

Homework 1 - Virtual Machine Scheduling Analysis

Jared Klingenberg

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1 Rosenblum Paper

To summarize, Rosenblum's paper on virtual machines is a good overview of the numerous motivations behind virtual machines. In the early days of virtual machine computing, a big motivation was for compatibility between different types of hardware by having a single target abstract machine to code to. However, a different style of virtual machine made a huge comeback in recent years with the arrival of VMWare, a hardware-level virtual machine that made it possible to emulate computer hardware devices. This is quite useful for many reasons; two such reasons are that these VMs provide superior isolation and that one can manage the execution of these VMs from a higher level with a Virtual Machine Manager.

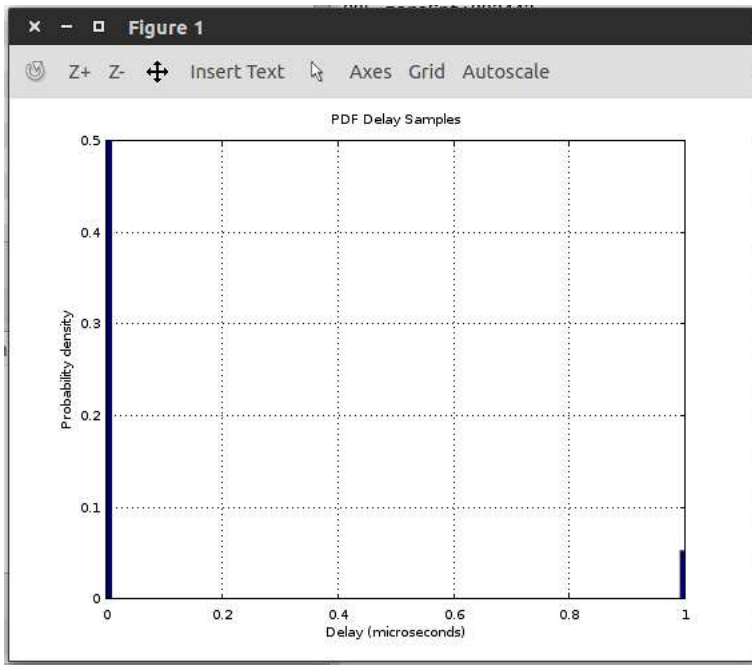
2 Manual Dataset Creation and Analysis

Overall for question 2, I noticed that as I increased the blocksize, there seemed to be noticeable periodic effects in the datasets. So most of the results would fall around the same value, but some delays were much longer and stacked around the same times. This likely has something to do with how the scheduler assigns clock time to different processes. The most noticeable effect can be seen with blocksize of 1 million.

2.1 Statistics

Here are histogram plots and numerical statistics for different blocksizes.

2.1.1 Blocksize 4

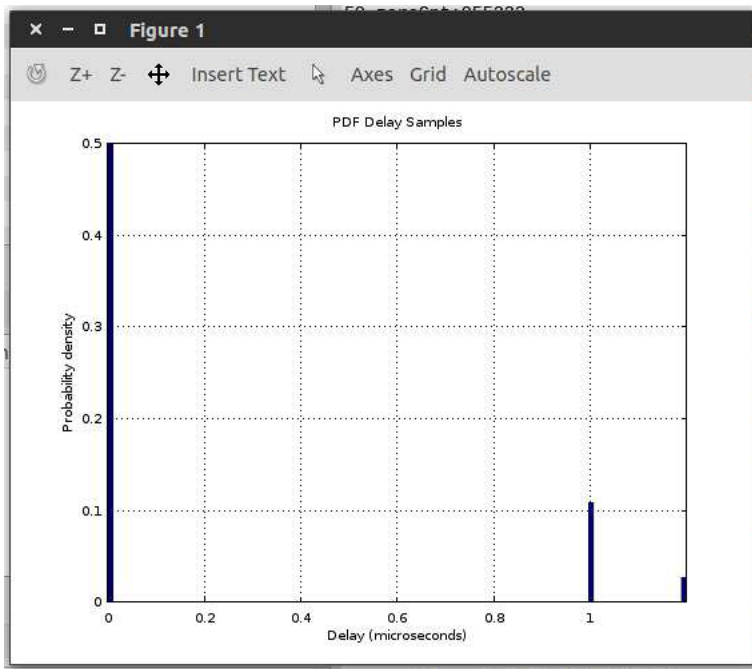


```

1 plotDataPDF (nargin:1):  sampleSize:1000000, maxValue:65.100000, MAX_ALLOWED_VALUE:1000.000000
2 #samples:1000000 Mean:    0 microseconds, median:    0, std:    0, max:    65, min:    0, maxCount:10173
   zeroCnt:947490
3 percentiles (2.5 25 50 75 97.5): :    0    0    0    0    1

```

2.1.2 Blocksize 256

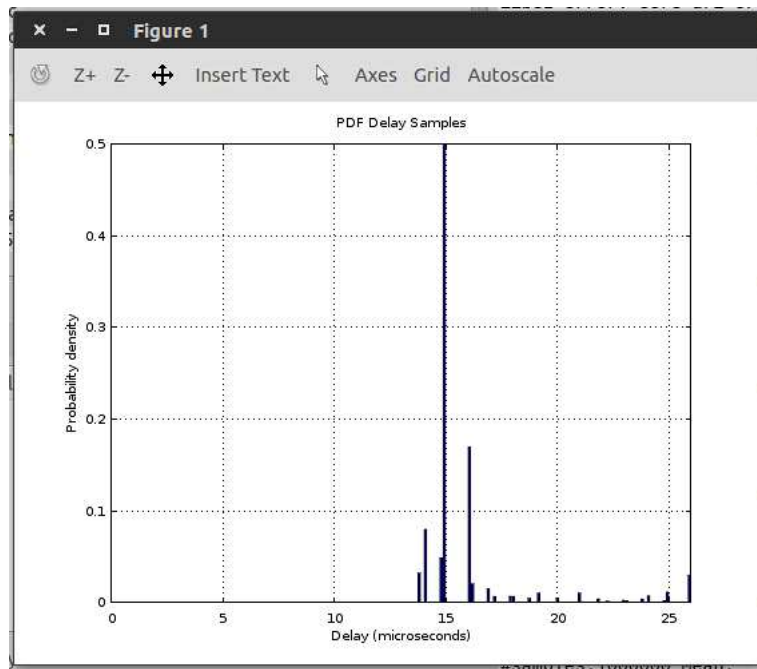


```

1 plotDataPDF (nargin:1):  sampleSize:1000000, maxValue:70.100000, MAX_ALLOWED_VALUE:1000.000000
2 #samples:1000000 Mean:    0 microseconds, median:    0, std:    0, max:    70, min:    0, maxCount:235
   zeroCnt:865266
3 percentiles (2.5 25 50 75 97.5): :    0    0    0    0    1

```

2.1.3 Blocksize 65535

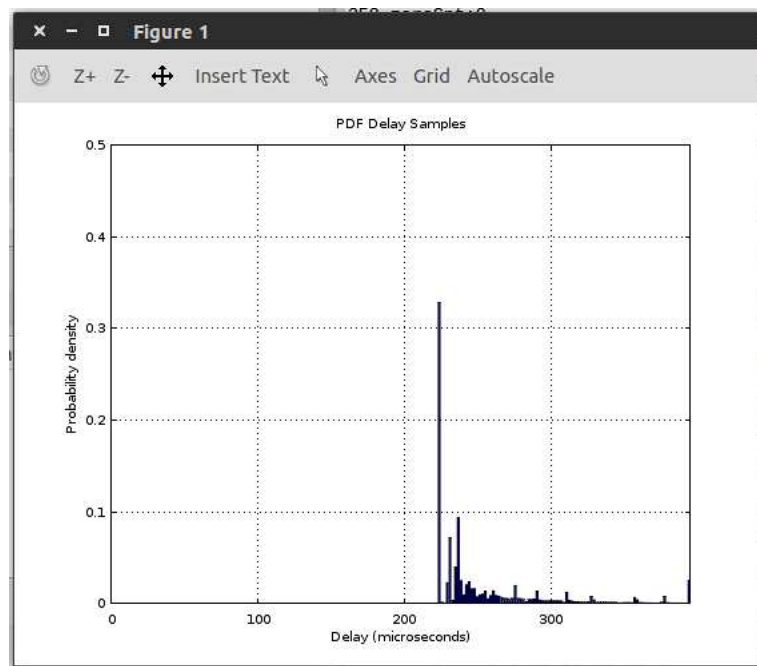


```

1 plotDataPDF (nargin:1):  sampleSize:1000000, maxValue:4635.100000,  MAX_ALLOWED_VALUE:1000.000000
2 #samples:1000000 Mean:    16 microseconds, median:    15, std:    7, max:  4635, min:    12, maxCount:22358
   zeroCnt:0
3 percentiles (2.5 25 50 75 97.5): :    14    15    15    16    26

```

2.1.4 Blocksize 1000000



```

1 plotDataPDF (nargin:1):  sampleSize:1000000, maxValue:5667.200000,  MAX_ALLOWED_VALUE:1000.000000
2 #samples:1000000 Mean:    255 microseconds, median:    236, std:    51, max:  5667, min:    210, maxCount:24825
   zeroCnt:0
3 percentiles (2.5 25 50 75 97.5): :    223    224    236    263    395

```

2.2 Parallel execution

I think the programs were completing too quickly to affect mpstat, but I was able to see a spike in CPU usage through using the 'top' command.

```

1 11:30:35 PM CPU      %usr   %nice    %sys %iowait    %irq   %soft  %steal  %guest  %gnice   %idle
2 11:30:35 PM all      0.38    0.00    0.03   0.00    0.00   0.00   0.00   0.00   0.00   99.58
3 11:30:35 PM  0      0.46    0.00    0.05   0.00    0.00   0.00   0.00   0.00   0.00   99.48
4 11:30:35 PM  1      0.34    0.01    0.03   0.00    0.00   0.00   0.00   0.00   0.00   99.62
5 11:30:35 PM  2      0.35    0.00    0.03   0.00    0.00   0.00   0.00   0.00   0.00   99.62
6 11:30:35 PM  3      0.36    0.00    0.02   0.01    0.00   0.00   0.00   0.00   0.00   99.61

```

2.2.1 Statistics - shell 1

```

1 plotDataPDF (nargin:1):  sampleSize:1000000, maxValue:683.100000, MAX_ALLOWED_VALUE:1000.000000
2 #samples:1000000 Mean:    0 microseconds, median:    0, std:    1, max:    683, min:    0, maxCount:259
   zeroCnt:835032
3 percentiles (2.5 25 50 75 97.5): :    0    0    0    0    1

```

2.2.2 Statistics - shell 2

```

1 plotDataPDF (nargin:1):  sampleSize:1000000, maxValue:90.100000, MAX_ALLOWED_VALUE:1000.000000
2 #samples:1000000 Mean:    0 microseconds, median:    0, std:    1, max:    90, min:    0, maxCount:284
   zeroCnt:835508
3 percentiles (2.5 25 50 75 97.5): :    0    0    0    0    1

```

3 Experiments in Parallel VM Scheduling

3.1 Experiment 1

This first experiment was simply an exercise in automating the testing process. With a blocksize that varies by $2^i, i \in \{1, 2, \dots, 20\}$, the runExp.sh program automatically performs the experiment all at once.

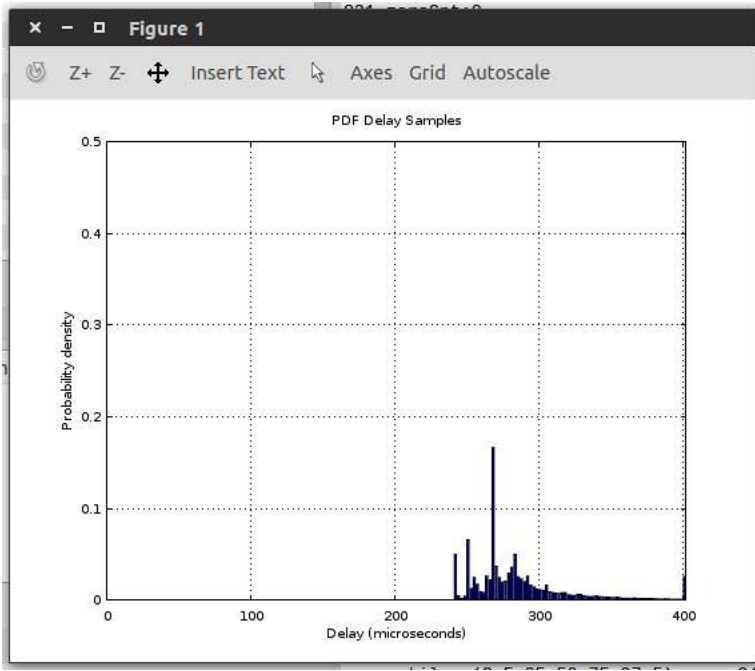
3.1.1 Overall stats

```

1 Experiment 1
2 1000000 1024 0.400 0.000 2.408
3 1000000 1048576 287.784 275.900 53.599
4 1000000 128 0.153 0.000 0.569
5 1000000 131072 36.570 33.900 17.870
6 1000000 16 0.082 0.000 1.135
7 1000000 16384 4.572 4.100 2.826
8 1000000 2 0.092 0.000 0.493
9 1000000 2048 0.782 1.000 3.638
10 1000000 256 0.278 0.000 2.141
11 1000000 262144 73.582 67.900 18.960
12 1000000 32 0.061 0.000 0.422
13 1000000 32768 9.244 8.100 6.677
14 1000000 4 0.095 0.000 0.630
15 1000000 4096 1.190 1.000 1.365
16 1000000 512 0.211 0.000 3.652
17 1000000 524288 143.082 134.000 32.334
18 1000000 64 0.084 0.000 1.034
19 1000000 65536 18.039 16.900 6.872
20 1000000 8 0.093 0.000 0.495
21 1000000 8192 2.286 2.100 1.999

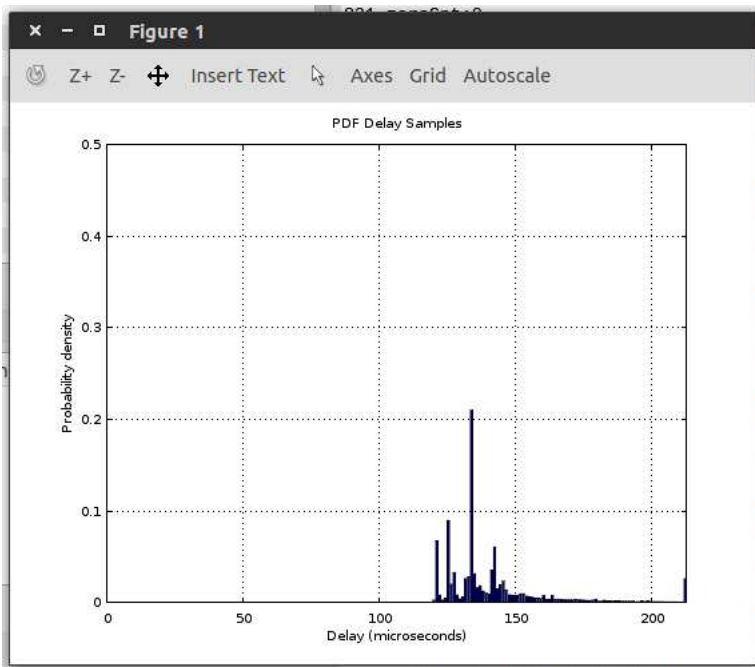
```

3.1.2 Statistics - blocksize 1048576



```
1 plotDataPDF (nargin:1):  sampleSize:1000000, maxValue:5829.100000,  MAX_ALLOWED_VALUE:1000.000000
2 #samples:1000000 Mean:    288 microseconds, median:    276, std:    54, max:  5829, min:  184, maxCount:24693
   zeroCnt:0
3 percentiles (2.5 25 50 75 97.5): :    242    267    276    296    402
```

3.1.3 Statistics - blocksize 524288



```
1 plotDataPDF (nargin:1):  sampleSize:1000000, maxValue:9854.100000,  MAX_ALLOWED_VALUE:1000.000000
2 #samples:1000000 Mean:    143 microseconds, median:    134, std:    32, max:  9854, min:  107, maxCount:24795
   zeroCnt:0
3 percentiles (2.5 25 50 75 97.5): :    121    132    134    145    213
```

3.1.4 Interpretation

The results of this experiment are pretty clear. The larger blocksize definitely has a higher variability, which can be seen visually in the plot by how the distribution is more spread. This is probably because with more bits to checksum, there is a higher chance of scheduling affecting the timing with more granularity.

3.2 Experiment 2

Experiment 2 was more interesting because it was meant to do the same thing as experiment 1, but with the program competing for the CPU by running two instances of hw1 in parallel. This is what runExp.sh does – simply runs experiment 1 twice simultaneously.

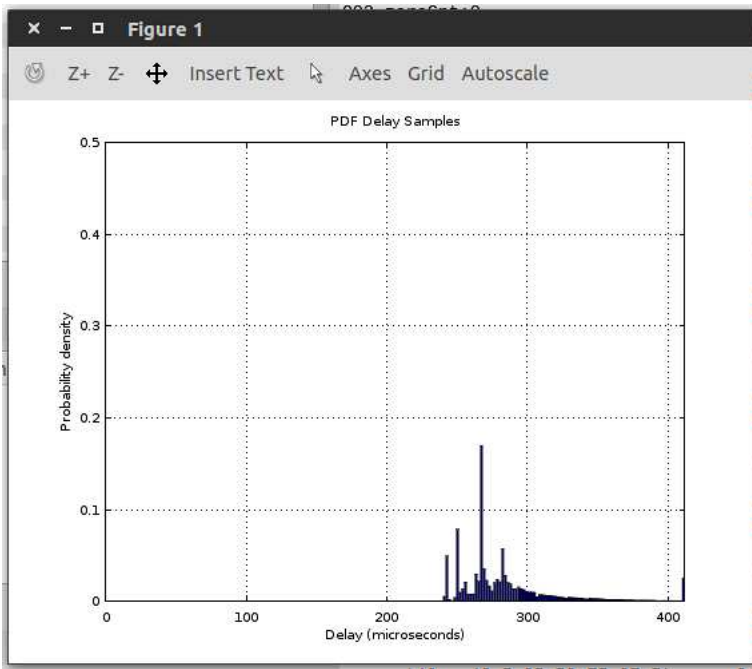
3.2.1 Overall stats - core 1

```
1 Experiment 2
2 1000000 1024 0.396 0.000 7.013
3 1000000 1048576 287.971 273.900 67.686
4 1000000 128 0.118 0.000 0.550
5 1000000 131072 35.803 33.100 14.463
6 1000000 16 0.078 0.000 1.587
7 1000000 16384 4.431 4.100 11.559
8 1000000 2 0.092 0.000 0.430
9 1000000 2048 0.828 1.000 1.000
10 1000000 256 0.299 0.000 2.810
11 1000000 262144 70.562 67.000 19.655
12 1000000 32 0.049 0.000 0.384
13 1000000 32768 8.706 8.100 4.817
14 1000000 4 0.091 0.000 1.428
15 1000000 4096 1.196 1.000 4.301
16 1000000 512 0.176 0.000 1.366
17 1000000 524288 144.228 134.000 36.245
18 1000000 64 0.080 0.000 1.815
19 1000000 65536 17.792 16.900 10.709
20 1000000 8 0.088 0.000 0.429
21 1000000 8192 2.240 1.900 5.022
```

3.2.2 Overall stats - core 2

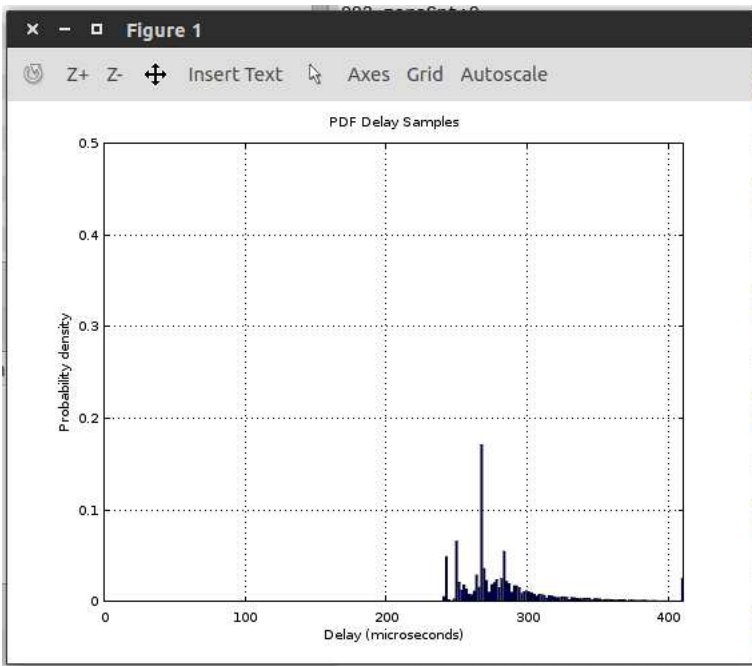
```
1 Experiment 2
2 1000000 1024 0.395 0.000 3.535
3 1000000 1048576 287.680 273.000 65.885
4 1000000 128 0.118 0.000 0.492
5 1000000 131072 35.738 33.100 15.173
6 1000000 16 0.075 0.000 1.518
7 1000000 16384 4.416 4.100 6.982
8 1000000 2 0.091 0.000 0.523
9 1000000 2048 0.831 1.000 3.241
10 1000000 256 0.284 0.000 2.709
11 1000000 262144 70.584 67.000 21.541
12 1000000 32 0.051 0.000 0.405
13 1000000 32768 8.735 8.100 4.718
14 1000000 4 0.081 0.000 1.261
15 1000000 4096 1.203 1.000 7.994
16 1000000 512 0.174 0.000 0.694
17 1000000 524288 143.792 134.000 40.463
18 1000000 64 0.084 0.000 4.540
19 1000000 65536 17.807 16.900 9.195
20 1000000 8 0.087 0.000 0.446
21 1000000 8192 2.237 1.900 5.171
```

3.2.3 Statistics - core 1 (blocksize 1048576)



```
1 plotDataPDF (nargin:1):  sampleSize:1000000, maxValue:22301.900000,  MAX_ALLOWED_VALUE:1000.000000
2 #samples:1000000 Mean:    288 microseconds, median:    274, std:    68, max: 22302, min:    223, maxCount:24821
   zeroCnt:0
3 percentiles (2.5 25 50 75 97.5): :    242    265    274    294    412
```

3.2.4 Statistics - core 2 (blocksize 1048576)



```
1 plotDataPDF (nargin:1):  sampleSize:1000000, maxValue:25430.000000,  MAX_ALLOWED_VALUE:1000.000000
2 #samples:1000000 Mean:    288 microseconds, median:    273, std:    66, max: 25430, min:    233, maxCount:24657
   zeroCnt:0
3 percentiles (2.5 25 50 75 97.5): :    242    265    273    294    411
```

3.2.5 Interpretation

In this experiment, the differences were really hard to discern. I didn't notice any striking changes when scaling up the blocksize, nor when comparing the statistics of each core. I suspect that this is because my VM had four cores to work with, thanks to how I configured the VM. In the future, I may want to increase the number of parallel processes at work.

3.3 Experiment 3

This experiment is largely a repeat of experiment 2, but the difference comes in to how each process is prioritized. I assign one core a nice value of 0 and the other core a nice value of 19. (Normal users cannot set negative nice values by default in Ubuntu.)

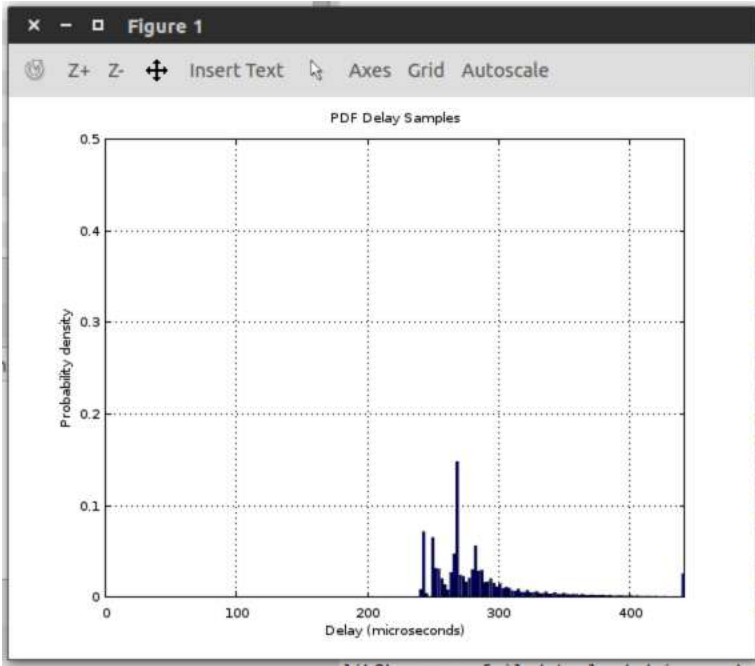
3.3.1 Overall stats - core 1

```
1 Experiment 3
2 1000000 1024 0.386 0.000 5.003
3 1000000 1048576 289.974 272.000 73.226
4 1000000 128 0.116 0.000 2.633
5 1000000 131072 37.451 33.900 21.779
6 1000000 16 0.080 0.000 1.124
7 1000000 16384 4.463 4.100 4.246
8 1000000 2 0.096 0.000 0.546
9 1000000 2048 0.881 1.000 5.817
10 1000000 256 0.273 0.000 0.611
11 1000000 262144 72.662 67.000 27.157
12 1000000 32 0.047 0.000 1.658
13 1000000 32768 8.811 8.100 6.075
14 1000000 4 0.092 0.000 2.417
15 1000000 4096 1.193 1.000 2.703
16 1000000 512 0.155 0.000 2.092
17 1000000 524288 141.603 134.000 33.523
18 1000000 64 0.132 0.000 7.266
19 1000000 65536 17.985 16.900 12.531
20 1000000 8 0.090 0.000 1.283
21 1000000 8192 2.354 1.900 8.776
```

3.3.2 Overall stats - core 2

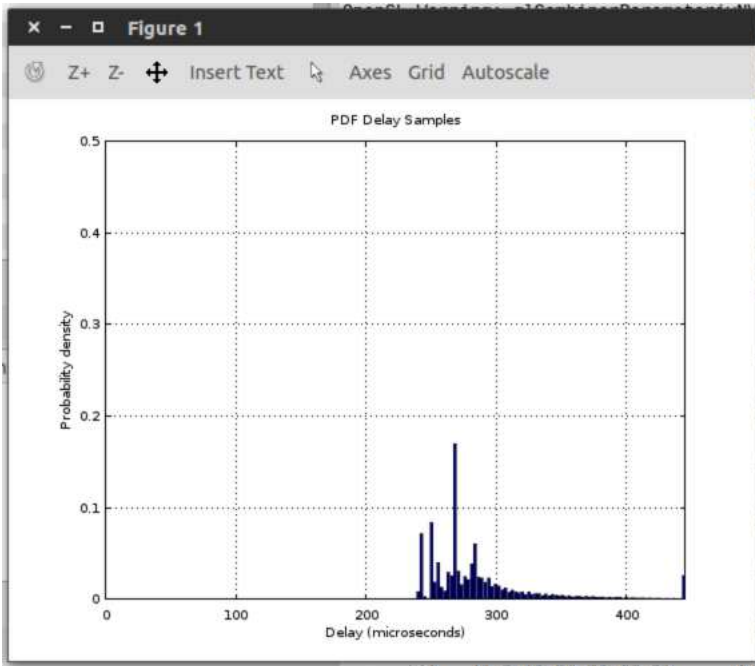
```
1 Experiment 3
2 1000000 1024 0.385 0.000 3.961
3 1000000 1048576 290.656 272.000 76.704
4 1000000 128 0.115 0.000 2.711
5 1000000 131072 37.443 33.900 27.228
6 1000000 16 0.060 0.000 1.825
7 1000000 16384 4.478 4.100 6.304
8 1000000 2 0.096 0.000 0.549
9 1000000 2048 0.865 1.000 5.666
10 1000000 256 0.286 0.000 0.668
11 1000000 262144 72.529 67.000 29.583
12 1000000 32 0.042 0.000 1.999
13 1000000 32768 8.815 8.100 4.721
14 1000000 4 0.096 0.000 1.277
15 1000000 4096 1.201 1.000 3.675
16 1000000 512 0.163 0.000 6.748
17 1000000 524288 141.794 134.000 40.413
18 1000000 64 0.071 0.000 1.391
19 1000000 65536 18.100 16.900 16.403
20 1000000 8 0.091 0.000 1.125
21 1000000 8192 2.346 1.900 7.503
```


3.3.3 Statistics - core 1 (blocksize 1048576)



```
1 plotDataPDF (nargin:1):  sampleSize:1000000, maxValue:7099.900000, MAX_ALLOWED_VALUE:1000.000000
2 #samples:1000000 Mean:    290 microseconds, median:    272, std:    73, max:    7100, min:    209, maxCount:24881
   zeroCnt:0
3 percentiles (2.5 25 50 75 97.5): :    242    262    272    294    442
```

3.3.4 Statistics - core 2 (blocksize 1048576)



```
1 plotDataPDF (nargin:1):  sampleSize:1000000, maxValue:12529.900000, MAX_ALLOWED_VALUE:1000.000000
2 #samples:1000000 Mean:    291 microseconds, median:    272, std:    77, max: 12530, min:    187, maxCount:24902
   zeroCnt:0
3 percentiles (2.5 25 50 75 97.5): :    242    262    272    295    445
```

3.3.5 Interpretation

In experiment 3, there was slightly more variability in the lower priority process. This makes intuitive sense, since the scheduler will have a higher chance of skipping over the core if other system processes need the processor more.

4 Code

Listing 1: hw1.c

```
1  /*****
2  * exampleUnixTime - this program illustrates how to obtain
3  * a Unix timestamp, how to compute a RTT, and how to print
4  * a timestamp as a human readable string.
5  *
6  * Notes:
7  *
8  * Revisions
9  * $A0: 1-21-2016 release v1.0
10 *
11 *****/
12 #include "hw1.h"
13
14 void signal_handler();
15 double getTime();
16
17 #define TEST_SLEEP 1
18 // 1: test sleep for TEST_SLEEP seconds
19 // 0: loop forever running instructions
20 #define LOOP_TEST 1
21
22
23
24 int main(int argc, char *argv[])
25 {
26     double t = 0.0;
27     struct sigaction sig;
28     unsigned int k = 0;
29     unsigned int iters = atoi(argv[1]); //Purposefully not validating input
30     unsigned int bs = atoi(argv[2]);
31     int sum;
32     unsigned char *block = NULL;
33
34     /* initialize RNG */
35     srand(time(NULL));
36
37     /* setup signals */
38     memset(&sig,0,sizeof(sig));
39     sig.sa_handler = signal_handler;
40     sigaction (SIGINT, &sig, NULL);
41     sigaction (SIGALRM, &sig, NULL);
42
43     /* allocate and initialize data block */
44     block = (unsigned char*)malloc(sizeof(unsigned char) * bs);
45     memset(block,rand()%256,sizeof(unsigned char)*bs);
46
47     while (k < iters)
48     {
49         t = getTime();
50         sum = csum((unsigned short*)block, bs);
51         t = getTime() - t;
52         printf("%3.7f 0X%x\n",t,sum);
53         k++;
54     }
55
56     exit(0);
57 }
58
59 double getTime()
60 {
61     struct timeval curTime;
62     (void) gettimeofday (&curTime, (struct timezone *) NULL);
63     return (((double) curTime.tv_sec) * 1000000.0)
64         + (double) curTime.tv_usec) / 1000000.0);
65 }
66
67 void signal_handler(int sig) {
68     switch(sig) {
69         case SIGINT:
70             printf("SIGINT: Exit! \n");
71             exit(0);
```

```

72     break;
73     case SIGALRM:
74         printf("SIGALRM:  Exit! \n");
75         exit(0);
76         break;
77 }
78 }

```

Listing 2: runHW1.sh

```

1 #!/bin/bash
2
3 if [[ $# -ne 5 ]]; then
4     echo "Invalid parameters."
5     echo "Syntax: $0 [iterationCountP] [firstScalingP] [numberRuns]
6     [resultsDirectory] [baseDataFileName]"
7     exit 1
8 fi
9
10 mkdir -p $4
11 rm -rf "$4/*"
12
13 for i in `seq $2 $3 | awk '{print 2 ^ $1}'`; do
14     echo "Running $1 iterations on blocksize $i..."
15     ./hw1 $1 $i > "$4/$5.$i"
16 done

```

Listing 3: runExp.sh

```

1 #!/bin/bash
2
3 if [[ $# -ne 6 ]]; then
4     echo "Invalid parameters."
5     echo "Syntax: $0 [exp#] [parameters 1-5 for ./runHW1.sh]"
6     exit 1
7 fi
8
9 ctrl_c() {
10     for job in `jobs -p`; do
11         kill -9 $job
12     done
13 }
14
15 exp1() {
16     ./runHW1.sh $1 $2 $3 $4 $5
17 }
18
19 exp2() {
20     trap ctrl_c SIGINT
21     ./runHW1.sh $1 $2 $3 $4 "$5.1" &
22     ./runHW1.sh $1 $2 $3 $4 "$5.2" &
23     # Wait until background tasks complete
24     for job in `jobs -p`; do
25         wait $job
26     done
27     trap - SIGINT
28 }
29
30 exp3() {
31     trap ctrl_c SIGINT
32     # Users can't set negative nice values by default
33     nice -n 0 ./runHW1.sh $1 $2 $3 $4 "$5.1" &
34     nice -n 20 ./runHW1.sh $1 $2 $3 $4 "$5.2" &
35     # Wait until background tasks complete
36     for job in `jobs -p`; do
37         wait $job
38     done
39     trap - SIGINT
40 }
41
42 case $1 in
43     1)
44         echo "Experiment 1!"
45         exp1 $2 $3 $4 $5 $6
46         echo "Done."

```

```

47     ;;
48 2)
49     echo "Experiment 2!"
50     exp2 $2 $3 $4 $5 $6
51     echo "Done."
52     ;;
53 3)
54     echo "Experiment 3!"
55     exp3 $2 $3 $4 $5 $6
56     echo "Done."
57     ;;
58 *)
59     echo "Invalid experiment"
60     ;;
61 esac

```

Listing 4: analysisHW1.sh

```

1 #!/bin/bash
2
3 if [[ $# -ne 3 ]]; then
4     echo "Invalid parameters."
5     echo "Syntax: $0 [baseDataFilename] [resultsDirectory] [resultsFile]"
6     exit 1
7 fi
8
9 base=$1
10 dir=$2
11 out=$3
12
13 if [ ! -d $dir ]; then
14     echo "Directory $dir not found"
15     exit 1
16 fi
17
18 rm -f ${dir}/${out}
19 echo "Enter experiment name:"
20 read name
21 echo "Experiment $name" >> ${dir}/${out}
22
23 for f in ${dir}/${base}.*; do
24     sort -n $f | awk -f analyzeResults.awk scale=${f##*.} >> ${dir}/${out}
25 done

```

Listing 5: analyzeResults.awk

```

1 #!/usr/bin/awk
2 # assumes variable 'scale' set from shell script
3 # assumes input is pre-sorted by $1
4
5 BEGIN {
6     i = 0
7     sum = 0
8     sumsq = 0
9 }
10
11 {
12     usec = $1 * 1000000
13     a[i++] = usec
14     sum += usec
15     sumsq += usec^2
16 }
17
18 END {
19     if (NR > 0) {
20         printf("%d %d %.3f %.3f %.3f\n",
21             NR, scale, sum/NR, a[NR/2], sqrt(sumsq/NR - (sum/NR)^2))
22     }
23 }

```