Kafka Topics Partition Count Recommender Application

> **TL;DR:** ***End Kafka performance headaches.*** *This smart recommender reads your historical consumption data and delivers precise partition recommendations that optimize throughput and enable effortless scaling—no more over-provisioning or under-utilizing your topics.*

The **Kafka Cluster Topics Partition Count Recommender Application** offers data-driven accuracy for Kafka topic sizing. By analyzing past consumption trends, that is, the average consumption records in bytes, it uses this information to determine consumer throughput. Then, over a rolling seven-day period, it identifies the peak consumption of records in bytes, scaling that number by a factor of X to forecast future demand and calculate the required throughput. Next, it divides the required throughput by the consumer throughput and rounds the result to the nearest whole number to determine the optimal number of partitions. The result is an intelligent, automated recommendation system that ensures each Kafka topic has the appropriate number of partitions to handle current workload and support future growth effectively.

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1.1 Download the Application

Clone the repo: `shell git clone https://github.com/j3-signalroom/kafka_cluster-topics-partition_count_recommender-app.git`

Since this project was built using **`uv`**, please install it, and then run the following command to install all the project dependencies:

```
uv sync
```

1.1.1 Special Note on two custom dependencies

This project has *two custom dependencies* that we want to bring to your attention:

1. **`cc-clients-python_lib`**: *This library offers a simple way to interact with Confluent Cloud services, including the Metrics API. It makes it easier to send API requests and manage responses. It is used in this project to connect to the Confluent Cloud Metrics API and retrieve topic consumption metrics.*
2. **`aws-clients-python_lib`**: *This library is used to interact with AWS services, specifically AWS Secrets Manager in this case. It enables the application to securely retrieve secrets stored in AWS Secrets Manager.*

1.2 Configure the Application

Now, you need to set up the application by creating a `.env` file in the root directory of your project. This file will store all the essential environment variables required for the application to connect to your Confluent Cloud Kafka cluster and function correctly. Additionally, you can choose to use **AWS Secrets Manager** to manage your secrets.

> **Note**: *Your Confluent Cloud API Key, Secret, and Kafka Cluster ID are required to access the Confluent Cloud Metrics API and retrieve topic metrics. Additionally, your Bootstrap Server URI, along with your Kafka API Key and Secret, are necessary to access the designated Kafka Cluster.*

1.2.1 Create the `.env` file

Create the `.env` file and add the following environment variables, filling them with your Confluent Cloud credentials and other required values:

```
# Environment variables credentials for Confluent Cloud and Kafka clusters
CONFLUENT_CLOUD_CREDENTIAL={"confluent_cloud_api_key":"
<YOUR_CONFLUENT_CLOUD_API_KEY>", "confluent_cloud_api_secret": "
<YOUR_CONFLUENT_CLOUD_API_SECRETS>"}
KAFKA_CREDENTIALS=[{"kafka_cluster_id": "<YOUR_KAFKA_CLUSTER_ID>",
"bootstrap.servers": "<YOUR_BOOTSTRAP_SERVER_URI>", "sasl.username": "
<YOUR_KAFKA_API_KEY>", "sasl.password": "<YOUR_KAFKA_API_SECRET>"}]

# AWS Secrets Manager Secrets for Confluent Cloud and Kafka clusters
USE_AWS_SECRETS_MANAGER=<True|False>
CONFLUENT_CLOUD_API_SECRET_PATH={"region_name": "
<YOUR_SECRET_AWS_REGION_NAME>", "secret_name": "
<YOUR_CONFLUENT_CLOUD_API_KEY_AWS_SECRETS>"}
KAFKA_API_SECRET_PATHS=[{"region_name": "<YOUR_SECRET_AWS_REGION_NAME>",
"secret_name": "<YOUR_KAFKA_API_KEY_AWS_SECRETS>"}]

# Topic analysis configuration
INCLUDE_INTERNAL_TOPICS=<True|False>
TOPIC_FILTER=<YOUR_TOPIC_FILTER, IF ANY>

# Throughput and partition calculation configuration
REQUIRED_CONSUMPTION_THROUGHPUT_FACTOR=
<YOUR_REQUIRED_CONSUMPTION_THROUGHPUT_FACTOR>

# Sampling configuration
USE_SAMPLE_RECORDS=<True|False>
SAMPLING_DAYS=<YOUR_SAMPLING_DAYS>
SAMPLING_BATCH_SIZE=<YOUR_SAMPLING_BATCH_SIZE>
```

The environment variables are defined as follows:

Environment Variable Name	Description
`CONFLUENT_CLOUD_CREDENTIAL`	JSON Object with Confluent Cloud API Key and Secret keys.
`KAFKA_CREDENTIALS`	JSON Object Array with Kafka Cluster API Keys, API Secrets, Kafka Cluster IDs, and bootstrap server URIs.
`USE_AWS_SECRETS_MANAGER`	Set to `True` if you want to use AWS Secrets Manager to manage your secrets; otherwise, set to `False`. Default is `False`.
`CONFLUENT_CLOUD_API_SECRET_PATH`	JSON Object with the Secrets' AWS Region Name and the name of the AWS Secrets Manager secrets that contains your Confluent Cloud API Key and secret.

Environment Variable Name	Description
KAFKA_API_SECRET_PATHS	JSON Object Array with the Secrets' AWS Region Name and the name of the AWS Secrets Manager secrets that contains your Kafka Cluster API Key, API Secret, Kafka Cluster ID, and bootstrap server URI.
INCLUDE_INTERNAL_TOPICS	Set to True if you want to include internal topics in the analysis; otherwise, set to False. Default is False.
TOPIC_FILTER	A comma-separated list of topic names to include in the analysis. Leave empty to include all topics.
REQUIRED_CONSUMPTION_THROUGHPUT_FACTOR	A multiplier to scale the peak consumption for future demand forecasting (e.g., 3 for 300%). Default is 3.
USE_SAMPLE_RECORDS	Set to True if you want to sample records for analysis; otherwise, set to False. Default is True.
SAMPLING_BATCH_SIZE	The number of records to sample if USE_SAMPLE_RECORDS is set to True (e.g., 50,000). Default is 50,000.
SAMPLING_DAYS	The number of days to look back when sampling records if USE_SAMPLE_RECORDS is set to True (for example, 7). This creates a rolling window that always looks back the specified number of days from the current time. **Note**: *This value will be ignored for topics that do not retain records for the number of days specified by* SAMPLING_DAYS. Default is 7.

1.2.2 Using the AWS Secrets Manager (optional)

If you use **AWS Secrets Manager** to manage your secrets, set the USE_AWS_SECRETS_MANAGER variable to True and the application will retrieve the secrets from AWS Secrets Manager using the names provided in CONFLUENT_CLOUD_API_KEY_AWS_SECRETS and KAFKA_API_KEY_AWS_SECRETS.

The code expects the CONFLUENT_CLOUD_API_KEY_AWS_SECRETS to be stored in JSON format with these keys:

- confluent_cloud_api_key
- confluent_cloud_api_secret

The code expects the KAFKA_API_KEY_AWS_SECRETS to be stored in JSON format with these keys:

- kafka_cluster_id
- bootstrap.servers

- `sasl.username`
- `sasl.password`

1.3 Run the Application

Navigate to the Project Root Directory

Open your Terminal and navigate to the root folder of the `kafka_cluster-topics-partition_count_recommender-app/` repository that you have cloned. You can do this by executing:

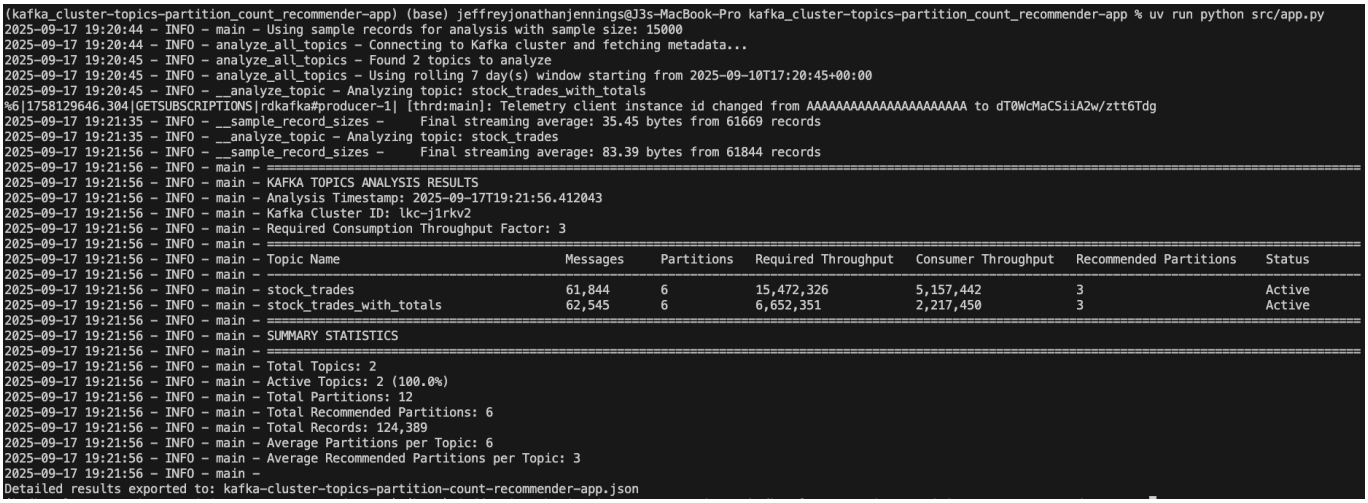
```
cd path/to/kafka_cluster-topics-partition_count_recommender-app/
```

> Replace `path/to/` with the actual path where your repository is located.

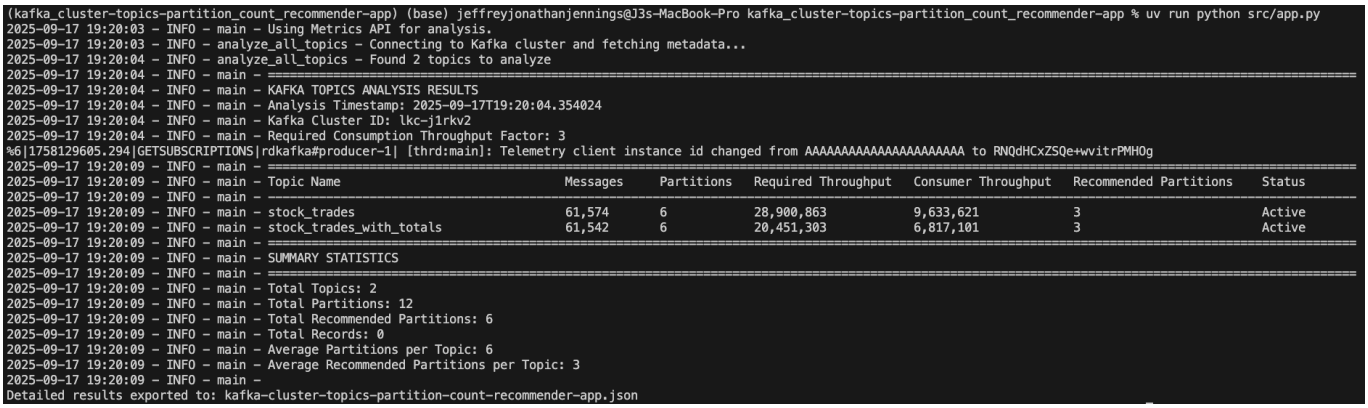
Then enter the following command below to run the application:

```
uv run python src/app.py
```

If `USE_SAMPLE_RECORDS` environment variable is set to `True`, the application will sample records from each topic to calculate the average record size in bytes. For example, below is a screenshot of the application running successfully:



If `USE_SAMPLE_RECORDS` is set to `False`, the application will use the Confluent Cloud Metrics API to retrieve the average and peak consumption in bytes over a rolling seven-day period. For example, below is a screenshot of the application running successfully:



1.3.1 Did you notice we prefix `uv run` to `python src/app.py`?

You maybe asking yourself why. Well, `uv` is an incredibly fast Python package installer and dependency resolver, written in **Rust**, and designed to seamlessly replace `pip`, `pipx`, `poetry`, `pyenv`, `twine`, `virtualenv`, and more in your workflows. By prefixing `uv run` to a command, you're ensuring that the command runs in an optimal Python environment.

Now, let's go a little deeper into the magic behind `uv run`:

- When you use it with a file ending in `.py` or an HTTP(S) URL, `uv` treats it as a script and runs it with a Python interpreter. In other words, `uv run file.py` is equivalent to `uv run python file.py`. If you're working with a URL, `uv` even downloads it temporarily to execute it. Any inline dependency metadata is installed into an isolated, temporary environment—meaning zero leftover mess! When used with `-`, the input will be read from `stdin`, and treated as a Python script.
- If used in a project directory, `uv` will automatically create or update the project environment before running the command.
- Outside of a project, if there's a virtual environment present in your current directory (or any parent directory), `uv` runs the command in that environment. If no environment is found, it uses the interpreter's environment.

So what does this mean when we put `uv run` before `python src/app.py`? It means `uv` takes care of all the setup—fast and seamless—right in your local environment. If you think AI/ML is magic, the work the folks at Astral have done with `uv` is pure wizardry!

Curious to learn more about Astral's `uv`? Check these out:

- Documentation: Learn about `uv`.
- Video: `uv` IS THE FUTURE OF PYTHON PACKING!.

If you have Kafka connectivity issues, you can verify connectivity using the following command:

1.3.2 Troubleshoot Connectivity Issues (if any)

To verify connectivity to your Kafka cluster, you can use the `kafka-topics.sh` command-line tool. First, download the Kafka binaries from the Apache Kafka website and extract them. Navigate to the `bin` directory of the extracted Kafka folder. Second, create a `client.properties` file with your Kafka credentials:

```
# For SASL_SSL (most common for cloud services)
security.protocol=SASL_SSL
sasl.mechanism=PLAIN
sasl.jaas.config=org.apache.kafka.common.security.plain.PlainLoginModule
required \
  username="<YOUR_KAFKA_API_KEY>" \
  password="<YOUR_KAFKA_API_SECRET>";

# Additional SSL settings if needed
ssl.endpoint.identification.algorithm=https
```

Finally, run the following command to list all topics in your Kafka cluster:

```
./kafka-topics.sh --list --bootstrap-server <YOUR_BOOTSTRAP_SERVER_URI> --
command-config ./client.properties
```

If the connection is successful, you should see a list of topics in your Kafka cluster. If you encounter any errors, double-check your credentials and network connectivity.

2.0 How the app calculates the recommended partition count

The app uses the Kafka `AdminClient` to retrieve all Kafka Topics (based on the `TOPIC_FILTER` specified) stored in your Kafka Cluster, including the original partition count per topic. Then, it iterates through each Kafka Topic, calling the Confluent Cloud Metrics RESTful API to retrieve the topic's average (i.e., the *Consumer Throughput*) and peak consumption in bytes over a rolling seven-day period. Next, it calculates the required throughput by multiplying the peak consumption by the `REQUIRED_CONSUMPTION_THROUGHPUT_FACTOR` (i.e., the *Required Throughput*). Finally, it divides the required throughput by the consumer throughput and rounds the result to the nearest whole number to determine the optimal number of partitions.

> **Note**: *This why the app requires the Kafka API Key and Secret to connect to your Kafka Cluster via the AdminClient, and the Confluent Cloud API Key and Secret to connect to the Confluent Cloud Metrics API.*

For example, suppose you have a consumer that consumes at **25MB/s**, but the the consumer requirement is a throughput of **1.22GB/s**. How many partitions should you have?

To determine the number of partitions needed to support a throughput of **1.22GB/s** for a Kafka consumer that can only consume at **25MB/s**, you can calculate it as follows:

1. Convert the target throughput to the same units:
    - **1.22GB/s = 1250MB/s**
2. Divide the target throughput by the consumer's capacity:

$$\textbf{Partition Count} = \frac{Required\ Throughput}{Consumer\ Throughput} = \frac{1250\ MB/s}{25\ MB/s} = \mathbf{50}$$

3. Since you can only have a whole number of partitions, you should always round up to the nearest whole number:

$$\textbf{Partition Count} = \mathbf{50}$$

The **50 partitions** ensure that the consumer can achieve the required throughput of **1.22GB/s** while consuming at a rate of **25MB/s** per partition. This will allow the workload to be distributed across partitions so that multiple consumers can work in parallel to meet the throughput requirement.

2.1 End-to-End Application Workflow

```
---
id: 9958c339-5496-4c34-bcb4-3ba359a17ee3
---
sequenceDiagram
   participant Main as main()
   participant Env as Environment/.env
   participant AWS as AWS Secrets Manager
   participant MC as MetricsClient
   participant KTA as KafkaTopicsAnalyzer
   participant Kafka as Kafka Cluster
   participant File as JSON Output File

   Main->>Env: load_dotenv()
   Main->>Env: Get configuration variables

   alt USE_AWS_SECRETS_MANAGER == "True"
      Main->>AWS: get_secrets(confluent_cloud_secrets)
      AWS-->>Main: API credentials or empty dict
      Main->>AWS: get_secrets(kafka_secrets)
      AWS-->>Main: Kafka credentials or empty dict
      alt Secrets retrieved successfully
         Note over Main: Use AWS secrets
      else Secrets empty
         Main->>Env: Fallback to environment variables
      end
   else
      Main->>Env: Use environment variables directly
   end

   alt use_sample_records == False
      rect rgb(173, 216, 230)
         Note over Main,MC: METRICS API ANALYSIS PATH
         Main->>MC: MetricsClient(metrics_config)
         Note over MC: Initialize Confluent Cloud API client
```

```
      end
   end

   Main->>KTA: KafkaTopicsAnalyzer(bootstrap_server, api_key, api_secret)

   Main->>KTA: analyze_all_topics(params)
   KTA->>Kafka: Connect to Kafka cluster
   KTA->>Kafka: List all topics
   Kafka-->>KTA: Topic list

   loop For each topic
      KTA->>Kafka: Get topic metadata (partitions)
      Kafka-->>KTA: Partition count

      alt use_sample_records == True
         rect rgb(144, 238, 144)
               Note over KTA,Kafka: SAMPLE RECORDS ANALYSIS PATH
               KTA->>Kafka: Sample records from topic
               Kafka-->>KTA: Sample data
               KTA->>KTA: Calculate avg_bytes_per_record
               KTA->>KTA: Calculate total_record_count
         end
      else
         rect rgb(173, 216, 230)
               Note over KTA: METRICS API PATH - Skip sampling
         end
      end
   end

   KTA-->>Main: Analysis results array

   alt results empty
      Main->>Main: Log error and return
   else
      loop For each result
         alt use_sample_records == True
               rect rgb(144, 238, 144)
                  Note over Main: SAMPLE RECORDS THROUGHPUT CALCULATION
                  Main->>Main: Calculate throughput from samples
               end
         else
               rect rgb(173, 216, 230)
                  Note over Main,MC: METRICS API THROUGHPUT CALCULATION
                  Main->>MC:
get_topic_daily_aggregated_totals(RECEIVED_BYTES)
                  MC->>MC: Query Confluent Cloud Metrics API
                  MC-->>Main: Bytes throughput data
                  Main->>MC:
get_topic_daily_aggregated_totals(RECEIVED_RECORDS)
                  MC->>MC: Query Confluent Cloud Metrics API
                  MC-->>Main: Records count data
               end
         end
         Main->>Main: Calculate recommended partition count
```

```
        end

        Main->>Main: Sort results by topic name
        Main->>Main: Format and log analysis table
        Main->>Main: Calculate summary statistics
        Main->>Main: Log summary statistics

        Main->>File: Export results to JSON
        File-->>Main: File written successfully
        Main->>Main: Log completion message
    end
```

3.0 Unlocking High-Performance Consumer Throughput

The throughput of a **Kafka consumer** refers to the rate at which it can read data from Kafka topics, typically measured in terms of **megabytes per second (MB/s)** or **records per second**. Consumer throughput depends on several factors, including the configuration of Kafka, the consumer application, and the underlying infrastructure.

3.1 Key Factors Affecting Consumer Throughput

3.1.1 Partitions

- Throughput scales with the number of partitions assigned to the consumer. A consumer can read from multiple partitions concurrently, but the total throughput is bounded by the number of partitions and their data production rates.
- Increasing the number of partitions can improve parallelism and consumer throughput.

3.1.2 Consumer Parallelism

- A single consumer instance reads from one or more partitions, but it can be overwhelmed if the data rate exceeds its capacity.
- Adding more consumers in a consumer group increases parallelism, as Kafka reassigns partitions to balance the load.

3.1.3 Fetch Configuration

- `fetch.min.bytes`: Minimum amount of data (in bytes) the broker returns for a fetch request. Larger values reduce fetch requests but may introduce latency.
- `fetch.max.bytes`: Maximum amount of data returned in a single fetch response. A higher value allows fetching larger batches of messages, improving throughput.
- `fetch.max.wait.ms`: Maximum time the broker waits before responding to a fetch request. A higher value can increase batch sizes and throughput but may increase latency.

For more details, see the Confluent Cloud Client Optimization Guide - Consumer Fetching.

3.1.4 Batch Size

- Consumers process messages in batches for better efficiency. Larger batches reduce processing overhead but require sufficient memory.
- Configuration: `max.poll.records` controls the number of records fetched in a single poll.

3.1.5 Message Size

- Larger messages can reduce throughput if the network or storage systems are bottlenecks. Use compression (e.g., `lz4`, `snappy`) to optimize data transfer.

3.1.6 Network Bandwidth

- Network speed between Kafka brokers and consumers is critical. A consumer running on a limited-bandwidth network will see reduced throughput.

3.1.7 Deserialization Overhead

- The time required to deserialize records impacts throughput. Efficient deserialization methods (e.g., Avro, Protobuf with optimized schemas) can help.

3.1.8 Broker Load

- Broker performance and replication overhead impact the throughput seen by consumers. If brokers are under heavy load, consumer throughput may decrease.

3.1.9 Consumer Poll Frequency

- Consumers must frequently call `poll()` to fetch messages. If the consumer spends too much time processing messages between polls, throughput can drop.

3.1.10 System Resources

- CPU, memory, and disk I/O on the consumer's machine affect how fast it can process data.

3.2 Typical Consumer Throughput

- **Single Partition Throughput**: A single consumer reading from a single partition can typically achieve **10-50 MB/s** or higher, depending on record size, compression, and hardware.
- **Multi-Partition Throughput**: For a consumer group reading from multiple partitions, throughput can scale linearly with the number of partitions (subject to other system limits).

3.3 Seven Strategies to Improve Consumer Throughput

1. **Increase Partitions**: Scale partitions to allow more parallelism.
2. **Add Consumers**: Add more consumers in the consumer group to distribute the load.
3. **Optimize Fetch Settings**: Tune `fetch.min.bytes`, `fetch.max.bytes`, and `fetch.max.wait.ms`.
4. **Batch Processing**: Use `max.poll.records` to fetch and process larger batches.
5. **Compression**: Enable compression to reduce the amount of data transferred.
6. **Efficient SerDe (Serialization/Deserialization)**: Use optimized serializers and deserializers.

7. **Horizontal Scaling**: Ensure consumers run on high-performance hardware with sufficient network bandwidth.

By optimizing these factors, Kafka consumers can achieve higher throughput tailored to the specific use case and infrastructure.

4.0 Resources

4.1 Optimization Guides

- Optimize Confluent Cloud Clients for Throughput
- Choose and Change the Partition Count in Kafka

4.2 Confluent Cloud Metrics API

- Confluent Cloud Metrics API
- Confluent Cloud Metrics API: Metrics Reference
- Confluent Cloud Metrics

4.3 Confluent Kafka Python Client

- Confluent Kafka Python Client Documentation