Query Processing, Resource Management, and Approximation in a Data Stream Management System*

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**Abridged by CZ*

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Data Streams

- Continuous, unbounded, rapid, time-varying streams of data elements
- Occur in a variety of modern applications
  - Network monitoring and traffic engineering
  - Sensor networks
  - Telecom call records
  - Financial applications
  - Web logs and click-streams
  - Manufacturing processes
- DSMS = Data Stream Management System

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DBMS versus DSMS

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DBMS versus DSMS

- Persistent relations
- Transient streams (and persistent relations)

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DBMS versus DSMS

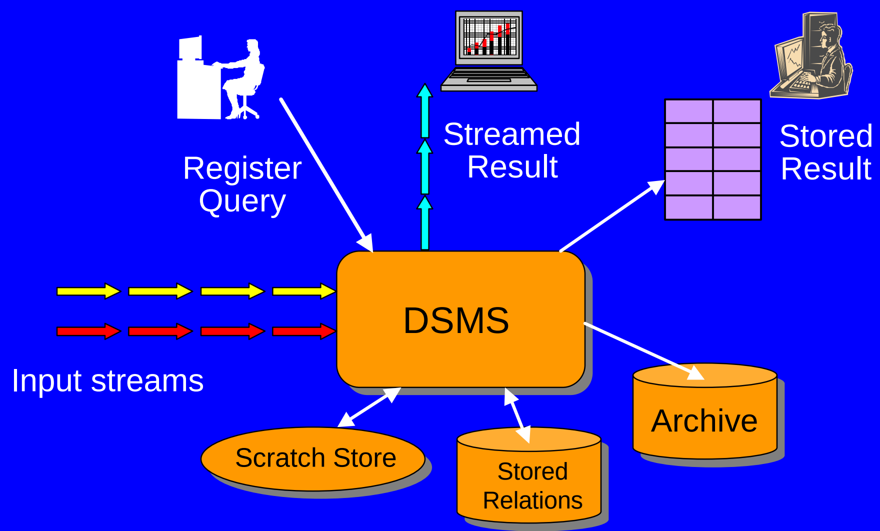
- Persistent relations
- One-time queries
- Random access
- Access plan determined by query processor and physical DB design

- Transient streams (and persistent relations)
- Continuous queries
- Sequential access
- Unpredictable data characteristics and arrival patterns

The STREAM System

- Data streams and stored relations
- Declarative language for registering continuous queries
- Flexible query plans
- Designed to cope with high data rates and query workloads
  - Graceful approximation when needed
  - Careful resource allocation and usage
- Relational, centralized (for now)

The (Simplified) Big Picture



Using Conventional DBMS

- Data streams as relation inserts, continuous queries as triggers or materialized views
- Problems with this approach
  - Inserts are typically batched, high overhead
  - Expressiveness: simple conditions (triggers), no built-in notion of sequence (views)
  - No notion of approximation, resource allocation
  - Current systems don’t scale to large # of triggers
  - Views don’t provide streamed results
- But we (and others) plan to compare

Declarative Language for Continuous Queries

- A distinction between STREAM and the Aurora project
  - Aurora users directly manipulate one large execution plan
  - STREAM compiles declarative queries into individual plans, system may merge plans
  - STREAM also supports direct entry of plans
- Syntax based on SQL, additional constructs for sliding windows and sampling

Example Query 1

Two streams, contrived for ease of examples:

Orders (orderID, customer, cost)
Fulfillments (orderID, clerk)

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Total cost of orders fulfilled over the last day by clerk "Sue" for customer "Joe"

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Select  Sum(O.cost)
From Orders O, Fulfillments F [Range 1 Day]
Where O.orderID = F.orderID And F.clerk = "Sue"
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Example Query 2

Using a 10% sample of the Fulfillments stream, take the 5 most recent fulfillments for each clerk and return the maximum cost

```
Select F.clerk, Max(O.cost)
From Orders O,
     Fulfillments F [Partition By clerk Rows 5] 10% Sample
Where O.orderID = F.orderID
Group By F.clerk
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Semantics of Database Languages

- An often neglected topic
- Traditional relational databases are in reasonable shape
  - Relational algebra ? SQL
- But triggers were a mess
- The semantics of an innocent-looking continuous query over data streams may not be obvious

A Nonobvious Continuous Query

- Stream of stock quotes: Stocks(ticker,price)
- Monitor last 10 minutes of quotes:
  Select ? From Stocks [Range 10 minutes]
- Is result a relation, a stream, or something else?
- If a relation, what exactly does it contain?
- If a stream, how does query differ from:
  Select ? From Stocks [Range 1 minute]
  or Select ? From Stocks [?]

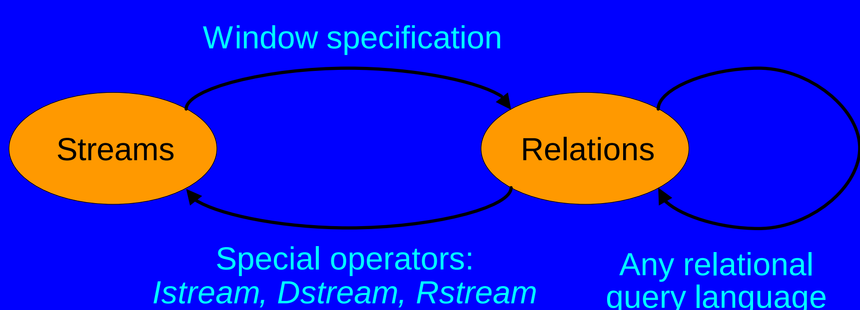
Our Semantics and Language for Continuous Queries

- Abstract: interpretation for CQs based on certain "black boxes"
- Concrete: SQL-based instantiation for our system; includes syntactic shortcuts, defaults, equivalences
- Goals
  - CQs over multiple streams and relations
  - Exploit relational semantics to the extent possible
  - Easy queries should be easy to write, simple queries should do what you expect

Relations and Streams

- Assume global, discrete, ordered time domain (more on this later)
- Relation
  - Maps time *T* to set-of-tuples *R*
- Stream
  - Set of (*tuple,timestamp*) elements

Conversions



Conversion Definitions

- Stream-to-relation
  - *S* [*W*] is a relation — at time *T* it contains all tuples in window *W* applied to stream *S* up to *T*
  - When *W* = ? , contains all tuples in stream *S* up to *T*
- Relation-to-stream
  - Istream(*R*) contains all (*r*,*T*) where *r*? *R* at time *T* but *r*? *R* at time *T–1*
  - Dstream(*R*) contains all (*r*,*T*) where *r*? *R* at time *T–1* but *r*? *R* at time *T*
  - Rstream(*R*) contains all (*r*,*T*) where *r*? *R* at time *T*

Abstract Semantics

- Take any relational query language
- Can reference streams in place of relations
  - But must convert to relations using any window specification language
    (default window = [?])
- Can convert relations to streams
  - For streamed results
  - For windows over relations
    (note: converts back to relation)

Query Result at Time *T*

- Use all relations at time *T*
- Use all streams up to *T*, converted to relations
- Compute relational result
- Convert result to streams if desired

Time

- Easiest: global system clock
  - Stream elements and relation updates timestamped on entry to system
- Application-defined time
  - Streams and relation updates contain application timestamps, may be out of order
  - Application generates “heartbeat”
    - Or deduce heartbeat from parameters: stream skew, scrambling, latency, and clock progress
  - Query results in application time

Abstract Semantics – Example 1

Select F.clerk, Max(O.cost)
From O [?], F [Rows 1000]
Where O.orderID = F.orderID
Group By F.clerk

- Maximum-cost order fulfilled by each clerk in last 1000 fulfillments

Abstract Semantics – Example 1

Select F.clerk, Max(O.cost)
From O [?], F [Rows 1000]
Where O.orderID = F.orderID
Group By F.clerk

- At time *T*: entire stream *O* and last 1000 tuples of *F* as relations
- Evaluate query, update result relation at *T*

Abstract Semantics – Example 1

Select Istream(F.clerk, Max(O.cost))
From O [?], F [Rows 1000]
Where O.orderID = F.orderID
Group By F.clerk

- At time *T*: entire stream *O* and last 1000 tuples of *F* as relations
- Evaluate query, update result relation at *T*
- Streamed result: New element (<clerk,max>,T) whenever <clerk,max> changes from *T–1*

Abstract Semantics – Example 2

Relation CurPrice(stock, price)

Select stock, Avg(price)
From Istream(CurPrice) [Range 1 Day]
Group By stock

- Average price over last day for each stock

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Select stock, Avg(price)
From Istream(CurPrice) [Range 1 Day]
Group By stock
```

- *Istream* provides history of *CurPrice*
- Window on history, back to relation, group and aggregate

Concrete Language – CQL

- Relational query language: SQL
- Window spec. language derived from SQL-99
  - Tuple-based, time-based, partitioned
- Syntactic shortcuts and defaults
  - *So easy queries are easy to write and simple queries do what you expect*
- Equivalences
  - Basis for query-rewrite optimizations
  - Includes all relational equivalences, plus new stream-based ones

Two Extremely Simple CQL Examples

Select ? From Strm

- Had better return *Strm* (It does)
  - Default ? window for *Strm*
  - Default *Istream* for result

Select ? From Strm, Rel Where Strm.A = Rel.B

- Often want "NOW" window for *Strm*
- But may not want as default

Query Execution

- When a continuous query is registered, generation a query plan
  - Users can also register plans directly
- Plans composed of three main components:
  - Operators (as in most conventional DBMS's)
  - Inter-operator Queues (as in many conventional DBMS's)
  - State (synopses)
- Global scheduler for plan execution

Memory Overhead in Query Processing

- Queues + State
- Continuous queries keep state indefinitely
- Online requirements suggest using memory rather than disk
  – But we realize this assumption is shaky
- Goal: minimize memory use while providing timely, accurate answers

Reducing Memory Overhead

Two main techniques to date

1) Exploit constraints on streams to reduce state
2) Clever operator scheduling to reduce queue sizes

http://www-db.stanford.edu/stream

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