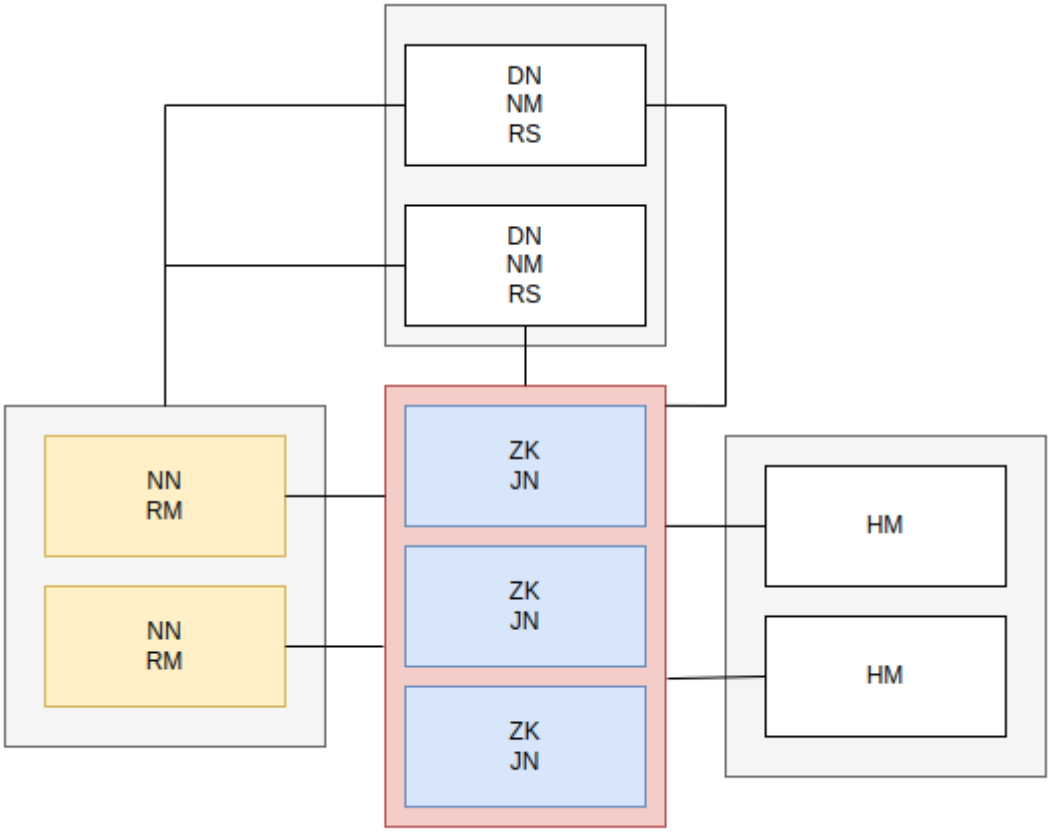
Hbase documentation



HBase Cluster Architecture and Integration:

1. HBase Layer in Dockerfile

Multi-stage Build Structure

- The **`hbase` stage** in the Dockerfile builds on top of the `hadoop-node` stage.
- It installs and configures HBase 2.4.9:
    - Downloads the HBase tarball and extracts it into `/usr/local/hbase`.
    - Copies your `hbase-site.xml` configuration file into the container.
    - Copies Hadoop common libraries to HBase's `lib` folder to ensure compatibility.

    - Sets environment variables (`HBASE_HOME`, updates `PATH`) for easy execution of HBase commands.
    - Runs the container as the non-root user `hadoop` for better security and consistency.

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2. HBase Setup in Docker Compose

- Multiple containers are defined for HBase **masters** (`hm1`, `hm2`) and **region servers** (`s1`, `s2`).
- These depend on:
    - **Hadoop namenodes** (`m1`, `m2`) to be healthy — since HBase stores data in HDFS.
    - A **ZooKeeper ensemble** (`zk1`, `zk2`, `zk3`) for coordination and leader election.
- Containers share volumes to persist data and logs.
- Containers are all connected on the custom Docker network `hnet` for service discovery by hostname.
- Healthchecks ensure dependent services are ready before starting HBase nodes.
- Exposed ports allow external access to HBase master UI, RPC, and ZooKeeper client.

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3. HBase Startup Process Explained (from `entrypoint.sh`)

SSH Setup

- Starts SSH service for intra-cluster communication.
- Adds all cluster node hostnames (`m1`, `m2`, `zk1`… `s2`) to SSH known_hosts to allow passwordless SSH between containers.

ZooKeeper Nodes (`zk*`)

- Dynamically assigns ZooKeeper node ID (`myid`) based on hostname number suffix.
- Starts ZooKeeper server.
- Starts Hadoop JournalNode daemon used for HDFS HA.

Hadoop Master Nodes (`m*`)

- For `m1` **(active namenode)**:
    - Formats the HDFS namenode if not initialized.
    - Starts HDFS namenode, ZK Failover Controller (zkfc), and YARN ResourceManager daemons.
- For `m2` **(standby namenode)**:
    - Bootstraps standby namenode if not initialized.
    - Starts namenode, zkfc, and ResourceManager.

HBase Master Nodes (`hm*`)

- Checks if HBase root directory exists in HDFS, creates it if missing.
- Starts the HBase Master daemon in the background.

HBase Region Server Nodes (`s*`)

- Starts Hadoop DataNode and YARN NodeManager daemons.
- Starts the HBase RegionServer daemon.

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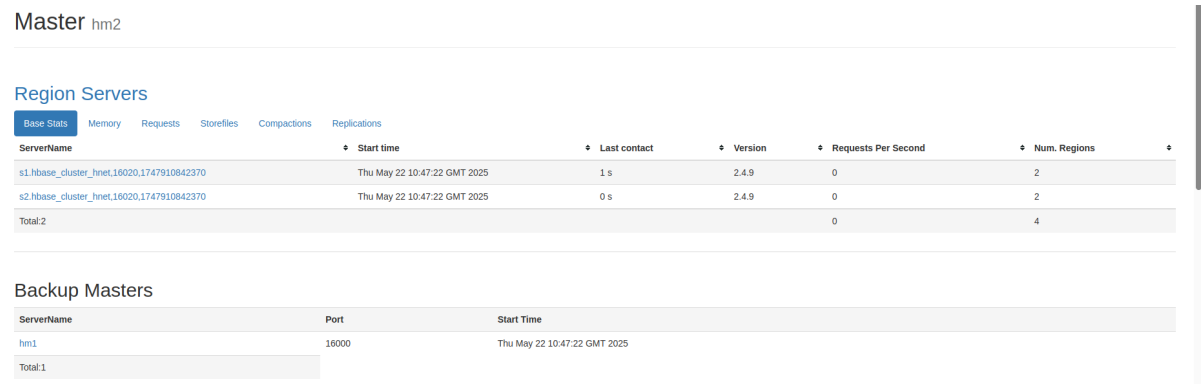
4. Key Points About This Setup

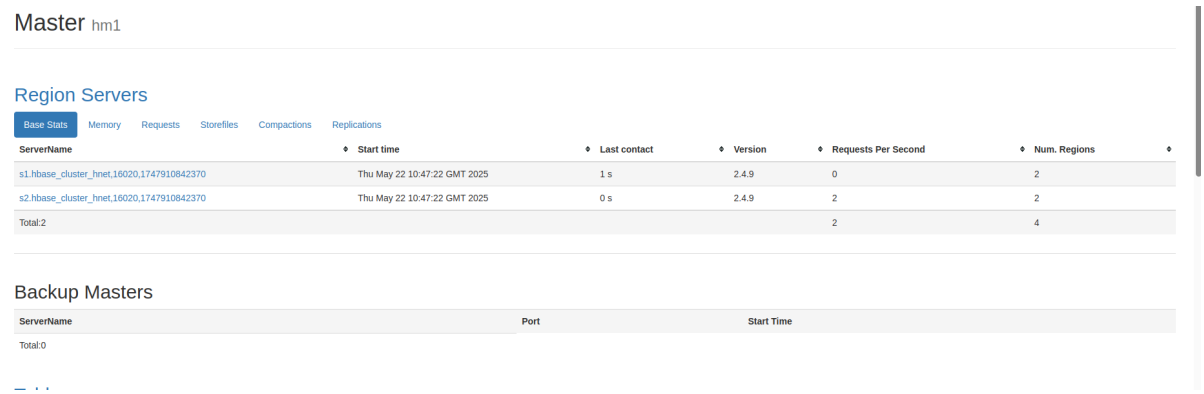
- **Multi-node coordination**: ZooKeeper provides coordination for HBase and Hadoop HA.

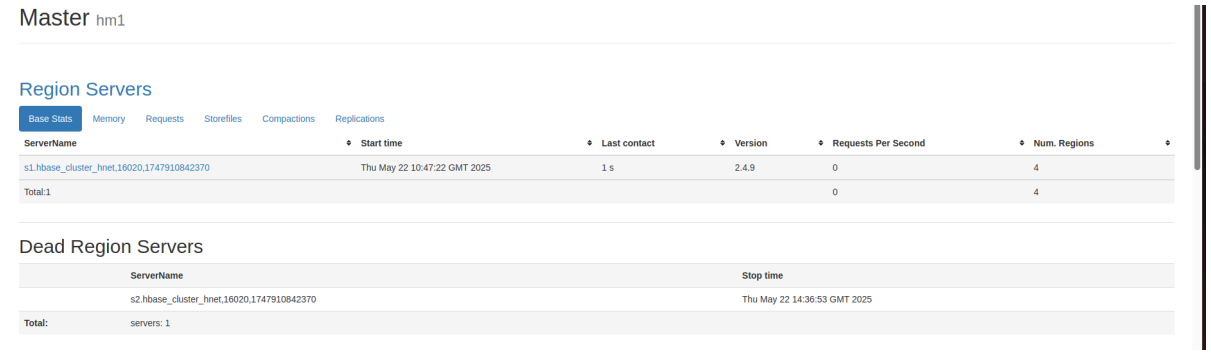
- **HDFS is underlying storage** for HBase data; thus, HDFS services must be running first.
- **Service readiness**: Health checks and dependencies ensure containers start in the correct order.
- **SSH between nodes**: Facilitates cluster operations and possibly command execution within nodes.
- **Persistence**: Docker volumes maintain data and logs across container restarts.
- **Port mapping**: Enables access to key services (HBase Master UI, HDFS Namenode UI, ZooKeeper client port).

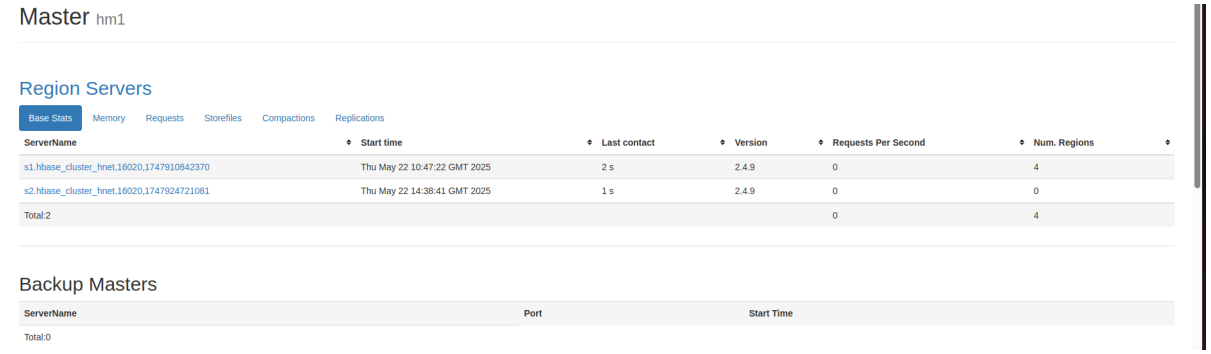
Failover testing :



After killing hm2







WebTable Use Case Implementation:

Task 1.1: HBase Table Design and Implementation

The HBase table, named **`webpages`**, was designed with four distinct column families to efficiently store different types of web page data. Each column family has tailored versioning and TTL (time-to-live) settings to balance data retention, historical tracking, and storage optimization:

- **Content family (`content`):**
    - Stores the HTML content of web pages under the column `content:html`.

    - Configured to keep up to **3 versions** to support tracking of content changes over time.
    - A TTL of **90 days** (7,776,000 seconds) ensures automatic expiry of outdated content to optimize storage.

- **Metadata family (`metadata`):**
    - Stores static page metadata including title, author, and crawl date in columns such as `metadata:title`, `metadata:author`, and `metadata:crawl_date`.
    - Configured to retain only the **latest version** (1 version), reflecting that metadata changes are less frequent and historical versions are not needed.
    - No TTL is set to preserve metadata indefinitely for auditing and analysis.
- **Outlinks family (`outlinks`):**
    - Captures outbound links from each page under `outlinks:out_links`.
    - Configured with **2 versions** to allow tracking of link structure changes.
    - TTL of **180 days** (15,552,000 seconds) is set to expire stale link data.
- **Inlinks family (`inlinks`):**
    - Stores inbound links to each page under `inlinks:in_links`.
    - Shares the same versioning and TTL policy as the outlinks family.

These column family configurations enable efficient data lifecycle management, balancing the need to preserve useful historical data while controlling storage costs through TTL expiry.

Task 1.2: Data Generation and Insertion

To simulate a realistic dataset reflecting diverse web content and link structures, a Python script was developed to generate and insert at least **20 sample web pages** with the following characteristics:

- **Multiple Domains:**
  The dataset includes pages from **five distinct domains** (`example.com`,

`test.org`, `sample.net`, `demo.io`, and `mysite.edu`) to represent a variety of sources.

- **Varied Content Sizes:**
  Pages contain HTML content of varying sizes—classified as small, medium, or large—using randomly generated paragraphs. This variation tests system handling of diverse content volumes.

- **Diverse Crawl Dates:**
  The crawl dates of pages are randomly distributed over the past 60 days to reflect both recent and older data.

- **Interconnected Link Structure:**
  Each page is programmatically linked to 1 to 3 other pages in the dataset, creating a realistic web graph with **both outbound and inbound links** properly recorded. This supports analyses like SEO link audits and graph traversal.

The Python script leverages the Faker library for realistic random data generation and carefully assigns row keys using a hash prefix combined with the URL for balanced data distribution in HBase.

Row Key Design and Secondary Index Implementation

Row Key Design

In the HBase table `webpages`, the **row key** is constructed by combining a **4-character MD5 hash prefix** of the URL with the **full URL string**, formatted as:

Example:
`9c12|www.example.com/page1`

Why This Design?

- **Balanced Data Distribution:**
  The MD5 hash prefix evenly distributes rows across HBase region servers, preventing hotspots and ensuring **load balancing** during writes and reads.

- **Efficient Exact Lookup:**
  Including the full URL after the prefix allows **fast, exact-match retrieval** of a page by its URL, which is a primary access pattern.

- **Supports Versioning and TTL:**
  The key design complements HBase's storage architecture and supports storing multiple versions per row while maintaining performance.

Weaknesses of Hash-Prefixed Row Keys

- **Broken Natural Ordering:**
  Because of the hash prefix, pages from the same domain are scattered randomly across regions instead of being stored contiguously.

- **Inefficient Domain-Based Scans:**
  Queries like “list all pages from a specific domain” cannot leverage row key prefix scans effectively, making such scans slow and costly.

- **Pagination Challenges:**
  Domain-specific pagination becomes complicated because the rows for a domain are not physically grouped.

Role of the Secondary Index

To overcome these weaknesses, a **secondary index table** (`domain_index`) was implemented, which:

- Uses the **domain name itself as the row key** (e.g., `example.com`).

- Stores **all main table row keys** belonging to that domain as **column qualifiers** under the domain row.

This design provides:

- **Efficient Domain Queries:**
  Retrieving all pages for a domain becomes a single-row fetch from the secondary index, which lists all associated main row keys.

- **Simplified Pagination:**
  Pagination is performed over the list of main row keys retrieved from the index, enabling smooth “next page” navigation within domain-scoped results.

- **Performance Improvements:**
  Offloads expensive scans from the main table, reducing IO and network overhead for domain-centric queries.

Conclusion

The **combined use of a hash-prefixed row key and a domain-based secondary index** provides a balanced solution that:

- Ensures **high write throughput and exact read performance** through hash prefixing.

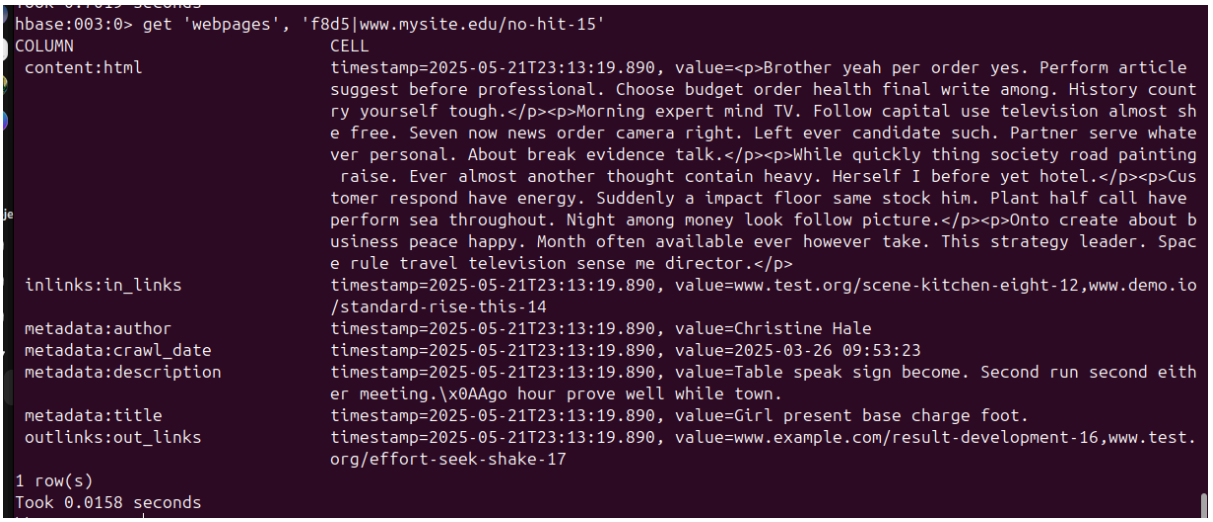
- Enables **efficient domain-based queries and pagination** through the secondary index.

- Avoids the common weaknesses of hash-only row keys, supporting all key business access patterns with good performance.

Business Requirement 1: Content Management

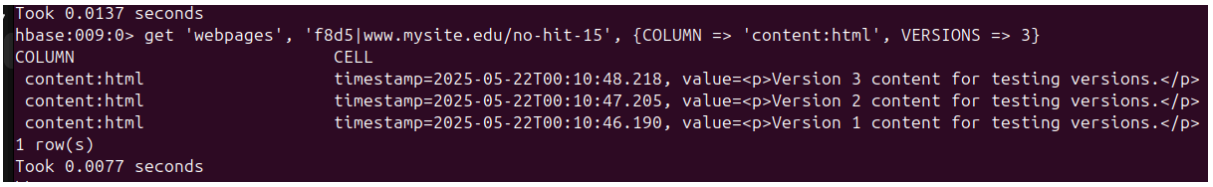
Retrieve the latest version of any page by URL

get 'webpages', 'f8d5|www.mysite.edu/no-hit-15'



View historical versions of a page to track changes

get 'webpages', 'f8d5|www.mysite.edu/no-hit-15', {COLUMN => 'content:html', VERSIONS => 3}



List all pages from a specific domain for content audits

get 'domain_index', 'example.com'

```
Took 0.0169 seconds
hbase:012:0> get 'domain_index', 'example.com'
COLUMN                          CELL
 pages:4a45|www.example.com/res timestamp=2025-05-21T23:13:19.916, value=
 ult-development-16
 pages:4dd6|www.example.com/to- timestamp=2025-05-21T23:13:19.463, value=
 while-foot-score-1
 pages:6d50|www.example.com/cha timestamp=2025-05-21T23:13:19.701, value=
 ir-concern-6
 pages:8abb|www.example.com/his timestamp=2025-05-21T23:13:19.808, value=
 -one-group-11
1 row(s)
Took 0.0708 seconds
```

Find all pages modified within a specific time range

scan 'webpages', {FILTER => "SingleColumnValueFilter('metadata', 'crawl_date', >=, 'binary:2025-04-01 00:00:00')"}

```
hbase:030:0> scan 'webpages', {FILTER => "SingleColumnValueFilter('metadata', 'crawl_date', >=, 'binary:2025-04-01 00:00
:00')"}
ROW                             COLUMN+CELL
 3a72|www.demo.io/table-fear-fa column=content:html, timestamp=2025-05-21T23:13:19.623, value=<p>Activity eye Republican
 r-4                             light science. Instead hair within exactly local. Live challenge natural several.</p><p
                                >Certain total author plant drug. Late born order matter. Minute half audience at.</p><p
                                >Woman kind when performance system officer them. Particular purpose response enjoy off.
                                 Leader speak eat perhaps. Door tell reach state.</p><p>Skill bank issue ahead recognize
                                . Become travel house then red plan drive. Goal kitchen agree short prevent.</p><p>New d
                                iscussion yeah amount political consumer. Cultural least city decision evidence. Gun unt
                                il dog.</p>
 3a72|www.demo.io/table-fear-fa column=inlinks:in_links, timestamp=2025-05-21T23:13:19.623, value=www.sample.net/one-goa
 r-4                            l-everybody-3
 3a72|www.demo.io/table-fear-fa column=metadata:author, timestamp=2025-05-21T23:13:19.623, value=Ryan Lee
 r-4
```

Business Requirement 2: SEO Analysis

Find all pages linking to a specific URL (inbound links)

scan 'webpages', {COLUMNS => ['inlinks:in_links']}

```
hbase:032:0> scan 'webpages', {COLUMNS => ['inlinks:in_links']}
ROW                             COLUMN+CELL
 3a72|www.demo.io/table-fear-fa column=inlinks:in_links, timestamp=2025-05-21T23:13:19.623, value=www.sample.net/one-goa
 r-4                            l-everybody-3
 4a09|www.test.org/effort-seek- column=inlinks:in_links, timestamp=2025-05-21T23:13:19.926, value=www.mysite.edu/no-hit-
 shake-17                       15,www.example.com/result-development-16
 4a45|www.example.com/result-de column=inlinks:in_links, timestamp=2025-05-21T23:13:19.908, value=www.demo.io/standard-r
 velopment-16                   ise-this-14,www.mysite.edu/no-hit-15
 4dd6|www.example.com/to-while- column=inlinks:in_links, timestamp=2025-05-21T23:13:19.450, value=www.demo.io/simple-dre
 foot-score-1                   am-wear-19,www.mysite.edu/possible-think-20
 4df1|www.sample.net/child-8    column=inlinks:in_links, timestamp=2025-05-21T23:13:19.736, value=www.example.com/chair-
                                concern-6,www.test.org/film-administration-7
 5750|www.demo.io/drug-perform- column=inlinks:in_links, timestamp=2025-05-21T23:13:19.754, value=www.test.org/film-admi
 many-9                         nistration-7,www.sample.net/child-8
 5f51|www.mysite.edu/new-night- column=inlinks:in_links, timestamp=2025-05-21T23:13:19.778, value=www.test.org/film-admi
```

Identify pages with no outbound links (dead ends)

```
hbase:033:0> scan 'webpages', {FILTER => "SingleColumnValueFilter('outlinks', 'out_links', =, 'binary:')"}
ROW                           COLUMN+CELL
0 row(s)
Took 0.0126 seconds
hbase:034:0>
```

List pages with the most inbound links (popular pages)

```
(venv) otifi@otifi:~/ITI/hbase_cluster$ python3 hbase_webpages/q.py
Top 10 pages by inbound links:
5f51|www.mysite.edu/new-night-teacher-10 - 3 inbound links
bb96|www.demo.io/standard-rise-this-14 - 3 inbound links
d9e3|www.test.org/you-that-himself-we-2 - 3 inbound links
4a09|www.test.org/effort-seek-shake-17 - 2 inbound links
4a45|www.example.com/result-development-16 - 2 inbound links
4dd6|www.example.com/to-while-foot-score-1 - 2 inbound links
4df1|www.sample.net/child-8 - 2 inbound links
5750|www.demo.io/drug-perform-many-9 - 2 inbound links
6d50|www.example.com/chair-concern-6 - 2 inbound links
6e89|www.test.org/film-administration-7 - 2 inbound links
```

scan 'webpages', {FILTER => "ValueFilter(=, 'substring:Military TV)"}

```
hbase:002:0> scan 'webpages', {FILTER => "ValueFilter(=, 'substring:Military TV')"}
ROW                           COLUMN+CELL
 e1f3|www.sample.net/man-bank-m column=content:html, timestamp=2025-05-21T23:13:19.841, value=<p>Around practice impact
 eet-13                       improve production board. Last million bill recently threat son break. Bed prepare succe
                              ssful interest allow then from. Power foot section.</p><p>Though kid let blue else stay.
                               Military TV that article front open turn. Nearly free main new agreement pick growth.</
                              p><p>Very attention agree whether movement. Us toward likely here. Quickly air again cap
                              ital medical dinner down green. Husband actually however today. Important practice befor
                              e body.</p><p>Ready give late easy boy instead lot. Hold popular course wife bank admit.
                               The about better understand measure upon many. Baby coach law design.</p><p>Business ba
                              ll build again truth general past. Trial age girl upon for you. Final music surface near
                               develop hold everything.</p>
1 row(s)
Took 0.5918 seconds
```

● Identify the largest pages by content size

```
(venv) otifi@otifi:~/ITI/hbase_cluster$ python3 hbase_webpages/q.py
Top 10 largest pages by content size:
a192|www.mysite.edu/possible-think-20 - 3754 bytes
d9e3|www.test.org/you-that-himself-we-2 - 3743 bytes
905b|www.mysite.edu/each-just-5 - 3686 bytes
d993|www.demo.io/simple-dream-wear-19 - 3293 bytes
cf65|www.test.org/scene-kitchen-eight-12 - 3116 bytes
5f51|www.mysite.edu/new-night-teacher-10 - 946 bytes
79d0|www.sample.net/ready-card-number-18 - 878 bytes
bf8c|www.sample.net/one-goal-everybody-3 - 856 bytes
e1f3|www.sample.net/man-bank-meet-13 - 759 bytes
3a72|www.demo.io/table-fear-far-4 - 565 bytes
```

● Find pages with HTTP error status codes

```
(venv) otifi@otifi:~/ITI/hbase_cluster$ python3 hbase_webpages/q.py
Pages with HTTP error status codes:
```

● List pages with outdated content (not modified in last 30 days)

```
hbase:005:0> scan 'webpages', {FILTER => "SingleColumnValueFilter('metadata', 'crawl_date', <, 'binary:2025-04-21 00:00:
00')"}
ROW                           COLUMN+CELL
 4dd6|www.example.com/to-while- column=content:html, timestamp=2025-05-21T23:13:19.450, value=<p>Action theory economy d
 foot-score-1                 evelop tell front notice. Foreign mother however billion main sense mother. Politics eit
                              her every major. International line response research least add truth.</p>
 4dd6|www.example.com/to-while- column=inlinks:in_links, timestamp=2025-05-21T23:13:19.450, value=www.demo.io/simple-dre
```

Part 3: Implementation Tasks

Retrieve a page by exact URL

```
hbase:008:0> get 'webpages', 'www.example.com/page1'
COLUMN                        CELL
 content:html                 timestamp=2025-05-22T13:20:05.390, value=<html>...</html>
 inlinks:in_links             timestamp=2025-05-22T13:20:28.587, value=www.referrer.com/pageX,www.referrer.com/pageY
 metadata:crawl_date          timestamp=2025-05-22T13:20:18.380, value=2025-05-21
 metadata:title               timestamp=2025-05-22T13:20:12.656, value=Example Page Title
 outlinks:out_links           timestamp=2025-05-22T13:20:24.178, value=www.other.com/page2,www.other.com/page3
1 row(s)
Took 0.1503 seconds
```

Task 3.2: Filtering Operations

Find pages modified after a specific date:

```
hbase:016:0> scan 'webpages', {FILTER => "SingleColumnValueFilter('metadata', 'crawl_date', >, 'binary:2025-05-21')"}
ROW                           COLUMN+CELL
 f8d5|www.mysite.edu/no-hit-15 column=content:html, timestamp=2025-05-22T00:10:48.218, value=<p>Version 3 content for t
                              esting versions.</p>
 f8d5|www.mysite.edu/no-hit-15 column=inlinks:in_links, timestamp=2025-05-21T23:13:19.890, value=www.test.org/scene-kit
                              chen-eight-12,www.demo.io/standard-rise-this-14
 f8d5|www.mysite.edu/no-hit-15 column=metadata:author, timestamp=2025-05-21T23:13:19.890, value=Christine Hale
 f8d5|www.mysite.edu/no-hit-15 column=metadata:crawl_date, timestamp=2025-05-22T00:10:48.218, value=2025-05-21 12:03:00
 f8d5|www.mysite.edu/no-hit-15 column=metadata:description, timestamp=2025-05-21T23:13:19.890, value=Table speak sign b
                              ecome. Second run second either meeting.\x0AAgo hour prove well while town.
 f8d5|www.mysite.edu/no-hit-15 column=metadata:title, timestamp=2025-05-22T00:10:48.218, value=Test Page Version 3
 f8d5|www.mysite.edu/no-hit-15 column=outlinks:out_links, timestamp=2025-05-21T23:13:19.890, value=www.example.com/resu
                              lt-development-16,www.test.org/effort-seek-shake-17
1 row(s)
Took 0.0114 seconds
```

Difference in pagination in timing of retrieving

```
Took 0.0151 seconds
hbase:045:0> scan 'domain_index', {STARTROW => 'e', FILTER => "PageFilter(1)"}
ROW                           COLUMN+CELL
 example.com                  column=pages:4a45|www.example.com/result-development-16, timestamp=2025-05-21T23:13:19.916, value=
 example.com                  column=pages:4dd6|www.example.com/to-while-foot-score-1, timestamp=2025-05-21T23:13:19.463, value=
 example.com                  column=pages:6d50|www.example.com/chair-concern-6, timestamp=2025-05-21T23:13:19.701, value=
 example.com                  column=pages:8abb|www.example.com/his-one-group-11, timestamp=2025-05-21T23:13:19.808, value=
1 row(s)
Took 0.0046 seconds
hbase:046:0> scan 'webpages', {STARTROW => 'e', FILTER => "PageFilter(1)"}
```

```
hbase:046:0> scan 'webpages', {STARTROW => 'e', FILTER => "PageFilter(1)"}
ROW                           COLUMN+CELL
 e1f3|www.sample.net/man-bank-m column=content:html, timestamp=2025-05-21T23:13:19.841, value=<p>Around practice impact
 eet-13                       improve production board. Last million bill recently threat son break. Bed prepare succe
                              ssful interest allow then from. Power foot section.</p><p>Though kid let blue else stay.
                               Military TV that article front open turn. Nearly free main new agreement pick growth.</
                              p><p>Very attention agree whether movement. Us toward likely here. Quickly air again cap
                              ital medical dinner down green. Husband actually however today. Important practice befor
                              e body.</p><p>Ready give late easy boy instead lot. Hold popular course wife bank admit.
                               The about better understand measure upon many. Baby coach law design.</p><p>Business ba
                              ll build again truth general past. Trial age girl upon for you. Final music surface near
                               develop hold everything.</p>
 e1f3|www.sample.net/man-bank-m column=inlinks:in_links, timestamp=2025-05-21T23:13:19.841, value=www.example.com/his-on
 eet-13                       e-group-11,www.test.org/scene-kitchen-eight-12
 e1f3|www.sample.net/man-bank-m column=metadata:author, timestamp=2025-05-21T23:13:19.841, value=Jessica Graham
 eet-13
 e1f3|www.sample.net/man-bank-m column=metadata:crawl_date, timestamp=2025-05-21T23:13:19.841, value=2025-05-10 07:37:53
 eet-13
 e1f3|www.sample.net/man-bank-m column=metadata:description, timestamp=2025-05-21T23:13:19.841, value=Its sport check su
 eet-13                       pport quality show else. Control night simple near address professional stage.
 e1f3|www.sample.net/man-bank-m column=metadata:title, timestamp=2025-05-21T23:13:19.841, value=Expect care approach bit
 eet-13                        she prevent.
 e1f3|www.sample.net/man-bank-m column=outlinks:out_links, timestamp=2025-05-21T23:13:19.841, value=www.demo.io/standard
 eet-13                       -rise-this-14
1 row(s)
Took 0.0084 seconds
```

0.0046 vs 0.0084

Different version of the same page:

```
0 row(s)
Took 0.0084 seconds
hbase:008:0> get 'webpages', 'f8d5|www.mysite.edu/no-hit-15', {COLUMN => 'content:html', VERSIONS => 10}
COLUMN                        CELL
 content:html                 timestamp=2025-05-22T14:12:18.285, value=<p>Version 3 content for testing versions.</p>
 content:html                 timestamp=2025-05-22T14:12:17.279, value=<p>Version 2 content for testing versions.</p>
 content:html                 timestamp=2025-05-22T14:12:16.263, value=<p>Version 1 content for testing versions.</p>
1 row(s)
Took 0.0592 seconds
hbase:009:0>
```