Characterizing Execution Times on Realistic Programs

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1 Description

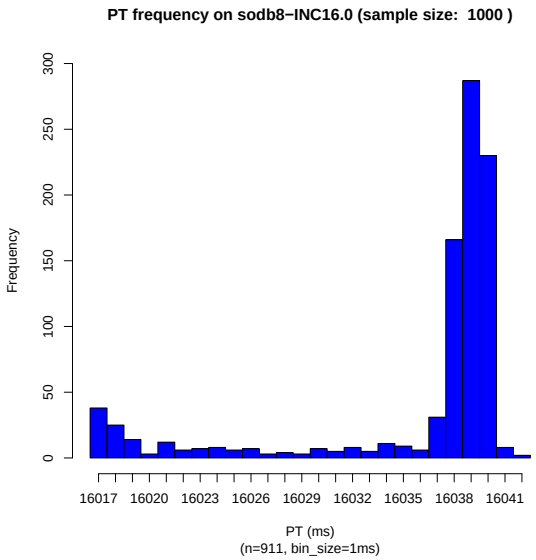
This document characterizes execution times measured on several real-world programs with different input sizes. To achieve this characterization, we discuss various histograms of execution times, measured in program time (PT), of the programs throughout this document. In this work we wish to achieve several goals as follows. The first goal is to unravel any structure behind the histograms and present insights into how such structure is formed. Another goal is to build a statistical distribution (or model) fitting in the histograms. From that distribution, we may reach predicting a concrete execution time considering system noise via the model on an arbitrary algorithm with a given input on a real execution environment. As a note, the execution times were measured along with the EMPv5 [1] protocol.

2 Preliminary Experiments

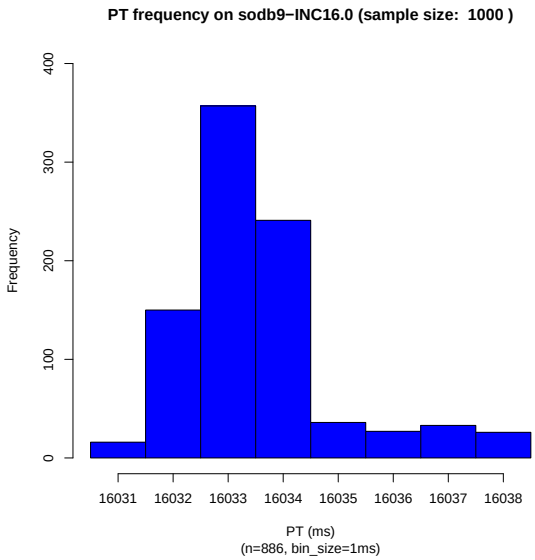
2.1 Inter-machine Repeatability Check

In this section we check if the use of different machines affects the distribution of execution (process) times on the same program. In other words, we examine *inter-machine repeatability*. For this examination, we use a nested for loop program, here termed INC, with different task lengths: 16 seconds, 13 seconds, and 17.2 seconds, each termed *INC16*, *INC13*, and *INC17.2*, respectively.

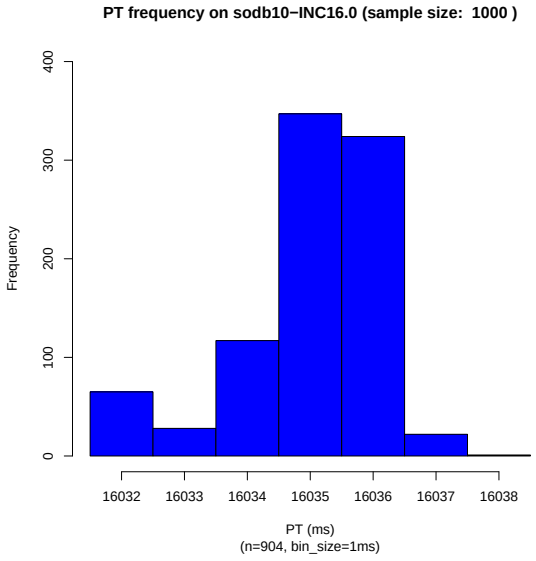
Figures 1, 2, and 3 display the process time (PT) histograms on INC16, INC13, and INC17.2 run on our machines (from `sodb8` to `sodb12`), respectively. Based on these figures, we conclude that we should stick to one machine for consistency, and `sodb9` should be chosen in a sense that the data measured there consistently reveals a distinct binormal pattern.



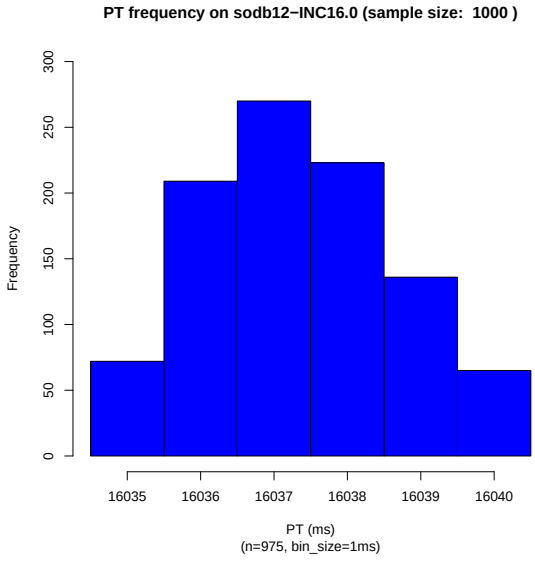
(a) PT frequency on INC16



(b) PT frequency on INC16

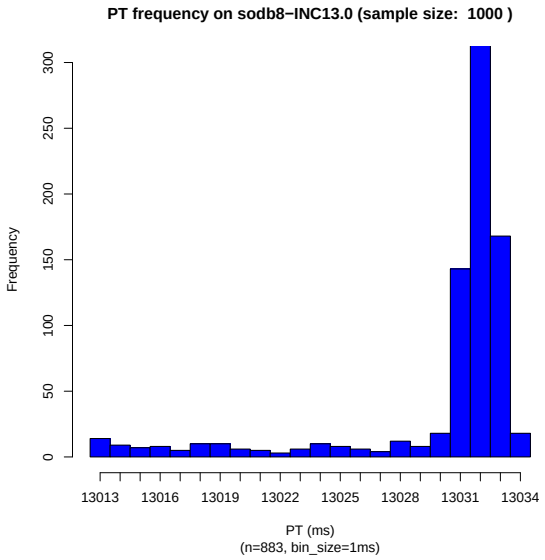


(c) PT frequency on INC16

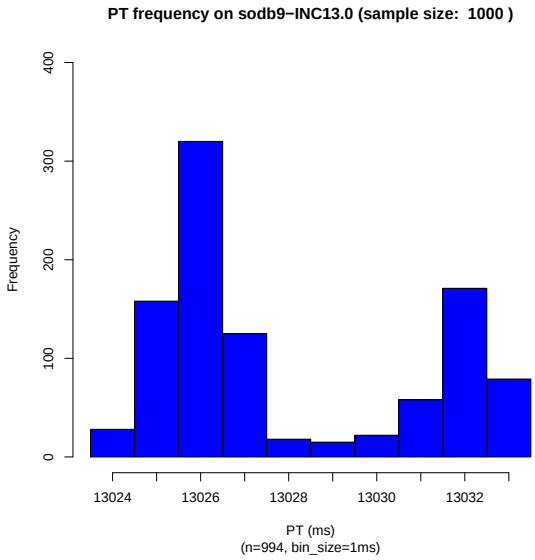


(d) PT frequency on INC16

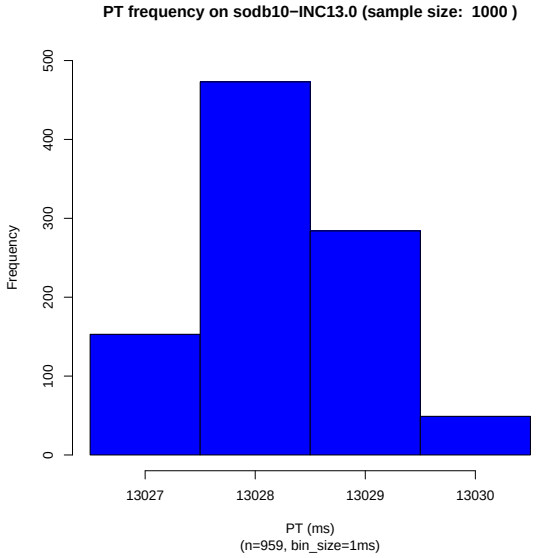
Figure 1: PT Histograms on INC16



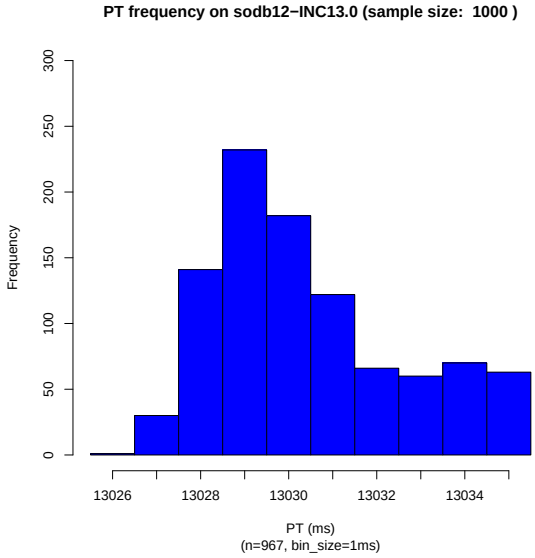
(a) PT frequency on INC13



(b) PT frequency on INC13

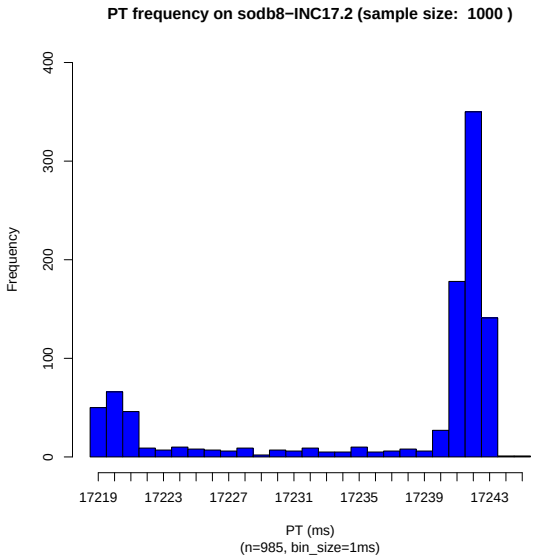


(c) PT frequency on INC13

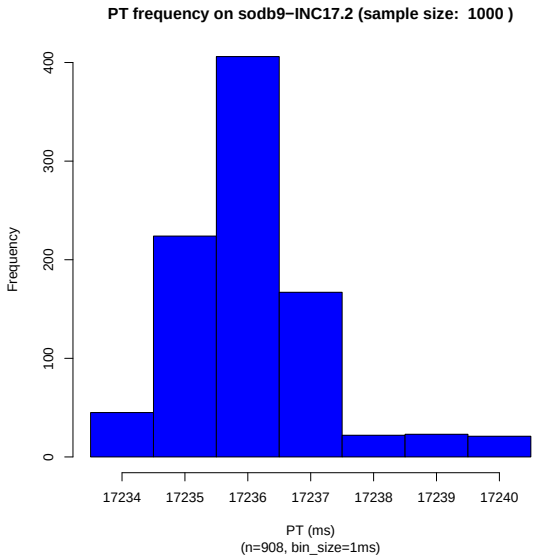


(d) PT frequency on INC13

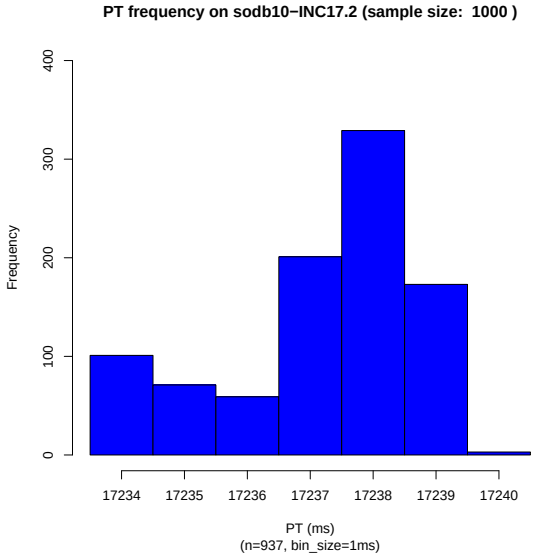
Figure 2: PT Histograms on INC13



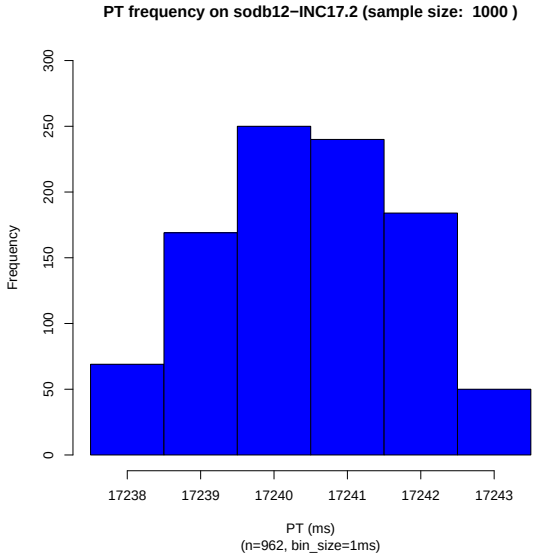
(a) PT frequency on INC17.2



(b) PT frequency on INC17.2



(c) PT frequency on INC17.2



(d) PT frequency on INC17.2

Figure 3: PT Histograms on INC17.2

2.1.1 Investigation of Daemons' Influence on Program Time on Different Machines

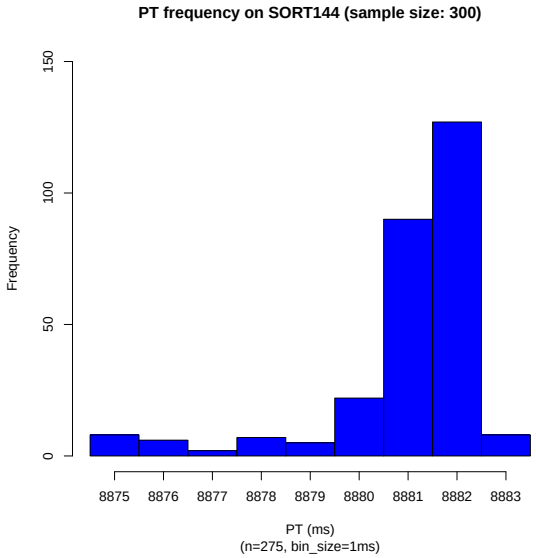
For the same task length, or INC16, I examined in each of the four runs a few iterations at which more than three daemons (except INC and proc monitor processes) that had positive PT were captured. From Table 1, I suspect that PT distribution seems most likely to be affected by two facts: *how longer the same daemon ran than usual*, and *how many different daemon processes appeared and how long it ran.*

Machine Name	Iteration #	Process Name (id, PT(msec))
sodb8	174	java (2349, 15), java (2335, 2), md127_raid1 (457, 1), kslowd000 (166, 1), kslowd001 (167, 1)
	278	java (2877, 16), java (2335, 2), kslowd000 (166, 1), kslowd001 (167, 1)
	486	java (3190, 21), java (2335, 2), md127_raid1 (457, 1), kslowd000 (166, 1)
	526	md127_raid1 (457, 1), kslowd000 (166, 1), kslowd001 (167, 1), jbd2/md127-8 (470, 1)
	555	java (3815, 8), java (2335, 2), kslowd000 (166, 1), kslowd001 (167, 1)
sodb9	105	java (6634, 16), java (6621, 2), kslowd000 (166, 1), kslowd001 (167, 1)
	175	java (6942, 7), java (6621, 2), kslowd000 (166, 1), kslowd001 (167, 1)
	245	java (7259, 6), java (6621, 2), kslowd000 (166, 1), kslowd001 (167, 1)
	280	java (7365, 3), java (6621, 2), kslowd000 (166, 1), kslowd001 (167, 1)
	350	java (7577, 3), java (6621, 2), kslowd000 (166, 1), kslowd001 (167, 1)
	420	java (7683, 3), java (6621, 2), kslowd000 (166, 1), kslowd001 (167, 1)
	490	java (7894, 4), java (6621, 2), kslowd000 (166, 1), kslowd001 (167, 1)
sodb10	105	java (28394, 14), java (28381, 2), kslowd000 (166, 1), kslowd001 (167, 1)
	314	java (28702, 18), java (28381, 2), md127_raid1 (455, 1), kslowd001 (167, 1)
sodb12	280	kslowd001 (167, 154), kslowd000 (166, 150), java (14820, 37), java (14807, 2)
	311	kslowd000 (166, 154), kslowd001 (167, 153), java (14807, 2), java (15653, 1), khugepaged (30, 1)
	373	kslowd000 (166, 154), kslowd001 (167, 152), java (14807, 2), java (15747, 2)
	435	kslowd000 (166, 154), kslowd001 (167, 153), java (15934, 6), java (14807, 2)
	466	kslowd000 (166, 152), java (16121, 6), java (14807, 2), kblockd/0 (16, 1)

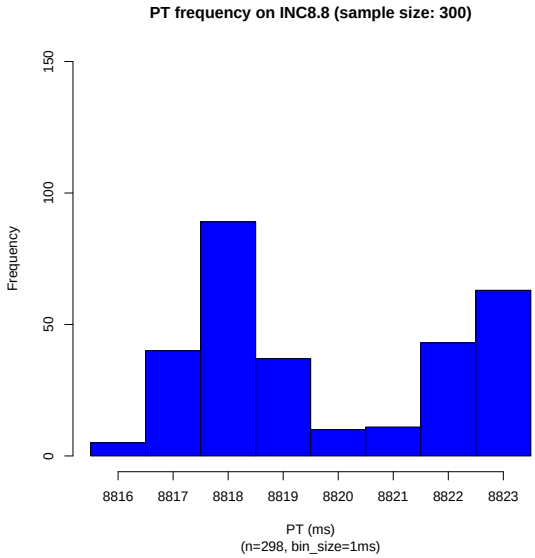
Table 1: Some daemon processes captured across different machines

2.2 One-to-One Comparison between An Insertion Sort & A Corresponding INC Programs

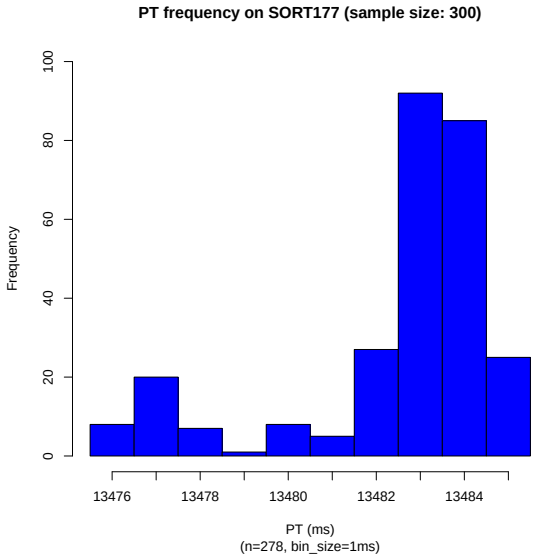
This section compares program time histograms of an insertion sort and a nested-for-loop programs (termed INC) with different input sizes. The insertion sort program sorts the elements of a given array in non-decreasing order. The program repeatedly runs 300 times for a given input size. The input size for the program varies from 144K to 344K integer elements, which are randomly generated. Note that each sort program over a specific input size is termed SORTx: for instance, SORT100 indicates the insertion sort program over 100K elements. An INC program's task length is correspondingly determined by the program time of an SORT program. In Figures 4, 5, and 6 we perform a match on an SORT program and its corresponding INC program.



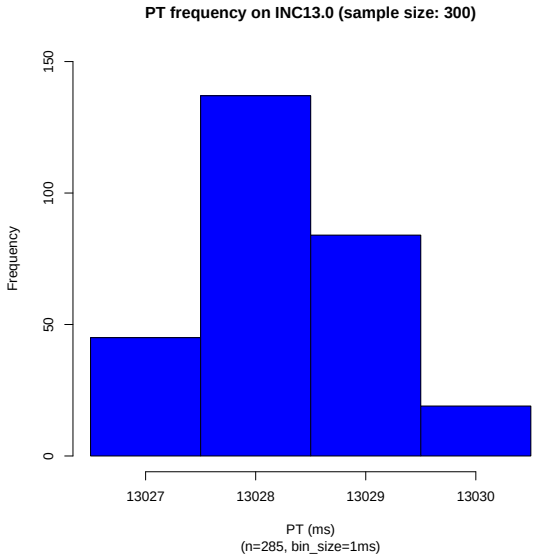
(a) PT frequency on SORT144 on `sodb8`



(b) PT frequency on INC8.8 on `sodb10`

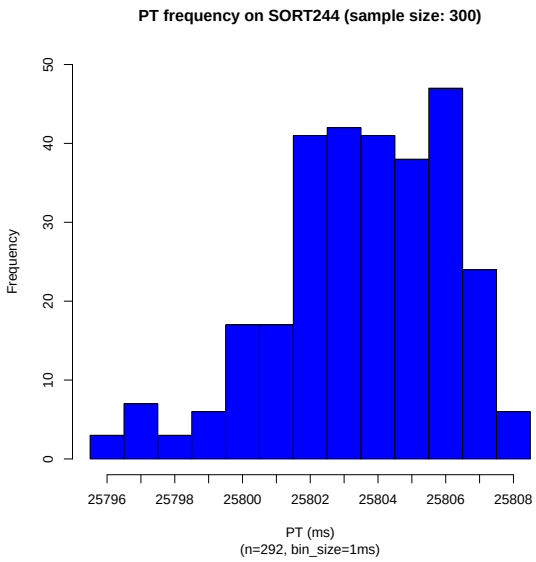


(c) PT frequency on SORT177 on `sodb8`

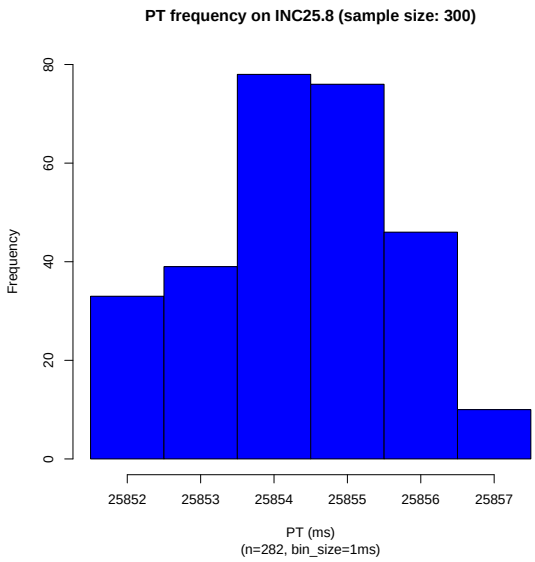


(d) PT frequency on INC13 on `sodb10`

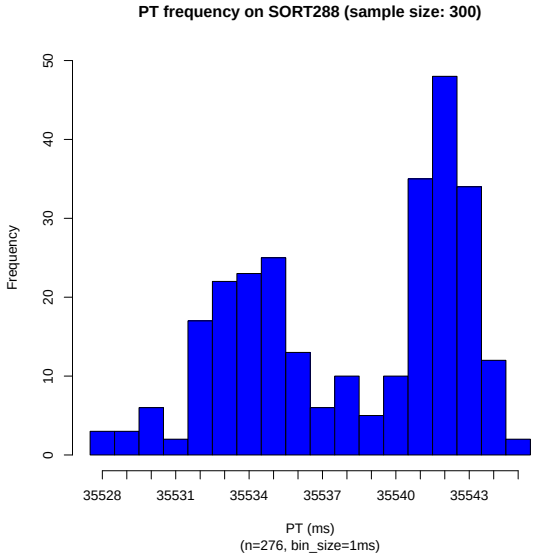
Figure 4: PT Histograms I



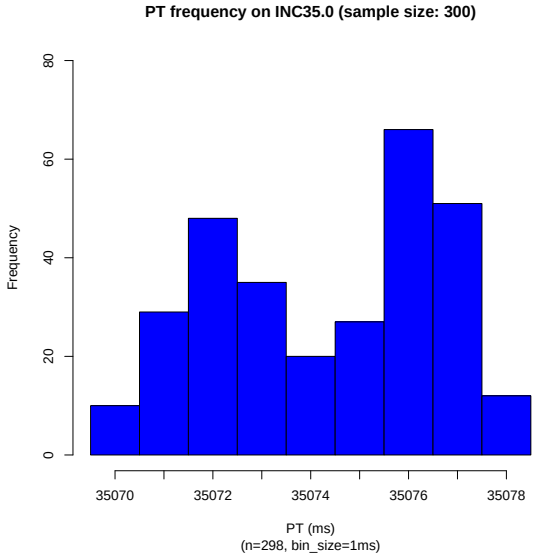
(a) PT frequency on SORT244 on `sodb8`



(b) PT frequency on INC25.8 on `sodb10`

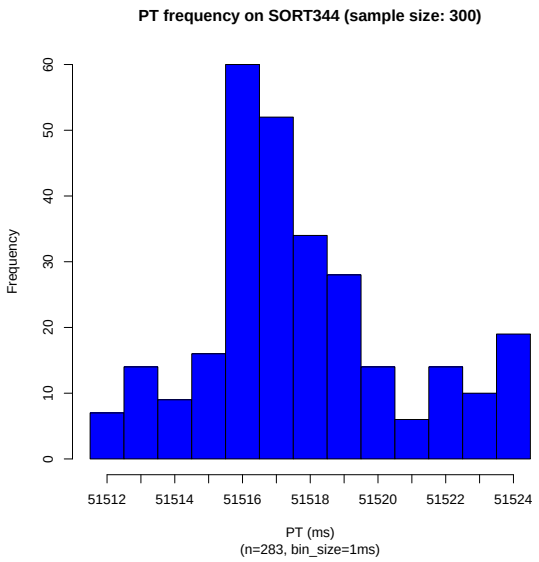


(c) PT frequency on SORT288 on `sodb8`

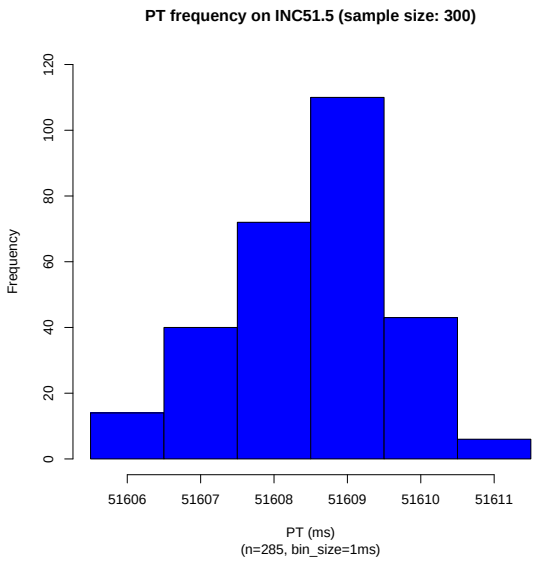


(d) PT frequency on INC35 on `sodb10`

Figure 5: PT Histogram Comparison II



(a) PT frequency on SORT344 on `sodb8`



(b) PT frequency on INC51.5 on `sodb10`

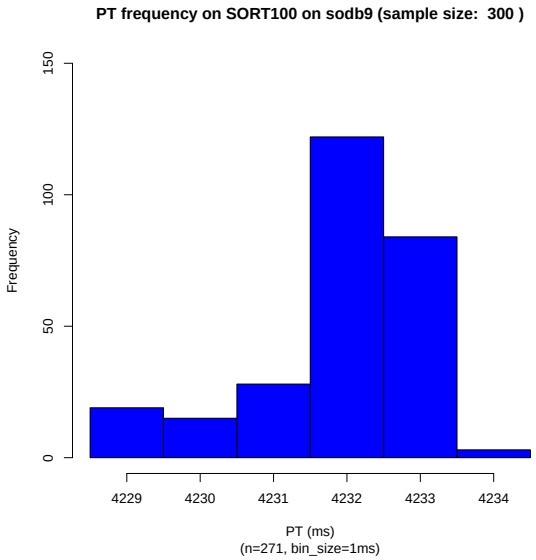
Figure 6: PT Histogram Comparison III

3 Histograms of the Execution Times on Real-World Programs

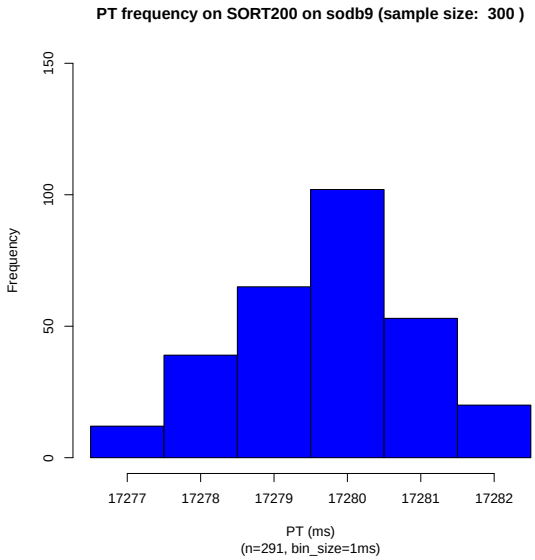
This section shows histograms for runs on different real-world programs with varying input sizes. In addition to the insertion sort program, we use another kind of program—*matrix multiplication*. For these programs, we varied their input sizes by $2\times$ while trying some intermediate sizes increased by $\sqrt{2}$ and measured execution times of the programs over each input size. We then exhibit different kinds of histograms in the subsequent sections.

3.1 Insertion Sort on `sodb9`

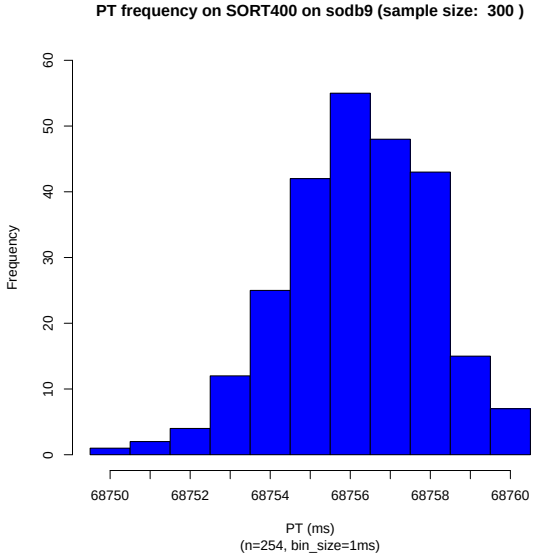
This section shows a series of histograms of an insertion sorting program that sorts the elements of a given array in non-decreasing order. The program repeatedly runs 300 times for a given input size. Note that each sort program over a specific input size is termed SORTx: for instance, SORT100 indicates the insertion sort program over 100K elements. (This experiment was performed on `sodb9`.)



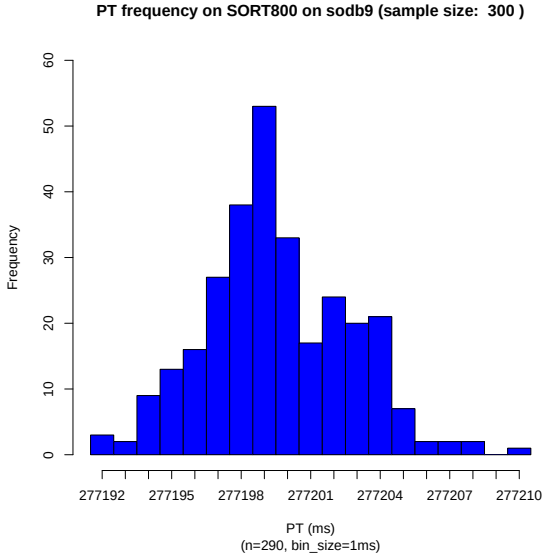
(a) PT frequency on SORT100 on `sodb9`



(b) PT frequency on SORT200 on `sodb9`



(c) PT frequency on SORT400 on `sodb9`



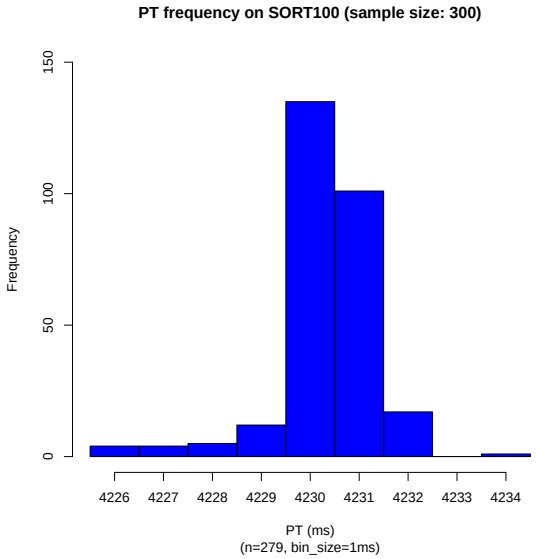
(d) PT frequency on SORT800 on `sodb9`

Figure 7: PT Histograms of SORT100 ... SORT800 on `sodb9`

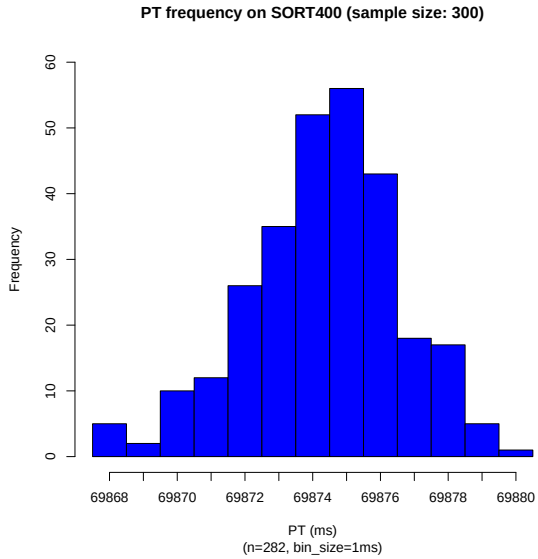
4 Appendix

4.1 Insertion Sort on `sodb8`

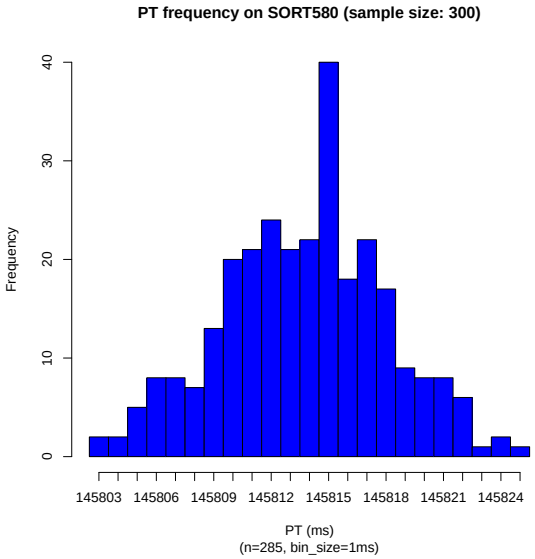
This section shows a series of histograms of an insertion sorting program that sorts the elements of a given array in non-decreasing order. The program repeatedly runs 300 times for a given input size. The input size for the program varies from 100,000 to 1,160,000 integer elements, which are randomly generated. Note that each sort program over a specific input size is termed SORTx: for instance, SORT100 indicates the insertion sort program over 100K elements. This experiment was performed on `sodb8`.



(a) PT frequency on SORT100 on `sodb8`

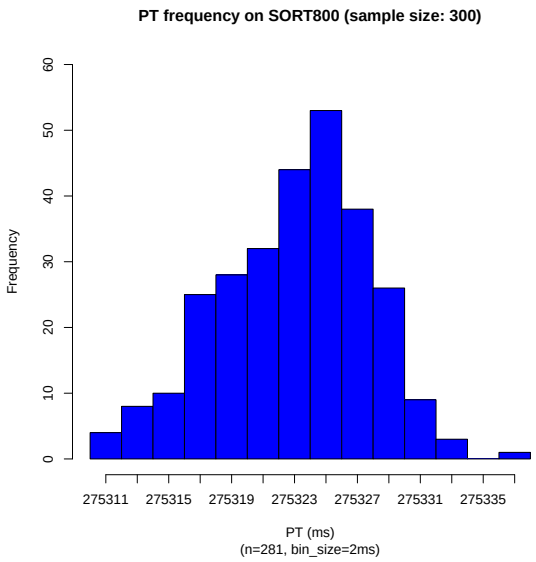


(b) PT frequency on SORT400 on `sodb8`

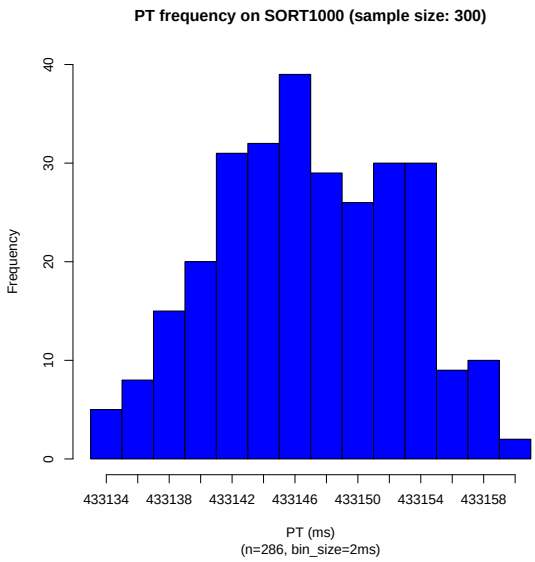


(c) PT frequency on SORT580 on `sodb8`

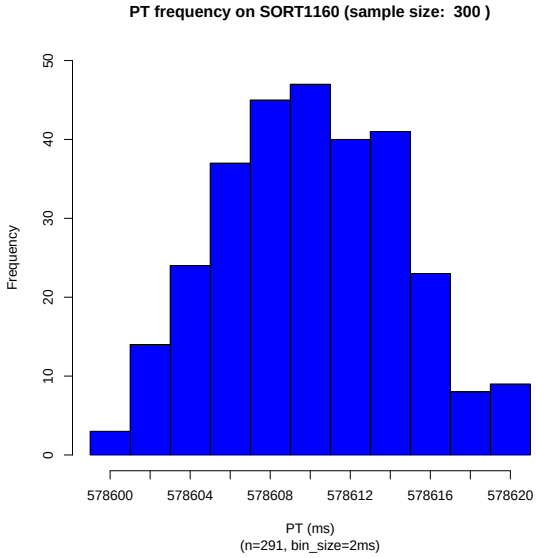
Figure 8: PT Histograms of SORT100 ... SORT580



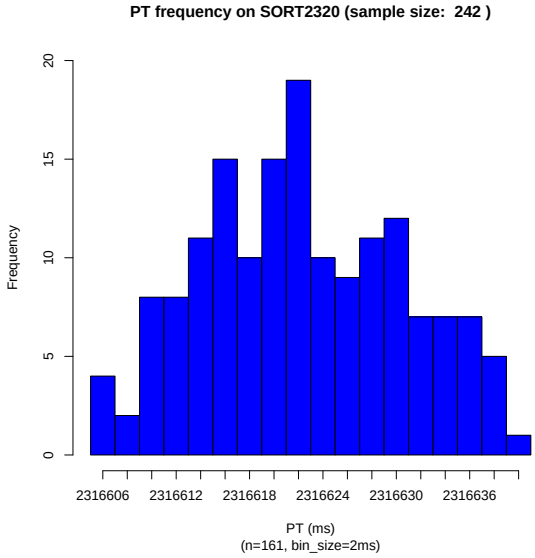
(a) PT frequency on SORT800 on `sodb8`



(b) PT frequency on SORT1000 on `sodb8`



(c) PT frequency on SORT1160 on `sodb8`



(d) PT frequency on SORT2320 on `sodb8`

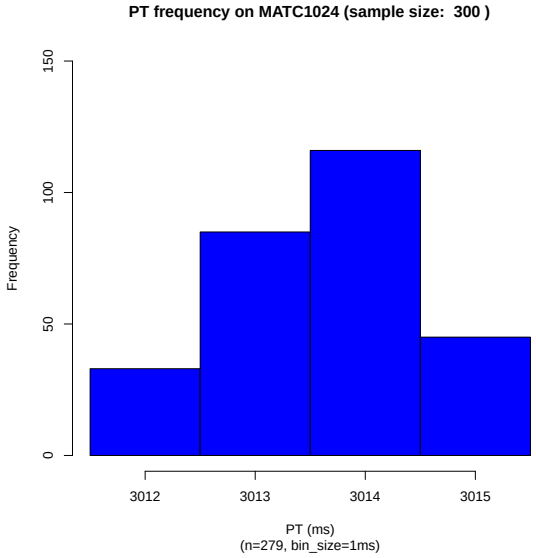
Figure 9: PT Histograms of SORT800 ... SORT2320

4.2 Matrix Multiplication

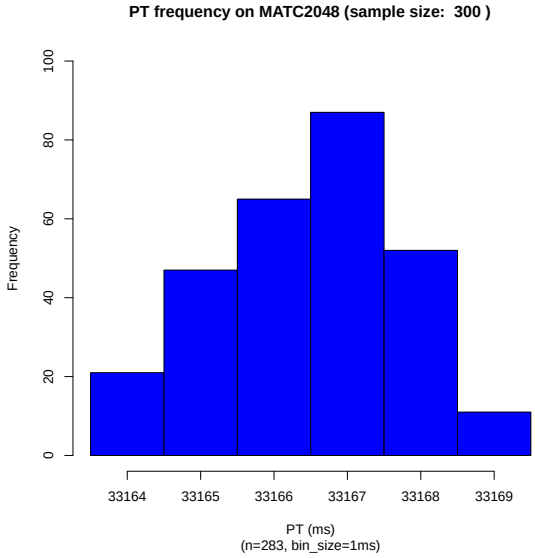
This section shows a series of histograms of the execution times of an matrix multiplication program. We used the same sample size for each input size of this program: i.e., 40 iterations. For simplicity, we used two square matrices for performing their multiplication in the program. We also varied the input sizes of each of the two matrices: from 1K×1K to 8K×8K integer elements that are also randomly generated. Note that each matrix multiplication program for a specific size is called MAT*xyyyy*, where *x* indicates which major, specifically *column* vs. *row*, is used, and *yyyy*, how large a given matrix is. For instance, MATC1000 represents a matrix multiplication program in column major over two square matrices having 1,000 integer (random) elements in a row (and a column).

4.2.1 Column Major

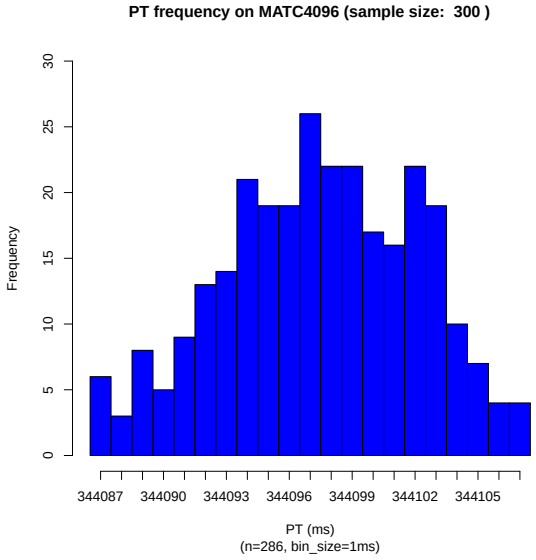
Figure 10 shows a series of histograms of the execution times measured on the same matrix multiplication program in column major as the input sizes grows. The program was run on `sodb10`.



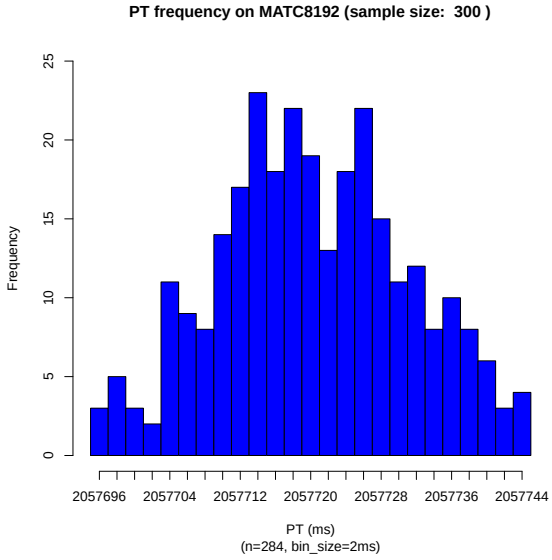
(a) PT frequency on MATC1K on `sodb10`



(b) PT frequency on MATC2K on `sodb10`



(c) PT frequency on MATC4K on `sodb10`

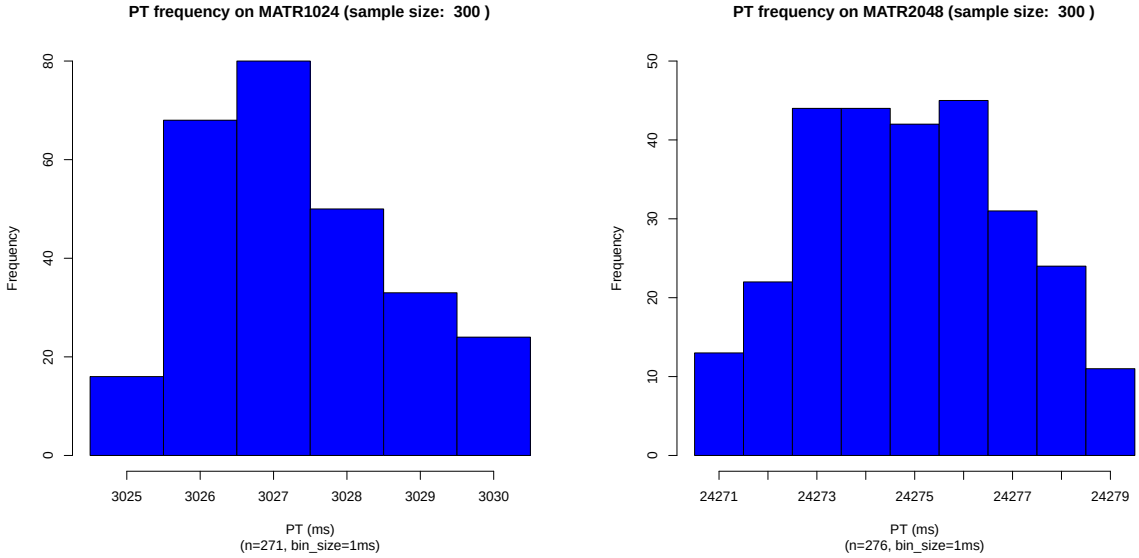


(d) PT frequency on MATC8K on `sodb10`

Figure 10: PT Histograms of MATC1024 ... MATC8192

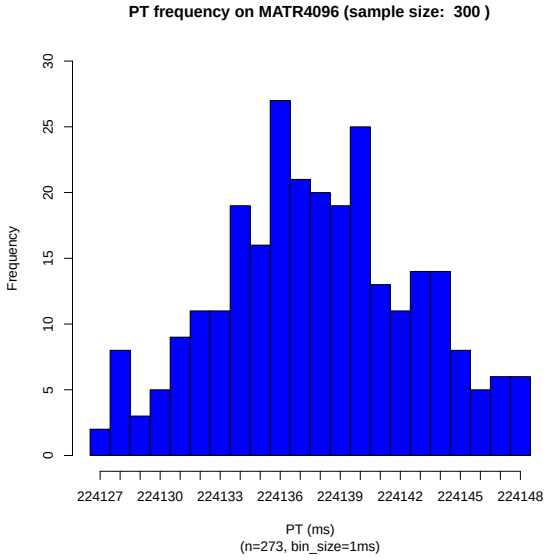
4.2.2 Row Major

Figure 10 shows a series of histograms of the execution times measured on the same matrix multiplication program in row major as the input sizes grows. The program was run on `sodb12`.

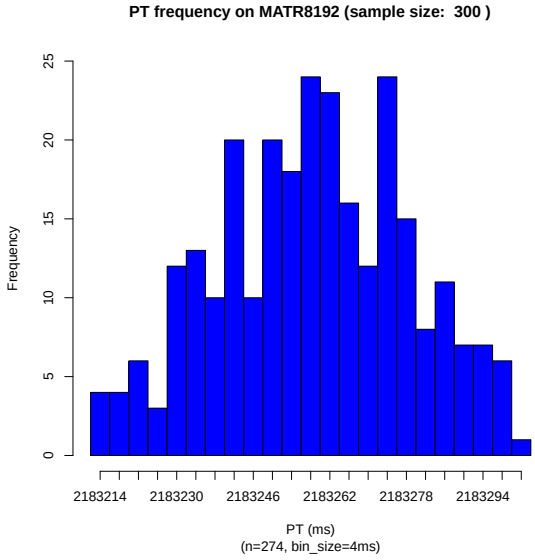


(a) PT frequency on MATR1K on `sodb12`

(b) PT frequency on MATR2K on `sodb12`



(c) PT frequency on MATR4K on `sodb12`



(d) PT frequency on MATR8K on `sodb12`

Figure 11: PT Histograms of MATR1K ... MATR8K

References

[1] Young-Kyoon Suh, Richard T. Snodgrass, John Kececioglu, Peter J. Downey, Rob S. Maier, and Cheng Yi, "EMP: Execution Time Measurement Protocol for Compute-Bound Programs", in *Software: Practice and Experience*, 47(4):559–597, 2017.

[2] Sabah Currim,Richard T. Snodgrass, Young-Kyoon Suh, and Rui Zhang, "DBMS Metrology: Measuring Query Time", in *ACM Transactions on Database Systems*, 42(1):3:1–42(+8), 2017.