One SQL to Rule them All

an Efficient and Syntactically Idiomatic Approach to Management of Streams and Tables

https://arxiv.org/pdf/1905.12133.pdf

Edmon Begoli, Tyler Akidau, Fabian Hueske, Julian Hyde, Kathryn Knight, Kenneth Knowles

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slides authored by Tyler Akidau & Fabian Hueske.

Slides: https://s.apache.org/streaming-sql-beam-summit-berlin-2019

Background

- Apache Flink and Beam communities have been working on SQL support
  - Leveraging Apache Calcite as building block
- All three communities aim for unified batch/streaming semantics for SQL
  - Frequent exchange among communities
  - Agreement on a common model / feature set
- Idea: Write a paper to summarize our ideas and get it peer-reviewed
  - Paper accepted at SIGMOD 2019 Industry Track (to be presented next week)

Our Motivation

- Share our experience of building OS streaming systems with SQL support
  - Our software powers many real-world streaming use cases
- The SQL Standards Committee is investigating extensions for streaming SQL
  - We want to offer our experience and help to shape the standard

What we came up with

- Guiding principles
  - Unified semantics for SQL over tables and streams
  - Minimal additions to the standard
  - Use as much as possible of SQL in a streaming context

- Our proposal is threefold
  1. Time-varying relations
  2. Event time semantics
  3. Controlling the materialization of time-varying results

Time-Varying Relations

Regular and Streaming SQL

- Regular SQL queries process point-in-time relations
  - Transactions & isolation levels ensure consistency of relations
- Time is the new dimension of streaming SQL
  - Streaming SQL queries process relations that evolve over time

Time-Varying Relations (TVRs)

- A time-varying relation (TVR) is a regular relation that changes over time
  - A table that is updated by transactional applications
  - A stream that is interpreted as the changelog of a table
- For each point in time, a TVR can return a static relation
  - The full set of SQL operations remains valid!
- A SQL query on a TVR is continuously evaluated and produces a result TVR
  - Result TVR can be computed in lock step with input TVRs
  - Equivalent to maintaining a materialized view

Key Insight

Streams and Tables are different representations of the same semantic object - a TVR.

*“Streams **are** Tables” instead of “Streams **and** Tables”*

TVR Representations

TVR of auction bids

```
--------------------------
| bidtime | price | item |
--------------------------
```

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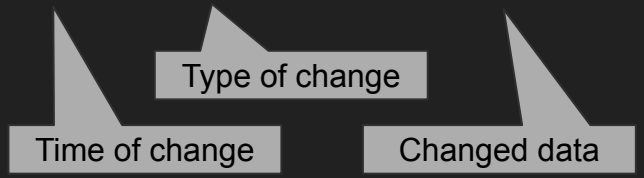
Stream representation of TVR

```
8:08    INSERT (8:07, $2, A)
8:12    INSERT (8:11, $3, B)
8:13    INSERT (8:05, $4, C)
8:15    INSERT (8:09, $5, D)
8:17    INSERT (8:13, $1, E)
8:18    INSERT (8:17, $6, F)
```



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8:18    INSERT (8:17, $6, F)
```

Time of query

Table representation of TVR

```
8:14> SELECT * FROM bids;
-------------------------
| bidtime | price | item |
-------------------------
| 8:07    |    $2 |    A |
| 8:11    |    $3 |    B |
| 8:05    |    $4 |    C |
-------------------------
```

TVR Representations

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Stream representation of TVR

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8:08    INSERT (8:07, $2, A)
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```

Table representation of TVR

```
8:14> SELECT * FROM bids;
-------------------------
| bidtime | price | item |
-------------------------
| 8:07    |    $2 |    A |
| 8:11    |    $3 |    B |
| 8:05    |    $4 |    C |
-------------------------

8:20> SELECT * FROM bids;
-------------------------
| bidtime | price | item |
-------------------------
| 8:07    |    $2 |    A |
| 8:11    |    $3 |    B |
| 8:05    |    $4 |    C |
| 8:09    |    $5 |    D |
| 8:13    |    $1 |    E |
| 8:17    |    $6 |    F |
-------------------------
```

No SQL Extension

- No SQL extensions needed!
- All SQL operations remain valid on TVRs

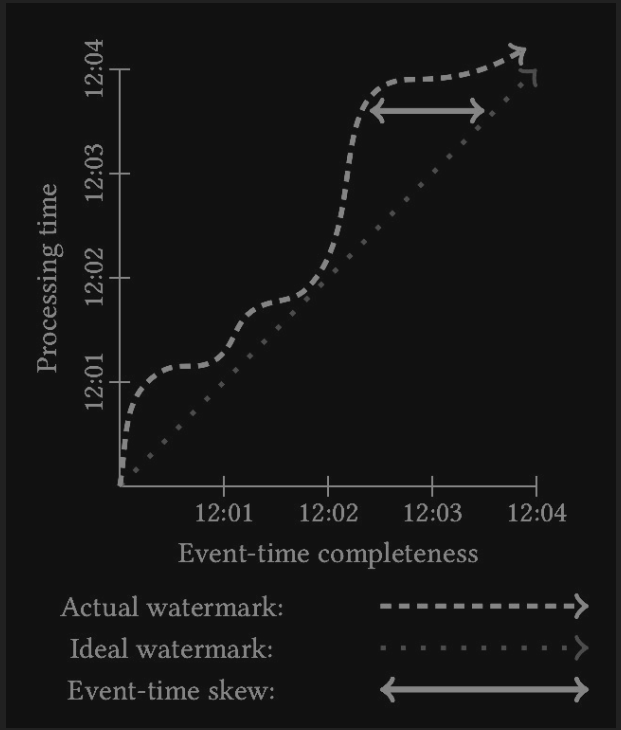
Event Time Semantics

Event Time vs. Processing Time

- Time-based operations are very common in stream processing
  - Count clicks per URL and hour
  - Join events that are at most 5 minutes apart from each other
- An engine needs a notion of time to evaluate such queries
  - Using arrival time of events (a.k.a. processing time) results in arbitrary results
- Event time semantics are required for correct and consistent results
  - Using timestamps that are provided by/embedded in the data
  - Correct results when live data is delayed or out-of-order is processed
  - Correct results when recorded data is processed

Implementing Event Time Semantics

- Event timestamps and watermarks* to implement event time semantics
  - Event timestamps define point in time of an event
  - Watermarks define a temporal margin of completeness for a stream
- General approach to support full breadth of streaming use cases
  - Temporal aggregations
  - Notifications and alerts

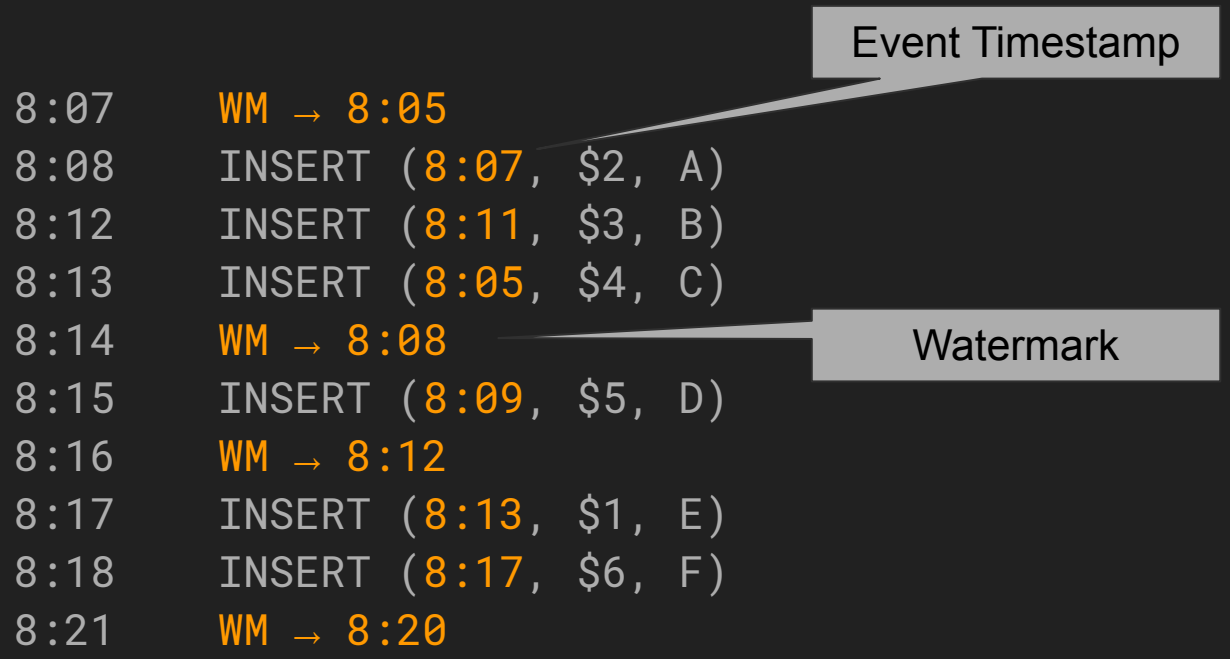


*Millwheel (VLDB'13) proposed watermarks. Later adopted by Cloud Dataflow, Beam, and Flink

SQL Extension 1: Event Time Attributes

- Add DDL syntax to declare watermarked event time attributes
  - Similar to `PRIMARY KEY`, `UNIQUE`, `NOT NULL`, or other constraints
- Event time attribute is a regular `TIMESTAMP` type
  - Attribute can be used like any other `TIMESTAMP` attribute
  - Attribute is “roughly” increasing
  - Watermarks report minimum of future values
- Optimizer uses knowledge of event time attributes to build plans that leverage watermarks to reason about progress

SQL Extension 1: Event Time Attributes



SQL Extension 2: Event Time Windowing Functions

- Add build-in table-valued functions to assign rows to event time windows
- TUMBLE function assigns each row to a fixed sized window
  - Enriches rows of a TVR with start and end timestamps

```
8:21> SELECT *
      FROM
        Tumble (
          data    => TABLE(Bid),
          timecol => DESCRIPTOR(bidtime),
          dur     => INTERVAL '10 ' MINUTES);
```

wstart	wend	bidtime	price	item
8:00	8:10	8:07	$2	A
8:10	8:20	8:11	$3	B
8:00	8:10	8:05	$4	C
8:00	8:10	8:09	$5	D
8:10	8:20	8:13	$1	E
8:10	8:20	8:17	$6	F

SQL Extension 2: Event Time Windowing Functions

- Aggregate rows per event time window

```
8:21> SELECT MAX(wstart), wend, SUM(price)
      FROM
        Tumble (
          data    => TABLE(Bid),
          timecol => DESCRIPTOR(bidtime),
          dur     => INTERVAL '10 ' MINUTES)
      GROUP BY wend;
```

```
------------------------
| wstart | wend | price |
------------------------
| 8:00   | 8:10 |   $11 |
| 8:10   | 8:20 |   $10 |
------------------------
```

Controlling the Materialization of Time-Varying Results

Control *How* and *When* to Materialize a TVR

- A query on a TVR produces a result TVR
  - There are several options how to materialize a TVR
- Materialize a TVR as table or as stream?
  - Table materialization is the default
  - Stream materialization needs to be explicitly chosen
- Choose when or how often to materialize TVR changes
  - Only materialize complete results
  - Only materialize changes once per minute

SQL Extension 3: Stream Materialization

- Add `EMIT STREAM` clause for stream materialization
- Materializes the changes of a TVR in a changelog TVR
  - All operations on TVR are supported

SQL Extension 3: Stream Materialization

```
8:08    INSERT (8:07, $2, A)
8:12    INSERT (8:11, $3, B)
8:13    INSERT (8:05, $4, C)
8:15    INSERT (8:09, $5, D)
8:17    INSERT (8:13, $1, E)
8:18    INSERT (8:17, $6, F)
```

```
8:20> SELECT ...;
-------------------------
| wstart | wend | price |
-------------------------
| 8:00   | 8:10 |   $11 |
| 8:10   | 8:20 |   $10 |
-------------------------
```

```
8:08> SELECT ... EMIT STREAM;
-----------------------------------------------
| wstart | wend | price | undo | ptime | ver |
-----------------------------------------------
| 8:00   | 8:10 |    $2 |      | 8:08  |   0 |
| 8:10   | 8:20 |    $3 |      | 8:12  |   0 |
| 8:00   | 8:10 |    $2 | undo | 8:13  |   1 |
| 8:00   | 8:10 |    $6 |      | 8:13  |   2 |
| 8:00   | 8:10 |    $6 | undo | 8:15  |   3 |
| 8:00   | 8:10 |   $11 |      | 8:15  |   4 |
| 8:10   | 8:20 |    $3 | undo | 8:17  |   1 |
| 8:10   | 8:20 |    $4 |      | 8:17  |   2 |
| 8:10   | 8:20 |    $4 | undo | 8:18  |   3 |
| 8:10   | 8:20 |   $10 |      | 8:18  |   4 |
...
```

SQL Extension 4: Delay for Completeness

- Add `EMIT AFTER WATERMARK` clause to materialize only complete results
  - Watermark indicates completeness

```
8:07    WM → 8:05
8:08    INSERT (8:07, $2, A)
8:12    INSERT (8:11, $3, B)
8:13    INSERT (8:05, $4, C)
8:14    WM → 8:08
8:15    INSERT (8:09, $5, D)
8:16    WM → 8:12
8:17    INSERT (8:13, $1, E)
8:18    INSERT (8:17, $6, F)
8:21    WM → 8:20
```

```
8:15> SELECT ... EMIT AFTER WATERMARK;
------------------------
| wstart | wend | price |
------------------------
------------------------

8:17> SELECT ... EMIT AFTER WATERMARK;
------------------------
| wstart | wend | price |
------------------------
| 8:00   | 8:10 |   $11 |
------------------------
```

SQL Extension 4: Delay for Completeness

- Add `EMIT AFTER WATERMARK` clause can be combined with `EMIT STREAM`

```
8:07    WM → 8:05
8:08    INSERT (8:07, $2, A)
8:12    INSERT (8:11, $3, B)
8:13    INSERT (8:05, $4, C)
8:14    WM → 8:08
8:15    INSERT (8:09, $5, D)
8:16    WM → 8:12
8:17    INSERT (8:13, $1, E)
8:18    INSERT (8:17, $6, F)
8:21    WM → 8:20
```

```
8:08> SELECT ... EMIT STREAM AFTER WATERMARK;
------------------------------------------------
| wstart | wend | price | undo | ptime | ver |
------------------------------------------------
| 8:00   | 8:10 |   $11 |      | 8:16  |   0 |
| 8:10   | 8:20 |   $10 |      | 8:21  |   0 |
...
```

SQL Extension 5: Periodic Delays

- Materializing every change of a TVR can result in many updates
  - Can overload downstream systems
  - Often not necessary / required

- Add `EMIT AFTER DELAY` clause to control frequency of updates

SQL Extension 5: Periodic Delays

```
8:08    INSERT (8:07, $2, A)
8:12    INSERT (8:11, $3, B)
8:13    INSERT (8:05, $4, C)
8:15    INSERT (8:09, $5, D)
8:17    INSERT (8:13, $1, E)
8:18    INSERT (8:17, $6, F)
```

```
8:08> SELECT ... EMIT STREAM
      AFTER DELAY INTERVAL '6' MINUTES;
-----------------------------------------------
| wstart | wend | price | undo | ptime | ver |
-----------------------------------------------
| 8:00   | 8:10 |    $6 |      | 8:14  | 0   |
| 8:10   | 8:20 |   $10 |      | 8:18  | 0   |
| 8:00   | 8:10 |    $6 | undo | 8:21  | 1   |
| 8:00   | 8:10 |   $11 |      | 8:21  | 2   |
...
```

```
8:15> SELECT ...;
-------------------------
| wstart | wend | price |
-------------------------
| 8:00   | 8:10 |    $6 |
-------------------------
```

```
8:19> SELECT ...;
-------------------------
| wstart | wend | price |
-------------------------
| 8:00   | 8:10 |    $6 |
| 8:10   | 8:20 |   $10 |
-------------------------
```

```
8:21> SELECT ...;
-------------------------
| wstart | wend | price |
-------------------------
| 8:00   | 8:10 |   $11 |
| 8:10   | 8:20 |   $10 |
-------------------------
```

Adoption

- Flink
  - Available via Table and SQL APIs
  - In use at companies such as Alibaba, Huawei, Lyft, Uber
- Beam
  - Available via Java SQL API, SQL CLI, and Google Cloud Dataflow UI.
  - In use by companies such as eBay, Spotify

Future Work

- Expanded / Custom Event-Time Windowing
  - Pre-built: transitive closure sessions, keyed sessions, calendar months, etc.
  - Custom windows defined via a SQL expression
- Time-progressing expressions:
  - E.g., (bidtime > CURRENT_TIME - INTERVAL ’1’ HOUR)
  - Expressions like CURRENT_TIME are fixed to query evaluation time in current standard
- Correlated access to temporal tables
  - Need dynamic AS OF SYSTEM TIME expressions for time-varying correlations
- Streaming changelog options
  - E.g, render changelog as sequence of deltas rather than updates.

Future Work

- Nested EMIT
  - EMIT within nested queries could add additional power, at cost of increased complexity
- Graceful evolution
  - Need clean ways to evolve stateful streaming pipelines over time
- More rigorous formal semantics
  - What are the formal properties of streaming systems in general?
  - Watermarks, latency, materialization, etc.
  - Greater understanding of differences between different systems.

Summary

- Guiding principles
  - Unified semantics for SQL over tables and streams
  - Minimal additions to the standard
  - Use as much as possible of SQL in a streaming context

- Our proposal
  1. Time-varying relations
  2. Event time semantics
     - Ext 1: Event time attributes ← DDL for watermarks, etc.
     - Ext 2: Event time windowing functions ← TUMBLE, HOP, etc. via table-valued functions
  3. Controlling the materialization of time-varying results
     - Ext 3: Stream materialization ← EMIT STREAM
     - Ext 4: Watermark delays for completeness ← EMIT AFTER WATERMARK
     - Ext 5: Periodic delays for rate limiting ← EMIT AFTER DELAY

Thank you!
Questions?