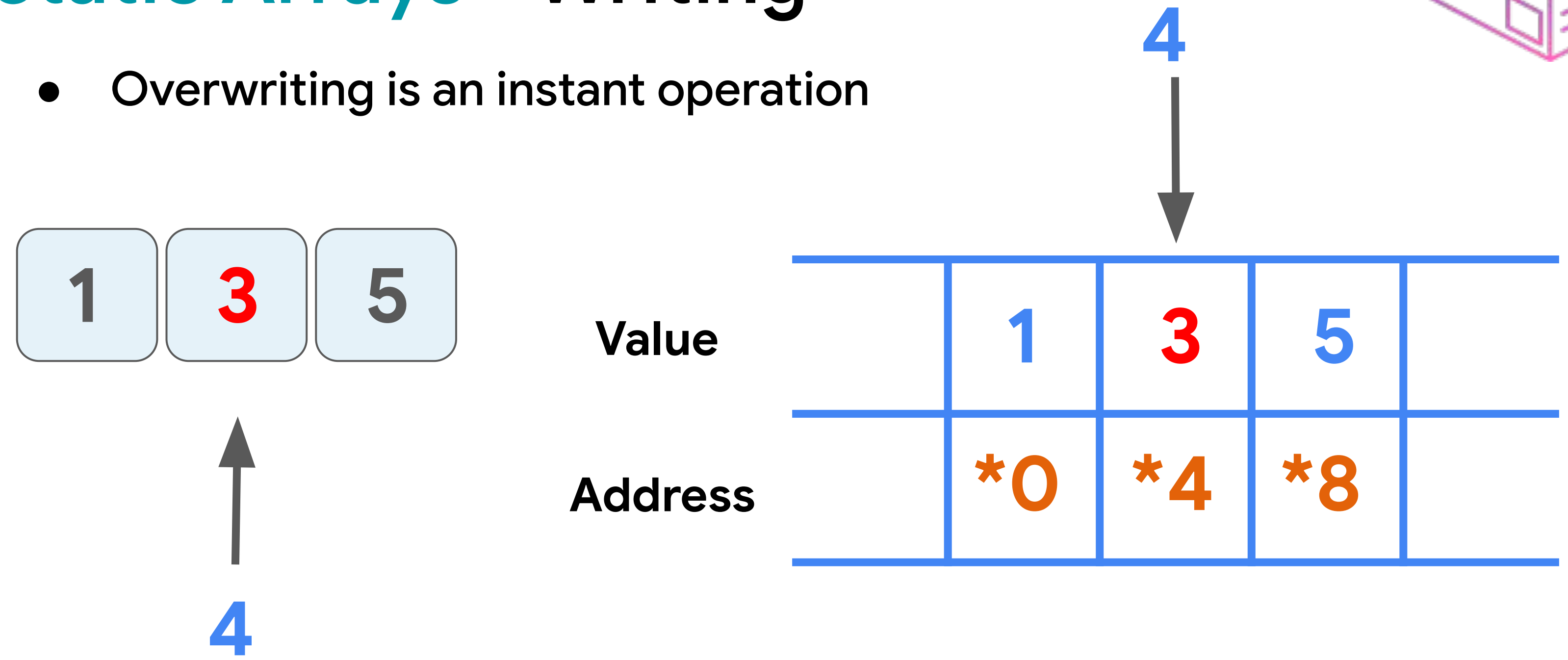
Static Arrays - Writing

- Writing is an instant operation



Static Arrays - Writing

- Overwriting is an instant operation



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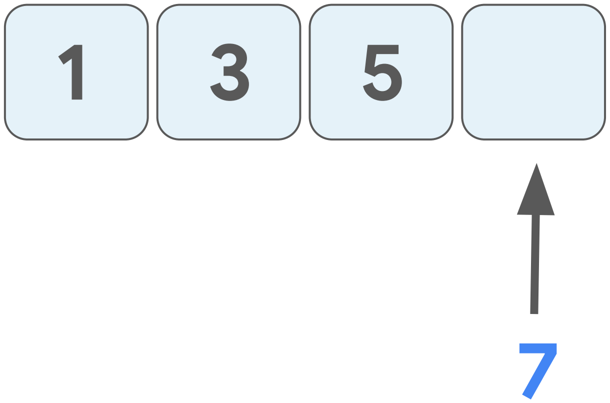
Static Arrays - Writing

- What happens when we want to add an element to our array but don't have any empty spots?



Value	1	3	5	
Address	*0	*4	*8	

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Static Arrays - Writing

- The operating system might be using this part of the memory for some other purpose.
- So we are not necessarily allowed to put our seven there.

Value	1	3	5	🚫
Address	*0	*4	*8	

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Static Arrays - Summary

Operation	Big-O Time
Read i-th Element	O(1)
Write i-th Element	O(1)

Dynamic Arrays

Dynamic Arrays

- A Dynamic array has the ability to resize itself automatically when an element is inserted or deleted.

- Double the size when it reaches capacity, cut by half when it's down to quarter

Does Python list allow the storage of different types ?

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Dynamic Arrays

- No way to find out arr[3] without traversing the full list

```
arr = [3, 0.5, ‘a’, “1”]
```

Value		3	0.5	a	“1”	
Address		*0	*4	*12	*13	

Dynamic Arrays

- A list in Python is implemented as an array of references.
- That is that you are actually creating an array of references like so:

0	1	2	3
[0xa3d25342,	0x635423fa,	0xff243546,	0x2545fade]

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Dynamic Arrays

- Each element is a reference that "points" to the respective objects in memory

	*0	*1	*2	*3	
Reference	*10	*14	*22	*23	
Value	3	0.5	a	“1”	

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Dynamic Arrays

- This works because the all references are of the same size unlike the actual values they point to.

	*0	*1	*2	*3	
Reference	*10	*14	*22	*23	
Value	3	0.5	a	“1”	

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Common Terminologies

- Pushing/Appending : inserting an element at the next empty spot

- Popping: removing the element from the end of the list

Pushing

- Whenever we reach our array's capacity, our interpreter allocates another memory which is double our original capacity and copies over all the old elements with now more space.

- Isn't this operation costly?

Pushing

- It takes amortized O(1) time! Let’s see why

Pushing

- Our goal is to push 8 elements to a dynamic array.
- Assumption: Our initial capacity is of size one.

5	6	7	8	9	1	2	3

Pushing

- After pushing 5, no place for 6

Operation count: 1

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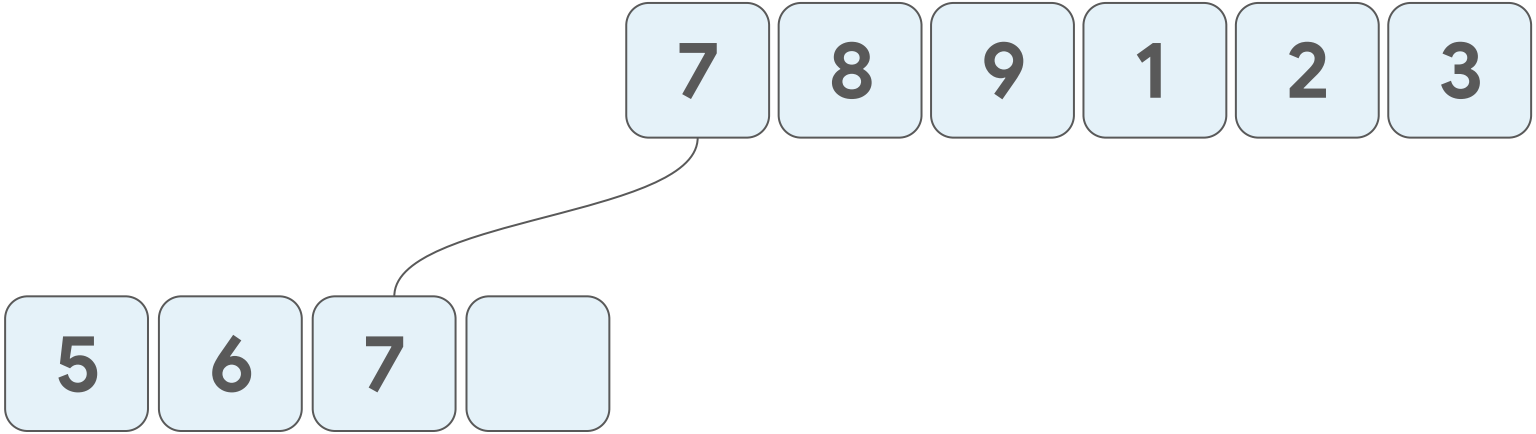
Pushing

- Copy the original array ([5]) to the new allocated memory which is double the old size and push 6 onto it

Operation count: 1 + 2

Pushing

- Allocate a new array of size 4 and copy over all the old elements and then we append 7



Operation count: 1 + 2 + 3

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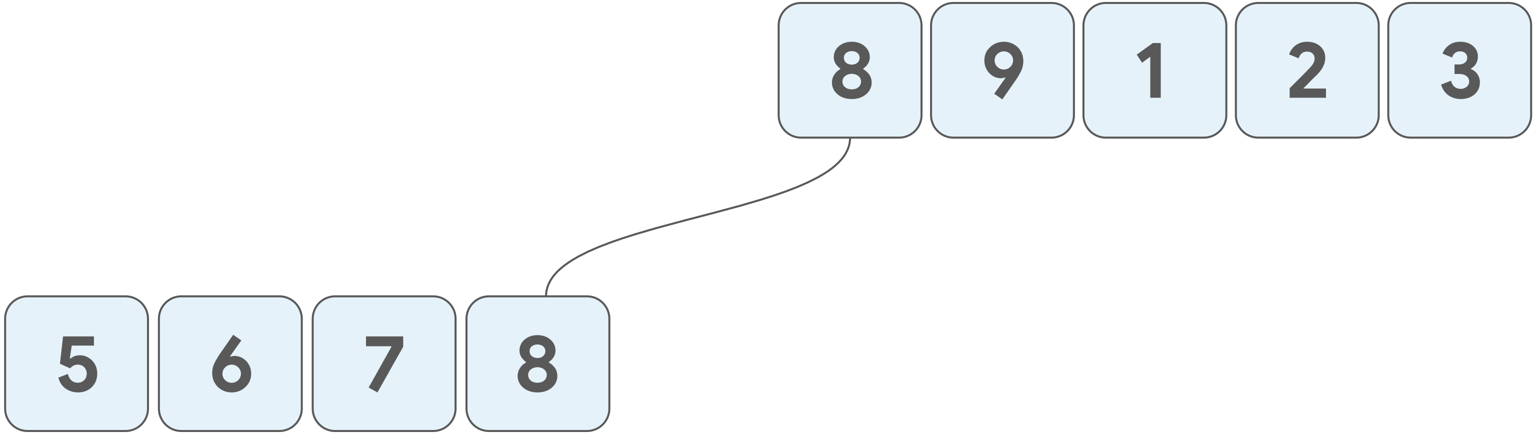
Pushing

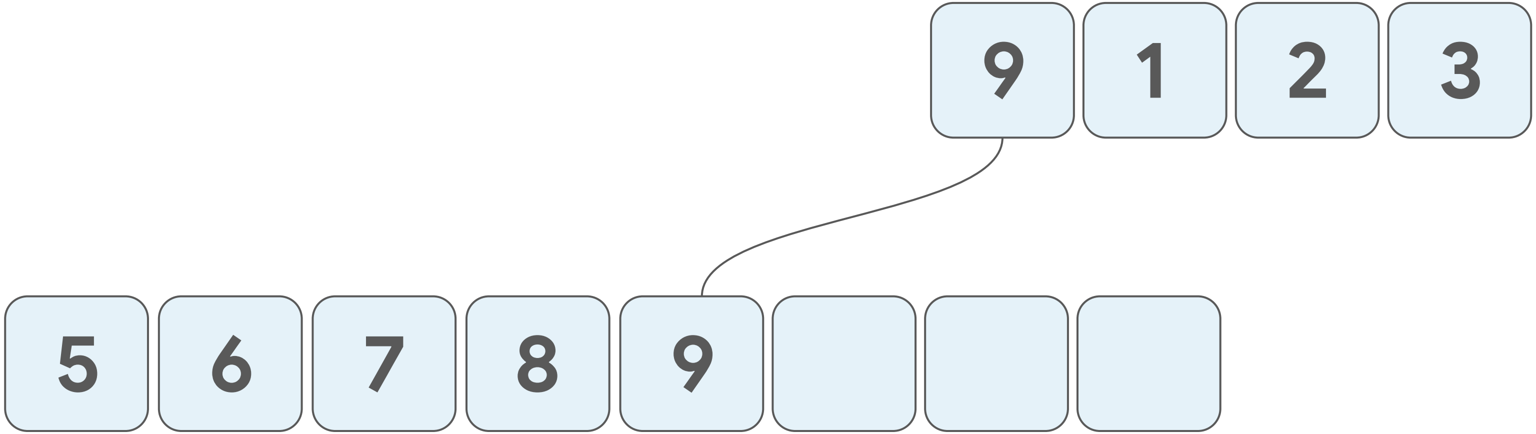
- Push 8 onto the array. Now we have run out of space for the next elements.



Operation count: 1 + 2 + 4

Pushing

- Allocate a new array of size 8 and copy over all the old elements and then we append the element 9



Operation count: 1 + 2 + 4 + 5

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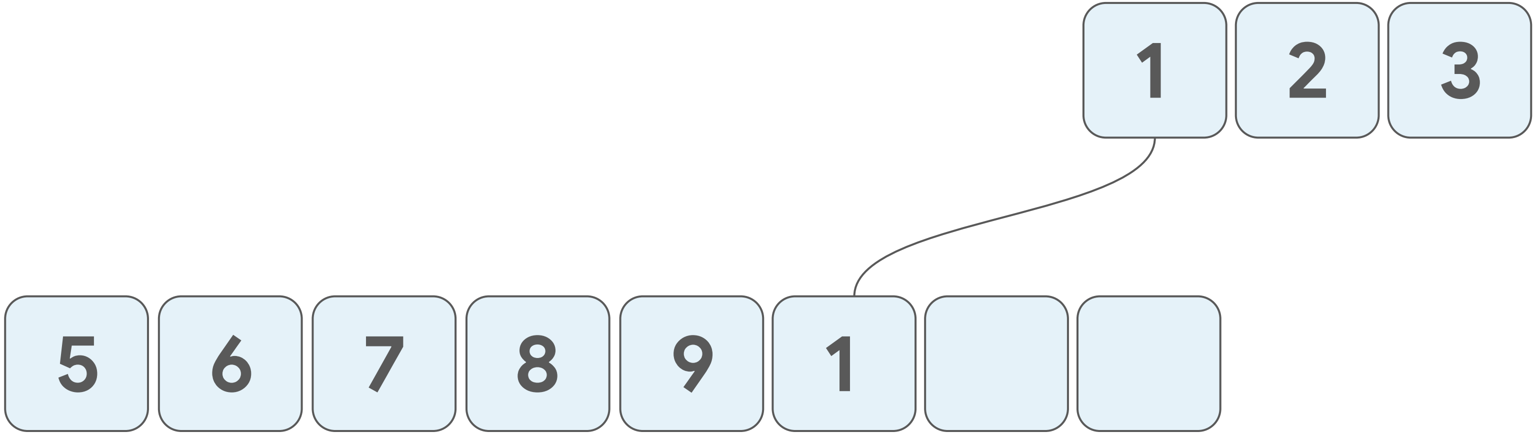
Pushing

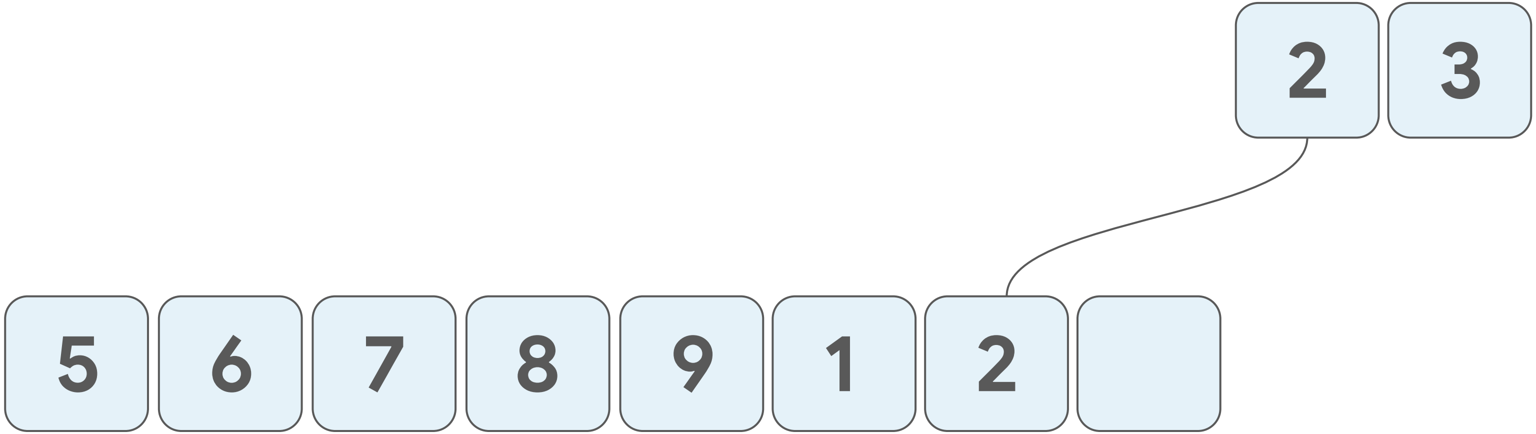
- Push/append 1 into the array



Operation count: 1 + 2 + 4 + 6

Pushing

- Push/append 2 into the array



Operation count: 1 + 2 + 4 + 7

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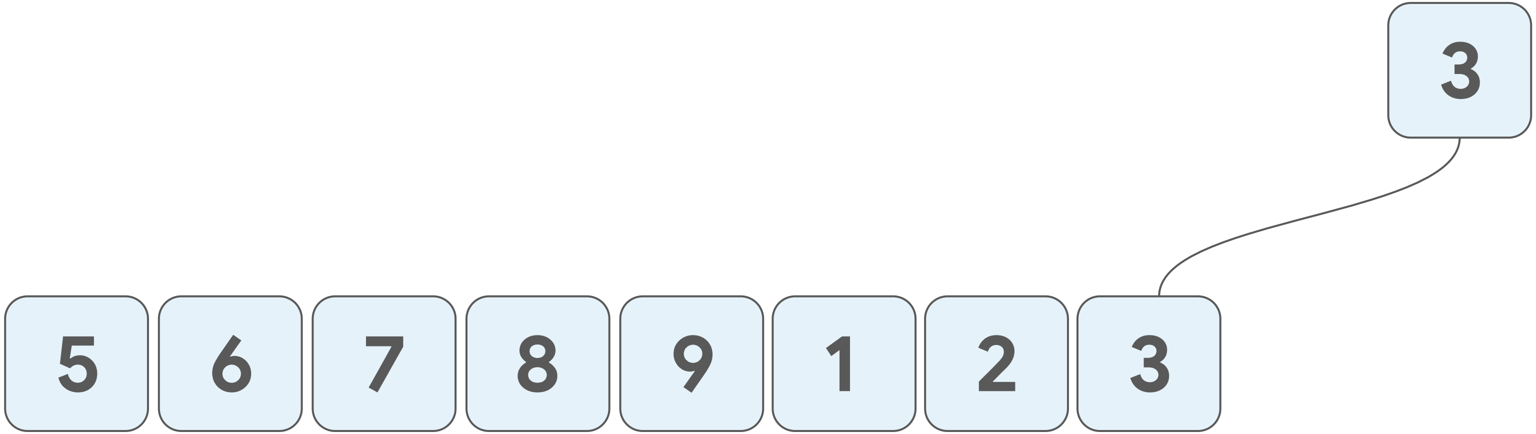
Pushing

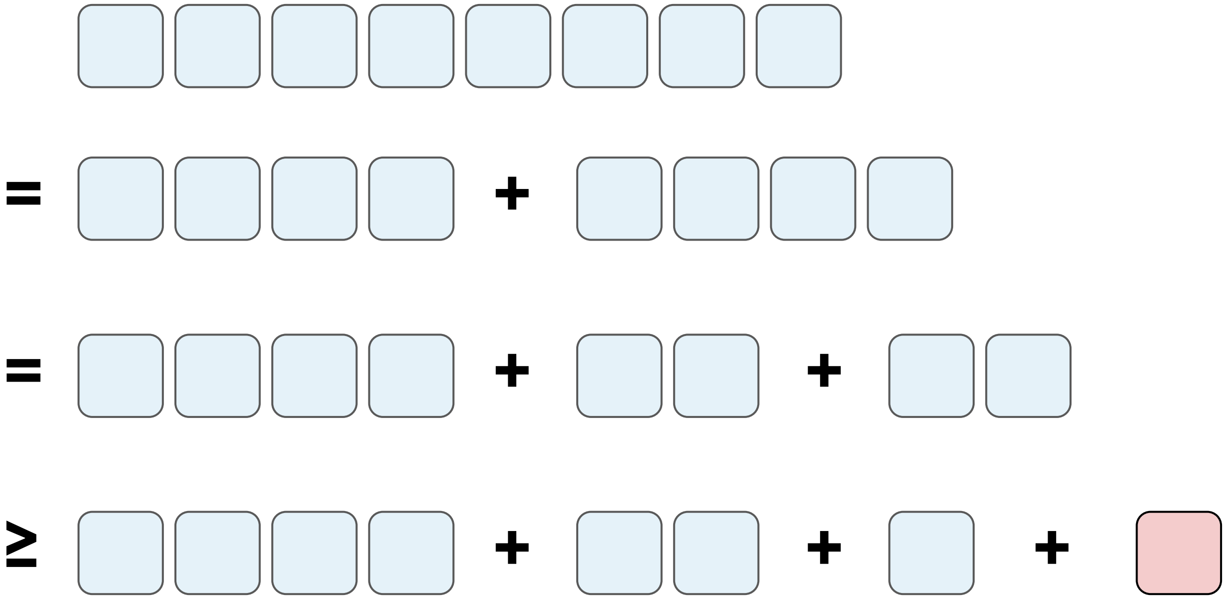
- Push/append 3 into the array



Operation count: 1 + 2 + 4 + 8

Pushing- Power Series

- For a length of 8, it took us 1 + 2 + 4 + 8 operations.
- The last summand always dominates the sum.



Pushing - Power Series

- For a length of 8, it took us $1 + 2 + 4 + 8$ operations.
- The last summand always dominates the sum.

$$2 \geq 1$$

$$4 \geq 1 + 2$$

$$8 \geq 1 + 2 + 4$$

.

.

.

$$2*N \geq 1 + 2 + 4 + 8 + \ldots + N$$

- Thus to push N elements, it will take us no more than 2N operations, making the time complexity O(N).

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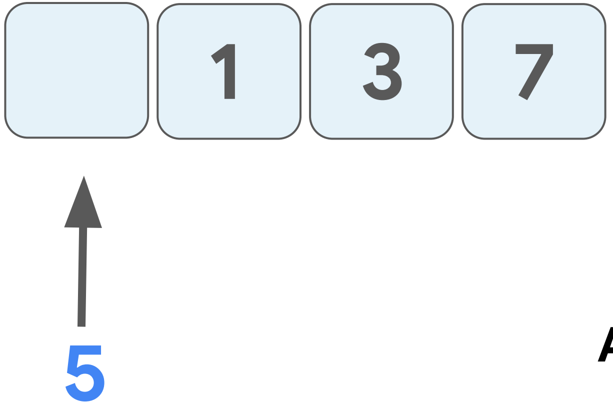
Pushing - Power Series

- This means, to push a single element onto an array, on average, we say it is an instant - O(1) - operation.
- Because after a while, the copying operation becomes very infrequent.
- Hence, pushing an element onto an array is Amortized O(1) operation.

Dynamic Arrays - Insertion

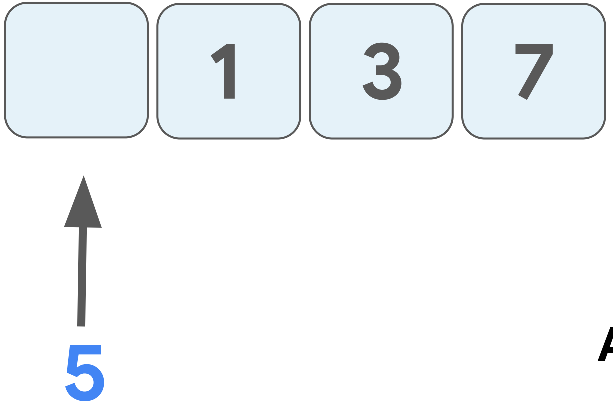
- Inserting an element in an arbitrary position is, in the worst case, an O(n) operation.

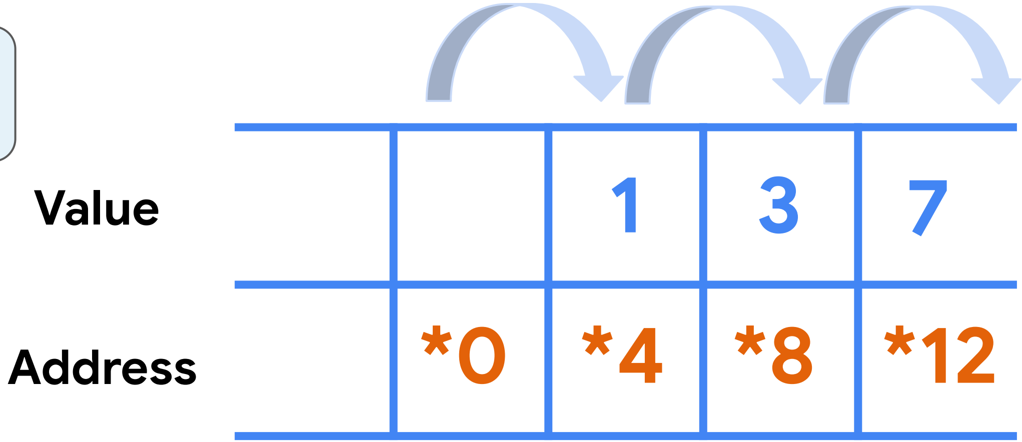


Value		1	3	7
Address	*0	*4	*8	*12

Dynamic Arrays - Insertion

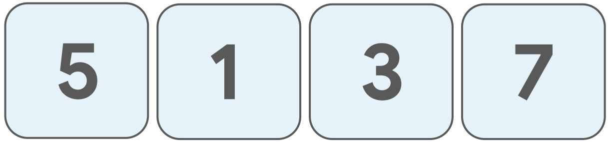
- We need to shift all elements to the right of the new element, to not lose data, and create the empty space needed.





Dynamic Arrays - Insertion

- The shifting is what costs us time.



Value		5	1	3	7
Address		*0	*4	*8	*12

Dynamic Arrays - Removal

- What about removing an element?

5	1	3	7

Value	5	1	3	7
Address	*0	*4	*8	*12

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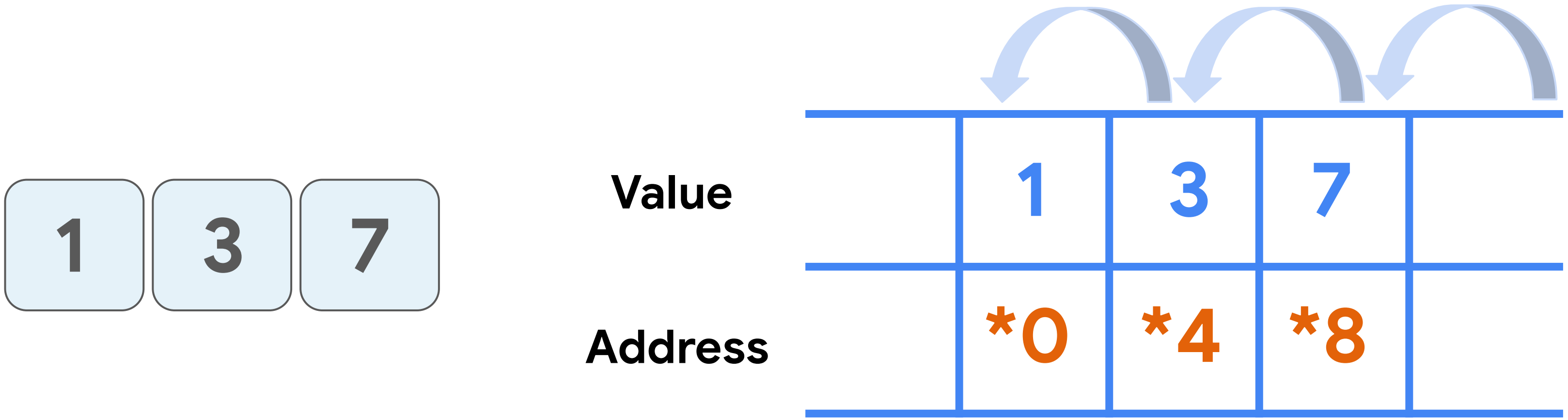
Dynamic Arrays - Removal

- It is O(n) at worst.



Traversing Lists

Traversing Lists - Reverse Traversal

Approach

- Start from the last index
- Decrement by 1 until -1

Implementation

```
for index in range(len(array)-1, -1, -1):
    print(array[index])
```

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Traversing Lists - Even/Odd Indices Traversal

Approach

- Start from the first even/odd index
- Increment by 2

Implementation

```
step = 2 # incremental value
# even indices traversal
size = len(array)
for index in range(0, size, step):
    print(array[index])
```

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Traversing Lists - Circular Traversal

Approach

- Start from first index to size*2
- Incrementally go 1 step but modulo index by size

Implementation

```
size = len(array)
for index in range(0, 2 * size):
    value = array[index % size]
    print(value)
```

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Pair Programming
Find the winner of the circular game

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Swapping Elements

Swapping Elements

Approach

- Approach 1
  - Store first element in a variable
  - Change first element with second element
  - Change second element with stored value
- Approach 2 : Use tuple unpacking to swap

Implementation

```
# approach 1
temp = arr[i]
arr[i] = arr[j]
arr[j] = temp

# approach 2
arr[i], arr[j] = arr[j], arr[i]
```

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Pair Programming
Reverse string

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Storing letter and Numbers

Storing - Using Arrays as Dictionaries

- For Letters
  - Character's ASCII value can be the index by correcting the offset by 65 ('A') for uppercase letters and 97 ('a') for lower case letters

- For Numbers
  - The number itself is the key

- Note: the advantage of this approach is that you can use built in functions like `sum`, `sort`, `max`, `min` on the frequency list whereas maps don't give you this flexibilities.

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Storing - Implementation

```
word = "abceabce"
arrayDictionary = [0]*26
offset = ord('a') # 'a' has ASCII value of 97
for char in word:
    ascii = ord(char)
    arrayDictionary[ascii - offset] += 1

print(arrayDictionary)
# [2, 2, 2, 0, 2, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]
#  a  b  c  d  e  f  g  h  i  j  k  l  m  n, o  p  q  r  s  t  u  v  w  x  y  z
```

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Read and Write Indices

Read and Write and Indices

Approach

- Set your read index accordingly to your need
- Set your write index accordingly to your need
- Your read should always move
- Your write only moves after write operation

Implementation

[(Question Link)]

```python
def moveZeroes(self, nums: List[int])
    write = 0
    read  = 0

    while read < len(nums):
        if nums[read] != 0:
            temp = nums[read]
            nums[read] = nums[write]
            nums[write] = temp

            write =  write + 1

        read = read + 1
```

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Practice Problem

[Apply operations to an array]

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Matrices

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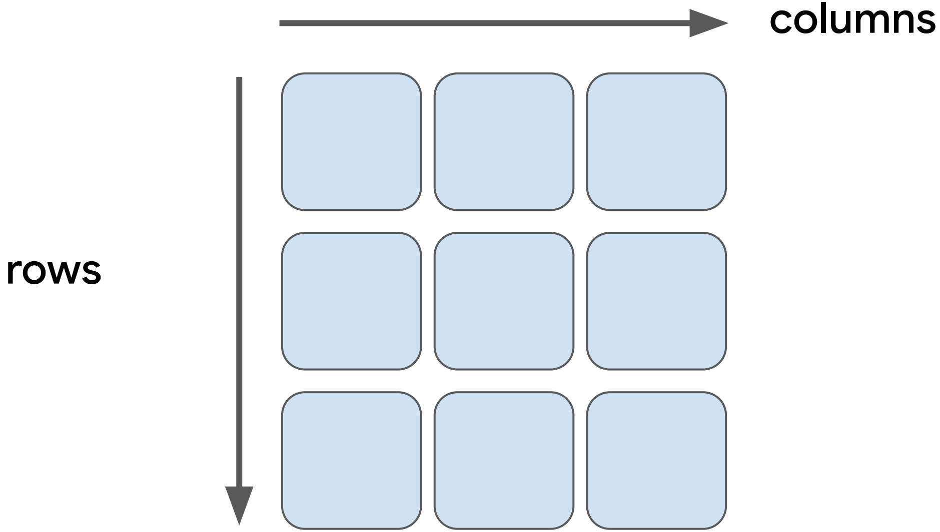
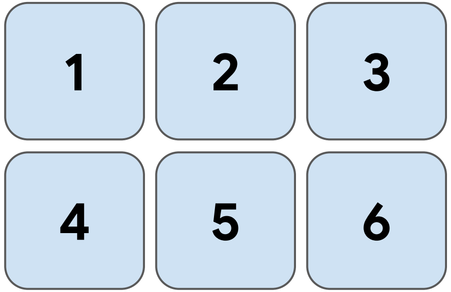
Matrices

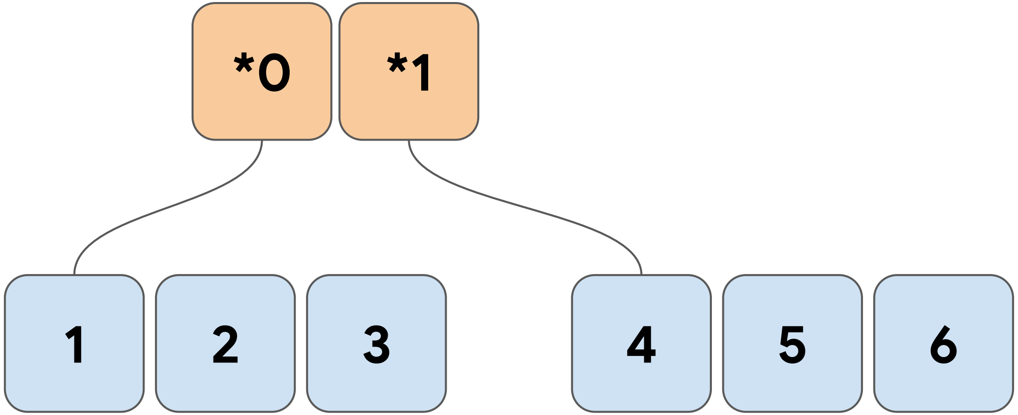
- Two-dimensional arrays can be defined as arrays within an array.
- 2D arrays erected as matrices, which is a collection of rows and columns.



Matrices

- You should think two dimensional arrays as matrices.
- In reality, they are arrays holding references to other arrays





Common Approaches

Traversing Matrices

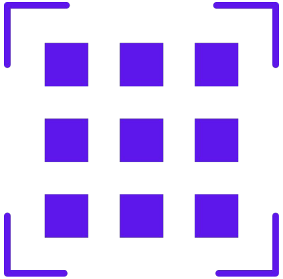
Traversing - from Top-left to Bottom-right

Approach

- Start from (0, 0)
- Increment column index by one for each row you visit

Implementation

```
for row_idx in range(len(matrix)):
    for col_idx in range(len(matrix[0])):
        print(matrix[row_idx][col_idx])
```



Traversing - From Bottom-right to Top-left

Approach

- Start from (`last_row - 1, last_col - 1`)
- Decrement column index by one for each row you visit.

Implementation

```
for row_idx in range(len(matrix) - 1, -1, -1):
    for col_idx in range(len(matrix[0]) - 1, -1, -1):
        print(matrix[row_idx][col_idx])
```

Enumerating Cells/ 2D - 1D Mapping

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Enumerating Cells - Approach

	0	1	2	3
0	0	1	2	3
1	4	5	6	7
2	8	9	10	11

Enumerating Cells - Approach

Consecutive elements in a column differ by the number of columns

	0	1	2	3
0	0	1	2	3
1	4	5	6	7
2	8	9	10	11

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Enumerating Cells - Approach

Consecutive elements in a row differ by 1

	0	1	2	3
0	0	1	2	3
1	4	5	6	7
2	8	9	10	11

Enumerating Cells - Approach

Therefore the 1D number of a cell is `row_number*n_columns + column_number`

	0	1	2	3
0	0	1	2	3
1	4	5	6	7
2	8	9	10	11

Enumerating Cells - Remainder Theorem

```
cell_number = row_number*n_columns + column_number

row_number = cell_number // n_columns

column_number = cell_number % n_columns
```

Diagonal Keys

Diagonal Keys

What is common about the highlighted column and row numbers?

	0	1	2	3
0	0	1	2	3
1	4	5	6	7
2	8	9	10	11

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Diagonal Keys

What is common about the highlighted column and row numbers?

	0	1	2	3
0	0	1	2	3
1	4	5	6	7
2	8	9	10	11

Common Pitfalls

Common Pitfalls - Index Out of Bound

- Trying to access elements using indices that are greater (or equal to) than the size of our array will result in this exception.

Testcase Result

```
IndexError: list index out of range
    print(nums[i])
Line 4 in twoSum (Solution.py)
    ret = Solution().twoSum(param_1, param_2)
Line 28 in _driver (Solution.py)
    _driver()
Line 39 in <module> (Solution.py)
```

Stdout

```
2
```

Console Run Submit

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Common Pitfalls - Negative Indexing

- Because we may use negative indices in Python, it is a typical problem to use negative indices accidently, which can result in a highly troublesome misunderstanding if no exception is triggered.

Negative indices:	-4	-3	-2	-1
Positive indices:	0	1	2	3
Values:	[1,	2,	3,	4]

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Common Pitfalls - Copying lists

- A list is a reference. Take care when you want to you want to pass only the content of the list.

```
nums[::]
nums.copy()
```

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Common Pitfalls - Initializing with *

- The * operator can be used as `[object]*n` where n is the number of elements in the array.
- In the case of 2D arrays, this will result in shallow lists
- Hence using list comprehensions is a safer way to create 2D lists.

```
row = len(matrix)
col = len(matrix[0])

transposed  = [[0]*rows for _ in range(cols)]
```

Common Pitfalls - Using `insert`, `pop` and `in`

- insert - inserts a given element at a given index
    - `insert(i, value)` : O(N)
- pop - returns the value at a given index and removes it from the list where the default is the last index
    - `pop` : O(1)
    - `pop(i)` : O(n)

- The `in` operator is returns a boolean denoting whether an element is present in the iterable data structure we use it on.
- Lists O(N)
- Map, Set O(1)T

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Common Pitfalls - Mistaking Row Iterators with Column iterators

- It is pretty common to mistake your `i` and `j`'s representing rows and columns. And sometimes, especially when the matrix is a square one, it does not throw an exception but hours of confusion

```
for col_idx in range(len(matrix[0])):
    for row_idx in range(len(matrix)):
        print(matrix[col_idx][row_idx])
```

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Practice Question
Image smoother

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Practice Questions

Reverse string

Count Equal and Divisible Pairs in an..

All Divisions With the Highest Score..

Transpose matrix

Diagonal traverse

Rotate image

Resources

- https://neetcode.io/courses/dsa-for-beginners/0: useful on laying out the fundamentals
- https://www.geeksforgeeks.org/python-arrays/: covers large range of topics for python
- Python List pop() Method - GeeksforGeeks: good examples
- Python List insert() Method With Examples - GeeksforGeeks: good examples
- Python | Which is faster to initialize lists? - GeeksforGeeks: good article on list initialization

Quote of the Day

If you want to enjoy the rainbow, be prepared to endure the storm

Warren W. Wiersbe

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