

A Comprehensive Study of Characterizing Program Execution Time

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1 Experiment Notes

| Task Length | Description | Time Length |
|--|---|--|
| Regular PUT experiment. Refer to Sections 2, 3, and 4. | | |
| PUT1~PUT64 | Runs of 1000 samples (on <code>sodb12</code>). | 2013-10-14 ~ 2013-10-15 |
| PUT128~PUT2048 | Runs of 300 samples (on <code>sodb12</code>). | 2013-12-12 ~ 2013-12-21 |
| PUT4096 | A run of 300 samples (on <code>sodb12</code>). | 2014-06-23 ~ 2014-07-10 |
| PUT8192 | Runs of 40/260 samples (on <code>sodb12</code>). | 2015-04-23 ~ 2015-04-27 / 2015-10-31 ~ 2015-11-24 |
| PUT16384 | Runs of 40/260 samples (on <code>sodb12</code>). | 2015-04-23 ~ 2015-04-23 / 2015-11-25 ~ 2016-01-14 |

Table 1: Notes on the regular PUT data used for the histograms

| Task Length | Description | Time Length |
|---|---|-------------------------|
| Regular PUT experiment. Refer to Section 5. | | |
| PUT1/2 | Runs of 20k samples on <code>sodb9/sodb10</code> . | 2015-12-15 ~ 2015-12-15 |
| PUT4/8 | Runs of 20k samples on <code>sodb10</code> . | 2016-01-20 ~ 2016-01-20 |
| PUT16 | Runs of 2k, 4k, 8k, 16k, and 32k samples (on <code>sodb12</code>). | 2016-01-25 ~ 2016-02-09 |
| Dual PUT experiment. Refer to Section 6. | | |
| PUT4096 | A run of 500 samples on <code>sodb8</code> . | 2015-11-08 ~ 2015-12-25 |
| PUT2 | A run of 1k samples on <code>sodb9</code> . | 2015-12-27 ~ 2015-12-27 |
| PUT4~PUT32 | Runs of 1k samples on <code>sodb9</code> . | 2016-01-27 ~ 2016-01-31 |
| PUT64~PUT4096 | Runs of 1k samples on <code>sodb9</code> . | 2016-02-17 ~ ? |

Table 2: Notes on the new PUT experiments

2 Summary of the EMPv4 data

EMPv4: Running PUT with a specific task length under a controlled environment, with i) daemon processes disabled, ii) the NTP daemon process activated, iii) major CPU features (turbo and speedstep) disabled, and iv) an up-to-date Linux version (RHEL 6.0) installed.

| | Num. of Samples | Minimum (msec) | Maximum (msec) | Average (msec) | Std. Dev. (msec) |
|----------|-----------------|----------------|----------------|----------------|------------------|
| PUT1 | 1,000 | 999.0 | 1,005.0 | 1,002.4 | 0.73 |
| PUT2 | 1,000 | 1,996.0 | 2,007.0 | 2,004.5 | 1.38 |
| PUT4 | 1,000 | 4,004.0 | 4,012.0 | 4,008.6 | 1.64 |
| PUT8 | 1,000 | 8,014.0 | 8,023.0 | 8,018.1 | 1.72 |
| PUT16 | 1,000 | 16,029.0 | 16,041.0 | 16,034.3 | 1.86 |
| PUT32 | 1,000 | 32,064.0 | 32,084.0 | 32,068.2 | 2.05 |
| PUT64 | 1,000 | 64,129.0 | 64,145.0 | 64,135.0 | 2.27 |
| PUT128 | 300 | 128,244.0 | 128,260.0 | 128,251.2 | 2.32 |
| PUT256 | 300 | 256,494.0 | 256,523.0 | 256,502.3 | 3.29 |
| PUT512 | 300 | 512,995.0 | 513,152.0 | 513,005.1 | 9.41 |
| PUT1024 | 300 | 1,025,997.0 | 1,026,141.0 | 1,026,012.4 | 11.43 |
| PUT2048 | 300 | 2,051,981.0 | 2,052,156.0 | 2,052,012.0 | 11.19 |
| PUT4096 | 300 | 4,105,451.0 | 4,105,629.0 | 4,105,526.0 | 25.98 |
| PUT8192 | 40 (last Apr) | 8,207,870.0 | 8,207,967.0 | 8,207,918.0 | 21.03 |
| PUT8192 | 260 (Nov) | 8,210,940.0 | 8,211,196.0 | 8,211,049.0 | 36.60 |
| PUT16384 | 40 (last Apr) | 16,415,757.0 | 16,415,964.0 | 16,415,810.3 | 40.43 |
| PUT16384 | 260 (Nov) | 16,422,028 | 16,422,389 | 16,422,153.0 | 52.54 |

Table 3: PT statistics by EMPv4 (See Table 1.)

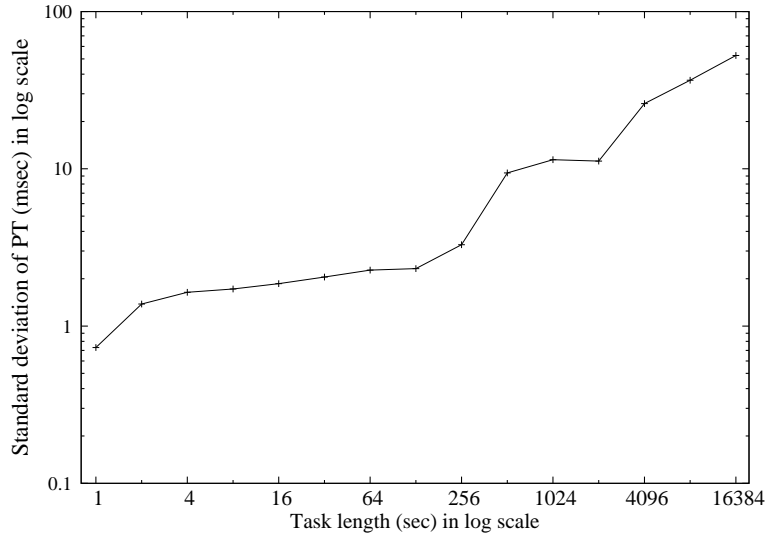


Figure 1: Std. dev. of PT over increasing task length (See Table 1.)

3 Histograms on the EMPv4 Data

The base data of the following histograms are from Table 1.

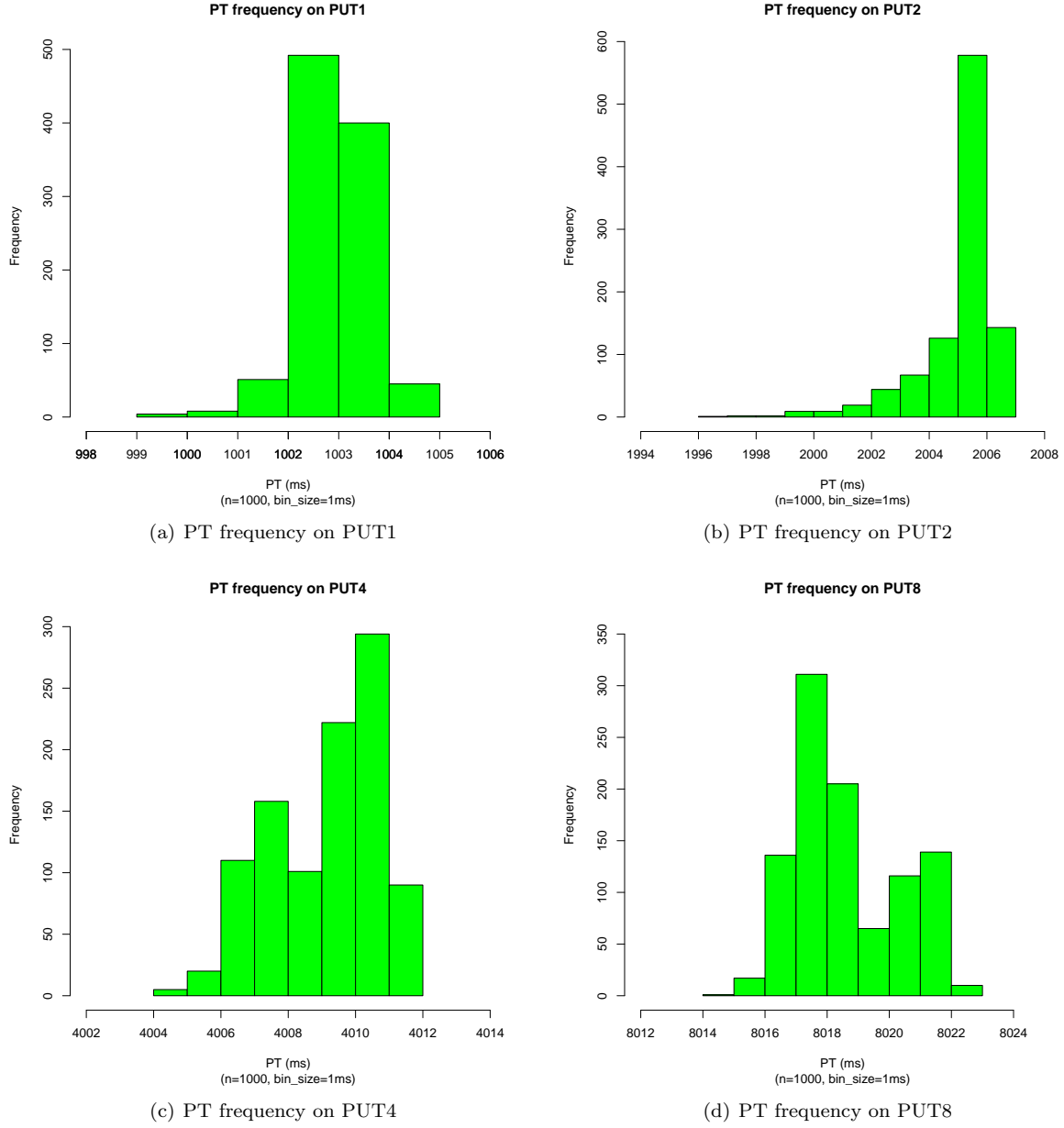
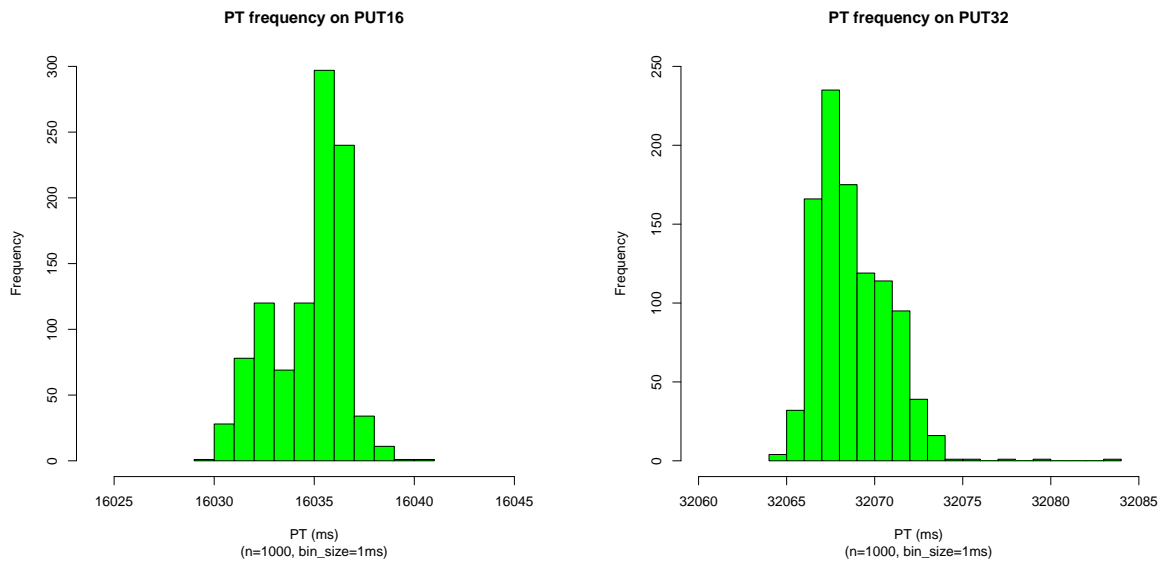
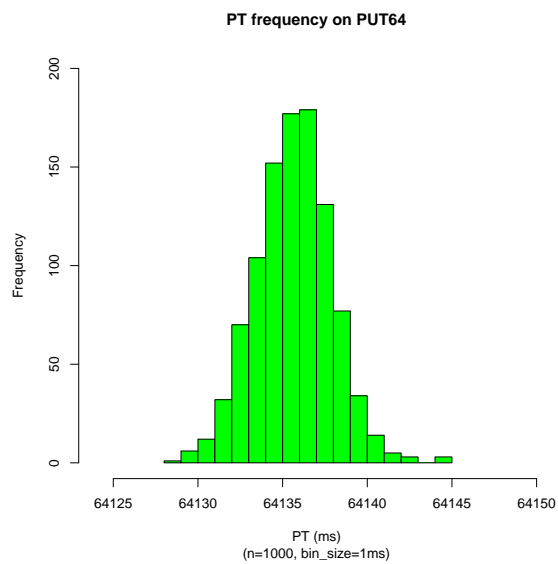


Figure 2: PT Histograms of PUT1 ... PUT8



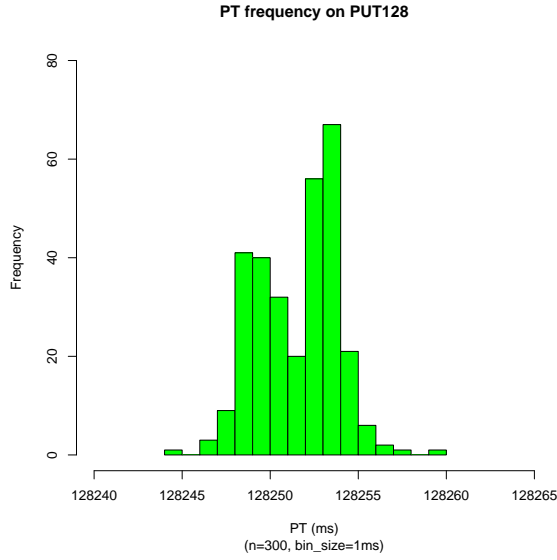
(a) PT frequency on PUT16

(b) PT frequency on PUT32

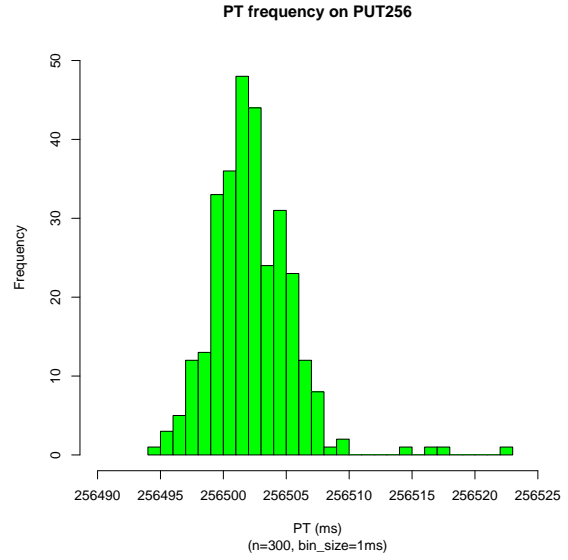


(c) PT frequency on PUT64

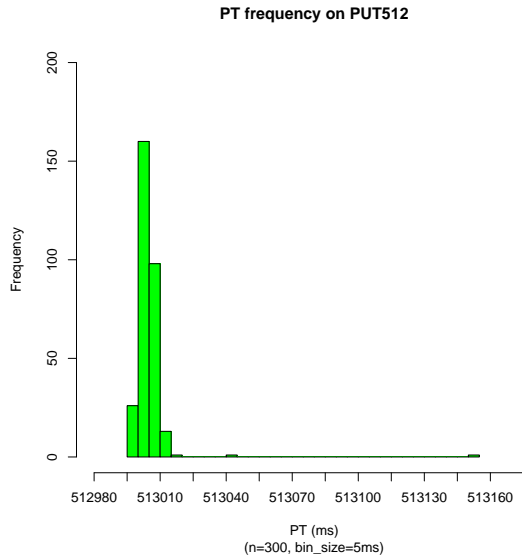
Figure 3: PT Histograms of PUT16 ... PUT64



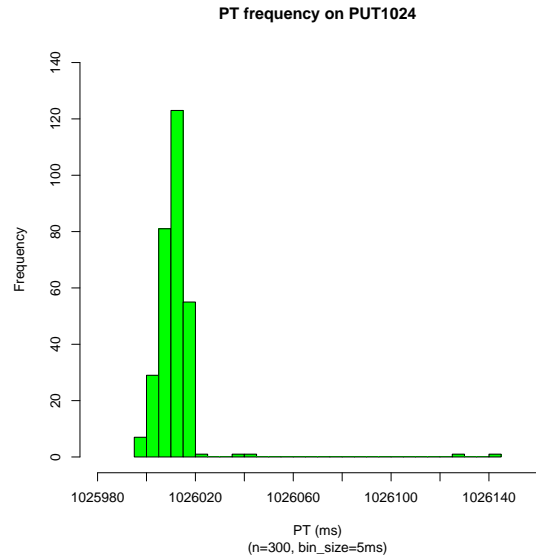
(a) PT frequency on PUT128



(b) PT frequency on PUT256

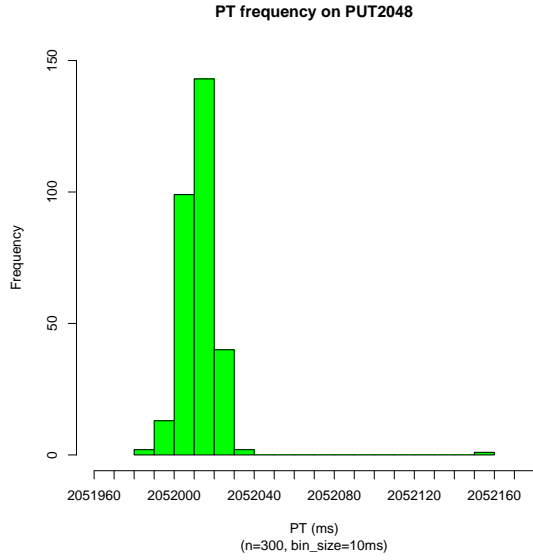


(c) PT frequency on PUT512

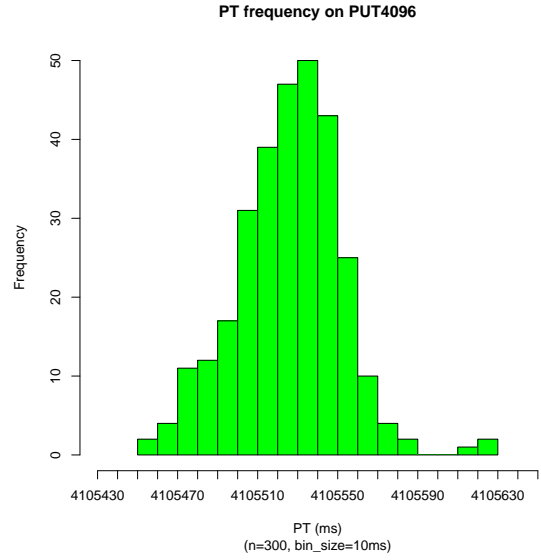


(d) PT frequency on PUT1024

Figure 4: PT Histograms of PUT128 ... PUT1024

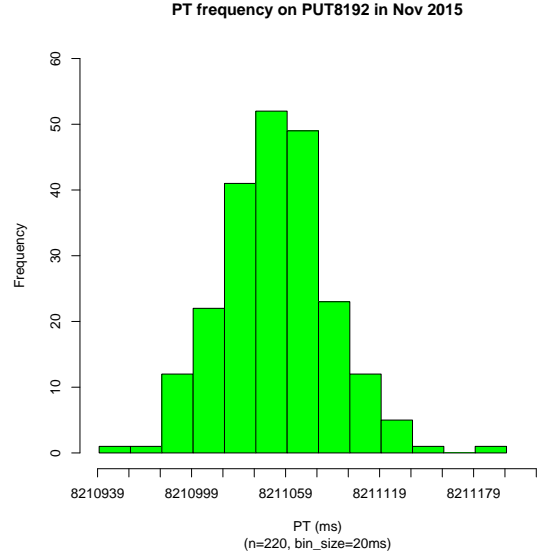
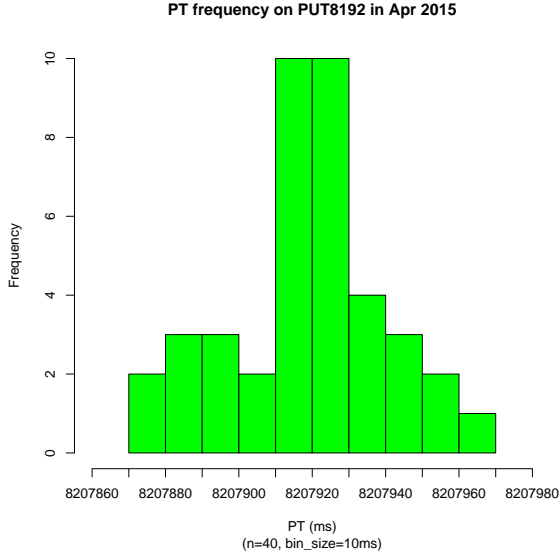


(a) PT frequency on PUT2048

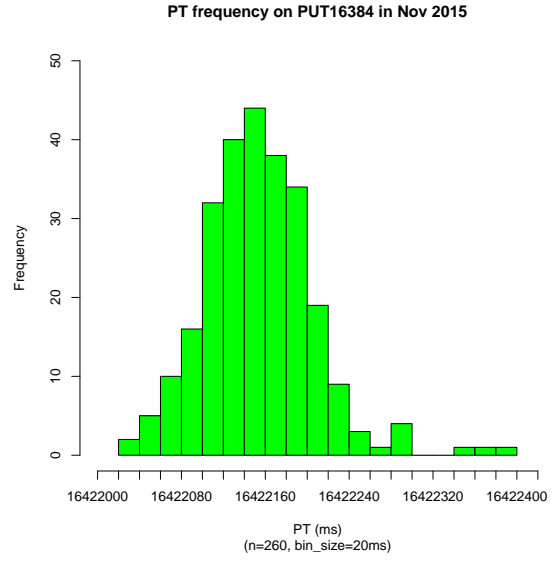
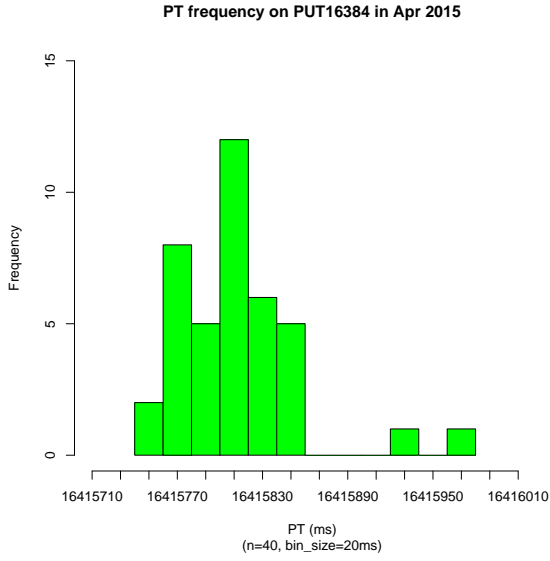


(b) PT frequency on PUT4096

Figure 5: PT Histograms of PUT2048 and PUT4096



(a) PT frequency on PUT8192 with 40 samples (See Table 1.) (b) PT frequency on PUT8192 with 260 samples (See Table 1.)



(c) PT frequency on PUT16384 with 40 samples (See Table 1.) (d) PT frequency on PUT16384 with 260 samples (See Table 1.)

Figure 6: PT Histograms of PUT8192 and PUT16384

4 Histograms on the EMPv5 Data

The base data of the following histograms are from Table 1. EMPv5(-relaxed) trims outliers from the data of each PUT by EMPv4. To be more specific, for each run of PUT an outlier is determined as the one above and below the average \pm *five¹* standard deviations computed from the EMPv4 data.

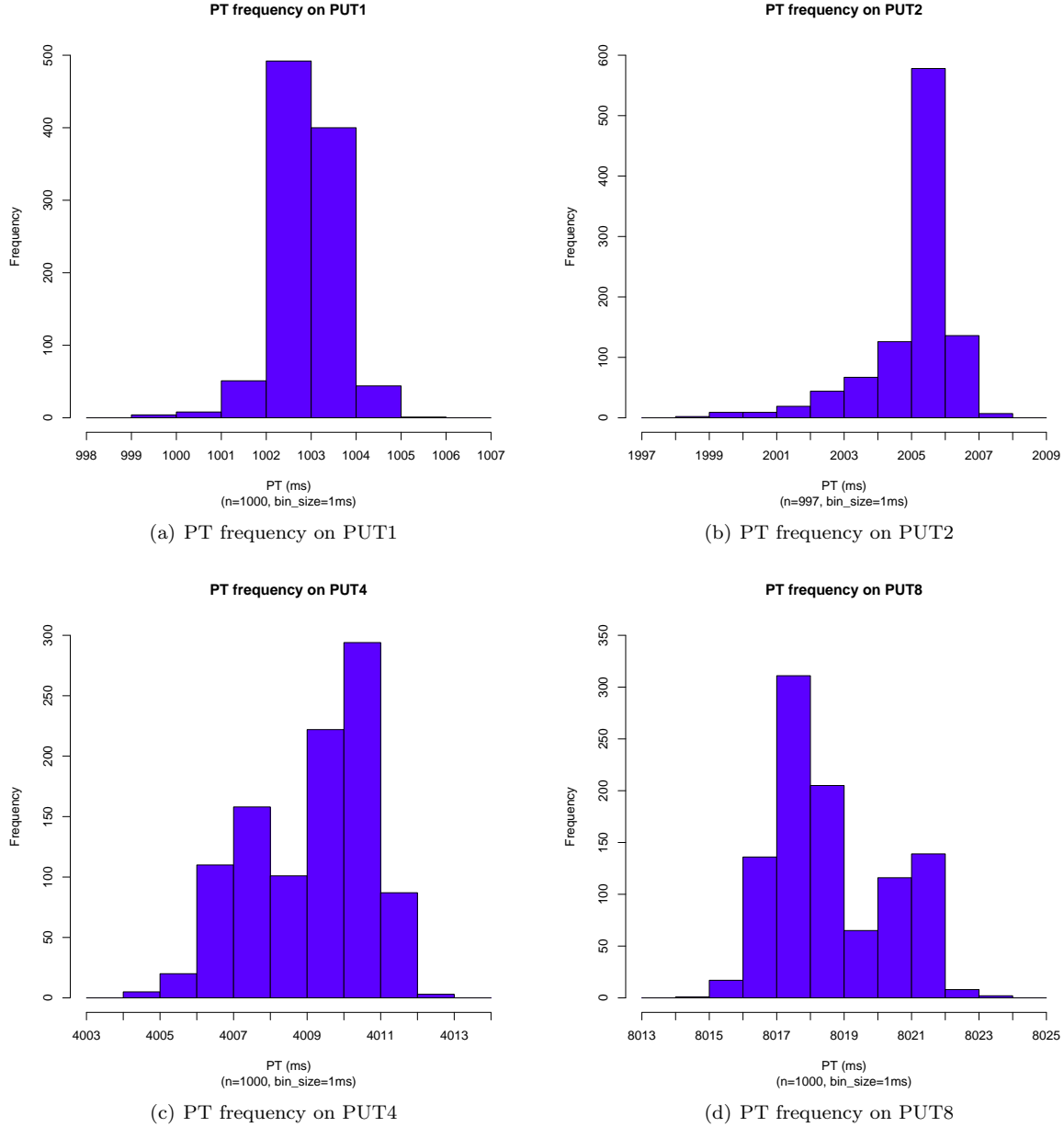
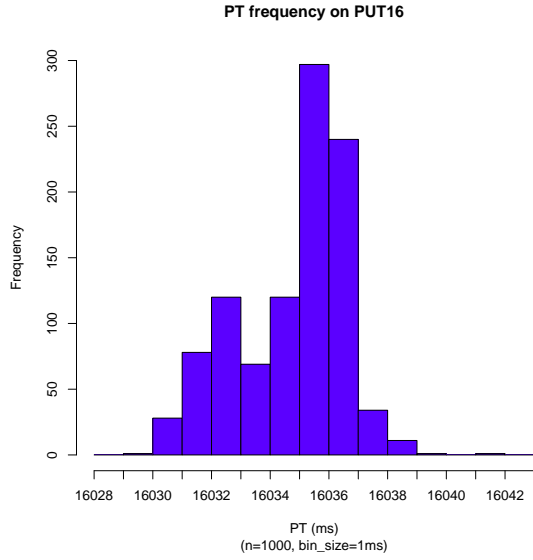
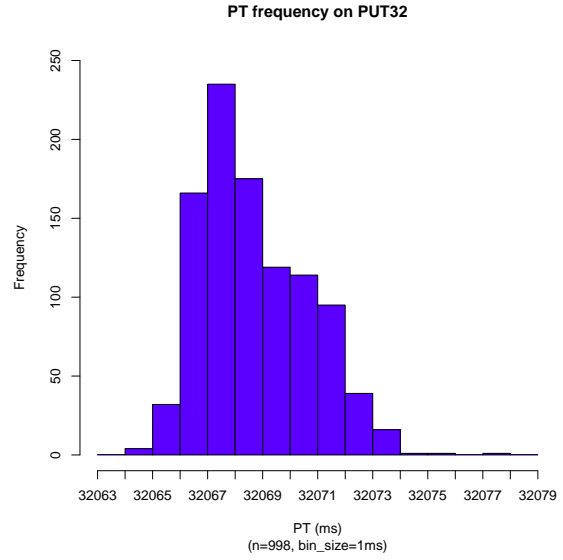


Figure 7: PT Histograms of PUT1 ... PUT8

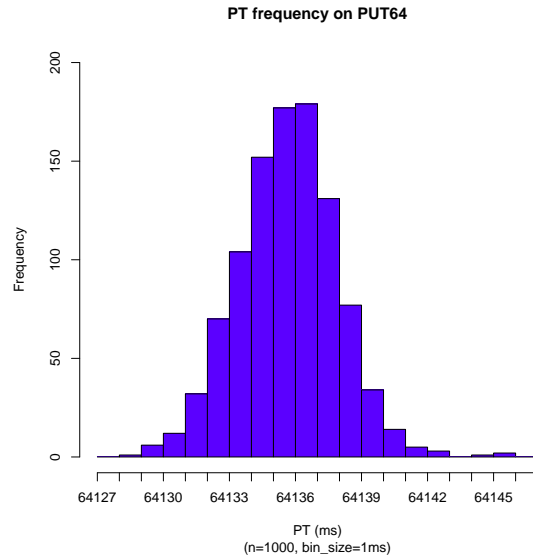
¹In the stricter version, we use *two*.



(a) PT frequency on PUT16

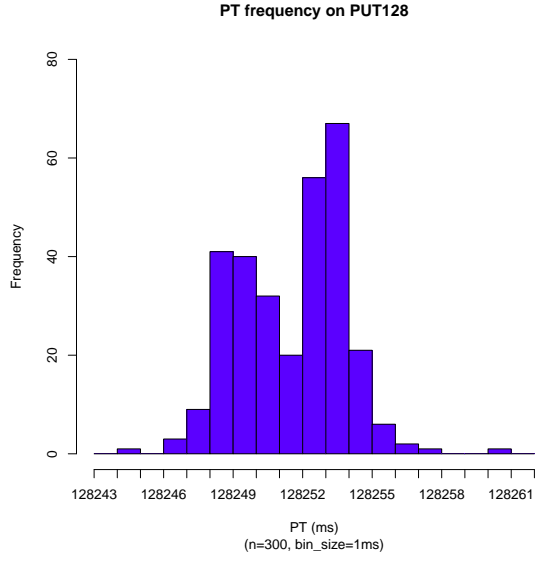


(b) PT frequency on PUT32

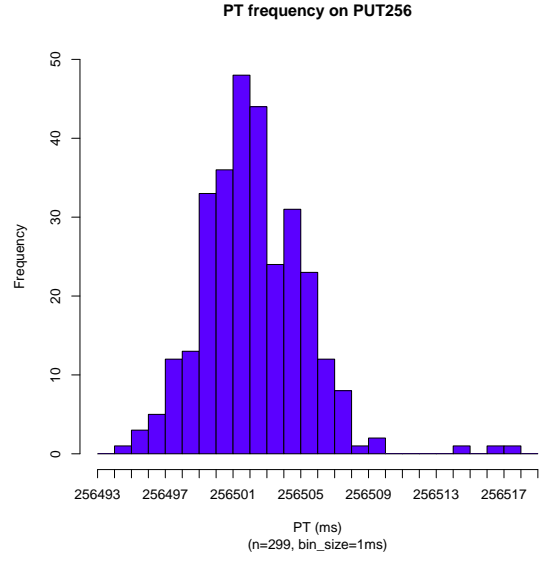


(c) PT frequency on PUT64

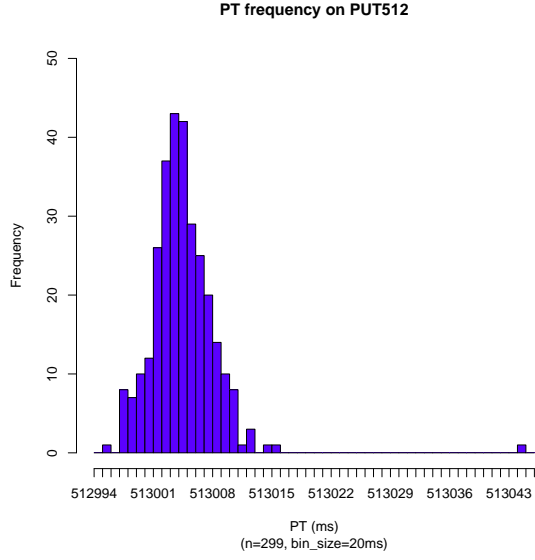
Figure 8: PT Histograms of PUT16 ... PUT64



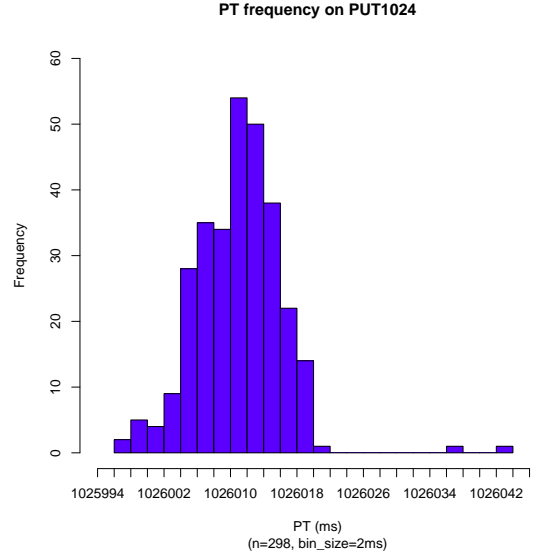
(a) PT frequency on PUT128



(b) PT frequency on PUT256

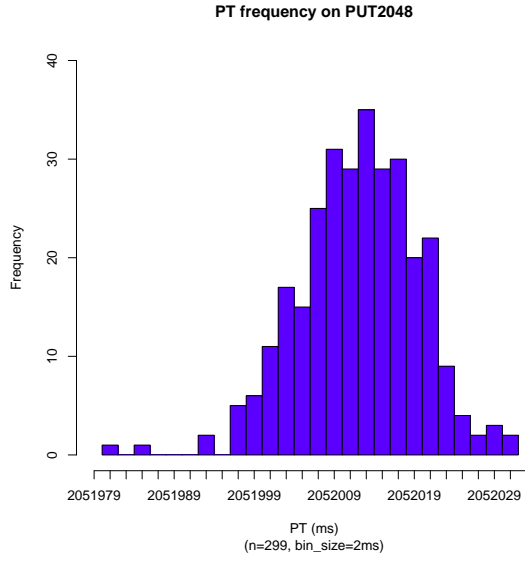


(c) PT frequency on PUT512

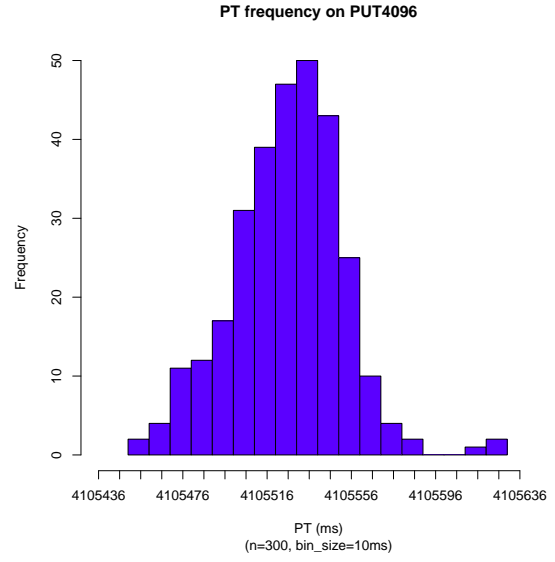


(d) PT frequency on PUT1024

Figure 9: PT Histograms of PUT128 ... PUT1024

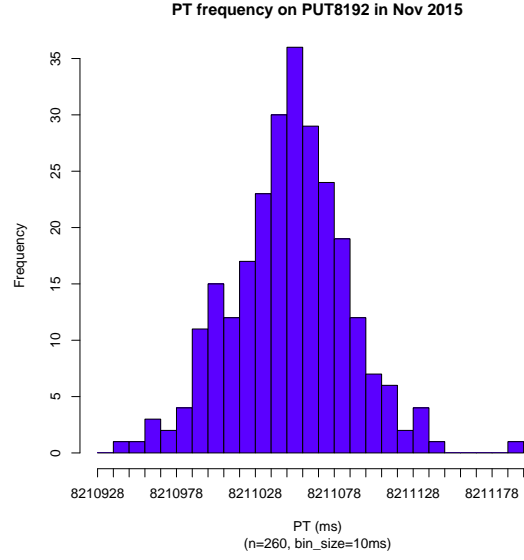
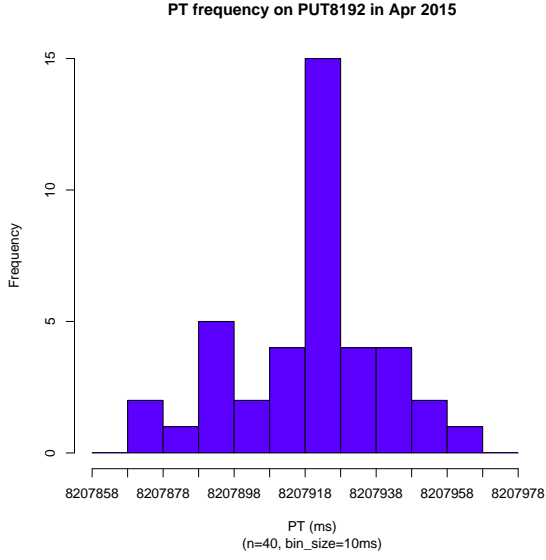


(a) PT frequency on PUT2048

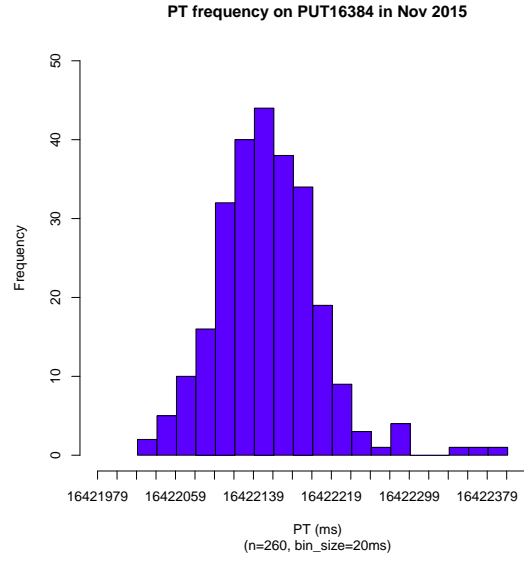
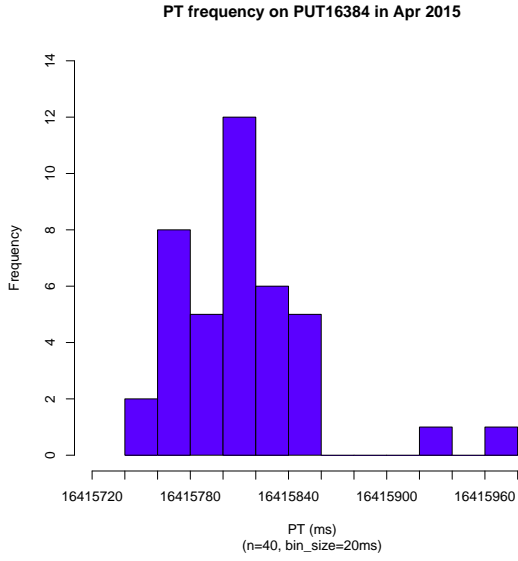


(b) PT frequency on PUT4096

Figure 10: PT Histograms of PUT2048 and PUT4096



(a) PT frequency on PUT8192 with 40 samples (See Table 1.) (b) PT frequency on PUT8192 with 260 samples (See Table 1.)



(c) PT frequency on PUT16384 with 40 samples (See Table 1.) (d) PT frequency on PUT16384 with 260 samples (See Table 1.)

Figure 11: PT Histograms of PUT8192 and PUT16384

5 Sample Size vs. Standard Deviation of PT

The base data of the following histograms are from Table 2.

5.1 PUT1 and PUT2

Table 4 exhibits varying standard deviations over increasing sample size on PUT1 and PUT2. EMPv4 is applied to the table's data.

| Num. of Samples | Std. Dev. (msec) | |
|-----------------|------------------|------|
| | PUT1 | PUT2 |
| 1,000 | 1.07 | 1.40 |
| 2,000 | 1.06 | 1.39 |
| 3,000 | 1.07 | 1.38 |
| 4,000 | 1.07 | 1.37 |
| 5,000 | 1.07 | 1.40 |
| 6,000 | 1.06 | 1.70 |
| 7,000 | 1.06 | 1.65 |
| 8,000 | 1.07 | 1.62 |
| 9,000 | 1.07 | 1.60 |
| 10,000 | 1.07 | 1.58 |
| 11,000 | 1.08 | 1.57 |
| 12,000 | 1.08 | 1.56 |
| 13,000 | 1.08 | 1.54 |
| 14,000 | 1.08 | 1.53 |
| 15,000 | 1.08 | 1.52 |
| 16,000 | 1.08 | 1.51 |
| 17,000 | 1.08 | 1.50 |
| 18,000 | 1.08 | 1.50 |
| 19,000 | 1.08 | 1.50 |
| 20,000 | 1.08 | 1.49 |

Table 4: Std. Dev. of PUT1 and PUT2 over increasing sample size

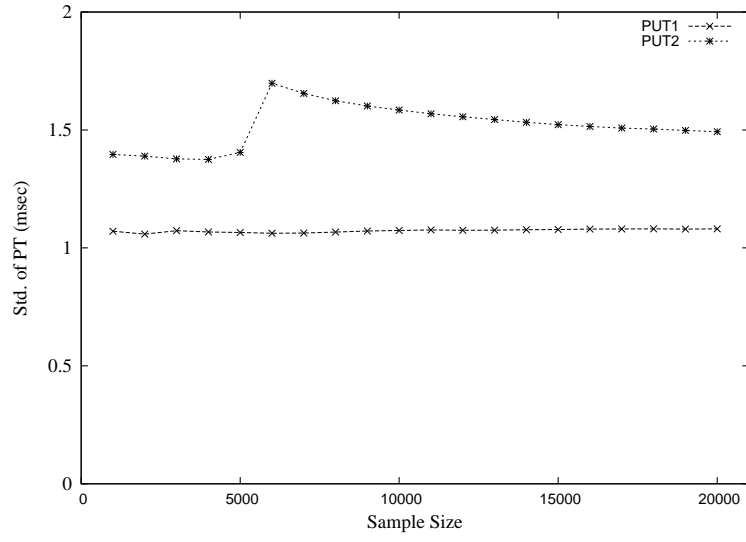


Figure 12: Std. dev. of PT on PUT1 and PUT2 over increasing sample size

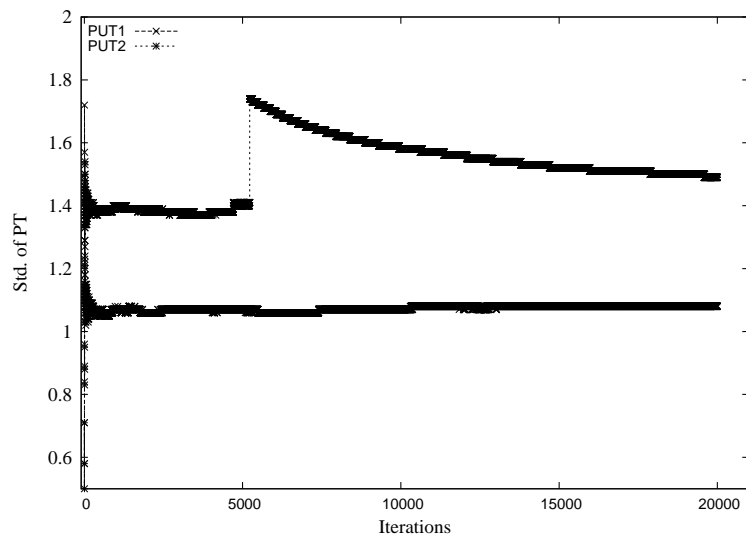
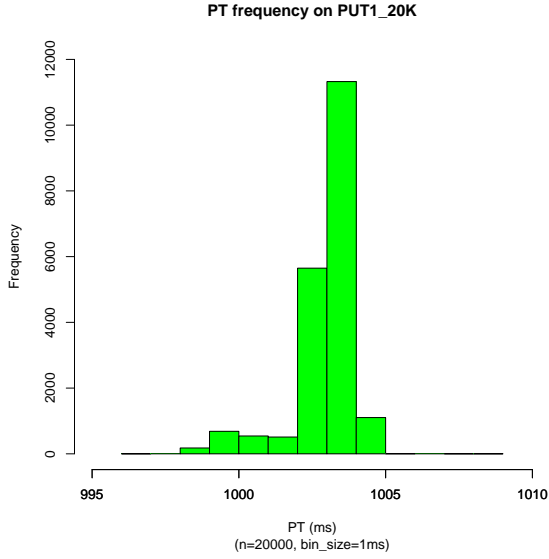


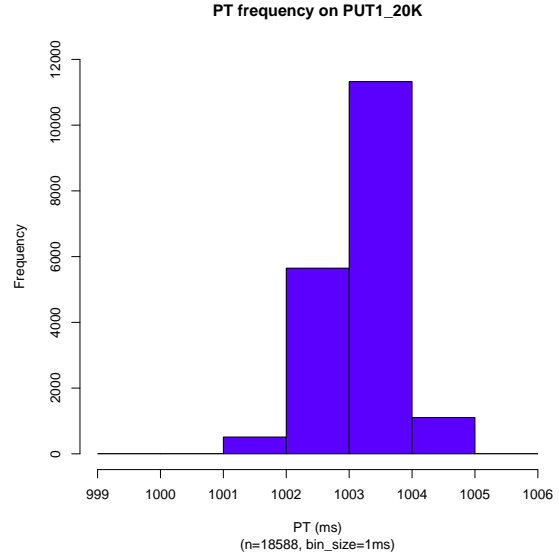
Figure 13: Std. dev. of PT on PUT1 and PUT2 over increasing sample size

| | |
|---------------------|-------------------------------------|
| PUT2 | Program Time |
| incr_work | 2078 msec (at the 5276th iteration) |
| Daemon Processes | Program Time |
| md0_raid1 | 1 msec |
| proc_monitor | 198 msec |
| rhn_check | 460 msec |
| Total | 659 msec |

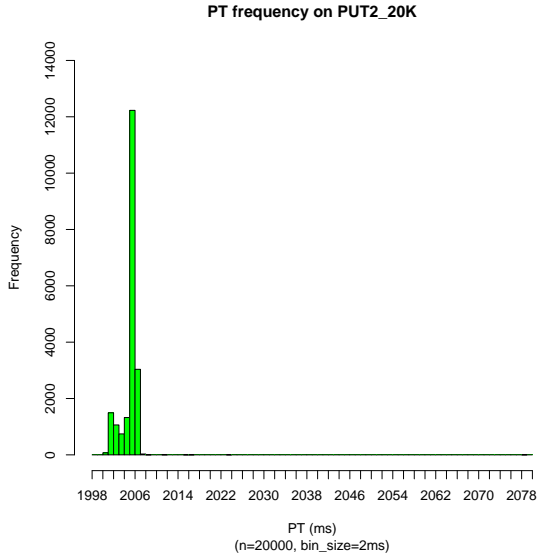
Table 5: The daemon processes captured at the hike of PUT2



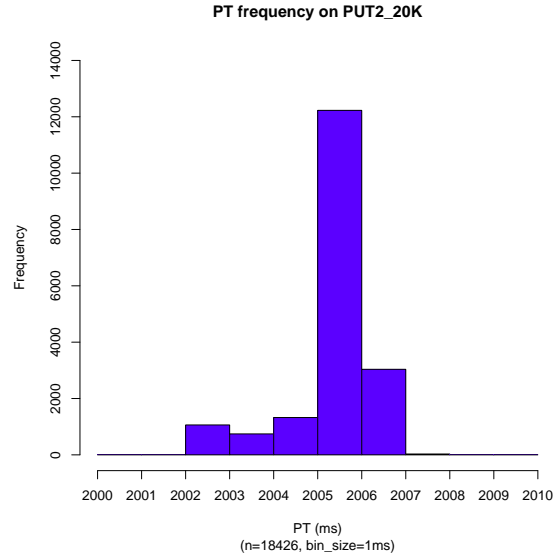
(a) PT frequency on PUT1 by EMPv4 (See Table 2.)



(b) PT frequency on PUT1 by EMPv5 (See Table 2.)

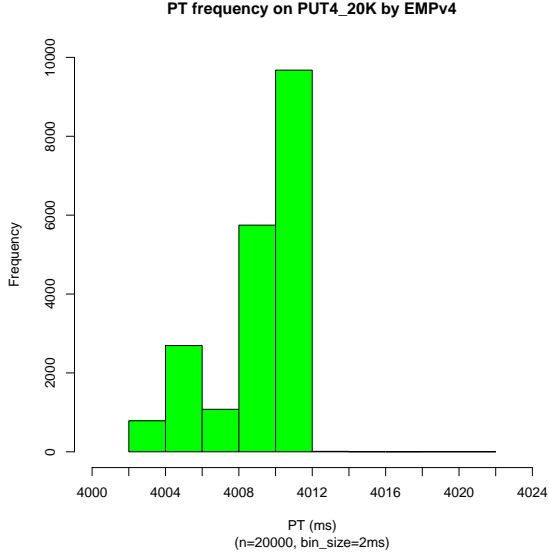


(c) PT frequency on PUT2 by EMPv4 (See Table 2.)

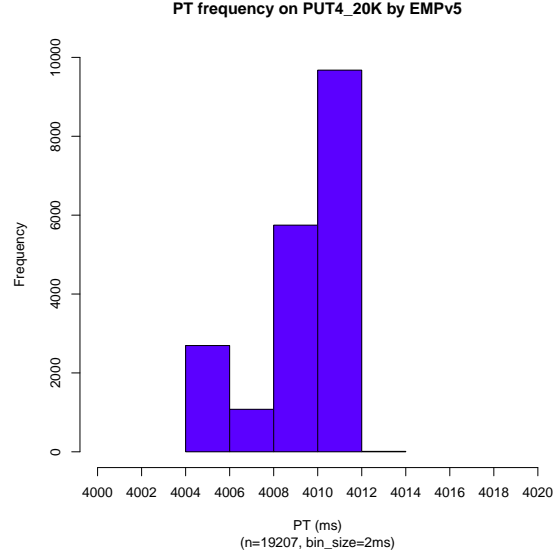


(d) PT frequency on PUT2 by EMPv5 (See Table 2.)

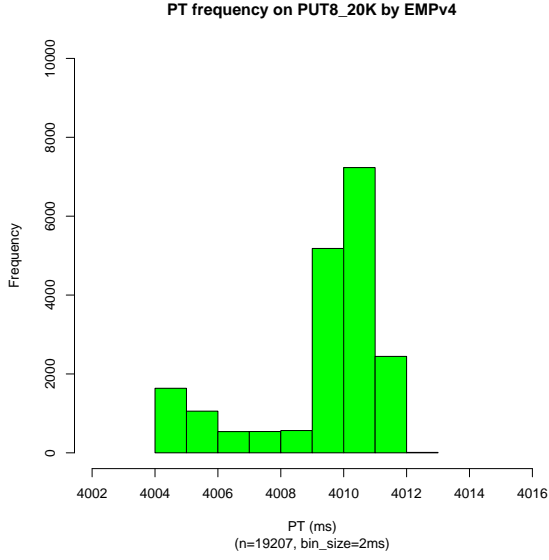
Figure 14: PT Histograms of PUT1 and PUT2 by 20,000 trials



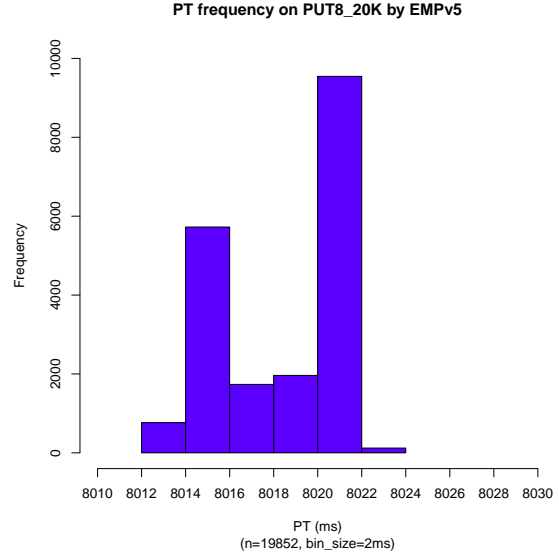
(a) PT frequency on PUT4 by EMPv4 (See Table 2.)



(b) PT frequency on PUT4 by EMPv5 (See Table 2.)



(c) PT frequency on PUT8 by EMPv4 (See Table 2.)



(d) PT frequency on PUT8 by EMPv5 (See Table 2.)

Figure 15: PT Histograms of PUT4 and PUT8 by 20,000 trials

5.2 PUT16

In this experiment we ran PUT16 up to 32,000 from 1,000 times by a factor of two. The relaxed version of EMPv5 (called *EMPv5-relaxed*) uses *five* standard deviations whereas its strict version (called *EMPv5-strict*) does *two* standard deviations for a vertical gap below and above the average. (Young: 2k samples seem most appropriate to represent the whole population of PUT16, in that the standard deviations by EMPv5 on the 2k sample size are almost at peak compared to those of the other sample sizes.)

| Num. of Samples | Std. Dev. (msec) | | |
|-----------------|------------------|---------------|--------------|
| | EMPv4 | EMPv5-relaxed | EMPv5-strict |
| 1,000 | 1.86 | 1.86 | 1.68 |
| 2,000 | 2.20 | 2.12 | 1.81 |
| 4,000 | 2.21 | 1.89 | 1.65 |
| 8,000 | 2.23 | 1.97 | 1.71 |
| 16,000 | 2.07 | 2.00 | 1.61 |
| 32,000 | 1.81 | 1.75 | 1.53 |

Table 6: Standard deviations of PUT16 over increasing sample size

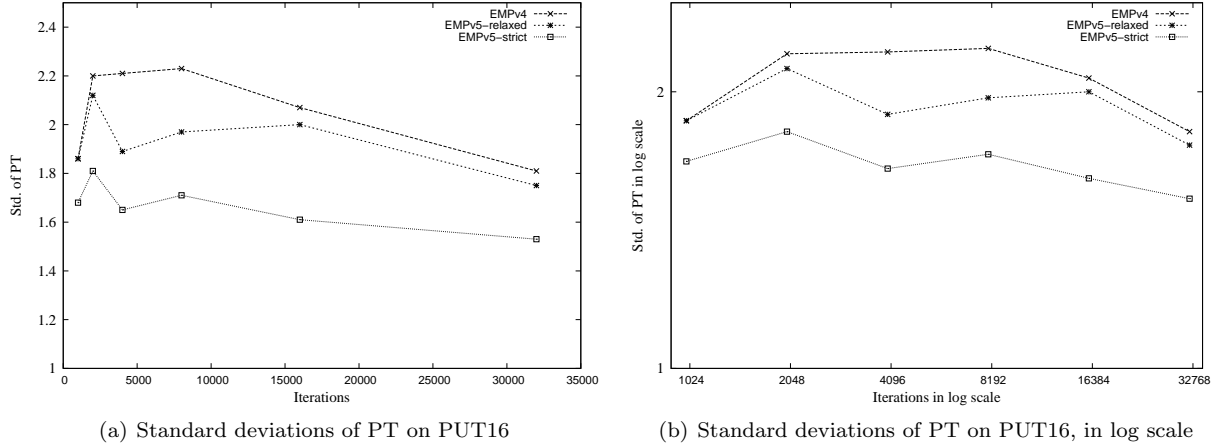


Figure 16: Standard deviations of PT on PUT16 over increasing sample size

5.3 Histograms by EMPv4

We apply EMPv4 to the runs of PUT16 as mentioned above. The following histograms are the results of EMPv4.

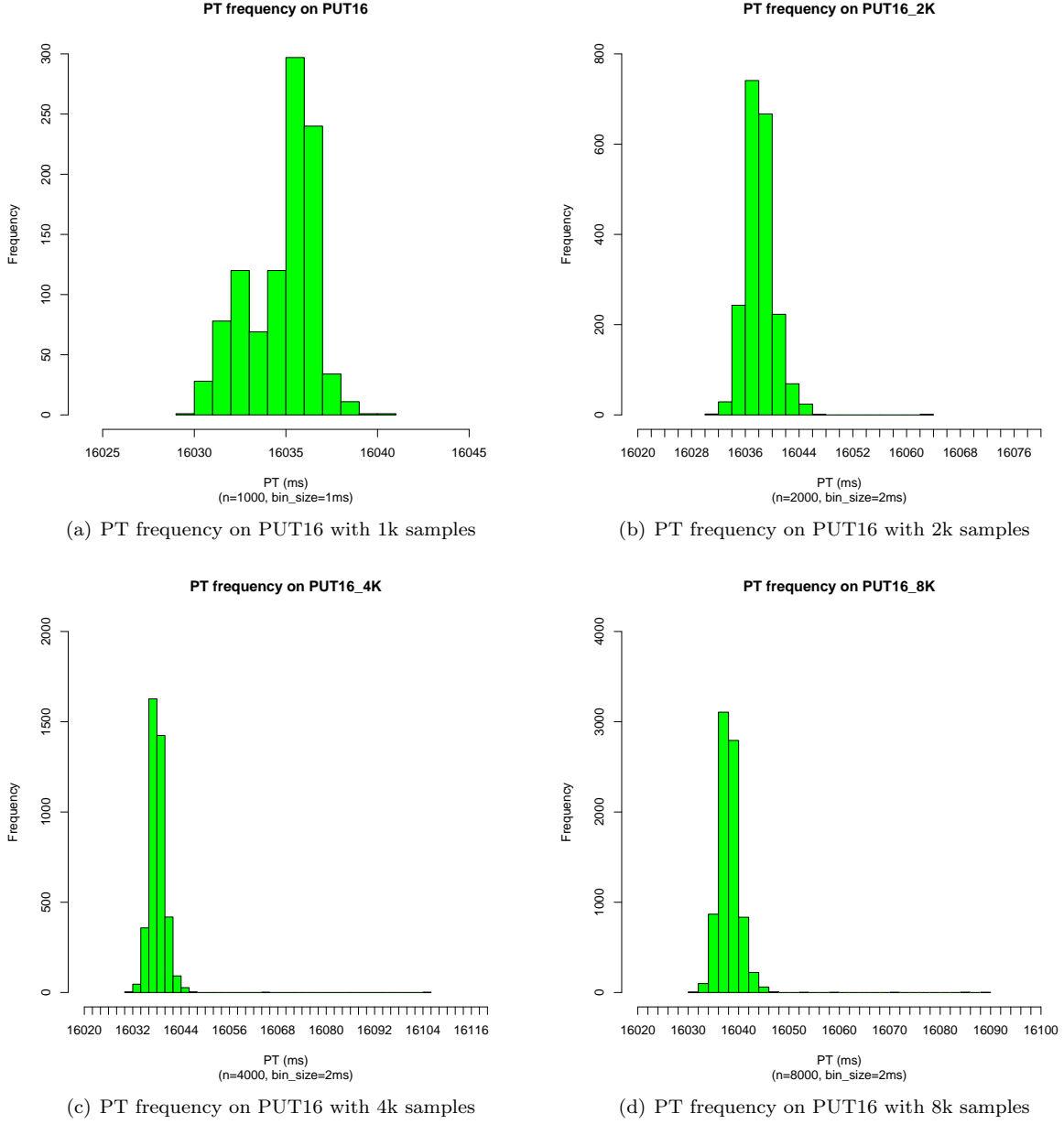
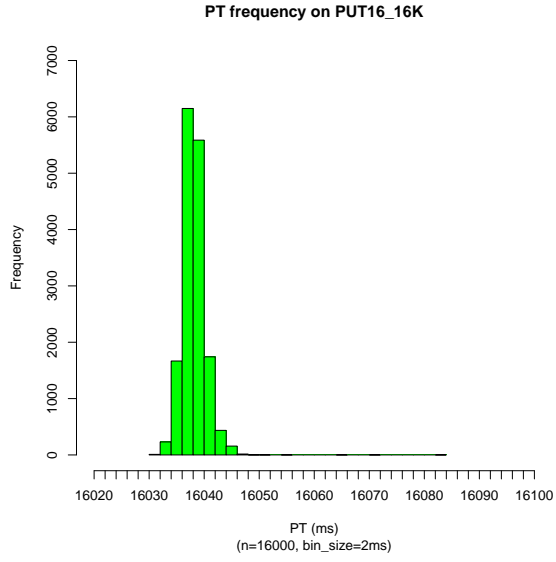
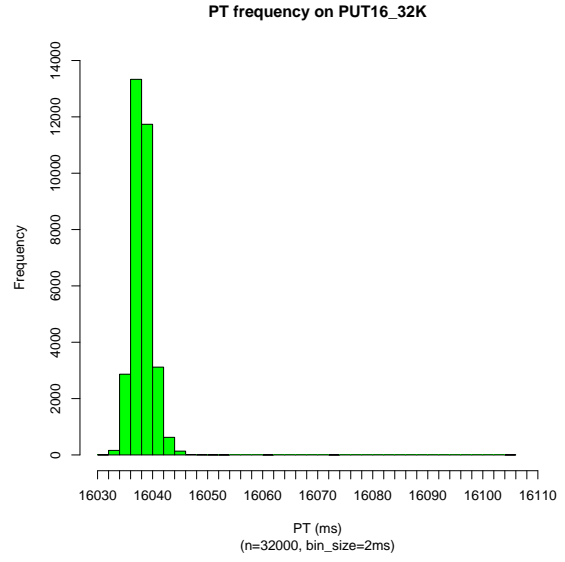


Figure 17: PT histogram of PUT16 by EMPv4, with the sample size increasing from 1k to 8k



(a) PT frequency on PUT16 with 16k samples



(b) PT frequency on PUT16 with 32k samples

Figure 18: PT histogram of PUT16 by EMPv4, with the sample size increasing from 16k to 32k

5.4 Histograms by EMPv5

We now apply EMPv5 to the same data of PUT16. To be more specific, we use EMPv5-strict, by which the following histograms are obtained.

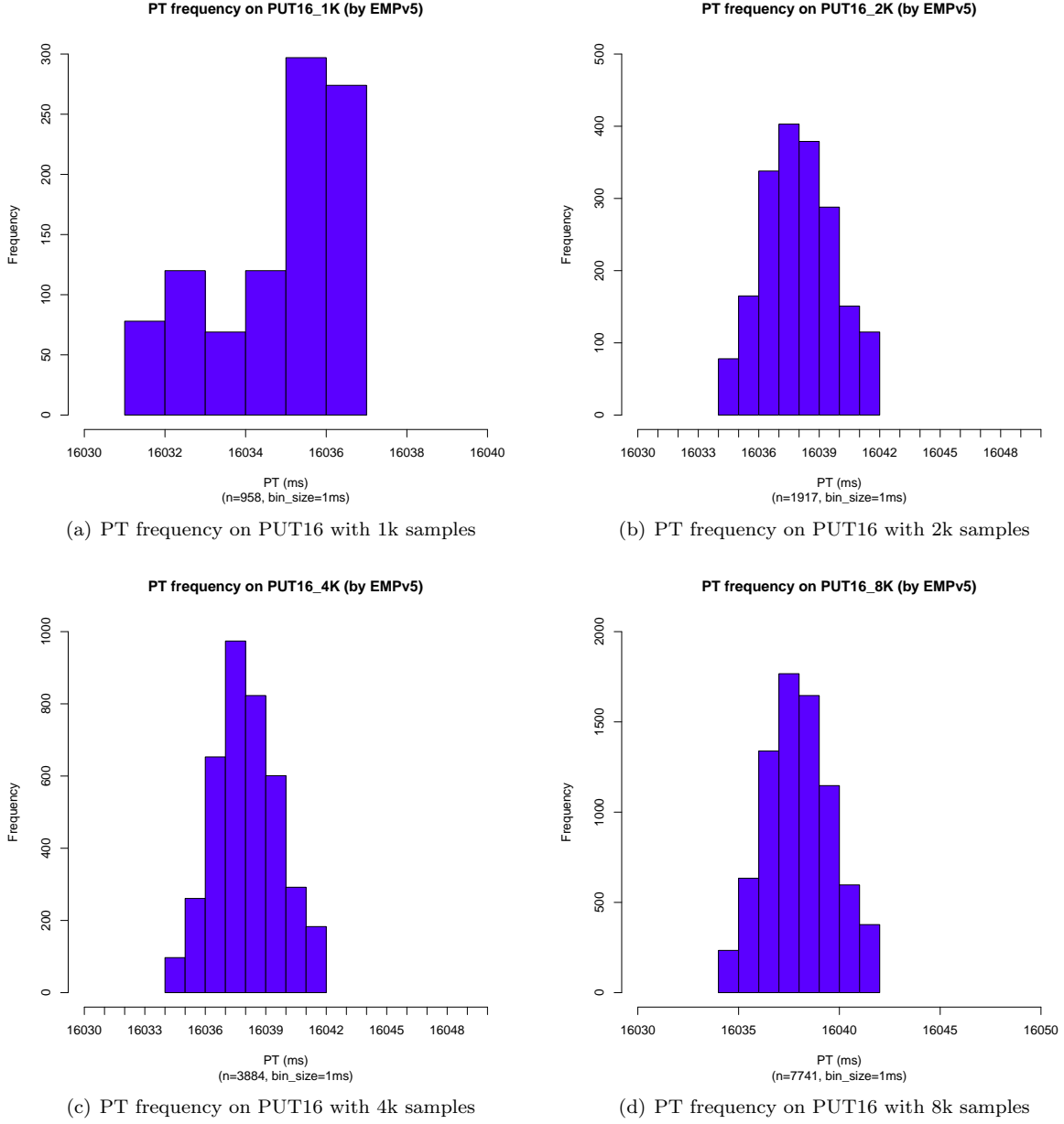
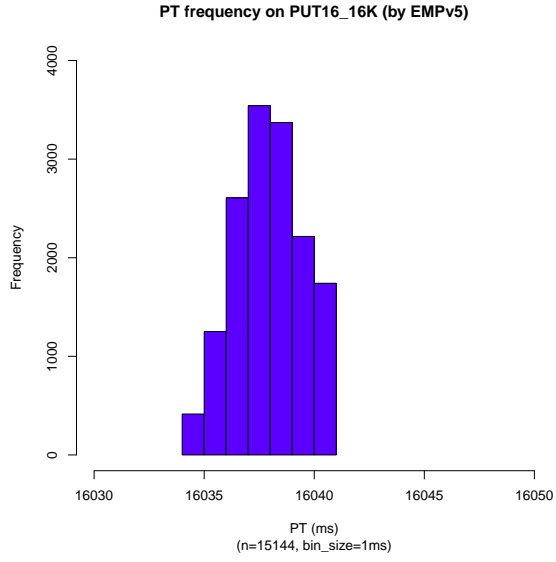
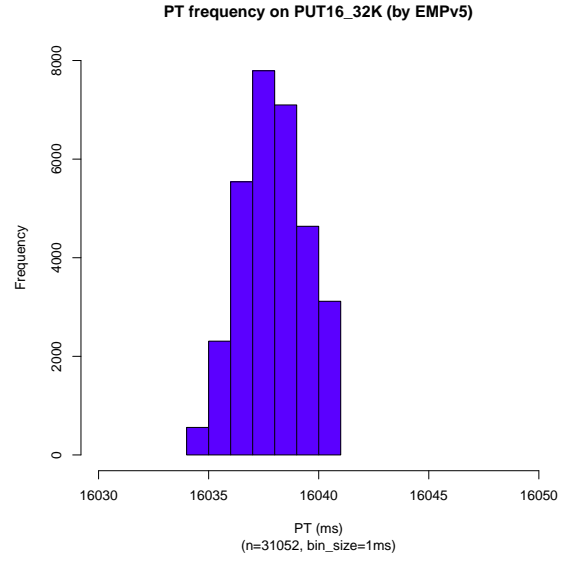


Figure 19: PT histogram of PUT16 by EMPv5, with the sample size increasing from 1k to 8k



(a) PT frequency on PUT16 with 16k samples



(b) PT frequency on PUT16 with 32k samples

Figure 20: PT histogram of PUT16 by EMPv5, with the sample size increasing from 16k to 32k

6 Dual PUT Experiment

In this section we study the characteristics of program times measured in dual PUT experiment, in which the for-loop of PUT is broken up into two equal-sized for-loops (for_1 and for_2) of which elapsed times are individually measured using `gettimeofday()`. The experiment is designed to see whether there exists “internal dependency” of measured times of the two for-loops when PUT is timed. To be more specific, we compute correlation coefficients between corresponding measured times of for_1 and for_2 , within the same run of each PUT. In this experiment we expect that little dependency will be observed within the same run for any PUT.

The base data of the following table and histograms are from Table 2.

| | Corr. Coeff. | Corr. Coeff. with outliers removed | Sample Size (# of regulars) |
|---------|--------------|--|-----------------------------|
| PUT2 | 0.3 | 0.5 | 1,000 |
| PUT4 | -0.07 | -0.2 | 1,000 |
| PUT8 | 0.8 | -0.2 | 1,000 |
| PUT16 | 0.3 | -0.6 | 1,000 |
| PUT32 | 0.01 | -0.4 | 1,000 |
| PUT64 | 0.003 | -0.5 | 1,000 |
| PUT128 | 0.04 | -0.5 | 1,000 |
| PUT256 | 0.004 | -0.1 | 1,000 |
| PUT512 | ? | ? | 1,000 |
| PUT1024 | ? | ? | 1,000 |
| PUT2048 | ? | ? | 1,000 |
| PUT4096 | -0.01 | -0.2 | 500 |

Table 7: Overall statistics of dual PUT experiment

6.1 Scatter Plots

In this section we plot measures times of dual PUT experiments. We provide not only scatter plots of raw data but also those of focused clouds to further look inside.

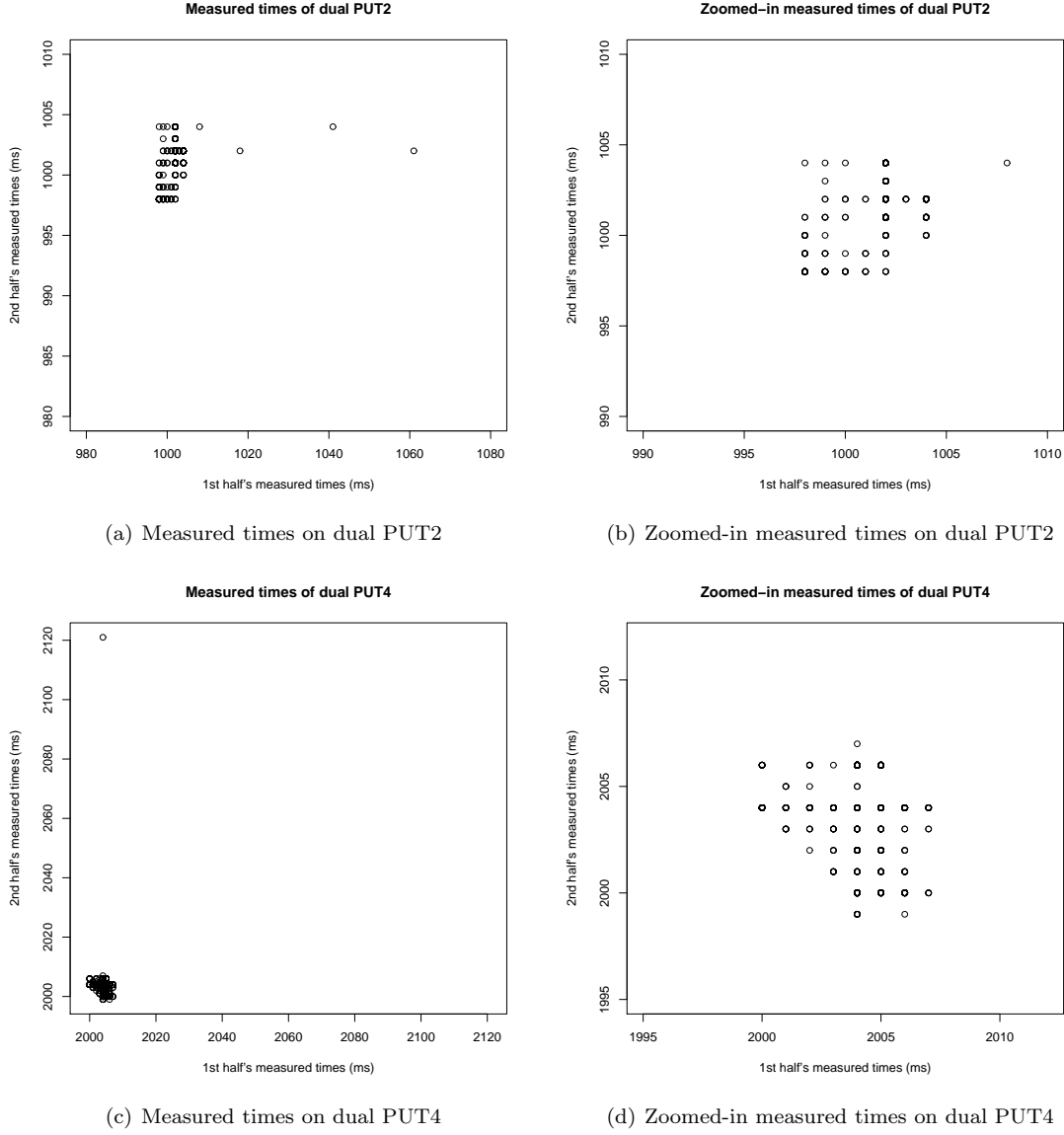
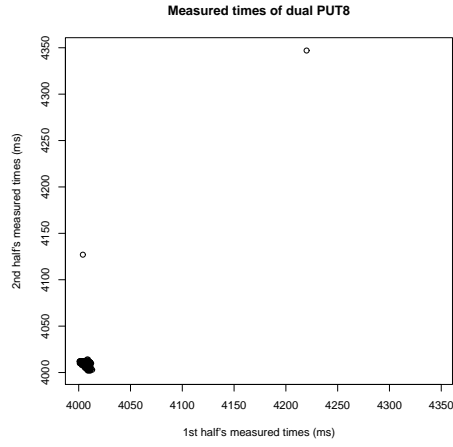
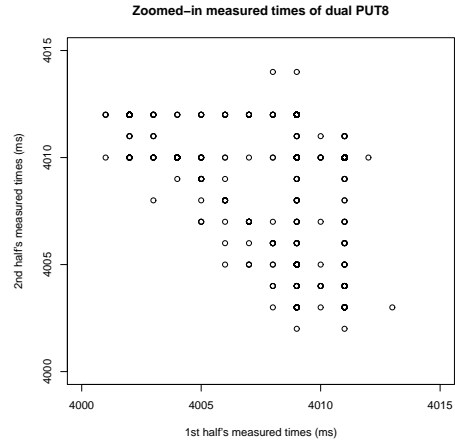


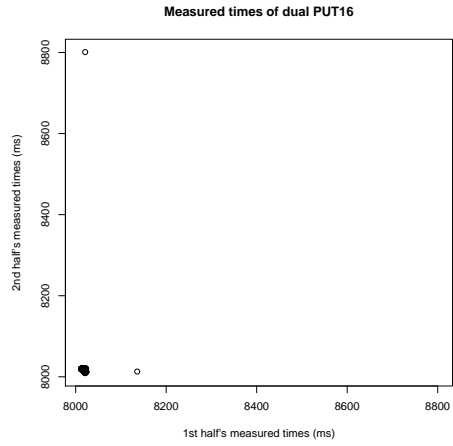
Figure 21: Scatter plots on dual PUT2~PUT8



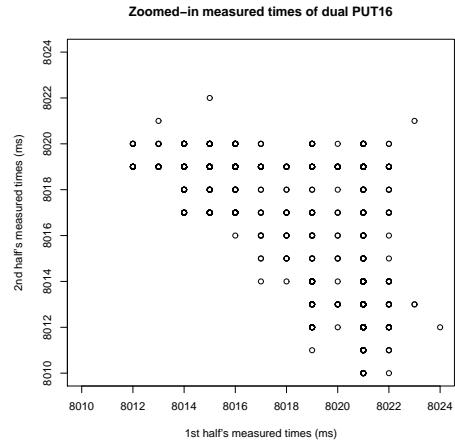
(a) Measured times on dual PUT8



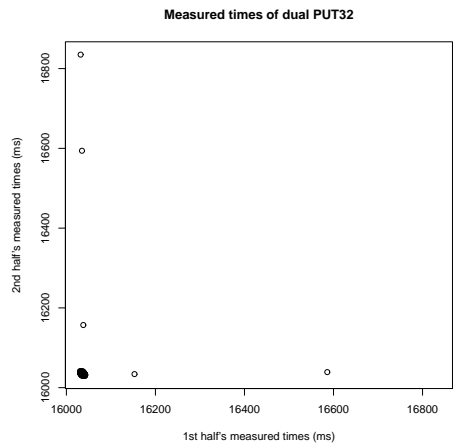
(b) Zoomed-in measured times on dual PUT8



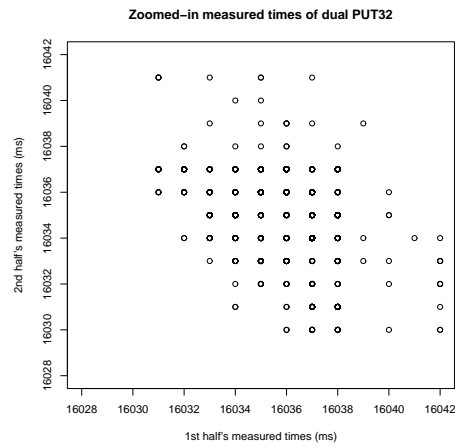
(c) Measured times on dual PUT16



(d) Zoomed-in measured times on dual PUT16

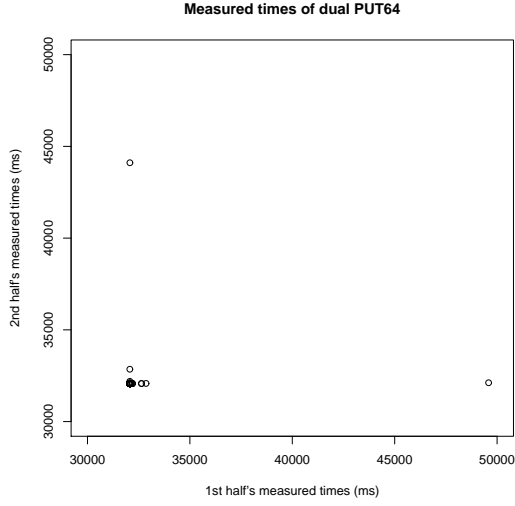


(e) Measured times on dual PUT32

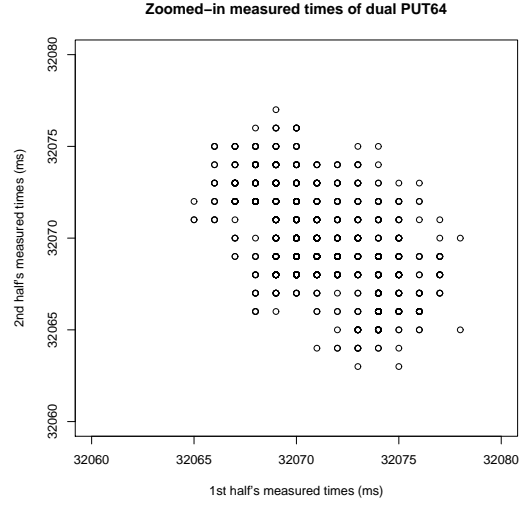


(f) Zoomed-in measured times on dual PUT32

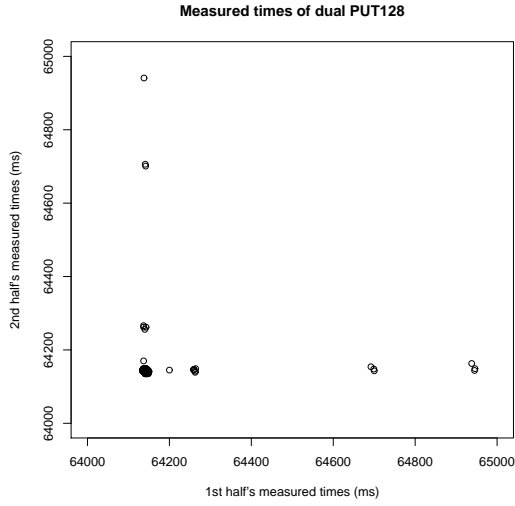
Figure 22: Scatter plots on dual PUT8~PUT32



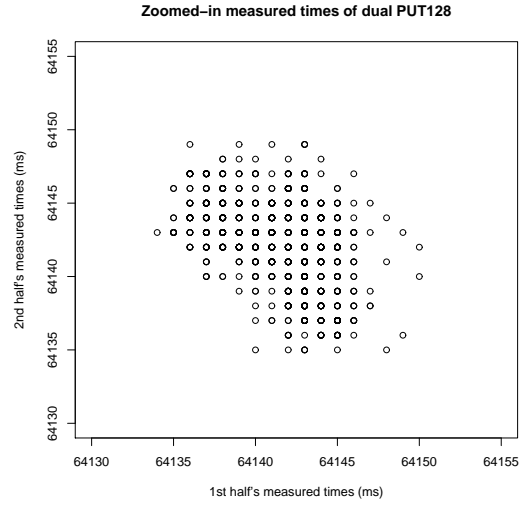
(a) Measured times on dual PUT64



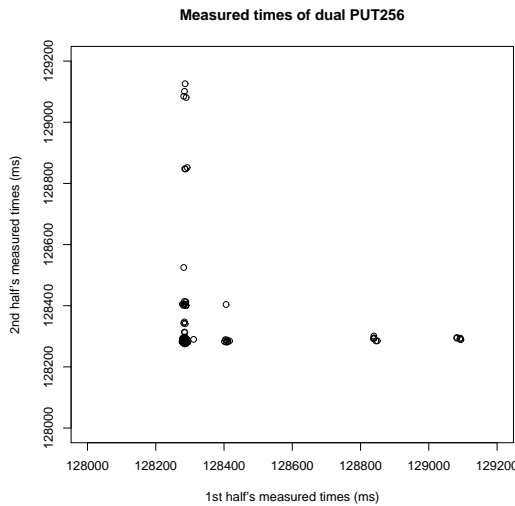
(b) Zoomed-in measured times on dual PUT64



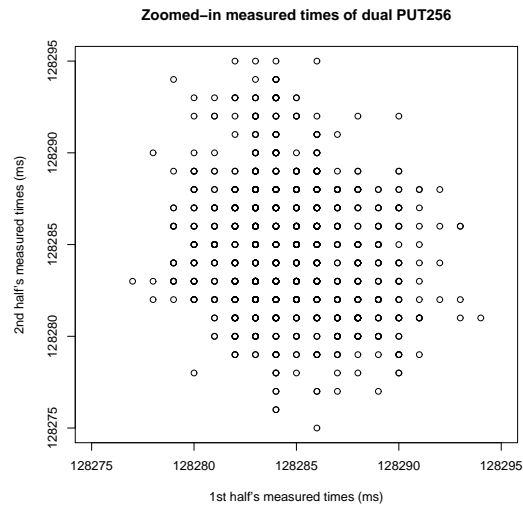
(c) Measured times on dual PUT128



(d) Zoomed-in measured times on dual PUT128

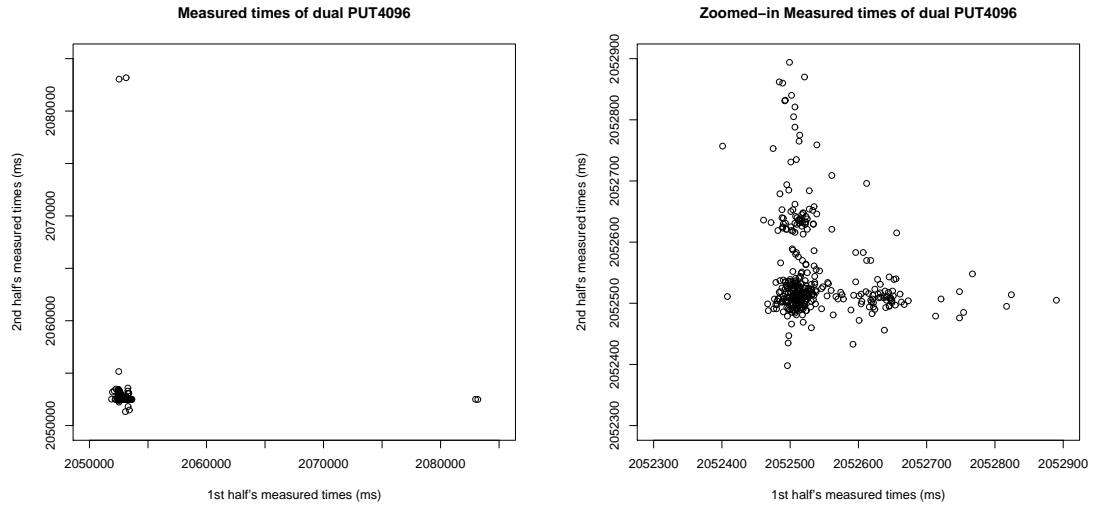


(e) Measured times on dual PUT256



(f) Zoomed-in measured times on dual PUT256

Figure 23: Scatter plots on dual PUT64~PUT256



(a) Measured times on dual PUT4096

(b) Zoomed-in measured times on dual PUT4096

Figure 24: Scatter plots on dual PUT4096

6.2 Program Time Comparison

In this section we perform one-to-one comparison on measured times of parts I and II for the same iteration of each PUT.

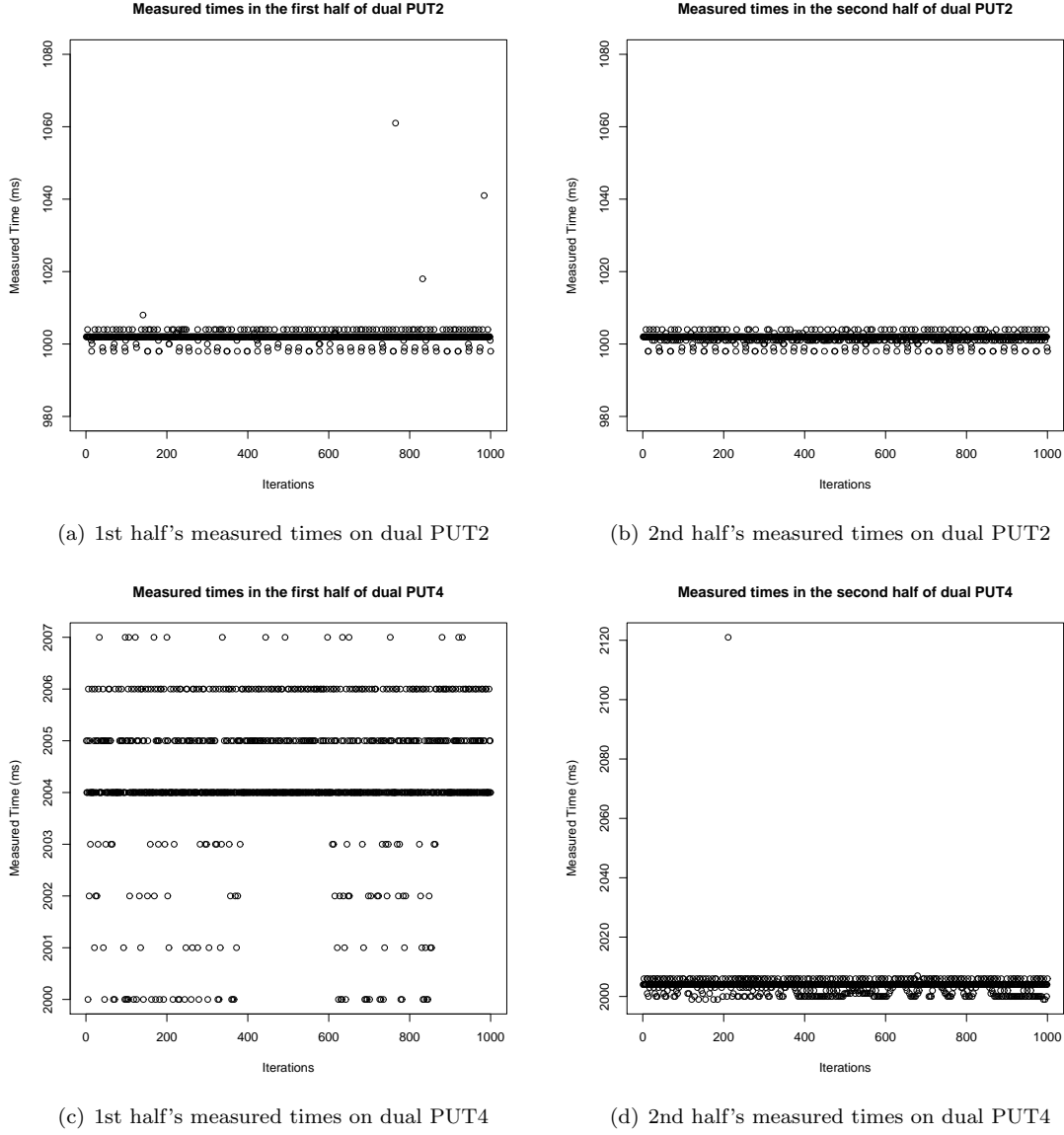
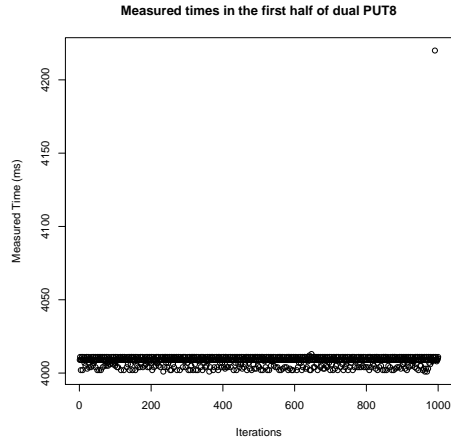
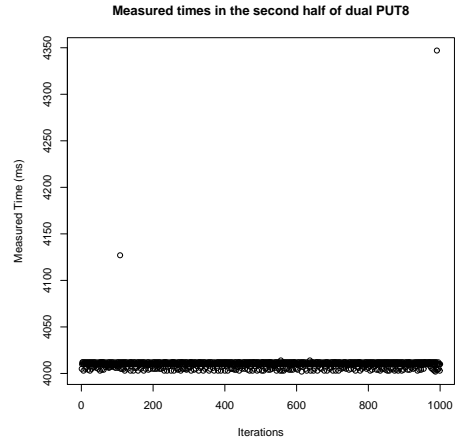


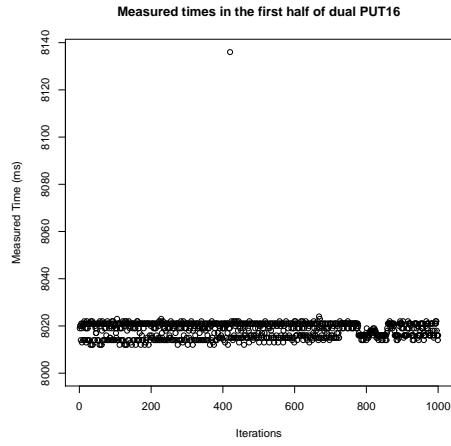
Figure 25: Measured time comparison on dual PUT2~PUT8



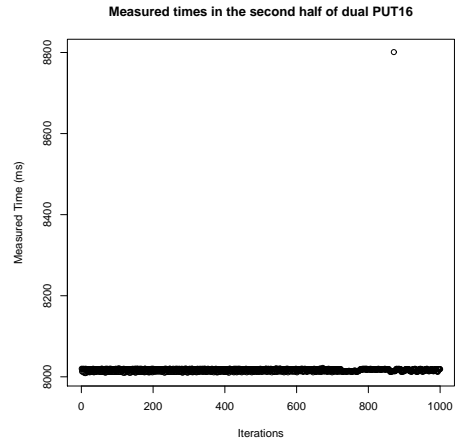
(a) 1st half's measured times on dual PUT8



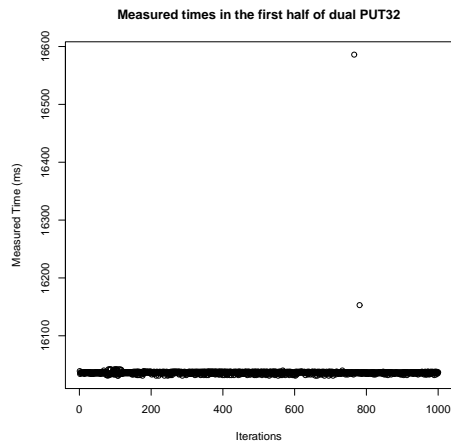
(b) 2nd half's measured times on dual PUT8



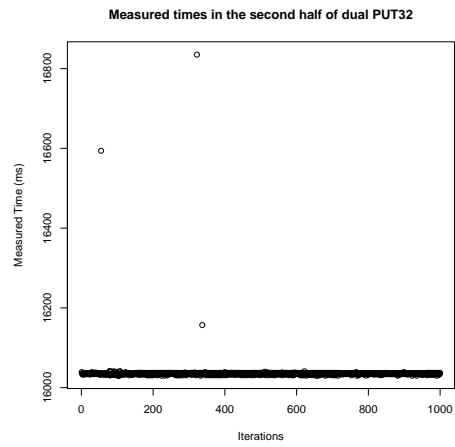
(c) 1st half's measured times on dual PUT16



(d) 2nd half's measured times on dual PUT16

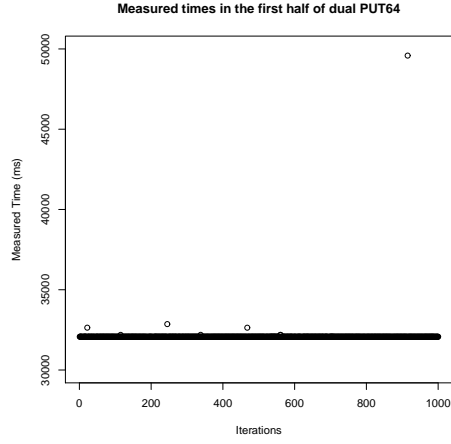


(e) 1st half's measured times on dual PUT32

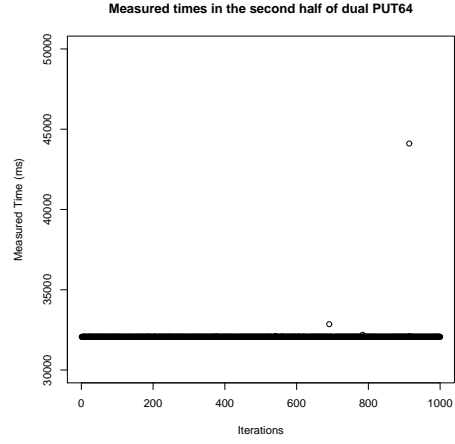


(f) 2nd half's measured times on dual PUT32

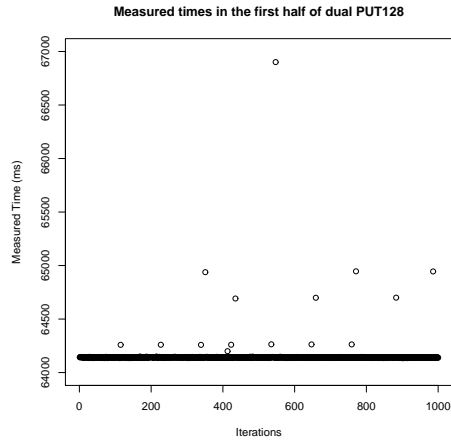
Figure 26: Measured time comparison on dual PUT8~PUT16



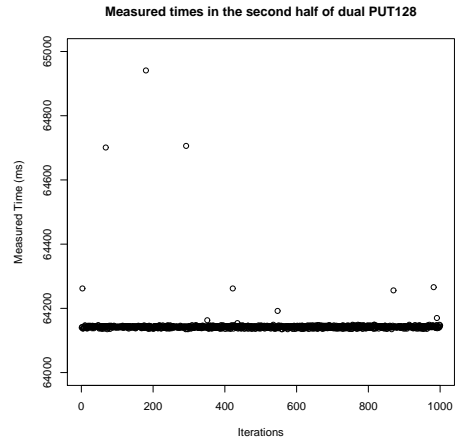
(a) 1st half's measured times on dual PUT64



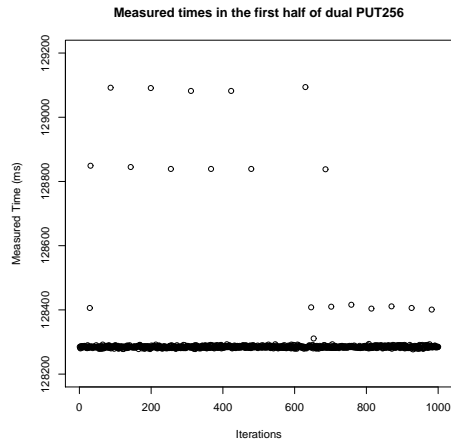
(b) 2nd half's measured times on dual PUT64



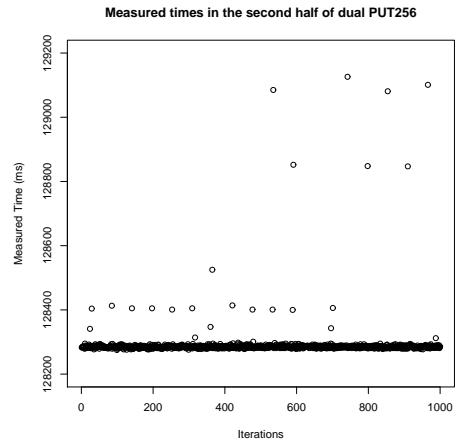
(c) 1st half's measured times on dual PUT128



(d) 2nd half's measured times on dual PUT128

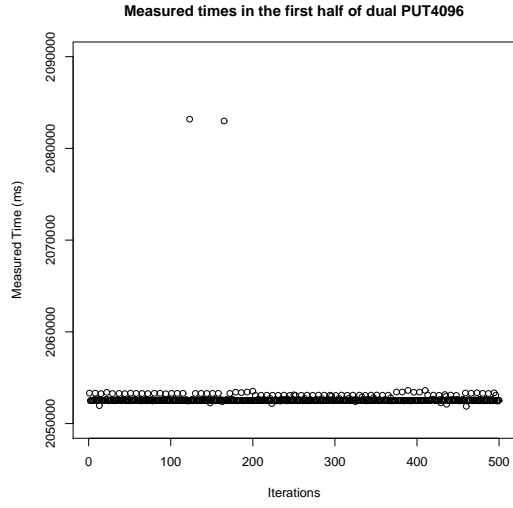


(e) 1st half's measured times on dual PUT256

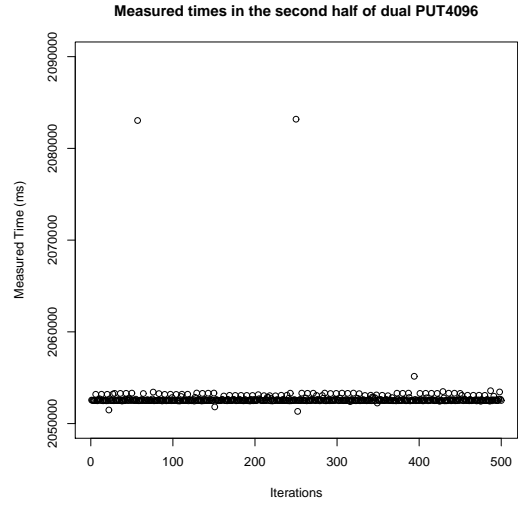


(f) 2nd half's measured times on dual PUT256

Figure 27: Measured time comparison on dual PUT64 and PUT128



(a) 1st half's measured times on dual PUT4096



(b) 2nd half's measured times on dual PUT4096

Figure 28: Measured time comparison on dual PUT4096

7 Successive Iterations' Dependency

In this section we plot measured times of each iteration pair consisting of odd and even iterations. Specifically, the measured times at adjacent, odd and even iterations consist of x and y coordinates and plotted. The data are described in Table 1.

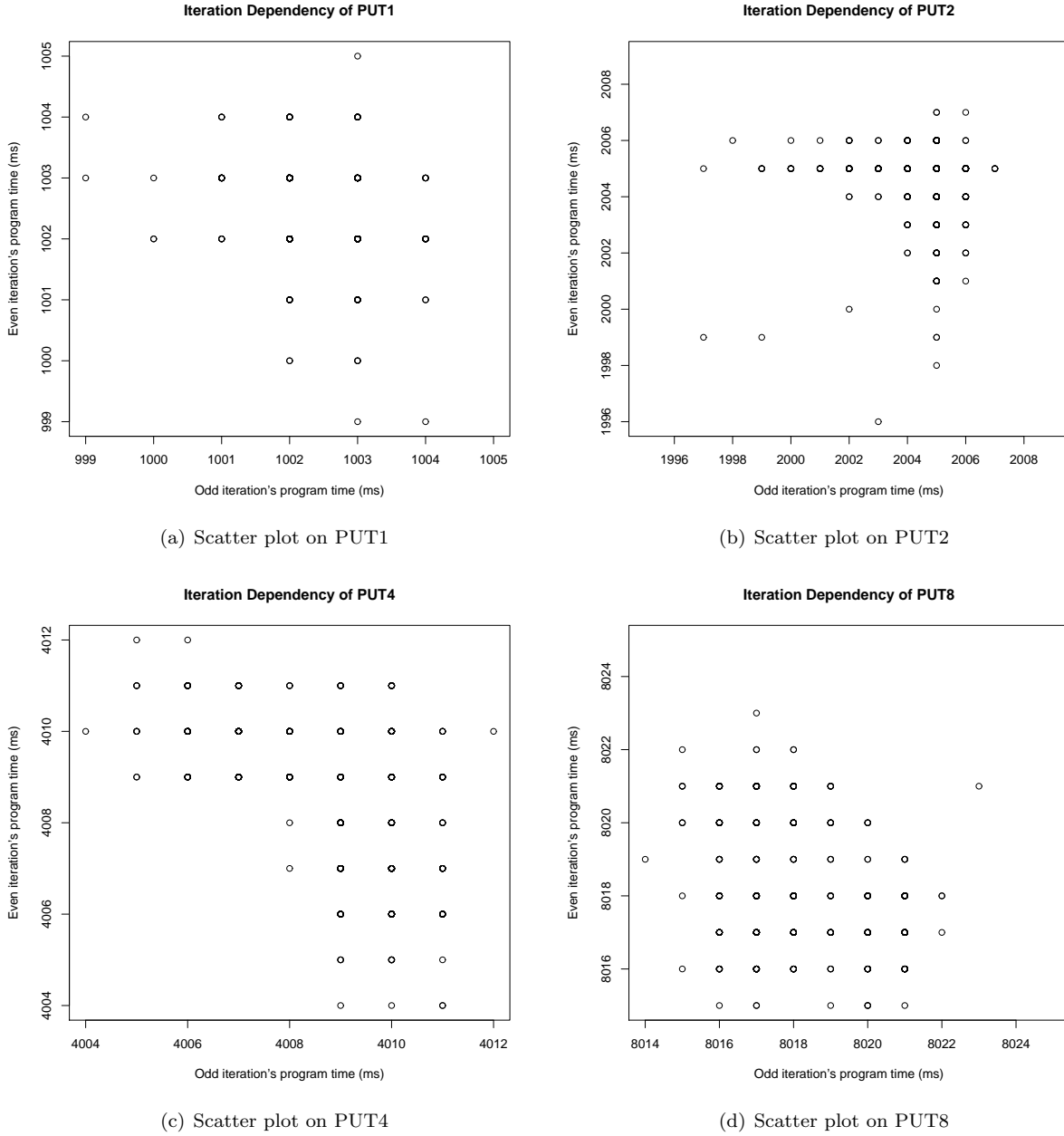
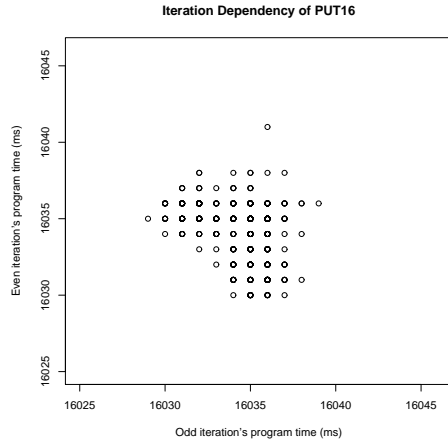
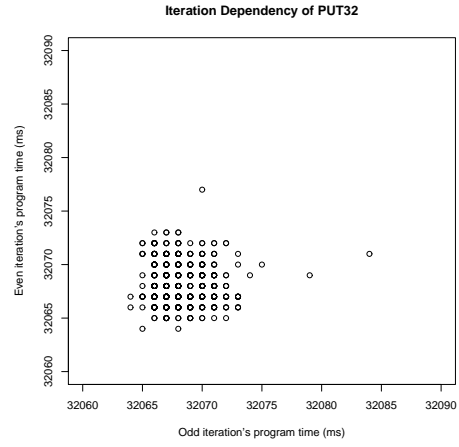


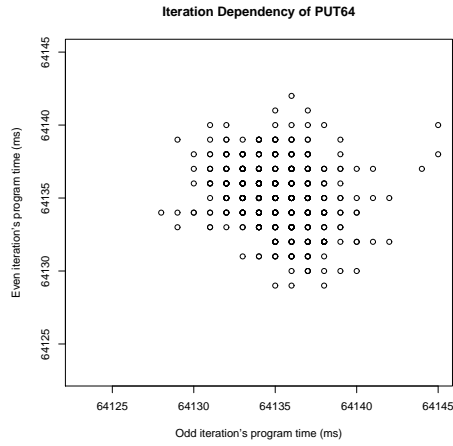
Figure 29: Iteration dependency on PUT1~PUT8



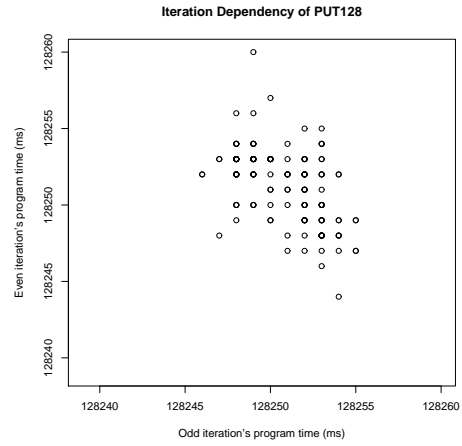
(a) Scatter plot on PUT16



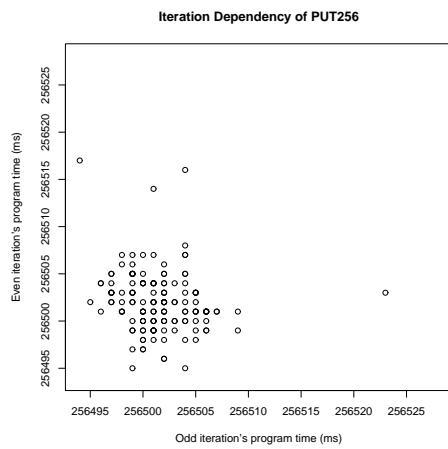
(b) Scatter plot on PUT32



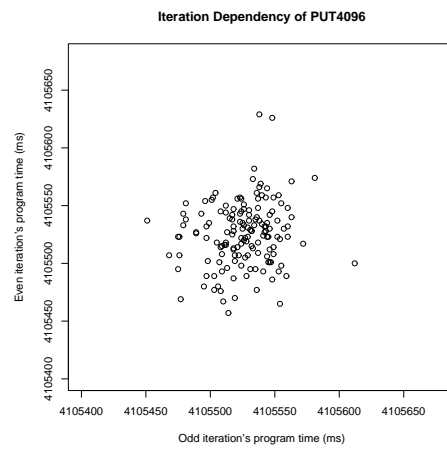
(c) Scatter plot on PUT64



(d) Scatter plot on PUT128

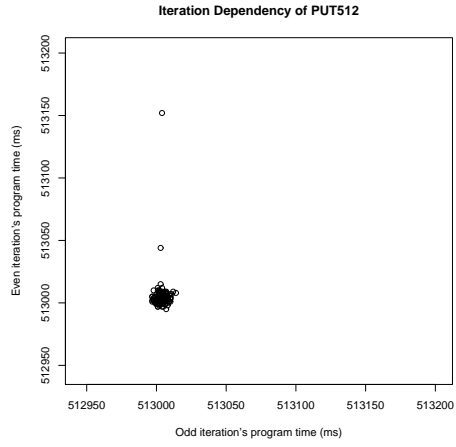


(e) Scatter plot on PUT256

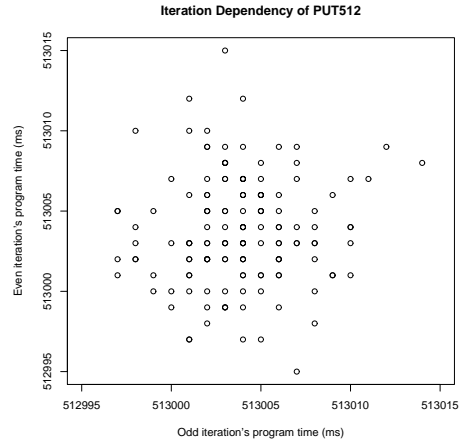


(f) Scatter plot on PUT4096

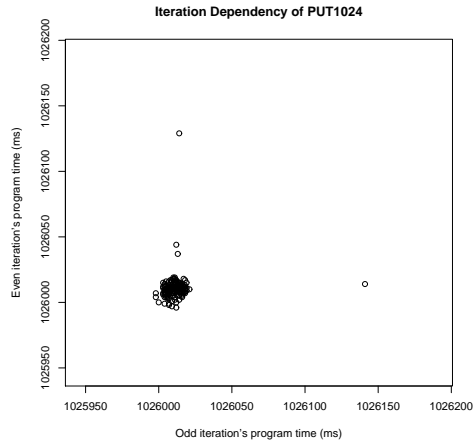
Figure 30: Iteration Dependency on PUT16~PUT256 and PUT4096



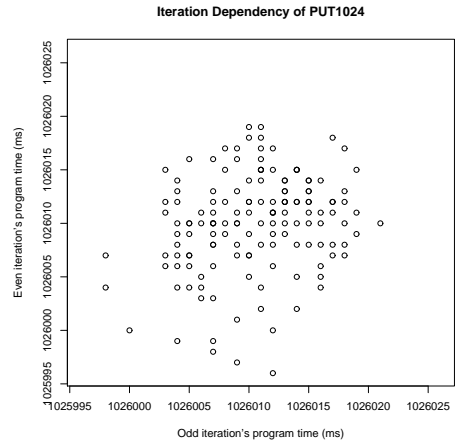
(a) Scatter plot on PUT512



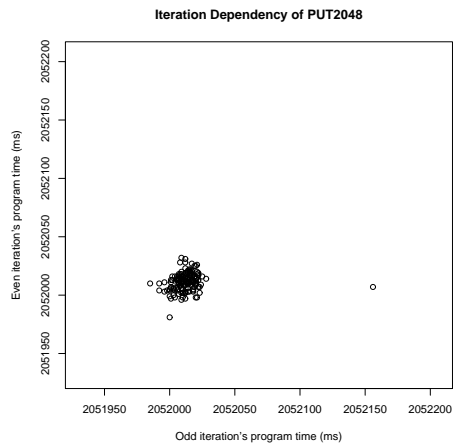
(b) Scatter plot on trimmed data of PUT512



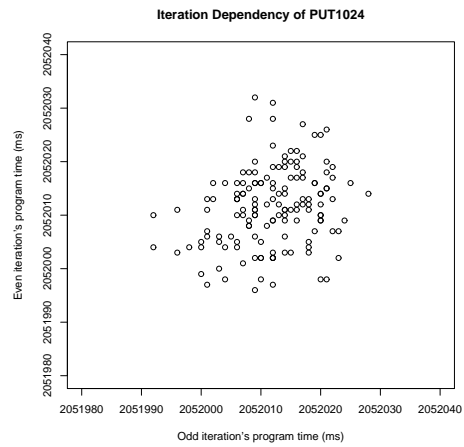
(c) Scatter plot on PUT1024



(d) Scatter plot on trimmed data of PUT1024

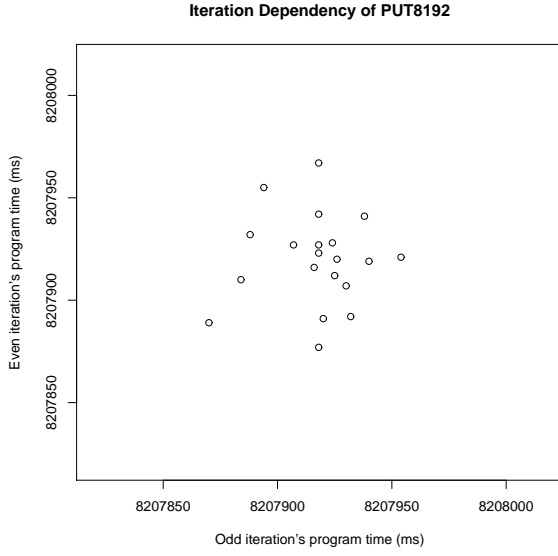


(e) Scatter plot on PUT2048

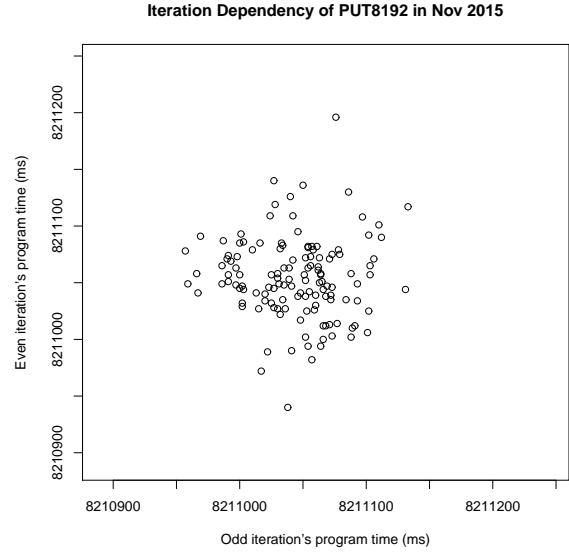


(f) Scatter plot on trimmed data of PUT2048

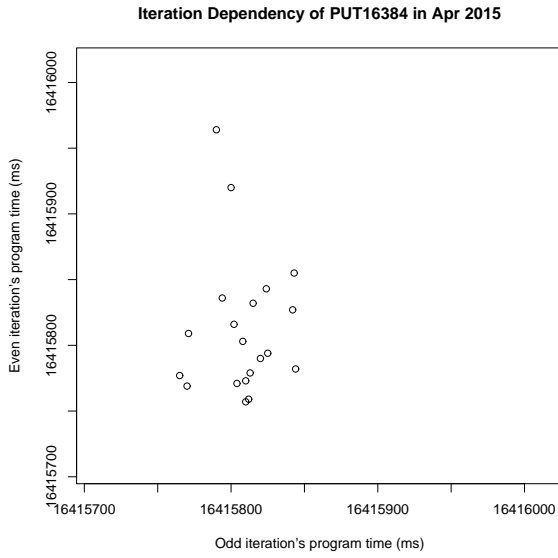
Figure 31: Iteration dependency on PUT512, PUT1024, and PUT2048



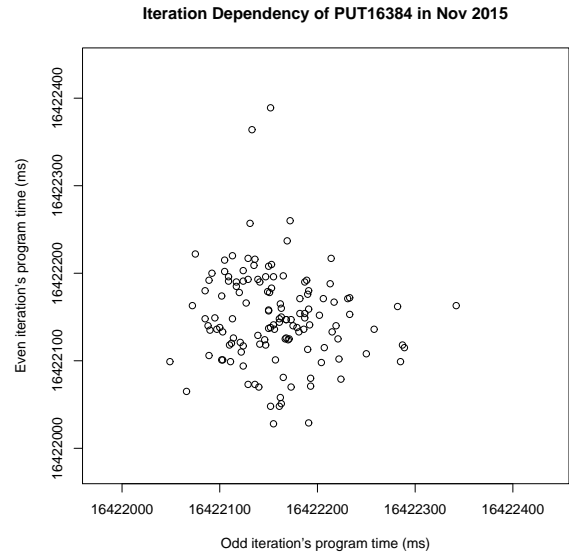
(a) Scatter plot on PUT8192 in Apr 2015



(b) Scatter plot on PUT8192 in Nov 2015



(c) Scatter plot on PUT16384 in Apr 2015



(d) Scatter plot on PUT16384 in Nov 2015

Figure 32: Iteration dependency on PUT8192~PUT16384

8 Influence of Daemon Process on Program Time Measurement

In this section we investigate correlations of program times between PUT and a group of daemon processes. The base data are from Table 1. It seems that the longer PUT, the stronger correlation of its PT with that of daemon processes.

| PUT | Correlation Coefficient by EMPv4 | Correlation Coefficient by EMPv5-relaxed |
|-----------------|----------------------------------|--|
| PUT1 | -0.2 | -0.2 |
| PUT2 | -0.005 | -0.009 |
| PUT4 | -0.05 | -0.05 |
| PUT8 | 0.1 | 0.1 |
| PUT16 | 0.1 | 0.1 |
| PUT32 | 0.3 | 0.15 |
| PUT64 | 0.2 | 0.2 |
| PUT128 | 0.2 | 0.2 |
| PUT256 | 0.4 | 0.4 |
| PUT512 | 0.9 | 0.6 |
| PUT1024 | 0.9 | 0.2 |
| PUT2048 | 0.8 | 0.24 |
| PUT4096 | 0.4 | 0.4 |
| PUT8192 in Apr | 0.4 | 0.4 |
| PUT8192 in Nov | 0.3 | 0.3 |
| PUT16384 in Apr | 0.4 | 0.8 |
| PUT16384 in Nov | 0.5 | 0.5 |

Table 8: Correlation Coefficients between Program Times of Daemon and PUT by EMPv4 and EMPv5

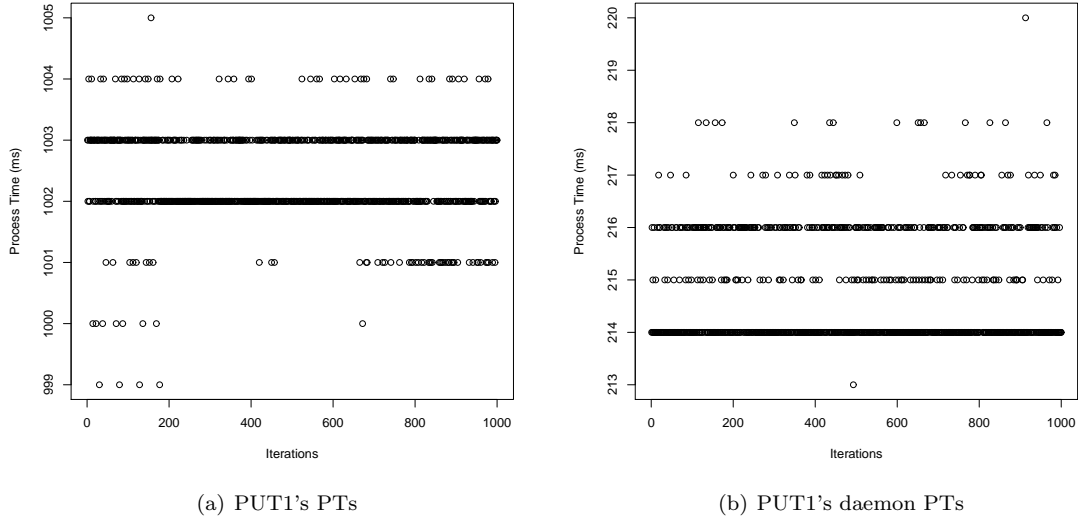
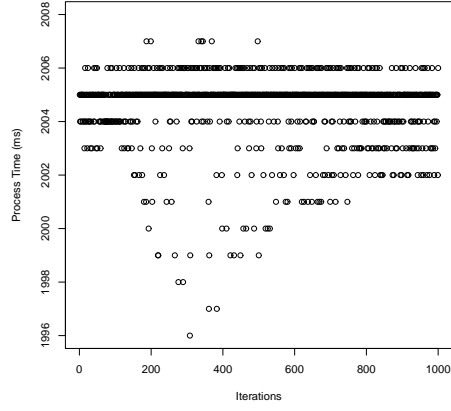
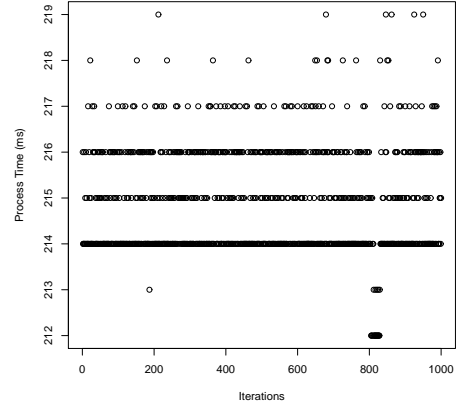


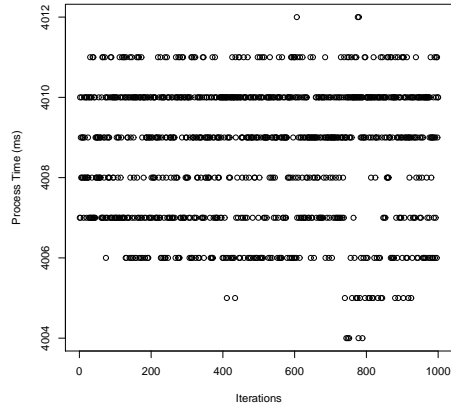
Figure 33: Program times between PUT1 vs. Daemon processes



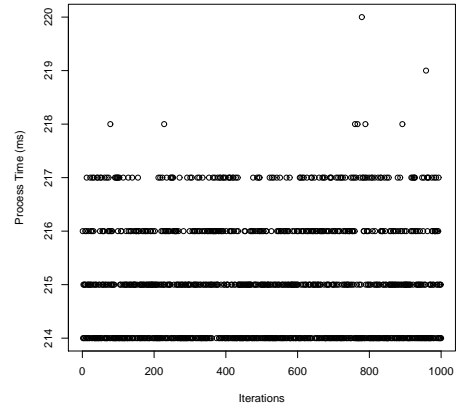
(a) PUT2's PTs



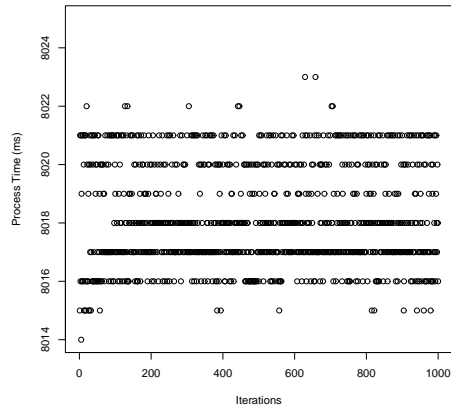
(b) PUT2's daemon PTs



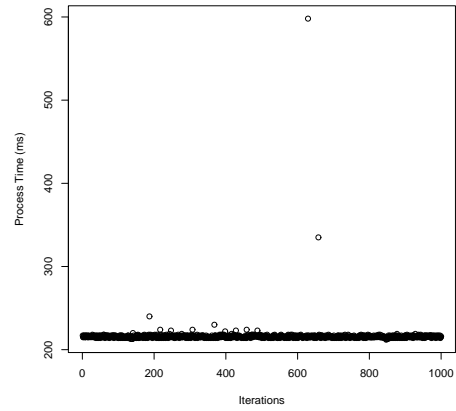
(c) PUT4's PTs



(d) PUT4's daemon PTs

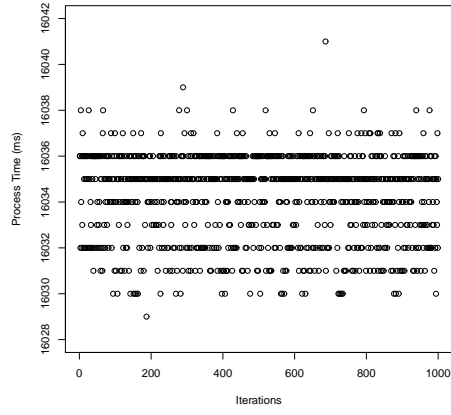


(e) PUT8's PTs

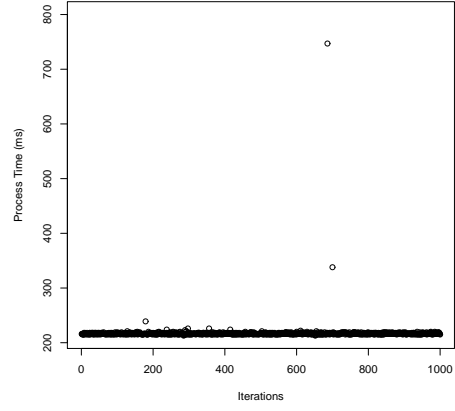


(f) PUT8's daemon PTs

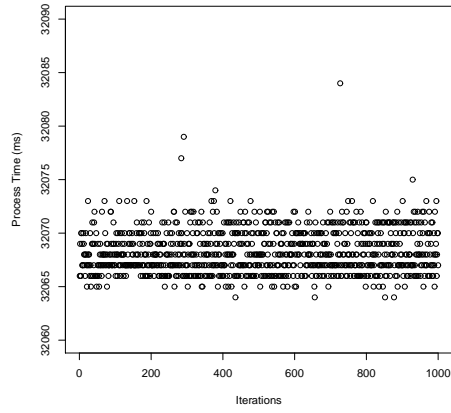
Figure 34: Program times between PUT2~PUT8 vs. Daemon processes



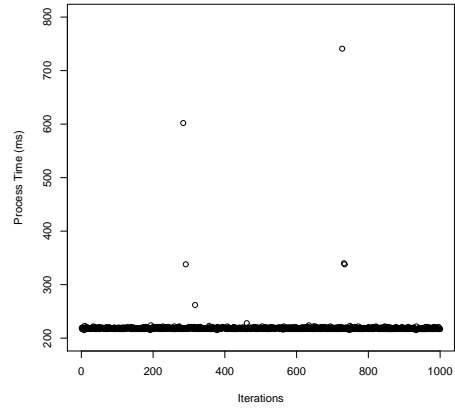
(a) PUT16's PTs



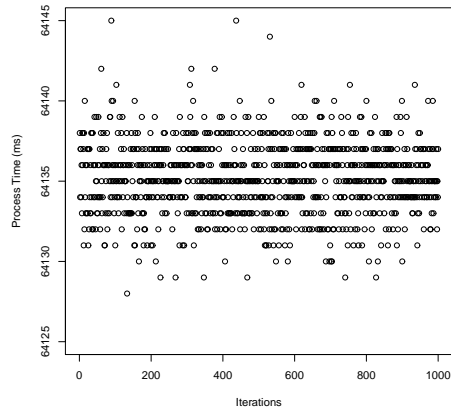
(b) PUT16's daemon PTs



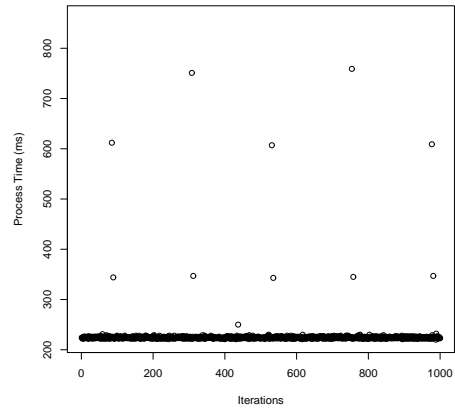
(c) PUT32's PTs



(d) PUT32's daemon PTs

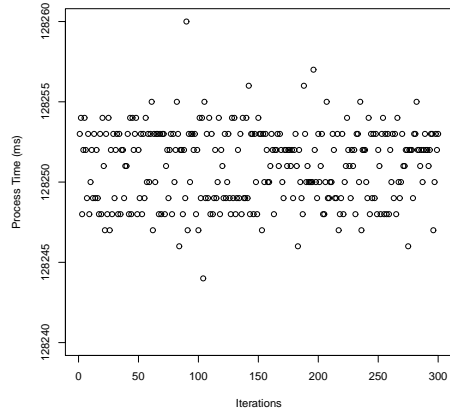


(e) PUT64's PTs

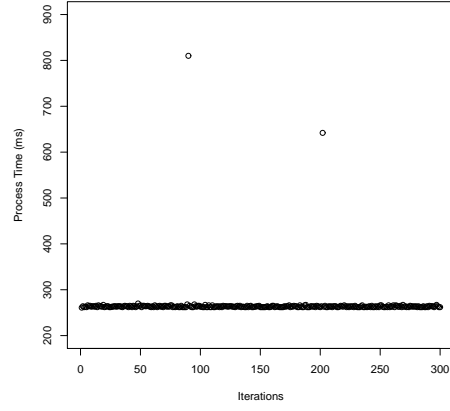


(f) PUT64's daemon PTs

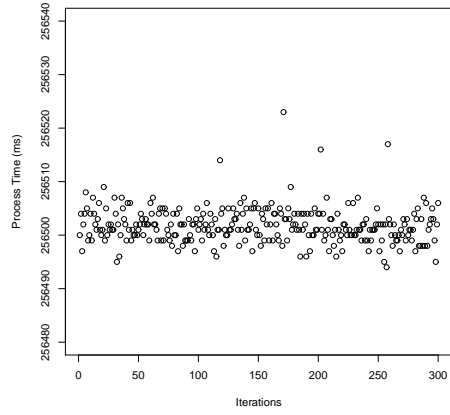
Figure 35: Program times between PUT16~PUT64 vs. Daemon processes



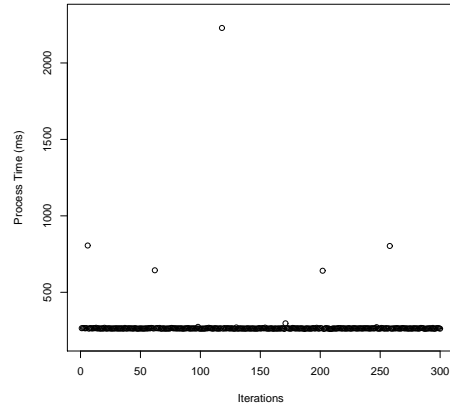
(a) PUT128's PTs



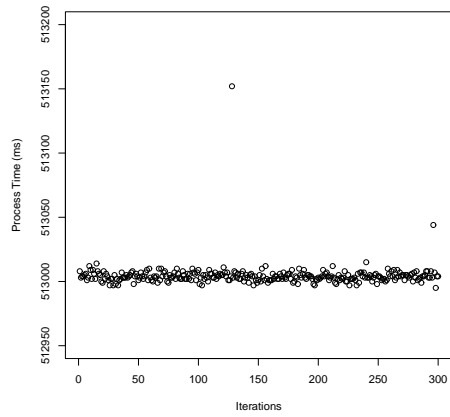
(b) PUT128's daemon PTs



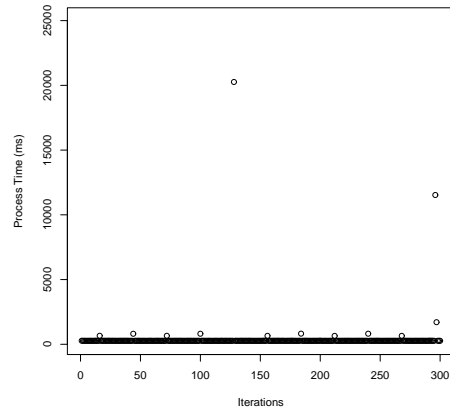
(c) PUT256's PTs



(d) PUT256's daemon PTs

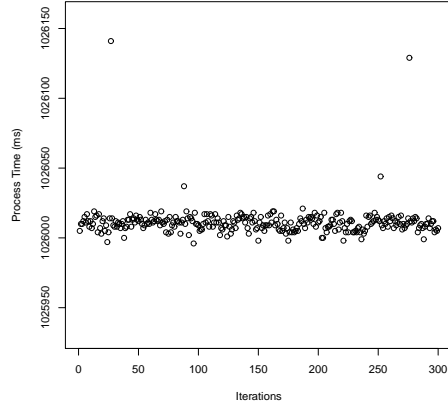


(e) PUT512's PTs

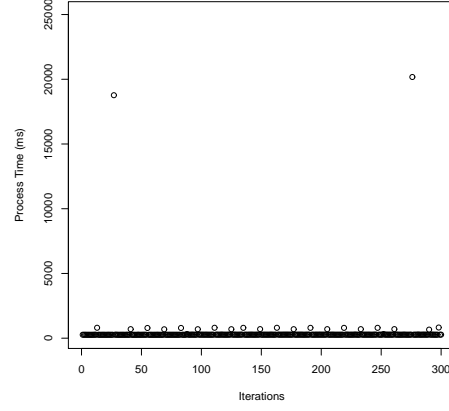


(f) PUT512's daemon PTs

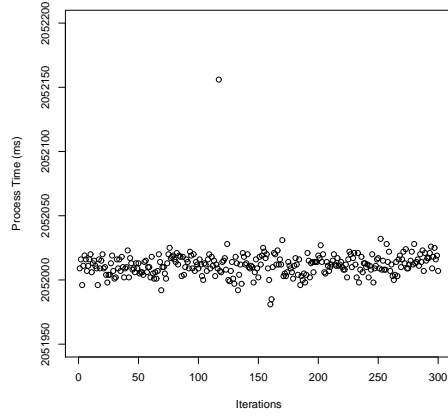
Figure 36: Program times between PUT128~PUT512 vs. Daemon processes



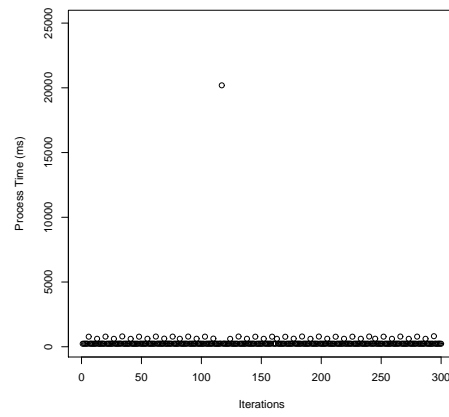
(a) PUT1024's PTs



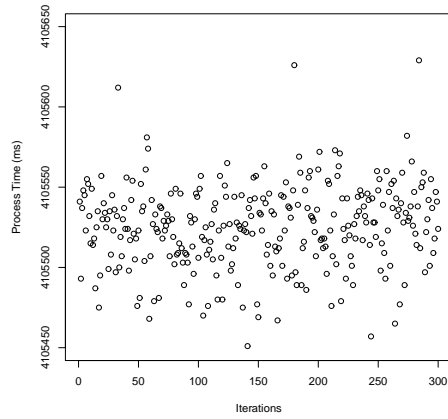
(b) PUT1024's daemon PTs



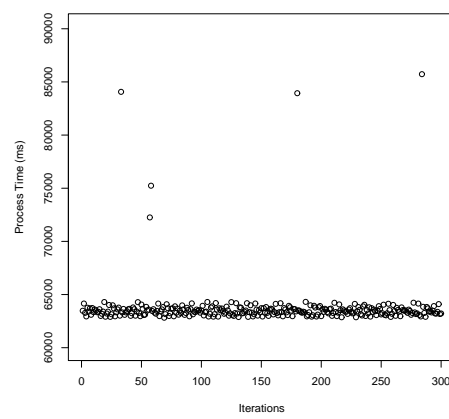
(c) PUT2048's PTs



(d) PUT2048's daemon PTs

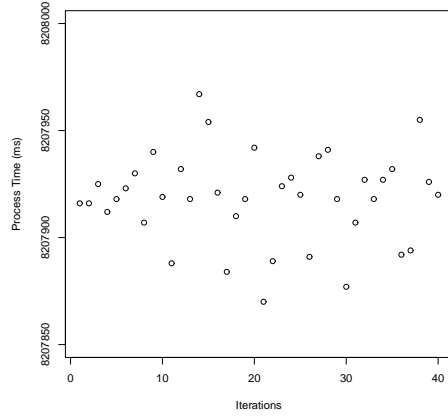


(e) PUT4096's PTs

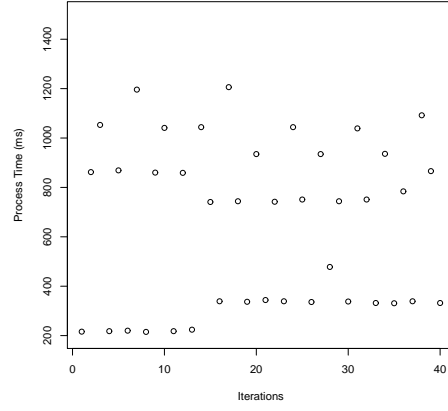


(f) PUT4096's daemon PTs

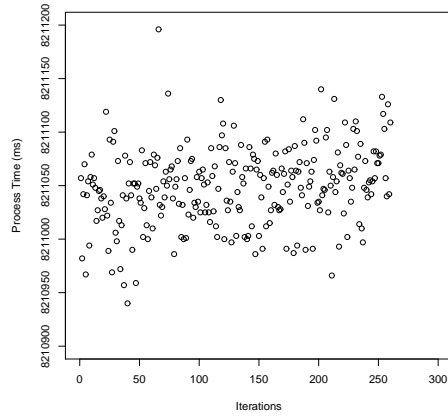
Figure 37: Program times between PUT1024~PUT4096 vs. Daemon processes



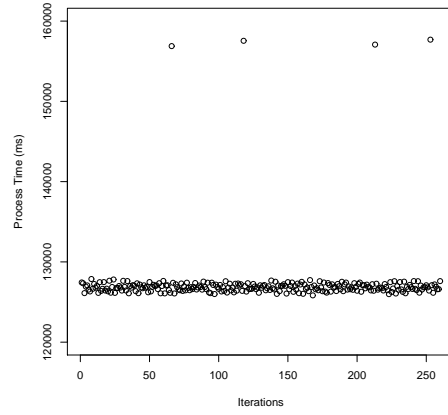
(a) PUT8192's PTs in Apr 2015



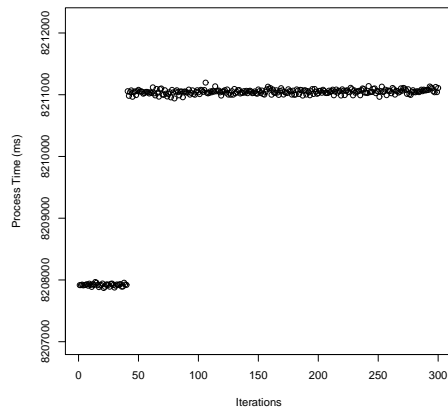
(b) PUT8192's daemon PTs in Apr 2015



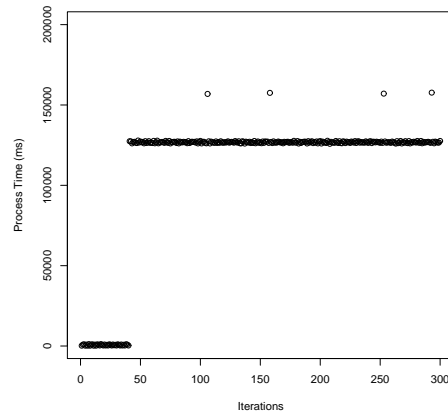
(c) PUT8192's PTs in Nov 2015



(d) PUT8192's daemon PTs in Nov 2015

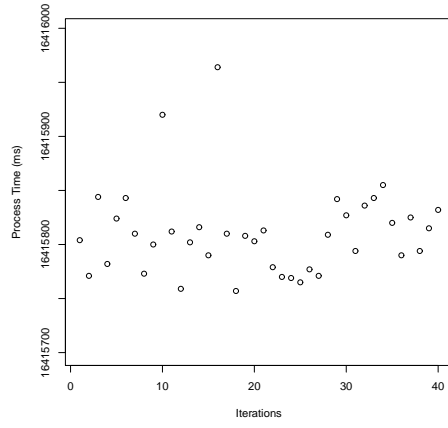


(e) Combined PUT8192's PTs

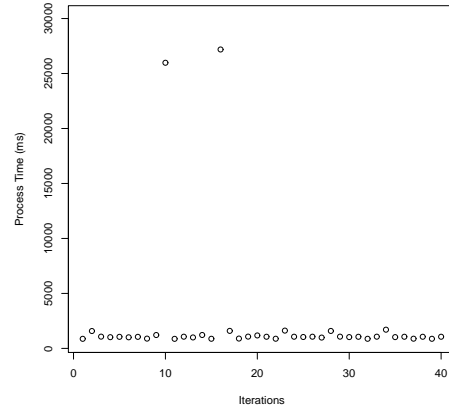


(f) Combined PUT8192's daemon PTs

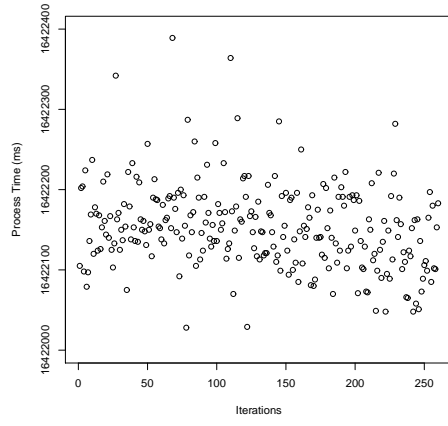
Figure 38: Program times between PUT8192 vs. Daemon processes



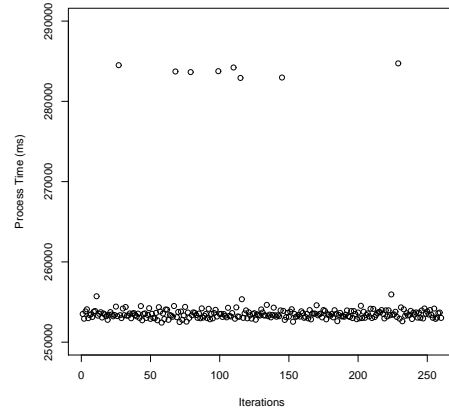
(a) PUT16384's PTs in Apr 2015



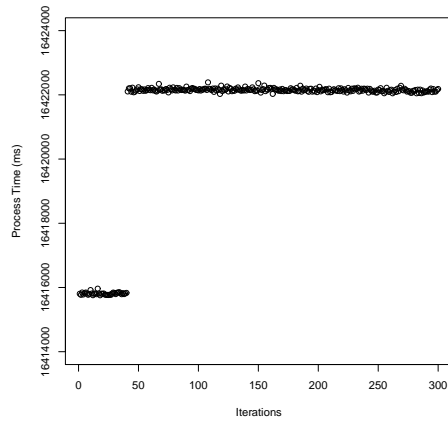
(b) PUT16384's daemon PTs in Apr 2015



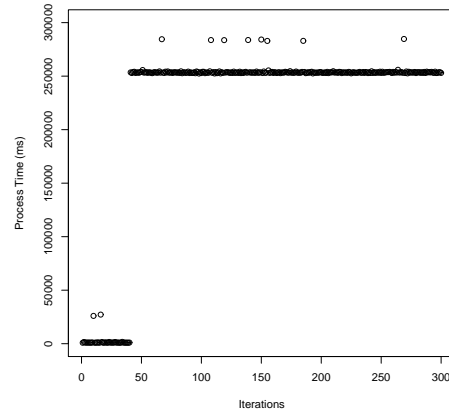
(c) PUT16384's PTs in Nov 2015



(d) PUT16384's daemon PTs in Nov 2015



(e) Combined PUT16384's PTs



(f) Combined PUT16384's daemon PTs

Figure 39: Program times between PUT16384 vs. Daemon processes

9 Conclusion

Below are the summarized observations by this study. (Order does not matter.)

1. Typically, the distribution of program times (PTs) of PUT is somewhat mixture of two models.
2. Outlier trimming does not well shape a normal distribution of PT.
3. For a short task length of PUT, it seems theres dependency between iterations in the same run of PUT.
4. Presence and activation of daemon processes strongly contribute to creating high variance in PT measurement.
5. The bigger task length, the stronger correlation between PTs of PUT and daemon processes.
6. When PUT is timed affects PT distribution, due to the presence of daemon processes whose running can't be controlled.
7. Measurement protocol is scalable with growing sample size and increasing task length.

10 Appendix

This appendix provides specific details of what daemon processes was captured and how much time was taken at a specific iteration revealing the most program time of a certain PUT.

10.1 Breakdown on Program Times of Daemon Processes

| | |
|------------------|--|
| PUT256 | Program Time |
| incr_work | 256,514 msecs (at the 118th iteration) |
| Daemon Processes | Program Time |
| java | 2 msecs |
| md0_raid1 | 4 msecs |
| jbd2/md0-8 | 1 msec |
| flush-9:0 | 10 msecs |
| proc_monitor | 262 msecs |
| rhnsd | 6 msecs |
| rhn_check | 1,944 msecs |
| Total | 2,229 msecs |

Table 9: The daemon processes captured at the worst PT of PUT256

| | |
|------------------|--|
| PUT256 | Program Time |
| incr_work | 513,152 msecs (at the 128th iteration) |
| Daemon Processes | Program Time |
| java | 2 msecs |
| md0_raid1 | 51 msecs |
| jbd2/md0-8 | 27 msecs |
| flush-9:0 | 86 msecs |
| proc_monitor | 270 msecs |
| rhnsd | 6 msecs |
| rhn_check | 19,820 msecs |
| Total | 20,262 msecs |

Table 10: The daemon processes captured at the worst PT of PUT512

| | |
|------------------|---|
| PUT4096 | Program Time |
| incr_work | 4,105,629 msec (at the 284th iteration) |
| Daemon Processes | Program Time |
| events/0 | 1 msec |
| kblockd/0 | 1 msec |
| kslowd000 | 31,710 msec |
| kslowd001 | 31,782 msec |
| md0_raid1 | 82 msec |
| jbd2/md0-8 | 21 msec |
| flush-9:0 | 79 msec |
| proc_monitor | 206 msec |
| rhnsd | 3 msec |
| ntpd | 1 msec |
| java | 2 msec |
| rhn_check | 21,840 msec |
| Total | 85,728 msec |

Table 11: The daemon processes captured at the worst PT of PUT4096

| | |
|------------------|---|
| PUT8192 | Program Time |
| incr_work | 8,207,884 msec (at the 244th iteration) |
| Daemon Processes | Program Time |
| kblockd/0 | 3 msec |
| kslowd000 | 31,710 msec |
| kslowd001 | 31,782 msec |
| md0_raid1 | 12 msec |
| jbd2/md0-8 | 2 msec |
| proc_monitor | 204 msec |
| rhnsd | 6 msec |
| java | 1 msec |
| rhsmcertd-worke | 114 msec |
| rhsmcertd-worke | 114 msec |
| rhn_check | 708 msec |
| Total | 64,656 msec |

Table 12: The daemon processes captured at the worst PT of PUT8192

| Daemon Processes | Descriptions |
|---|---|
| <code>kslowd000</code> (<code>kslowd001</code>) | A kernel threads for performing things that take a relatively long time. “Typically, when processing something, these items will spend a lot of time, blocking a thread on I/O, thus making that thread unavailable for doing other work.” (http://www.mjmwired.net/kernel/Documentation/slow-work.txt) |
| <code>rhn_check</code> | An external program for check for updates, run by <code>rhnsd</code> |
| <code>rhnsd</code> | “A background daemon process that periodically polls the Red Hat Network to see if there are any queued actions available. Typically started from the initialization (<code>init</code>) scripts in <code>/etc/init.d/rhnsd</code> when its time to poll the Red Hat Network server for available updates and actions. The default interval is every 240 minutes. The minimum polling interval is 60 minutes. Any network activity is done via the <code>rhn_check</code> utility.” (http://linuxcommand.org/man_pages/rhnsd8.html) |

Table 13: Descriptions of some daemon processes