Streaming

COS 518: Advanced Computer Systems
Lecture 12
Michael Freedman

What is streaming?
• Fast data!
• Fast processing!
• Lots of data!

Simple stream processing
• Single node
  – Read data from socket
  – Process
  – Write output

Examples: Stateless conversion
• Convert Celsius temperature to Fahrenheit
  – Stateless operation: `emit (input * 9 / 5) + 32`
Examples: Stateless filtering

- Function can filter inputs
  - if (input > threshold) { emit input }

Examples: Stateful conversion

- Compute EWMA of Fahrenheit temperature
  - new_temp = α * ( CtoF(input) ) + (1- α) * last_temp
  - last_temp = new_temp
  - emit new_temp

Examples: Aggregation (stateful)

- E.g., Average value per window
  - Window can be # elements (10) or time (1s)
  - Windows can be disjoint (every 5s)
  - Windows can be “tumbling” (5s window every 1s)
The challenge of stream processing

- Large amounts of data to process in real time
- Examples
  - Social network trends (#trending)
  - Intrusion detection systems (networks, datacenters)
  - Sensors: Detect earthquakes by correlating vibrations of millions of smartphones
  - Fraud detection
    - Visa: 2000 txn/sec on average, peak ~47,000/sec

Scale “up”

<table>
<thead>
<tr>
<th>Tuple-by-Tuple</th>
<th>Micro-batch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Latency</td>
<td>Higher Latency</td>
</tr>
<tr>
<td>Lower Throughput</td>
<td>Higher Throughput</td>
</tr>
</tbody>
</table>

Why? Each read/write is an system call into kernel. More cycles performing kernel/application transitions (context switches), less actually spent processing data.

Scale “out”
Stateless operations: trivially parallelized

State complications parallelization

• Aggregations:
  – Need to join results across parallel computations

State complicates parallelization

• Aggregations:
  – Need to join results across parallel computations

Parallelization complicates fault-tolerance

• Aggregations:
  – Need to join results across parallel computations
Can parallelize joins

- Compute trending keywords
  - E.g.,

Parallelization complicates fault-tolerance

A Tale of Four Frameworks

1. Record acknowledgement (Storm)
2. Micro-batches (Spark Streaming, Storm Trident)
3. Transactional updates (Google Cloud dataflow)
4. Distributed snapshots (Flink)
Fault tolerance via record acknowledgement (Apache Storm -- at least once semantics)

- **Goal:** Ensure each input "fully processed"
- **Approach:** DAG / tree edge tracking
  - Record edges created as tuple processed
  - Wait for all edges to be marked done
  - Inform source of data when complete; otherwise, they resend tuple.
- **Challenge:** "at least once" means:
  - Operators can receive tuple > once
  - Replay can be out-of-order
  - ... application needs to handle.

Fault Tolerance via distributed snapshots (Apache Flink)

- Rather than log each record for each operator, take system-wide snapshots
- **Snapshotting:**
  - Determine consistent snapshot of system-wide state (includes in-flight records and operator state)
  - Store state in durable storage
- **Recover:**
  - Restoring latest snapshot from durable storage
  - Rewinding the stream source to snapshot point, and replay inputs
- **Algorithm** is based on Chandy-Lamport distributed snapshots, but also captures stream topology

Fault Tolerance via distributed snapshots (Apache Flink)

- Use markers (barriers) in the input data stream to tell downstream operators when to consistently snapshot

But another big issue:

**Streaming** = unbounded data

(Batch = bounded data)
Three major challenges

• **Consistency**: historically, streaming systems were created to decrease latency and made many sacrifices (e.g., at-most-once processing)

• **Throughput vs. latency**: typically a trade-off

• **Time**: new challenge

We’ve covered consistency in a lot of detail, let’s investigate time

New Concerns

• Once data is unbounded, new concerns:
  – Sufficient capacity so processing speed \( \geq \) arrival velocity (on average)
  – Support for handling out-of-order data

• Easiest thing to do:

Windowing by processing time is great

• Easy to implement and verify correctness

• Great for applications like filtering or monitoring
What if care about *when* events happen?

- If we associate event times, then items could now come out-of-order! (why?)

Time creates new wounds

This would be nice

But not the case, so we need tools

- **Windows**: how should we group together data?
- **Watermarks**: how can we mark when the last piece of data in some window has arrived?
- **Triggers**: how can we initiate an early result?
- **Accumulators**: what do we do with the results (correct, modified, or retracted)?

All topics covered in next week’s readings!