Research Project Proposal: Towards a unifying model for data-intensive applications

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Data-intensive applications

What is a «data-intensive» application?

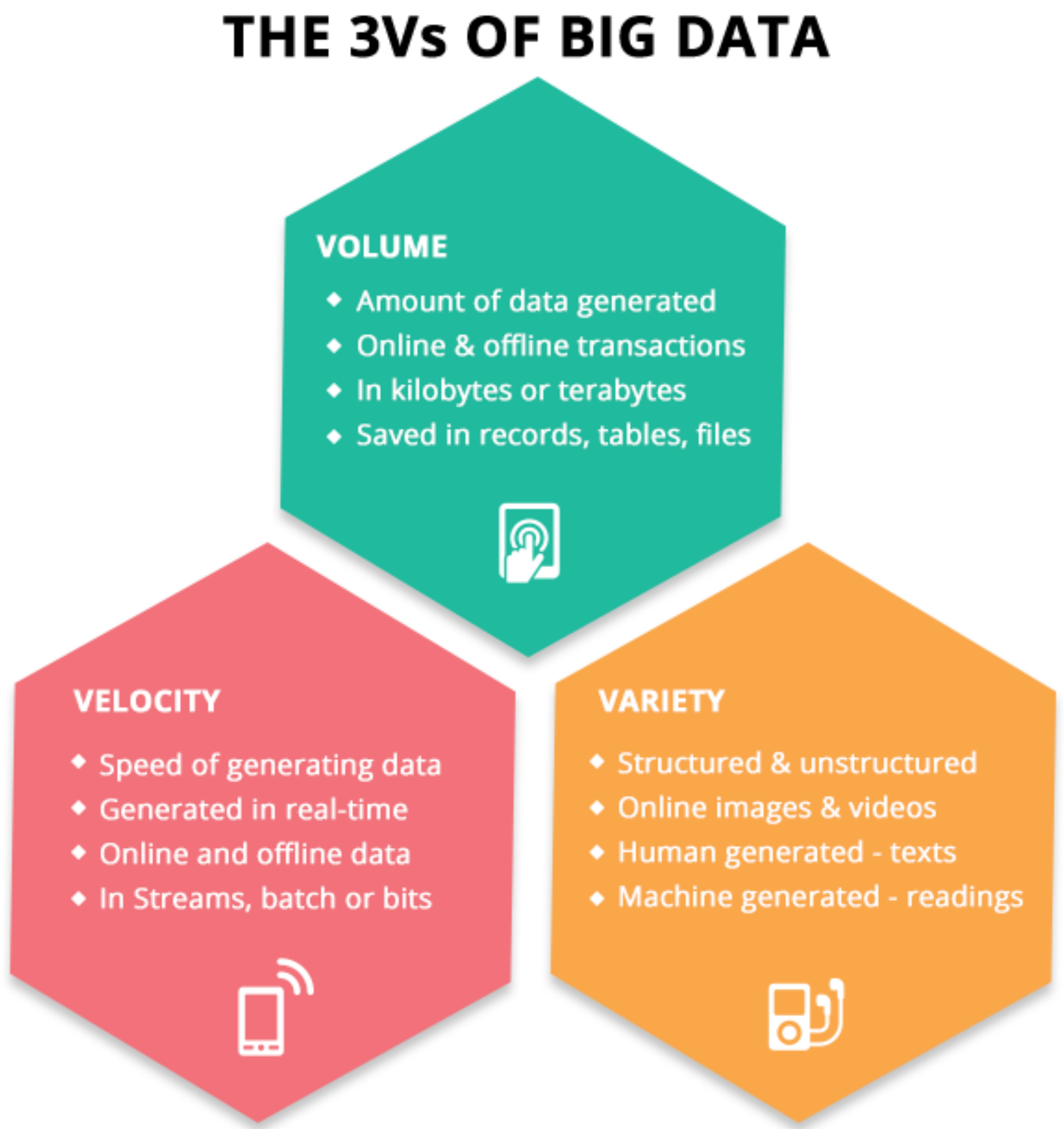
We are talking about:

- Software applications
- Big data

The Big Data era

Big data means (at least) three problems:

1. Big Volume
2. Big Velocity
3. Big Variety



Data-intensive vs. Compute-intensive

Data-intensive application:
  data (the quantity, the speed at which it is changing, the variety) is the primary challenge

Compute-intensive application:
  CPU is the bottleneck

A tale of two worlds

Now a step back into the state of the art

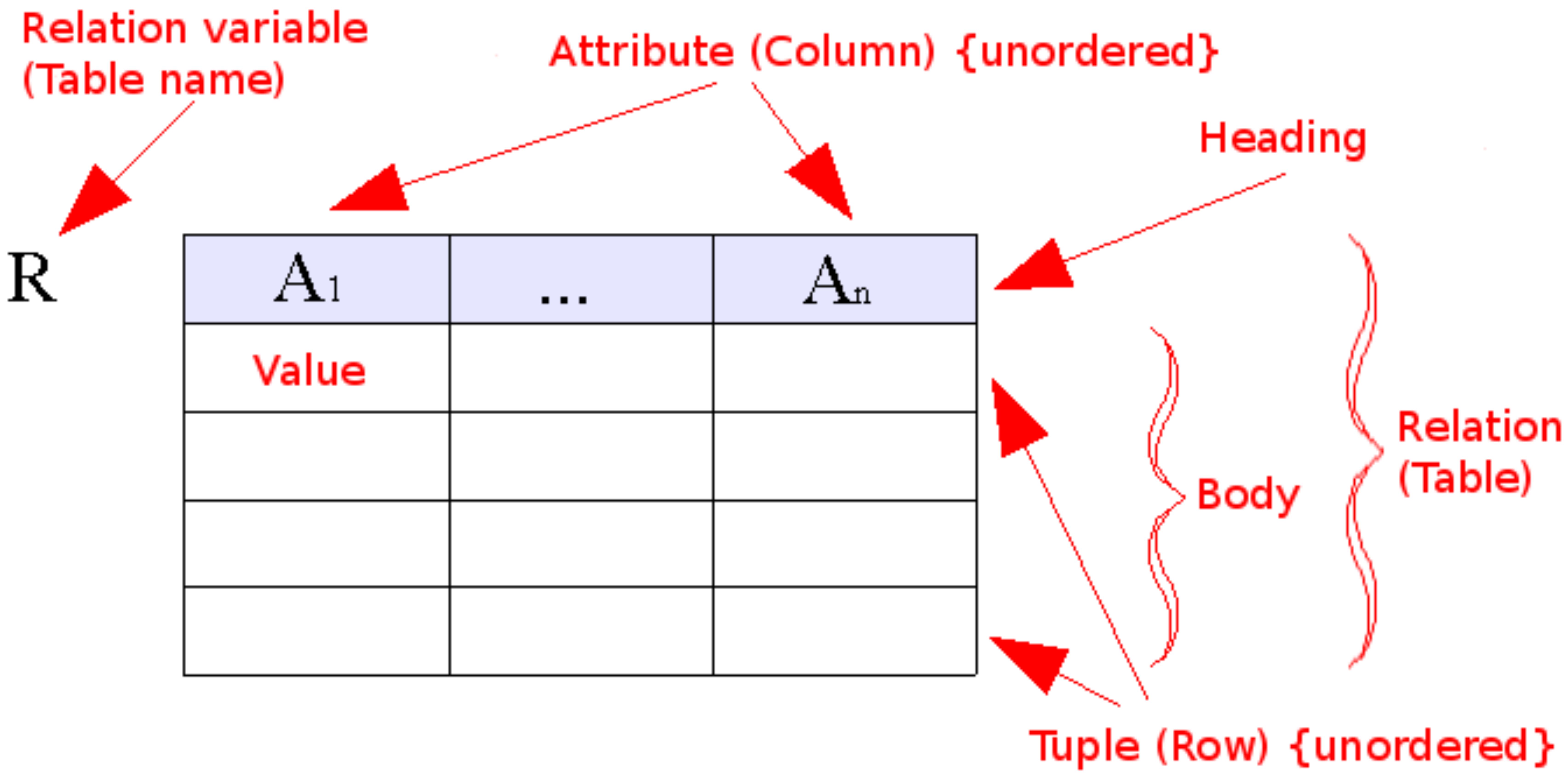
Two main areas:

- Database research area
- Distributed systems research area

Database basics

- Collection of data
- Software used to manage databases is called Database Management System (DBMS)
- The first data model was the relational model

Relational model

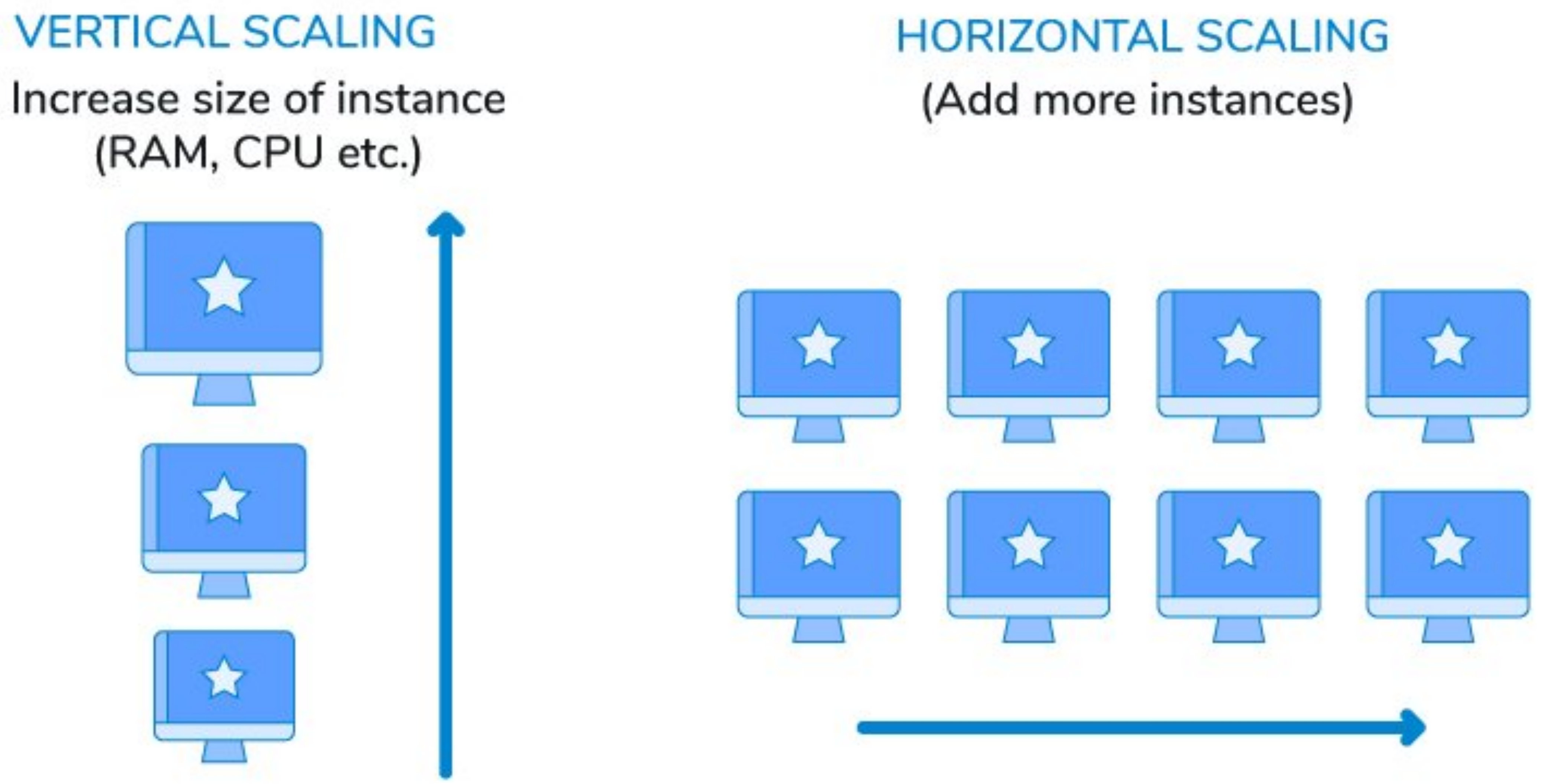


Transactions

- Classical DBMSs usually support transactions
- A transaction is a unit of work that must be Atomic, Consistent, Isolated and Durable (ACID)
- On-line Transaction Processing (OLTP) is a scenario where a database is used mainly for processing multiple transactions
- The transaction management can be a bottleneck when implemented in data-intensive systems

Issues with early databases

- Classical solutions (Oracle, MySQL) were not good at “horizontal” scaling



- A new type of systems called NoSQL started to gain relevance in the 2000s

Image from:https://www.redswitches.com/hs-fs/hubfs/scaling-image.jpg?width=1580&name=scaling-image.jpg

NoSQL

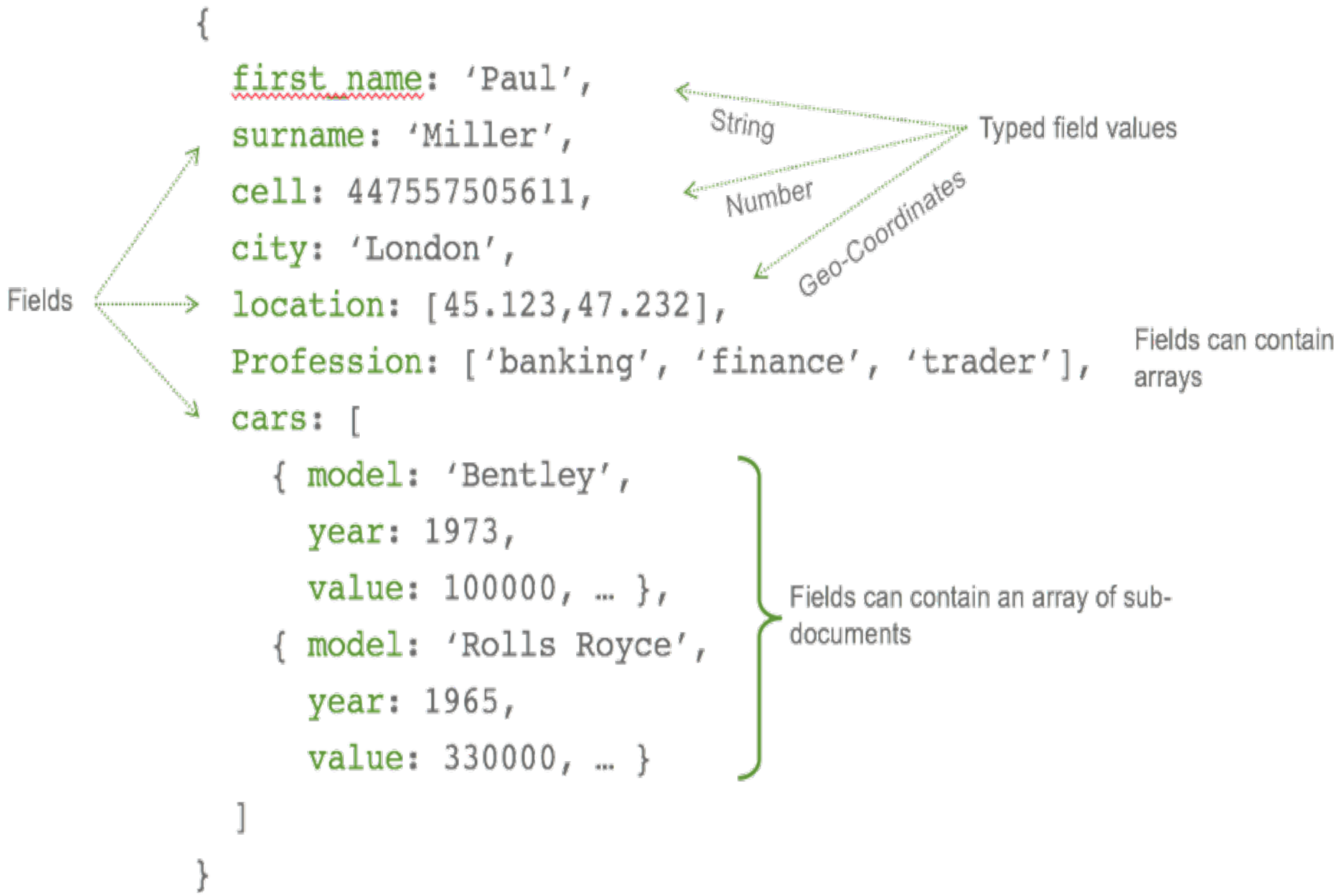
NoSQL started for data-intensive needs – Volume, Variety

Usually a NoSQL database is:

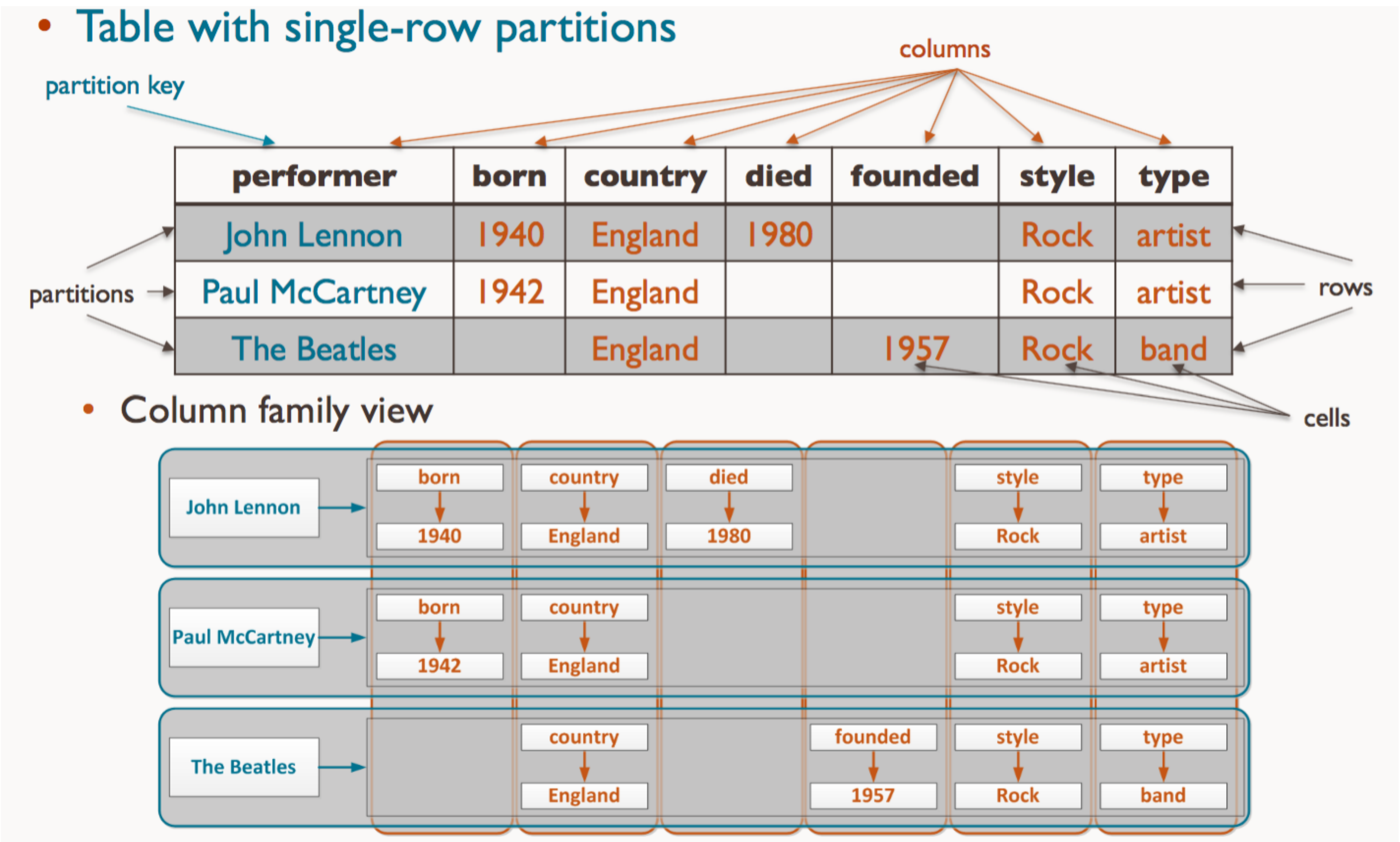
- non-relational
- distributed
- open-source
- horizontally scalable

NoSQL data models

- NoSQL is an inherently heterogeneous category



Document data model (e.g. MongoDB)



Wide column data model (e.g. Cassandra)

Images from https://studio3t.com/knowledge-base/articles/nosql-database-types/#key-value-data-store

NoSQL issues

- NoSQL systems are valuable tools, especially for data-intensive requirements
- Though they have a big flaw: lack of support for full ACID transactions
- And OLTP market is still relevant

NewSQL

- The solution for scalable OLTP scenarios: NewSQL
- They try to make scalable as much as possible the traditional relational systems, while preserving all their guarantees
- Different approaches were adopted to implement transactions with strong consistency and isolation with sufficient performance and availability

NewSQL approaches

- Synchronization based on specialized hardware like atomic clocks, adopted by Google Spanner
- Limit transaction expressivity, adopted by Calvin
- Using information on replication provided explicitly by the user the to optimize transactions in distributed settings, adopted by VoltDB

A tale of two worlds

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MapReduce

- In Distributed Systems research, systems explicitly designed for distributed processing in large-scale compute infrastructures started to gain popularity
- These systems trace their roots to Google's programming model called MapReduce (2004)

MR fundamentals

- The computation is split into two phases, Map and Reduce
- **Map** processes individual elements
  For each of them outputs one or more <key, value> pairs
- **Reduce** processes all the values with the same key and outputs a value
- The runtime system controls scheduling, load balancing, communication, fault tolerance

From the slides of A. Margara from Distributed Systems course

MR word count example

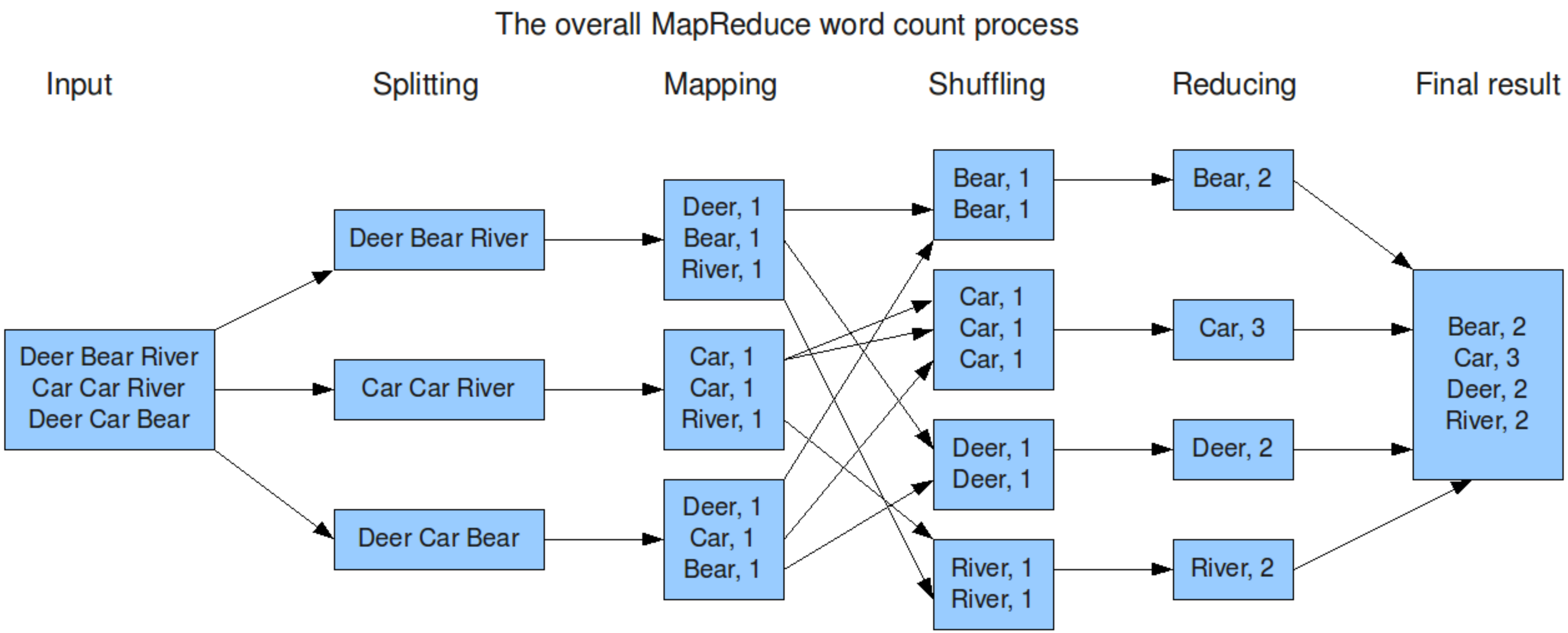


Image from: https://blog.trifork.com/wp-content/uploads/2009/08/MapReduceWordCountOverview1.png

Beyond MapReduce

In the last decade, many systems extended and improved the MapReduce abstraction in many ways

- From two processing steps to arbitrary acyclic graphs of transformations
- From batch processing to stream processing
- From disk to main-memory or hybrid approaches

Examples:

- Apache Spark for batch processing
- Apache Flink for stream processing

Batch processing - Spark

- Similar to MapReduce
  - Instead of only two stages (map and reduce) …
  - … arbitrary number of stages
- Intermediate results can be cached in main memory if they are reused multiple times
- Scheduling of tasks (stages) ensures that the computation takes place close to the data

From the slides of A. Margara from Distributed Systems course

Stream processing - Flink

- A job is not split into stages that are scheduled
- Instead, all the operators are instantiated as soon as the job is submitted
    - They communicate using TCP channels
    - An operator can start processing as soon as it has some data available from the previous ones
        - Pipeline architecture where multiple operators are simultaneously running

From the slides of A. Margara from Distributed Systems course

Data-intensive issues

- The presented data systems –relational DB, NoSQL, NewSQL, MR, batch/stream processing– offer solutions to solve specific data processing and management tasks
- But often requirements of a data-intensive application can be heterogeneous
- Therefore they cannot be satisfied by any of these systems alone

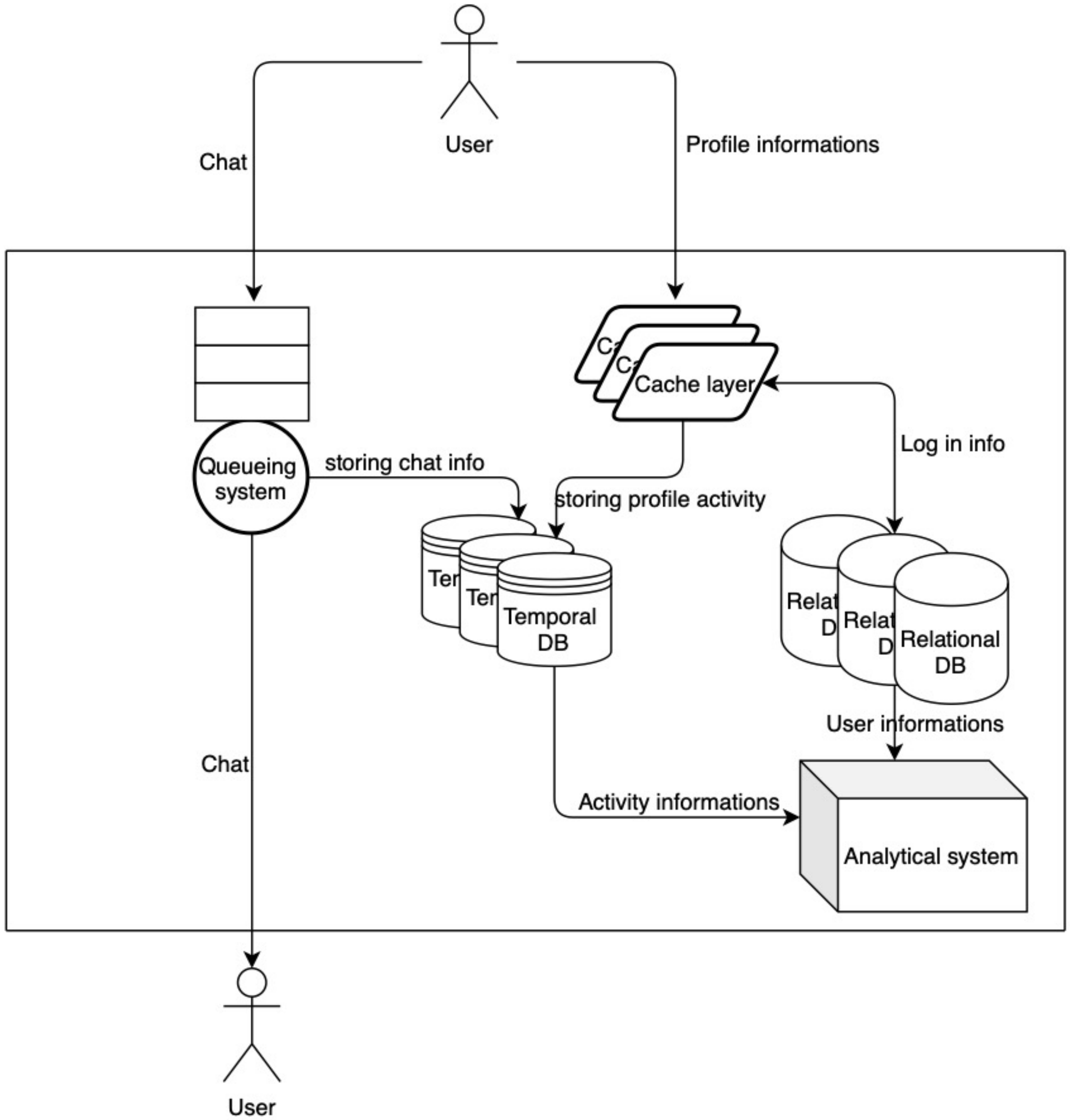
Current approach

- Developers in practice build complex architectures that combine multiple systems
- They implement application logic in order to orchestrate their interaction

Current problems

- In doing so, they lose the benefits provided by the systems in terms of guarantees on the data and transparent deployment and communication
- Also, integrating data systems together necessitates a deep understanding of:
    - Semantics
    - Workload assumptions
    - Performance characteristics
    - Deployment strategies
    - Configuration opportunities

An online collaboration tool example



Developers need to :

- configure individual subsystems
- manually integrate the subsystems
- implement the mechanisms that ensure correctness criteria (profile information is consistent across replicas, temporal database and the queuing system have consistent order of messages, …)
- Take care of performance concerns

A unifying model

- The goal of the research is finding a formal model that defines high-level notions and structures

- The purpose is twofold:

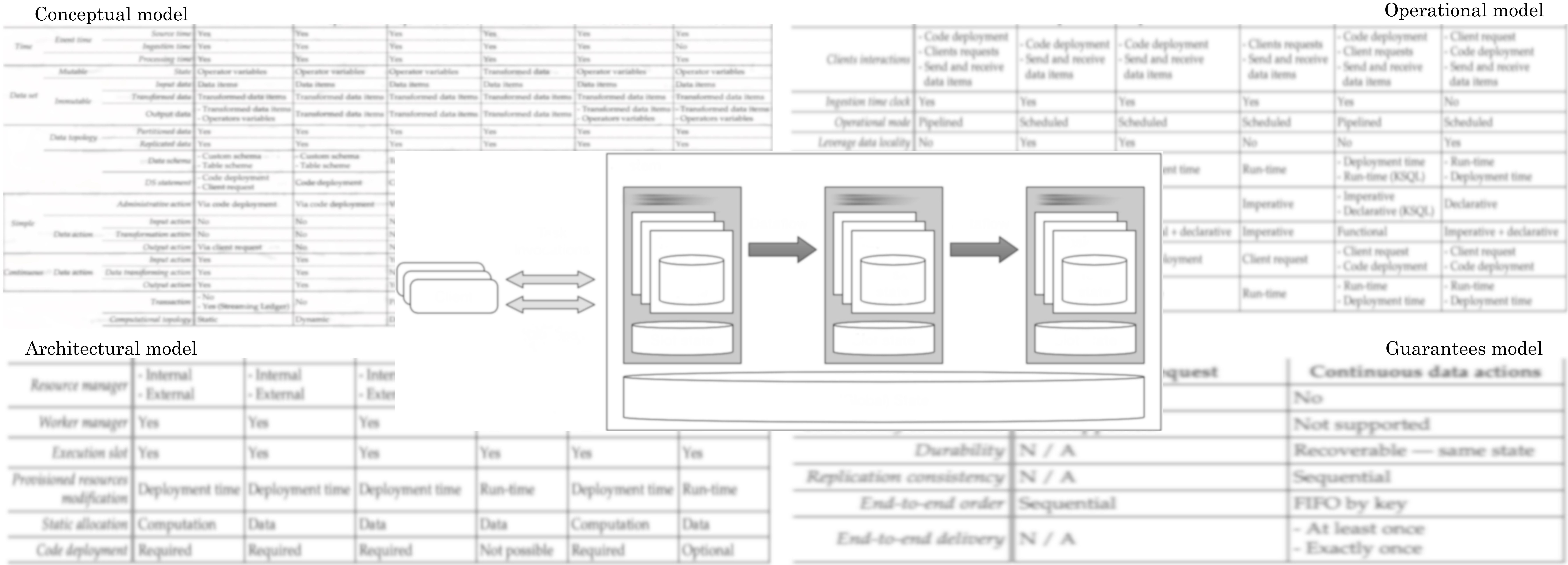
1. the various data-intensive systems usually present intersections among them, therefore a unifying model can be useful to better understand the semantics of the converging concepts of different systems

2. this modeling framework can be a first fundamental step in the direction of a change of paradigm, that leads to a new approach for designing data-intensive application

A unifying model

- In this way, developers no more have to deal with trying to put different and independently developed systems together in a sort of "software collage", where the formal guarantees provided by the single systems could be lost.

A unifying model



Research activity

1. Scope definition

Research activity

1. Scope definition
2. Systems identification and classification

VOLTDB

Flink

cassandra

mongoDB®

APACHE Spark™

Research activity

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3. Preliminary study of the tools

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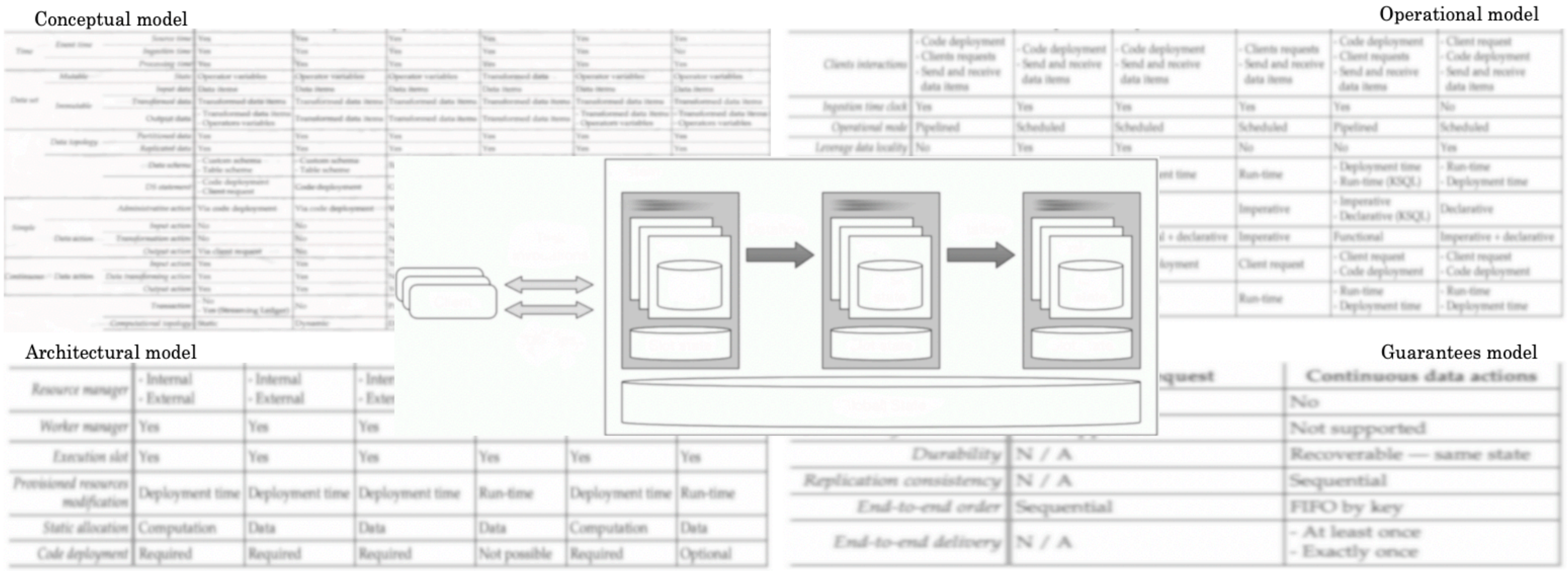
4. First model



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5. Experiments and consolidated model (iterative task)

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5. Experiments and consolidated model (iterative task)
6. Writing

Research activity