
# CDC Stream Processing with Apache Flink®

## A peek under the hood of a changelog engine

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# About me

## Open source

- Long-term committer since 2014 (before ASF)
- Member of the project management committee (PMC)
- Top 5 contributor (commits), top 1 contributor (additions)
- Among core architects of Flink SQL

## Career

- Early Software Engineer @ DataArtisans (acquired by Alibaba)
- SDK Team, SQL Team Lead @ Ververica
- Co-Founder @ Immerok (acquired by Confluent)
- Principal Software Engineer @ Confluent


# What is Apache Flink?

# Building Blocks for Stream Processing

## Streams

- Pipeline
- Distribute
- Join
- Enrich
- Control
- Replay

## Time

- Synchronize
- Progress
- Wait
- Timeout
- Fast-forward
- Replay

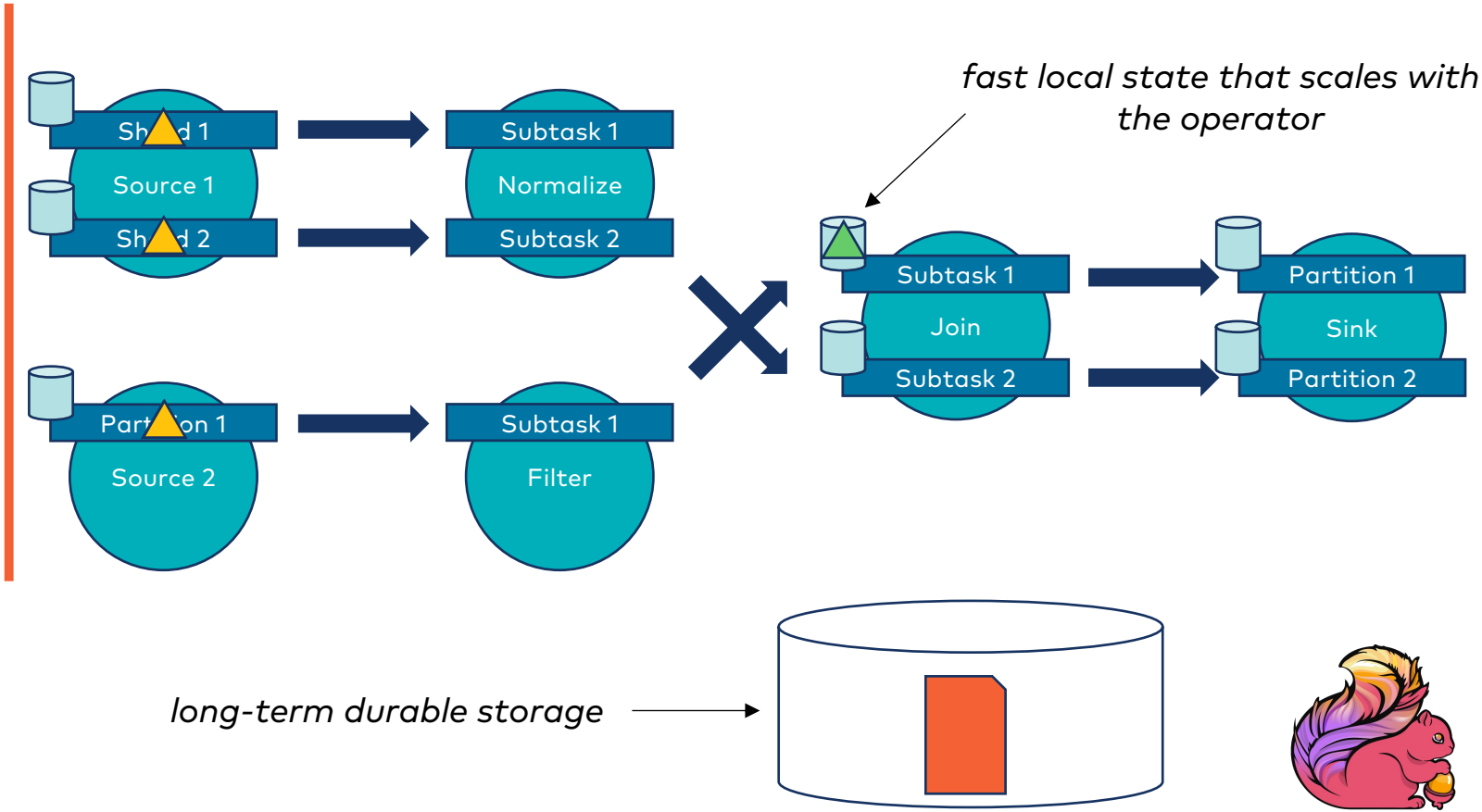
## State

- Store
- Buffer
- Cache
- Model
- Grow
- Expire

## Snapshots

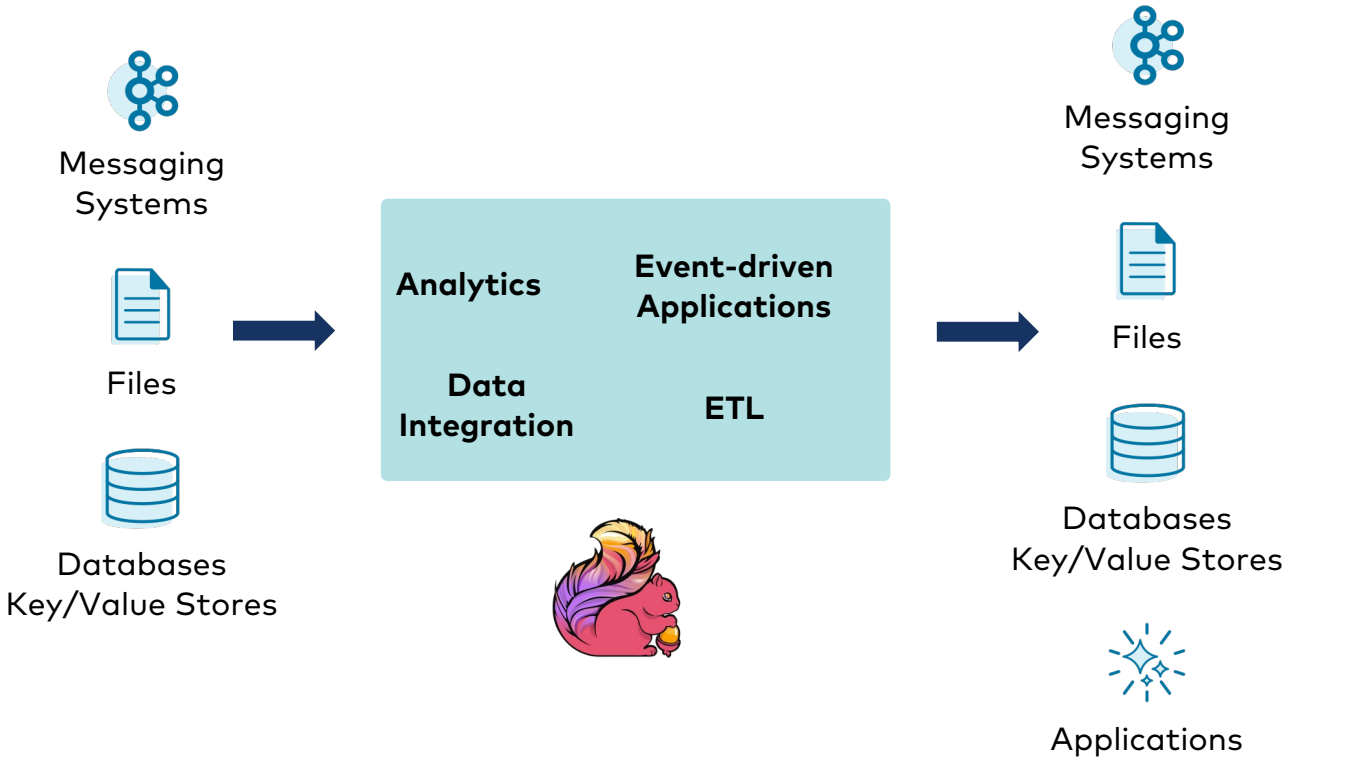
- Backup
- Version
- Fork
- A/B test
- Time-travel
- Restore

# What makes Apache Flink unique?



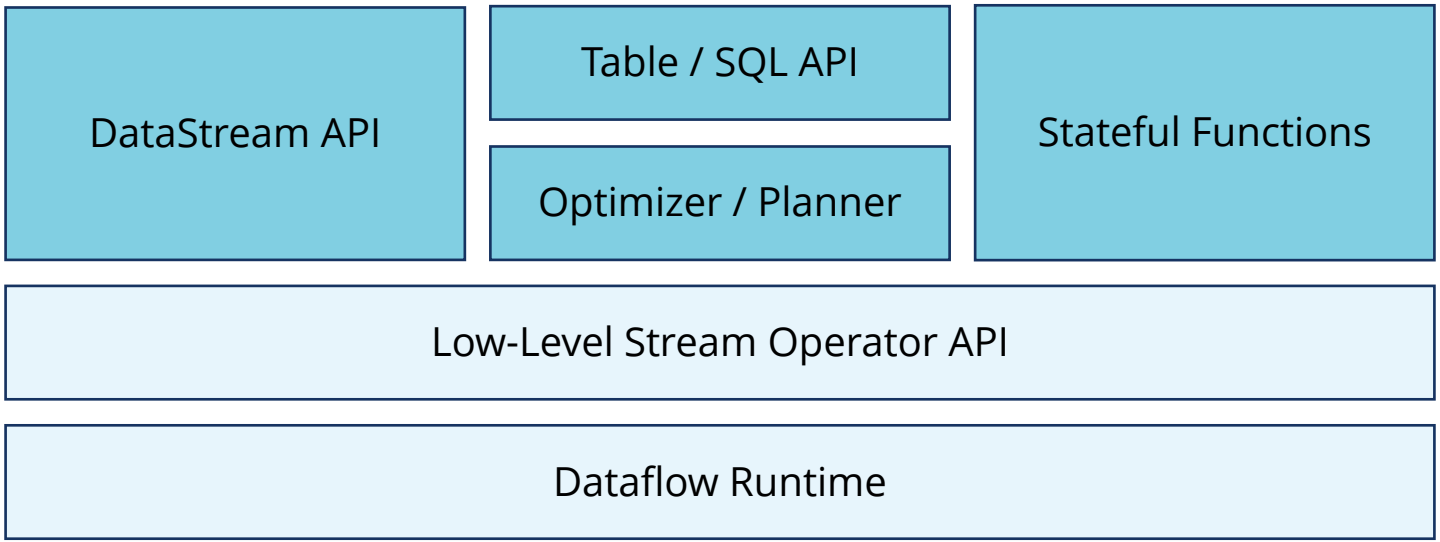
# What is Apache Flink used for?

- Transactions
- Logs
- IoT
- Events
- Interactions
- ...




# Apache Flink's APIs

# API Stack


DataStream API
Table / SQL API
Optimizer / Planner
Stateful Functions
Low-Level Stream Operator API
Dataflow Runtime

# DataStream API

```
StreamExecutionEnvironment env = StreamExecutionEnvironment.getExecutionEnvironment();

env.setRuntimeMode(STREAMING);

DataStream<Integer> stream = env.fromElements(1, 2, 3);

stream.executeAndCollect().forEachRemaining(System.out::println);
```

***Output***

```
1
2
3
```

## Properties

- **Exposes** the building blocks for stream processing
- Arbitrary operator **topologies** using map(), process(), connect(), ...
- Business logic is written in **user-defined functions**
- Arbitrary **user-defined record** types flow in-between
- Conceptually always an **append-only / insert-only** log!

# Table / SQL API

```
TableEnvironment env = TableEnvironment.create(EnvironmentSettings.inStreamingMode());

// Programmatic
Table table = env.fromValues(row(1), row(2), row(3));

// SQL
Table table = env.sqlQuery("SELECT * FROM (VALUES (1), (2), (3))");

table.execute().print();
```

***Output***

```
+----+-------------+
| op |          f0 |
+----+-------------+
| +I |           1 |
| +I |           2 |
| +I |           3 |
```

## Properties

- **Abstracts** the building blocks for stream processing
- Operator topology is determined by **planner**
- Business logic is **declared** in SQL and/or Table API
- Internal record types flow, **Flink's `Row` type** is exposed in Table API
- Conceptually a table, but a **changelog** under the hood!

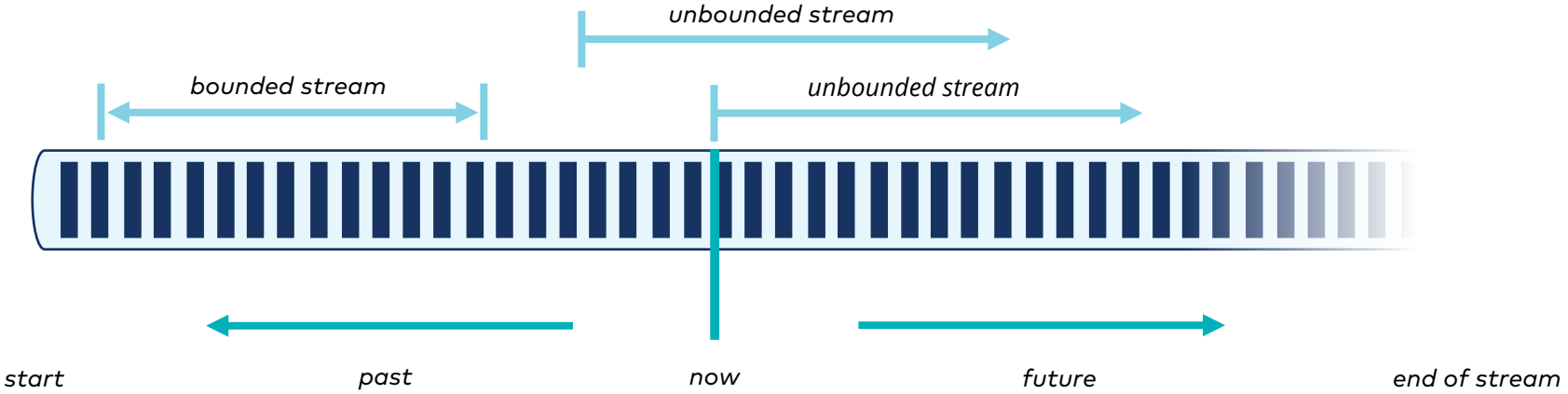
# DataStream API ↔ Table / SQL API

## Mix and match APIs!

```
StreamExecutionEnvironment env = StreamExecutionEnvironment.getExecutionEnvironment();

StreamTableEnvironment tableEnv = StreamTableEnvironment.create(env);

// Stream -> Table
DataStream<?> inStream1 = ...
Table appendOnlyTable = tableEnv.fromDataStream(inStream1)

DataStream<Row> inStream2 = ...
Table anyTable = tableEnv.fromChangelogStream(inStream2)


// Table -> Stream
DataStream<T> appendOnlyStream = tableEnv.toDataStream(insertOnlyTable, T.class)

DataStream<Row> changelogStream = tableEnv.toChangelogStream(anyTable)
```


# Changelog Stream Processing

# Data Processing is a Stream of Changes




- Business data is always a stream: **bounded** or **unbounded**
- Every record is a changelog entry: **insertion as the default**
- Batch processing is just a **special case** in the runtime

# How do I Work with Streams in Flink SQL?

- You don't. You work with **dynamic tables**!
- A concept similar to **materialized views**

```
CREATE TABLE Transactions
  (name STRING, amount INT)
  WITH (…)
```

| name | amount |
|---|---|
| Alice | 56 |
| Bob | 10 |
| Alice | 89 |

```
INSERT INTO Revenue
SELECT name, SUM(amount)
FROM Transactions
GROUP BY name
```

```
CREATE TABLE Revenue
 (name STRING, total INT)
 WITH (…)
```

| name | total |
|---|---|
| Alice | 145 |
| Bob | 10 |

**So, is Flink SQL a database?**

**No, bring your own data and systems!**

# Stream-Table Duality - Basics

- A stream is the changelog of a **dynamic table**
- Sources, operators, and sinks work on **changelogs under the hood**

| Short name | Long name | Semantics |
|---|---|---|
| `+I` | Insertion | Default for scans + output of bounded results. |
| `-U` | Update Before | Retracts a previously emitted result. |
| `+U` | Update After | Updates a previously emitted result.<br>Requires a primary key if -U is omitted for idempotent updates. |
| `-D` | Delete | Removes the last result. |

- Each component declares the **kind of changes it consumes/produces**

| | |
|---|---|
| only `+I` | Appending/Insert-only |
| contains `-…` | Updating |
| contains `-U` | Retracting |
| never `-U` but `+U` | Upserting |

# Stream-Table Duality - Example

## An applied changelog becomes a real (materialized) table.

```
CREATE TABLE Transactions
  (name STRING, amount INT)
  WITH (…)
```

```
CREATE TABLE Revenue
 (name STRING, total INT)
 WITH (…)
```

| name | amount |
|---|---|
| Alice | 56 |
| Bob | 10 |
| Alice | 89 |

```
INSERT INTO Revenue
SELECT name, SUM(amount)
FROM Transactions
GROUP BY name
```

| name | total |
|---|---|
| Alice | 145 |
| Bob | 10 |

*materialization*

+I[Alice, 89] +I[Bob, 10] +I[Alice, 56]

+U[Alice, 145] -U[Alice, 56] +I[Bob, 10] +I[Alice, 56]

*changelog*

# Stream-Table Duality - Example

## An applied changelog becomes a real (materialized) table.

```
CREATE TABLE Transactions
  (name STRING, amount INT)
  WITH (…)
```

```
CREATE TABLE Revenue
 (PRIMARY KEY(name) …)
 WITH (…)
```

| name | amount |
|---|---|
| Alice | 56 |
| Bob | 10 |
| Alice | 89 |

```
INSERT INTO Revenue
SELECT name, SUM(amount)
FROM Transactions
GROUP BY name
```

| name | total |
|---|---|
| Alice | 145 |
| Bob | 10 |

*materialization*



## Save ~50% of traffic if downstream system supports upserting!

# Stream-Table Duality - Propagation

- Source declares set of emitted changes i.e. **changelog mode**

  `CREATE TABLE …` *(for sources)*

  `… WITH ('connector'='filesystem')` **+I**

  `… WITH ('connector'='kafka')` **+I**

  `… WITH ('connector'='kafka-upsert')` **+I** **-D**

  `… WITH ('connector'='jdbc')` **+I**

  `… WITH ('connector'='kafka', 'format' = 'debezium-json')` **+I** **-U** **+U** **-D**

- **Optimizer tracks** changelog mode and primary key through pipeline
- Sink declares changes it **can digest**

# Retract vs. Upsert

## Retract

- No primary key requirements
- Works for almost every external system
- Supports duplicate rows
- In distributed system often unavoidable

→ **most flexible changelog mode**

→ **default mode**

```
SELECT c, COUNT(*) FROM (
  SELECT COUNT(*) AS c
  FROM T
  GROUP BY user
)
GROUP BY c
```


## Upsert

- Traffic + computation **optimization**
- In-place updates (**idempotency**)

# Changelog Insights – Append-only

```
CREATE TABLE Transaction (tid BIGINT, amount INT);
CREATE TABLE Payment (tid BIGINT, method STRING);
CREATE TABLE Result (tid BIGINT, …); // accepts all changes
INSERT INTO Result SELECT * FROM Transactions T JOIN Payments P ON T.tid = P.tid;

Sink(table=[Result], changelogMode=[NONE])
+- Join(leftInputSpec=[NoUniqueKey], rightInputSpec=[NoUniqueKey], changelogMode=[I])
   :- Exchange(changelogMode=[I])
   :  +- TableSourceScan(table=[[Transaction]], changelogMode=[I])
   +- Exchange(changelogMode=[I])
      +- TableSourceScan(table=[[Payment]], changelogMode=[I])
```

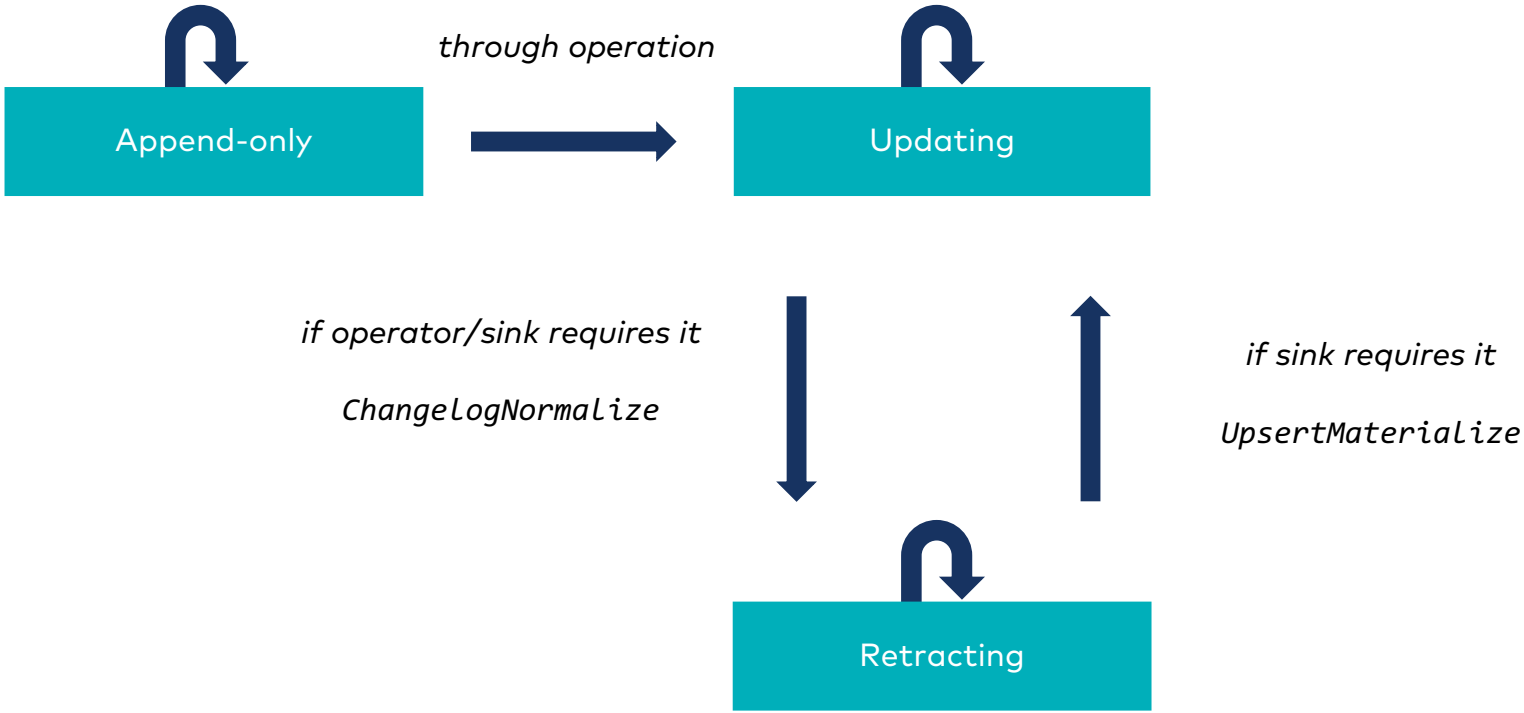
# Changelog Insights – Updating

```
CREATE TABLE Transaction (tid BIGINT, amount INT);
CREATE TABLE Payment (tid BIGINT, method STRING);
CREATE TABLE Result (tid BIGINT, …);
INSERT INTO Result SELECT * FROM Transactions T LEFT JOIN Payments P ON T.tid = P.tid;

Sink(table=[Result], changelogMode=[NONE])
+- Join(leftInputSpec=[NoUniqueKey], rightInputSpec=[NoUniqueKey], changelogMode=[I,UB,UA,D])
   :- Exchange(changelogMode=[I])
   :  +- TableSourceScan(table=[[Transaction]], changelogMode=[I])
   +- Exchange(changelogMode=[I])
      +- TableSourceScan(table=[[Payment]], changelogMode=[I])
```

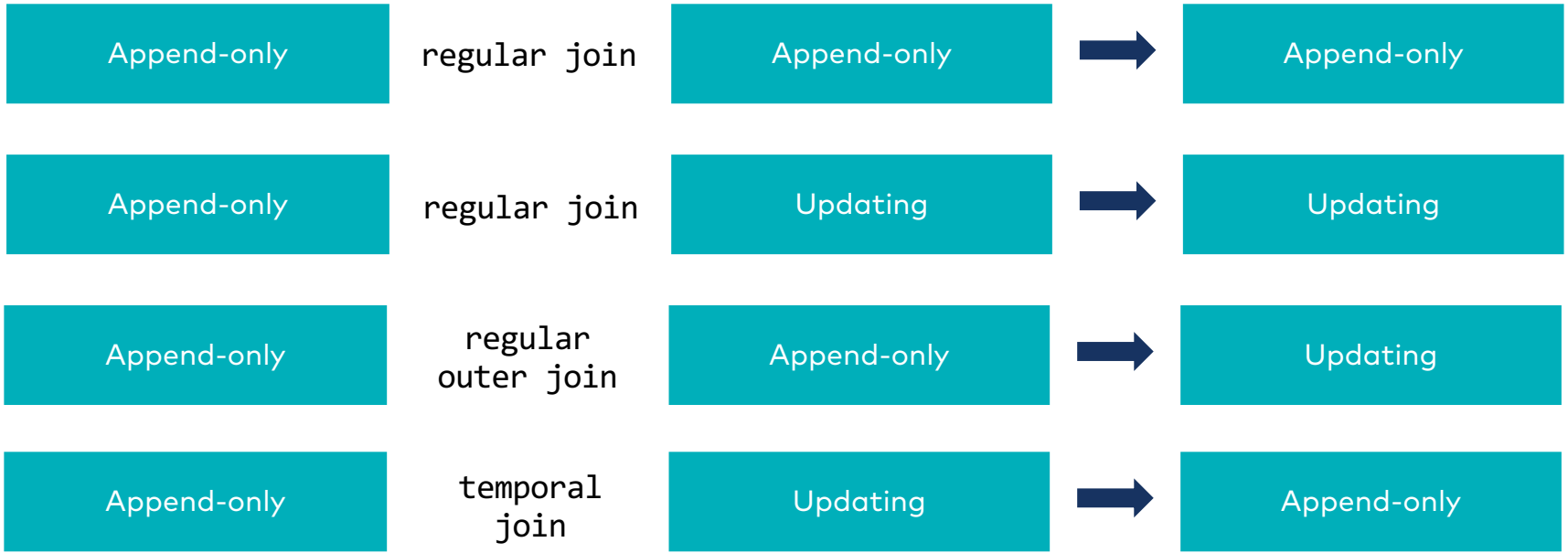
# Changelog Insights – Updating with PK

```
CREATE TABLE Transaction (tid BIGINT, …, PRIMARY KEY(tid) NOT ENFORCED);
CREATE TABLE Payment (tid BIGINT, …, PRIMARY KEY(tid) NOT ENFORCED);
CREATE TABLE Result (tid BIGINT, …, PRIMARY KEY(tid) NOT ENFORCED);
INSERT INTO Result SELECT * FROM Transactions T LEFT JOIN Payments P ON T.tid = P.tid;

Sink(table=[Result], changelogMode=[NONE])
+- Join(leftInputSpec=[UniqueKey], rightInputSpec=[UniqueKey], changelogMode=[I,UA,D])
   :- Exchange(changelogMode=[I])
   :  +- TableSourceScan(table=[[Transaction]], changelogMode=[I])
   +- Exchange(changelogMode=[I])
      +- TableSourceScan(table=[[Payment]], changelogMode=[I])
```

# Mode Transitions



# Mode Transitions – Joins



# Mode Transitions – Temporal Join

```
CREATE TABLE CurrencyRates (
  WATERMARK FOR update_time AS …, PRIMARY KEY(currency) NOT ENFORCED,…);

SELECT
  order_id,
  price,
  currency,
  conversion_rate,
  order_time
FROM Orders
LEFT JOIN CurrencyRates FOR SYSTEM_TIME AS OF Orders.order_time
ON Orders.currency = CurrencyRates.currency;
```


# Demo

https://github.com/twalthr/flink-api-examples

# Summary

## TLDR

- Flink's SQL engine is a powerful changelog processor
- Flexible tool for integrating systems with different semantics

## There is more...

- **Large coverage of the SQL standard**
  → `OVER` for streaming aggregation and dedup
  → `MATCH_RECOGNIZE` for pattern matching
  → `TUMBLE/HOP/SESSION` for windowing
  → ...
- **CDC connector ecosystem**
  → 3.5k Github stars
  https://flink-packages.org/packages/cdc-connectors
- **Table Store**
  → unified storage engine for dynamic tables
  https://nightlies.apache.org/flink/flink-table-store-docs-master/docs/concepts/overview/

| Connector | Database | Driver |
|---|---|---|
| mongodb-cdc | • MongoDB: 3.6, 4.x, 5.0 | MongoDB Driver: 4.3.1 |
| mysql-cdc | • MySQL: 5.6, 5.7, 8.0.x<br>• RDS MySQL: 5.6, 5.7, 8.0.x<br>• PolarDB MySQL: 5.6, 5.7, 8.0.x<br>• Aurora MySQL: 5.6, 5.7, 8.0.x<br>• MariaDB: 10.x<br>• PolarDB X: 2.0.1 | JDBC Driver: 8.0.27 |
| oceanbase-cdc | • OceanBase CE: 3.1.x<br>• OceanBase EE (MySQL mode): 2.x, 3.x | JDBC Driver: 5.1.4x |
| oracle-cdc | • Oracle: 11, 12, 19 | Oracle Driver: 19.3.0.0 |
| postgres-cdc | • PostgreSQL: 9.6, 10, 11, 12 | JDBC Driver: 42.2.27 |
| sqlserver-cdc | • Sqlserver: 2012, 2014, 2016, 2017, 2019 | JDBC Driver: 7.2.2.jre8 |
| tidb-cdc | • TiDB: 5.1.x, 5.2.x, 5.3.x, 5.4.x, 6.0.0 | JDBC Driver: 8.0.27 |
| Db2-cdc | • Db2: 11.5 | Db2 Driver: 11.5.0.0 |


# Thank you!

**Feel free to follow:**

**@twalthr**

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