

Start the environment

Download the repository and start the environment:

```
docker compose up -d
```

Verify the services

-Apache Pinot's Web UI: <http://localhost:9000>

Create a kafka topic:

```
docker exec \
-t kafka kafka-topics.sh \
--bootstrap-server localhost:9092 \
--partitions=1 --replication-factor=1 \
--create --topic ingest-kafka
```

Learn more about Apache Pinot

- Apache Pinot's home page: <https://docs.pinot.apache.org/>

Basic setup

Understand the content of [ingest schema file](#) and [table creation file](#). Then, navigate to Apache Pinot's Web UI and add a table schema and a realtime table.

Table Name	Reported Size	Estimated Size	Number of Segments	Status
ingest_kafka_REALTIME	N/A	N/A	1 / 1	GOOD

Schema Name	Dimension Columns	Date-Time Columns	Metrics Columns	Complex Columns	Total Columns
ingest_kafka	6	1	0	0	7

Navigate to [Query Console](#) and run your first query:

```
select * from ingest.kafka
```

The screenshot shows the Apache Pinot Query Console interface. On the left, there's a sidebar with links to Cluster Manager, Query Console, Swagger REST API, and Zookeeper Browser. The main area has tabs for Cluster Manager, Query Type (SQL Query selected), and Timeseries Query. Under SQL Query, the table 'ingest_kafka' is selected. The SQL Editor contains the query: 'SELECT * from ingest_kafka'. Below it, the Query Response Stats table shows performance metrics: timeUsedMs (28), numDocsScanned (0), totalDocs (0), numServersQueried (1), numServersResponded (1), numSegmentsQueried (1), numSegmentsProcessed (0), numSegmentsMatched (0), numConsumingSegmentsQueried (1), numEntriesScannedInFilter (0), and numEntries (0). Buttons for 'FORMAT SQL' and 'RUN QUERY' are at the bottom.

More advanced query:

```
SELECT source_ip, COUNT(*) AS match_count FROM ingest_kafka
WHERE
    content LIKE '%vulnerability%' AND severity = 'High'
GROUP BY source_ip
ORDER BY match_count DESC
```

This screenshot shows the same Pinot Query Console interface after executing the advanced query. The SQL Editor now displays the full query with syntax highlighting. The Query Response Stats table shows similar metrics to the previous query, with timeUsedMs (18), numDocsScanned (0), totalDocs (0), numServersQueried (1), numServersResponded (1), numSegmentsQueried (1), numSegmentsProcessed (0), numSegmentsMatched (0), numConsumingSegmentsQueried (1), numEntriesScannedInFilter (0), and numEntries (0). Below the stats, there are buttons for EXCEL, CSV, and COPY. The Query Result section shows a table with columns 'source_ip' and 'match_count', containing the message 'No Record(s) found'.

See more about queries' syntax: <https://docs.pinot.apache.org/users/user-guide-query>

What are we missing when we execute the queries?

- There is no data in Pinot at the moment.

See how to ingest data on Apache Pinot: <https://docs.pinot.apache.org/manage-data/data-import>

Load generator

Inside the **load-generator** folder, understand the content of the docker compose file and start generating log records:

```
docker compose up -d
```

What is the relation between these records being generated and Apache Pinot's table?

- The load generator creates synthetic log which are send to the Kafka topic ingest-kafka

- Two ingestion variants
 - Schema: pinot consumes the ingest-kafka topic and structures the messages according to the json schema provided
 - Real-time: records are continuously consumed from Kafka and structured according to realtime json

The screenshot shows the Pinot Query Console interface. The top navigation bar includes 'Home > Query Console' and a cluster name 'PinotCluster'. The left sidebar has a 'Query Type' dropdown set to 'SQL Query' and a 'Tables' section listing 'ingest_kafka'. The main area has a 'SQL EDITOR' with the following query:

```
1 SELECT source_ip, COUNT(*) AS match_count FROM ingest_kafka
2 WHERE
3   content LIKE '%vulnerability%' AND severity = 'High'
4 GROUP BY source_ip
5 ORDER BY match_count DESC
```

Below the editor are 'Tracing' and 'Use Multi-Stage Engine' checkboxes, a 'Timeout (Milliseconds)' input field, and 'FORMAT SQL' and 'RUN QUERY' buttons. The 'QUERY RESPONSE STATS' section displays performance metrics. The 'QUERY RESULT' section shows the execution output:

source_ip	match_count
192.168.1.72	46
192.168.1.60	45
192.168.1.53	44
192.168.1.74	44
192.168.1.89	42
192.168.1.77	42
192.168.1.94	40
192.168.1.88	39

Buttons for 'EXCEL', 'CSV', and 'COPY' are at the bottom, along with 'View' and 'TABULAR' options.

Run again the advanced query:

```
SELECT source_ip, COUNT(*) AS match_count FROM ingest_kafka
WHERE
  content LIKE '%vulnerability%' AND severity = 'High'
GROUP BY source_ip
ORDER BY match_count DESC
```

The screenshot shows the Pinot SQL Editor interface. At the top, there is a SQL editor window containing the following query:

```

1 SELECT source_ip, COUNT(*) AS match_count FROM ingest_kafka
2 WHERE
3   content LIKE '%vulnerability%' AND severity = 'High'
4 GROUP BY source_ip
5 ORDER BY match_count DESC

```

Below the editor are several controls: "Tracing" (unchecked), "Use Multi-Stage Engine" (unchecked), "Timeout (Milliseconds)" (set to 0), "FORMAT SQL" (button with keyboard shortcut CTRL+V), and "RUN QUERY" (button with keyboard shortcut CTRL+R).

The "QUERY RESPONSE STATS" section displays the following metrics:

timeUsedMs	numDocsScanned	totalDocs	numServersQueried	numServersResponded	numSegmentsQueried	numSegmentsProces
4852	156116	5000000	1	1	13	13

At the bottom of this section are buttons for "EXCEL", "CSV", and "COPY". To the right, there are "View" buttons for "TABULAR" (selected), "JSON", and "VISUAL".

The "QUERY RESULT" section shows the actual query results:

source_ip	match_count
192.168.1.97	1638
192.168.1.23	1632
192.168.1.68	1625

Are there any changes in query results? What and why?

Yes, now there is data.

Before load generator:

- Query returned 0 rows
- Result was empty because no data existed in Pinot yet

After load generator:

- Query returns actual results with source IPs and their match counts
- Shows multiple source_ip values with varying counts of high-severity vulnerability logs
- Results continue to grow in real-time as the generator produces more records

Why these changes occur:

1. Load generator sends records to Kafka topic ingest-kafka
2. Pinot consumes these records immediately from Kafka
3. When the query is executed one gets the result
4. As the generator is still running, the result set grows with each query execution (with time)

Moreover, what is the amount of data in the table?

Total Documents: 5 000 000 records in the ingest_kafka table

- This represents the amount of data ingested from Kafka at the time of query execution

- The generator has finished running before the query was executed

Metrics

- **Docs scanned (156 116):** Records that matched the WHERE clause filters (content `LIKE '%vulnerability%' AND severity = 'High'`)
- **Entries scanned in filter (5 885 347):** Total character/field comparisons performed during filtering phase
- **Segments (13):** Number of data segments queried, processed, and matched - Pinot created 13 segments to store 5M records
- **Total table size (5 000 000):** Total number of documents in the ingest_kafka table

How this last query relates to the Spark Structured Streaming logs processing example from Exercise 3?

Both achieve a similar/the same result using different query methods:

Key differences highlighted:

Architecture:

- Spark: Code-based stream processing with DataFrames/RDDs
- Pinot: SQL-based OLAP with automatic indexing

Query model:

- Spark: Write Python transformation logic, deploy as jobs
- Pinot: Ad-hoc SQL queries, no code deployment needed

State management:

- Spark: Manual watermarking and windowing configuration
- Pinot: Automatic segment management and time-based queries

Latency:

- Spark: Micro-batch (seconds) with periodic writes
- Pinot: True real-time with sub-second query response

Use cases:

- Spark: Complex ETL, ML pipelines, multi-stage transformations
- Pinot: Interactive analytics, dashboards, real-time reporting

How performant is the advanced query? How long it takes to run and how many queries like this one could be served per second?

Query speed:

- One run takes 4 852 ms (~ 4.9 seconds) for analytical query on 5M records with filtering and aggregation
- So approximately 0.2 such queries can be served per second

Practical Exercise: From the material presented in the previous lecture on **Analytical Processing** and Apache Pinot's features (available at <https://docs.pinot.apache.org/>), analyze and explain how the performance of the advanced query could be improved without demanding additional computing resources. Then, implement and demonstrate such an approach in Apache Pinot.

Analysis: Query Performance Bottleneck

Bottlenecks:

- Most time spent scanning entries in filter phase
- The `LIKE '%vulnerability%'` pattern matching is the main cost
- Post-filter processing is very fast compared to pattern matching

The `LIKE '%vulnerability%'` clause is the performance killer because:

1. Pinot must scan every character in every `content` value
2. No existing index accelerates substring matching
3. Scales linearly with data growth

Solution: Add Index and use Text Match

Add a text index to enable fast substring/keyword searches without scanning every character in every record

Implementation Steps

Step 1: Update Table Configuration

Modify `ingest_kafka_realtime_table.json` to add text index:

```
{
  "tableName": "ingest_kafka",
  "tableType": "REALTIME",
  "segmentsConfig": {
    "timeType": "MILLISECONDS",
    "schemaName": "ingest_kafka",
    "timeColumnName": "timestamp",
    "replicasPerPartition": "1"
  },
  "tenants": {},
  "tableIndexConfig": {
    "loadMode": "MMAP",
    "noDictionaryColumns": [
      "content"
    ],
    "streamConfigs": {
      "streamType": "kafka",
      "stream.kafka.topic.name": "ingest-kafka",
      "stream.kafka.decoder.class.name":
        "org.apache.pinot.plugin.inputformat.json.JSONMessageDecoder",
      "stream.kafka.consumer.factory.class.name":
        "org.apache.pinot.plugin.stream.kafka20.KafkaConsumerFactory",
      "stream.kafka.consumer.group.id": "ingest-kafka"
    }
  }
}
```

```

    "stream.kafka.broker.list": "kafka:9092",
    "realtime.segment.flush.threshold.rows": "0",
    "realtime.segment.flush.threshold.time": "24h",
    "realtime.segment.flush.threshold.segment.size": "50M",
    "stream.kafka.consumer.prop.auto.offset.reset": "smallest"
  }
},
"fieldConfigList": [
  {
    "name": "content",
    "encodingType": "RAW",
    "indexTypes": [
      "TEXT"
    ]
  }
],
"metadata": {
  "customConfigs": {}
}
}

```

Key changes:

- Added "noDictionaryColumns": ["content"] - Stores raw text values without dictionary encoding for efficient text indexing
- Added "fieldConfigList" - Defines index configuration for the content field
- Added "encodingType": "RAW" - Uses raw encoding instead of dictionary encoding (required for TEXT index)
- Added "indexTypes": ["TEXT"] - Creates TEXT index on content field (enables TEXT_MATCH queries)

Step 2: Update Table in Pinot Web UI

1. Navigate to <http://localhost:9000>
2. Go to tables and delete or edit the existing table
3. Replace the Table Configuration JSON with the updated version above

Step 3: Update query:

```

SELECT source_ip, COUNT(*) AS match_count FROM ingest_kafka
WHERE
  TEXT_MATCH(content, 'vulnerability') AND severity = 'High'
GROUP BY source_ip
ORDER BY match_count DESC

```

Step 4: Verify Performance difference

Before Optimization: (takes 4 852 ms)

SQL EDITOR

```
1 SELECT source_ip, COUNT(*) AS match_count FROM ingest_kafka
2 WHERE
3   content LIKE '%vulnerability%' AND severity = 'High'
4 GROUP BY source_ip
5 ORDER BY match_count DESC
```

Tracing Use Multi-Stage Engine Timeout (Milliseconds) **FORMAT SQL** CTRL+V **RUN QUERY** CTRL+D

QUERY RESPONSE STATS

timeUsedMs	numDocsScanned	totalDocs	numServersQueried	numServersResponded	numSegmentsQueried	numSegmentsProces
4852	156116	5000000	1	1	13	13

View **TABULAR** **JSON** **VISUAL**

QUERY RESULT

source_ip	match_count
192.168.1.97	1638
192.168.1.23	1632
192.168.1.68	1625

After Optimization: (takes 31 ms)

Query Type

- SQL Query**
- Timeseries Query

TABLES

Tables
ingest_kafka

SQL EDITOR

```
1 SELECT source_ip, COUNT(*) AS match_count FROM ingest_kafka
2 WHERE
3   TEXT_MATCH(content, 'vulnerability') AND severity = 'High'
4 GROUP BY source_ip
5 ORDER BY match_count DESC
```

Tracing Use Multi-Stage Engine Timeout (Milliseconds) **FORMAT SQL** CTRL+V **RUN QUERY** CTRL+D

QUERY RESPONSE STATS

timeUsedMs	numDocsScanned	totalDocs	numServersQueried	numServersResponded	numSegmentsQueried	numSegmentsProces
31	156116	5000000	1	1	13	13

View **TABULAR** **JSON** **VISUAL**

QUERY RESULT

source_ip	match_count
192.168.1.97	1638
192.168.1.23	1632

Why This Works Without Additional Resources

- Uses existing server memory for index structures
- Pinot maintains index as new data arrives from Kafka

- Dramatic performance improvements through intelligent indexing without requiring infrastructure changes

Foundational Exercise: Considering the material presented in the lecture [NoSQL - Data Processing & Advanced Topics](#) and Apache Pinot's concepts <https://docs.pinot.apache.org/basics/concepts> and architecture <https://docs.pinot.apache.org/basics/concepts/architecture>, how an OLAP system such as Apache Pinot relates to NoSQL and realizes Sharding, Replication, and Distributed SQL?

Pinot as a NoSQL OLAP System

Relationship to NoSQL:

- Pinot is a distributed NoSQL system designed for OLAP
- Optimized for high-throughput read operations on large datasets rather than consistent writes
- Supports flexible schema with JSON documents from streaming sources (Kafka)
- Trades ACID consistency for eventual consistency and real-time performance
- Horizontal scalability across commodity servers instead of vertical scaling
- No rigid schema enforcement like traditional relational databases

Sharding

Definition:

- Horizontal data partitioning across multiple servers
- Each shard holds a subset of the total data
- Queries execute in parallel on all shards simultaneously

How it works in Pinot:

- Data is distributed based on a partition key (e.g., source_ip)
- Hash-based partitioning: data is hashed and assigned to shards
- Multiple servers store different shards, reducing data per server

Replication

Definition:

- Creating multiple copies of data across different servers
- Ensures data availability even if some servers fail

How it works in Pinot:

- Each shard is replicated across multiple servers (replication factor: 1, 2, or 3)
- Replica factor of 3 means 3 copies of each shard on different servers
- Broker automatically routes queries to available replicas

Distributed SQL

Definition:

- Query execution coordinated across multiple servers with results merged at broker
- Broker acts as query coordinator, distributing work to data-holding servers

How it works in Pinot:

- Broker receives SQL query from client
- Determines which shards contain relevant data
- Routes query to all relevant shard servers in parallel
- Each server applies filters and performs aggregations locally
- Broker collects partial results and merges them
- Final result returned to client

Benefits:

- Sub-second query latency through parallel execution
- Network efficiency: filters and aggregations done on servers
- Automatic query optimization without application changes
- Linear scaling with cluster size

How They Work Together

Combined System:

- **Sharding** divides data across servers for parallel processing
- **Replication** copies each shard on multiple servers for fault tolerance
- **Distributed SQL** coordinates query execution across all shards/replicas

Comparison with Traditional Databases

- **RDBMS**: Centralized, vertical scaling, ACID consistency, slow analytics
- **Pinot**: Distributed, horizontal scaling, eventual consistency, fast analytics
- Pinot trades strong consistency for performance and scalability (acceptable for analytics)
- Real-time ingestion from Kafka instead of batch processing
- Designed specifically for OLAP workloads (aggregations, filtering, grouping)

Expected Deliverables

Complete answers to all questions above, including brief analyses, configuration files, and performance metrics for the practical exercise.

Clean up in the **root folder** and inside the **load-generator** folder. In both cases with the command:

```
docker compose down -v
```