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Live Data Integration

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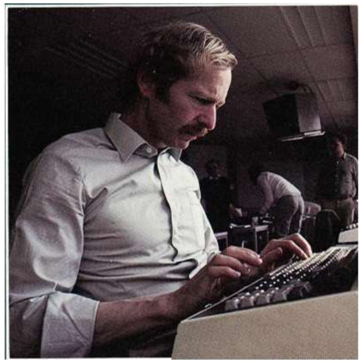
My short CV



Once upon a time …
~40 years ago

- *Education: MSc (Diplom) and PhD (Dr. rer. nat.) in Mathematics*
- *Working as SW-analyst, designer and architect of commercial information systems for ZF, Porsche, Bosch/ Junkers, Telekurs, and Swiss PTT*
- *Full Professor for Database and Information Systems at Reutlingen University. Dean of Studies. Supervised >200 Bachelor and Master students, and 3 Ph.D. students*
- *Cofounded DBTechNet (www.dbtechnet.org)*
- *Research activities in Database Modelling, Transaction Processing, Data Warehousing, and Data Mining.*
- *Research Award, IARIA fellow.*

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Outline

- *Motivation for Live Data Integration*
- *Requirements & Challenges*
- *Framework for Integration*
- *Live Data using Views and REST-Service*
- *Data Preparation Precondition for Data Quality*
- *Data Integration using the Typed Graph Model illustrated by Example*
- *ReadCheck for Transaction support*

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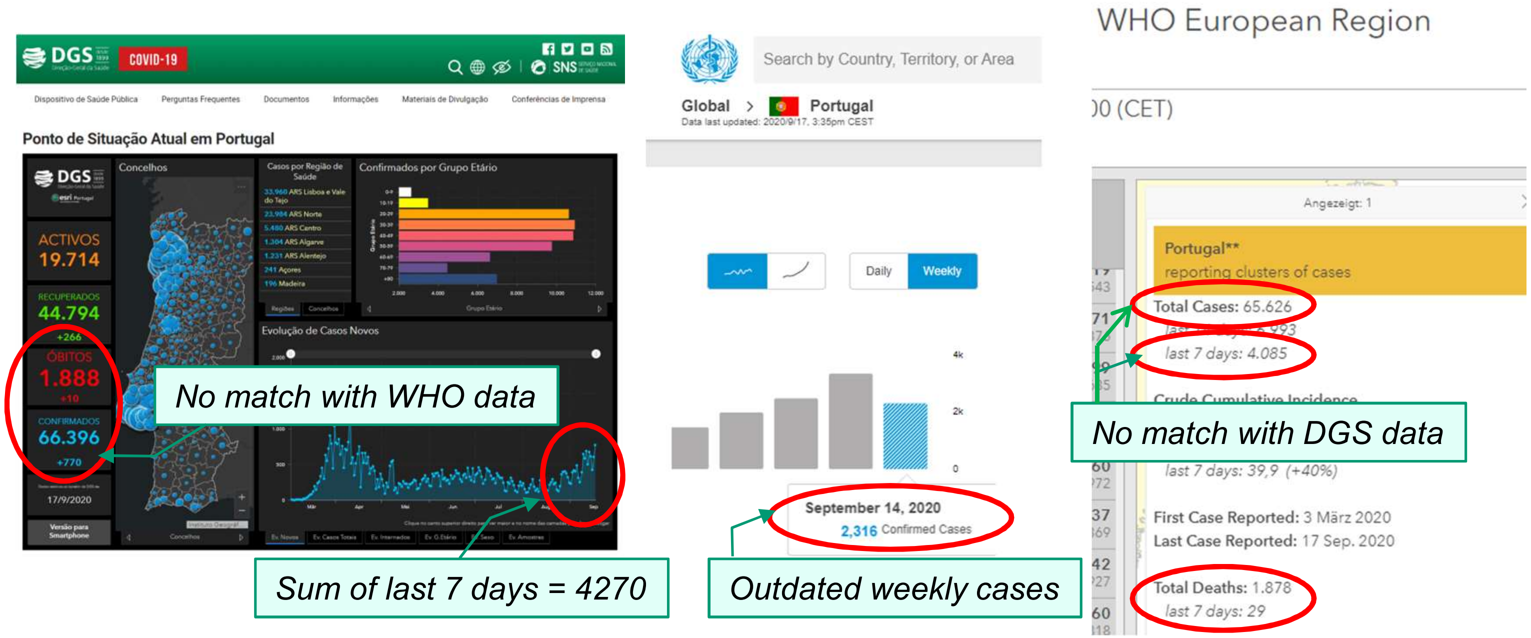
Motivation for Live Data Integration

↳ *There is a need to integrate heterogeneous data sources to…*

- gain added value (knowledge, insights) for decision support, predictive analysis, performance management, etc.
- coordinate complex processes in (near) real-time with transaction support (e.g. traffic control, industry 4.0, fight epidemic)

Need for Live Data Integration (Example)

- *Covid-19 Pandemic Analysis and Control*
  - *Collected from 196* states under the International Health Regulations (IHR 2005)
    - ⇨ *Case numbers differ due to collection methods and actuality of sources*
  - *National authorities like RKI (Germany), CDC (USA), DGS (Portugal), … collect the case data on county or city level, others collect on district level (e.g. SPF (France))*
    - ⇨ *Data need to be adjusted to the same granularity for transnational analysis*
  - *ETL is not sufficient because of periodic updates as can be seen from the Covid-19 data below for Portugal (all from the same day 18.09.20)*

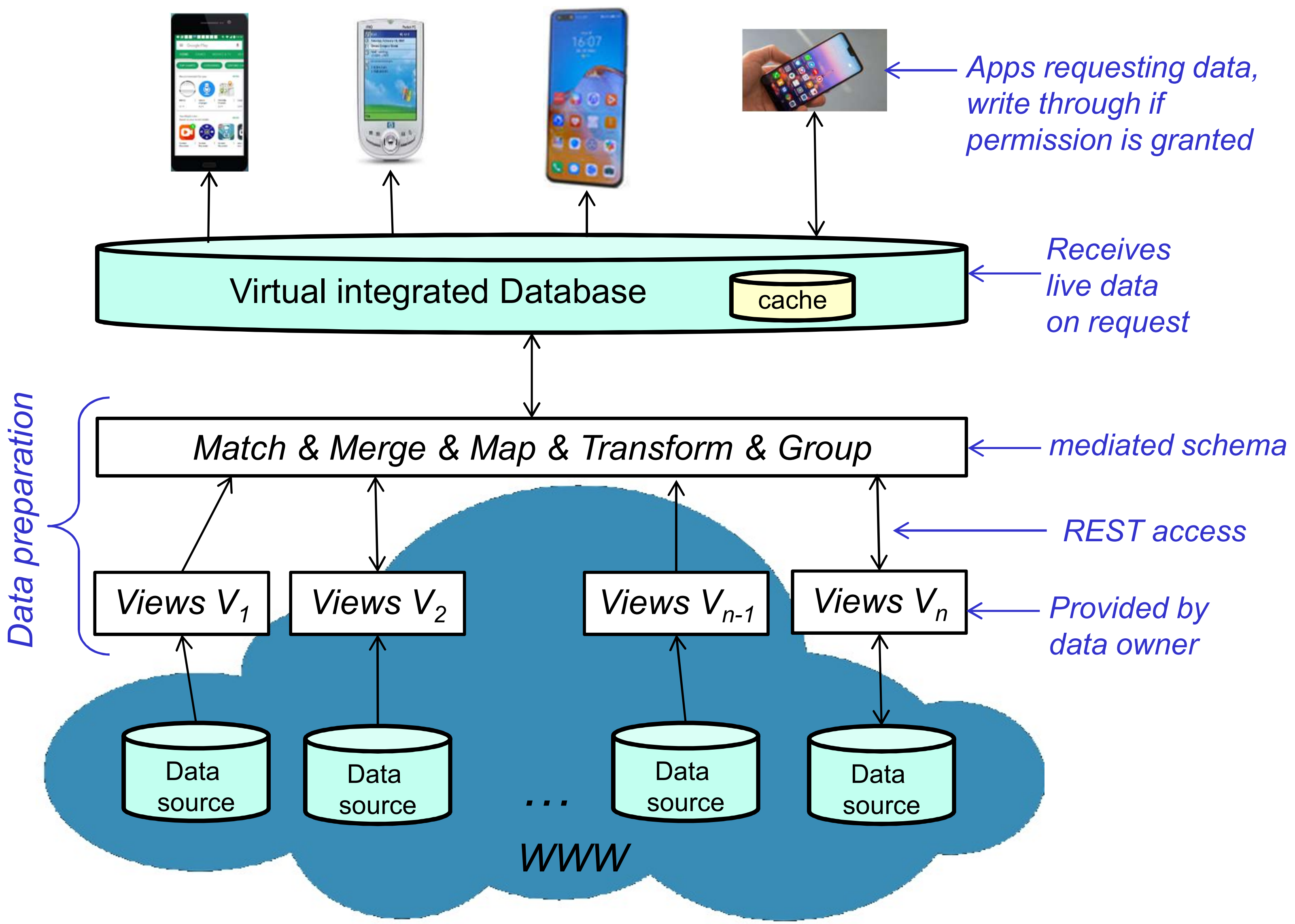


- *Live (permanent) data integration is necessary for up-to-date information and epidemic control.*

Requirements and Challenges

- *Combine data from heterogeneous sources*
  - ☞ Challenge: transform data to be compatible for integration
- Integrate latest data (even real-time data)
  - ☞ Challenge: get data on the fly, increased network traffic
- *Ensure high data quality*
  - ☞ Challenge: prepare and improve data quality
- *Transaction support*
  - ☞ Challenge: distributed transactions for data management

Framework Architecture for Live Data Integration



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Data Sources for Live Data

- *Heterogeneous sources with different data structures need to be integrated.*

- *Issues*
  - Find quality sources with up-to-date (live) data suitable for the application purpose
  - Disclose (hidden) semantics of data require cooperation with the data owners
    - ⇨ Data owners should provide mediated data views and semantic information for integration
  - If two sources contain overlapping (redundant) data they usually do not match
    - ⇨ Different granularity, actuality, semantics
    - ⇨ Examples: Covid-19 Pandemic data vary between WHO, JHU, ECDC (European and national authorities (e.g. RKI, DGS) due to different collection and registration

Live Data [Crowe2017]

- *Ensure that only latest data (even real-time data) is collected*

- *Issues*
  - get data on the fly using mediated views on the live data
    - This needs cooperation with the source owner
  - Reduce network traffic using ReadCheck [Crowe2017] validation and caching
  - ReadCheck is a validator for freshness that checks if the requested data is (partially) in the cache and still up-to-date.
  - ReadCheck combines ideas from Etag (Fielding and Reschke RFC 7232) and RVV [Laiho2010]

Model for Virtual Data Integration

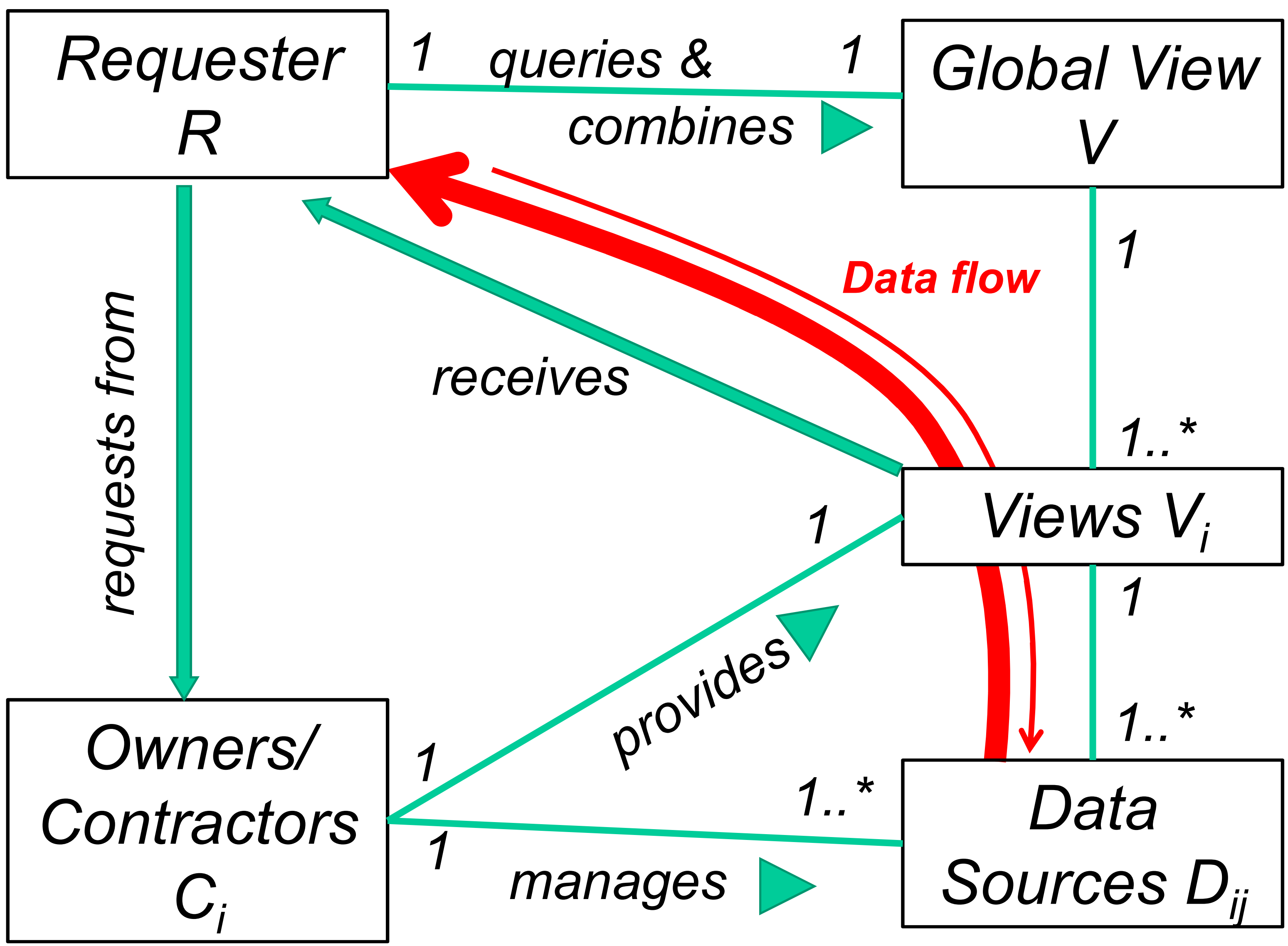

Figure taken from [Crowe2017, p.30] with modifications

ReadCheck Mechanism for Live Data

To reduce network traffic and ensure freshness of data

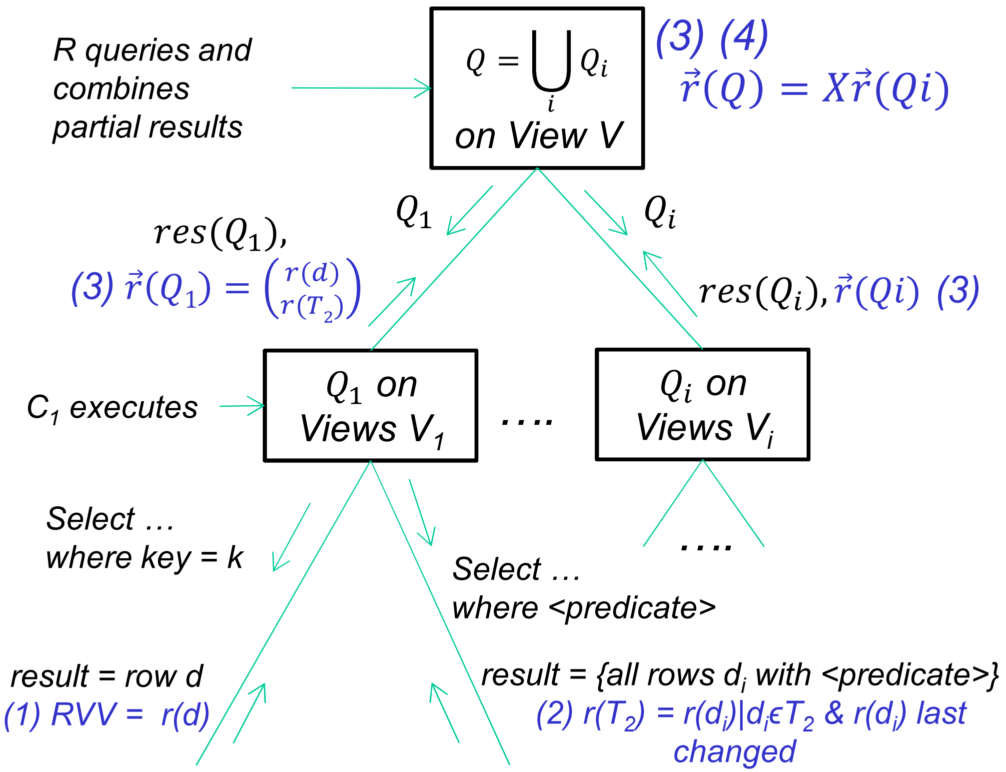

Table T_1

Key	Attributes	RVV
…	…	…
k		r(d)
…	…	…

Table T_2

Key	Attributes	RVV
k_1	…	$r(d_1)$
k_2		$r(d_2)$
…	…	…

Figure taken from [Crowe2017, p.34]

(4) Data selected or aggregated from (3) is no fresher

(3) For data from multiple tables or databases, concatenate of build a vector of readCheck

(2) For data selected by range query need a table version

Compare time of latest change to the table with readCheck

(1) ReadCheck for a single row is the row-version validator

The RVVs for joined rows can be concatenated

For several specific rows these can be combined

Data preparation

- *Prepare data to meet highest quality for its purpose*

- *Preparation steps [Sim2005] [Kemp2010] [Caf2009]*
  1. Select data
  2. Adjust measurement units
  3. Harmonize semantics
  4. Group and classify
  5. Correct and amend data
  - Steps 1 – 3 are mostly application neutral and should be realized by specific views
  - Steps 4 and 5 depend on the application and can be provided by the integration mapping

- *Issues*
  - Requires semantic knowledge (coding, type, granularity, etc.) for all steps
  - Processing costs for step 4
  - Human decisions for step 5 required

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Data Preparation Example

- *Step 1 (Covid-19 data from Web page)*
  - Identify and retrieve data

```
<div role="row" class="tr depth_0 " ...">
 <div class="column_name td" role="cell" ...">
  <div class="sc-AxjAm sc-fzqzlV eqdybr">
   <img src="/countryFlags/us.png" alt="flag US" ...>
   <span>United States of America</span>
  </div>
 </div>
 <div class="column_Cumulative_Confirmed td" ...">
  ...
   <div class="sc-fznOgF fRrkWV">6.613.737</div>
    <div data-id="bar" ...F">
     .....
```

- *Step 2*
  - Get units and other meta information from HTML page for unit adjustments
- *Step 3*
  - Synonyms: apart from national language differences, the English names: cases, positive cases, reported cases, hospitalized, etc. could mean all the same or could mean different things.
- *Step 4*
  - Group patients according cost factors (ABC analysis)
  - For time series bin data into equidistant intervals
- *Step 5*
  - Apparently incorrect: age < 0 or age > 130, interpolate missing data in time series.

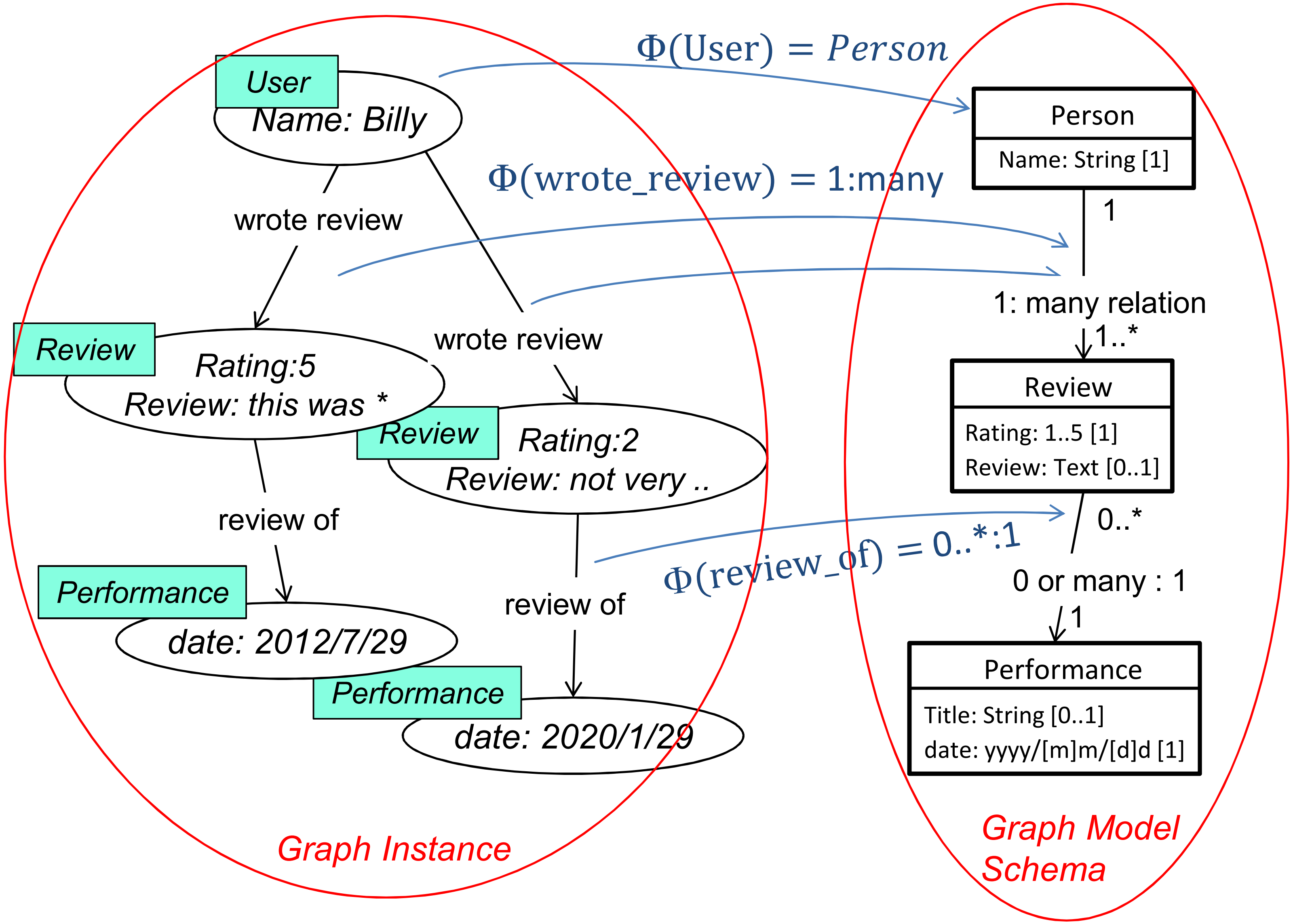
Data Integration

- *Match and map data with compatible semantics*

- *Solution*
  - The Typed Graph Model (TGM) [Laux2020] can help to identify, visualize, and map the data correctly
  - TGM is flexible to support various data structures and visualizes the integration process.
  - TGM provides clear quality criteria for the data mapping. [Laux2017]

- *Issues*
  - The matching and mapping task is manual
  - Choosing the best quality (freshness, reliability, precision) data is the task of the integration schema designer

Typed Graph Model (TGM)



Homomorphism Φ guaranties type and structural integrity of the graph instance

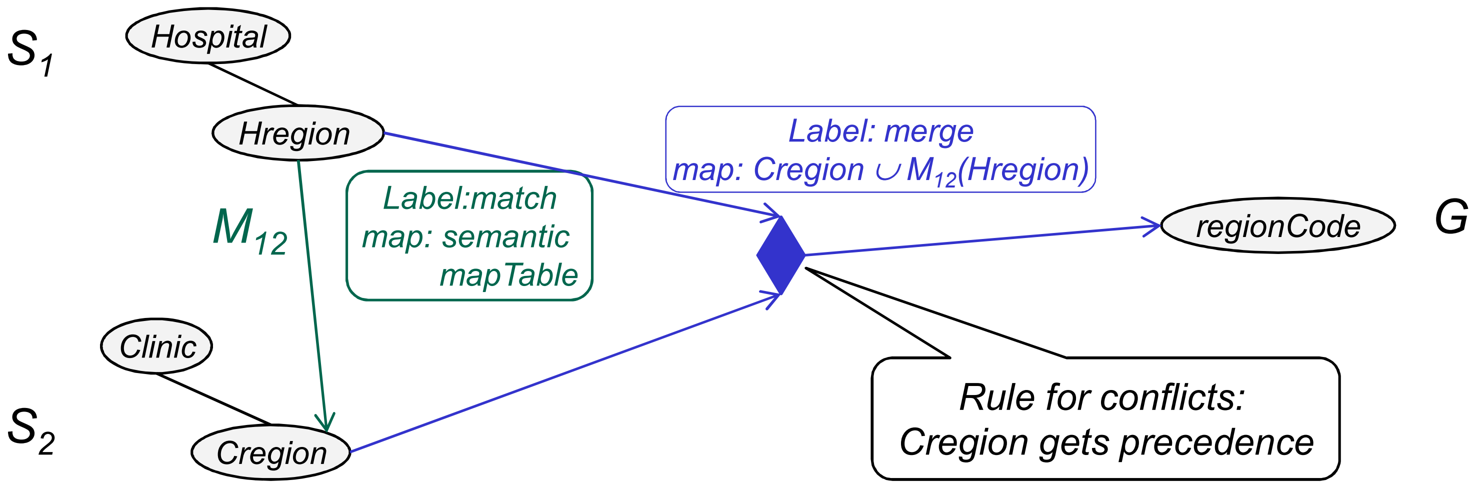
Graph Mapping Patterns

Match — used in preparation steps 2 and 3

- Given schema S and G. A 1:1- or renaming mapping is called a Match. The mapping preserves the semantics.

Merge — used in preparation steps 1 - 4

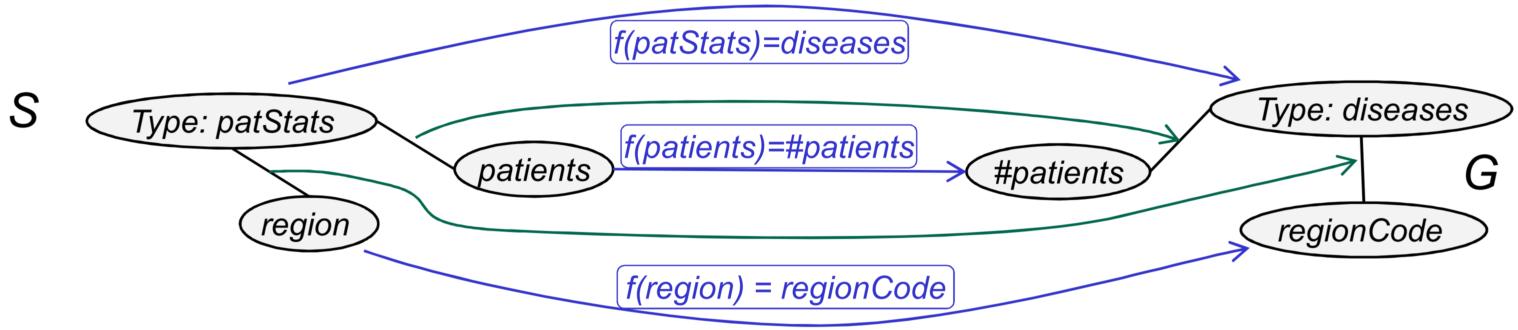
- Given mapping $M_{12}: S_1 \rightarrow S_2$, $G = S_1 \cup S_2$



Important Graph Mapping Types

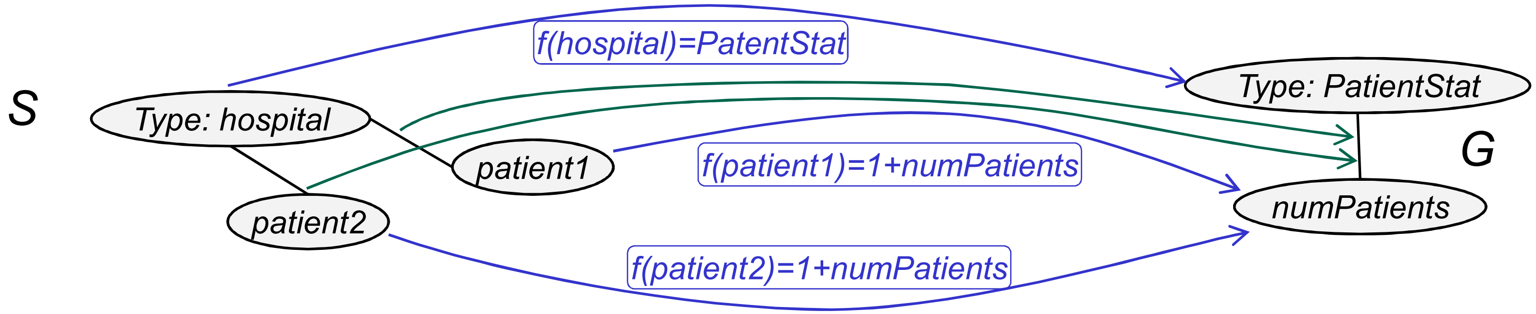
Isomorphism (Edge preserving injection) used for steps 2 and 3

- Given two graphs $S=(V_1, E_1)$ and $G=(V_2, E_2)$
  $f: (V_1) \rightarrow (V_2)$ is injection and
  $\forall (v_1,v_2) \epsilon E_1 \Longleftrightarrow (f(v_1),f(v_2)) \epsilon E_2$



Homomorphism (Edge preserving map) used for step 4

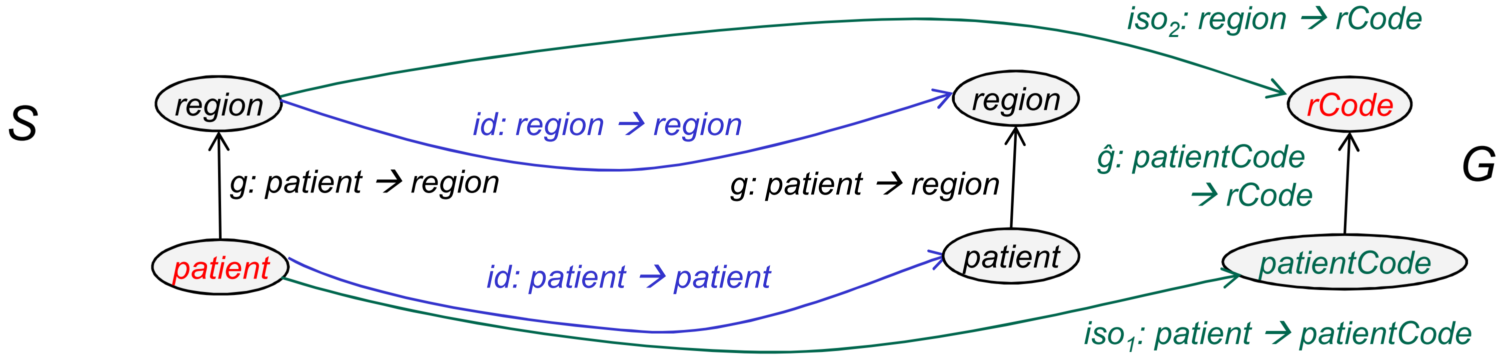
- $f: (V_1) \rightarrow (V_2)$ is mapping and
  $\forall (v_1,v_2) \epsilon E_1 \Longrightarrow (f(v_1),f(v_2)) \epsilon E_2$



Commutative Mappings

Commutative Mapping *used for quality control*

- A function chain is called commutative if and only if $f_2 \circ f_1 = f_1 \circ f_2$, i.e. $f_2(f_1(x)) = f_1(f_2(x))\ \forall x \in dom(f_1)$
- Example: g o id = id o g (and more general $\hat{g} \circ iso_1 = iso_2 \circ g$)



- For a consistent mapping from patient to rCode it is irrelevant if the projection g to region is done first or the isomorphic mapping iso_1 to patientCode.

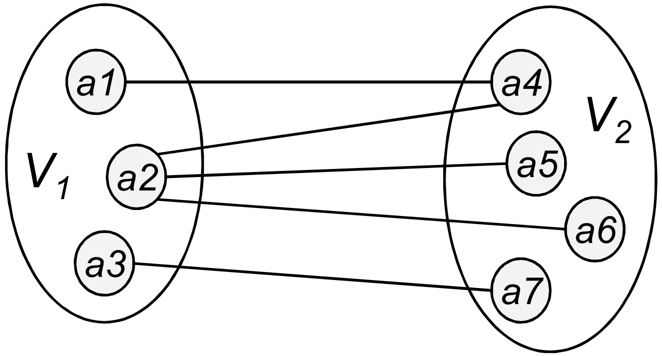
Desirable Mappings

- Projection π, Homomorphism hom, and Isomorphism iso are good candidates for commutative mappings. (e.g. $\pi \circ iso = iso \circ \pi$)

Quality Criteria for TGM Schema Mapping (1/2)

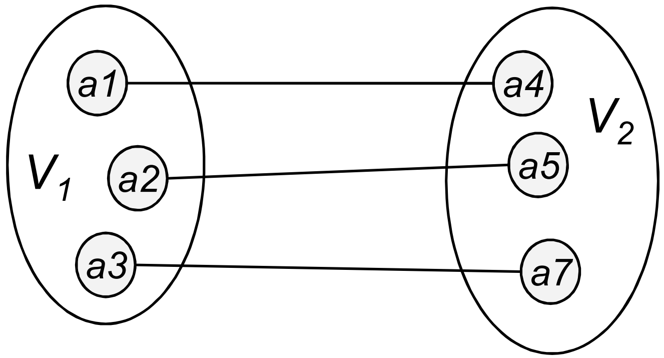
Bipartite Graph

- Let G = (V,E) with $V = V_1 \cup V_2$ and $V_1 \cap V_2 = \varnothing$. If there are no edges within V_1 and V_2 then G is bipartite.
- Example 1:



Graph Matching *quality criteria*

- Let G be a bipartite Graph. A matching is a subset of edges where no two edges share an endpoint (node)
- Maximum matching = maximum number of vertices are matched
- Perfect matching = all vertices are matched (not merged)
- Example 2:



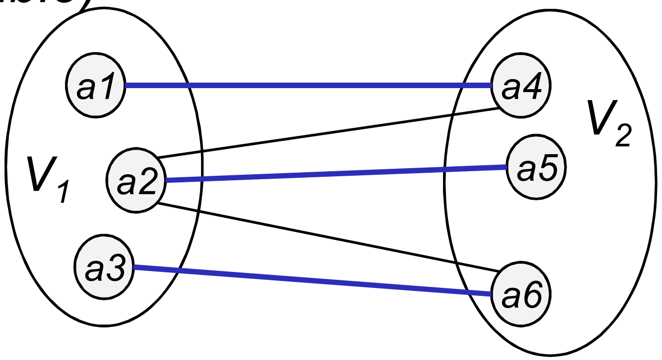
Quality Criteria for TGM Schema Mapping (2/2)

Theorem of Hall (Marriage Theorem)

- Let G = (V1 ∪ V2, E) be a bipartite Graph. In G exist a perfect matching if $\forall\, U_1 \subseteq V_1$: $d(U_1) \geq |U_1|$.
  $d(U_1) := |\{v \in V_2 \mid u \in U_1 \wedge (u,v) \in E\}|$
  general criteria for data integration coverage/completeness

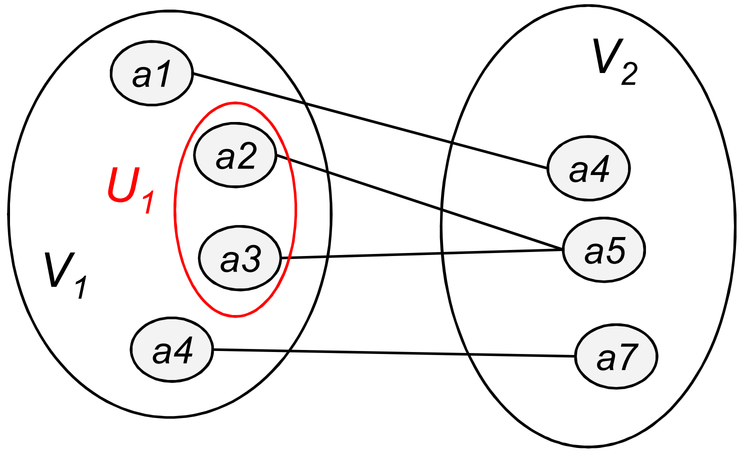
Example 3 (perfect match possible)

- All subsets U_1 of V1 have $d(U_1) \geq |U_1|$
- (a1,a4), (a2,a5), (a3,a6) is a (the only) possible perfect matching



Example 4 (no perfect match possible)

- Subset U_1={a2, a3} has $d(U_1)$=|{a5}|=1, but $|U_1|$ = 2.

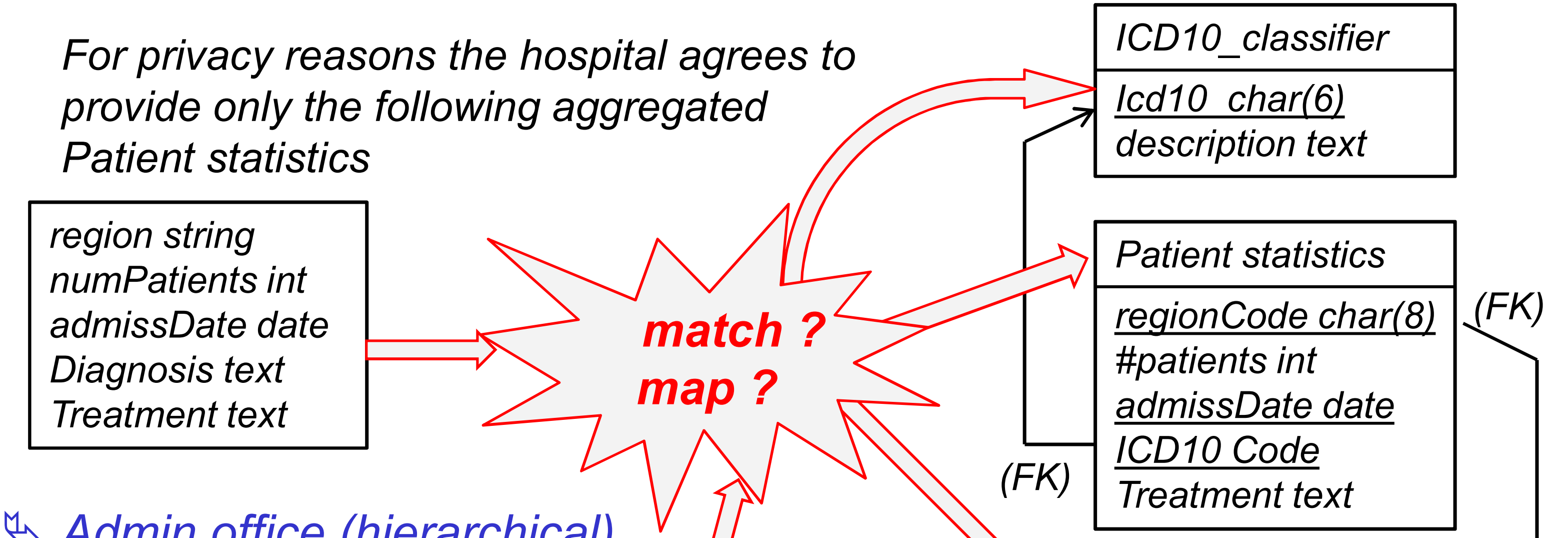


Data Integration Example Scenario

Patient stats (semi-structured)

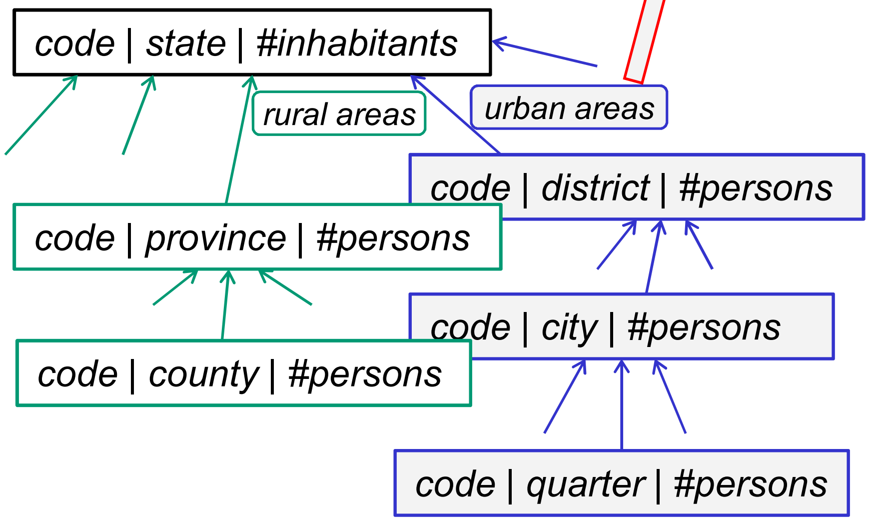
For privacy reasons the hospital agrees to provide only the following aggregated Patient statistics

Mediated Schema (relational)

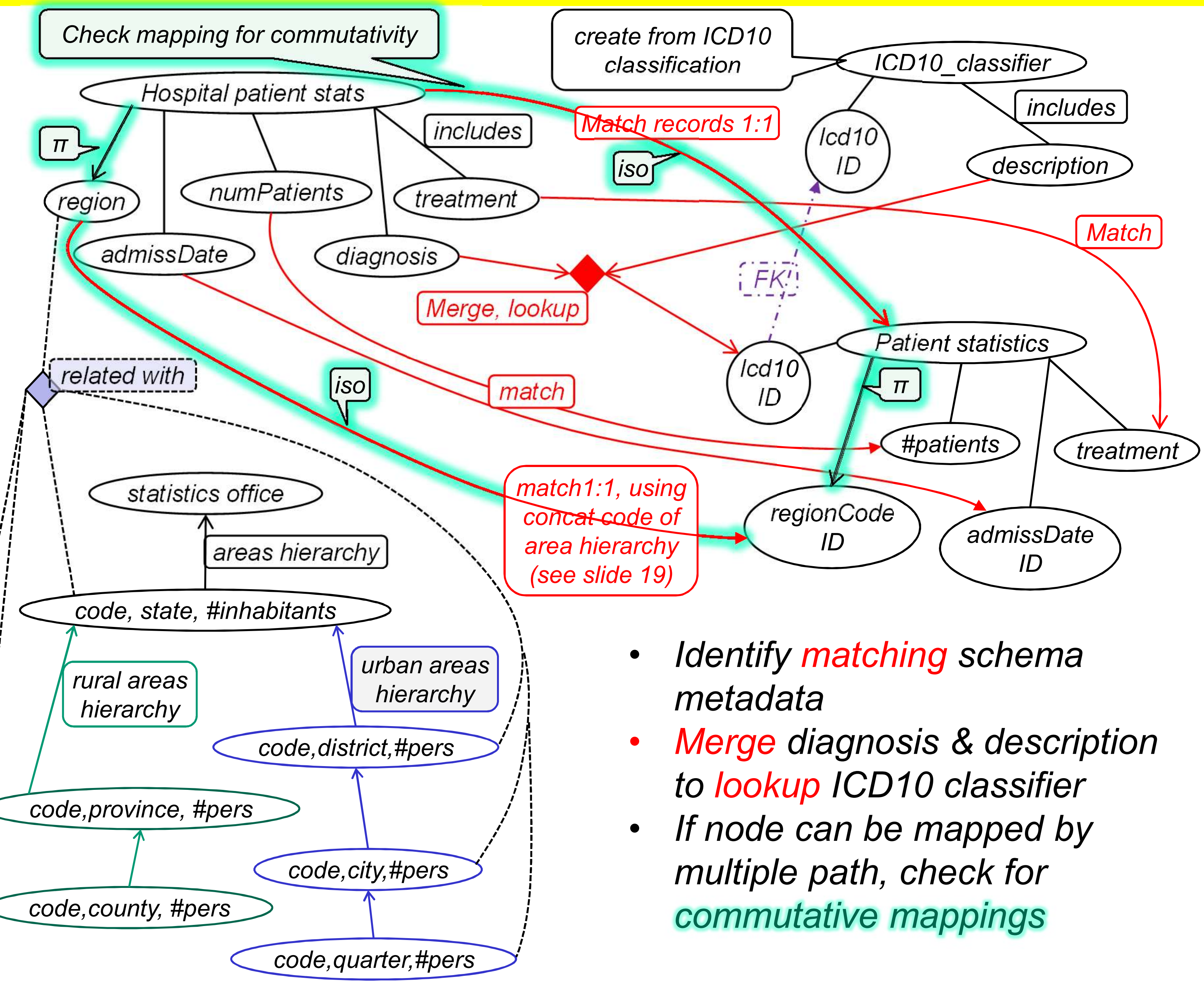


Admin office (hierarchical)

Population in hierarchically organized administrative areas



Data Integration Example Solution (1st part)



- Identify matching schema metadata
- Merge diagnosis & description to lookup ICD10 classifier
- If node can be mapped by multiple path, check for commutative mappings

Data Integration Example Solution (2nd part)

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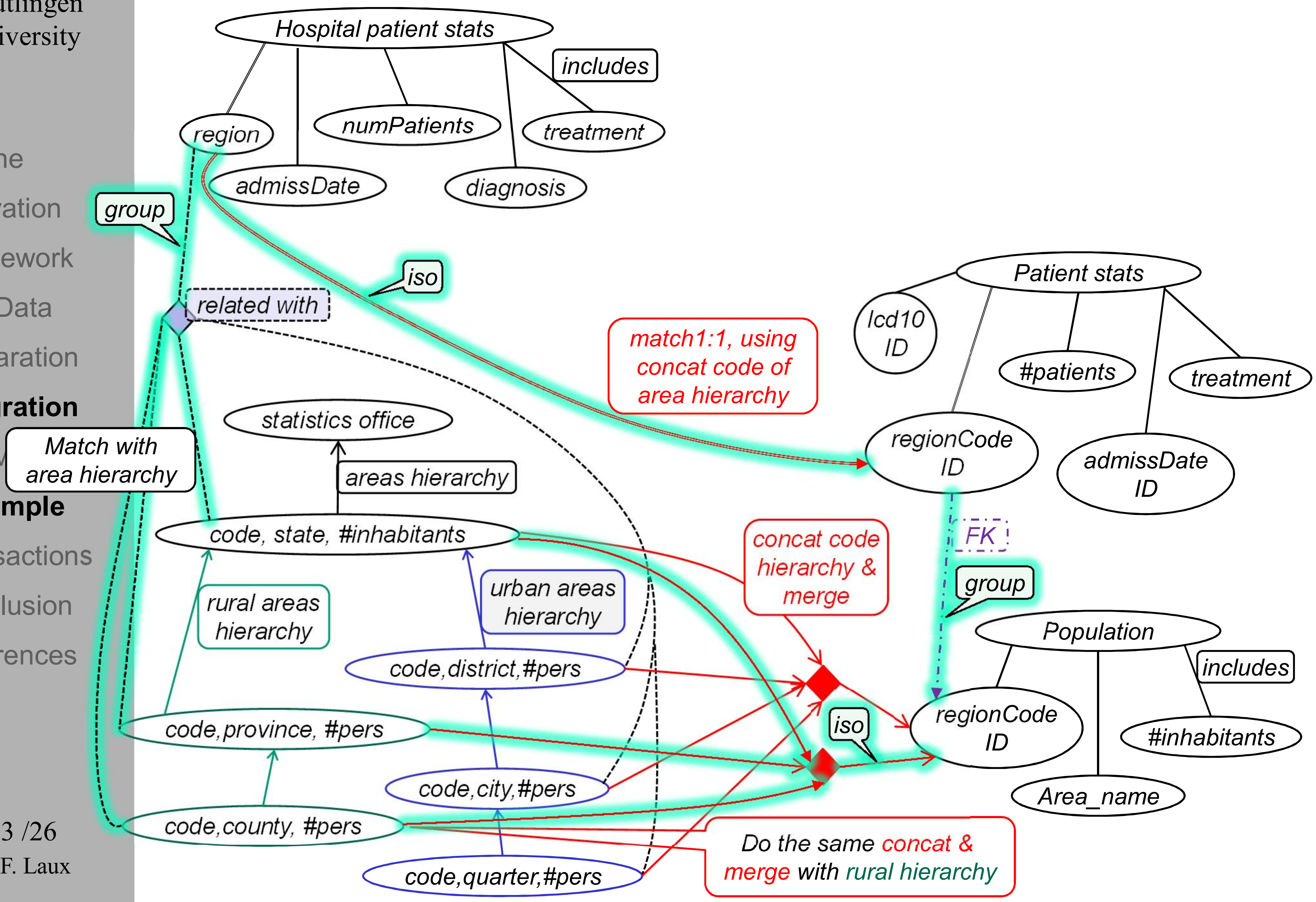

Transaction support

- *Some data require transactional guaranties for manual updates, corrections, and processing*
  - These Apps need permission to write data
- *Solution*
  - ReadCheck make distributed transactions feasible in loosely coupled environments
  - ReadCheck can be used for an Optimistic Concurrency Control (OCC) like Row Version Verifying (RVV) [Laiho2010]
- *Issues*
  - Update and insert transaction must operate on the source data
    - only possible when data that is passed one-to-one to an App
    - It does not work on aggregated data

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Lessons learned

- *Live Data Integration is possible with high quality and freshness if*
  - Sources provide Live Views of data
  - A mediated data schema is used for integration
  - TGM helps to match, map, and merge data for integration
  - Data is prepared in 5 steps for quality improvement
- *Key points for successful integration*
  - Cooperation of data sources is necessary
  - Careful semantic analysis and preparation of data is required to ensure quality data
  - The integration process is iterative as most aspects are interwoven

References

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