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 Design and Analysis of Algorithms
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 Extra-Credit Assignment 1

The task presented was to develop a program implementing the selection and bubble sort algorithms, and to analyze the times taken for different input sizes contrasted with the algorithm's computational complexity $\mathcal{O}(f(n))$. The first page of this paper describes the minimal analysis and prediction for $n = 5000$ vs. $n = 50000$, while the following pages contain a more in-depth analysis of the performance between the two algorithms and between the two languages, as well as an explanation for the performance gap between the two algorithms and the two languages.

Time (milliseconds) to sort elements, assignment-given tests

Implementation	$n=5000$	$n=50000$
Selection [ISO C99]	25.211	1854.049
Selection [Python 3.5]	1299.779	154338.610
Bubble [ISO C99]	65.803	5637.274
Bubble [Python 3.5]	5906.187	736724.950

We know from previous analysis of the selection sort and the bubble sort that both algorithms belong to the complexity class $\mathcal{O}(n^2)$. To predict the times for $n=50000$ given only the time for $n=5000$, we would have to take that into account. We know that both algorithms operate on an order of n^2 , with some deviation due to startup time and other time spent not related to the algorithm. To find the time it takes to perform one basic operation k , we divide the time t taken by the algorithm to compute by the number of elementary operations n^2 .

Given the time to compute a basic operation k , we can compute the estimated amount of time for an input size n by calculating kn^2 . The calculations can be shown for the selection sort [Python] with $n = 5000$ vs $n = 50000$:

$$k = \frac{5000^2}{1299.779ms} = 5.1991 * 10^{-5} \text{ ms}$$

$$t = k * 50000^2 = 129977.9 \text{ ms (actual result 154338.6 ms)}$$

This prediction has only 15% error (24360.7 ms) and came reasonably close to the actual result. Sources of error include floating-point precision (the time in milliseconds for an elementary operation is very small), as well as confounding variables in the execution environment. Linux is a multitasking kernel and not all programs will always receive sufficient CPU time for consistent results.

The following pages will contain a more in-depth analysis of the performance of the two languages and the performance of the two algorithms.

The extended analysis tested three ranges of values for both of the algorithms. The language names are abbreviated in the table as to preserve room.

Time (milliseconds) to sort elements, small-scale tests

	$n = 128$	$n = 256$	$n = 384$	$n = 512$	$n = 640$
Selection [C]	0.055	0.211	0.469	0.830	1.336
Selection [Py]	0.752	2.645	7.958	15.038	21.902
Bubble [C]	0.128	0.572	1.328	2.300	3.805
Bubble [Py]	2.805	12.098	32.168	55.175	96.536

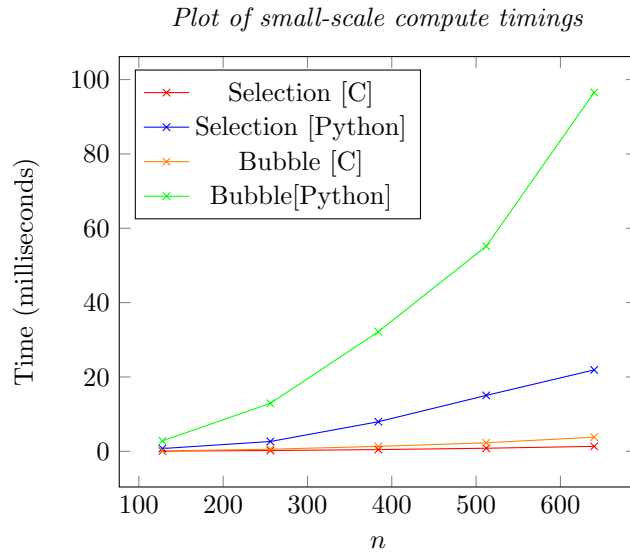
Time (milliseconds) to sort elements, medium-scale tests

	$n = 2048$	$n = 4096$	$n = 6144$	$n = 8192$	$n = 10240$
Selection [C]	12.252	24.137	39.507	57.308	85.884
Selection [Py]	236.447	953.649	1943.829	3532.748	5760.187
Bubble [C]	15.804	44.319	94.440	159.352	248.895
Bubble [Py]	1012.824	3993.341	9254.053	15841.523	25239.121

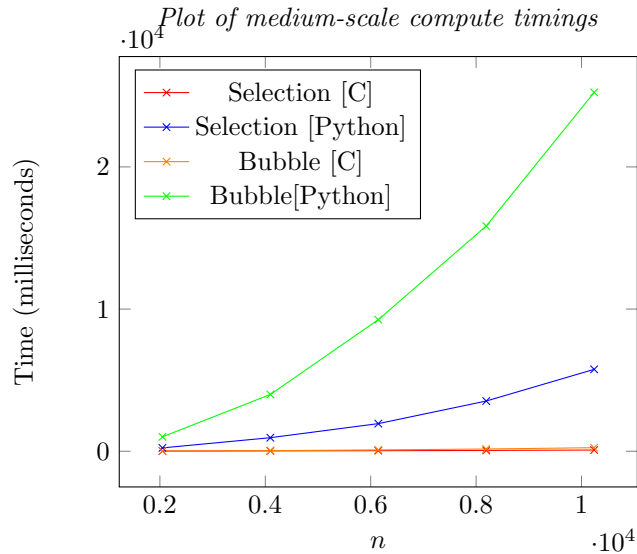
Time (milliseconds) to sort elements, large-scale tests

	$n = 16384$	$n = 32768$	$n = 49152$	$n = 65536$
Selection [C]	205.684	814.151	1792.096	3181.213
Selection [Py]	13976.302	58543.965	131223.770	240732.600
Bubble [C]	618.205	2426.378	5414.361	9614.802
Bubble [Py]	62854.785	264360.650	594066.920	1060772.400

The last test of the large-scale group was omitted as the Python implementation was predicted to take an unreasonable amount of time to compute the solution. The analysis and contrast between the two implementations is surprising, especially considering the large-scale bubble sort. The Python implementation seems to take significantly longer to compute the solutions, in this case by a factor greater than 1000. The graph of the respective tests certainly demonstrates a difference in both absolute performance and relative growth.

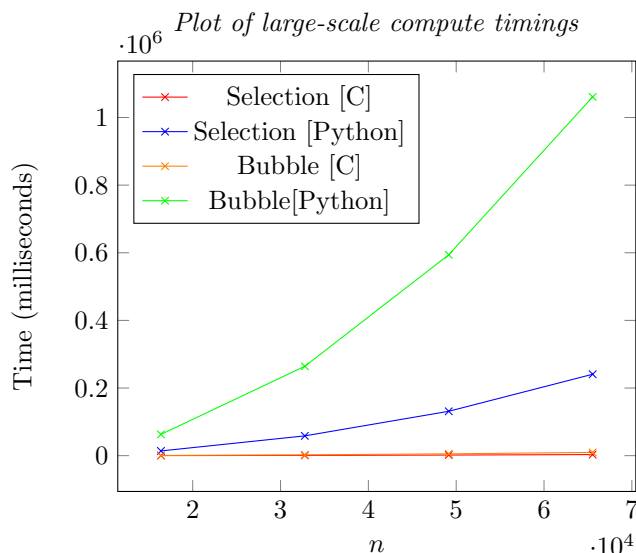


The small-scale graph definitely shows a major difference in performance vs input size, with Python and C performing similarly for very small inputs but Python growing in complexity much faster than C. Around 512, there is already a major difference in performance between Python and C. This difference in growth can be seen in the later graphs as well, with a much higher magnitude. Both bubble sort are significantly slower than their selection sort counterparts.



This graph appears to resemble the small-scale plot remarkably. The plot of the C timings appears to not be increasing as much. The Python timings

continue to increase greatly, while the C performance seems to be very close to 0 in comparison. The difference in performance between the bubble sort and the selection sort seems to be much greater in Python than in C. The Python bubble sort algorithm is quickly identified as the least effective algorithm amongst the other for large input sizes.



As expected, the graph of the large-scale compute times resembles the other graphs as well. The Python implementation appears to be consistent with the n^2 growth rate compared to C. Interestingly, the information gathered on the C implementation timings actually *does* resemble n^2 growth. It seems that the Python implementation distorts the scale of the graph significantly enough to hide the fact that the C implementation is indeed growing at an n^2 rate. The scale of the graph is also misleading as to the difference in performance between the C selection sort and the C bubble sort, which turns out to be substantial.

The algorithms examined in this assignment and their respective implementations have several differences. Both the bubble sort and the selection sort algorithms belong to $\mathcal{O}(n^2)$, but bubble sort appears to consistently perform worse than the selection sort for both implementations. This difference can be explained with the fact that \mathcal{O} does not describe immediate complexity differences but rather complexity growth as input size increases to large values. The bubble sort algorithm has the same growth over time as the selection sort algorithm, but the selection sort tends to generally be much faster for small inputs. This could be due to the nature of the bubble sort algorithm, which requires significantly more swaps and temporary stack variables than the selection sort. The bubble sort also must create and destroy temporary variables significantly more than the selection sort does. This explains the difference in performance between the selection sort and the bubble sort algorithms.

The two languages also appear to have a clear performance difference. The Python implementations used appear to consistently perform worse than the C implementations. This has a much simpler explanation: C is compiled to native code and does not require a hypervisor to execute instructions. Python runs under a virtual environment and must make the equivalent of several operations in C to perform basic operations. Python is also interpreted, not compiled in this instance. This explains the large gap in performance as well as the larger time growth for input size.