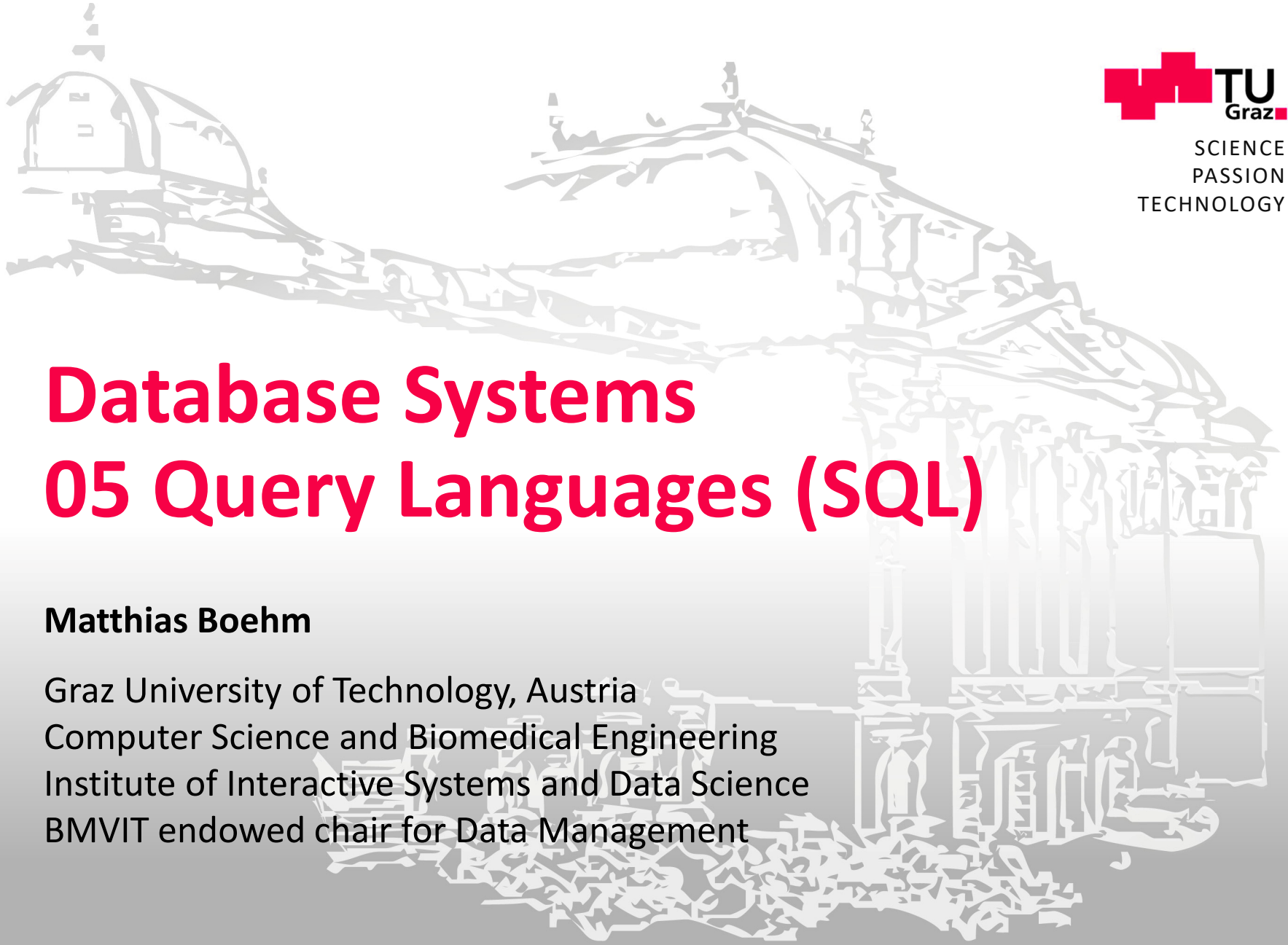

SCIENCE
PASSION
TECHNOLOGY

Database Systems
05 Query Languages (SQL)

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Last update: Apr 01, 2019

ISDS

Announcements/Org

- **#1 Video Recording**
  - Since lecture 03, video/audio recording (**setting**)
  - Link in **TeachCenter** & **TUbe** (but not public yet)

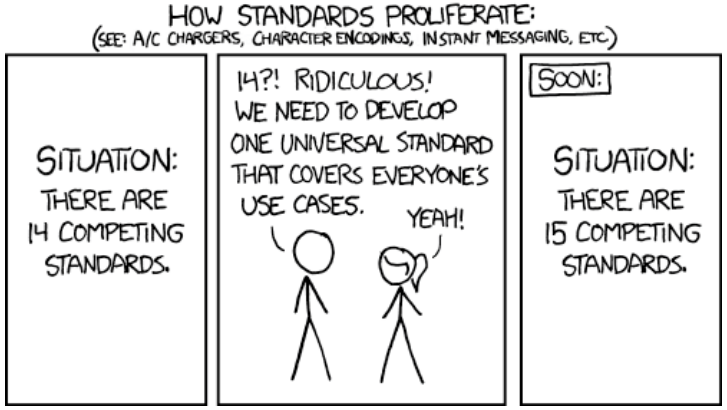
- **#2 Exercise 1**
  - Submission through **TeachCenter** (max 5MB, draft possible)
  - **Submission open** (deadline **Apr 02, 12.59pm**)
- **#3 Exercise 2**
  - Modified published date **Apr 3 → Apr 08**
  - Introduced during **next lecture**
- **#4 Participation**
  - Awesome to see **active involvement** via newsgroup, PRs, etc
  - Reminder: **office hours** Monday 1pm-2pm

Agenda

- **Structured Query Language (SQL)**
- **Other Query Languages (XML, JSON)**

Why should I care?

- **SQL as a Standard**
  - Standards ensure **interoperability**, avoid **vendor lock-in**, and protect **application investments**
  - **Mature standard** with heavy industry support for decades
  - **Rich eco system** (existing apps, BI tools, services, frameworks, drivers, design tools, systems)



[https://xkcd.com/927/]

- **SQL is here to stay**
  - Foundation of mobile/server **application data management**
  - **Adoption of existing standard** by new systems (e.g., SQL on Hadoop, cloud DBaaS)
  - Complemented by NoSQL abstractions, see lecture **10 NoSQL (key-value, document, graph)**

SQLite

Google BigQuery

amazon REDSHIFT

Microsoft SQL VS SQL

Structured Query Language (SQL)

Overview SQL

- **Structured Query Language (SQL)**
  - **Data Definition Language (DDL)** → Manipulate the database schema
  - **Data Manipulation Language (DML)** → Update and query database (includes data query language, truncation control language)
  - **Data Control Language (DCL)** → Modify permissions
- **Current Standard: ISO/IEC 9075:2016 (SQL:2016)**
- **Dialects**
  - Spectrum of system-specific dialects for **non-core features**
  - Data types and size constraints
  - Catalog, builtin functions, and tools
  - Support for new/optional features
  - Case-sensitive identifiers

Name	Examples
T-SQL	Microsoft, Sybase
PL/SQL	Oracle, (IBM)
PL/pgSQL	PostgreSQL, derived
Unnamed	Most systems

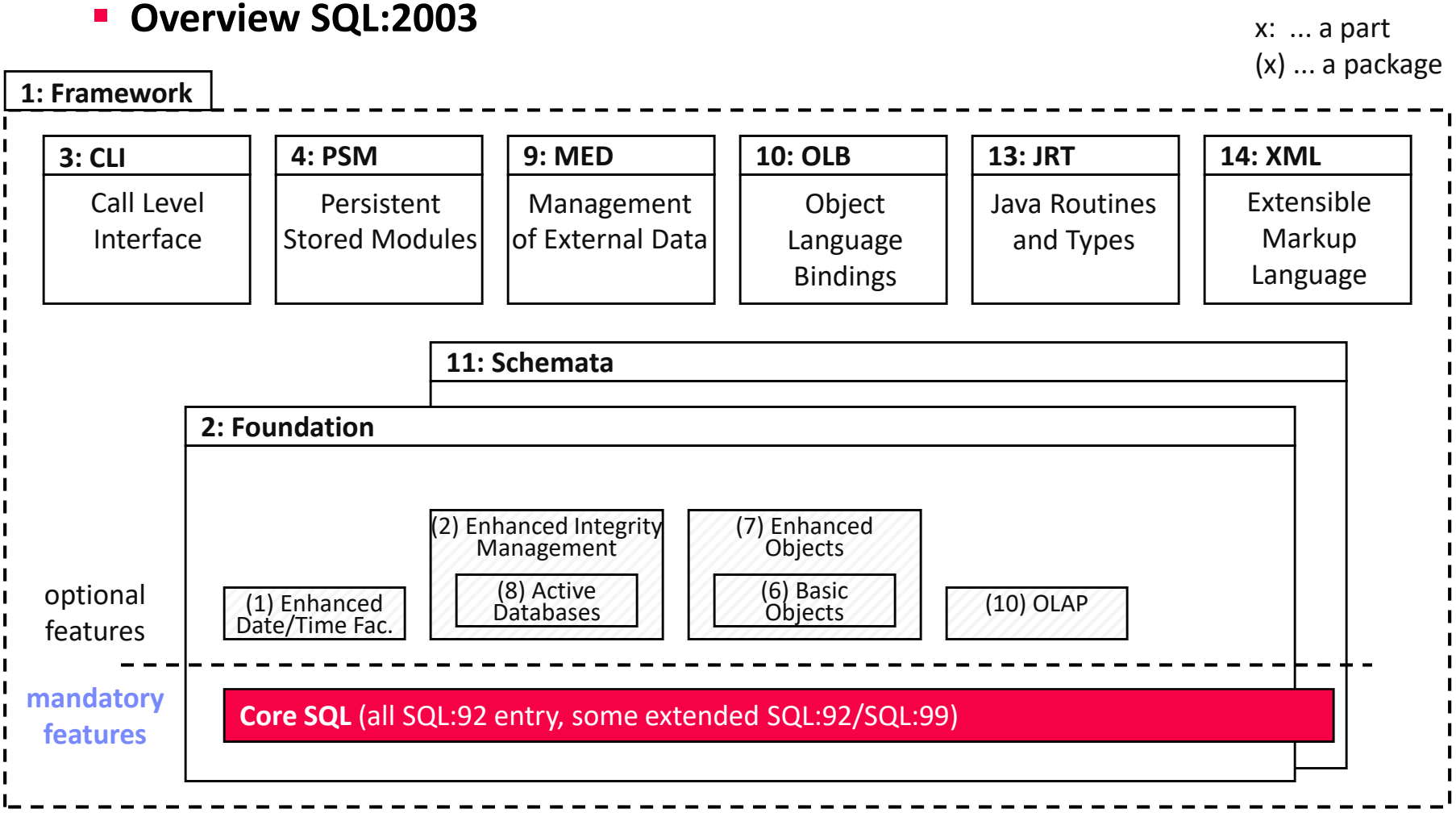
The History of the SQL Standard

[C. J. Date: A Critique of the SQL Database Language. **SIGMOD Record 1984**]

- **SQL:1986**
  - Database Language SQL, ANSI X3.135-1986, ISO-9075-1987(E)
  - '87 international edition
- **SQL:1989** (120 pages)
  - Database Language SQL with Integrity Enhancements, ANSI X3.135-1989, ISO-9075-1989(E)
- **SQL:1992** (580 pages)
  - Database Language SQL, ANSI X3-1992, ISO/IEC-9075 1992, DIN 66315
  - '95 SQL/CLI (part 3), '96 SQL/PSM (part 4)
- **SQL:1999** (2000 pages)
  - Information Technology – Database Language – SQL, ANSI/ISO/IEC-9075 1999
  - Complete reorg, '00 OLAP, '01 SQL/MED, '01 SQL/OLB, '02 SQL/JRT
- **SQL:2003** (3764 pages)
  - Information Technology – Database Language – SQL, ANSI/ISO/IEC-9075 2003

The History of the SQL Standard, cont.

- **Overview SQL:2003**



The History of the SQL Standard, cont.

Since SQL:2003 overall structure remained unchanged ...

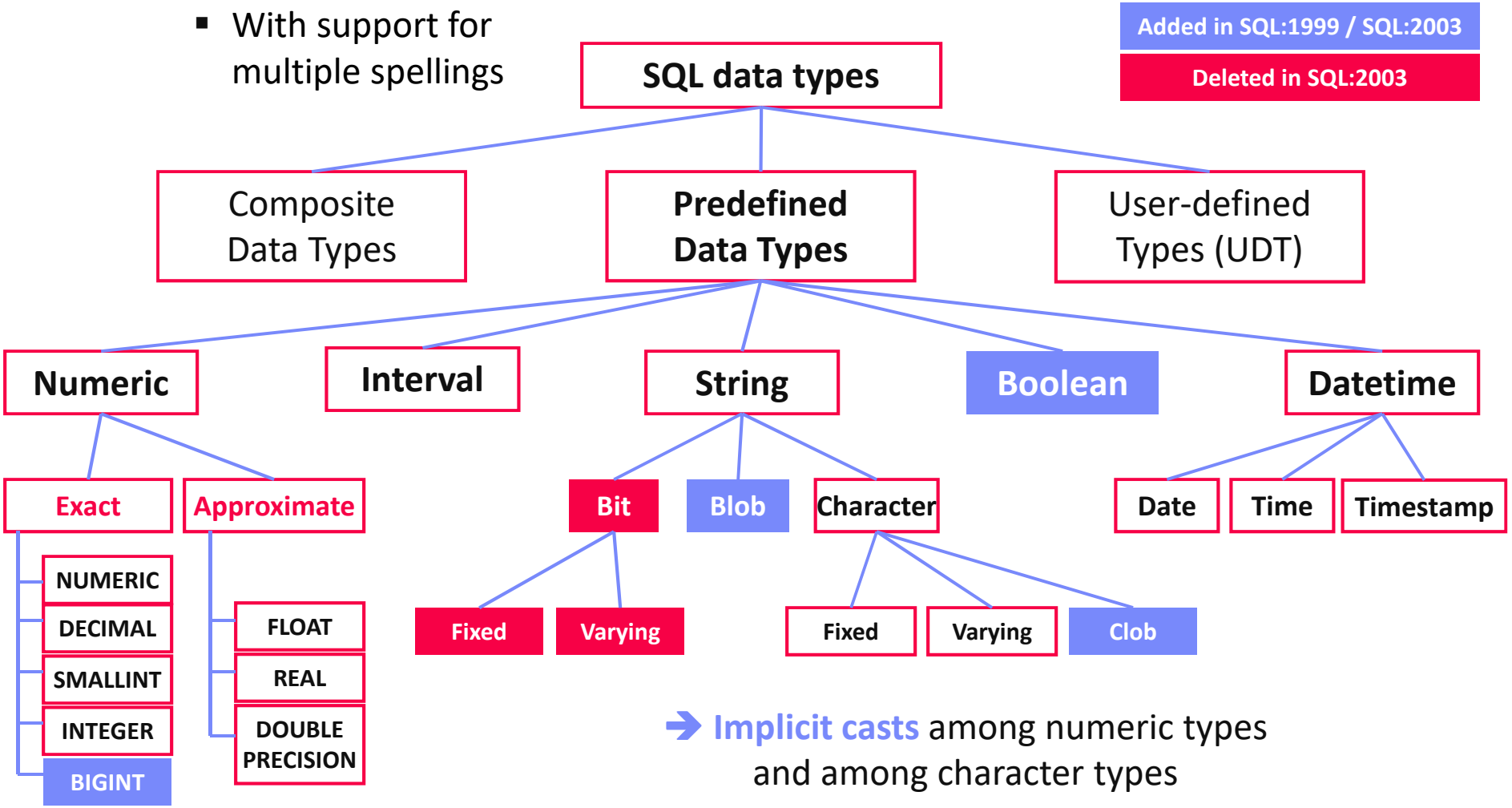
- **SQL:2008** (???? pages)
  - **Information Technology – Database Language – SQL**, ANSI/ISO/IEC-9075 2003
  - E.g., **XML** XQuery extensions, case/trigger extension
- **SQL:2011** (4079 pages)
  - **Information Technology – Database Language – SQL**, ANSI/ISO/IEC-9075 2011
  - E.g., time periods, temporal constraints, time travel queries
- **SQL:2016** (???? pages)
  - **Information Technology – Database Language – SQL**, ANSI/ISO/IEC-9075 2016
  - E.g., **JSON** documents and functions (optional)

➔ **Note: We can only discuss common primitives**

[Working Draft SQL:2011: https://www.wiscorp.com/SQLStandards.html]

Data Types in SQL:2003

- **Large Variety of Types**
  - With support for multiple spellings



➔ **Implicit casts** among numeric types and among character types

Data Types in PostgreSQL

Appropriate, Brief, Complete

- **Strings**
  - **CHAR(n)** → fixed-length character sequence (padded to n)
  - **VARCHAR(n)** → variable-length character sequence (n max)
  - TEXT → variable-length character sequence
- **Numeric**
  - SMALLINT → 2 byte integer (signed short)
  - **INT/INTEGER** → 4 byte integer (signed int)
  - SERIAL → INTEGER w/ auto increment
  - **NUMERIC(p, s)** → exact real with p digits and s after decimal point
- **Time**
  - **DATE** → date
  - TIMESTAMP/TIMESTAMPTZ → date and time, timezone-aware if needed
- **JSON**
  - JSON → text JSON representation (requires reparsing)
  - JSONB → binary JSON representation

Create, Alter, and Delete Tables

Templates in SQL
Examples in PostgreSQL

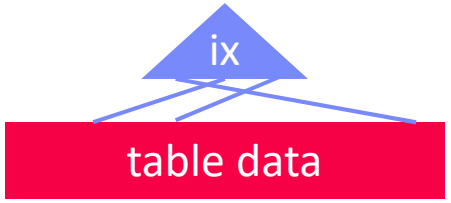
- **Create Table**
  - Typed attributes
  - Primary and foreign keys
  - NOT NULL, UNIQUE constraints
  - DEFAULT values
  - CHECK constraints
- **Alter Table**
  - ADD/DROP columns
  - ALTER data type, defaults, constraints, etc
- **Delete Table**
  - Delete table
  - **Note:** order of tables matters due to referential integrity

```
CREATE TABLE Students (
   SID INTEGER PRIMARY KEY,
   Fname VARCHAR(128) NOT NULL,
   Lname VARCHAR(128) NOT NULL,
   Mtime DATE DEFAULT CURRENT_DATE
);
CREATE TABLE Students AS SELECT …;

ALTER TABLE Students ADD DoB DATE;

ALTER TABLE Students ADD CONSTRAINT
   PKStudent PRIMARY KEY(SID);


DROP TABLE Students; -- sorry
DROP TABLE Students CASCADE;
```

Create and Delete Indexes

- **Create Index**
  - Create a secondary (nonclustered) index on a set of attributes
  - **Clustered:** tuples sorted by index
  - **Non-clustered:** sorted attribute with tuple references
  - Can specify uniqueness, order, and indexing method
  - **PostgreSQL methods:** btree, hash, gist, and gin
    - ➔ see lecture **07 Physical Design and Tuning**

```
CREATE INDEX ixStudLname
   ON Students USING btree
   (Lname ASC NULLS FIRST);
```



- **Delete Index**
  - Drop indexes by name

```
DROP INDEX ixStudLname;
```

- **Tradeoffs**
  - Indexes often automatically created for **primary keys** / **unique** attributes
  - **Lookup/scan performance** vs **insert performance**

Database Catalog

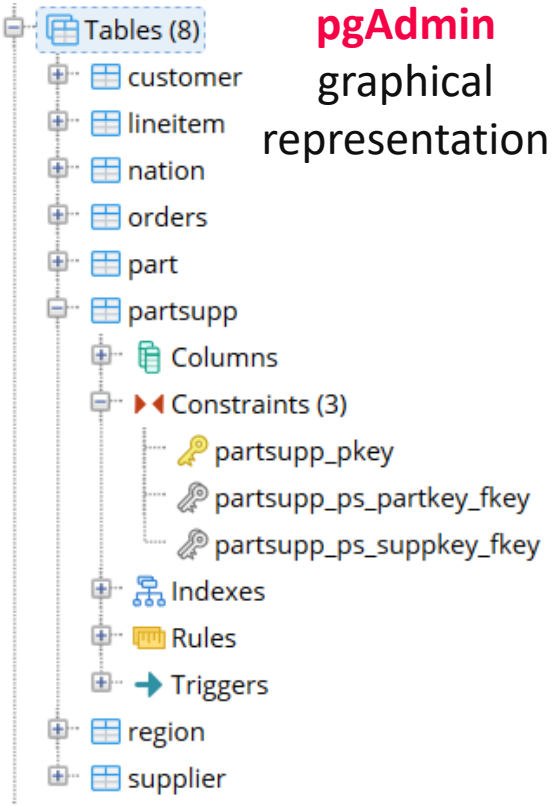
[Meikel Poess: **TPC-H**. **Encyclopedia of Big Data Technologies 2019**]

- **Catalog Overview**
  - **Meta data** of all database objects (tables, constraints, indexes) → **mostly read-only**
  - **Accessible through SQL**
  - Organized by schemas (**`CREATE SCHEMA tpch;`**)

- **SQL `Information_Schema`**
  - Schema with tables for all tables, views, constraints, etc
  - **Example:** check for existence of accessible table

```
SELECT 1 FROM information_schema.tables
WHERE table_schema = 'tpch'
   AND table_name = 'customer'
```

(defined as views over PostgreSQL catalog tables)



pgAdmin graphical representation

Insert

- **Insert Tuple**
  - Insert a single tuple with implicit or explicit attribute assignment

```
INSERT INTO Students (SID, Lname, Fname, MTime, DoB)
   VALUES (7,'Boehm','Matthias','2002-10-01','1982-06-25');
```

  - Insert attribute key-value pairs to use auto increment, defaults, NULLs, etc

```
INSERT INTO Students (Lname, Fname, DoB)
   VALUES ('Boehm','Matthias','1982-06-25'),
          (...), (...);
```

SERIAL SID,
DEFAULT MTime

- **Insert Table**
  - Redirect query result into INSERT (append semantics)

```
INSERT INTO Students
   SELECT * FROM NewStudents;
```

Analogy Linux redirect (append):
cat NewStudents.txt >> Students.txt

Update and Delete

- **Update Tuple/Table**
  - Set-oriented update of attributes
  - Update single tuple via predicate on primary key

```
UPDATE Students
   SET MTime = '2002-10-02'
   WHERE LName = 'Boehm';
```

- **Delete Tuple/Table**
  - Set-oriented delete of tuples
  - Delete single tuple via predicate on primary key

```
DELETE FROM Students
   WHERE extract(year
      FROM mtime) < 2010;
```

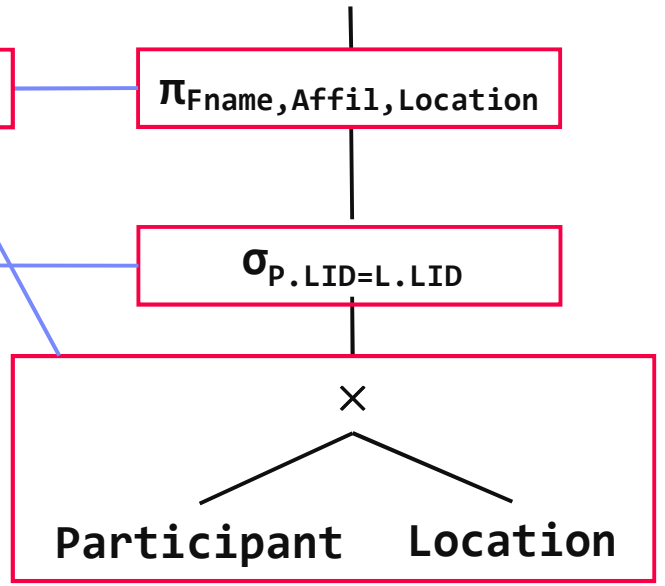
- **Note: Time travel and multi-version concurrency control**
  - Deleted tuples might be just marked as inactive
  - See lecture 09 Transaction Processing and Concurrency

Basic Queries

- **Basic Query Template**
  - Select-From-Where
  - Grouping and Aggregation
  - Having and ordering
  - Duplicate elimination

```
SELECT [DISTINCT] <column_list>
  FROM [<table_list> |
    <table1> [RIGHT | LEFT | FULL] JOIN
    <table2> ON <condition>]
[WHERE <predicate>]
[GROUP BY <column_list>]
  [HAVING <grouping predicate>]
[ORDER BY <column_list> [ASC | DESC]]
```

- **Example**
  - **SELECT** Fname, Affil, Location
    FROM Participant AS R,
    Locale AS S
    WHERE R.LID=S.LID;



Basic Queries, cont.

- **Distinct and All**
  - Distinct and all alternatives
  - Projection w/ **bag semantics** by default

```
SELECT DISTINCT Lname, Fname
   FROM Students;
```

- **Sorting**
  - Convert a bag into a **sorted list** of tuples; order lost if used in other ops
  - Single order: `(Lname, Fname) DESC`
  - Evaluated last in a query tree

```
SELECT * FROM Students
   ORDER BY Lname DESC,
            Fname DESC;
```

- **Set Operations**
  - See lecture **04 Relational Algebra and Tuple Calculus**
  - Distinct (set) and all (bag) alternatives
  - Set operations w/ **set semantics** by default

```
SELECT Firstname, Lastname
FROM Participant2018
  UNION
SELECT Firstname, Lastname
FROM Participant2013
```

Grouping and Aggregation

- **Grouping and Aggregation**
  - **Grouping:** determines the distinct groups
  - **Aggregation:** compute aggregate f(B) per group
  - Column list can only contain **grouping columns**, **aggregates**, or **literals**
  - **Having:** selection predicate on groups and aggregates

- **Example**
  - Sales (Customer, Location, Product, Quantity, Price)
  - **Q: Compute number of sales and revenue per product**

```
SELECT Product, sum(Quantity), sum(Quantity*Price)
   FROM Sales
   GROUP BY Product
```

Subqueries

- **Subqueries in Table List**
  - Use a subquery result like a base table
  - Modularization with **WITH** C **AS** (**SELECT** …)

```
SELECT S.Fname, S.Lname, C.Name
FROM Students AS S,
  (SELECT CID, Name FROM County
  WHERE …) AS C
WHERE S.CID=C.CID;
```

- **Subqueries w/ IN**
  - Check containment of values in result set of sub query

```
SELECT Product, Quantity, Price
FROM Sales
WHERE Product NOT IN(
   SELECT Product FROM Sales
   GROUP BY Product
   HAVING sum(Quantity*Price)>1e6)
```

- **Other subqueries**
  - **EXISTS:** existential quantifier **∃x** for correlated subqueries
  - **ALL:** comparison (w/ universal quantifier **∀x**)
  - **SOME/ANY:** comparison (w/ existential quantifier **∃x**)

Correlated and Uncorrelated Subqueries

- **Correlated Subquery**
  - **Evaluated subquery for every tuple** of outer query
  - Use of attribute from table bound in outer query inside subquery

```
SELECT P.Fname, P.Lname
FROM Professors P,
WHERE NOT EXISTS(
   SELECT * FROM Courses C
   WHERE C.PID=P.PID);
```

- **Uncorrelated Subquery**
  - Evaluate subquery just once
  - No attribute correlations between subquery and outer query

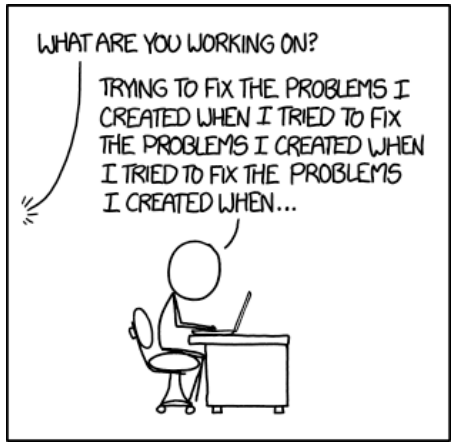
```
SELECT P.Fname, P.Lname
FROM Professors P,
WHERE P.PID NOT IN(
   SELECT PID FROM Courses);
```

- **Query Unnesting (de-correlation)**
  - Rewrite during query compilation
  - See lecture **08 Query Processing**

[Thomas Neumann, Alfons Kemper: Unnesting Arbitrary Queries. **BTW 2015**]

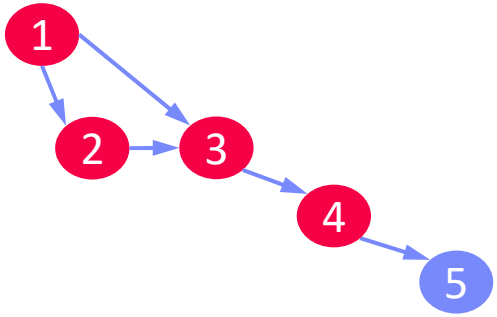
Recursive Queries

- **Approach**
  - `WITH RECURSIVE <name> (<arguments>)`
  - Compose recursive table from **non-recursive term**, **union all/distinct**, and **recursive term**
  - Terminates when recursive term yields empty result



[https://xkcd.com/1739/]

- **Example**
  - Courses(CID, Name), Precond(pre REF CID, suc REF CID)
  - Dependency graph (pre→suc)




```
WITH RECURSIVE rPrereq(p,s) AS(
   (SELECT pre, suc
      FROM Precond WHERE suc=5)
  UNION DISTINCT
   (SELECT B.pre, B.suc
    FROM precond B, rPrereq R
    WHERE B.suc = R.p)
)
SELECT DISTINCT p FROM rPrereq
```

4
3
1
2

Procedures and Functions

- **Overview Procedures and Functions**
  - Stored programs, written in **PL/pgSQL** or other languages
  - **Control flow (loops, branches) and SQL queries**

- **(Stored) Procedures**
  - Can be called standalone via `CALL <proc_name>(<args>);`
  - Procedures return no outputs

- **Functions**
  - Can be called standalone or inside queries
  - Functions are value mappings
  - Table functions can return sets of records with multiple attributes

```
CREATE PROCEDURE prepStud(a INT)
LANGUAGE PLPGSQL AS $$
BEGIN
   DELETE FROM Students;
   INSERT INTO Students
      SELECT * FROM NewStudents;
END; $$;
```

```
CREATE FUNCTION sampleProp(FLOAT)
   RETURNS FLOAT
   AS 'SELECT $1 * (1 - $1);'
   LANGUAGE SQL;
```

Triggers

- **Overview Trigger**
  - Similar to stored procedure but register ON INSERT, DELETE, or UPDATE
  - Allows complex check constraints and active behavior such as replication, auditing, etc (good and bad)

- **Trigger Template**

```
CREATE TRIGGER <triggername>
    BEFORE | AFTER | INSTEAD OF
    INSERT | DELETE | (UPDATE OF <column_list>)
    ON <tablename>
    [REFERENCING <old_new_alias_list>]
    [FOR EACH {ROW | STATEMENT}]
    [WHEN (<search condition>)]
    <SQL procedure statement> |
    BEGIN ATOMIC
      {<SQL Procedure statement>;}...
    END
```

Event

Condition

Action

Not supported in PostgreSQL (need single UDF)

Views and Authorization

- **Creating Views**
  - Create a logical table from a query
  - Inserts can be propagated back to base relations only in special cases
  - Allows authorization for subset of

```
CREATE VIEW TeamDM AS
  SELECT * FROM
    Employee E, Employee M
  WHERE E.MgrID = M.EID
    AND M.login = 'mboehm';
```

- **Access Permissions Tables/Views**
  - Grant query/modification rights on database objects for specific users, roles
  - Revoke access rights from users, roles (recursively revoke permissions of dependent views via **CASCADE**)

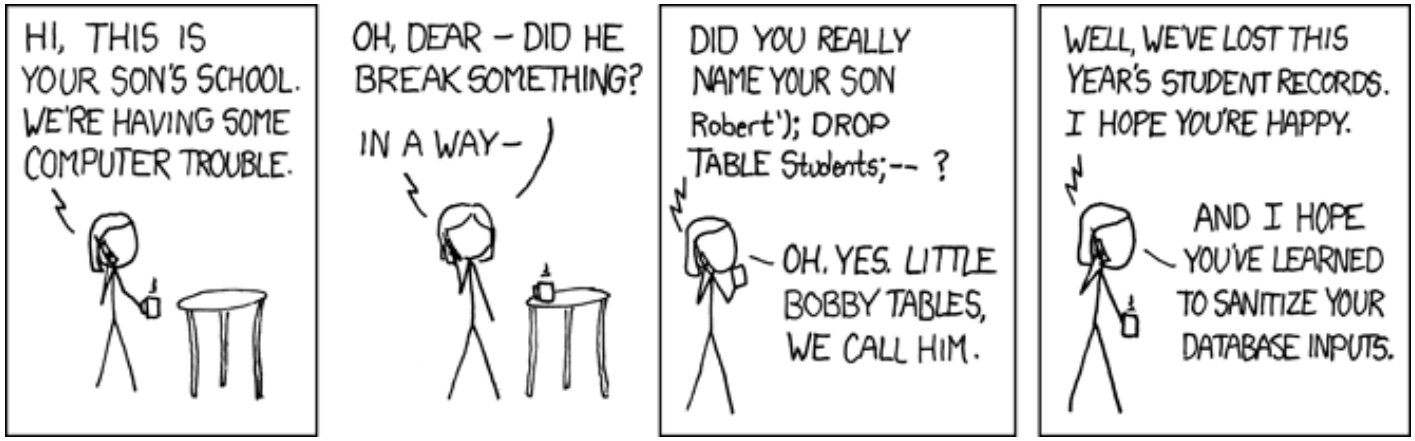
```
GRANT SELECT
    ON TABLE TeamDM
    TO mboehm;

REVOKE SELECT
    ON TABLE TeamDM
    FROM mboehm;
```

Beware of SQL Injection

- **Problematic SQL String Concatenation**

```
INSERT INTO Students (Lname, Fname)
   VALUES (‘“+ @lname +”‘,’“+ @fname +”’);”;
```

- **Possible SQL-Injection Attack**



[https://xkcd.com/327/]

```
INSERT INTO Students (Lname, Fname) VALUES (‘Smith‘,’Robert’);
DROP TABLE Students; --’);
```

Other Query Languages (XML, JSON)

No really, why should I care?

- **Semi-structured XML and JSON**
  - **Self-contained documents** for representing nested data
  - **Common data exchange formats** without redundancy of flat files
  - Human-readable formats → often used for SW configuration

- **Goals**
  - **Awareness of XML and JSON** as data models
  - Query languages and embedded querying in SQL

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
```

↓

```
"Databases"
"AMLS"
```

- **XSLT** (XML Stylesheet Language Transformations)
  - Schema mapping (transformation) language for XML documents
- **XQuery**
  - Query language to extract, transform, and analyze XML documents

XML in PostgreSQL, cont.

- **Overview XML in PostgreSQL**
  - Data types **TEXT** or **XML** (well-formed, type-safe operations)
  - ISO/IEC 9075-14 XML-related specifications (SQL/XML)

- **Creating XML**
  - Various **builtin functions** to parse documents, and create elements/attributes
  - XMLPARSE(<xml_document>) → **XML type**
  - XMLELEMENT / XMLATTRIBUTES

```
INSERT INTO Students
  (Fname,Lname,Doc)
 VALUES('John','Smith',
 xmlparse(<source_doc>));
```

- **Processing XML**
  - Execute **XPath** expressions on XML types
  - XMLEXIST with **XPath instead of XQuery**
  - XPATH with optional namespace handling

```
SELECT Fname, Lname,
  xpath('/student/@id',Doc)
  FROM Students
```

JSON (JavaScript Object Notation)

- **JSON Data Model**
  - Data exchange format for **semi-structured data**
  - **Not as verbose as XML** (especially for arrays)
  - Popular format (e.g., Twitter)

```
{“students:”[
  {“id”: 1, “courses”:[
    {“id“:“INF.01014UF”, “name“:“Databases”},
    {“id“:“706.550”, “name“:“AMLS”}]},
 {“id”: 5, “courses”:[
    {“id“:“706.004”, “name“:“Databases 1”}]},
]}
```

- **Query Languages**
  - **Most common: libraries** for tree traversal and data extraction
  - **JSONig:** XQuery-like query language
  - **JSONPath:** XPath-like query language

JSONiq Example:

```
declare option jsoniq-version “…”;
for $x in collection(“students”)
  where $x.id lt 10
  let $c := count($x.courses)
  return {“sid”:$x.id, “count”:$c}
```

[http://www.jsoniq.org/docs/JSONiq/html-single/index.html]

JSON in PostgreSQL, cont.

- **Overview JSON in PostgreSQL**
  - Alternative data types: **JSON** (text), **JSONB** (binary, with restrictions)
  - Implements RFC 7159, builtins for conversion and access

- **Creating JSON**
  - Builtin functions for creating JSON from tables and tables from JSON input

```
SELECT row_to_json(t) FROM
   (SELECT Fname, Lname
   FROM Students) t
```

- **Processing JSON**
  - Specialized operators for **tree traversal and data extraction**

```
SELECT Fname, Lname,
   Doc->students->>id
   FROM Students
```

  - **-> operator:** get JSON array element/object
  - **->> operator:** get JSON array element/object as text
  - Builtin functions for extracting json (e.g., json_each)

Conclusions and Q&A

- **Summary**
  - History and fundamentals of the **Structured Query Language (SQL)**
  - Awareness of **XML and JSON** (data model and querying)

- **Exercise 1 Reminder**
  - All background to solve tasks 1.1-1.3 since last lecture
  - Submission: **since Mar 25**, Deadline: **Apr 02 11.59pm**

- **Next Lectures**
  - Apr 08: **06 APIs (ODBC, JDBC, OR frameworks)**, **incl. Exercise 2**