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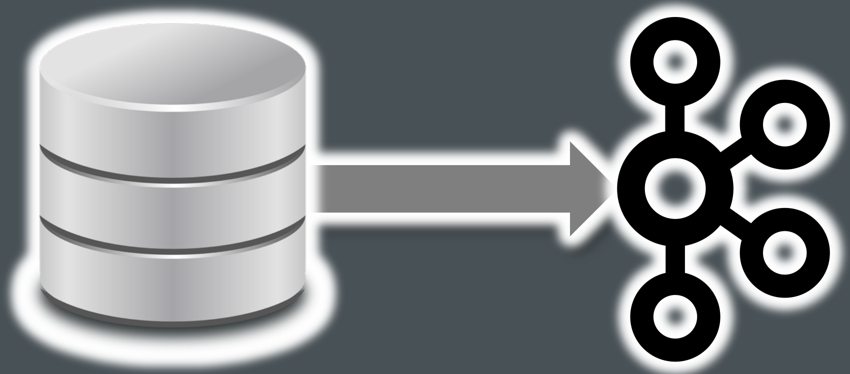
MOVEX Change Data Capture

Lightweight tool for change data capture in relational databases



Peter Ramm, Otto Group Solution Provider (OSP) GmbH

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Otto Group Solution Provider (OSP)

Founded:
March 1991

Parent company:
Otto Group

Locations:
Dresden, Hamburg, Altenkunstadt, Madrid, Taipei

Number of employees:
> 450

Managing Directors:
Dr. Stefan Borsutzky, Norbert Gödicke, Jens Gruhl

Homepage:
https://www.osp.de

About me

Peter Ramm
Team lead strategic-technical consulting at OSP Dresden

> 30 years of history in IT projects

Main focus:
- Development of OLTP systems based on Oracle databases
- Architecture consulting to trouble shooting
- Performance optimization of existing systems

Tasks to be solved by a requested solution

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- Capture data change events (insert/update/delete) in relational databases and transfer these events in a timely manner in JSON format to a Kafka Event Hub.
  - Set monitoring per per table, column and event type (insert/update/delete)
  - Definition of optional filter conditions as SQL expression
  - Definition of Kafka topics per table as target
  - Authorization concept with named users and rights assignment on schema level
  - Tracking of configuration changes (history)
  - Generation of triggers based on configuration data
  - Initial transfer of existing data when starting up the CDC tracking of a table
  - Execute changes via Web-GUI as well as by http API calls.

Differentiation from established CDC solutions
Why yet another tool for this purpose

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- Several solutions for change data capture exist, both commercial and open source (Oracle Golden Gate, Quest SharePlex, Red Hat Debezium, etc.).
- Most are based on scanning the transaction logs of a DB (late filtering for relevant events)
- This has no impact on the runtime of the original transactions, but:
  - To compensate the potential unavailability of the target (Kafka) in an automated way requires to keep the transaction logs in DB for the maximum assumed target downtime
  - Taking into account response time, weekends, etc., this usually means at least 3 days.
  - For small proportion of change events in a large transaction processing system, there would be a disproportionate effort and complexity in dealing with transaction logs
- Other pull alternatives like Kafka-Connect on JDBC level need individual structural adjustments in the application to work sufficiently performant.

Our solution approach

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- Use of DB triggers to initially capture the change events that take place
- DB-independent, first implementations for Oracle and SQLite
- Own schema for MOVEX-CDC in source DB, no objects or operations outside this schema, => thus no structure impact on the application to be 'skimmed'.
- Buffering of the change events to be transmitted by triggers in local table of the DB in MOVEX-CDCs schema
  => thus no dependency of the event-triggering transactions on external resources like MOVEX-CDC application or Kafka
- Asynchronous transfer of events from Kafka buffer table to triggering transaction
  Scalable number of parallel threads to ensure timely transmission
- Generation of triggers based on the configuration entered via GUI or JSON import
- Provision of relevant functions by a http API for automating processes

Pros and cons of this solution approach

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Pro:

- Saving resources by filtering for relevant events at the time they occur
- No dependencies or complexities for technical DB operation
- No adaptations of existing applications necessary
- Convenient configuration via GUI, but can also be automated via API

Contra:

- Load on original transactions by trigger (double write)
- Possibly downtime needed for trigger deployment and release update
- Possible coupling of operational risks for all participants

Motivation from first use case in a large scale PIM

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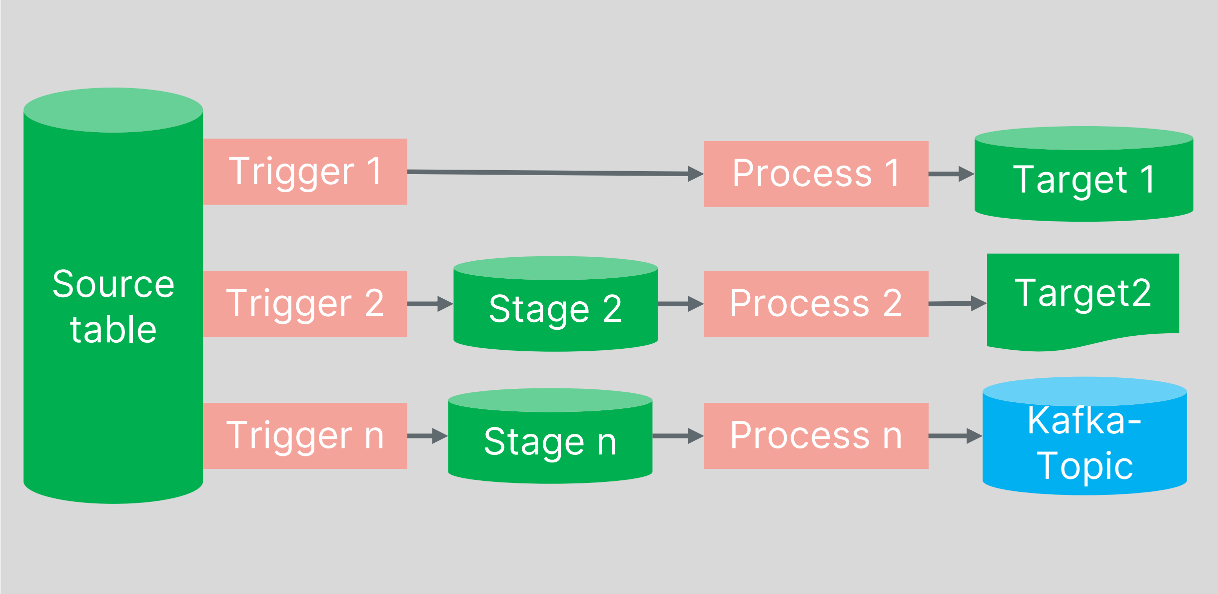
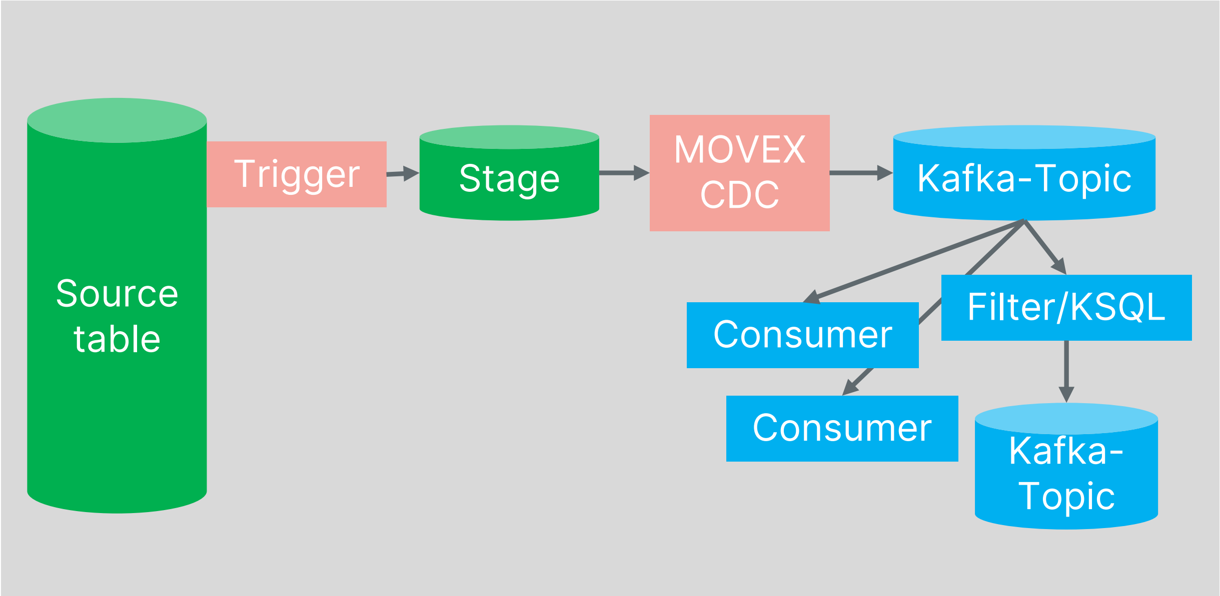
Starting situation:

- Each customer redundantly establishes its own trigger on tables of interest (up to > 100 triggers per table)
- Solutions for further processing of the events in different architecture and quality

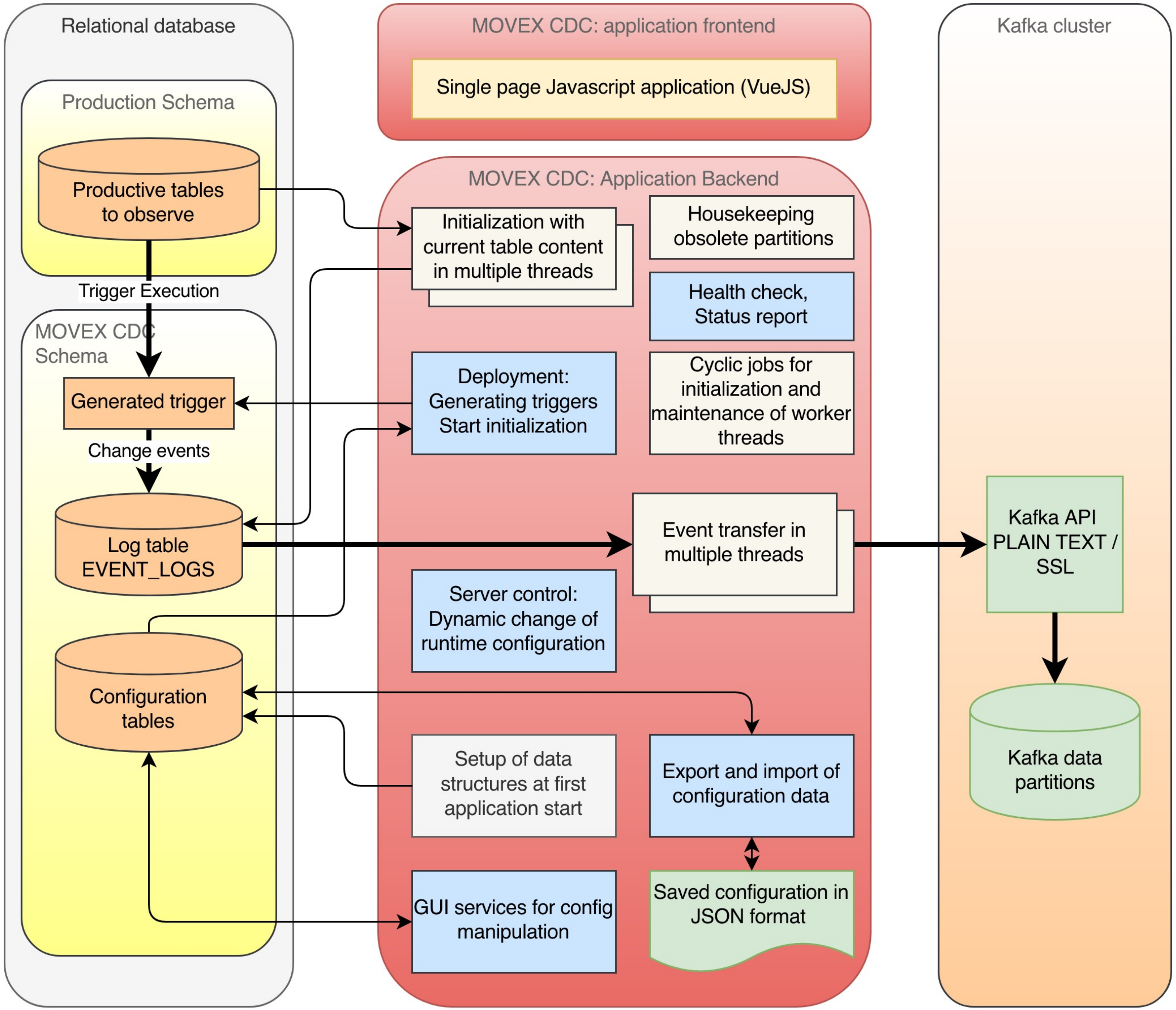
Target scenario with MOVEX-CDC:

- Exactly one trigger per table and event type
- One hardened function for catching events in source DB and transfer to Kafka
- Use publish/subscribe etc. in Kafka





MOVEX-CDC module structure



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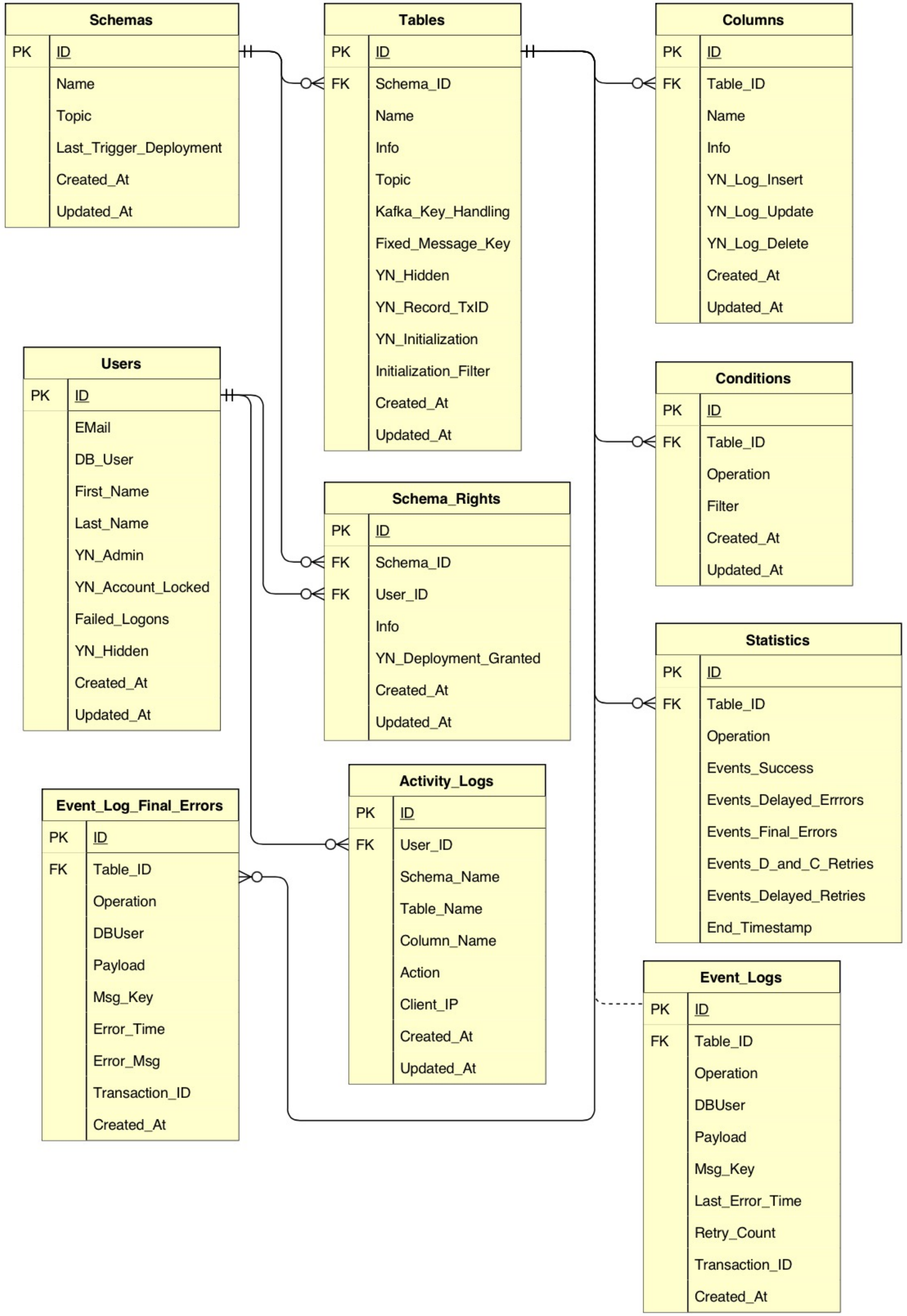

Entity relationship model

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- Own schema encapsulates all MOVEX-CDC-relevant DB objects
- Export of configuration data to JSON file allows backup outside DB
- Import of configuration data via JSON file e.g. for setup test systems
- Via JSON import generation of MOVEX-CDC configuration from external sources possible
- Separate export/import per DB target schema possible

Supported database systems

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- MOVEX-CDC was developed modular and DB-independent based on Ruby on Rails.

- Runtime environment is a Java VM with jRuby, encapsulated in a Docker container.

- Adaptations are thus in principle imaginable for all relational DB systems with trigger function and available JDBC driver.

Currently supported databases :

- Oracle: all editions with optimization for EE/partitioning
- SQLite: Ensure DB independence in development

Further supported databases planned in the medium term:

- PostgreSQL: Favorite free alternative to Oracle dependency
- MS SQL-Server: For announced use in BI environment
- MySQL / Maria-DB: Possibly if requirements exist

Demo

There's a how-to guide with several steps to install, setup and use MOVEX CDC.

Implement change data tracking on an existing Oracle DB including event transfer to Kafka within 10 minutes:

https://otto-group-solution-provider.gitlab.io/movex-cdc/movex-cdc_demo.html

Implementation: Trigger example

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```
CREATE OR REPLACE TRIGGER T1 FOR INSERT ON SCHEMA.TABLE COMPOUND TRIGGER
… /* Deklariere Memory-Collection payload_tab */

PROCEDURE Flush IS
BEGIN
  … /* Schreibe Memory-Collection payload_tab in Event_Log-table */
END Flush;

BEFORE STATEMENT IS
BEGIN
  payload_tab.DELETE; /* remove possible fragments of previous transactions */
END BEFORE STATEMENT;

AFTER EACH ROW IS
BEGIN
  … /* Schreibe JSON-Record in Memory-Collection, Flush wenn > 1000 Records */
END AFTER EACH ROW;

AFTER STATEMENT IS
BEGIN
  Flush; /* Flush Collection in Table */
END AFTER STATEMENT;

END T1;
```

Implementation: Uniqueness

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Uniqueness at the target Kafka:

- Each change event recorded in DB is transferred to Kafka and committed exactly once

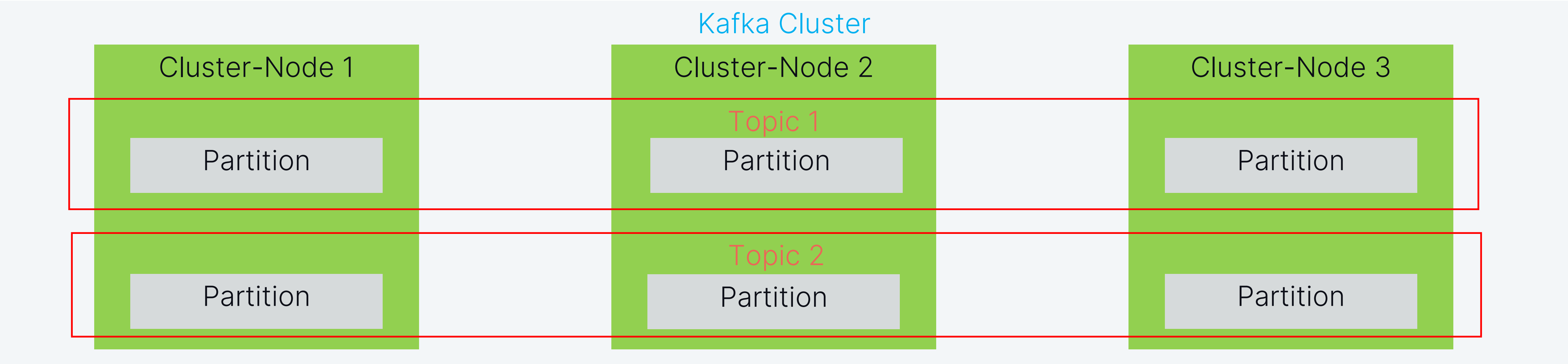
- A non commited transmission to Kafka can occur several times if repeated on error
  - Kafka distinguishes between read_uncommited and read_commited when consuming

- Each event has a unique sequential event ID created by a DB sequence

- Transactional coupling between the two resources DB and Kafka is implemented with two nested transactions in the MOVEX CDC application
- There are no XA or 2-phase commit transactions between them
- Due to this, there is at least a tiny hypothetically risk of double transfers

Implementation: guaranteed sequences

- Kafka guarantees delivery of events in the order of their creation only within a partition
- Events with the same key value always end up in the same partition in Kafka
- MOVEX CDC supports optional keys: no key, primary key, fixed value or transaction ID
- MOVEX-CDC only transmits events with the same key value in an ordered sequence, all others without guarantee of the sequence (conflict of objectives with parallel processing)



Implementation: Horizontal scalability

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- Bottleneck in the transfer between trigger event and Kafka is the transfer of events from the staging table EVENT_LOGS to Kafka

- Scalability is given by configurable number of worker threads in the MOVEX CDC application, each working isolated with own DB and Kafka session
  - Depending on the capacity of the runtime env. (CPU, network) several 100 threads are possible

- The allocation / synchronization of the events from EVENT_LOG to the worker threads is controlled by DB-Locks (SELECT ... FOR UPDATE SKIP LOCKED)

- The guarantee of the order for events with key is ensured by processing events with the same key only by exactly one worker thread in the order of their occurrence
  - Distribution of keys to threads per modulo on a hash value of the key
  - Sequence violation can occur if DB transaction is committed only after successors with the same key from other DB transactions have already been transferred to Kafka.

Implementation: Fail-safe / Instance redundancy

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- Synchronization via DB locks using SELECT ... FOR UPDATE SKIP LOCKED would in principle also allow several MOVEX-CDC instances to be actively operated in parallel.
- However, in this mode of operation the sequence of events can no longer be guaranteed with key
- Hot redundancy with multiple active instances should normally not be necessary, because:
  - An instance has enough potential for throughput optimization by thread scaling
  - A continous gapless operation of the MOVEX-CDC application is not mandatory :
    - For catching the events via DB trigger no running MOVEX CDC instance is needed
    - Suspension of MOVEX-CDCs Docker container does not lead to data loss, but only to delay in transmission to Kafka
    - This allows scenarios such as version updates, changes in runtime environment, etc. to be carried out with short downtimes during ongoing production operation

Implementation: Bulk operations

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The process chain works consistently with bulk operations:

- Trigger implemented as compound trigger with
  - Limitation to max. 1000 JSON records buffered in PL/SQL session memory
  - Bulk operation for insert in stage table EVENT_LOGS

- Read records from EVENT_LOGS with SELECT FOR UPDATE SKIP LOCKED
  - No indexes for EVENT_LOGS means: Full Table Scan for each access to this table
  - Predictable load through interval partitioning with housekeeping of empty partitions
  - Max. size of DB transaction towards Kafka is configurable (default: 10.000)

- Transfer of events to Kafka (Produce) with transaction in Kafka cluster
  - Size of the transaction corresponds to DB transaction
  - Bulk size when transferring to Kafka is limited by Kafka (default 1000, configurable)

Implementation: Fault tolerance

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- In case of transmission errors / rejection of events by Kafka a Divide&Conquer procedure takes effect
- The number of events transmitted by bulk operation is reduced until only a single event is processed. Among other things, this ensures immediate retry several times.
- If an isolated event still remains erroneous, it is marked and retried with a time delay. After x unsuccessful attempts, this event will be sorted out in the error table.
- From error table, events can be manually activated for post-processing, otherwise they will be permanently deleted after a holding period
- Reasons for not broadcasting events can be e.g. :
  - Non-existent Kafka topic
  - Exceeding the permissible event size
  - Configuration without key although log compaction was configured on Kafka side

Implementation: Performance of DB actions (EE)

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- The staging table of the events is an interval-partitioned table without any index. This ensures minimal overhead and maximum availability when inserting the event data in the productive transactions by trigger.
- The partitioning interval as well as the maximum number of simultaneous transactions (INI_TRANS) are controllable via the configuration of MOVEX CDC.
- Fully processed partitions are promptly dropped by a housekeeping process.
- Since the events are stored in a table without indexes, this means that reading the events for transmission to Kafka can only be done via Full Table Scan.
- Interval partitioning ensures a limit to the amount of data to be read via full table scan
- Even with temporarily massive data traffic, the reading effort due to Full Table Scan is reduced again with the next partition change (no problem with non-reducible high water mark).

Implementation: Behaviour of DB actions (SE)

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- For Oracle Standard Edition rsp. Enterprise Edition without Partitioning Option the staging table EVENT_LOGS is implemented as a regular heap table with an index on column ID.

- That means: several optimizations based on partitioning do not take place.

  - The staging table EVENT_LOGS needs an index on column ID for proper performance. This adds additional index maintenance load on triggering transaction and a very tiny risk of blocking between transactions at index block split operations.

  - The high water mark of table EVENT_LOGS is not automatically reduced after peak usage.

  - Additional reorganization activities on staging table EVENT_LOGS can by necessary from time to time depending on type and frequency of usage:
    - ALTER TABLE Event_Logs MOVE; to reduce the high water mark
    - ALTER INDEX Event_Logs_PK REBUILD; to reduce the size of the index

Performance parameters / limitations

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The achievable throughput depends in reality strongly on:

- Database performance
- Performance of the Kafka cluster
- Network latency and throughput / distance between DB, MOVEX-CDC instance and Kafka cluster
- Number of worker threads
- Size of the JSON structure of the events, from 4 KB on, Oracle stores in significantly slower CLOB structures instead of heap tables.
- Example throughput for small distance between DB, MOVEX CDC and Kafka with 3 worker threads and JSON < 4K:
  820,000 events per minute 1.18 billion events per day

Application operation

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- Delivery artifact of MOVEX-CDC is exactly one consistent Docker image
- Configuration is done via a config file or environment variables
- Complete self-initialization of the system in DB schema at the start of the container.
- Logging is done via console output of the Docker container, logging level can be changed dynamically via GUI or API
- Operating status can be queried via HealthCheck API / monitored externally
- Operating statistics (throughputs, error rates, etc.) are collected in table "Statstistics" every minute, condensed after some time
- Temporary downtime or inaccessibility of DB or Kafka will be tolerated. After resources are available again, operation will be resumed without further external activity.
- Several configuration parameters can be adjusted at runtime, like no. of worker threads

Thank you for your interest

Resources:

Project root:	https://gitlab.com/otto-group-solution-provider/movex-cdc
Documentation:	https://otto-group-solution-provider.gitlab.io/movex-cdc/movex-cdc.html
Quick start howto:	https://otto-group-solution-provider.gitlab.io/movex-cdc/movex-cdc_demo.html

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