2020 OS Project 1 - Process Scheduling

資工二 b07902078 沈韋辰

1. Kernel Version

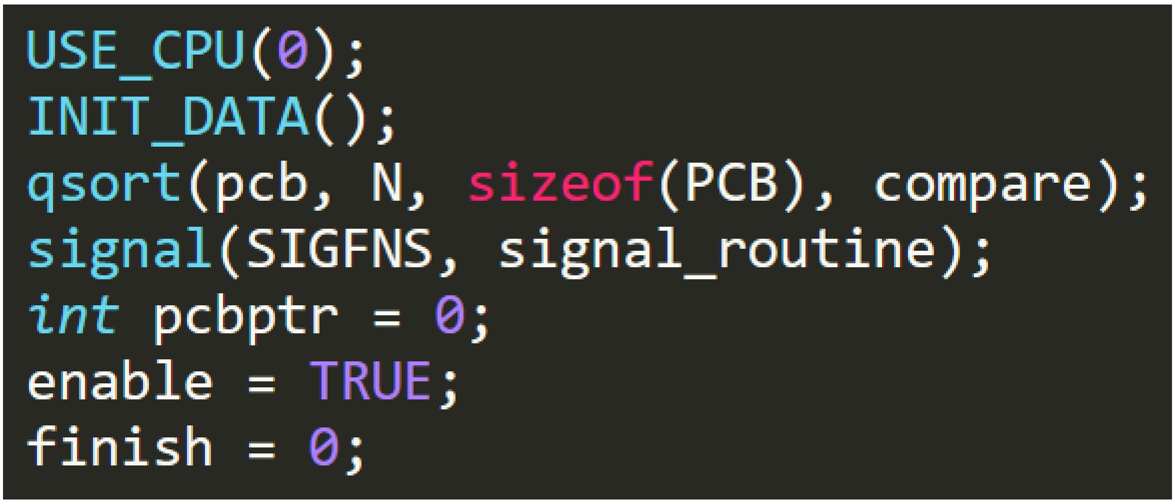
Kernel的部分本次選用linux4.10.13，在數次嘗試中發現，太新的版本會有一些不知名的bug

2. Design

每筆資料的處理方式如下:

```
  ./scheduler
=> ./FIFO or ./RR or ./SJF or ./PSJF
=> fork()
=> run the process
=> send a signal to parent
```

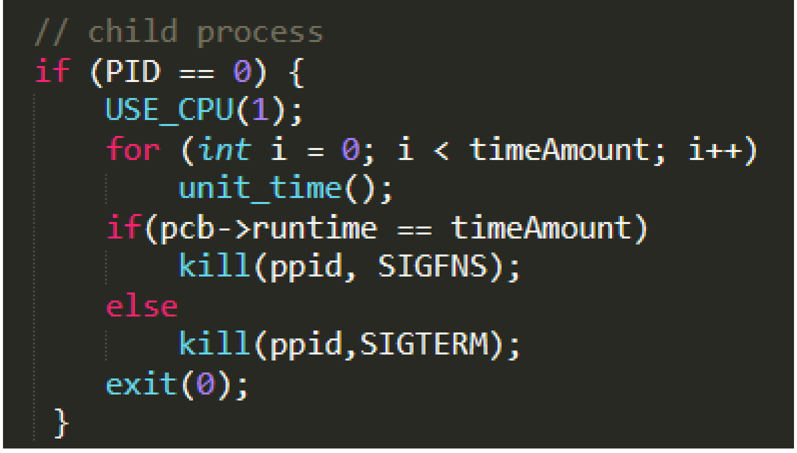
(1) Initialization



```
USE_CPU(0);
INIT_DATA();
qsort(pcb, N, sizeof(PCB), compare);
signal(SIGFNS, signal_routine);
int pcbptr = 0;
enable = TRUE;
finish = 0;
```

- PCB: store ready, run time, pid, etc.
- USE_CPU(x): set the cpu affinity
- qsort(...): sort the process by ready time
- signal_routine: my signal handler
- enable: a lock to determine whether CPU is available
- finish: counter of the finished task

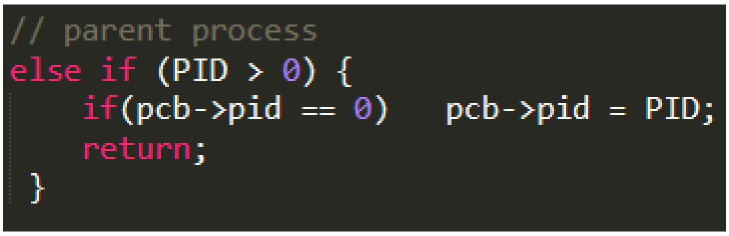
(2-1) fork()-child



```
// child process
if (PID == 0) {
    USE_CPU(1);
    for (int i = 0; i < timeAmount; i++)
        unit_time();
    if(pcb->runtime == timeAmount)
        kill(ppid, SIGFNS);
    else
        kill(ppid,SIGTERM);
    exit(0);
}
```

- USE_CPU(1): child use another CPU
- unit_time(): do 1000000 times for-loop
- SIGFNS: the process has finished
- SIGTERM: the process hasn’t finished

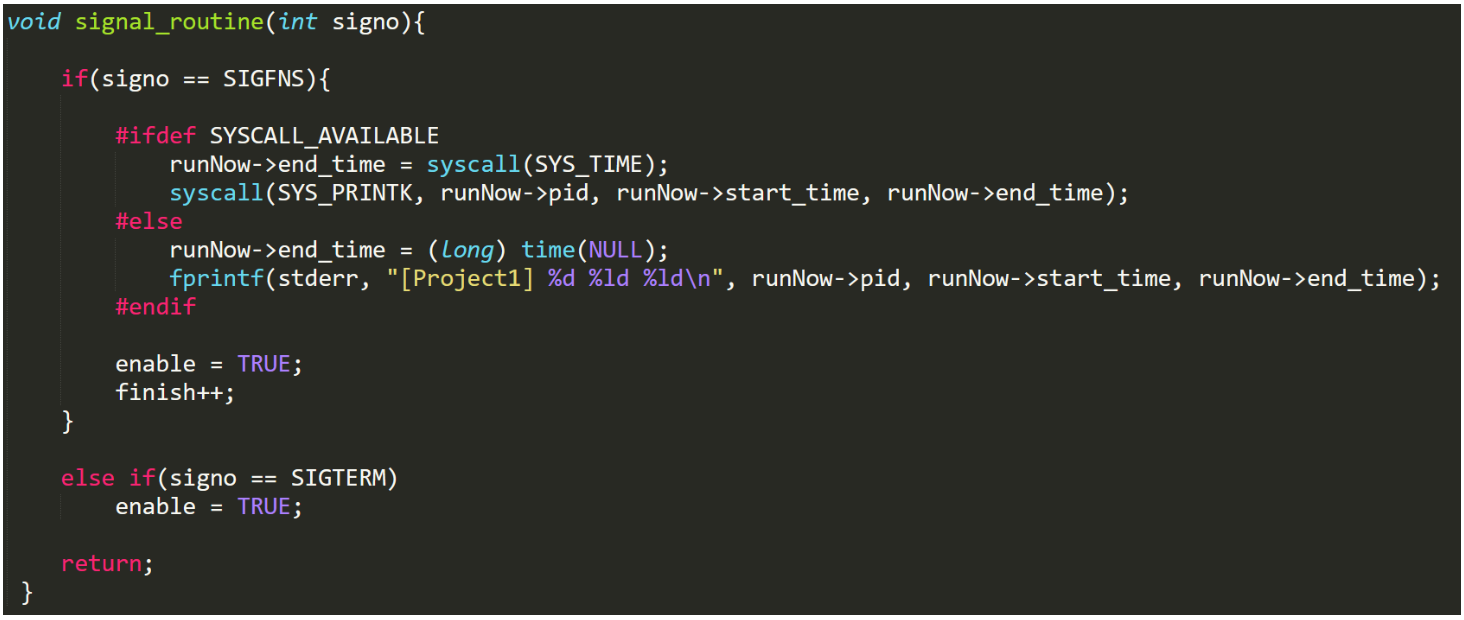
(2-2) fork()-parent



```
// parent process
else if (PID > 0) {
    if(pcb->pid == 0)   pcb->pid = PID;
    return;
}
```

- when we first run this process, store the PID.

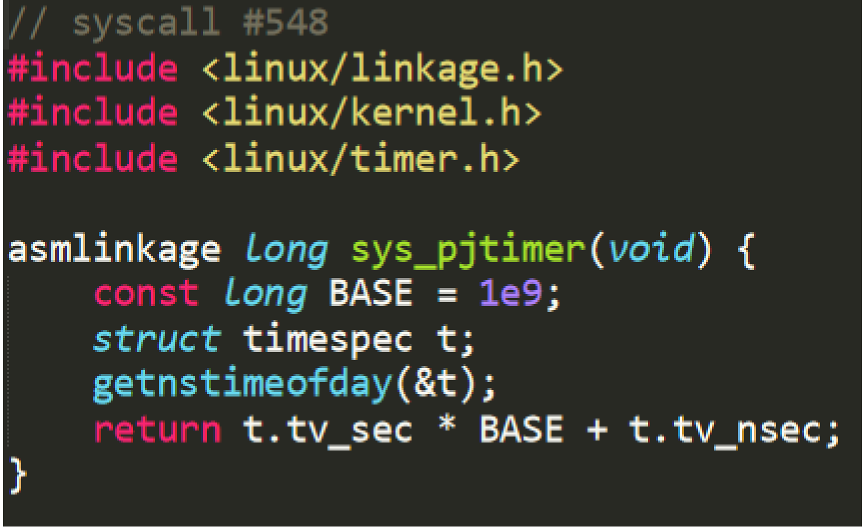
(3) signal handler



```
void signal_routine(int signo){

    if(signo == SIGFNS){

        #ifdef SYSCALL_AVAILABLE
            runNow->end_time = syscall(SYS_TIME);
            syscall(SYS_PRINTK, runNow->pid, runNow->start_time, runNow->end_time);
        #else
            runNow->end_time = (long) time(NULL);
            fprintf(stderr, "[Project1] %d %ld %ld\n", runNow->pid, runNow->start_time, runNow->end_time);
        #endif

        enable = TRUE;
        finish++;
    }

    else if(signo == SIGTERM)
        enable = TRUE;

    return;
}
```

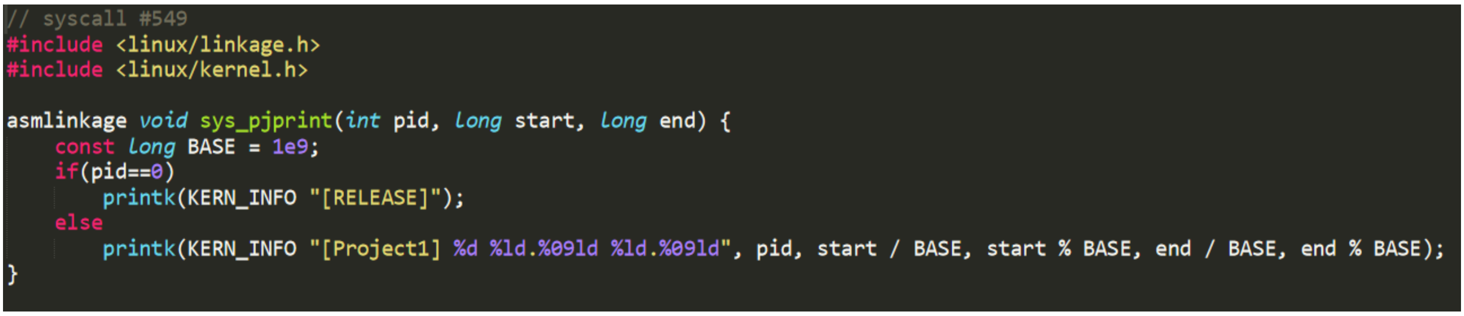
- SYSCALL_AVAILABLE: defined if run in syscall installed environment

(4-1) system call - pjtimer



```
// syscall #548
#include <linux/linkage.h>
#include <linux/kernel.h>
#include <linux/timer.h>

asmlinkage long sys_pjtimer(void) {
    const long BASE = 1e9;
    struct timespec t;
    getnstimeofday(&t);
    return t.tv_sec * BASE + t.tv_nsec;
}
```

(4-2) system call - pjprint



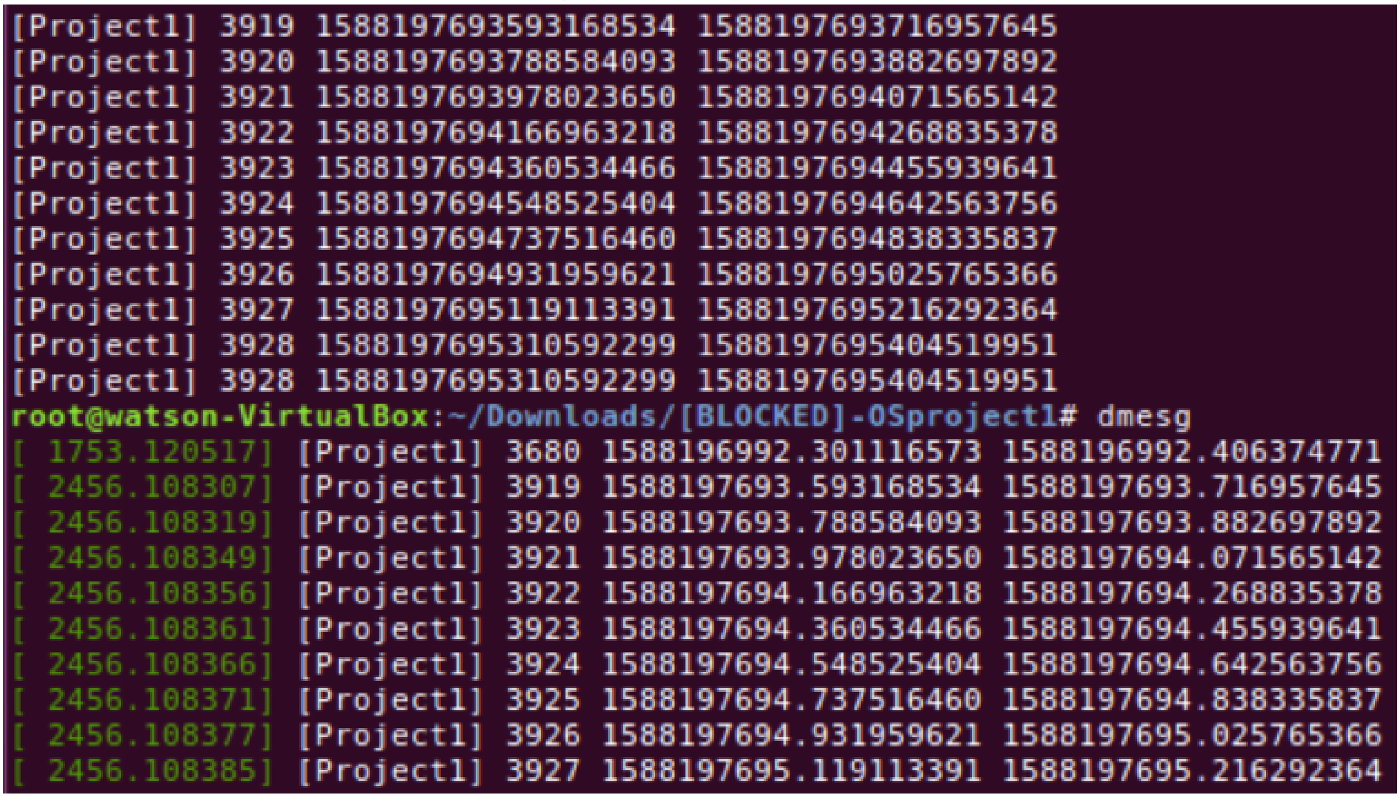
```
// syscall #549
#include <linux/linkage.h>
#include <linux/kernel.h>

asmlinkage void sys_pjprint(int pid, long start, long end) {
    const long BASE = 1e9;
    if(pid==0)
        printk(KERN_INFO "[RELEASE]");
    else
        printk(KERN_INFO "[Project1] %d %ld.%09ld %ld.%09ld", pid, start / BASE, start % BASE, end / BASE, end % BASE);
}
```

- [Project1] tag - 紀錄process完成
- [RELEASE] tag - 另有特殊用途，將由下則說明

(4-3) system call - append on the end of policy

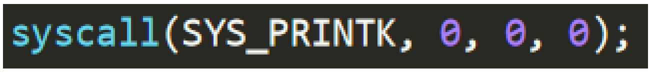
- 此為本人在作業中發生的一個問題: 同時發出stderr和sys_pjprint時，兩者得到的數據不同，似乎平移了一個進程。
- 經過本人多次實驗後發現，每個policy發出的最後一個printk會被block住，直到下一個case呼叫時，上一個case的最後一個printk message則會被呼叫，並且會讓之後的訊息全部被往後推一個進程，連帶影響後續的結果。

(下圖的上半部stderr, 下半部則是dmesg，可見兩者的PID有錯位發生)



```
[Project1] 3919 1588197693593168534 1588197693716957645
[Project1] 3920 1588197693788584093 1588197693882697892
[Project1] 3921 1588197693978023650 1588197694071565142
[Project1] 3922 1588197694166963218 1588197694268835378
[Project1] 3923 1588197694360534466 1588197694455939641
[Project1] 3924 1588197694548525404 1588197694642563756
[Project1] 3925 1588197694737516460 1588197694838335837
[Project1] 3926 1588197694931959621 1588197695025765366
[Project1] 3927 1588197695119113391 1588197695216292364
[Project1] 3928 1588197695310592299 1588197695404519951
[Project1] 3928 1588197695310592299 1588197695404519951
root@watson-VirtualBox:~/Downloads/[BLOCKED]-OSproject1# dmesg
[ 1753.120517] [Project1] 3680 1588196992.301116573 1588196992.406374771
[ 2456.108307] [Project1] 3919 1588197693.593168534 1588197693.716957645
[ 2456.108319] [Project1] 3920 1588197693.788584093 1588197693.882697892
[ 2456.108349] [Project1] 3921 1588197693.978023650 1588197694.071565142
[ 2456.108356] [Project1] 3922 1588197694.166963218 1588197694.268835378
[ 2456.108361] [Project1] 3923 1588197694.360534466 1588197694.455939641
[ 2456.108366] [Project1] 3924 1588197694.548525404 1588197694.642563756
[ 2456.108371] [Project1] 3925 1588197694.737516460 1588197694.838335837
[ 2456.108377] [Project1] 3926 1588197694.931959621 1588197695.025765366
[ 2456.108385] [Project1] 3927 1588197695.119113391 1588197695.216292364
```

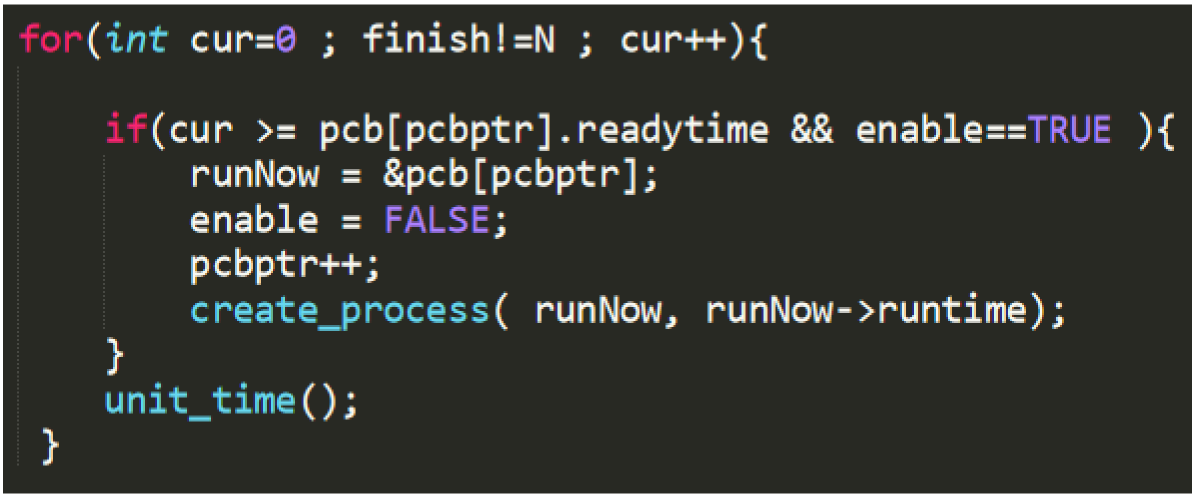
- 然而，printk為Non-blocking的system call，因此其無法正常運作的原因仍不明(maybe: kernel version, race condition, etc)
- 但實做上，我們可以在pjprint內加一個用來release那個無法成功的printk，類似用自身卡位使得每次做出N+1個printk，這樣最後輸出的release反而成為下一個的第一個
- 我們會將下面這個system call 家在所有policy的最後一行



```
syscall(SYS_PRINTK, 0, 0, 0);
```

而每個Policy大致相同，只有以下部分有所區別:

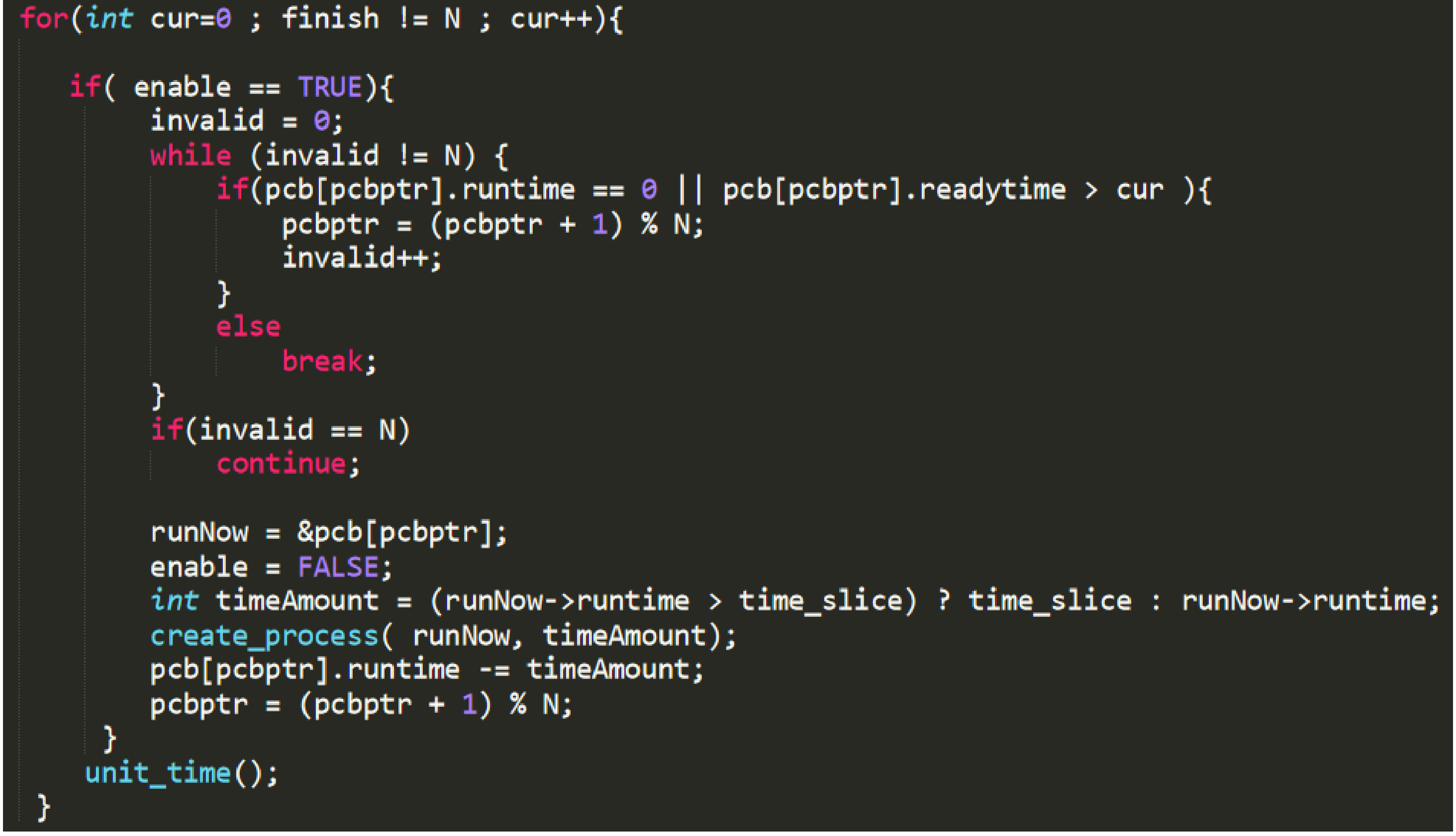
a. First in, first served (FCFS)



```
for(int cur=0 ; finish!=N ; cur++){

    if(cur >= pcb[pcbptr].readytime && enable==TRUE ){
        runNow = &pcb[pcbptr];
        enable = FALSE;
        pcbptr++;
        create_process( runNow, runNow->runtime);
    }
    unit_time();
 }
```

- 目標: 先進來的先跑
- 直接把pcb當作ready queue, 當process離開queue時，enable就設成FALSE(鎖門)
- enable設成TRUE(開門)的方式是使用signal handler來開鎖

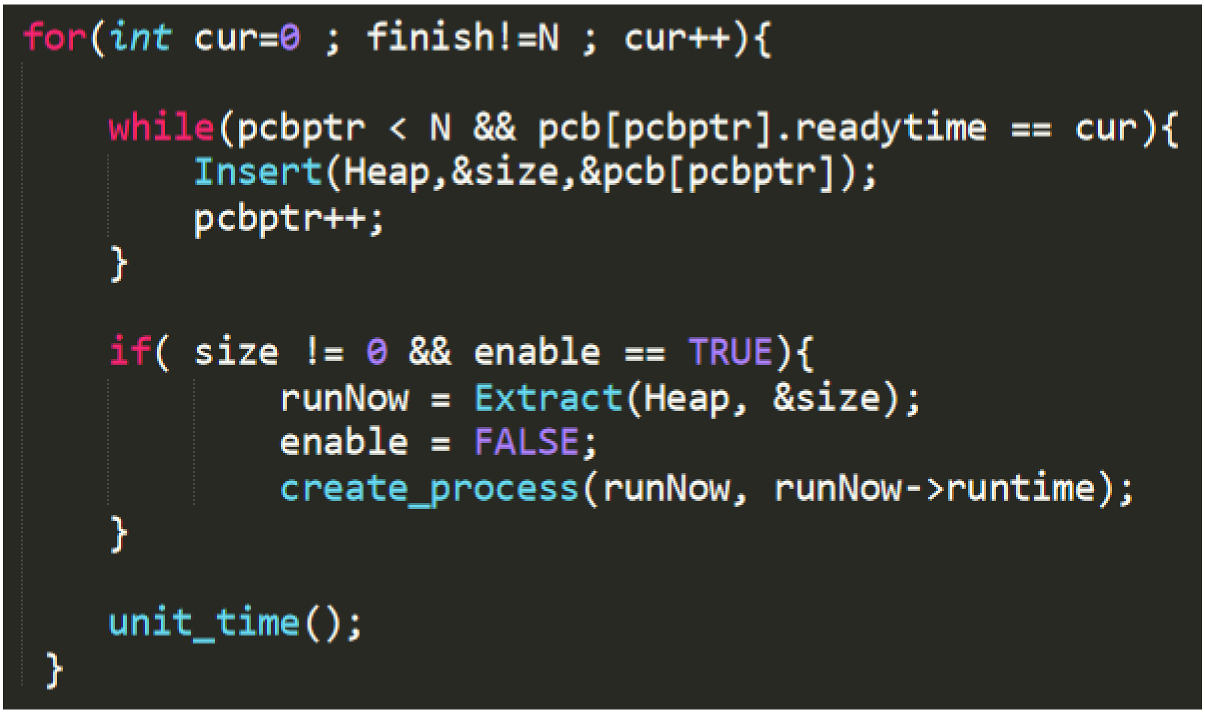
b. Round Robin (RR)



```
for(int cur=0 ; finish != N ; cur++){

   if( enable == TRUE){
        invalid = 0;
        while (invalid != N) {
            if(pcb[pcbptr].runtime == 0 || pcb[pcbptr].readytime > cur ){
                pcbptr = (pcbptr + 1) % N;
                invalid++;
            }
            else
                break;
        }
        if(invalid == N)
            continue;

        runNow = &pcb[pcbptr];
        enable = FALSE;
        int timeAmount = (runNow->runtime > time_slice) ? time_slice : runNow->runtime;
        create_process( runNow, timeAmount);
        pcb[pcbptr].runtime -= timeAmount;
        pcbptr = (pcbptr + 1) % N;
     }
    unit_time();
 }
```

- 上半部(continue之前): polling一輪去找下個ready的process。為了以防陷入無限迴圈，用invalid去紀錄有幾個現在不能跑(跑完or還沒ready)
- 下半部(continue之後) 每次能跑的上限時間是給定的time slice，跑完後計算尚需的時間。
- 整體: SIGFNS和SIGTERM都可以開鎖，但SIGFNS會去increase finish的數量。

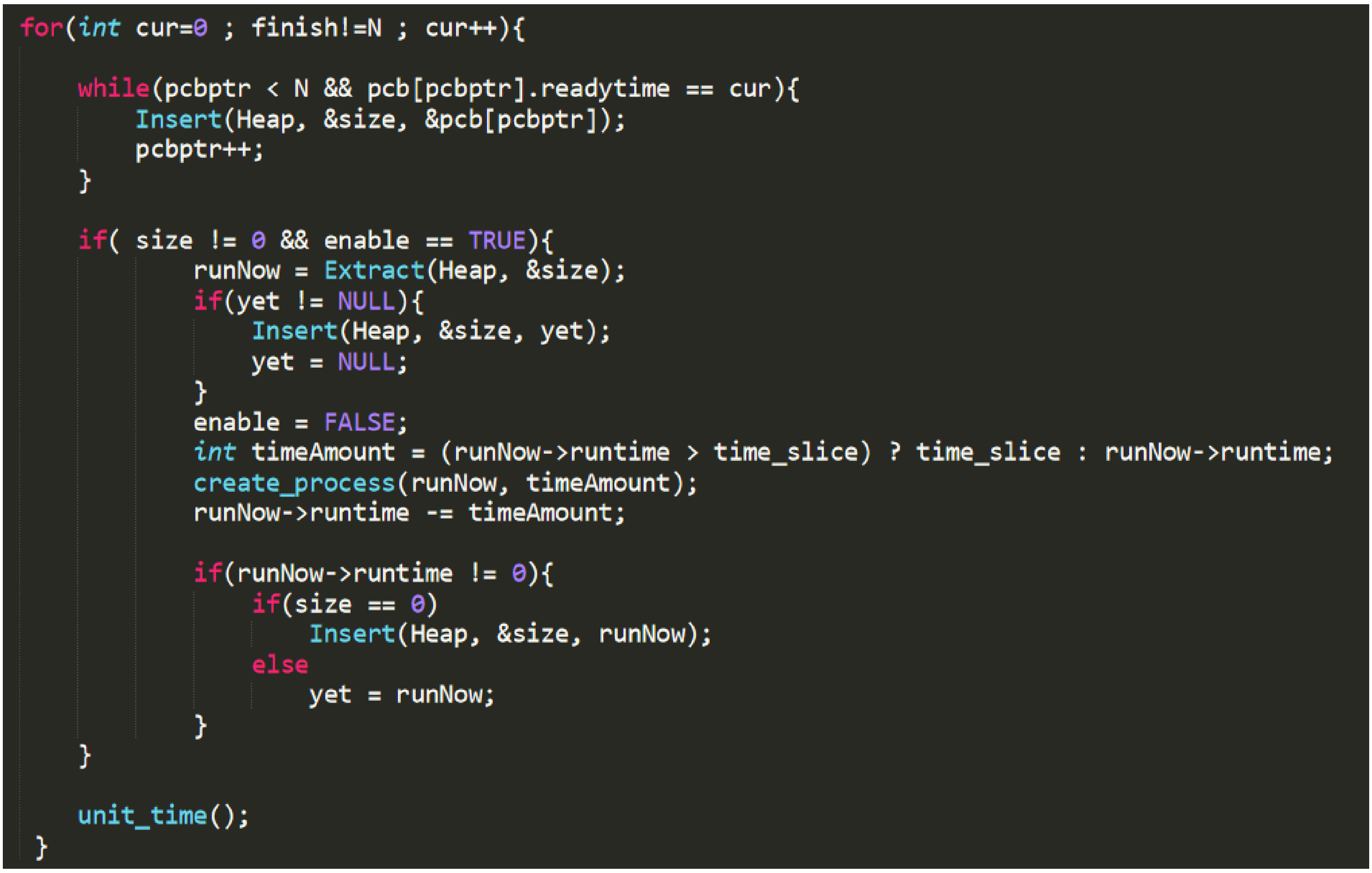
c. Shortest Job First (SJF)



```
for(int cur=0 ; finish!=N ; cur++){

    while(pcbptr < N && pcb[pcbptr].readytime == cur){
        Insert(Heap,&size,&pcb[pcbptr]);
        pcbptr++;
    }

    if( size != 0 && enable == TRUE){
            runNow = Extract(Heap, &size);
            enable = FALSE;
            create_process(runNow, runNow->runtime);
    }

    unit_time();
 }
```

- 用一個heap來maintain processes，heap的最上面都是run time最小的(runtime一樣的話就看誰先來)
- 只要ready time到了可以就insert到heap裡，每次開鎖時就extract一個去跑。

d. Preemptive Shortest Job First (PSJF)



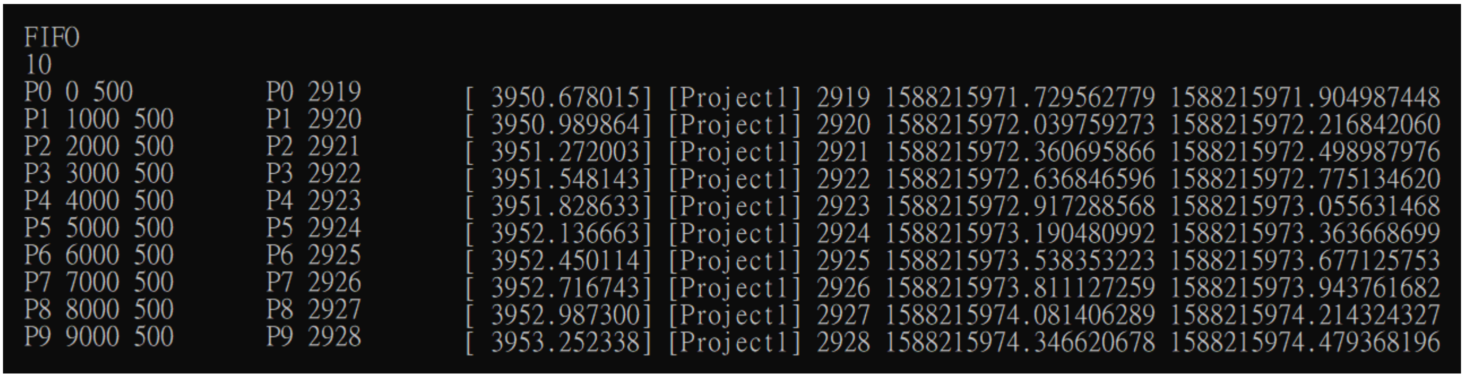
```c
for(int cur=0 ; finish!=N ; cur++){

    while(pcbptr < N && pcb[pcbptr].readytime == cur){
        Insert(Heap, &size, &pcb[pcbptr]);
        pcbptr++;
    }

    if( size != 0 && enable == TRUE){
            runNow = Extract(Heap, &size);
            if(yet != NULL){
                Insert(Heap, &size, yet);
                yet = NULL;
            }
            enable = FALSE;
            int timeAmount = (runNow->runtime > time_slice) ? time_slice : runNow->runtime;
            create_process(runNow, timeAmount);
            runNow->runtime -= timeAmount;

            if(runNow->runtime != 0){
                if(size == 0)
                    Insert(Heap, &size, runNow);
                else
                    yet = runNow;
            }
    }

    unit_time();
 }
```

- 上半部 (while-loop): 跟SJF一樣，用一個heap去排ready的processes.
- 下半部 (大if裡面): 當enable且heap不為空時，就從頂端拿一個來跑一段時間(time slice 與 run time較小的那個):

1. 跑完了 => do nothing
2. 還沒跑完，heap有人 => 把自己放到yet，下一個extract後再把自己insert進去
3. 還沒跑完，heap沒人 => 沒人也要跑那就可以繼續跑

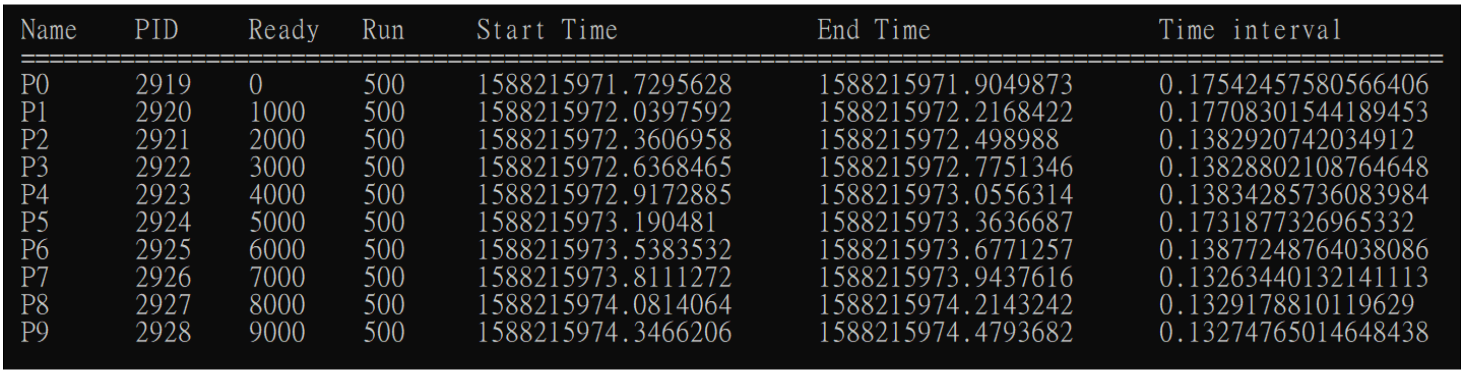
3. Comparison

每一筆測資都有.txt, stdout.txt 和 dmesg.txt (如下圖由左到右為TIME_MEASUREMENT的這三筆資料)



```
FIFO
10
P0  0  500        P0  2919
P1  1000  500     P1  2920     [  3950.678015] [Project1] 2919 1588215971.729562779 1588215971.904987448
P2  2000  500     P2  2921     [  3950.989864] [Project1] 2920 1588215972.039759273 1588215972.216842060
P3  3000  500     P3  2922     [  3951.272003] [Project1] 2921 1588215972.360695866 1588215972.498987976
P4  4000  500     P4  2923     [  3951.548143] [Project1] 2922 1588215972.636846596 1588215972.775134620
P5  5000  500     P5  2924     [  3951.828633] [Project1] 2923 1588215972.917288568 1588215973.055631468
P6  6000  500     P6  2925     [  3952.136663] [Project1] 2924 1588215973.190480992 1588215973.363668699
P7  7000  500     P7  2926     [  3952.450114] [Project1] 2925 1588215973.538353223 1588215973.677125753
P8  8000  500     P8  2927     [  3952.716743] [Project1] 2926 1588215973.811127259 1588215973.943761682
P9  9000  500     P9  2928     [  3952.987300] [Project1] 2927 1588215974.081406289 1588215974.214324327
                               [  3953.252338] [Project1] 2928 1588215974.346620678 1588215974.479368196
```

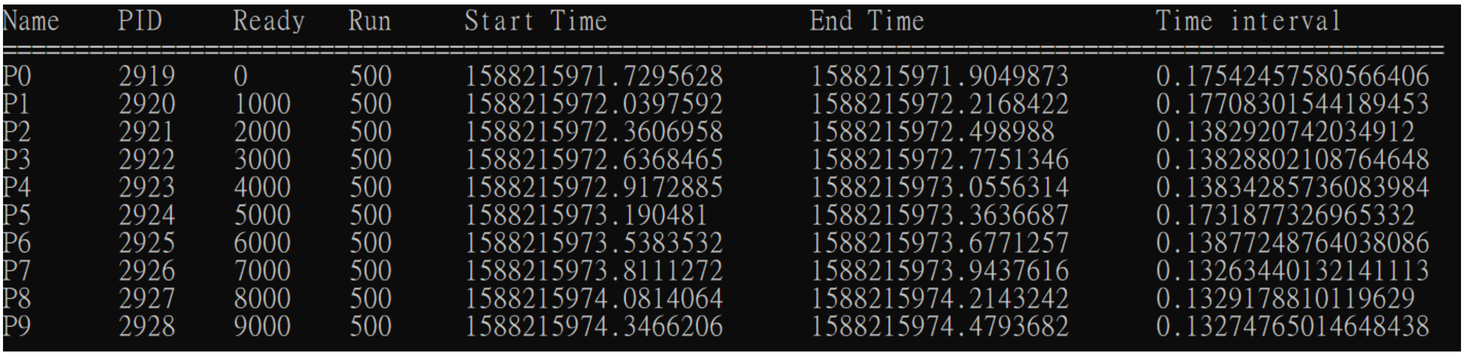
由於為了節省空間，下方的每個比較將使用以下這個我自己寫的table以方便比較，如:



```
Name    PID     Ready   Run     Start Time              End Time                Time interval
=============================================================================================
P0      2919    0       500     1588215971.7295628      1588215971.9049873      0.17542457580566406
P1      2920    1000    500     1588215972.0397592      1588215972.2168422      0.17708301544189453
P2      2921    2000    500     1588215972.3606958      1588215972.498988       0.1382920742034912
P3      2922    3000    500     1588215972.6368465      1588215972.7751346      0.13828802108764648
P4      2923    4000    500     1588215972.9172885      1588215973.0556314      0.13834285736083984
P5      2924    5000    500     1588215973.190481       1588215973.3636687      0.1731877326965332
P6      2925    6000    500     1588215973.5383532      1588215973.6771257      0.13877248764038086
P7      2926    7000    500     1588215973.8111272      1588215973.9437616      0.13263440132141113
P8      2927    8000    500     1588215974.0814064      1588215974.2143242      0.1329178810119629
P9      2928    9000    500     1588215974.3466206      1588215974.4793682      0.13274765014648438
```

(其中time interval為end time - start time)

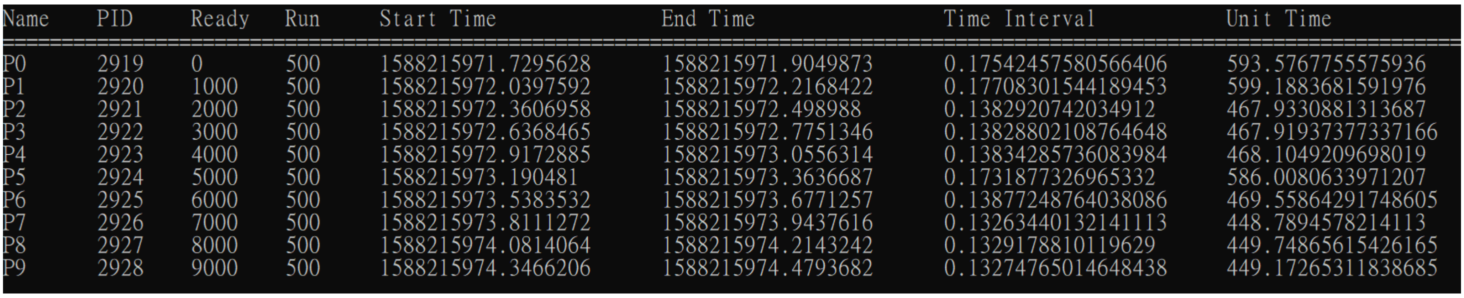
TIME_MEASUREMENT



```
Name    PID     Ready   Run     Start Time              End Time                Time interval
=============================================================================================
P0      2919    0       500     1588215971.7295628      1588215971.9049873      0.17542457580566406
P1      2920    1000    500     1588215972.0397592      1588215972.2168422      0.17708301544189453
P2      2921    2000    500     1588215972.3606958      1588215972.498988       0.1382920742034912
P3      2922    3000    500     1588215972.6368465      1588215972.7751346      0.13828802108764648
P4      2923    4000    500     1588215972.9172885      1588215973.0556314      0.13834285736083984
P5      2924    5000    500     1588215973.190481       1588215973.3636687      0.1731877326965332
P6      2925    6000    500     1588215973.5383532      1588215973.6771257      0.13877248764038086
P7      2926    7000    500     1588215973.8111272      1588215973.9437616      0.13263440132141113
P8      2927    8000    500     1588215974.0814064      1588215974.2143242      0.1329178810119629
P9      2928    9000    500     1588215974.3466206      1588215974.4793682      0.13274765014648438
```

平均500個unit time是 0.14776906967163086 s = 147769069.67163086 ns

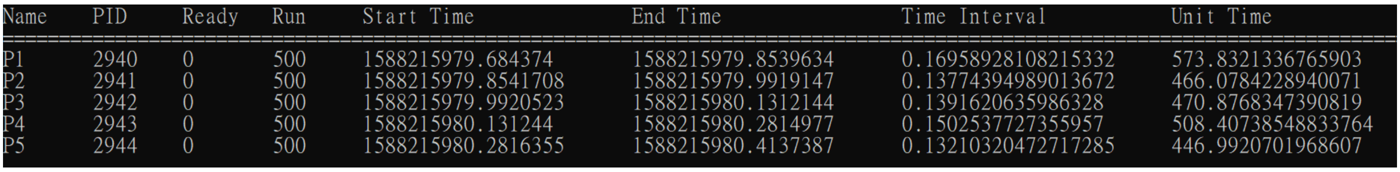
因此之後我們考慮一個unit time = **295538.1393432617 ns**



```
Name    PID     Ready   Run     Start Time              End Time                Time Interval           Unit Time
=================================================================================================================
P0      2919    0       500     1588215971.7295628      1588215971.9049873      0.17542457580566406     593.5767755575936
P1      2920    1000    500     1588215972.0397592      1588215972.2168422      0.17708301544189453     599.1883681591976
P2      2921    2000    500     1588215972.3606958      1588215972.498988       0.1382920742034912      467.9330881313687
P3      2922    3000    500     1588215972.6368465      1588215972.7751346      0.13828802108764648     467.91937377337166
P4      2923    4000    500     1588215972.9172885      1588215973.0556314      0.13834285736083984     468.1049209698019
P5      2924    5000    500     1588215973.190481       1588215973.3636687      0.1731877326965332      586.0080633971207
P6      2925    6000    500     1588215973.5383532      1588215973.6771257      0.13877248764038086     469.55864291748605
P7      2926    7000    500     1588215973.8111272      1588215973.9437616      0.13263440132141113     448.7894578214113
P8      2927    8000    500     1588215974.0814064      1588215974.2143242      0.1329178810119629      449.74865615426165
P9      2928    9000    500     1588215974.3466206      1588215974.4793682      0.13274765014648438     449.17265311838685
```

a. First in, first served (FCFS)

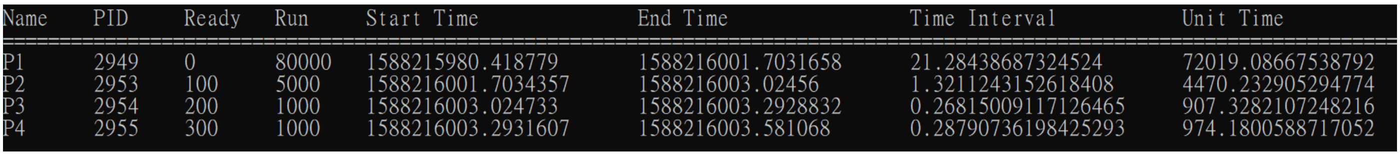
- FIFO_1.txt



```
Name    PID     Ready   Run     Start Time              End Time                Time Interval           Unit Time
=================================================================================================================
P1      2940    0       500     1588215979.684374       1588215979.8539634      0.16958928108215332     573.8321336765903
P2      2941    0       500     1588215979.8541708      1588215979.9919147      0.13774394989013672     466.0784228940071
P3      2942    0       500     1588215979.9920523      1588215980.1312144      0.1391620635986328      470.8768347390819
P4      2943    0       500     1588215980.131244       1588215980.2814977      0.1502537727355957      508.40738548833764
P5      2944    0       500     1588215980.2816355      1588215980.4137387      0.13210320472717285     446.9920701968607
```

  - 理論值(Unit time): 500 500 500 500 500
  - 實際值(Unit time): 574 466 470 508 446

- FIFO_2.txt

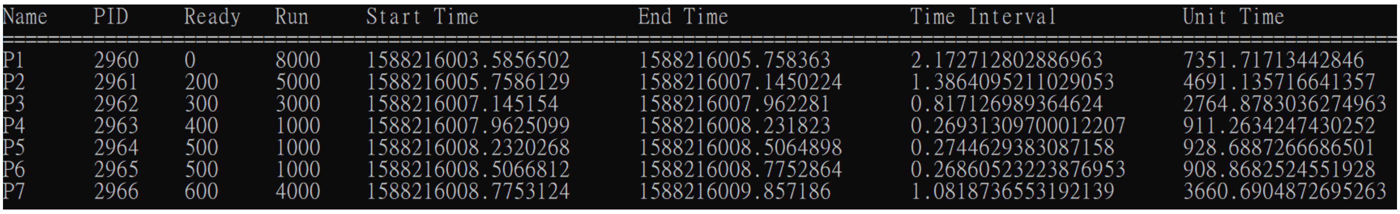


```
Name    PID     Ready   Run     Start Time              End Time                Time Interval           Unit Time
=================================================================================================================
P1      2949    0       80000   1588215980.418779       1588216001.7031658      21.28438687324524       72019.08667538792
P2      2953    100     5000    1588216001.7034357      1588216003.02456        1.3211243152618408      4470.232905294774
P3      2954    200     1000    1588216003.024733       1588216003.2928832      0.26815009117126465     907.3282107248216
P4      2955    300     1000    1588216003.2931607      1588216003.581068       0.28790736198425293     974.1800588717052
```

  - 理論值(Unit time): 80000 5000 1000 1000

    - 實際值(Unit time): 72019 4470 907 974

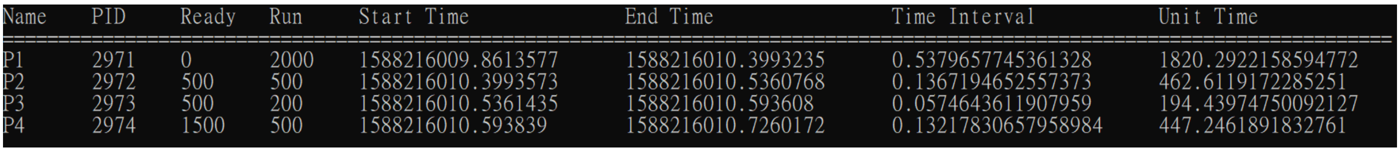
- FIFO_3.txt



```
Name    PID     Ready   Run     Start Time              End Time                Time Interval           Unit Time
=======================================================================================================================
P1      2960    0       8000    1588216003.5856502      1588216005.758363       2.172712802886963       7351.71713442846
P2      2961    200     5000    1588216005.7586129      1588216007.1450224      1.3864095211029053      4691.135716641357
P3      2962    300     3000    1588216007.145154       1588216007.962281       0.817126989364624       2764.8783036274963
P4      2963    400     1000    1588216007.9625099      1588216008.231823       0.26931309700012207     911.2634247430252
P5      2964    500     1000    1588216008.2320268      1588216008.5064898      0.2744629383087158      928.6887266686501
P6      2965    500     1000    1588216008.5066812      1588216008.7752864      0.26860523223876953     908.8682524551928
P7      2966    600     4000    1588216008.7753124      1588216009.857186       1.0818736553192139      3660.6904872695263
```

    - 理論值(Unit time): 8000 5000 3000 1000 1000 1000 4000
    - 實際值(Unit time): 7352 4691 2765 911 928 908 3660

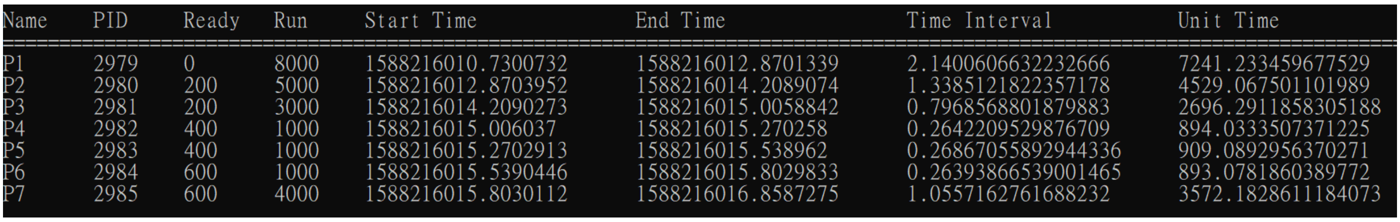
- FIFO_4.txt



```
Name    PID     Ready   Run     Start Time              End Time                Time Interval           Unit Time
=======================================================================================================================
P1      2971    0       2000    1588216009.8613577      1588216010.3993235      0.5379657745361328      1820.2922158594772
P2      2972    500     500     1588216010.3993573      1588216010.5360768      0.1367194652557373      462.6119172285251
P3      2973    500     200     1588216010.5361435      1588216010.593608       0.0574643611907959      194.43974750092127
P4      2974    1500    500     1588216010.593839       1588216010.7260172      0.13217830657958984     447.2461891832761
```

    - 理論值(Unit time): 2000 500 200 500
    - 實際值(Unit time): 1820 463 194 447

- FIFO_5.txt

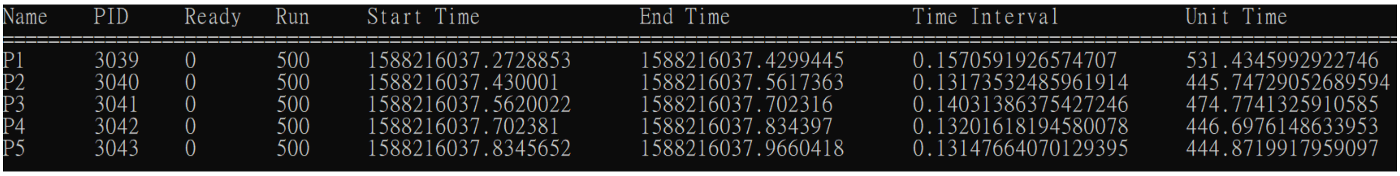


```
Name    PID     Ready   Run     Start Time              End Time                Time Interval           Unit Time
=======================================================================================================================
P1      2979    0       8000    1588216010.7300732      1588216012.8701339      2.1400606632232666      7241.233459677529
P2      2980    200     5000    1588216012.8703952      1588216014.2089074      1.3385121822357178      4529.067501101989
P3      2981    200     3000    1588216014.2090273      1588216015.0058842      0.7968568801879883      2696.2911858305188
P4      2982    400     1000    1588216015.006037       1588216015.270258       0.2642209529876709      894.0333507371225
P5      2983    400     1000    1588216015.2702913      1588216015.538962       0.26867055892944336     909.0892956370271
P6      2984    600     1000    1588216015.5390446      1588216015.8029833      0.26393866539001465     893.0781860389772
P7      2985    600     4000    1588216015.8030112      1588216016.8587275      1.0557162761688232      3572.1828611184073
```

    - 理論值(Unit time): 8000 5000 3000 1000 1000 1000 4000
    - 實際值(Unit time): 7241 4529 2696 894 909 893 3572

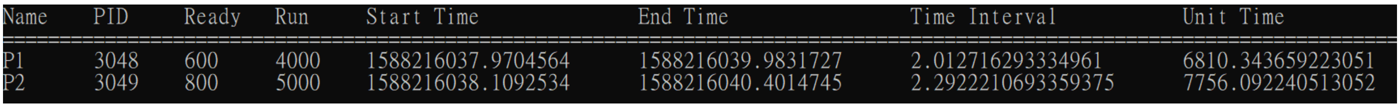
b. Round Robin (RR)

- RR_1.txt



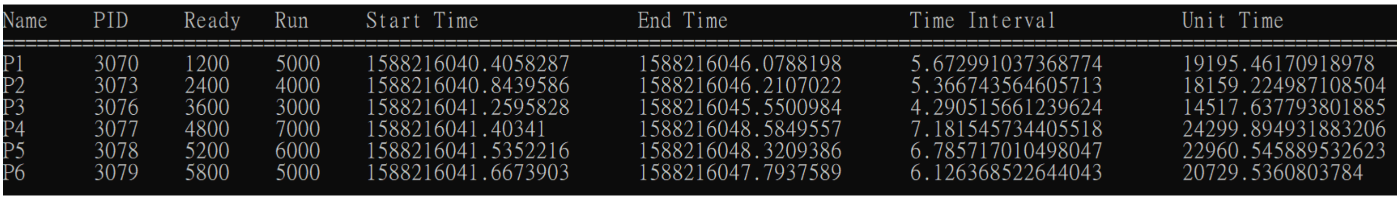
```
Name    PID     Ready   Run     Start Time              End Time                Time Interval           Unit Time
=======================================================================================================================
P1      3039    0       500     1588216037.2728853      1588216037.4299445      0.1570591926574707      531.4345992922746
P2      3040    0       500     1588216037.430001       1588216037.5617363      0.13173532485961914     445.74729052689594
P3      3041    0       500     1588216037.5620022      1588216037.702316       0.14031386375427246     474.7741325910585
P4      3042    0       500     1588216037.702381       1588216037.834397       0.13201618194580078     446.6976148633953
P5      3043    0       500     1588216037.8345652      1588216037.9660418      0.13147664070129395     444.8719917959097
```

- RR_2.txt



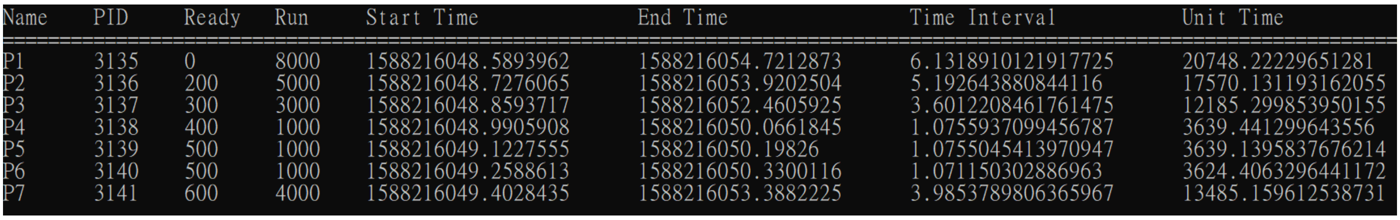
```
Name    PID     Ready   Run     Start Time              End Time                Time Interval           Unit Time
=======================================================================================================================
P1      3048    600     4000    1588216037.9704564      1588216039.9831727      2.012716293334961       6810.343659223051
P2      3049    800     5000    1588216038.1092534      1588216040.4014745      2.2922210693359375      7756.092240513052
```

- RR_3.txt



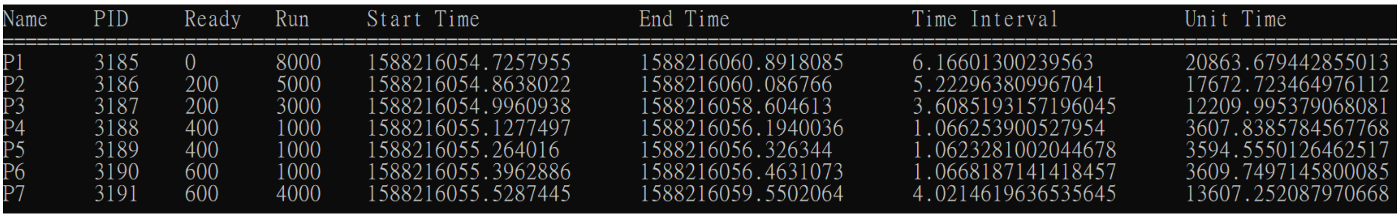
```
Name    PID     Ready   Run     Start Time              End Time                Time Interval           Unit Time
=======================================================================================================================
P1      3070    1200    5000    1588216040.4058287      1588216046.0788198      5.672991037368774       19195.46170918978
P2      3073    2400    4000    1588216040.8439586      1588216046.2107022      5.366743564605713       18159.224987108504
P3      3076    3600    3000    1588216041.2595828      1588216045.5500984      4.290515661239624       14517.637793801885
P4      3077    4800    7000    1588216041.40341        1588216048.5849557      7.181545734405518       24299.894931883206
P5      3078    5200    6000    1588216041.5352216      1588216048.3209386      6.785717010498047       22960.545889532623
P6      3079    5800    5000    1588216041.6673903      1588216047.7937589      6.126368522644043       20729.5360803784
```

- RR_4.txt



```
Name    PID     Ready   Run     Start Time              End Time                Time Interval           Unit Time
========================================================================================================================
P1      3135    0       8000    1588216048.5893962      1588216054.7212873      6.1318910121917725      20748.22229651281
P2      3136    200     5000    1588216048.7276065      1588216053.9202504      5.192643880844116       17570.131193162055
P3      3137    300     3000    1588216048.8593717      1588216052.4605925      3.6012208461761475      12185.299853950155
P4      3138    400     1000    1588216048.9905908      1588216050.0661845      1.0755937099456787      3639.441299643556
P5      3139    500     1000    1588216049.1227555      1588216050.19826        1.0755045413970947      3639.1395837676214
P6      3140    500     1000    1588216049.2588613      1588216050.3300116      1.071150302886963       3624.4063296441172
P7      3141    600     4000    1588216049.4028435      1588216053.3882225      3.9853789806365967      13485.159612538731
```

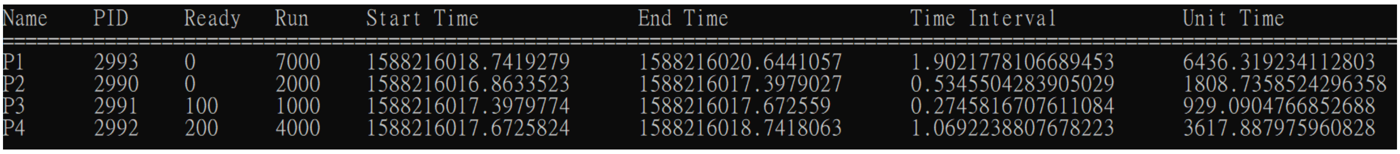
- RR_5.txt



```
Name    PID     Ready   Run     Start Time              End Time                Time Interval           Unit Time
========================================================================================================================
P1      3185    0       8000    1588216054.7257955      1588216060.8918085      6.16601300239563        20863.679442855013
P2      3186    200     5000    1588216054.8638022      1588216060.086766       5.222963809967041       17672.723464976112
P3      3187    200     3000    1588216054.9960938      1588216058.604613       3.6085193157196045      12209.995379068081
P4      3188    400     1000    1588216055.1277497      1588216056.1940036      1.066253900527954       3607.8385784567768
P5      3189    400     1000    1588216055.264016       1588216056.326344       1.0623281002044678      3594.5550126462517
P6      3190    600     1000    1588216055.3962886      1588216056.4631073      1.0668187141418457      3609.7497145800085
P7      3191    600     4000    1588216055.5287445      1588216059.5502064      4.0214619636535645      13607.252087970668
```

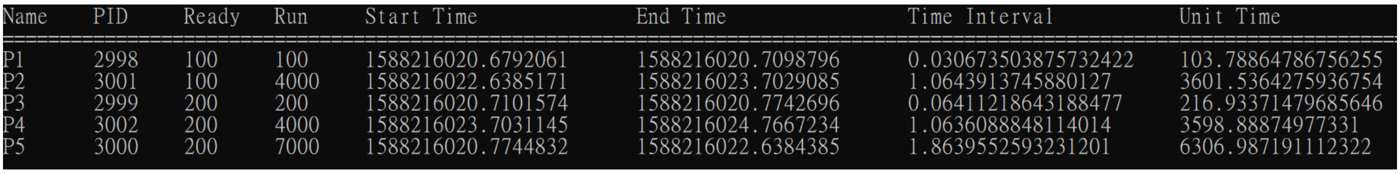
c. Shortest Job First (SJF)

- SJF_1.txt



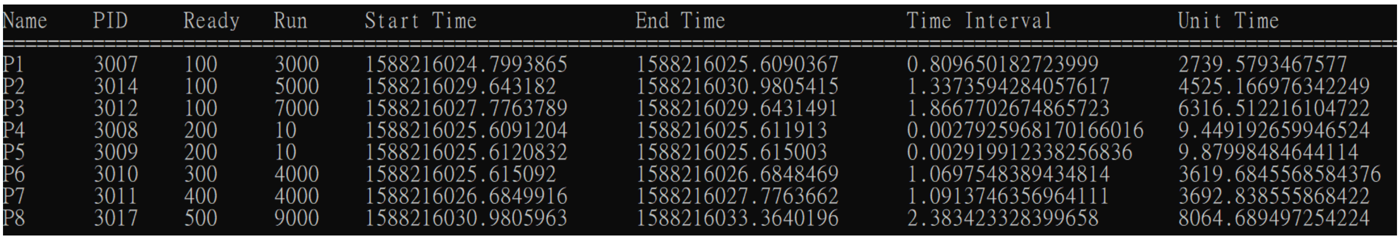
```
Name    PID     Ready   Run     Start Time              End Time                Time Interval           Unit Time
========================================================================================================================
P1      2993    0       7000    1588216018.7419279      1588216020.6441057      1.9021778106689453      6436.319234112803
P2      2990    0       2000    1588216016.8633523      1588216017.3979027      0.5345504283905029      1808.7358524296358
P3      2991    100     1000    1588216017.3979774      1588216017.672559       0.2745816707611084      929.0904766852688
P4      2992    200     4000    1588216017.6725824      1588216018.7418063      1.0692238807678223      3617.887975960828
```

- SJF_2.txt



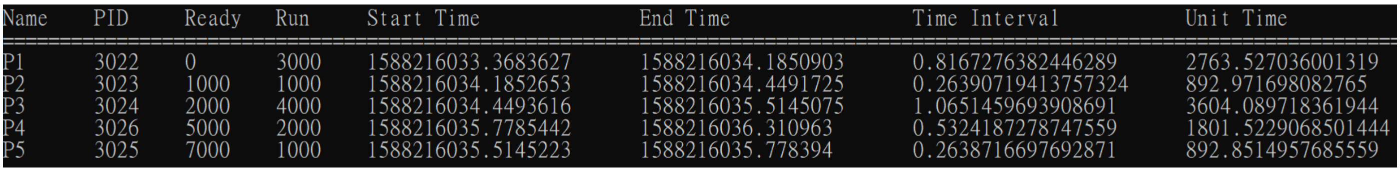
```
Name    PID     Ready   Run     Start Time              End Time                Time Interval           Unit Time
========================================================================================================================
P1      2998    100     100     1588216020.6792061      1588216020.7098796      0.030673503875732422    103.78864786756255
P2      3001    100     4000    1588216022.6385171      1588216023.7029085      1.0643913745880127      3601.5364275936754
P3      2999    200     200     1588216020.7101574      1588216020.7742696      0.06411218643188477     216.93371479685646
P4      3002    200     4000    1588216023.7031145      1588216024.7667234      1.0636088848114014      3598.88874977331
P5      3000    200     7000    1588216020.7744832      1588216022.6384385      1.8639552593231201      6306.987191112322
```

- SJF_3.txt



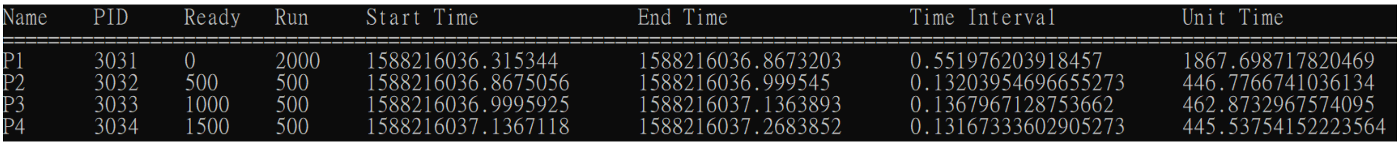
```
Name    PID     Ready   Run     Start Time              End Time                Time Interval           Unit Time
========================================================================================================================
P1      3007    100     3000    1588216024.7993865      1588216025.6090367      0.809650182723999       2739.5793467577
P2      3014    100     5000    1588216029.643182       1588216030.9805415      1.3373594284057617      4525.166976342249
P3      3012    100     7000    1588216027.7763789      1588216029.6431491      1.8667702674865723      6316.512216104722
P4      3008    200     10      1588216025.6091204      1588216025.611913       0.0027925968170166016   9.449192659946524
P5      3009    200     10      1588216025.6120832      1588216025.615003       0.002919912338256836    9.87998484644114
P6      3010    300     4000    1588216025.615092       1588216026.6848469      1.0697548389434814      3619.6845568584376
P7      3011    400     4000    1588216026.6849916      1588216027.7763662      1.0913746356964111      3692.838555868422
P8      3017    500     9000    1588216030.9805963      1588216033.3640196      2.383423328399658       8064.689497254224
```

- SJF_4.txt



```
Name    PID     Ready   Run     Start Time              End Time                Time Interval           Unit Time
========================================================================================================================
P1      3022    0       3000    1588216033.3683627      1588216034.1850903      0.8167276382446289      2763.527036001319
P2      3023    1000    1000    1588216034.1852653      1588216034.4491725      0.26390719413757324     892.971698082765
P3      3024    2000    4000    1588216034.4493616      1588216035.5145075      1.0651459693908691      3604.089718361944
P4      3026    5000    2000    1588216035.7785442      1588216036.310963       0.5324187278747559      1801.5229068501444
P5      3025    7000    1000    1588216035.5145223      1588216035.778394       0.2638716697692871      892.8514957685559
```

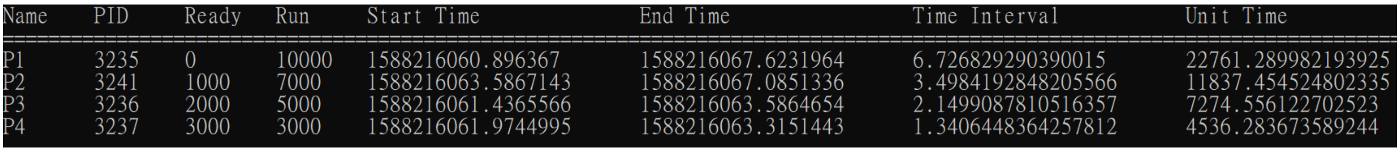
- SJF_5.txt



```
Name    PID     Ready   Run     Start Time              End Time                Time Interval           Unit Time
========================================================================================================================
P1      3031    0       2000    1588216036.315344       1588216036.8673203      0.551976203918457       1867.698717820469
P2      3032    500     500     1588216036.8675056      1588216036.999545       0.13203954696655273     446.7766741036134
P3      3033    1000    500     1588216036.9995925      1588216037.1363893      0.1367967128753662      462.8732967574095
P4      3034    1500    500     1588216037.1367118      1588216037.2683852      0.13167333602905273     445.53754152223564
```

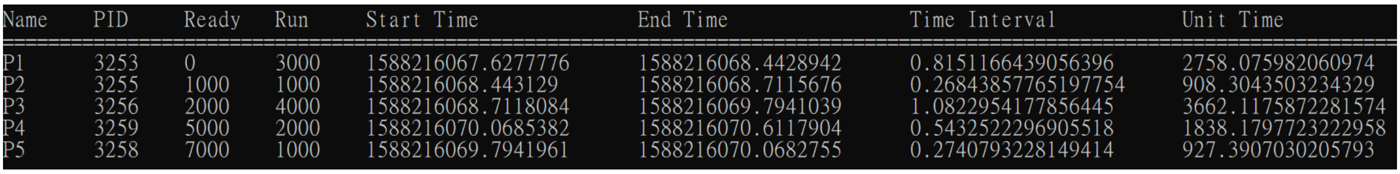
d. Preemptive Shortest Job First (PSJF)

- PSJF_1.txt



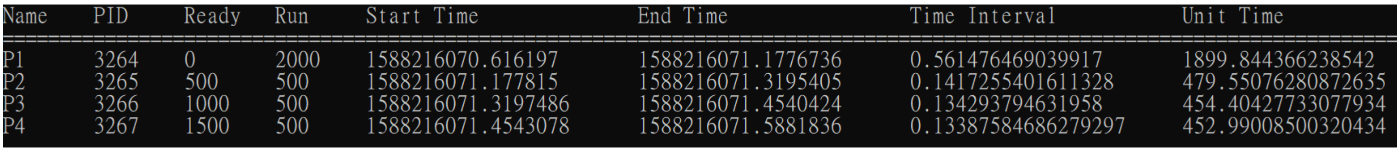
```
Name    PID     Ready   Run     Start Time              End Time                Time Interval           Unit Time
=====================================================================================================================
P1      3235    0       10000   1588216060.896367       1588216067.6231964      6.726829290390015       22761.289982193925
P2      3241    1000    7000    1588216063.5867143      1588216067.0851336      3.4984192848205566      11837.454524802335
P3      3236    2000    5000    1588216061.4365566      1588216063.5864654      2.1499087810516357      7274.556122702523
P4      3237    3000    3000    1588216061.9744995      1588216063.3151443      1.3406448364257812      4536.283673589244
```

- PSJF_2.txt



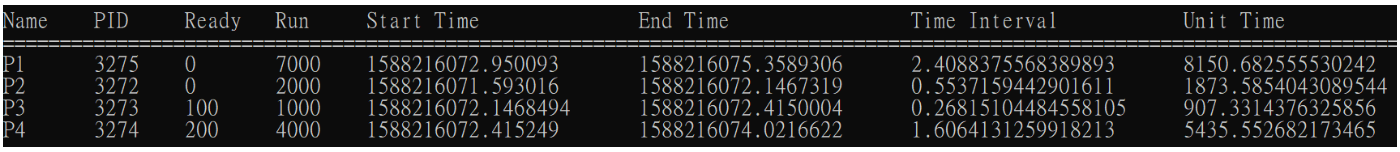
```
Name    PID     Ready   Run     Start Time              End Time                Time Interval           Unit Time
=====================================================================================================================
P1      3253    0       3000    1588216067.6277776      1588216068.4428942      0.8151166439056396      2758.075982060974
P2      3255    1000    1000    1588216068.443129       1588216068.7115676      0.26843857765197754     908.3043503234329
P3      3256    2000    4000    1588216068.7118084      1588216069.7941039      1.0822954177856445      3662.1175872281574
P4      3259    5000    2000    1588216070.0685382      1588216070.6117904      0.5432522296905518      1838.1797723222958
P5      3258    7000    1000    1588216069.7941961      1588216070.0682755      0.2740793228149414      927.3907030205793
```

- PSJF_3.txt



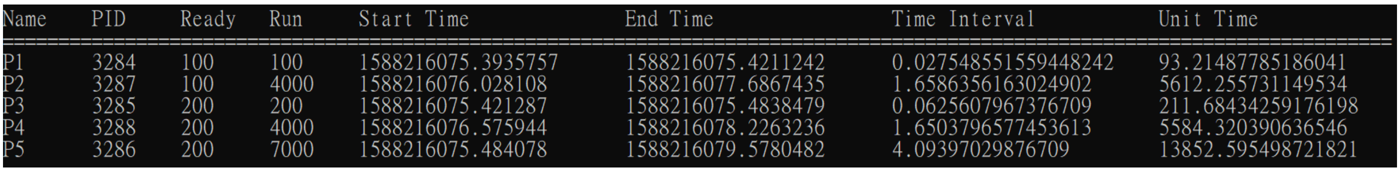
```
Name    PID     Ready   Run     Start Time              End Time                Time Interval           Unit Time
=====================================================================================================================
P1      3264    0       2000    1588216070.616197       1588216071.1776736      0.561476469039917       1899.844366238542
P2      3265    500     500     1588216071.177815       1588216071.3195405      0.1417255401611328      479.55076280872635
P3      3266    1000    500     1588216071.3197486      1588216071.4540424      0.134293794631958       454.40427733077934
P4      3267    1500    500     1588216071.4543078      1588216071.5881836      0.13387584686279297     452.99008500320434
```

- PSJF_4.txt



```
Name    PID     Ready   Run     Start Time              End Time                Time Interval           Unit Time
=====================================================================================================================
P1      3275    0       7000    1588216072.950093       1588216075.3589306      2.4088375568389893      8150.682555530242
P2      3272    0       2000    1588216071.593016       1588216072.1467319      0.5537159442901611      1873.5854043089544
P3      3273    100     1000    1588216072.1468494      1588216072.4150004      0.26815104484558105     907.3314376325856
P4      3274    200     4000    1588216072.415249       1588216074.0216622      1.6064131259918213      5435.552682173465
```

- PSJF_5.txt



```
Name    PID     Ready   Run     Start Time              End Time                Time Interval           Unit Time
=====================================================================================================================
P1      3284    100     100     1588216075.3935757      1588216075.4211242      0.027548551559448242    93.21487785186041
P2      3287    100     4000    1588216076.028108       1588216077.6867435      1.6586356163024902      5612.255731149534
P3      3285    200     200     1588216075.421287       1588216075.4838479      0.0625607967376709      211.68434259176198
P4      3288    200     4000    1588216076.575944       1588216078.2263236      1.6503796577453613      5584.320390636546
P5      3286    200     7000    1588216075.484078       1588216079.5780482      4.09397029876709        13852.595498721821
```

4. Conclusion

- Q1. 為什麼各個結果所耗費的unit time會比理論值小?
  - A1.1 可能因為當初生成的unit time比理論上還大一些
  - A1.2 此外，排程器上的counter基本上無法和child process上的counter同步，scheduler 還要忙signal handle, system call, heap maintain 之類的是，當counter跑到一定時間後，這些差異就會很明顯了
- Q2. 為什麼生成的unit time會比理論值大?
  - A2.1 除了排程外，系統也同時在做別的事
  - A2.2 VM上仍無可避免有其他程式在運行，當他們跟我們的行程context switch時，也會產生許多overhead
  - A2.3 同時，CPU也在處裡I/O，這些interrupt會讓overhead更大