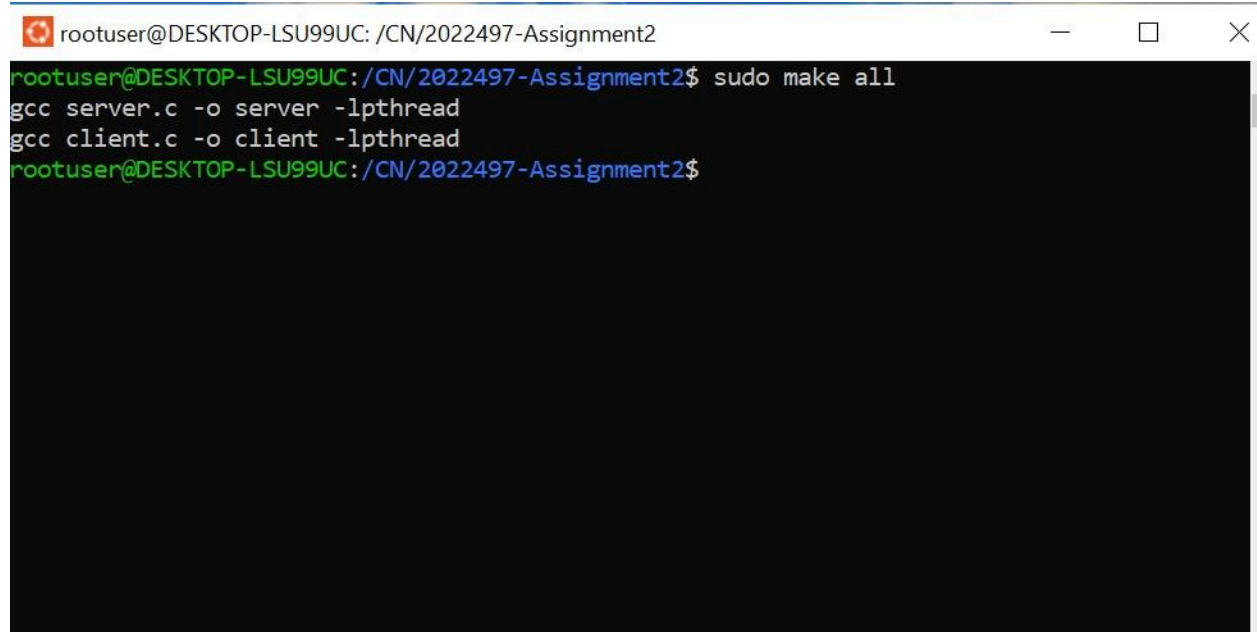


Report

Question1

Compile server.c and client.c into executable file

A terminal window with a black background and green text. The window title bar shows 'rootuser@DESKTOP-LSU99UC: /CN/2022497-Assignment2'. The terminal content shows the execution of 'sudo make all', which triggers two compilation commands: 'gcc server.c -o server -lpthread' and 'gcc client.c -o client -lpthread'. The prompt returns to 'rootuser@DESKTOP-LSU99UC: /CN/2022497-Assignment2\$'.

```
rootuser@DESKTOP-LSU99UC: /CN/2022497-Assignment2$ sudo make all
gcc server.c -o server -lpthread
gcc client.c -o client -lpthread
rootuser@DESKTOP-LSU99UC: /CN/2022497-Assignment2$
```

Initial configuration of the CPUs: using top command

```
rootuser@DESKTOP-LSU99UC: /CN/2022497-Assignment2
rootuser@DESKTOP-LSU99UC:/CN/2022497-Assignment2$ top
top - 13:36:32 up 2 min, 1 user, load average: 0.05, 0.05, 0.02
Tasks: 39 total, 1 running, 38 sleeping, 0 stopped, 0 zombie
%Cpu0  :  0.0 us,  0.0 sy,  0.0 ni,100.0 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu1  :  0.0 us,  0.8 sy,  0.0 ni, 99.2 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu2  :  0.0 us,  0.7 sy,  0.0 ni, 99.3 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu3  :  0.0 us,  0.0 sy,  0.0 ni,100.0 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu4  :  0.0 us,  0.0 sy,  0.0 ni, 99.2 id,  0.8 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu5  :  0.0 us,  0.0 sy,  0.0 ni,100.0 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu6  :  0.8 us,  0.0 sy,  0.0 ni, 99.2 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu7  :  0.0 us,  0.0 sy,  0.0 ni,100.0 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu8  :  0.0 us,  0.0 sy,  0.0 ni,100.0 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu9  :  0.0 us,  0.0 sy,  0.0 ni,100.0 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu10 :  0.0 us,  0.0 sy,  0.0 ni,100.0 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu11 :  0.7 us,  0.7 sy,  0.0 ni, 98.5 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
MiB Mem : 3655.9 total, 2697.9 free, 582.9 used, 375.2 buff/cache
MiB Swap: 1024.0 total, 1024.0 free, 0.0 used. 2920.3 avail Mem

  PID USER      PR  NI    VIRT    RES    SHR S  %CPU  %MEM     TIME+ COMMAND
    1 root        20   0   165804   11248   8276 S   0.8   0.3   0:02.05 systemd
  982 rootuser    20   0     7816    3636   3040 R   0.8   0.1   0:00.01 top
    2 root        20   0     2476    1436    132 S   0.0   0.0   0:00.00 init-sys+
    6 root        20   0     2504     136     132 S   0.0   0.0   0:00.01 init
   44 root        19  -1   39544   14836  13852 S   0.0   0.4   0:00.18 systemd-+
   64 root        20   0    22108    5844   4456 S   0.0   0.2   0:00.22 systemd-+
   77 root        20   0   152992     220     56 S   0.0   0.0   0:00.00 snapfuse
   78 root        20   0   377284   11504    372 S   0.0   0.3   0:00.73 snapfuse
   80 root        20   0   152992     192     32 S   0.0   0.0   0:00.00 snapfuse
   89 root        20   0   153124     168      4 S   0.0   0.0   0:00.00 snapfuse
   96 root        20   0   152992     196     36 S   0.0   0.0   0:00.00 snapfuse
  103 root        20   0   227888     520    248 S   0.0   0.0   0:00.03 snapfuse
  107 root        20   0   152992     160      0 S   0.0   0.0   0:00.00 snapfuse
  114 root        20   0   302520   10132    196 S   0.0   0.3   0:01.48 snapfuse
  139 root        20   0     4308    2672   2436 S   0.0   0.1   0:00.00 cron
  145 message+    20   0     8592    4644   4108 S   0.0   0.1   0:00.04 dbus-dae+
  164 root        20   0    30108   19000  10208 S   0.0   0.5   0:00.22 networkd+
  165 syslog      20   0   222404   11372   4416 S   0.0   0.3   0:00.04 rsyslogd
  166 root        20   0     4784    3292   3052 S   0.0   0.1   0:00.10 subiquit+
  168 root        20   0  1838136   38032  17628 S   0.0   1.0   0:01.05 snapd
  171 root        20   0     15332    7156   6212 S   0.0   0.2   0:00.18 systemd-+
```

Execute the server using taskset and pin it to CPU 0:

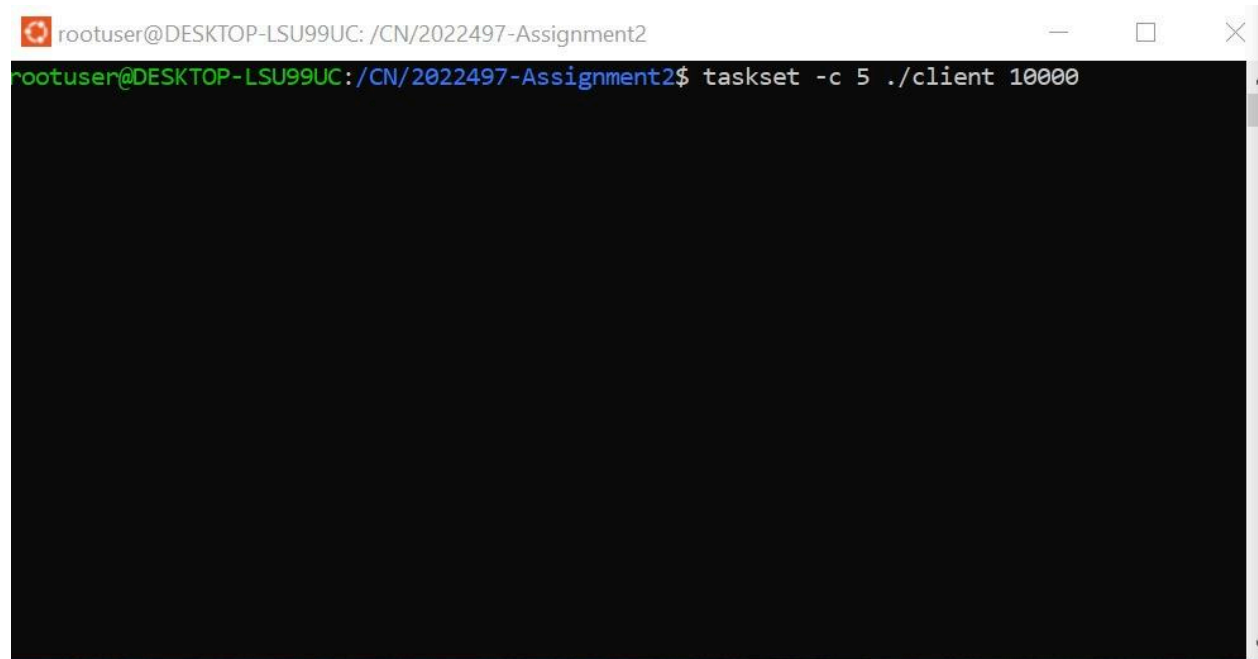
```
rootuser@DESKTOP-LSU99UC: /CN/2022497-Assignment2
rootuser@DESKTOP-LSU99UC:/CN/2022497-Assignment2$ taskset -c 0 ./server
Server is listening on port 5000
```

Configuration of CPUs after starting server:

```
Select rootuser@DESKTOP-LSU99UC: /CN/2022497-Assignment2
rootuser@DESKTOP-LSU99UC:/CN/2022497-Assignment2$ top
top - 13:36:35 up 2 min, 1 user, load average: 0.05, 0.05, 0.01
Tasks: 39 total, 1 running, 38 sleeping, 0 stopped, 0 zombie
%Cpu0 :  0.0 us,  1.7 sy,  0.0 ni, 98.3 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu1 :  1.0 us,  0.7 sy,  0.0 ni, 98.3 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu2 :  0.0 us,  0.0 sy,  0.0 ni,100.0 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu3 :  0.0 us,  0.0 sy,  0.0 ni,100.0 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu4 :  0.0 us,  0.0 sy,  0.0 ni,100.0 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu5 :  0.0 us,  0.0 sy,  0.0 ni,100.0 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu6 :  0.7 us,  0.0 sy,  0.0 ni, 99.3 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu7 :  0.0 us,  0.0 sy,  0.0 ni,100.0 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu8 :  0.0 us,  0.0 sy,  0.0 ni,100.0 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu9 :  0.7 us,  0.0 sy,  0.0 ni, 99.3 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu10 : 0.0 us,  0.0 sy,  0.0 ni,100.0 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu11 : 0.7 us,  0.0 sy,  0.0 ni, 99.3 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
MiB Mem : 3655.9 total, 2697.9 free, 582.9 used, 375.2 buff/cache
MiB Swap: 1024.0 total, 1024.0 free, 0.0 used, 2920.3 avail Mem
```

PID	USER	PR	NI	VIRT	RES	SHR	S	%CPU	%MEM	TIME+	COMMAND
1	root	20	0	165804	11248	8276	S	1.3	0.3	0:02.09	systemd
400	root	20	0	43164	37232	10044	S	0.7	1.0	0:02.31	python3
168	root	20	0	1838136	38032	17628	S	0.3	1.0	0:01.06	snappd
287	root	20	0	154352	69248	17996	S	0.3	1.8	0:04.37	python3.+
2	root	20	0	2476	1436	1320	S	0.0	0.0	0:00.00	init-sys+
6	root	20	0	2504	136	132	S	0.0	0.0	0:00.01	init
44	root	19	-1	39544	14836	13852	S	0.0	0.4	0:00.18	systemd-+
64	root	20	0	22108	5844	4456	S	0.0	0.2	0:00.22	systemd-+
77	root	20	0	152992	220	56	S	0.0	0.0	0:00.00	snappfuse
78	root	20	0	377284	11504	372	S	0.0	0.3	0:00.73	snappfuse
80	root	20	0	152992	192	32	S	0.0	0.0	0:00.00	snappfuse
89	root	20	0	153124	168	4	S	0.0	0.0	0:00.00	snappfuse
96	root	20	0	152992	196	36	S	0.0	0.0	0:00.00	snappfuse
103	root	20	0	227888	520	248	S	0.0	0.0	0:00.03	snappfuse
107	root	20	0	152992	160	0	S	0.0	0.0	0:00.00	snappfuse
114	root	20	0	302520	10132	196	S	0.0	0.3	0:01.48	snappfuse
139	root	20	0	4308	2672	2436	S	0.0	0.1	0:00.00	cron
145	message+	20	0	8592	4644	4108	S	0.0	0.1	0:00.04	dbus-dae+
164	root	20	0	30108	19000	10208	S	0.0	0.5	0:00.22	networkd+
165	syslog	20	0	222404	11372	4416	S	0.0	0.3	0:00.04	rsyslogd
166	root	20	0	4784	3292	3052	S	0.0	0.1	0:00.10	subiquit+

Execute the client using taskset and pin it to CPU 5:

A terminal window with a black background and green text. The title bar at the top reads 'rootuser@DESKTOP-LSU99UC: /CN/2022497-Assignment2'. The command 'taskset -c 5 ./client 10000' is entered at the prompt. The rest of the terminal area is empty.

```
rootuser@DESKTOP-LSU99UC: /CN/2022497-Assignment2$ taskset -c 5 ./client 10000
```

Client and server running:


```
rootuser@DESKTOP-LSU99UC: /CN/2022497-Assignment2
Client 1398 Response form server: Top 2 CPU-consuming processes:
1. PID: 287, Name: (python3.10), CPU User Time: 400, CPU Kernel Time: 58, CPU Total Time (User + Kernel): 458
2. PID: 1, Name: (systemd), CPU User Time: 322, CPU Kernel Time: 79, CPU Total Time (User + Kernel): 401

Client 1399 Response form server: Top 2 CPU-consuming processes:
1. PID: 287, Name: (python3.10), CPU User Time: 400, CPU Kernel Time: 58, CPU Total Time (User + Kernel): 458
2. PID: 1, Name: (systemd), CPU User Time: 322, CPU Kernel Time: 79, CPU Total Time (User + Kernel): 401

Client 1401 Response form server: Top 2 CPU-consuming processes:
1. PID: 287, Name: (python3.10), CPU User Time: 400, CPU Kernel Time: 58, CPU Total Time (User + Kernel): 458
2. PID: 1, Name: (systemd), CPU User Time: 322, CPU Kernel Time: 79, CPU Total Time (User + Kernel): 401
```

```
rootuser@DESKTOP-LSU99UC: /CN/2022497-Assignment2
Connection accepted
Response sent to client
Response sent to client
Response sent to client
Response sent to client
Response sent to client
Connection accepted
Connection accepted
Connection accepted
Connection accepted
Connection accepted
Connection accepted
Connection accepted
Connection accepted
Connection accepted
Connection accepted
Connection accepted
```

CPU configurations during running client and server:

```
rootuser@DESKTOP-LSU99UC: /CN/2022497-Assignment2
top - 13:39:23 up 5 min, 1 user, load average: 2.92, 1.19, 0.43
Tasks: 42 total, 4 running, 38 sleeping, 0 stopped, 0 zombie
%Cpu0  :  8.8 us, 88.5 sy,  0.0 ni,  0.5 id,  0.0 wa,  0.0 hi,  2.3 si,  0.0 st
%Cpu1  :  2.1 us,  0.0 sy,  0.0 ni, 88.4 id,  0.0 wa,  0.0 hi,  9.5 si,  0.0 st
%Cpu2  :  0.4 us,  1.8 sy,  0.0 ni, 92.1 id,  0.0 wa,  0.0 hi,  5.7 si,  0.0 st
%Cpu3  :  0.0 us,  3.2 sy,  0.0 ni, 96.8 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu4  :  1.9 us,  7.7 sy,  0.0 ni, 89.4 id,  1.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu5  :  5.0 us, 92.7 sy,  0.0 ni,  0.0 id,  0.0 wa,  0.0 hi,  2.3 si,  0.0 st
%Cpu6  :  1.8 us,  3.6 sy,  0.0 ni, 94.5 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu7  :  0.0 us,  1.9 sy,  0.0 ni, 98.1 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu8  :  4.7 us, 12.2 sy,  0.0 ni, 83.1 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu9  :  0.0 us,  7.8 sy,  0.0 ni, 91.2 id,  0.9 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu10 :  0.0 us,  5.6 sy,  0.0 ni, 94.4 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu11 :  1.5 us,  7.8 sy,  0.0 ni, 90.7 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
MiB Mem : 3655.9 total, 2485.5 free, 793.5 used, 376.9 buff/cache
MiB Swap: 1024.0 total, 1024.0 free,  0.0 used. 2708.8 avail Mem

  PID USER      PR  NI  VIRT  RES  SHR S %CPU  %MEM    TIME+  COMMAND
 25616 rootuser  20   0 510736 2016 1648 R  71.9   0.1   0:01.56 server
 25725 rootuser  20   0   56.3g 63588 1676 R  50.7   1.7   0:01.10 client
   408 root      20   0   2496   124    0 R  14.7   0.0   0:01.47 Relay(41+
26493 root      20   0  14700  6312 5508 S  10.1   0.2   0:00.22 systemd-+
   325 root      20   0   2496   120    0 S   5.1   0.0   0:00.67 Relay(32+
    1 root      20   0 165804 11248 8276 S   2.8   0.3   0:03.99 systemd
   400 root      20   0  44188 37528 10080 S   0.9   1.0   0:03.41 python3
   44 root      19  -1  47740 14908 13916 S   0.5   0.4   0:00.19 systemd-+
    2 root      20   0   2476   1436 1320 S   0.0   0.0   0:00.00 init-sys+
    6 root      20   0   2504   136   132 S   0.0   0.0   0:00.01 init
   64 root      20   0  22108  5844  4456 S   0.0   0.2   0:00.23 systemd-+
   77 root      20   0 152992   220    56 S   0.0   0.0   0:00.00 snapfuse
   78 root      20   0 377284 15588   372 S   0.0   0.4   0:00.73 snapfuse
   80 root      20   0 152992   192    32 S   0.0   0.0   0:00.00 snapfuse
   89 root      20   0 153124   168    4 S   0.0   0.0   0:00.00 snapfuse
   96 root      20   0 152992   196    36 S   0.0   0.0   0:00.00 snapfuse
  103 root      20   0 227888  2556   248 S   0.0   0.1   0:00.03 snapfuse
  107 root      20   0 152992   160    0 S   0.0   0.0   0:00.00 snapfuse
  114 root      20   0 302520 11352   196 S   0.0   0.3   0:01.48 snapfuse
  139 root      20   0   4308  2672  2436 S   0.0   0.1   0:00.00 cron
  145 message+ 20   0   8592  4644  4108 S   0.0   0.1   0:00.04 dbus-dae+
  164 root      20   0  30108 19000 10208 S   0.0   0.5   0:00.22 networkd+
```

Performance Analysis-

Server is running with PID 25616
Client is running with PID 25725

Server running on CPU0 with cpu utilization of 71.9 %
Client running on CPU5 with cpu utilization of 50.7 %

This suggests that computation power is high as they utilize a large amount of CPU for their processes. Client is running for 10000 threads. Overhead to manage these thousands of threads. Also they are pinned to a specific CPU so scheduler can not change CPUs of the server and client.

Question2

Perf for part 2A:

```
root@DESKTOP-8METIQG:/mnt/d/Shubham/CN_Assignment2/CN_Assignment2/2A# perf stat -e cycles,instructions,branches,branch-misses,task-clock,context-switches,cpu-migrations,page-faults,stalled-cycles-frontend,stalled-cycles-backend ./client 2
Client 1 message send to server
Client 1 Response form server: Top 2 CPU-consuming processes:
1. PID: 305, Name: (python3.10), User CPU Time: 254, Kernel CPU Time: 35, Total CPU Time: 289
2. PID: 132, Name: (snapfuse), User CPU Time: 71, Kernel CPU Time: 29, Total CPU Time: 100

Client 2 message send to server
Client 2 Response form server: Top 2 CPU-consuming processes:
1. PID: 305, Name: (python3.10), User CPU Time: 254, Kernel CPU Time: 35, Total CPU Time: 289
2. PID: 132, Name: (snapfuse), User CPU Time: 71, Kernel CPU Time: 29, Total CPU Time: 100

Performance counter stats for './client 2':

      2121050      cycles                  #    0.844 GHz
      884473      instructions             #    0.42  insn per cycle
     185678      branches                  #   73.890 M/sec
       11068      branch-misses              #    5.96% of all branches
       2.51 msec  task-clock                #    0.142 CPUs utilized
           11      context-switches         #    4.377 K/sec
            1      cpu-migrations            #  397.947 /sec
           61      page-faults              #   24.275 K/sec
```

Perf for part 2B:

```
root@DESKTOP-8METIQG:/mnt/d/Shubham/CN_Assignment2/CN_Assignment2/2B# perf stat -e cycles,instructions,branches,branch-misses,task-clock,context-switches,cpu-migrations,page-faults,stalled-cycles-frontend,stalled-cycles-backend ./client 2
Client 1 message send to server
Client 2 message send to server
Client 1 Response form server: Top 2 CPU-consuming processes:
1. PID: 305, Name: (python3.10), User CPU Time: 254, Kernel CPU Time: 35, Total CPU Time: 289
2. PID: 132, Name: (snapfuse), User CPU Time: 71, Kernel CPU Time: 29, Total CPU Time: 100

Client 2 Response form server: Top 2 CPU-consuming processes:
1. PID: 305, Name: (python3.10), User CPU Time: 254, Kernel CPU Time: 35, Total CPU Time: 289
2. PID: 132, Name: (snapfuse), User CPU Time: 71, Kernel CPU Time: 29, Total CPU Time: 100

Performance counter stats for './client 2':

     3119600      cycles                  #    0.569 GHz
     1035075      instructions             #    0.33  insn per cycle
      217935      branches                  #   39.747 M/sec
       14389      branch-misses              #    6.60% of all branches
       5.48 msec  task-clock                #    0.270 CPUs utilized
           13      context-switches         #    2.371 K/sec
            3      cpu-migrations            #   547.146 /sec
           66      page-faults              #   12.037 K/sec
```

Perf for part 2C:

```
root@DESKTOP-8METIQG:/mnt/d/Shubham/CN_Assignment2/CN_Assignment2/2C# perf stat -e cycles,instructions,branches,branch-misses,task-clock,context-switches,cpu-migrations,page-faults,stalled-cycles-frontend,stalled-cycles-backend ./client 2
Client 1 message send to server
Client 1 Response form server: Top 2 CPU-consuming processes:
1. PID: 305, Name: (python3.10), User CPU Time: 254, Kernel CPU Time: 35, Total CPU Time: 289
2. PID: 132, Name: (snapfuse), User CPU Time: 71, Kernel CPU Time: 29, Total CPU Time: 100

Client 2 message send to server
Client 2 Response form server: Top 2 CPU-consuming processes:
1. PID: 305, Name: (python3.10), User CPU Time: 254, Kernel CPU Time: 35, Total CPU Time: 289
2. PID: 132, Name: (snapfuse), User CPU Time: 71, Kernel CPU Time: 29, Total CPU Time: 100

Performance counter stats for './client 2':

      2759791    cycles                    #    0.131 GHz
     1048042    instructions                #    0.38  insn per cycle
      218205    branches                    #   10.321 M/sec
       14614    branch-misses                #    6.70% of all branches
      21.14 msec task-clock              #    0.846 CPUs utilized
           11    context-switches          #   520.284 /sec
            2    cpu-migrations            #   94.597 /sec
            68    page-faults              #    3.216 K/sec
```

Metric	Single-threaded	Concurrent	Using "select"
Cycles	2,121,050	3,119,600	2,759,791
Instructions	884,473	1,035,075	1,048,042
Instructions per Cycle	0.42	0.33	0.38
Branches	185,678	217,935	218,205
Branch Misses	11,068 (5.96%)	14,389 (6.60%)	14,614 (6.70%)
Task Clock (ms)	2.51	5.48	21.14
CPU Utilization	0.142 CPUs	0.270 CPUs	0.846 CPUs
Context Switches	1	13	305
CPU Migrations	1	3	2
Page Faults	61	66	68
GHz	0.844 GHz	0.569 GHz	0.131 GHz

Performance Analysis:

1. Instructions per Cycle (IPC):

Single-threaded: Has the highest IPC at 0.42, indicating better CPU efficiency.

Concurrent: Shows the lowest IPC at 0.33, likely due to the overhead of managing multiple threads.

Using "select": Slightly better than the concurrent method at 0.38, showing improved efficiency in handling multiple connections.

2. Branch Misses:

The **single-threaded** method has the lowest branch miss rate (5.96%), while both the **concurrent** (6.60%) and **select** (6.70%) approaches show increased mispredictions, likely due to handling more complex branching patterns.

3. Task Clock and CPU Utilization:

Select-based method consumes significantly more CPU (0.846 CPUs utilized) and task clock time (21.14 ms) compared to the other methods. This indicates that while it is effective at managing multiple connections, it comes at the cost of higher resource usage.

Single-threaded shows minimal CPU usage and task clock time, being more efficient in terms of processing single requests.

4. Context Switches and CPU Migrations:

Using "select" has the highest number of context switches (305) compared to 13 in the **concurrent** and only 1 in the **single-threaded** version. This overhead is due to managing multiple file descriptors, which leads to frequent switching.

The number of CPU migrations is low across all methods, with a slight increase in the **concurrent** method (3 migrations) compared to the **single-threaded** and **select** approaches.

5. Page Faults:

The number of page faults is similar across all methods, with **single-threaded** having the lowest at 61 and the **select** method having the highest at 68. This indicates that memory access patterns remain relatively stable across methods.