G24AI2008

Fundamentals of Distributed Systems

1. Vector Clocks and Causal Ordering

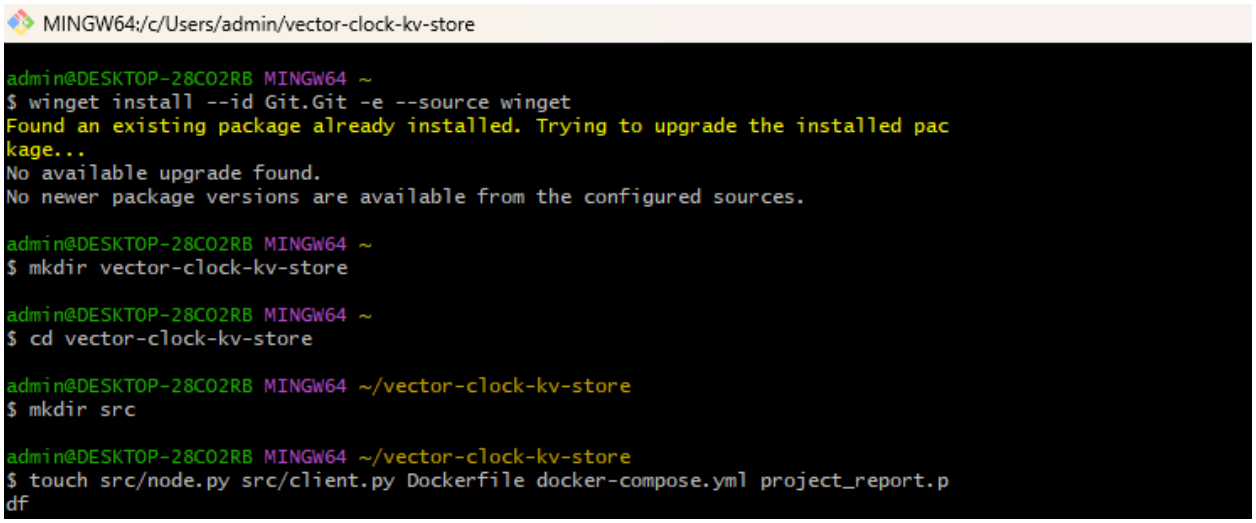
This project simulates a real-world scenario where operations across nodes must respect causal relationships. The system includes multiple Python-based nodes. Each node maintains a local key-value store and a vector clock.

On every local write, the node increments its own clock. When sending messages, it includes this clock. When a node receives a message, it checks if the causal dependencies are met using vector clock comparison. If dependencies are satisfied, the message is applied immediately. If not, the message is buffered. This mechanism prevents issues where an update is applied before the data it depends on is available.

For example, if Node A writes a value and Node B reads and modifies it, all nodes must apply A's write before B's update.

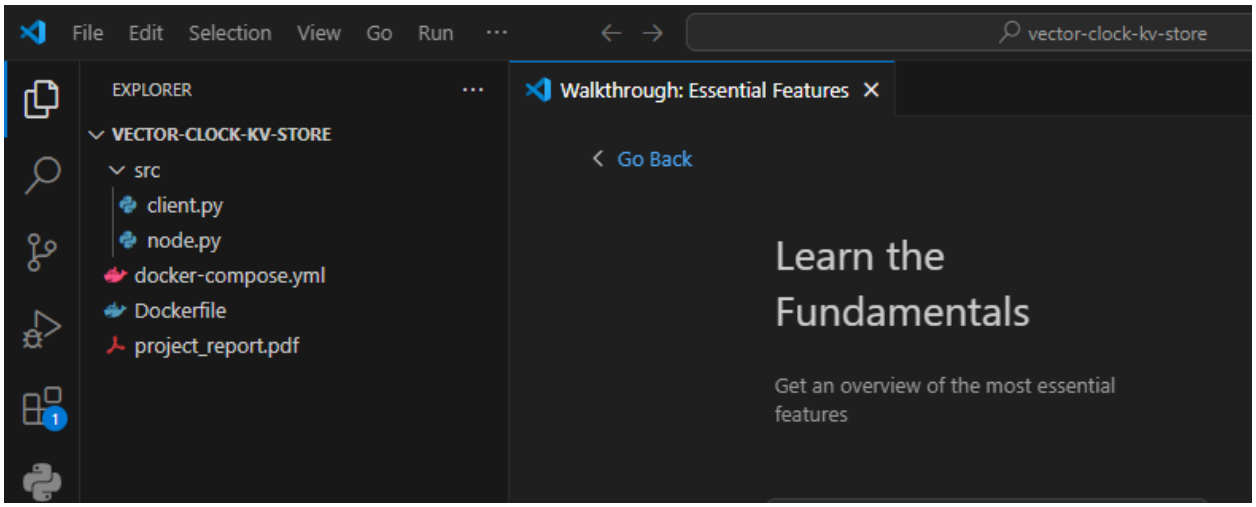
I containerized the system using Dockers, with a docker-compose.yml to simulate a 3-node environment. A client script simulates realistic scenarios, like a read followed by a write depending on it. The logs show that updates only occur when causal order is preserved, even if network messages arrive out of order. This verifies that vector clocks are functioning as intended and causal consistency is maintained. This project deepened my understanding of logical time, causality, and how buffering helps preserve consistency in distributed systems. All code and tests are organized in the required folder structure.

Folder structure creation in GIT Bash:

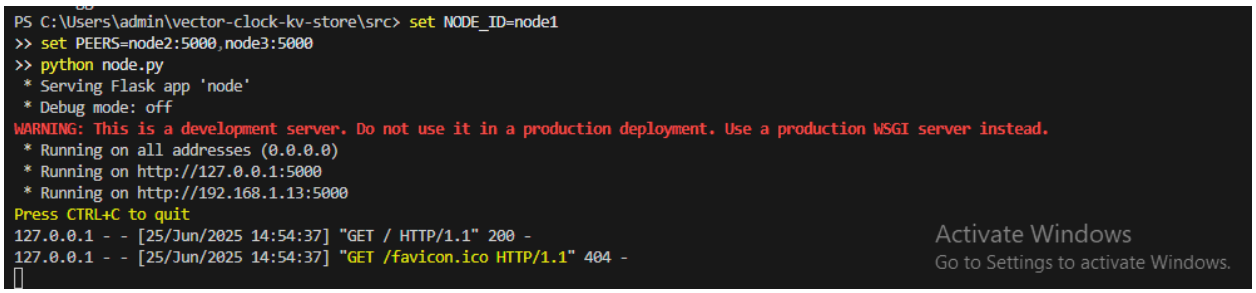


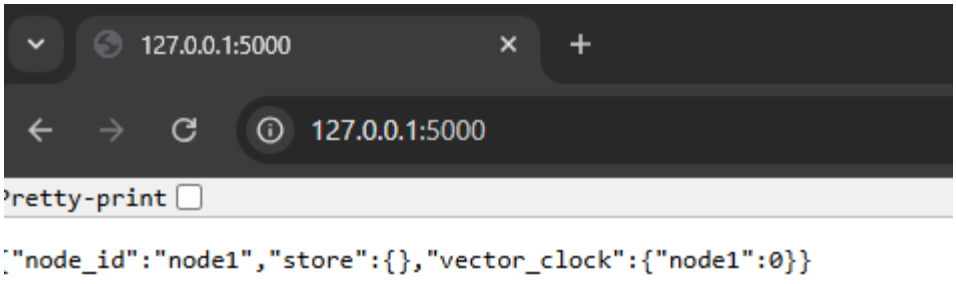
```
admin@DESKTOP-28CO2RB MINGW64 ~/vector-clock-kv-store
$ ls -R
.:
Dockerfile  docker-compose.yml  project_report.pdf  src/

./src:
client.py  node.py
```

Folder Structure in Visual Studio Code:



1. Node Implementation with Vector Clocks:





2. Vector Clock Logic:

```
PS C:\Users\admin\vector-clock-kv-store\src> Invoke-RestMethod -Uri http://localhost:5000/write -Method POST -ContentType "appl
ication/json" -Body '{"key":"foo","value":"bar"}'
>>

status  store      vector_clock
------  -----      ------------
success @{foo=bar} @{node1=1}


PS C:\Users\admin\vector-clock-kv-store\src>
```


3. Causal Write Propagation:

```
PS C:\Users\admin\vector-clock-kv-store\src> Invoke-RestMethod -Uri http://localhost:5000/write -Method POST -ContentType "appl
ication/json" -Body '{"key":"x","value":"1"}'
>>

status              store  vector_clock
------              -----  ------------
local_write_success @{x=1} @{node1=1}


PS C:\Users\admin\vector-clock-kv-store\src>
```


4. Containerization and Networking:

```
PS C:\Users\admin\vector-clock-kv-store> docker-compose up
time="2025-06-25T15:33:52+05:30" level=warning msg="C:\\Users\\admin\\vector-clock-kv-store\\docker-compose.yml: the attribute
`version` is obsolete, it will be ignored, please remove it to avoid potential confusion"
[+] Running 4/4
 ✓ Network vector-clock-kv-store_default    Created                                                    0.1s
 ✓ Container vector-clock-kv-store-node3-1  Created                                                    0.3s
 ✓ Container vector-clock-kv-store-node2-1  Created                                                    0.3s
 ✓ Container vector-clock-kv-store-node1-1  Created                                                    0.3s
Attaching to node1-1, node2-1, node3-1
node1-1  |  * Serving Flask app 'node'
```



```
status    store  vector_clock
------    -----  ------------
delivered @{k=A} @{node1=1; node2=0; node3=0}
```

5. Verification and Scenario Testing:

```
RawContent        : HTTP/1.1 200 OK
                    Connection: close
                    Content-Length: 99
                    Content-Type: application/json
                    Date: Wed, 25 Jun 2025 10:09:38 GMT
                    Server: Werkzeug/3.1.3 Python/3.10.18

                    {"buffered":[],"node_id":"node1","...
Forms             : {}
Headers           : {[Connection, close], [Content-Length, 99], [Content-Type, application/json], [Date,
```

```
admin@DESKTOP-28CO2RB MINGW64 ~/vector-clock-kv-store (master)
$ git commit -m "First Commit"
[master (root-commit) 6ed7cfa] First Commit
 4 files changed, 44 insertions(+)
 create mode 100644 Dockerfile
 create mode 100644 docker-compose.yml
 create mode 100644 project_report.pdf
 create mode 160000 src
```