Query Processing over Data Streams

Joint project with Prof. Rajeev Motwani
and a group of graduate students

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Formula for a Database Research Project

- Pick a simple but fundamental assumption underlying traditional database systems
  - Drop it
- Reconsider all aspects of data management and query processing
  - Many Ph.D. theses
  - Prototype from scratch

Following the Formula

- We followed this formula once before
  - The LORE project
  - Dropped assumption:
    Data has a fixed schema declared in advance
  - XML
- The STREAM Project
  - Dropped assumption:
    First load data, then index it, then run queries
  - Continuous data streams (+ continuous queries)

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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The STREAM System

- Data streams and stored relations
- Declarative language for registering continuous queries
- Designed to cope with high data rates and query workloads
  - Graceful approximation when needed
  - Careful resource allocation and usage

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The STREAM System

- Designed to cope with bursty streams and changing workloads
  - Continuous monitoring of data and system behavior
  - Continuous reoptimization
- Relational, centralized (for now)

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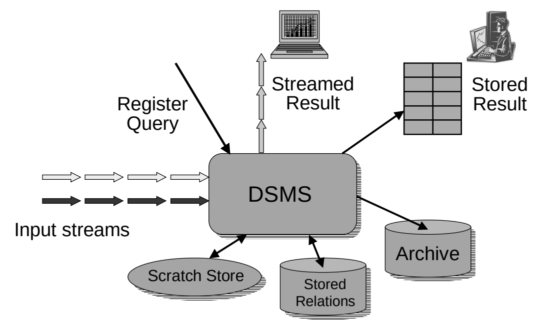
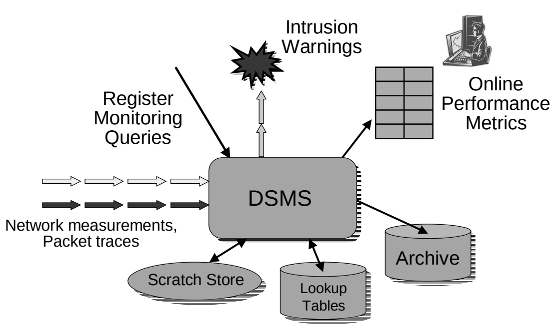
Contributions to Date

- Language for continuous queries
- Query plans
- Query optimization and dynamic reoptimization
- Exploiting stream constraints
- Operator scheduling
- Approximation techniques
- Resource allocation to maximize precision
- Initial running prototype

The (Simplified) Big Picture



(Simplified) Network Monitoring



Language for Continuous Queries

GOALS

- Continuous queries over multiple streams and relations
- Exploit relational semantics to the extent possible
- Easy queries should be easy to write
- Queries should do what you expect

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Example Query 1

Two streams, contrived for ease of examples:

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

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

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

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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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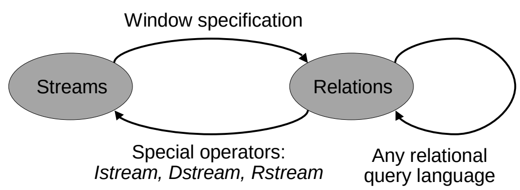
Abstract Semantics and Concrete Language

- Abstract: window specification language and relational query language as "black boxes"
- Concrete: SQL-based instantiation for our system; includes syntactic shortcuts, defaults, equivalences

Relations and Streams

- Assume global, discrete, ordered time domain
- 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 $W = \infty$, contains all tuples in stream *S* up to *T*
- Relation-to-stream
  - Istream(*R*) contains all (*r,T*) where $r \in R$ at time *T* but $r \notin R$ at time *T–1*
  - Dstream(*R*) contains all (*r,T*) where $r \in R$ at time *T–1* but $r \notin R$ at time *T*
  - Rstream(*R*) contains all (*r,T*) where $r \in R$ at time *T*

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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)

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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

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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

Abstract Semantics – Example 2

Relation CurPrice(stock, price)

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

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Stream Systems

- (At least) three general-purpose DSMS prototypes underway
  - STREAM (Stanford)
  - Aurora (MIT, Brown, Brandeis)
  - TelegraphCQ (Berkeley)
- All will be demo'd at conference next week
- Cooperating to develop stream system benchmark
  - ➢ Goal: demonstrate that conventional systems are far inferior for data stream applications

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