Programming Assignment 4:
Investigating the Linux Scheduler

CSCI 3753 – Operating Systems
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1. Abstract

The goal of this experiment was to test the behaviors of different process scheduling algorithms. The three shceduling policies used were SCHED_OTHER(CFS), SCHED_FIFO(RT) and SCHED_RR(RT). The tests were run on three program types; An IO bound program which reads random data from /dev/urandom and writes it to /dev/null, a CPU bound program which statistically calculates pi, and a mixed program which calculates pi and writes it to /dev/null.

2. Introduction

Tests were done using the C programming language and a bit of bash scripting. Some of the libraries used were sched.h, sys/wait.h, sys/resource.h and sys/time.h. These standard libraries are used to collect data about each individual process.

2.1 Test System

Output of ‘lscpu’

```
Architecture:          x86_64
CPU op-mode(s):        32-bit, 64-bit
Byte Order:            Little Endian
CPU(s):                8
On-line CPU(s) list:   0-7
Thread(s) per core:    2
Core(s) per socket:    4
Socket(s):             1
NUMA node(s):          1
Vendor ID:             GenuineIntel
CPU family:            6
Model:                 60
Model name:            Intel(R) Core(TM) i7-4710HQ CPU @ 2.50GHz
Stepping:              3
CPU MHz:               3100.000
CPU max MHz:           3500.0000
CPU min MHz:           800.0000
BogoMIPS:              4988.83
Virtualization:        VT-x
L1d cache:             32K
L1i cache:             32K
L2 cache:              256K
L3 cache:              6144K
NUMA node0 CPU(s):     0-7
```

3. Method (Experiment Design):

3.1 Files:

1. **calc_pi.c:** A CPU bound program that uses a statistical method to calculate pi across specified iterations. I used the default number of iterations, 1,000,000, for all tests.
2. **rw.c:** An IO bound program that reads bytes into a buffer and writes the data out to a file. The input and output files used were /dev/urandom and /dev/null, respectively.
3. **rwpi.c:** A program that is a mix of CPU and IO bound. The program calculates pi using the same method as calc_pi.c and writes out to a file. In this case the output file was /dev/null. This program also uses the same size buffer as rw.c and the same number of iterations as in calc_pi.c.
4. **shed_test.c:** This is the parent program. The three important functions are runIOBound(), runCPUBound() and runMixed(). Each function spawns a specified number of children with vfork(). Each child process simply executes the corresponding program using exec(). The parent process reaps the children using wait3() and acquires CPU data through the rusage struct. This data is printed out to a specified output file. System time, user time, number of voluntary context switches and number of involuntary context switches for each individual process are summed here. After all children processes have finished, the program writes the data out to the bottom of the output file in the form of a table.
5. **run_benchmarks.sh:** This script has two tasks. First, launch ‘./sched_test’ with different scheduling policies and process counts. Then, compile the data from the different sched_test.c output files into a single file called ‘table-data’.
6. **Makefile:** compiles C files.

3.2 Summary:

run_benchmarks.sh runs ‘./sched_test’ nine times, each with a different scheduling policy and number of processes. The bash script creates nine different output files; each containing data for all three program types (CPU bound, IO bound and mixed). The script then compiles this data into a final data file called table_data. Table data contains data for all 27 cases.
The 27 cases are as follows:

IO bound	SHED_OTHER,	100 processes
CPU bound	SHED_OTHER,	100 processes
Mixed	SHED_OTHER,	100 processes
IO bound	SHED_OTHER,	1000 processes
CPU bound	SHED_OTHER,	1000 processes
Mixed	SHED_OTHER,	1000 processes
IO bound	SHED_OTHER,	10000 processes
CPU bound	SHED_OTHER,	10000 processes
Mixed	SHED_OTHER,	10000 processes
IO bound	SHED_FIFO,	100 processes
CPU bound	SHED_FIFO,	100 processes
Mixed	SHED_FIFO,	100 processes

IO bound	SHED_FIFO,	1000 processes
CPU bound	SHED_FIFO,	1000 processes
Mixed	SHED_FIFO,	1000 processes

IO bound	SHED_FIFO,	10000 processes
CPU bound	SHED_FIFO,	10000 processes
Mixed	SHED_FIFO,	10000 processes

IO bound	SHED_RR,	100 processes
CPU bound	SHED_RR,	100 processes
Mixed	SHED_RR,	100 processes

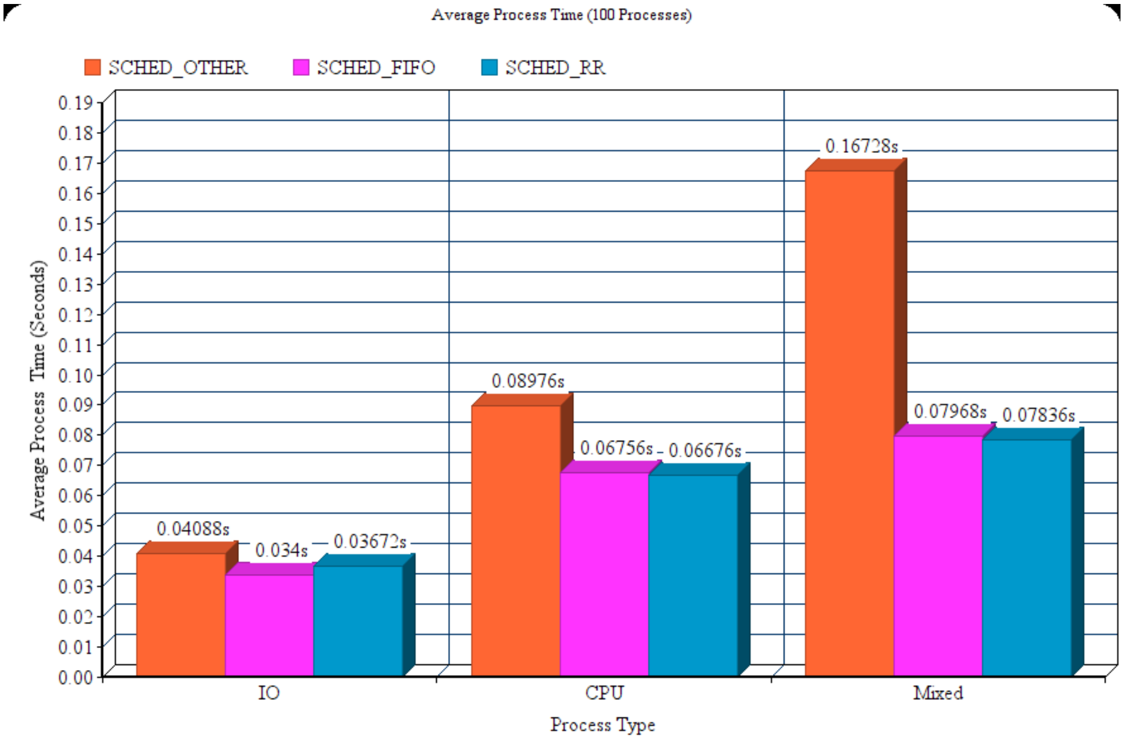
IO bound	SHED_RR,	1000 processes
CPU bound	SHED_RR,	1000 processes
Mixed	SHED_RR,	1000 processes

IO bound	SHED_RR,	10000 processes
CPU bound	SHED_RR,	10000 processes
Mixed	SHED_RR,	10000 processes

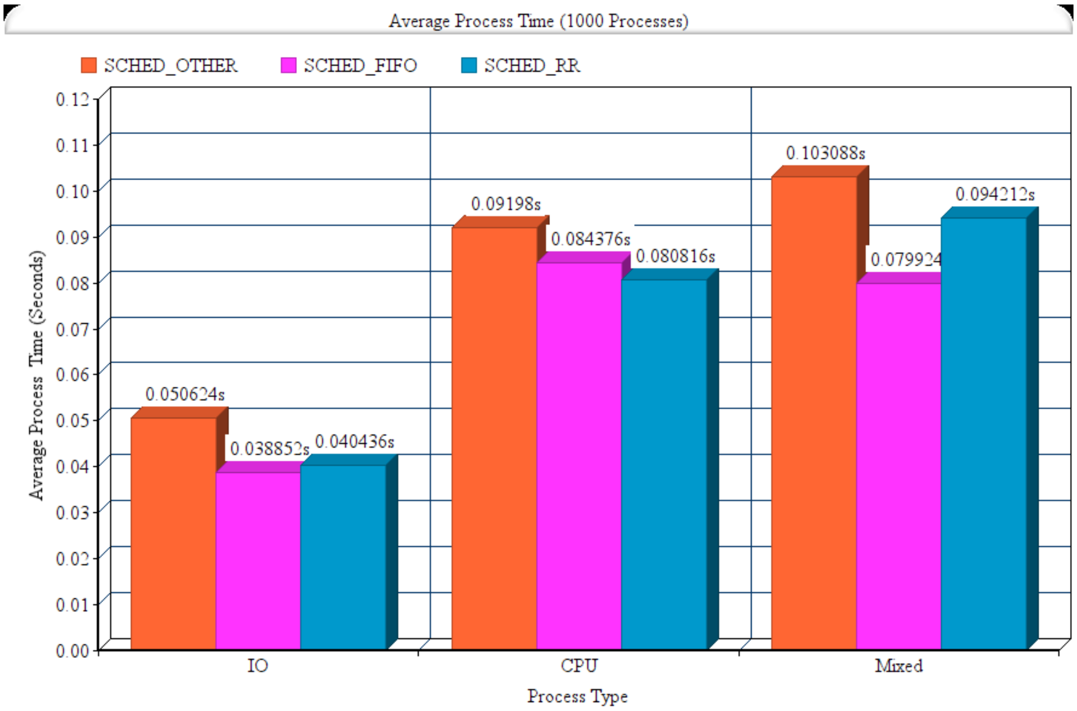
The table_data file contains nine tables, each containing the following data for all three program types: system time, user time, total time (system+user), average time, voluntary context switches, average voluntary context switches, involuntary context switches and average involuntary context switches. Data for each program type can be compared side by side.

4. Results:

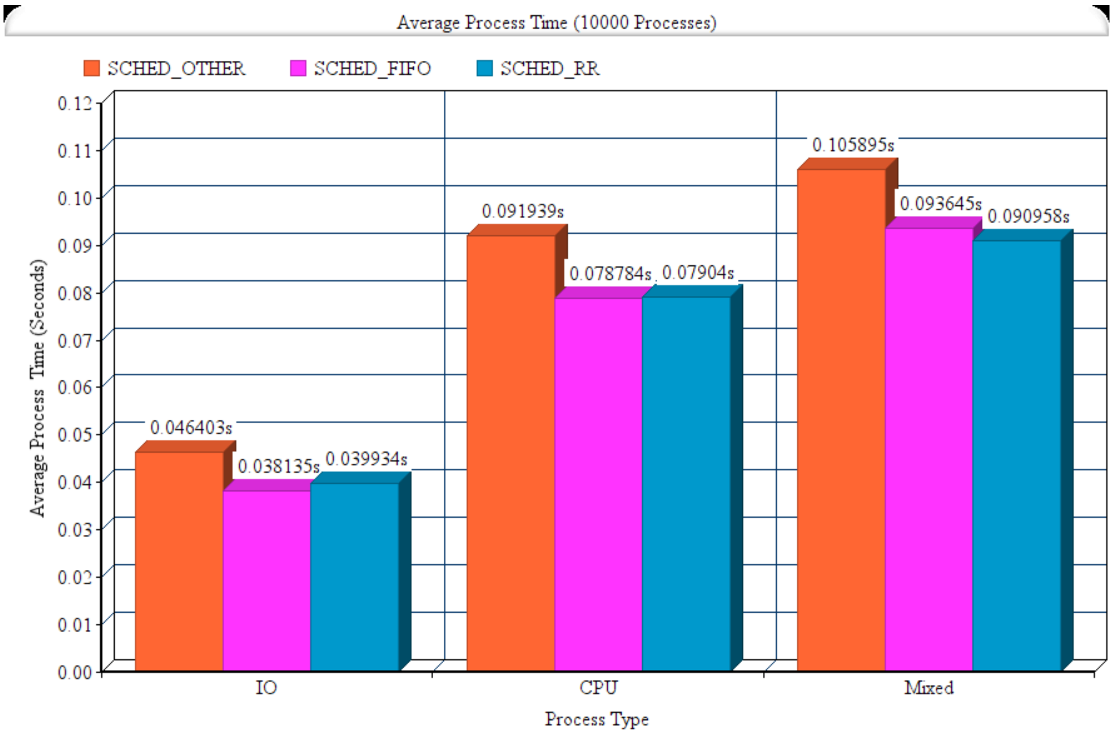
Average Process Time (100 Processes)



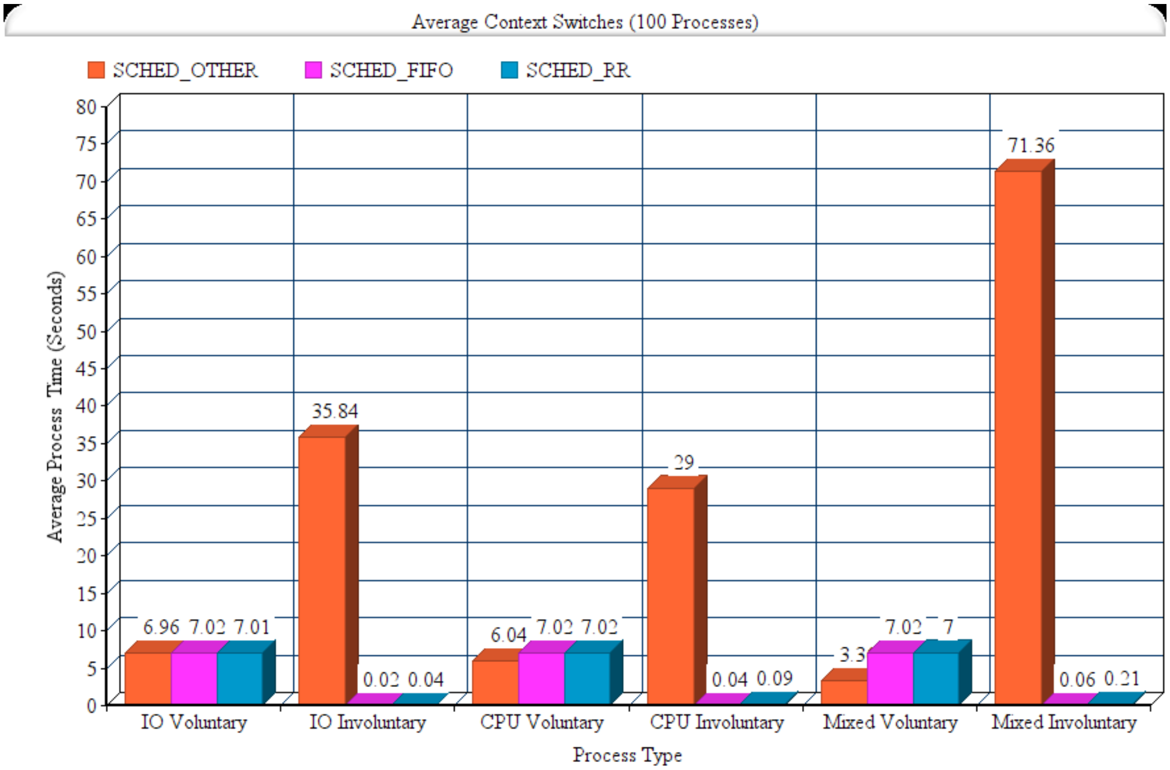
Average Process Time (1,000 Processes)



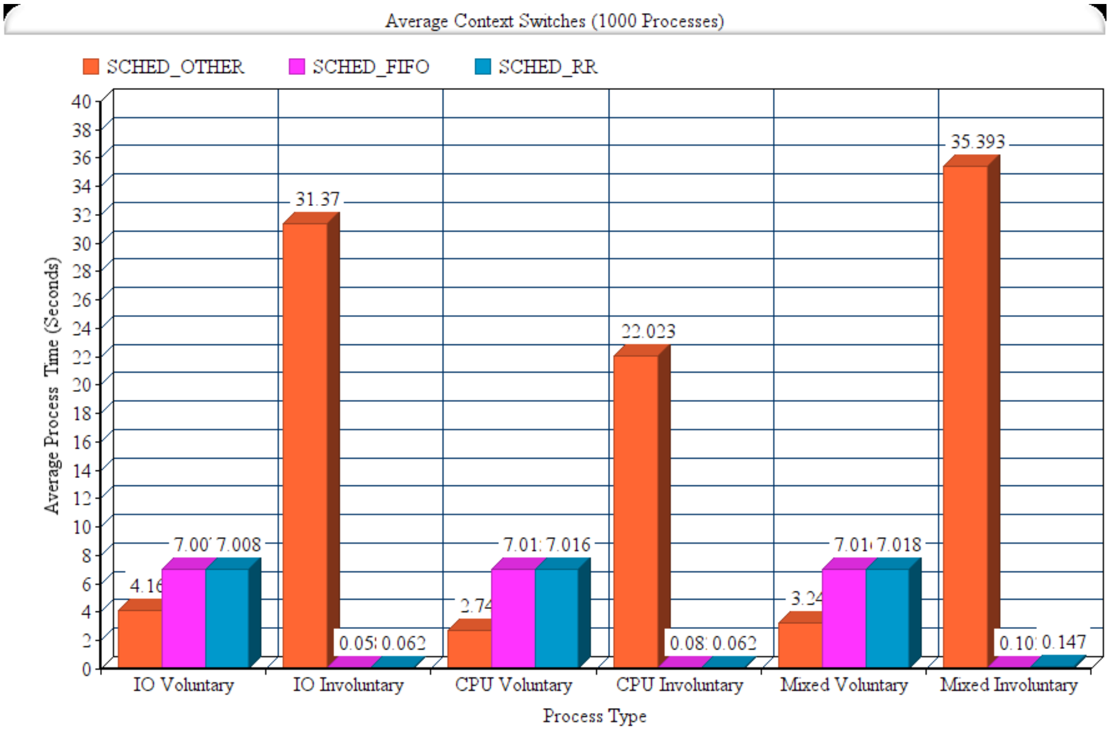
Average Process Time (10,000 Processes)



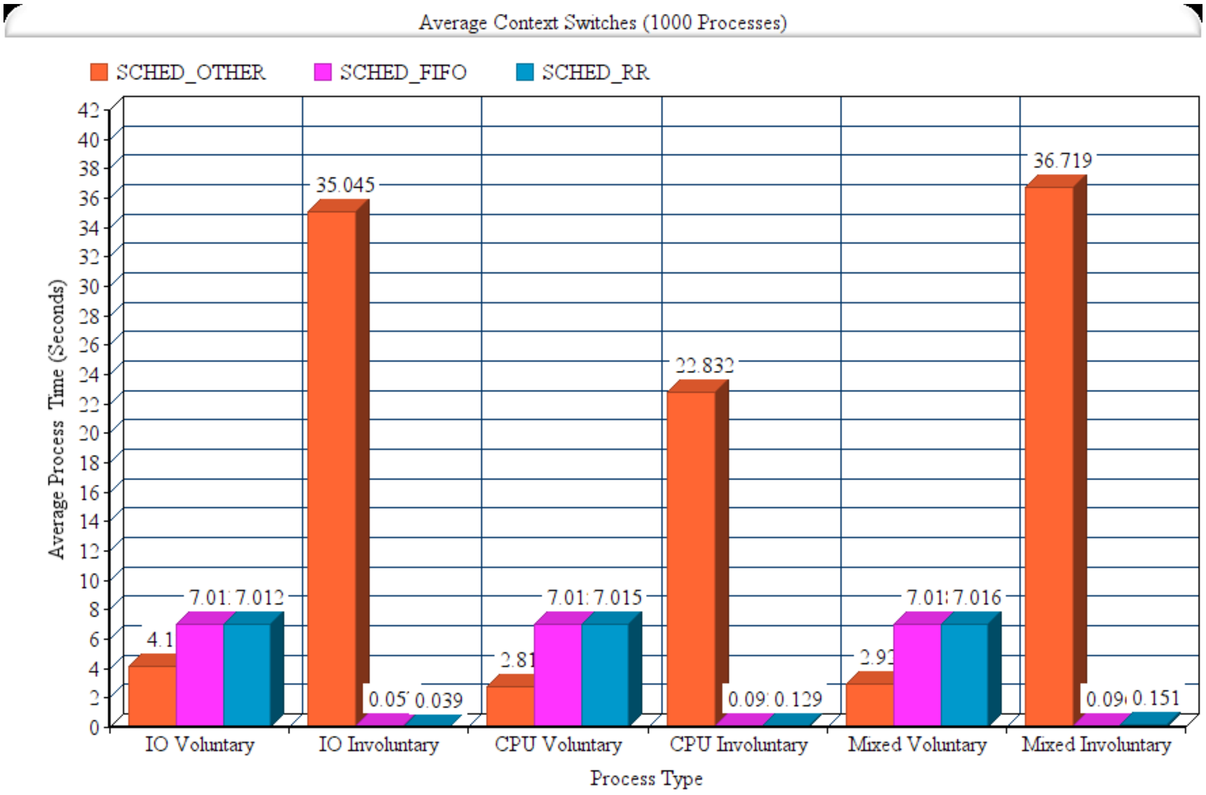
Average Context Switches (100 Processes)



Average Context Switches (1,000 Processes)



Average Context Switches (10,000 Processes)



5. Analysis:

The Completely Fair Scheduler (SCHED_OTHER) always takes the most time. This is because it causes more context switches. Processes run with SCHED_FIFO and SCHED_RR always have very similar durations. IO bound processes typically finish fastest with SCHED_FIFO. CPU bound processes typically have shortest duration when run with SCHED_RR. However, theses durations are very similar to those of CPU bound processes run with SCHED_FIFO. There is no clear winner for best scheduling policy for mixed processes. SCHED_OTHER causes the longest durations but SCHED_FIFO and SCHED_RR typically have very similar durations.

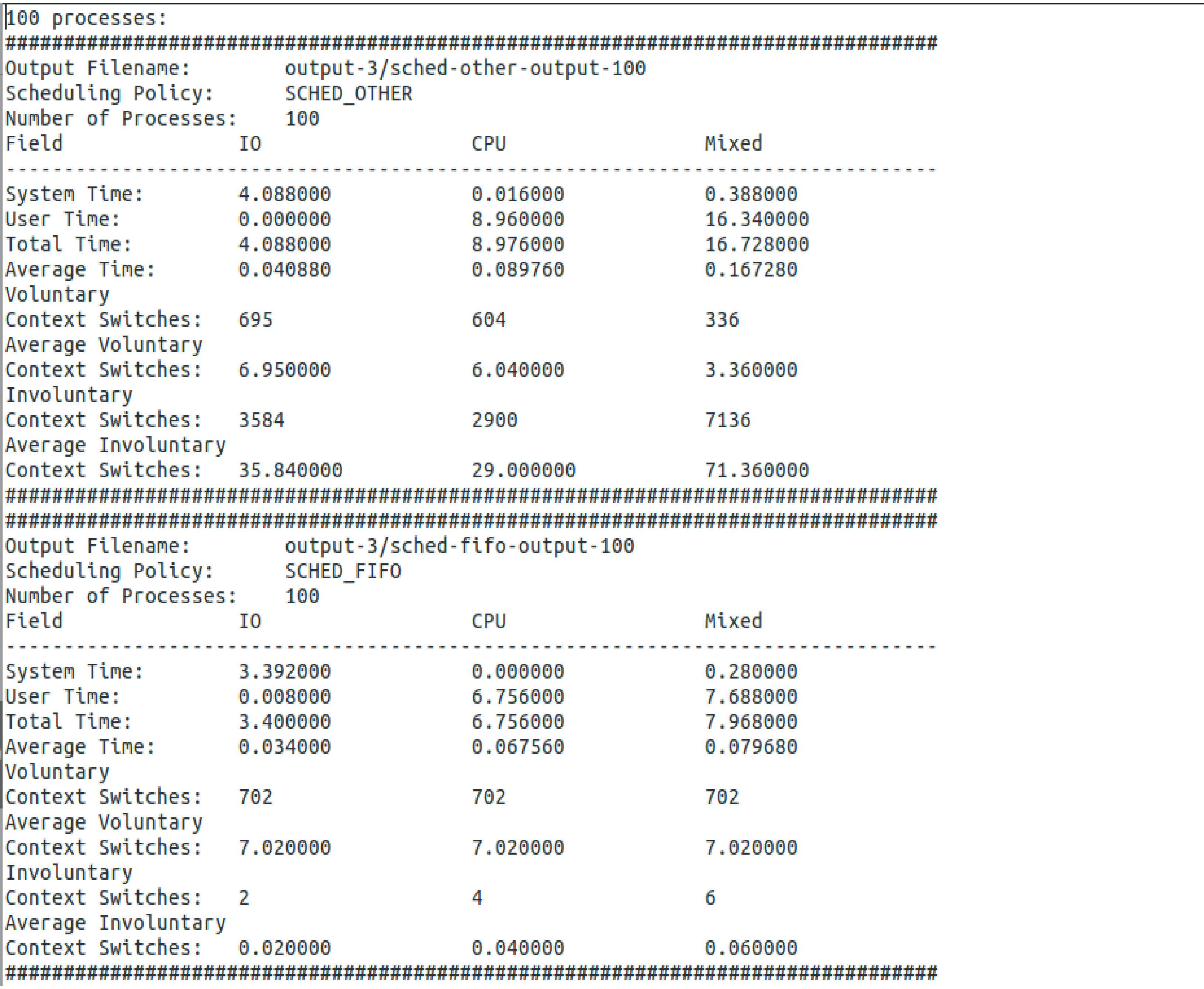
6. Conclusion:

Processes that use SCHED_FIFO and SCHED_RR policies always have shorter durations than those that use SCHED_OTHER. This makes theses policies more suited for real time systems. The drawback of these policies is that they cause high response and turnaround time and low throughput. On the other hand, processes using the SCHED_OTHER policy have low response and turnaround time and high throughput. This makes this policy better suited for interactive processes.

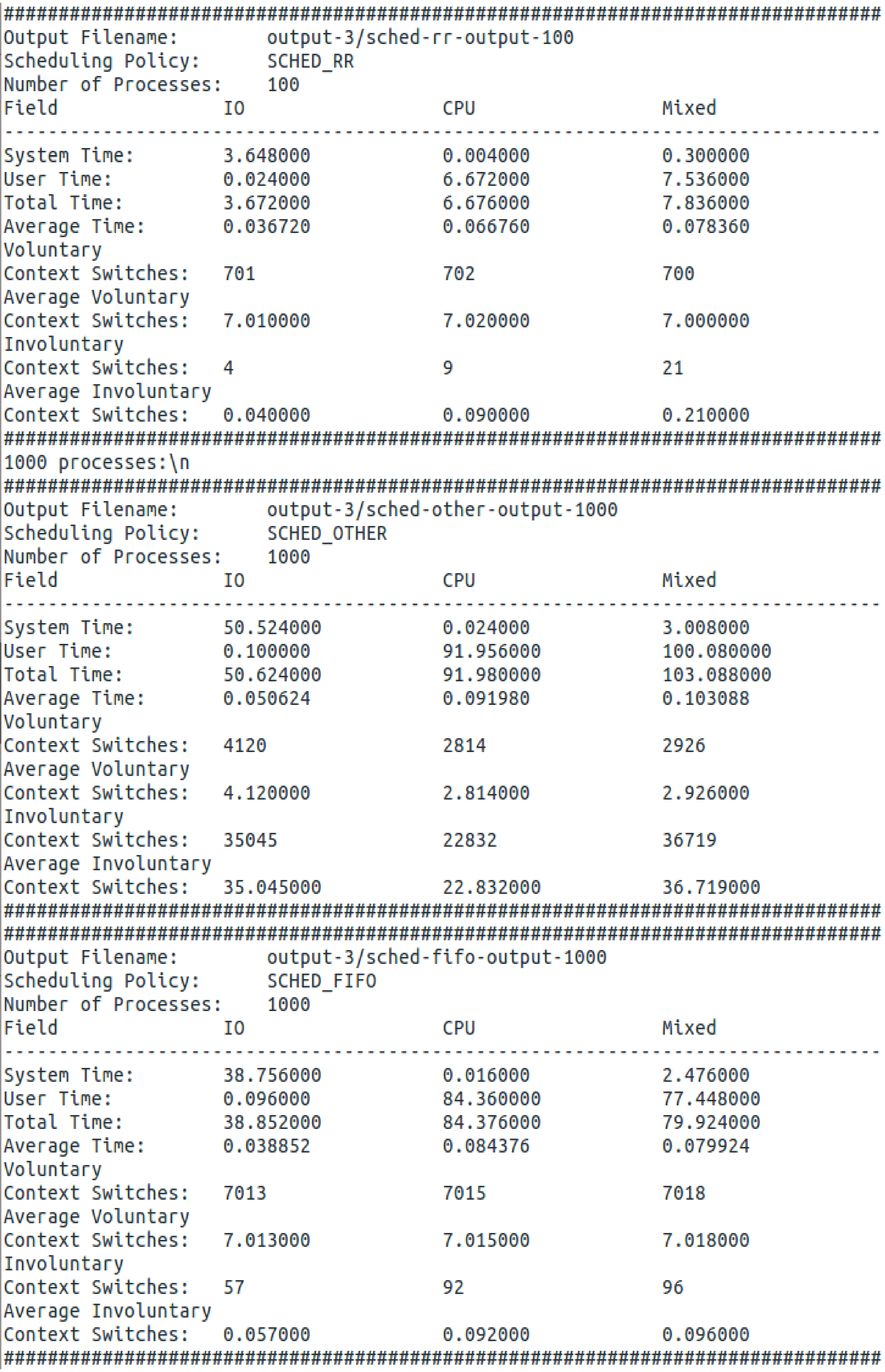
7. References:

Operating System Concepts, Silberchatz
man7.org

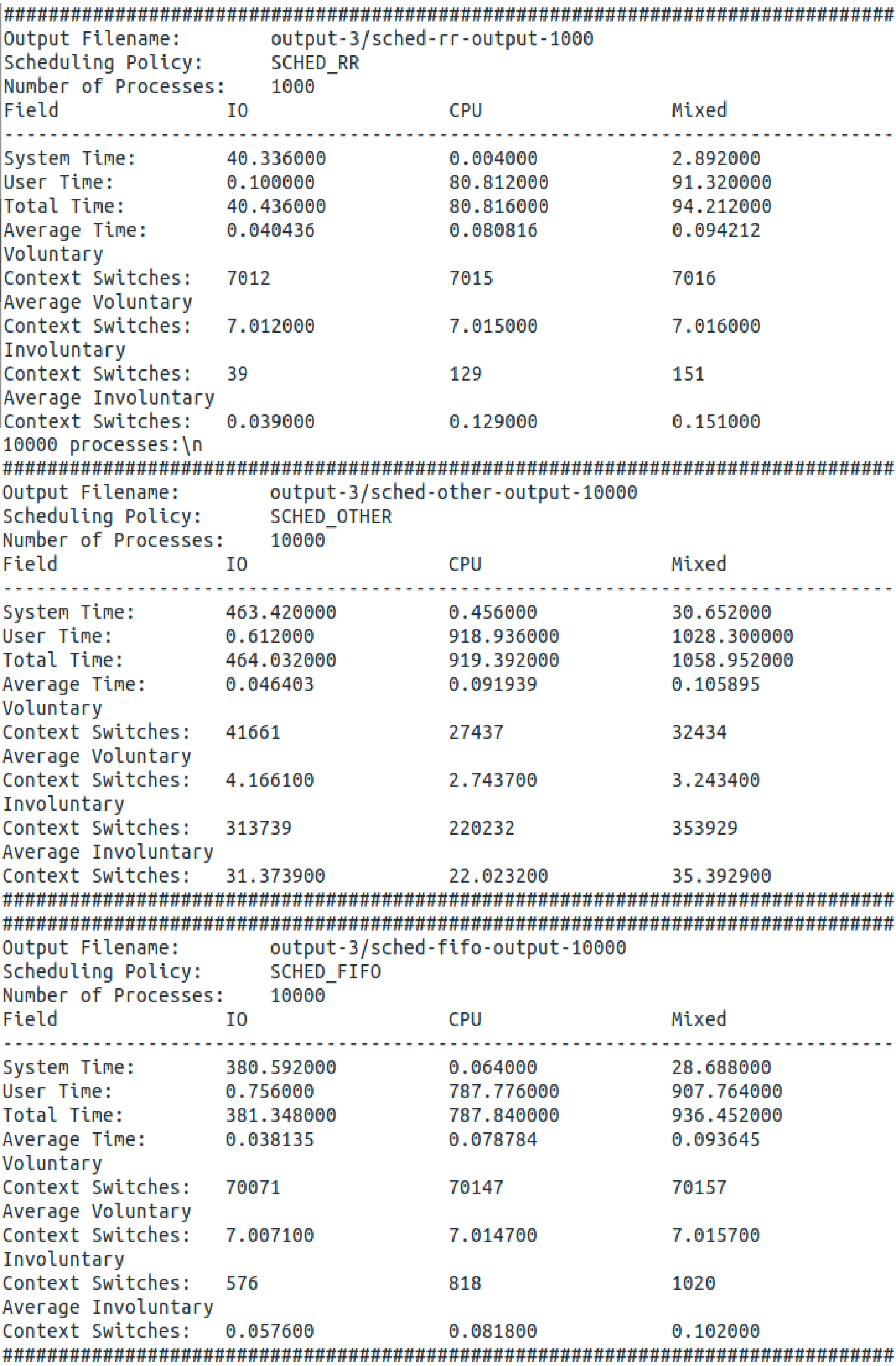
8. Appendix a: Raw Data



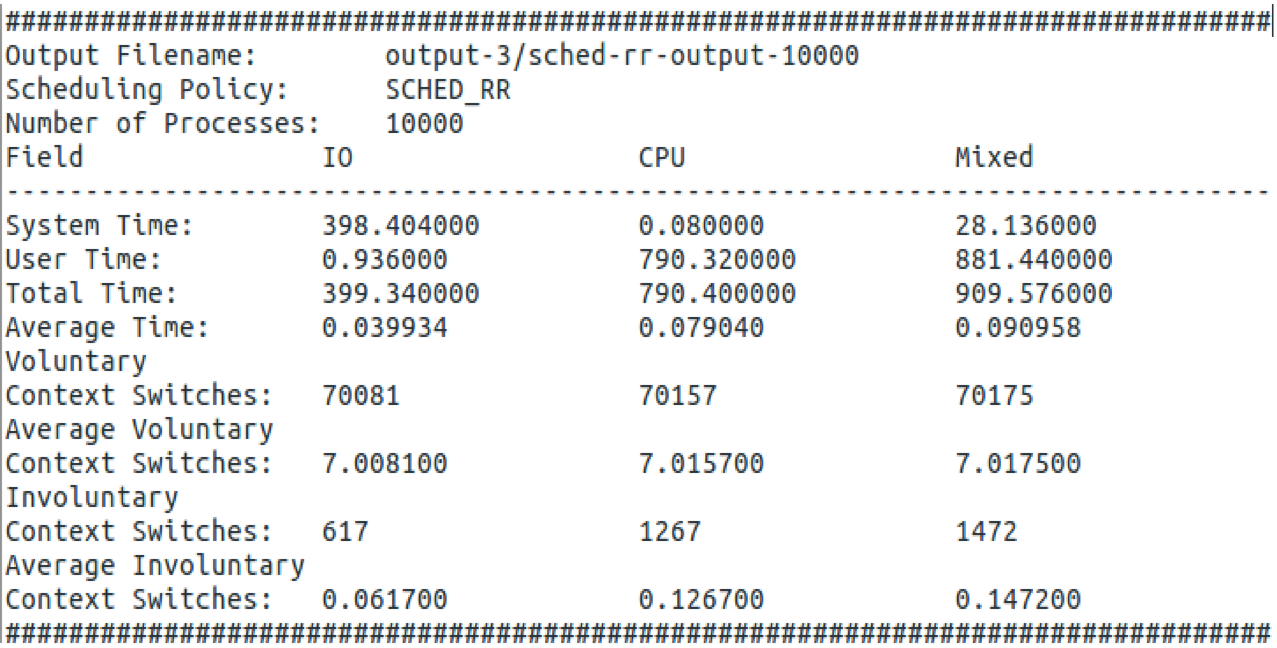
```
100 processes:
################################################################################
Output Filename:        output-3/sched-other-output-100
Scheduling Policy:      SCHED_OTHER
Number of Processes:    100
Field               IO                  CPU                 Mixed
--------------------------------------------------------------------------------
System Time:        4.088000            0.016000            0.388000
User Time:          0.000000            8.960000            16.340000
Total Time:         4.088000            8.976000            16.728000
Average Time:       0.040880            0.089760            0.167280
Voluntary
Context Switches:   695                 604                 336
Average Voluntary
Context Switches:   6.950000            6.040000            3.360000
Involuntary
Context Switches:   3584                2900                7136
Average Involuntary
Context Switches:   35.840000           29.000000           71.360000
################################################################################
################################################################################
Output Filename:        output-3/sched-fifo-output-100
Scheduling Policy:      SCHED_FIFO
Number of Processes:    100
Field               IO                  CPU                 Mixed
--------------------------------------------------------------------------------
System Time:        3.392000            0.000000            0.280000
User Time:          0.008000            6.756000            7.688000
Total Time:         3.400000            6.756000            7.968000
Average Time:       0.034000            0.067560            0.079680
Voluntary
Context Switches:   702                 702                 702
Average Voluntary
Context Switches:   7.020000            7.020000            7.020000
Involuntary
Context Switches:   2                   4                   6
Average Involuntary
Context Switches:   0.020000            0.040000            0.060000
################################################################################
```



```
################################################################################
Output Filename:        output-3/sched-rr-output-100
Scheduling Policy:      SCHED_RR
Number of Processes:    100
Field               IO                  CPU                 Mixed
--------------------------------------------------------------------------------
System Time:        3.648000            0.004000            0.300000
User Time:          0.024000            6.672000            7.536000
Total Time:         3.672000            6.676000            7.836000
Average Time:       0.036720            0.066760            0.078360
Voluntary
Context Switches:   701                 702                 700
Average Voluntary
Context Switches:   7.010000            7.020000            7.000000
Involuntary
Context Switches:   4                   9                   21
Average Involuntary
Context Switches:   0.040000            0.090000            0.210000
################################################################################
1000 processes:\n
################################################################################
Output Filename:        output-3/sched-other-output-1000
Scheduling Policy:      SCHED_OTHER
Number of Processes:    1000
Field               IO                  CPU                 Mixed
--------------------------------------------------------------------------------
System Time:        50.524000           0.024000            3.008000
User Time:          0.100000            91.956000           100.080000
Total Time:         50.624000           91.980000           103.088000
Average Time:       0.050624            0.091980            0.103088
Voluntary
Context Switches:   4120                2814                2926
Average Voluntary
Context Switches:   4.120000            2.814000            2.926000
Involuntary
Context Switches:   35045               22832               36719
Average Involuntary
Context Switches:   35.045000           22.832000           36.719000
################################################################################
################################################################################
Output Filename:        output-3/sched-fifo-output-1000
Scheduling Policy:      SCHED_FIFO
Number of Processes:    1000
Field               IO                  CPU                 Mixed
--------------------------------------------------------------------------------
System Time:        38.756000           0.016000            2.476000
User Time:          0.096000            84.360000           77.448000
Total Time:         38.852000           84.376000           79.924000
Average Time:       0.038852            0.084376            0.079924
Voluntary
Context Switches:   7013                7015                7018
Average Voluntary
Context Switches:   7.013000            7.015000            7.018000
Involuntary
Context Switches:   57                  92                  96
Average Involuntary
Context Switches:   0.057000            0.092000            0.096000
################################################################################
```



```
################################################################################
Output Filename:        output-3/sched-rr-output-1000
Scheduling Policy:      SCHED_RR
Number of Processes:    1000
Field               IO                  CPU                 Mixed
--------------------------------------------------------------------------------
System Time:        40.336000           0.004000            2.892000
User Time:          0.100000            80.812000           91.320000
Total Time:         40.436000           80.816000           94.212000
Average Time:       0.040436            0.080816            0.094212
Voluntary
Context Switches:   7012                7015                7016
Average Voluntary
Context Switches:   7.012000            7.015000            7.016000
Involuntary
Context Switches:   39                  129                 151
Average Involuntary
Context Switches:   0.039000            0.129000            0.151000
10000 processes:\n
################################################################################
Output Filename:        output-3/sched-other-output-10000
Scheduling Policy:      SCHED_OTHER
Number of Processes:    10000
Field               IO                  CPU                 Mixed
--------------------------------------------------------------------------------
System Time:        463.420000          0.456000            30.652000
User Time:          0.612000            918.936000          1028.300000
Total Time:         464.032000          919.392000          1058.952000
Average Time:       0.046403            0.091939            0.105895
Voluntary
Context Switches:   41661               27437               32434
Average Voluntary
Context Switches:   4.166100            2.743700            3.243400
Involuntary
Context Switches:   313739              220232              353929
Average Involuntary
Context Switches:   31.373900           22.023200           35.392900
################################################################################
################################################################################
Output Filename:        output-3/sched-fifo-output-10000
Scheduling Policy:      SCHED_FIFO
Number of Processes:    10000
Field               IO                  CPU                 Mixed
--------------------------------------------------------------------------------
System Time:        380.592000          0.064000            28.688000
User Time:          0.756000            787.776000          907.764000
Total Time:         381.348000          787.840000          936.452000
Average Time:       0.038135            0.078784            0.093645
Voluntary
Context Switches:   70071               70147               70157
Average Voluntary
Context Switches:   7.007100            7.014700            7.015700
Involuntary
Context Switches:   576                 818                 1020
Average Involuntary
Context Switches:   0.057600            0.081800            0.102000
################################################################################
```



```
################################################################################
Output Filename:        output-3/sched-rr-output-10000
Scheduling Policy:      SCHED_RR
Number of Processes:    10000
Field               IO                  CPU                 Mixed
--------------------------------------------------------------------------------
System Time:        398.404000          0.080000            28.136000
User Time:          0.936000            790.320000          881.440000
Total Time:         399.340000          790.400000          909.576000
Average Time:       0.039934            0.079040            0.090958
Voluntary
Context Switches:   70081               70157               70175
Average Voluntary
Context Switches:   7.008100            7.015700            7.017500
Involuntary
Context Switches:   617                 1267                1472
Average Involuntary
Context Switches:   0.061700            0.126700            0.147200
################################################################################
```

9. Appendix b: All Code

All code can be found in this directory. Check the README for more information on compiling and running the code.