

Medians and Order Statistics & Elementary Data Structures

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MSCS532

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Medians and Order Statistics & Elementary Data Structures

GitHub link- <https://github.com/udhakal1s/MSCS532A6>

Implementation and Analysis of Selection Algorithms

Implementation

Here I implemented two different algorithms to find the smallest k-th element in a list. and both of the algorithm follow the general idea of breaking a complex problem into simpler problems. In the randomized version uses a random pivot to divide the datasets into smaller parts. As discussed in other assignments, doing so makes the problem easier to solve as large dataset is divided into smaller and we only needs to focus on one divided section at a time. The deterministic Median-of-Medians algorithm uses a step-by-step approach to choose the pivot. In this version instead of picking pivots randomly, it groups the datasets into smaller datasets, finds the median of each dataset, and then uses the median of those medians as the pivot. Even though it might be time consuming, it makes the algorithm more consistent and helps avoid the worst-case scenarios.

The screenshot below shows the coding implementation and output we got after implementation

Source Code snippets

```

File Edit Selection View Go Run Terminal Help ← → Search
MSCS532A6PART1.py MSCS532A6PART2.py
C:> Users > umesh > Downloads > MSCS532A6PART1.py > ...
1 # Umesh Dhakal
2 # MSCS532A6 - Part 1
3 # Randomized and Deterministic Selection (Quickselect & Median-of-Medians)
4 import time
5 import tracemalloc
6 import sys
7 sys.setrecursionlimit(10000)
8
9
10 def _partition_by_pivotvalue(arraylist, pivotvalue):
11     # splitting the list into three parts: less than pivot, equal to pivot, and greater than pivot.
12     smallerlist, equalist, greaterlist = [], [], []
13     for item in arraylist:
14         if item < pivotvalue:
15             smallerlist.append(item)
16         elif item > pivotvalue:
17             greaterlist.append(item)
18         else:
19             equalist.append(item)
20     return smallerlist, equalist, greaterlist
21
22 def _median_of_five(block):
23     # taking up to five items, sorting them, and returning the middle one.
24     b = sorted(block)
25     return b[len(b) // 2]
26
27 def _choose_pivot_median_of_medians(arraylist):
28     # choosing a safe pivot by using the median-of-medians.
29     n = len(arraylist)
30     if n <= 5:
31         return _median_of_five(arraylist)
32     medianlist = []
33     for i in range(0, n, 5):
34         medianlist.append(_median_of_five(arraylist[i:i+5]))
35     # finding the median of these medians as the final pivot.
36     return deterministic_select(medianlist, len(medianlist) // 2)
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```

File Edit Selection View Go Run Terminal Help ← → Search
MSCS532A6PART1.py MSCS532A6PART2.py
C:> Users > umesh > Downloads > MSCS532A6PART1.py > randomized_quickselect
38 def randomized_quickselect(arraylist, kthindex):
39     # picking a random pivot
40     if not arraylist:
41         raise ValueError("arraylist must not be empty")
42     if kthindex < 0 or kthindex >= len(arraylist):
43         raise IndexError("kthindex out of range")
44
45     if len(arraylist) == 1:
46         return arraylist[0]
47
48     pivotvalue = random.choice(arraylist)
49     smallerlist, equalist, greaterlist = _partition_by_pivotvalue(arraylist, pivotvalue)
50
51     if kthindex < len(smallerlist):
52         return randomized_quickselect(smallerlist, kthindex)
53     elif kthindex < len(smallerlist) + len(equalist):
54         return pivotvalue
55     else:
56         return randomized_quickselect(greaterlist, kthindex - len(smallerlist) - len(equalist))
57
58 def deterministic_select(arraylist, kthindex):
59     # using the median-of-medians pivot to avoid worst cases.
60     if not arraylist:
61         raise ValueError("arraylist must not be empty")
62     if kthindex < 0 or kthindex >= len(arraylist):
63         raise IndexError("kthindex out of range")
64
65     if len(arraylist) == 1:
66         return arraylist[0]
67
68     pivotvalue = _choose_pivot_median_of_medians(arraylist)
69     smallerlist, equalist, greaterlist = _partition_by_pivotvalue(arraylist, pivotvalue)
70
71     if kthindex < len(smallerlist):
72         return deterministic_select(smallerlist, kthindex)
73     elif kthindex < len(smallerlist) + len(equalist):
74         return pivotvalue
75
76
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```

File Edit Selection View Go Run Terminal Help ← → Search
MSCS532A6PART1.py × MSCS532A6PART2.py
C:\> Users > umesh > Downloads > MSCS532A6PART1.py > randomized_quickselect
58 def deterministic_select(arraylist, kthindex):
77     return deterministic_select(greaterlist, kthindex - len(smallerlist) - len(equallist))
78
79     def _make_datasets(test_size):
80         # four datasets for testing and comparison.
81         return {
82             "Sorted Data": list(range(1, test_size + 1)),
83             "Reverse Data": list(range(test_size, 0, -1)),
84             "Random Data": [random.randint(1, test_size) for _ in range(test_size)],
85             "Repeated Data": [5] * test_size
86         }
87
88     def _runttest(algorithm, dataset, dataset_name, kthindex):
89         arraylist = dataset[:]
90         tracemalloc.start()
91         t0 = time.perf_counter()
92         result = algorithm(arraylist, kthindex)
93         t1 = time.perf_counter()
94         peak = tracemalloc.get_traced_memory()
95         tracemalloc.stop()
96
97         # Results
98         print(f"{algorithm.__name__} on {dataset_name} took {t1 - t0:.5f}s and used {peak/1024:.2f}KB memory")
99         return result, (t1 - t0), peak
100
101 if __name__ == "__main__":
102     # test size 2000
103     test_size = 2000
104     datasets = _make_datasets(test_size)
105
106     print("\nSelection Algorithms Performance Analysis\n")
107     for dataset_name, dataset in datasets.items():
108
109         kthindex = len(dataset) // 2
110         ground_truth = sorted(dataset)[kthindex]
111         # randomized version
112         res1, _, _ = _runttest(randomized_quickselect, dataset, dataset_name, kthindex)
113         # deterministic version
114         res2, _, _ = _runttest(deterministic_select, dataset, dataset_name, kthindex)
115         assert res1 == ground_truth, f"randomized_quickselect incorrect on {dataset_name}"
116         assert res2 == ground_truth, f"deterministic_select incorrect on {dataset_name}"

```

Ln 47, Col 1 Spaces: 4 UTF-8 CRLF {} Python 3.13.5 5:37 PM 11/1/2025

Output

```

File Edit Selection View Go Run Terminal Help ← → Search MSCS532A6
EXPLORER ... MSCS532A6PART1.py × MSCS532A6PART2.py
MSCS532A6
MSCS532A6PART1.py > ...
87 def _runttest(algorithm, dataset, dataset_name, kthindex):
98     return result, (t1 - t0), peak
99
100 if __name__ == "__main__":
101     # test size 2000
102     test_size = 2000
103     datasets = _make_datasets(test_size)
104
105     print("\nSelection Algorithms Performance Analysis\n")
106     for dataset_name, dataset in datasets.items():
107
108         kthindex = len(dataset) // 2
109         ground_truth = sorted(dataset)[kthindex]
110         # randomized version
111         res1, _, _ = _runttest(randomized_quickselect, dataset, dataset_name, kthindex)
112         # deterministic version
113         res2, _, _ = _runttest(deterministic_select, dataset, dataset_name, kthindex)
114         assert res1 == ground_truth, f"randomized_quickselect incorrect on {dataset_name}"
115         assert res2 == ground_truth, f"deterministic_select incorrect on {dataset_name}"

PROBLEMS OUTPUT DEBUG CONSOLE TERMINAL PORTS
PS C:\Users\udhak\MSCS532A6> & c:/Users/udhak/AppData/Local/Programs/Python/Python311/python.exe c:/Users/udhak/MSCS532A6/MSCS532A6PART1.py
Selection Algorithms Performance Analysis

randomized_quickselect on Sorted Data took 0.03452s and used 64.86KB memory
deterministic_select on Sorted Data took 0.00730s and used 33.76KB memory
randomized_quickselect on Reverse Data took 0.00128s and used 47.14KB memory
deterministic_select on Reverse Data took 0.00590s and used 33.98KB memory
randomized_quickselect on Random Data took 0.00114s and used 39.08KB memory
deterministic_select on Random Data took 0.00744s and used 32.98KB memory
randomized_quickselect on Repeated Data took 0.00224s and used 15.81KB memory
deterministic_select on Repeated Data took 0.00317s and used 15.81KB memory
PS C:\Users\udhak\MSCS532A6>

& 41°F Sunny

```

Performance Analysis

The performance of all kinds of quicksort depends on how the pivot is selected during sorting processes. In the case of selection algorithm, the performance depends on how they

choose their pivot and how they break the large datasets into smaller parts. The randomized selection algorithm works fast in almost all situations as it picks a pivot randomly. When the pivot is good, it results into balanced partitions and as a result the randomized algorithm normally runs in $O(n)$ time. However, if the pivot selection is bad this makes the data split unevenly. And If pivot selection happen to be bad all the time than the algorithm becomes slower as there is too many uneven partitions and that make the run time $O(n^2)$ making it worst case. It is very unlikely that this scenario happen in real life.

The deterministic Median-of-Medians algorithm uses a step-by-step approach to choose the pivot. In this version instead of picking pivots randomly, it groups the datasets into smaller datasets, finds the median of each dataset, and then uses the median of those medians as the pivot. Even though it might be time consuming, it makes the algorithm more consistent and helps avoid the worst-case scenarios and it always runs in $O(n)$ worst-case time. This is why the deterministic algorithm is more predictable and reliable.

For space complexity, as both algorithms in Python use extra memory because they split the dataset into smaller parts during partitioning. Both the versions take $O(n)$ space in the partitioning process. The deterministic algorithm also has extra overhead as it should build groups of five and store medians in it, as a result it uses more memory and does more work in each step. As it involve extra steps it could be slower in practice, but it always guarantee that it will not fall into a worst-case scenario. Overall, the randomized version is faster on average, while the deterministic version is more stable and predictable.

Empirical Analysis

```

File Edit Selection View Go Run Terminal Help < > | MSCS532A6
EXPLORER ... MSCS532A6PART1.py MSCS532A6PART2.py
MSCS532A6PART1.py > ...
87 def _runttest(algorithm, dataset, dataset_name, kthindex):
88     return result, (t1 - t0), peak
89
90 if __name__ == "__main__":
91     # test size 2000
92     test_size = 2000
93     datasets = _make_datasets(test_size)
94
95     print("nSelection Algorithms Performance Analysisn")
96     for dataset_name, dataset in datasets.items():
97
98         kthindex = len(dataset) // 2
99         ground_truth = sorted(dataset)[kthindex]
100
101         # randomized version
102         res1, _, _ = _runttest(randomized_quickselct, dataset, dataset_name, kthindex)
103
104         # deterministic version
105         res2, _, _ = _runttest(deterministic_select, dataset, dataset_name, kthindex)
106
107         assert res1 == ground_truth, f"randomized_quickselct incorrect on {dataset_name}"
108         assert res2 == ground_truth, f"deterministic_select incorrect on {dataset_name}"
109
110
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PROBLEMS OUTPUT DEBUG CONSOLE TERMINAL PORTS
PS C:\Users\udhak\MSCS532A6> & C:/Users/udhak/AppData/Local/Programs/Python/Python311/python.exe c:/Users/udhak/MSCS532A6/MSCS532A6PART1.py
Selection Algorithms Performance Analysis
randomized_quickselct on Sorted Data took 0.03452s and used 64.86KB memory
deterministic_select on Sorted Data took 0.00730s and used 33.76KB memory
randomized_quickselct on Reverse Data took 0.00128s and used 47.14KB memory
deterministic_select on Reverse Data took 0.00509s and used 33.90KB memory
randomized_quickselct on Random Data took 0.00114s and used 39.08KB memory
deterministic_select on Random Data took 0.00244s and used 32.98KB memory
randomized_quickselct on Repeated Data took 0.00224s and used 15.81KB memory
deterministic_select on Repeated Data took 0.00317s and used 15.81KB memory
PS C:\Users\udhak\MSCS532A6>

```

Here the analysis we tested both the randomized selection algorithm and the deterministic selection algorithm on four different types of datasets such as sorted data, reverse data, random data, and repeated data. Each dataset had 2,000 elements. For each dataset we recorded the total running time and the memory used. This helped us analyze how each algorithm behaves under different kinds of input.

On the sorted dataset, the randomized selection algorithm version took 0.03452 seconds and used 64.86 kb of memory. Whereas deterministic algorithm only took 0.00730 seconds and use 33.76 kb which performed faster compared to randomized version. The results shows that the deterministic algorithm works better on sorted data because it always chooses a safe pivot, while the randomized algorithm depends on better the pivot choice. On the reverse dataset, the randomized algorithm version took 0.00128 seconds with 47.14 kb of memory use. The deterministic method took 0.00509 seconds and used 33.90 kb memory.

On the random dataset, both deterministic and randomized algorithms performed very efficiently. The randomized algorithm only took 0.00114 seconds and used 39.90 kb memory,

where the deterministic algorithm took 0.00744 seconds and used 32.98 kb of memory. This fits what we expect in theory because random data usually creates balanced partitions for both algorithms, helping them run in linear time.

On the repeated dataset, both algorithms used less memory. The randomized algorithm took 0.00224 seconds, and the deterministic one took 0.00317 seconds, and both used 15.81 kb of memory. Repeated data usually makes the partition step easier because many elements are equal, so the algorithms do not have to search as deeply.

Elementary Data Structures Implementation

For data structure implementation I created several basic data structures such as Array, Matrices, Queue and Linked list. First, I started with arrays and matrices, where I inserted, deleted, and accessed values. After that I implemented a stack and a queue using Python lists. At last, I implemented a singly linked list by creating nodes that point to the next node as shown in the source code in the GitHub file.

Source Code snippets

```

File Edit Selection View Go Run Terminal Help ⏪ ⏩ Search
C:> Users > umesh > Downloads > MSCS532A6PART2.py > ...
1 #! /usr/bin/python
2 # MSCS532A6 - Part 2
3 # Arrays and Matrices, Stacks and Queues, and singly linked list in one file
4 # I included short demos so I can see outputs directly.
5
6 # Arrays and Matrices
7
8 class ArrayList:
9     # I use a Python list underneath to simulate a dynamic array.
10    def __init__(self):
11        self.arraylist = []
12
13    def insertitem(self, index, value):
14        if index < 0 or index > len(self.arraylist):
15            raise IndexError("index out of bounds")
16        self.arraylist.insert(index, value)
17
18    def appenditem(self, value):
19        self.arraylist.append(value)
20
21    def deleteitem(self, index):
22        if index < 0 or index >= len(self.arraylist):
23            raise IndexError("index out of bounds")
24        return self.arraylist.pop(index)
25
26    def getitem(self, index):
27        if index < 0 or index >= len(self.arraylist):
28            raise IndexError("index out of bounds")
29        return self.arraylist[index]
30
31    def setitem(self, index, value):
32        if index < 0 or index >= len(self.arraylist):
33            raise IndexError("index out of bounds")
34        self.arraylist[index] = value
35
36    def __len__(self):
37        return len(self.arraylist)

```

```

File Edit Selection View Go Run Terminal Help ⏪ ⏩ Search
C:> Users > umesh > Downloads > MSCS532A6PART2.py > ...
8 class ArrayList:
9     def __len__(self):
10        return len(self.arraylist)
11
12     def __repr__(self):
13        return f"ArrayList({self.arraylist})"
14
15     class MatrixList:
16         # I use a list of lists to represent a matrix.
17         def __init__(self, rows, columns, fill=0):
18             if rows <= 0 or columns <= 0:
19                 raise ValueError("rows/columns must be positive")
20             self.matrix = [[fill for _ in range(columns)] for _ in range(rows)]
21
22         def getcell(self, row, column):
23             return self.matrix[row][column]
24
25         def setcell(self, row, column, value):
26             self.matrix[row][column] = value
27
28         def insertrow(self, rowindex, newrow=None):
29             cols = len(self.matrix[0])
30             if newrow is None:
31                 newrow = [0] * cols
32             if len(newrow) != cols:
33                 raise ValueError("new row must match column count")
34             if rowindex < 0 or rowindex > len(self.matrix):
35                 raise IndexError("row index out of bounds")
36             self.matrix.insert(rowindex, newrow)
37
38         def deleterow(self, rowindex):
39             if rowindex < 0 or rowindex >= len(self.matrix):
40                 raise IndexError("row index out of bounds")
41             self.matrix.pop(rowindex)
42
43         def rows(self):
44

```

The screenshot shows a Windows desktop environment. In the foreground, there is a code editor window titled "MSCS532A6PART1.py" and "MSCS532A6PART2.py" (closed). The code editor displays Python code for implementing stacks and queues using lists. In the background, a file explorer window is open, showing the directory path: C:\Users\umesh\Downloads\MSCS532A6PART2.py. The taskbar at the bottom of the screen shows various pinned icons and the current date and time (11/1/2025) in the bottom right corner.

```
File Edit Selection View Go Run Terminal Help ← → Search

MSCS532A6PART1.py MSCS532A6PART2.py x
C:\Users\umesh\Downloads\MSCS532A6PART2.py ...
80
81 # Stacks and Queues
82
83 class Stacklist:
84     # I use a list and append/pop for stack behavior.
85     def __init__(self):
86         self.stacklist = []
87
88     def pushitem(self, value):
89         self.stacklist.append(value)
90
91     def popitem(self):
92         if not self.stacklist:
93             raise IndexError("pop from empty stack")
94         return self.stacklist.pop()
95
96     def peekitem(self):
97         return self.stacklist[-1] if self.stacklist else None
98
99     def isempty(self):
100        return len(self.stacklist) == 0
101
102     def __len__(self):
103         return len(self.stacklist)
104
105     def __repr__(self):
106         return f"StackList({self.stacklist})"
107
108
109 class QueueList:
110     # I use a list and pop(0) for queue behavior. This is simple and clear for assignments.
111     def __init__(self):
112         self.queueList = []
113
114     def enqueueitem(self, value):
115         self.queueList.append(value)

Ln 1, Col 1 Spaces: 4 UTF-8 CRLF Python 3.13.5
```

Output

The screenshot shows a Windows desktop environment with the Visual Studio Code (VS Code) application open. The title bar includes standard window controls (minimize, maximize, close) and the VS Code logo.

The main area displays two tabs: "MSCS532A6PART1.py" and "MSCS532A6PART2.py". The "MSCS532A6PART1.py" tab contains Python code for a stack implementation:

```
223     st.pushitem(1)
224     st.pushitem(2)
225     st.pushitem(3)
226     print("stack peek:", st.peekitem())
227     print("stack pop:", st.popitem())
228
```

The "TERMINAL" tab shows the command-line output of running the script:

```
PS C:\Users\umesh> & C:/Users/umesh/AppData/Local/Programs/Python/Python313/python.exe c:/Users/umesh/Downloads/MSCS532A6PART2.py
```

The output shows the execution of arrays and matrices, stacks, and queues, followed by a linked list operation:

```
Arrays and Matrices
arraylist now: ArrayList([5, 20])
getitem(): 20
after delete index 1: ArrayList([5])
matrix now:
[0, 0, 0]
[9, 9, 9]
[0, 0, 7]
after delete row 0:
[9, 9, 9]
[0, 0, 7]

Stacks and Queues
stack peek: 3
stack pop: 3
stack now: StackList([1, 2])
queue front: A
queue dequeue: A
queue now: QueueList(['B', 'C'])

Linked List
list now: 1 -> 2 -> 3 length: 3
find 3: 2
after delete value 2: 1 -> 3 length: 2
PS C:\Users\umesh>
```

The status bar at the bottom provides information about the current file (ln 233, Col 23), the number of selected items (118), and the system configuration (Spaces: 4, UTF-8, CRLF). It also shows the Python icon and the current date and time (5:43 PM, 11/1/2025).

Performance Analysis

Arrays and matrices are very fast when we want to get or change an item by its position. This just takes O (1) time because the computer knows exactly where the value is. Adding to the end is also fast and also take O (1) time, but adding or removing in the item from middle is slower and taking O(n) as many items must move in between. As Matrices are just arrays inside another array the time complexity of matrices are same as array.

Stacks that are with arrays are also fast as array. Pushing and popping from the end take just O (1) time. For queues, adding to the end is fast, but removing from the front is slow and take O(n)) as everything need to shift left before element can be fully removed. In Linked lists adding or removing the items take O (1) time but finding an item or deleting something in the middle is slower and take O(n) as we must move through each node one by one.

Arrays and linked lists have different strengths. Arrays are good when we want fast access to any position and when the data doesn't change a lot. Linked lists are better when we add and remove items often, especially at the front or back. In conclusion arrays work best for quick lookups, and linked lists work best when the size changes often.

Discussion and application of these data structures

The data structures used in many real-life applications and understanding them is important for solving problems smoothly and efficiently. Arrays and matrices are used in almost every part of computing, such as in storing images, in organizing data in tables, and running scientific or machine learning calculations. Stacks are very common in programming to do tasks like undo features, function calls, and commonly used depth-first search. Queues are used in systems that need to process tasks in order, like print queues, customer service systems, and scheduling processes in an operating system and Linked lists are more helpful where data needs to change often because inserting or deleting items is easier compared to arrays. LinkedList are

used in memory management, graph algorithms, and implementing hash tables. Understanding these core structures also helps when learning more advanced topics like trees, graphs, and hashing.

GitHub Commit



```

$ cd MSCS3246
$ git add MSCS3246PART1.py
$ git commit -m "Selection Algorithms implementation"
[main 46d2193] Selection Algorithms implementation
 1 file changed, 1 insertion(+)
$ git push origin main
Enumerating objects: 4, done.
Counting objects: 4 (delta 0), done.
Delta compression using up to 12 threads
Compressing objects: 3 (delta 0), done.
writing objects: 100% (3/3), 1.54 KIB | 1.54 MiB/s, done.
Total 3 (delta 0), reused 0 (delta 0), pack-reused 0
To https://github.com/admalaisi/MSCS3246
 46d2193..46d2393 main -> main

$ cd MSCS3246
$ git add MSCS3246PART2.py
$ git commit -m "Elementary Data Structures Implementation"
[main 535df11] Elementary Data Structures Implementation
 1 file changed, 1 insertion(+)
$ git push origin main
Enumerating objects: 4, done.
Counting objects: 4 (delta 0), done.
Delta compression using up to 12 threads
Compressing objects: 3 (delta 0), done.
writing objects: 100% (3/3), 1.98 KIB | 1.98 MiB/s, done.
Total 3 (delta 0), reused 0 (delta 0), pack-reused 0
To https://github.com/admalaisi/MSCS3246
 535df11..535df11 main -> main

```