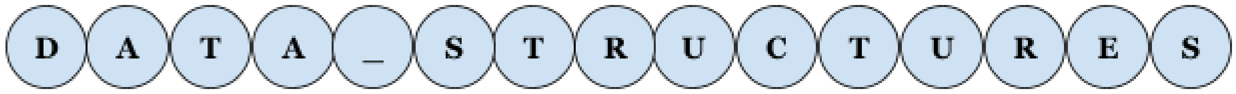
CS261 Data Structures

Assignment 1

Summer 2025

Python Fundamentals Review



Contents

Summary

For this assignment, you will write a few short Python functions. The primary objectives are to ensure that:

- You are familiar with basic Python syntax constructs
- Your programming environment is set up correctly
- You are familiar with submitting assignments through Gradescope and troubleshooting your solutions based on Gradescope output
- You know how to import and use classes that have been pre-written for you

For this course, we assume you are comfortable with:

- Iterating over a list of elements using `for` and `while` loops
- Accessing elements in a list or array using their indices
- Passing functions as parameters to other functions
- Using classes pre-written for you (imported into your code to create objects)
- Writing your own classes (including extending existing classes)
- Writing unit tests for your code
- Debugging your solutions

None of the functions in this assignment, or CS261 in general, will require Python knowledge beyond what was covered in CS161 and CS162. If you completed the CS161/CS162 classes in Python, you should be able to complete this assignment. In case you need help, please post questions on Ed Discussion and feel free to contact the instructor/ULAs in Teams during Office Hours.

General Instructions

1. Programs in this assignment must be written in Python 3 and submitted to Gradescope before the due date specified on Canvas and in the Course Schedule. You may resubmit your code as many times as necessary (this is encouraged). Gradescope allows you to revert to prior submissions if needed. **We will grade the currently activated submission.**

2. In Gradescope, your code will run through several tests. Any failed tests will provide a brief explanation of testing conditions to help you with troubleshooting. You earn points as you pass tests. There are no hidden Gradescope tests and you will know your maximum possible score with each submission.

3. We encourage you to create your own test cases (such as with Python's **unittest** unit testing framework, which is more powerful and efficient than "print statement debugging"), even though this work doesn't have to be submitted and won't be graded. Gradescope tests are limited in scope and may not cover all edge cases. Your submission must work on all valid inputs. We reserve the right to test your submission with additional tests beyond Gradescope.

4. Unless indicated otherwise, we will test your implementation with different types of objects, not just integers. We guarantee that all such objects will have correct implementation of:

    a. "rich comparison" methods:

        i. `__eq__()`

        ii. `__lt__()`

        iii. `__gt__()`

        iv. `__ge__()`

        v. `__le__()`

    b. `__str__()`

5. **Your code must have an appropriate level of comments.** At minimum, each method must have a descriptive docstring. Additionally, write comments throughout your code to make it easy to follow and understand any non-obvious code. However, be mindful of the amount of comments in your code. Cluttering comments negatively impact readability and are discouraged. If your code includes an excessive amount of comments, consider refactoring. Please refer to "Styling Your Code" from the "Coding Guides and Tips - Style and Debugging" module for specifics.

6. You will be provided with a starter "skeleton" code, on which you will build your implementation. Methods defined in the skeleton code must retain their names and input/output parameters. Variables defined in the skeleton code must also retain

their names. We will only test your solution by making calls to methods defined in the skeleton code, and by checking values of variables defined in the skeleton code.

You are allowed to:

- add more helper methods and variables, as needed
- add optional default parameters to method definitions
- modify or add to the basic testing section within the scope of:

```
if __name__ == "__main__":
```

However, certain classes and methods cannot be changed in any way. Please see the comments in the skeleton code for guidance. The content of any methods pre-written for you as part of the skeleton code must not be changed.

7. The skeleton code and code examples provided in this document are part of assignment requirements. Please read all of them very carefully. They have been carefully selected to demonstrate requirements for each method. Refer to them for detailed descriptions of expected method behavior, input/output parameters, and handling of edge cases.

8. **For each method, you are required to use an iterative solution**. Recursion is not permitted.

9. You may not use any imports beyond the ones included in the assignment source code.

Specific Instructions

There are 10 separate problems in this assignment. For each problem, you will write a Python function according to the provided specifications. The skeleton code and some basic test cases for each problem are provided in the file `assignment1.py`

Most problems will take as input (and sometimes return as output) an object of the StaticArray class. The StaticArray class has been pre-written for you, and is located in the file `static_array.py`

StaticArray is a very simple class that simulates the behavior of a fixed size array. It has only four methods, and contains code to support bracketed indexing (`[]`):

1) `init()` - Creates a new static array that will store a fixed number of elements. Once the StaticArray is created, its size cannot be changed.
2) `set()` - Changes the value of any element using its index.
3) `get()` - Reads the value of any element using its index.
4) `length()` - Queries the number of elements in the array.

Please review the code and comments in the StaticArray class to better understand the available methods, their use, and input/output parameters. Note that since StaticArray is intentionally a very simple class, it does not possess the many capabilities typically associated with Python lists. You need to write your solutions using only the available StaticArray functionality, as described above.

RESTRICTIONS: You are NOT allowed to use ANY built-in Python data structures and/or their methods in any of your solutions. This includes built-in Python lists, dictionaries, or anything else. Variables for holding a single value, or a tuple holding at most three values, are allowed. It is also OK to use `range()`.

You are NOT allowed to directly access any variables of the StaticArray class (e.g. `self._size` or `self._data`). Access to StaticArray variables must be done by using the StaticArray class methods.

Read the *Coding Guides and Tips* module for a detailed description of these topics.

You may not use any imports beyond the ones included in the assignment source code.

min_max(arr: StaticArray) -> tuple[int, int]:

Write a function that receives a one-dimensional array of integers and returns a Python tuple with two values - the minimum and maximum values of the input array.

The content of the input array must not be changed. You may assume that the input array will contain only integers, and will have at least one element. You do not need to check for these conditions.

For full credit, the function must be implemented with **O(N)** complexity.

Example #1:

```
arr = StaticArray(5)
for i, value in enumerate([7, 8, 6, -5, 4]):
    arr[i] = value
print(arr)
result = min_max(arr)
if result:
    print(f"Min: {result[0]: 3}, Max: {result[1]}")
else:
    print("min_max() not yet implemented")
```

Output:

```
STAT_ARR Size: 5 [7, 8, 6, -5, 4]
Min:  -5, Max: 8
```

Example #2:

```
arr = StaticArray(1)
arr[0] = 100
print(arr)
result = min_max(arr)
if result:
    print(f"Min: {result[0]}, Max: {result[1]}")
else:
    print("min_max() not yet implemented")
```

Output:

```
STAT_ARR Size: 1 [100]
Min: 100, Max: 100
```

Example #3:

```
test_cases = (
    [3, 3, 3],
    [-10, -30, -5, 0, -10],
    [25, 50, 0, 10],
)
for case in test_cases:
    arr = StaticArray(len(case))
    for i, value in enumerate(case):
        arr[i] = value
    print(arr)
    result = min_max(arr)
    if result:
        print(f”Min: {result[0]: 3}, Max: {result[1]}”)
    else:
        print(“min_max() not yet implemented”)
```

Output:

```
STAT_ARR Size: 3 [3, 3, 3]
Min:   3, Max: 3
STAT_ARR Size: 5 [-10, -30, -5, 0, -10]
Min: -30, Max: 0
STAT_ARR Size: 4 [25, 50, 0, 10]
Min:   0, Max: 50
```

fizz_buzz(arr: StaticArray) -> StaticArray:

Write a function that receives a StaticArray of integers and returns a new StaticArray object with the content of the original array, modified as follows:

1) If the number in the original array is divisible by 3, the corresponding element in the new array will be the string 'fizz'.
2) If the number in the original array is divisible by 5, the corresponding element in the new array will be the string 'buzz'.
3) If the number in the original array is both a multiple of 3 and a multiple of 5, the corresponding element in the new array will be the string 'fizzbuzz'.
4) In all other cases, the element in the new array will have the same value as in the original array.

The content of the input array must not be changed. You may assume that the input array will contain only integers, and will have at least one element. You do not need to check for these conditions.

For full credit, the function must be implemented with **O(N)** complexity.

Example #1:

```
source = [_ for _ in range(-5, 20, 4)]
arr = StaticArray(len(source))
for i, value in enumerate(source):
    arr[i] = value
print(fizz_buzz(arr))
print(arr)
```

Output:

```
STAT_ARR Size: 7 ['buzz', -1, 'fizz', 7, 11, 'fizzbuzz', 19]
STAT_ARR Size: 7 [-5, -1, 3, 7, 11, 15, 19]
```

reverse(arr: StaticArray) -> None:

Write a function that receives a StaticArray and reverses the order of the elements in the array. The reversal must be done 'in place', meaning that the original input array will be modified, and you may not create another array (nor need to). You may assume that the input array will contain at least one element. You do not need to check for this condition.

For full credit, the function must be implemented with **O(N)** complexity.

Example #1:

```
source = [_ for _ in range(-20, 20, 7)]
arr = StaticArray(len(source))
for i, value in enumerate(source):
    arr.set(i, value)
print(arr)
reverse(arr)
print(arr)
reverse(arr)
print(arr)
```

Output:

```
STAT_ARR Size: 6 [-20, -13, -6, 1, 8, 15]
STAT_ARR Size: 6 [15, 8, 1, -6, -13, -20]
STAT_ARR Size: 6 [-20, -13, -6, 1, 8, 15]
```

rotate(arr: StaticArray, steps: int) -> StaticArray:

Write a function that receives two parameters - a StaticArray and an integer value (called `steps`). The function will create and return a new StaticArray, which contains all of the elements from the original array, but their position has shifted right or left `steps` number of times. The original array must not be modified.

If `steps` is a positive integer, the elements will be rotated to the right. If `steps` is a negative integer, they will rotate to the left. Please see the code examples below for additional details. You may assume that the input array will contain at least one element. You do not need to check for this condition.

Please note that the value of the `steps` parameter can be very large (between -10^9 and 10^9). Your implementation must rotate an array of at least 1,000,000 elements in a reasonable amount of time (under a minute).

For full credit, the function must be implemented with **O(N)** complexity.

Example #1:

```
source = [_ for _ in range(-20, 20, 7)]
arr = StaticArray(len(source))
for i, value in enumerate(source):
    arr.set(i, value)
print(arr)
for steps in [1, 2, 0, -1, -2, 28, -100, 2 ** 28, -2 ** 31]:
    space = " " if steps >= 0 else ""
    print(f"{rotate(arr, steps)} {space}{steps}")
print(arr)
```

Output:

```
STAT_ARR Size: 6 [-20, -13, -6, 1, 8, 15]
STAT_ARR Size: 6 [15, -20, -13, -6, 1, 8]  1
STAT_ARR Size: 6 [8, 15, -20, -13, -6, 1]  2
STAT_ARR Size: 6 [-20, -13, -6, 1, 8, 15]  0
STAT_ARR Size: 6 [-13, -6, 1, 8, 15, -20] -1
STAT_ARR Size: 6 [-6, 1, 8, 15, -20, -13] -2
STAT_ARR Size: 6 [-6, 1, 8, 15, -20, -13]  28
STAT_ARR Size: 6 [8, 15, -20, -13, -6, 1] -100
STAT_ARR Size: 6 [-6, 1, 8, 15, -20, -13]  268435456
STAT_ARR Size: 6 [-6, 1, 8, 15, -20, -13] -2147483648
STAT_ARR Size: 6 [-20, -13, -6, 1, 8, 15]
```

Example #2:

```
array_size = 1_000_000
source = [random.randint(-10 ** 9, 10 ** 9) for _ in range(array_size)]
arr = StaticArray(len(source))
for i, value in enumerate(source):
    arr[i] = value
print(f'Started rotating large array of {array_size} elements')
rotate(arr, 3 ** 14)
rotate(arr, -3 ** 15)
print(f'Finished rotating large array of {array_size} elements')
```

Output:

```
Started rotating large array of 1000000 elements
Finished rotating large array of 1000000 elements
```

sa_range(start: int, end: int) -> StaticArray:

Write a function that receives the two integers `start` and `end`, and returns a StaticArray that contains all the consecutive integers between `start` and `end` (inclusive).

For full credit, the function must be implemented with **O(N)** complexity.

Example #1:
```
cases = [
    (1, 3), (-1, 2), (0, 0), (0, -3),
    (-95, -89), (-89, -95)
]
for start, end in cases:
    print(f"Start: {start: 4}, End: {end: 4}, {sa_range(start, end)}")
```

Output:
```
Start:    1, End:    3, STAT_ARR Size: 3 [1, 2, 3]
Start:   -1, End:    2, STAT_ARR Size: 4 [-1, 0, 1, 2]
Start:    0, End:    0, STAT_ARR Size: 1 [0]
Start:    0, End:   -3, STAT_ARR Size: 4 [0, -1, -2, -3]
Start:  -95, End:  -89, STAT_ARR Size: 7 [-95, -94, -93, -92, -91, -90, -89]
Start:  -89, End:  -95, STAT_ARR Size: 7 [-89, -90, -91, -92, -93, -94, -95]
```

is_sorted(arr: StaticArray) -> int:

Write a function that receives a StaticArray and returns an integer that describes whether the array is sorted. The method must return:

- 1 if the array is sorted in strictly ascending order.
- -1 if the list is sorted in strictly descending order.
- 0 otherwise.

Arrays consisting of a single element are considered sorted in strictly ascending order.

You may assume that the input array will contain one or more homogeneous elements (either all numbers, or strings, or custom objects, but never a mix of these). You do not need to write checks for these conditions.

The original array must not be modified.

For full credit, the function must be implemented with **O(N)** complexity, with no additional data structures (including Static Arrays) being created.

Example #1:

```
test_cases = (
    [-100, -8, 0, 2, 3, 10, 20, 100],
    ['A', 'B', 'Z', 'a', 'z'],
    ['Z', 'T', 'K', 'A', '5'],
    [1, 3, -10, 20, -30, 0],
    [-10, 0, 0, 10, 20, 30],
    [100, 90, 0, -90, -200],
    ['apple']
)
for case in test_cases:
    arr = StaticArray(len(case))
    for i, value in enumerate(case):
        arr[i] = value
    result = is_sorted(arr)
    space = "  " if result is not None and result >= 0 else " "
    print(f"Result:{space}{result}, {arr}")
```

Output:

```
Result:  1, STAT_ARR Size: 8 [-100, -8, 0, 2, 3, 10, 20, 100]
Result:  1, STAT_ARR Size: 5 ['A', 'B', 'Z', 'a', 'z']
Result: -1, STAT_ARR Size: 5 ['Z', 'T', 'K', 'A', '5']
Result:  0, STAT_ARR Size: 6 [1, 3, -10, 20, -30, 0]
Result:  0, STAT_ARR Size: 6 [-10, 0, 0, 10, 20, 30]
Result: -1, STAT_ARR Size: 5 [100, 90, 0, -90, -200]
Result:  1, STAT_ARR Size: 1 ['apple']
```

find_mode(arr: StaticArray) -> tuple[object, int]:

Write a function that receives a StaticArray that is sorted in either non-descending or non-ascending order. The function will return the mode (the most-occurring element) of the array and its frequency (how many times it appears).

If there is more than one element that has the highest frequency, select the one that occurs first in the array.

You may assume that the input array will contain one or more homogeneous elements (either all numbers, or strings, or custom objects, but never a mix of these). You do not need to write checks for these conditions.

For full credit, the function must be implemented with **O(N)** complexity, **with no additional data structures (including Static Arrays) being created.**

Example #1:
```
test_cases = (
    [1, 20, 30, 40, 500, 500, 500],
    [2, 2, 2, 2, 1, 1, 1, 1],
    ["zebra", "sloth", "otter", "otter", "moose", "koala"],
    ["Albania", "Belgium", "Chile", "Denmark", "Egypt", "Fiji"]
)
for case in test_cases:
    arr = StaticArray(len(case))
    for i, value in enumerate(case):
        arr[i] = value

    result = find_mode(arr)
    if result:
        print(f"{arr}\nMode: {result[0]}, Frequency: {result[1]}\n")
    else:
        print(“find_mode() not yet implemented”)
```

Output:
```
STAT_ARR Size: 7 [1, 20, 30, 40, 500, 500, 500]
Mode: 500, Frequency: 3

STAT_ARR Size: 8 [2, 2, 2, 2, 1, 1, 1, 1]
Mode: 2, Frequency: 4

STAT_ARR Size: 6 ['zebra', 'sloth', 'otter', 'otter', 'moose', 'koala']
Mode: otter, Frequency: 2

STAT_ARR Size: 6 ['Albania', 'Belgium', 'Chile', 'Denmark', 'Egypt', 'Fiji']
Mode: Albania, Frequency: 1
```

remove_duplicates(arr: StaticArray) -> StaticArray:

Write a function that receives a StaticArray that is already in sorted order, either non-descending or non-ascending. The function will return a new StaticArray with all duplicate values removed. **The original array must not be modified**.

You may assume that the input array will contain one or more homogeneous elements in sorted order (either all numbers, or strings, or custom objects, but never a mix of these). You do not need to write checks for these conditions.

For full credit, the function must be implemented with **O(N)** complexity.

Example #1:

```
test_cases = (
    [1], [1, 2], [1, 1, 2], [1, 20, 30, 40, 500, 500, 500],
    [5, 5, 5, 4, 4, 3, 2, 1, 1], [1, 1, 1, 1, 2, 2, 2, 2]
)
for case in test_cases:
    arr = StaticArray(len(case))
    for i, value in enumerate(case):
        arr[i] = value
    print(arr)
    print(remove_duplicates(arr))
print(arr)
```

Output:

```
STAT_ARR Size: 1 [1]
STAT_ARR Size: 1 [1]
STAT_ARR Size: 2 [1, 2]
STAT_ARR Size: 2 [1, 2]
STAT_ARR Size: 3 [1, 1, 2]
STAT_ARR Size: 2 [1, 2]
STAT_ARR Size: 7 [1, 20, 30, 40, 500, 500, 500]
STAT_ARR Size: 5 [1, 20, 30, 40, 500]
STAT_ARR Size: 9 [5, 5, 5, 4, 4, 3, 2, 1, 1]
STAT_ARR Size: 5 [5, 4, 3, 2, 1]
STAT_ARR Size: 8 [1, 1, 1, 1, 2, 2, 2, 2]
STAT_ARR Size: 2 [1, 2]
STAT_ARR Size: 8 [1, 1, 1, 1, 2, 2, 2, 2]
```

count_sort(arr: StaticArray) -> StaticArray:

Use the **count sort algorithm** to write a function that receives a StaticArray and returns a new StaticArray with the same content sorted in non-ascending order. The original array must not be modified.

You may assume that the input array will contain at least one element, and that all elements will be integers in the range [-10^9, 10^9]. It is guaranteed that the difference between the maximum and minimum values in the input will be less than 1,000. You do not need to write checks for these conditions.

Implement a solution that can sort at least 5,000,000 elements in a reasonable amount of time (under a minute). Note that using a traditional sorting algorithm (even a fast sorting algorithm like **merge sort** or **shell sort**) will not pass the largest test case of 5,000,000 elements.

For full credit, the function must be implemented with **O(n+k)** time complexity, **where n is the number of elements and k is the range of values.**

Hint: The **count sort algorithm** (also known as **counting sort**) creates a sorted array by counting the number of times each value appears in the unsorted array.

A possible first step would be to find the range of numbers in the array, and use that range to create a new 'count array' that tabulates the number of times each element is present in the original array. The 'count array' will then provide you with the information you need to generate a sorted array.

Other functions in this assignment will help you determine how many different values could be in the array, as well as the range of possible values present.

This problem may be challenging, but try to implement this algorithm yourself. For further clarification on the **count sort algorithm**, here is some suggested reading:

- https://opendatastructures.org/ods-python/11_2_Counting_Sort_Radix_So.html

Example #1:

```
test_cases = (
    [1, 2, 4, 3, 5], [5, 4, 3, 2, 1], [0, -5, -3, -4, -2, -1, 0],
    [-3, -2, -1, 0, 1, 2, 3], [1, 2, 3, 4, 3, 2, 1, 5, 5, 2, 3, 1],
    [10100, 10721, 10320, 10998], [-100320, -100450, -100999, -100001],
)
for case in test_cases:
    arr = StaticArray(len(case))
    for i, value in enumerate(case):
        arr[i] = value
    print(f”Before: {arr}”)
    result = count_sort(arr)
    print(f”After : {result}”)
```

Output:result

```
Before: STAT_ARR Size: 5 [1, 2, 4, 3, 5]
After : STAT_ARR Size: 5 [5, 4, 3, 2, 1]
Before: STAT_ARR Size: 5 [5, 4, 3, 2, 1]
After : STAT_ARR Size: 5 [5, 4, 3, 2, 1]
Before: STAT_ARR Size: 7 [0, -5, -3, -4, -2, -1, 0]
After : STAT_ARR Size: 7 [0, 0, -1, -2, -3, -4, -5]
Before: STAT_ARR Size: 7 [-3, -2, -1, 0, 1, 2, 3]
After : STAT_ARR Size: 7 [3, 2, 1, 0, -1, -2, -3]
Before: STAT_ARR Size: 12 [1, 2, 3, 4, 3, 2, 1, 5, 5, 2, 3, 1]
After : STAT_ARR Size: 12 [5, 5, 4, 3, 3, 3, 2, 2, 2, 1, 1, 1]
Before: STAT_ARR Size: 4 [10100, 10721, 10320, 10998]
After : STAT_ARR Size: 4 [10998, 10721, 10320, 10100]
Before: STAT_ARR Size: 4 [-100320, -100450, -100999, -100001]
After : STAT_ARR Size: 4 [-100001, -100320, -100450, -100999]
```

Example #2:

```
array_size = 5_000_000
min_val = random.randint(-10 ** 9, 10 ** 9 - 998)
max_val = min_val + 998
case = [random.randint(min_val, max_val) for _ in range(array_size)]
arr = StaticArray(len(case))
for i, value in enumerate(case):
    arr[i] = value
print(f'Started sorting large array of {array_size} elements')
result = count_sort(arr)
print(f'Finished sorting large array of {array_size} elements')
```

Output:

```
Started sorting large array of 5000000 elements
Finished sorting large array of 5000000 elements
```

sorted_squares(arr: StaticArray) -> StaticArray:

Write a function that receives a StaticArray where the elements are in sorted order, and returns a new StaticArray with squares of the values from the original array, sorted in non-descending order. The original array must not be modified.

You may assume that the input array will have at least one element, will contain only integers in the range [-10^9, 10^9], and that elements of the input array are already in non-descending order. You do not need to write checks for these conditions.

Implement a FAST solution that can process at least 5,000,000 elements in a reasonable amount of time (under a minute).

Note: Using a traditional sorting algorithm (even a fast sorting algorithm like merge sort or shell sort) will not pass the largest test case of 5,000,000 elements. Also, a solution using count_sort() as a helper method will also not work here, due to the wide range of values in the input array.

For full credit, the function must be implemented with **O(N)** complexity.

Example #1:
```
test_cases = (
    [1, 2, 3, 4, 5],
    [-5, -4, -3, -2, -1, 0],
    [-3, -2, -2, 0, 1, 2, 3],
)
for case in test_cases:
    arr = StaticArray(len(case))
    for i, value in enumerate(sorted(case)):
        arr[i] = value
    print(arr)
    result = sorted_squares(arr)
    print(result)
```

Output:
```
STAT_ARR Size: 5 [1, 2, 3, 4, 5]
STAT_ARR Size: 5 [1, 4, 9, 16, 25]
STAT_ARR Size: 6 [-5, -4, -3, -2, -1, 0]
STAT_ARR Size: 6 [0, 1, 4, 9, 16, 25]
STAT_ARR Size: 7 [-3, -2, -2, 0, 1, 2, 3]
STAT_ARR Size: 7 [0, 1, 4, 4, 4, 9, 9]
```

Example #2:

```
array_size = 5_000_000
case = [random.randint(-10 ** 9, 10 ** 9) for _ in range(array_size)]
arr = StaticArray(len(case))
for i, value in enumerate(sorted(case)):
     arr[i] = value
print(f'Started sorting large array of {array_size} elements')
result = sorted_squares(arr)
print(f'Finished sorting large array of {array_size} elements')
```

Output:

```
Started sorting large array of 5000000 elements
Finished sorting large array of 5000000 elements
```