Pattern Matching with MATCH_RECOGNIZE

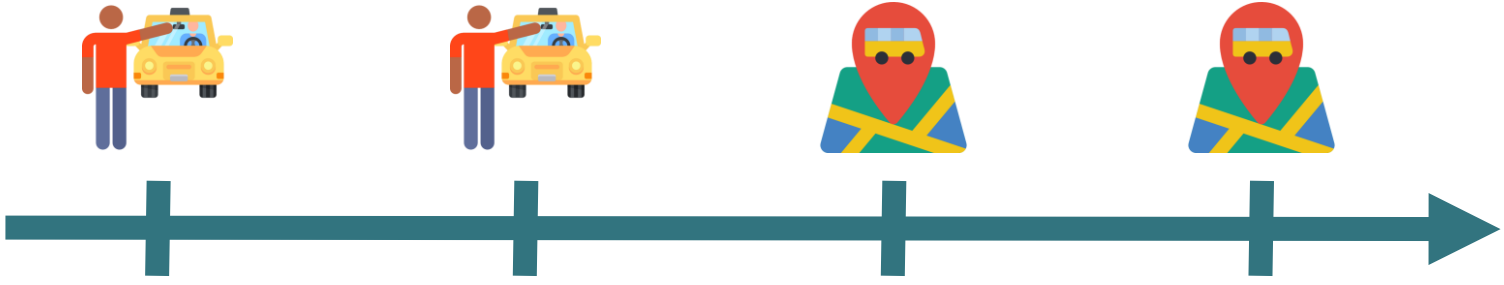
Flink SQL Training

https://github.com/ververica/sql-training

ververica

How can I detect Patterns in SQL?

- Find taxi rides with mid-stops



MATCH_RECOGNIZE

SQL:2016

Row Pattern Recognition in SQL

- Flink comes with a complex event processing (CEP) library
- MATCH_RECOGNIZE clause allows to consolidate CEP and SQL API
- Can be applied to append-only tables that define a time attribute

Common Use-Cases

- Stock market analysis
- Customer behavior
- Tracking money laundering
- Service quality
- Network intrusion detection
- …

Position in a SQL Query

SELECT …

FROM …

MATCH_RECOGNIZE (…)

WHERE …

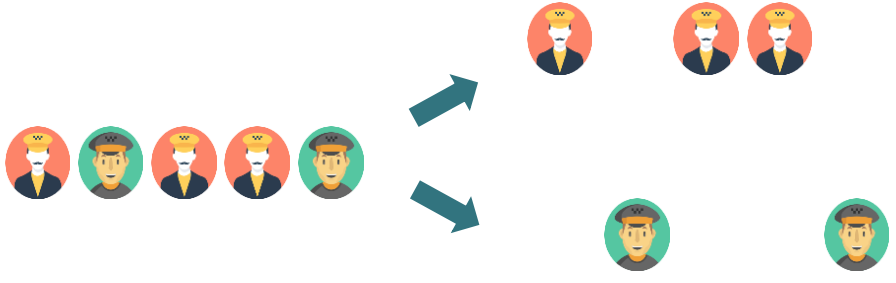
GROUP BY …

Example: Rides with Mid-Stops

```
SELECT *
FROM Rides
MATCH_RECOGNIZE (
      PARTITION BY taxiId
      ORDER BY rideTime
      MEASURES
            S.rideId as sRideId
      AFTER MATCH SKIP PAST LAST ROW
      PATTERN (S E)
      DEFINE
            S AS S.isStart = true,
            E AS E.isStart = true
)
```

partition the data by given field

similar to GROUP BY or keyBy()

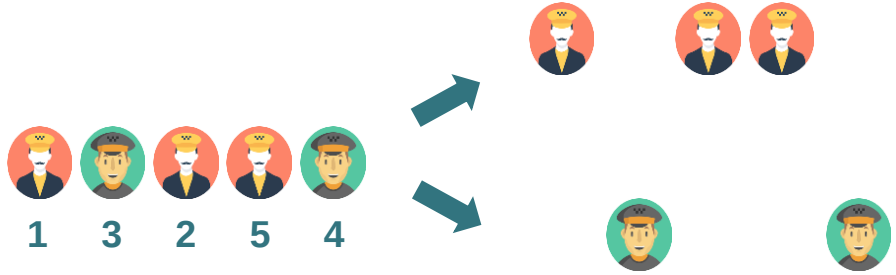


Example: Rides with Mid-Stops

```
SELECT *
FROM Rides
MATCH_RECOGNIZE (
    PARTITION BY taxiId
    ORDER BY rideTime
    MEASURES
        S.rideId as sRideId
    AFTER MATCH SKIP PAST LAST ROW
    PATTERN (S E)
    DEFINE
        S AS S.isStart = true,
        E AS E.isStart = true
)
```

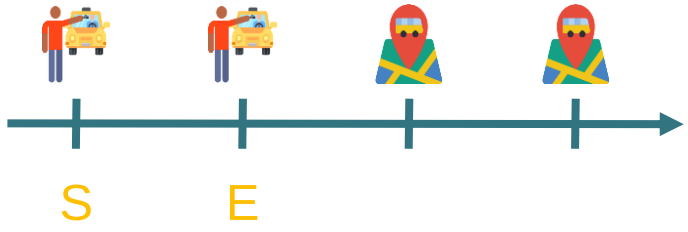
specify order

primary order = Event or Processing time



Example: Rides with Mid-Stops

```
SELECT *
FROM Rides
MATCH_RECOGNIZE (
      PARTITION BY taxiId
      ORDER BY rideTime
      MEASURES
            S.rideId as sRideId
      AFTER MATCH SKIP PAST LAST ROW
      PATTERN (S E)
      DEFINE
            S AS S.isStart = true,
        E AS E.isStart = true
)
```



construct a pattern

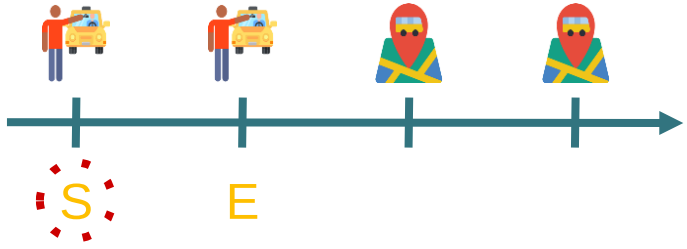
with a regular expression-like syntax

Example: Rides with Mid-Stops

```
SELECT *
FROM Rides
MATCH_RECOGNIZE (
    PARTITION BY taxiId
    ORDER BY rideTime
    MEASURES
        S.rideId as sRideId
    AFTER MATCH SKIP PAST LAST ROW
    PATTERN (S E)
    DEFINE
      S AS S.isStart = true,
      E AS E.isStart = true
)
```

extract measures from matched sequence

defines output of the clause; similar to a SELECT clause



MATCH_RECOGNIZE in detail

```
MATCH_RECOGNIZE (
  PARTITION BY …

  ORDER BY …

  MEASURES …

  ONE ROW PER MATCH

  AFTER MATCH SKIP …

  PATTERN …

  DEFINE …
)
```

PATTERN: Defining a Pattern

- Constructed from basic building blocks, called *pattern variables*

```
PATTERN (A B+ C* D)
```

- Operators (quantifiers and other modifiers) can be applied

- DEFINE assigns a meaning to pattern variables

PATTERN: Defining a Pattern

- *Concatenation:*
  - All rows of a pattern must be mapped to pattern variables
  - A pattern like (A B) means that the contiguity is strict between A and B
  - In other words: No rows between A and B
- *Quantifiers*
  - Number of rows mapped to a pattern variable

*	0 or more rows
+	1 or more rows
?	0 or 1 rows
{ n }, { n, }, { n, m }, { , m }	Define intervals (inclusive)
B*?	Perform mapping *reluctant* instead of *greedy* (default behavior)

DEFINE/MEASURES: Define/Access Variables

- MEASURES
  - Defines what will be included in the output of a matching pattern
  - Project columns and define expressions for evaluation
  - Number of produced rows depends on the output mode.

    Currently, ONE ROW PER MATCH = one output summary row per match only
  - Output schema: *[partitioning columns] + [measures columns]*

- DEFINE
  - Conditions that a row has to fulfill to be classified to the corresponding variable
  - No condition for a variable evaluates to *TRUE*

DEFINE/MEASURES: Define/Access Variables

- *Pattern Variable Referencing*
  - Access to the set of rows mapped to a particular pattern variable (so far)
  - A.price = set of rows mapped so far to A plus the current row if we try to match the current row to A
  - If A is a set, the last row is selected for scalar operations.
  - If no pattern variable is specified (e.g. SUM(price)), the default pattern variable "*" is used. This set contains all rows matched for pattern + current row.

```
PATTERN (A B+)
DEFINE
  A AS A.price > 10,
  B AS B.price > A.price AND
    SUM(price) < 100 AND SUM(B.price) < 80
```

DEFINE/MEASURES: Define/Access Variables

- *Pattern Variable Navigation*
  - Logical offsets enable navigation within the events that were mapped to a particular pattern variable.
  - FIRST(variable.field, n) n starts from the beginning
  - LAST(variable.field, n) n starts from the end

```
PATTERN (A B+)
DEFINE
  A AS A.price > 10,
  B AS (LAST(B.price, 1) IS NULL OR B.price > LAST(B.price, 1)) AND
    (LAST(B.price, 2) IS NULL OR B.price > 2 * LAST(B.price, 2))
```

  - Expressions on same "list" are supported: LAST(A.price * A.tax)

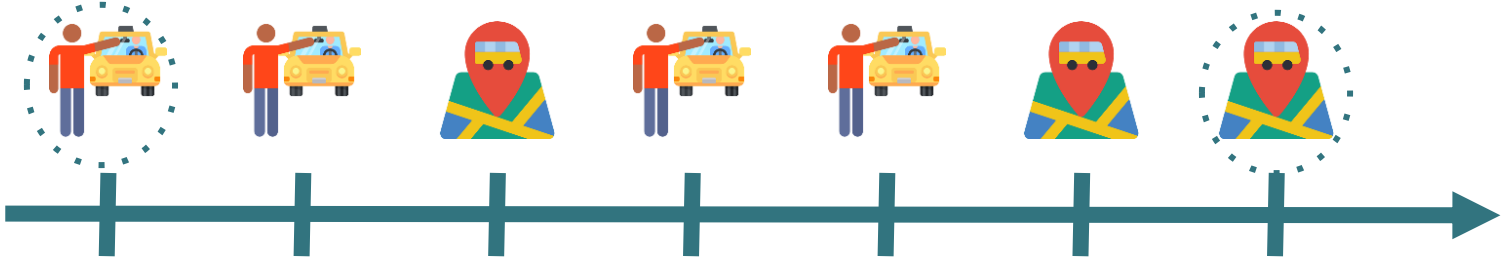
AFTER MATCH SKIP: Continuation strategy

- Location where to start a new matching procedure after a complete match was found

SKIP PAST LAST ROW	next row after the last row of the current match
SKIP TO NEXT ROW	next row after the starting row of the match
SKIP TO LAST variable	last row that is mapped to the specified pattern variable
SKIP TO FIRST variable	first row that is mapped to the specified pattern variable

- Thus, also specifies how many matches a single event can belong to

Example: Multi-Stop

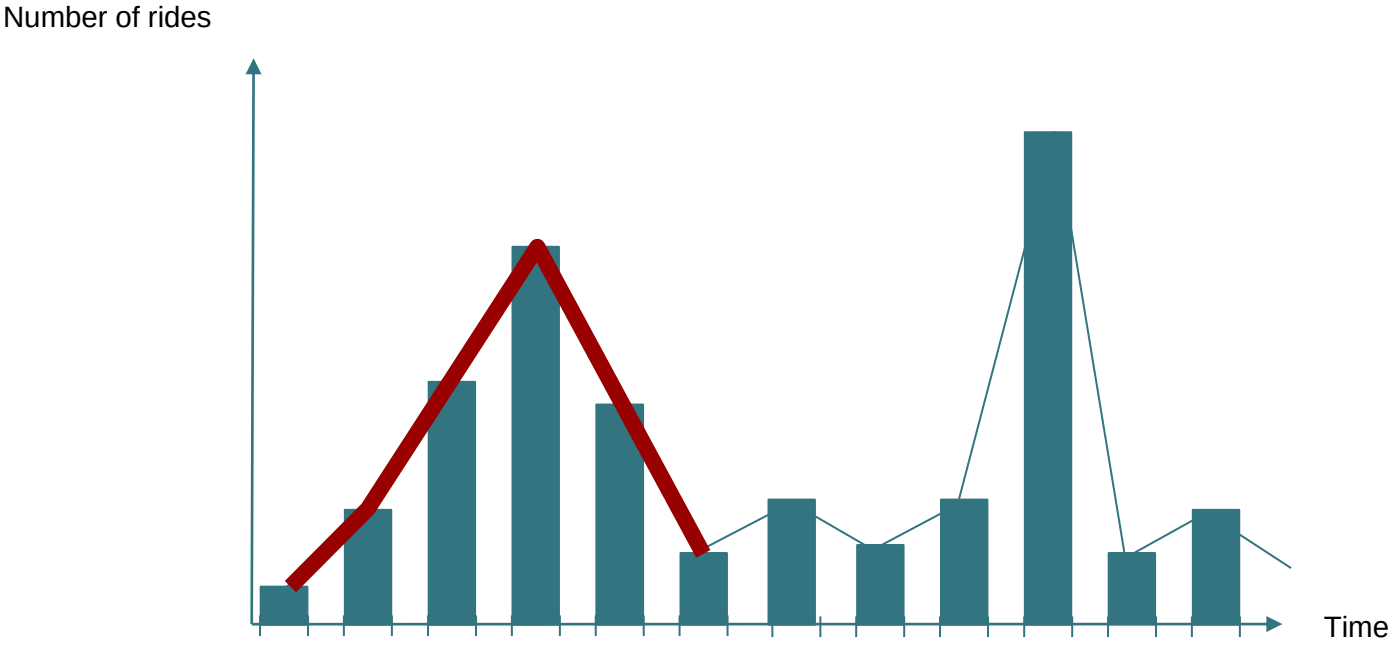


Rides with More Than One Mid-Stop

```
SELECT *
FROM Rides
MATCH_RECOGNIZE (
    PARTITION BY taxiId
    ORDER BY rideTime
    MEASURES
        S.rideId as sRideId
    AFTER MATCH SKIP PAST LAST ROW
    PATTERN (S E)
    DEFINE
      S AS S.isStart = true,
      E AS E.isStart = true
)
```

```
SELECT *
FROM Rides
MATCH_RECOGNIZE (
    PARTITION BY taxiId
    ORDER BY rideTime
    MEASURES
        S.rideId as sRideId,
        COUNT(M.rideId) as countMidStops
    AFTER MATCH SKIP PAST LAST ROW
    PATTERN (S M{2,} E)
    DEFINE
      S AS S.isStart = true,
      M AS M.rideId <> S.rideId,
      E AS E.isStart = false AND
    E.rideId = S.rideId
)
```

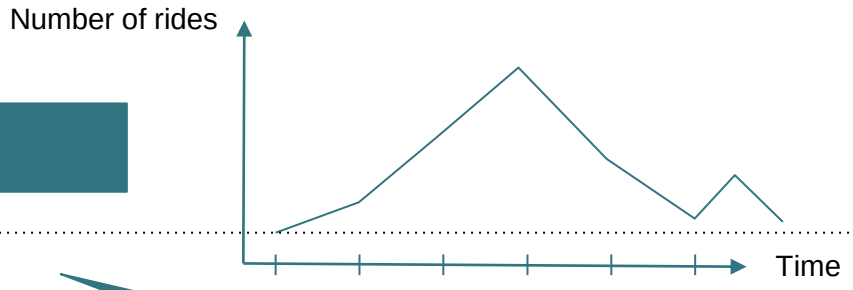
Example: Rush (peak) hours - V shape



Statistics per Area

```
CREATE VIEW RidesInArea AS
SELECT
    toAreaId(lat, lon) as cellId,
    COUNT(distinct rideId) as rideCount,
    TUMBLE_ROWTIME(rideTime, INTERVAL '30' minute) AS rowTime,
    TUMBLE_START(rideTime, INTERVAL '30' minute) AS startTime,
    TUMBLE_END(rideTime, INTERVAL '30' minute) AS endTime
FROM
    Rides
GROUP BY
    toAreaId(lat, lon),
    TUMBLE(rideTime, INTERVAL '30' minute)
```

Rush (peak) hours



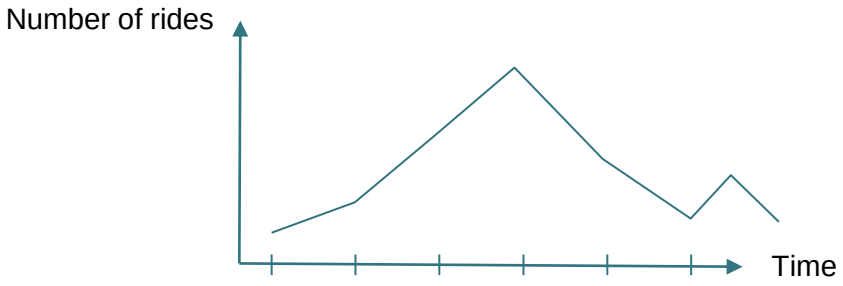
SELECT * FROM RidesInArea

Use previous view.

```
MATCH_RECOGNIZE(
        PARTITION BY cellId
        ORDER BY rowTime
        MEASURES
          FIRST(UP.startTime) as rushStart,
          LAST(DOWN.endTime) AS rushEnd,
          SUM(UP.rideCount) + SUM(DOWN.rideCount) AS rideSum
        AFTER MATCH SKIP PAST LAST ROW
        PATTERN (UP{4,} DOWN{2,} E)
        DEFINE
          UP AS UP.rideCount > LAST(UP.rideCount, 1) OR
            LAST(UP.rideCount, 1) IS NULL,
          DOWN AS DOWN.rideCount < LAST(DOWN.rideCount, 1) OR
                    LAST(DOWN.rideCount, 1) IS NULL,
          E AS E.rideCount > LAST(DOWN.rideCount)
)
```

Apply match to result of the inner query.

Rush (peak) hours

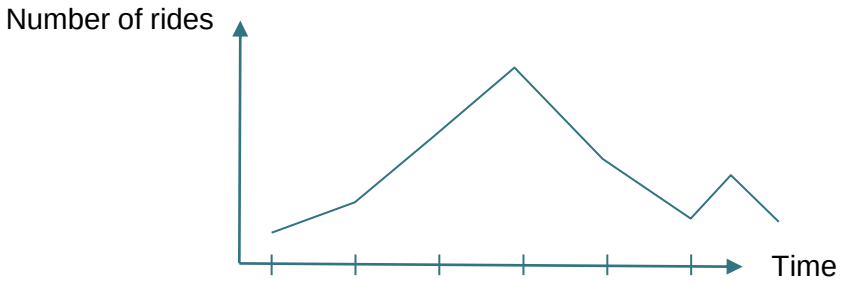



```
SELECT * FROM RidesInArea

MATCH_RECOGNIZE(
        PARTITION BY cellId
        ORDER BY rowTime
        MEASURES
          FIRST(UP.startTime) as rushStart,
          LAST(DOWN.endTime) AS rushEnd,
          SUM(UP.rideCount) + SUM(DOWN.rideCount) AS rideSum
        AFTER MATCH SKIP PAST LAST ROW
        PATTERN (UP{4,} DOWN{2,} E)
        DEFINE
          UP AS UP.rideCount > LAST(UP.rideCount, 1) OR
            LAST(UP.rideCount, 1) IS NULL,
          DOWN AS DOWN.rideCount < LAST(DOWN.rideCount, 1) OR
                    LAST(DOWN.rideCount, 1) IS NULL,
          E AS E.rideCount > LAST(DOWN.rideCount)
)
```

Access elements of looping pattern.

Rush (peak) hours




```
SELECT * FROM RidesInArea

MATCH_RECOGNIZE(
        PARTITION BY cellId
        ORDER BY rowTime
        MEASURES
          FIRST(UP.startTime) as rushStart,
          LAST(DOWN.endTime) AS rushEnd,
          SUM(UP.rideCount) + SUM(DOWN.rideCount) AS rideSum
        AFTER MATCH SKIP PAST LAST ROW
        PATTERN (UP{4,} DOWN{2,} E)
        DEFINE
          UP AS UP.rideCount > LAST(UP.rideCount, 1) OR
            LAST(UP.rideCount, 1) IS NULL,
          DOWN AS DOWN.rideCount < LAST(DOWN.rideCount, 1) OR
                    LAST(DOWN.rideCount, 1) IS NULL,
          E AS E.rideCount > LAST(DOWN.rideCount)
)
```

Aggregate values from looping patterns

Feature set of MATCH_RECOGNIZE

- Quantifiers support
  - +, *, {x,y} , Greedy (default), ? (reluctant)
  - With some restrictions (not working for last pattern)
- After Match Skip
  - Skip to first/last, skip past last, skip to next
- Aggregates and UDFs
- Allow time attribute extraction
- Time constraints using the WITHIN clause
- Not supported: alter(|), permute, exclude ‘{- -}’

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