

## Performance Statistics and Experiments

1. We compute the average response time for queries and buys for 1000 sequential requests at the different points in the system. We compute them with and without the cache. We find that the cache speeds the average query response time. However, a cache hit for a particular query followed by a cache miss for the same query sees a much bigger difference than the average response time. This is likely due to a lot of cache missing when multiple clients make buys and invalidate the cache to preserve consistency.

### 1 Client with Cache:

Function	Client	Frontend	Catalog	Order
Search()	67.2ms	15.9ms	2.9 ms	
Lookup()	90.1ms	38.8 ms	1.8 ms	
Buy()	396.5ms	346 ms	2.5 ms	278.2ms

### 1 Client without Cache:

Function	Client	Frontend	Catalog	Order
Search()	110.2ms	55.3ms	2.6ms	
Lookup()	100.8ms	52.1ms	1.96ms	
Buy()	373.9ms	321ms	2.61ms	255.7ms

As we can see above using the cache does not really affect the latency of query requests within the catalog server. Also, it does not speed up buy requests as there is no lookup initiated by the frontend in the process of a buy. Therefore, it does not benefit from cache hits. The frontend and end-to-end client queries do see significant speed up because of cache hits however.

Here are the stats for multiple clients:

### 5 Clients with Cache:

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Function	Client	Frontend	Catalog	Order
Search()	92.9ms	22.4ms	3.0ms	
Lookup()	103.3ms	44.6ms	2.19ms	
Buy()	400.8ms	341ms	2.9ms	271.3ms

### 5 Clients without Cache:

Function	Client	Frontend	Catalog	Order
Search()	103.4ms	59.9ms	3.6ms	
Lookup()	120.3ms	60.9ms	2.2ms	
Buy()	404.1ms	325ms	2.6ms	260.4ms

### 10 Clients with Cache:

Function	Client	Frontend	Catalog	Order
Search()	70.7ms	14.5ms	4.2ms	
Lookup()	99.6ms	46.1ms	2.29ms	
Buy()	463.3ms	374ms	3.1ms	301.2ms

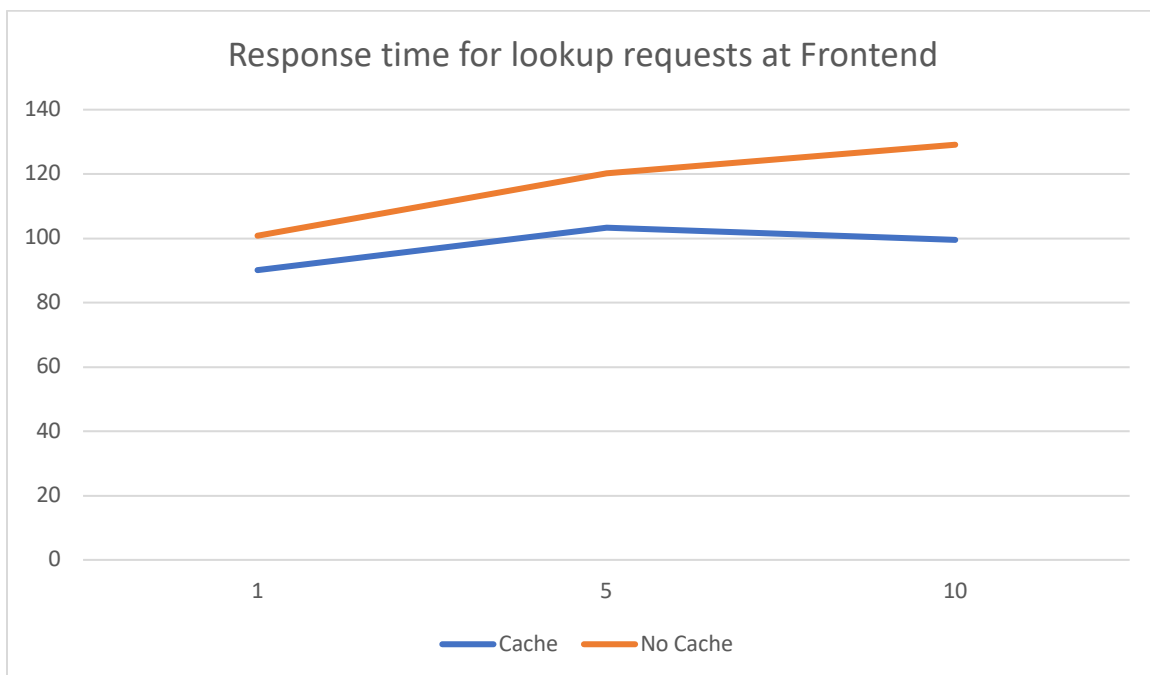
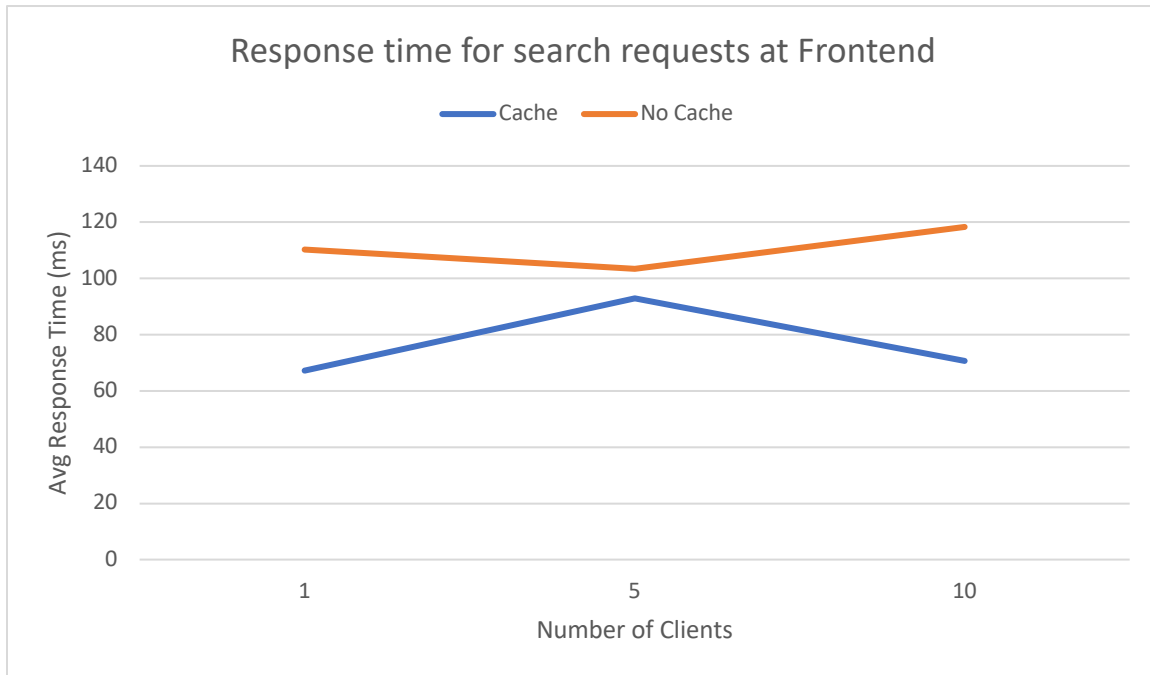
### 10 Clients without Cache:

Function	Client	Frontend	Catalog	Order
Search()	118.3ms	66.2ms	4.4ms	
Lookup()	129.1ms	67.4ms	2.5ms	
Buy()	437ms	360ms	3.2ms	288.3ms

As can be seen from the tables above, queries do not slow down much with an increasing number of clients. This is probably because of multiple catalog servers and load balancing providing high availability. Once again, caches do not help with buy requests and queries within the catalog server, but speed up queries for the frontend and end-to-end client requests. Despite this, the difference in latency is

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not as high as it can be because there are likely many cache misses as multiple clients could be making successful buys that invalidate cache entries. As in lab2, the latency of buy request go up as the number of clients increase as clients the system ensures consensus before proceeding with the next buy.



As the plots above show, the cache helps in reducing response time for queries at the frontend. The difference in the average response times for queries with a

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cache and without a cache are not as high as the difference for a particular query before and after it has been invalidated (as we will see below in 2.) as there might be many cache misses when the system is allowed to run.

2. We now compute the difference in response time for a query when it sees a cache hit followed immediately by a cache miss. Our experiment make a query request to put the item into the cache. We then query it again to see a cache hit. Then we buy a unit of the item invalidating the cache, and then query it to see a cache miss. The outputs on edlab are shown below. As we can see, a cache hit followed by an immediate cache miss on the same item results in a slow down of one order of magnitude. The cache hit sees a response time of 1.9 ms and the subsequent cache miss sees a response time of 9.04 ms.

```
[2020-04-25 06:04:32,012] INFO in connectionpool: Starting new HTTP connection (1): 128.119.243.147
[2020-04-25 06:04:32,016] INFO in remote: http://128.119.243.147:35100/echo - status: {'status': 1, 'retry': 0}
[2020-04-25 06:04:32,017] INFO in connectionpool: Starting new HTTP connection (1): 128.119.243.147
[2020-04-25 06:04:32,018] INFO in remote: http://128.119.243.147:35101/echo - status: {'status': 0, 'retry': 7}
[2020-04-25 06:04:34,624] INFO in connectionpool: Starting new HTTP connection (1): 128.119.243.147
[2020-04-25 06:04:34,634] INFO in frontend: [Cache] Set cache: {'stock': 10, 'book_name': 'How to get a good grade in 677 in 20 minutes a day', 'cost': 30}
[2020-04-25 06:04:34,634] INFO in frontend: Success, 0.018074
[2020-04-25 06:04:34,636] INFO in internal: 128.119.243.168 - - [25/Apr/2020 06:04:34] "GET /search?lookupNum=1 HTTP/1.1" 200 -
[2020-04-25 06:04:34,642] INFO in frontend: [Cache] Return cached value: {'book_name': 'How to get a good grade in 677 in 20 minutes a day', 'stock': 10, 'cost': 30}
[2020-04-25 06:04:34,642] INFO in frontend: Success, 0.001967
[2020-04-25 06:04:34,643] INFO in internal: 128.119.243.168 - - [25/Apr/2020 06:04:34] "GET /search?lookupNum=1 HTTP/1.1" 200 -
[2020-04-25 06:04:34,650] INFO in connectionpool: Starting new HTTP connection (1): 128.119.243.164
[2020-04-25 06:04:34,693] INFO in frontend: [Cache]----- Remove cache of ('lookupNum', '1')
[2020-04-25 06:04:34,693] INFO in frontend: Success, 0.046141
[2020-04-25 06:04:34,694] INFO in internal: 128.119.243.168 - - [25/Apr/2020 06:04:34] "POST /buy?buyNum=1 HTTP/1.1" 200 -
[2020-04-25 06:04:34,700] INFO in frontend: Cannot get a catalog server IP; retry time(s): 1
[2020-04-25 06:04:34,701] INFO in connectionpool: Starting new HTTP connection (1): 128.119.243.147
[2020-04-25 06:04:34,707] INFO in frontend: [Cache] Set cache: {'stock': 9, 'book_name': 'How to get a good grade in 677 in 20 minutes a day', 'cost': 30}
[2020-04-25 06:04:34,707] INFO in frontend: Success, 0.009044
[2020-04-25 06:04:34,707] INFO in internal: 128.119.243.168 - - [25/Apr/2020 06:04:34] "GET /search?lookupNum=1 HTTP/1.1" 200 -
[2020-04-25 06:04:35,024] INFO in connectionpool: Starting new HTTP connection (1): 128.119.243.164
[2020-04-25 06:04:35,028] INFO in remote: http://128.119.243.164:35102/echo - status: {'status': 1, 'retry': 0}
[2020-04-25 06:04:35,030] INFO in connectionpool: Starting new HTTP connection (1): 128.119.243.164
[2020-04-25 06:04:35,032] INFO in remote: http://128.119.243.164:35103/echo - status: {'status': 0, 'retry': 8}
[2020-04-25 06:04:35,034] INFO in connectionpool: Starting new HTTP connection (1): 128.119.243.147
[2020-04-25 06:04:35,038] INFO in remote: http://128.119.243.147:35100/echo - status: {'status': 1, 'retry': 0}
[2020-04-25 06:04:35,040] INFO in connectionpool: Starting new HTTP connection (1): 128.119.243.147
[2020-04-25 06:04:35,042] INFO in remote: http://128.119.243.147:35101/echo - status: {'status': 0, 'retry': 8}
[2020-04-25 06:04:38,047] INFO in connectionpool: Starting new HTTP connection (1): 128.119.243.164
[2020-04-25 06:04:38,051] INFO in remote: http://128.119.243.164:35102/echo - status: {'status': 1, 'retry': 0}
[2020-04-25 06:04:38,053] INFO in connectionpool: Starting new HTTP connection (1): 128.119.243.164
[2020-04-25 06:04:38,055] INFO in remote: http://128.119.243.164:35103/echo - status: {'status': 0, 'retry': 8}
```

3. The last experiment is to show that the system continues to run when a backend server crashes. We also show synchronization and consensus when a catalog server restarts from a crash. The test client makes 9 buys of a book number 1. A crash is induced in catalog server 1 in the middle of the buys. As the outputs below show, catalog 2 continues to process the buy requests as if there was no fault. Then catalog server 1 is restarted and catalog server 2 is killed. After the 9 buys, we restart catalog server 2. At this point, if the

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servers had been in sync during the time they were both alive, and if catalog server 2 correctly performs its function while catalog server 1 was down and vice versa, catalog server 2 should have a stock of 1 of the book on restarting and syncing back up with catalog server 1. For this simple experiment we only send buy requests direct to order server 1.

### Catalog Server 1: Note it is killed and restarted after 4 successful buys

```
elinux1 catalog) > ls
catalog_server.py  inventory.csv
elinux1 catalog) > python3 catalog_server.py 0
In except
[[{"id": "How to get a good grade in 677 in 20 minutes a day", 10, 30, 'DS'}, {"id": "RPCs for Dummies", 4, 40, 'DS'}, {"id": "Xen and the Art of Surviving Graduate School", 10, 75, 'GS'}, {"id": "Cooking for the Impatient Graduate Student", 5, 150, 'GS'}]]
* Serving Flask app "catalog_server" (lazy loading)
* Environment: production
  WARNING: This is a development server. Do not use it in a production deployment.
  Use a production WSGI server instead.
* Debug mode: off
* Running on http://128.119.243.147:35100/ (Press CTRL+C to quit)
128.119.243.147 - - [25/Apr/2020 01:53:37] "GET /sync HTTP/1.1" 200 -
128.119.243.147 - - [25/Apr/2020 01:53:37] "PUT /hold HTTP/1.1" 200 -
128.119.243.164 - - [25/Apr/2020 02:02:44] "GET /lookup/1 HTTP/1.1" 200 -
128.119.243.164 - - [25/Apr/2020 02:02:44] "PUT /update/1 HTTP/1.1" 200 -
128.119.243.147 - - [25/Apr/2020 02:02:44] "GET /sync HTTP/1.1" 200 -
128.119.243.147 - - [25/Apr/2020 02:02:44] "PUT /hold HTTP/1.1" 200 -
128.119.243.164 - - [25/Apr/2020 02:02:49] "GET /lookup/1 HTTP/1.1" 200 -
128.119.243.164 - - [25/Apr/2020 02:02:49] "PUT /update/1 HTTP/1.1" 200 -
128.119.243.147 - - [25/Apr/2020 02:02:49] "GET /sync HTTP/1.1" 200 -
128.119.243.147 - - [25/Apr/2020 02:02:49] "PUT /hold HTTP/1.1" 200 -
elinux1 catalog) > python3 catalog_server.py 0
[[{"id": "How to get a good grade in 677 in 20 minutes a day", 6, 30, 'DS'}, {"id": "RPCs for Dummies", 4, 40, 'DS'}, {"id": "Xen and the Art of Surviving Graduate School", 10, 75, 'GS'}, {"id": "Cooking for the Impatient Graduate Student", 5, 150, 'GS'}]]
* Serving Flask app "catalog_server" (lazy loading)
* Environment: production
  WARNING: This is a development server. Do not use it in a production deployment.
  Use a production WSGI server instead.
* Debug mode: off
* Running on http://128.119.243.147:35100/ (Press CTRL+C to quit)
128.119.243.164 - - [25/Apr/2020 02:03:05] "GET /order_sync HTTP/1.1" 200 -
128.119.243.164 - - [25/Apr/2020 02:03:10] "GET /order_sync HTTP/1.1" 200 -
128.119.243.164 - - [25/Apr/2020 02:03:15] "GET /lookup/1 HTTP/1.1" 200 -
128.119.243.164 - - [25/Apr/2020 02:03:15] "PUT /update/1 HTTP/1.1" 200 -
128.119.243.164 - - [25/Apr/2020 02:03:20] "GET /lookup/1 HTTP/1.1" 200 -
128.119.243.164 - - [25/Apr/2020 02:03:20] "PUT /update/1 HTTP/1.1" 200 -
128.119.243.164 - - [25/Apr/2020 02:03:25] "GET /lookup/1 HTTP/1.1" 200 -
128.119.243.164 - - [25/Apr/2020 02:03:25] "PUT /update/1 HTTP/1.1" 200 -
128.119.243.147 - - [25/Apr/2020 02:03:35] "GET /sync HTTP/1.1" 200 -
128.119.243.147 - - [25/Apr/2020 02:03:35] "PUT /hold HTTP/1.1" 200 -
```

### Catalog Server 2: Note how it is killed restarted after all the processes.

```
elinux1 catalog) > python3 catalog_server.py 1
[[{"id": "How to get a good grade in 677 in 20 minutes a day", 10, 30, 'DS'}, {"id": "RPCs for Dummies", 4, 40, 'DS'}, {"id": "Xen and the Art of Surviving Graduate School", 10, 75, 'GS'}, {"id": "Cooking for the Impatient Graduate Student", 5, 150, 'GS'}]]
* Serving Flask app "catalog_server" (lazy loading)
* Environment: production
  WARNING: This is a development server. Do not use it in a production deployment.
  Use a production WSGI server instead.
* Debug mode: off
* Running on http://128.119.243.147:35101/ (Press CTRL+C to quit)
128.119.243.164 - - [25/Apr/2020 02:02:44] "GET /order_sync HTTP/1.1" 200 -
128.119.243.164 - - [25/Apr/2020 02:02:49] "GET /order_sync HTTP/1.1" 200 -
128.119.243.164 - - [25/Apr/2020 02:02:54] "GET /lookup/1 HTTP/1.1" 200 -
128.119.243.164 - - [25/Apr/2020 02:02:54] "PUT /update/1 HTTP/1.1" 200 -
128.119.243.164 - - [25/Apr/2020 02:03:00] "GET /lookup/1 HTTP/1.1" 200 -
128.119.243.164 - - [25/Apr/2020 02:03:00] "PUT /update/1 HTTP/1.1" 200 -
128.119.243.147 - - [25/Apr/2020 02:03:04] "GET /sync HTTP/1.1" 200 -
128.119.243.147 - - [25/Apr/2020 02:03:04] "PUT /hold HTTP/1.1" 200 -
128.119.243.164 - - [25/Apr/2020 02:03:05] "GET /lookup/1 HTTP/1.1" 200 -
128.119.243.164 - - [25/Apr/2020 02:03:05] "PUT /update/1 HTTP/1.1" 200 -
128.119.243.147 - - [25/Apr/2020 02:03:10] "GET /sync HTTP/1.1" 200 -
128.119.243.147 - - [25/Apr/2020 02:03:10] "PUT /hold HTTP/1.1" 200 -
128.119.243.147 - - [25/Apr/2020 02:03:10] "GET /lookup/1 HTTP/1.1" 200 -
128.119.243.147 - - [25/Apr/2020 02:03:10] "PUT /hold HTTP/1.1" 200 -
elinux1 catalog) > python3 catalog_server.py 1
[[{"id": "How to get a good grade in 677 in 20 minutes a day", 1, 30, 'DS'}, {"id": "RPCs for Dummies", 4, 40, 'DS'}, {"id": "Xen and the Art of Surviving Graduate School", 10, 75, 'GS'}, {"id": "Cooking for the Impatient Graduate Student", 5, 150, 'GS'}]]
* Serving Flask app "catalog_server" (lazy loading)
* Environment: production
  WARNING: This is a development server. Do not use it in a production deployment.
  Use a production WSGI server instead.
* Debug mode: off
* Running on http://128.119.243.147:35101/ (Press CTRL+C to quit)
```

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Order Server 1: Order Server showing 9 GET requests. If you add the number of UPDATE requests in both catalog servers, you would see a total of 9.

```
eLinux2 order1> python3 order_server.py 0
* Serving Flask app "order_server" (lazy loading)
* Environment: production
  WARNING: This is a development server. Do not use it in a production deployment.
  Use a production WSGI server instead.
* Debug mode: off
* Running on http://128.119.243.164:35102/ (Press CTRL+C to quit)
128.119.243.168 - - [25/Apr/2020 02:02:59] "GET /buy/1 HTTP/1.1" 200 -
128.119.243.168 - - [25/Apr/2020 02:03:05] "GET /buy/1 HTTP/1.1" 200 -
128.119.243.168 - - [25/Apr/2020 02:03:10] "GET /buy/1 HTTP/1.1" 200 -
128.119.243.168 - - [25/Apr/2020 02:03:15] "GET /buy/1 HTTP/1.1" 200 -
128.119.243.168 - - [25/Apr/2020 02:03:20] "GET /buy/1 HTTP/1.1" 200 -
128.119.243.168 - - [25/Apr/2020 02:03:25] "GET /buy/1 HTTP/1.1" 200 -
128.119.243.168 - - [25/Apr/2020 02:03:30] "GET /buy/1 HTTP/1.1" 200 -
128.119.243.168 - - [25/Apr/2020 02:03:35] "GET /buy/1 HTTP/1.1" 200 -
128.119.243.168 - - [25/Apr/2020 02:03:40] "GET /buy/1 HTTP/1.1" 200 -
```

Test Client: Shows 9 successful buys despite crashing and restarting both servers.

```
eLinux3 src> python3 test.py
{'Item': 'How to get a good grade in 677 in 20 minutes a day', 'BuyStatus': 'Success'}
{'Item': 'How to get a good grade in 677 in 20 minutes a day', 'BuyStatus': 'Success'}
{'Item': 'How to get a good grade in 677 in 20 minutes a day', 'BuyStatus': 'Success'}
{'Item': 'How to get a good grade in 677 in 20 minutes a day', 'BuyStatus': 'Success'}
{'Item': 'How to get a good grade in 677 in 20 minutes a day', 'BuyStatus': 'Success'}
{'Item': 'How to get a good grade in 677 in 20 minutes a day', 'BuyStatus': 'Success'}
{'Item': 'How to get a good grade in 677 in 20 minutes a day', 'BuyStatus': 'Success'}
{'Item': 'How to get a good grade in 677 in 20 minutes a day', 'BuyStatus': 'Success'}
{'Item': 'How to get a good grade in 677 in 20 minutes a day', 'BuyStatus': 'Success'}
eLinux3 src>
```

4. A dockerized version of our system also runs on our local systems.

```
((base) Kameshs-MacBook-Pro:lab-3-lab-3-balasubramanian-chen kameshb$ cd src/
((base) Kameshs-MacBook-Pro:src kameshb$ ./deploy_docker.sh
=====
===== Initializing Containers =====
=====
a811bfd89c08f326db58e702268249675ba27e01d4fe9f75f4582492cb89ed15
b5a3915f1b3c1e5e5c8982795e08b293da6f1b74b4662601373157669784f8e2
2e09aa6308054d9bb87a1140f789c91917c3148b5808aab17ad900f525e78ab
4b6470b2d3b4297f47d0e812fb109dc685e9e2851d3144bfb3f0aaa6a019fb02
40a4f5758a445c7594b2bb14cebd5e0f977bf4e84989a04e74d7e454efe3d0fd
9ca616fe3ce127b3afc98af3a7b0bfbd4f46dbf2818b8ef74491f89b032cf9a
2cbe9a8074bcf8bab11d1f2fe73d7f675cb133a7205e7535fecbc86e05bb2d54
((base) Kameshs-MacBook-Pro:src kameshb$ docker ps
CONTAINER ID        IMAGE               COMMAND             CREATED             STATUS              PORTS              NAMES
2cbe9a8074bc        lab3_img:v1        "python client.py"  3 seconds ago       Up 3 seconds       8080-8081           competent_boyd
9ca616fe3ce1        lab3_img:v1        "python order/order..." 3 seconds ago       Up 3 seconds       8080-8081           great_tu
40a4f5758a44        lab3_img:v1        "python order/order..." 4 seconds ago       Up 3 seconds       8080-8081           magical_diffie
4b6470b2d3b4        lab3_img:v1        "python order/lock_s..." 4 seconds ago       Up 3 seconds       8080-8081           sleepy_babbage
2e09aa630805        lab3_img:v1        "python catalog/cata..." 4 seconds ago       Up 4 seconds       8080-8081           condescending_shamir
b5a3915f1b3c        lab3_img:v1        "python catalog/cata..." 4 seconds ago       Up 4 seconds       8080-8081           lucid_franklin
a811bfd89c08        lab3_img:v1        "python frontend/fro..." 4 seconds ago       Up 4 seconds       8080-8081           jovial_goldstine
((base) Kameshs-MacBook-Pro:src kameshb$
```

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## 5. Screenshots showing the entire system running end to end on edlab

### Client

```
Client 0 starts
Client 0 starts looking for item: 3
Client 1 starts
Client 1 starts searching topic: DS
Client 2 starts
Client 2 starts looking for item: 4
Client 3 starts
Client 3 starts looking for item: 2
Client 4 starts
Client 4 starts searching topic: GS
Client 0 lookup request success! Time: 0.058664
Client 1 search request success! Time: 0.063937
Client 3 lookup request success! Time: 0.063258
Client 2 lookup request success! Time: 0.066734
Client 4 search request success! Time: 0.063090
Client 0 starts searching topic: GS
Client 1 starts looking for item: 3
Client 0 search request success! Time: 0.008345
Client 0 is going to buy item number: 4
Client 2 starts searching topic: GS
Client 4 is going to buy item number: 1
Client 1 lookup request success! Time: 0.008753
Client 2 search request success! Time: 0.017740
Client 3 buy request success! Time: 0.075740
Client 4 buy request success! Time: 0.118018
Client 0 starts searching topic: GS
Client 1 is going to buy item number: 1
Client 0 search request success! Time: 0.017628
Client 2 is going to buy item number: 3
Client 3 is going to buy item number: 1
Client 1 buy request success! Time: 0.066921
Client 2 buy request success! Time: 0.105447
Client 4 starts looking for item: 2
Client 4 lookup request success! Time: 0.006768
Client 3 buy request success! Time: 0.093251
Client 0 starts searching topic: GS
Client 0 search request success! Time: 0.016245
Client 1 is going to buy item number: 2
Client 2 starts searching topic: DS
Client 4 is going to buy item number: 1
Client 1 buy request success! Time: 0.068204
Client 2 search request success! Time: 0.020885
Client 3 starts looking for item: 3
Client 3 lookup request success! Time: 0.020573
Client 4 buy request success! Time: 0.066981
Client 0 is going to buy item number: 2
Client 0 buy request success! Time: 0.064314
Client 1 starts searching topic: GS
Client 2 starts searching topic: DS
Client 1 search request success! Time: 0.010401
Client 2 search request success! Time: 0.021230
Client 3 starts searching topic: GS
Client 3 search request success! Time: 0.006342
Client 4 starts looking for item: 3
Client 4 lookup request success! Time: 0.006692
Client 0 is going to buy item number: 2
Client 1 starts looking for item: 2
Client 0 buy request success! Time: 0.065950
Client 2 is going to buy item number: 2
Client 1 lookup request success! Time: 0.018470
Client 3 starts searching topic: GS
Client 4 starts looking for item: 3
Client 3 search request success! Time: 0.009637
Client 4 lookup request success! Time: 0.007792
Client 2 buy request success! Time: 0.069124
Client 0 starts searching topic: DS
Client 1 starts looking for item: 1
```



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```
2020-04-27 18:30:30.145 INFO in remote: http://128.119.243.147:35151/echo - status: {'status': 1, 'retry': 0}
2020-04-27 18:30:33.008 INFO in connectionpool: Starting new HTTP connection (1): 128.119.243.147
2020-04-27 18:30:33.011 INFO in connectionpool: Starting new HTTP connection (1): 128.119.243.147
2020-04-27 18:30:33.013 INFO in connectionpool: Starting new HTTP connection (1): 128.119.243.147
2020-04-27 18:30:33.021 INFO in connectionpool: Starting new HTTP connection (1): 128.119.243.147
2020-04-27 18:30:33.018 INFO in connectionpool: Starting new HTTP connection (1): 128.119.243.147
2020-04-27 18:30:33.022 INFO in frontend: [Cache] Set cache: {'stock': 10, 'cost': 75, 'book_name': 'Xen and the Art of Surviving Graduate School'}
2020-04-27 18:30:33.023 INFO in frontend: Success, 0.032654
2020-04-27 18:30:33.024 INFO in internal: 128.119.243.168 - - [27/Apr/2020 18:30:33] "GET /search?lookupNum=3 HTTP/1.1" 200 -
2020-04-27 18:30:33.026 INFO in frontend: [Cache] Set cache: {'books': [{'item_no': 1, 'stock': 10, 'cost': 30, 'topic': 'DS', 'book_name': 'How to get a good grade in 677 in 20 minutes a day'}, {'item_no': 2, 'stock': 4, 'cost': 40, 'topic': 'DS', 'book_name': 'RPCs for Dummies'}]}
2020-04-27 18:30:33.027 INFO in frontend: [Cache] Set cache: {'stock': 4, 'cost': 40, 'book_name': 'RPCs for Dummies'}
2020-04-27 18:30:33.030 INFO in frontend: [Cache] Set cache: {'stock': 5, 'cost': 150, 'book_name': 'Cooking for the Impatient Graduate Student'}
2020-04-27 18:30:33.030 INFO in frontend: Success, 0.037705
2020-04-27 18:30:33.031 INFO in internal: 128.119.243.168 - - [27/Apr/2020 18:30:33] "GET /search?topic=DS HTTP/1.1" 200 -
2020-04-27 18:30:33.031 INFO in frontend: Success, 0.038185
2020-04-27 18:30:33.032 INFO in frontend: [Cache] Set cache: {'books': [{'item_no': 3, 'stock': 10, 'cost': 75, 'topic': 'GS', 'book_name': 'Xen and the Art of Surviving Graduate School'}, {'item_no': 4, 'stock': 5, 'cost': 150, 'topic': 'GS', 'book_name': 'Cooking for the Impatient Graduate Student'}]}
2020-04-27 18:30:33.033 INFO in internal: 128.119.243.168 - - [27/Apr/2020 18:30:33] "GET /search?lookupNum=2 HTTP/1.1" 200 -
2020-04-27 18:30:33.032 INFO in frontend: Success, 0.040556
2020-04-27 18:30:33.035 INFO in internal: 128.119.243.168 - - [27/Apr/2020 18:30:33] "GET /search?lookupNum=4 HTTP/1.1" 200 -
2020-04-27 18:30:33.034 INFO in frontend: Success, 0.03869
2020-04-27 18:30:33.036 INFO in internal: 128.119.243.168 - - [27/Apr/2020 18:30:33] "GET /search?topic=GS HTTP/1.1" 200 -
2020-04-27 18:30:33.150 INFO in connectionpool: Starting new HTTP connection (1): 128.119.243.164
2020-04-27 18:30:33.155 INFO in remote: http://128.119.243.164:35152/echo - status: {'status': 1, 'retry': 0}
2020-04-27 18:30:33.157 INFO in connectionpool: Starting new HTTP connection (1): 128.119.243.164
2020-04-27 18:30:33.161 INFO in remote: http://128.119.243.164:35153/echo - status: {'status': 1, 'retry': 0}
2020-04-27 18:30:33.163 INFO in connectionpool: Starting new HTTP connection (1): 128.119.243.147
2020-04-27 18:30:33.166 INFO in remote: http://128.119.243.147:35150/echo - status: {'status': 1, 'retry': 0}
2020-04-27 18:30:33.168 INFO in connectionpool: Starting new HTTP connection (1): 128.119.243.147
2020-04-27 18:30:33.172 INFO in remote: http://128.119.243.147:35151/echo - status: {'status': 1, 'retry': 0}
2020-04-27 18:30:35.035 INFO in frontend: [Cache] Return cached value: {'books': [{'item_no': 3, 'stock': 10, 'cost': 75, 'topic': 'GS', 'book_name': 'Xen and the Art of Surviving Graduate School'}, {'item_no': 4, 'stock': 5, 'cost': 150, 'topic': 'GS', 'book_name': 'Cooking for the Impatient Graduate Student'}]}
2020-04-27 18:30:35.036 INFO in frontend: Success, 0.001668
2020-04-27 18:30:35.036 INFO in internal: 128.119.243.168 - - [27/Apr/2020 18:30:35] "GET /search?topic=GS HTTP/1.1" 200 -
2020-04-27 18:30:35.042 INFO in frontend: [Cache] Return cached value: {'stock': 10, 'cost': 75, 'book_name': 'Xen and the Art of Surviving Graduate School'}
2020-04-27 18:30:35.042 INFO in frontend: Success, 0.001605
2020-04-27 18:30:35.043 INFO in internal: 128.119.243.168 - - [27/Apr/2020 18:30:35] "GET /search?lookupNum=3 HTTP/1.1" 200 -
2020-04-27 18:30:35.050 INFO in connectionpool: Starting new HTTP connection (1): 128.119.243.164
2020-04-27 18:30:35.056 INFO in connectionpool: Starting new HTTP connection (1): 128.119.243.164
2020-04-27 18:30:35.056 INFO in frontend: [Cache] Return cached value: {'books': [{'item_no': 3, 'stock': 10, 'cost': 75, 'topic': 'GS', 'book_name': 'Xen and the Art of Surviving Graduate School'}, {'item_no': 4, 'stock': 5, 'cost': 150, 'topic': 'GS', 'book_name': 'Cooking for the Impatient Graduate Student'}]}
2020-04-27 18:30:35.057 INFO in frontend: Success, 0.004063
2020-04-27 18:30:35.057 INFO in internal: 128.119.243.168 - - [27/Apr/2020 18:30:35] "GET /search?topic=GS HTTP/1.1" 200 -
2020-04-27 18:30:35.061 INFO in frontend: [Cache]----- Remove ('lookupNum', '4')
2020-04-27 18:30:35.083 INFO in frontend: [Cache]----- Remove ('topic', 'GS')
2020-04-27 18:30:35.083 INFO in internal: 128.119.243.147 - - [27/Apr/2020 18:30:35] "PUT /invalidate?item_num=4&topic=GS HTTP/1.1" 200 -
2020-04-27 18:30:35.114 INFO in frontend: Success, 0.007895
2020-04-27 18:30:35.114 INFO in internal: 128.119.243.168 - - [27/Apr/2020 18:30:35] "POST /buy?buyNum=4 HTTP/1.1" 200 -
2020-04-27 18:30:35.132 INFO in frontend: [Cache]----- Remove ('lookupNum', '1')
2020-04-27 18:30:35.132 INFO in frontend: [Cache]----- Remove ('topic', 'DS')
2020-04-27 18:30:35.133 INFO in internal: 128.119.243.147 - - [27/Apr/2020 18:30:35] "PUT /invalidate?item_num=1&topic=DS HTTP/1.1" 200 -
2020-04-27 18:30:35.162 INFO in frontend: Success, 0.110344
2020-04-27 18:30:35.162 INFO in internal: 128.119.243.168 - - [27/Apr/2020 18:30:35] "POST /buy?buyNum=1 HTTP/1.1" 200 -
2020-04-27 18:30:36.177 INFO in connectionpool: Starting new HTTP connection (1): 128.119.243.164
2020-04-27 18:30:36.181 INFO in remote: http://128.119.243.164:35152/echo - status: {'status': 1, 'retry': 0}
2020-04-27 18:30:36.183 INFO in connectionpool: Starting new HTTP connection (1): 128.119.243.164
2020-04-27 18:30:36.183 INFO in remote: http://128.119.243.164:35153/echo - status: {'status': 1, 'retry': 0}
2020-04-27 18:30:36.188 INFO in connectionpool: Starting new HTTP connection (1): 128.119.243.147
2020-04-27 18:30:36.192 INFO in remote: http://128.119.243.147:35150/echo - status: {'status': 1, 'retry': 0}
2020-04-27 18:30:36.194 INFO in connectionpool: Starting new HTTP connection (1): 128.119.243.147
2020-04-27 18:30:36.198 INFO in remote: http://128.119.243.147:35151/echo - status: {'status': 1, 'retry': 0}
2020-04-27 18:30:37.058 INFO in frontend: [Cache] Set cache: {'books': [{'item_no': 3, 'stock': 10, 'cost': 75, 'topic': 'GS', 'book_name': 'Xen and the Art of Surviving Graduate School'}, {'item_no': 4, 'stock': 4, 'cost': 150, 'topic': 'GS', 'book_name': 'Cooking for the Impatient Graduate Student'}]}
2020-04-27 18:30:37.058 INFO in frontend: Success, 0.012321
2020-04-27 18:30:37.059 INFO in internal: 128.119.243.168 - - [27/Apr/2020 18:30:37] "GET /search?topic=GS HTTP/1.1" 200 -
```

## FrontEnd.

## Catalog Server 1

```
128.119.243.164 - - [27/Apr/2020 18:30:37] "PUT /update/3 HTTP/1.1" 200 -
128.119.243.147 - - [27/Apr/2020 18:30:37] "GET /sync HTTP/1.1" 200 -
128.119.243.147 - - [27/Apr/2020 18:30:37] "PUT /hold HTTP/1.1" 200 -
128.119.243.164 - - [27/Apr/2020 18:30:37] "GET /lookup/1 HTTP/1.1" 200 -
128.119.243.164 - - [27/Apr/2020 18:30:37] "PUT /update/1 HTTP/1.1" 200 -
128.119.243.147 - - [27/Apr/2020 18:30:37] "GET /sync HTTP/1.1" 200 -
128.119.243.147 - - [27/Apr/2020 18:30:37] "PUT /hold HTTP/1.1" 200 -
128.119.243.175 - - [27/Apr/2020 18:30:39] "GET /search/GS HTTP/1.1" 200 -
128.119.243.164 - - [27/Apr/2020 18:30:39] "GET /lookup/2 HTTP/1.1" 200 -
128.119.243.164 - - [27/Apr/2020 18:30:39] "PUT /update/2 HTTP/1.1" 200 -
128.119.243.147 - - [27/Apr/2020 18:30:39] "GET /sync HTTP/1.1" 200 -
128.119.243.147 - - [27/Apr/2020 18:30:39] "PUT /hold HTTP/1.1" 200 -
128.119.243.164 - - [27/Apr/2020 18:30:39] "GET /lookup/1 HTTP/1.1" 200 -
128.119.243.175 - - [27/Apr/2020 18:30:39] "GET /echo HTTP/1.1" 200 -
128.119.243.164 - - [27/Apr/2020 18:30:39] "PUT /update/1 HTTP/1.1" 200 -
128.119.243.147 - - [27/Apr/2020 18:30:39] "GET /sync HTTP/1.1" 200 -
128.119.243.147 - - [27/Apr/2020 18:30:39] "PUT /hold HTTP/1.1" 200 -
128.119.243.175 - - [27/Apr/2020 18:30:39] "GET /lookup/3 HTTP/1.1" 200 -
128.119.243.164 - - [27/Apr/2020 18:30:41] "GET /lookup/2 HTTP/1.1" 200 -
128.119.243.164 - - [27/Apr/2020 18:30:41] "PUT /update/2 HTTP/1.1" 200 -
128.119.243.147 - - [27/Apr/2020 18:30:41] "GET /sync HTTP/1.1" 200 -
128.119.243.147 - - [27/Apr/2020 18:30:41] "PUT /hold HTTP/1.1" 200 -
128.119.243.175 - - [27/Apr/2020 18:30:42] "GET /echo HTTP/1.1" 200 -
128.119.243.164 - - [27/Apr/2020 18:30:43] "GET /lookup/2 HTTP/1.1" 200 -
128.119.243.164 - - [27/Apr/2020 18:30:43] "PUT /update/2 HTTP/1.1" 200 -
128.119.243.147 - - [27/Apr/2020 18:30:43] "GET /sync HTTP/1.1" 200 -
128.119.243.147 - - [27/Apr/2020 18:30:43] "PUT /hold HTTP/1.1" 200 -
128.119.243.175 - - [27/Apr/2020 18:30:43] "GET /lookup/3 HTTP/1.1" 200 -
128.119.243.164 - - [27/Apr/2020 18:30:43] "GET /lookup/2 HTTP/1.1" 200 -
128.119.243.164 - - [27/Apr/2020 18:30:43] "PUT /update/2 HTTP/1.1" 200 -
128.119.243.147 - - [27/Apr/2020 18:30:43] "GET /sync HTTP/1.1" 200 -
128.119.243.147 - - [27/Apr/2020 18:30:43] "PUT /hold HTTP/1.1" 200 -
128.119.243.175 - - [27/Apr/2020 18:30:45] "GET /echo HTTP/1.1" 200 -
128.119.243.175 - - [27/Apr/2020 18:30:47] "GET /lookup/2 HTTP/1.1" 200 -
128.119.243.164 - - [27/Apr/2020 18:30:47] "GET /lookup/2 HTTP/1.1" 200 -
128.119.243.164 - - [27/Apr/2020 18:30:47] "GET /lookup/4 HTTP/1.1" 200 -
128.119.243.164 - - [27/Apr/2020 18:30:47] "PUT /update/4 HTTP/1.1" 200 -
128.119.243.147 - - [27/Apr/2020 18:30:47] "GET /sync HTTP/1.1" 200 -
128.119.243.147 - - [27/Apr/2020 18:30:47] "PUT /hold HTTP/1.1" 200 -
128.119.243.175 - - [27/Apr/2020 18:30:47] "GET /lookup/3 HTTP/1.1" 200 -
128.119.243.164 - - [27/Apr/2020 18:30:47] "GET /lookup/2 HTTP/1.1" 200 -
128.119.243.164 - - [27/Apr/2020 18:30:47] "PUT /update/2 HTTP/1.1" 200 -
128.119.243.147 - - [27/Apr/2020 18:30:47] "GET /sync HTTP/1.1" 200 -
128.119.243.147 - - [27/Apr/2020 18:30:47] "PUT /hold HTTP/1.1" 200 -
128.119.243.175 - - [27/Apr/2020 18:30:48] "GET /echo HTTP/1.1" 200 -
128.119.243.164 - - [27/Apr/2020 18:30:49] "GET /lookup/3 HTTP/1.1" 200 -
128.119.243.164 - - [27/Apr/2020 18:30:49] "PUT /update/1 HTTP/1.1" 200 -
128.119.243.147 - - [27/Apr/2020 18:30:49] "GET /sync HTTP/1.1" 200 -
128.119.243.147 - - [27/Apr/2020 18:30:49] "PUT /hold HTTP/1.1" 200 -
128.119.243.175 - - [27/Apr/2020 18:30:49] "GET /lookup/3 HTTP/1.1" 200 -
128.119.243.164 - - [27/Apr/2020 18:30:49] "PUT /update/3 HTTP/1.1" 200 -
128.119.243.147 - - [27/Apr/2020 18:30:49] "GET /sync HTTP/1.1" 200 -
128.119.243.147 - - [27/Apr/2020 18:30:49] "PUT /hold HTTP/1.1" 200 -
128.119.243.175 - - [27/Apr/2020 18:30:49] "GET /lookup/4 HTTP/1.1" 200 -
128.119.243.147 - - [27/Apr/2020 18:30:49] "GET /sync HTTP/1.1" 200 -
128.119.243.147 - - [27/Apr/2020 18:30:51] "GET /echo HTTP/1.1" 200 -
128.119.243.175 - - [27/Apr/2020 18:30:51] "GET /search/GS HTTP/1.1" 200 -
```



## Performance Statistics and Experiments

[illegible][illegible]

## Catalog Server 2

## Order Server 1

128.119.243.175	[27/Apr/2020 18:31:27]	"GET /buy/4 HTTP/1.1"	500
128.119.243.175	[27/Apr/2020 18:31:28]	"GET /echo HTTP/1.1"	200
128.119.243.175	[27/Apr/2020 18:31:31]	"GET /echo HTTP/1.1"	200
128.119.243.175	[27/Apr/2020 18:31:34]	"GET /echo HTTP/1.1"	200
128.119.243.175	[27/Apr/2020 18:31:37]	"GET /echo HTTP/1.1"	200
128.119.243.175	[27/Apr/2020 18:31:40]	"GET /echo HTTP/1.1"	200
128.119.243.175	[27/Apr/2020 18:31:43]	"GET /echo HTTP/1.1"	200
128.119.243.175	[27/Apr/2020 18:31:46]	"GET /echo HTTP/1.1"	200
128.119.243.175	[27/Apr/2020 18:31:49]	"GET /echo HTTP/1.1"	200
128.119.243.175	[27/Apr/2020 18:31:52]	"GET /echo HTTP/1.1"	200
128.119.243.175	[27/Apr/2020 18:31:55]	"GET /echo HTTP/1.1"	200
128.119.243.175	[27/Apr/2020 18:31:58]	"GET /echo HTTP/1.1"	200
128.119.243.175	[27/Apr/2020 18:32:01]	"GET /echo HTTP/1.1"	200
128.119.243.175	[27/Apr/2020 18:32:04]	"GET /echo HTTP/1.1"	200
128.119.243.175	[27/Apr/2020 18:32:07]	"GET /echo HTTP/1.1"	200
128.119.243.175	[27/Apr/2020 18:32:10]	"GET /echo HTTP/1.1"	200
128.119.243.175	[27/Apr/2020 18:32:13]	"GET /echo HTTP/1.1"	200
128.119.243.175	[27/Apr/2020 18:32:16]	"GET /echo HTTP/1.1"	200
128.119.243.175	[27/Apr/2020 18:32:19]	"GET /echo HTTP/1.1"	200
128.119.243.175	[27/Apr/2020 18:32:22]	"GET /echo HTTP/1.1"	200
128.119.243.175	[27/Apr/2020 18:32:25]	"GET /echo HTTP/1.1"	200
128.119.243.175	[27/Apr/2020 18:32:28]	"GET /echo HTTP/1.1"	200
128.119.243.175	[27/Apr/2020 18:32:31]	"GET /echo HTTP/1.1"	200
128.119.243.175	[27/Apr/2020 18:32:34]	"GET /echo HTTP/1.1"	200
128.119.243.175	[27/Apr/2020 18:32:37]	"GET /echo HTTP/1.1"	200
128.119.243.175	[27/Apr/2020 18:32:40]	"GET /echo HTTP/1.1"	200
128.119.243.175	[27/Apr/2020 18:32:43]	"GET /echo HTTP/1.1"	200
128.119.243.175	[27/Apr/2020 18:32:46]	"GET /echo HTTP/1.1"	200
128.119.243.175	[27/Apr/2020 18:32:49]	"GET /echo HTTP/1.1"	200
128.119.243.175	[27/Apr/2020 18:32:52]	"GET /echo HTTP/1.1"	200
128.119.243.175	[27/Apr/2020 18:32:55]	"GET /echo HTTP/1.1"	200
128.119.243.175	[27/Apr/2020 18:32:58]	"GET /echo HTTP/1.1"	200

[illegible]