Repeatability Test

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1 Description

This document characterizes execution times measured on a simple program in pure-computation mode, called *INC*, with increasing task lengths (up to 16,384 seconds from 1 second). For the characterization, we present various histograms of INC throughout this document. The main goal of examining these histograms is to make sure if two (or more) histograms of INC with the same task length have the same shape or not. If that's the case, then we can say that such an INC run is so called *repeatable*; in other words, *repeatability* is satisfied in our experimental settings. Another goal is to uncover and explicate several interesting structures behind the histograms. The third goal is to build a statistical distribution (or model) fitting in the histograms, so that later we are capable of predicting a concrete execution time via the model on an arbitrary algorithm with a given input on a real execution environment.

In our experiments, we used EMPv5 [1]. (That said, the second step of EMPv5 was on purpose omitted, just to obtain better histograms by retaining more samples.) In the protocol, we use taskstats C struct to get measures of a captured process. The taskstat's data is delivered via a netlink socket from the kernel space. The receive buffer for the socket is not robust for many observed processes [2]. Fortunately, there is an average of 95 processes per iteration of a run, which turns out to be fine with the struct. For a much more number of processes, the use of `/proc/`[pid]`/stat` is preferred, as (i) there are equivalent measures available in the `/proc` filesystem, and (ii) there's little constraint on the use as opposed to taskstats.

Now we show histograms of elapsed time (ET) and process time (PT) of INC via the EMPv5 protocol.

2 Histograms on the First Run

This section exhibits histograms on the first run of INC with its task length increasing from 1 second to 4096 seconds. The detailed description of the base data is from Table 1.

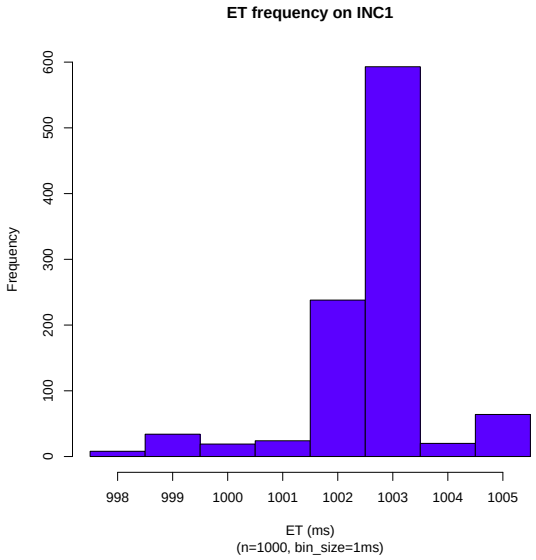
3 Experiment Notes

Table 1 provides a short description of our experimental runs, on which the following histograms are based.

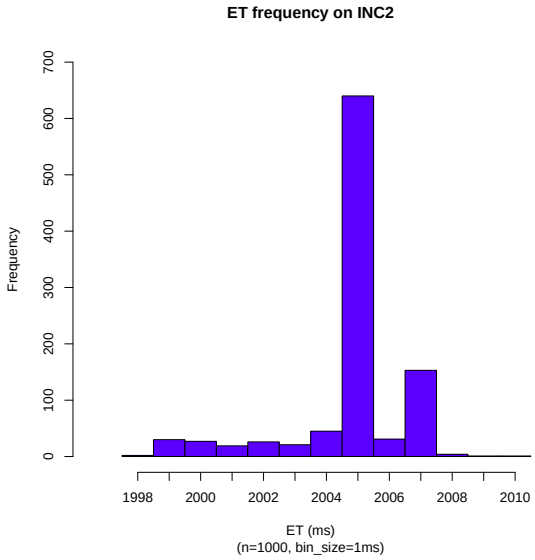
Machine	Task Length (sec)	Description	Experiment Period	Relevant Histograms
`sodb9`	INC1∼INC64	1000 samples, each	2017-03-02 ∼ 2017-03-04	Figs. 1, 2, 5, and 6
`sodb9`	INC128∼INC1024	300 samples, each	2017-03-04 ∼ 2017-03-11	Figs. 3 and 7
`sodb10`	INC2048	300 samples	2017-03-02 ∼ 2017-03-09	Figs. 4(a) and 8(a)
`sodb12`	INC4096	300 samples	2017-02-13 ∼ 2017-02-27	Figs. 4(b) and 8(b)

Table 1: Notes on experiment runs used for histograms

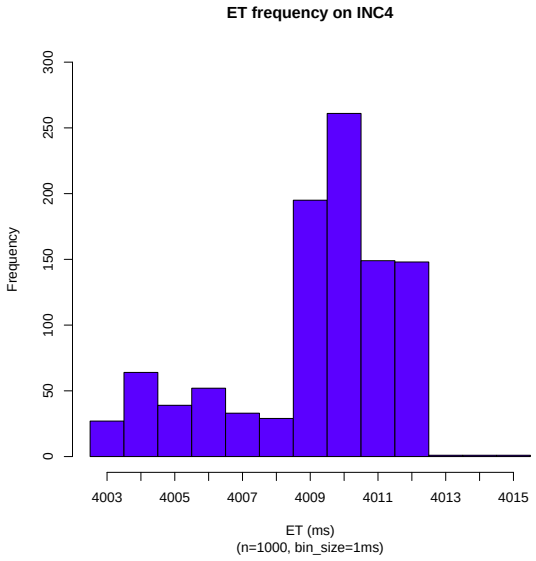
3.1 ET



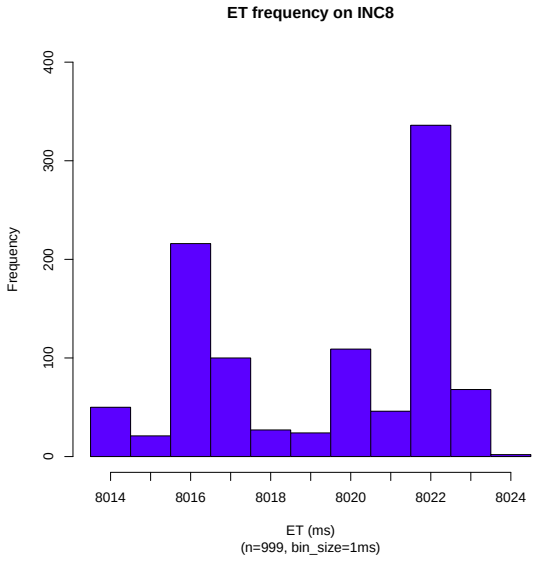
(a) ET frequency on INC1



(b) ET frequency on INC2

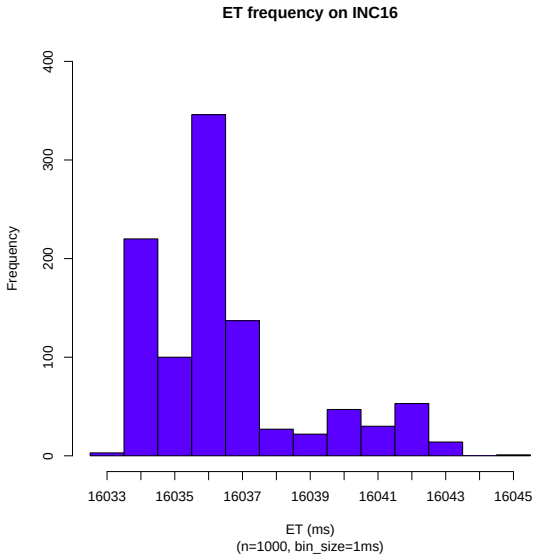


(c) ET frequency on INC4

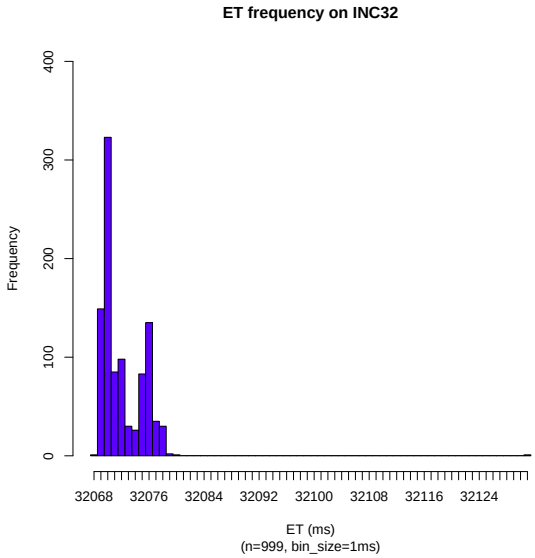


(d) ET frequency on INC8

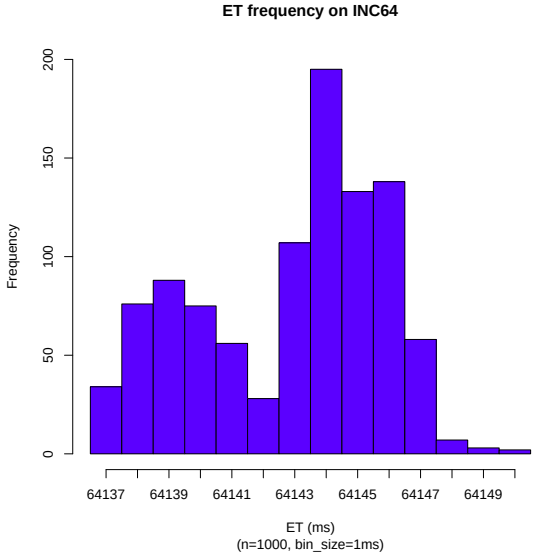
Figure 1: ET Histograms of INC1 ... INC8



(a) ET frequency on INC16

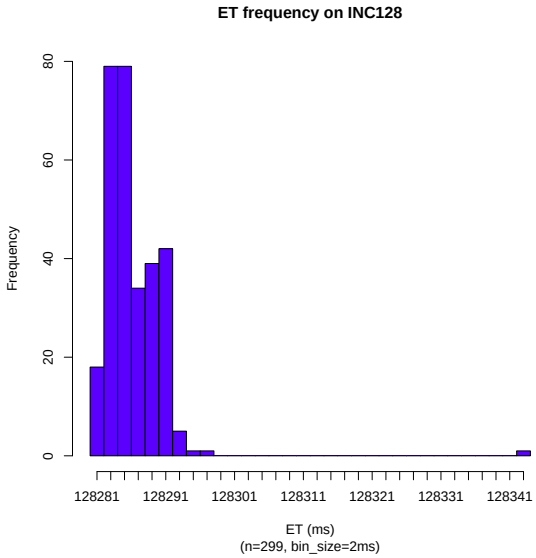


(b) ET frequency on INC32

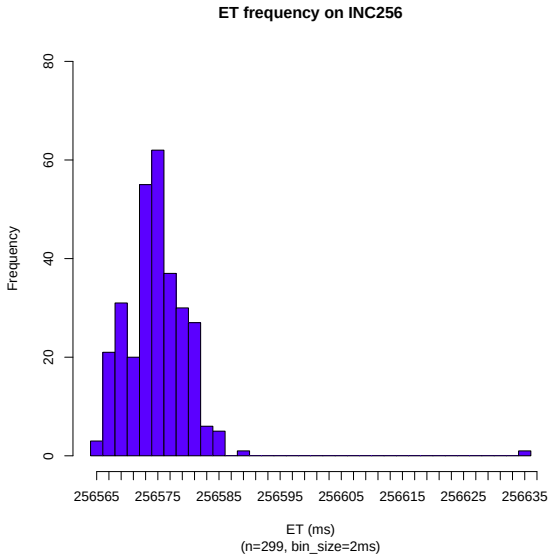


(c) ET frequency on INC64

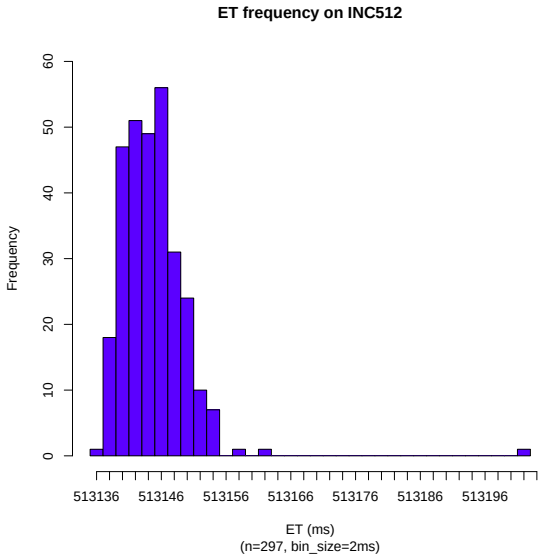
Figure 2: ET Histograms of INC16 ... INC64



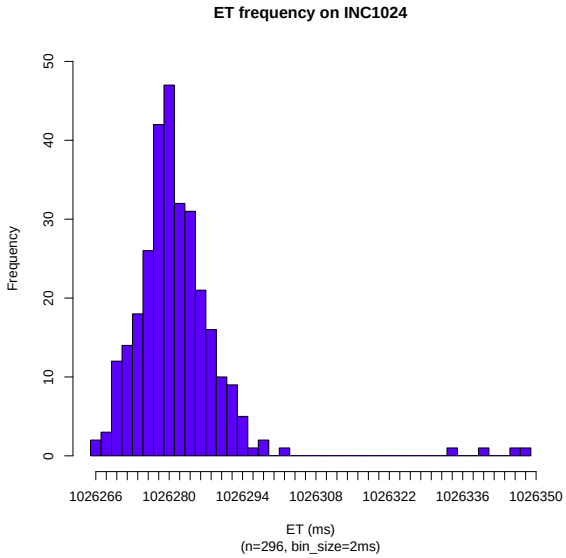
(a) ET frequency on INC128



(b) ET frequency on INC256

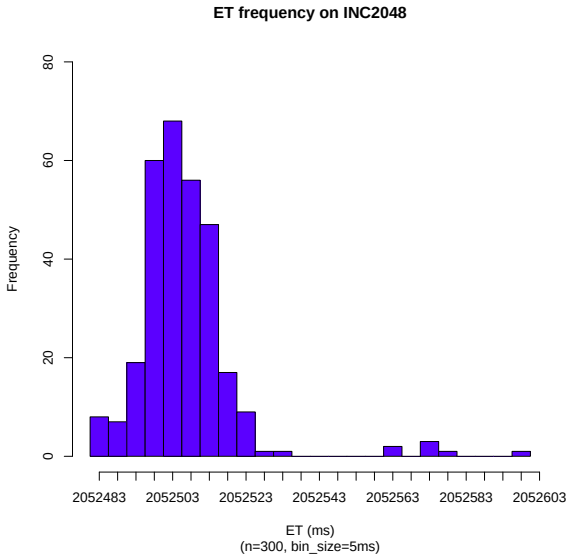


(c) ET frequency on INC512

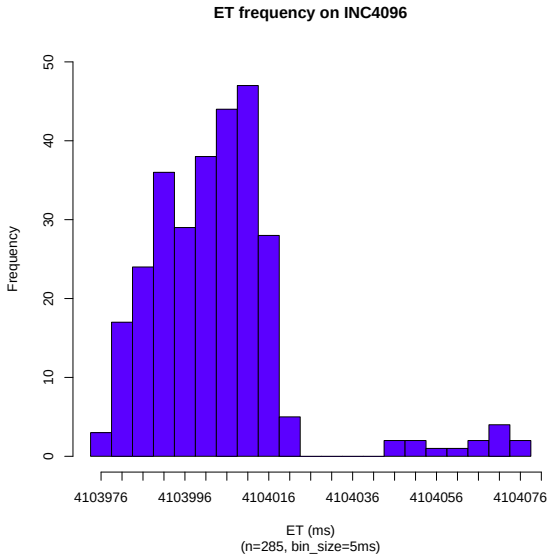


(d) ET frequency on INC1024

Figure 3: ET Histograms of INC128 ... INC1024



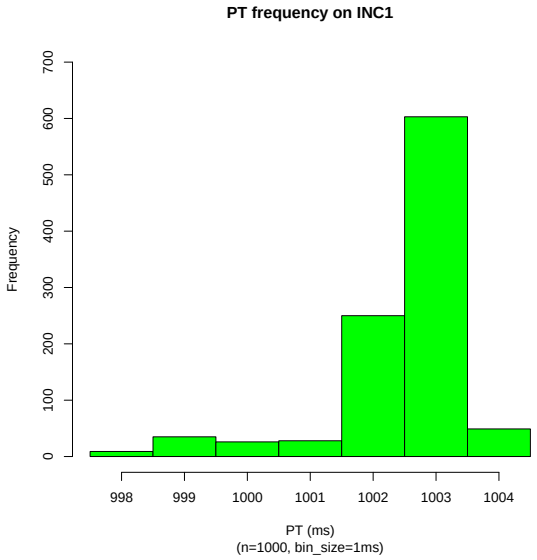
(a) ET frequency on INC2048



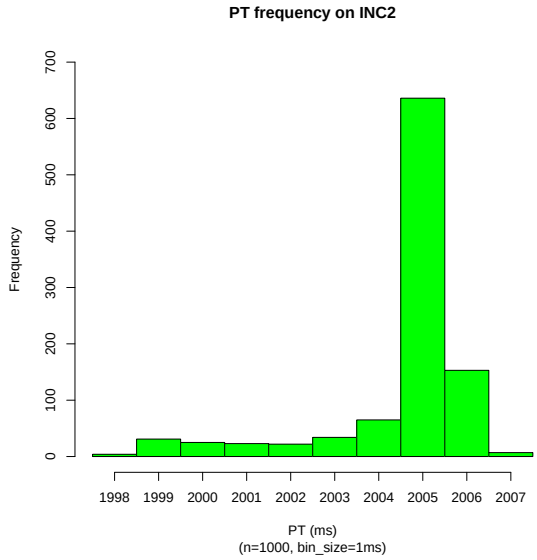
(b) ET frequency on INC4096

Figure 4: ET Histograms of INC2048 and INC4096

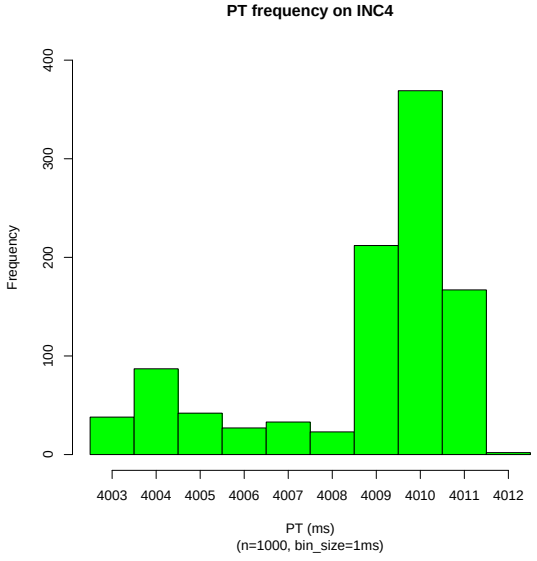
3.2 PT



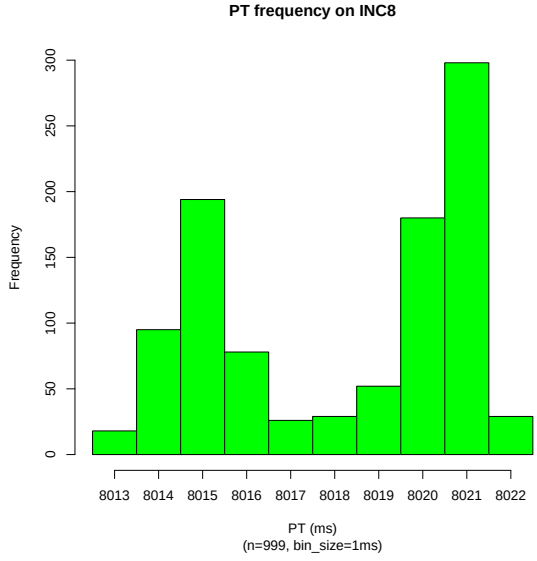
(a) PT frequency on INC1



(b) PT frequency on INC2

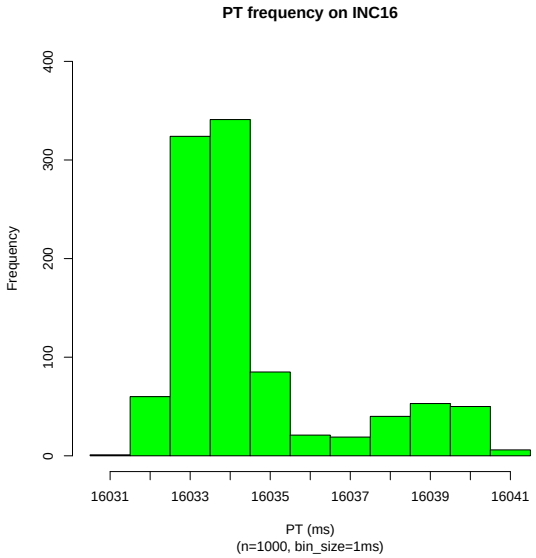


(c) PT frequency on INC4

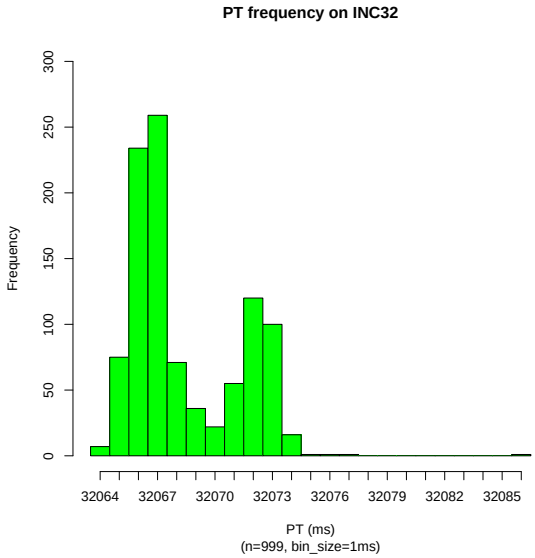


(d) PT frequency on INC8

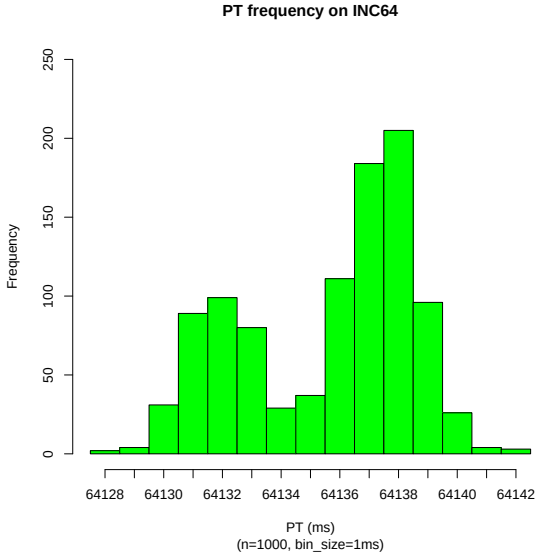
Figure 5: PT Histograms of INC1 ... INC8



(a) PT frequency on INC16

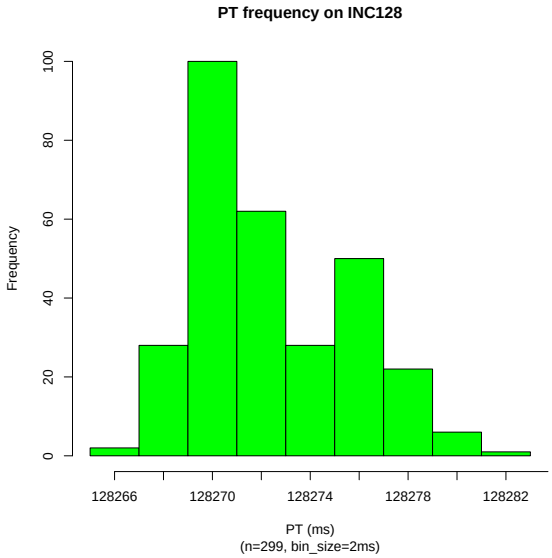


(b) PT frequency on INC32

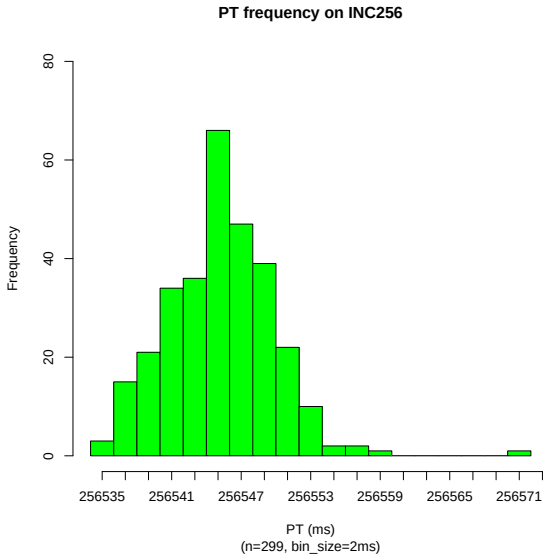


(c) PT frequency on INC64

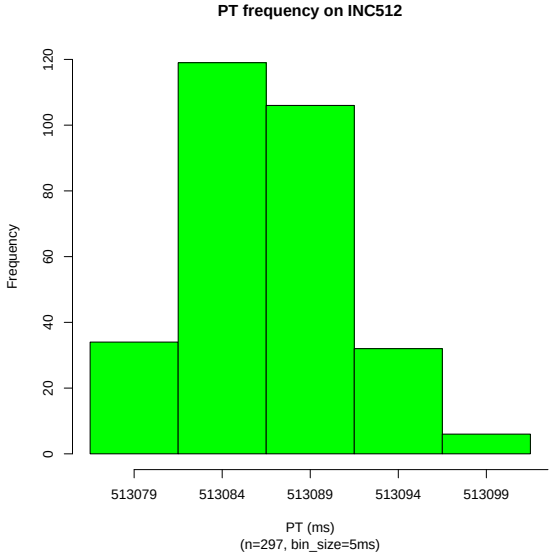
Figure 6: PT Histograms of INC16 ... INC64



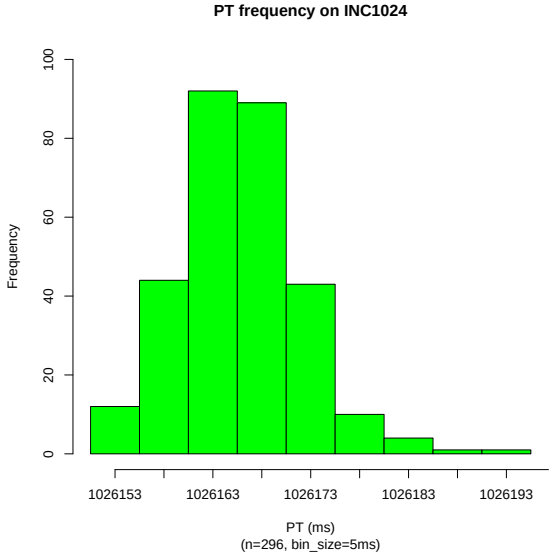
(a) PT frequency on INC128



(b) PT frequency on INC256

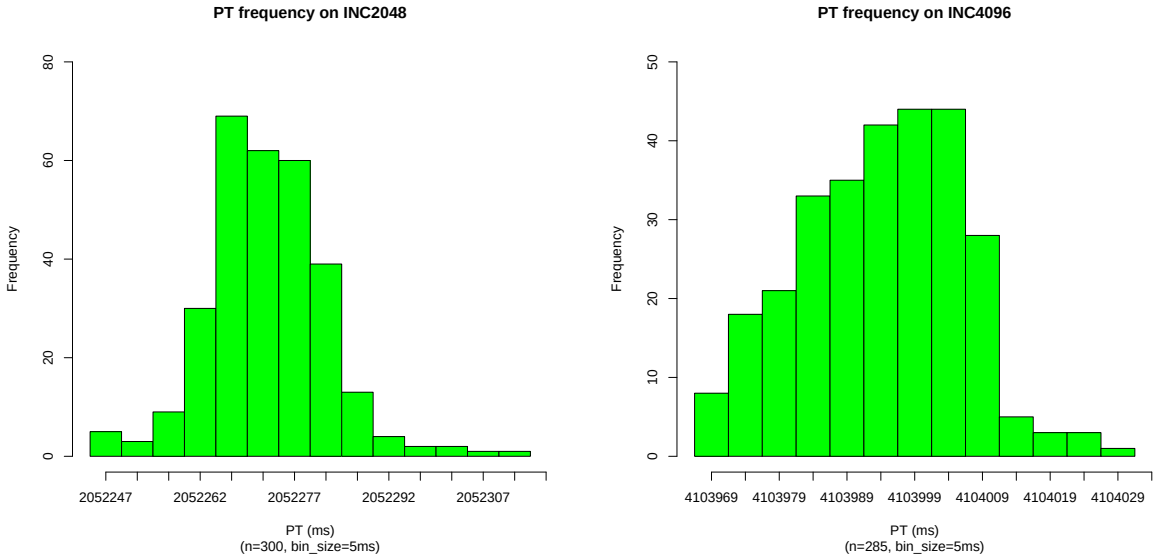


(c) PT frequency on INC512



(d) PT frequency on INC1024

Figure 7: PT Histograms of INC256 ... INC1024



(a) PT frequency on INC2048

(b) PT frequency on INC4096

Figure 8: PT Histograms of INC2048 and INC4096

4 Histograms on the Second Run

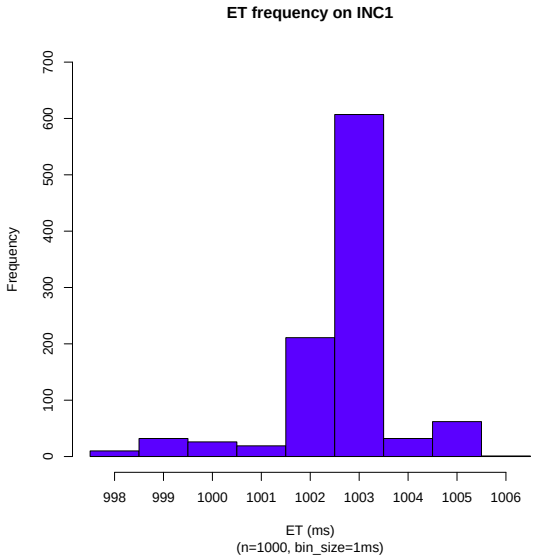
This section exhibits histograms on the second run of INC with its task length increasing from 1 second to 4096 seconds, via EMPv5 without Step 2. The detailed description of the base data is from Table 2.

Machine	Task Length (sec)	Description	Experiment Period	Relevant Histograms
`sodb9`	INC1∼INC64	1000 samples, each	2017-03-13 ∼ 2017-03-14	Figs. 9, 10, 13, and 14
`sodb9`	INC512∼INC1024	300 samples, each	2017-03-17 ∼ 2017-03-21	Figs. 11 and 15
`sodb10`	INC2048	300 samples	2017-03-13 ∼ 2017-03-20	Figs. 12(a) and 16(a)
`sodb12`	INC4096	300 samples	2017-03-02 ∼ 2017-03-17	Figs. 12(b) and 16(b)
`sodb10`	INC8192	261 samples	2017-04-27 ∼ 2017-05-21	Figs. 12(c) and 16(c)
`sodb12`	INC16384	130 samples	2017-04-27 ∼ 2017-05-21	Figs. 12(d) and 16(d)

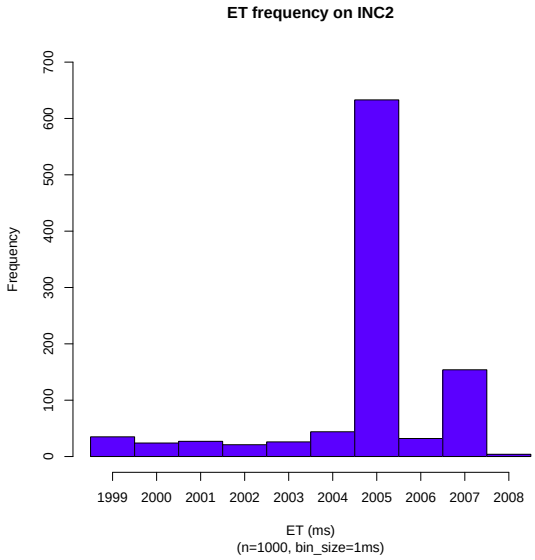
Table 2: Notes on experiment runs used for histograms

INC8192/INC16384 unfortunately stopped in the middle of their runs due to a frozen vnc problem. So couldn't finish 300 samples.

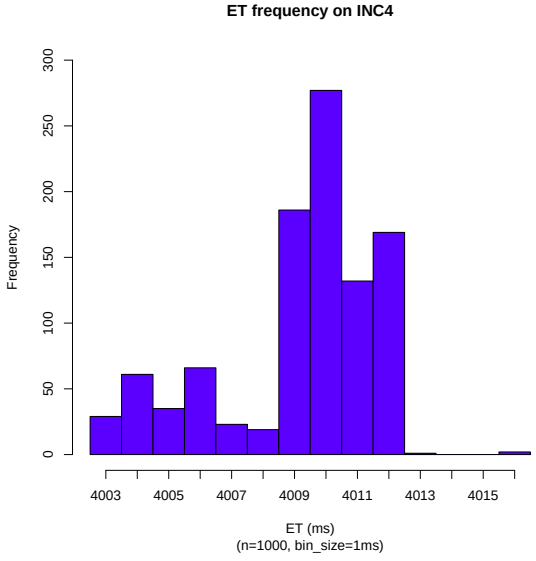
4.1 ET



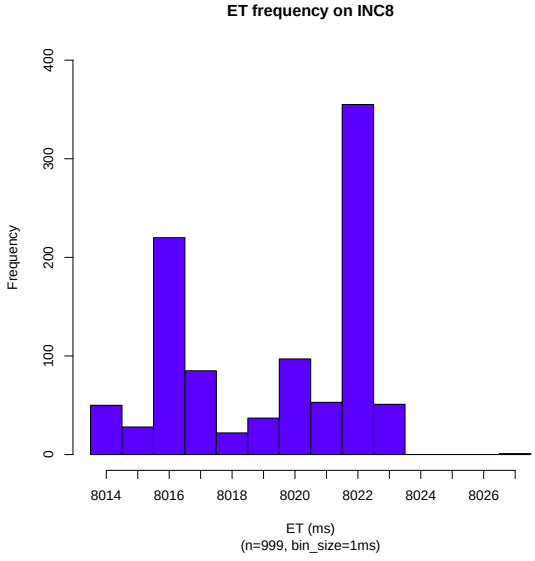
(a) ET frequency on INC1



(b) ET frequency on INC2

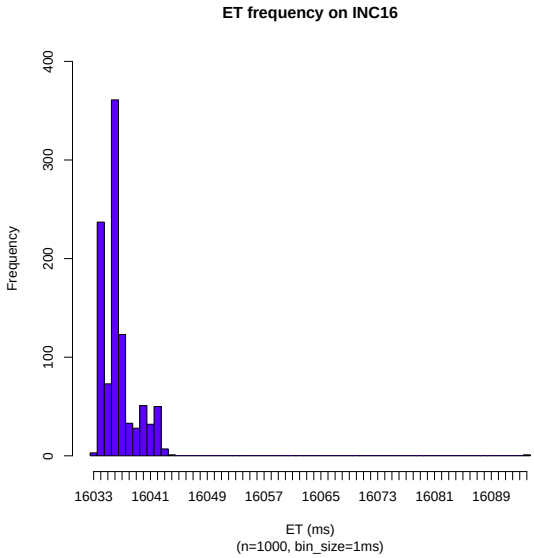


(c) ET frequency on INC4

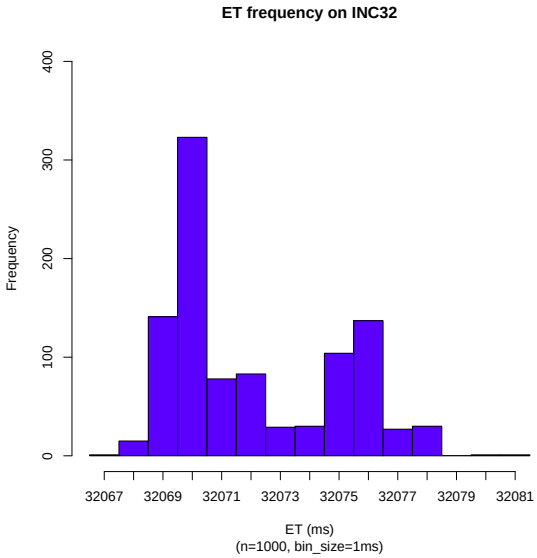


(d) ET frequency on INC8

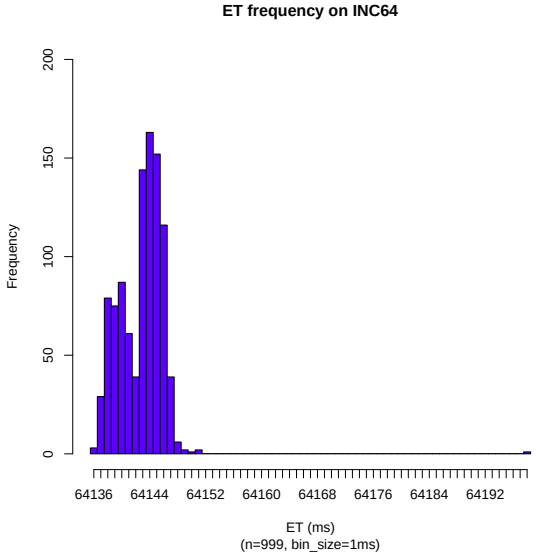
Figure 9: ET Histograms of INC1 ... INC8



(a) ET frequency on INC16

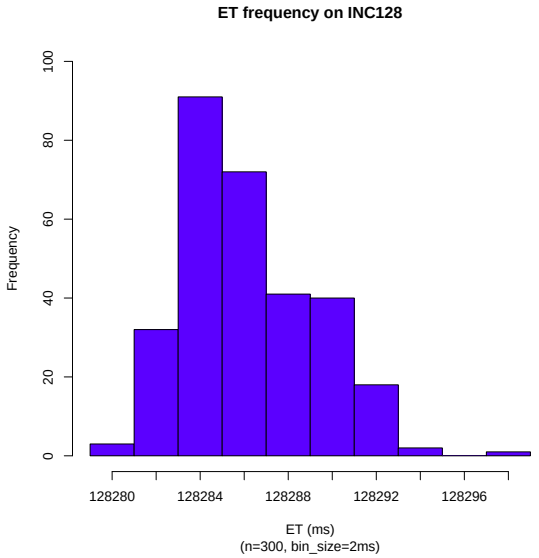


(b) ET frequency on INC32

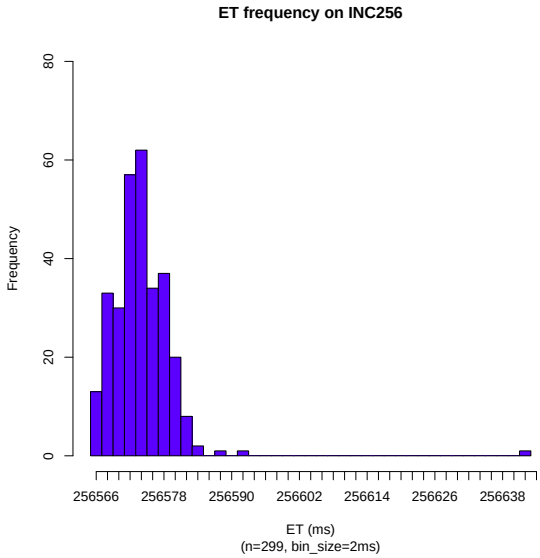


(c) ET frequency on INC64

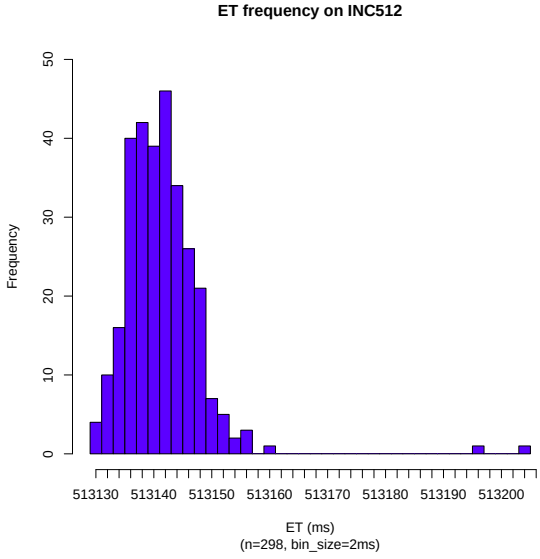
Figure 10: ET Histograms of INC16 ... INC64



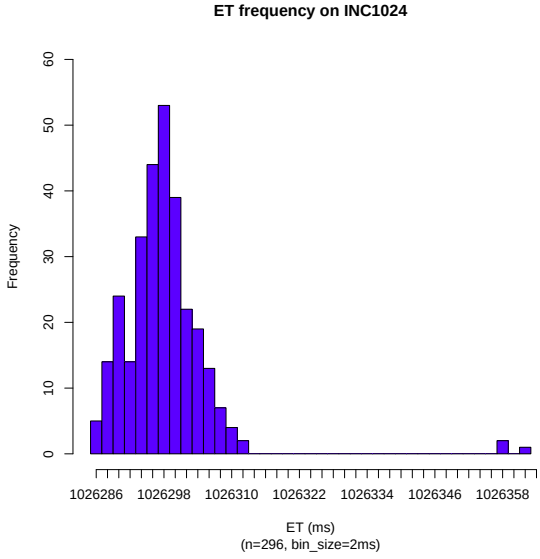
(a) ET frequency on INC128



(b) ET frequency on INC256

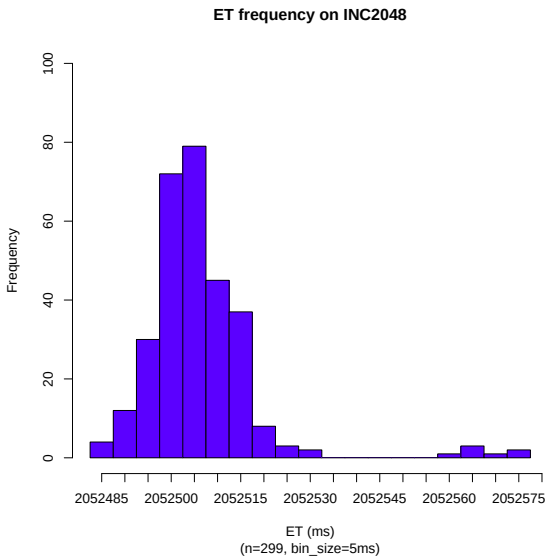


(c) ET frequency on INC512

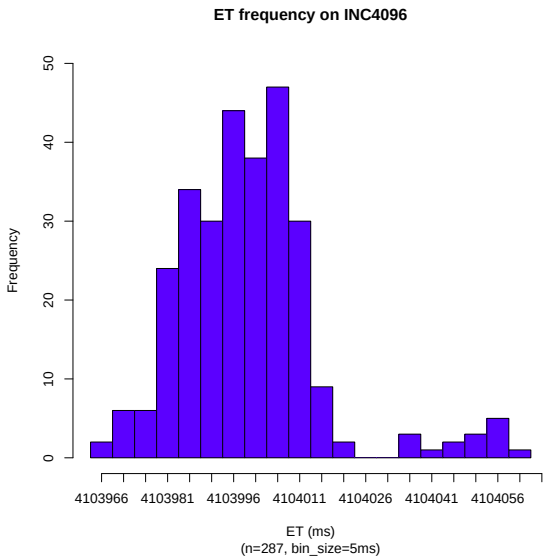


(d) ET frequency on INC1024

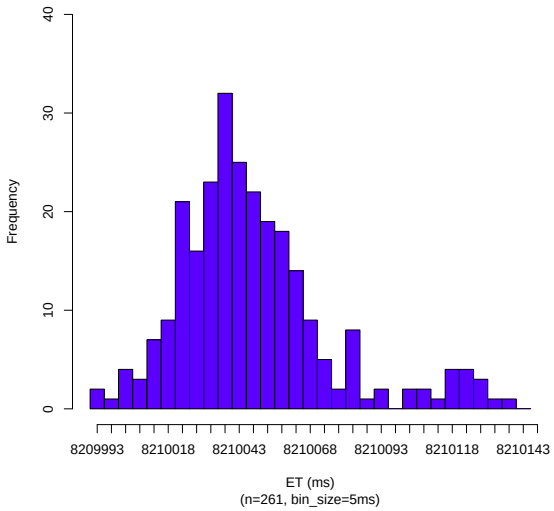
Figure 11: ET Histograms of INC128 ... INC1024



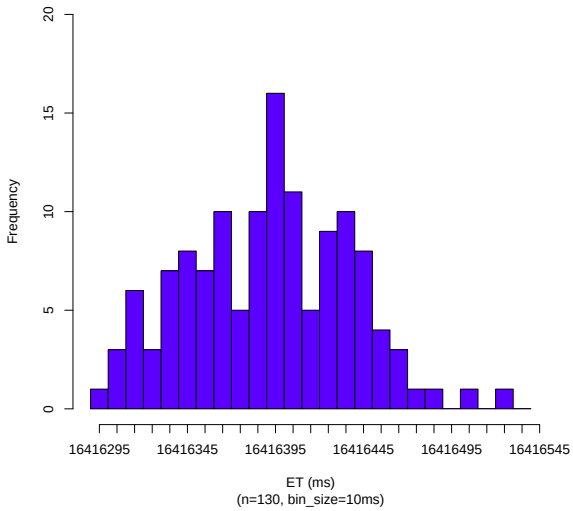
(a) ET frequency on INC2048



(b) ET frequency on INC4096



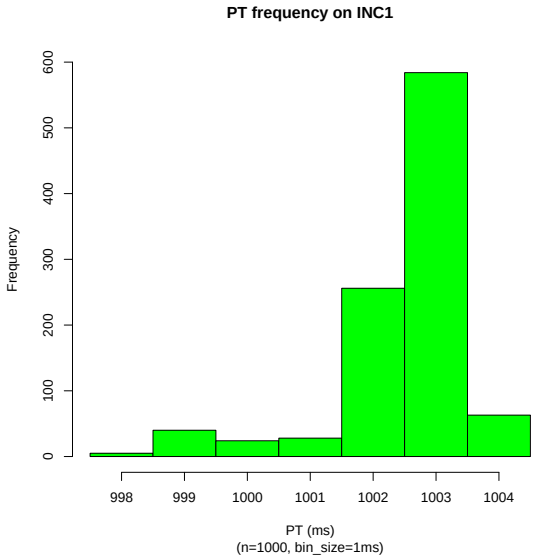
(c) ET frequency on INC8192



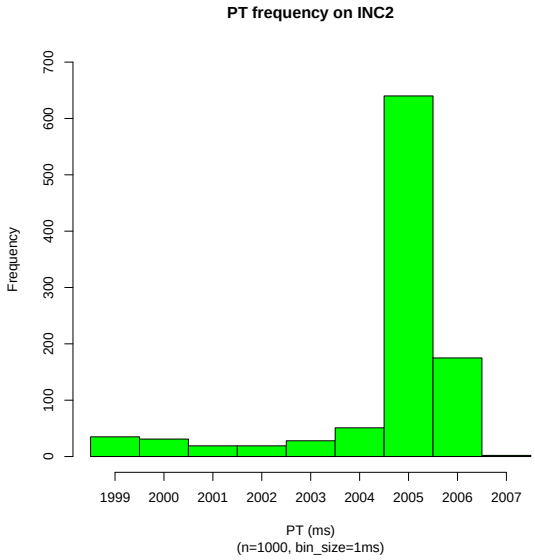
(d) ET frequency on INC16384

Figure 12: ET Histograms of INC2048 ... INC16384

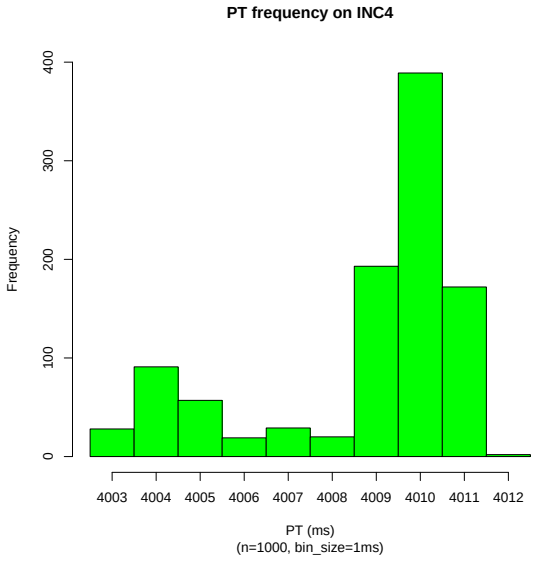
4.2 PT



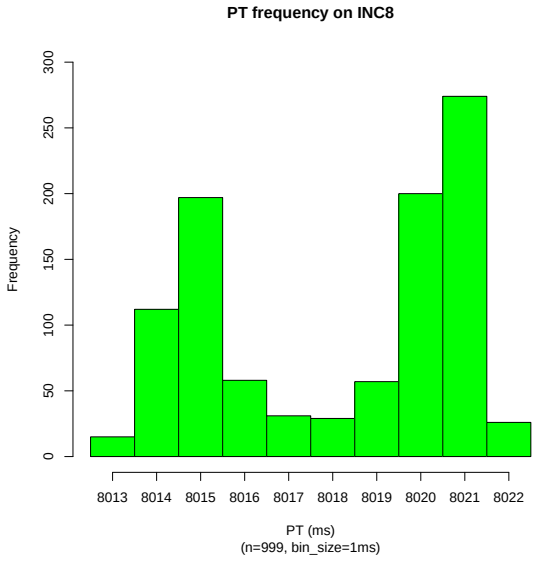
(a) PT frequency on INC1



(b) PT frequency on INC2

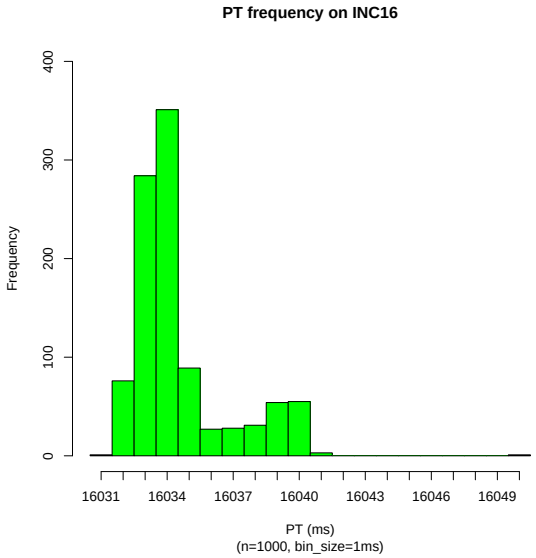


(c) PT frequency on INC4

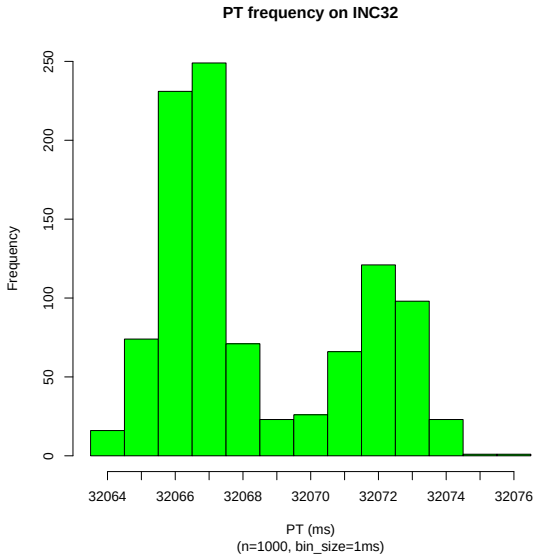


(d) PT frequency on INC8

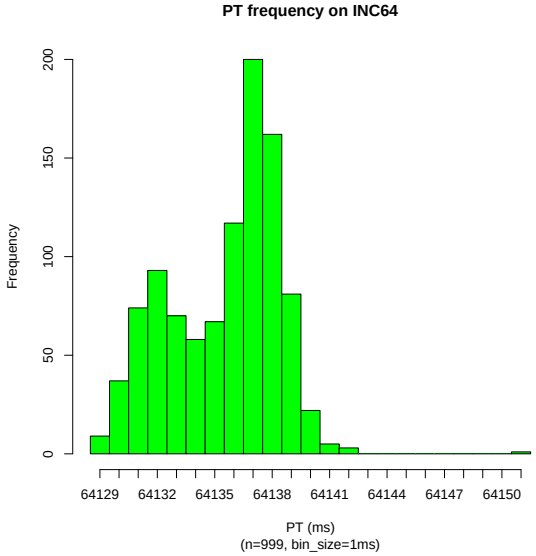
Figure 13: PT Histograms of INC1 ... INC8



(a) PT frequency on INC16

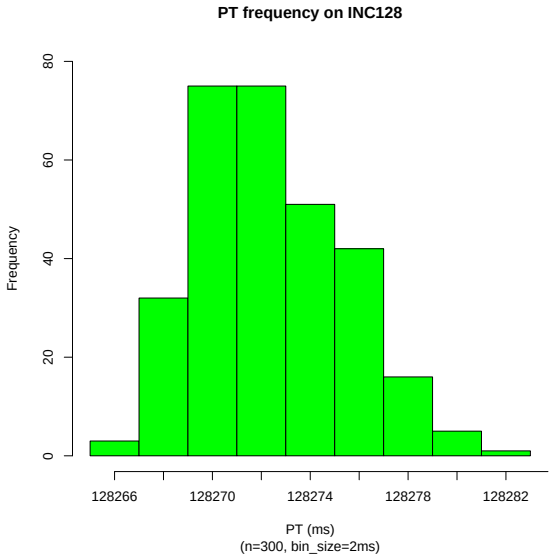


(b) PT frequency on INC32

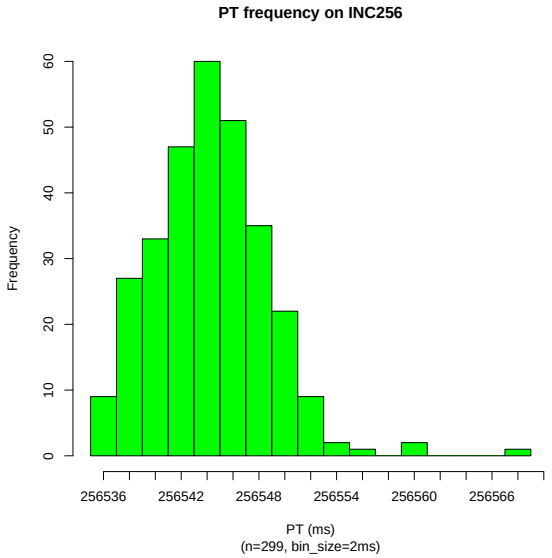


(c) PT frequency on INC64

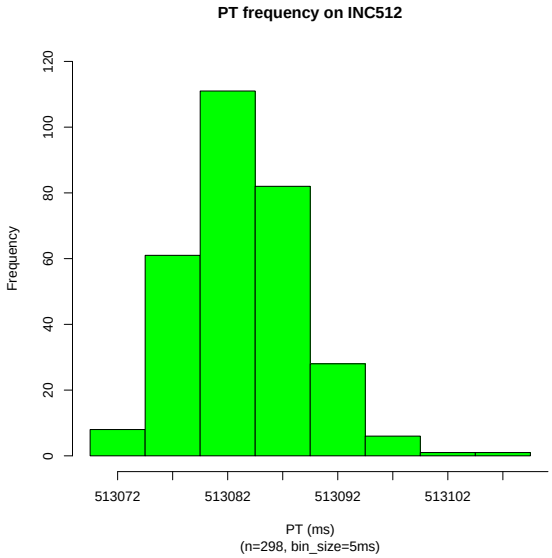
Figure 14: PT Histograms of INC16 ... INC64



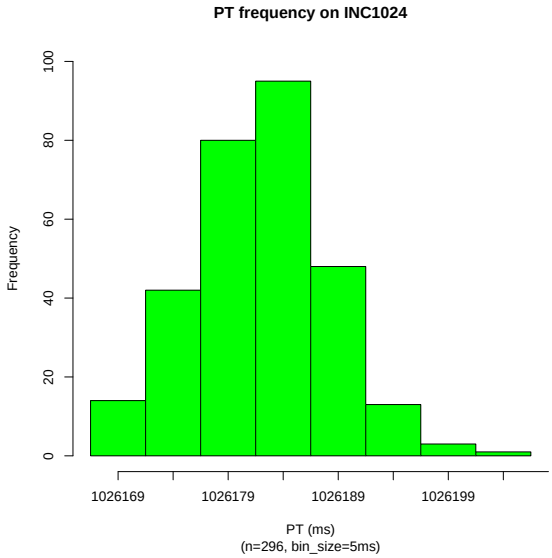
(a) PT frequency on INC128



(b) PT frequency on INC256

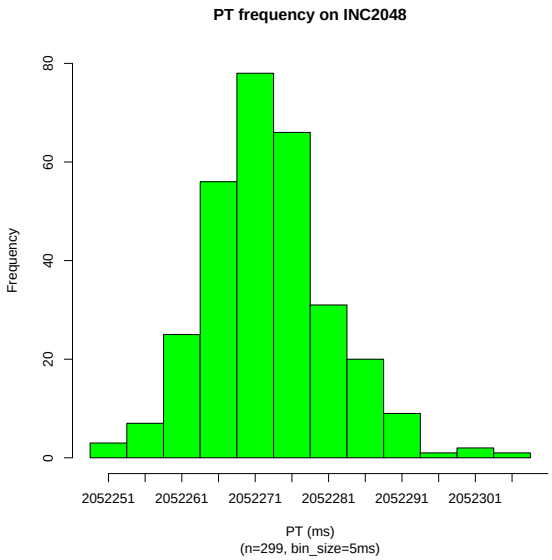


(c) PT frequency on INC512

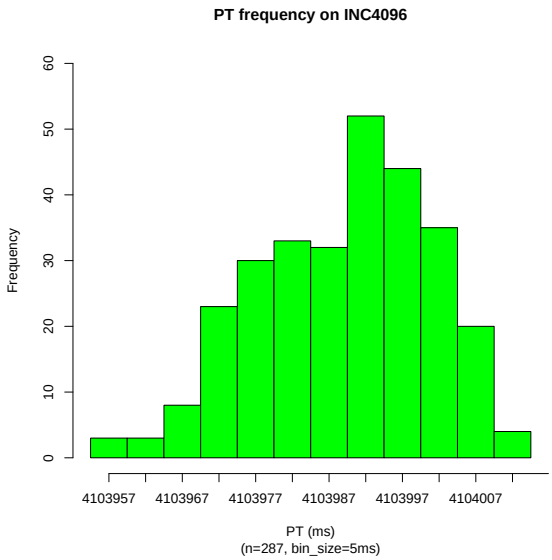


(d) PT frequency on INC1024

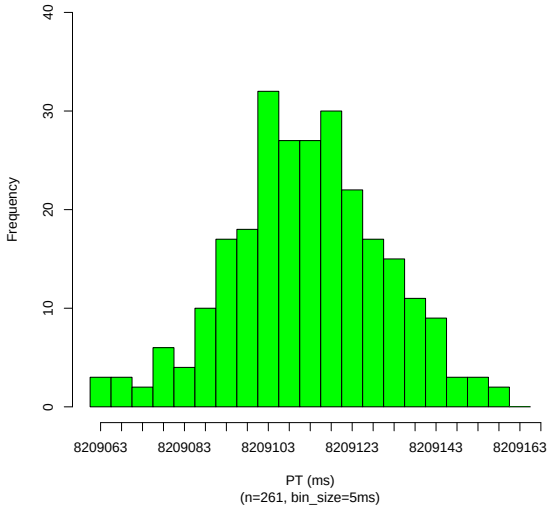
Figure 15: PT Histograms of INC256 ... INC1024



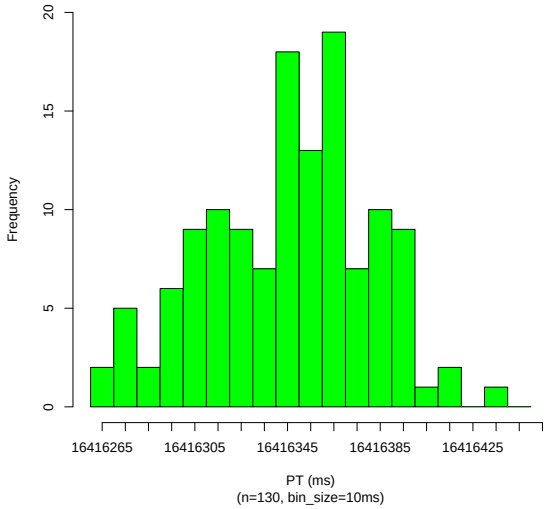
(a) PT frequency on INC2048



(b) PT frequency on INC4096



(c) PT frequency on INC8192



(d) PT frequency on INC16384

Figure 16: PT Histograms of INC2048 ... INC16384

4.2.1 Analysis

In this section we look into what happened inside the peaks observed in a certain histogram. We consider Figure 13(d) for this study. In the figure, we see the peaks at 8015 msec, 8020 msec, and 8021 msec.

Table 3 shows captured daemons and their runtime statistics per bin of figure. Note that bin is at the unit of PT. It appears that the peaks are definitely correlated with (1) appearances of some daemons and (2) times that those daemons co-ran with INC8.

TASK_LEN	BIN (PT)	DAEMON	MIN_PT	MAX_PT	AVG_PT	STD_PT	Counts
INC8	8013	jbd2/md0-8	1	1	1	0	1
INC8	8013	kslowd000	1	1	1	0	1
INC8	8013	md0_raid1	1	1	1	0	17
INC8	8013	proc_monitor	196	200	197.72	1.07	18
INC8	8014	jbd2/md0-8	1	1	1	0	5
INC8	8014	kslowd000	1	1	1	0	35
INC8	8014	kslowd001	1	1	1	0	26
INC8	8014	md0_raid1	1	1	1	0	58
INC8	8014	proc_monitor	196	200	197.31	1.06	95
INC8	**8015**	java	2	7	4.5	3.54	2
INC8	**8015**	jbd2/md0-8	1	1	1	0	2
INC8	**8015**	kslowd000	1	1	1	0	86
INC8	**8015**	kslowd001	1	1	1	0	89
INC8	**8015**	md0_raid1	1	1	1	0	18
INC8	**8015**	proc_monitor	196	200	197.28	1.01	194
INC8	8016	kslowd000	1	1	1	0	36
INC8	8016	kslowd001	1	1	1	0	40
INC8	8016	md0_raid1	1	1	1	0	8
INC8	8016	proc_monitor	196	200	196.45	.95	78
INC8	8017	kslowd000	1	1	1	0	11
INC8	8017	kslowd001	1	1	1	0	10
INC8	8017	md0_raid1	1	1	1	0	3
INC8	8017	proc_monitor	196	200	197.15	1.16	26
INC8	8018	kslowd000	1	1	1	0	13
INC8	8018	kslowd001	1	1	1	0	9
INC8	8018	md0_raid1	1	1	1	0	6
INC8	8018	proc_monitor	196	200	197.24	1.27	29
INC8	8019	jbd2/md0-8	1	1	1	0	3
INC8	8019	kslowd000	1	1	1	0	9
INC8	8019	kslowd001	1	2	1.06	.24	18
INC8	8019	md0_raid1	1	1	1	0	27
INC8	8019	proc_monitor	196	200	197.1	1.18	52
INC8	**8020**	jbd2/md0-8	1	1	1	0	8
INC8	**8020**	kslowd000	1	1	1	0	52
INC8	**8020**	kslowd001	1	1	1	0	57
INC8	**8020**	md0_raid1	1	1	1	0	91
INC8	**8020**	proc_monitor	196	200	197.03	1.02	180
INC8	**8021**	cifsd	1	1	1	0	1
INC8	**8021**	java	2	37	19.5	24.75	2
INC8	**8021**	kslowd000	1	1	1	0	146
INC8	**8021**	kslowd001	1	1	1	0	143
INC8	**8021**	md0_raid1	1	1	1	0	11
INC8	**8021**	proc_monitor	196	198	197.15	.98	299
INC8	8022	kslowd000	1	1	1	0	20
INC8	8022	kslowd001	1	1	1	0	9
INC8	8022	proc_monitor	196	198	196.07	.37	29

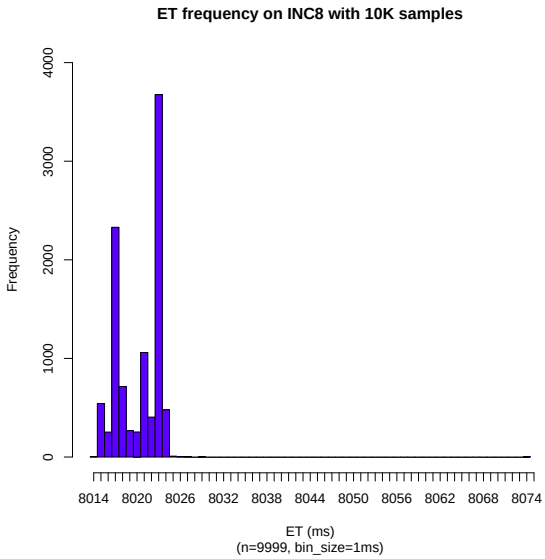
Table 3: Daemons observed from the INC8 run

5 Histograms with 10,000 samples

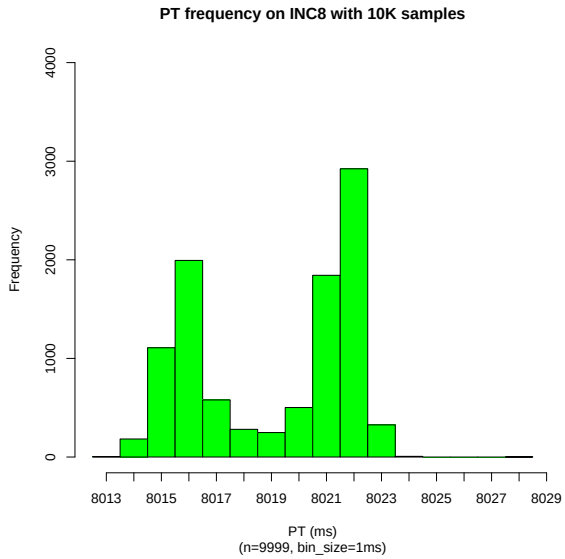
This section exhibits histograms on two runs of INC, each with 8 and 16 seconds as its task length, having 10,000 repetitions. The detailed description of the base data is from Table 4.

Machine	Task Length (sec)	Description	Experiment Period	Relevant Histograms
`sodb9`	INC8	10000 samples	2017-03-29 $\sim$ 2017-03-30	Figs. 17(a) and 17(b)
`sodb10`	INC16	10000 samples	2017-03-29 $\sim$ 2017-03-31	Figs. 17(c) and 17(d)

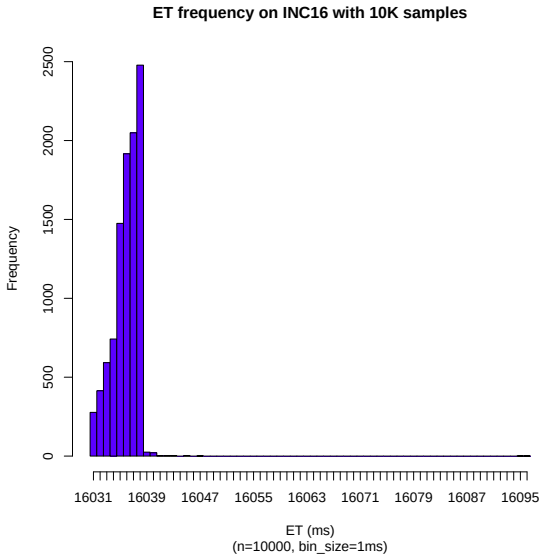
Table 4: Notes on experiment runs used for histograms



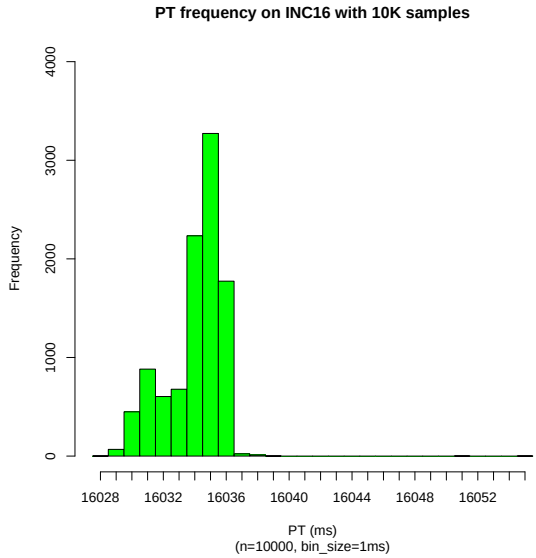
(a) ET frequency on INC8



(b) PT frequency on INC8



(c) ET frequency on INC16



(d) PT frequency on INC16

Figure 17: Histograms of INC8 and INC16 with 10,000 samples

6 Further Investigation of the First Run and Some Additional Runs

This section exhibits user and system time histograms on the second run of INC with its task length increasing from 1 second to 4096 seconds via EMPv5 with no Step 2. The detailed description of the base data is from Table 1, and for some additional data, the corresponding description is given in Table 5.

Machine	Task Length (sec)	Description	Experiment Period	Relevant Histograms
`sodb9`	INC96∼INC256	1000 samples, each	2017-05-24 ∼ 2017-06-06	Figs. 26, 29(d), and 30(a)
	INC3, 6, 12, 24, 48, 72, 80, 88, 104, 112, and 120	1000 samples, each	2017-06-07 ∼ 2017-06-16	Figs. 24(c), 25(a), 25(c), 26(a), 26(c), 27(a), 27(b), 27(c), 28(a), 28(b), and 28(d)

Table 5: Notes on experiment runs used for histograms

6.1 Summary of Histograms

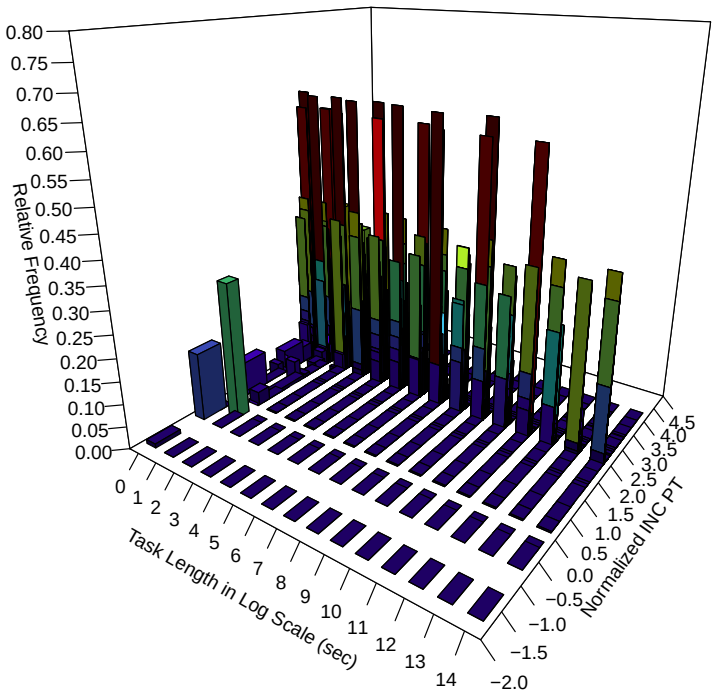
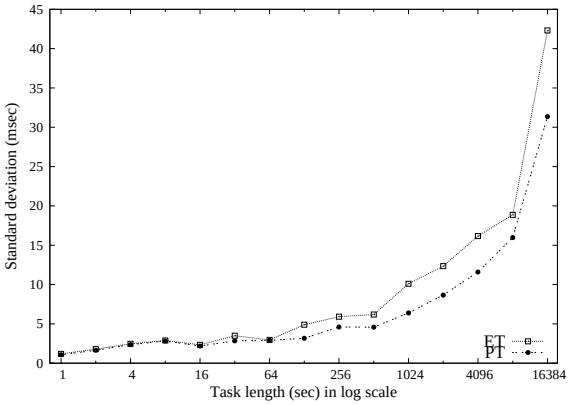
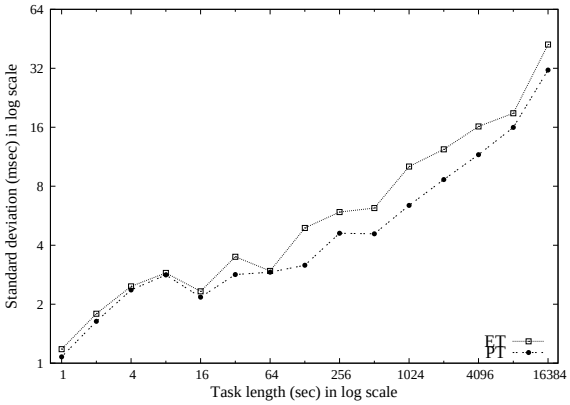


Figure 18: 3D histograms on INC

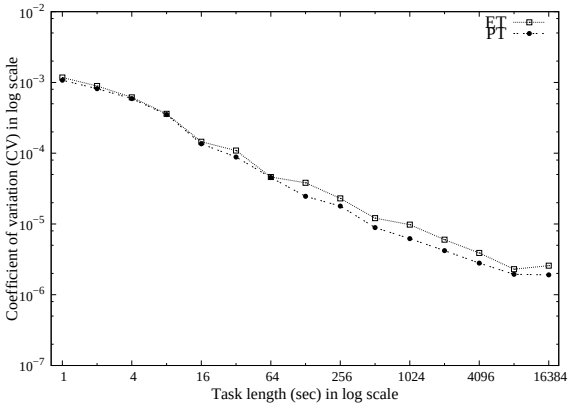
6.2 Absolute and Relative Variance over Increasing Task Length



(a) Standard deviation (absolute)



(b) Standard deviation (absolute) in log scale



(c) Coefficient of variation in log scale (relative)

Figure 19: Absolute and relative variances

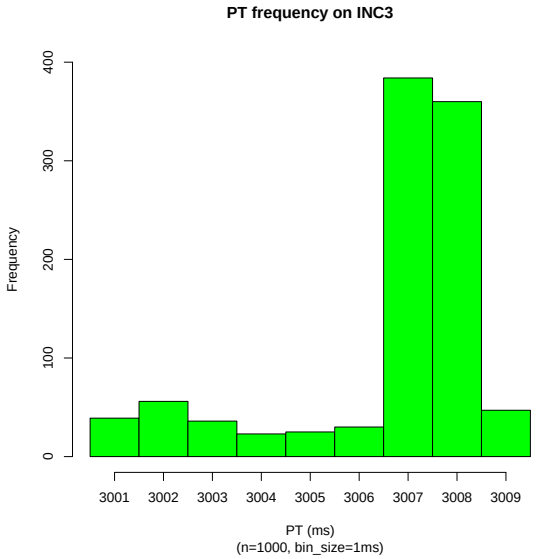
6.3 Additional Histograms

6.3.1 ET

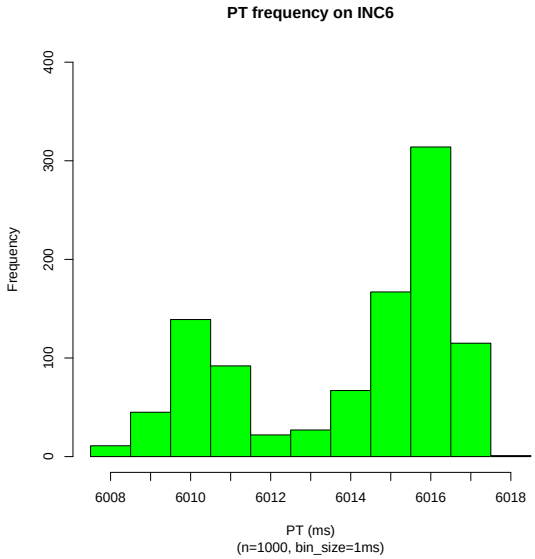
Not available at this point, due to the labshelf server's unavailability for the time being.

6.3.2 PT

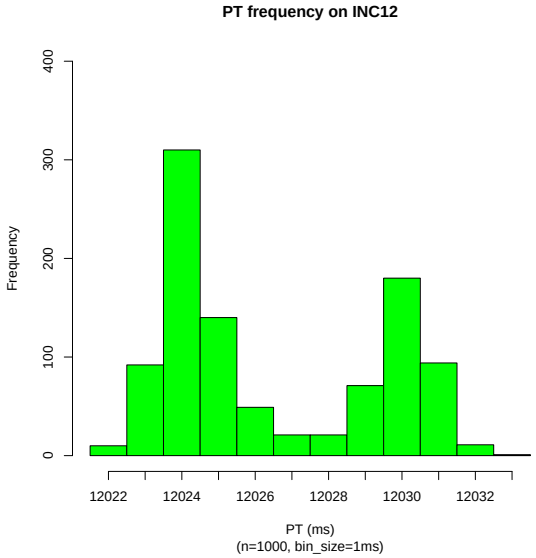
The histograms of INC1 through INC4096 are the same as those of Figures 5, 6, 7, and 8. The following are the histograms of INC with some intermediate task lengths.



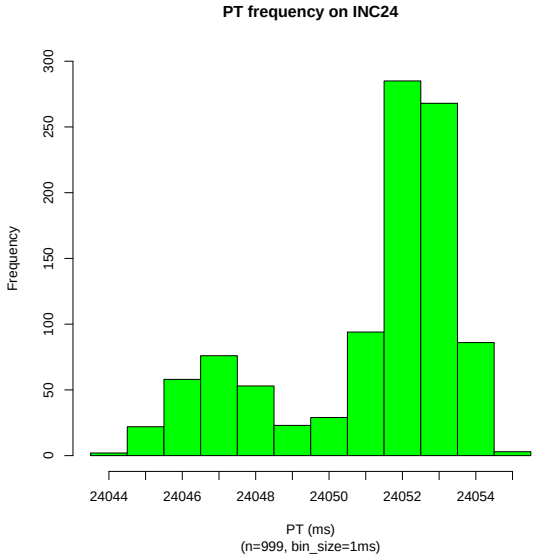
(a) PT frequency on INC3



(b) PT frequency on INC6

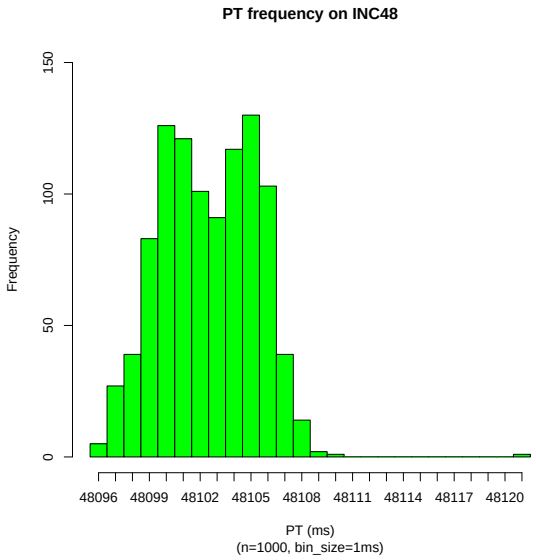


(c) PT frequency on INC12

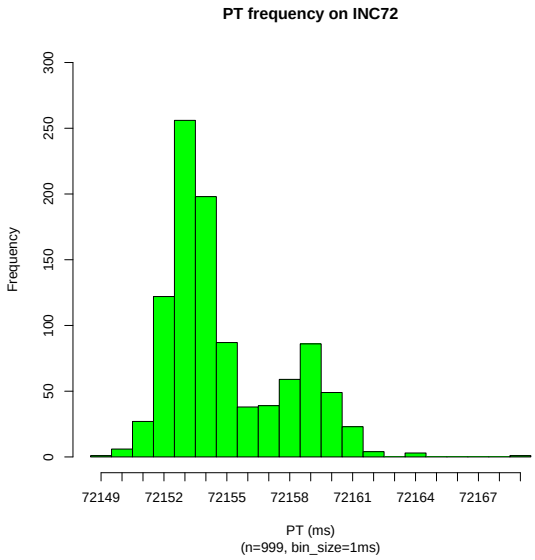


(d) PT frequency on INC24

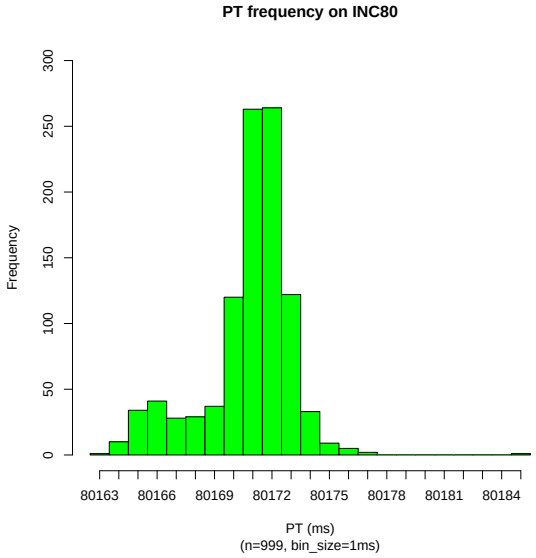
Figure 20: PT Histograms of INC3 ... INC24



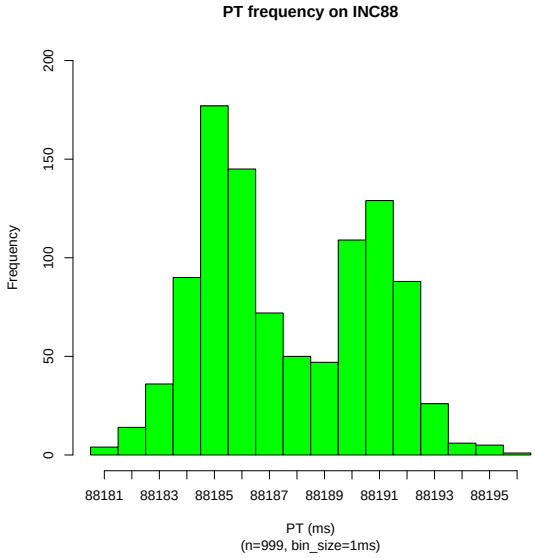
(a) PT frequency on INC48



(b) PT frequency on INC72

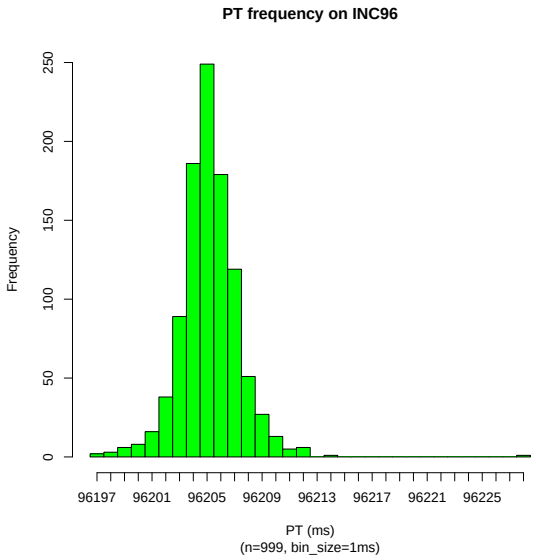


(c) PT frequency on INC80

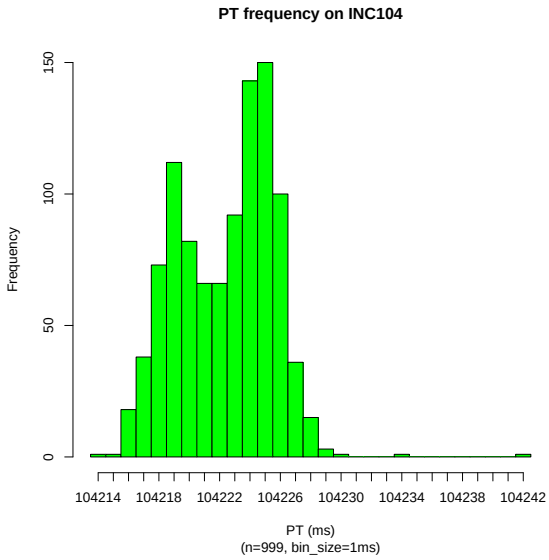


(d) PT frequency on INC88

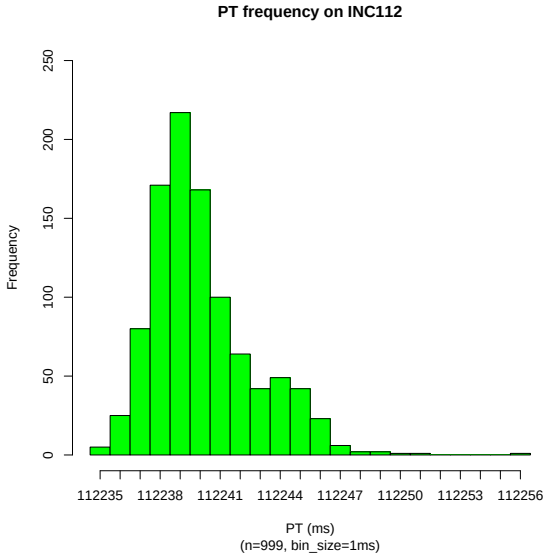
Figure 21: PT Histograms of INC48 ... INC88



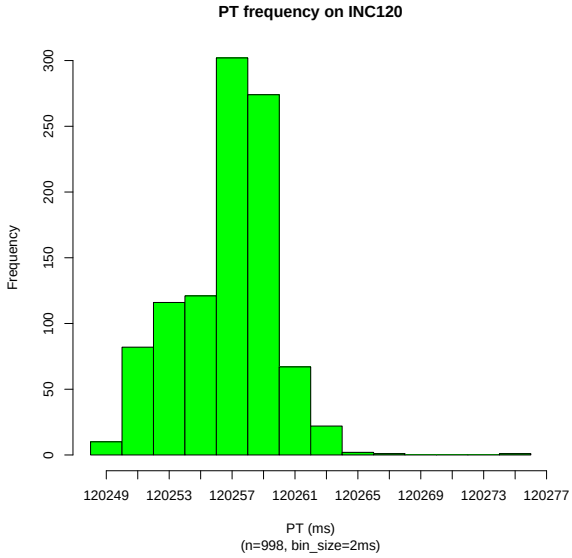
(a) PT frequency on INC96



(b) PT frequency on INC104

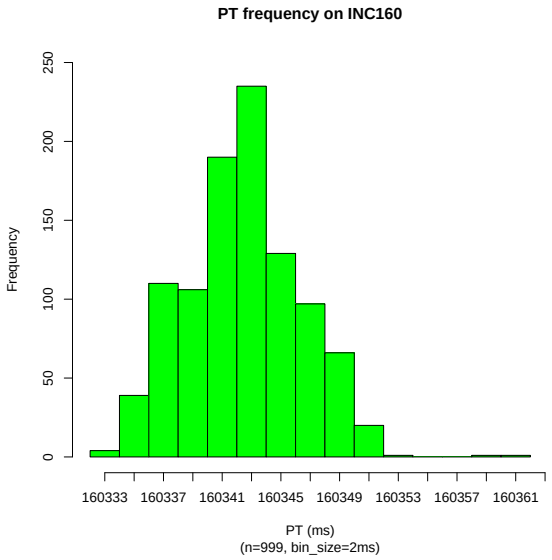


(c) PT frequency on INC112

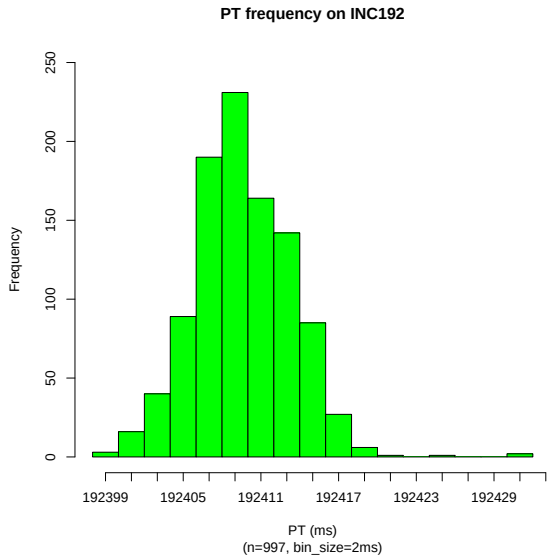


(d) PT frequency on INC120

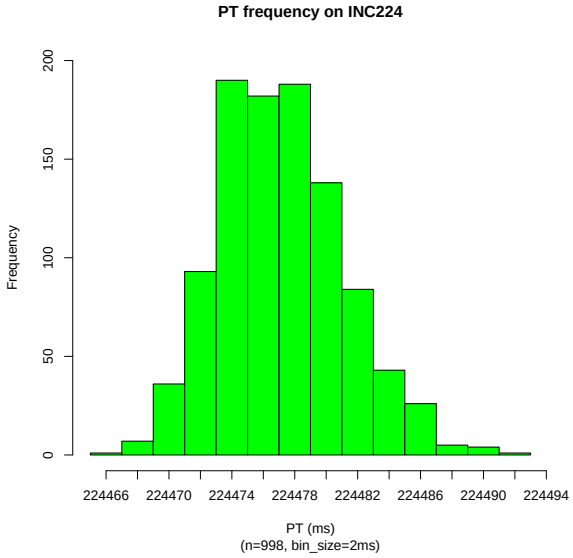
Figure 22: PT Histograms of INC96 ... INC120



(a) PT frequency on INC160



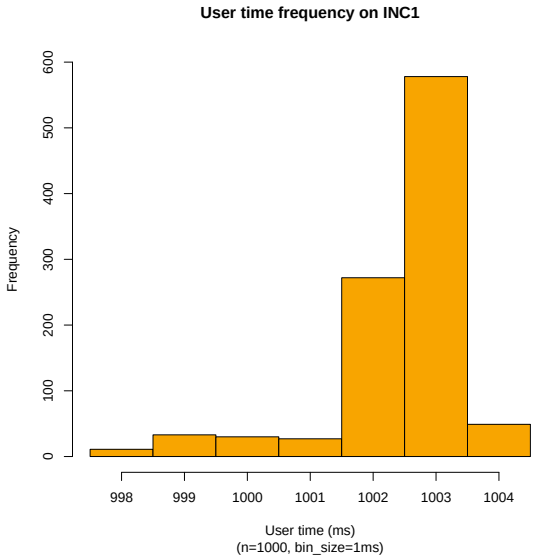
(b) PT frequency on INC192



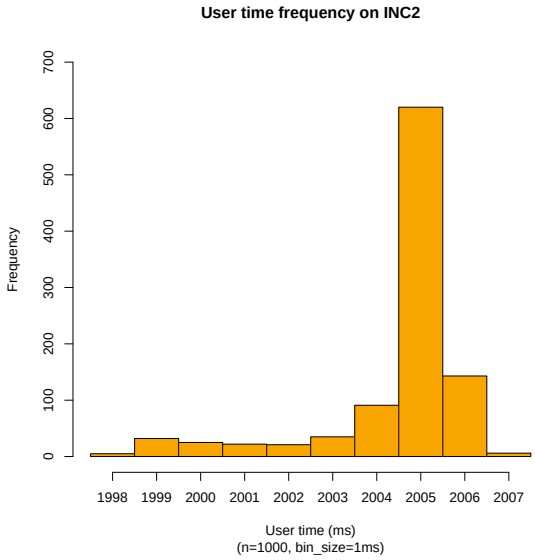
(c) PT frequency on INC224

Figure 23: PT Histograms of INC169 ... INC224

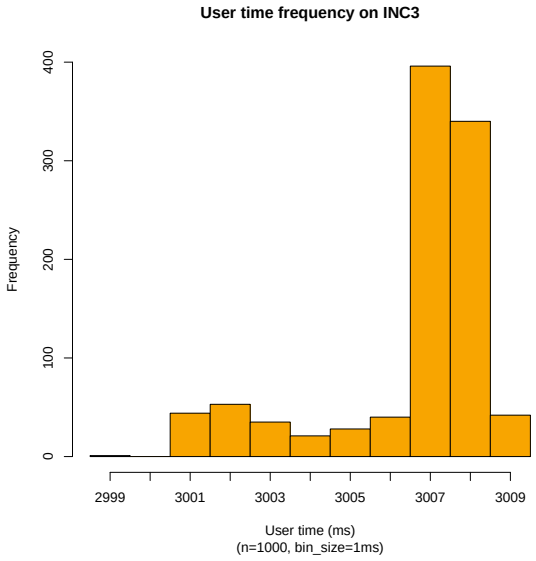
6.4 User Time



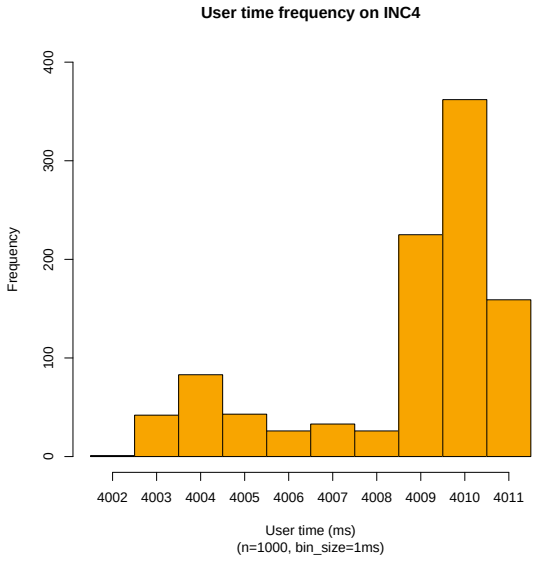
(a) User time frequency on INC1



(b) User time frequency on INC2

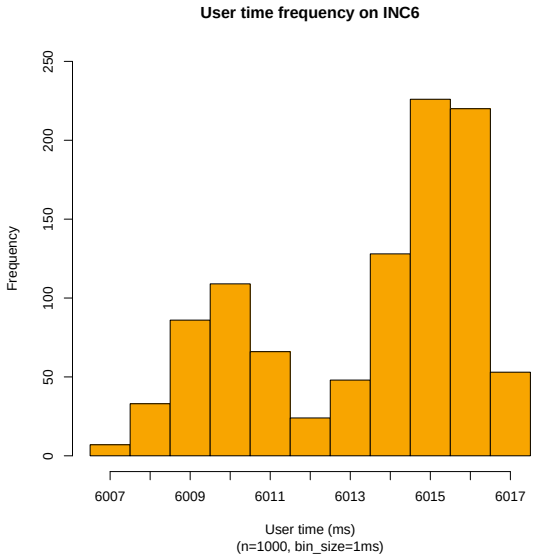


(c) User time frequency on INC3

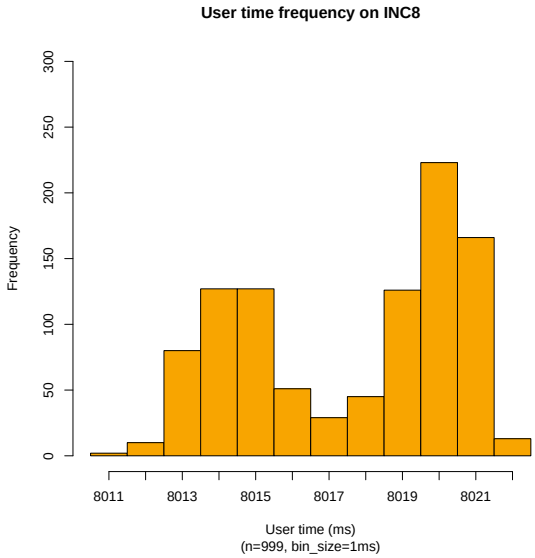


(d) User time frequency on INC4

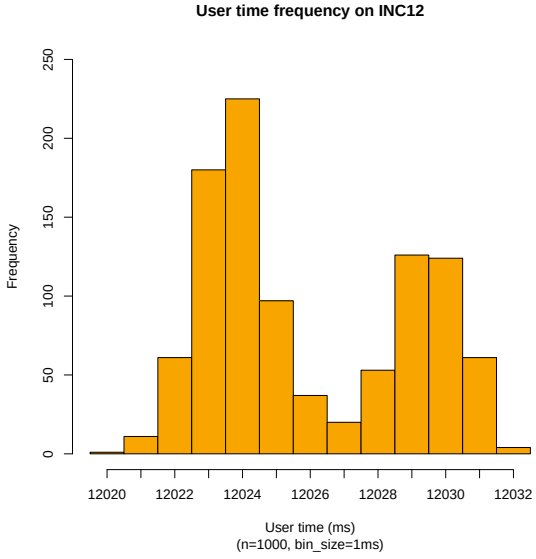
Figure 24: User Time Histograms of INC1 ... INC4



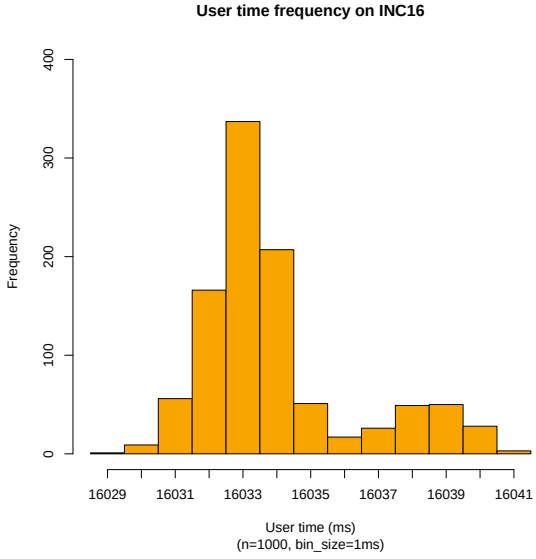
(a) User time frequency on INC6



(b) User time frequency on INC8

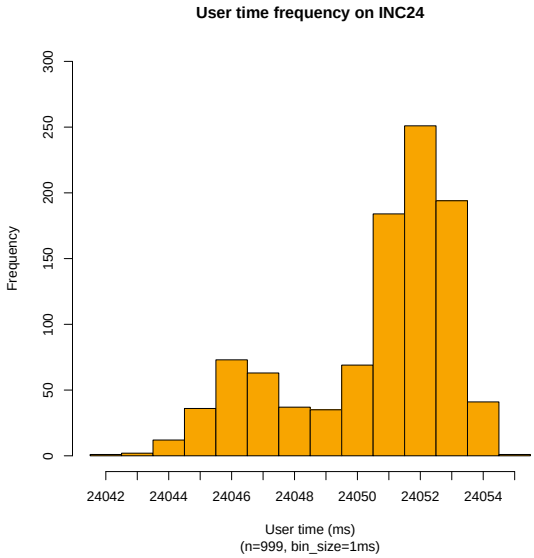


(c) User time frequency on INC12

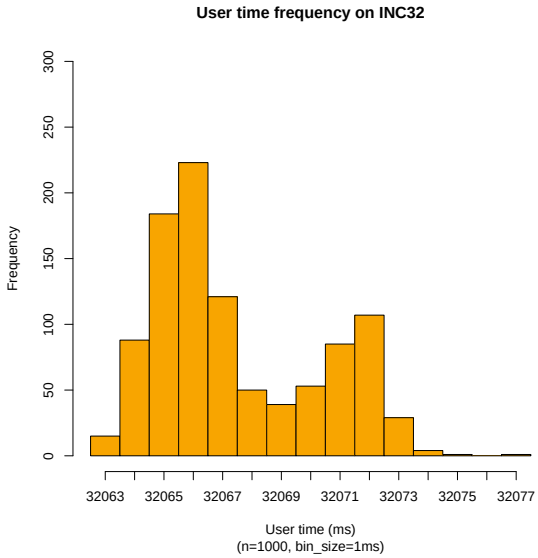


(d) User time frequency on INC16

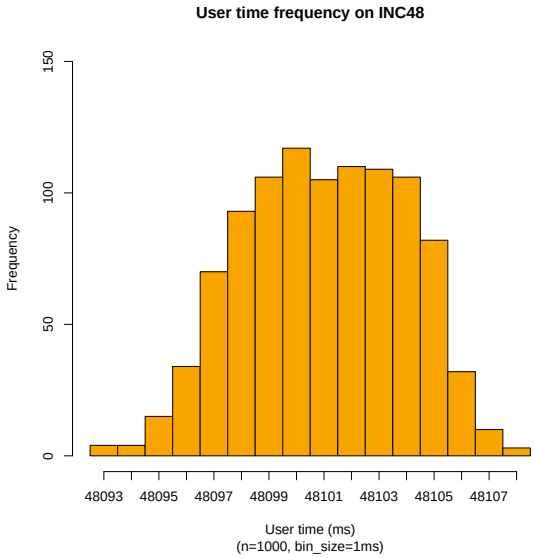
Figure 25: User Time Histograms of INC6 ... INC16



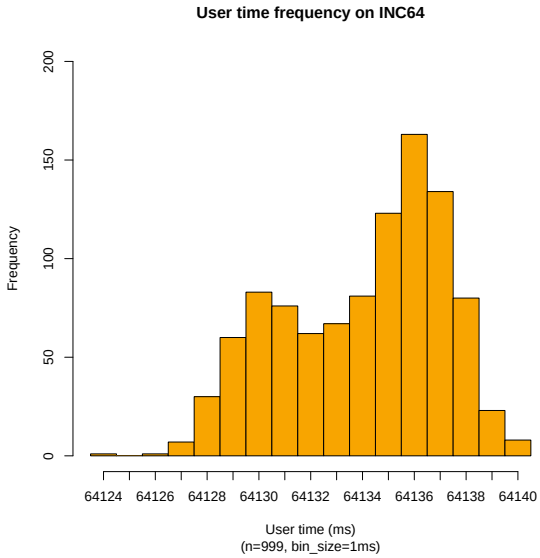
(a) User time frequency on INC24



(b) User time frequency on INC32

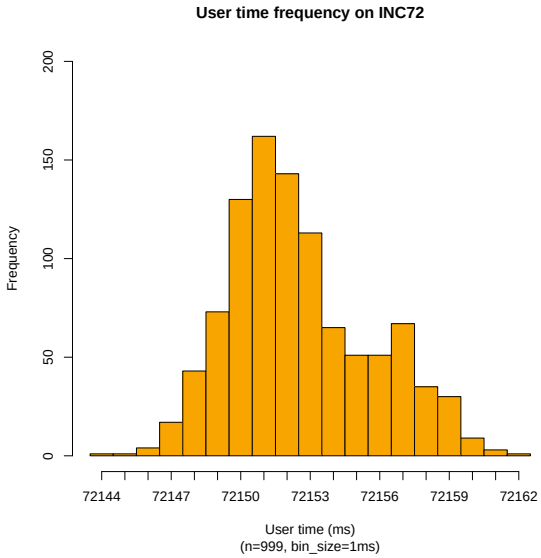


(c) User time frequency on INC48

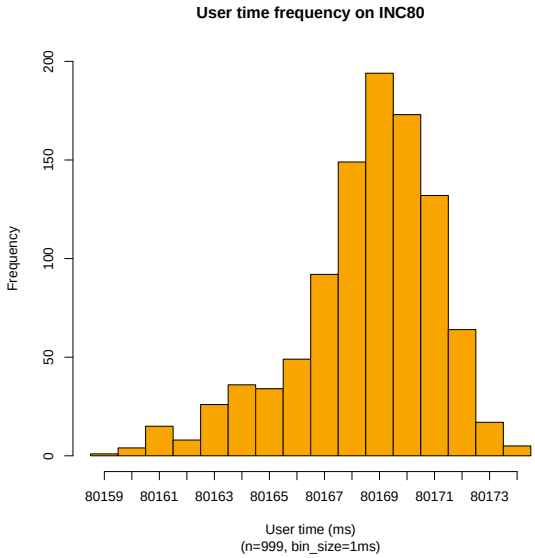


(d) User time frequency on INC64

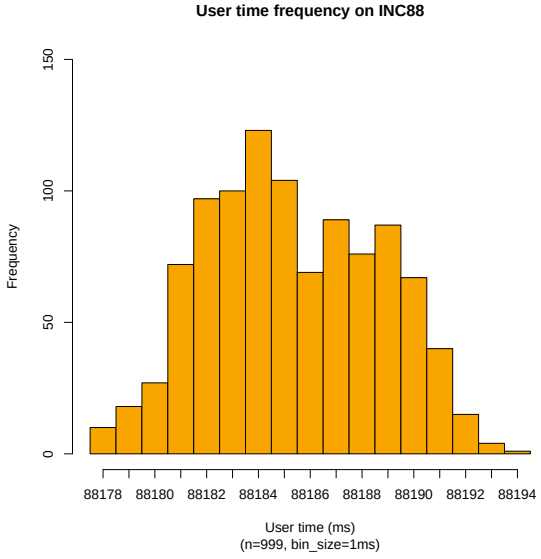
Figure 26: User Time Histograms of INC24 ... INC64



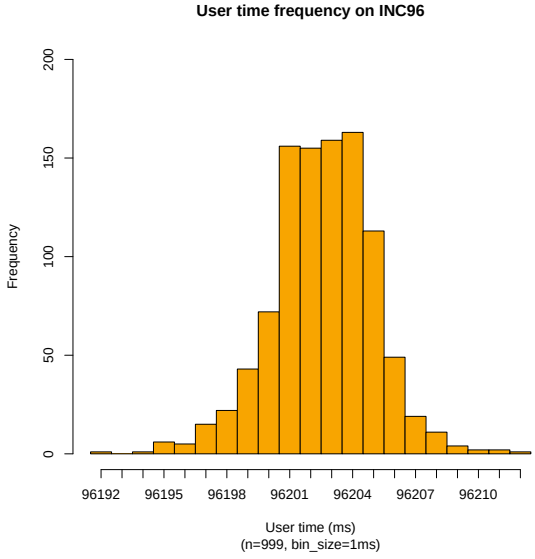
(a) User time frequency on INC72



(b) User time frequency on INC80

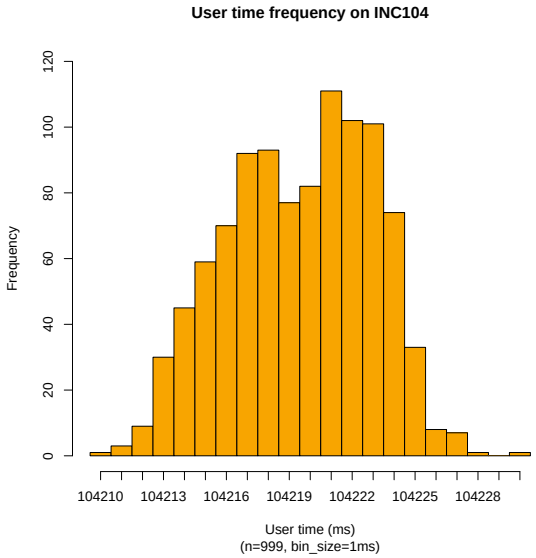


(c) User time frequency on INC88

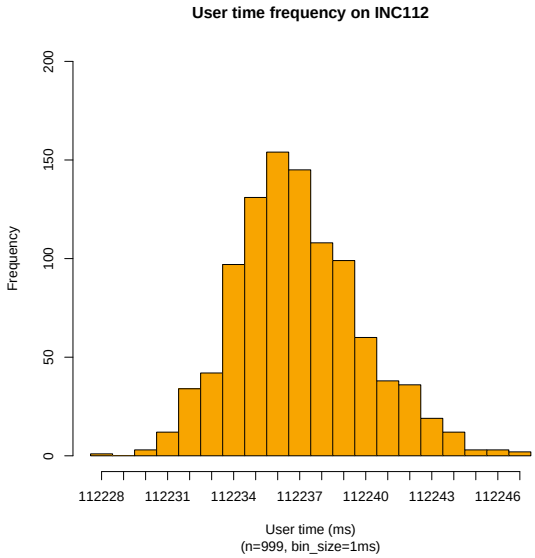


(d) User time frequency on INC96

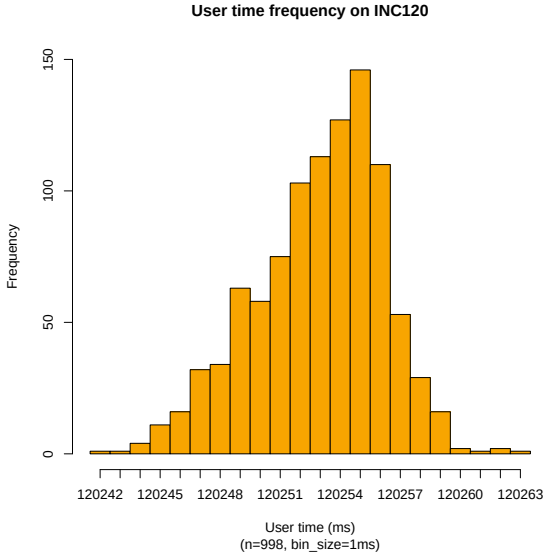
Figure 27: User Time Histograms of INC72 ... INC96



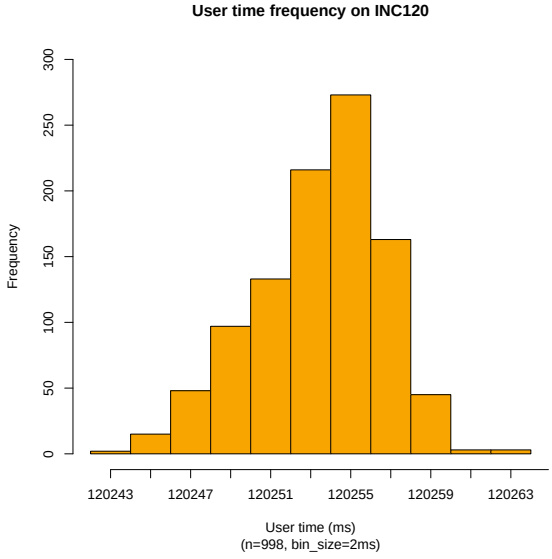
(a) User time frequency on INC104



(b) User time frequency on INC112

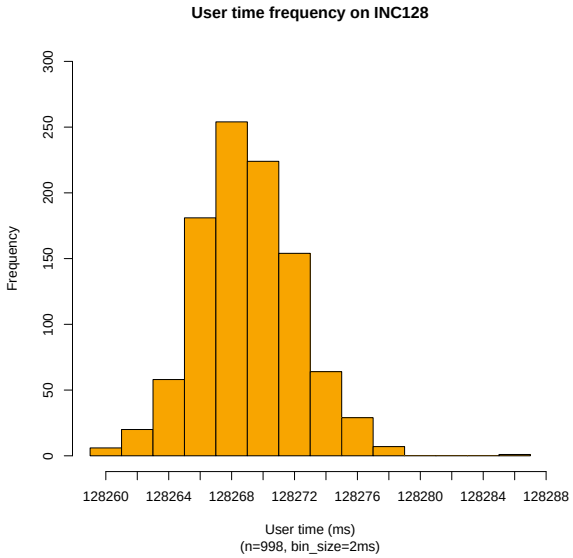


(c) User time frequency on INC120 with bin size = 1 ms

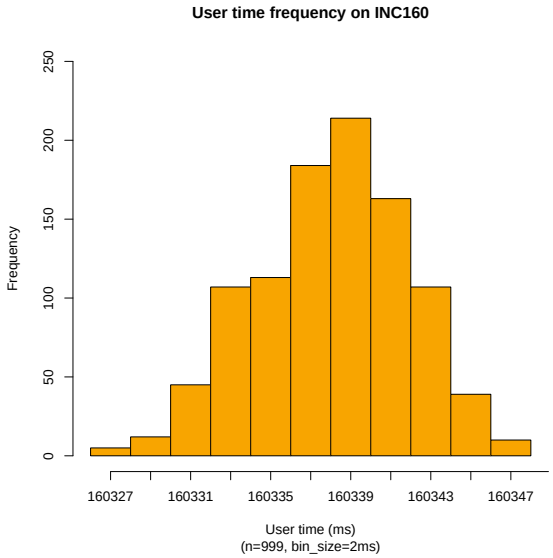


(d) User time frequency on INC120 with bin size = 2 ms

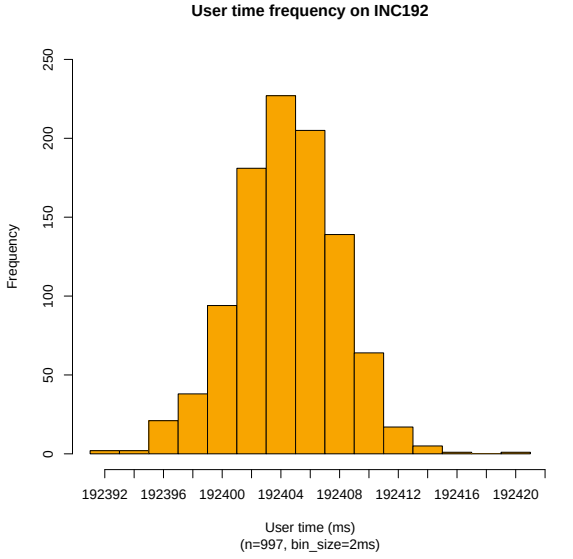
Figure 28: User Time Histograms of INC104 and INC120



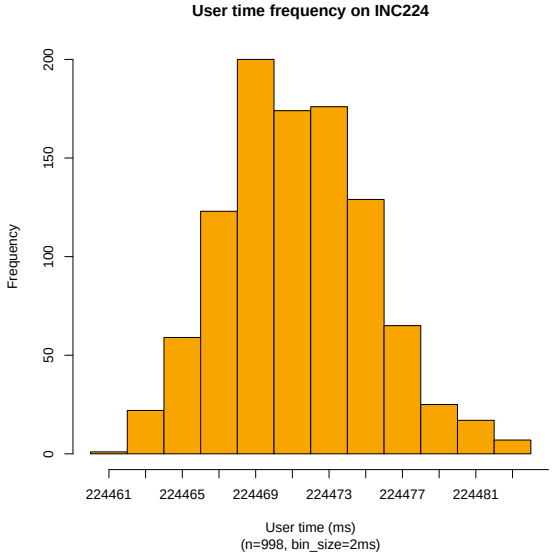
(a) User time frequency on INC128



(b) User time frequency on INC160

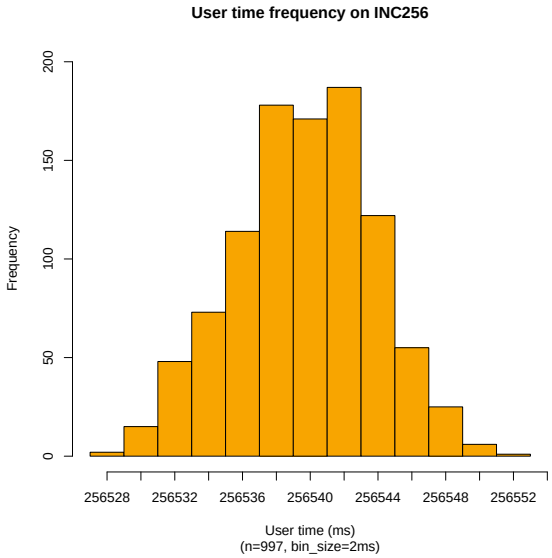


(c) User time frequency on INC192

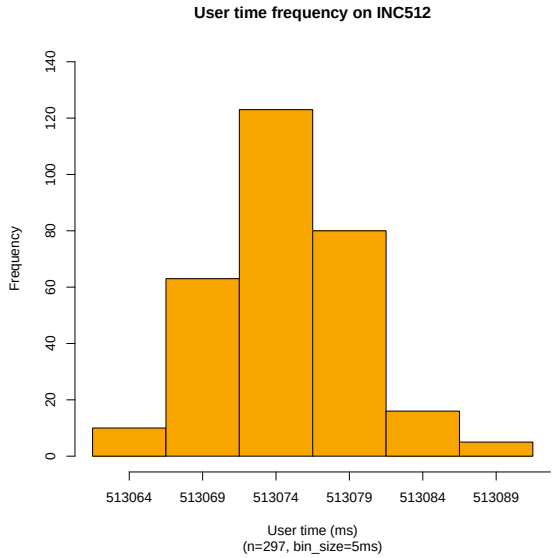


(d) User time frequency on INC224

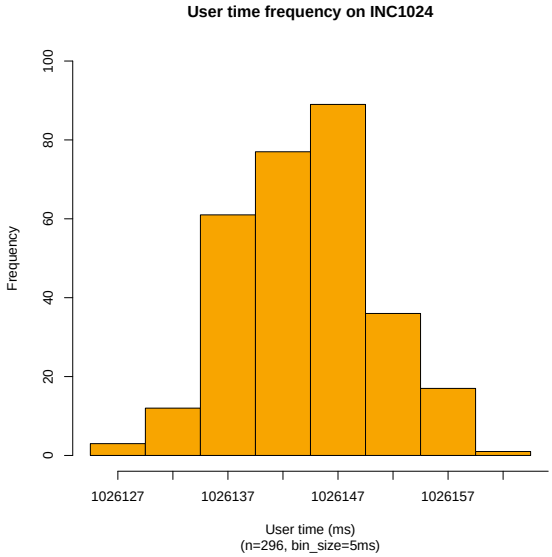
Figure 29: User Time Histograms of INC160 ... INC224



(a) User time frequency on INC256

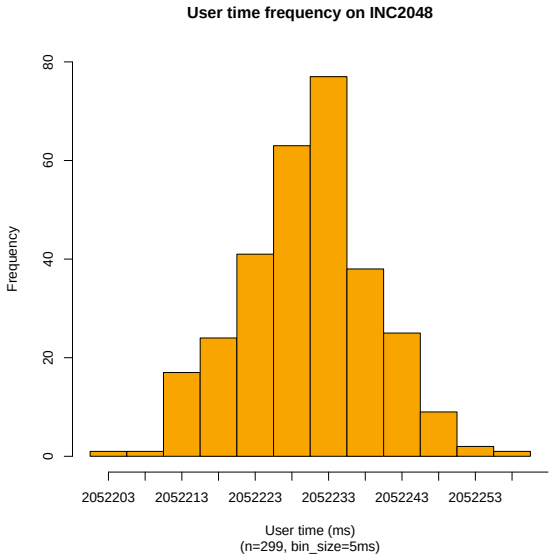


(b) User time frequency on INC512 (with one extreme outlier of 513,259 msec removed)

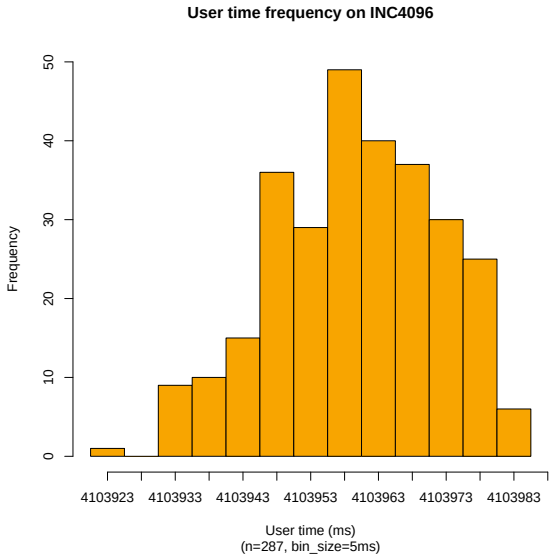


(c) User time frequency on INC1024

Figure 30: User Time Histograms of INC256 ... INC1024



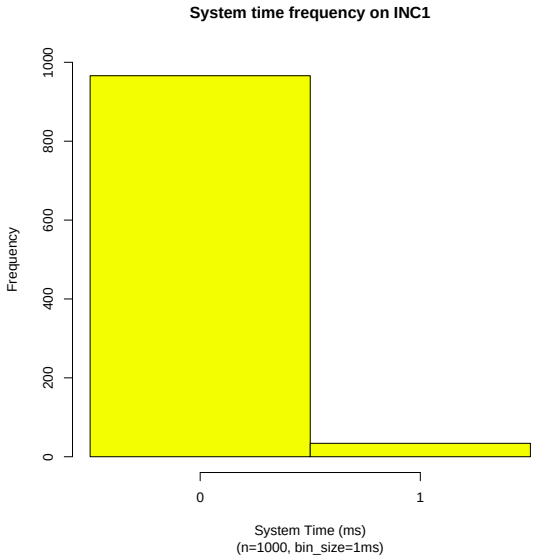
(a) User time frequency on INC2048



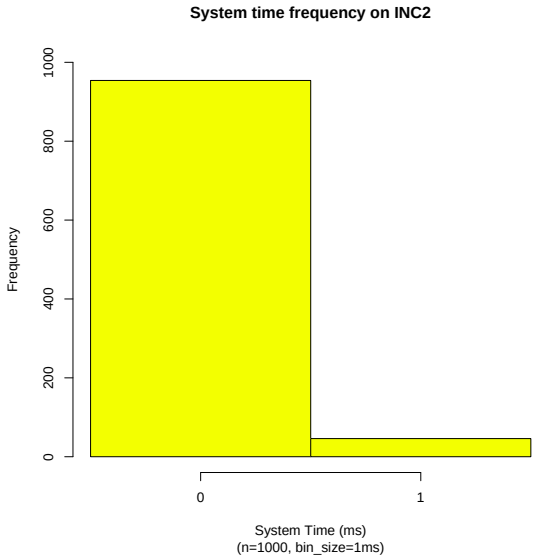
(b) User time frequency on INC4096

Figure 31: User Time Histograms of INC512 ... INC4096

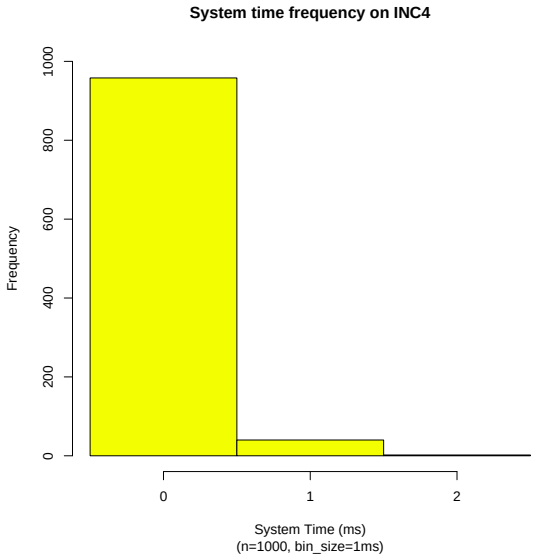
6.5 System Time



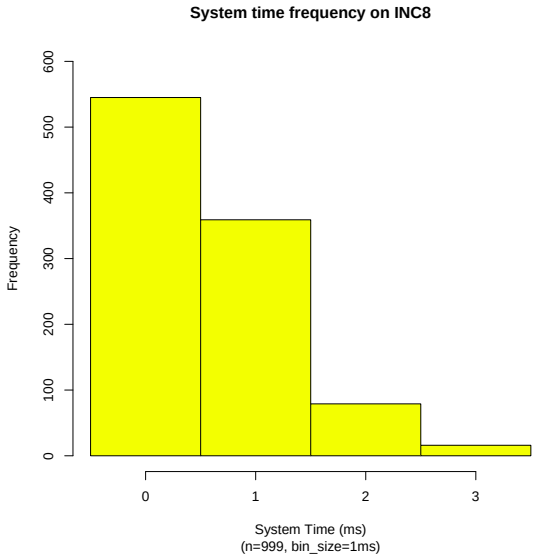
(a) System time frequency on INC1



(b) System time frequency on INC2

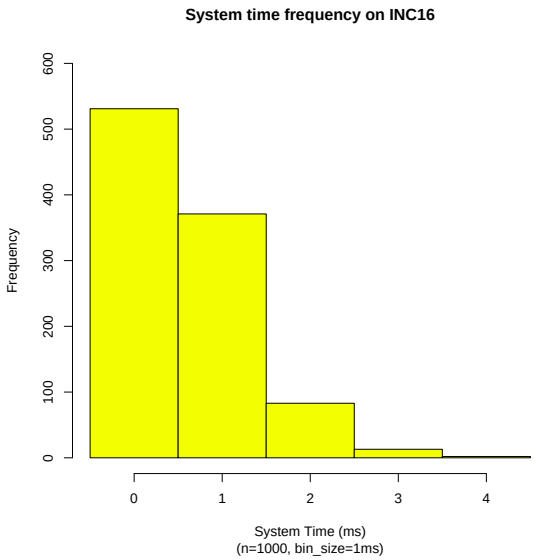


(c) System time frequency on INC4

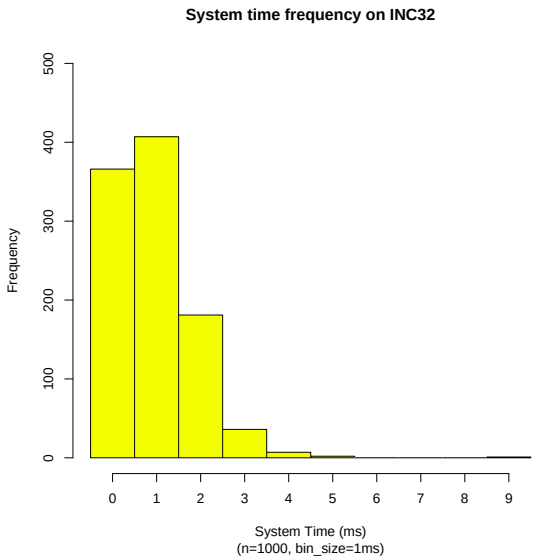


(d) System time frequency on INC8

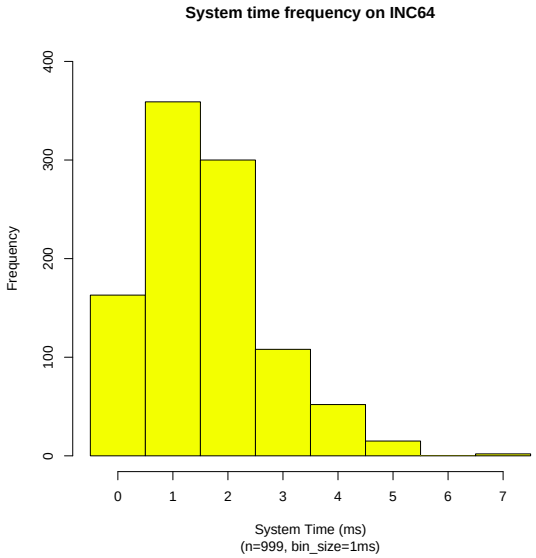
Figure 32: System Time Histograms of INC1 ... INC8



(a) System time frequency on INC16

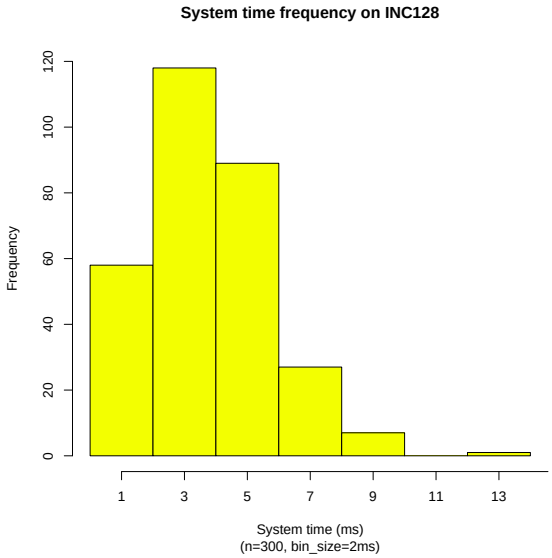


(b) System time frequency on INC32

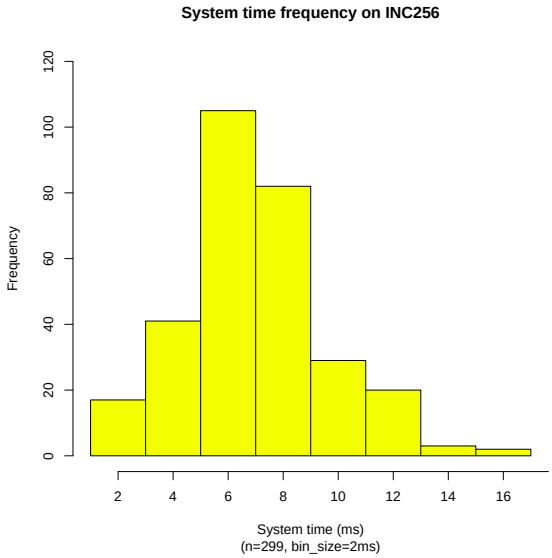


(c) System time frequency on INC64

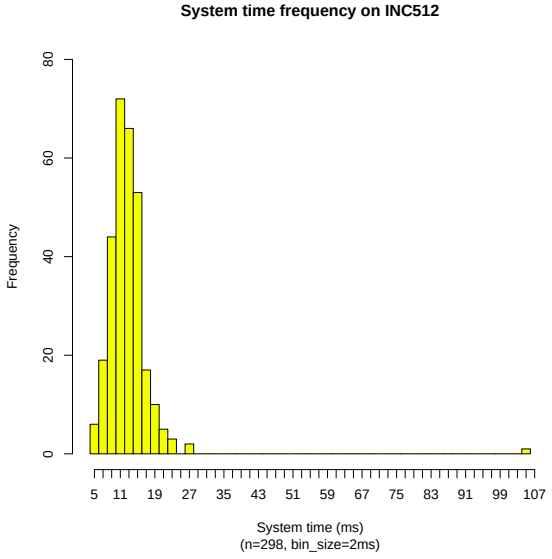
Figure 33: System Time Histograms of INC16 ... INC64



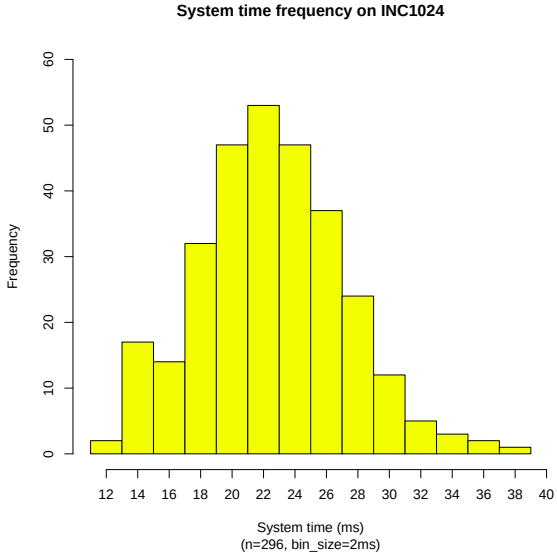
(a) System time frequency on INC128



(b) System time frequency on INC256

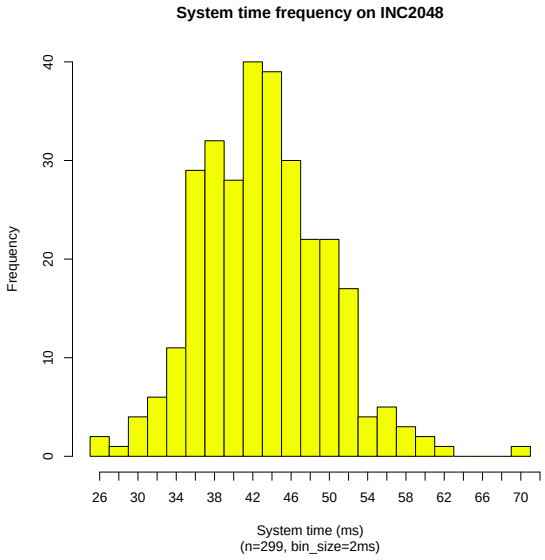


(c) System time frequency on INC512

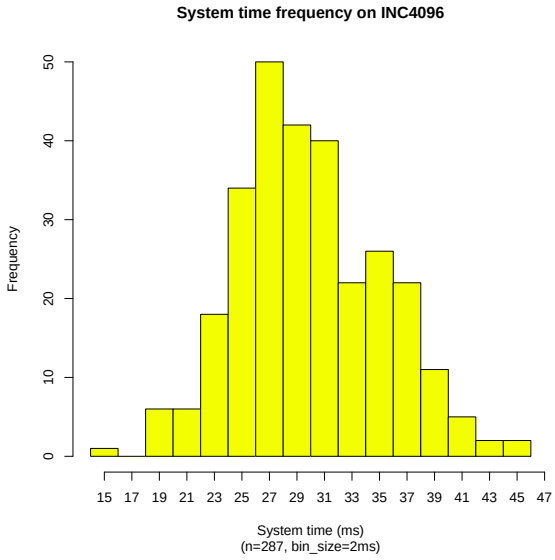


(d) System time frequency on INC1024

Figure 34: System Time Histograms of INC256 ... INC1024



(a) System time frequency on INC2048



(b) System time frequency on INC4096

Figure 35: System Time Histograms of INC2048 and INC4096

6.6 Correlation

	INC2048's u time	INC2048's s time
INC2048's u time	-	0.05
daemon u time	0.56	0.61
daemon s time	0.48	0.57
daemon minor faults	0.53	0.62
daemon major faults	0.55	0.59
daemon read bytes	0.55	0.59
daemon read char	0.56	0.61
daemon read sys calls	0.57	0.63
daemon write bytes	0.57	0.64
daemon write char	0.53	0.62

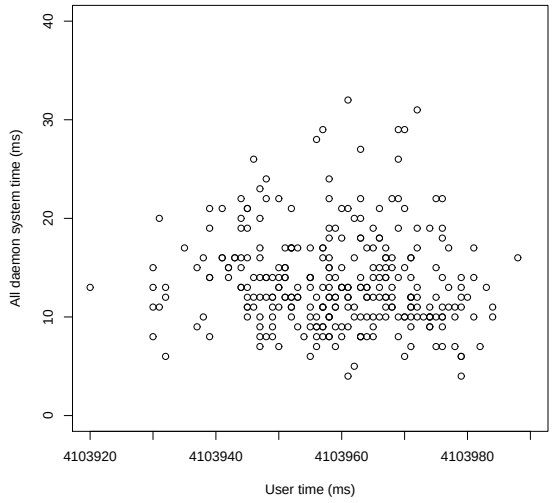
Table 6: Correlation of user and system time of INC2048 with some daemon measures

	INC4096's u time	INC4096's s time
INC4096's u time	-	-0.30
daemon u time	0.1	**0.3**
daemon s time	-0.09	**0.19**
daemon minor faults	**0.11**	**0.32**
daemon read char	0.1	**0.32**
daemon read sys calls	0.11	**0.32**
daemon write bytes	0	**0.26**
daemon write char	0.11	**0.32**

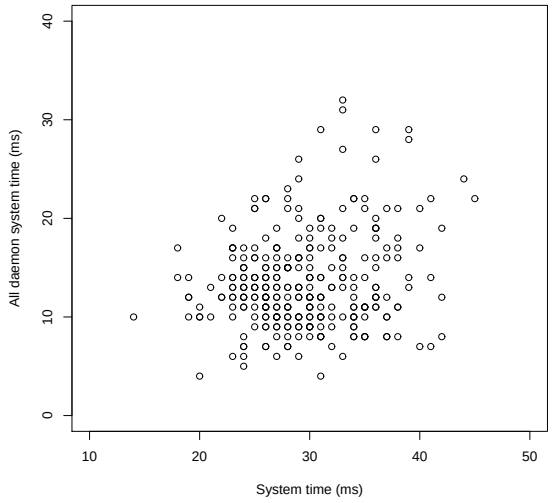
Table 7: Correlation of user and system time of INC4096 with some daemon measures

6.7 Scatter Plots on Some Significant Correlations

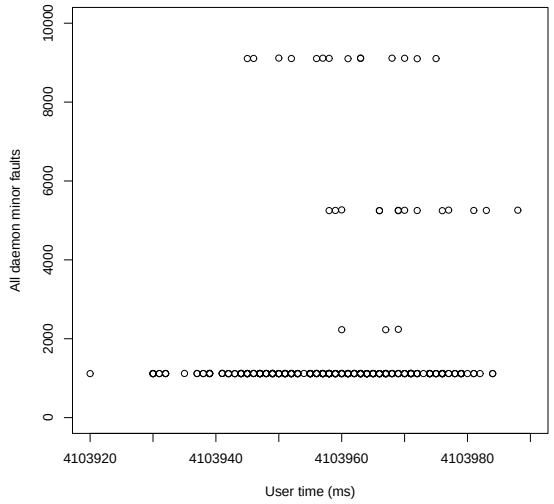
The following scatter plots correspond to the correlations bold in Table 7.



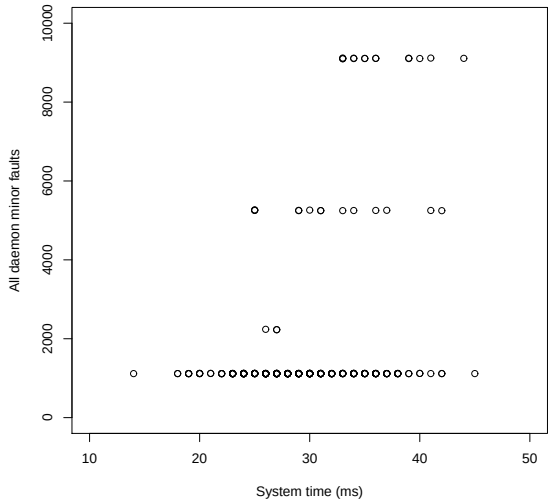
(a) User time vs. Sum of all daemon system time



(b) System time vs. Sum of all daemon system time

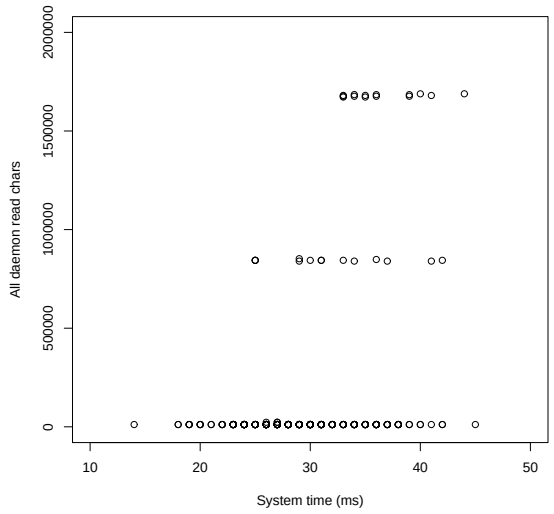


(c) User time vs. Sum of all daemon minor faults

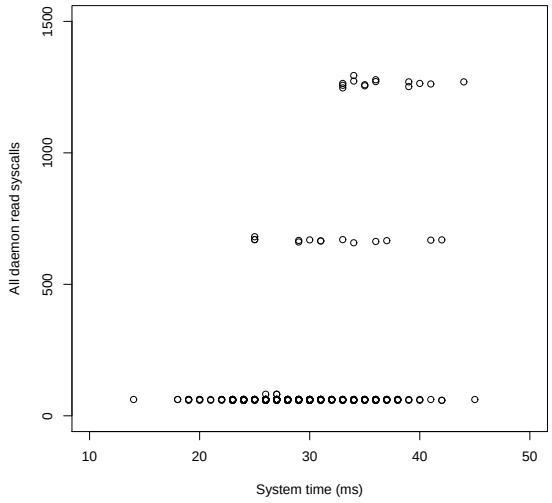


(d) System time vs. Sum of all daemon minor faults

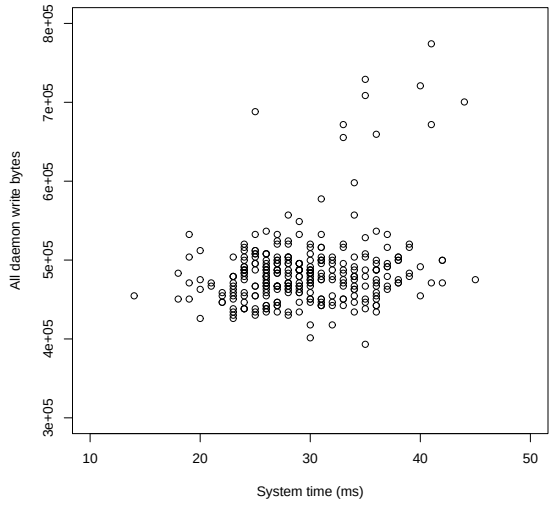
Figure 36: Scatter plots between measures on INC4096



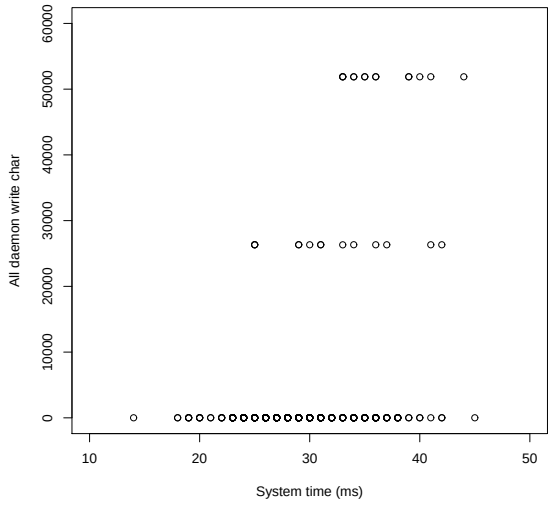
(a) System time vs. Sum of all daemon read char



(b) System time vs. Sum of all daemon read syscalls



(c) System time vs. Sum of all daemon write bytes



(d) System time vs. Sum of all daemon write char

Figure 37: Scatter plots between measures on INC4096

6.8 Further Investigation of Some Samples

6.8.1 Samples in Fig. 36(c)

proc name (id)	u time	s time	min flt	maj flt	r bytes	r char	r sysc	w bytes	w char	w sysc
INC4096 (3559)	4103920	36	0	0	0	1	1	0	0	0
proc_monitor (25917)	194	6	2	0	0	0	0	0	0	0
md0_raid1 (484)	0	3	0	0	0	0	0	0	0	0
java (3549)	2	1	1093	0	0	11480	20	0	0	0
cifsd (1927)	0	1	0	0	0	0	0	0	0	0
kblockd/0 (16)	0	1	0	0	0	0	0	0	0	0
ntpd (28232)	0	1	1	0	0	0	42	4096	7	0

Table 8: Observed values of measures of processes on the leftmost sample in Fig. 36(c)

proc name (id)	u time	s time	min flt	maj flt	r bytes	r char	r sysc	w bytes	w char	w sysc
INC4096 (3559)	4103984	19	0	0	0	1	1	0	0	0
proc_monitor (25917)	190	6	2	0	0	0	0	0	0	0
java (3549)	2	1	1093	0	0	11480	20	0	0	0
md0_raid1 (484)	0	3	0	0	0	0	0	0	0	0
ntpd (28232)	0	0	1	0	0	0	39	4096	7	0
java (4108)	0	0	20	0	0	0	0	0	0	0

Table 9: Observed values of measures of processes on the second rightmost sample in Fig. 36(c)

proc name (id)	u time	s time	min flt	maj flt	r bytes	r char	r sysc	w bytes	w char	w sysc
INC4096 (3559)	4103988	25	0	0	0	1	1	0	0	0
proc_monitor (25917)	194	2	2	0	0	0	0	0	0	0
sshd (3609)	8	4	1382	0	0	512357	400	0	20881	0
bash (3611)	4	1	835	0	0	283911	155	0	136	0
md0_raid1 (484)	0	3	0	0	0	0	0	0	0	0
java (3549)	2	1	1093	0	0	11480	20	0	0	0
cifsd (1927)	0	2	0	0	0	0	0	0	0	0
java (3606)	0	1	22	0	0	0	0	0	0	0
jbd2/md0-8 (497)	0	1	0	0	0	0	0	450560	0	0
kblockd/0 (16)	0	1	0	0	0	0	0	0	0	0
grep (3617)	1	0	311	0	0	5417	11	0	0	0
bash (3612)	0	0	158	0	0	0	0	0	0	0
consoletype (3613)	0	0	127	0	0	1956	6	0	7	0
bash (3614)	0	0	174	0	0	0	0	0	0	0
uname (3615)	0	0	189	0	0	1956	6	0	7	0
sshd (3610)	0	0	425	0	0	22656	29	0	4630	0
sshd (2105)	0	0	14	0	0	0	0	0	594	0
bash (3618)	0	0	170	0	0	0	0	0	0	0
id (3619)	0	0	225	0	0	4352	12	0	2	0
ntpd (28232)	0	0	1	0	0	0	42	4096	7	0
bash (3616)	0	0	131	0	0	0	0	0	61	0

Table 10: Observed values of measures of processes on the rightmost sample in Fig. 36(c)

6.8.2 Samples in Fig. 37(c)

proc name (id)	u time	s time	min flt	maj flt	r bytes	r char	r sysc	w bytes	w char	w sysc
INC4096 (3559)	4103981	14	0	0	0	1	1	0	0	0
proc_monitor (25917)	194	2	2	0	0	0	0	0	0	0
md0_raid1 (484)	0	5	0	0	0	0	0	0	0	0
java (3549)	2	1	1093	0	0	11480	20	0	0	0
flush-9:0 (3548)	0	2	0	0	0	0	0	0	0	0
ntpd (28232)	0	0	1	0	0	0	42	4096	7	0
java (4585)	0	0	20	0	0	0	0	0	0	0

Table 11: Observed values of measures of processes on the leftmost sample in Fig. 37(c)

proc name (id)	u time	s time	min flt	maj flt	r bytes	r char	r sysc	w bytes	w char	w sysc
INC4096 (3559)	4103958	44	0	0	0	1	1	0	0	0
proc_monitor (25917)	194	2	2	0	0	0	0	0	0	0
sshd (4877)	10	4	1382	0	0	519568	392	0	20868	0
sshd (4886)	10	3	1383	0	0	515456	393	0	20868	0
grep (4888)	6	1	994	0	0	287034	154	0	136	0
grep (4879)	3	2	991	0	0	286801	159	0	136	0
java (3549)	2	1	1093	0	0	11480	20	0	0	0
md0_raid1 (484)	0	3	0	0	0	0	0	0	0	0
sshd (4878)	2	1	424	0	0	22403	26	0	4268	0
jbd2/md0-8 (497)	0	2	0	0	0	0	0	696320	0	0
flush-9:0 (3548)	0	2	0	0	0	0	0	0	0	0
cifsd (1927)	0	1	0	0	0	0	0	0	0	0
kblockd/0 (16)	0	1	0	0	0	0	0	0	0	0
grep (4892)	0	1	309	0	0	5417	11	0	0	0
grep (4883)	1	0	310	0	0	5417	11	0	0	0
id (4894)	0	0	226	0	0	4352	12	0	2	0
bash (4884)	0	0	164	0	0	0	0	0	0	0
id (4885)	0	0	226	0	0	0	12	0	2	0
sshd (2105)	0	0	28	0	0	0	0	0	1188	0
sshd (4887)	0	0	425	0	0	22403	26	0	4268	0
ntpd (20232)	0	0	1	0	0	0	42	4096	7	0
bash (4880)	0	0	165	0	0	0	0	0	0	0
uname (4890)	0	0	190	0	0	1956	6	0	7	0
bash (4891)	0	0	128	0	0	0	0	0	61	0
java (4874)	0	0	20	0	0	0	0	0	0	0
bash (4893)	0	0	164	0	0	0	0	0	0	0
uname (4881)	0	0	191	0	0	1956	6	0	7	0
bash (4889)	0	0	165	0	0	0	0	0	0	0

Table 12: Observed values of measures of processes on the second rightmost sample in Fig. 37(c)

proc name (id)	u time	s time	min flt	maj flt	r bytes	r char	r sysc	w bytes	w char	w sysc
INC4096 (3559)	4103948	45	0	0	0	1	1	0	0	0
proc_monitor (25917)	190	10	2	0	0	0	0	0	0	0
md0_raid1 (484)	0	5	0	0	0	0	0	0	0	0
jbd2/md0-8 (497)	0	3	0	0	0	0	0	471040	0	0
java (3549)	2	1	1093	0	0	11480	20	0	0	0
cifsd (1927)	0	2	0	0	0	0	0	0	0	0
flush-9:0 (3548)	0	1	0	0	0	0	0	0	0	0
java (5022)	1	0	21	0	0	0	0	0	0	0
ntpd (28232)	0	0	1	0	0	0	42	4096	7	0

Table 13: Observed values of measures of processes on the rightmost sample in Fig. 37(c)

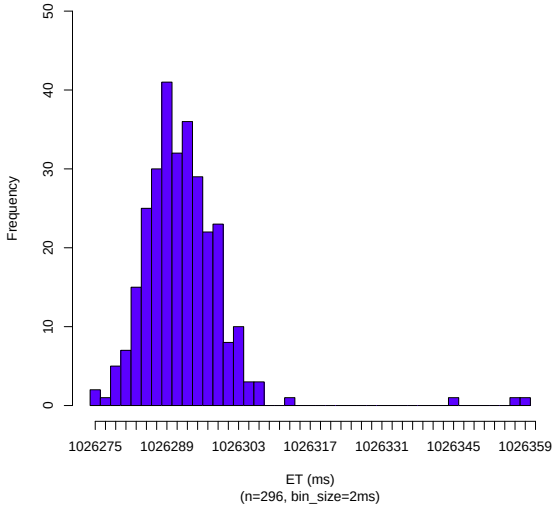
7 Histograms on Consecutive INC1024 Runs

This section exhibits histograms on (three) consecutive runs of INC1024. The detailed description of the base data is from Table 2.

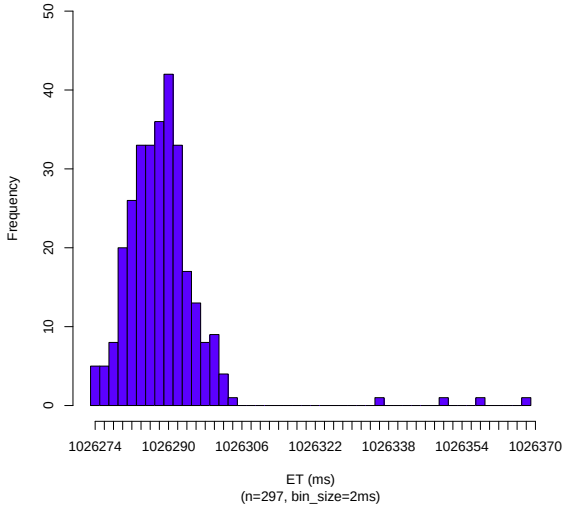
Machine	Task Length (sec)	Description	Experiment Period	Relevant Histograms
`sodb9`	INC1024	300 samples, each	2017-04-12 $\sim$ 2017-04-23	Figs. 38 and 39

Table 14: Notes on experiment runs used for histograms

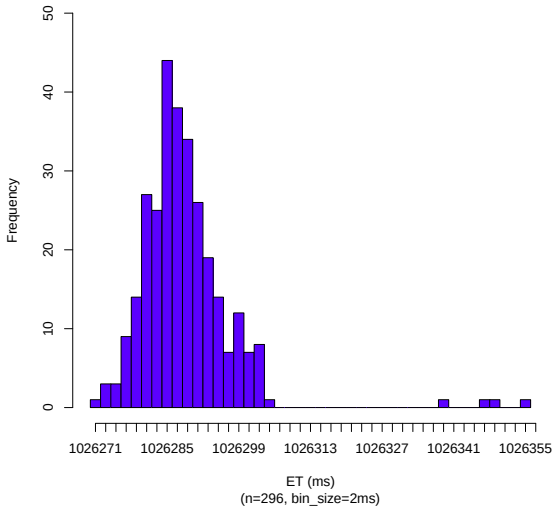
7.1 ET



(a) ET frequency on INC1024-Run1



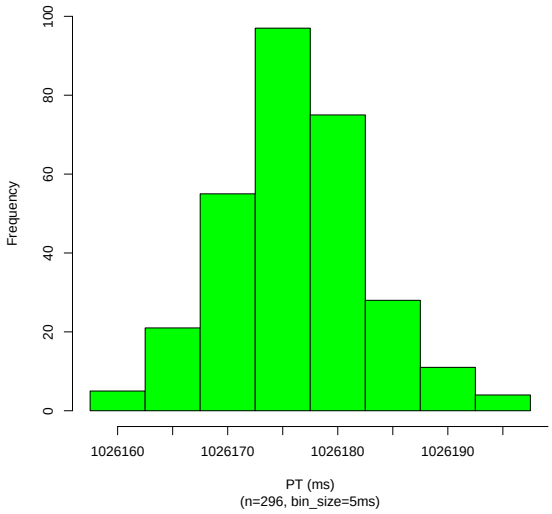
(b) ET frequency on INC1024-Run2



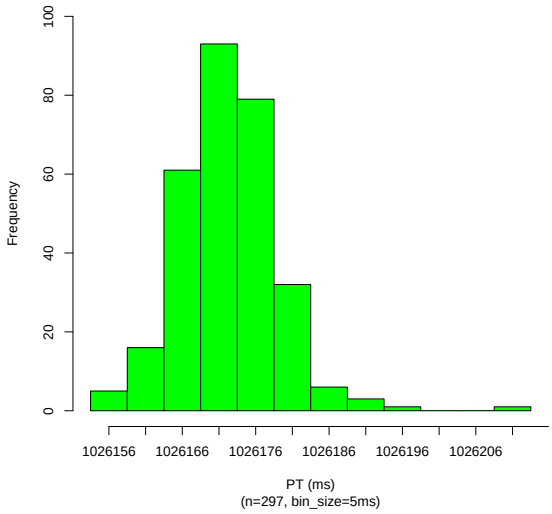
(c) ET frequency on INC1024-Run3

Figure 38: ET Histograms of Three Consecutive INC1024 Runs

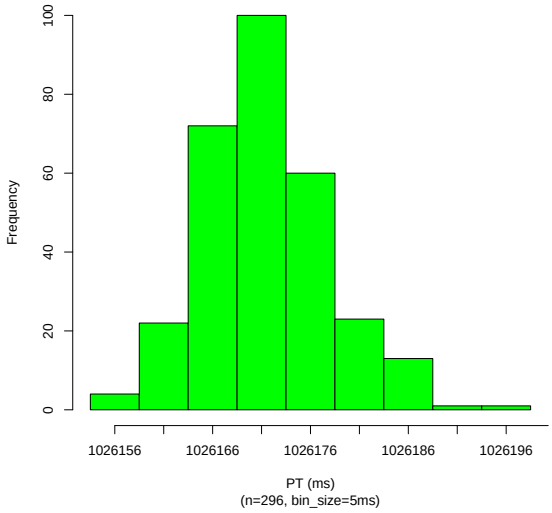
7.2 PT



(a) PT frequency on INC1024-Run1



(b) PT frequency on INC1024-Run2



(c) PT frequency on INC1024-Run3

Figure 39: PT Histograms of Three Consecutive INC1024 Runs

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.