Database Theory

Unit 0 — What is Database Theory?

Matthias Lanzinger, 13.06.2024

TU WIEN Informatics

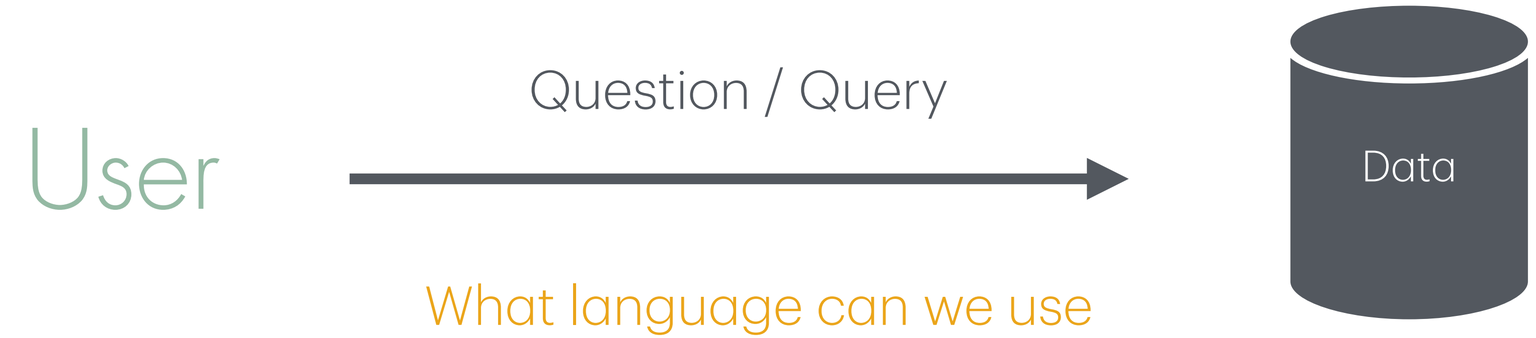
What is the “shape” of our data?

User Side
(very minor role in this course)

Interpretability of queries.
Natural language to formal query language.

Relational, Graph, Text, Semi-structured XML/JSON/etc), ...

Streaming, distributed, privacy preserving, ...



What language can we use to define the question?

Logic, Automata, SQL, GQL, Regular Path Queries, SPARQL, XPATH, GNNs, Document Spanners, ...

Queries

Query Languages

Complexity

How difficult is it to answer queries in the language?

Expressivity

What can be asked with the language?

Equivalence

When do two queries always give the same result over every database?

Complexity

- Dependence on only the data, only the query, both, tradeoffs?
- If intractable, can we identify special cases for which there are efficient algorithms?
- Which features of the language are the cause of higher complexity?

  → Influence back on language design.

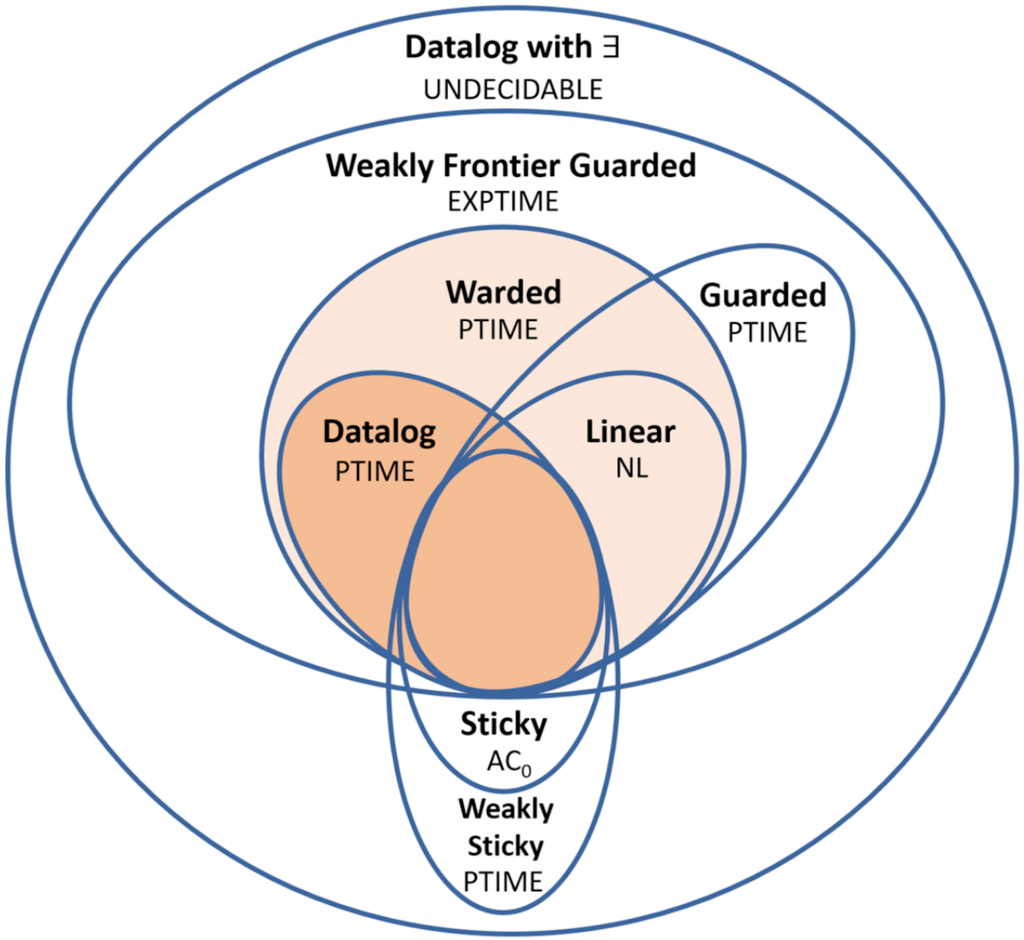


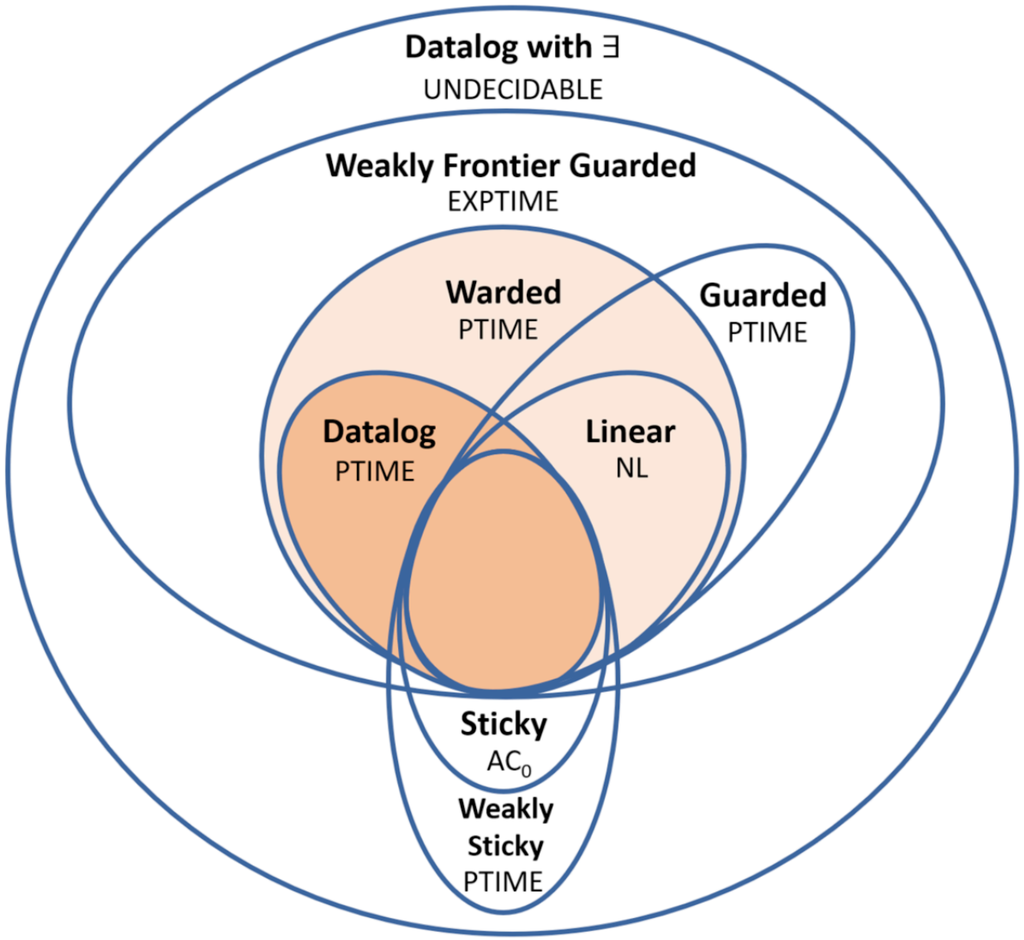
Figure 1: Syntactic containment of Datalog$^{\pm}$ languages. Annotations (non-bold) denote data complexity. All names that do not explicitly mention Datalog refer to the respective Datalog$^{\pm}$ languages. E.g., "Sticky" refers to "Sticky Datalog$^{\pm}$".

Bellomarini, L., Sallinger, E., & Gottlob, G. (2018).
The Vadalog System: Datalog-based Reasoning for Knowledge Graphs. PVLDB

Expressivity

- Given two query languages $\mathscr{L}_1$ and $\mathscr{L}_2$. For every query q in $\mathscr{L}_1$, can we write a query in $\mathscr{L}_2$ that always produces the same outputs as q?

- What kinds of concepts can a query language not ask about?
  For instance, with first-order logic we cannot ask about reachability in a graph.



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Equivalence

- Say we have two queries q and q' in the same query language. Are the outputs of the two queries the same on every database?
- If there are many equivalent ways to write the same query, which way is the most efficient with respect to evaluation?

Data Models

Data Model Dimensions

"Shape"

What is the formal description of how the data is stored?

Common examples:
- Relational
- Graphs
- Semi-structured
- Documents

Availability

How can data be accessed?

In distributed settings, access to data that is not local induces additional cost.

Streaming data only gives a small window into the whole data at any given time.

Further Complexities

Various additional notions have been added on top of the other two.

Data can be stored in some way that inherently preserves privacy.

Data can be probabilistic.

Further Topics

Data Quality

Cleaning up data in a formally justified way.

Discovering new data / expanding on the data currently in the database

Incompleteness & Uncertainty

Parts of data is missing (e.g. NULLs)

Data might not be 100% certain, e.g., data from ML models or crowdsourcing.

Data Access

Managing data under concurrency / transactions.

Indexing structures.

Connections to Other Areas

Complexity Theory

Complexity of Query Evaluation

Logic / Model Theory

Expressiveness of languages.

Logic Programming

More advanced query languages fall into logic programming.

Graph Theory

Structure of queries and data matters. Homomorphisms.

Constraint Satisfaction

CSP = Conjunctive Queries.

Automata

XML, Document Spanners, Stream processing, Graph Queries

This Lecture

- The lecture will focus primarily on the relational model.
  Inherent connections to logic.
  Most commonly studied and compatible with most query languages.
  Common in practice (SQL, Logic, Graphs, Datalog, ...).

- Opportunity to look into other models via presentations.
  Semi-structured data (XML/JSON).
  Plain text as a data model.
  Probabilistic data.

Database Theory

Unit 0.5 — General Information

Matthias Lanzinger, 13.06.2024

TU WIEN Informatics

Classes

Language:
All parts of the class are held in English

Time:
Every week of term: Tuesday, 11:15 - 13:00
(see TISS in case of uncertainty)

Place:
All classes will be in person in room FAV EG C (Seminarraum Gödel).

Prerequisites

Level

This course is designed for master's and doctoral students.

Familiarity with mathematical notation and proof is assumed.

Courses

It is highly recommended to take Formal Methods in CS (185.291) and a database course before this course.

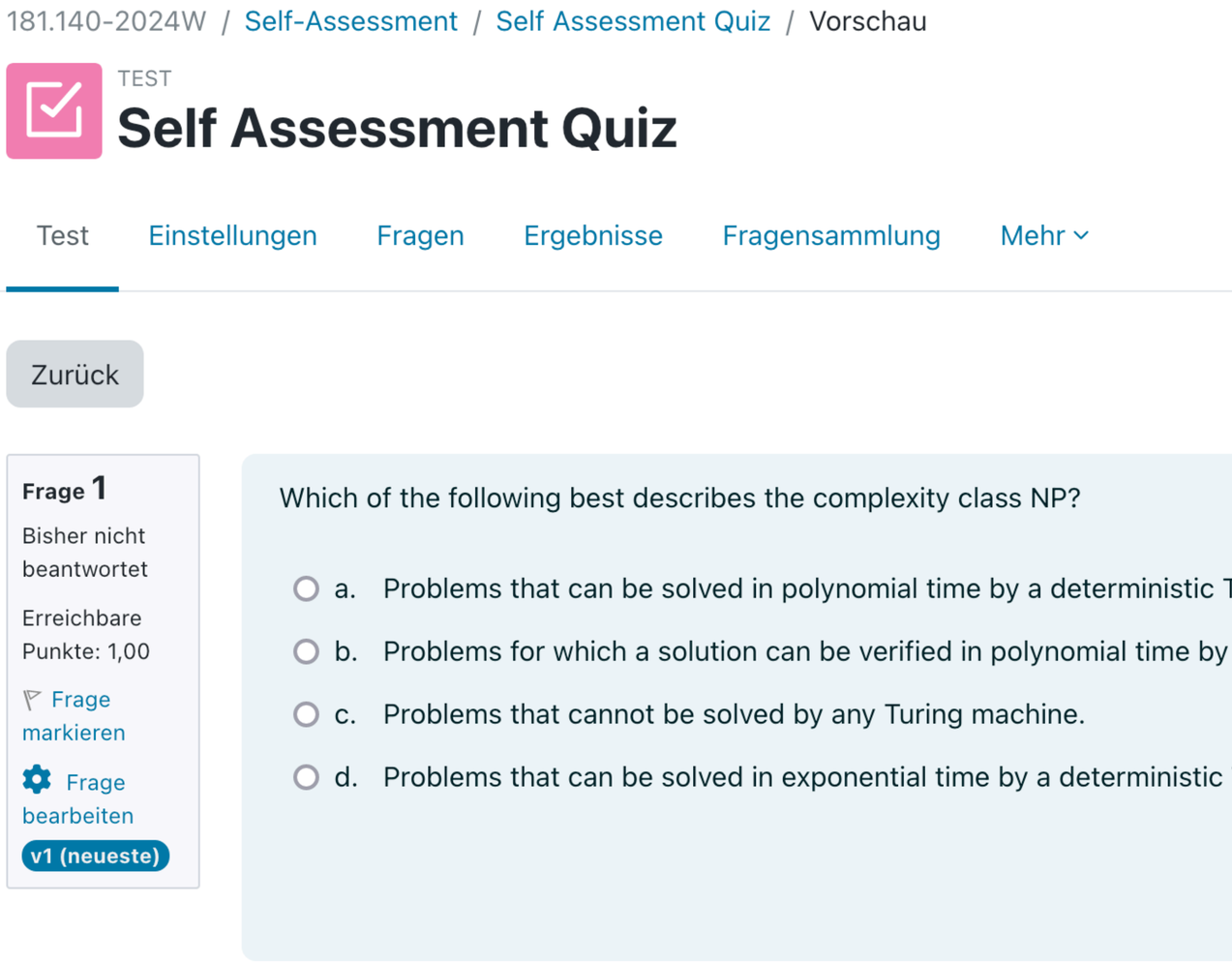
Complexity Theory (181.142) can be helpful in parallel to this course.

Helpful Knowledge

- Database basics
- Formal logic
- Intro complexity theory
  In particular, reductions!

Self Assessment

- Quiz on TUWEL course for you to judge your own knowledge on course prerequisites.
- Not graded, entirely optional.
- If you are still unsure, talk to me.



Communication

- During & after classes
- TUWEL
- TISS
  (room and time information)
- Course homepage
  https://dbai.tuwien.ac.at/staff/mlanzing/dbt/

Assessment

Presentation

Presentation on one database theory research article.

Sufficient for mark 3.

Oral Exam

Only possible if presentation part was done. Optional if happy with lower mark.

Necessary for marks 1 and 2.

Presentation

- Choose a paper
  Preselected list of around 20 database theory research papers on various topics that go beyond the lecture material.

- Read and present
  Understand the main contributions and summarise them in a ~20min presentation for your colleagues.

- More information on the papers to choose from in a later class.

A Good Presentation

- Basic understanding of the article. ***Absolutely necessary to pass course!***
- Honestly identify parts which you did not understand.
  E.g.: which prerequisites were missing or were not available to look up?
- Relate the paper to the contents of the course.
- Provide context of important background articles / topics.
- Think about how to communicate these theoretical ideas to the audience.
  E.g., proof ideas and intuitions can be interesting but full proofs
  are often problematic in 20minutes.
- Be ready to answer questions about the article.

Base Literature

The following two books are recommended if you would like to supplement the contents of this lecture:

- Abiteboul, Vianu, Hull — Foundations of Databases

- Arenas, Barceló, Libkin, Martens, Pieris — Database Theory
  (Still in progress but fully usable already for the parts concerning this lecture)
  https://github.com/pdm-book/community