

Lab: Search Runs

This lab will walk you through how to search your MLflow runs through the MLflow UI and Python API. This resource will be valuable if you're interested in querying specific runs based on their metrics, params, tags, dataset information, or run metadata.

In short, you can leverage SQL-like syntax to filter your runs based on a variety of conditions. Note that the `OR` keyword is not supported and there are a few other differences from SQL mentioned below, but despite these limitations, the run search functionality is quite powerful.

Lab Solution

Complete solution for this lab is available in the `lab4_search_runs.ipynb` notebook.

Search Runs on MLflow UI

The MLflow UI provides a powerful search interface that allows you to filter runs. Below we'll...

1. Create example MLflow runs
2. Look at a simple querying example
3. Deep dive into query syntax
4. Provide a variety of example queries

Create Example MLflow Runs

First, let's create some example MLflow runs. This documentation is based on experiments created with the below script. If you don't want to interactively explore this on your machine, skip this section.

Before running the script, let's simply start the MLflow UI on a local host.

```
mlflow ui
```

Let's visit `http://localhost:5000/` in our web browser. After doing so, you'll notice that we don't have any experiments or models. Let's resolve this by creating a few MLflow runs via the script below.

Note that when you run this script, you'll want to do so from the same directory that you ran the `mlflow ui` command.

```
import mlflow
import numpy as np

mlflow.set_experiment("search-run-guide")

accuracy = np.arange(0, 1, 0.1)
loss = np.arange(1, 0, -0.1)
log_scale_loss = np.log(loss)
f1_score = np.arange(0, 1, 0.1)

batch_size = [2] * 5 + [4] * 5
learning_rate = [0.001, 0.01] * 5
model = ["GPT-2", "GPT-3", "GPT-3.5", "GPT-4"] + [None] * 6

task = ["classification", "regression", "causal lm"] + [None] * 7
environment = ["notebook"] * 5 + [None] * 5
```

```

dataset_name = ["custom"] * 5 + ["also custom"] * 5
dataset_digest = ["s8ds293b", "jks834s2"] + [None] * 8
dataset_context = ["train"] * 5 + ["test"] * 5

for i in range(10):
    with mlflow.start_run():
        mlflow.log_metrics(
            {
                "loss": loss[i],
                "accuracy": accuracy[i],
                "log-scale-loss": log_scale_loss[i],
                "f1 score": f1_score[i],
            }
        )

        mlflow.log_params(
            {
                "batch_size": batch_size[i],
                "learning rate": learning_rate[i],
                "model": model[i],
            }
        )

        mlflow.set_tags(
            {
                "task": task[i],
                "environment": environment[i],
            }
        )

        dataset = mlflow.data.from_numpy(
            features=np.random.uniform(size=[20, 28, 28, 3]),
            targets=np.random.randint(0, 10, size=[20]),
            name=dataset_name[i],
            digest=dataset_digest[i],
        )
        mlflow.log_input(dataset, context=dataset_context[i])

```

The code above creates 10 MLflow runs with different metrics, params, tags and dataset information. After successful execution, if you return to the MLflow UI in your browser, you should find all of these runs under the experiment "search-run-guide", as shown by the following screenshot:

The screenshot shows the MLflow Experiments page. At the top, there's a search bar with the text 'search-run-guide' entered. Below it, a table lists runs. A red circle highlights the 'search-run-guide' experiment in the search bar. Another red circle highlights the table of runs. A red arrow points from the text 'MLflow Experiment' to the search bar. Another red arrow points from the text 'MLflow Runs' to the table. The table has columns: Run Name, Created, Dataset, Duration, Source, and Models. The runs are sorted by 'Created' and are in 'Active' state. The search query is 'metrics.rmse < 1 and params.model = "tree"'. The table shows 10 matching runs.

Run Name	Created	Dataset	Duration	Source	Models
mercurial-shark-477	39 seconds ago	also custom (4965bbbd) Test	26ms	delete.py	-
gaudy-toad-977	39 seconds ago	also custom (6efd27a7) Test	24ms	delete.py	-
puzzled-gnu-272	39 seconds ago	also custom (80b3ed44) Test	25ms	delete.py	-
enthused-ram-468	39 seconds ago	also custom (4b218f0d) Test	25ms	delete.py	-
vaunted-stork-741	40 seconds ago	also custom (cca8b58e) Test	26ms	delete.py	-
nimble-gnat-675	40 seconds ago	custom (65e99d28) Train	26ms	delete.py	-
orderly-quail-568	40 seconds ago	custom (5c432a8b) Train	26ms	delete.py	-
merciful-lynx-301	40 seconds ago	custom (bfc733bd) Train	26ms	delete.py	-

In real-world production deployments of MLflow, it's common to have thousands or even hundreds of thousands of runs. In such cases, it's important to be able to filter and search for runs based on specific criteria.

Search Query Example

In order to filter your MLflow runs, you will need to write **search queries**, which are pseudo-SQL conditions expressed in a distinct syntax.

To showcase this functionality, let's look at the below code examples.

```
import mlflow

all_runs = mlflow.search_runs(search_all_experiments=True)
print(all_runs)
```

```

      run_id  ... tags.mlflow.user
0  5984a3488161440f92de9847e846b342  ...   michael.berk
1  41160f238a5841998dda263794b26067  ...   michael.berk
2  babe221a676b4fa4b204f8240f2c4f14  ...   michael.berk
3  45eb4f02c5a1461aa6098fa550233be6  ...   michael.berk
4  1c7c459486c44b23bb016028aee1f153  ...   michael.berk
5  4453f59f1ab04491bb9582d8cba5f437  ...   michael.berk
6  22db81f070f6413588641c8c343cdd72  ...   michael.berk
7  c3680e37d0fa44eb9c9fb7828f6b5481  ...   michael.berk
8  67973142b9c0470d8d764ada07c5a988  ...   michael.berk
9  59853d5f17f946218f63de1dc82de07b  ...   michael.berk

[10 rows x 19 columns]
```

Second, let's try filtering the runs for our really bad models: `metrics.loss > 0.8`.

```
import mlflow

bad_runs = mlflow.search_runs(
    filter_string="metrics.loss > 0.8", search_all_experiments=True
)
print(bad_runs)
```

```

              run_id  ... tags.mlflow.source.name
0  67973142b9c0470d8d764ada07c5a988  ...          delete.py
1  59853d5f17f946218f63de1dc82de07b  ...          delete.py

[2 rows x 19 columns]
```

You'll notice that we now are displaying 2 runs instead of 10. Pretty easy, right?

Now let's go over the search query syntax in more detail.

Search Query Syntax Deep Dive

As noted above, MLflow search syntax is similar to SQL with a few notable exceptions.

- The SQL `OR` keyword is not supported.
- For fields that contain special characters or start with numbers, you need to wrap them in double quotes.

```
- Bad:  metrics.cross-entropy-loss < 0.5
+ Good: metrics."cross-entropy-loss" < 0.5

- Bad:  params.1st_iteration_timestamp = "2022-01-01"
+ Good: params."1st_iteration_timestamp" = "2022-01-01"
```

- For the SQL `IN` keyword, you must surround the values of your list with single quotes.

```
- Bad:  attributes.run_id IN ("5984a3488161440f92de9847e846b342",
"babe221a676b4fa4b204f8240f2c4f14")
+ Good: attributes.run_id IN ('5984a3488161440f92de9847e846b342',
'babe221a676b4fa4b204f8240f2c4f14')
```

- For the SQL `IN` keyword, you can only search the following fields:
 - `datasets.name`
 - `datasets.digest`
 - `datasets.context`
 - `attributes.run_id`
- Non-None conditions for numeric fields are not supported e.g. `metrics.accuracy != "None"` will fail.

Other than the that, the syntax should be intuitive to anyone who has used SQL. To assemble a single search condition, you must assemble an inequality using the following components...

1. **An MLflow field:** a metric, param, tag, dataset or run metadata.

2. **A comparator:** an inequality operator.

- For numerics, MLflow supports `=`, `!=`, `>`, `>=`, `<`, and `<=`. Examples include:

```
metrics.accuracy > 0.72
metrics.loss <= 0.15
metrics.accuracy != 0.15
```

- For strings, MLflow supports `=`, `!=`, `LIKE` (case-sensitive) and `ILIKE` (case-insensitive). Examples include:

```
params.model = "GPT-3"
params.model LIKE "GPT%"
params.model ILIKE "gpt%"
```

- For sets, MLflow supports `IN`. Examples include:

```
datasets.name IN ('custom', 'also custom', 'another custom name')
datasets.digest IN ('s8ds293b', 'jks834s2')
attributes.run_id IN ('5984a3488161440f92de9847e846b342')
```

3. **A reference value:** a numeric value, string, or set of strings.

Let's look at some more examples.

Example Queries

In this section we will go over how to search by different categories of MLflow fields. For each category we provide a few sample queries. If you have executed the run creation script we provided, these queries should fetch certain runs but sometimes require modification for run-specific information, such as `start_time`.

1 - Searching By Metrics

Metrics are quantitative measures typically used to evaluate the model's performance during or after training. Metrics can include values like accuracy, precision, recall, F1 score, etc., and can change over time as the model trains. They are logged manually via `mlflow.log_metric` or `mlflow.log_metrics` or automatically via autologging.

To search for runs by filtering on metrics, you must include the `metrics` prefix in the left side of the inequality.

Note that they are **stored as numbers**, so you must use numeric comparators.

```
metrics.accuracy > 0.72
metrics."accuracy" > 0.72
metrics.loss <= 0.15
metrics."log-scale-loss" <= 0
metrics."f1 score" >= 0.5
metrics.accuracy > 0.72 AND metrics.loss <= 0.15
```

2 - Searching By Params

Params are strings that typically represent the configuration aspects of the model. Parameters can include values like learning rate, batch size, and number of epochs. They are logged manually via `mlflow.log_param` or `mlflow.log_params` or automatically via autologging.

To search for runs by filtering on params, you must include the `params` prefix in the left side of the inequality. Note that they are **stored as strings**, so you must use string comparators, such as `=` and `!=`.

```
params.batch_size = "2"
params.model LIKE "GPT%"
params.model ILIKE "gPt%"
params.model LIKE "GPT%" AND params.batch_size = "2"
```

3 - Searching By Tags

Tags are metadata that typically provide additional context about the run. Tags can include values like user name, team, etc. They are logged manually via `mlflow.set_tag` or `mlflow.set_tags`. In addition, system tags, such as `mlflow.user`, are automatically logged.

To search for runs by filtering on tags, you must include the `tags` or `mlflow` prefixes in the left side of the inequality. Note that tags are **stored as strings**, so you must use string comparators, such as `=` and `!=`.

```
tags."environment" = "notebook"
tags.environment = "notebook"
tags.task = "Classification"
tags.task ILIKE "classif%"
```

4 - Searching By Dataset Information

Datasets represent data used in model training or evaluation, including features, targets, predictions, and metadata such as the dataset's name, digest (hash) schema, profile, and source. They are logged via `mlflow.log_input` or automatically via autologging.

To search for runs by filtering on dataset information, you must filter on one of the below fields

1. `datasets.name`, which is the dataset's name.
2. `datasets.digest`, which is a unique identifier for the dataset.
3. `datasets.context`, which represents if the dataset is used for train, evaluation or test.

Note that dataset information is **stored as strings**, so you must use string comparators, such as `=` and `!=`. Also note that datasets support set comparators, such as `IN`.

```
datasets.name LIKE "custom"
datasets.digest IN ('s8ds293b', 'jks834s2')
datasets.context = "train"
```

5 - Searching By Run's Metadata

Run metadata are a variety of user-specified and system-generated attributes that provide additional context about the run.

To search for runs by filtering on the metadata of runs, you must include the attributes prefix in the left side of the inequality. Note that run metadata can be either a string or a numeric depending on the attribute, so you must use the appropriate comparator.

To search for runs by filtering on tags, you must include the `tags` or `mlflow` prefixes in the left side of the inequality. Note that tags are **stored as strings**, so you must use string comparators, such as `=` and `!=`.

Examples for Strings

```
attributes.status = 'ACTIVE'
attributes.user_id LIKE 'user1'
attributes.run_name = 'my-run'
attributes.run_id = 'a1b2c3d4'
attributes.run_id IN ('a1b2c3d4', 'e5f6g7h8')
```

Examples for Numerics

```
attributes.start_time >= 1664067852747
attributes.end_time < 1664067852747
attributes.created > 1664067852747
```

6 - Searching over a Set

You can search for runs by filtering on a set of acceptable values via the `IN` keyword. As noted above, this is only supported for the following fields:

- `datasets.{any_attribute}`
- `attributes.run_id`

```
datasets.name IN ('custom', 'also custom')
datasets.digest IN ('s8ds293b', 'jks834s2')
attributes.run_id IN ('a1b2c3d4', 'e5f6g7h8')
```

7 - Chained Queries

You can chain multiple queries together using the `AND` keyword. For example, to search for runs with a variety of conditions, you can use the following queries:

```
metrics.accuracy > 0.72 AND metrics.loss <= 0.15
metrics.accuracy > 0.72 AND metrics.batch_size != 0
metrics.accuracy > 0.72 AND metrics.batch_size != 0 AND attributes.run_id IN
('a1b2c3d4', 'e5f6g7h8')
```

You can also apply multiple conditions on the same field, for example searching for all loss metrics `BETWEEN` 0.1 and 0.15, inclusive:

```
metrics.loss <= 0.15 AND metrics.loss >= 0.1
```

Finally, before moving on it's important to revisit that that you cannot use the `OR` keyword in your queries.

8 - Non-None Queries

To search for runs where a field (only type string is supported) is not null, use the `field != "None"` syntax. For example, to search for runs where the `batch_size` is not null, you can use the following query:

```
params.batch_size != "None"
```

Programmatically Searching Runs

When scaling out to large production systems, typically you'll want to interact with your runs outside the MLflow UI. This can be done programmatically using the MLflow client APIs.

Python

`mlflow.client.MlflowClient.search_runs()` or `mlflow.search_runs()` take the same arguments as the above UI examples and more! They return all the runs that match the specified filters.

1 - Complex Filter

Python provides powerful ways to build these queries programmatically. Some tips:

- For complex filters, specifically those with both single and double quotes, use multi-line strings or `\` to escape the quotes.
- When working with lists, use the `.join()` method to concatenate the list elements with a delimiter.
- It's often most concise to use the fluent APIs, so below we demo only with the fluent API.

```
import mlflow

run_ids = ["UPDATE_RUNID_HERE", "UPDATE_RUNID2_HERE"]
run_id_condition = "'" + "','".join(run_ids) + "'"

complex_filter = f"""
attributes.run_id IN ({run_id_condition})
AND metrics.loss > 0.3
AND metrics."f1 score" < 0.5
AND params.model LIKE "GPT%"
"""

runs_with_complex_filter = mlflow.search_runs(
    experiment_names=["search-run-guide"],
    filter_string=complex_filter,
)
print(runs_with_complex_filter)
```

The output will be a pandas DataFrame with the runs that match the specified filters, as shown below.

```
           run_id  ... tags.mlflow.runName
0  22db81f070f6413588641c8c343cdd72  ...   orderly-quail-568
1  c3680e37d0fa44eb9c9fb7828f6b5481  ...   melodic-lynx-301

[2 rows x 19 columns]
```

2 - run_view_type

The `run_view_type` parameter exposes additional filtering options, as noted in the `mlflow.entities.ViewType` enum. For example, if you want to filter only active runs, which is a dropdown in the UI, simply pass

```
run_view_type=ViewType.ACTIVE_ONLY.
```

```
import mlflow
from mlflow.entities import ViewType

active_runs = mlflow.search_runs(
    experiment_names=["search-run-guide"],
    run_view_type=ViewType.ACTIVE_ONLY,
```



```
    order_by=["metrics.accuracy DESC"],
)
```

2 - Ordering

Another useful feature that is available in the search API is allowing for ordering of the returned search results. You can specify a list of columns of interest along with `DESC` or `ASC` in the `order_by` kwarg. Note that the `DESC` or `ASC` value is optional, so when the value is not provided, the default is `ASC`. Also note that the default ordering when the `order_by` parameter is omitted is to sort by `start_time DESC`, then `run_id ASC`.

```
import mlflow
from mlflow.entities import ViewType

active_runs_ordered_by_accuracy = mlflow.search_runs(
    experiment_names=["search-run-guide"],
    run_view_type=ViewType.ACTIVE_ONLY,
    order_by=["metrics.accuracy DESC"],
)

active_runs_ordered_by_accuracy
```

A common use case is getting the top n results, for example, the top 5 runs by accuracy. When combined with the `max_results` parameter, you can get the top n that match your query.

```
import mlflow
from mlflow.entities import ViewType

highest_accuracy_run = mlflow.search_runs(
    experiment_names=["search-run-guide"],
    run_view_type=ViewType.ACTIVE_ONLY,
    max_results=1,
    order_by=["metrics.accuracy DESC"],
)
```

Print output:

```
highest_accuracy_run
```

3 - Searching All Experiments

Now you might be wondering how to search all experiments. It's as simple as specifying `search_all_experiments=True` and omitting the `experiment_ids` parameter.

```
import mlflow
from mlflow.entities import ViewType

model_of_interest = "GPT-4"
gpt_4_runs_global = mlflow.search_runs(
    filter_string=f"params.model = '{model_of_interest}'",
    run_view_type=ViewType.ALL,
    search_all_experiments=True,
)
```

Print output:

gpt_4_runs_global