Implementation of Scalable Servers - Epoll versus Select versus Multithreading

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COMP 6D

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Background

The purpose of this assignment is to compare three different approaches to implementing a scalable server. The objective is to create three distinct servers using multi-threading processes, epoll and select functionalities and then to provide them “work” using a TCP client.

For this assignment, “work” will be provided by scripting enough executable TCP clients on one host, and having many client terminals send multiple text lengths to a single server, which will sit on another host entirely (refer to **Design Work** document for further clarification). Our client, as a multi threaded application, will maintain a sustained connection with it’s multi threaded capabilities. In other words, the server will not terminate connection with the client until all of the clients’ threads are finished.

In our **Observations** section, we will highlight important differences between our three servers. The intention is to find the most efficient implementation of a server so that our goal of developing scalable servers can be achieved. Our goal of “scalable” and “efficient” includes time management, memory usage, and processing capabilities. Through theory and some initial analysis, our hypothesis is that multi threaded servers will be the least scalable, with Epoll servers being the most and followed by Select servers being second.

Tools & Equipment

Hardware

- 8GB RAM
- Intel i5 Quad Core
- 500GB HDD
- Client Host
- Server Host

Software

- Fedora Linux 19 64-bit
- C Programming
- htop
- Valgrind
- Wireshark

Testing Procedure

Test Cases Table

Case #	Test Case	Tools Used	Expected Outcome	Results
1	Multithreaded client can send varied string lengths up to the user's input	Terminal, csv file	It can send different string lengths	PASSED. See results.
2	Multithreaded server receives varied lengths of string	csv file	It can receive varied lengths of string	PASSED. See results.
3	Select server receives varied lengths of string	Wireshark	It can receive varied lengths of string	PASSED. See results.
4	Epoll server receives varied lengths of string	Wireshark	It can receive varied lengths of string	PASSED. See results.
5	Multithreaded Client is sending some sort of string	Wireshark, Terminal	It sends some sort of expected string	PASSED. See results.
6	When the client runs, Multithreaded server receives said string	Wireshark	It receives the same string being sent from client	PASSED. See results.
7	When the client runs, Select server receives said string	Wireshark	It receives the same string being sent from client	PASSED. See results.
8	When the client runs, Epoll server receives said string	Wireshark	It receives the same string being sent from client	PASSED. See results.
9	Multithreaded client is sending multiple sets of strings (via many requests)	Wireshark	We expect to see more than one packet of strings being sent	PASSED. See results.
10	When the client runs, Multithreaded server receives many strings equal to the number of requests	Wireshark	We expect to see an equal number of packets coming to the server	PASSED. See results.
11	When the client runs, Select	Terminal	We expect to see an	PASSED.

	server receives many strings equal to the number of requests		equal number of packets coming to the server	See results.
12	When the client runs, Epoll server receives many strings equal to the number of requests	Wireshark	We expect to see an equal number of packets coming to the server	PASSED. See results.
13	Client keeps track of requests made	GDBC	requests made are equal to requests	PASSED. See results.
14	Multithreaded server keeps track of number of requests received	GDBC	requests made are equal to the client's requests	PASSED. See results.
15	Select server keeps track of number of requests received	GDBC	requests made are equal to the client's requests	FAILED. No results.
16	Epoll server keeps track of number of requests received	GDBC	requests made are equal to the client's requests	PASSED. See results.
17	Multithreaded server closes the sockets after each client finishes requests	GDBC	closes after requests are processed	PASSED. See results.
18	Select server closes the sockets after each client finishes requests	GDBC	closes after requests are processed	FAILED. No results.
19	Epoll server closes the sockets after each client finishes requests	GDBC	closes after requests are processed	PASSED. See results.
20	Client closes after number of threads are finished	GDBC	closes after requests are processed	PASSED. See results.
21	No memory leaks from multithreaded server	Valgrind	no memory leaks	Permitted. See results.
22	No memory leaks from select server	Valgrind	no memory leaks	FAILED. No results.
23	No memory leaks from epoll server	Valgrind	no memory leaks	Permitted. See results.

24	No memory leaks from client	Valgrind	no memory leaks	PASSED. See results.

Test Case Evidence & Details

1. Client can send varied lengths

```
[root@DataComm Downloads]# ./client -a 192.168.0.20 -b 1 -c 5
Remote Address: 192.168.0.20
Remote Port: 24862
32069 Sent Data: NWLRB
32069 Received Data: NWLRB
[root@DataComm Downloads]# ./client -a 192.168.0.20 -b 1 -c 10
Remote Address: 192.168.0.20
Remote Port: 24862
32073 Sent Data: NWLRBBMQBH
32073 Received Data: NWLRBBMQBH
[root@DataComm Downloads]# ./client -a 192.168.0.20 -b 1 -c 15
Remote Address: 192.168.0.20
Remote Port: 24862
32077 Sent Data: NWLRBBMQBHCDARZ
32077 Received Data: NWLRBBMQBHCDARZ
[root@DataComm Downloads]# ./client -a 192.168.0.20 -b 1 -c 20
Remote Address: 192.168.0.20
Remote Port: 24862
32081 Sent Data: NWLRBBMQBHCDARZOWKKY
32081 Received Data: NWLRBBMQBHCDARZOWKKY
[root@DataComm Downloads]# ./client -a 192.168.0.20 -b 1 -c 50
Remote Address: 192.168.0.20
Remote Port: 24862
32085 Sent Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXRJMOWFRXSJYBLDBEFSARC
32085 Received Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXRJMOWFRXSJYBLDBEFSARC
```

In the following CSV file, these are the following columns:
Server IP, String Length, Time to Process

test.sh | client.c | Client_Results.csv

```
1 192.168.0.20,5,0.000437
2 192.168.0.20,10,0.000377
3 192.168.0.20,15,0.000382
4 192.168.0.20,20,0.000361
5 192.168.0.20,50,0.000343
```

2. Multi thread Server can receive varied lengths of string
In the following CSV file, these are the following columns:
Server IP, Socket, Number of Requests, String Length

selectServer.c × jakeServer.c × epollServer2.c × multiThread_log.csv ×

```
192.168.0.21,7100,1,5
192.168.0.21,7356,1,10
192.168.0.21,7612,1,15
192.168.0.21,7868,1,20
192.168.0.21,8124,1,50
```

3. Select Server can receive varied lengths of string.

```
[root@DataComm Downloads]# ./sel_srv
Currently serving 1 connections...
Received: NWLRBBMQBH
Sending: NWLRBBMQBH...
Received:
Received:
Received:
Received: NWLRBBMQBH
Currently serving -2 connections...
Received: NWLRBBMQBHCDARZOWKKY
Sending: NWLRBBMQBHCDARZOWKKY...
Received:
Received:
Received:
Received: NWLRBBMQBHCDARZOWKKY
Received:
Currently serving -6 connections...
Received: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
Sending: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR...
Received:
Received:
Received: NWLRBBMQBHCDARZOWKKY
Received: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
```

4. Epoll Server can receive varied lengths of string.

Here's a screen capture of our Client's requests of varied string:

```
[root@DataComm Downloads]# ./client -a 192.168.0.20 -b 1 -c 5
Remote Address: 192.168.0.20
Remote Port: 24862
4356 Sent Data: NWLRB
4356 Received Data: NWLRB
[root@DataComm Downloads]# ./client -a 192.168.0.20 -b 1 -c 10
Remote Address: 192.168.0.20
Remote Port: 24862
4360 Sent Data: NWLRBBMQBH
4360 Received Data: NWLRBBMQBH
[root@DataComm Downloads]# ./client -a 192.168.0.20 -b 1 -c 15
Remote Address: 192.168.0.20
Remote Port: 24862
4380 Sent Data: NWLRBBMQBHCDARZ
4380 Received Data: NWLRBBMQBHCDARZ
[root@DataComm Downloads]# ./client -a 192.168.0.20 -b 1 -c 20
Remote Address: 192.168.0.20
Remote Port: 24862
4384 Sent Data: NWLRBBMQBHCDARZOWKKY
4384 Received Data: NWLRBBMQBHCDARZOWKKY
[root@DataComm Downloads]# ./client -a 192.168.0.20 -b 1 -c 50
Remote Address: 192.168.0.20
Remote Port: 24862
4388 Sent Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXRJMOWFRXSJYBLDBEFSARC
4388 Received Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXRJMOWFRXSJYBLDBEFSARC
[root@DataComm Downloads]#
```

Here is the CSV dump from our Epoll Server. Note the last value, for it is the size of data per client request:

epollServer.c × epoll_log.csv ×

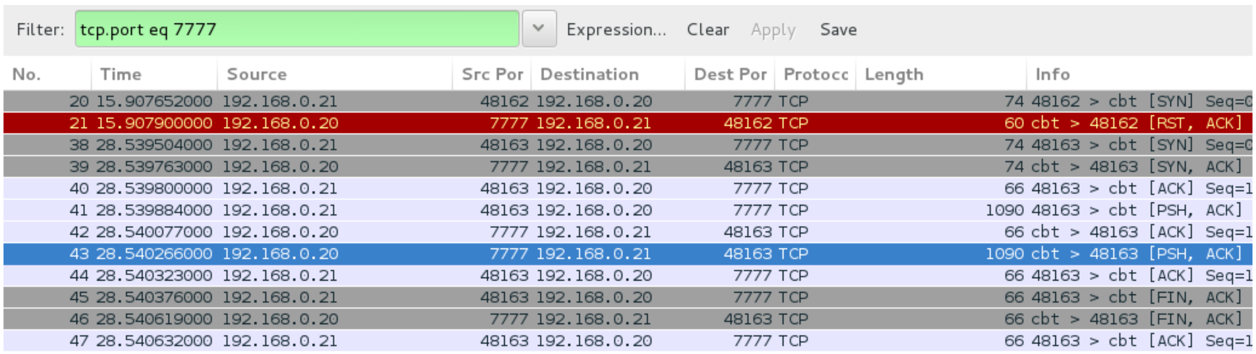
```
192.168.0.21,43708,1,5
192.168.0.21,43964,1,10
192.168.0.21,44220,1,15
192.168.0.21,44476,1,20
192.168.0.21,44732,1,50
```

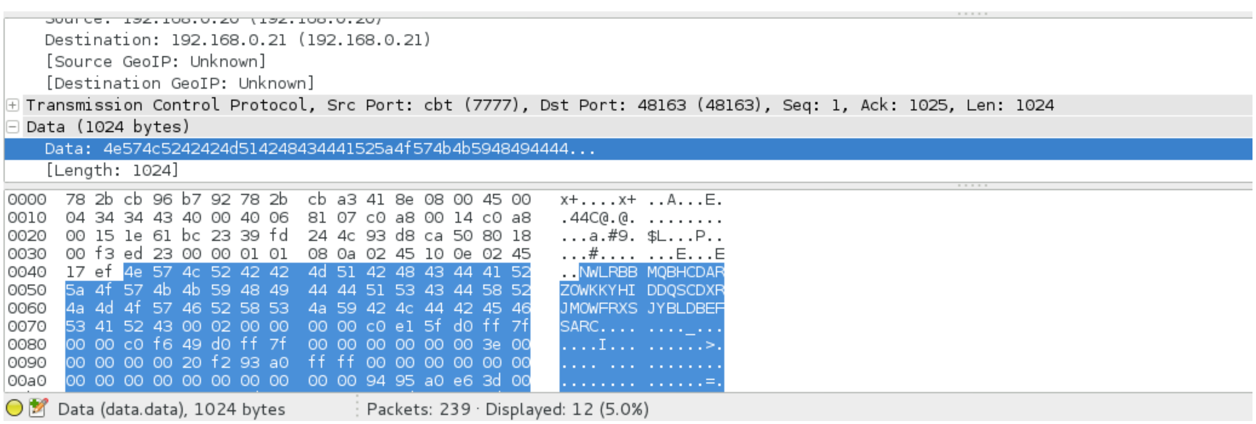
5. Multi threaded Client is sending some sort of string.

In Terminal, here is the expected sending and receiving of our text:

```
[root@DataComm Downloads]# ./client -a 192.168.0.20 -b 1 -c 50
Remote Address: 192.168.0.20
Remote Port: 24862
32413 Sent Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXRJMOWFRXSJYBLDBEFSARC
32413 Received Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXRJMOWFRXSJYBLDBEFSARC
[root@DataComm Downloads]#
```

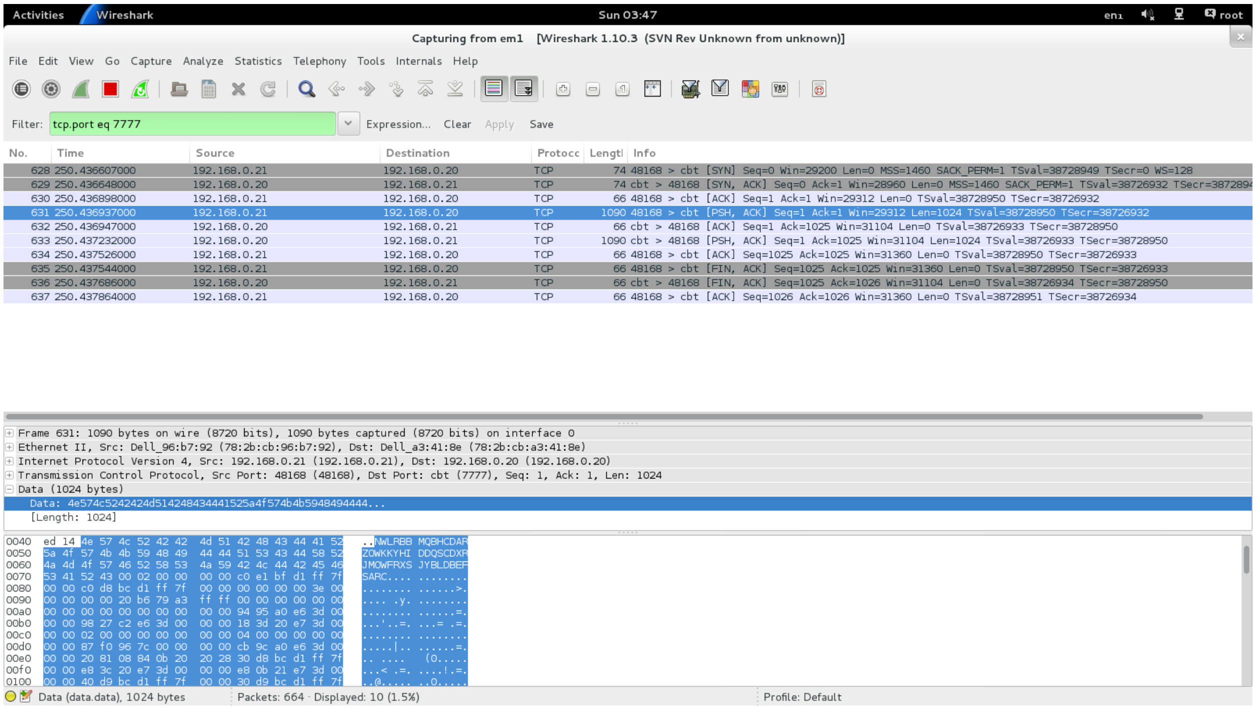
On Wireshark, here is the capture:





6. Multi threaded Server is receiving data from the Client.

Here's the Wireshark capture on the Server Host from the previous message from the Client:



7. Select Server is receiving the same string from the Client.

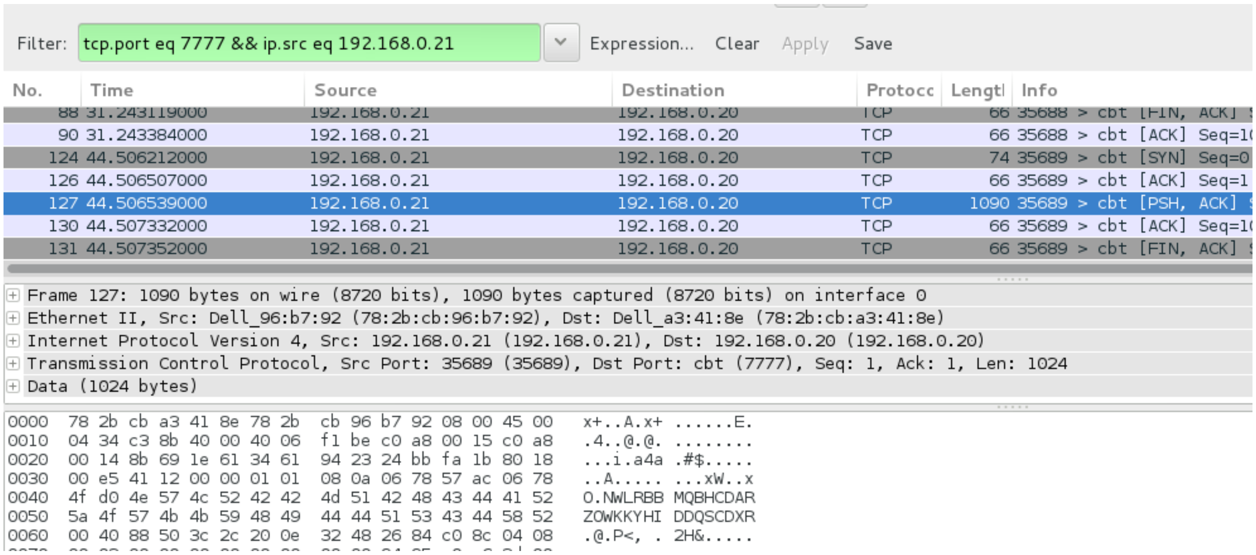
Screen capture from Client:

```
[root@DataComm Downloads]# ./client -a 192.168.0.20 -b 1 -c 30
Remote Address: 192.168.0.20
Remote Port: 24862
14486 Sent Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
14486 Received Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
```

Screen Capture from Server:

```
[root@DataComm Downloads]# ./sel_srv
Currently serving 1 connections...
Received: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
Sending: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR...
Received:
Received:
Received: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
Received:
Received:
```

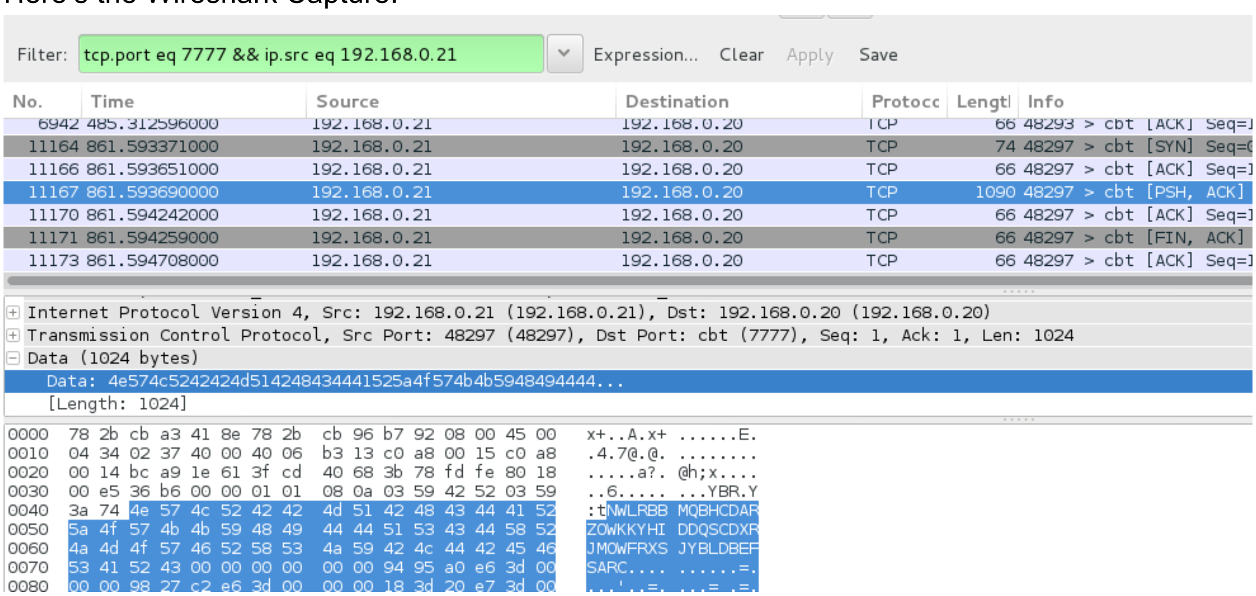
Wireshark Capture:



8. Epoll Server is receiving the correct string value from Client.
Here is a screen capture of the Client's string from Terminal:

```
[root@DataComm Downloads]# ./client -a 192.168.0.20 -b 1 -c 50
Remote Address: 192.168.0.20
Remote Port: 24862
4243 Sent Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXRJMOWFRXSJYBLDBEFSARC
4243 Received Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXRJMOWFRXSJYBLDBEFSARC
[root@DataComm Downloads]#
```

Here's the Wireshark Capture:



Finally, if the server received correctly, it will send back the exact same string. Here's the Terminal screen shot of our Server echoing back:

```
^C[root@DataComm Downloads]# ./epoll_svr
Maximum Connections Achieved: 1
sending: NWLRBBMQBHCDARZOWKKYHIDDQSCDXRJMOWFRXSJYBLDBEFSARC
```

9. Client is sending multiple strings via multiple requests.

In our executable, we've specified to send 5 requests to the Server. In our Terminal output, we have 5 pairs of send and receive data:

```
[root@DataComm Downloads]# ./client -a 192.168.0.20 -b 5 -c 50
Remote Address: 192.168.0.20
Remote Port: 24862
32720 Sent Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXRJMOWFRXSJYBLDBEFSARC
32720 Received Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXRJMOWFRXSJYBLDBEFSARC
32720 Sent Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXRJMOWFRXSJYBLDBEFSARC
32720 Received Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXRJMOWFRXSJYBLDBEFSARC
32720 Sent Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXRJMOWFRXSJYBLDBEFSARC
32720 Received Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXRJMOWFRXSJYBLDBEFSARC
32720 Sent Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXRJMOWFRXSJYBLDBEFSARC
32720 Received Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXRJMOWFRXSJYBLDBEFSARC
32720 Sent Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXRJMOWFRXSJYBLDBEFSARC
32720 Received Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXRJMOWFRXSJYBLDBEFSARC
```

In our Wireshark, here's our capture on the Client side:

Filter: tcp.port eq 7777 | Expression... | Clear | Apply | Save

No.	Time	Source	Src Por	Destination	Dest Por	Protocc	Length	Info
6	6.486791000	192.168.0.21	48172	192.168.0.20	7777	TCP	74	48172 > cbt [SYN] Seq=0
7	6.487056000	192.168.0.20	7777	192.168.0.21	48172	TCP	74	cbt > 48172 [SYN, ACK]
8	6.487094000	192.168.0.21	48172	192.168.0.20	7777	TCP	66	48172 > cbt [ACK] Seq=1
9	6.487188000	192.168.0.21	48172	192.168.0.20	7777	TCP	1090	48172 > cbt [PSH, ACK]
10	6.487409000	192.168.0.20	7777	192.168.0.21	48172	TCP	66	cbt > 48172 [ACK] Seq=1
11	6.487474000	192.168.0.20	7777	192.168.0.21	48172	TCP	1090	cbt > 48172 [PSH, ACK]
12	6.487503000	192.168.0.21	48172	192.168.0.20	7777	TCP	66	48172 > cbt [ACK] Seq=1
28	11.487679000	192.168.0.21	48172	192.168.0.20	7777	TCP	1090	48172 > cbt [PSH, ACK]
29	11.488035000	192.168.0.20	7777	192.168.0.21	48172	TCP	1090	cbt > 48172 [PSH, ACK]
30	11.488102000	192.168.0.21	48172	192.168.0.20	7777	TCP	66	48172 > cbt [ACK] Seq=2
37	16.488250000	192.168.0.21	48172	192.168.0.20	7777	TCP	1090	48172 > cbt [PSH, ACK]
38	16.488640000	192.168.0.20	7777	192.168.0.21	48172	TCP	1090	cbt > 48172 [PSH, ACK]
39	16.488710000	192.168.0.21	48172	192.168.0.20	7777	TCP	66	48172 > cbt [ACK] Seq=3
44	21.488845000	192.168.0.21	48172	192.168.0.20	7777	TCP	1090	48172 > cbt [PSH, ACK]
45	21.489191000	192.168.0.20	7777	192.168.0.21	48172	TCP	1090	cbt > 48172 [PSH, ACK]
46	21.489257000	192.168.0.21	48172	192.168.0.20	7777	TCP	66	48172 > cbt [ACK] Seq=4
55	26.489411000	192.168.0.21	48172	192.168.0.20	7777	TCP	1090	48172 > cbt [PSH, ACK]
56	26.489755000	192.168.0.20	7777	192.168.0.21	48172	TCP	1090	cbt > 48172 [PSH, ACK]
57	26.489822000	192.168.0.21	48172	192.168.0.20	7777	TCP	66	48172 > cbt [ACK] Seq=5
58	26.489865000	192.168.0.21	48172	192.168.0.20	7777	TCP	66	48172 > cbt [FIN, ACK]
59	26.490162000	192.168.0.20	7777	192.168.0.21	48172	TCP	66	cbt > 48172 [FIN, ACK]
60	26.490176000	192.168.0.21	48172	192.168.0.20	7777	TCP	66	48172 > cbt [ACK] Seq=5

```
Frame 6: 74 bytes on wire (592 bits), 74 bytes captured (592 bits) on interface 0
Ethernet II, Src: Dell_96:b7:92 (78:2b:cb:96:b7:92), Dst: Dell_a3:41:8e (78:2b:cb:a3:41:8e)
Internet Protocol Version 4, Src: 192.168.0.21 (192.168.0.21), Dst: 192.168.0.20 (192.168.0.20)
  Version: 4

0000  78 2b cb a3 41 8e 78 2b  cb 96 b7 92 08 00 45 00   x+..A.x+ ......E.
0010  00 3c a7 b2 40 00 40 06  11 90 c0 a8 00 15 c0 a8   .<..@.@. ........
0020  00 14 bc 2c 1e 61 ce f3  b4 6c 00 00 00 00 a0 02   ...,.a.. .l......
0030  72 10 81 a8 00 00 02 04  05 b4 04 02 08 0a 02 51   r....... .......Q
0040  13 de 00 00 00 00 01 03  03 07                     ........ ..
```

10. Server is receiving that many strings equal to the number of requests.
In our previous test case, we’ve specified the client to send 5 requests. Here is our Wireshark capture of the server:

Filter: tcp.port eq 7777 Expression... Clear Apply Save

No.	Time	Source	Destination	Protocc	Lengtl	Info
56	24.530502000	192.168.0.21	192.168.0.20	TCP	74	48172 > cbt [SYN] Seq=0
57	24.530539000	192.168.0.20	192.168.0.21	TCP	74	cbt > 48172 [SYN, ACK]
58	24.530802000	192.168.0.21	192.168.0.20	TCP	66	48172 > cbt [ACK] Seq=1
59	24.530918000	192.168.0.21	192.168.0.20	TCP	1090	48172 > cbt [PSH, ACK]
60	24.530931000	192.168.0.20	192.168.0.21	TCP	66	cbt > 48172 [ACK] Seq=1
61	24.530963000	192.168.0.20	192.168.0.21	TCP	1090	cbt > 48172 [PSH, ACK]
62	24.531206000	192.168.0.21	192.168.0.20	TCP	66	48172 > cbt [ACK] Seq=1
77	29.531409000	192.168.0.21	192.168.0.20	TCP	1090	48172 > cbt [PSH, ACK]
78	29.531497000	192.168.0.20	192.168.0.21	TCP	1090	cbt > 48172 [PSH, ACK]
79	29.531805000	192.168.0.21	192.168.0.20	TCP	66	48172 > cbt [ACK] Seq=2
84	34.532011000	192.168.0.21	192.168.0.20	TCP	1090	48172 > cbt [PSH, ACK]
85	34.532090000	192.168.0.20	192.168.0.21	TCP	1090	cbt > 48172 [PSH, ACK]
86	34.532416000	192.168.0.21	192.168.0.20	TCP	66	48172 > cbt [ACK] Seq=3
89	39.532564000	192.168.0.21	192.168.0.20	TCP	1090	48172 > cbt [PSH, ACK]
90	39.532644000	192.168.0.20	192.168.0.21	TCP	1090	cbt > 48172 [PSH, ACK]
91	39.532969000	192.168.0.21	192.168.0.20	TCP	66	48172 > cbt [ACK] Seq=4
114	44.533114000	192.168.0.21	192.168.0.20	TCP	1090	48172 > cbt [PSH, ACK]
115	44.533215000	192.168.0.20	192.168.0.21	TCP	1090	cbt > 48172 [PSH, ACK]
116	44.533500000	192.168.0.21	192.168.0.20	TCP	66	48172 > cbt [ACK] Seq=5
117	44.533514000	192.168.0.21	192.168.0.20	TCP	66	48172 > cbt [FIN, ACK]
118	44.533646000	192.168.0.20	192.168.0.21	TCP	66	cbt > 48172 [FIN, ACK]
119	44.533866000	192.168.0.21	192.168.0.20	TCP	66	48172 > cbt [ACK] Seq=5

```
Frame 119: 66 bytes on wire (528 bits), 66 bytes captured (528 bits) on interface 0
Ethernet II, Src: Dell_96:b7:92 (78:2b:cb:96:b7:92), Dst: Dell_a3:41:8e (78:2b:cb:a3:41:8e)
Internet Protocol Version 4, Src: 192.168.0.21 (192.168.0.21), Dst: 192.168.0.20 (192.168.0.20)
Transmission Control Protocol, Src Port: 48172 (48172), Dst Port: cbt (7777), Seq: 5122, Ack: 5122, Len: 0
```

And here is our CSV dump. Note the highlighted line, and the last value of 250, which is 5 requests of 50 bytes each:

selectServer.c × jakeServer.c × epollServer2.c × multiThread_log.csv ×

```
192.168.0.21,7100,1,5
192.168.0.21,7356,1,10
192.168.0.21,7612,1,15
192.168.0.21,7868,1,20
192.168.0.21,8124,1,50
192.168.0.21,9148,1,50
192.168.0.21,10428,1,50
192.168.0.21,11452,5,250
```

11. Select Server receives many strings equal to the number of requests:
Screen Capture of the Client. Note the 10 requests:

```
[root@DataComm Downloads]# ./client -a 192.168.0.20 -b 10 -c 30
Remote Address: 192.168.0.20
Remote Port: 24862
14550 Sent Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
14550 Received Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
14550 Sent Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
14550 Received Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
14550 Sent Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
14550 Received Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
14550 Sent Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
14550 Received Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
14550 Sent Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
14550 Received Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
14550 Sent Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
14550 Received Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
14550 Sent Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
14550 Received Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
14550 Sent Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
14550 Received Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
14550 Sent Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
14550 Received Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
14550 Sent Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
14550 Received Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
[root@DataComm Downloads]#
```

Screen Capture of the Server:

```
[root@DataComm Downloads]# ./sel_srv
Currently serving 1 connections...
Received: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
Sending: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR...
Received: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
Sending: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR...
Received: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
Sending: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR...
Received: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
Sending: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR...
Received: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
Sending: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR...
Received: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
Sending: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR...
Received: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
Sending: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR...
Received: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
Sending: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR...
Received: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
Sending: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR...
Received: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
Sending: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR...
Received: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
Received: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
Received: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
Received: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
Received: NWLRBBMQBHCDARZOWKKYHIDDQSCDXR
```

12. Epoll Server receives many strings equal to the number of requests from Client. Here's a screen capture of the Client's requests:

```
[root@DataComm Downloads]# ./client -a 192.168.0.20 -b 10 -c 10
Remote Address: 192.168.0.20
```

Here is the CSV dump from the Server Side. Note the last two values; 10 is the number of requests received and 100 is the total data processed:

```
epollServer.c   epoll_log.csv
1 192.168.0.21,42428,10,100
```

13. Clients are keeping track of the number of requests made.
In our Terminal, we've specified the Client to send a request 20 times. Here's our Terminal output. Note, we cut short the screenshot:

File Edit View Search Terminal Help

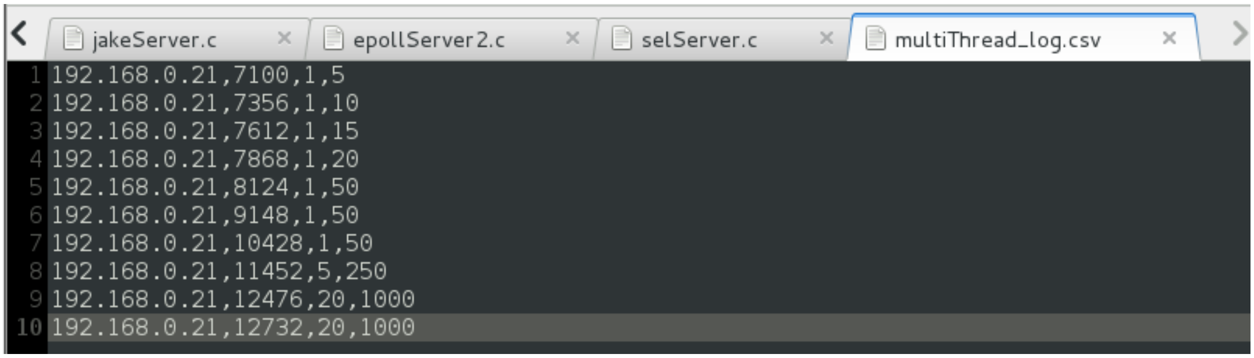
```
[root@DataComm Downloads]# ./client -a 192.168.0.20 -b 20 -c 50
Remote Address: 192.168.0.20
Remote Port: 24862
647 Sent Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXRJMOWFRXSJYBLDBEFSARC
647 Received Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXRJMOWFRXSJYBLDBEFSARC
647 Sent Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXRJMOWFRXSJYBLDBEFSARC
647 Received Data: NWLRBBMQBHCDARZOWKKYHIDDQSCDXRJMOWFRXSJYBLDBEFSARC
```

Here is our finished CSV dump:

test.sh | client.c | Client_Results.csv

```
192.168.0.20,50,0.000336
192.168.0.20,50,0.000483
192.168.0.20,50,0.000458
192.168.0.20,50,0.000474
192.168.0.20,50,0.000462
192.168.0.20,50,0.000481
192.168.0.20,50,0.000497
192.168.0.20,50,0.000473
192.168.0.20,50,0.000513
192.168.0.20,50,0.000474
192.168.0.20,50,0.000469
192.168.0.20,50,0.000481
192.168.0.20,50,0.000469
192.168.0.20,50,0.000476
192.168.0.20,50,0.000455
192.168.0.20,50,0.000506
192.168.0.20,50,0.000474
192.168.0.20,50,0.000466
192.168.0.20,50,0.000488
192.168.0.20,50,0.000501
```

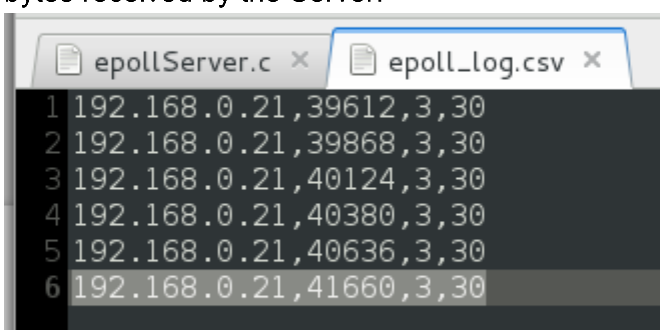
14. Multi threaded Server is keeping track of number of requests received.
In our previous Client, we've specified to run 20 requests to the server with 50 bytes of data each. Here is our CSV dump from the Server. Note the highlighted value and the last two values. The second last value is the number of requests and the other is the total bytes sent by that transaction:




```
192.168.0.21,7100,1,5
192.168.0.21,7356,1,10
192.168.0.21,7612,1,15
192.168.0.21,7868,1,20
192.168.0.21,8124,1,50
192.168.0.21,9148,1,50
192.168.0.21,10428,1,50
192.168.0.21,11452,5,250
192.168.0.21,12476,20,1000
192.168.0.21,12732,20,1000
```

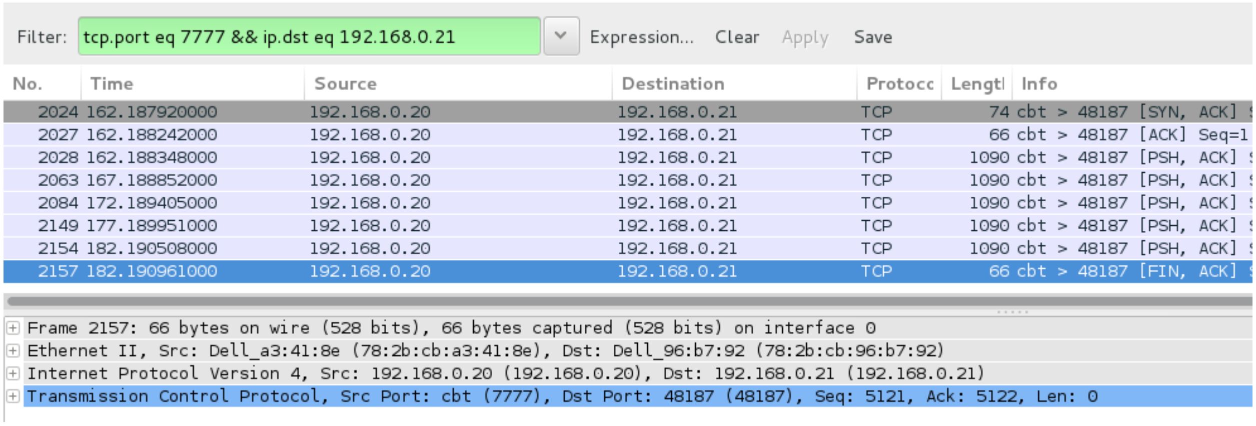
15. Select Server keeps track of number of requests received. FAILED.

16. Epoll Server keeps track of number of requests received.
We've specified our client to send 3 packets of 10 bytes each in a separate instance. Here is the screen capture of the CSV dump from our Server. Note the two last values. The second to last value indicates the number of packets received, and the last value indicates the total data in bytes received by the Server:



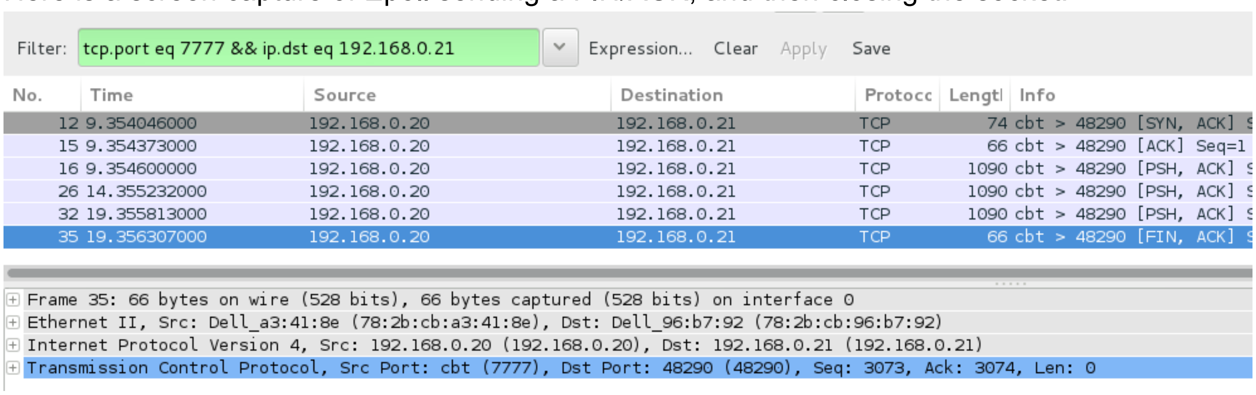

```
192.168.0.21,39612,3,30
192.168.0.21,39868,3,30
192.168.0.21,40124,3,30
192.168.0.21,40380,3,30
192.168.0.21,40636,3,30
192.168.0.21,41660,3,30
```

17. Multi thread Server closes the sockets after each client thread finishes requests.
Here is the Wireshark dump of our Server closing the socket:

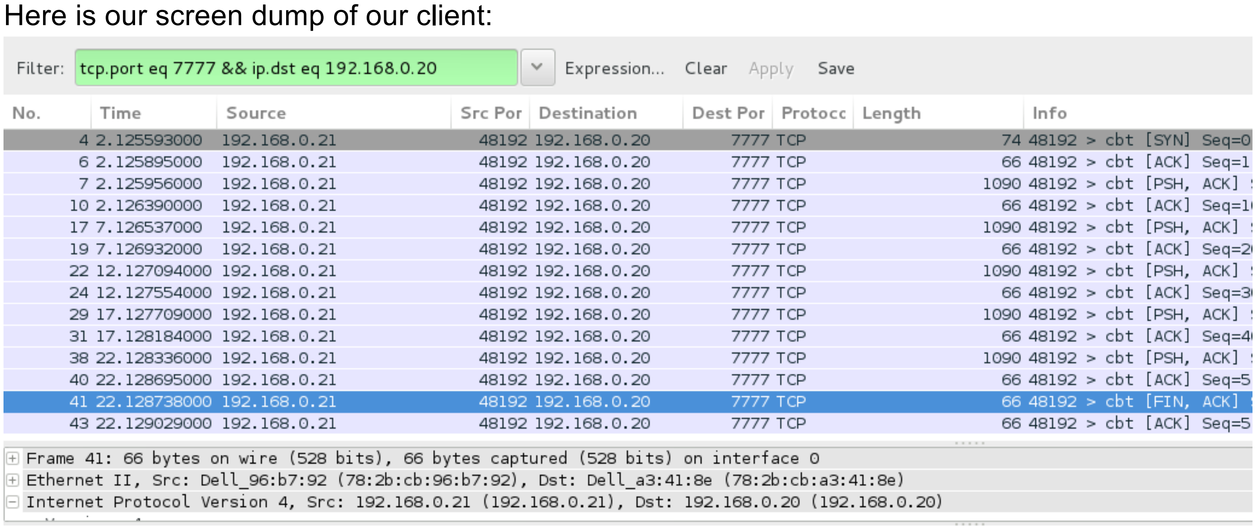


18. Select Server closes the sockets after each client finishes requests. FAILED.

19. Epoll Server closes the sockets after each client finishes requests.
Here is a screen capture of Epoll sending a FIN/ACK, and then closing the socket:



20. Client closes socket after finishing requests.
Here is our screen dump of our client:



21. No memory leaks from Multi threaded Server.

After running Valgrind on our multi threaded server, the screen capture below shows some erroneous values:

```
==15792== Memcheck, a memory error detector
==15792== Copyright (C) 2002-2012, and GNU GPL'd, by Julian Seward et al.
==15792== Using Valgrind-3.8.1 and LibVEX; rerun with -h for copyright info
==15792== Command: ./mthread_svr
==15792==
Maximum Connections Achieved: 1
^C==15792==
==15792== HEAP SUMMARY:
==15792==     in use at exit: 328 bytes in 3 blocks
==15792==   total heap usage: 6 allocs, 3 frees, 952 bytes allocated
==15792==
==15792== LEAK SUMMARY:
==15792==    definitely lost: 0 bytes in 0 blocks
==15792==    indirectly lost: 0 bytes in 0 blocks
==15792==      possibly lost: 272 bytes in 1 blocks
==15792==    still reachable: 56 bytes in 2 blocks
==15792==         suppressed: 0 bytes in 0 blocks
==15792== Rerun with --leak-check=full to see details of leaked memory
==15792==
==15792== For counts of detected and suppressed errors, rerun with: -v
==15792== ERROR SUMMARY: 0 errors from 0 contexts (suppressed: 2 from 2)
```

These values are revealed because of our code design. Please refer to the following two screenshots:

```c

host* addToList(int port, char* ipAddr)
{
    host *node;

    if (head->next == NULL)
    {
        node = malloc(sizeof(host));
        head->next = node;
        node->status = "connected";
        node->port = port;
        node->ipAddress = ipAddr;
        node->numOfRequest = 0;
        node->numOfBytesSent = 0;
        node->next = NULL;
    } else {
        host *previous = findEndOfList();
        node = malloc(sizeof(host));
        previous->next = node;
        node->status = "connected";
        node->port = port;
        node->ipAddress = ipAddr;
        node->numOfRequest = 0;
        node->numOfBytesSent = 0;
        node->next = NULL;
    }

    return node;
}
```

Note the two mallocs() from addToList(). Now, note the one free() in deleteFromList().

```c
void deleteFromList(host *nodeToDelete)
{
    host *current = head;
    host *previous = NULL;

    while(current != NULL)
    {
        if((nodeToDelete->port == current->port) && (strcmp(nodeToDelete->ipAddress, current->ipAddress) == 0))
        {
            host *temp = current;
            previous->next = current->next;
            fp = fopen("multiThread_log.csv", "a");
            fprintf(fp,  "%s,%d,%d,%d\n", temp->ipAddress, temp->port, temp->numOfRequest, temp->numOfBytesSent);
            free(temp);
            fclose(fp);
            return;
        } else {
            previous = current;
            current = current->next;
        }
    }
    return;
}
```

Because these calls are made within other methods, they resulted a mismatch. This then triggers a false positive for Valgrind because it's embedded in other methods. We will allow this to be permissible since it's not a definite or indirect loss of memory.

22. No memory leaks from Select Server. FAILED.

23. No memory leaks from epoll server.
Again, same expected results that are similar with our Multi threaded Server. Here we see some erroneous values of memory leaks:

```
==16475== Memcheck, a memory error detector
==16475== Copyright (C) 2002-2012, and GNU GPL'd, by Julian Seward et al.
==16475== Using Valgrind-3.8.1 and LibVEX; rerun with -h for copyright inf
==16475== Command: ./epoll_svr
==16475==
Maximum Connections Achieved: 1
sending: NWLRBBMQBH
sending: NWLRBBMQBH
sending: NWLRBBMQBH
^C==16475==
==16475== HEAP SUMMARY:
==16475==     in use at exit: 1,128 bytes in 5 blocks
==16475==   total heap usage: 7 allocs, 2 frees, 1,736 bytes allocated
==16475==
==16475== LEAK SUMMARY:
==16475==    definitely lost: 0 bytes in 0 blocks
==16475==    indirectly lost: 0 bytes in 0 blocks
==16475==      possibly lost: 1,088 bytes in 4 blocks
==16475==    still reachable: 40 bytes in 1 blocks
==16475==         suppressed: 0 bytes in 0 blocks
==16475== Rerun with --leak-check=full to see details of leaked memory
==16475==
==16475== For counts of detected and suppressed errors, rerun with: -v
==16475== ERROR SUMMARY: 0 errors from 0 contexts (suppressed: 2 from 2)
```

However, because these calls are made within other methods, they resulted a mismatch. This then triggers a false positive for Valgrind because it’s embedded in other methods. We will allow this to be permissible since it’s not a definite or indirect loss of memory.

24. No memory leaks from our Client.
After running Valgrind on our Client machine, the screen capture below shows no erroneous values:

```
==3214==
==3214== HEAP SUMMARY:
==3214==     in use at exit: 0 bytes in 0 blocks
==3214==   total heap usage: 5 allocs, 5 frees, 2,248 bytes allocated
==3214==
==3214== All heap blocks were freed -- no leaks are possible
==3214==
==3214== For counts of detected and suppressed errors, rerun with: -v
==3214== ERROR SUMMARY: 6 errors from 2 contexts (suppressed: 2 from 2)
```

Observations

To begin our comparisons, we will start the three servers and fill in the following table:

Host	IP Address
Servers (Multi Threaded, Select, Epoll)	192.168.0.20
Client (1)	192.168.0.19
Client (2)	192.168.0.21
Client (3)	192.168.0.22
Client (4)	192.168.0.18

Case / Server	Multi Thread Server	Select Implemented Server	Epoll Implemented Server
Max Clients*	1782	574	19990+
Max Requests*	13547	**2870000; 2775	**199 900 000; 321410
Avg. Time to Process	0.00036335 s	0.0004602 s	0.001196839 s
Memory Usage	1.825 GB	1.400 GB	2.651 GB
Avg. Processing Power	93.25%	29.5%	12.33%

* the maximum value before server or client crashes

** theoretical value; actual value

Multi Threaded Server

	Client 1	Client 2	Client 3	Client 4
Max Clients	3000	3000	x	x
Max Req’s	6870	6870	x	x
Avg. Time	0.0003648 s	0.0003619 s	x	x
Mem. Usg.	1067	1054	x	x
Prcs. Power	6.3%	5.8%	x	x

Clients 3 and 4 were omitted in this test because their inclusion would result in a quick crash of the server.

Select Server

	Client 1	Client 2	Client 3	Client 4
Max Clients	1000	1000	1000	1000
Max Req's	5000	5000	5000	5000
Time	0.0004602	0.000451607	x	x
Mem. Usg.	1.200 GB	1.225 GB	x	x
Prcs. Power	20%	21.2%	x	x

Epoll Server

	Client 1	Client 2	Client 3	Client 4
Max Clients	5000	5000	5000	5000
Max Req's	10 000	10 000	10 000	10 000
Time	*0.000535055 s	*0.000566556 s	*0.001023102 s	*0.002662644 s
Mem. Usg.	2.200 GB	2.000 GB	1.650 GB	2.500 GB
Prcs. Power	13.8%	12.2%	12.6%	16.2%

*these stress tests were cut short to grab data earlier; values are actually greater than specified

Figure 1 - An Interpretation of Max Clients for the three Servers

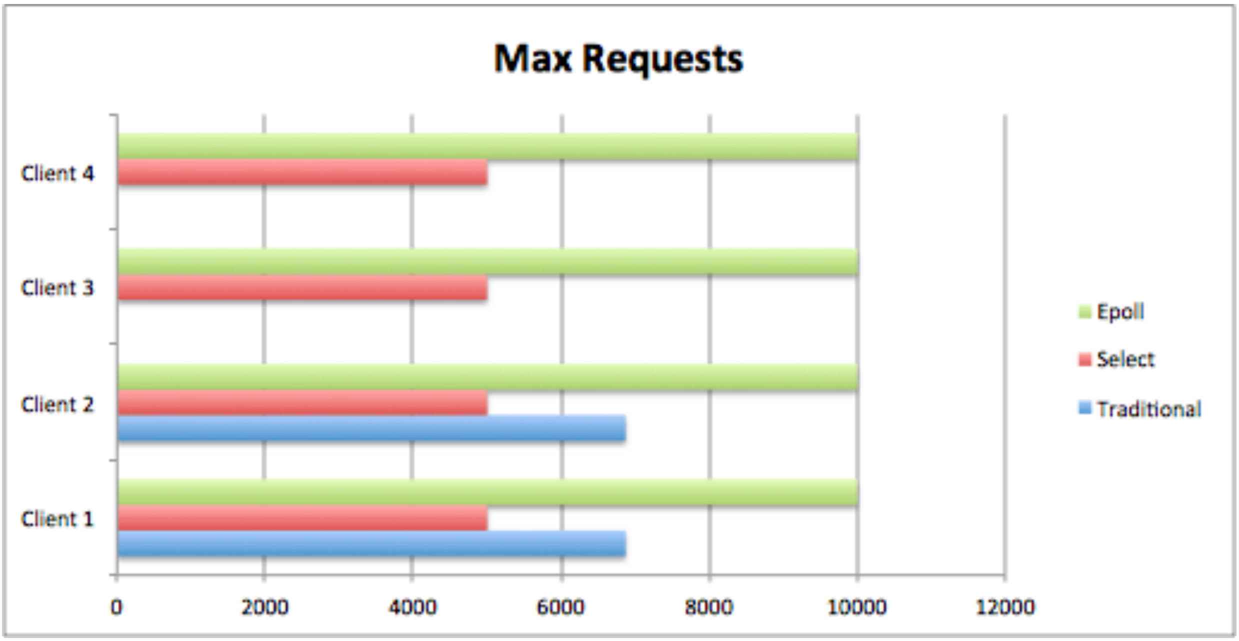


Figure 2 - An Interpretation of Max Requests for the three Servers

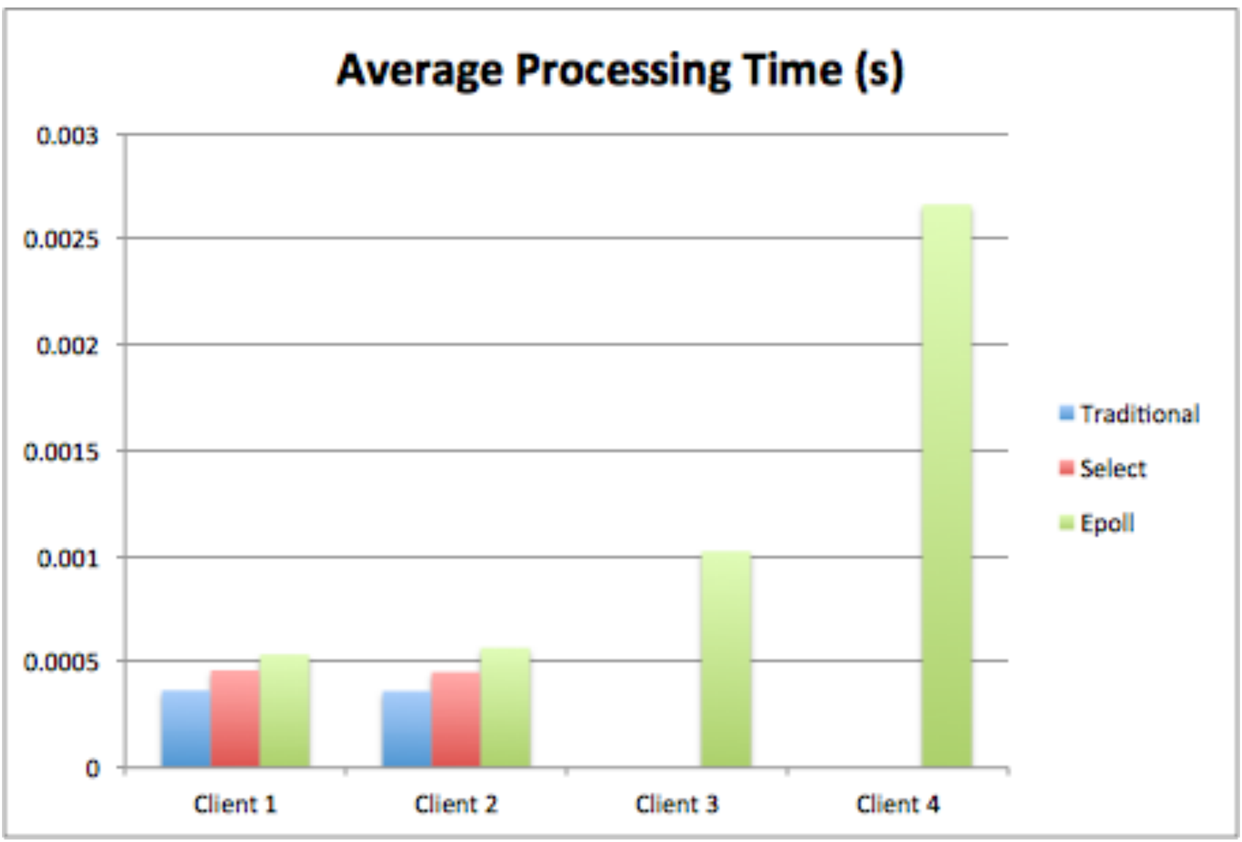


Figure 3 - An interpretation of Average Processing Power for the three Servers

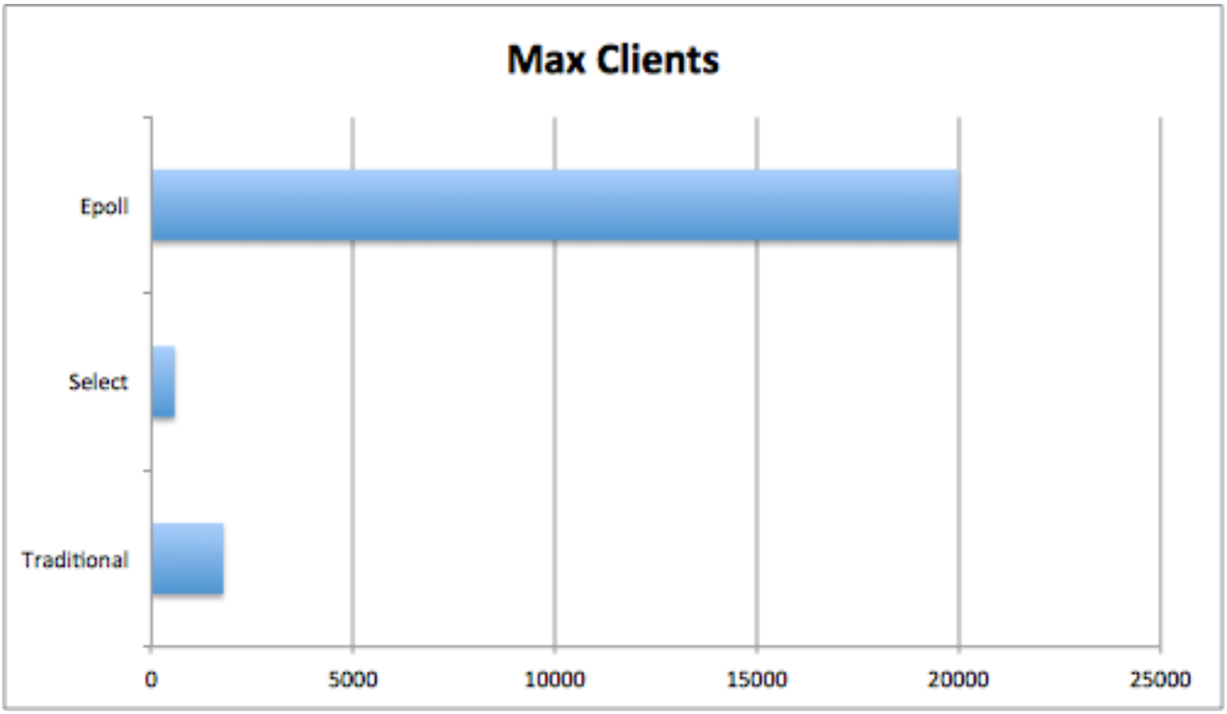


Figure 4 - The Maximum Clients per server at run time

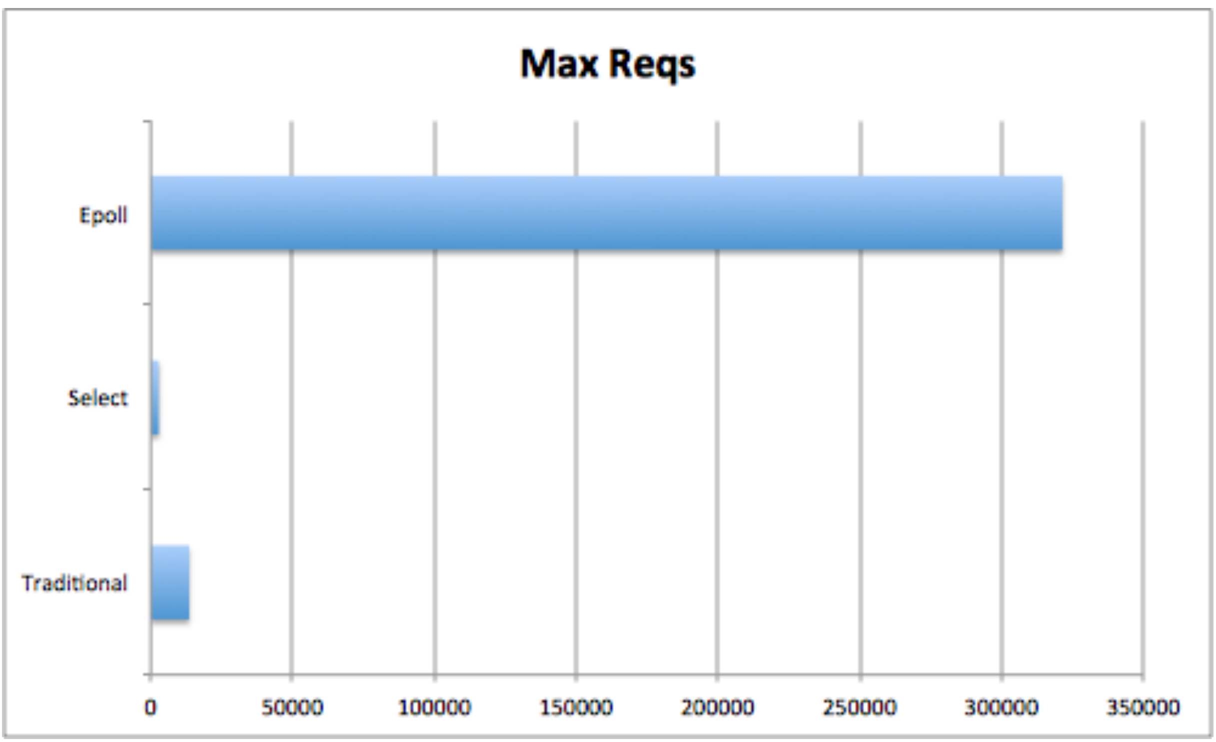


Figure 5 - The Maximum Requests per server at run time

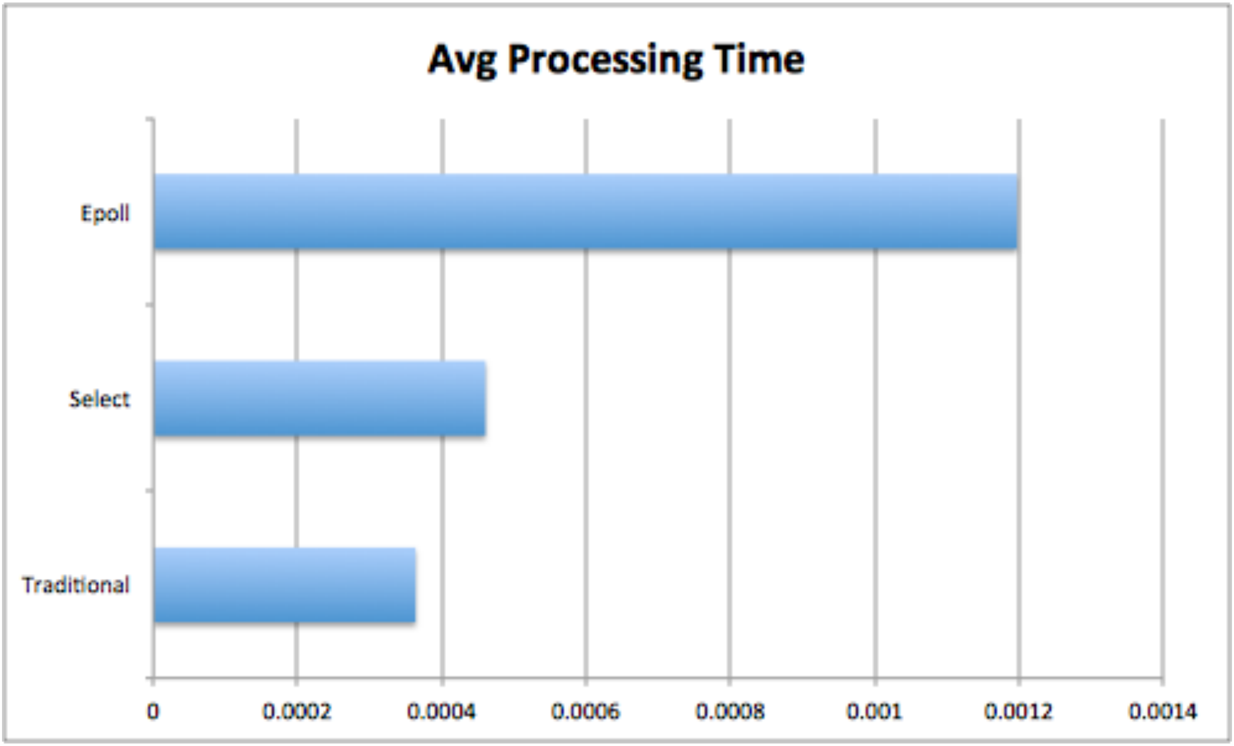


Figure 6 - The Average Processing Time per server at run time (s)

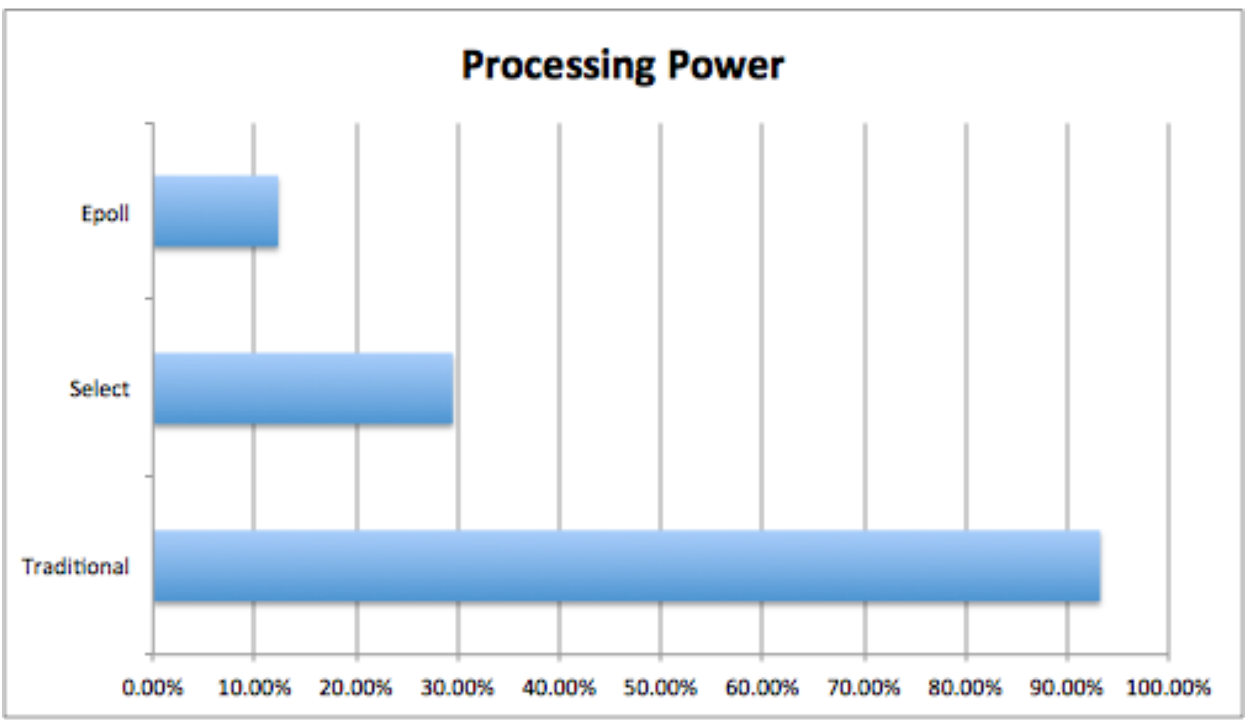


Figure 7 - The Average Processing Power over four cores per server at run time

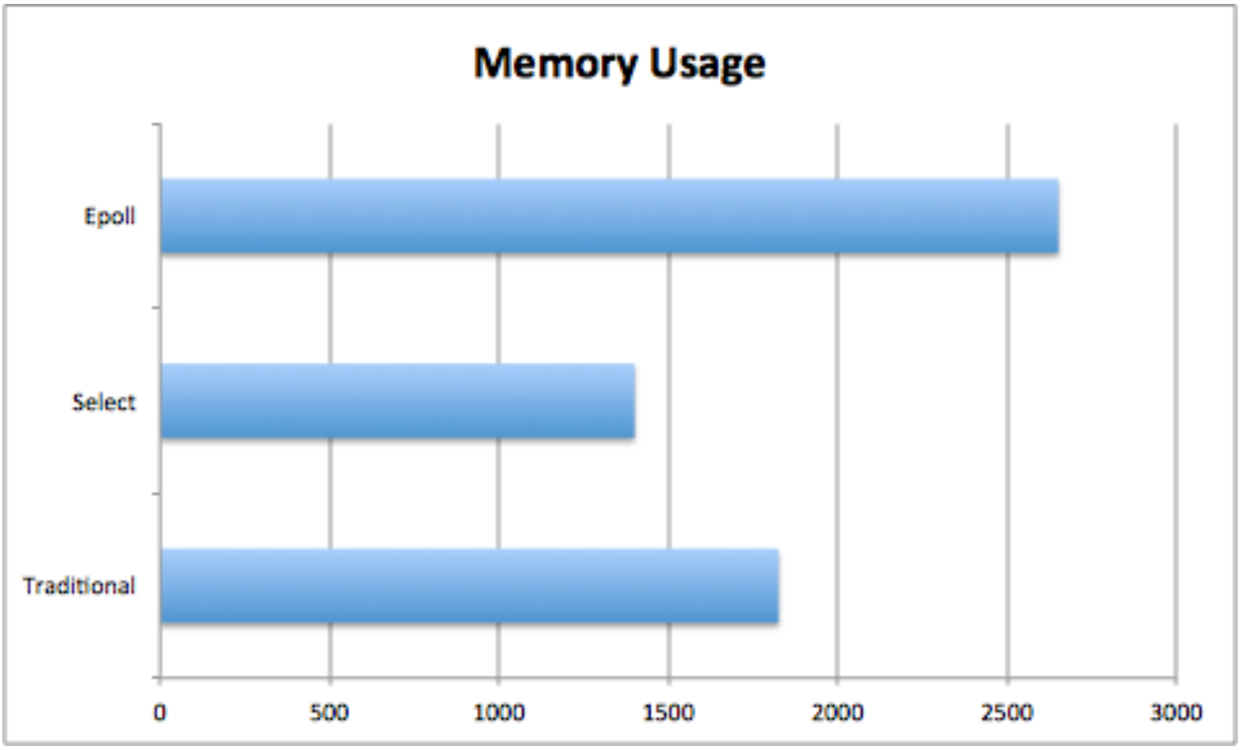


Figure 8 - Average Memory usage over 8 GB of RAM per server at run time

Limitations

Due to time constraints, we have failed to develop a working and functional Select server. The Select server provided in this assignment was designed to follow our initial ideas and thought process on how to approach the problem. However, the approach was flawed and it was too late for us to change the Server design for a more complete one.

Our Select server is able to sustain at least 1000+ connections. The logic within our code was at fault for the lack of a sufficient server. Our problem lies within the Server closing sockets and how we were storing file descriptors. We failed to implement proper logic to designate which file descriptors have been used. What resulted was, when a file descriptor was cleared it was still being used by the client.

To redeem ourselves, we focused more heavily early on with the traditional multithreaded server in the hopes we would get a more thorough understanding. Afterwards, we dedicated more research and time into the Epoll server, which is fully functional as intended. We feel that since we will be using Epoll later on, we had a heavier emphasis on it versus the Select server.

Conclusion

From the observations in our experiment, we conclude that our hypothesis is true to an extent. Firstly, we see that our Epoll server implementation outperforms any of the other servers by far in terms of scalability and reliability. Unfortunately, the case where we assumed that Select was more functional than the traditional multi threaded server is proven to be a false case (see **Limitations** section for more details).

In Figure 1, we see the 4 Clients being serviced by the Servers. Obviously, it's important to note that only Epoll was able to service all four clients without either crashing or being compromised.
Edge: Epoll Server

In Figure 2, the maximum requests are proportionate to the number of Clients and their client spawns. It is important to note that here, we expected Select server to be more dominant than our multi threaded server. Instead, because our Select server was much more inefficiently designed, our multi threaded server outperforms. Still, it is important to see that Epoll is designed to handle more requests per customer.
Edge: Epoll Server

In Figure 3, analyzing Clients 1 and 2, we see that Epoll takes slightly longer to process the client's requests versus Select and traditional multi threaded server. However, the slightness is minute, so we can neglect it.
Edge: Multi Threaded Server

In Figures 4 and 5, only the Epoll server was able to satisfy the maximum amount of requests and clients at run time versus the other two, which ended up crashing. The request are proportionate to the number of clients as well.
Edge: Epoll Server

In Figure 6, it is apparent that Epoll server takes a longer time to process these requests. Since these requests are small in size, it is consistent that multi threaded servers are servicing faster, but albeit less.
Edge: Multi Threaded Server

In Figure 7, it is important to see that, while the traditional server is quickly processing these requests, it is taking up a large amount of processing power over four cores. Instead, it is better to see that Epoll and Select servers are pacing themselves, only consuming up to 30%.
Edge: Epoll Server

In Figure 8, it is interesting to see that Select is consuming less memory than its counterparts.
Edge: Select Server

Verdict

	Traditional Server	Select Server	Epoll Server
Figure 1			x
Figure 2			x
Figure 3	x		
Figure 4			x
Figure 5			x
Figure 6	x		
Figure 7			x
Figure 8		x	
TOTAL	2	1	5

In conclusion, it is important to note that Epoll Server wins its case 5 out of 7 comparisons. It is wise to develop and design future projects using Epoll implementation.

Appendix

Located on disk are the following:

- Implementation of Scalable Servers - Epoll versus Select versus Multithreading (.pdf)
- Implementation of Scalable Servers - Design Work (.pdf)
- selServer.c (and selServer.exe)
- multiThreadServer.c (and multiThreadServer.c)
- epollServer.c (and epollServer.exe)
- test.sh
- Makefile
- Client.c
- README.txt