

Data Integration and Analysis

03 Replication, MoM, and EAI

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Announcements/Org

■ #1 Video Recording

- Link in [TeachCenter](#) & [TUbe](#) (lectures will be public)
- Optional attendance (independent of COVID)



■ #2 COVID-19 Restrictions (HS i5)

- Max 25% room capacity (TC registrations)

max 18/98

■ #3 Exercises/Programming Projects

- Reminder: project selection by **Oct 30**
- Email to m.boehm@tugraz.at (call invites after Oct 30)
- So far 6 projects assigned / preferences collected

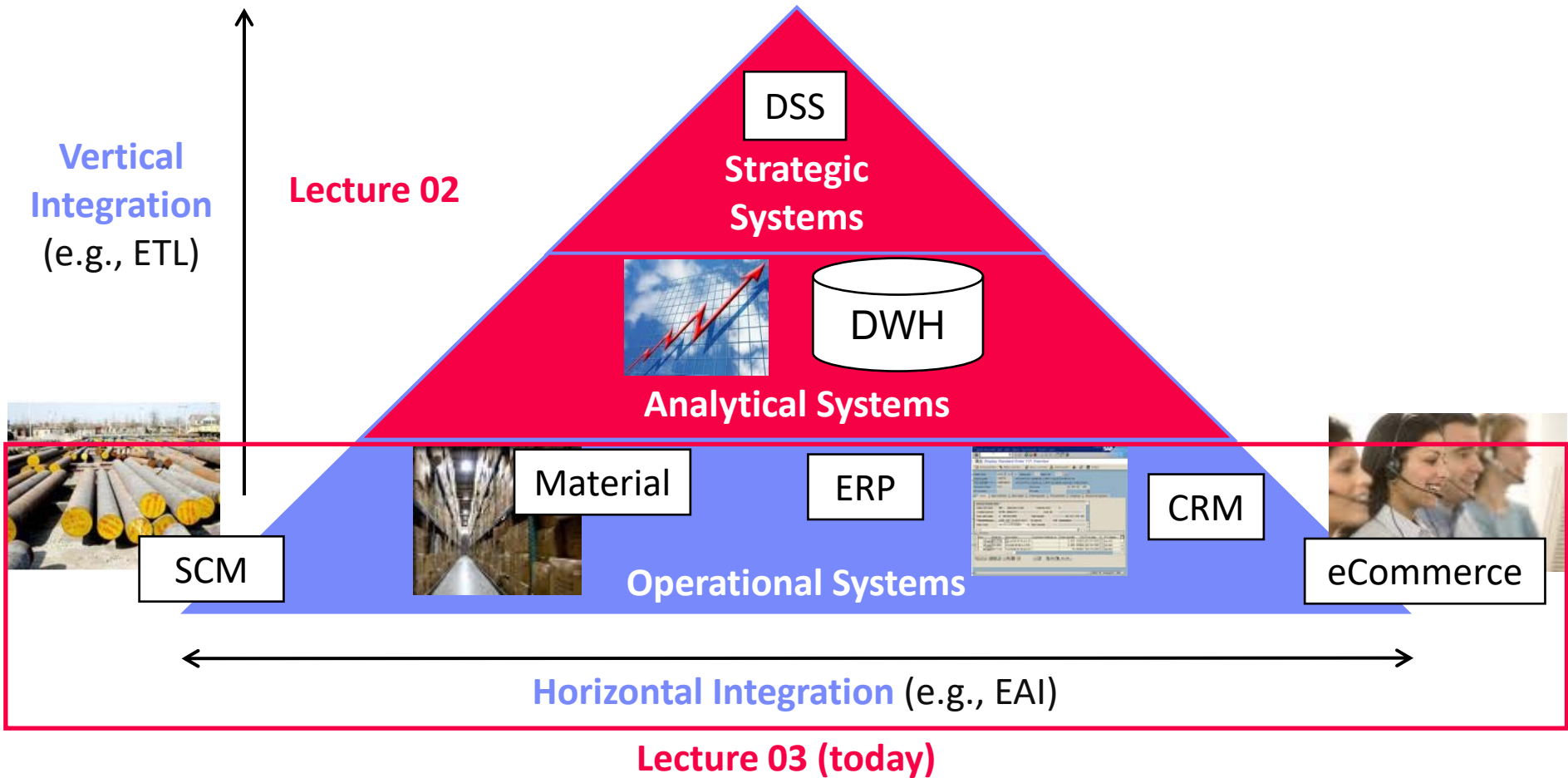


Agenda

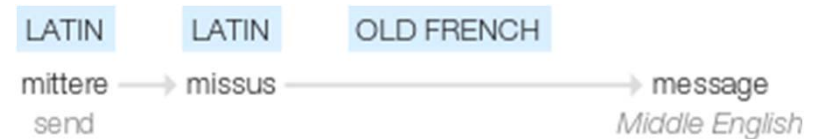
- **Motivation and Terminology**
- **Distributed TX & Replication Techniques**
- **Asynchronous Messaging**
- **Message-oriented Integration Platforms**

Motivation and Terminology

Recap: Information System Pyramid



Messaging



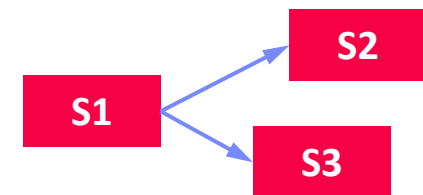
[Credit: <https://www.gstatic.com/onebox/dictionary/etymology/>]

Def: Message

- Piece of information in certain structure
- Send from source (transmitter) over channel to destination (receiver)
- **Syntax:** different message formats (binary, text, XML, JSON, Protobuf)
- **Semantic:** different domain-specific message schemas (aka data models)

Synchronous Messaging

- **Strict consistency requirements**
- Overhead for distributed transactions via 2PC
- Low local autonomy, usually data-driven



Asynchronous Messaging

- **Loose coupling**, eventual consistency requirements
- Batching for efficient replication and updates
- Latency of update propagation



Types of Data Formats

■ General-Purpose Formats

- **CLI/API** access to DBs, KV-stores, doc-stores, time series DBs, etc
- **CSV** (comma separated values)
- **JSON** (javascript object notation), **XML**, **Protobuf**

■ Sparse Matrix Formats

- **Matrix market**: text IJV (row, col, value)
- **Libsvm**: text compressed sparse rows
- Scientific formats: **NetCDF**, **HDF5**

```
%%MatrixMarket matrix coordinate real general
% -----
% 0 or more comment lines
% -----
5 5 8
1 1 1.000e+00
2 2 1.050e+01
3 3 1.500e-02
1 4 6.000e+00
4 2 2.505e+02
4 4 -2.800e+02
4 5 3.332e+01
5 5 1.200e+01
```

■ Large-Scale Data Format

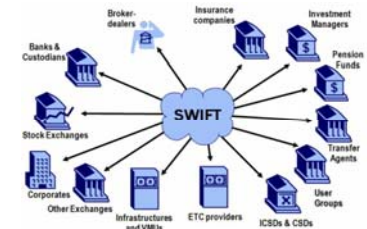
- ORC, Parquet (column-oriented file formats)
- **Arrow** (cross-platform columnar in-memory data)

■ Domain-specific Formats: often binary, structured text, XML

Example Domain-specific Message Formats

■ Finance: **SWIFT**

- Society for Worldwide Interbank Financial Telecommunication
- >10,000 orgs (banks, stock exchanges, brokers and traders)
- Network and message formats for financial messaging
- MT and MX (XML, ISO 20022) messages



[<https://ihodl.com>]

■ Health Care: **HL/7, DICOM**

- Health Level 7 (HL7) messages for clinical and admin data exchange
→ v2.x structured text msgs, v3 XML-based msgs
- Digital Imaging and Communications in Medicine (DICOM)

■ Automotive: **ATF, MDF**

- Association for Standardisation of Automation and Measuring Systems (ASAM)
- E.g., Open Transport Data Format (ATF), Measurement Data Format (MDF), calibrations (CDF), auto-lead XML (ADF), open platform communications (OPC)

- **Note:** Sometimes Large-scale analytics over histories of messages (e.g., health care analytics, fraud detection, money laundering)

Types of Message-Oriented Middleware

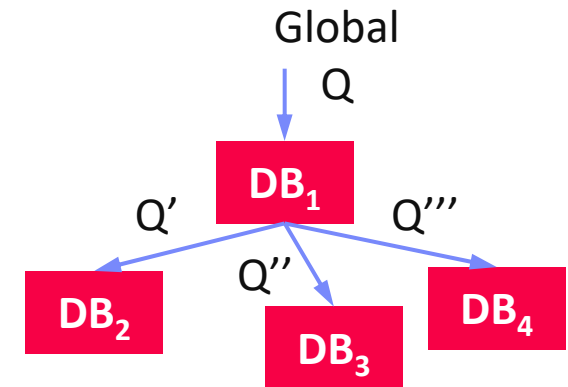
- **#1 Distributed TXs & Replication**
- **#2 Message Queueing**
 - Persistent message queues with well-defined delivery semantics
 - Loose coupling of connected systems or services (e.g., availability)
- **#3 Publish Subscribe**
 - Large number of subscribers to messages of certain topics/predicates
 - Published messages forwarded to qualifying subscriptions
- **#4 Integration Platforms**
 - Inbound/outbound adapters for external systems
 - Sync and async messaging, message transformations, enrichment

Distributed TX & Replication Techniques

Distributed Database Systems

■ Distributed DBS

- Distributed database: Virtual (logical) database that appears like a local database but consists of multiple physical databases
- Multiple local DBMS, components for global query processing
- **Terminology:** **virtual DBS** (homogeneous), **federated DBS** (heterogeneous)



■ Challenges

- **Tradeoffs:** Transparency – autonomy, **consistency – efficiency/fault tolerance**
- **#1** Global view and query language → schema architecture
- **#2** Distribution transparency → global catalog
- **#3** Distribution of data → data partitioning
- **#4** Global queries → distributed join operators, etc
- **#5** Concurrent transactions → **2PC**
- **#6** Consistency of copies → **replication**

Beware: Meaning of “Transparency” (invisibility) here

Two-Phase Commit (2PC)

Recap: Database Transaction

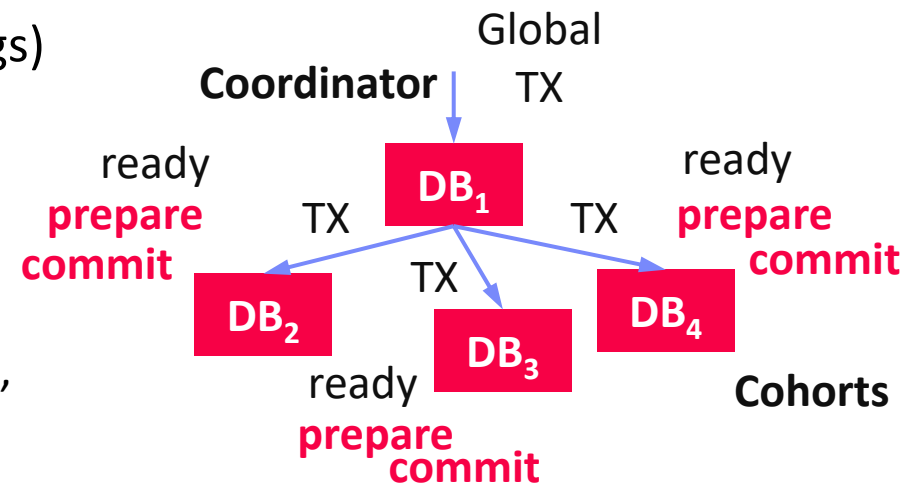
- A transaction (TX) is a **series of steps** that brings a database from a **consistent state** into another (not necessarily different) **consistent state**
- **ACID properties** (atomicity, consistency, isolation, durability)

Problems in Distributed DBS

- Node failures, and communication failures (e.g., network partitioning)
- → **Distributed TX processing to ensure consistent view** (atomicity/durability)

Two-Phase Commit (via $4 \cdot (n-1)$ msgs)

- **Phase 1 PREPARE:** check for successful completion, logging
- **Phase 2 COMMIT:** commit/abort, release locks, and other cleanups
- What happens if nodes unavailable, or report errors on prepare



Two-Phase Commit (2PC), cont.

■ Excursus: Wedding Analogy

- Coordinator: marriage registrar
- **Phase 1:** Ask for willingness
- **Phase 2:** If all willing, declare marriage



■ #1 Problem: **Many Messages**

- $4(n-1)$ messages in successful case, otherwise additional msgs

■ #2 Problem: **Blocking Protocol**

- Local node PREPARE → FAILED → TX is guaranteed to be aborted
- Local node PREPARE → READY → waiting for global response
- Failure of coordinator+cohort, or participating coordinator → **outcome unknown**

■ Other Problems

- Atomicity in heterogeneous systems w/o XA
- Deadlock detection, optimistic concurrency control, etc

Note: APIs for automatic
vs programmatic 2PC

Extended Distributed Commit Protocols

■ 2PC Improvements

- **Hierarchical Commit:** establish message tree from coordinator to local nodes
→ parallelization of message handling over inner nodes
- **Presumed Abort:** assume abort if there are no commit log entries
→ asynchronous logging of aborts, no ACK on abort

■ 1PC (fewer messages)

- Combine TX operations w/ PREPARE to reduce $2(n-1)$ messages
- Local nodes enter waiting state earlier

■ 3PC (non-blocking)

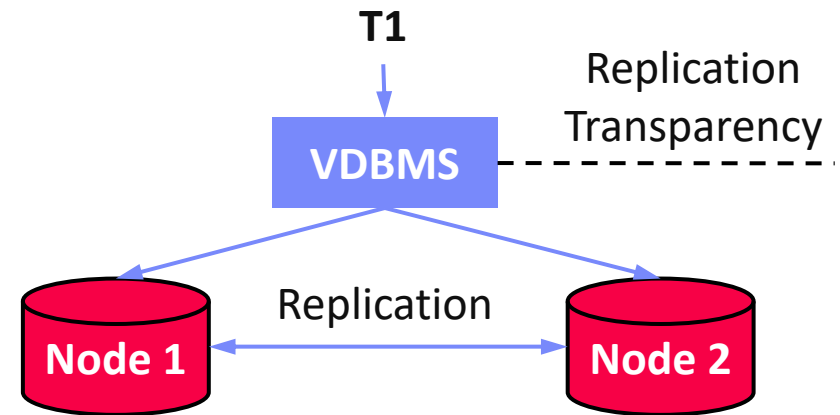
- a) CAN COMMIT? Yes/no
- b) PREPARE COMMIT? Ack
- c) COMMIT? Ack
- Cohorts can collectively decide on commit if at least one in PRE-COMMIT

Protocol	# Msgs
1PC	$2(n-1)$
2PC	$4(n-1)$
3PC	$6(n-1)$

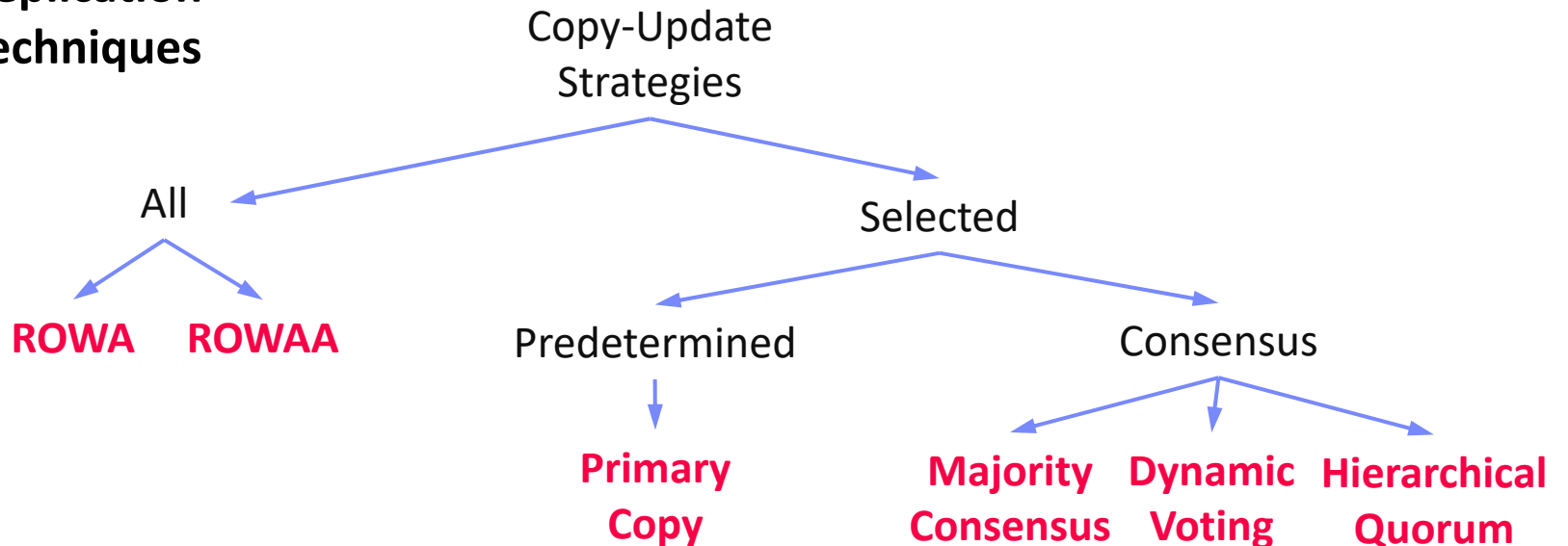
Replication Overview

Replication

- Redundancy of stored fragments
- Availability/efficiency (read) vs update overhead / storage



Replication Techniques



Replication Techniques

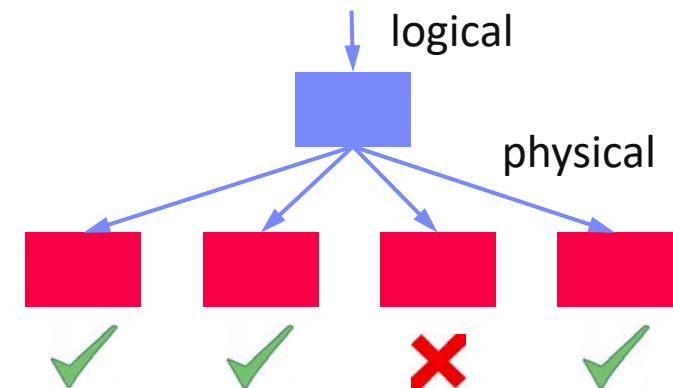
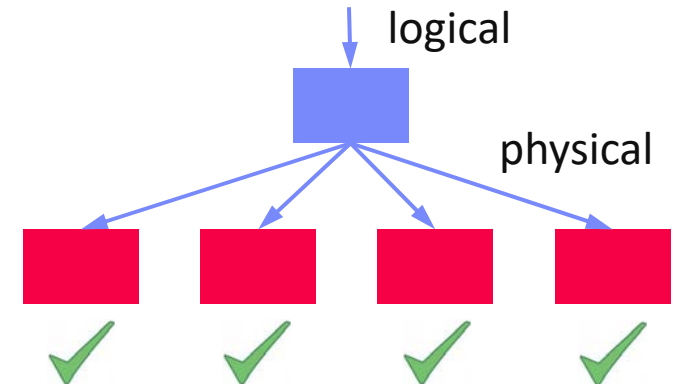
▪ ROWA

- Read-One/Write-All
- Read: good performance/availability
- Write: high overhead and only successful if all available

▪ ROWAA

- Read-One/Write-All-Available
- Relaxed availability requirement for write operations

„Update anywhere-anytime-anyway transactional replication has unstable behavior as the workload scales up: **a ten-fold increase in nodes and traffic gives a thousand fold increase in deadlocks or reconciliations**. Master copy replication (**primary copy**) schemes reduce this problem.”

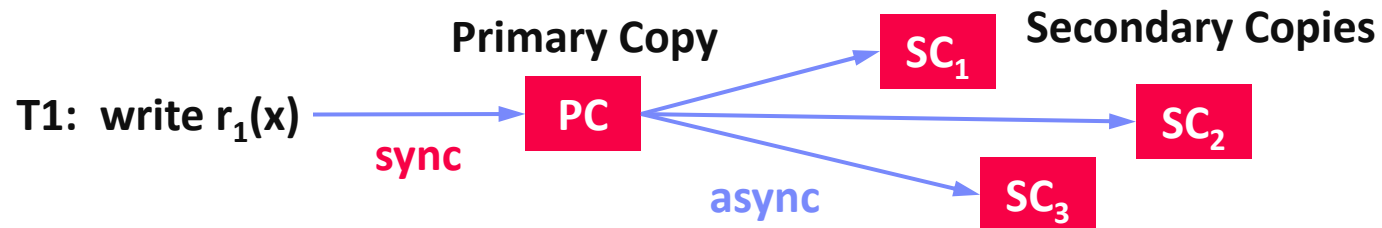


[**Jim Gray**, Pat Helland, Patrick E. O'Neil, Dennis Shasha: The Dangers of Replication and a Solution, **SIGMOD 1996**]

Replication Techniques, cont.

■ Primary Copy

- Update single primary copy **synchronously**
- **Asynchronous propagation** of updates to other replicates, read from all



- **Pro:** Higher update performance, good locality, and availability
- **Con:** Potentially stale read on secondary copies (w/ and w/o locks)
- **Load balancing:** place PC of different objects on different nodes

Replication Techniques, cont.

Consensus Protocols

- **Basic idea:** voting if read/write access is permissible (with regard to serializability)
- Each replicate has vote \rightarrow all votes Q
- Read quorum Q_R and write quorum Q_W

Overlap Rules:

$$Q_R + Q_W > Q$$

$$Q_W > Q/2$$

#1 Majority Consensus

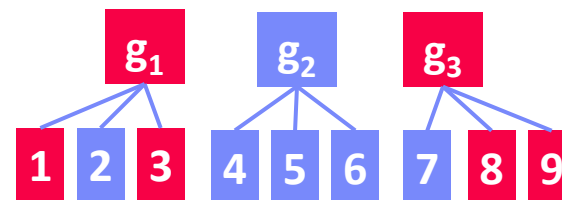
- Read requires $Q_R > Q/2$, lock all and read newest replica
- Write requires $Q_W > Q/2$, lock and update all

#2 Dynamic Quorums

- Problem: network partitioning \rightarrow retain vote for updated replica

#3 Hierarchical Quorums

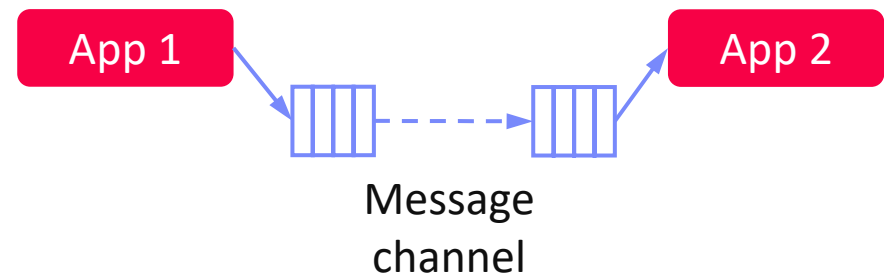
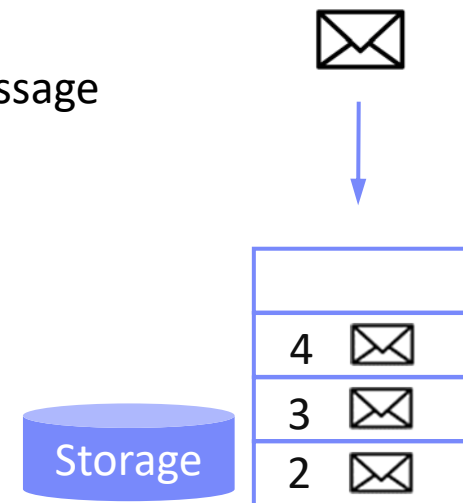
- Obtain majority of nodes in multiple levels of the tree



Asynchronous Messaging

Message Queueing

- **Message**
 - Atomic packet of data + meta data, wrapped as a message
- **Message Queue**
 - FIFO or priority queue of messages
 - In-memory, sometimes with persistent storage backend and transactional semantics
 - Internal IDs, receive time
- **Remote Message Queues**
 - Loose coupling of applications (no direct API calls, etc)
 - Independent of HW and OS



Recap: Message Delivery Guarantees

- **#1 At Most Once**
 - “Send and forget”, ensure data is never counted twice
 - Might cause data loss on failures

- **#2 At Least Once**
 - “Store and forward” or acknowledgements from receiver, replay stream from a checkpoint on failures
 - Might create incorrect state (processed multiple times)

- **#3 Exactly Once**
 - “Store and forward” w/ guarantees regarding state updates and sent msgs
 - Often via dedicated transaction mechanisms

Example Systems

■ IBM MQSeries

- Message-oriented middleware for async queue communication
- Connections/objects: **MQCONN**, MQDISC, MQOPEN, MQCLOSE
- Queue ops: MQCRTMH, **MQPUT**, **MQGET**, MQSET, MQINQ, MQSTAT
- Transactions: MQBEGIN, MQBACK, MQCMIT



■ JMS (Java Message Service)

- J2EE API of messaging services in Java (messages, queues, sessions, etc)
- JMS providers: e.g., **IBM Websphere MQ**, **Apache ActiveMQ**, **RabbitMQ**

■ AWS Simple Queueing Service (SQS)

- Message queueing service for loose coupling of micro services
- Default queue: best effort order, **at-least-once**, high throughput
- FIFO: guarantees FIFO order, and **exactly-once**



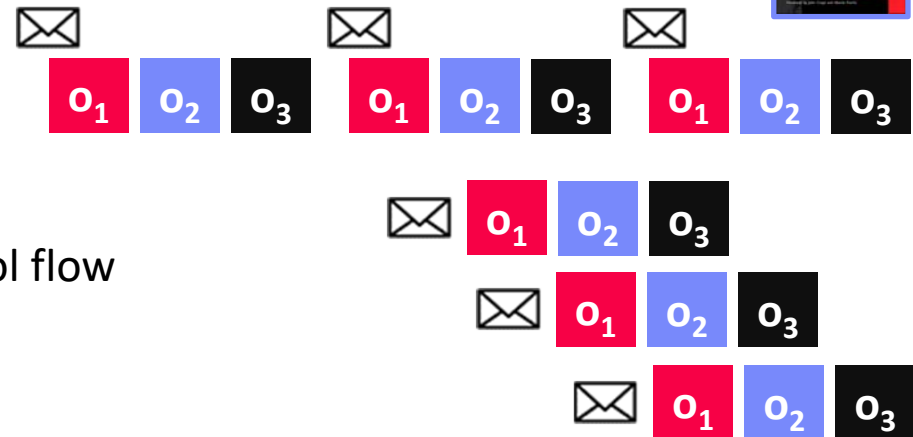
Parallel Message Processing

[Gregor Hohpe, Bobby Woolf:
Enterprise Integration Patterns,
Addison-Wesley, 2004]



#1 Pipeline Parallelism

- **“Pipes and filters”**: leverage pipeline parallelism of chains of operators
- More complex w/ routing / control flow (possible via punctuations)

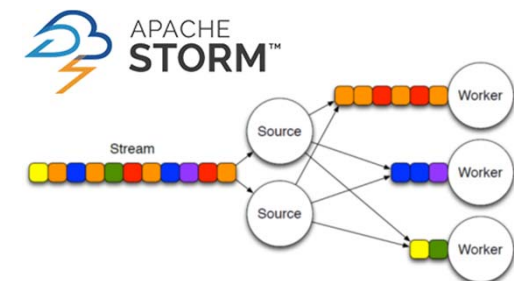


#2 Operator Parallelism

- Multi-threaded execution of multiple messages within one operator (pattern **“competing consumers”**)
- Requires robustness against partial out-of-order, or resequencing

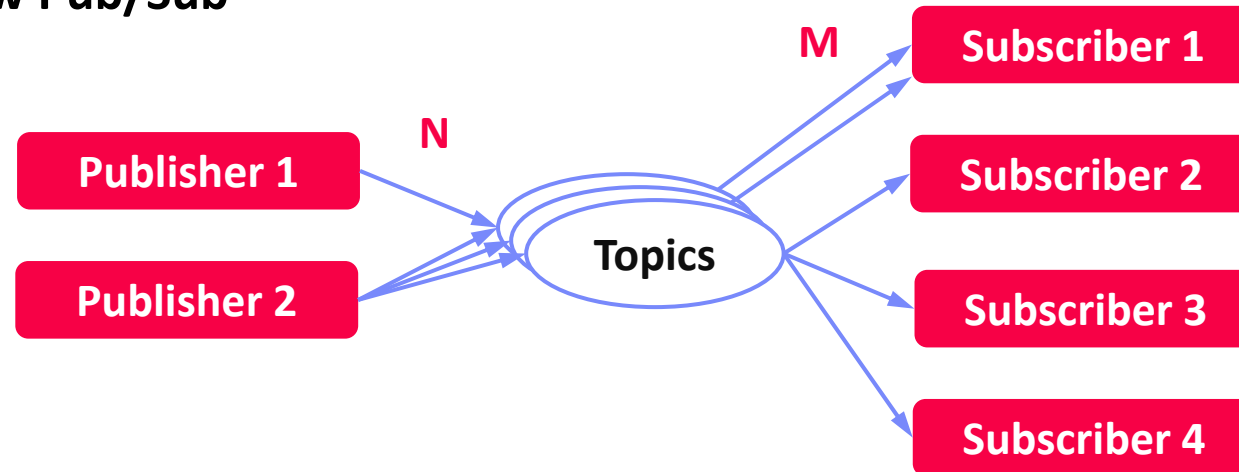
#3 Key Range Partitioning

- Explicit routing to independent pipelines (patterns **“message router”**, **“content-based router”**)
- Ordering requirements only within each pipeline



Publish/Subscribe Architecture

Overview Pub/Sub



Key Characteristics

- Often imbalance between few publishers and many subscribers
- **Topics**: explicit or implicit (e.g., predicates) groups of messages to publish into or subscribe from
- Addition and deletion of subscribers rare compared to message load
- ECA (event condition action) evaluation model
- Often **at-least-once** guarantee

Publish/Subscribe Architecture, cont.

- Subscriber Filtering

- Complex predicates of range filters, equi-predicates, and negation
- Goal:** Avoid naïve scan over all subscriber predicates / topics

- Matching Algorithm

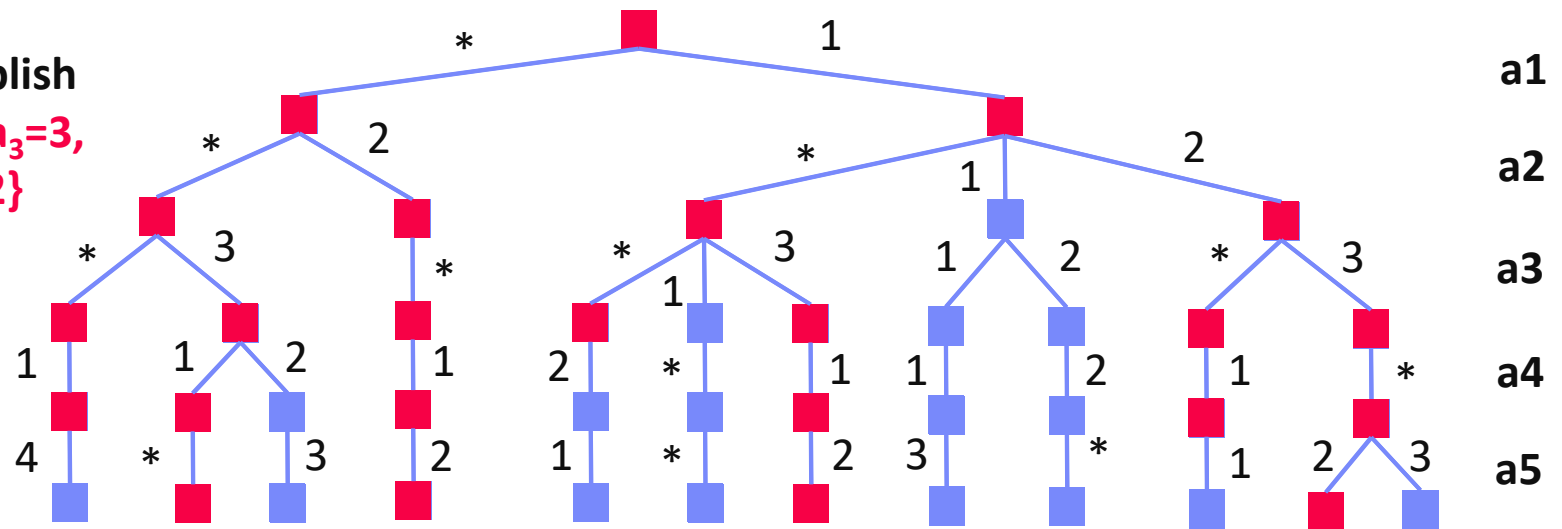
- Matching event against a set of subscriptions
- Approach:** sorting and parallel search tree

[Guruduth Banavar et al: An Efficient Multicast Protocol for Content-Based Publish-Subscribe Systems. ICDCS 1999]



Example Publish

{ $a_1=1, a_2=2, a_3=3, a_4=1, a_5=2$ }



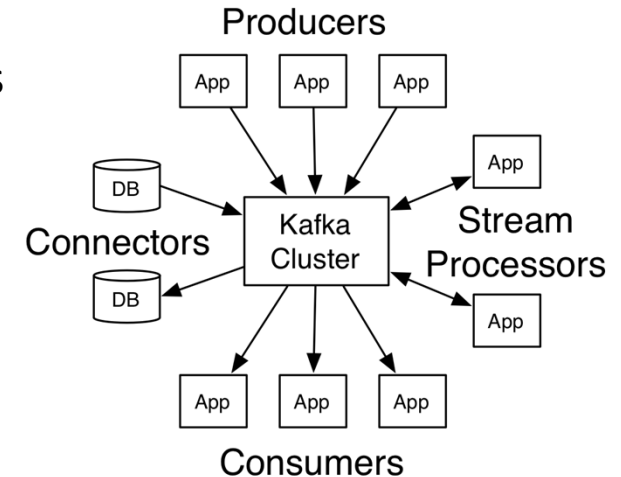
Apache Kafka

[\[https://kafka.apache.org/documentation\]](https://kafka.apache.org/documentation)



Overview System Architecture

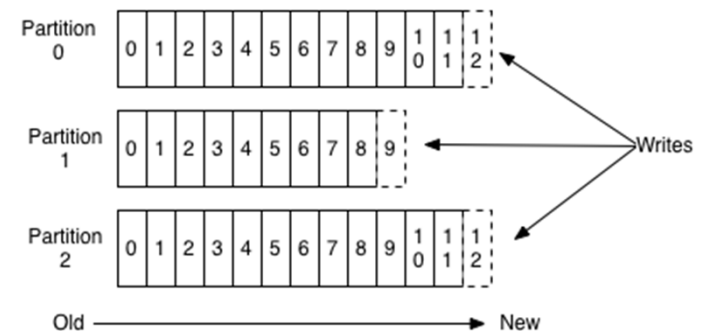
- **Publish & Subscribe** system w/ partitioned topics
- **Storage of data streams** in distributed, fault-tolerant cluster (replicated)
- Configurable **retention periods** (e.g., days)
- **APIs:** producer API, consumer API, streams API, Connector API



Topics

- Explicit categories w/ user-defined (semantic) partitioning
- Partitions are ordered, immutable sequences of records (log) w/ **offsets**
- Current **offset** per consumer stored

Anatomy of a Topic

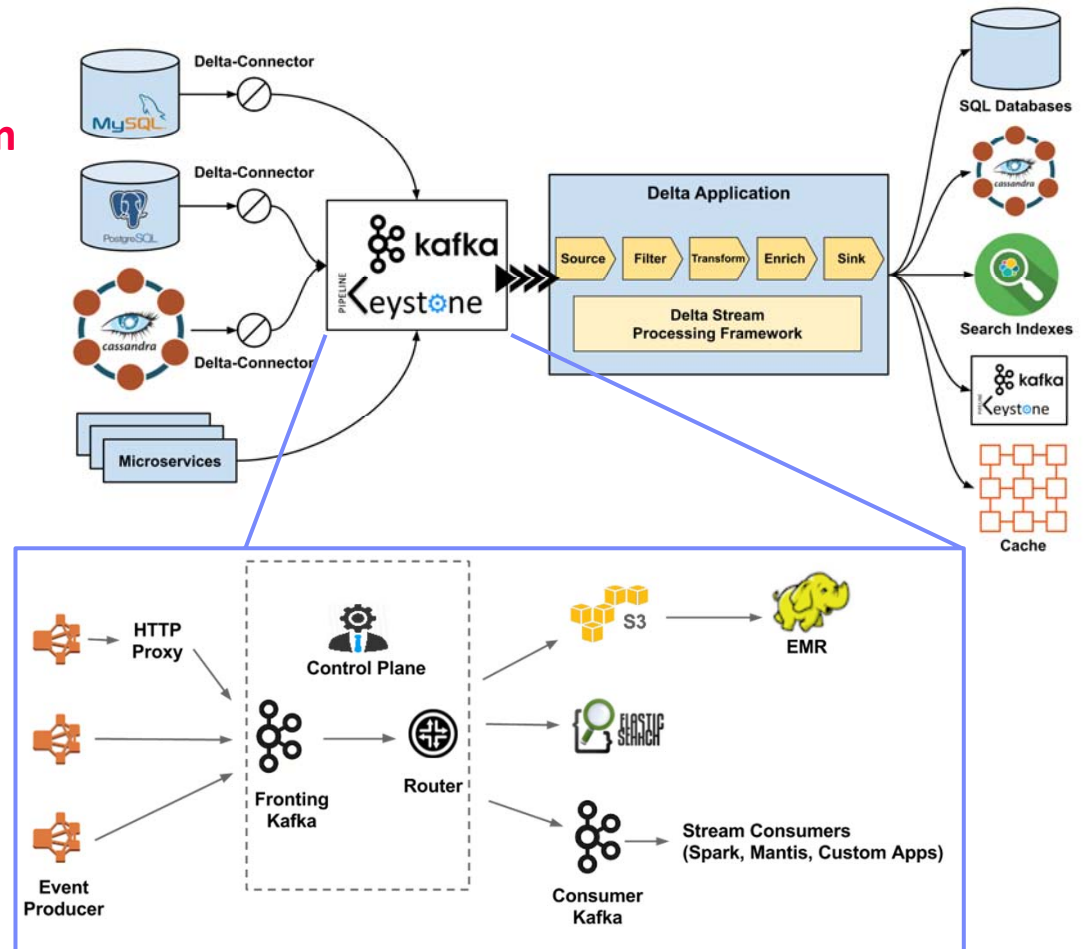


Apache Kafka, cont.

[<https://medium.com/netflix-techblog/delta-a-data-synchronization-and-enrichment-platform-e82c36a79aee>, Oct 15 2019]

Netflix Delta

- **A Data Synchronization and Enrichment Platform**
- DSL and UDF APIs for custom filters and transformations



Netflix Keystone (Kafka frontend)

- **~500G events/day**
(5M events/s peak)
- **~1.3PB/day**

[<https://medium.com/netflix-techblog/evolution-of-the-netflix-data-pipeline-da246ca36905>]

Message-oriented Integration Platforms

Overview

- **Motivation**

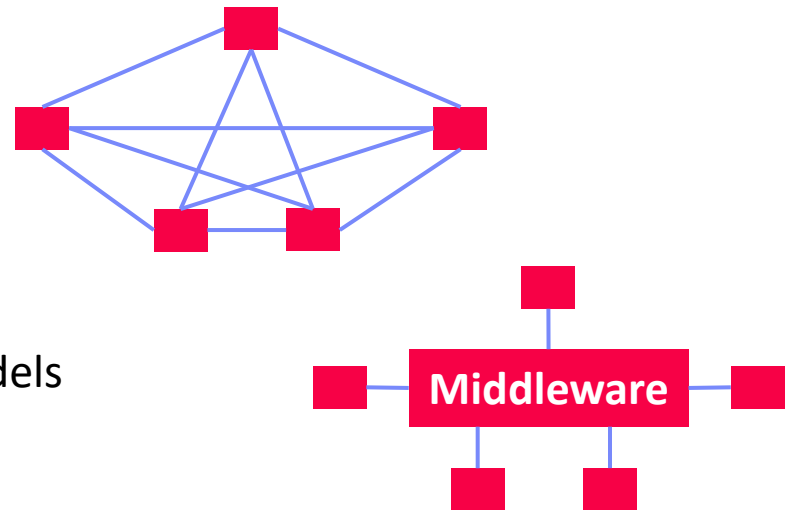
- Integration of many applications and systems via common IR
- **Beware:** syntactic vs semantic data models

- **Evolving Names**

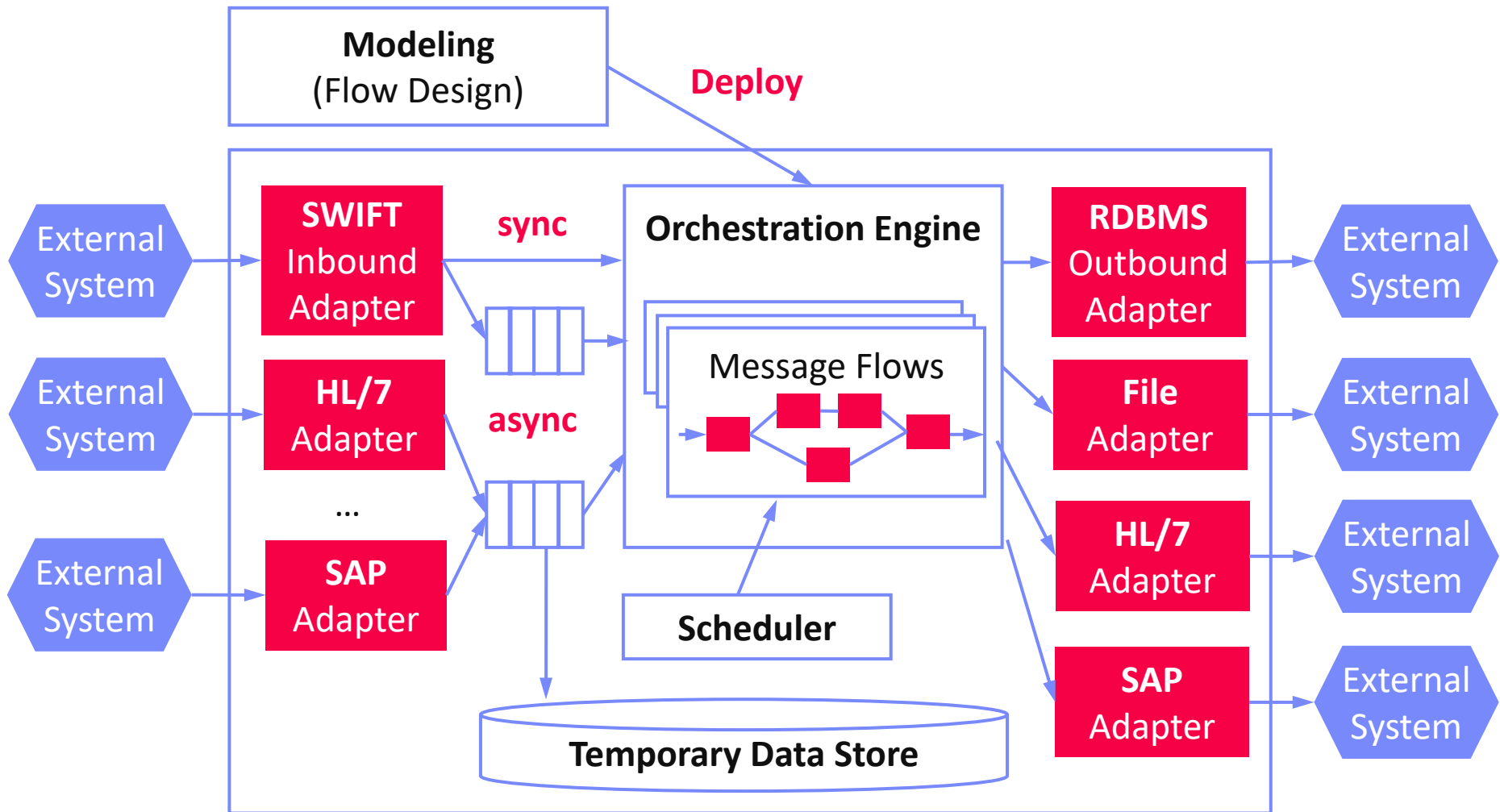
- Enterprise Application Integration (EAI)
- Enterprise Service Bus (ESB)
- Message Broker

- **Example Systems**

- IBM App Connect Enterprise (aka Integration Bus, aka Message Broker)
- MS Azure Integration Services + Service Bus (aka Biztalk Server)
- SAP Process Integration (aka Exchange Infrastructure)
- SQL AG TransConnect



Common System Architecture



Common System Architecture, cont.

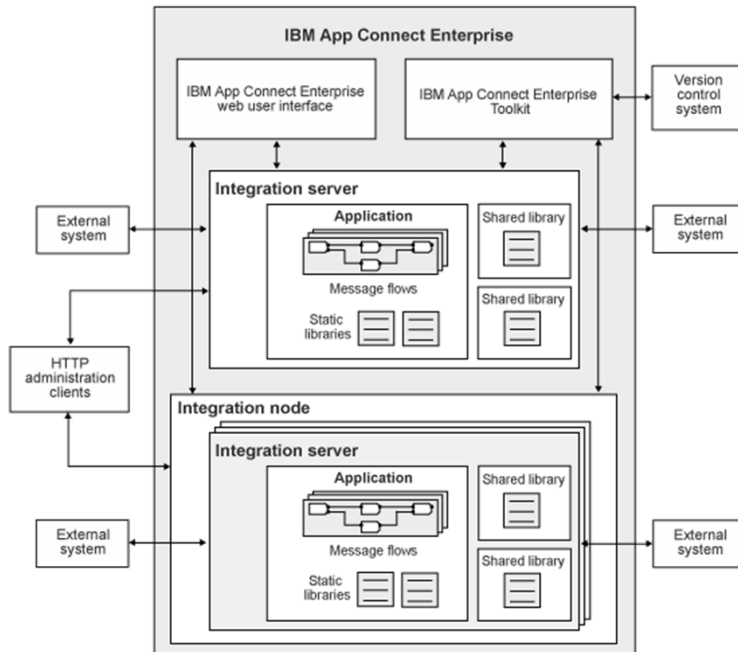
- **#1 Synchronous Message Processing**
 - **Event:** **client input message**
 - Client system blocks until message flow executed to output messages delivered to target systems

- **#2 Asynchronous Message Processing**
 - **Event:** **client input message from queue**
 - Client system blocks until input message stored in queue
 - Asynchronous message flow processing and output message delivery
 - Optional acknowledgement, when input message successfully processed

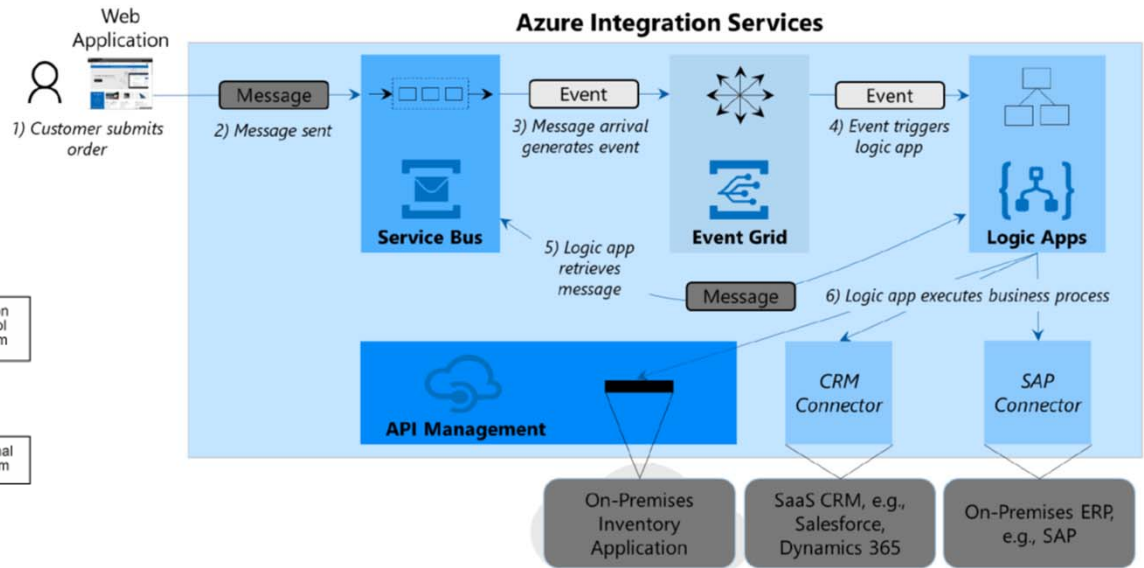
- **#3 Scheduled Processing**
 - **Event:** **time-based scheduled** message flows (cron jobs)
 - Periodic data replication and loading (e.g., ETL use cases)

Commercial Systems

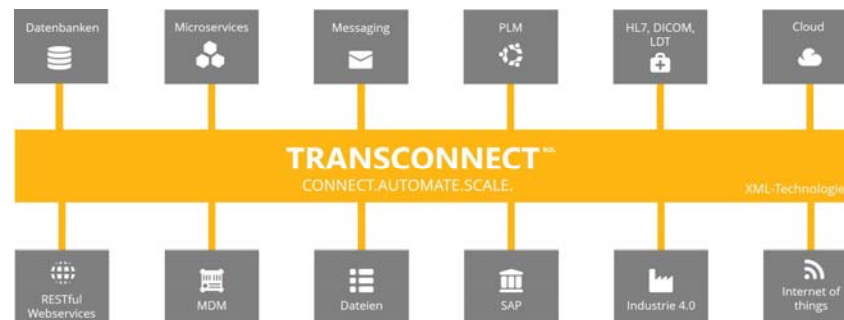
[**IBM App Connect Enterprise:**
https://www.ibm.com/support/knowledgecenter/en/SSTTDS_11.0.0/com.ibm.etools.mft.doc/ab20551_.htm]



[<https://azure.microsoft.com/mediahandler/files/resourcefiles/azure-integration-services/Azure-Integration-Services-Whitepaper-v1-0.pdf>]



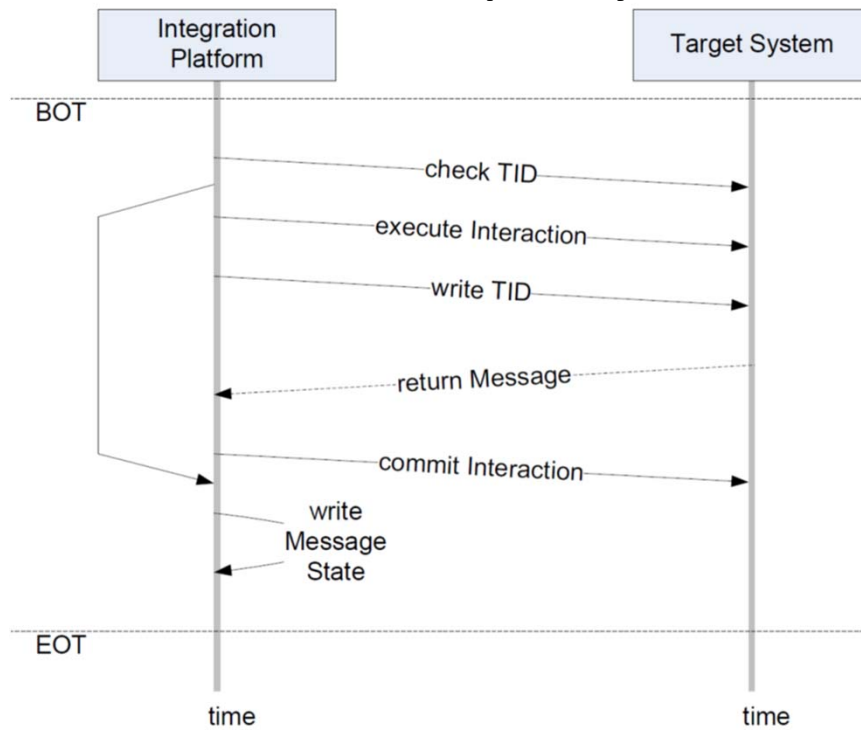
[SQL AG: <https://www.transconnect-online.de/>]



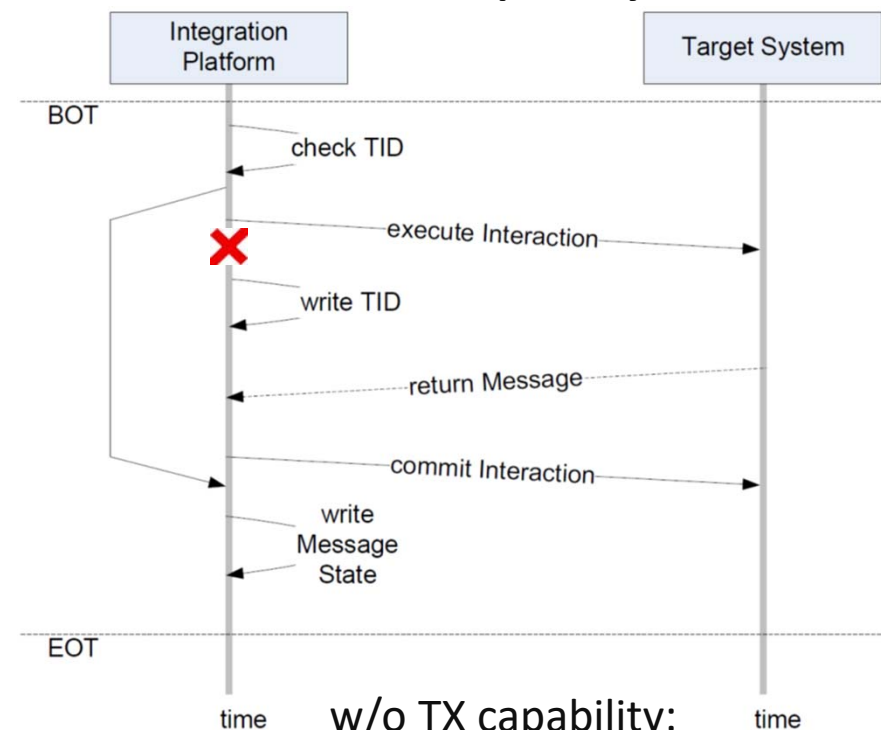
Message Delivery Guarantees, cont.

- Example **Exactly-Once**

**Remote ID Maintenance
w/ TX capability**



**Local ID Maintenance
w/ TX capability**



w/o TX capability:
at-least-once

[Credit: SQL AG - <https://www.transconnect-online.de/>]

Recap: XML (Extensible Markup Language)

- **XML Data Model**

- Meta language to define specific **exchange formats**
- Document format for **semi-structured data**
- Well formedness
- XML schema / DTD

```
<?xml version="1.0" encoding="UTF-8"?>
<data>
  <student id="1">
    <course id="INF.01014UF" name="Databases"/>
    <course id="706.550" name="AMLS"/>
  </student>
  <student id="5">
    <course id="706.004" name="Databases 1"/>
  </student>
</data>
```

- **XPath (XML Path Language)**

- Query language for **accessing collections of nodes** of an XML document
- Axis specifies for ancestors, descendants, siblings, etc

```
/data/student[@id='1']/course/@name
```



- **XSLT (XML Stylesheet Language Transformations)**

- Schema mapping (transformation) language for XML documents

- **XQuery**

- Query language to extract, transform, and analyze XML documents

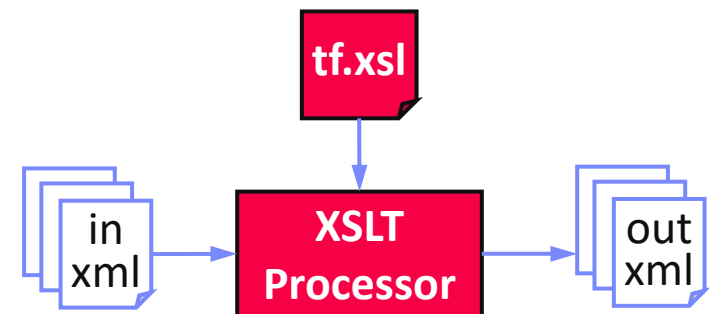
XSLT in Integration Platforms

■ Problem

- XML often used as **external and internal data representation**
- Different schemas (message types) → **requires mapping**

■ XSLT Overview

- XSLT processor transforms input XML document according to XML stylesheet to output XML documents
- Subtree specifications via XPath, loops, branches built-in functions for text processing, etc
- **Streaming:** STX or XSLT 3.0 streaming
- **CSV** and **JSON** input/output possible



■ Note: Similar tools/libraries for JSON

XSLT Example

```
<?xml version="1.0" encoding="UTF-8"?>
<xsl:stylesheet version="2.0" xmlns:xsl="http://www.w3.org/1999/XSL/Transform">
<xsl:template match="/">
  <xsl:element name="suppliers">
    <xsl:for-each select="/resultsets/resultset[@Tablename='Supplier']/row">
      <xsl:element name="supplier">
        <xsl:attribute name="ID"><xsl:value-of select="Suppkey"/></xsl:attribute>
        <xsl:element name="Name"><xsl:value-of select="Suppname"/></xsl:element>
        <xsl:element name="Address"><xsl:value-of select="SuppAddress"/></xsl:element>
      </xsl:element>
    </xsl:for-each>
  </xsl:element>
</xsl:template>
</xsl:stylesheet>
```

```
<resultsets>
  <resultset Tablename="Supplier">
    <row>
      <Suppkey>7</Suppkey>
      <Suppname>MB</Suppname>
      <SuppAddress>1035 Coleman Rd</SuppAddress>
    </row>
    <row> ... </row>
  </resultset>
</resultsets>
```



```
<suppliers>
  <supplier ID="7">
    <Name>MB</Name>
    <Address>1035 Coleman Rd</Address>
  </supplier>
  <supplier> ... </supplier>
</suppliers>
```

Summary and Q&A

- **Distributed TX & Replication Techniques**
 - Distributed commit protocols
 - Different replication techniques
- **Asynchronous Messaging**
 - Message queueing systems
 - Publish/subscribe systems
- **Message-oriented Integration Platforms**
 - System architecture and systems
 - Schema mappings via transformations
- **Next Lectures (Data Integration Techniques)**
 - **04 Schema Matching and Mapping** [Oct 30]
 - **05 Entity Linking and Deduplication** [Nov 06]
 - **06 Data Cleaning and Data Fusion** [Nov 13]
 - **07 Data Provenance and Blockchain** [Nov 20]

Macroscopic
View

Microscopic
View