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Stream Processing Essentials

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Introduction

Lab Setup

Requirements

- Java 8 JDK or higher
- An IDE like IntelliJ IDEA, Eclipse, Netbeans
- Maven

Steps

1/ Download the lab source
github.com/hazelcast/hazelcast-jet-training

2/ Import it to your IDE as a Maven project

3/ Build it to download dependencies!

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Course Objectives

- When you leave this class, you will be able to
  - Define stream processing and explain when to use it
  - List the building blocks of a streaming application
  - Transform, match, and aggregate streaming data
  - Perform continuous processing of time-series data
  - Scale, deploy, and operate streaming apps

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Agenda

Introductions	15 minutes
Stream Processing Overview	15 minutes
The Building Blocks	30 minutes
Break	5 minutes
Transforming a Data Stream (lab)	25 minutes
Enrichment (lab)	30 minutes
Break	15 minutes
Aggregations and Stateful Streaming (3 labs)	50 minutes
Break	5 minutes
Scaling and Operations (lab – no coding)	35 minutes
Q&A and Conclusion	15 minutes

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Warning - Lambdas Ahead!

```
int sum = streamCache().collect(
        DistributedCollector.of(
                () -> new Integer[]{0},
                (r, v) -> r[0] += v.getValue(),
                (l, r) -> {
                    l[0] += r[0];
                    return l;
                },
                a -> a[0]
        )
);
```

This is the kind of code we'll be looking at. If you don't understand it, you won't get much out of this class.

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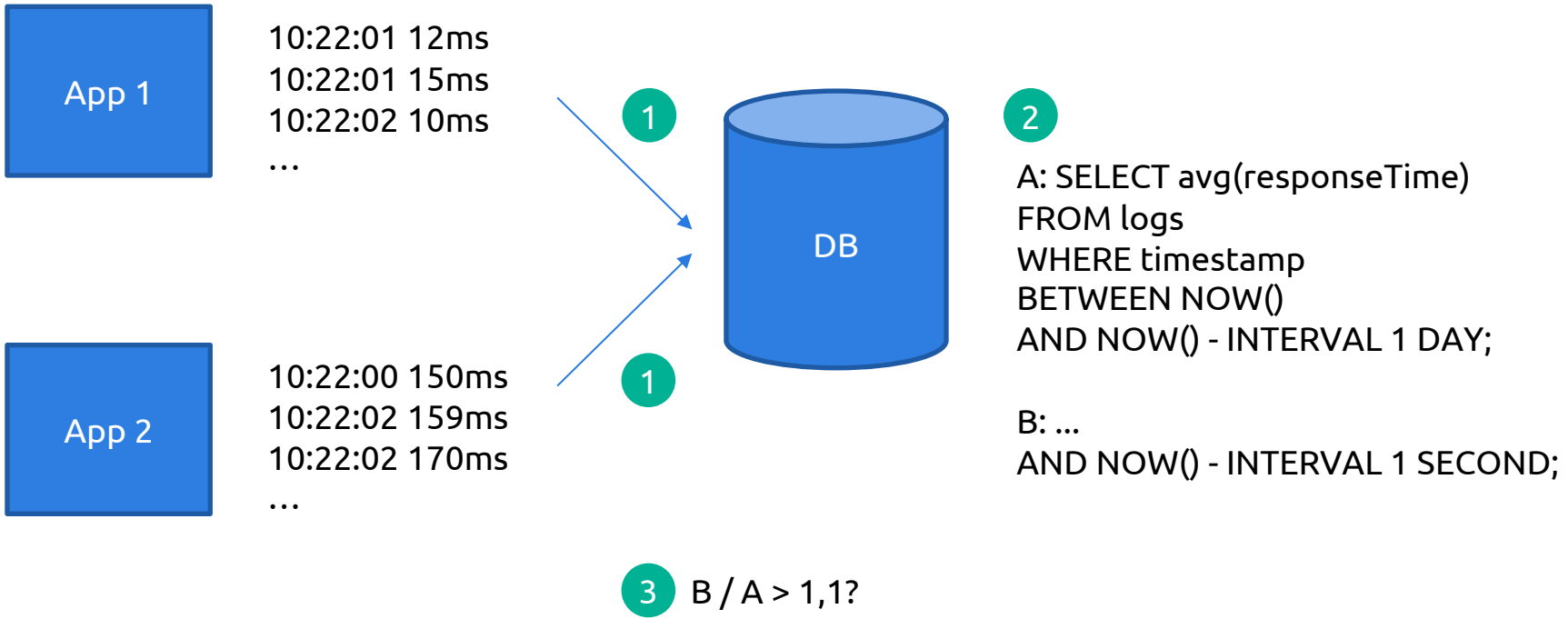
Stream Processing Overview

System Health Monitoring



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System Health Monitoring - Challenges

- Scale
  - 1k records per sec -> 86 mio per day
  - Increases latency
- Timing
  - How to coordinate data loading and querying?
  - When to submit the query?
    - Network transfer times may vary
    - Timestamps from various sources -> unordered data
  - Balancing correctness and latency

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Batch Processing

Linear process
No overlap = huge latency!

Use-cases

Post-mortem analysis

ML training/data science

Offline transaction processing

Extract Transform Load (ETL)

Tools

Hadoop

Hive for SQL people

Often custom

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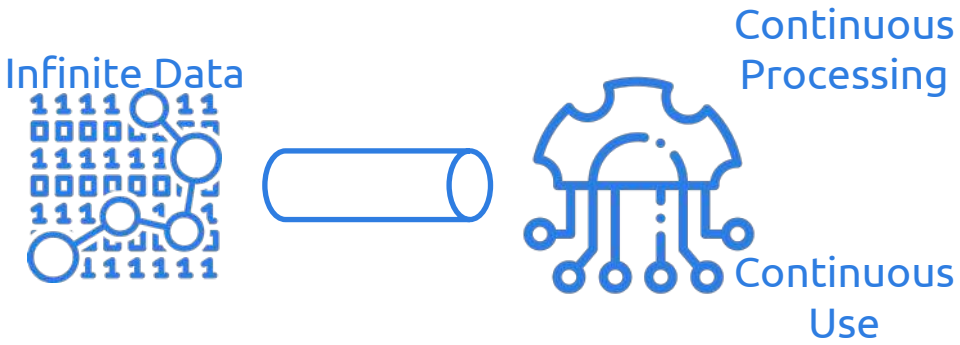
Stream Processing

Real world data doesn't come in batches!



Characteristics

Querying made pro-active

Push instead of pull

Pre-processing for database

Benefits

Low latency

Continuous programming model

Deals with time - event-time, watermakrs, late data

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Stream Processing and Databases

- Database allows clients to **pull** data by querying it's state
- Stream processor runs a continuous query and **pushes** updates to consumers

- Continuous programming model maps better to reality
- Things happen continuously in real world, not in batches.

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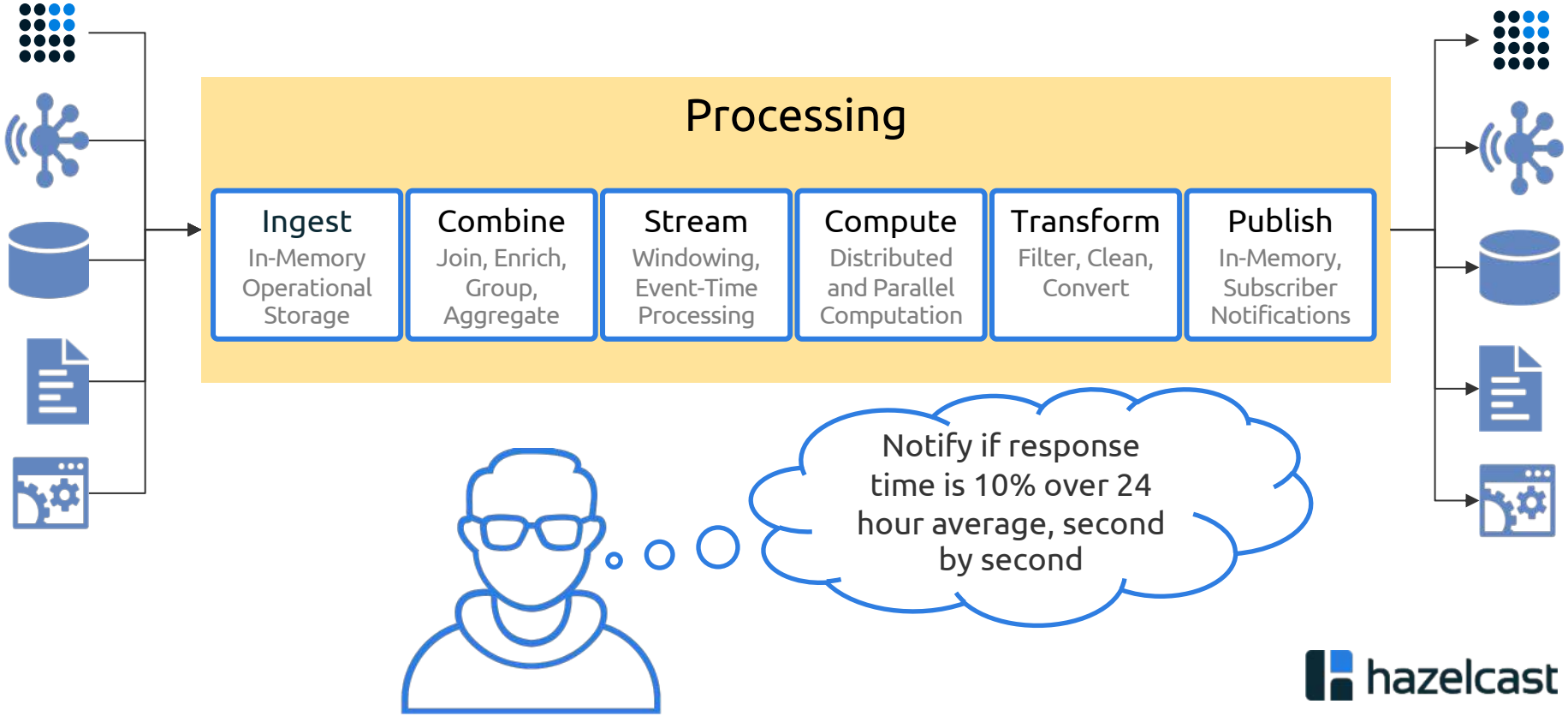
Streaming is “Smart ETL”



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What Stream Processing Brings

… to traditional ETL (data pumps)	Scale
… to batch analytics (MapReduce)	Continuous programming, reduces latency
… to JMS topic with Java worker	Fault-tolerance, higher level programming. model
… to CEP	Scale
… to DB triggers	Time as first-class citizen

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Use Case: Continuous ETL

- ETL - Data Integration
- ETL in the 21st Century
  - Maintains the derived data (keeps it in sync)
  - Performance - adapt data to various workloads
  - Modularization - microservices own the data
- Why continuous ETL?
  - Latency
  - Global operations (no after hours)
  - Continuous resource consumption

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Use Case: Analytics and Decision Making

- Real-time dashboards
- Stats (gaming, infrastructure monitoring)
- Decision making
- Recommendations
- Prediction - often based on algorithmic prediction (push stream through ML model)
- Complex Event Processing

Use Case: Event-Driven Applications

- Event Sourcing
  - Sequence of change events as a shared database.
    - Simpler than replicating every database to every service
  - Apps publish and subscribe to the shared event log.
  - App state is a cache of the event store
- Stream processor is the event handler
- Consumes events from the event store
- Updates the application state

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DEMO: How do people feel about crypto?

https://github.com/hazelcast/hazelcast-jet-demos

1. Get Tweets
2. Filter out irrelevant ones
3. Predict the sentiment
4. Compute avg per cryptocurrency in last 30s / 5m

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Key Points

- Stream processing is an evolution of the traditional data processing pipeline
  - Continuous programming model for infinite data sets
  - Pre-process data before storing / using it -> reduces access times when you need the results
  - Processed results kept in sync with latest updates
  - Driven by data – no external coordination
  - Stays big-data ready (design decision for most streaming tools)

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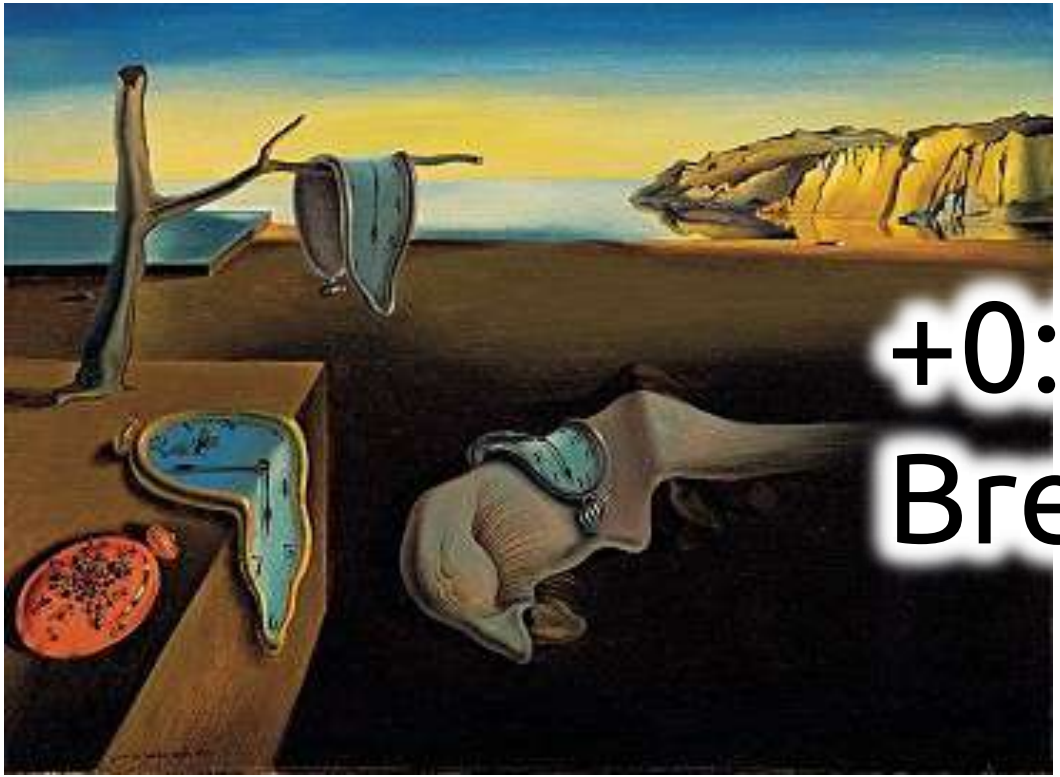
Time Check



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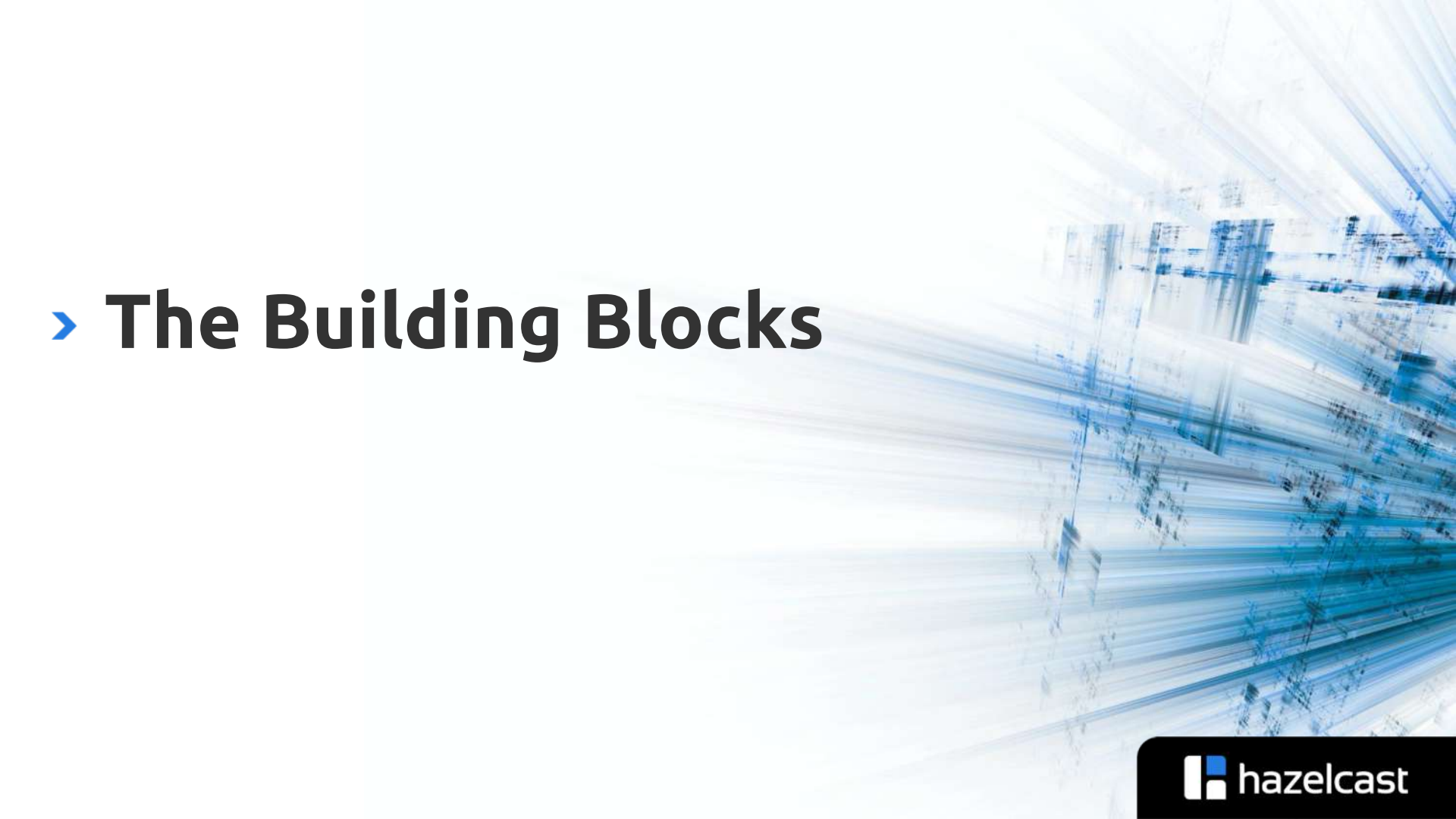
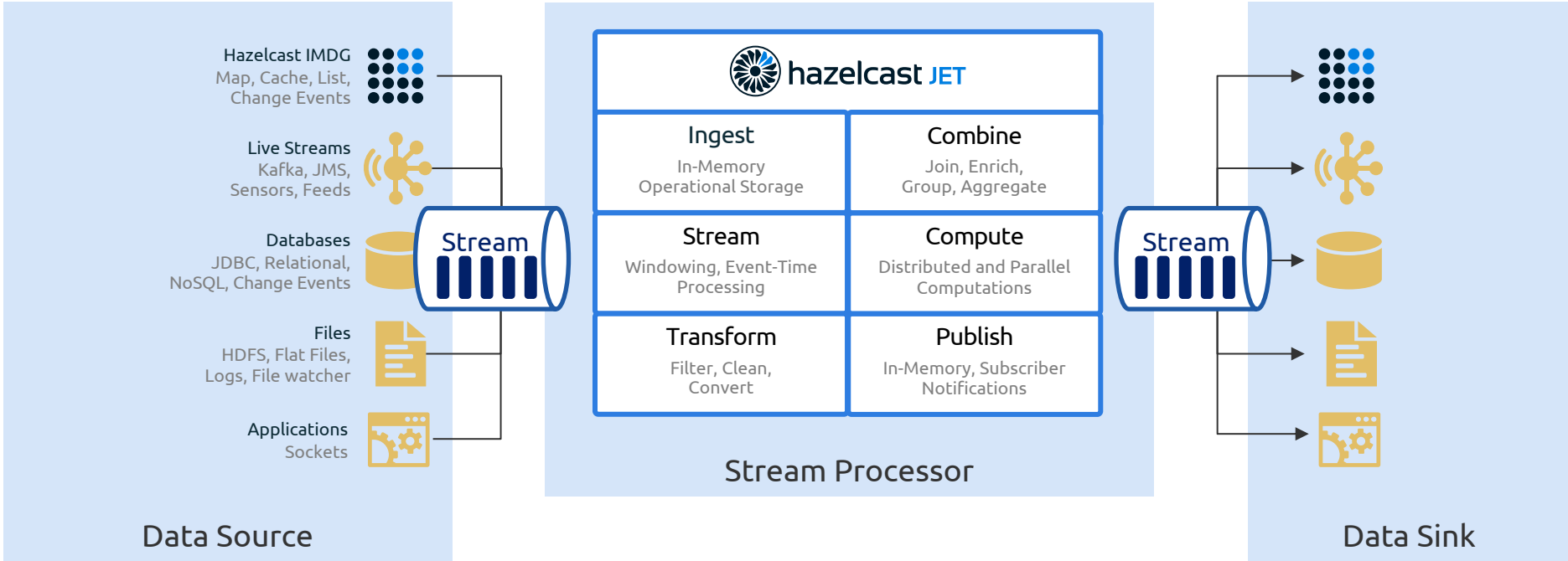
The Building Blocks



The Big Picture



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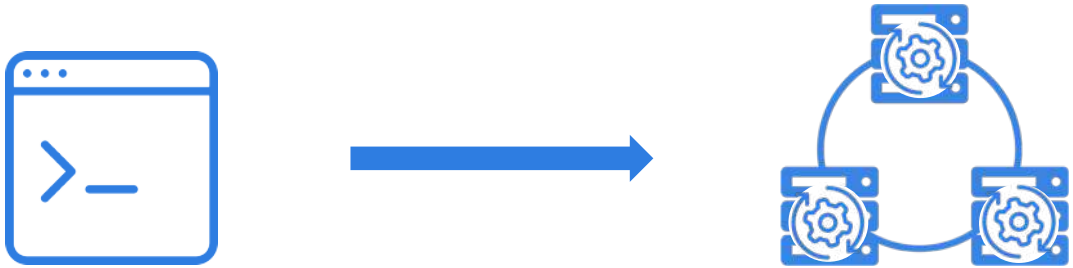
Pipeline and Job



Pipeline

- Declaration (code) that defines and links sources, transforms, and sinks
- Platform-specific SDK (Pipeline API in Jet)
- Client submits pipeline to the Stream Processing Engine (SPE)

Job

- Running instance of pipeline in SPE
- SPE executes the pipeline
  - Code execution
  - Data routing
  - Flow control
- Parallel and distributed execution

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Declarative Programming Model

- Compare counting words in Java 8
  - Imperative - Iterators (user controls the flow)

```
final String text = "...";
final Map<String, Long> counts = new HashMap<>();

for (String word : text.split("\\W+")) {
    Long count = counts.get(word);
    counts.put(count == null ? 1L : count + 1);
}
```

  - Declarative – Java Streams (code defines logic, not flow)

```
Map<String, Long> counts = lines.stream()
    .map(String::toLowerCase)
    .flatMap(line -> Arrays.stream(line.split("\\W+")))
    .filter(word -> !word.isEmpty())
    .collect(Collectors.groupingBy(word -> word, Collectors.counting()));
```

Why Pipelines Use Declarative

- ”What” vs. “How”
- SPE handles the “how”
  - Data routing
  - Partitioning
  - Invoking pipeline stages
  - Running your pipeline in parallel

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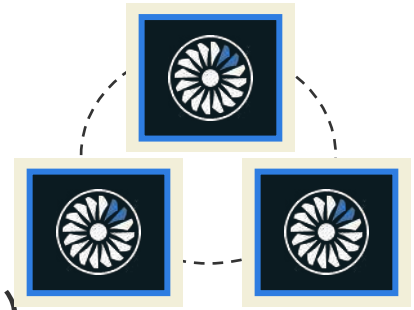
The SPE: Hazelcast Jet



- Distributed data processing engine
- Supports bounded (batch) and unbounded (stream) data sources
- Java API to define the processing (Pipeline API)
- Built on Hazelcast IMDG
- Single embeddable JAR
- Open-source, Cloud-native (managed srv. for IMDG parts)
- Java SDK
  - JDK 8 minimum

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Hazelcast IMDG

- IMDG = “In-Memory Data Grid”, distributed in-memory data structures with computational capabilities
  - Map, List, Queue
  - Querying, Entry Processor
  - Executor Service
  - Lock, Semaphore, AtomicLong, Unique ID generator, HyperLogLog..
- Used as cache, operational database and for coordination
- Clients for Java, Scala, C++, C#/.NET, Python, Node.js, Go
- Good foundation for distributed computing

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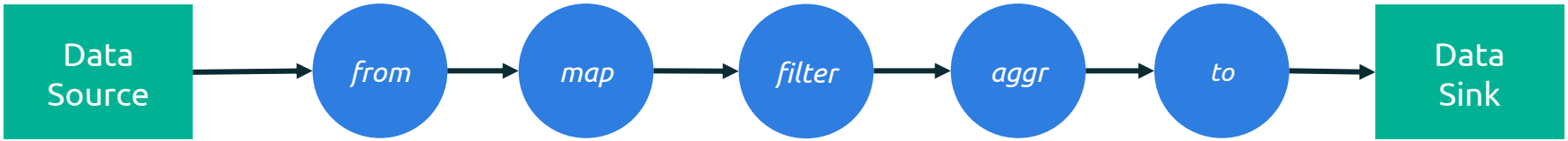
What Distributed Means to Hazelcast

- Multiple nodes (cluster)
- Scalable storage and performance
- Elasticity (can expand during operation)
- Data is stored partitioned and replicated
- No single point of failure

Jet Does Distributed Parallel Processing

- Jet translates declarative code to a DAG (Task Parallelism)

```
Pipeline p = Pipeline.create();
p.drawFrom(Sources.<Long, String>map(BOOK_LINES))
    .flatMap(line -> traverseArray(line.getValue().split("\\W+")))
    .filter(word -> !word.isEmpty())
    .groupingKey(wholeItem())
    .aggregate(counting())
    .drainTo(Sinks.map(COUNTS));
```



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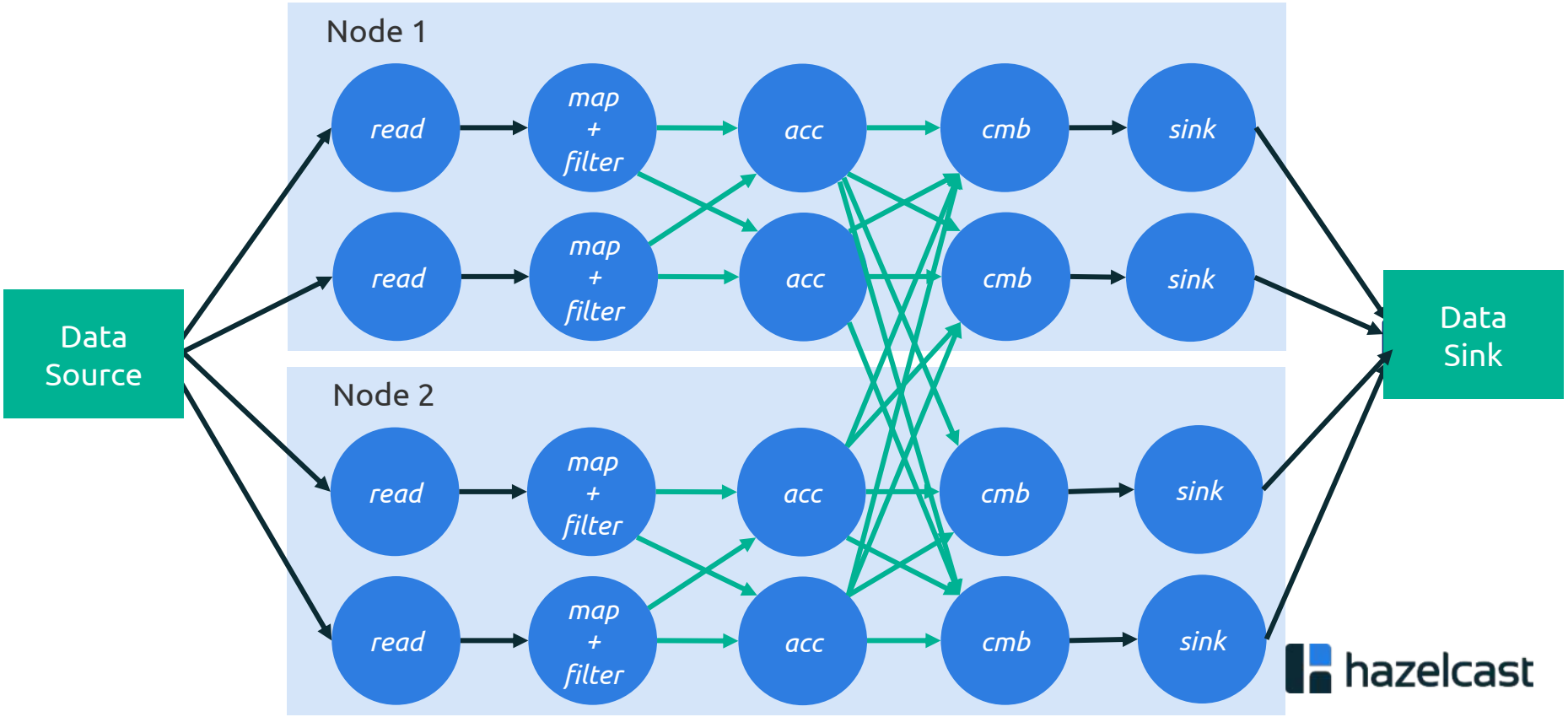
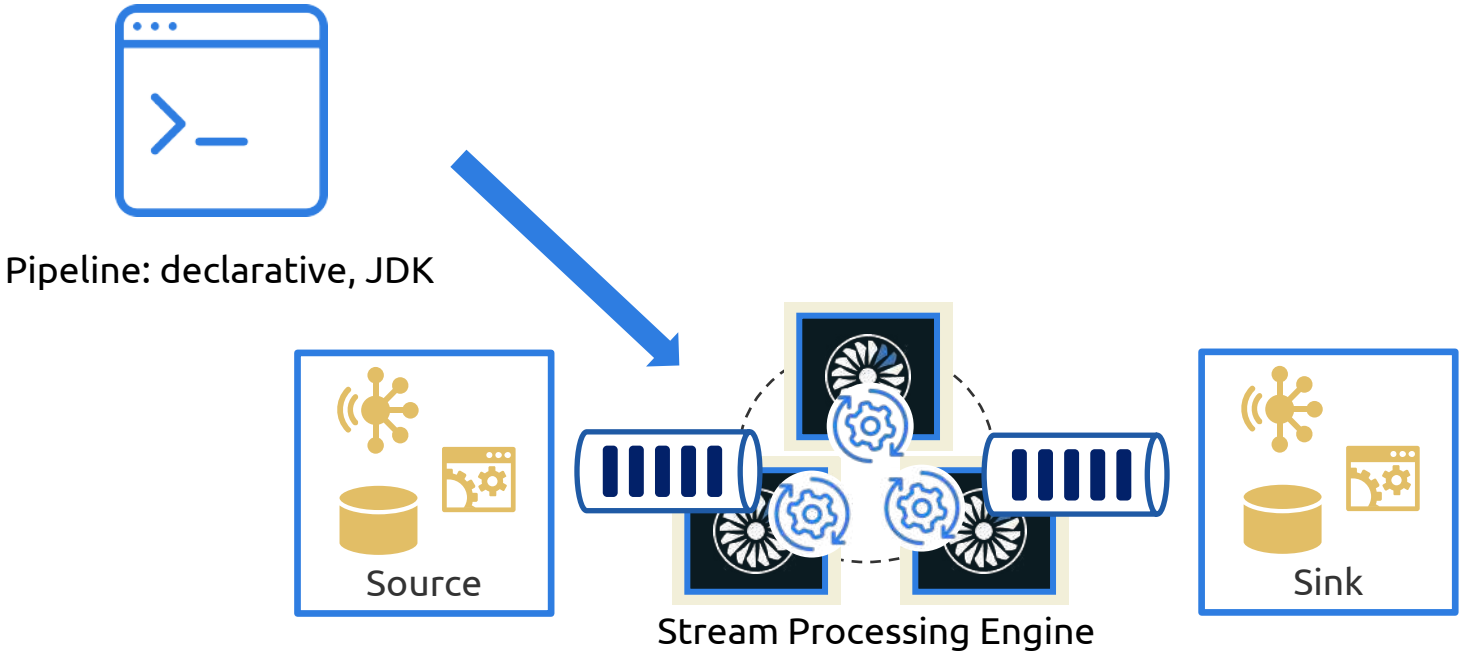
Jet Does Distributed Parallel Processing



All the Building Blocks



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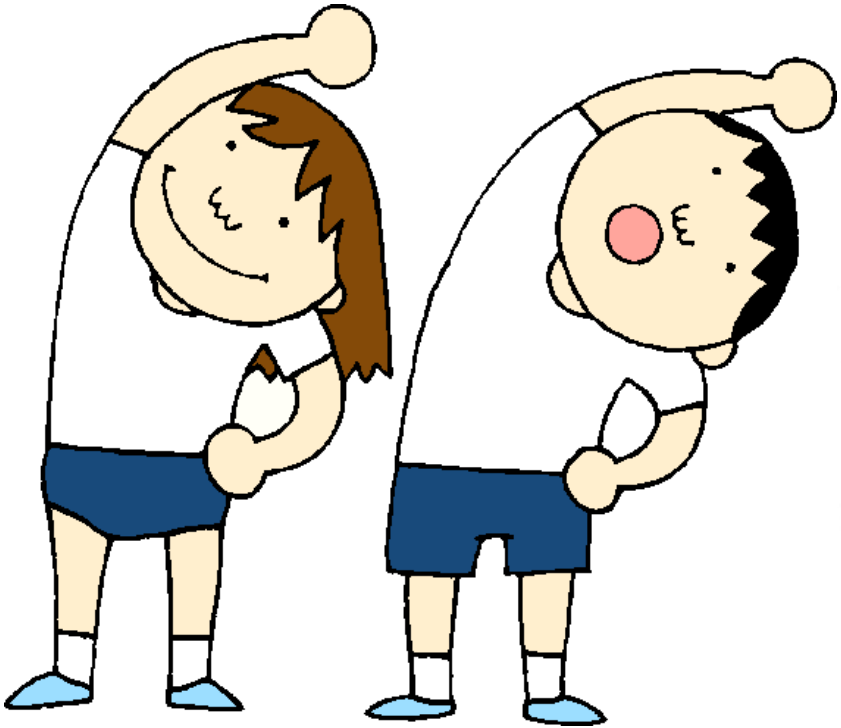
Stretch Break



+1:00

5 Minute Break

Please do not leave the room

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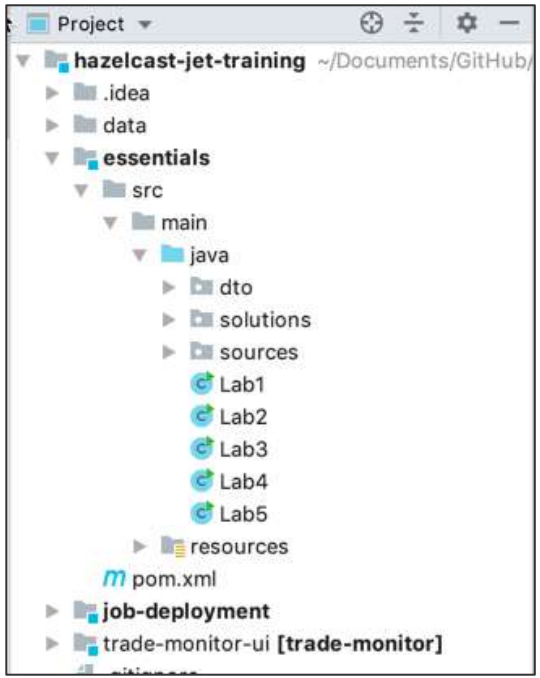
Transforming a Data Stream

Checking Your Lab Setup



- Download the lab source github.com/hazelcast/hazelcast-jet-training
- Import it to your IDE as a Maven project
- Build it to download dependencies!
- Open the essentials module

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Pipeline API

- Remember our building blocks?

- API follows same pattern

```
Pipeline p = Pipeline.create();

//specify source(s) for stream
p.drawFrom(Sources.<String>list("input"))

//specify transform operation(s)
        .map(String::toUpperCase)

//specify sink(s) for transform results
        .drainTo(Sinks.list("result"));
```

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Sources and Sinks

- drawFrom and drainTo require a source as a parameter

```
p.drawFrom( Source definition )
```

- Libraries with sources and sinks available out-of-the-box

```
com.hazelcast.jet.pipeline.Sources

com.hazelcast.jet.pipeline.Sinks
```

- Data generators for quick start and testing

```
com.hazelcast.jet.pipeline.test.TestSources
```

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We'll Start Simple

- Turn off event-time processing for now

```
p.drawFrom( Source definition )
        .withoutTimestamps()
```

  - We'll explain this when talking about windowing and event-time processing

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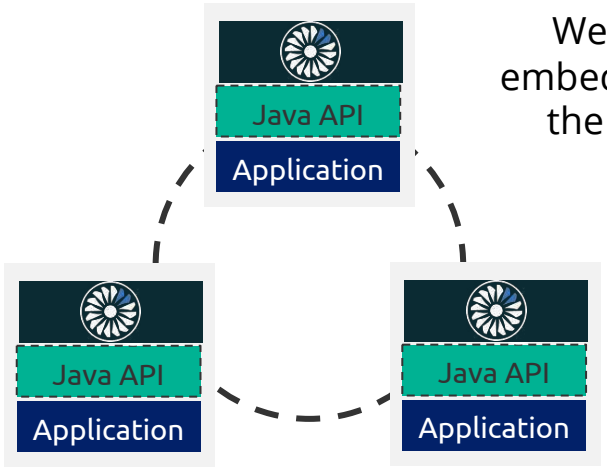
Interacting with the Cluster

Embedded

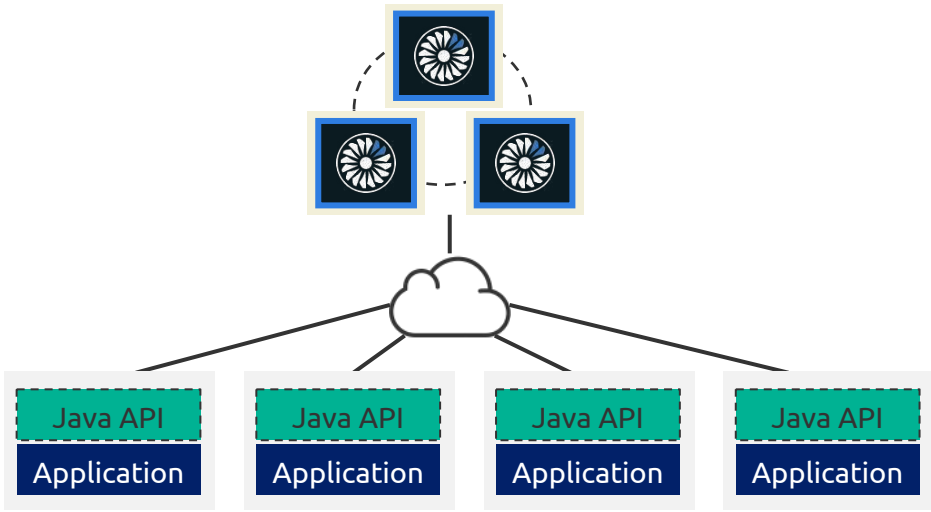


We use embedded in the labs

```
// Create new cluster member

JetInstance jet = Jet.newJetInstance();
```

Client/Server




```
// Connect to  running cluster

JetInstance jet = Jet.newJetClient();
```

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Submitting the Pipeline

```
public static void main (String[] args) {
    JetInstance jet = Jet.newJetInstance();
    Pipeline p = buildPipeline();
    try {
        jet.newJob(p).join();
    }
    finally {
        jet.shutdown();
    }
}
```

- Use the cluster handle
- Submit the job
  - Submit and return
  - `jet.newJob(pipeline);`
  - `jet.newJob(pipeline).join();`
- Stop cluster when processing is done

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Lab 1: Filter Records from Stream

- Step 1: Run your first streaming job
  - Open Lab 1
  - Explore the boilerplate
  - Run the lab and follow results

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Basic Transformation Operations

- Filter: discards items that don’t match the predicate
  - Data cleaning, reformatting, etc.
- Map: transforms each item to another item
  - Trim records to only required data
- flatMap: transforms each item into 0 or more output items
  - Example: separate a line of text into individual words

Transformation Examples

- NewPowerCo has installed smart meters at all homes in a service area
  - Meters stream constant usage data: address, region code, kw/hour consumption, etc.
- Filter example
  - Keep all records exceeding a given kw/hour rate
- Map example
  - Strip addresses – keep only region code and kw/hour data
- flatMap example
  - Separate record with multiple measurements to multiple records

Lab 1: Filter Records from Stream

- Step 2: Filter out odd numbers

- Step 3: Read stream from a file instead of the generator
  - Use `Sources.fileWatcher` source

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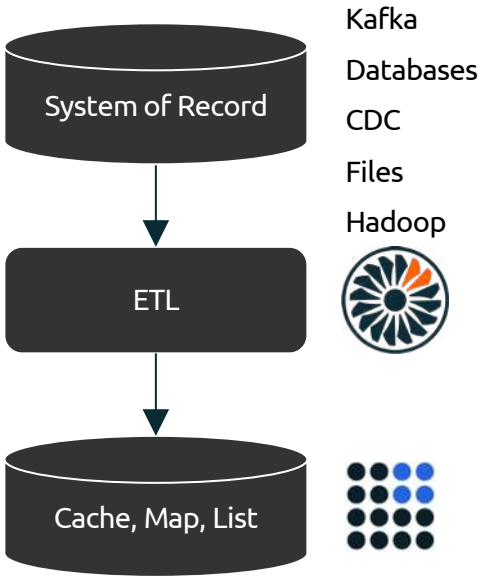
What We Learned…

- The Pipeline
- Generate data for testing: TestSources
- Basic connectors: fileWatcher, logging sink
- Basic operators: filter, map, flatMap
- Lambdas (serializable)
- Embedded (in-process) JetInstance
- Obtaining a cluster handle and submitting the job

Hot Cache

- Offload data to a distributed cache
  - Enrichment
  - In-memory compute
- Jet brings:
  - Speed (works in parallel)
  - Fault Tolerance
  - Declarative API - Focus on business logic, not on infrastructure / integration



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Honorable Mentions

- Connectors in Jet Library
  - Hazelcast, Journal, Kafka, HDFS, JMS, JDBC, Elasticsearch, MongoDB, InfluxDB, Redis, Socket, File
  - CDC connectors using Debezium (4.0 January)
- Custom connectors
  - Builders: see the code samples
  - Examples: Twitter Source, REST JSON Service Source, Web Camera Source
- Pipeline can have multiple sources, sinks and branches

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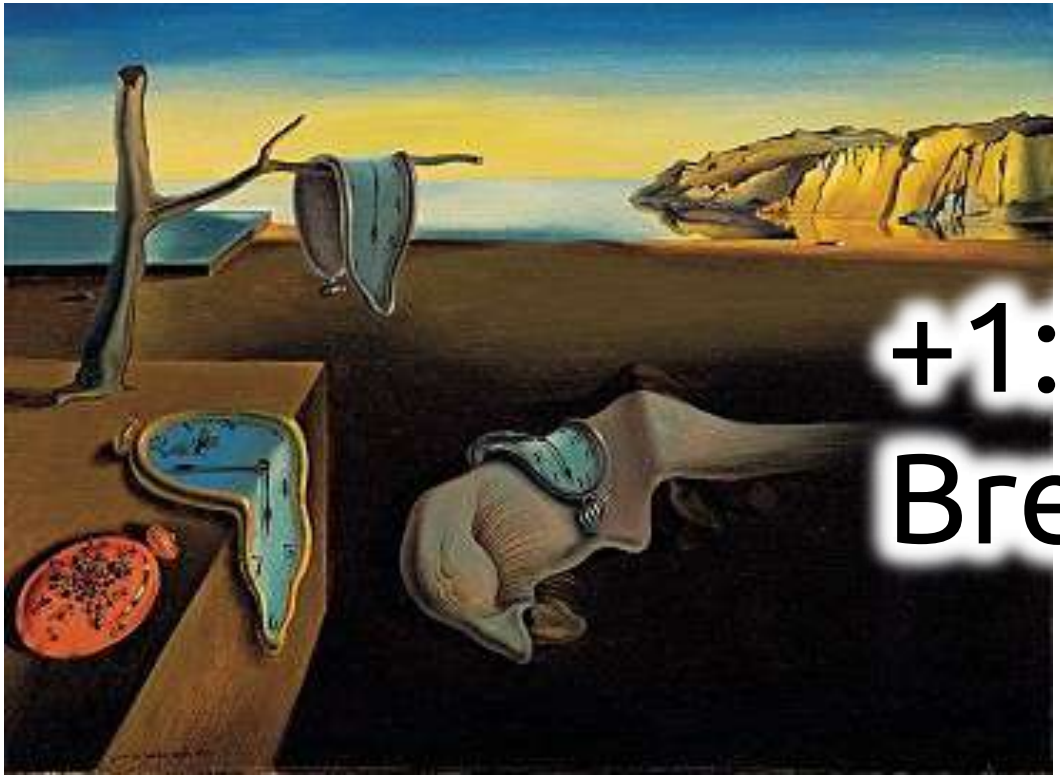
Time Check



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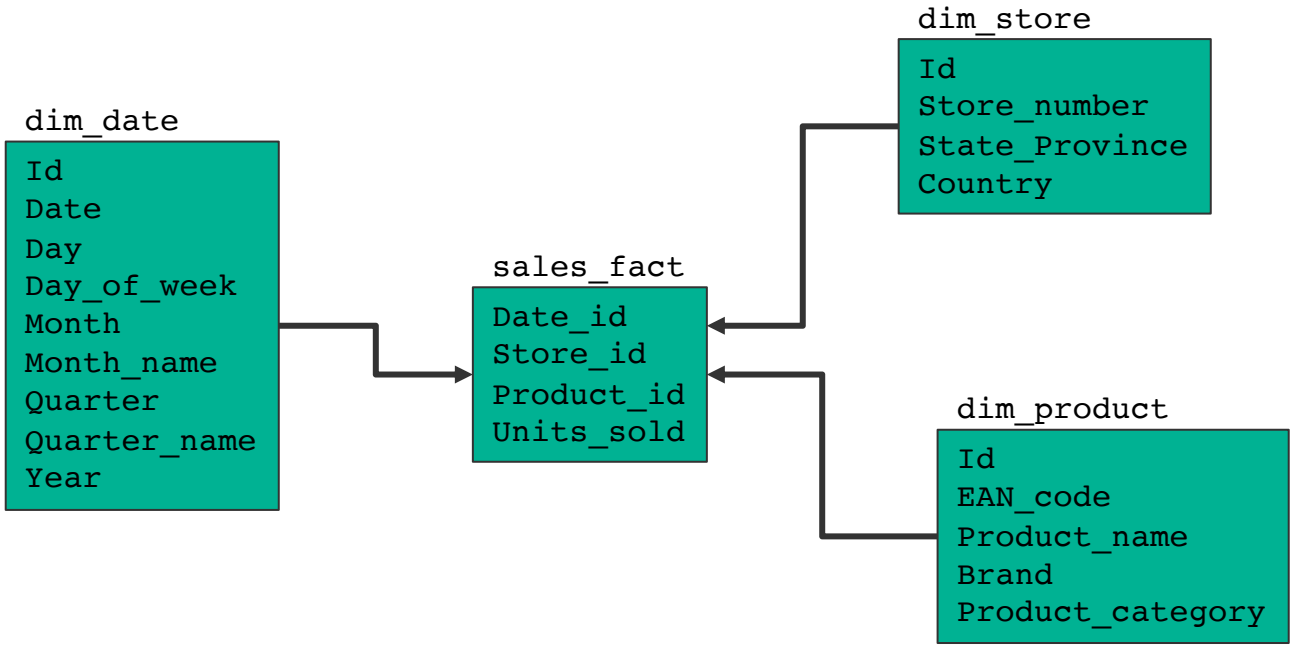
Enrichment

Enriching the Stream

- Do a lookup to enrich the stream
- Similar to relations in RDBMS



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Enrichment Options

- Local map
  - Advantage: fast, hard-coded
  - Disadvantage: change = redeploy
- Remote service lookup (database, RPC call)
  - Advantge: always up to date
  - Disadvantage: slow retrieval
- Cache local the custer
  - Hazelcast Jet contains rich distributed cache (thanks to embedded IMDG)

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Caching in Hazelcast Jet

- Jet comes with distributed in-memory data structures
  - Implements Java collections and JCache
  - Map, List, Queue
- Data partitioned and distributed across the cluster
- Elastic, scales with cluster size (more nodes = more space)
- Read/Write through for databases

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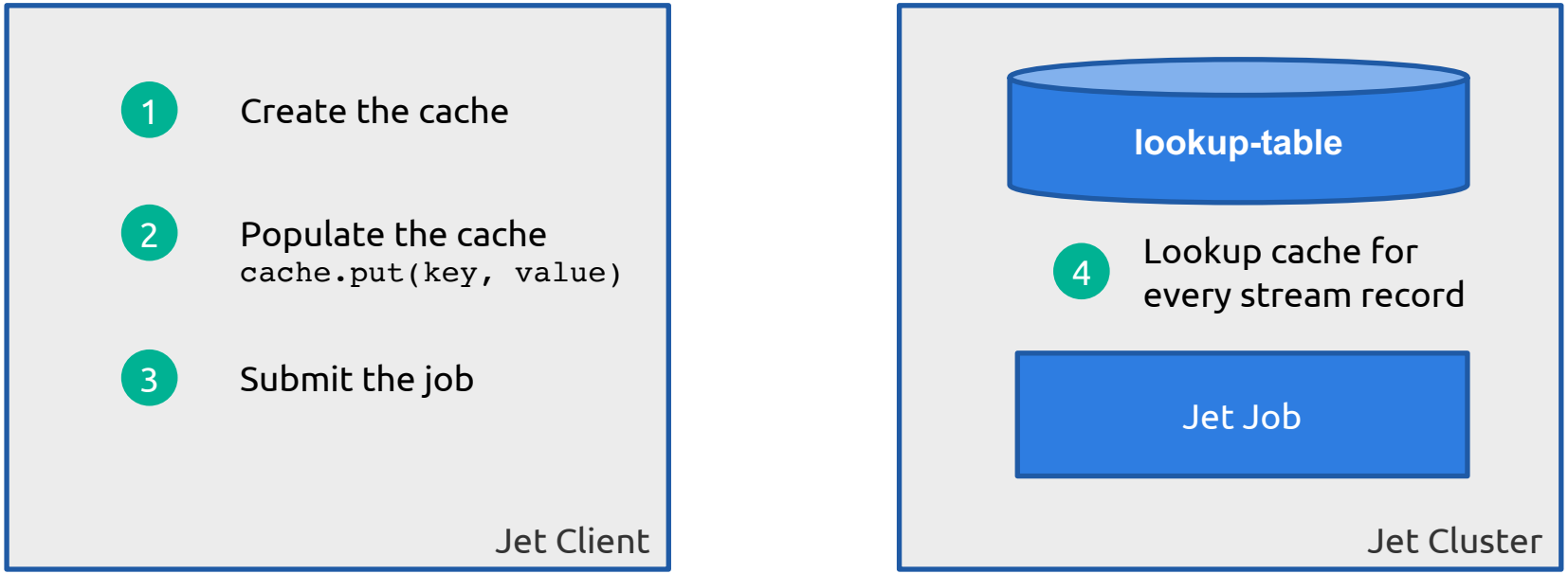
Lab - Architecture



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Enrichment API in Jet

```
items.mapUsingIMap(
      // the name of the lookup cache in the cluster
      "enriching-map",
      // how to obtain foreign key from the stream?
      item -> item.getDetailId(),
      // how to merge the stream with looked up data
      (Item item, ItemDetail detail)
            -> item.setDetail(detail)
 )
```

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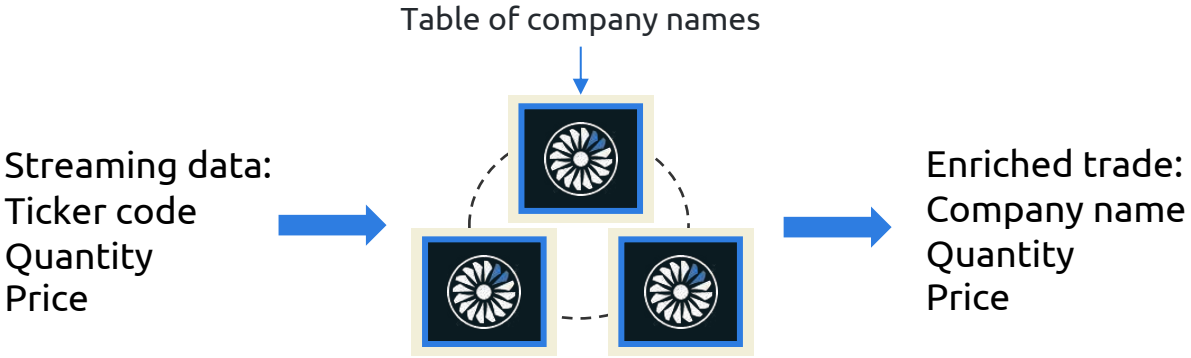
Lab 2: Enrich the Stream



- Enrich a trade stream using the cache
  - Randomly-generated “trade“ stream
  - Replace ticker code with company name
    - IMap (distributed map) caches name table

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Lab 2: Enrich the Stream

- Enrich a trade stream using the cache
  - Use the Trade generator as a source
    - sources.TradeSource.tradeSource()
  - Trade contains the symbol - a foreign key, referring to a company
  - Lookup company name
  - Convert Trades to EnrichedTrades by enriching it with company name
  - IMap (distributed map) used for caching

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What We Learned…

- Trading off flexibility and performance
  - Enrich from local memory
  - Remote lookup
  - Enrichment from a cache
- https://blog.hazelcast.com/ways-to-enrich-stream-with-jet/
- Operators: hashJoin, mapUsingImap, mapWithContext
- Jet Cluster provides powerful caching services

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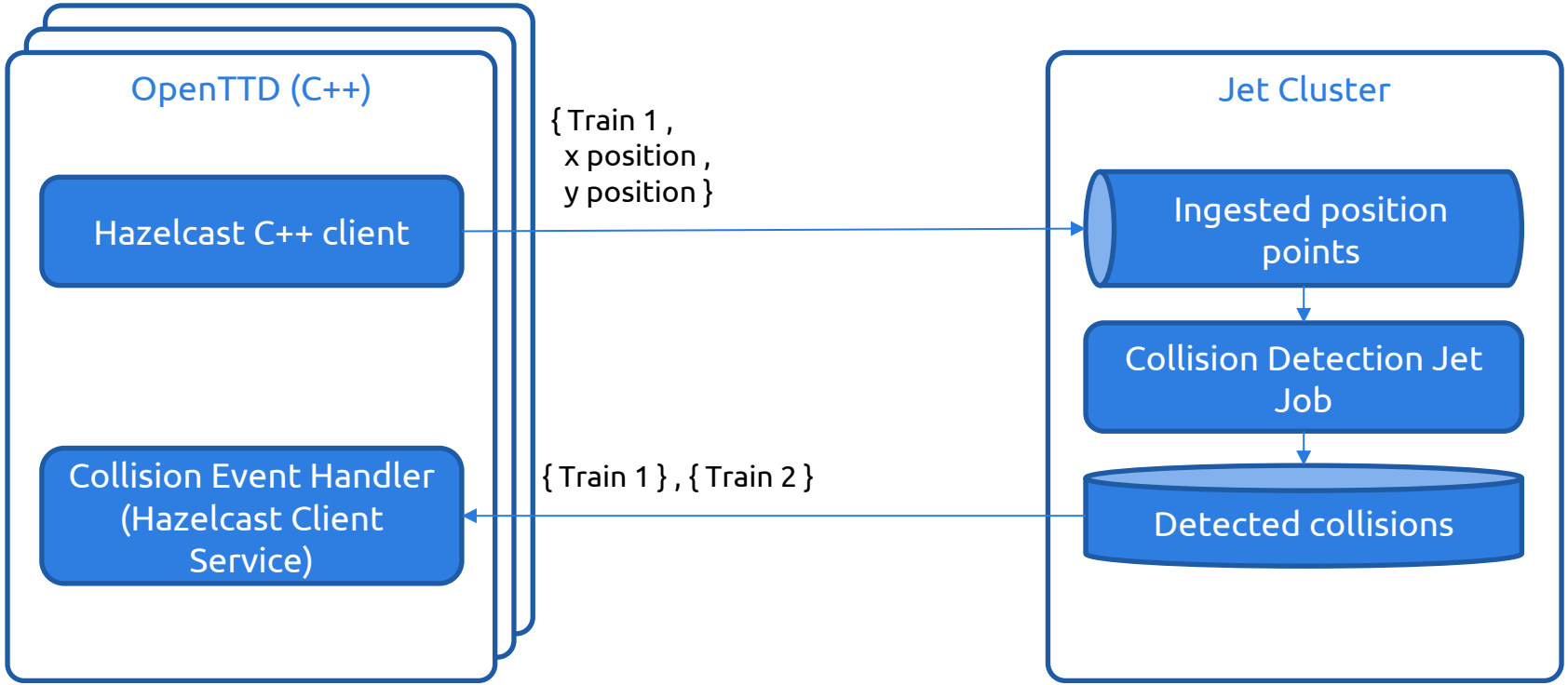
Honorable Mentions

- Hazelcast is a powerful distributed in-memory framework
  - Caching: read/write-through, JCache support
  - Messaging: buffer to connect multiple Jet jobs (journal)
  - Storage: in-mem NoSQL for low-latency use-cases (source, sink)
  - Coordination: unique
  - Polyglot (Java, Scala, C++, C#/.NET, Python, Node.js, Go)
    - These are IMDG clients – Jet pipelines are Java-only

Hazelcast as a Platform - Train Demo



https://github.com/vladoschreiner/transport-tycoon-demo

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Coffee Break

+2:00

15 Minute Break

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Before we start, please

1. Download Hazelcast Enterprise

   https://hazelcast.com/download/customer/#hazelcast-jet

2. Send me an e-mail to vladimir@hazelcast.com
   - To get the slides and the trial license
   - Useful before 4th part of the workshop

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Aggregations and Stateful Streaming

Starting at 2 PM

Stateful Processing

- Map with a state
- Remembers events or intermediate results
- Use-Cases:
  - Pattern matching
  - Correlation (of multiple events)
  - Complex Event Processing

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Stateful Processing API in Jet

```
items.mapStateful(
        // Object that holds the state. Must be mutable!
        LongAccumulator::new,
        // Mapping function that updates the state
        (sum, currentEvent) -> {
            sum.add(currentEvent); // Update the state object
            return (sum.get() <= THRESHOLD)
                    ? null // Nothing is emitted
                    : sum.get();
        }
 );
```

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Lab 3: Stateful Processing

- Detect if price between two consecutive trades drops by more then 200
  - Return the price difference if drop is detected
- Ignore various trade symbols for now

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Aggregations

- Combine multiple records to produce a single value

- Aggregate operation - How to aggregate records?
  - Examples: sum, average, min, max, count
- Scope - Which data to aggregate?
- Frequency - When is the result provided?

- Special case of Stateful processing

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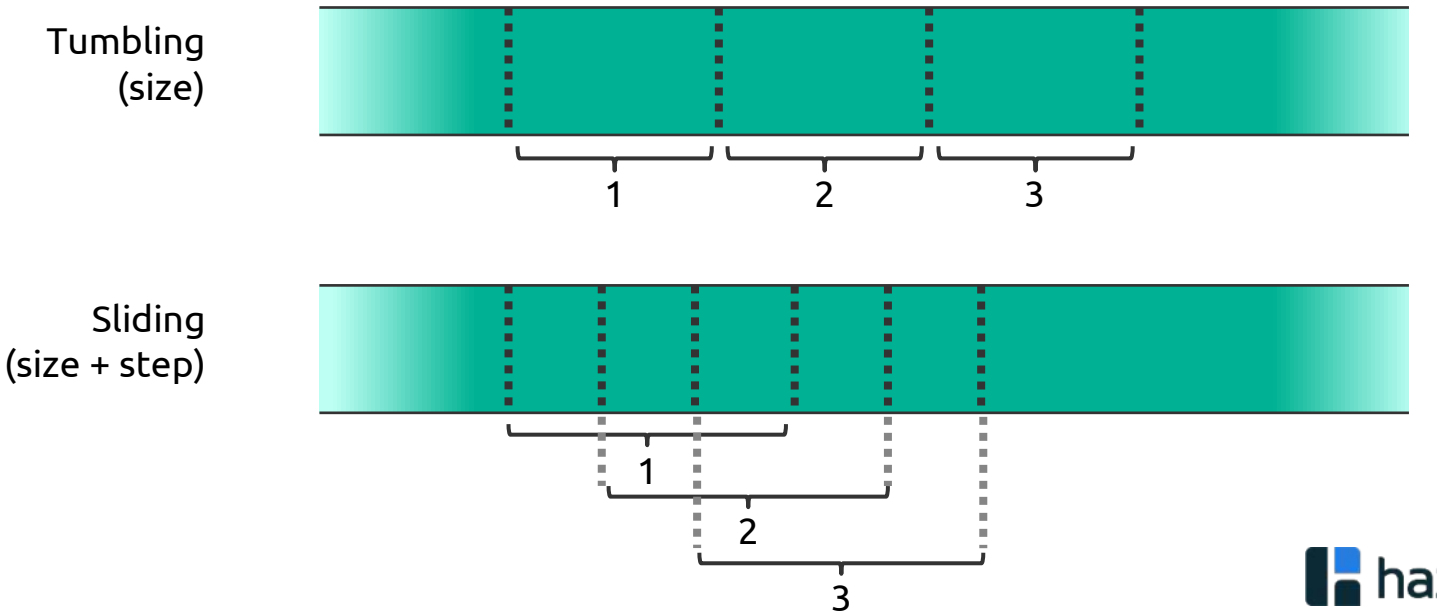
Scope - which data to aggregate?

- Streaming data is mostly time series
- Windows - time ranges to assign records to



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Frequency - When is the result provided?

- When window closes
  - All the data in the window were processed
  - Non-practical for long time ranges (hour and more)
- In specified time intervals - early results
- With each item
  - Use stateful mapping

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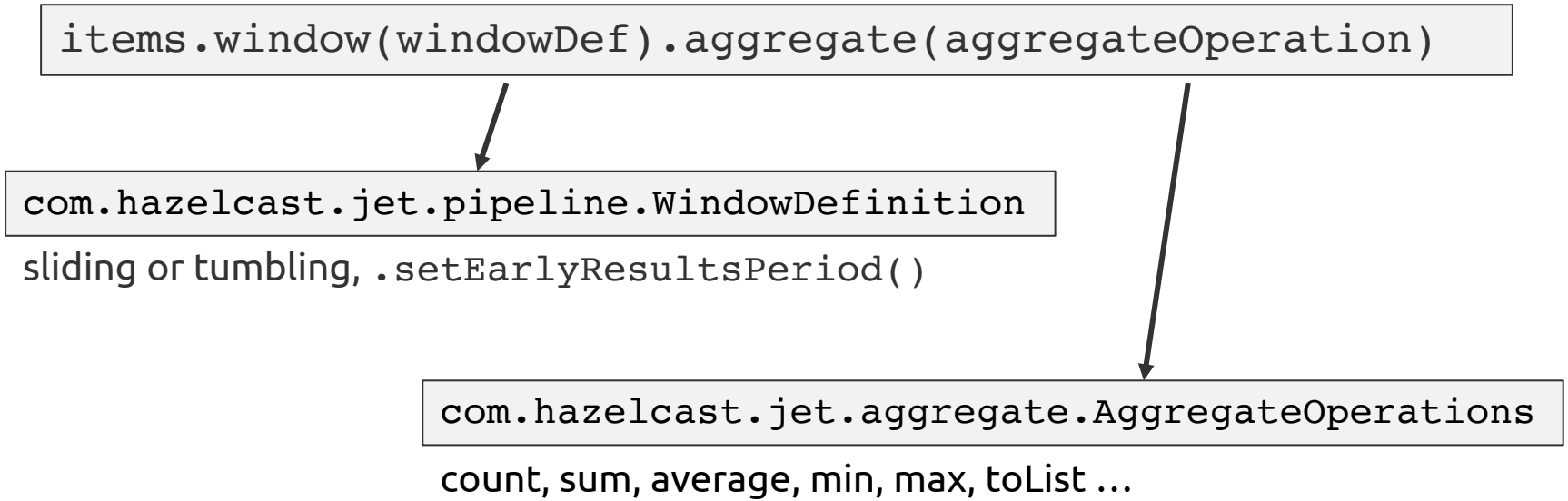
Windowing API in Jet



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Lab 4: Windowing

- Compute sum of trades for 3-second intervals
  - Tumbling window
  - Output each 3 seconds, should be roughly constant
- Compute sum of trades for 3-second intervals, result so far each second
  - Tumbling windows with early results
  - Output each second, grows for 3 seconds and then drops
- Compute sum of trades in last 3 seconds, update each second
  - Sliding windows
  - Output each second, should be roughly constant

Grouping

- Global aggregation
  - One aggregator sees the whole dataset
  - Complex Event Processing use-cases (if A is observed after B then do C)
- Keyed aggregation
  - GROUP BY from the SQL
  - Splits the stream to sub-streams using the key extracted from each record
  - Sub-streams processed in parallel
- Grouping API in Jet
  - `users.groupingKey(User::getId)`

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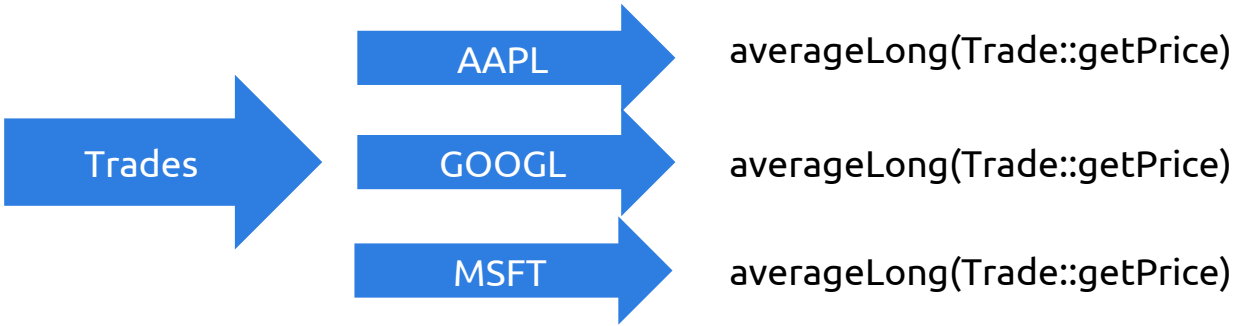
Grouping

- Global aggregation
  - One aggregator sees the whole dataset
  - Complex Event Processing use-cases
    - if A is observed after B then do C
- Keyed aggregation (SQL GROUP BY)



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Grouping API

```
users.groupingKey(User::getID)
```

- Groups event objects by specified key
- Groups processed in parallel

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Lab 4: Windowing with Grouping

- Compute sum of trades **per ticker** in last 3 seconds, update each second
  - Per-ticker results for the previous lab

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Timestamps

- Timestamps necessary to assign records to window
- Uses wall clock - Ingestion-time processing
  - Simple but possibly not correct!

```
.withIngestionTimestamps()
```

- Timestamp embedded in record - Event-time processing
  - Need to specify how to extract the timestamp

```
.withTimestamps(r -> r.getTimestamp())
```

```
.withNativeTimestamps()
```

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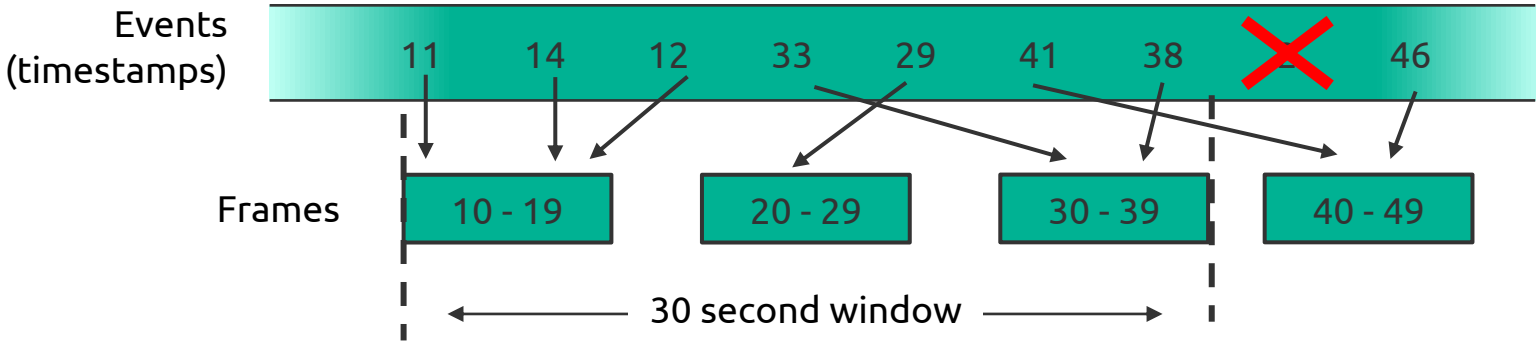
Event Time Processing



- No ordering
  - How long will we wait for stragglers?
- Watermarks
  - “No older items will follow."
  - Trading off latency for correctness

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Aggregations and State - Takeaways

- Operator remembers the events or intermediate results
- Aggregations is a special case: combines multiple input records to a single value
  - Define the scope of the aggregation: whole dataset or a window
  - Aggregated result is provided
    - With each record
    - When the scope has been processed
    - Something in between
- Split the stream using a key and aggregate the sub-streams (GROUP BY)

Honorable Mentions

- Custom aggregation API
- Stateful mapping with timeouts and custom evictor

- Cascade aggregate operations
  - Aggregate aggregations (e.g. maximal average value)
  - Flight Telemetry Demo
- Use grouping for join and correlation
  - Windowing to be added for streaming join
  - https://docs.hazelcast.org/docs/jet/latest/manual/#cogroup

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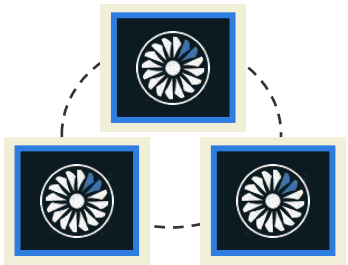
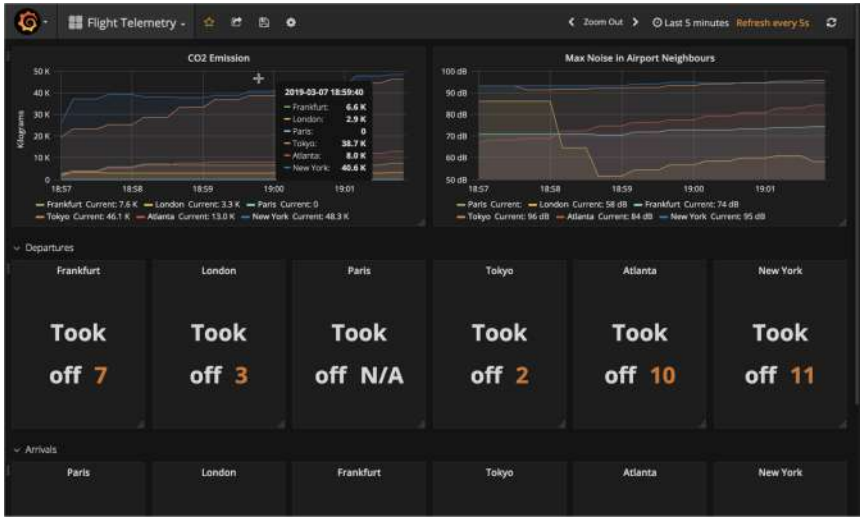
DEMO: Flight Telemetry

"Jets with Jet" - https://github.com/hazelcast/hazelcast-jet-demos

Streaming flight data:
Type of aircraft
Aircraft position





- Filter to defined airports only
- Sliding over last 1 minute, detect altitude changes
- Based on the plane type and phase of flight, calculate noise and CO_2 emissions

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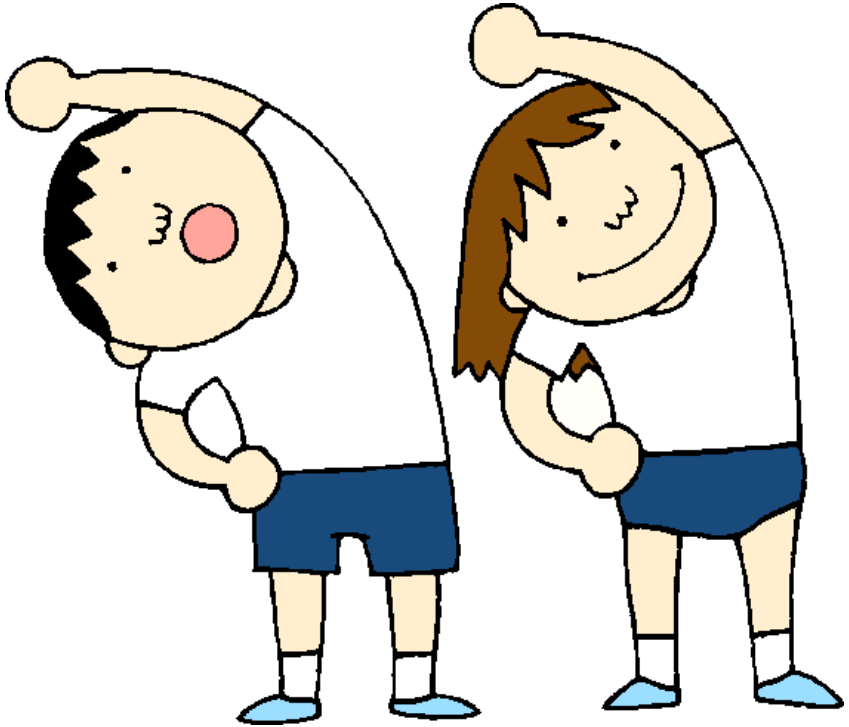
Stretch Break



+3:05

5 Minute Break

Please do not leave the room

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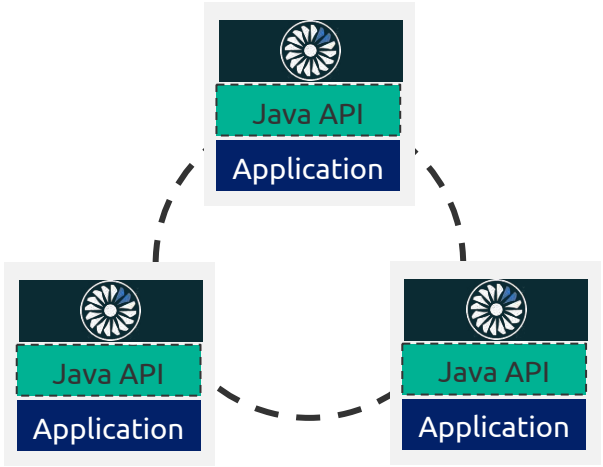
Scaling and Operations

Deployment Options

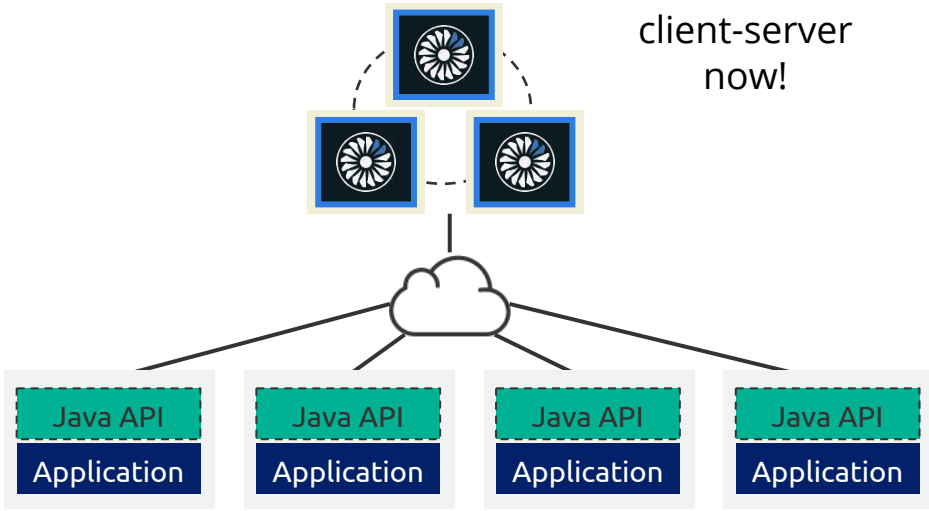
Embedded



- No separate process to manage
- Prototyping, Microservices. OEM.
- Java API for management
- Simplest for Ops – nothing extra

Client/Server

We switch to client-server now!



- Separate Jet cluster
- Isolate Jet from the application lifecycle
- Jet CLI for management
- Managed by Ops

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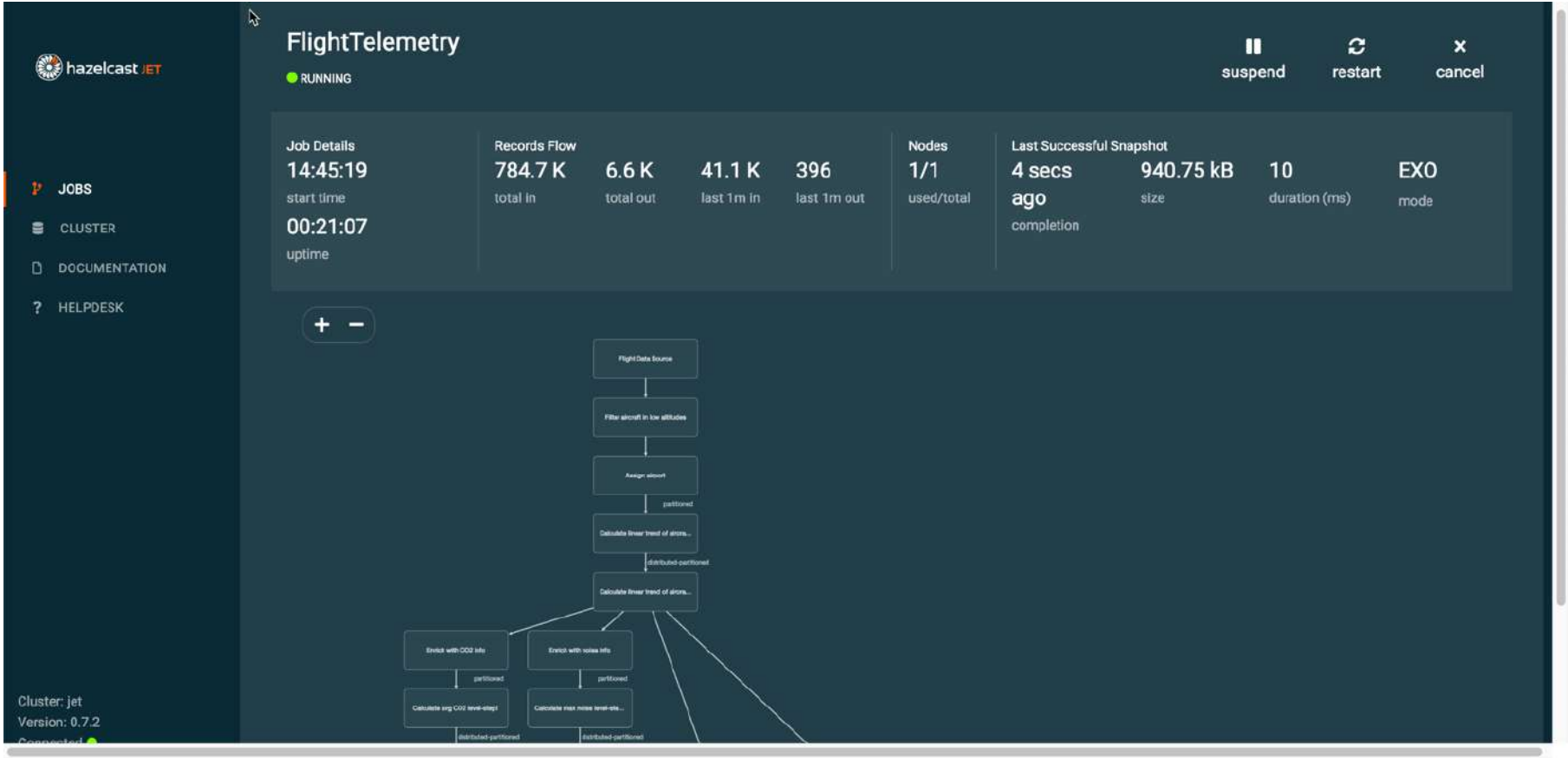
Jet Management Center



Command Line Tools

- `/bin/`
  - Command line tooling for Jet
- `jet-start.sh, jet-stop.sh`
  - Control cluster lifecycle
- `jet.sh`
  - Control job lifecycle
  - Command-line alternative to the Java API

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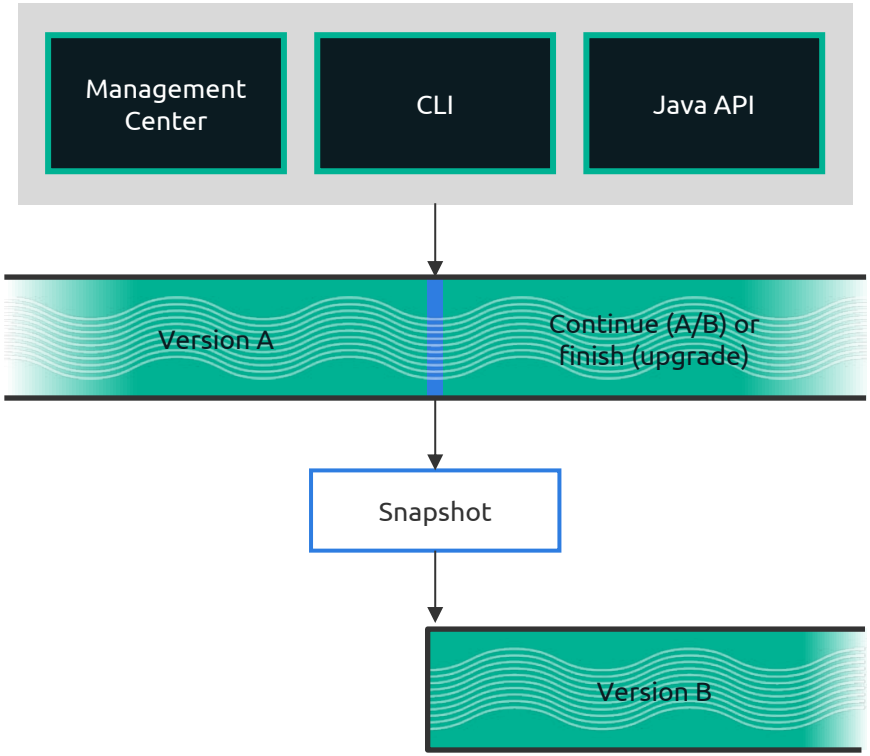
Scaling and Fault Tolerance

- Jet clusters can grow and shrink elastically
  - Add members to accommodate workload spikes
  - Workload is dynamically distributed across all cluster members
- Resilience through redundancy
  - Fault tolerance (network, server)
  - Cluster redistributes workload to available members

How Jet Fault Tolerance Works

- Regular backups (snapshots)
  - Restart computation from last snapshot if topology changes
  - Single node failures/additions - snapshot restored from replicated memory storage
- Preconditions:
  - Replayable source (e.g Kafka, Hazelcast Event Journal, not JMS)
  - Deterministic (no mutable lookup tables, no randomness)
  - Idempotent sink

Job Upgrade



- Allow jobs to be upgraded without data loss or interruption
- Processing Steps
  1. Jet stops the current Job execution
  2. It then takes the state snapshot of the current Job and saves it
  3. The new classes/jars are distributed to the Jet nodes
  4. The job then restarts
  5. Data is read from the saved snapshots
- All of this in a few milliseconds!

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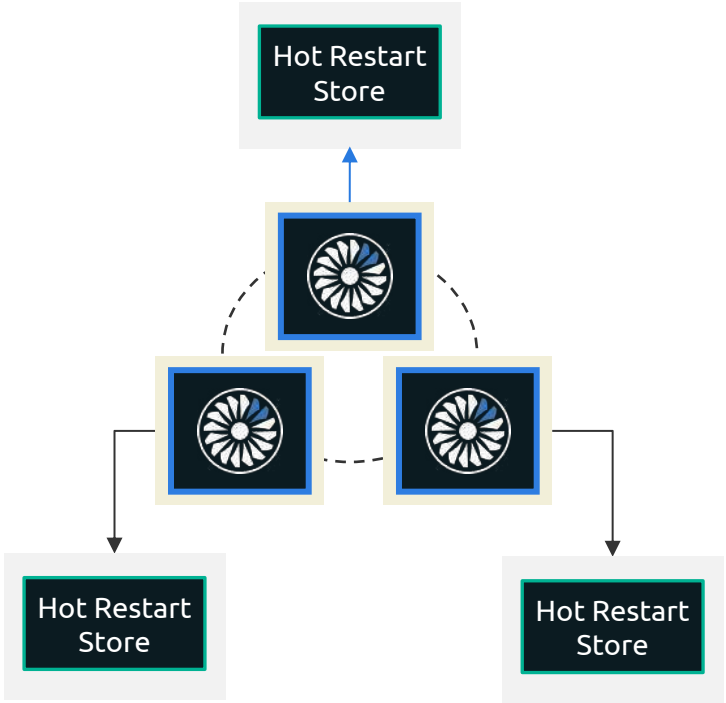
Lossless Recovery: Before Lights Out



- Jobs, Job State, Job Configuration configured to be persistent with Hazelcast's Hot Restart Store capability
- Checkpoints are similarly configured to be Hot Restartable
- Jet is configured to resume on restart

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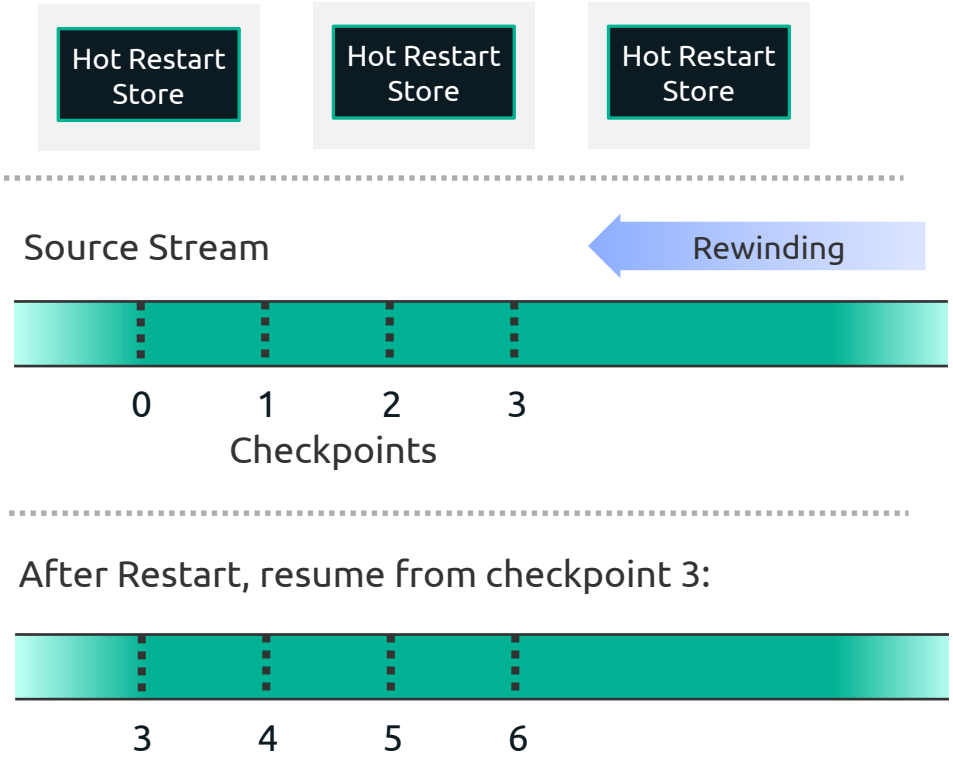
Lossless Recovery: Automatic Job Resumption



- When cluster is restarted, Jet discovers it was shut down with running jobs
- Jet restarts the jobs
- Checkpoints are recovered
- For streaming, rewindable sources are rewound using saved offsets (Kafka, Hazelcast IMap, Hazelcast ICache events).
- If the source cannot be fully rewound, the job is terminated with error, or continued, depending on configuration
- Batch sources are resumed from last pointer, otherwise from the beginning

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Ops demo

https://github.com/vladoschreiner/hazelcast-jet-job-upgrade/tree/instructions

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Lab 5: Start Jet from cmd line

- Get Jet ZIP and unpack it
  https://hazelcast.com/download/customer/#hazelcast-jet
- Jet must be configured not to join clusters within the room
  - `<multicast enabled="false">` `.g/hazelcast.xml`
- Enal `s to <join>`

```
<tcp-ip enabled="true">
  <member>localhost</member>
</tcp-ip>
```

- Start a node

```
${JET}/bin/jet-start
```

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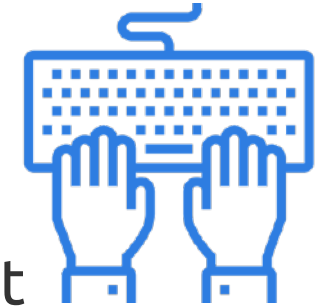
Lab 5: Submit a Job using CLI



- Get the JAR by building the `job-deployment` module of the training project (mvn package)
- Submit the job

```
${JET}/bin/jet.sh submit
```

- Use the JAR produced

```
${LABS}/job-deployment/target/job-deployment-3.*.jar
```

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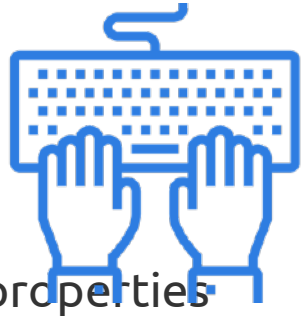
Lab 5: Management Center



- Plug in the license to the MC to see the cluster
  - ${HZL}/hazelcast-jet-management-center/application.properties
- Start MC
  - ${HZL}/hazelcast-jet-management-center/jet-management-center.sh
  - http://localhost:8081
- Check the cluster and job state in the MC

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Lab 5: Upscale the Job

- Add a node and observe the changes in the MC

```
${JET}/bin/jet.sh submit
```

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Scaling and Operations - Takeaways

- Jet can run embedded (in-process) or in a Client-Server mode
- Elastic clustering for scaling and increasing resilience
  - Preconditions: replayable source, deterministic computations without side effects, idempotent sink
- Tools for monitoring and managing the cluster and the jobs
  - Command line tools in `/bin`
  - Management Center

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Honorable Mentions

- Other deployment options
  - Docker
  - Kubernetes
  - Hazelcast Cloud
- Job Upgrades
- Lossless Recovery
- Security

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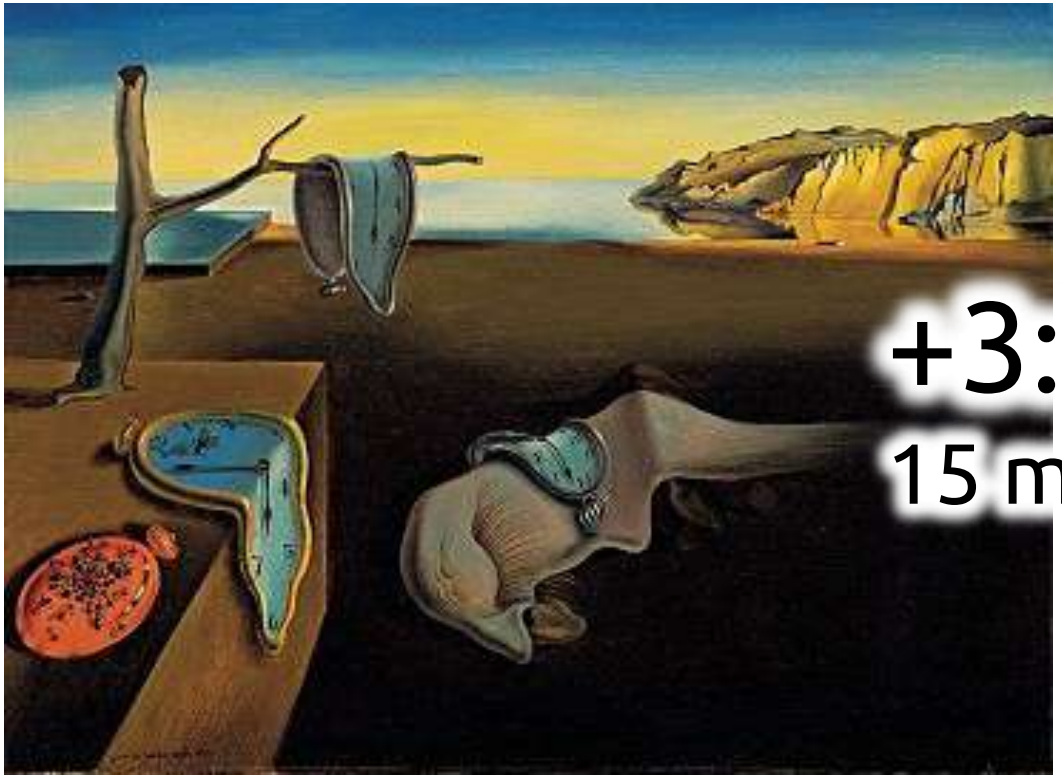
Time Check



+3:45

15 minutes left!

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Conclusion/Q&A

Helpful Resources

- Online training - https://training.hazelcast.com/stream-processing-essentials
- Jet website - https://jet.hazelcast.org/
  - especially the “Developer resources” section
- Reference card - https://dzone.com/refcardz/understanding-stream-processing
- Communities
  - Stack Overflow - Tag “hazelcast” or “hazelcast-jet”
  - Google Group- https://groups.google.com/forum/#!forum/hazelcast-jet
  - Gitter chat - https://gitter.im/hazelcast/hazelcast-jet
- Commercial
  sales@hazelcast.com
  or
  https://hazelcast.com/

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Thank You
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