Evolution of Relational Databases, NoSQL and Graph Databases

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Motivation

Databases are

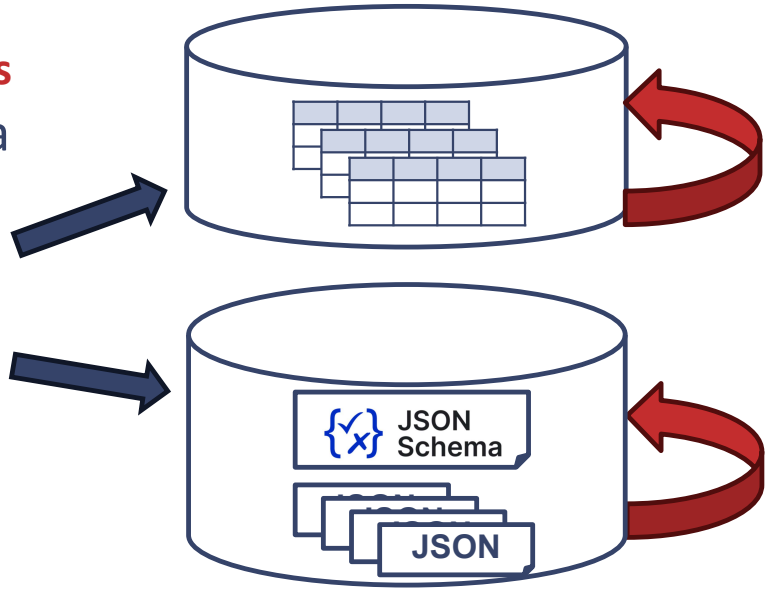
- the **backend** of most **Software Architectures** and **SLPs**
- **Software evolution** also triggers the **evolution of databases**

Database evolution is the **continuous change** of data structures

- in **relational database**: ALTER TABLE statements as part of SQL/DDL standard
- in **NoSQL databases (JSON, Graph)**: evolution methods are still under development

In this talk:

Handling of **Evolution** in the different **database management systems**



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Motivation, cont.

In **Software Product Lines**:

- **Variability** plays an import role and is the key concept in every subtask

In **Relational Databases Management Systems**:

- **Variability of Databases** is not a main concept but is only achieved in a subsequent step

NoSQL database systems:

- are usually **schema-less** (or can be used without schema)
- allow variability in data
- Methods how to **control variability** needed

In this talk:

Variability in the different database management

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Structure of this Talk

1. **Evolution of Relational Databases**
   1. Design vs. Evolution
   2. Capacity and Information Change of Evolution Operations
   3. Single-table and Multi-table Evolution Operations
   4. Schema Matching for deriving Evolution Operations
   5. Evolution Pattern
2. Developing **variable relational databases**
   1. View concept
   2. Using Views for Evolution
3. **Evolution of NoSQL Databases**
   1. Heterogeneity in NoSQL Databases
   2. Schemas for NoSQL Databases -- **Taming variable Non-relational Database**
   3. Reverse Engineering: Schema Extraction
   4. Evolution Operations for heterogeneous data

all parts with Take-Away Messages

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1. Database Evolution

"… software aging can, and will occur in all successful products" *(David Parnas, 1994)*

- SPLs have addressed this problem: built-in change
- and in **databases**?

Definition of Schema Evolution in Databases:

> Schema evolution deals with the need to **retain current data** when **database schema changes** are performed. Formally, Schema Evolution is accommodated when a database system facilitates database **schema modification without the loss of existing data** … *(John F. Roddick)*

Parnas, David. (1994). Software aging. **Proceedings - International Conference on Software Engineering,** 279-287. 10.1109/ICSE.1994.296790

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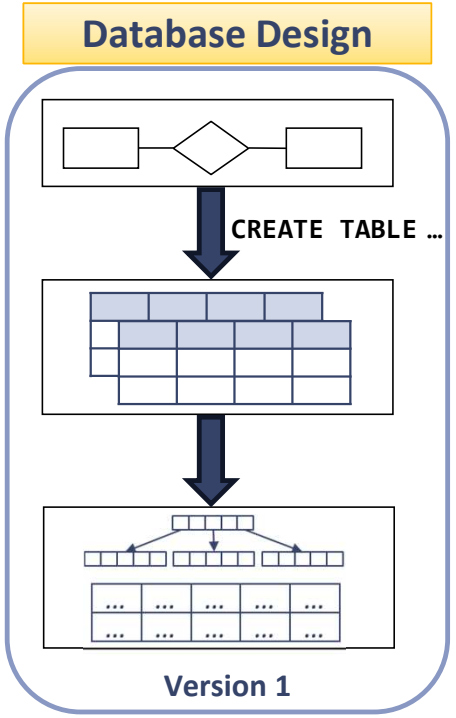
1.1. Design of Relational Databases

- Database design usually starts with a **conceptual model** (Entity-Relationship Model, UML class diagram)
- Rules to translate Entity Relationship Models into **relations**
- **Internal** optimal data storage

*(This process is taught in each **DB1 lecture** and is frequently **used in practice**.)*



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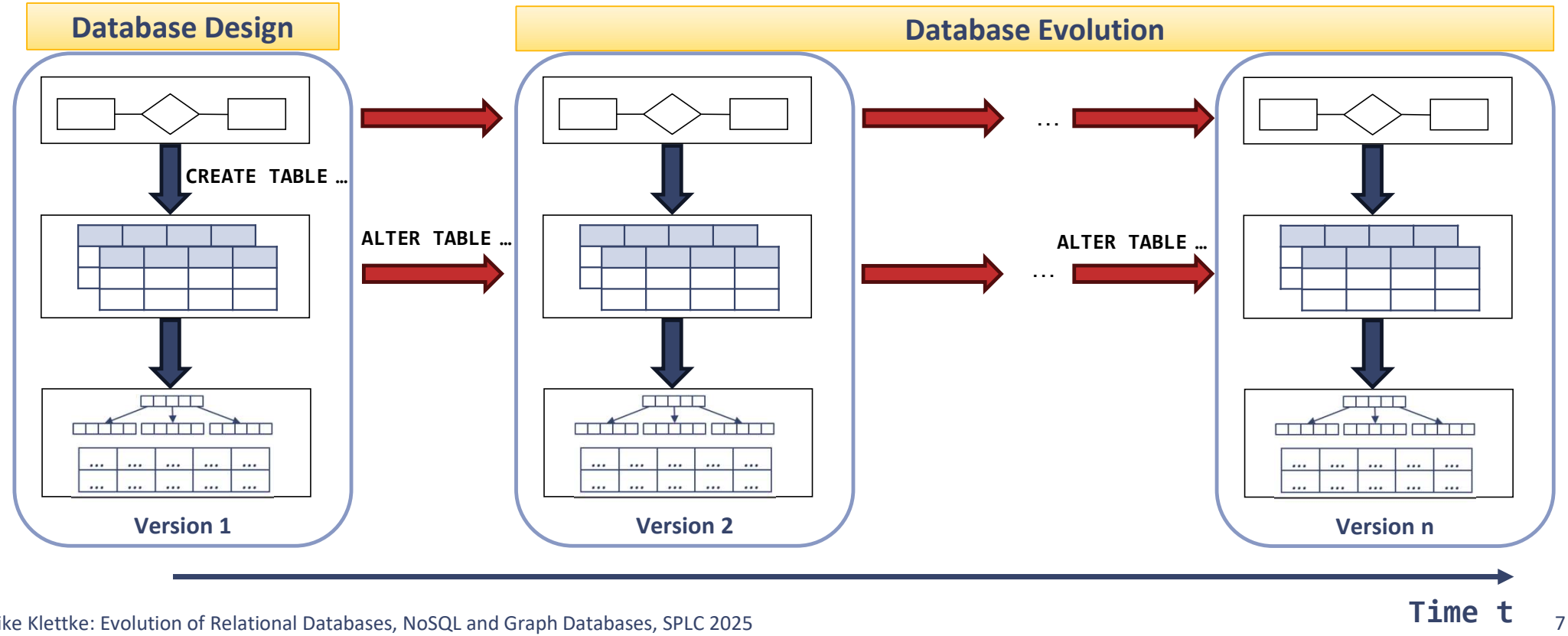
1.1. Database Design and Database Evolution in Theory



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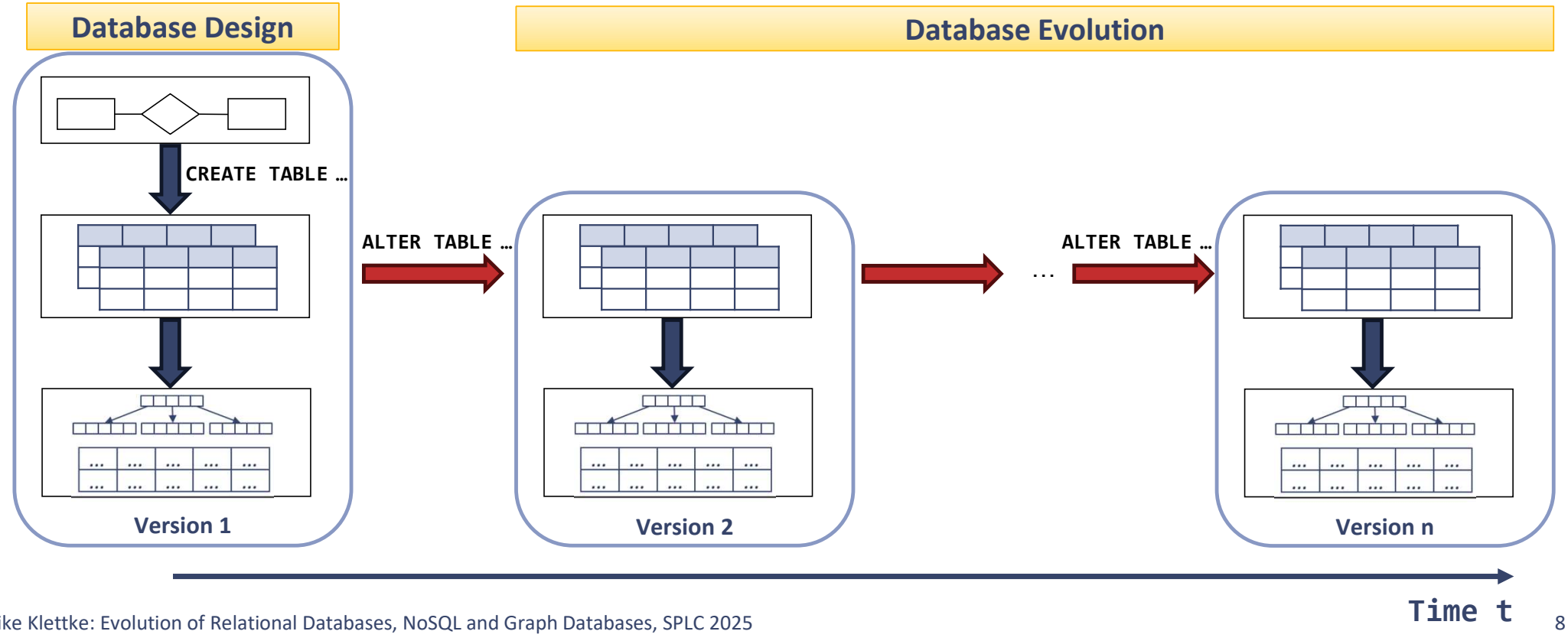
1.1. Database Design and Database Evolution in Practice



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1.1. Schema Evolution of Relational Database

In relational database systems:

- operations to **extend or modify relations** and **database constraints**
- specify the **operations** on the **logical level**
- standardized in the Data Definition Language (**SQL/DDL**) for relational databases
  → in all database management systems available in similar form

The evolution operations change
- the **schema** (also in the database catalogues)
- the **data values accordingly**

Data always fulfil the schema constraints:
- **defined structure** (attribute names, data types, not null constraints) and
- semantic constraints (key, foreign key)

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1.1. Schema Evolution of Relational Database

Evolution Operations for:

- **Attributes** (add column, rename, change column definition, drop column)

```
ALTER TABLE table_name …
        … ADD COLUMN column_name column_definition
        … ALTER COLUMN column_name column_definition
        … RENAME COLUMN column_name TO new_column_name
        … DROP COLUMN column_name
```

- **Constraints** (add or change constraints)

```
ALTER TABLE table_name …
        … ADD CONSTRAINT constraint_name UNIQUE(attribute(s))
        … ADD FOREIGN KEY (attribute)
              REFERENCES table_name(attribute_name)
        … DROP CONSTRAINT constraint_name
```

- **Tables** (rename tables)

```
ALTER TABLE table_name RENAME TO new_table_name
```

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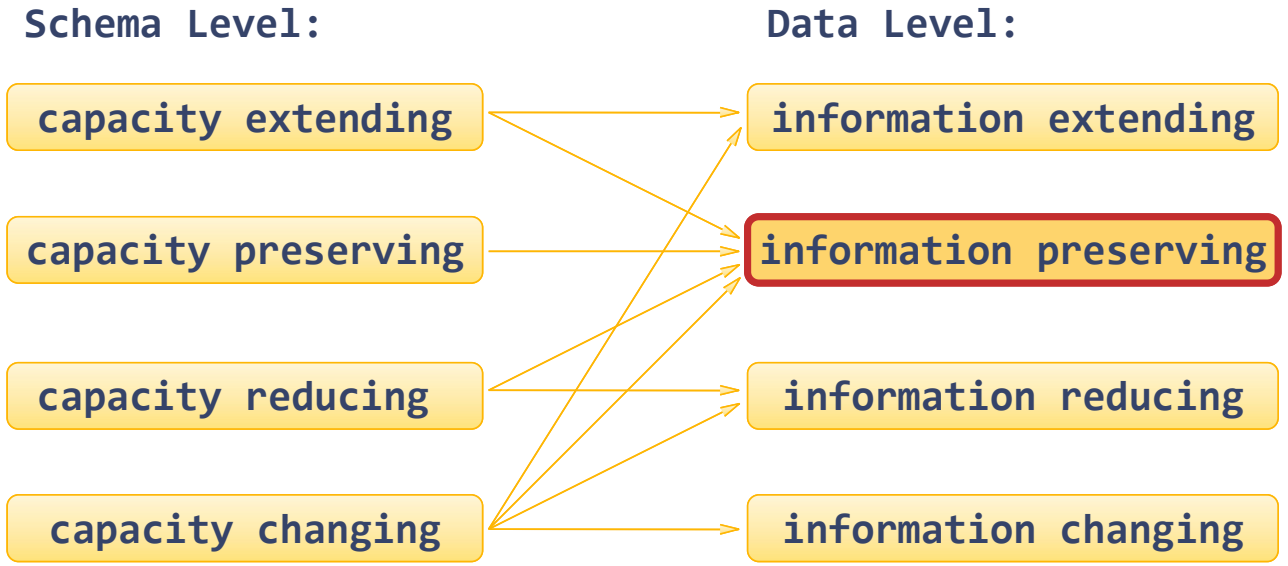
1.2. Characteristics of Evolution Operations

Evolution Operations change:

- the **capacity** of a database (ability to store data) and
- the **information content** of a database

Evolution operations that are **information preserving** guarantee

- old versions can be kept in the databases without changes
- forward compatibility



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1.3. Single-table and Multi-table Evolution Operations

- Single-table Evolution Operations:
  - `add`
  - `delete`
  - `rename`
  - `change`

  } part of the **SQL/DDL standard** (and available in all systems)

- Multi-table Evolution Operations:
  - `split`
  - `merge`
  - `move`
  - `copy`

  } need additional data **migration scripts** or transactions consisting of **several transformation steps**

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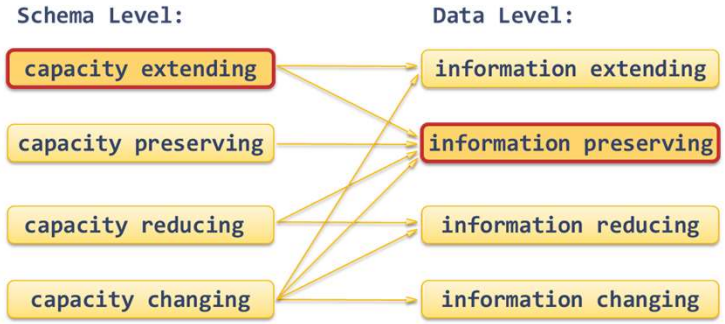
1.3. Relational Evolution Operations Single-table Operations



DDL evolution operations

- support **information preserving operations**
- prevents **information reducing, information changing, information extending** operations

Examples for **capacity extending/ information preserving operation**:

```
ALTER TABLE table_name ADD new_column datatype default
```

e.g.

```
ALTER TABLE T ADD E VARCHAR(10) NULL
```

T:

A	B	C	D	E
a1	b1	c1	d1	NULL
a2	b2	c2	d2	NULL

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1.3. Relational Evolution Operations Single-table Operations

Capacity extending/ information extending

evolution operation:

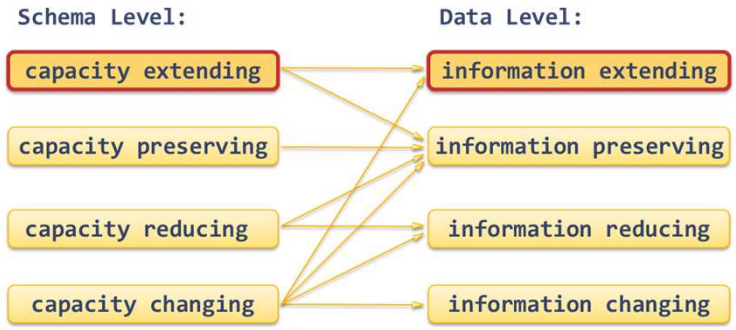
```
ALTER TABLE T ADD new_column VARCHAR(10) NOT NULL
```

Stepwise workaround:

```
ALTER TABLE T ADD E INT NULL;
```

```
UPDATE T
SET E = '…'
WHERE …;
```

```
ALTER TABLE T ALTER COLUMN E INT NOT NULL;
```



T:

A	B	C	D	E
a1	b1	c1	d1	NULL
a2	b2	c2	d2	NULL

← Null values allowed

T:

A	B	C	D	E
a1	b1	c1	d1	e1
a2	b2	c2	d2	e2

← Null values allowed

T:

A	B	C	D	E
a1	b1	c1	d1	e1
a2	b2	c2	d2	e2

← **NOT NULL** constraint

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1.3. Relational Evolution Operations
Multi-table Operations

Database in Version 1:

CID	Name	First Name	City	ProductID	Amount	ProductName	Product Price	Total Price	OrderDate	PaymentDate
C019	García	Ana	Madrid	P1001	2	Router X2000	89.99	179.98	2025-08-29	2025-08-31
C132	Martínez	Luis	Barcelona	P3400	10	Presenter	19,95	199.50	2025-08-30	2025-08-30
C004	Fernández	Maria	A Coruna	P1120	1	WiFi Access Point	59.90	59.90	2025-08-30	2025-09-01
C004	Fernández	Maria	A Coruna	P4001	1	Notebook	998.00	998.00	2025-08-20	NULL
C132	Martínez	Luis	Barcelona	P1120	1	WiFi Access Point	59.90	59.90	2025-07-20	NULL

Evolution Operation (split):

```
split Orders into
Customer(CID, Name, FirstName, City),
Products (ProductID, ProductName, ProductPrice),
Orders (CID, ProductID, Amount, TotalPrice, OrderDate, PaymentDate)
```

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1.3. Relational Evolution Operations
Multi-table Operations

Step 1:

- **create table** Customers
- **insert data** (without duplicates)

```
CREATE TABLE Customers (
    CustomerID VARCHAR(10) PRIMARY KEY,
    Name VARCHAR(50),
    FirstName VARCHAR(50),
    City VARCHAR(50)
);

INSERT INTO Customers (CustomerID, Name, FirstName, City)
SELECT DISTINCT(CustomerID, Name, FirstName, City)
FROM Orders;
```

Customer ID	Name	FirstName	City
C019	García	Ana	Madrid
C132	Martínez	Luis	Barcelona
C004	Fernández	Maria	A Coruna

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1.3. Relational Evolution Operations
Multi-table Operations

Step 2:

- **create table** Products
- **insert data** (without duplicates)

```
CREATE TABLE Products (
    ProductID VARCHAR(10) PRIMARY KEY,
    ProductName VARCHAR(100),
    ProductPrice DECIMAL(10,2)
);

INSERT INTO Products (ProductID, ProductName, ProductPrice)
SELECT DISTINCT(ProductID, ProductName, ProductPrice)
FROM Orders;
```

ProductID	ProductName	ProductPrice
P1001	Router X2000	89.99
P3400	Presenter	19.95
P1120	WiFi Access Point	59.90
P4001	Notebook	998.00

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1.3. Relational Evolution Operations
Multi-table Operations

Step 3:

- **delete attributes from table** Orders
- define new **foreign key constraints**

```
ALTER TABLE Orders DROP COLUMN Name,
                   DROP COLUMN FirstName,
                   DROP COLUMN City,
                   DROP COLUMN ProductName,
                   DROP COLUMN ProductPrice;
```

Customer ID	Product ID	Amount	Total Price	OrderDate	PaymentDate
C019	P1001	2	179.98	2025-08-29	2025-08-31
C132	P3400	10	199.50	2025-08-30	2025-08-30
C004	P1120	1	59.90	2025-08-30	2025-09-01
C004	P4001	1	998.00	2025-08-20	NULL
C132	P1120	1	59.90	2025-07-20	NULL

```
ALTER TABLE Orders ADD FOREIGN KEY (CustomerID) REFERENCES Customer(CustomerID),
                   ADD FOREIGN KEY (ProductID) REFERENCES Products(ProductID);
```

Advantages of Evolution Operations in Relational Databases

- Part of the **SQL/ DDL standard** ⇒ available in all relational db systems
- Changes of the **database structure and database constraints** can be defined
- Database management systems **guarantee** that in each evolution step **data consistency**

Limitations of Evolution Operations in Relational Databases

- Evolution operations on the **logical model** (not on the conceptual model)
- Evolution operation **only on one table at a time**
- **Workarounds** needed for
  - information extending, information reducing and information changing operations
  - **complex refactoring (involving two or more tables)**

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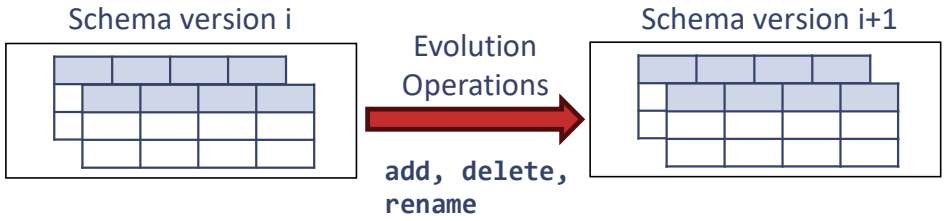
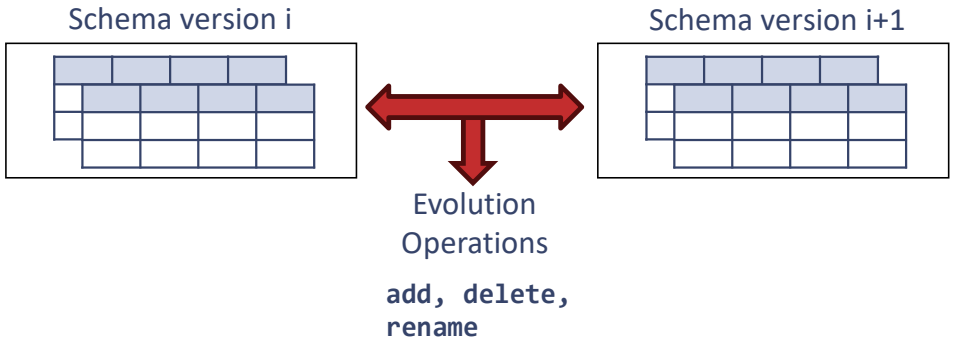
1.4. Evolution Operations vs. Schema Differences

Instead of Schema in version i and Evolution Operations:



If two different schemas are available –
Extraction of evolution operations:

1. **matching** of identical components (with **heuristics**)
2. determining the **differences**
3. deriving **evolution operations**, based on **heuristics**



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1.4. Schema Matching and Mapping in Detail

Step 1: Matching, based on Heuristics

Schema version i

CustomerID	ProductID	Amount	Price	TotalPrice	OrderDate	PaymentDate
C019	P1001	2	89.99	179.98	2025-08-29	2025-08-31
C132	P3400	10	19.95	199.50	2025-08-30	2025-08-30
C004	P1120	1	59.90	59.90	2025-08-30	2025-09-01
C004	P4001	1	998.00	998.00	2025-08-20	NULL
C132	P1120	1	59.00	59.90	2025-07-20	NULL

Schema version i+1

CustomerID	ProductID	Amount	OrderDate	PaymentID

PaymentID	Date	TotalSum	CreditcardNo	SecurityCode

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1.4. Schema Matching and Mapping in Detail

Step 1: Matching, based on Heuristics

Schema version i

CustomerID	ProductID	Amount	Price	TotalPrice	OrderDate	PaymentDate
C019	P1001	2	89.99	179.98	2025-08-29	2025-08-31
C132	P3400	10	19.95	199.50	2025-08-30	2025-08-30
C004	P1120	1	59.90	59.90	2025-08-30	2025-09-01
C004	P4001	1	998.00	998.00	2025-08-20	NULL
C132	P1120	1	59.00	59.90	2025-07-20	NULL

Schema version i+1

CustomerID	ProductID	Amount	OrderDate	PaymentID

PaymentID	Date	TotalSum	CreditcardNo	SecurityCode

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1.4. Schema Matching and Mapping in Detail

Step 2: Identification of differences, missing and additional parts

Schema version i

CustomerID	ProductID	Amount	Price	TotalPrice	OrderDate	PaymentDate
C019	P1001	2	89.99	179.98	2025-08-29	2025-08-31
C132	P3400	10	19.95	199.50	2025-08-30	2025-08-30
C004	P1120	1	59.90	59.90	2025-08-30	2025-09-01
C004	P4001	1	998.00	998.00	2025-08-20	NULL
C132	P1120	1	59.00	59.90	2025-07-20	NULL

Schema version i+1

CustomerID	ProductID	Amount	OrderDate	PaymentID

PaymentID	Date	TotalSum	CreditcardNo	SecurityCode

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1.4. Schema Matching and Mapping in Detail

Step 3: Deriving evolution operations, e.g.

```
delete T.Price
split T into ...
rename TotalPrice to TotalSum
add T1.PaymentID
add T2.PaymentID
add T2.CreditCardNo
add T2.SecurityCode
```

Schema version i

CustomerID	ProductID	Amount	Price	TotalPrice	OrderDate	PaymentDate
C019	P1001	2	89.99	179.98	2025-08-29	2025-08-31
C132	P3400	10	19.95	199.50	2025-08-30	2025-08-30
C004	P1120	1	59.90	59.90	2025-08-30	2025-09-01
C004	P4001	1	998.00	998.00	2025-08-20	NULL
C132	P1120	1	59.00	59.90	2025-07-20	NULL

CustomerID	ProductID	Amount	OrderDate	PaymentID

PaymentID	Date	TotalSum	CreditCardNo	SecurityCode

Evolution Operations vs. Schema Differences

Derving Evolution operations between two different schema versions (i and i+1) needs **heuristics**:

1. **in the matching process** (to identify the identical parts of the schemas)
2. **to derive evolution operations** (based on the differences of the schemas)

Heuristics always means that

- the algorithms can fail
- (do not find the optimal evolution operations)

This method should only be applied if no evolution operations are known

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Take-Away Message 1 (from a SPL perspective)

Important information to **design and evolve databases:**

- **requirements** (entities, relationships, attributes)
- **workloads** (queries, frequency of queries, importance, real-time requirements)
- **sample datasets**

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Take-Away Message 2 (from a SPL perspective)

Evolution is an important problem in database applications:
- **re-design database schemas** and
- **migrate** all **data values** (ideally **information preserving**)

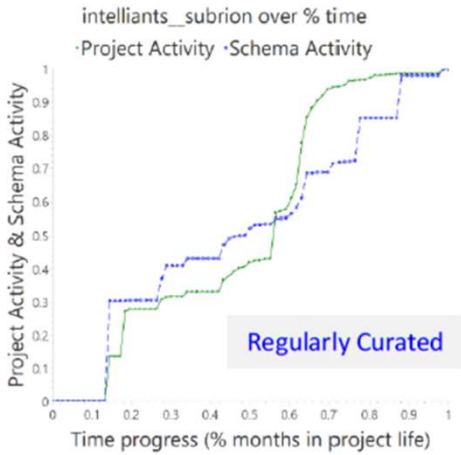
Database Evolution is
- easier to implement when the **evolution operations** are given
- **more complicated** if only **two consecutive schema versions** are known

1.5. Pattern of Evolution

Vassiliadis and Karakasidis compared

- **project change activities** and
- **schema change activities**

They observed: *"Almost 25% (37/151) projects evolve with regular change steps, distributed across time, progressively climbing to the top - band over a long period of time. "*



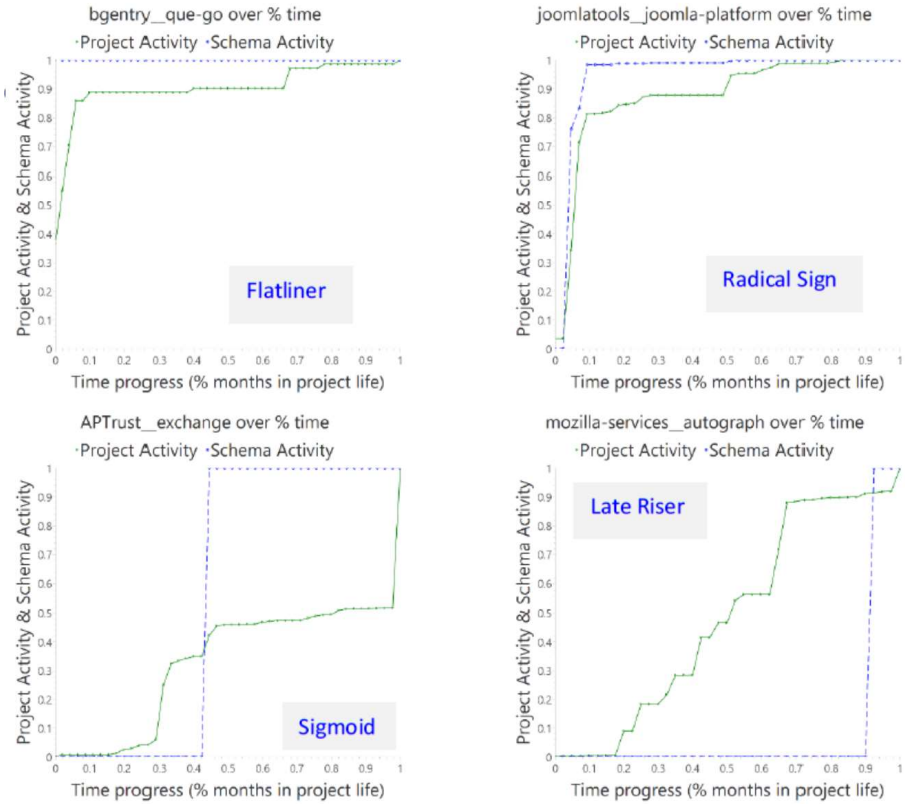
Paper: Panos Vassiliadis, Alexandros Karakasidis:
Time-Related Patterns Of Schema Evolution. 310-323

Source of the figure: https://www.cs.uoi.gr/~pvassil/publications/2025_EDBT/EDBT_2025_TimeEvoPatterns_PresentationLong.pdf

1.5. Pattern of Evolution

But they also noticed an **aversion to change the databases schema**: *"Almost 2/3 of the corpus, 97/151 evolve with very focused change very close to the point of schema birth - the only difference of the involved patterns is when schema birth takes place"*

Paper: Panos Vassiliadis, Alexandros Karakasidis:
Time-Related Patterns Of Schema Evolution. 310-323



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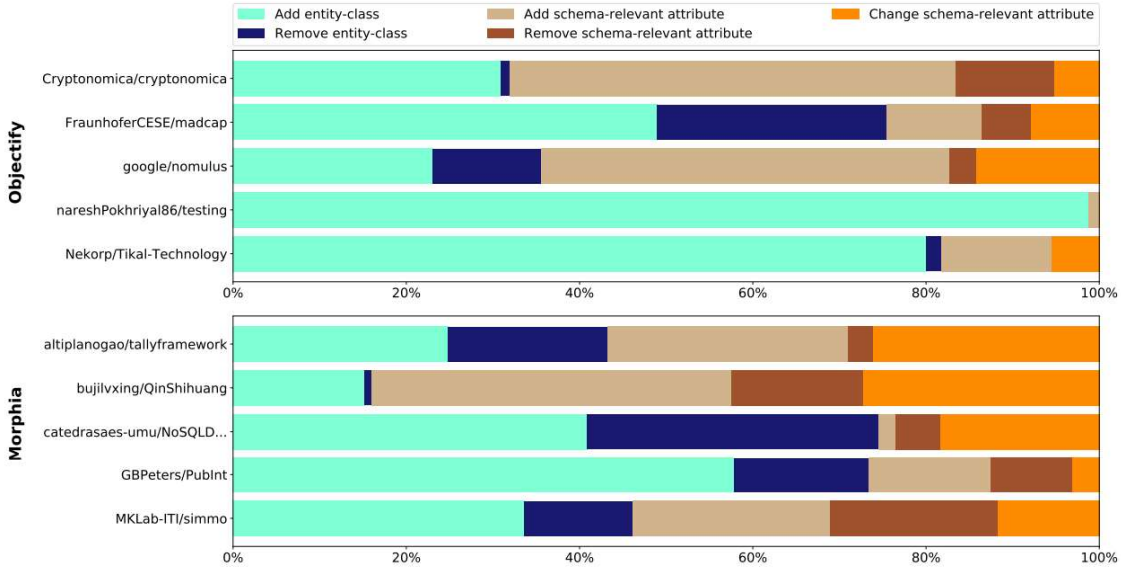
1.5. Evolution Operations in Real-world Projects

- Scherzinger et. al. made several studies on **distribution of evolution operations** for projects with Object-NoSQL mappers (to map Java objects to entities)
- two mappers are compared:
  - Objectify
  - Morphia
- Majority of operations are:
  - **`add entity class`** and
  - **`add attribute`**

Source: Stefanie Scherzinger, Sebastian Sidortschuck: *An Empirical Study on the Design and Evolution of NoSQL Database Schemas,* ER 2020



(a) By project.

	Entity-class add	Entity-class remove	Schema-relevant attribute add	Schema-relevant attribute remove	Schema-relevant attribute change
Objectify	56.3%	8.4%	24.7%	4.0%	6.5%
Morphia	34.5%	16.2%	21.6%	10.4%	17.2%
Overall	34.8%	15.1%	27.3%	7.4%	15.4 %

(b) Objectify-based vs. Morphia-based projects.

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Take-Away Message 3 (from a SPL perspective)

Evolution operations which are **information preserving** have to be preferred. These are ensuring that **data in the previous structural version(s)** can be kept in the database.

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But what about Variability?

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2. Variability

in Software Product Lines

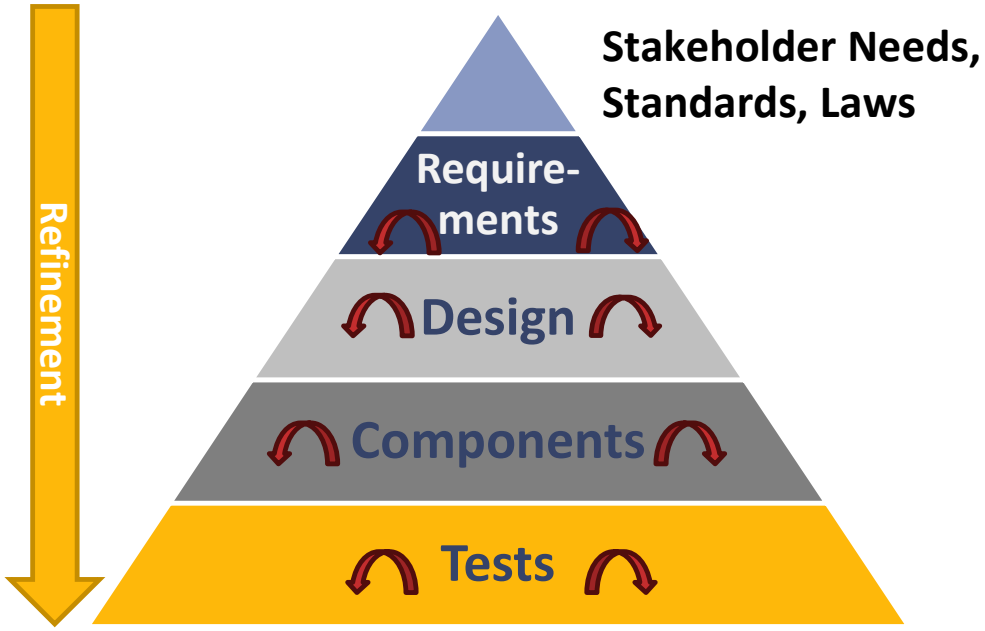
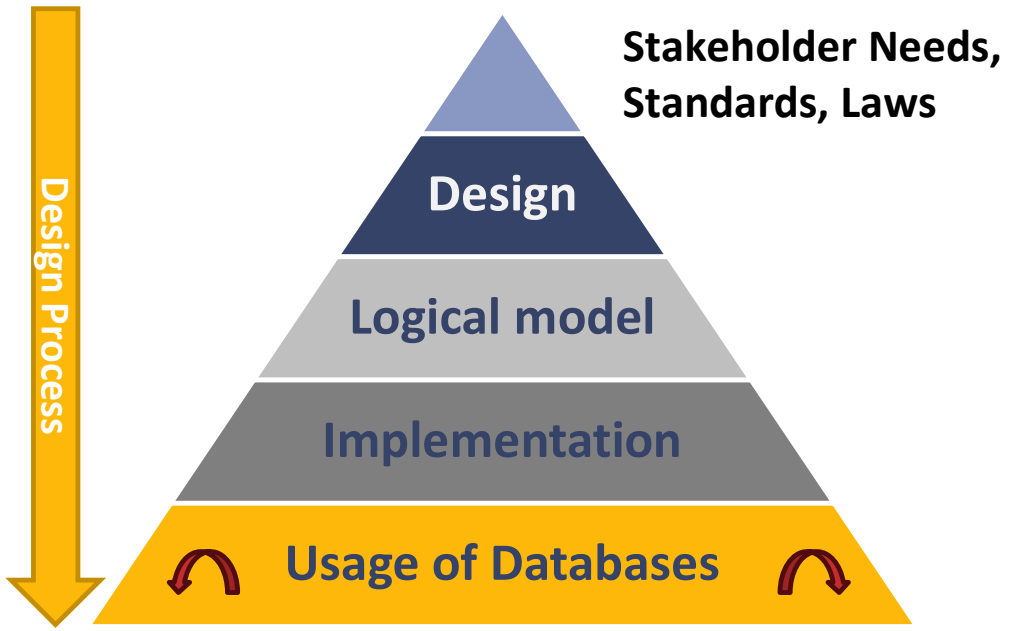


Figure similar in: Pohl, Böckle, van der Linden: Software Product Line Engineering, Springer, 2005

in relational databases



Data Variability is not a priority issue in relational databases.

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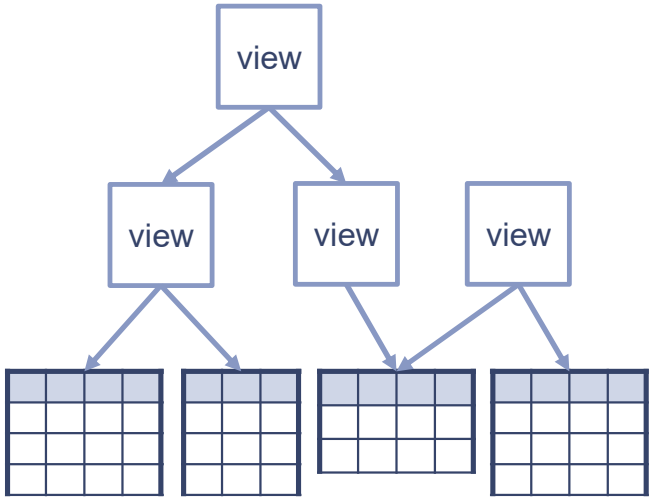
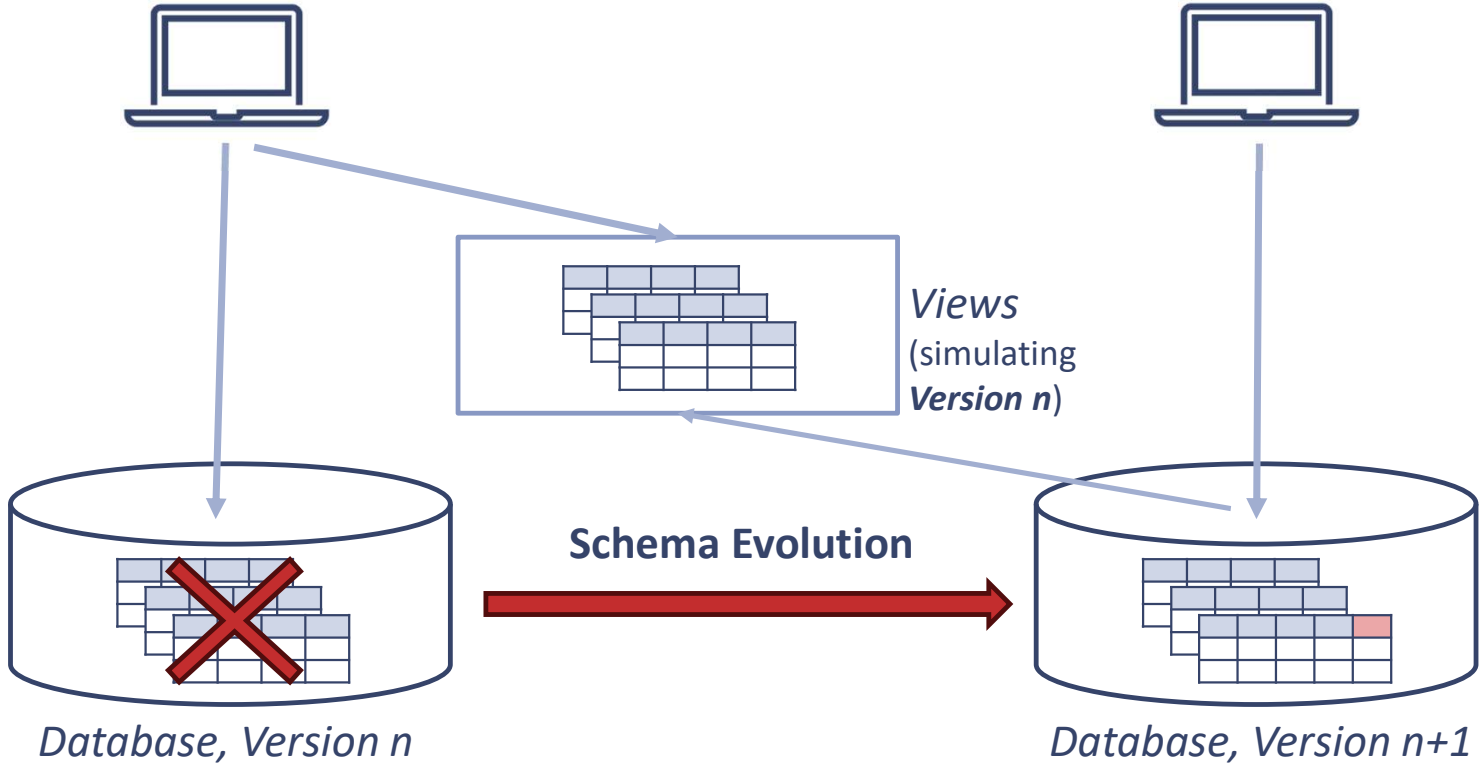
2.1. Views – Database Concept for Handling Variety

- Views and Materialized Views on Tables
- Views are be **created** by using **SQL** statements (with all relational algebra operations):
  - like **selection, projection, join, aggregation, grouping**
- the view concept is often connected with **specific access rights**
- can also be used for modelling different **"database variants"**
  - for different users/user group
  - for different versions
  - for different variants
- **Views on views** are allowed
- Views are resolved during query execution



2.2. Using Views for Handling Database Evolution



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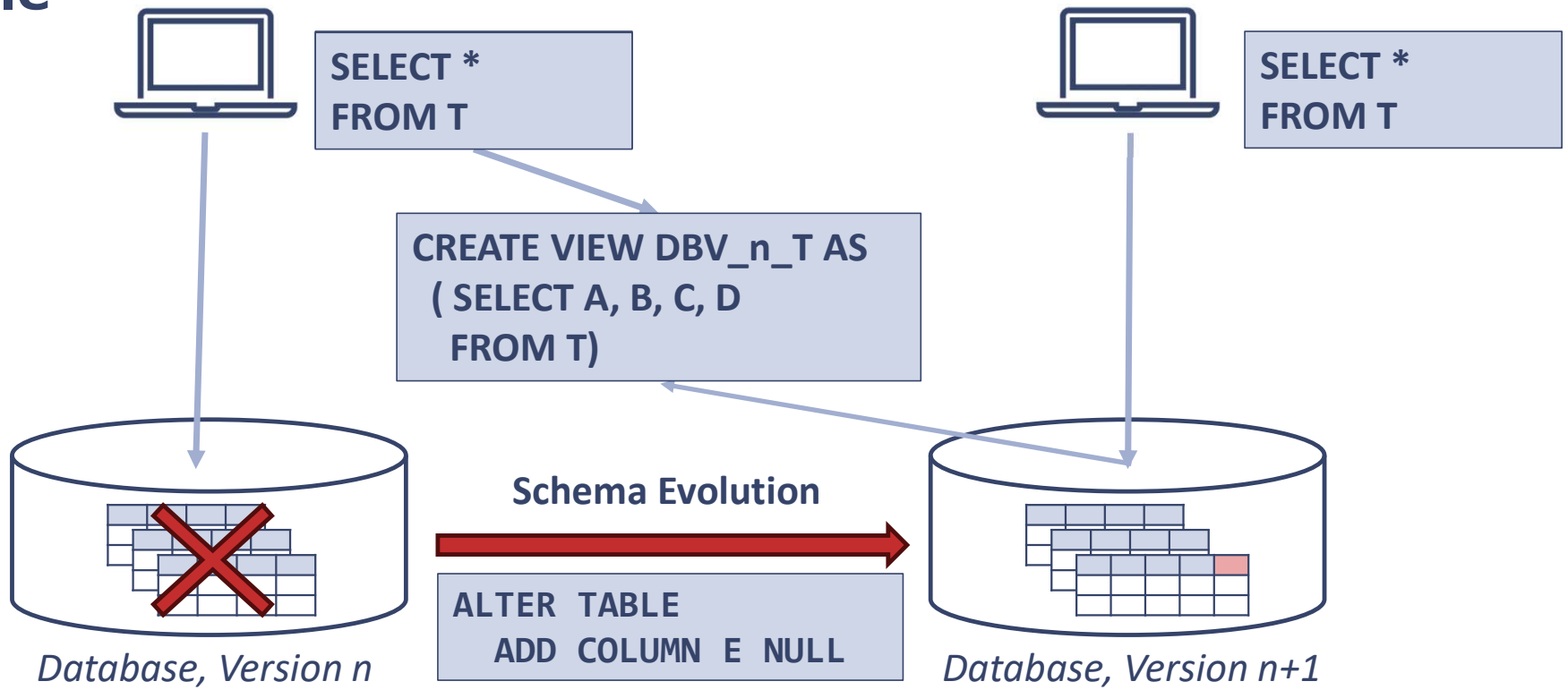
2.2. Using Views for Handling Database Evolution Example



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Take-Away Message 4

The Database View Mechanism can be used for definition of **different variants.**
The usage of the same dataset guarantees data consistency

Variety in Databases is in most cases only the **last step** in the Design process (on relational model)

Take-Away Message 5 (for database researchers)

Why don't we care about Variety in (relational) databases in the complete design process? We should develop models and methods for it !!

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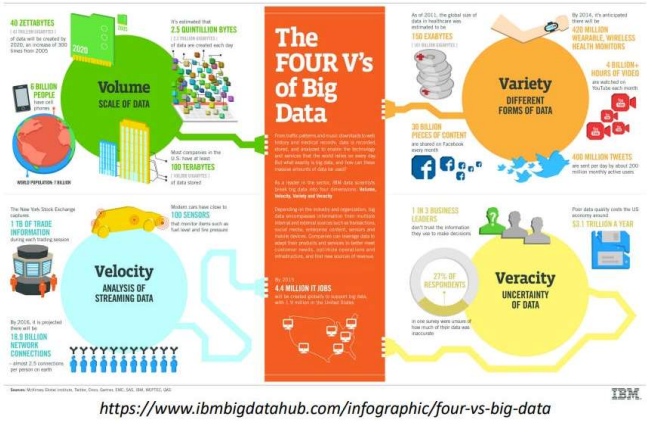
3. Big Data Movement as Driver for the Development of NoSQL databases

The **lack of Variety** was one of the drivers for the development of **NoSQL databases** …

Volume
Scale of data

Velocity
Analysis of streaming data



https://www.ibmbigdatahub.com/infographic/four-vs-big-data

Variety
Different forms of data

Veracity
Uncertainty of data

New Classes of Database Management Systems:

- **key-values** Stores - Redis, Amazon DynamoDB
- **Document Stores (JSON)** - MongoDB
- **Column Families** - Cassandra
- **Graph databases** - Neo4j

3. Main Characteristics of NoSQL databases

1. Non-relational data model
2. Schema less or flexible (optional) schema
3. horizontal scalable

NoSQL databases solve the "**Variability Requirement**" in a very simple way: **no schema constraints at all**

Advantages:

- everything can be stored
- evolution not necessary
- **different schema versions** in the same databases

Disadvantages:

- problems to use the (heterogeneous) data
- **no schema constraints** (**no error detection**)

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3.1. Heterogeneity in NoSQL Database

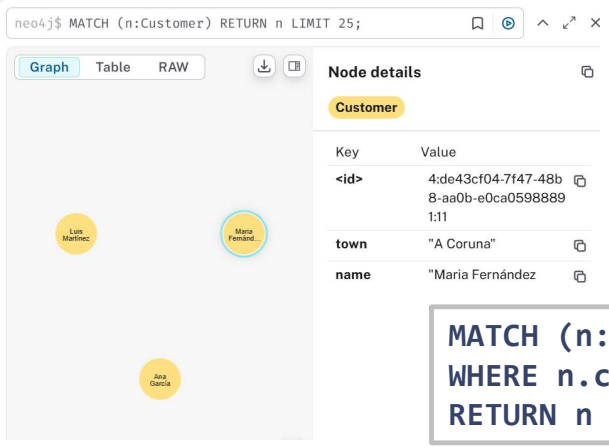
- .. but first, we start with some **unwanted side-effects** of **schema-less systems**
- e.g. **different property names**

```
{  "id": 7,
    "name": "Garcia",
    "firstname":"Ana",
    "address": {
        "city": "A Coruna",
        …
```

```
{  "id": 9,
    "name": "Lopez",
    "firstname":"Maria",
    "address": {
        "town": "A Coruna",
        …
```

Sample query in MongoDB:

```
db.Customer.find(
  { city: "A Coruna" },
  { name: 1, firstname: 1}
)
```



Sample query in Neo4j:

```
MATCH (n:Customer)
WHERE n.city = 'A Coruna'
RETURN n LIMIT 25;
```

These documents are not detected in **queries** (incomplete **selection**, **join** (dangling tuples), **grouping).**

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3.2. Data models and their schemas

Data models for structured data:

Data Model	Schema
Relational model, since 1970	Since 1970

Data models for semi-structured data:

Data Model	Schema
XML, 1998	DTD 1998 XML Schema, 2001
JSON as data model, ~2009 (MongoDB)	JSON schema 2013
Graph data, ~2007 (Neo4j)	Currently not standardized

Semi-structured data models:

- started **schema-less**
- **added schema languages** some years later
- database management systems usually allow **optional** and **partial schema control**

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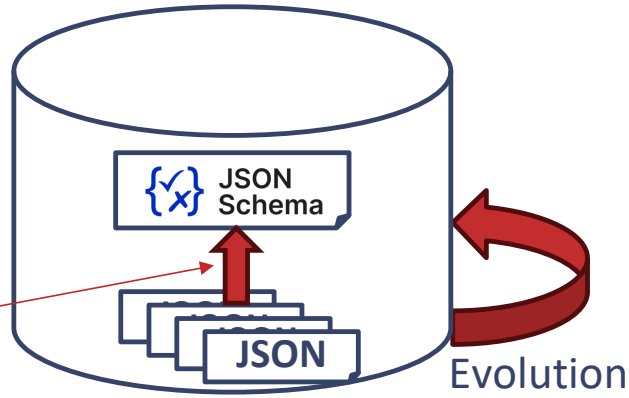
Evolution of NoSQL Databases (JSON, Graph)

- **Data** and their **implicit structures** are also **changing** in schema-less databases
- **Evolution operations are needed** to
  - evolve the schema (if available)
  - adapting the data (data migration)

At least simple evolution operations are needed:
- **`insert, update, delete*`**

If schema not available → **reverse engineering – schema extraction**



*same operations: create, update, delete as in: Maíra Marques, Jocelyn Simmonds, Pedro O. Rossel, María Cecilia Bastarrica: Software product line evolution: A systematic literature review, Information and Software Technology, Volume 105, 2019

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3.2. JSON Schema

- Schema definition for JSON Documents
- in **JSON Syntax**
- contains
  - **property names,**
  - **datatypes,**
  - **constraints**
  - **nesting of objects**

```
{ "$schema": "https://json-schema.org/draft/2020-12/schema",
  "type": "object",
  "properties": {
    "id": {"type": "integer"},
    "name": {"type": "string"},
    "firstname": {"type": "string"},
    "address": {
      "type": "object",
      "properties": {
        "city": {"type": "string"},
        "ZIP": {"type": "integer"},
        "street": {"type": "string"}}},
    "email": {"type": "string"}},
  "required": ["id", "name", "address"],
  "additionalProperties": false
}
```

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3.2. JSON Schema

JSON schema allows:

- **complete schema**
  (structured relational-like datasets)

```
"required": ["id", "name", "address"],
"additionalProperties": false,
```

- definition of **variants**

```
"oneOf" : [{ "required" : ["city"]},
           { "required" : ["state"]}],
```

- **heterogeneity**

```
"required": ["id", "name"],
```

- **extensibility** (definition of a partial schema that can be extended)

```
"additionalProperties": true,
```

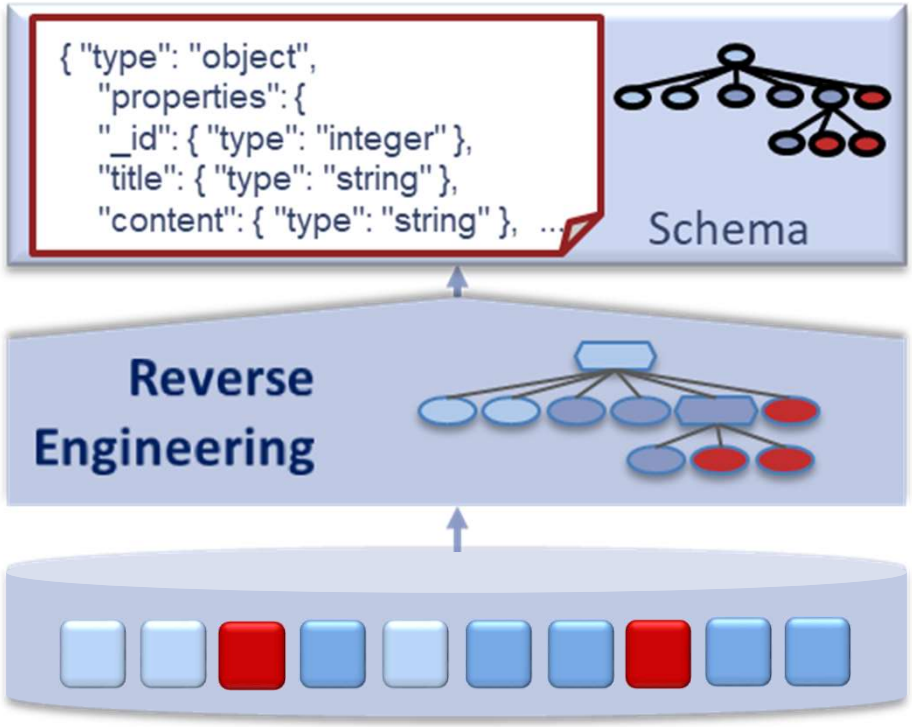
3.3. Schema Extraction

Schema Extraction from JSON databases
(= reverse engineering, data profiling)

- NoSQL database **without explicit schema**
- schema extraction is the first task to **understand** NoSQL databases

Algorithm for Extracting the Schema

- ***Input:*** Set of JSON documents
- ***Method:*** Using an internal **Graph Structure** *(Structure Identification Graph (SG))* to represents the schema
- ***Output:*** JSON schema

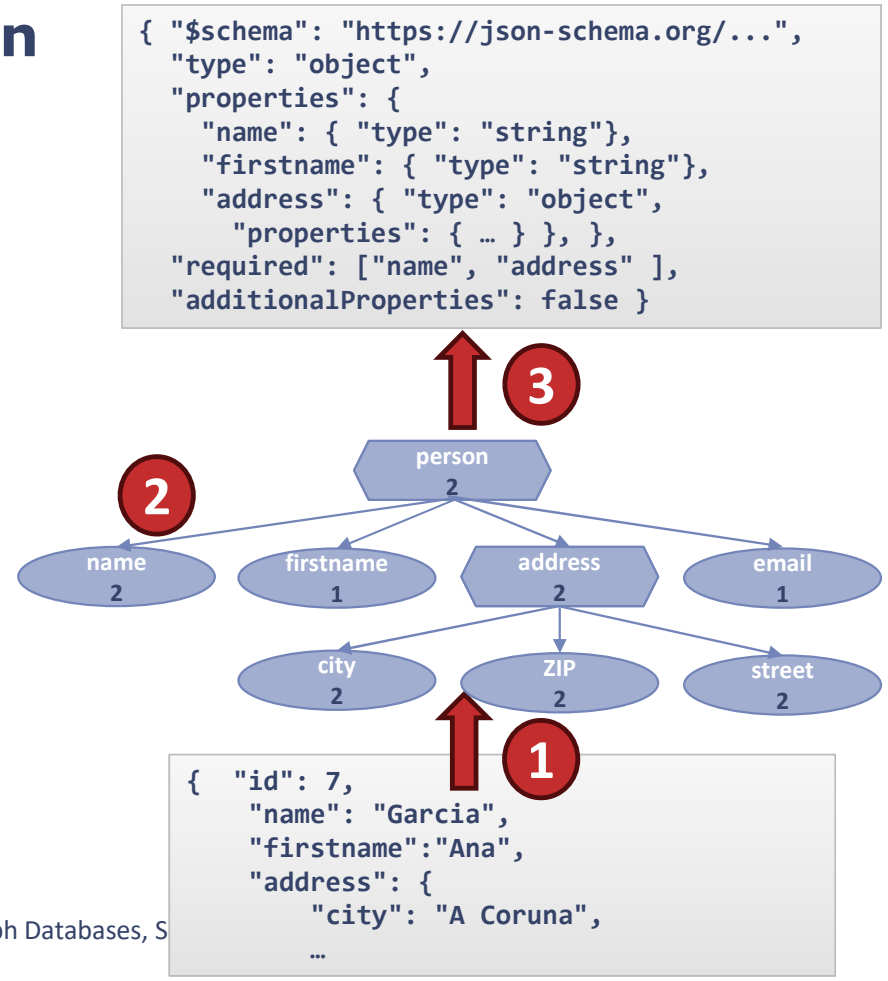


suggested in:
Meike Klettke, Uta Störl, Stefanie Scherzinger: *Schema Extraction and Structural Outlier Detection for NoSQL Data Stores*. BTW 2015

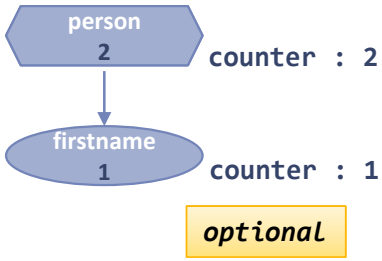
3.3. Schema Extraction Example

Substeps:

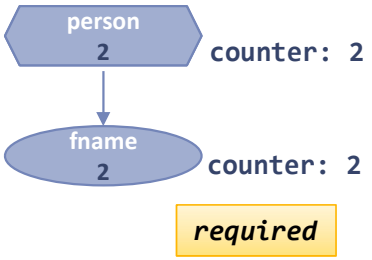
1. **parsing all JSON documents**
2. extracting the **implicit structure** (property names, data types)
3. storing a **counter** in a graph
4. generate the JSON schema from the graph
   - with **property names, data types, nesting** and
   - **required and optional elements**



Optional properties:



Required properties:



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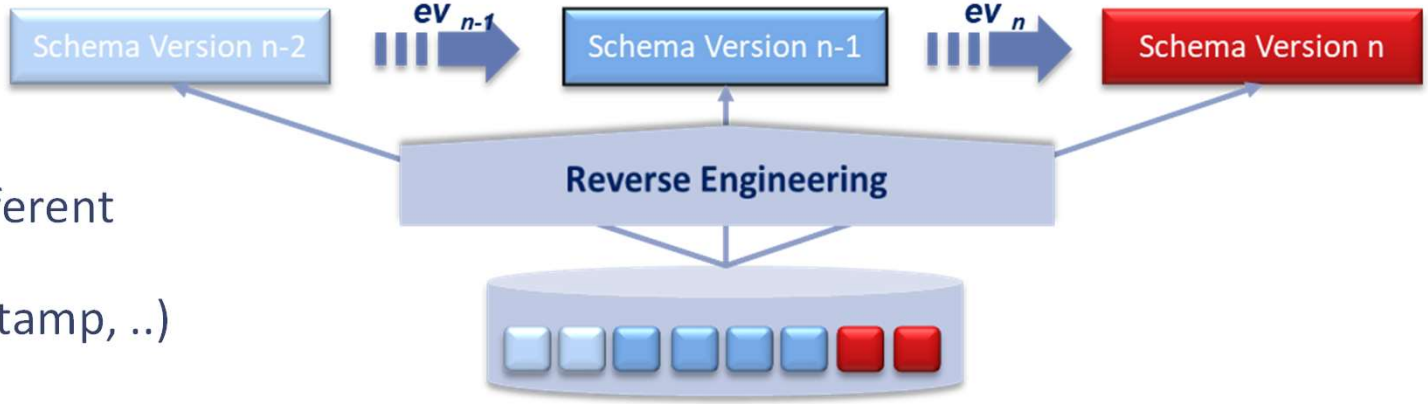
3.3. Schema Version Extraction

Next level:
Usually, **NoSQL database**

- have evolved over time
- can contain datasets in different structural versions
- timeline is available (timestamp, ..)



Aim: extracting

- **series of schema versions** and
- changes over time, specified through **evolution operations**

M. Klettke, H. Awolin, U. Störl, D. Müller, S. Scherzinger: *Uncovering the evolution history of data lakes*. SCDM@IEEE Big Data Conf.,2017
Uta Störl, Meike Klettke: Darwin: A Data Platform for Schema Evolution Management and Data Migration, *DataPlat@EDBT 2022*

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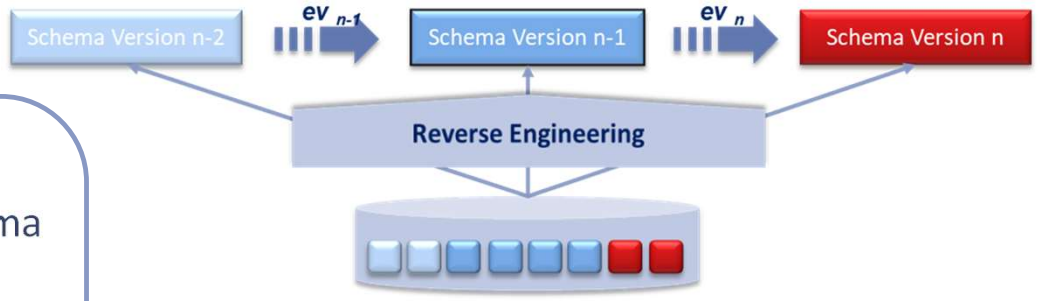
3.3. Schema Version Extraction

Algorithm for Extracting Schema Versions



Input: Set of JSON documents (with timestamps)
Method:
- Create a Graph structure that represents the schema
- Detecting **structural changes** between two consecutive datasets
- In case of such structural changes:
  - **new schema version** is generated
  - **evolution operations** are extracted

Output:
- Series of JSON schemas and
- evolution operations

Determining of Evolution operations is not trivial: e.g. between two versions:
- **`rename`** or a combination of **`delete + add`**?
- **`add`** or **`copy`**?
- **`move`** or a combination of **`delete + add`**?

M. Klettke, H. Awolin, U. Störl, D. Müller, S. Scherzinger: *Uncovering the evolution history of data lakes*. SCDM@IEEE Big Data Conf.,2017
Uta Störl, Meike Klettke: Darwin: A Data Platform for Schema Evolution Management and Data Migration, *DataPlat@EDBT 2022*

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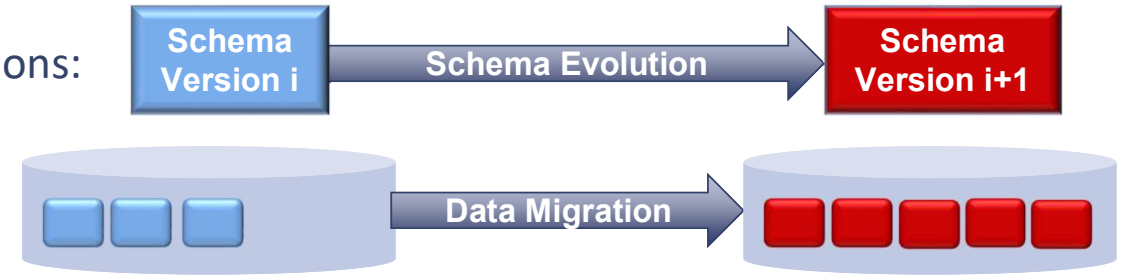
3.4. Evolution of NoSQL Databases (JSON, Graph)

No standardized NoSQL Evolution language available yet.
We still need the "**ALTER TABLE ..**" for **NoSQL**

Some research papers suggest evolution operations:

- **Single-type operations:**
  - `add` **property**
  - `rename` **property**
  - `delete` **property**
- **Multi-type operations:**
  - `copy` property (denormalization)
  - `move` property (refactoring)
  - `split/merge` (normalization/denormalization)

In our ongoing work: with **filter operations** to **consider variants**



Implementation:

- Specifying changes on **schema level** (**Evolution Operations**)
- **Data Migration** accordingly (**eager, lazy, predictive**)

Stefanie Scherzinger, Meike Klettke, and Uta Störl: Managing Schema Evolution in NoSQL Data Store, DBPL@VLDB, Italy, 2013
Andrea Hillenbrand, Maksym Levchenko, Uta Störl, Stefanie Scherzinger, Meike Klettke: MigCast: Putting a Price Tag on Data Model Evolution in NoSQL Data Stores. SIGMOD Conference 2019, Demo Program

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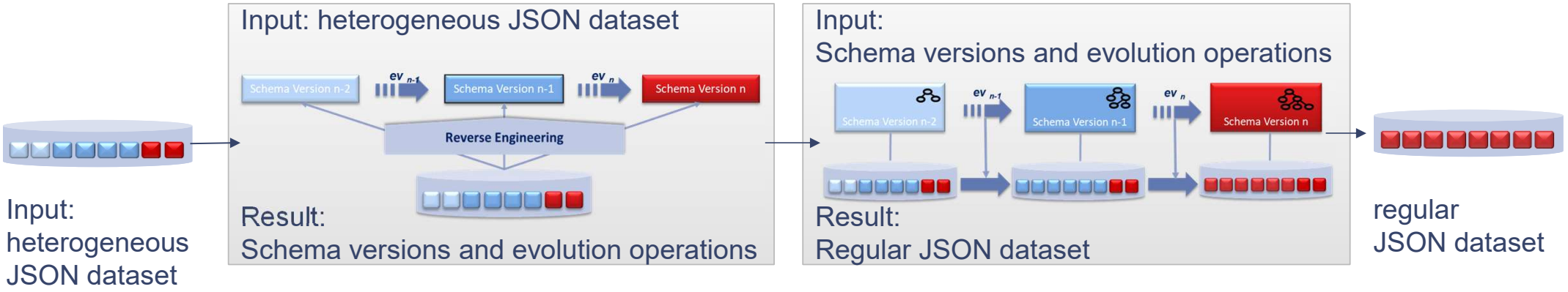
3.4. Combining Schema Version Extraction and Evolution

Step 1: Reverse Engineering
- **Schema Version Extraction** and
- Derivation of **Evolution Operations**

Step 2: Data Migration
- Generating data migration operations from the evolution operations
- **migration of all datasets** into the latest version



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Take-Away Message 6

Even in schema-less database systems, an (at least partial) schema control has advantages.
Evolution operations are needed to guarantee that data can be structured in the latest version.

Take-Away Message 7 (for database researcher)

We should continue developing the ecosystem for NoSQL databases.

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Conclusion

- **Evolution** in databases is an important task
  - in relational databases: **ALTER TABLE** statements or workarounds
  - in NoSQL databases: languages and tools are under development
- **Variability** can be realized by
  - in relational databases: views
  - in NoSQL databases: schema-less storage, but schema with variants or at least partial schema is recommended
- To combine SPLs and Databases:
  - Usage of databases should contain **Design** and **Evolution**
  - Concrete statements (**DDL statements, evolution operations**) can be processed more easily than examples (datasets in different structural versions)

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