The Eight Requirements of Real-Time Stream Processing:
STREAM vs Storm

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Introduction to Streams

- Why streaming processing?
- Two ideas
  - High-volume streams of real-time data
  - Low-latency

Applications

- Stream filters
- Stream-relation joins
  - Select Rstream(Item.id, PriceTable.price)
    From Item [Now], PriceTable
    Where Item.id = PriceTable.itemId
  - Stream items with current price appended
- Sliding-window joins
  - Select Istream(*)
    From s1[rows 5], s2[rows 10]
    Where s1.A = s2.A
  - natural join of s1 and s2 with 5-tuple window on s1 and 10-tuple window on s2
- Streaming aggregations
  - produce relation, not streams

Introduction to Streams(cont)

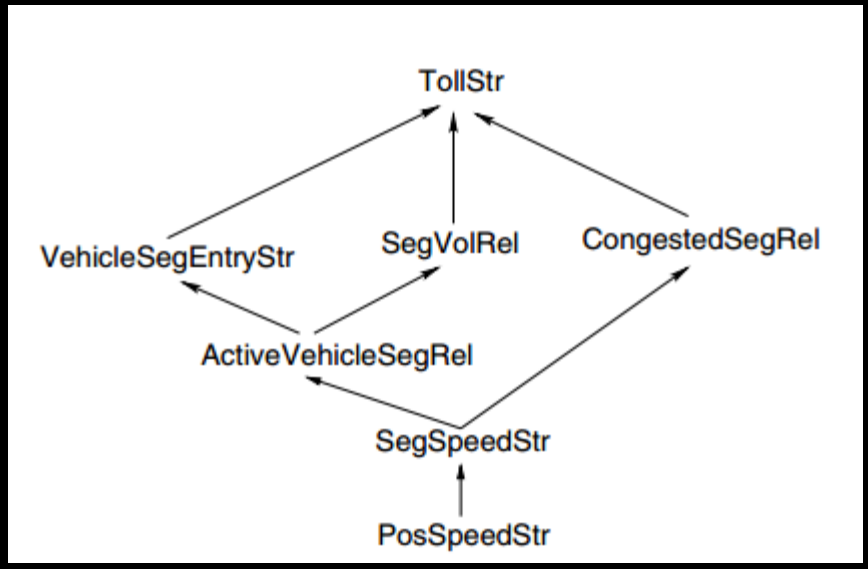
- Streaming Softwares
- Two Types
  - DB-based
  - Application-based

Introduction to STREAM / CQL

- DSMS (data stream management system) designed by Stanford in the early/mid 2000's
- Three main goals
  - Exploit well-understood relational semantics
  - Queries performing simple tasks are easy to write
  - Simple yet expressive
- SQL-like language

Streams and Relations

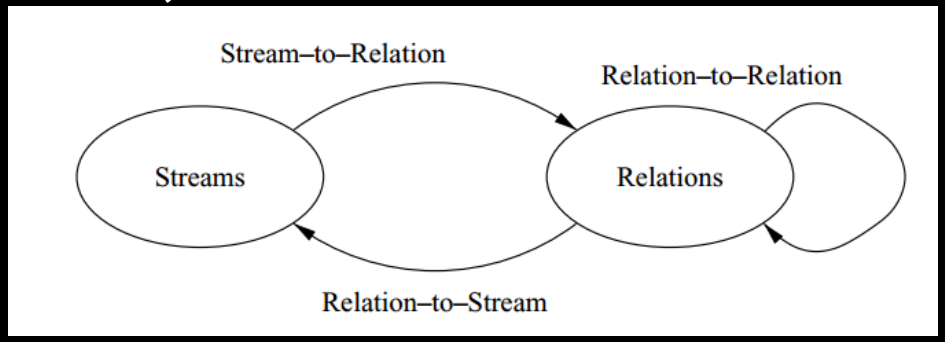
- Streams
  - Continuous, possibly infinite multiset of elements {tuple, timestamp}
- Relations
  - Static, finite multiset of tuples belonging to a given timestamp



Example: Moving vehicles through tolls

Streams vs Relations

- CQL is designed to perform all transformative operations on relations
- Streams are converted into relations before operations are performed, and then back into streams
- Tuples with the same timestamp are treated as a relation, similar to a "batch"



Transform Relations to Streams

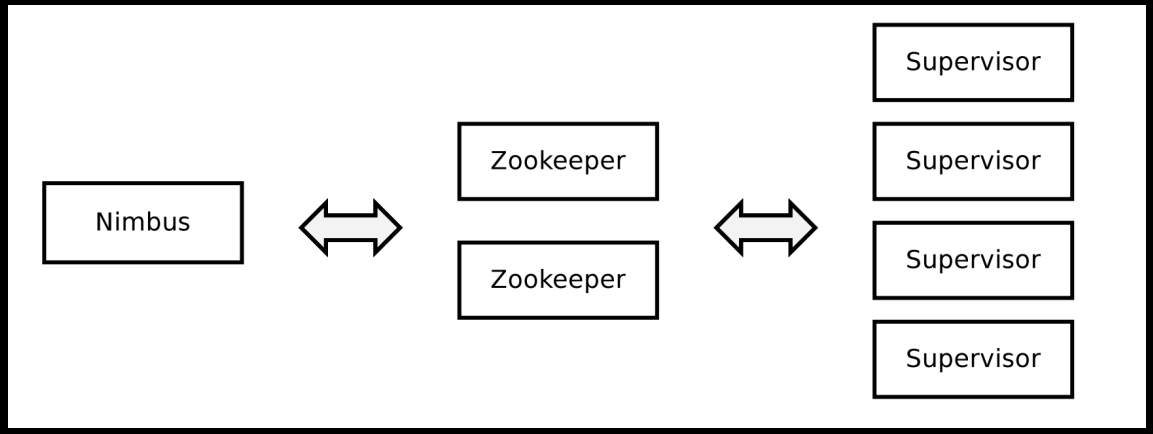
Time	S	LastRow	Filter	Istream
0	$\langle(a_0),0\rangle$	(a_0)	(a_0)	$\langle(a_0),0\rangle$
1	$\langle(a_0),0\rangle$ $\langle(a_1),1\rangle$	(a_1)	ϕ	$\langle(a_0),0\rangle$
2	$\langle(a_0),0\rangle$ $\langle(a_1),1\rangle$ $\langle(a_2),2\rangle$	(a_2)	(a_2)	$\langle(a_0),0\rangle$ $\langle(a_2),2\rangle$
3	$\langle(a_0),0\rangle$ $\langle(a_1),1\rangle$ $\langle(a_2),2\rangle$ $\langle(a_3),3\rangle$	(a_3)	ϕ	$\langle(a_0),0\rangle$ $\langle(a_2),2\rangle$
4	$\langle(a_0),0\rangle$ $\langle(a_1),1\rangle$ $\langle(a_2),2\rangle$ $\langle(a_3),3\rangle$ $\langle(a_4),4\rangle$	(a_4)	(a_4)	$\langle(a_0),0\rangle$ $\langle(a_2),2\rangle$ $\langle(a_4),4\rangle$
⋮	⋮	⋮	⋮	⋮

Three methods of generating a new stream

- Istream (insert stream)
  - new tuple at present
- Dstream (delete stream)
  - tuple removed at present
- Rstream (relation stream)
  - tuple exists at present

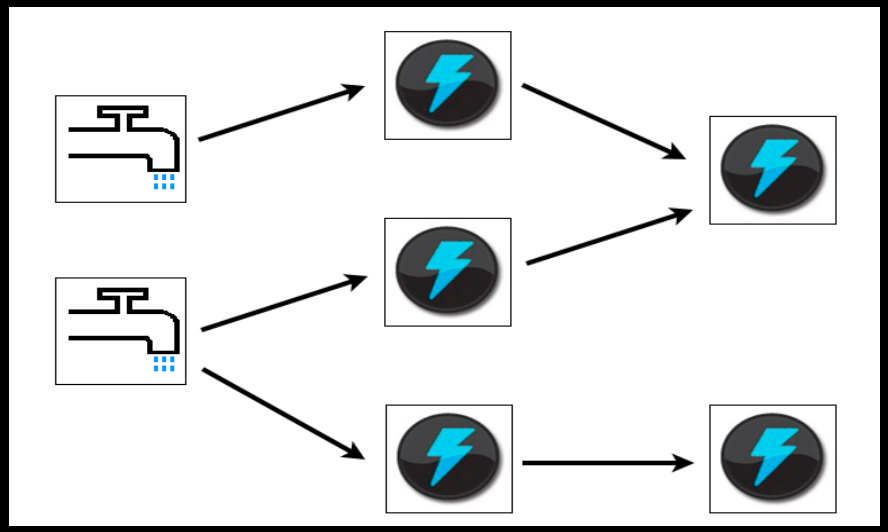
Introduction to Storm

- "Workflow engine" or "Computation Graph"
- Distributed, fault tolerant stream processing
- Hadoop : MapReduce Job :: Storm : Topology
- Scales horizontally
- No single point of failure

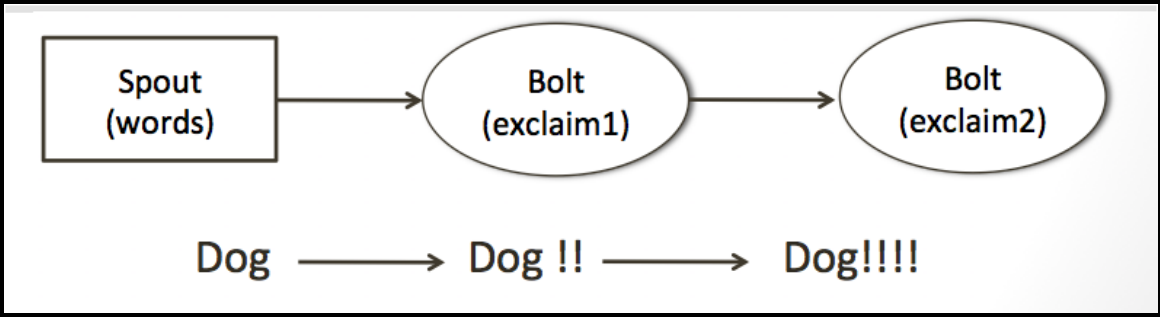


Topology

- Topology
  - network of spouts & bolts
  - runs indefinitely
- Spout -- source of a stream (Twitter API, queue)
- Bolt -- processes input stream(s) and can produce output stream(s)



Example




```
TopologyBuilder builder = new TopologyBuilder();

builder.setSpout("words", new TestWordSpout());

builder.setBolt("exclaim1", new ExclamationBolt()).
shuffleGrouping("words");

builder.setBolt("exclaim2", new ExclamationBolt()).
shuffleGrouping("exclaim1");
```

Features

- Guarantees
  - EVERY tuple will be processed
  - At-least-once & exactly once processing

- Fault Tolerant
  - Worker failures (Supervisor)
  - Coordinator failures (Nimbus)

- Scalable on commodity hardware
- Open Source
- Bolts defined in any language

Rule 1: Keep the Data Moving

- Latency of Storage operations and polling
- Process messages "in-stream"
- No requirement to store to perform any operations
- Active processing model(non-polling)

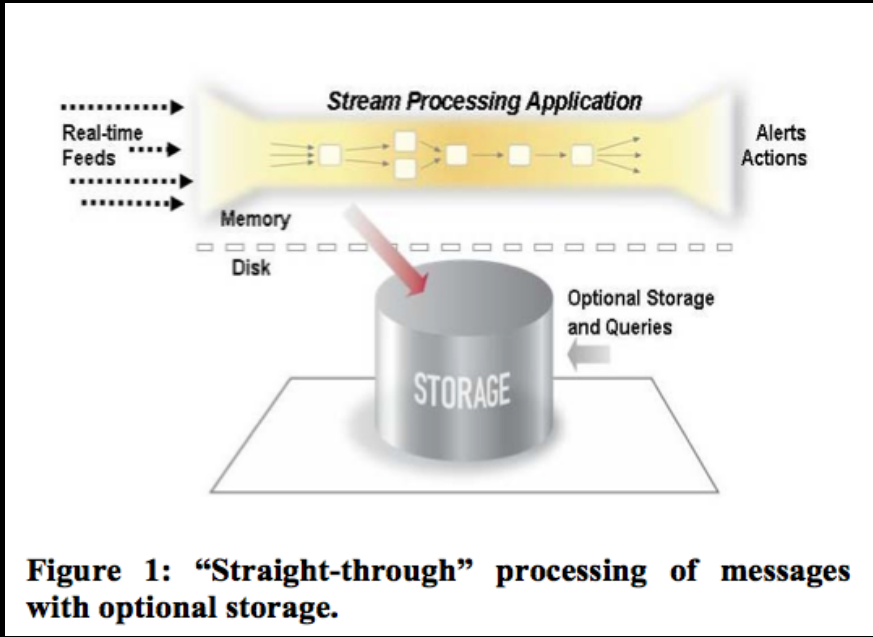


Figure 1: "Straight-through" processing of messages with optional storage.

Rule 1: STREAM / CQL

- Push-based system
  - Actively processes data as it arrives
- Able to output results as streams
- Stores data as a relation once operations are performed (joins, aggregates, etc.)
- Designed to facilitate incremental processing

Rule 1: Storm

- Data processed in real-time
- ZeroMQ used for messaging
  - Asynchronous messaging library
  - Push based communication
  - Automatic batching of messages
- No data is written during processing

Rule 2: Query using SQL on Streams

- Low-level language VS high-level "StreamSQL" language
- Built-in extensible stream-oriented primitives and operators
  - Window, Aggregate, joins

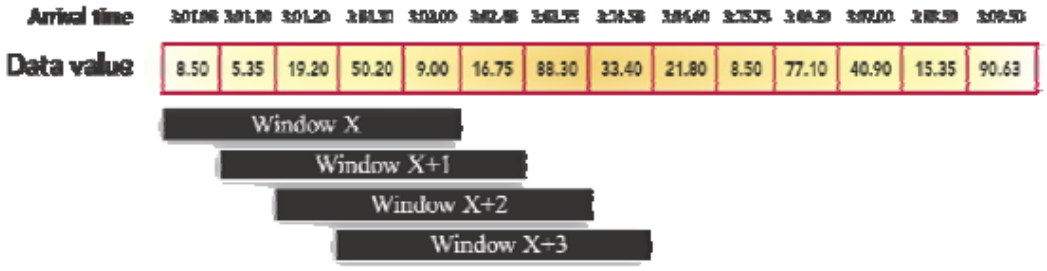


Figure 2: Windows define the scope of operations. The window has a size of 5 messages and slides by 1 each time the associated operator is executed. Consecutive windows overlap.

Rule 2: STREAM / CQL

- All comparisons are done between relations
- CQL is very SQL-like in its design
- Uses sliding window system

```
Select P.price
From Items[Rows 5] as I,
        PriceTable as P
Where I.itemID = P.itemID
```

```
Select *
From PosSpeedStr
Where speed > 65
```

```
Select Istream(*)
From ActiveVehicleSegRel
```

Rule 2: STREAM / CQL (cont)

Types of sliding windows:

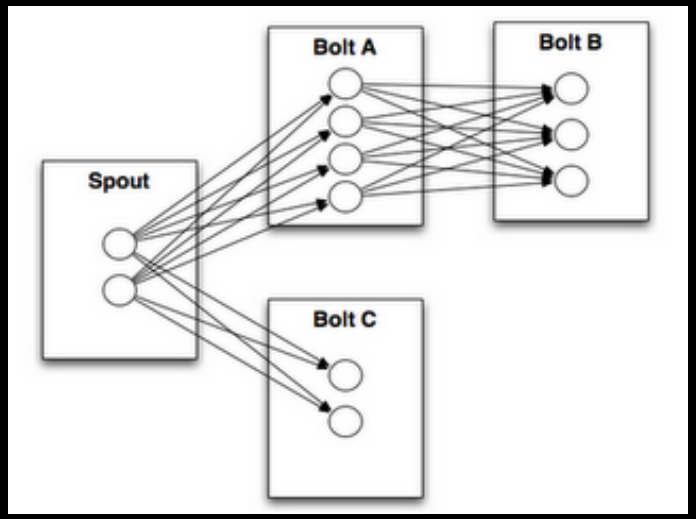
- Time-based
  - Uses only tuples from recent timestamps
- Tuple-based
  - Uses the last n tuples provided by the stream
- Partitioned windows
  - "Group-by" window that returns the latest n aggregated tuples
- Windows with a "slide" parameter
  - Time-based, but with a specified range

Rule 2: Storm

- All functionality defined in a general purpose language
  - Bolts
  - Spouts
- More control but more complex
- Basic functionality must be defined by user
  - Windowing
  - Joins
  - Aggregates

Rule 2 : Storm (cont.)

- Central window manager
- Using stream grouping to achieve windowing
  - Shuffle Grouping
  - Field Grouping
  - All Grouping



Rule 3: Handle Stream Imperfections

- Delayed data & time out
- Out of order data & stay open
- Time out vs. data moving

Rule 3: STREAM / CQL

- Processes each timestamp as a "batch"
- Must be able to recognize that all tuples for one "batch" have arrived
- Uses meta-input called "heartbeats"
  - Indicates that no new tuples will arrive with that timestamp

Rule 3: STREAM / CQL (cont)

Methods by which heartbeats are generated:

- Assigned using the DSMS clock when stream tuples arrive
- Stream source can generate its own heartbeats (only if tuples arrive in order)
- Properties of stream sources and the system environment can be used

Rule 3: Storm

- Manually handle imperfections in spout definition
  - Missing data
  - Out of order data
- Timeouts for blocking calculations specified in bolt definition

Rule 4: Generate Predictable Outcomes

- Time-ordered, deterministic processing
  - example:
    TICKS(stock_symbol, volume, price, time)
    SPLITS(symbol, time, split_factor)
  - process in ascending order
  - out-of-order process result in wrong ticks
  - sort-order messages are insufficient

- Fault tolerance and recovery
  - replay & reprocess

Rule 4: STREAM / CQL

- Time-based windowing is deterministic
  - All tuples within a window of timestamps are processed
- Tuple-based windowing is NOT deterministic
  - No guarantee which tuples are processed

Timestamp	Tuple
1	4
1	3
1	9
1	8
2	3
2	8
2	6
3	1
3	3
3	0

Rule 4: Storm

- Non-deterministic processing
- Use stream grouping to ensure deterministic processing
  - Field Grouping -- same tuple goes to same node

Rule 5: Integrated Stored and Streaming Data

- Compare "Present" with "Past"
  - Store, access, and modify state information
- Two motives
  - Switch to a live feed seamlessly(Trading app)
  - Compute from past and catch up to real time
- Low Latency
  - State stored in the same OS address space as application using an embedded database system

Rule 5: STREAM / CQL

- All streams are processed as relations, allowing easy comparison to other relations
  - Streams CANNOT be directly operated upon
  - Highly convenient for comparing stored data to streaming data
- Uses sliding window system in order to convert streams to relations

Rule 5: Storm

- Interact with database using a Bolt
  - Perform joins with stored data
  - Insert value into database
  - Modify existing stored data

- No common language
- JDBC / ODBC

Rule 6: Guarantee Data Safety and Availability

- "Tandem-style" hot backup and failover
- Secondary system synchronization

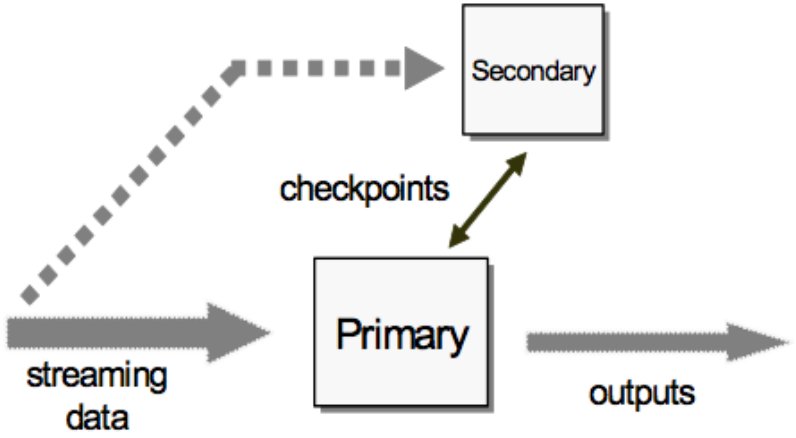


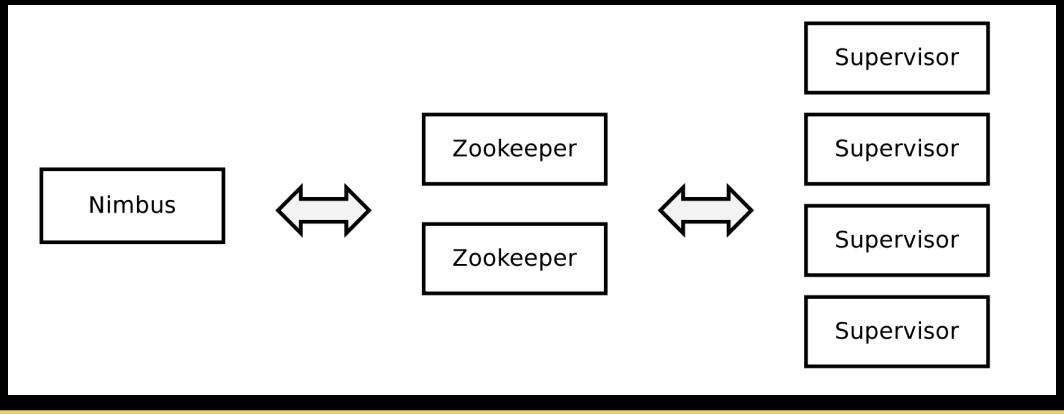
Figure 3: "Tandem-style" hot backup and failover can ensure high availability for real-time stream processing.

Rule 6: STREAM / CQL

- Provides similar data security to DBMS
- No obvious form of data backup, but could be accomplished with two separate systems taking in the same stream

Rule 6: Storm

- Guaranteed tuple processing
  - At-least-once
  - Exactly-once (Trident)
- Highly available / Automatic recovery
  - Worker node failure
  - Supervisor failure
  - Nimbus failure



Rule 7: Partition and Scale Applications Automatically

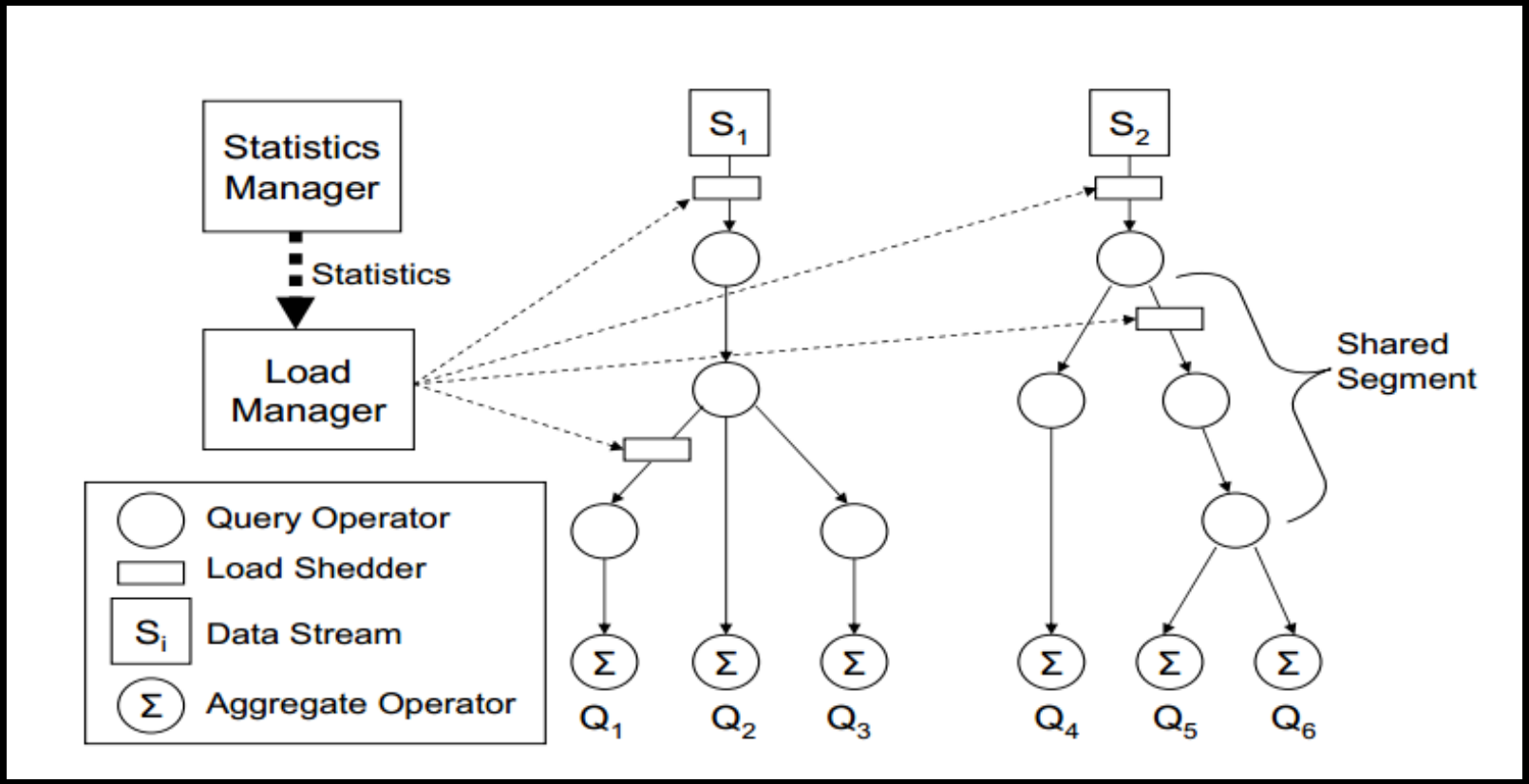
- Distribute processing across multiple processors and machines
- Incremental scalability
- Facilitating low latency

Rule 7: STREAM / CQL

- No distributed system
- Load shedding
  - Dynamically degrades performance based on the velocity of incoming data
  - Reduces load in order to minimize latency
  - Load manager chooses locations that will distribute error evenly across all queries

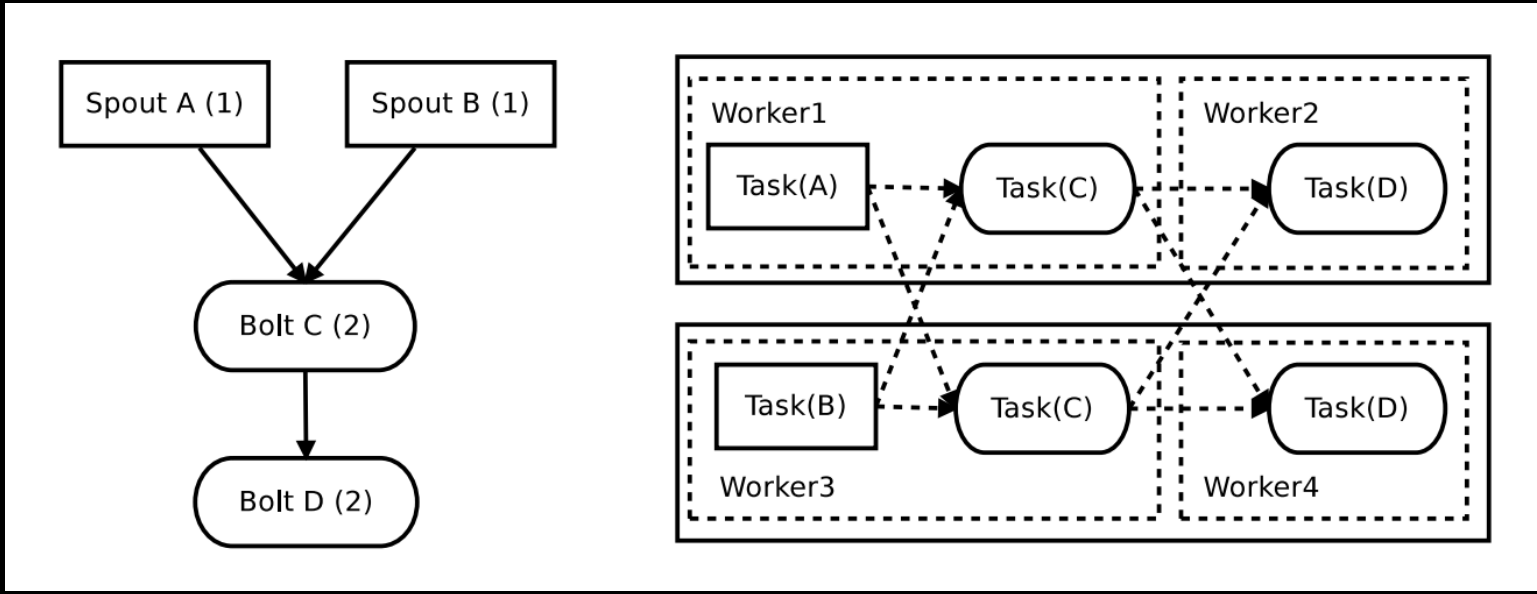
Rule 7: STREAM / CQL (cont)

Load Shedding



Rule 7: Storm

- Distributed
  - set number of workers
  - set level of parallelism for each component
- Automatic rebalancing for adding nodes

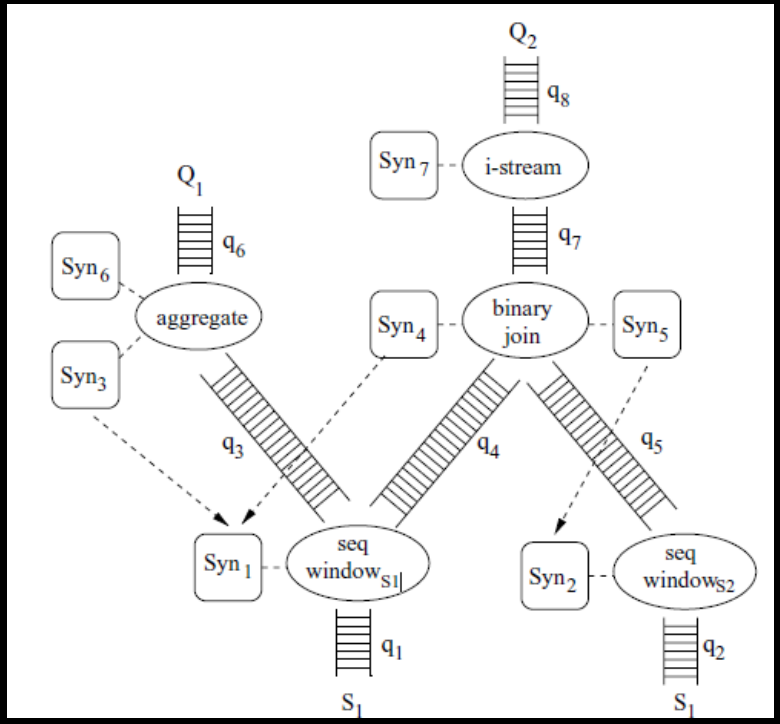


Rule 8: Process and Respond Instantaneously

- Low latency & real-time response
- Highly-optimized, minimal-overhead execution engine
  - minimize the ratio of overhead to useful work
  - All system components to be designed with high performance

Rule 8: STREAM / CQL

- Query plans are merged with existing plans when possible
- Heuristics to improve efficiency
  - Push selections below joins
  - Maintain and use indexes
  - Share synopses and operators



Rule 8: Storm

- Disk write not in critical path
- ZeroMQ used for efficient network communication
- Performance varies by topology
- One benchmark: 1m tuples per node per sec

Conclusions

- Greatly depends on the application
  - Not one-size-fits-all
- Rules were made to be broken
  - SQL not necessarily required
  - Non-deterministic processing can be ok
- Some rules more important than others
  - Maintain velocity of data
  - Integrate stored and streaming data
  - Data availability/scalability

Works cited

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