CSE 232: Programming Assignment 2
Socket Programming with Performance Analysis

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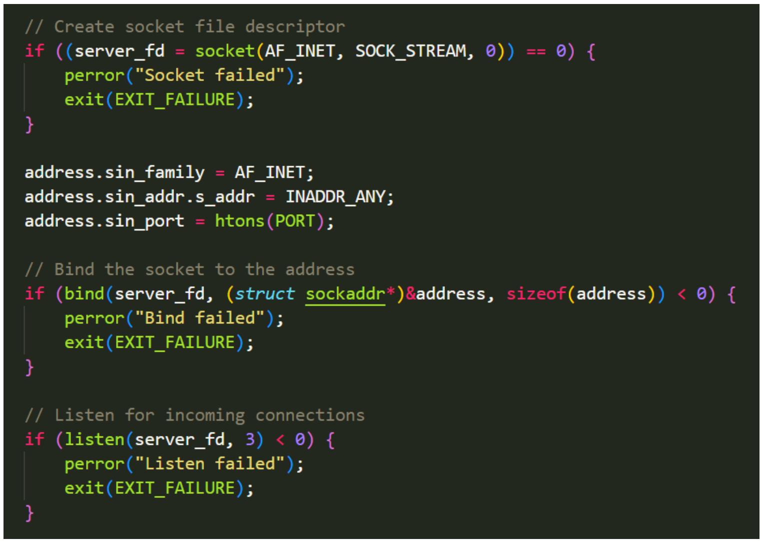
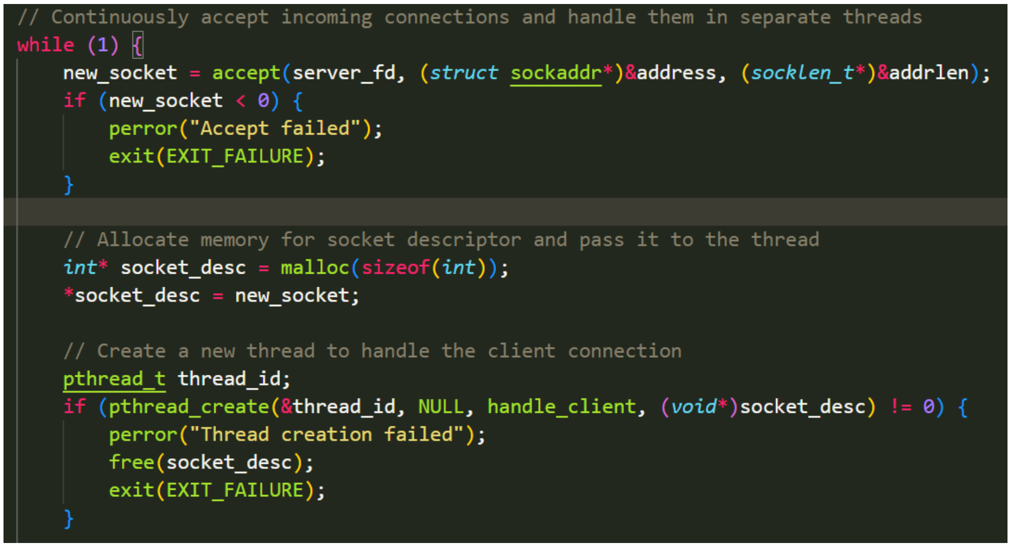
Q.1. TCP multithreaded client-server connection

1) The server sets up a TCP socket, binds a buffer space to receive requests and listens for client connections.



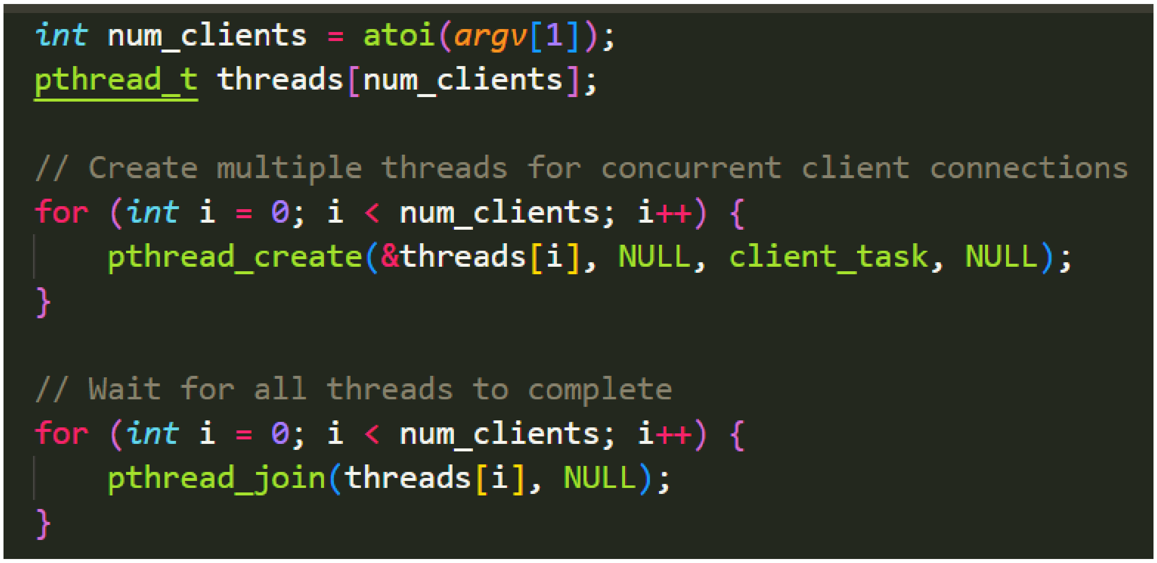
```
// Create socket file descriptor
if ((server_fd = socket(AF_INET, SOCK_STREAM, 0)) == 0) {
    perror("Socket failed");
    exit(EXIT_FAILURE);
}

address.sin_family = AF_INET;
address.sin_addr.s_addr = INADDR_ANY;
address.sin_port = htons(PORT);

// Bind the socket to the address
if (bind(server_fd, (struct sockaddr*)&address, sizeof(address)) < 0) {
    perror("Bind failed");
    exit(EXIT_FAILURE);
}

// Listen for incoming connections
if (listen(server_fd, 3) < 0) {
    perror("Listen failed");
    exit(EXIT_FAILURE);
}
```

2) The server accepts the client connection and creates a new thread that continues to process the client connection. The original server socket continues to listen on the same listening port for newer incoming client connections.



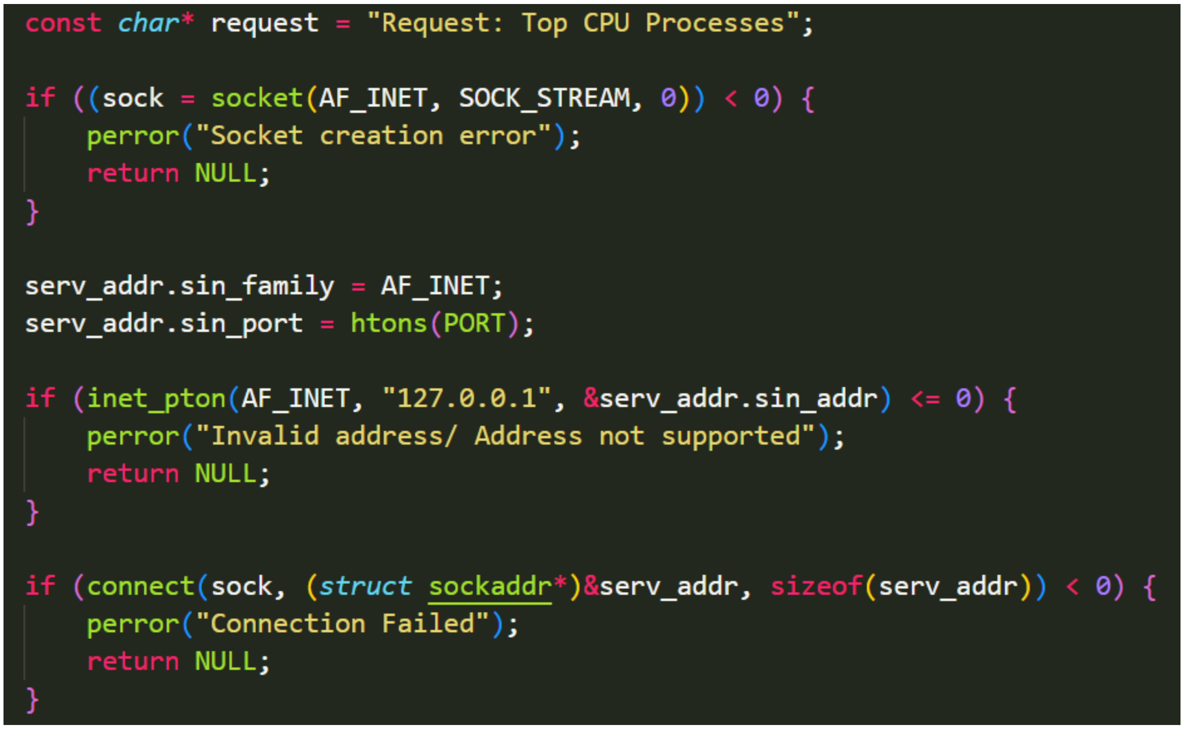
```
// Continuously accept incoming connections and handle them in separate threads
while (1) {
    new_socket = accept(server_fd, (struct sockaddr*)&address, (socklen_t*)&addrlen);
    if (new_socket < 0) {
        perror("Accept failed");
        exit(EXIT_FAILURE);
    }

    // Allocate memory for socket descriptor and pass it to the thread
    int* socket_desc = malloc(sizeof(int));
    *socket_desc = new_socket;

    // Create a new thread to handle the client connection
    pthread_t thread_id;
    if (pthread_create(&thread_id, NULL, handle_client, (void*)socket_desc) != 0) {
        perror("Thread creation failed");
        free(socket_desc);
        exit(EXIT_FAILURE);
    }
```

3) The client creates n concurrent client connection requests to the server, where n is a program argument.



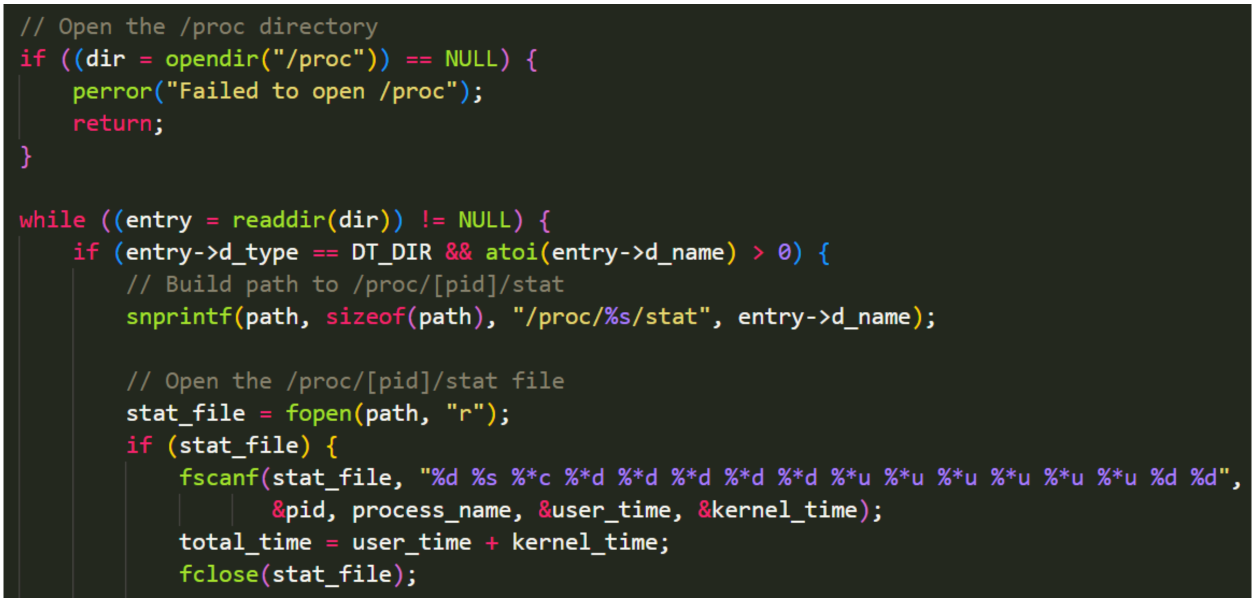
```c
int num_clients = atoi(argv[1]);
pthread_t threads[num_clients];

// Create multiple threads for concurrent client connections
for (int i = 0; i < num_clients; i++) {
    pthread_create(&threads[i], NULL, client_task, NULL);
}

// Wait for all threads to complete
for (int i = 0; i < num_clients; i++) {
    pthread_join(threads[i], NULL);
}
```

4) After the client connection is established, the client sends a request to the server to get information about the server's top TWO CPU-consuming processes.



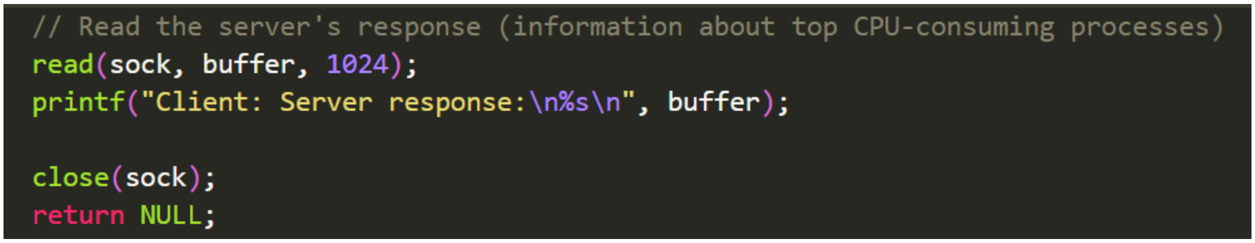
```c
const char* request = "Request: Top CPU Processes";

if ((sock = socket(AF_INET, SOCK_STREAM, 0)) < 0) {
    perror("Socket creation error");
    return NULL;
}

serv_addr.sin_family = AF_INET;
serv_addr.sin_port = htons(PORT);

if (inet_pton(AF_INET, "127.0.0.1", &serv_addr.sin_addr) <= 0) {
    perror("Invalid address/ Address not supported");
    return NULL;
}

if (connect(sock, (struct sockaddr*)&serv_addr, sizeof(serv_addr)) < 0) {
    perror("Connection Failed");
    return NULL;
}
```

5) The server sends the information about the top CPU-consuming process (using proc system call) to the client.



```c
// Open the /proc directory
if ((dir = opendir("/proc")) == NULL) {
    perror("Failed to open /proc");
    return;
}

while ((entry = readdir(dir)) != NULL) {
    if (entry->d_type == DT_DIR && atoi(entry->d_name) > 0) {
        // Build path to /proc/[pid]/stat
        snprintf(path, sizeof(path), "/proc/%s/stat", entry->d_name);

        // Open the /proc/[pid]/stat file
        stat_file = fopen(path, "r");
        if (stat_file) {
            fscanf(stat_file, "%d %s %*c %*d %*d %*d %*d %*d %*u %*u %*u %*u %*u %*u %d %d",
                   &pid, process_name, &user_time, &kernel_time);
            total_time = user_time + kernel_time;
            fclose(stat_file);
```

6) The client prints this information & closes the connection.

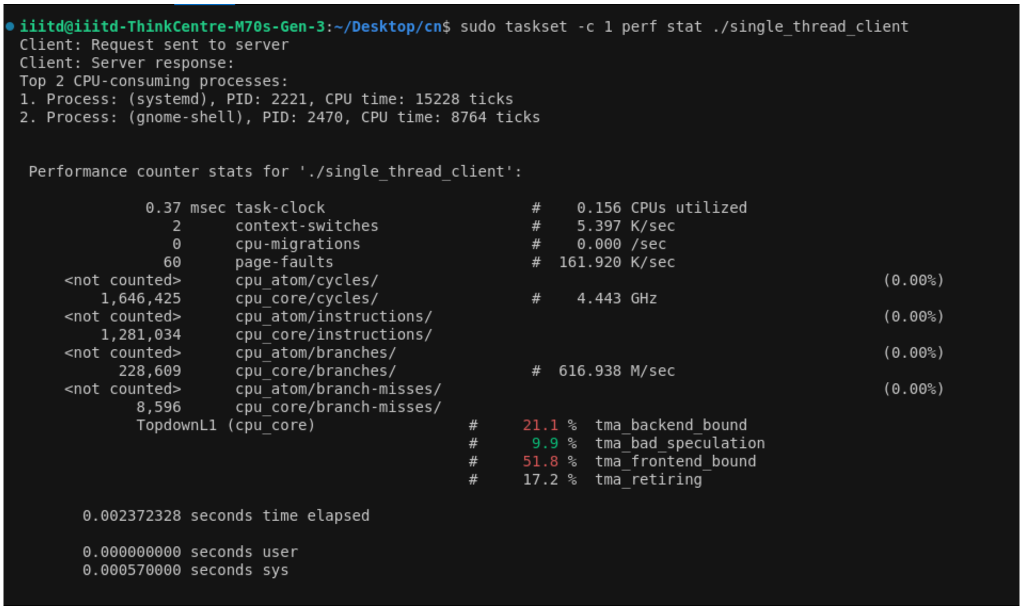


```c
// Read the server's response (information about top CPU-consuming processes)
read(sock, buffer, 1024);
printf("Client: Server response:\n%s\n", buffer);

close(sock);
return NULL;
```

Q.2. Performance Analysis

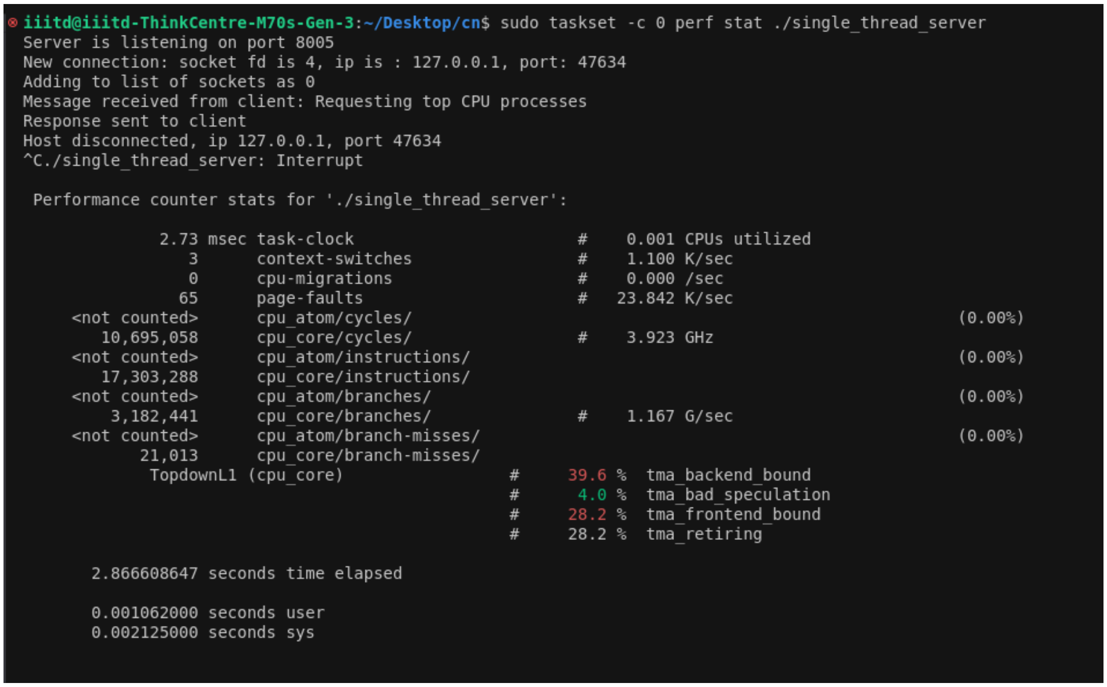
a) Single-threaded TCP client-server

In the single-threaded model, the server can only handle one client connection at a time. All other client requests are queued until the current request is completed.



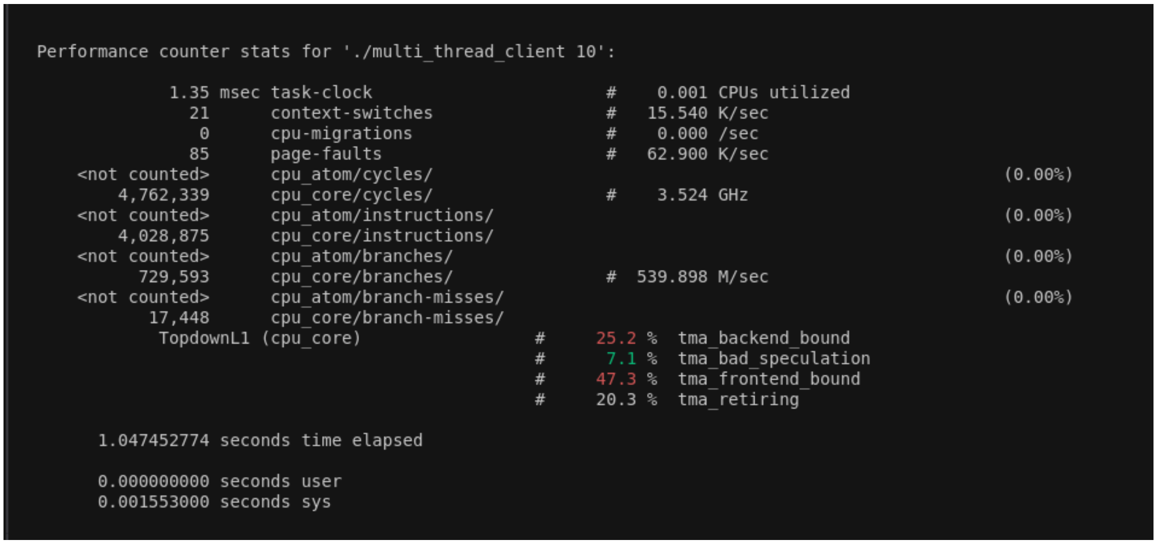
```
• iiitd@iiitd-ThinkCentre-M70s-Gen-3:~/Desktop/cn$ sudo taskset -c 1 perf stat ./single_thread_client
  Client: Request sent to server
  Client: Server response:
  Top 2 CPU-consuming processes:
  1. Process: (systemd), PID: 2221, CPU time: 15228 ticks
  2. Process: (gnome-shell), PID: 2470, CPU time: 8764 ticks


   Performance counter stats for './single_thread_client':

               0.37 msec task-clock                       #    0.156 CPUs utilized
                  2      context-switches                 #    5.397 K/sec
                  0      cpu-migrations                   #    0.000 /sec
                 60      page-faults                      #  161.920 K/sec
      <not counted>      cpu_atom/cycles/                                                        (0.00%)
          1,646,425      cpu_core/cycles/                 #    4.443 GHz
      <not counted>      cpu_atom/instructions/                                                  (0.00%)
          1,281,034      cpu_core/instructions/
      <not counted>      cpu_atom/branches/                                                      (0.00%)
            228,609      cpu_core/branches/               #  616.938 M/sec
      <not counted>      cpu_atom/branch-misses/                                                 (0.00%)
              8,596      cpu_core/branch-misses/
              TopdownL1 (cpu_core)                 #     21.1 %  tma_backend_bound
                                                   #      9.9 %  tma_bad_speculation
                                                   #     51.8 %  tma_frontend_bound
                                                   #     17.2 %  tma_retiring

        0.002372328 seconds time elapsed

        0.000000000 seconds user
        0.000570000 seconds sys
```

Single-threaded client connecting to single-threaded server



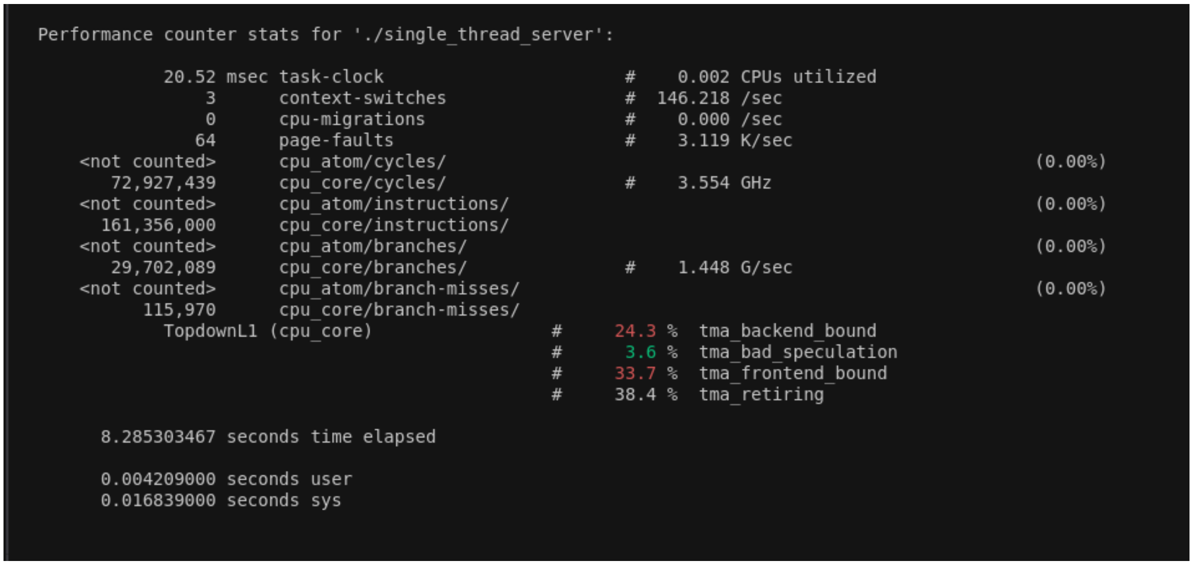
```
⊗ iiitd@iiitd-ThinkCentre-M70s-Gen-3:~/Desktop/cn$ sudo taskset -c 0 perf stat ./single_thread_server
  Server is listening on port 8005
  New connection: socket fd is 4, ip is : 127.0.0.1, port: 47634
  Adding to list of sockets as 0
  Message received from client: Requesting top CPU processes
  Response sent to client
  Host disconnected, ip 127.0.0.1, port 47634
  ^C./single_thread_server: Interrupt

   Performance counter stats for './single_thread_server':

               2.73 msec task-clock                       #    0.001 CPUs utilized
                  3      context-switches                 #    1.100 K/sec
                  0      cpu-migrations                   #    0.000 /sec
                 65      page-faults                      #   23.842 K/sec
      <not counted>      cpu_atom/cycles/                                                        (0.00%)
         10,695,058      cpu_core/cycles/                 #    3.923 GHz
      <not counted>      cpu_atom/instructions/                                                  (0.00%)
         17,303,288      cpu_core/instructions/
      <not counted>      cpu_atom/branches/                                                      (0.00%)
          3,182,441      cpu_core/branches/               #    1.167 G/sec
      <not counted>      cpu_atom/branch-misses/                                                 (0.00%)
             21,013      cpu_core/branch-misses/
              TopdownL1 (cpu_core)                 #     39.6 %  tma_backend_bound
                                                   #      4.0 %  tma_bad_speculation
                                                   #     28.2 %  tma_frontend_bound
                                                   #     28.2 %  tma_retiring

        2.866608647 seconds time elapsed

        0.001062000 seconds user
        0.002125000 seconds sys
```

Single-threaded client connecting to **single-threaded server**



```
 Performance counter stats for './multi_thread_client 10':

             1.35 msec task-clock                       #    0.001 CPUs utilized
               21      context-switches                 #   15.540 K/sec
                0      cpu-migrations                   #    0.000 /sec
               85      page-faults                      #   62.900 K/sec
    <not counted>      cpu_atom/cycles/                                                        (0.00%)
        4,762,339      cpu_core/cycles/                 #    3.524 GHz
    <not counted>      cpu_atom/instructions/                                                  (0.00%)
        4,028,875      cpu_core/instructions/
    <not counted>      cpu_atom/branches/                                                      (0.00%)
          729,593      cpu_core/branches/               #  539.898 M/sec
    <not counted>      cpu_atom/branch-misses/                                                 (0.00%)
           17,448      cpu_core/branch-misses/
            TopdownL1 (cpu_core)                 #     25.2 %  tma_backend_bound
                                                 #      7.1 %  tma_bad_speculation
                                                 #     47.3 %  tma_frontend_bound
                                                 #     20.3 %  tma_retiring

       1.047452774 seconds time elapsed

       0.000000000 seconds user
       0.001553000 seconds sys
```

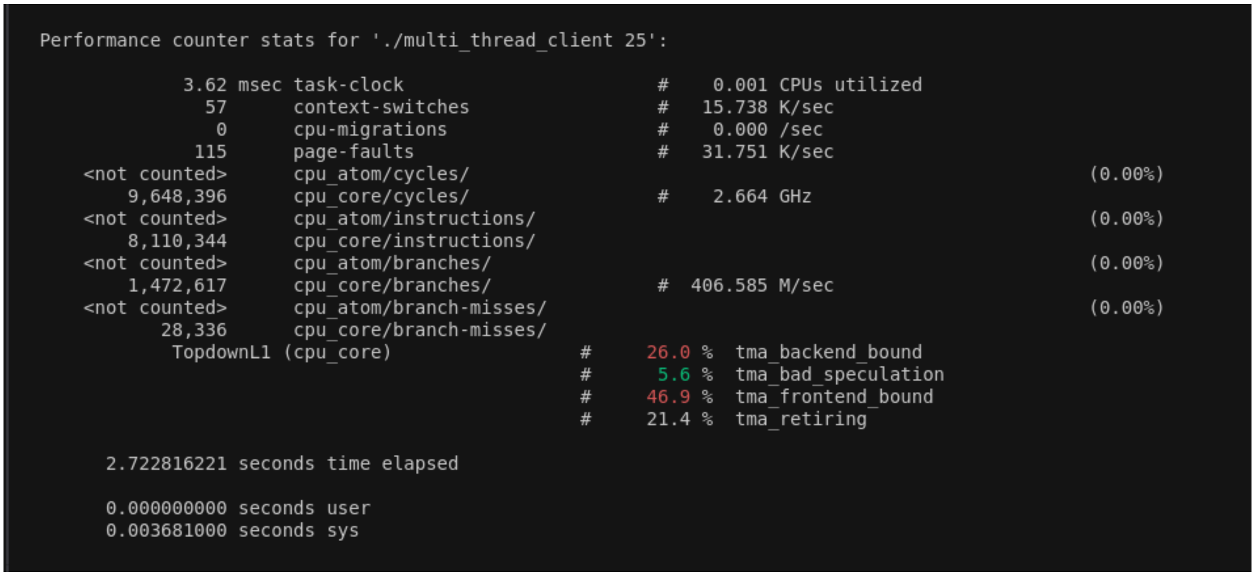
Multi-threaded (n=10) client connecting to single-threaded server



```
 Performance counter stats for './single_thread_server':

            20.52 msec task-clock                       #    0.002 CPUs utilized
                3      context-switches                 #  146.218 /sec
                0      cpu-migrations                   #    0.000 /sec
               64      page-faults                      #    3.119 K/sec
    <not counted>      cpu_atom/cycles/                                                        (0.00%)
       72,927,439      cpu_core/cycles/                 #    3.554 GHz
    <not counted>      cpu_atom/instructions/                                                  (0.00%)
      161,356,000      cpu_core/instructions/
    <not counted>      cpu_atom/branches/                                                      (0.00%)
       29,702,089      cpu_core/branches/               #    1.448 G/sec
    <not counted>      cpu_atom/branch-misses/                                                 (0.00%)
          115,970      cpu_core/branch-misses/
            TopdownL1 (cpu_core)                 #     24.3 %  tma_backend_bound
                                                 #      3.6 %  tma_bad_speculation
                                                 #     33.7 %  tma_frontend_bound
                                                 #     38.4 %  tma_retiring

       8.285303467 seconds time elapsed

       0.004209000 seconds user
       0.016839000 seconds sys
```

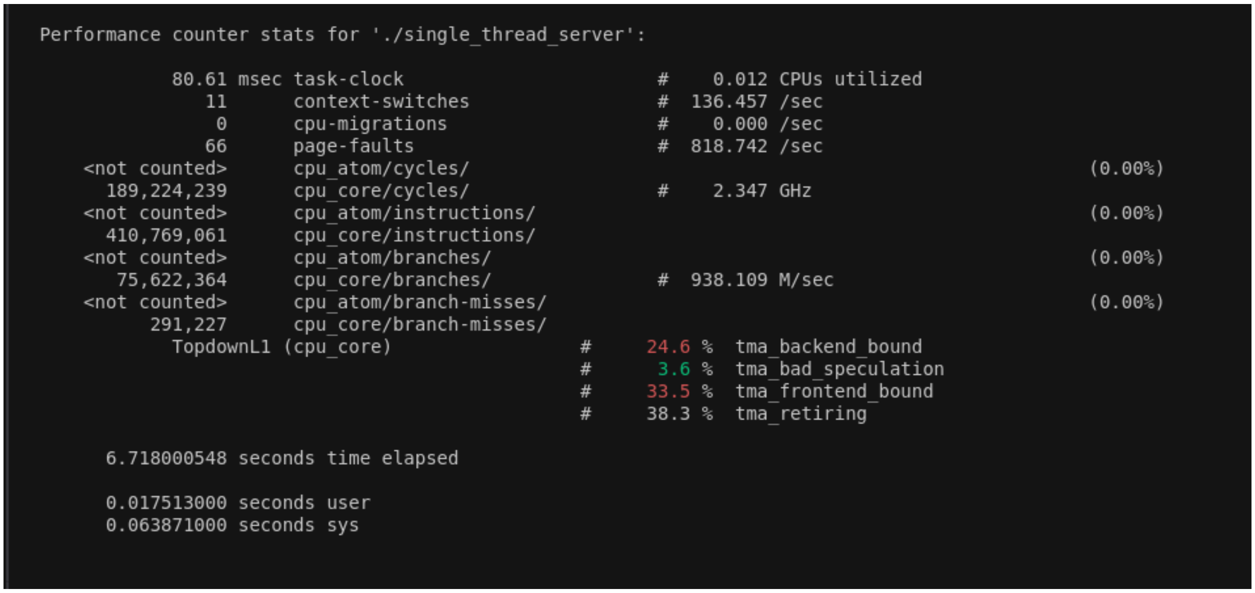
Multi-threaded (n=10) client connecting to **single-threaded server**

CPU clocks: Relatively low due to sequential processing. The CPU is not highly loaded.
Cache misses: Low, as the data size is small, and there's no multi-threading.
Context switches: Minimal context switches since only one thread is active.
Latency: Each connection waits until the server finishes the previous request, leading to increased latency for later clients.



```
Performance counter stats for './multi_thread_client 25':

            3.62 msec task-clock                       #    0.001 CPUs utilized
              57      context-switches                 #   15.738 K/sec
               0      cpu-migrations                   #    0.000 /sec
             115      page-faults                      #   31.751 K/sec
    <not counted>      cpu_atom/cycles/                                                        (0.00%)
       9,648,396      cpu_core/cycles/                 #    2.664 GHz
    <not counted>      cpu_atom/instructions/                                                  (0.00%)
       8,110,344      cpu_core/instructions/
    <not counted>      cpu_atom/branches/                                                      (0.00%)
       1,472,617      cpu_core/branches/               #  406.585 M/sec
    <not counted>      cpu_atom/branch-misses/                                                 (0.00%)
          28,336      cpu_core/branch-misses/
            TopdownL1 (cpu_core)                 #     26.0 %  tma_backend_bound
                                                 #      5.6 %  tma_bad_speculation
                                                 #     46.9 %  tma_frontend_bound
                                                 #     21.4 %  tma_retiring

      2.722816221 seconds time elapsed

      0.000000000 seconds user
      0.003681000 seconds sys
```

Multi-threaded (n=25) client connecting to single-threaded server



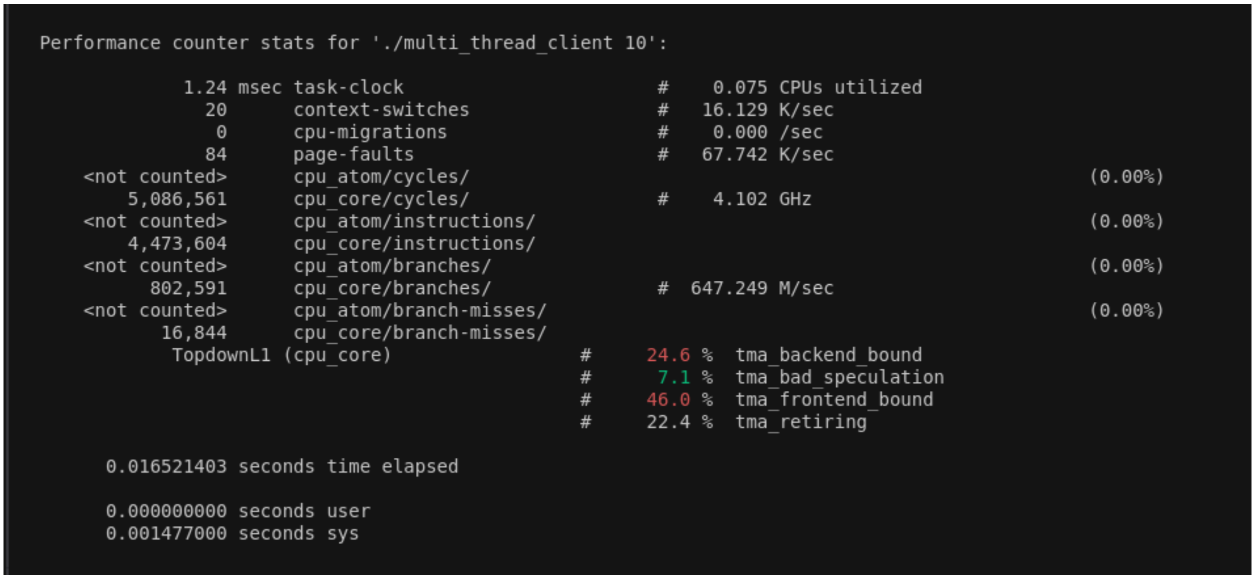
```
Performance counter stats for './single_thread_server':

           80.61 msec task-clock                       #    0.012 CPUs utilized
              11      context-switches                 #  136.457 /sec
               0      cpu-migrations                   #    0.000 /sec
              66      page-faults                      #  818.742 /sec
    <not counted>      cpu_atom/cycles/                                                        (0.00%)
     189,224,239      cpu_core/cycles/                 #    2.347 GHz
    <not counted>      cpu_atom/instructions/                                                  (0.00%)
     410,769,061      cpu_core/instructions/
    <not counted>      cpu_atom/branches/                                                      (0.00%)
      75,622,364      cpu_core/branches/               #  938.109 M/sec
    <not counted>      cpu_atom/branch-misses/                                                 (0.00%)
         291,227      cpu_core/branch-misses/
            TopdownL1 (cpu_core)                 #     24.6 %  tma_backend_bound
                                                 #      3.6 %  tma_bad_speculation
                                                 #     33.5 %  tma_frontend_bound
                                                 #     38.3 %  tma_retiring

      6.718000548 seconds time elapsed

      0.017513000 seconds user
      0.063871000 seconds sys
```

Multi-threaded (n=25) client connecting to **single-threaded server**

CPU clocks: Increased due to a higher number of requests, but still sequential.
Cache misses: Slightly increased but still low due to single-threaded operation.
Context switches: Very low (almost negligible).
Latency: The time to serve all clients grows linearly with the number of clients since the server handles each request one at a time.
CPU utilization: Underutilized, since the server could handle more work but is restricted to sequential processing.

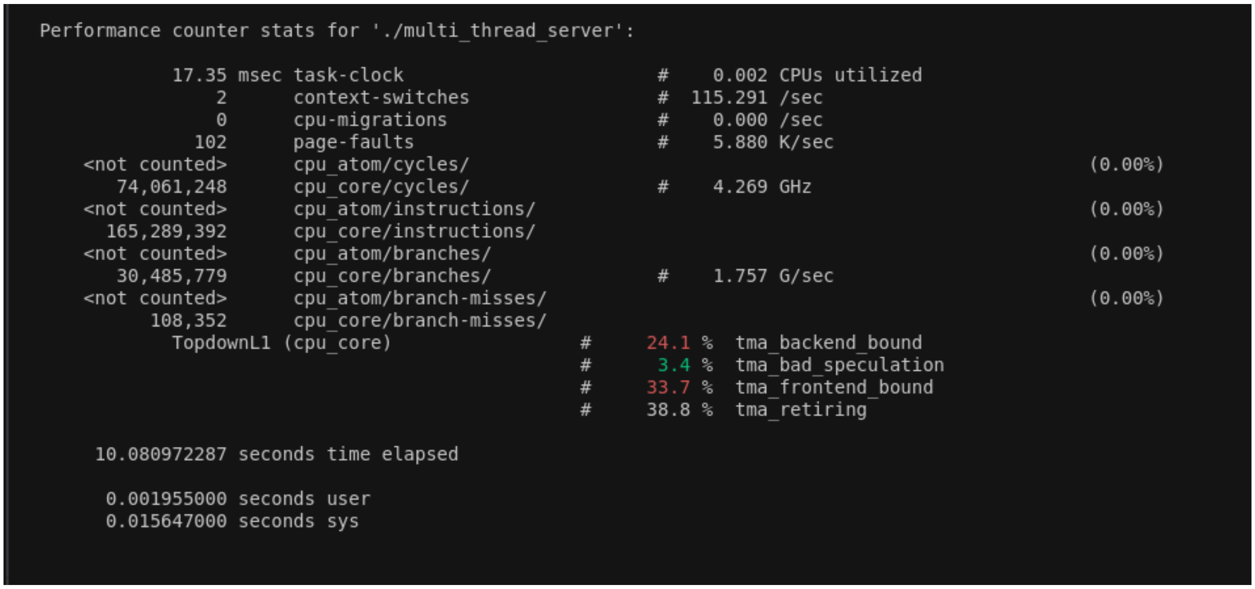
b) Concurrent TCP client-server

In the concurrent model, the server uses multiple threads (one per client), so multiple client requests are handled simultaneously.



```
 Performance counter stats for './multi_thread_client 10':

              1.24 msec task-clock                       #    0.075 CPUs utilized
                20      context-switches                 #   16.129 K/sec
                 0      cpu-migrations                   #    0.000 /sec
                84      page-faults                      #   67.742 K/sec
     <not counted>      cpu_atom/cycles/                                                        (0.00%)
         5,086,561      cpu_core/cycles/                 #    4.102 GHz
     <not counted>      cpu_atom/instructions/                                                  (0.00%)
         4,473,604      cpu_core/instructions/
     <not counted>      cpu_atom/branches/                                                      (0.00%)
           802,591      cpu_core/branches/               #  647.249 M/sec
     <not counted>      cpu_atom/branch-misses/                                                 (0.00%)
            16,844      cpu_core/branch-misses/
             TopdownL1 (cpu_core)                 #     24.6 %  tma_backend_bound
                                                  #      7.1 %  tma_bad_speculation
                                                  #     46.0 %  tma_frontend_bound
                                                  #     22.4 %  tma_retiring

       0.016521403 seconds time elapsed

       0.000000000 seconds user
       0.001477000 seconds sys
```

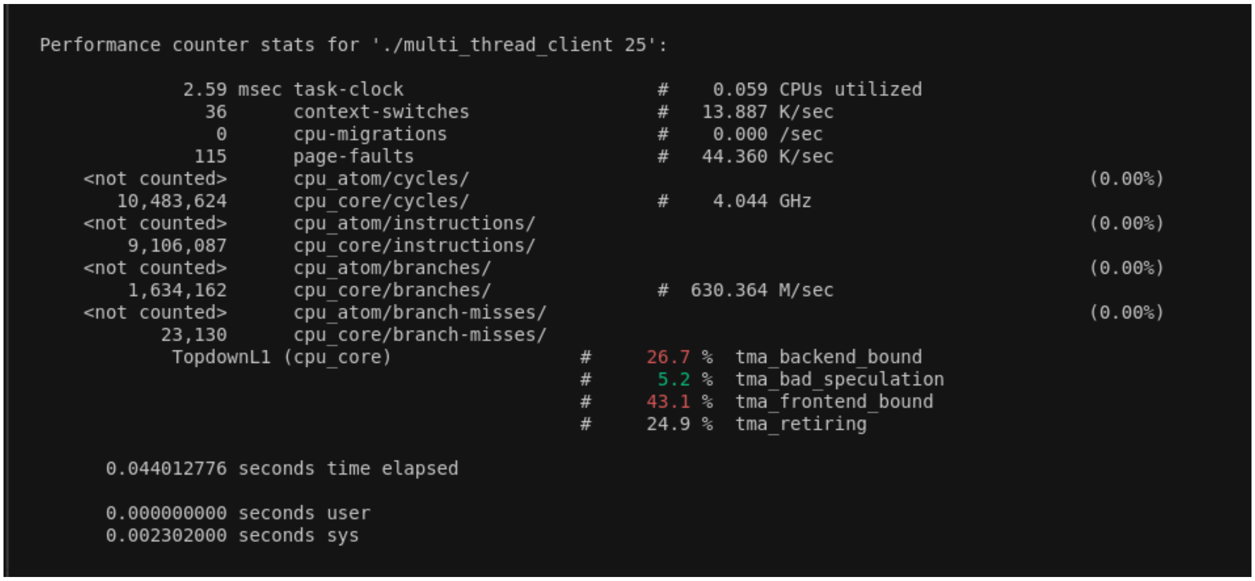
Multi-threaded (n=10) client connecting to multi-threaded server



```
 Performance counter stats for './multi_thread_server':

             17.35 msec task-clock                       #    0.002 CPUs utilized
                 2      context-switches                 #  115.291 /sec
                 0      cpu-migrations                   #    0.000 /sec
               102      page-faults                      #    5.880 K/sec
     <not counted>      cpu_atom/cycles/                                                        (0.00%)
        74,061,248      cpu_core/cycles/                 #    4.269 GHz
     <not counted>      cpu_atom/instructions/                                                  (0.00%)
       165,289,392      cpu_core/instructions/
     <not counted>      cpu_atom/branches/                                                      (0.00%)
        30,485,779      cpu_core/branches/               #    1.757 G/sec
     <not counted>      cpu_atom/branch-misses/                                                 (0.00%)
           108,352      cpu_core/branch-misses/
             TopdownL1 (cpu_core)                 #     24.1 %  tma_backend_bound
                                                  #      3.4 %  tma_bad_speculation
                                                  #     33.7 %  tma_frontend_bound
                                                  #     38.8 %  tma_retiring

      10.080972287 seconds time elapsed

       0.001955000 seconds user
       0.015647000 seconds sys
```

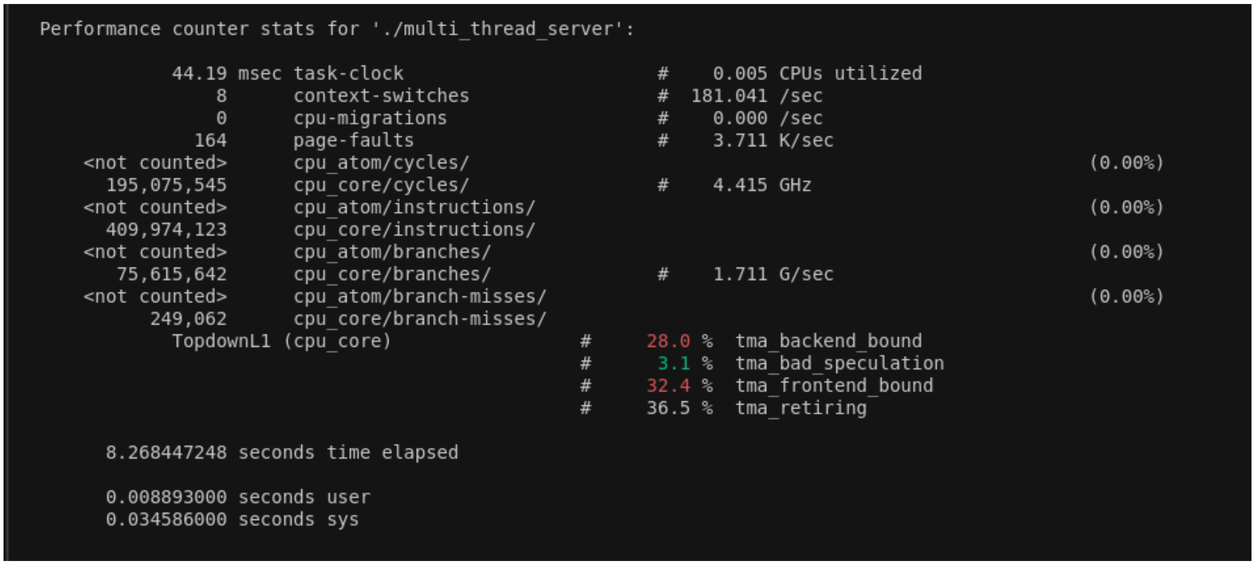
Multi-threaded (n=10) client connecting to **multi-threaded server**

CPU clocks: Increased due to the need to manage multiple threads.
Cache misses: Higher compared to single-threaded due to the need to context switch between threads.
Context switches: Noticeably higher since each client has its own thread, resulting in multiple context switches as the OS manages thread scheduling.
Latency: Significantly lower per client, as clients are served in parallel.



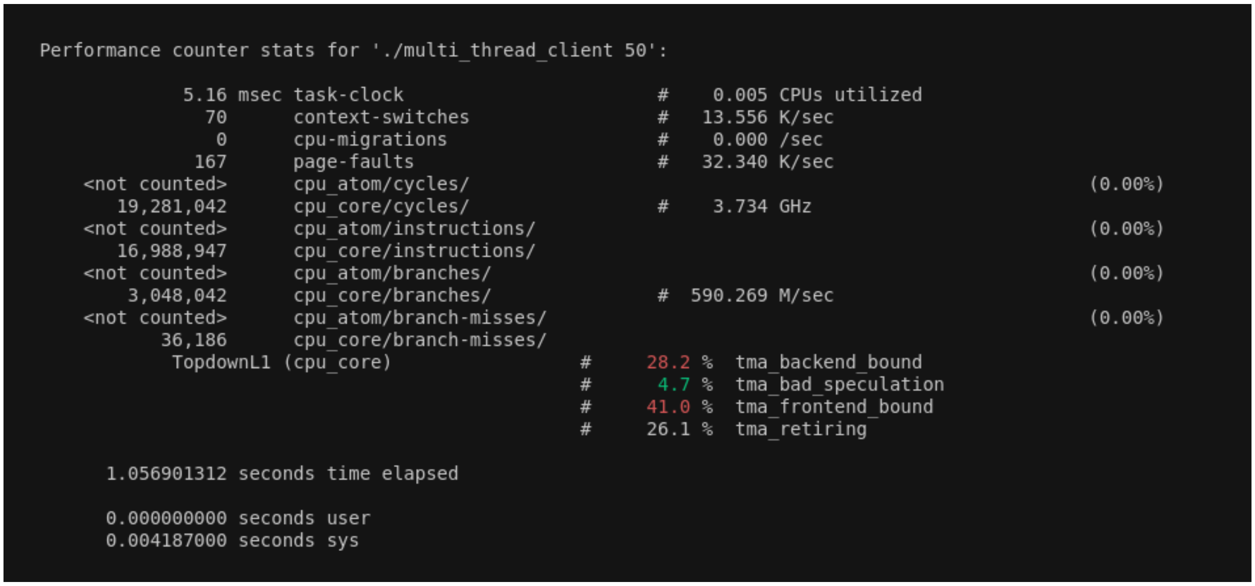
```
Performance counter stats for './multi_thread_client 25':

            2.59 msec task-clock                       #    0.059 CPUs utilized
              36      context-switches                 #   13.887 K/sec
               0      cpu-migrations                   #    0.000 /sec
             115      page-faults                      #   44.360 K/sec
    <not counted>      cpu_atom/cycles/                                                    (0.00%)
      10,483,624      cpu_core/cycles/                 #    4.044 GHz
    <not counted>      cpu_atom/instructions/                                              (0.00%)
       9,106,087      cpu_core/instructions/
    <not counted>      cpu_atom/branches/                                                  (0.00%)
       1,634,162      cpu_core/branches/               #  630.364 M/sec
    <not counted>      cpu_atom/branch-misses/                                             (0.00%)
          23,130      cpu_core/branch-misses/
           TopdownL1 (cpu_core)                 #     26.7 %  tma_backend_bound
                                                #      5.2 %  tma_bad_speculation
                                                #     43.1 %  tma_frontend_bound
                                                #     24.9 %  tma_retiring

      0.044012776 seconds time elapsed

      0.000000000 seconds user
      0.002302000 seconds sys
```

Multi-threaded (n=25) client connecting to multi-threaded server



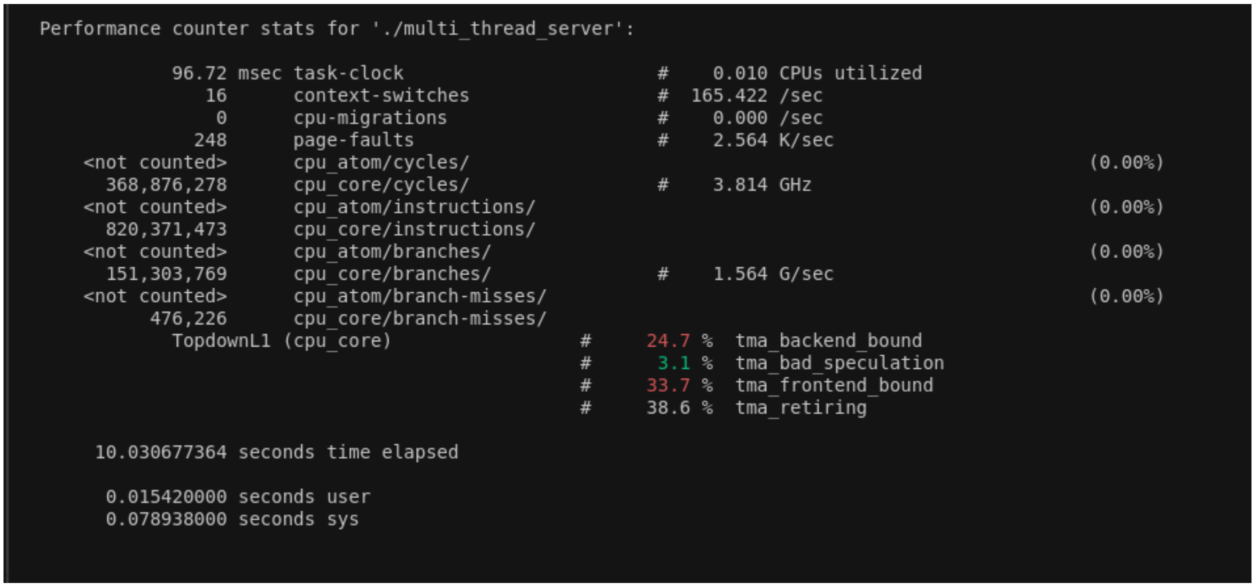
```
Performance counter stats for './multi_thread_server':

           44.19 msec task-clock                       #    0.005 CPUs utilized
               8      context-switches                 #  181.041 /sec
               0      cpu-migrations                   #    0.000 /sec
             164      page-faults                      #    3.711 K/sec
    <not counted>      cpu_atom/cycles/                                                    (0.00%)
     195,075,545      cpu_core/cycles/                 #    4.415 GHz
    <not counted>      cpu_atom/instructions/                                              (0.00%)
     409,974,123      cpu_core/instructions/
    <not counted>      cpu_atom/branches/                                                  (0.00%)
      75,615,642      cpu_core/branches/               #    1.711 G/sec
    <not counted>      cpu_atom/branch-misses/                                             (0.00%)
         249,062      cpu_core/branch-misses/
           TopdownL1 (cpu_core)                 #     28.0 %  tma_backend_bound
                                                #      3.1 %  tma_bad_speculation
                                                #     32.4 %  tma_frontend_bound
                                                #     36.5 %  tma_retiring

      8.268447248 seconds time elapsed

      0.008893000 seconds user
      0.034586000 seconds sys
```

Multi-threaded (n=25) client connecting to **multi-threaded server**



```
 Performance counter stats for './multi_thread_client 50':

              5.16 msec task-clock                       #    0.005 CPUs utilized
                70      context-switches                 #   13.556 K/sec
                 0      cpu-migrations                   #    0.000 /sec
               167      page-faults                      #   32.340 K/sec
     <not counted>      cpu_atom/cycles/                                                        (0.00%)
        19,281,042      cpu_core/cycles/                 #    3.734 GHz
     <not counted>      cpu_atom/instructions/                                                  (0.00%)
        16,988,947      cpu_core/instructions/
     <not counted>      cpu_atom/branches/                                                      (0.00%)
         3,048,042      cpu_core/branches/               #  590.269 M/sec
     <not counted>      cpu_atom/branch-misses/                                                 (0.00%)
            36,186      cpu_core/branch-misses/
             TopdownL1 (cpu_core)                 #     28.2 %  tma_backend_bound
                                                  #      4.7 %  tma_bad_speculation
                                                  #     41.0 %  tma_frontend_bound
                                                  #     26.1 %  tma_retiring

       1.056901312 seconds time elapsed

       0.000000000 seconds user
       0.004187000 seconds sys
```

Multi-threaded (n=50) client connecting to multi-threaded server

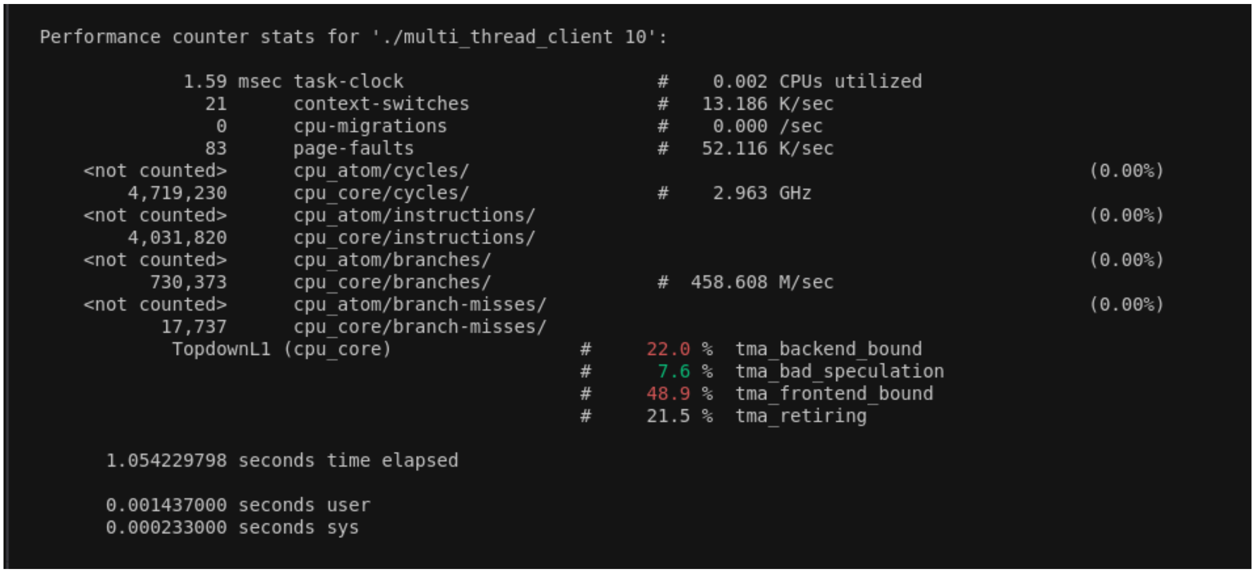


```
 Performance counter stats for './multi_thread_server':

             96.72 msec task-clock                       #    0.010 CPUs utilized
                16      context-switches                 #  165.422 /sec
                 0      cpu-migrations                   #    0.000 /sec
               248      page-faults                      #    2.564 K/sec
     <not counted>      cpu_atom/cycles/                                                        (0.00%)
       368,876,278      cpu_core/cycles/                 #    3.814 GHz
     <not counted>      cpu_atom/instructions/                                                  (0.00%)
       820,371,473      cpu_core/instructions/
     <not counted>      cpu_atom/branches/                                                      (0.00%)
       151,303,769      cpu_core/branches/               #    1.564 G/sec
     <not counted>      cpu_atom/branch-misses/                                                 (0.00%)
           476,226      cpu_core/branch-misses/
             TopdownL1 (cpu_core)                 #     24.7 %  tma_backend_bound
                                                  #      3.1 %  tma_bad_speculation
                                                  #     33.7 %  tma_frontend_bound
                                                  #     38.6 %  tma_retiring

      10.030677364 seconds time elapsed

       0.015420000 seconds user
       0.078938000 seconds sys
```

Multi-threaded (n=50) client connecting to **multi-threaded server**

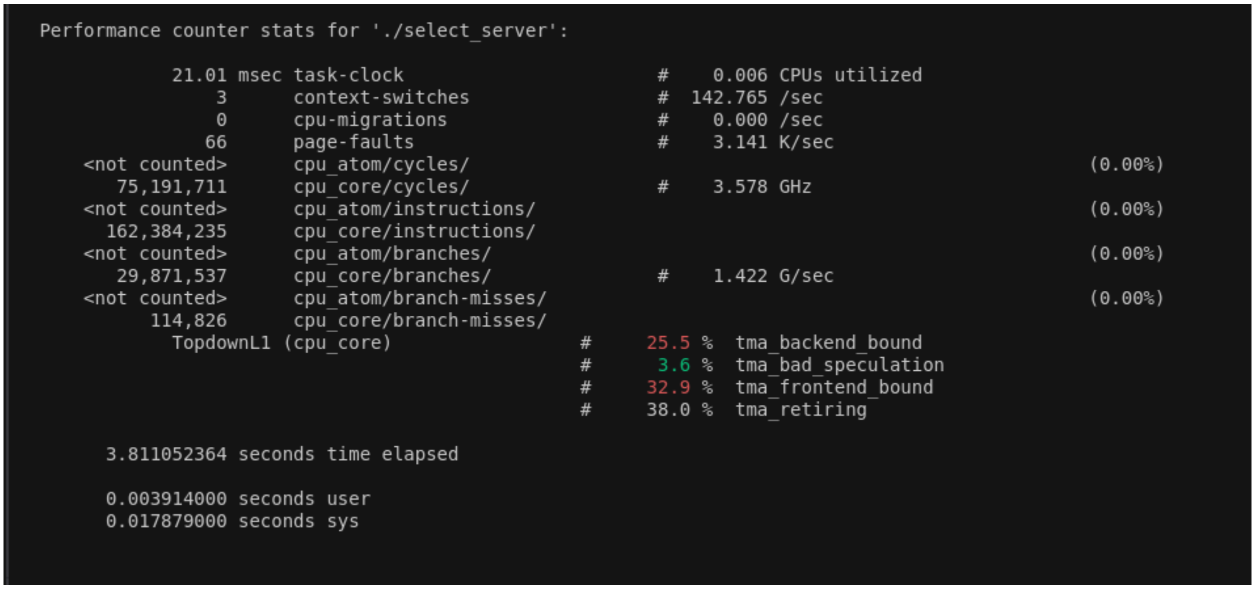
CPU clocks: Higher as more threads are created.
Cache misses: Increases with the number of clients due to thread contention for resources.
Context switches: Very high as more threads lead to frequent context switching.
Latency: Remains low for each client as long as the server is not overwhelmed.
CPU utilization: High CPU usage due to thread management, but more efficient utilization of available CPU resources.

c) TCP client-server using “select”



```
 Performance counter stats for './multi_thread_client 10':

             1.59 msec task-clock                       #    0.002 CPUs utilized
               21      context-switches                 #   13.186 K/sec
                0      cpu-migrations                   #    0.000 /sec
               83      page-faults                      #   52.116 K/sec
     <not counted>      cpu_atom/cycles/                                                        (0.00%)
         4,719,230      cpu_core/cycles/                #    2.963 GHz
     <not counted>      cpu_atom/instructions/                                                  (0.00%)
         4,031,820      cpu_core/instructions/
     <not counted>      cpu_atom/branches/                                                      (0.00%)
           730,373      cpu_core/branches/              #  458.608 M/sec
     <not counted>      cpu_atom/branch-misses/                                                 (0.00%)
            17,737      cpu_core/branch-misses/
            TopdownL1 (cpu_core)                 #     22.0 %  tma_backend_bound
                                                 #      7.6 %  tma_bad_speculation
                                                 #     48.9 %  tma_frontend_bound
                                                 #     21.5 %  tma_retiring

       1.054229798 seconds time elapsed

       0.001437000 seconds user
       0.000233000 seconds sys
```

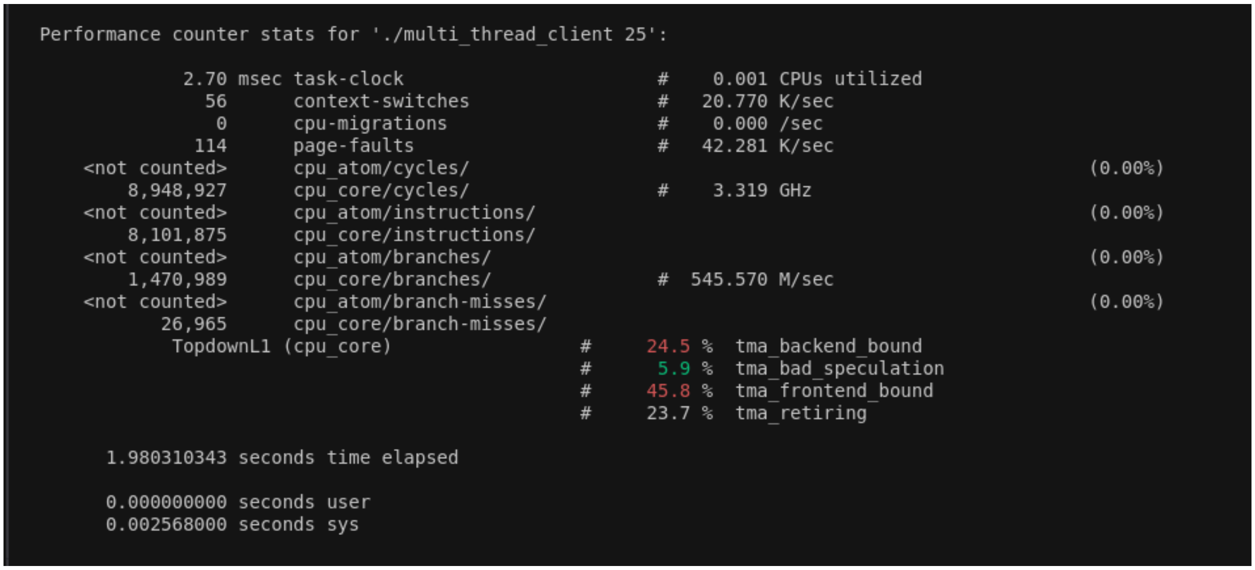
Multi-threaded (n=10) client connecting to server using select



```
 Performance counter stats for './select_server':

            21.01 msec task-clock                       #    0.006 CPUs utilized
                3      context-switches                 #  142.765 /sec
                0      cpu-migrations                   #    0.000 /sec
               66      page-faults                      #    3.141 K/sec
     <not counted>      cpu_atom/cycles/                                                        (0.00%)
        75,191,711      cpu_core/cycles/                #    3.578 GHz
     <not counted>      cpu_atom/instructions/                                                  (0.00%)
       162,384,235      cpu_core/instructions/
     <not counted>      cpu_atom/branches/                                                      (0.00%)
        29,871,537      cpu_core/branches/              #    1.422 G/sec
     <not counted>      cpu_atom/branch-misses/                                                 (0.00%)
           114,826      cpu_core/branch-misses/
            TopdownL1 (cpu_core)                 #     25.5 %  tma_backend_bound
                                                 #      3.6 %  tma_bad_speculation
                                                 #     32.9 %  tma_frontend_bound
                                                 #     38.0 %  tma_retiring

       3.811052364 seconds time elapsed

       0.003914000 seconds user
       0.017879000 seconds sys
```

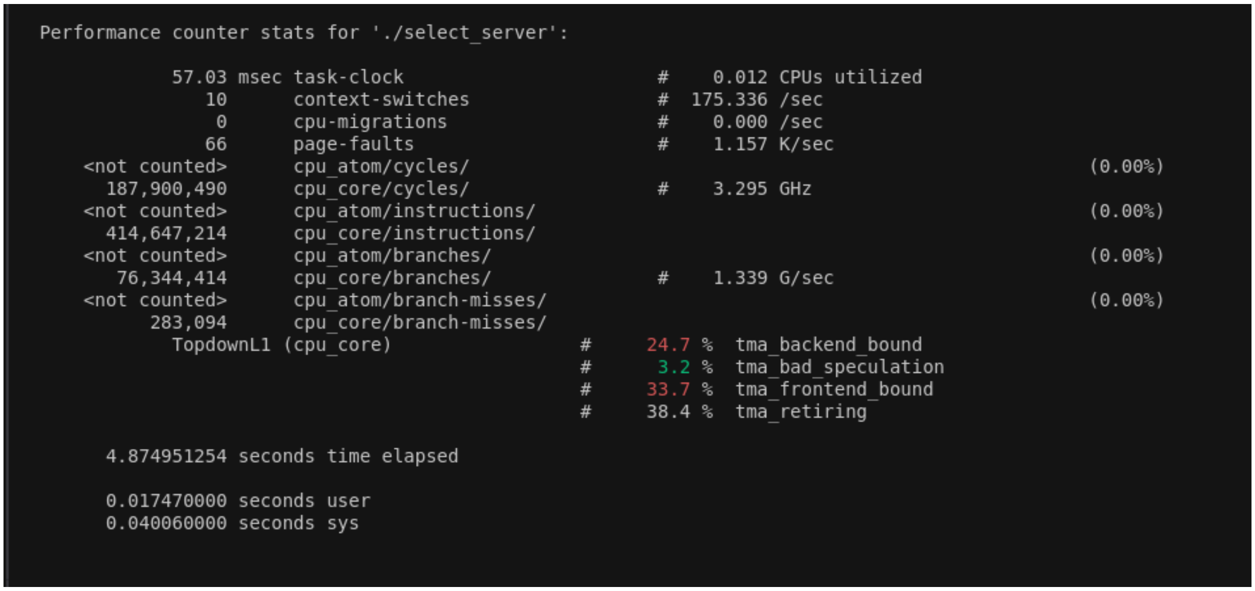
Multi-threaded (n=10) client connecting to **server using select**

CPU clocks: Moderate as the server efficiently manages multiple clients in one thread.
Cache misses: Relatively low compared to the concurrent model since only one thread is active.
Context switches: Low due to the absence of thread switching.
Latency: Comparable to the concurrent model since multiple clients are handled in parallel, but without the overhead of thread creation.



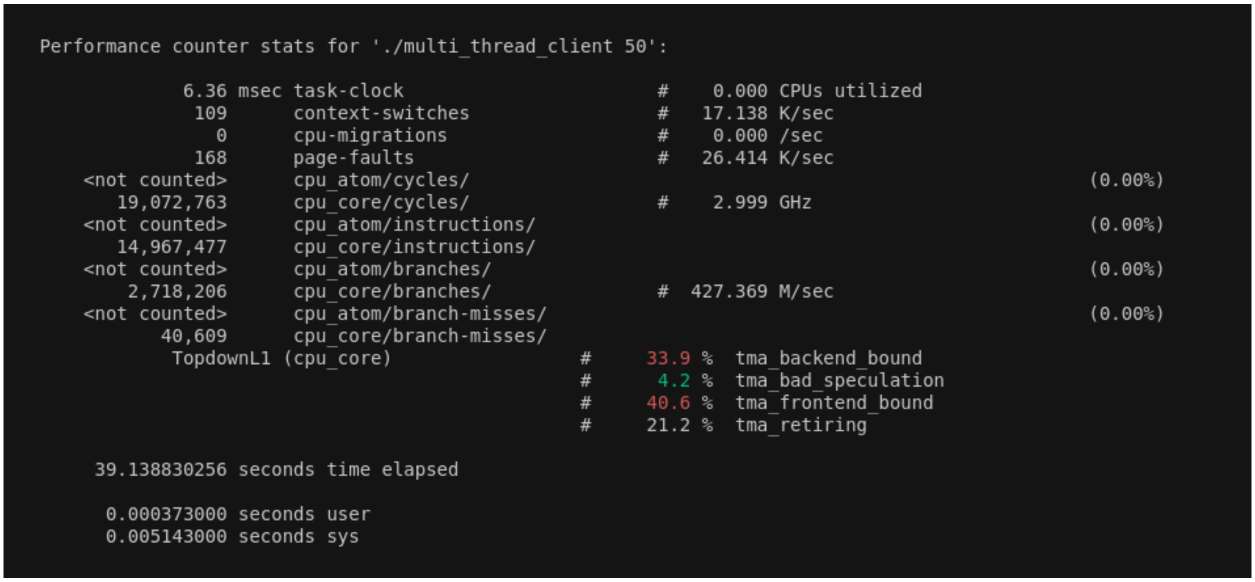
```
 Performance counter stats for './multi_thread_client 25':

             2.70 msec task-clock                       #    0.001 CPUs utilized
               56      context-switches                 #   20.770 K/sec
                0      cpu-migrations                   #    0.000 /sec
              114      page-faults                      #   42.281 K/sec
     <not counted>      cpu_atom/cycles/                                                        (0.00%)
         8,948,927      cpu_core/cycles/                 #    3.319 GHz
     <not counted>      cpu_atom/instructions/                                                  (0.00%)
         8,101,875      cpu_core/instructions/
     <not counted>      cpu_atom/branches/                                                      (0.00%)
         1,470,989      cpu_core/branches/               #  545.570 M/sec
     <not counted>      cpu_atom/branch-misses/                                                 (0.00%)
            26,965      cpu_core/branch-misses/
             TopdownL1 (cpu_core)                 #     24.5 %  tma_backend_bound
                                                  #      5.9 %  tma_bad_speculation
                                                  #     45.8 %  tma_frontend_bound
                                                  #     23.7 %  tma_retiring

       1.980310343 seconds time elapsed

       0.000000000 seconds user
       0.002568000 seconds sys
```

Multi-threaded (n=25) client connecting to server using select



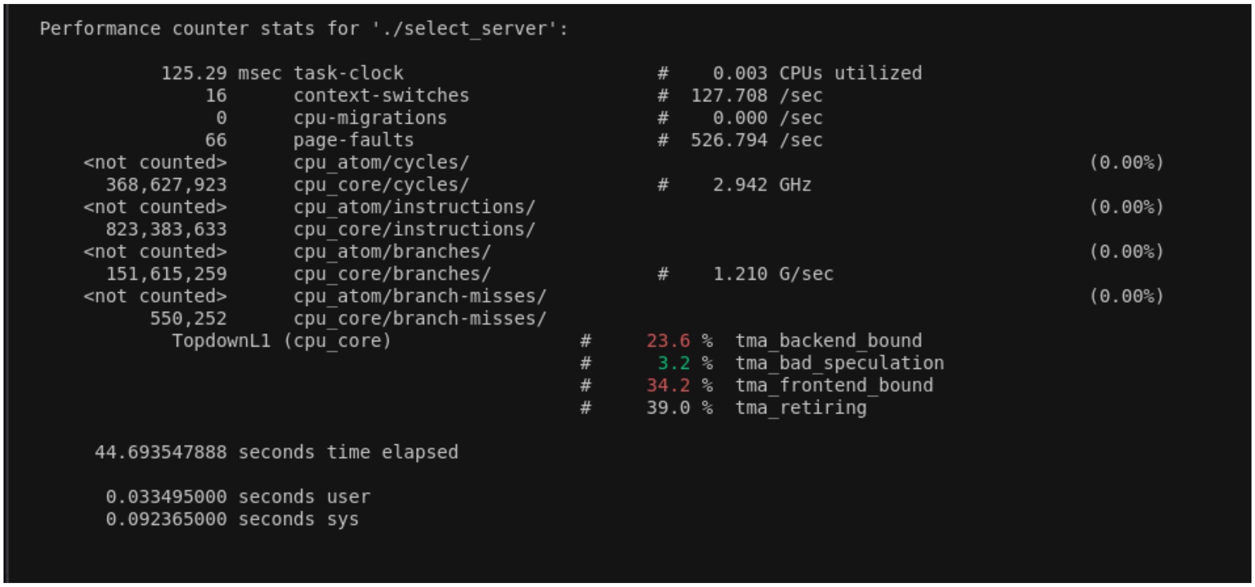
```
 Performance counter stats for './select_server':

            57.03 msec task-clock                       #    0.012 CPUs utilized
               10      context-switches                 #  175.336 /sec
                0      cpu-migrations                   #    0.000 /sec
               66      page-faults                      #    1.157 K/sec
     <not counted>      cpu_atom/cycles/                                                        (0.00%)
       187,900,490      cpu_core/cycles/                 #    3.295 GHz
     <not counted>      cpu_atom/instructions/                                                  (0.00%)
       414,647,214      cpu_core/instructions/
     <not counted>      cpu_atom/branches/                                                      (0.00%)
        76,344,414      cpu_core/branches/               #    1.339 G/sec
     <not counted>      cpu_atom/branch-misses/                                                 (0.00%)
           283,094      cpu_core/branch-misses/
             TopdownL1 (cpu_core)                 #     24.7 %  tma_backend_bound
                                                  #      3.2 %  tma_bad_speculation
                                                  #     33.7 %  tma_frontend_bound
                                                  #     38.4 %  tma_retiring

       4.874951254 seconds time elapsed

       0.017470000 seconds user
       0.040060000 seconds sys
```

Multi-threaded (n=25) client connecting to **server using select**



```
 Performance counter stats for './multi_thread_client 50':

             6.36 msec task-clock                       #    0.000 CPUs utilized
              109      context-switches                 #   17.138 K/sec
                0      cpu-migrations                   #    0.000 /sec
              168      page-faults                      #   26.414 K/sec
     <not counted>      cpu_atom/cycles/                                                       (0.00%)
       19,072,763      cpu_core/cycles/                 #    2.999 GHz
     <not counted>      cpu_atom/instructions/                                                 (0.00%)
       14,967,477      cpu_core/instructions/
     <not counted>      cpu_atom/branches/                                                     (0.00%)
        2,718,206      cpu_core/branches/               #  427.369 M/sec
     <not counted>      cpu_atom/branch-misses/                                                (0.00%)
           40,609      cpu_core/branch-misses/
            TopdownL1 (cpu_core)                 #     33.9 %  tma_backend_bound
                                                 #      4.2 %  tma_bad_speculation
                                                 #     40.6 %  tma_frontend_bound
                                                 #     21.2 %  tma_retiring

      39.138830256 seconds time elapsed

       0.000373000 seconds user
       0.005143000 seconds sys
```

Multi-threaded (n=50) client connecting to server using select



```
 Performance counter stats for './select_server':

           125.29 msec task-clock                       #    0.003 CPUs utilized
               16      context-switches                 #  127.708 /sec
                0      cpu-migrations                   #    0.000 /sec
               66      page-faults                      #  526.794 /sec
     <not counted>      cpu_atom/cycles/                                                       (0.00%)
      368,627,923      cpu_core/cycles/                 #    2.942 GHz
     <not counted>      cpu_atom/instructions/                                                 (0.00%)
      823,383,633      cpu_core/instructions/
     <not counted>      cpu_atom/branches/                                                     (0.00%)
      151,615,259      cpu_core/branches/               #    1.210 G/sec
     <not counted>      cpu_atom/branch-misses/                                                (0.00%)
          550,252      cpu_core/branch-misses/
            TopdownL1 (cpu_core)                 #     23.6 %  tma_backend_bound
                                                 #      3.2 %  tma_bad_speculation
                                                 #     34.2 %  tma_frontend_bound
                                                 #     39.0 %  tma_retiring

      44.693547888 seconds time elapsed

       0.033495000 seconds user
       0.092365000 seconds sys
```

Multi-threaded (n=50) client connecting to **server using select**

CPU clocks: Increased but still lower than the concurrent model, as only one thread is used.
Cache misses: Slightly higher due to more connections being handled, but still lower than the multi-threaded approach.
Context switches: Very low as it is a single-threaded event loop.
Latency**:** Scales well with the number of clients but may show increased delay if too many clients are connected, as the server has to juggle multiple file descriptors in the event loop.

CPU utilization: Efficient use of CPU with lower overhead than the concurrent model, but may struggle under extremely high loads compared to a fully multi-threaded approach.

CONCLUSIONS:

Single-threaded: Best for small client loads with minimal overhead but scales poorly.

Concurrent: Efficient for high client loads but introduces significant overhead due to thread management and context switching.

Select-based: Offers a balance between single-threaded simplicity and concurrent parallelism, excelling for moderate loads with lower overhead but can struggle with very high client numbers.