Systems Infrastructure for Data Science

Web Science Group
Uni Freiburg
WS 2014/15

Data Stream Processing

Topics

- Model Issues
- **System Issues**

System Issues

- Architecture and Run-time operation
- Resource limitations
  - CPU
  - Memory
  - Bandwidth (distributed case)
- Performance goals
  - Low latency
  - High throughput
  - Maximum QoS utility
  - Minimum error

General Concerns

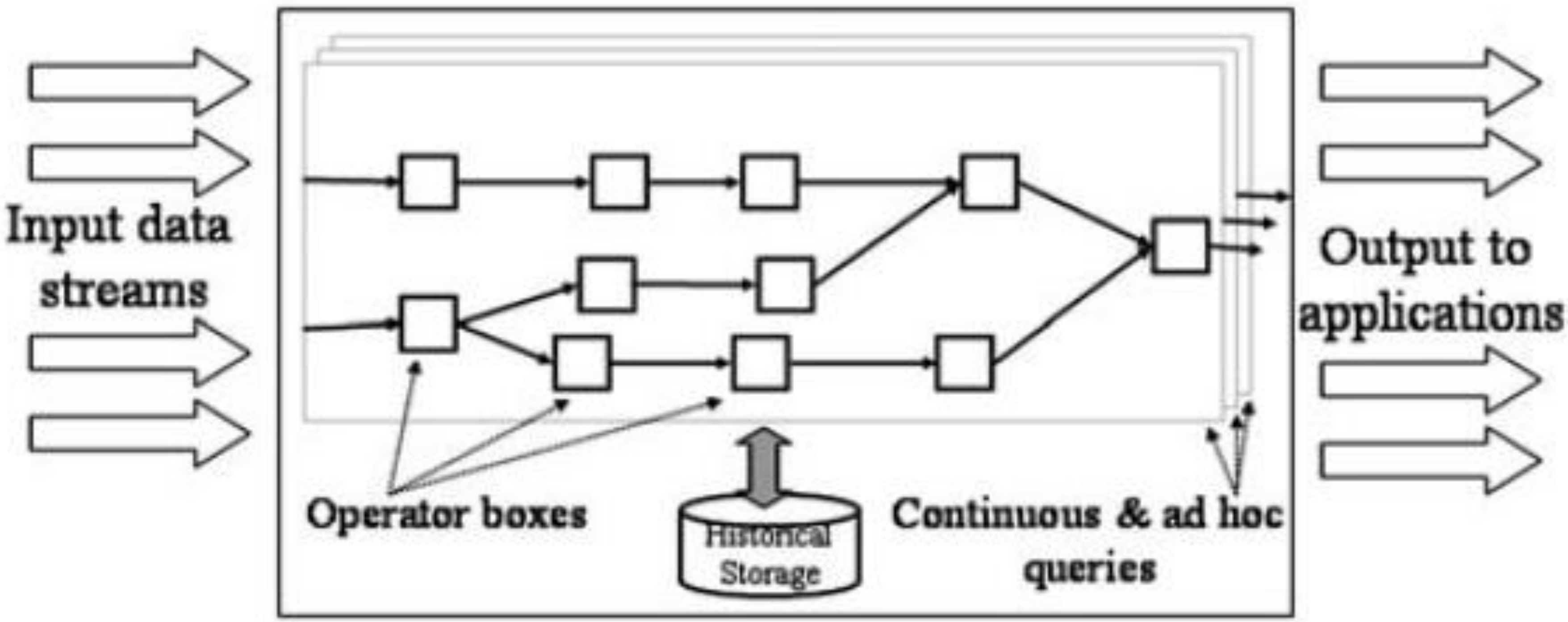
- In principle, same architecture choices as in databases
- Different tradeoffs:
  - Latency bounds more important than throughput
  - Processing driven by data arrival, not query optimization
- Architecture changes:
  - Push-based execution more popular (why?)
  - Decoupling using queues
  - Adaptive processing

System Issues

- Two systems as case studies:
  - Aurora [Brandeis-Brown-MIT]
  - STREAM [Stanford]

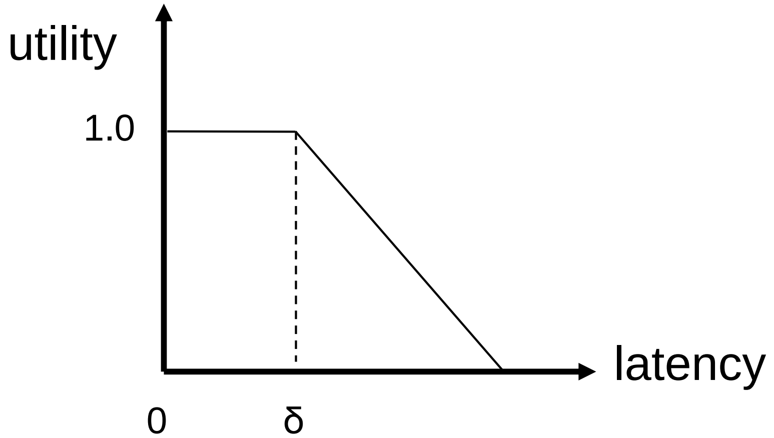
System Issues in Aurora

Aurora System Model

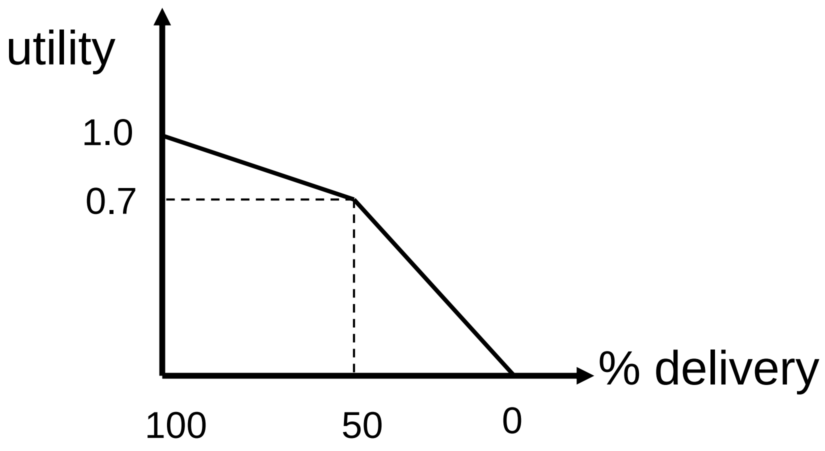


Aurora Quality of Service (QoS)

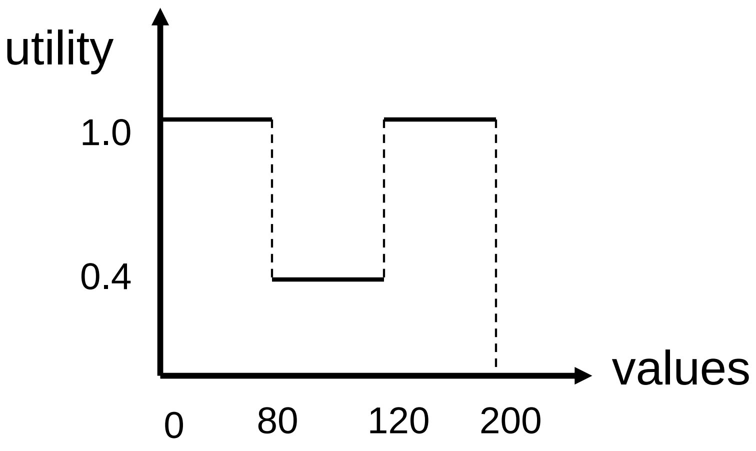
- Latency QoS



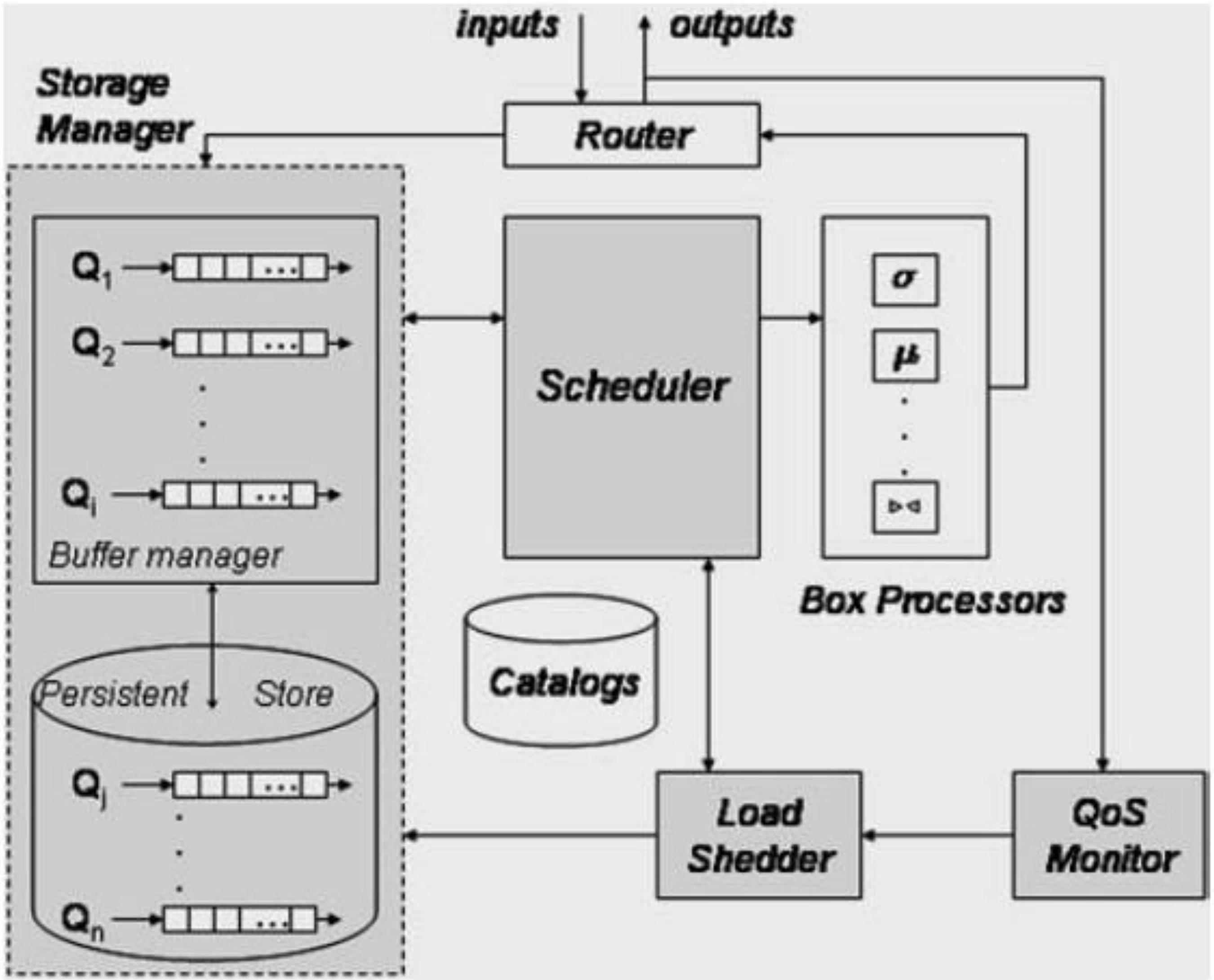
- Loss-tolerance QoS



- Value-based QoS



Aurora Architecture

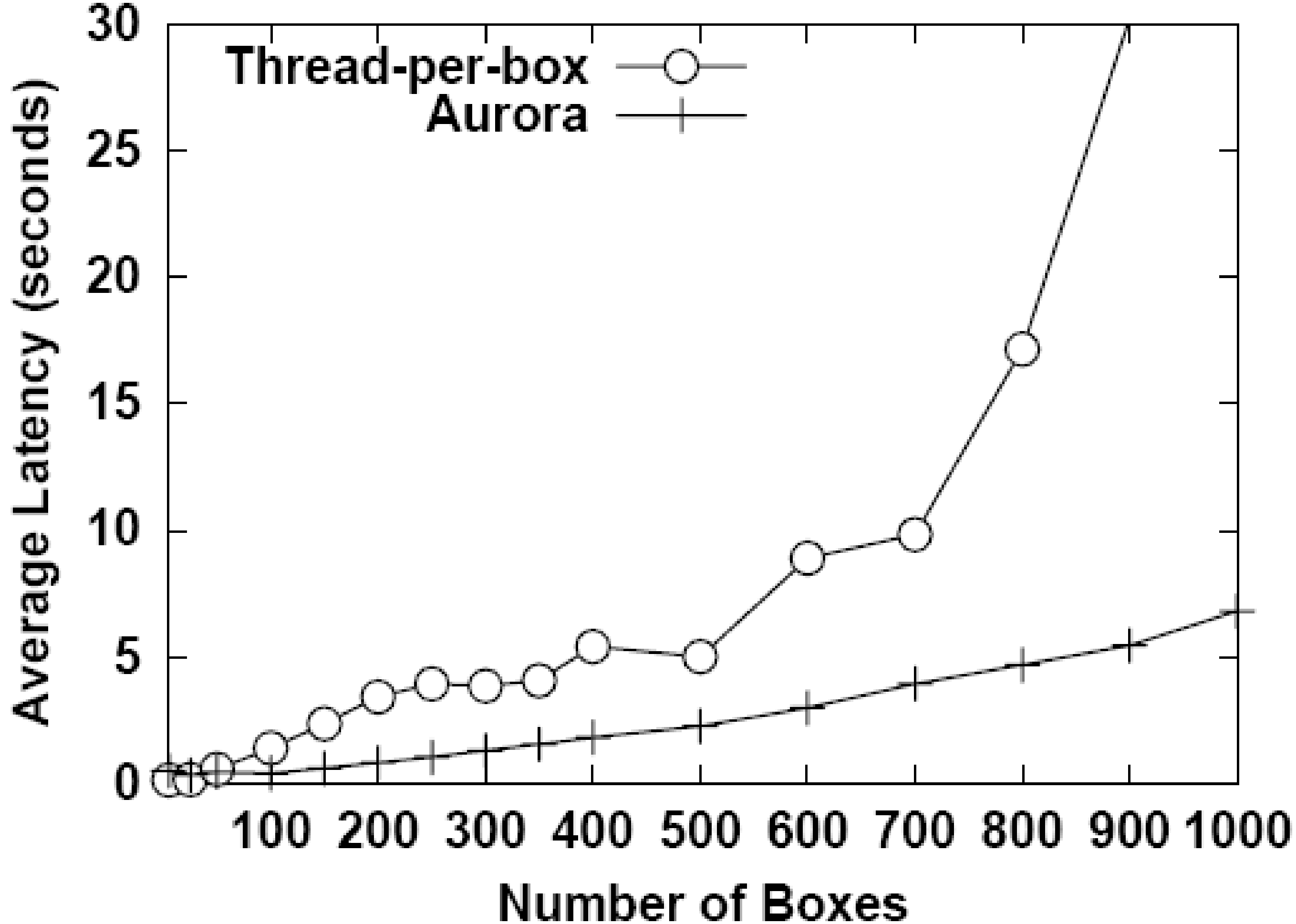


Operator Scheduling

- Goal: To allocate the CPU among multiple queries with multiple operators so as to optimize a metric, such as:
  - minimize total average latency
  - maximize total average latency QoS utility
  - maximize total average throughput
  - minimize total memory consumption
- Deciding which operator should run next, for how long or with how much input.
- Must be low overhead.

Why should the DSMS worry about scheduling?

Thread-based vs. State-based Execution



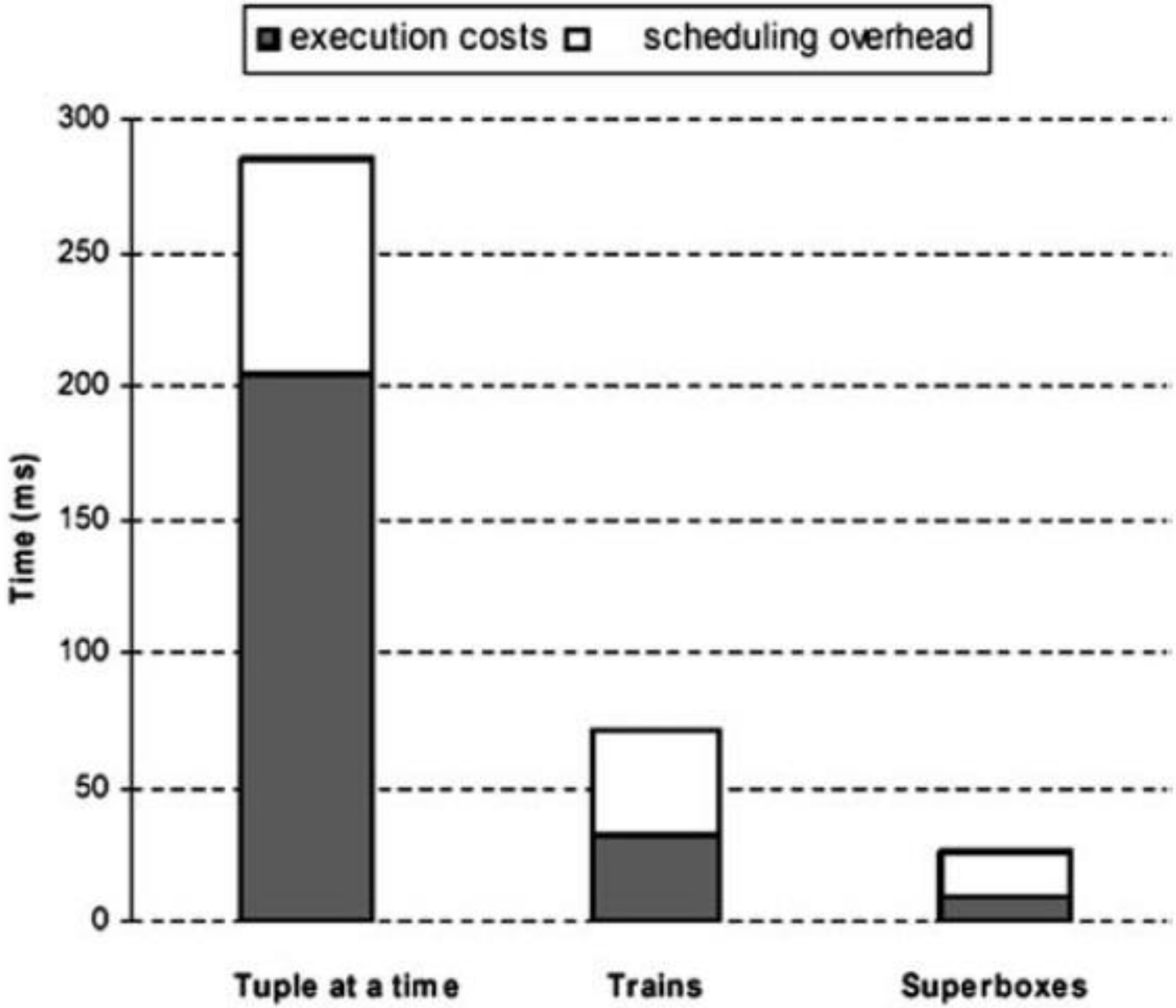
Batching

- Exploit inter-box and intra-box non-linearities in execution overhead

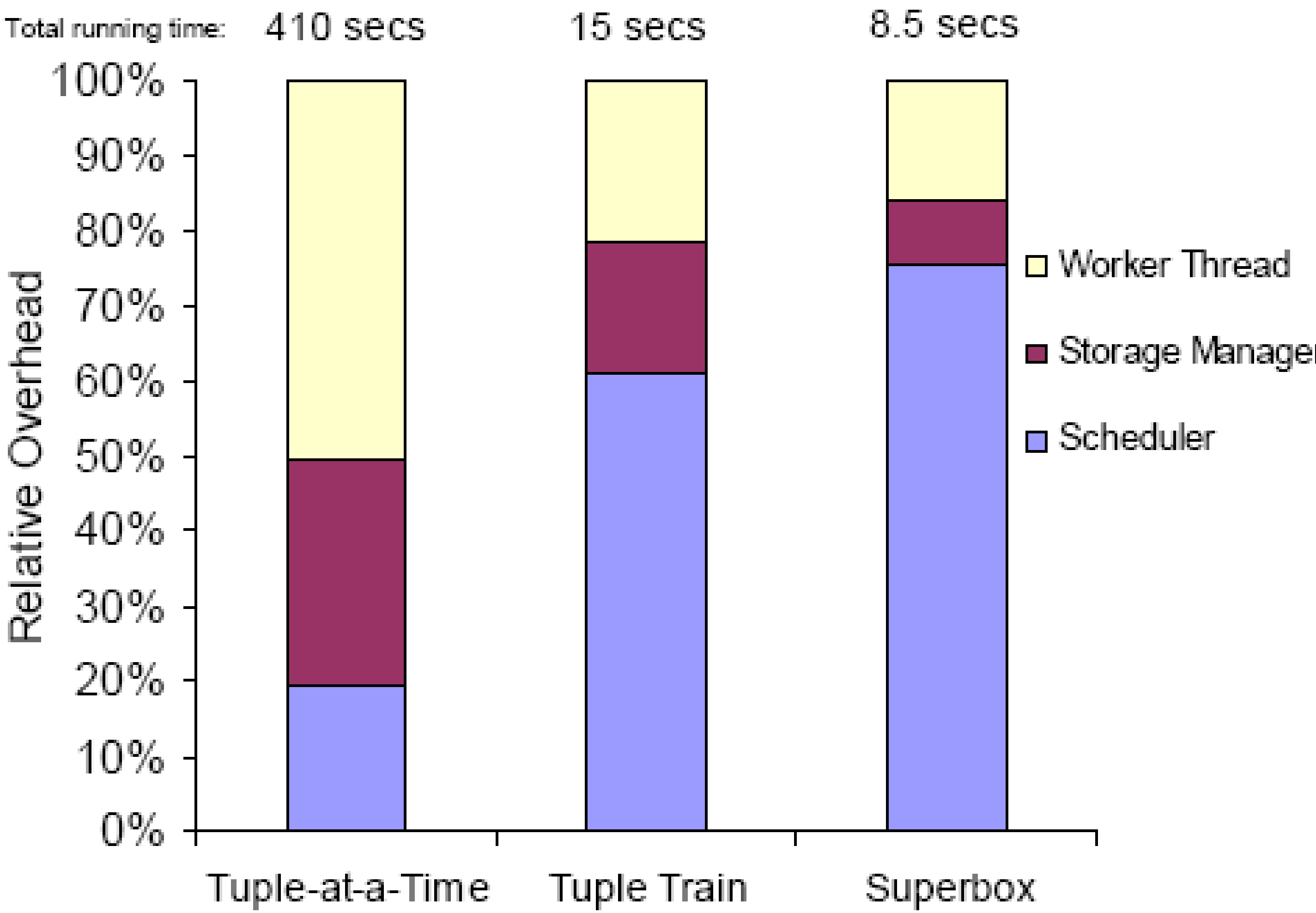
- Train scheduling
  – batching and executing multiple tuples together

- Superbox scheduling
  – batching and executing multiple boxes together

Batching reduces execution costs



Distribution of Execution Overhead

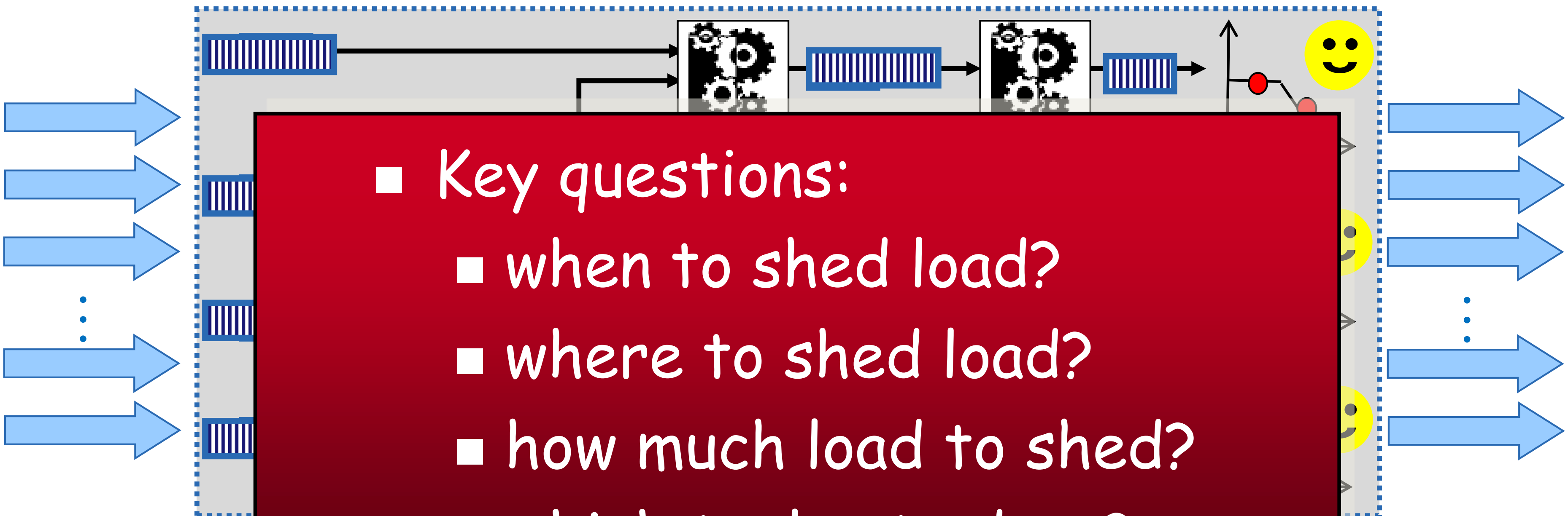


The Overload Problem

- If Load > Capacity during the spikes, then queues form and latency proliferates.
- Given a query network N, a set of input streams I, and a CPU with processing capacity C; when $Load(N(I)) > C$, transform N into N' such that:
  - $Load(N'(I)) < C$, and
  - $Utility(N(I)) - Utility(N'(I))$ is minimized.

Load Shedding in Aurora

Aurora Query Network



- Key questions:
  - when to shed load?
  - where to shed load?
  - how much load to shed?
  - which tuples to drop?

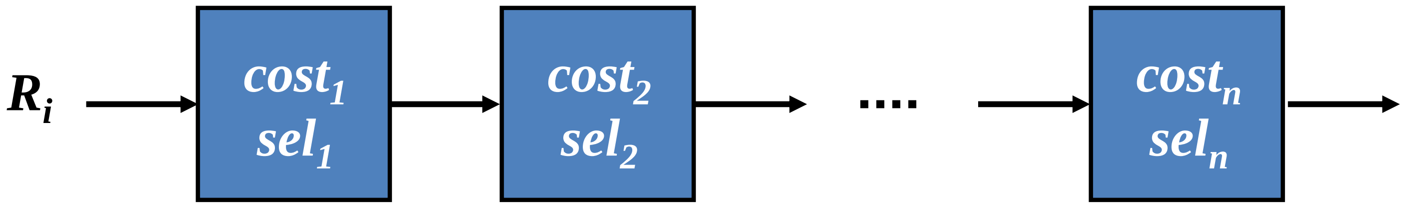
- Probl
- Solution: Insert drop operators into the query plan.
- Result: Deliver "approximate answers" with low latency.

The Drop Operator

- is an abstraction for load reduction
- can be added, removed, updated, moved
- reduces load by a factor
- produces a “subset” of its input
- picks its victims
  - probabilistically
  - semantically (i.e., based on tuple content)

When to Shed Load?

- Load coefficients



$$L_i = \sum_{j=1}^{n} \left(\prod_{k=1}^{j-1} sel_k \right) \times cost_j$$

(CPU cycles per tuple)

- Total load

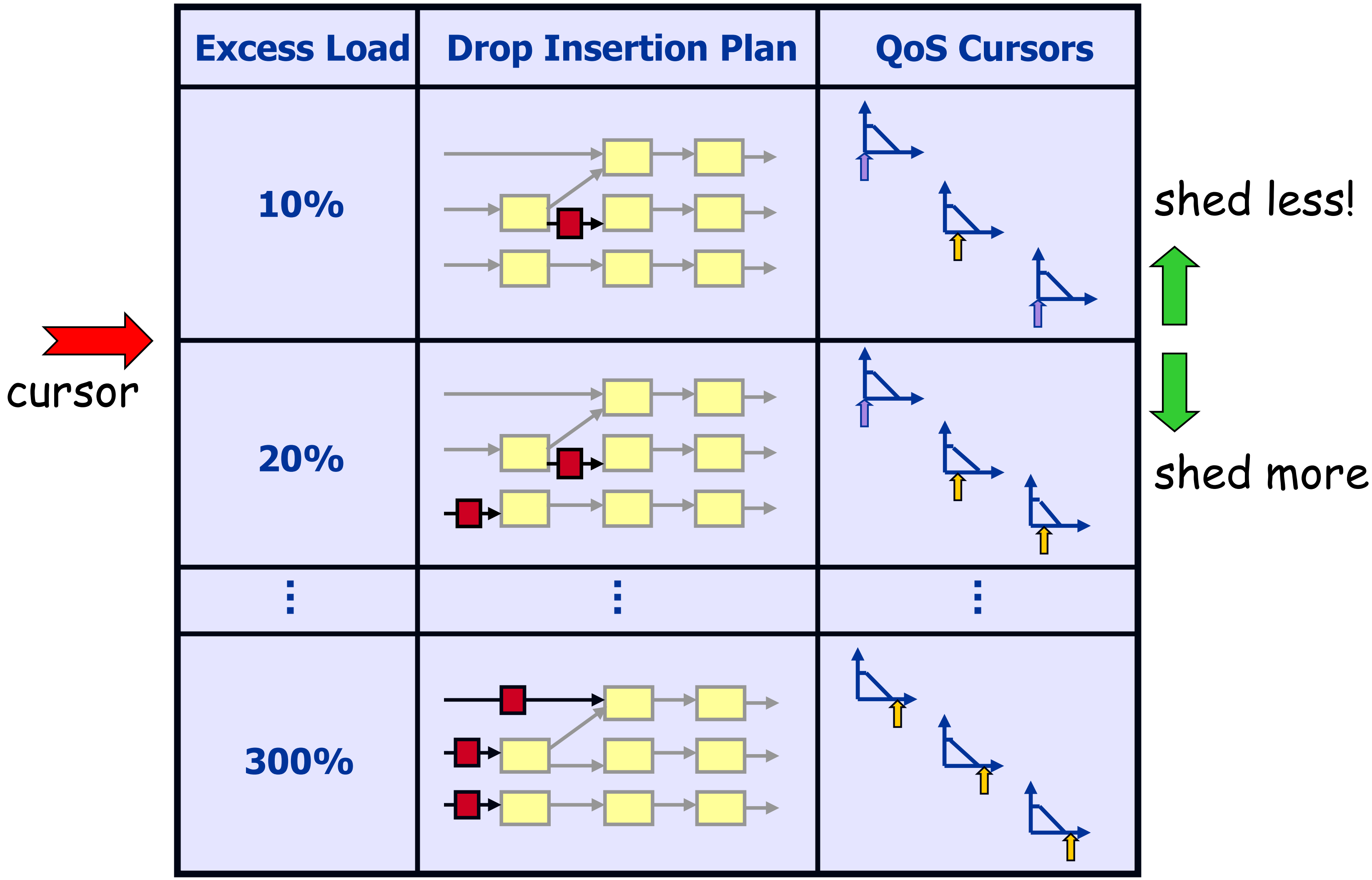
$$\sum_{i=1}^{m} L_i \times R_i$$

(CPU cycles per time unit)

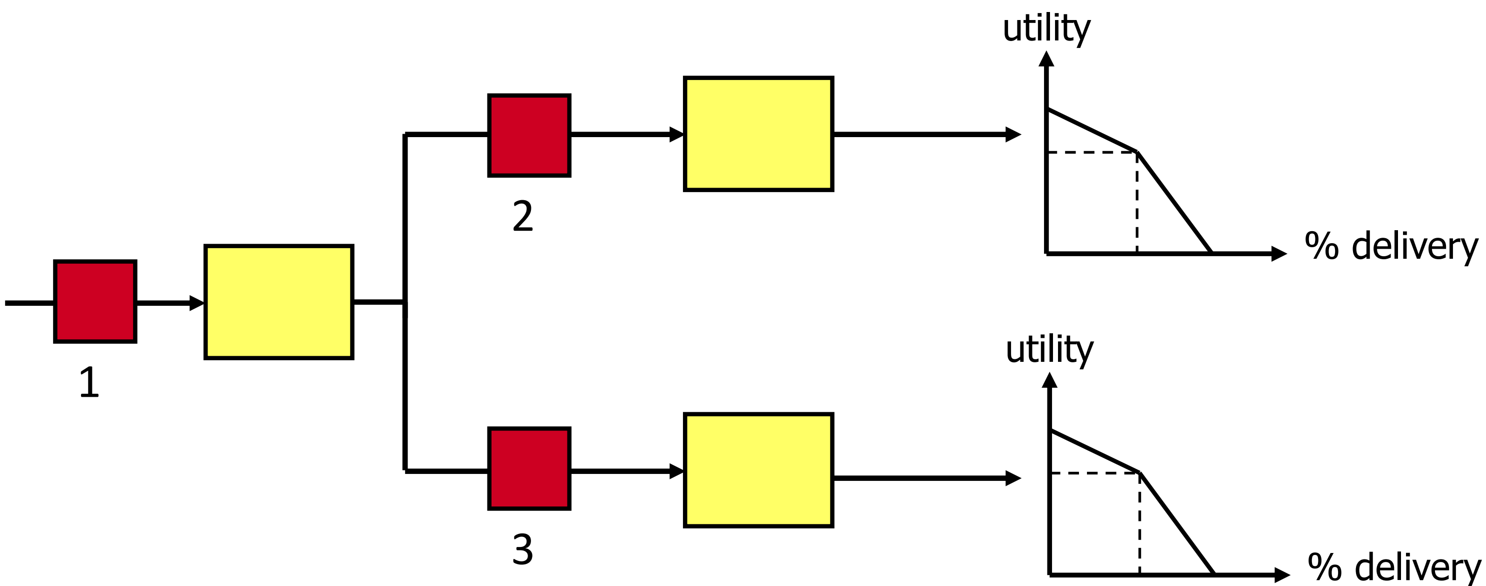
Aurora Load Shedding
Three Basic Principles

1. Minimize run-time overhead.
2. Minimize loss in query answer accuracy.
3. Deliver subset results.

Principle 1: Plan in advance.



Principle 2: Minimize error.



- Early drops save more processing cycles.
- Drops before sharing points can cause more accuracy loss.
- We rank possible drop locations by their loss/gain ratios.

Principle 3: Keep sliding windows intact.

- Two parameters: size and slide
- Example: **`Trades(time, symbol, price, volume)`**

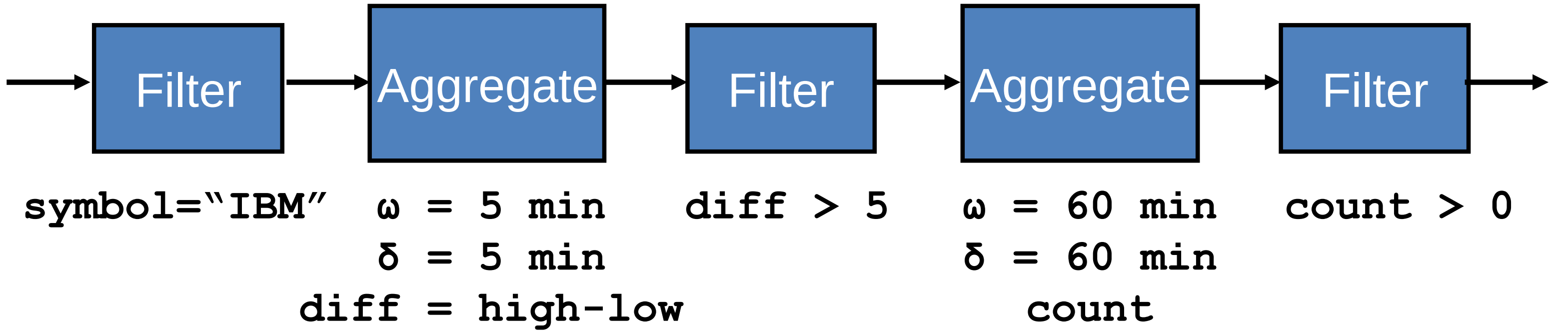
size = 10 min

slide by 5 min

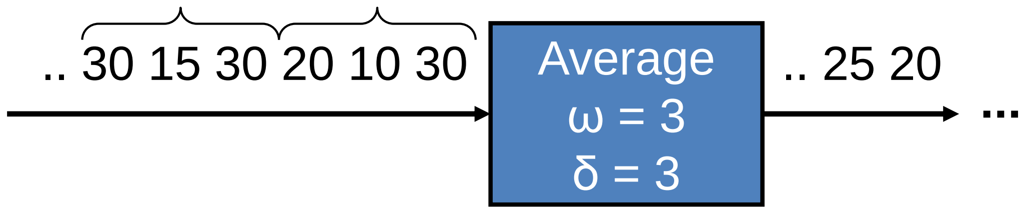
```
(10:00, "IBM",  20, 100)
(10:00, "INTC", 15, 200)
(10:00, "MSFT", 22, 100)
(10:05, "IBM",  18, 300)
(10:05, "MSFT", 21, 100)
(10:10, "IBM",  18, 200)
(10:10, "MSFT", 20, 100)
(10:15, "IBM",  20, 100)
(10:15, "INTC", 20, 200)
(10:15, "MSFT", 20, 200)
.
.
```

Windowed Aggregation

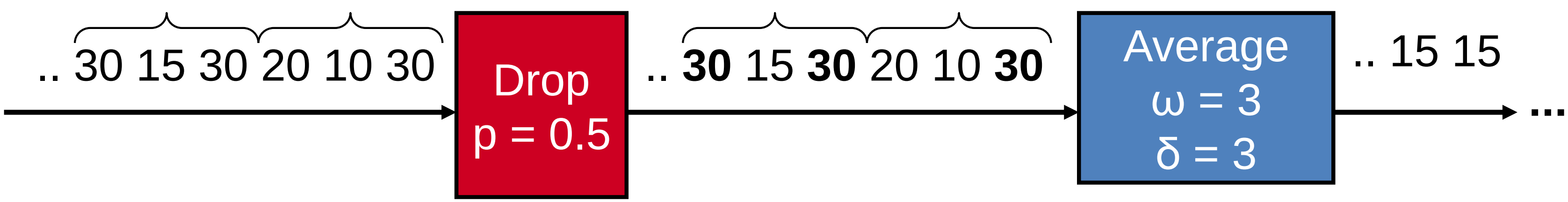
- Apply an aggregate function on the window
  - Average, Sum, Count, Min, Max
  - User-defined
- Can be nested
- Example:



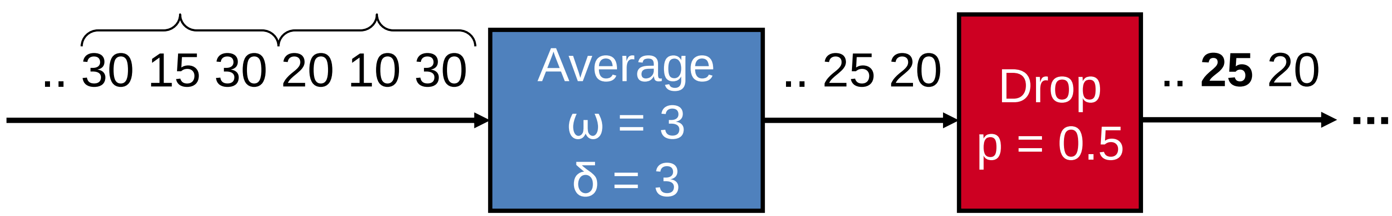
Dropping from an Aggregation Query
Tuple-based Approach



- Drop before : non-subset result of nearly the same size

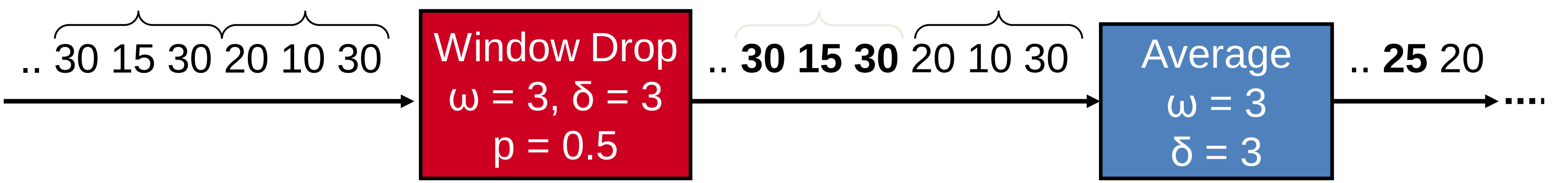


- Drop after : subset result of smaller size



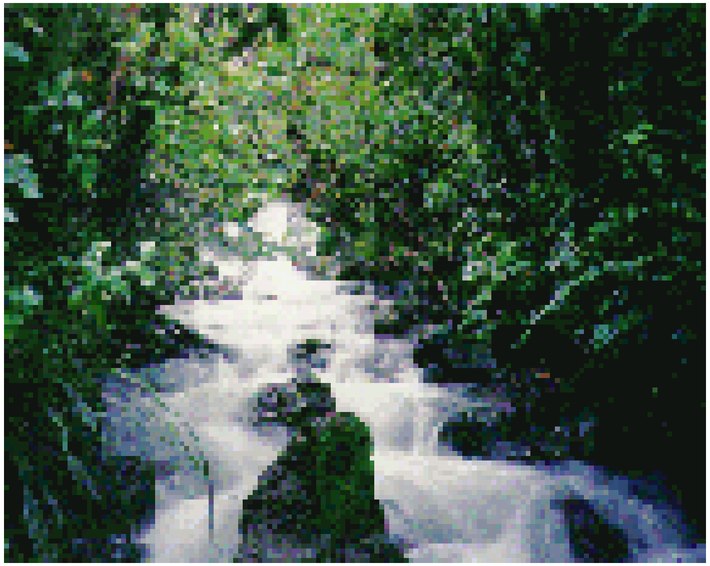
Dropping from an Aggregation Query
Window-based Approach

- Drop before : subset result of smaller size



- Window-aware load shedding
  - works with any aggregate function
  - delivers correct results
  - keeps error propagation under control
  - can handle nesting
  - can drop load early

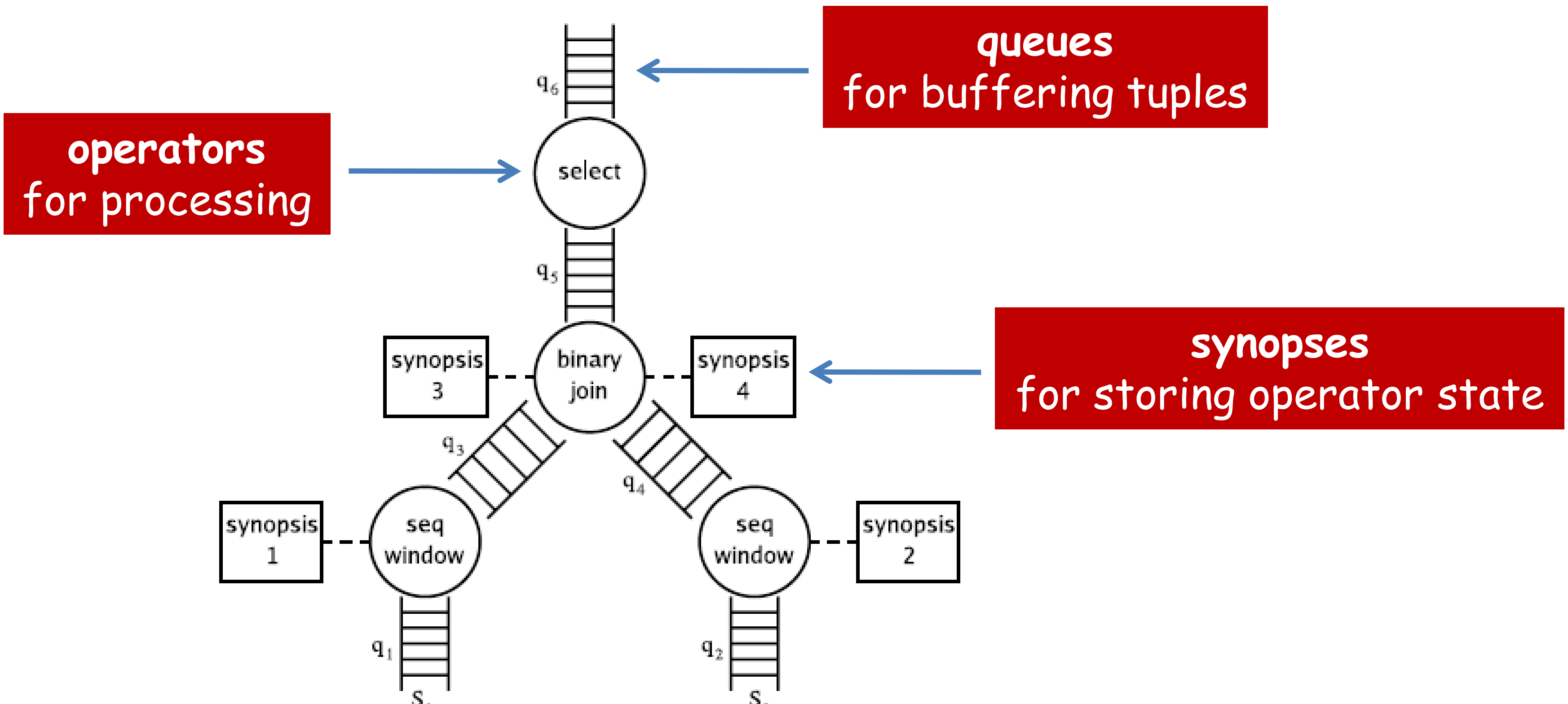
System Issues in STREAM



STREAM Query Plans

- Query in CQL -> Physical query plan tree

```
SELECT *
FROM S1 [ROWS 1000], S2 [RANGE 2 MINUTES]
WHERE S1.A = S2.A AND S1.A > 10
```



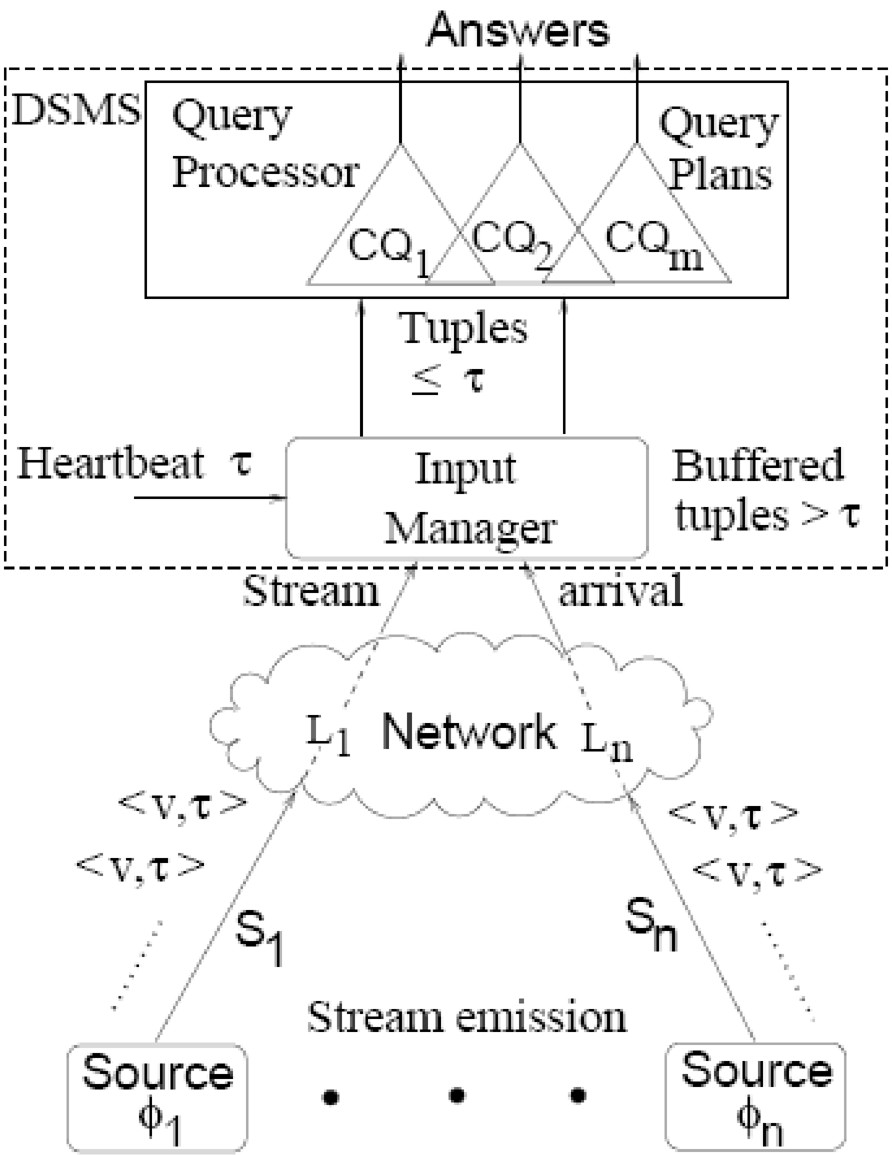
STREAM Operators

Name	Operator Type	Description
`select`	relation-to-relation	Filters elements based on predicate(s)
`project`	relation-to-relation	Duplicate-preserving projection
`binary-join`	relation-to-relation	Joins two input relations
`mjoin`	relation-to-relation	Multiway join from [22]
`union`	relation-to-relation	Bag union
`except`	relation-to-relation	Bag difference
`intersect`	relation-to-relation	Bag intersection
`antisemijoin`	relation-to-relation	Antisemijoin of two input relations
`aggregate`	relation-to-relation	Performs grouping and aggregation
`duplicate-eliminate`	relation-to-relation	Performs duplicate elimination
`seq-window`	stream-to-relation	Implements time-based, tuple-based, and partitioned windows
`i-stream`	relation-to-stream	Implements *Istream* semantics
`d-stream`	relation-to-stream	Implements *Dstream* semantics
`r-stream`	relation-to-stream	Implements *Rstream* semantics

STREAM Queues

- Queues encapsulate the typical producer-consumer relationship between the operators.
- They act as in-memory buffers.
- They enforce that tuple timestamps are non-decreasing.
  - ➢ Why is this necessary?
  - – Heartbeat mechanism for time management

STREAM Heartbeats in a Nutshell



- Problem: Out of order data arrival
  - Unsynchronized application clocks at the sources
  - Different network latencies from different sources to the DSMS
  - Data transmission over a non-order-preserving channel
- Solution: Order tuples at the input manager by generating heartbeats based on application-specified parameters
  - Heartbeat value T at a given time instant means that all tuples after that instant will have a timestamp greater than T.

STREAM Synopses

- A synopsis stores the internal state of an operator needed for its evaluation.
  - Example: A windowed join maintains a hash table for each of its inputs as a synopsis.
  - ➢ Do we need synopses for all types of operators?
- Like queues, synopses are also kept in memory.
- Synopses can also be used in more advanced ways:
  - shared among multiple operators (for space optimization)
  - store summary of stream tuples (for approximate processing)

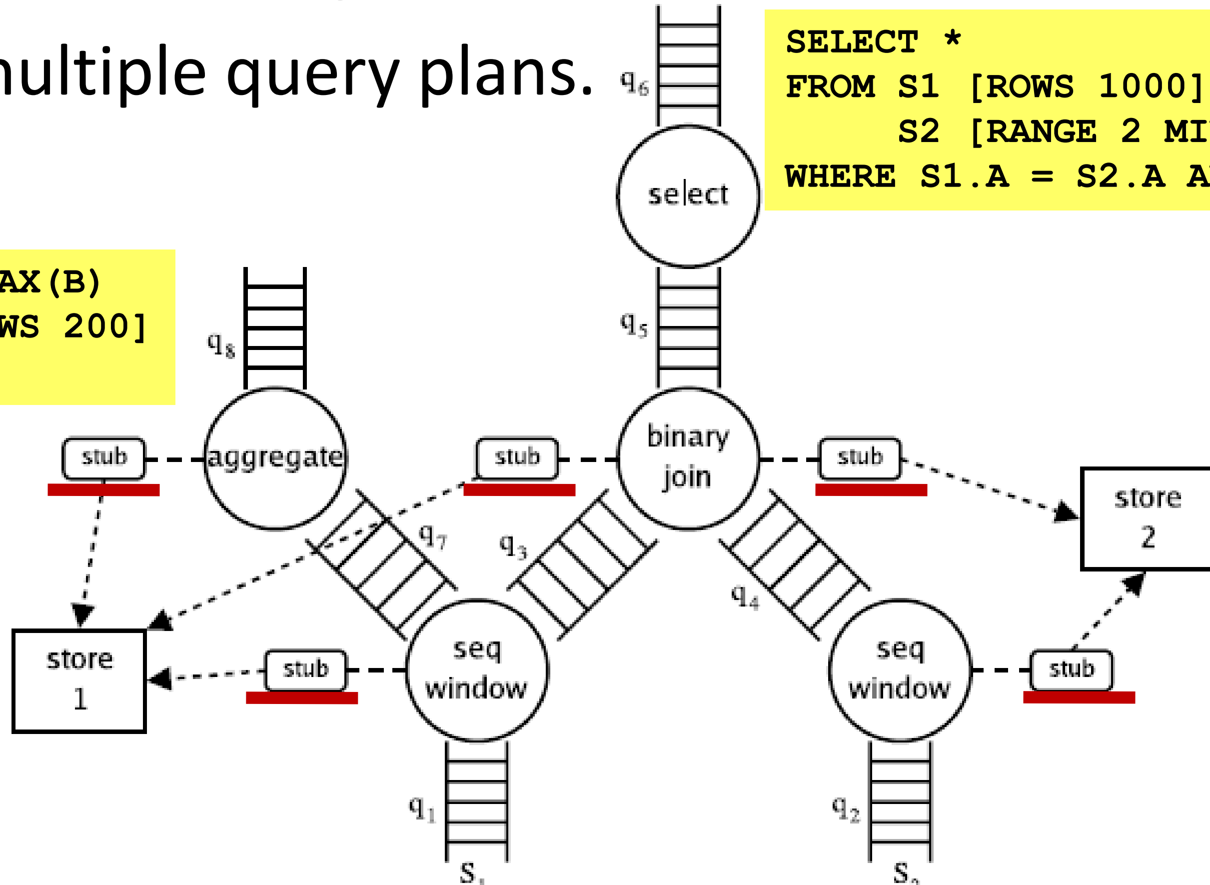
STREAM Performance Issues

Synopsis Sharing for Eliminating Data Redundancy

- Replace identical synopses with “stubs” and store the actual tuples in a single store.
- Also for multiple query plans.

```
SELECT *
FROM S1 [ROWS 1000],
     S2 [RANGE 2 MINUTES]
WHERE S1.A = S2.A AND S1.A > 10
```

```
SELECT A, MAX(B)
FROM S1 [ROWS 200]
GROUP By A
```



STREAM Performance Issues
Exploiting Constraints for Reducing Synopsis Sizes

- Constraints on data and arrival patterns to reduce, bound, eliminate memory state
- Schema-level constraints
  - Clustering (e.g., contiguous duplicates)
  - Ordering (e.g., slack parameter in SQuAl)
  - Referential integrity (e.g., timestamp synchronization)
  - In relaxed form: k-constraints (k: adherence parameter)
- Simple example:
  - Orders (orderID, customer, cost)
  - Fulfillments (orderID, portion, clerk)
  - If Fulfillments is k-clustered on orderID, can infer when to discard Orders.

STREAM Performance Issues
Exploiting Constraints for Reducing Synopsis Sizes

- Data-level constraints: “Punctuations”
- Punctuations are special annotations embedded in data streams to specify the end of a subset of data.
  - No more tuples will follow that match the punctuation.
- A punctuation is represented as an ordered set of patterns, where each pattern corresponds to an attribute of a tuple.
  - Patterns: *, constants, ranges [a, b] or (a b), lists {a, b, ..}, Ø
  - Example: < item_id, buyer_id, bid >

    < {10, 20}, *, * > => all bids on items 10 and 20.

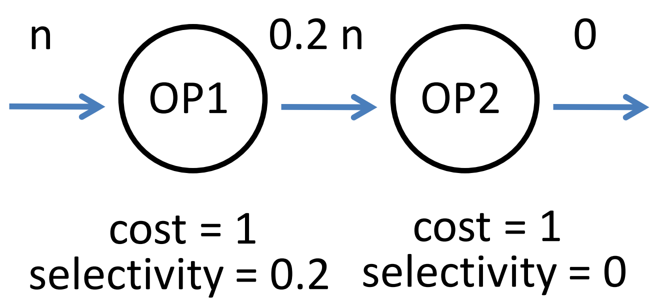
STREAM Performance Issues
Operator Scheduling for Reducing Intermediate State

- A global scheduler decides on the order of operator execution.
- Changing the execution order of the operators does not affect their semantic correctness, but may affect system’s total memory utilization.

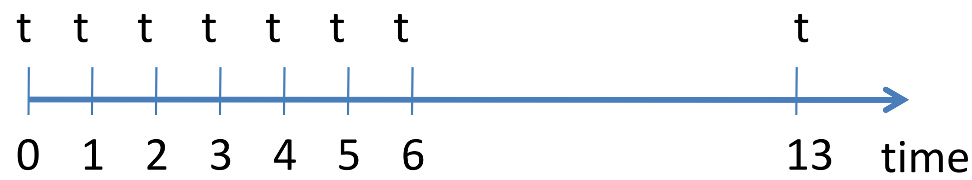
STREAM Performance Issues

Operator Scheduling for Reducing Intermediate State

- Example Query Plan:



- Input Arrival Pattern:



- Total Queue Sizes for two alternative scheduling policies:

Time	*Greedy scheduling*	*FIFO scheduling*
0	*1*	*1*
1	*1.2*	*1.2*
2	*1.4*	*2.0*
3	*1.6*	*2.2*
4	*1.8*	*3.0*
5	*2.0*	*3.2*
6	*2.2*	*4.0*

- Greedy always prioritizes OP1.
- FIFO schedules OP1-OP2 in sequence.
  - ➢ Greedy has smaller max. queue size.
- (Chain Scheduling Algorithm)