**Buğra Ekuklu, 150120016**

**You can compile and run application with following command:**

```
g++ AoAHW2ApplicationDelegate.cpp IO/Parser.cpp Bootstrapping/
Application.cpp Models/Line.cpp Models/SemanticWord.cpp Strategies/
DeterministicQuickSortStrategy.cpp Strategies/LineCountedQuickSortStrategy.cpp
Strategies/RandomizedQuickSortStrategy.cpp Supporting\ Files/main.cpp -std=c++11
-Wall -O3 -o main
```

## A. Probabilistic Analysis

1. We should have n indicator random variables, since we need to check whether letter is sent to proper recipient, which determines the domain of indicator random variables, {0, 1}.

$$\text{Number of properly sent letters} = X_1 + X_2 + \ldots + X_n$$

The definition of expected value states that $E[X_i]$ should be the probability of proper letter sent action.

Let $X = \sum X_i$, then E[X] yields

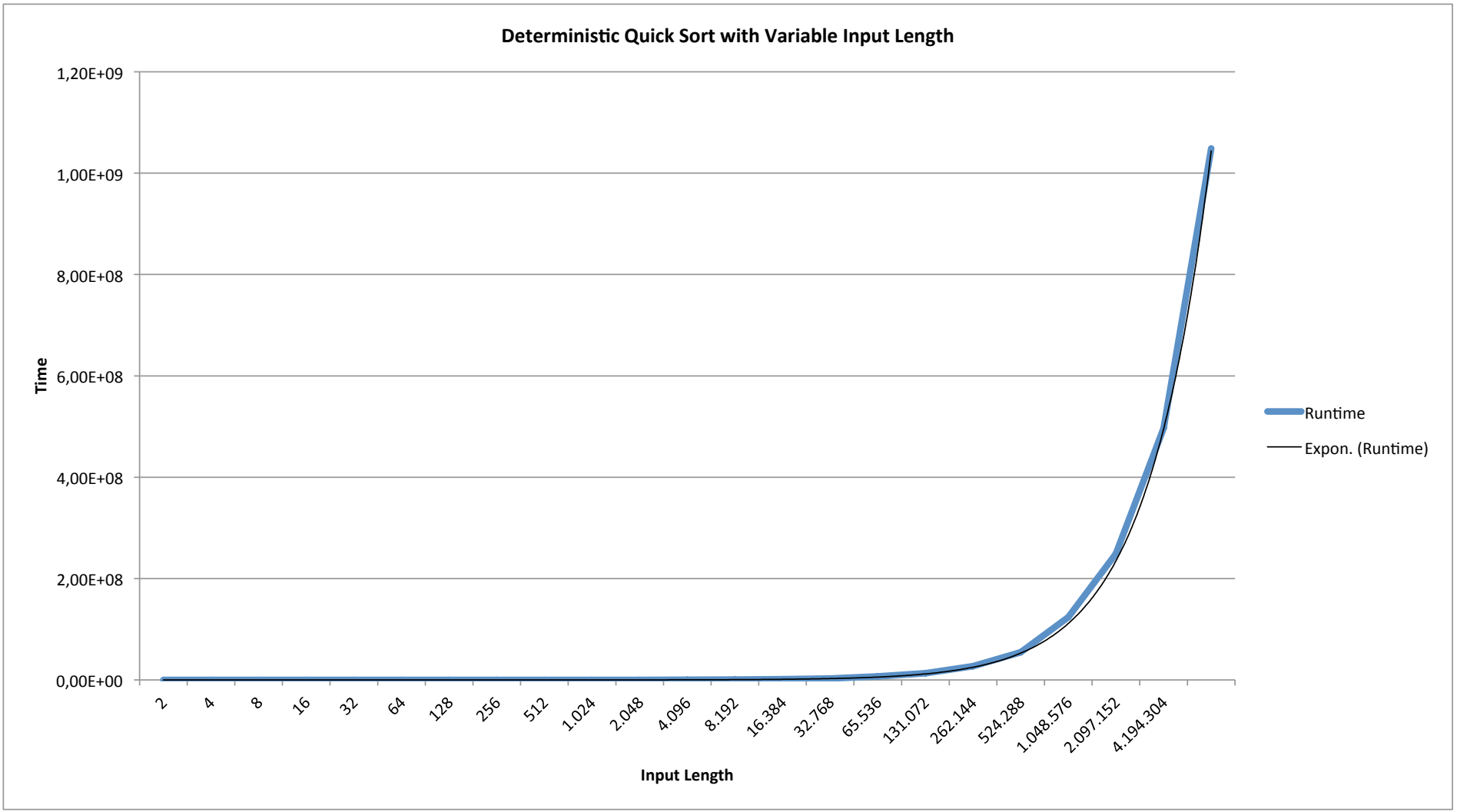
$$\begin{aligned} E[X] &= E[\sum X_i] \\ &= \sum \Pr\{X_i = 1\} \\ &= (n) * (n)^{-1} \\ &= 1 \end{aligned}$$

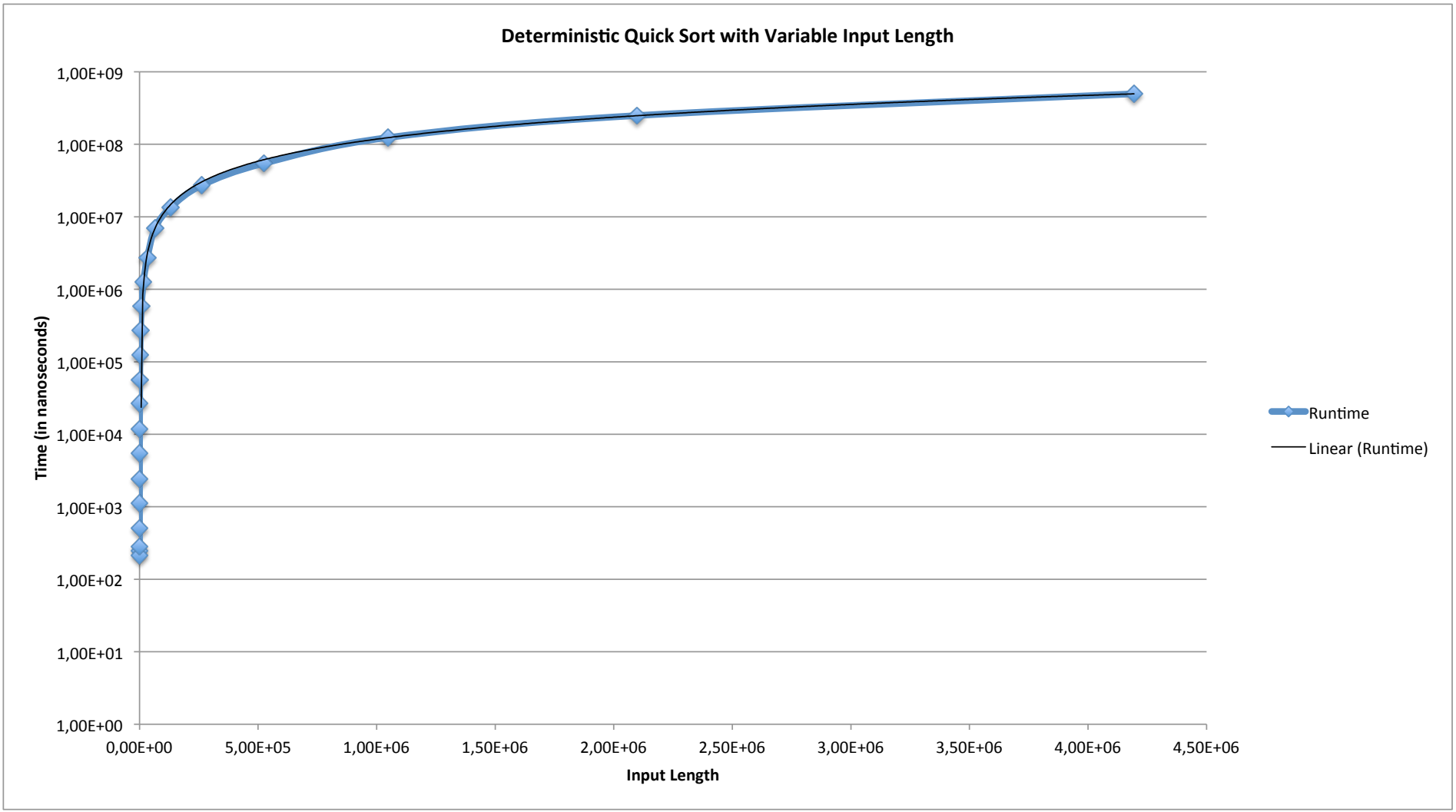
## C. Quick sort on numbers

Quicksort will have average running time,

$$T_a(n) = O(n \lg n)$$

which is proved by the graph. It also works in-place, therefore will be no additional memory overhead, nevertheless, its performance will vary how initial input is.


Deterministic Quick Sort with Variable Input Length
1,20E+09
1,00E+09
8,00E+08
6,00E+08
4,00E+08
2,00E+08
0,00E+00
Time
2
4
8
16
32
64
128
256
512
1.024
2.048
4.096
8.192
16.384
32.768
65.536
131.072
262.144
524.288
1.048.576
2.097.152
4.194.304
Input Length
Runtime
Expon. (Runtime)


Deterministic Quick Sort with Variable Input Length
Time (in nanoseconds)
1,00E+09
1,00E+08
1,00E+07
1,00E+06
1,00E+05
1,00E+04
1,00E+03
1,00E+02
1,00E+01
1,00E+00
0,00E+00
5,00E+05
1,00E+06
1,50E+06
2,00E+06
2,50E+06
3,00E+06
3,50E+06
4,00E+06
4,50E+06
Input Length
Runtime
Linear (Runtime)

# Deterministic Quick Sort On Constant Linear Sequence

| | | Complexity | | | | | | Runtime | | | Runtime Difference Relative To Base Run | Theoretical Runtime Estimation | | | Deviation of Theoretical vs. Practical | | | Logarithmic Success Exponent | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Worst Case | Average Case | Best Case | Benchmark nr. | Input Type | Input Length | | | | | Worst Case | Average Case | Best Case | Worst Case | Average Case | Best Case | Worst Case | Average Case | Best Case |
| Units | Sub-SI | N/A | N/A | N/A | N/A | N/A | N/A | ns | s | min | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| | SI | N/A | N/A | N/A | N/A | N/A | N/A | sE-09 | s | s * 60 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Deterministic Quick Sort | | *O(n2)* | *O(n lgn)* | *O(n lgn)* | 1 | *64-bit Unsigned Fast Integer* | 1 | 2,46E+02 | 0,000000 | 0,000000 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| | | | | | 2 | | 2 | 2,14E+02 | 0,000000 | 0,000000 | 8,70E-01 | 9,84E+02 | 3,41E+02 | 3,41E+02 | 8,84E-04 | 2,55E-03 | 2,55E-03 | -3,05E+00 | -2,59E+00 | -2,59E+00 |
| | | | | | 3 | | 4 | 2,82E+02 | 0,000000 | 0,000000 | 1,15E+00 | 3,94E+03 | 1,36E+03 | 1,36E+03 | 2,91E-04 | 8,40E-04 | 8,40E-04 | -3,54E+00 | -3,08E+00 | -3,08E+00 |
| | | | | | 4 | | 8 | 5,06E+02 | 0,000001 | 0,000000 | 2,06E+00 | 1,57E+04 | 4,09E+03 | 4,09E+03 | 1,31E-04 | 5,03E-04 | 5,03E-04 | -3,88E+00 | -3,30E+00 | -3,30E+00 |
| | | | | | 5 | | 16 | 1,13E+03 | 0,000001 | 0,000000 | 4,58E+00 | 6,30E+04 | 1,09E+04 | 1,09E+04 | 7,27E-05 | 4,20E-04 | 4,20E-04 | -4,14E+00 | -3,38E+00 | -3,38E+00 |
| | | | | | 6 | | 32 | 2,42E+03 | 0,000002 | 0,000000 | 9,84E+00 | 2,52E+05 | 2,73E+04 | 2,73E+04 | 3,91E-05 | 3,61E-04 | 3,61E-04 | -4,41E+00 | -3,44E+00 | -3,44E+00 |
| | | | | | 7 | | 64 | 5,45E+03 | 0,000005 | 0,000000 | 2,22E+01 | 1,01E+06 | 6,55E+04 | 6,55E+04 | 2,20E-05 | 3,38E-04 | 3,38E-04 | -4,66E+00 | -3,47E+00 | -3,47E+00 |
| | | | | | 8 | | 128 | 1,18E+04 | 0,000012 | 0,000000 | 4,81E+01 | 4,03E+06 | 1,53E+05 | 1,53E+05 | 1,19E-05 | 3,15E-04 | 3,15E-04 | -4,92E+00 | -3,50E+00 | -3,50E+00 |
| | | | | | 9 | | 256 | 2,66E+04 | 0,000027 | 0,000000 | 1,08E+02 | 1,61E+07 | 3,49E+05 | 3,49E+05 | 6,71E-06 | 3,10E-04 | 3,10E-04 | -5,17E+00 | -3,51E+00 | -3,51E+00 |
| | | | | | 10 | | 512 | 5,64E+04 | 0,000056 | 0,000001 | 2,29E+02 | 6,45E+07 | 7,86E+05 | 7,86E+05 | 3,56E-06 | 2,92E-04 | 2,92E-04 | -5,45E+00 | -3,53E+00 | -3,53E+00 |
| | | | | | 11 | | 1.024 | 1,25E+05 | 0,000125 | 0,000002 | 5,07E+02 | 2,58E+08 | 1,75E+06 | 1,75E+06 | 1,96E-06 | 2,90E-04 | 2,90E-04 | -5,71E+00 | -3,54E+00 | -3,54E+00 |
| | | | | | 12 | | 2.048 | 2,72E+05 | 0,000272 | 0,000005 | 1,11E+03 | 1,03E+09 | 3,84E+06 | 3,84E+06 | 1,07E-06 | 2,88E-04 | 2,88E-04 | -5,97E+00 | -3,54E+00 | -3,54E+00 |
| | | | | | 13 | | 4.096 | 5,90E+05 | 0,000590 | 0,000010 | 2,40E+03 | 4,13E+09 | 8,38E+06 | 8,38E+06 | 5,81E-07 | 2,86E-04 | 2,86E-04 | -6,24E+00 | -3,54E+00 | -3,54E+00 |
| | | | | | 14 | | 8.192 | 1,27E+06 | 0,001266 | 0,000021 | 5,15E+03 | 1,65E+10 | 1,82E+07 | 1,82E+07 | 3,12E-07 | 2,83E-04 | 2,83E-04 | -6,51E+00 | -3,55E+00 | -3,55E+00 |
| | | | | | 15 | | 16.384 | 2,73E+06 | 0,002726 | 0,000045 | 1,11E+04 | 6,60E+10 | 3,91E+07 | 3,91E+07 | 1,68E-07 | 2,83E-04 | 2,83E-04 | -6,78E+00 | -3,55E+00 | -3,55E+00 |
| | | | | | 16 | | 32.768 | 6,99E+06 | 0,006993 | 0,000117 | 2,84E+04 | 2,64E+11 | 8,38E+07 | 8,38E+07 | 1,08E-07 | 3,39E-04 | 3,39E-04 | -6,97E+00 | -3,47E+00 | -3,47E+00 |
| | | | | | 17 | | 65.536 | 1,34E+07 | 0,013408 | 0,000223 | 5,45E+04 | 1,06E+12 | 1,79E+08 | 1,79E+08 | 5,16E-08 | 3,05E-04 | 3,05E-04 | -7,29E+00 | -3,52E+00 | -3,52E+00 |
| | | | | | 18 | | 131.072 | 2,72E+07 | 0,027220 | 0,000454 | 1,11E+05 | 4,23E+12 | 3,80E+08 | 3,80E+08 | 2,62E-08 | 2,91E-04 | 2,91E-04 | -7,58E+00 | -3,54E+00 | -3,54E+00 |
| | | | | | 19 | | 262.144 | 5,46E+07 | 0,054602 | 0,000910 | 2,22E+05 | 1,69E+13 | 8,05E+08 | 8,05E+08 | 1,31E-08 | 2,76E-04 | 2,76E-04 | -7,88E+00 | -3,56E+00 | -3,56E+00 |
| | | | | | 20 | | 524.288 | 1,24E+08 | 0,123855 | 0,002064 | 5,03E+05 | 6,76E+13 | 1,70E+09 | 1,70E+09 | 7,45E-09 | 2,96E-04 | 2,96E-04 | -8,13E+00 | -3,53E+00 | -3,53E+00 |
| | | | | | 21 | | 1.048.576 | 2,49E+08 | 0,249043 | 0,004151 | 1,01E+06 | 2,70E+14 | 3,58E+09 | 3,58E+09 | 3,74E-09 | 2,83E-04 | 2,83E-04 | -8,43E+00 | -3,55E+00 | -3,55E+00 |
| | | | | | 22 | | 2.097.152 | 4,97E+08 | 0,497068 | 0,008284 | 2,02E+06 | 1,08E+15 | 7,51E+09 | 7,51E+09 | 1,87E-09 | 2,69E-04 | 2,69E-04 | -8,73E+00 | -3,57E+00 | -3,57E+00 |
| | | | | | 23 | | 4.194.304 | 1,05E+09 | 1,048676 | 0,017478 | 4,26E+06 | 4,33E+15 | 1,57E+10 | 1,57E+10 | 9,85E-10 | 2,71E-04 | 2,71E-04 | -9,01E+00 | -3,57E+00 | -3,57E+00 |