Cosmos

Big Data and Big Challenges

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Outline

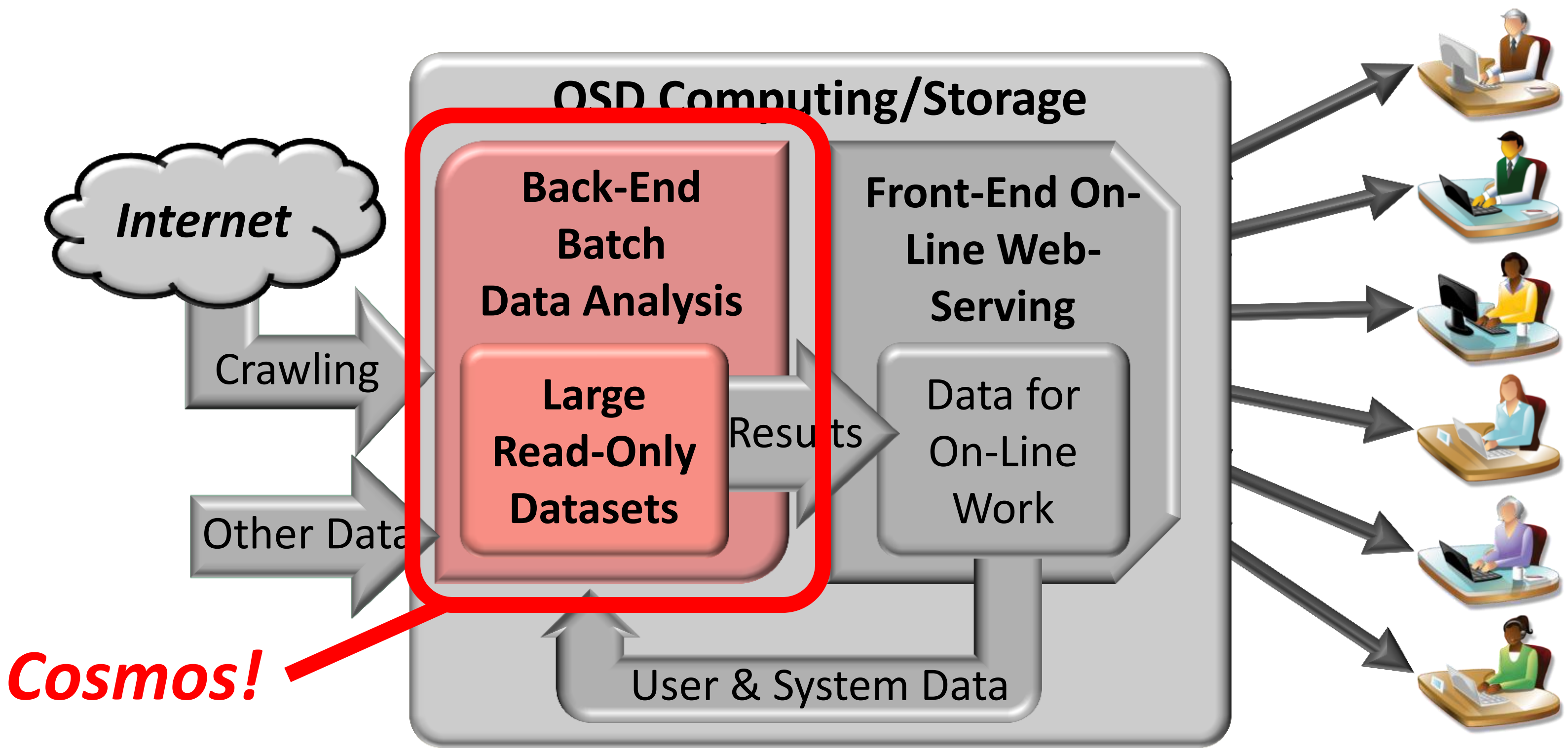
- Introduction
- Cosmos Overview
- The Structured Streams Project
- Some Other Exciting Projects
- Conclusion

What Is COSMOS?

- Petabyte Store and Computation System
  - About 62 physical petabytes stored (~275 logical petabytes stored)
  - Tens of thousands of computers across many datacenters
- Massively parallel processing based on Dryad
  - Similar to MapReduce but can represent arbitrary DAGs of computation
  - Automatic computation placement with data
- SCOPE (Structured Computation Optimized for Parallel Execution)
  - SQL-like language with set-oriented record and column manipulation
  - Automatically compiled and optimized for execution over Dryad
- Management of hundreds of “Virtual Clusters” for computation allocation
  - Buy your machines and give them to COSMOS
  - Guaranteed that many compute resources
  - May use more when they are not in use
- Ubiquitous access to OSD’s data
  - Combining knowledge from different datasets is today’s secret sauce

Cosmos and OSD Computation

- OSD Applications fall into two broad categories:
  - **Back-end**: Massive batch processing creates new datasets
  - **Front-end**: Online request processing serves up and captures information
- Cosmos provides storage and computation for Back-End Batch data analysis
  - It does not support storage and computation needs for the Front-End



COSMOS: The Service

- Data drives search and advertising
  - Web pages: Links, text, titles, etc
  - Search logs: What people searched for, what they clicked, etc
  - IE logs: What sites people visit, the browsing order, etc
  - Advertising logs: What ads do people click on, what was shown, etc
- We generate about 2 PB every day
  - SearchUX is hundreds of TB
  - Toolbar is many 10s of TB
  - Search is hundreds of TB
  - Web snapshots are many 10s of TB
  - MSN, Hotmail, IE, web, etc…
- COSMOS is the backbone for Bing analysis and relevance
  - Click-stream information is imported from many sources and “cooked”
  - Queries analyzing user context, click commands, and success are processed
- COSMOS is a service
  - We run the code ourselves (on many tens of thousands of servers)
  - Users simply feed in data, submit jobs, and extract the results

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Cosmos Architecture from 100,000 Feet

SCOPE Layer:

-- SCOPE Code is submitted to the SCOPE Compiler

-- The optimizer make decisions about execution plan and parallelism

-- Algebra (describing the job) is built to run on the SCOPE Runtime

Execution Layer:

-- Jobs queues up per Virtual Cluster

-- When a job starts, it gets a Job Mgr to deploy work in parallel close to its data

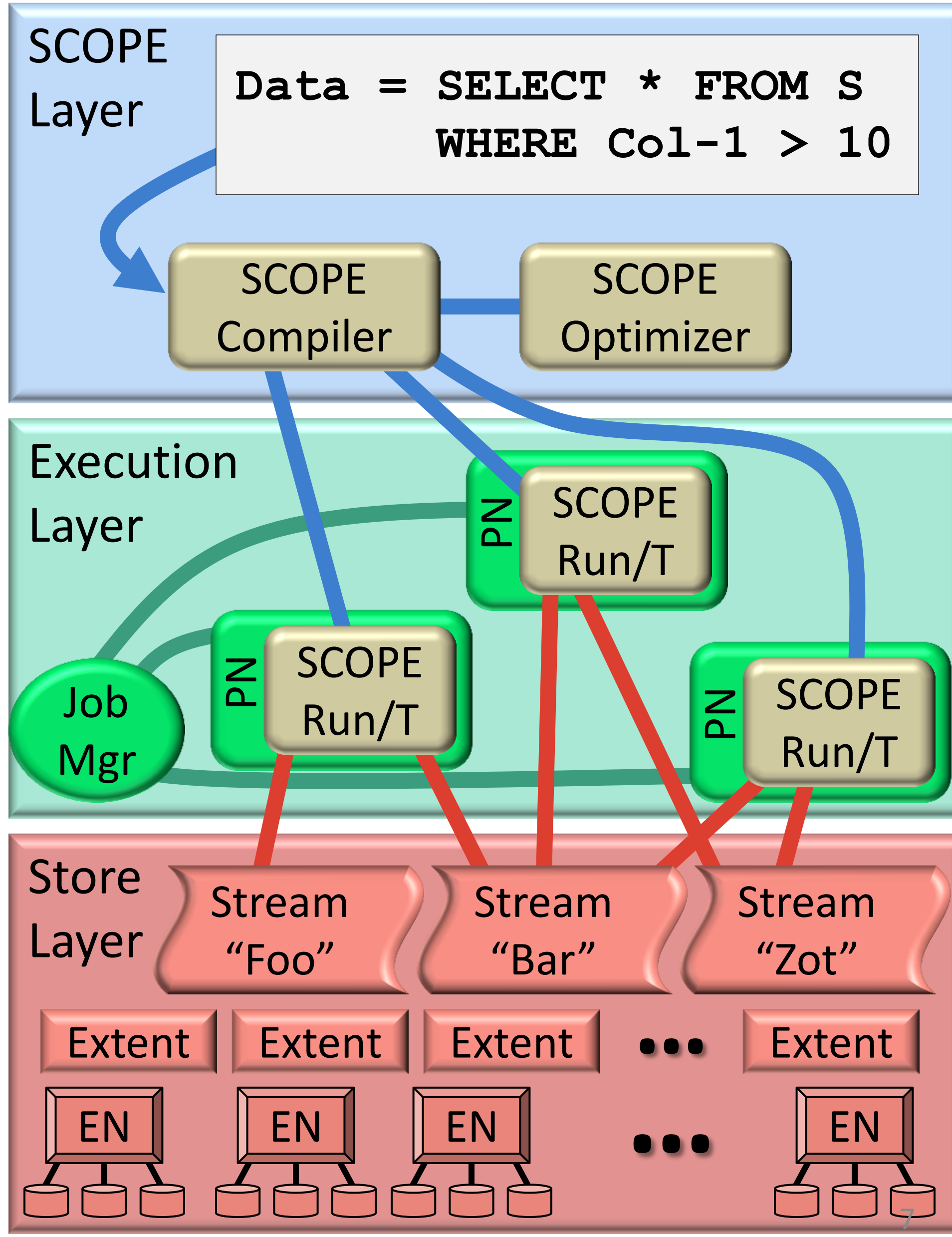
-- Many Processing Nodes (PNs) host execution vertices running SCOPE code

Store Layer:

-- Many Extent Nodes store and compress replicated extents on disk

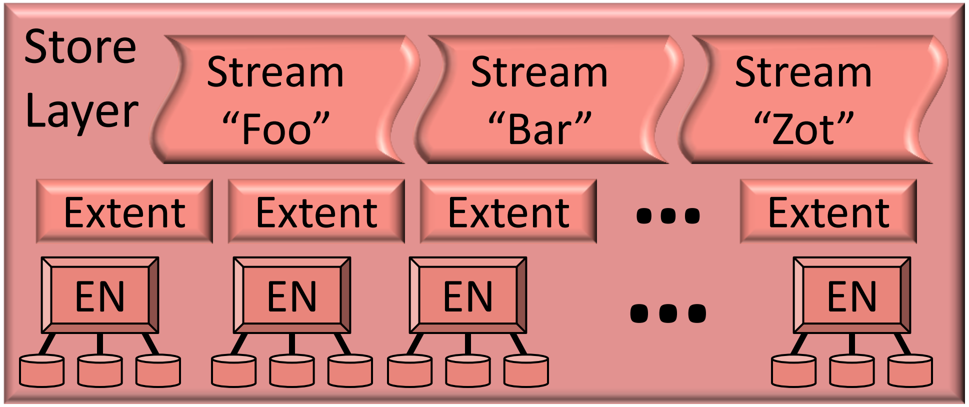
-- Extents are combined to make unstructured streams

-- CSM (COSMOS Store Manager) handles names, streams, & replication



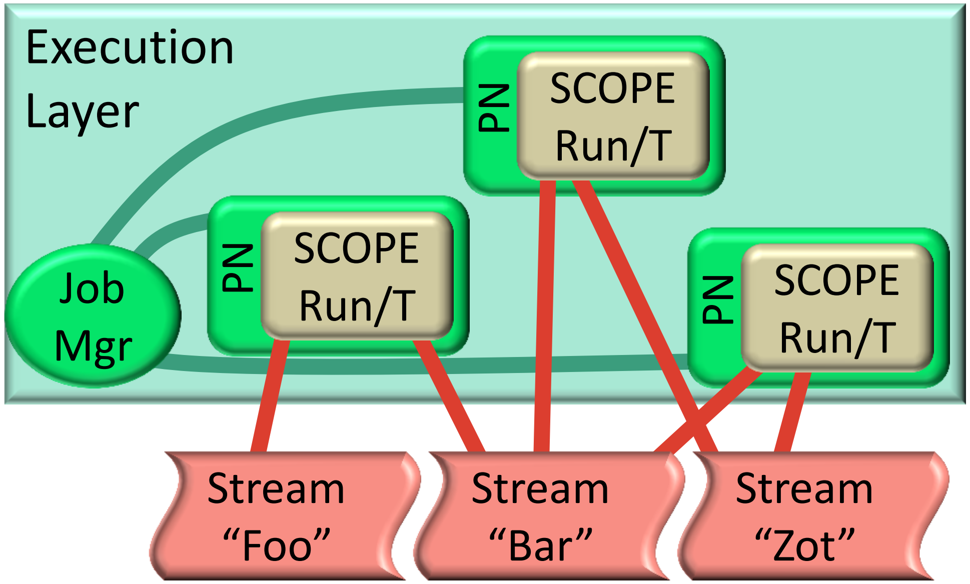
The Store Layer

- Extent Nodes:
  - Implement a file system holding extents
  - Each extent is up to 2GB
  - Compression and fault detection are important parts of the EN
- CSM: COSMOS Store Manager
  - Instructs replication across 3 different ENs per extent
  - Manages composition of streams out of extents
  - Manages the namespace of streams



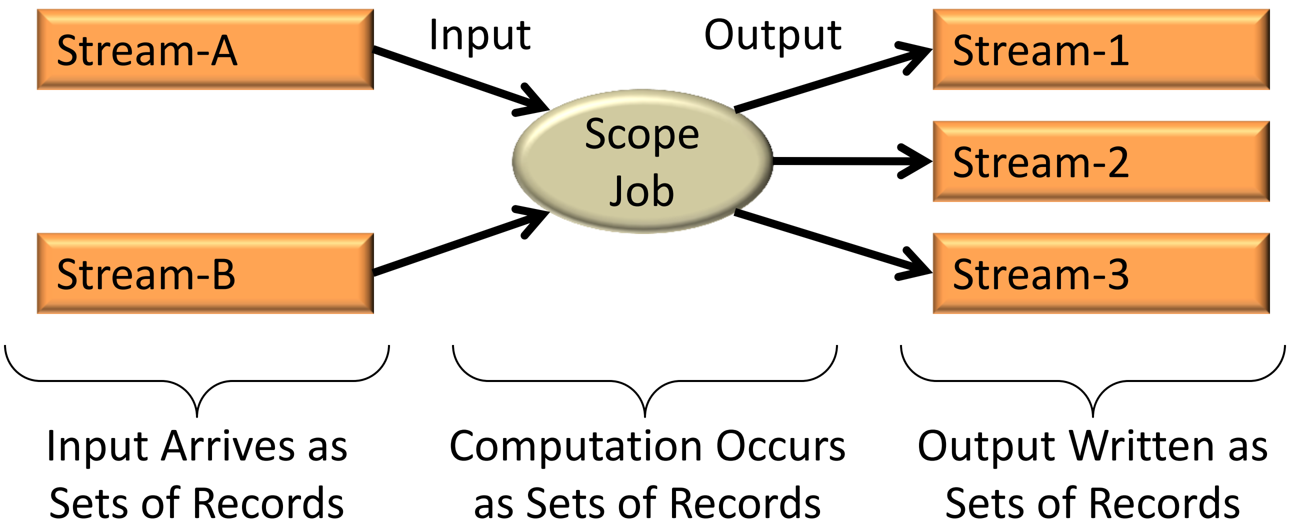
The Execution Engine

- Execution Engine:
  - Takes the plan for the parallel execution of a SCOPE job and finds computers to perform the work
  - Responsible for the placement of the computation close to the data it reads
  - Ensures all the inputs for the computation are available before firing it up
  - Responsible for failures and restarts
- Dryad is similar to Map-Reduce



The SCOPE Language

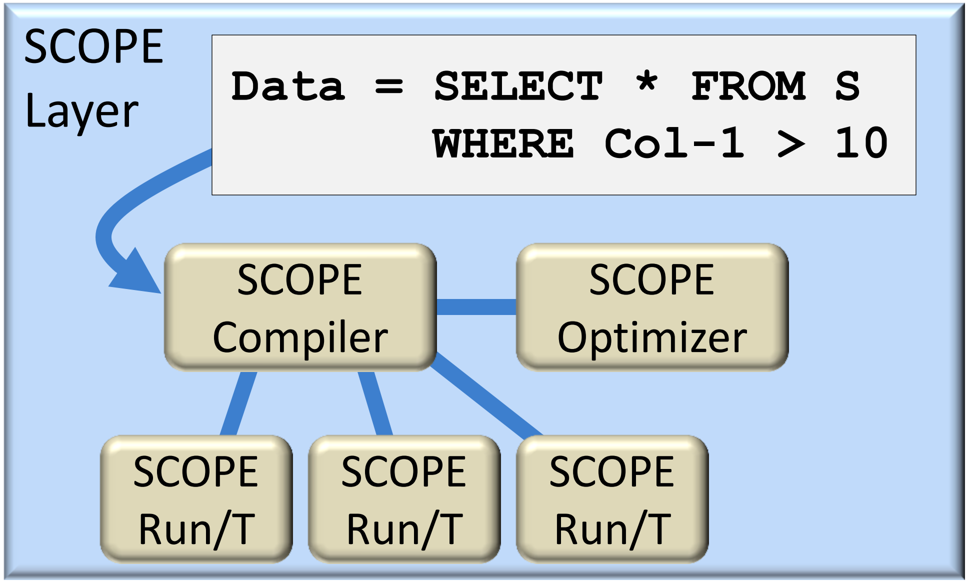
- SCOPE (Structured Computation Optimized for Parallel Execution)
  - Heavily influenced by SQL and relational algebra
  - Changed to deal with input and output streams



- SCOPE is a high level declarative language for data manipulation
  - It translates very naturally into parallel computation

The SCOPE Compiler and Optimizer

- The SCOPE Compiler and Optimizer take SCOPE programs and create:
  - The algebra describing the computation
  - The breakdown of the work into processing units
  - The description of the inputs and outputs from the processing units
- Many decisions about compiling and optimizing are driven by data size and minimizing data movement



The Virtual Cluster

- Virtual Cluster: a management tool
  - Allocates resources across groups within OSD
  - Cost model captured in a queue of work (with priority) within the VC
- Each Virtual Cluster has a guaranteed capacity
  - We will bump other users of the VC's capacity if necessary
  - The VC can use other idle capacity

100 Hi-Pri PNs	500 Hi-Pri PNs	20 Hi-Pri PNs	1000 Hi-Pri PNs	350 Hi-Pri PNs
Work Queue	Work Queue	Work Queue	Work Queue	Work Queue
VC-A	VC-B	VC-C	VC-D	VC-E

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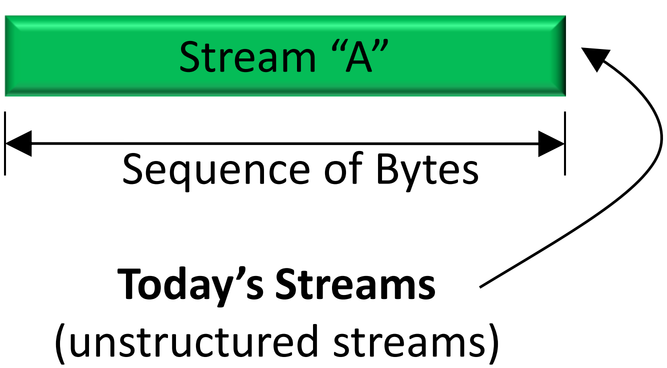
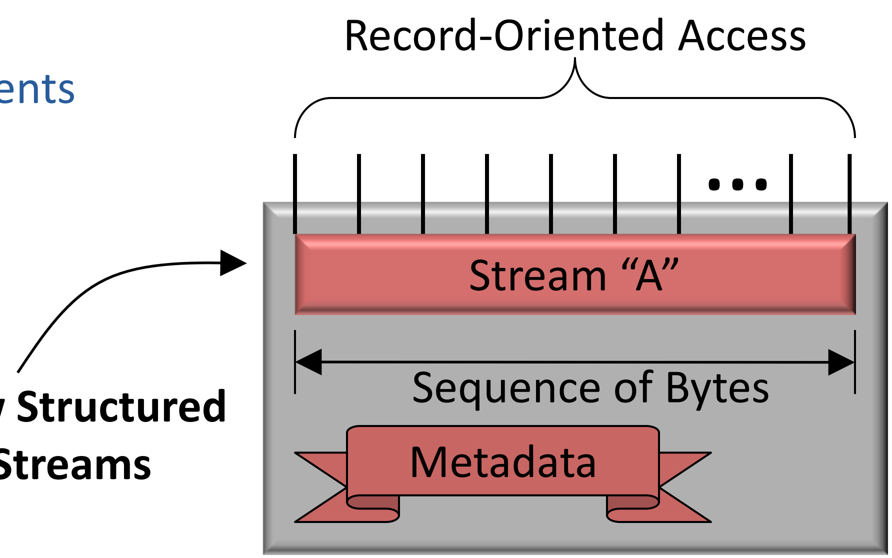
Introducing Structured Streams

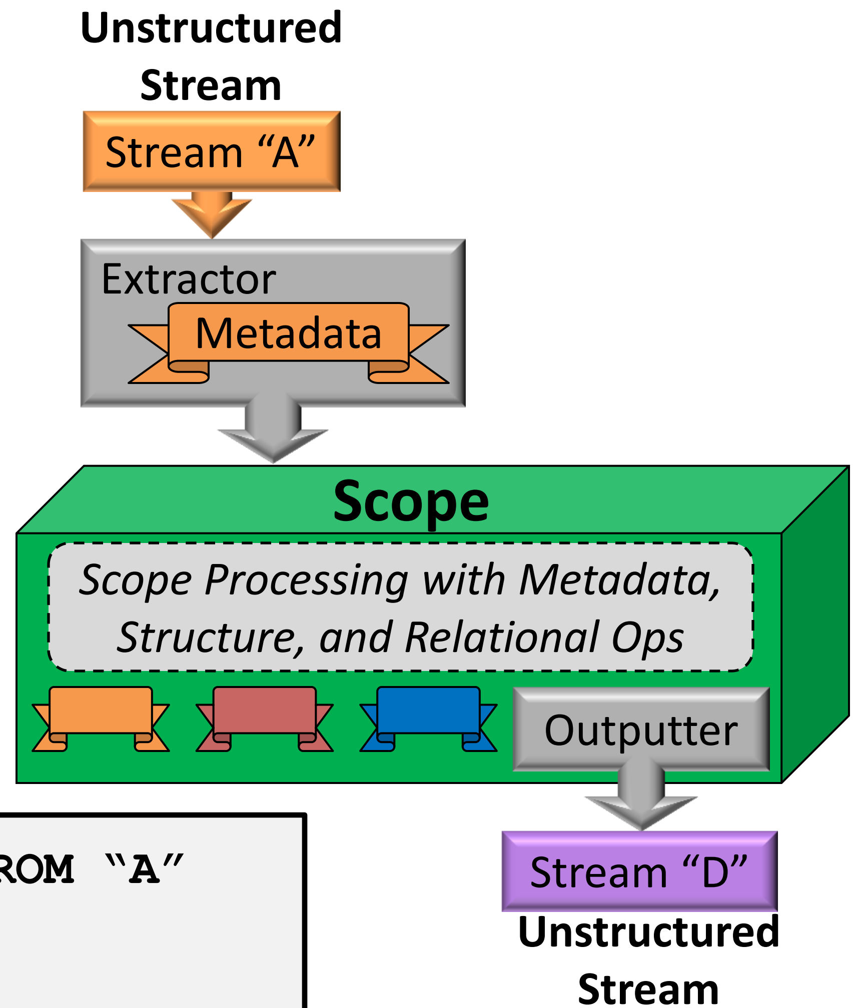
- Cosmos currently supports streams
  - An unstructured byte stream of data
  - Created by append-only writing to the end of the stream
- Structured streams are streams with metadata
  - Metadata defines column structure and affinity/clustering information
- Structured streams simplify extractors and outputters
  - A structured stream may be imported into scope without an extractor
- Structured streams offer performance improvements
  - Column features allow for processing optimizations
  - Affinity management can dramatically improve performance
  - Key-oriented features offer (sometimes very significant) access performance improvements





Today's Use of Extractors and Outputters

- Extractors
  - Programs to input data and supply metadata
- Outputters
  - Take Scope data and create a bytestream for storage
  - **<u>Discards metadata known to the system</u>**



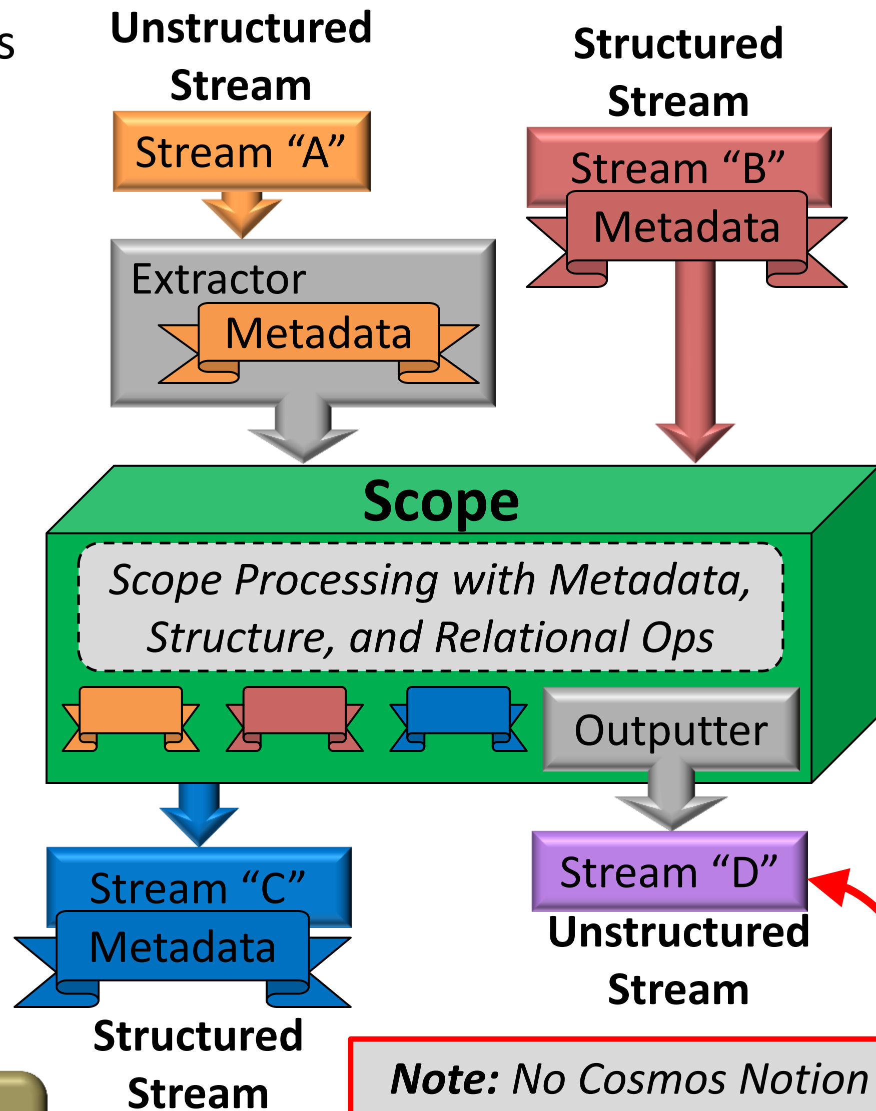

```
source = EXTRACT col1, col2 FROM "A"
Data = SELECT * FROM source

<process Data>

OUTPUT Data to "D"
```

Metadata, Streams, Extractors, & Outputters

- Scope has metadata for the data it is processing
  - Extractors provide metadata info as they suck up unstructured streams
- Processing the Scope queries ensures metadata is preserved
  - The new results may have different metadata than the old
  - Scope knows the new metadata
- Scope writes structured streams
  - The internal information used by Scope is written out as metadata
- Scope reads structured streams
  - Reading a structured stream allows later jobs to see the metadata

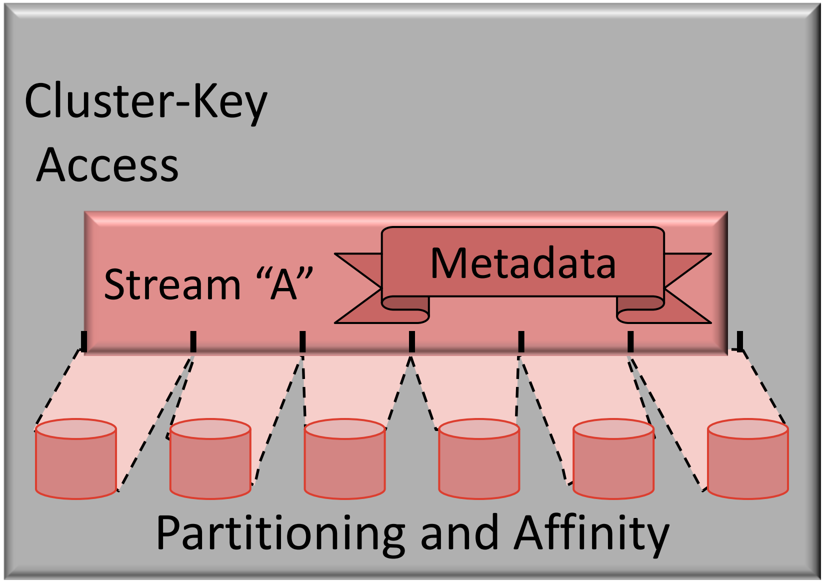


Note: *No Cosmos Notion of Metadata for Stream "D" -- Only the Outputter Knows…*

The Representation of a Structured Stream on Disk Is Only Visible to Scope!

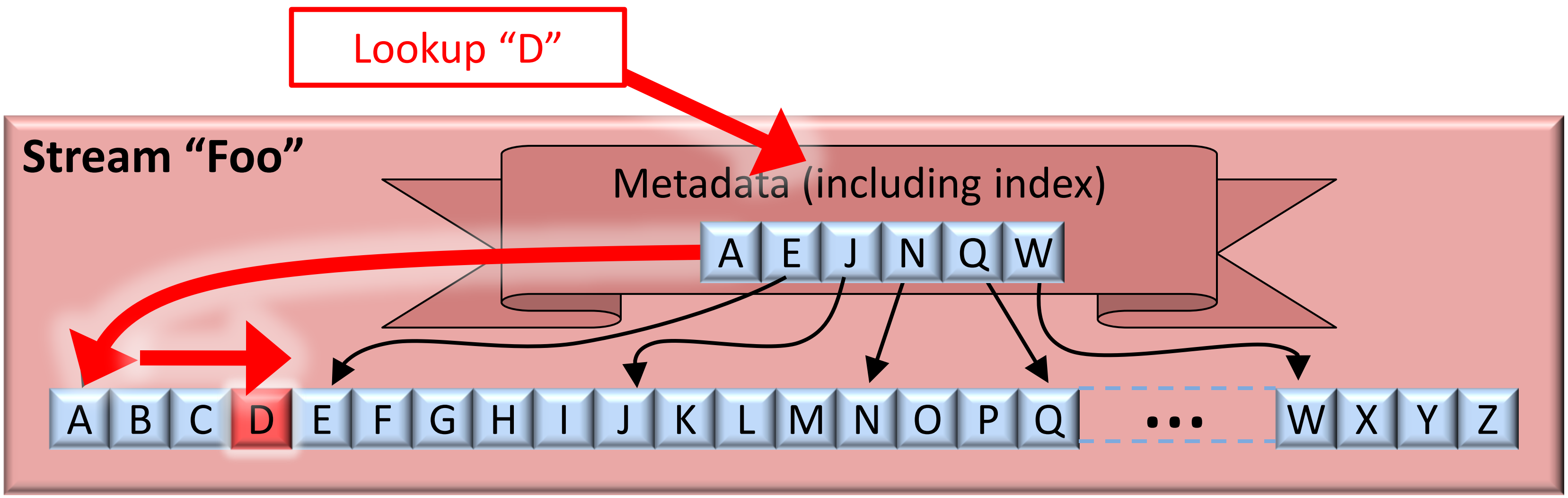
Streams, Metadata, and Increased Performance

- By adding metadata (describing the stream) *into* the stream, we can provide performance improvements:
  - Cluster-Key access: random reads of records identified by key
  - Partitioning and affinity: data to be processed together (sometimes across multiple streams), can be placed together for faster processing
- Metadata for a structured stream is kept *inside* the stream
  - The stream is a self-contained unit
  - The structured stream is still an unstructured stream (plus some stuff)



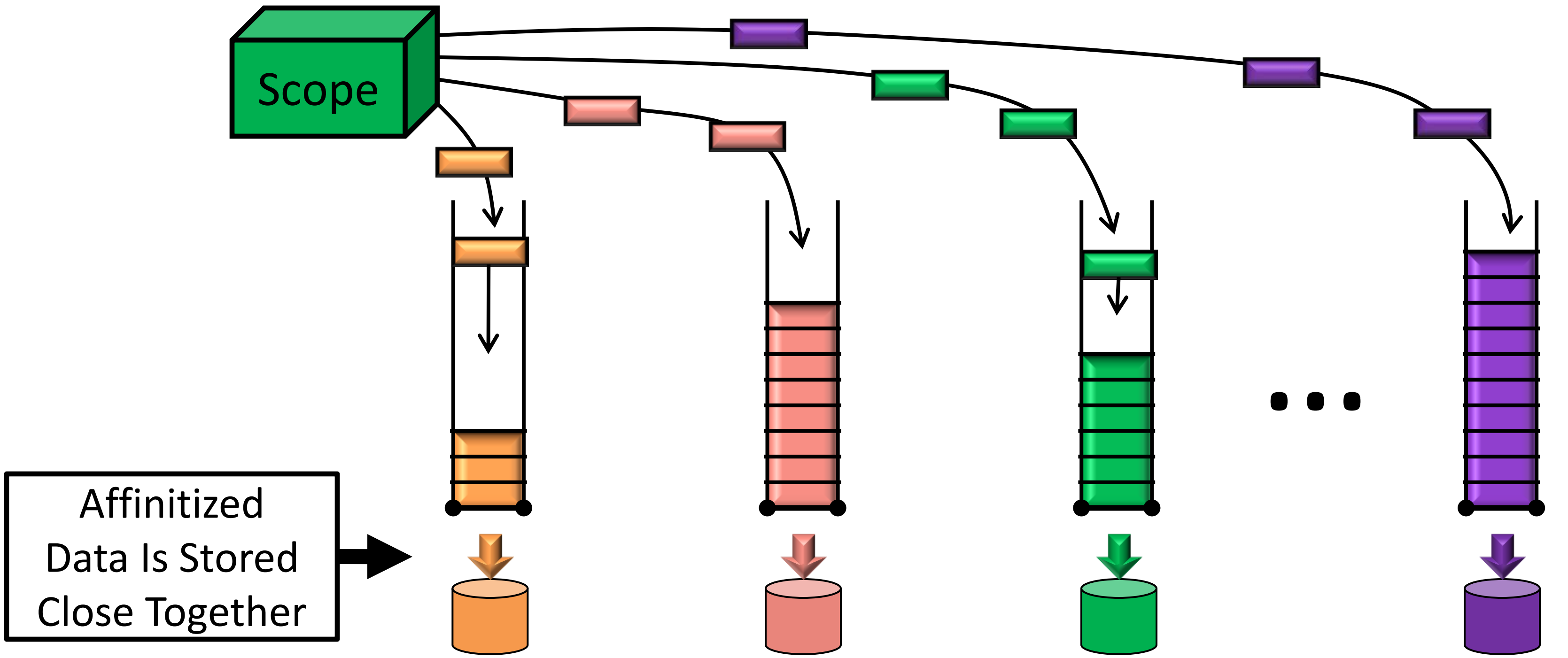
Cluster-Key Lookup

- Cluster-Key Indices make a huge performance improvement
  - Today: If you want a few records, you must process the whole stream
  - Structured Streams: Directly access the records by cluster-key index
- How it works:
  - Cluster-Key lookup is implemented by having indexing information contained in the metadata inside the stream
    - The records must be stored in cluster-key order to use cluster-key lookup
    - Cosmos managed index generated at structured stream creation



Implementing Partitioning and Affinity

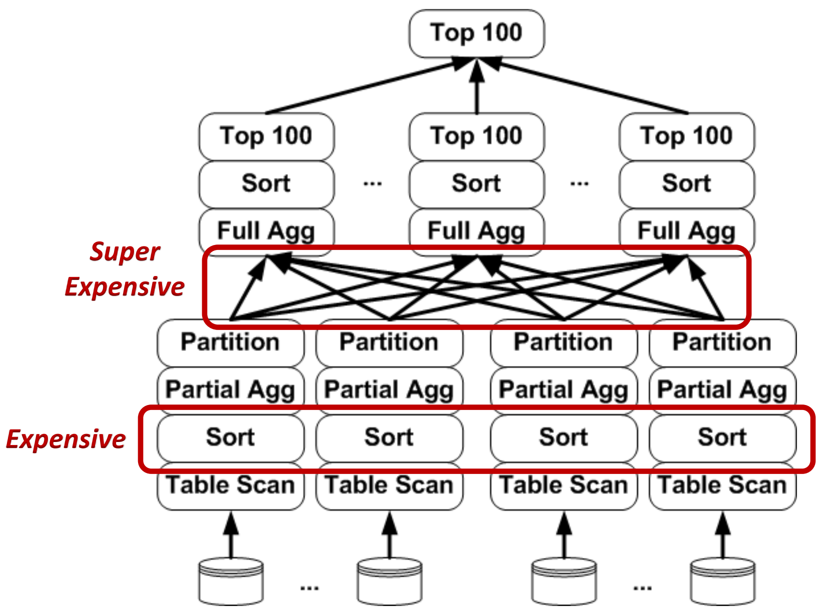
- Joins across streams can be very expensive
  - Network traffic is a major expense when joining large datasets together
  - Placing related data together can dramatically reduce processing cost
- We affinitize data when we believe it is likely to be processed together
  - Affinitization places the data close together
  - If we want affinity, we create a “partition” as we create a structured stream
  - A partition is a subset of the stream intended to be affinitized together



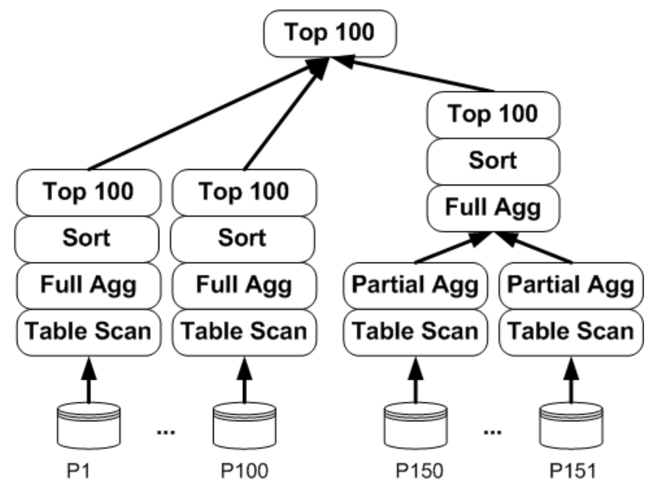
Case Study 1: Aggregation

```
SELECT GetDomain(URL) AS Domain,
        SUM((MyNewScoreFunction(A, B, ...)) AS TotalScore
FROM Web-Table
GROUP BY Domain;

SELECT TOP 100 Domain ORDER BY TotalScore;
```



Unstructured Datasets

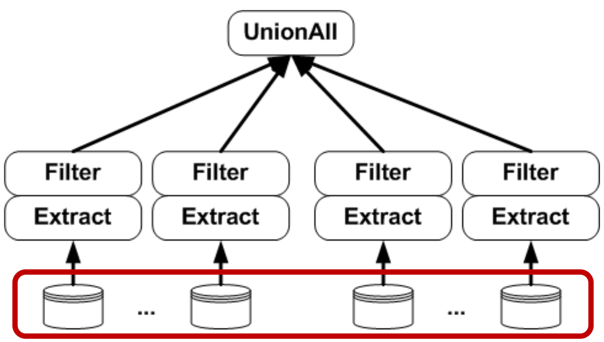


Structured Datasets (Sstream)
(partitioned by URL, sorted by URL)

Much more efficient w/o shuffling data across network

Case Study 2: Selection

```
SELECT URL, feature1, feature2
FROM Web-Table
WHERE URL == www.imdb.com;
```



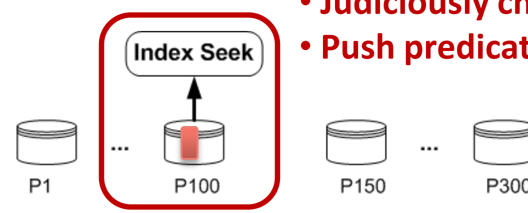
Massive data reads

Unstructured Datasets

Partition Metadata

Partition	Range	Metadata
...	...	...
P100	www.imc.com ⇔ www.imovie.com	
P101	www.imz.com ⇔ www.inode.com	
...	...	...

- **Judiciously choose partition**
- **Push predicate close to data**

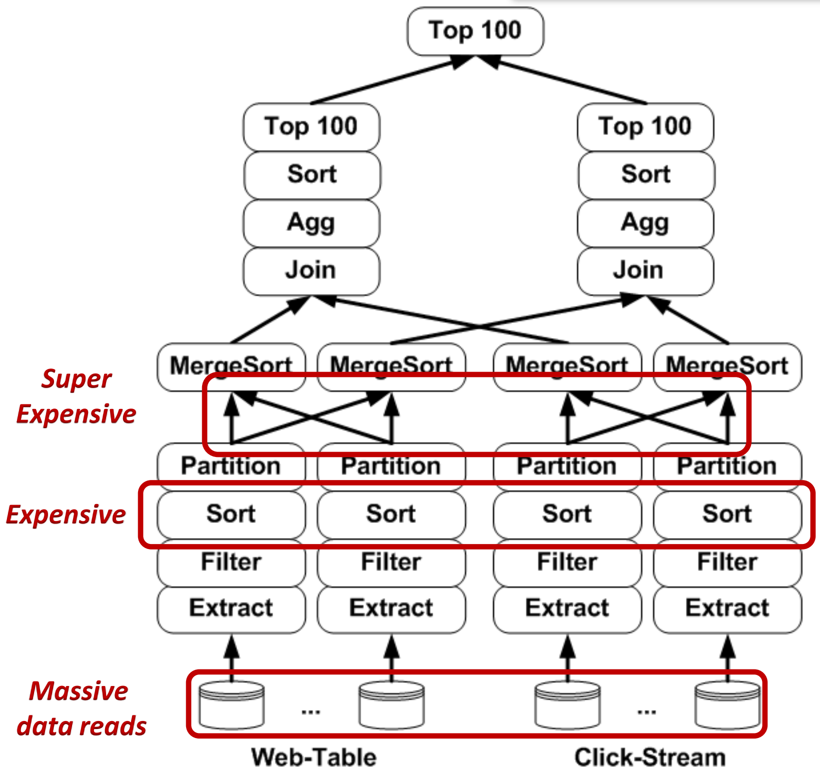


Structured Datasets (Sstream)
(partitioned by URL, sorted by URL)

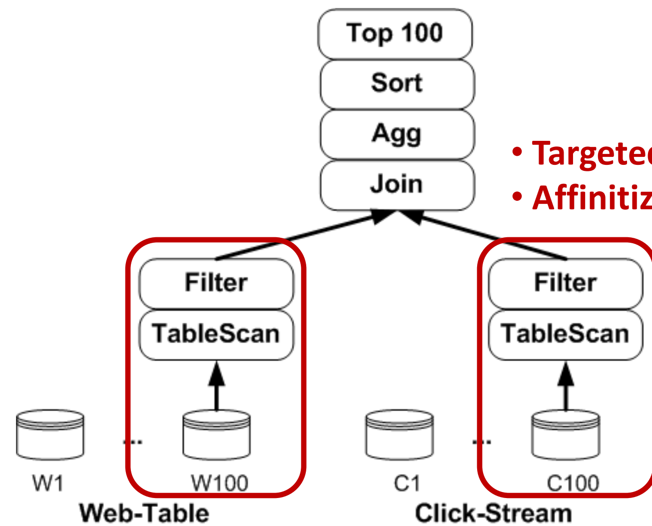
Case Study 3: Join Multiple Datasets

```
SELECT URL, COUNT(*) AS TotalClicks
FROM Web-Table AS W, Click-Stream AS C
WHERE GetDomain(W.URL) == www.shopping.com
   AND W.URL == C.URL AND W.Outlinks > 10
GROUP BY URL;

SELECT TOP 100 URL ORDER BY TotalClicks;
```



Unstructured Datasets



- **Targeted partitions**
- **Affinitized location**

Structured Datasets (Sstream)
(partitioned by URL, sorted by URL)

Much more efficient w/o shuffling data across network

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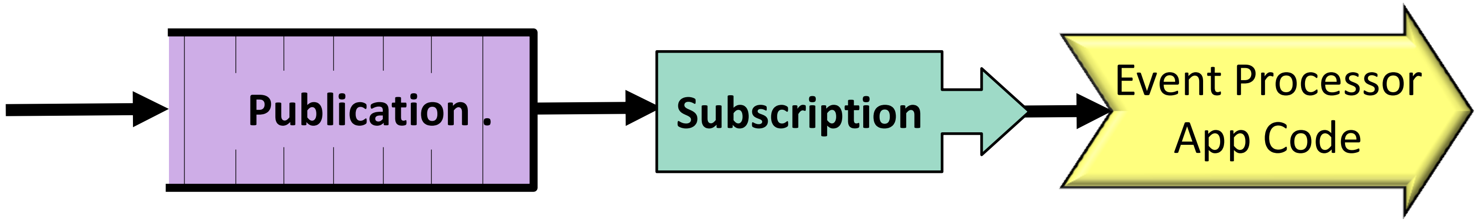
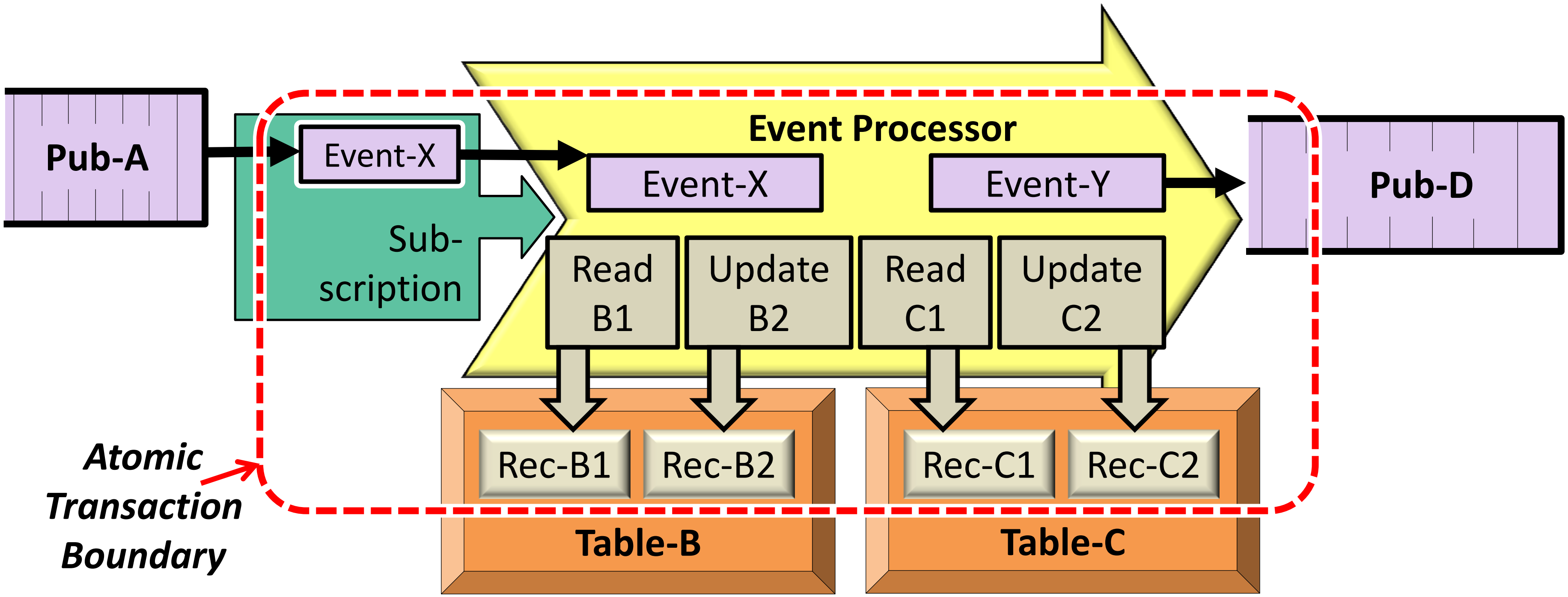
Reliable Pub-Sub Event Processing

- Cosmos will add high performance pub-sub event processing
  - **Publications** receive append-only events
  - **Subscriptions** define the binding of publications to event processing app code
- Publications and subscriptions are designed to handle many tens of thousands of events per second
  - Massively partitioned publications
  - Cosmos managed pools of event processors with automatic load balancing
- Events may be appended to publications by other event processors or by external applications feeding work into Cosmos



High-Performance Event Processing

- Event processors (user application code) may:
  - Read and update records within tables
  - Append to publications
- Each event will be consumed in a transaction atomic with its table and publication changes
  - Transactions may touch any record(s) in the tables
  - These may be running on thousands of computers



Combining Random & Sequential Processing

- Random Processing:
  - Event processor applications may be randomly reading and updating very large tables with extremely large throughput
  - Applications external to Cosmos may access tables for random reads & updates
  - Transactions control atomic updates by event processors
  - Changes are accumulated as deltas visible to other event processors as soon as the transaction commits
- Sequential Processing:
  - Massively parallel SCOPE jobs may read consistent snapshots of the same tables being updated by event processors
- Very interesting optimization tradeoffs in the storage, placement, and representation of data for sequential versus random access
  - The use of SSD offers very interesting opportunities
  - Of course, there’s not much SSD compared to the size of the data we manage

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