

# Solution Proposal Document

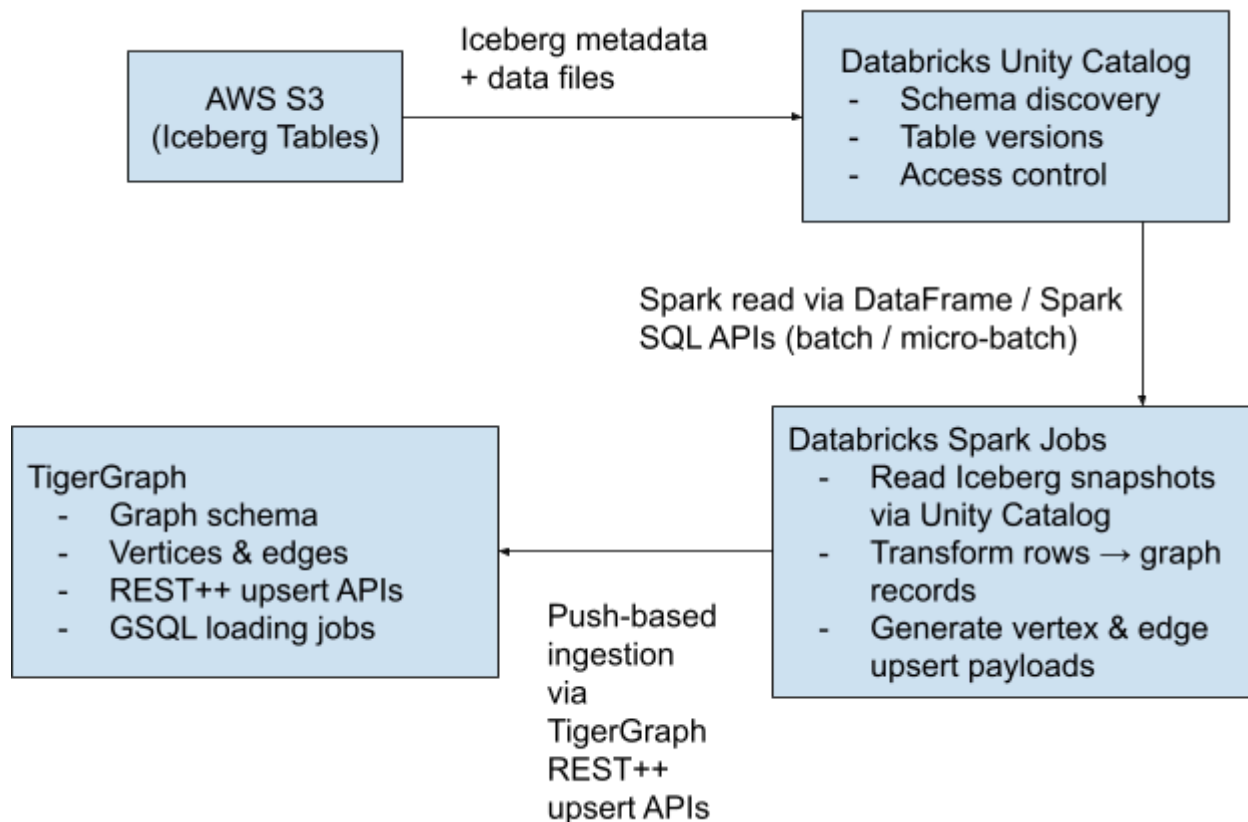
## 1. Overall architecture

### Architecture Goals

The architecture is designed to:

1. Reliably read **Apache Iceberg** tables stored in S3
2. Use **Databricks Unity Catalog** for schema discovery and access control
3. Transform relational data into **graph structures** (vertices & edges)
4. Load data efficiently into **TigerGraph**
5. Support future evolution from batch to near-real-time ingestion
6. Demonstrate Spark reading Iceberg tables via Unity Catalog and performing actual upserts into TigerGraph using native APIs

### High-Level Architecture Diagram



### Component-by-Component Breakdown

#### 1. Apache Iceberg on S3 (Source)

## Role

- Stores large-scale, immutable, versioned tabular datasets
- Provides snapshot-based consistency

## Key Characteristics

- Append-heavy, snapshot-based
- Supports schema evolution
- Well-suited for batch and micro-batch processing

## Why Iceberg matters here

- Allows reproducible graph rebuilds from snapshots
- Enables incremental reads (via snapshot comparison)

## 2. Databricks Unity Catalog (Metadata & Governance Layer)

### Role

- Central catalog for:
  - Table schemas
  - Versions
  - Permissions
- Single control plane for data access

### Responsibilities

- Exposes Iceberg metadata to Spark
- Enforces fine-grained access control
- Provides auditability
- Enforces access and schema resolution during Spark SQL and DataFrame reads

### Why does it sit in the middle

- TigerGraph should **not** directly access Iceberg
- Spark jobs inherit permissions automatically
- Decouples governance from ingestion logic

## 3. Databricks Spark (Transformation Layer)

**Role:** This is the **core integration engine**.

Spark is responsible for:

- Reading Iceberg tables via Unity Catalog using Spark SQL and DataFrame APIs
- Selecting the correct snapshot or time window

- Transforming relational rows into graph entities
- Preparing TigerGraph-compatible payloads for REST++ upsert APIs and batch loading jobs

### **Key Tasks**

- Entity extraction → vertices
- Relationship extraction → edges
- Data cleaning/enrichment (optional)
- Deduplication and key normalization

### **Why Spark**

- Native Iceberg support
- First-class Unity Catalog integration
- Scales easily
- Familiar operational model

## **4. TigerGraph (Destination)**

**Role:** Native graph database optimized for traversal and analytics

### **Responsibilities**

- Stores graph schema
- Hosts vertices and edges
- Executes graph queries and algorithms

### **Ingestion Mechanisms**

- **GSQL Loading Jobs** (batch)
- **REST++ APIs** (optional for incremental)

### **Why TigerGraph is not pulling**

- Iceberg metadata is complex
- Governance belongs in Unity Catalog
- Push keeps TigerGraph stateless and simpler

## **Data Flow (End-to-End)**

1. Spark job starts on Databricks
2. Spark reads Iceberg tables via Unity Catalog using catalog-qualified table identifiers and Spark DataFrame APIs
3. Schema is inferred dynamically
4. Rows are transformed:
  - Entities → vertices
  - Foreign-key relationships → edges

5. Transformed data is pushed to TigerGraph via REST++ upsert APIs for vertices and edges
  6. TigerGraph loads data into graph storage
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## 2. Choice of batch vs streaming

### Overview

The integration pipeline between Apache Iceberg and TigerGraph can be implemented using either **batch-based ingestion** or **streaming ingestion**. While both approaches are viable, this design **intentionally chooses batch (with optional micro-batching)** as the primary ingestion mode.

### Batch Ingestion (Chosen Approach)

#### How Batch Works in This Architecture

1. Spark periodically reads Iceberg tables via Unity Catalog using Spark SQL / DataFrame APIs
2. A consistent snapshot (or snapshot range) is selected
3. Data is transformed into graph vertices and edges
4. Data is ingested into TigerGraph via batch-oriented REST++ upsert APIs

Batch jobs may run:

- Hourly
- Daily
- Or on-demand (e.g., backfill, rebuild)

### Why Batch Fits Iceberg Naturally

Apache Iceberg is designed around **immutable snapshots**.

Key properties:

- Each snapshot represents a consistent point-in-time view
- Snapshots are ideal for repeatable batch reads
- Snapshot metadata enables incremental batch processing

This aligns well with:

- Graph rebuilds
- Periodic synchronization
- Large-scale bulk ingestion

### Why Batch Fits TigerGraph Well

TigerGraph ingestion is optimized for:

- REST++ upsert APIs for batch-oriented ingestion
- GSQL loading jobs as a bulk-loading alternative

Batch ingestion allows:

- Efficient creation and update of vertices and edges
  - Reduced per-record overhead
  - Easier recovery on failure (rerun job)
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## 3. Choice of push vs pull

### Overview

Data ingestion from Iceberg into TigerGraph can be implemented using either a **push-based** or **pull-based** integration model.

- **Push:** An external processing engine (e.g., Spark) reads Iceberg and pushes data into TigerGraph
- **Pull:** TigerGraph (or a custom connector) pulls data directly from Iceberg

This design **intentionally chooses a push-based model** as the primary ingestion strategy.

### Push-Based Ingestion (Chosen Approach)

#### How Push Works in This Architecture

1. Spark jobs running on Databricks read Iceberg tables via Unity Catalog using Spark SQL and DataFrame APIs
2. Spark transforms tabular data into graph primitives
3. Spark pushes transformed data into TigerGraph using REST++ upsert APIs

TigerGraph remains focused on **graph storage and query execution**, not data extraction.

#### Why Push Is the Right Default

##### 1. Native Integration with Unity Catalog

Unity Catalog is deeply integrated with Spark:

- Schema discovery
- Permission enforcement
- Auditing

A push model allows:

- Spark to inherit permissions automatically
- Centralized governance enforcement
- Zero custom security logic in TigerGraph

A pull model would require re-implementing:

- Catalog access
- Credential management
- Policy enforcement

##### 2. Clear Separation of Concerns

Component	Responsibility
Spark	Read, transform, validate
Unity Catalog	Governance & metadata
TigerGraph	Store and query graphs (via REST++ upserts from Spark)

Push-based ingestion keeps:

- ETL logic outside TigerGraph
- TigerGraph is lean and focused
- The architecture modular

### 3. Operational Simplicity

Push-based pipelines:

- They are easier to monitor
- Fail fast and visibly
- Can be retried safely
- Integrate with existing Spark tooling

Retries are straightforward:

- Re-run job
- Reload the same snapshot
- Idempotent graph upserts

### 4. Flexibility in Data Transformation

Graph modeling often requires:

- Joins
- Aggregations
- Deduplication
- Enrichment

Spark excels at these operations.

A pull-based approach would:

- Either reimplement the transformation logic
  - Or severely limit graph modeling complexity
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## 4. Data flows from Iceberg → Unity Catalog → TigerGraph

### Overview

This section describes the **end-to-end data flow** for ingesting tabular data stored in Apache Iceberg into TigerGraph, with **Databricks Unity Catalog** acting as the metadata and governance control plane.

The pipeline follows a **push-based, batch-oriented flow**, ensuring strong consistency, governance, and operational simplicity.

### Step 1: Data Storage in Iceberg (Source Layer)

Source data is stored as **Apache Iceberg tables** backed by files in AWS S3.

Key characteristics:

- Data is organized into immutable snapshots
- Each snapshot represents a consistent point-in-time view
- Schema evolution is tracked at the table level

Iceberg tables may include:

- Entity tables (e.g., users, products)
- Relationship tables (e.g., transactions, interactions)

Iceberg itself does not enforce access control directly; it relies on an external catalog.

### Step 2: Metadata & Access via Unity Catalog (Governance Layer)

**Unity Catalog** serves as the **single source of truth** for:

- Table schemas
- Table versions
- Access permissions
- Auditing

When Spark jobs run on Databricks:

- Table access is validated against Unity Catalog
- Column-level and table-level permissions are enforced
- The schema is discovered dynamically at runtime

This ensures:

- Secure access to Iceberg data
- No hardcoded schemas in the pipeline

- Governance policies are consistently applied

## Step 3: Data Read via Spark (Extraction Layer)

Databricks Spark jobs read Iceberg tables using Unity Catalog–managed identifiers via Spark SQL and DataFrame APIs.

At this stage:

- A specific snapshot or snapshot range is selected
- Only authorized tables and columns are accessible
- Spark loads data into DataFrames with inferred schema

Example actions:

- Full snapshot read (initial backfill)
- Incremental snapshot read (new or changed data)

This step establishes a **consistent and reproducible dataset** for graph ingestion.

## Step 4: Relational-to-Graph Transformation (Processing Layer)

Spark transforms tabular data into **graph primitives**:

### Vertex Extraction

- Each entity row becomes a vertex
- Primary keys map to vertex IDs
- Non-key columns become vertex attributes

### Edge Extraction

- Foreign-key relationships become edges
- Source and destination IDs map to vertex references
- Transactional or relational fields become edge attributes

This transformation may involve:

- Joins across tables
- Deduplication
- Attribute normalization
- Optional enrichment

All graph modeling logic is centralized in Spark.

## Step 5: Graph-Ready Payload Generation (Integration Layer)

After transformation, Spark produces TigerGraph-compatible JSON payloads for REST++ upsert APIs.

Payloads are structured to align with:

- Predefined TigerGraph vertex types
- Predefined TigerGraph edge types
- Required primary IDs and attributes

## Step 6: Data Ingestion into TigerGraph (Destination Layer)

The transformed data is pushed into TigerGraph using REST++ upsert APIs.

Vertices and edges are inserted or updated idempotently through authenticated REST calls from Spark.

GSQL loading jobs are supported by TigerGraph for large-scale bulk ingestion, but are not used in the prototype implementation.

TigerGraph is responsible only for:

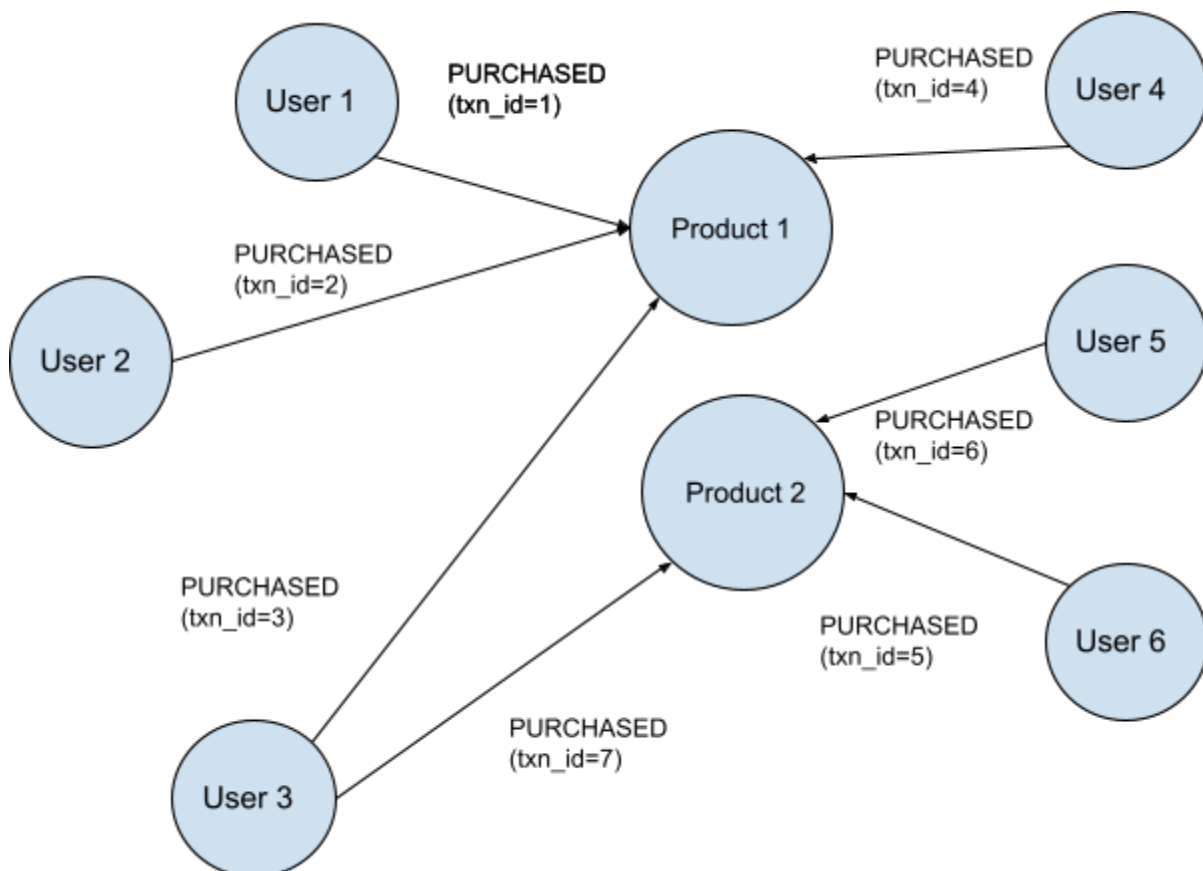
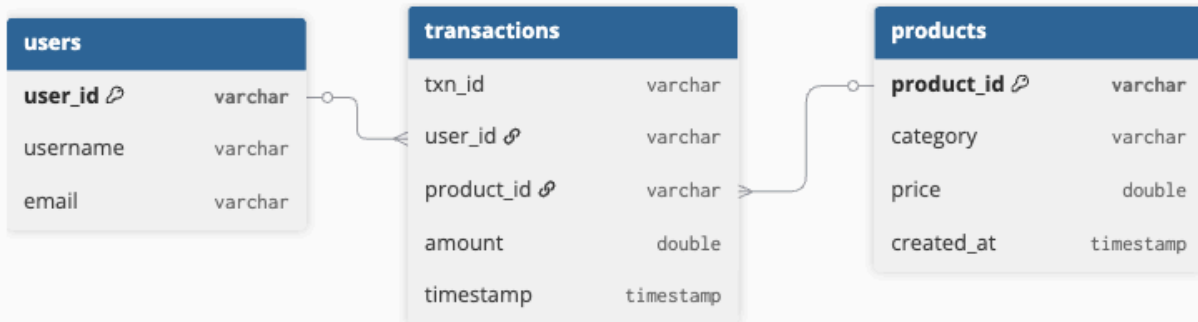
- Storing vertices and edges
- Maintaining graph indexes
- Serving graph queries

**In the event of partial ingestion or transient failures, Spark can safely retry REST++ upsert requests without creating duplicate graph entities.**

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## 5. Schema mapping example (e.g., **users** → vertex, **transactions** → edge)

### Source Tables (Iceberg)



Vertices represent Users and Products. Each directed edge represents a PURCHASED transaction with transaction-specific attributes stored on the edge.

### Sample Input: Iceberg Row (Source)

Example 1: **users** Table Row (Iceberg)

```
{
  "user_id": "u123",
  "name": "Alice Johnson",
  "email": "alice@example.com",
  "created_at": "2024-10-15T08:42:00Z"
}
```

This represents a single record stored in an Iceberg table on S3 and governed by Unity Catalog.

Example 2: **products** Table Row (Iceberg)

```
{
  "product_id": "p456",
  "category": "Electronics",
  "price": 99.99,
  "created_at": "2024-09-01T12:00:00Z"
}
```

Example 3: **transactions** Table Row (Iceberg)

```
{
  "txn_id": "t789",
  "user_id": "u123",
  "product_id": "p456",
  "amount": 99.99,
  "timestamp": "2024-11-01T10:30:00Z"
}
```

### Sample Output: TigerGraph Input (Destination)

User Vertex (TigerGraph)

```
{
  "vertex_type": "User",
  "primary_id": "u123",
  "attributes": {
    "name": "Alice Johnson",
    "email": "alice@example.com",
    "created_at": "2024-10-15T08:42:00Z"
  }
}
```

Product Vertex (TigerGraph)

```
{
  "vertex_type": "Product",
```

```
"primary_id": "p456",
"attributes": {
  "category": "Electronics",
  "price": 99.99,
  "created_at": "2024-09-01T12:00:00Z"
}
}
```

PURCHASED Edge (TigerGraph)

```
{
  "edge_type": "PURCHASED",
  "from_type": "User",
  "from_id": "u123",
  "to_type": "Product",
  "to_id": "p456",
  "attributes": {
    "txn_id": "t789",
    "amount": 99.99,
    "timestamp": "2024-11-01T10:30:00Z"
  }
}
```

**Each Iceberg row is transformed into a TigerGraph vertex or edge record and is upserted into TigerGraph using the REST++ upsert APIs in the prototype implementation.**

**Vertex upserts are idempotent based on primary IDs, while edge upserts preserve transactional semantics by creating or updating relationship records.**

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## 6. Tradeoff summary: when each approach is better

This section summarizes the key architectural tradeoffs considered in designing the Iceberg → TigerGraph integration and highlights when each approach is most appropriate.

### Batch Ingestion

#### Best suited when:

- Data is organized as snapshots or append-heavy tables
- Graph updates do not require sub-second latency
- Operational simplicity and reliability are priorities
- Periodic backfills or full graph rebuilds are required
- Cost predictability is important

#### Why it works well here:

- Apache Iceberg is snapshot-oriented by design
- TigerGraph supports high-throughput batch-oriented ingestion, including REST++ upserts and GSQL loading jobs.
- Batch jobs are easier to monitor, debug, and rerun

### Push-Based Ingestion

#### Best suited when:

- Source systems support scalable data processing engines
- Strong governance and access control are required
- Complex transformations or joins are needed
- Clear separation of responsibilities is desired

#### Why it works well here:

- Spark integrates natively with Unity Catalog
- Transformation logic is centralized and reusable
- TigerGraph remains focused on graph storage and querying

For the given scenario Iceberg tables on S3 governed by Unity Catalog and ingested into TigerGraph, the batch, push-based approach provides the best balance of scalability, simplicity, governance, and extensibility, and is validated by the prototype implementation using Spark and REST++ upserts.

### 1. Batch vs Streaming Decision Matrix

Condition	Batch Ingestion	Streaming Ingestion
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Data latency tolerance	Minutes to hours	Seconds to near-real-time
Data volume	Large, bulk datasets	Continuous event streams
Source system	Snapshot-based (Iceberg)	Event-driven sources
Operational complexity	Low	High
Cost predictability	High	Lower (always-on compute)
Failure recovery	Simple (rerun job)	Complex (stateful recovery)
Schema evolution	Easy to manage	More complex
Graph update pattern	Periodic rebuilds	Continuous incremental updates
Recommended for	Analytics, backfills, periodic sync	Fraud detection, live recommendations

**Batch ingestion** is the default choice due to Iceberg's snapshot semantics and TigerGraph's optimized bulk loading. While streaming ingestion can support lower-latency updates, it is intentionally out of scope for the current prototype, which focuses on batch execution using Iceberg snapshots and Spark.

## 2. Push vs Pull Decision Matrix

Condition	Push-Based Ingestion	Pull-Based Ingestion
Control plane	External (Spark)	Destination-centric
Unity Catalog integration	Native & strong	Limited / custom
Transformation complexity	High flexibility	Limited
Security & governance	Centralized	Duplicated logic
Development effort	Low	High
Operational burden	Lower	Higher
Failure handling	Simple retries	Custom recovery
TigerGraph responsibility	Storage & querying (via REST++ upserts from Spark)	Ingestion + processing
Recommended for	Lakehouse-centric architectures	Restricted or edge environments

**Push-based ingestion** is preferred to leverage Spark + Unity Catalog and keep TigerGraph focused on graph analytics. The push-based model is concretely realized in the prototype, where Spark reads Iceberg data via Unity Catalog and performs authenticated REST++ upserts into TigerGraph.

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# 7. Fault Tolerance & Reliability

The proposed Iceberg → TigerGraph integration is designed to be fault-tolerant across ingestion, transformation, and loading stages. The system leverages the guarantees provided by Iceberg, Spark, and TigerGraph to ensure correctness, recoverability, and idempotent execution.

## Fault Tolerance at Each Layer

- 1. **Iceberg (Source Layer):** Apache Iceberg provides snapshot-based fault tolerance by design. Each ingestion run operates on a well-defined snapshot or snapshot range, ensuring consistent reads even in the presence of concurrent writes. If a Spark job fails, the same snapshot can be reprocessed safely without data loss or duplication.
- 2. **Unity Catalog (Governance Layer):** Unity Catalog enforces schema and access validation at query time. Any unauthorized access or incompatible schema change causes Spark jobs to fail early, preventing partial or inconsistent ingestion. This fail-fast behavior improves overall pipeline reliability.
- 3. **Spark (Transformation Layer):** Spark provides fault tolerance through task-level retries and stage recomputation. In the event of executor failure, Spark automatically re-executes failed tasks without restarting the entire job. Transformations are deterministic and based on Iceberg snapshots, ensuring repeatable results across retries.
- 4. **TigerGraph (Destination Layer):** TigerGraph ingestion via REST++ upsert APIs is idempotent with respect to vertex primary IDs and edge identifiers. Replaying the same upsert requests does not create duplicate vertices or inconsistent relationships, enabling safe retries after partial failures.

Failure Scenario	Recovery Strategy
Spark job failure mid-run	Restart the job using the same Iceberg snapshot
Partial TigerGraph ingestion	Replay REST++ upserts (idempotent)
Schema evolution mismatch	Fail-fast via Unity Catalog validation
Network failure during upsert	Retry with exponential backoff
Duplicate ingestion attempt	Handled via idempotent vertex/edge upserts

## 8. Code Output

```
(agivant) souhardya@MTXs-MBP Agivant % python main.py
/Users/souhardya/.pyenv/versions/3.9.6/lib/python3.9/site-packages/requests/__init__.py:102: RequestsDependencyWarning: urllib3 (1.26.20) or chardet (5.2.0)/charset_normalizer (2.0.12) doesn't match a supported version!
  warnings.warn("urllib3 ({}), or chardet ({}), or charset_normalizer ({}), doesn't match a supported version".format(urllib3.__version__, chardet.__version__, charset_normalizer.__version__), RequestsDependencyWarning)
WARNING: Using incubator modules: jdk.incubator.vector
Using Spark's default log4j profile: org/apache/spark/log4j2-defaults.properties
Setting default log level to "WARN".
To adjust logging level use sc.setLogLevel(newLevel). For SparkR, use setLogLevel(newLevel).
26/01/30 06:04:31 WARN NativeCodeLoader: Unable to load native-hadoop library for your platform... using builtin-java classes where applicable
Unity Catalog not available locally.
Falling back to local mock data.
Reason: [REQUIRES_SINGLE_PART_NAMESPACE] spark_catalog requires a single-part namespace, but got `main`.`commerce`. SQLSTATE: 42K05
Upserting vertices and edges into TigerGraph...
[DRY RUN] Vertex upsert (User):
{
  "vertices": {
    "User": {
      "u1": {
        "attributes": {
          "username": "alice",
          "email": "alice@example.com",
          "created_at": "2024-01-01T00:00:00Z"
        }
      }
    }
  }
}
[DRY RUN] Vertex upsert (Product):
{
  "vertices": {
    "Product": {
      "p1": {
        "attributes": {
          "category": "books",
          "price": 19.99,
          "created_at": "2024-01-01T00:00:00Z"
        }
      }
    }
  }
}
[DRY RUN] Edge upsert (PURCHASED):
{
  "edges": {
    "PURCHASED": [
      {
        "from_id": "u1",
        "to_id": "p1",
        "attributes": {
          "txn_id": "t1",
          "amount": 19.99,
          "timestamp": "2024-01-02T10:00:00Z"
        }
      }
    ]
  }
}
```

```
[DRY RUN] Edge upsert (PURCHASED):
{
  "edges": {
    "PURCHASED": [
      {
        "from_id": "u1",
        "to_id": "p1",
        "attributes": {
          "txn_id": "t1",
          "amount": 19.99,
          "timestamp": "2024-01-02T10:00:00Z"
        }
      }
    ]
  }
}
Ingestion completed successfully.
(agivant) souhardya@MTXs-MBP Agivant %
```