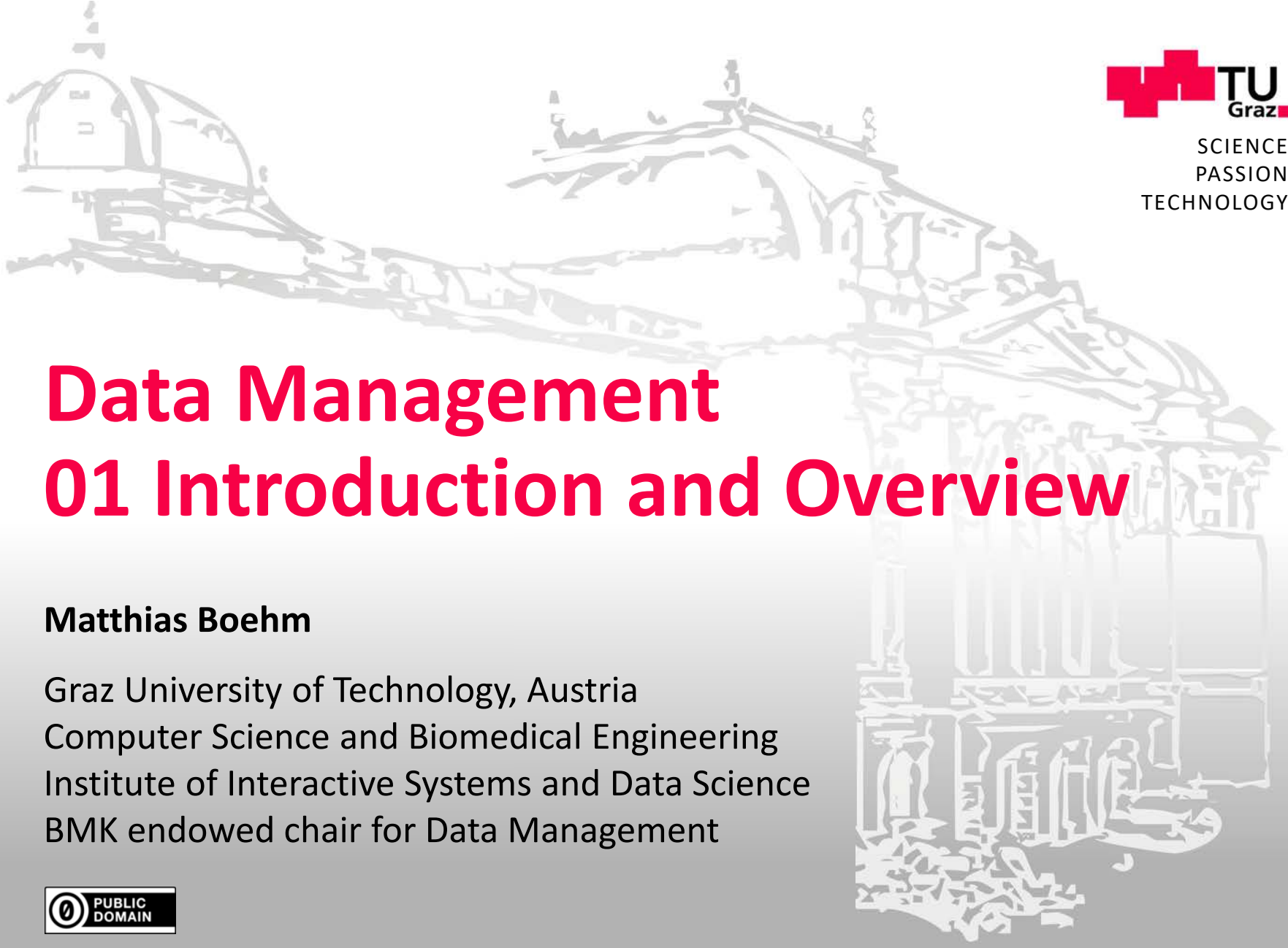


SCIENCE
PASSION
TECHNOLOGY

Data Management
01 Introduction and Overview

Matthias Boehm

Graz University of Technology, Austria
Computer Science and Biomedical Engineering
Institute of Interactive Systems and Data Science
BMK endowed chair for Data Management

Last update: Mar 04, 2022

ISDS

Announcements/Org

- **#1 Video Recording**
  - Link in **TeachCenter** & **TUbe** (lectures will be public)
  - Hybrid, in-person (optional), TUbe video-recording, and webex live: https://tugraz.webex.com/meet/m.boehm
  - **Update:** status **ORANGE**, max 50% capacity, 2.5G rule

- **#2 Course Registrations** (as of Mar 04)
  - **Data Management VO:** **459 (4)**
  - **Data Management KU:** 447 (2)
  - **Databases VU:** **67 (0)**, incl. CSS

526 (4)

- **#3 Gründungsgarage Volume XVIII**
  - Academic Startup Accelerator
  - https://www.gruendungsgarage.at/
  - Next application deadline: **Mar 13, 2022**

Announcements/Org, cont.

- **#4 Learning Analytics – Students in Focus**
  - Self-regulated Learning Strategies
  - Learner's Corner (overview, consent form) https://tc.tugraz.at/main/course/view.php?id=4390
  - **5min-overview** by Carla Souta Barreiros

Agenda

- **Data Management Group**
- **Course Motivation, Goals, and Outline**
- **Course Organization and Logistics**
- **History of Data Management**

Data Management Group

https://damslab.github.io/

About Me

- **2018-2022 TU Graz**, Austria
  - BMK endowed chair for data management
  - **Data management for data science**
    (ML systems internals, end-to-end data science lifecycle)

https://github.com/apache/systemds

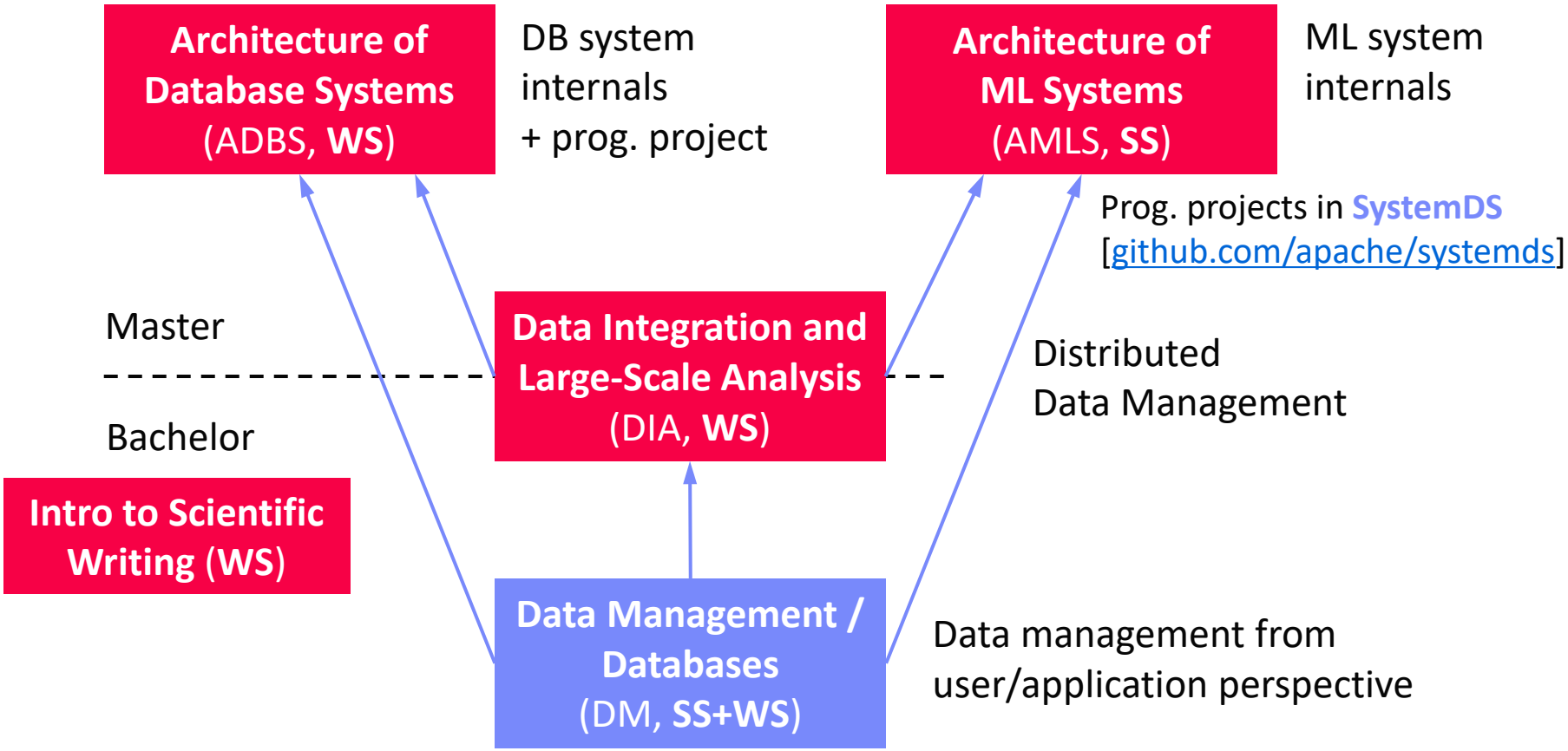
- **2012-2018 IBM Research – Almaden**, USA
  - Declarative large-scale machine learning
  - Optimizer and runtime of **Apache SystemML**

- **2011 PhD TU Dresden**, Germany
  - Cost-based optimization of integration flows
  - Systems support for time series forecasting
  - In-memory indexing and query processing

TECHNISCHE UNIVERSITÄT DRESDEN

DB group

Data Management Courses

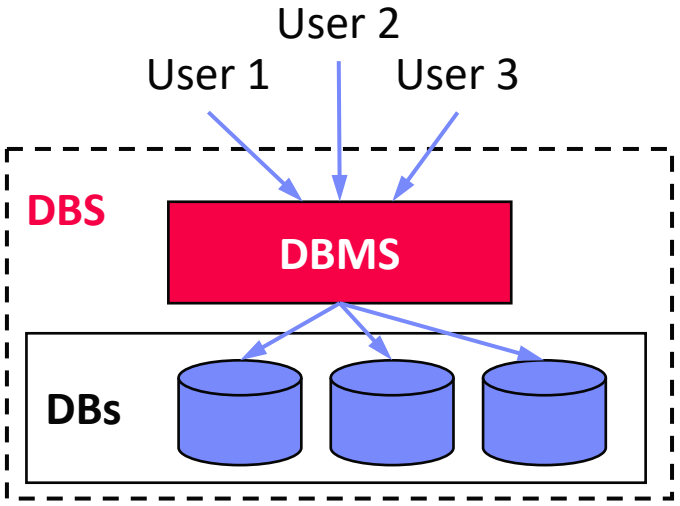


Course Motivation, Goals, and Outline

Database Systems and Modern Data Management

Definition and Impact

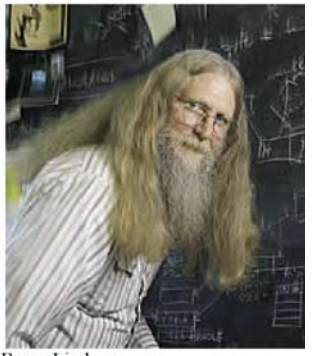
- **Def: Database System**
  - Overall system of DBMS + DBs
  - DBMS: Database Management System (SW to handle DBs)
  - DBs: Database (data/metadata collection of conceptual mini-world)
  - Note: DB also a short for DBS/DBMS



- **Importance in Practice**
  - Market Volume: **10-100B $US**
  - Foundation of many applications in various domains

"Relational databases are the foundation of western civilization"

[Marianne Winslett: Bruce Lindsay speaks out: […]. SIGMOD Record 34(2), **2005**]



Bruce Lindsay

Motivation Database Systems

- **Application development and maintenance costs**
  - Declarative queries (what not how) and data independence
  - Efficient, correct, and independent data organization, size, access
- **Multi-user operations and access control**
  - Synchronization of concurrent user queries and updates
  - Enforce access control (e.g., permissions on tables, views)
- **Consistency and data integrity**
  - Eliminates redundancy and thus, enforces consistency
  - Enforces integrity constraints (e.g., semantic rules)
- **Logging and Recovery**
  - Recovery of consistent state after HW or SW failure
- **Performance and Scalability**
  - High performance for large datasets or high transaction throughput
  - Scale to large datasets with low memory requirements

Goals

- **Course Goals**
  - **A:** Understanding of **database systems** (from user perspective)
  - **B:** Understanding of **modern data management** (from user perspective)

	INF.01017UF (VO) Data Mgmt.	**INF.02018UF (KU) Data Mgmt.**
706.010 (VU) Databases	Part A 9 Lectures	Part A 3 Exercises
3(2) ECTS	Part B 3 Lectures	Part B 1 Exercise
	3 ECTS	1 ECTS

- **Meta Goals**
  - **Understand**, **use**, **debug**, and **evaluate** data management systems
  - Awareness of **system alternatives** and their **tradeoffs**
  - Fundamental concepts as basis for advanced courses and other areas

Part A: Database System Fundamentals

- **01 Introduction and Overview** [Mar 07]
- **02 Conceptual Architecture and Design** [Mar 14]
- **03 Data Models and Normalization** [Mar 21]

→ Exercise 1: Data Modeling **[Mar 29]**

- **04 Relational Algebra and Tuple Calculus** [Mar 28]
- **05 Query Languages (SQL, XML, JSON)** [Apr 04]
- **06 APIs (ODBC, JDBC, OR frameworks)** [Apr 25]

→ Exercise 2: Queries **[May 03]**

- **07 Physical Design and Tuning** [May 02]
- **08 Query Processing** [May 09]
- **09 Transaction Processing and Concurrency** [May 16]

→ Exercise 3: Tuning **[May 31]**

For course Databases:
part of Exercise 3 is **extra credit**

Part B: Modern Data Management

- **10 NoSQL (key-value, document, graph, time series)** [May 23]
- **11 Distributed Storage and Data Analysis** [May 30]
- **12 Data Stream Processing Systems** [Jun 13]

→ Exercise 4: Spark (**extra credit**) **[Jun 21]**

- **13 Q&A and exam preparation** [Jun 13]
- **Final written exam** [TBD, Jan 20 / Jan 27?]

since WS2020/21: **Automated Grading System for Exercises 2, 3, 4** (grading time, and consistent grading)

Course Organization

Basic Course Organization

- **Staff**
  - **Lecturer:** Univ.-Prof. Dr.-Ing. Matthias Boehm, ISDS
    Assistant Lecturer: M.Tech. Arnab Phani, ISDS
  - **Teaching Assistants:**
    Nives Križanec, Luca Winkler, Katharina Aschbacher
    Ema Salkić, Alexander C. Friessnig, Adnan Karamehić,
    Harald Semmelrock








HS

- **Language**
  - Lectures and slides: **English**
  - Communication and exams: **English**/**German**

- **Course Format**
  - DM VO + KU 2/1 (**3+1 ECTS**), DB VU 1/1 (**3(2) ECTS**)
  - **Weekly lectures** (**start 4.10pm**, including **Q&A**), **attendance optional**
  - **3+1 exercises** (introduced in lecture) as individual assignments

Course Logistics

- **Communication**
  - **Informal language** (first name is fine)
  - Please, **immediate feedback** (unclear content, missing background)
  - **Newsgroup:** news://news.tugraz.at/tu-graz.lv.dbase (email for private issues)
  - **Office hour: Mo 12.30pm** (via https://tugraz.webex.com/meet/m.boehm), or after lecture

- **Website**
  - https://mboehm7.github.io/teaching/ss22_dbs/index.htm
  - All course material (lecture slides, exercises) and dates

- **Exam**
  - **Completed mandatory exercises** (Mar 29, May 03, May 31, [Jun 21])
  - **Final written exam** (TBD, doodle for oral exams)
  - **DB Grading** (30% exercises, 70% final), **DM Grading** (separate courses)

Course Logistics, cont.

- **Exercises**
  - Written and programming assignments, submitted through **TeachCenter**
  - Assignments **completed if >50% points in total** (**but all submitted**)
  - Deadlines are important (**at most 7 late days in total**)
  - Individual assignments (**academic honesty / no plagiarism**)

- **SW Tools and Languages**
  - **Open Source PostgreSQL** DBMS (setup on your own)
  - Distributed FS/object storage and **Apache Spark** for distributed computation
  - Languages for local/distributed programs (of your choice):
    e.g., **Python**, **Java**, **Scala**, C, C++, C#, Rust, Go, etc.

Exercises: Graz Districts

New

www.data.gv.at

- **Dataset**
  - Graz districts, streets, schools, universities, population counts by age and country (to be cleaned and prepared → Ex 02)
  - Clone or download your copy from https://github.com/tugraz-isds/datasets.git
  - Find CSV files in <datasets>/districts_graz

- **Exercises**
  - **01** Data modeling (relational schema)
  - **02** Data ingestion and SQL query processing
  - **03** Physical design tuning, query processing, and transaction processing
  - **04** Large-scale data analysis (distributed query processing and ML model training – anomalies?)

Literature

- **Not needed for lectures / exercises** (course is self-contained), **but second perspective on covered topics of first part**
- Raghu Ramakrishnan, Johannes Gehrke: Database Management Systems (3. ed.). McGraw-Hill 2003, ISBN 978-0-07-115110-8, pp. I-XXXII, 1-1065
- Jeffrey D. Ullman, Jennifer Widom: A first course in database systems (2. ed.). Prentice Hall 2002, ISBN 978-0-13-035300-9, pp. I-XVI, 1-511
- Ramez Elmasri, Shamkant B. Navathe: Fundamentals of Database Systems, 3rd Edition. Addison-Wesley-Longman 2000, ISBN 978-0-8053-1755-8, pp. I-XXVII, 1-955
- Alfons Kemper, André Eickler: Datenbanksysteme - Eine Einführung, 10. Auflage. De Gruyter Studium, de Gruyter Oldenbourg 2015, ISBN 978-3-11-044375-2, pp. 1-879

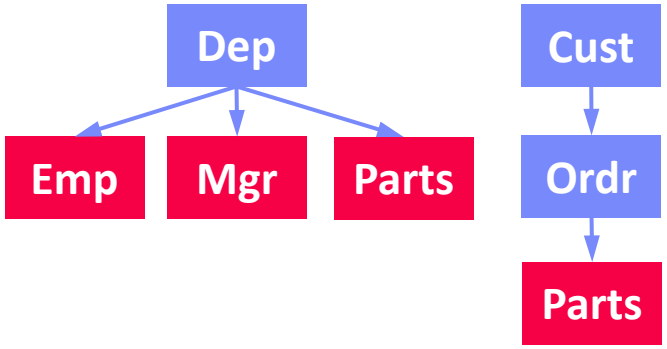
Additional Perspective: [Zachary G. Ives, Rachel Pottinger, Arun Kumar, Johannes Gehrke, Jana Giceva: The future of data(base) education: Is the "cow book" dead?, **VLDB 2021**]

History of Data Management

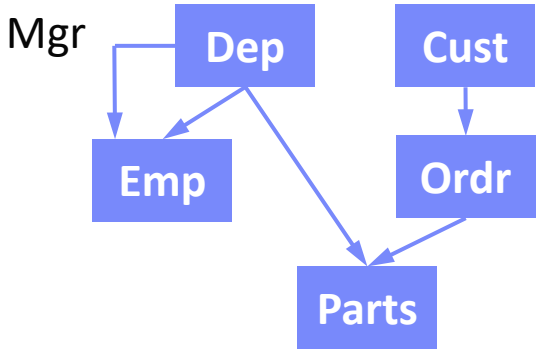
History 1960/70s (pre-relational)

CODASYL … Conference on Data Systems Languages

- **Hierarchical Model**
  - Tree of records
  - E.g., IBM Information Management System (IMS) – IMS 15 (Oct 2017)



- **Network Model**
  - CODASYL (COBOL, DB interfaces)
  - Graph of records
  - Charles Bachman (Turing Award '73)
  - E.g., Integrated Data Store (IDS)



- **Pros and Cons** (see NoSQL Doc-Stores)
  - Performance by **directly traversing static links**
  - **Duplicates** → inconsistencies on updates, **data dependence**

History 1970/80s (relational)

Ingres @ UC Berkeley (Stonebraker et al., Turing Award '14)

QUEL

SQL Standard (SQL-**86**)

SEQUEL

System R @ IBM Research – Almaden (Jim Gray et al., Turing Award '98)

Oracle, IBM DB2, Informix, Sybase → MS SQL

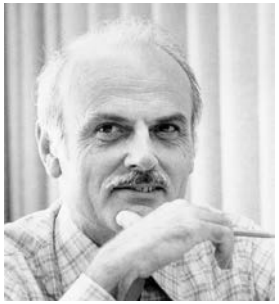
Tuple Calculus

Relational Algebra

Relational Model

Goal: Data Independence (physical data independence)

- Ordering Dependence
- Indexing Dependence
- Access Path Depend.



Edgar F. "Ted" Codd @ IBM Research (Turing Award '81)

[E. F. Codd: A Relational Model of Data for Large Shared Data Banks. Comm. ACM 13(6), **1970**]

Success of SQL / Relational Model

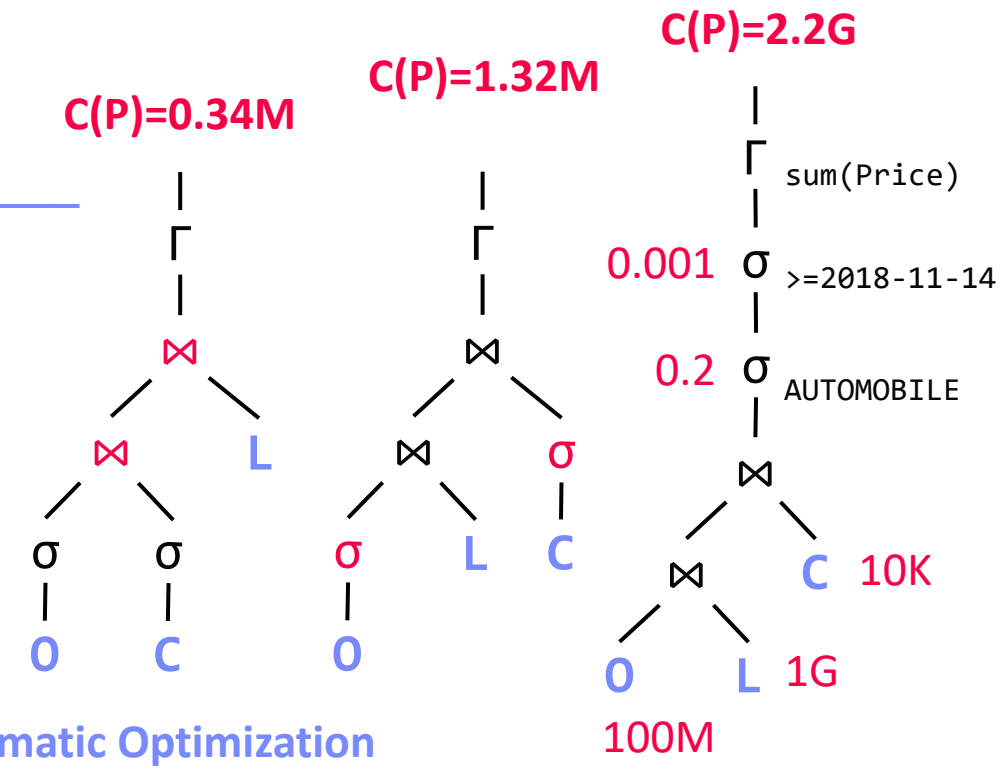
Query:

```
SELECT O_OID, sum(L_Price)
FROM Orders, Lineitem, Customer
WHERE O_OID = L_OID AND O_CID = C_CID
   AND O_Odate >= '2018-11-14'
   AND C_Msegment = 'AUTOMOBILE'
GROUP BY O_OID
```

#1 Declarative: what not how

#2 Flexibility: closure property → composability

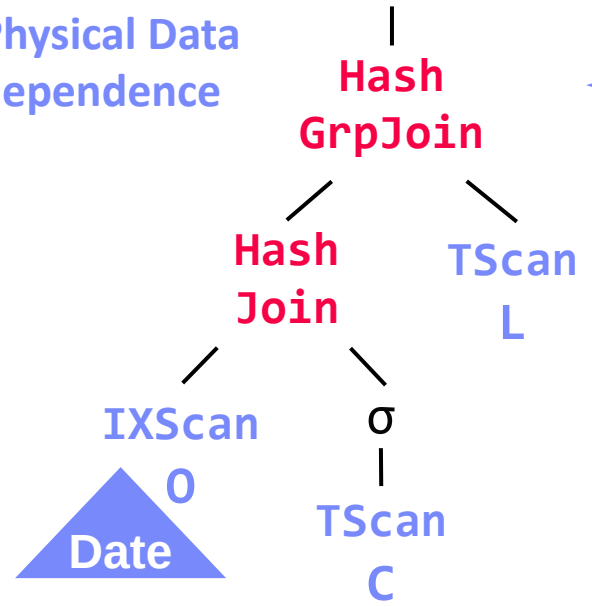
Logical Query Plans



#3 Automatic Optimization

#4 Physical Data Independence

Physical Query Plan



Excursus: PostgreSQL

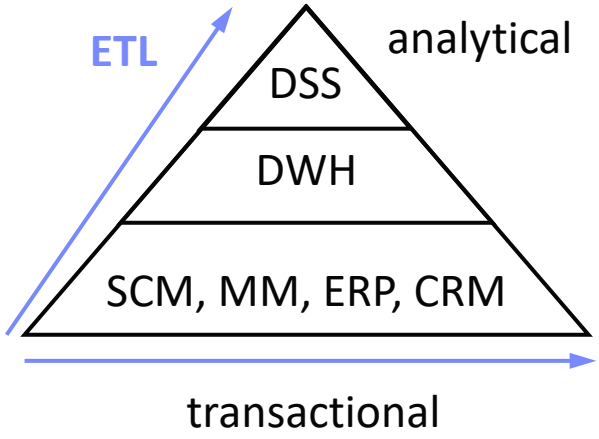
- **History of PostgreSQL** (used in the exercises)
  - Postgres is the successor project of commercialized Ingres
  - Focus on abstract data types, commercialized as Illustra
  - Prototype w/ SQL open sourced as **Postgres95** → **PostgreSQL**
  - Heavily used as **basis for research projects / startups**

- **Recommended Reading**
  - Michael Stonebraker: The land sharks are on the squawk box. Commun. ACM 59(2): 74-83 (2016), Turing Award Lecture, https://dl.acm.org/citation.cfm?doid=2886013.2869958
  - **Video:** http://www.youtube.com/watch?v=sEPTZVGk3WY
  - **Slides:** http://vldb.org/2015/wp-content/uploads/2015/09/stonebraker.pdf

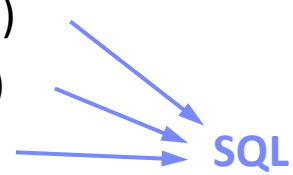
History 1980/90/2000s

OLTP … Online Transaction Processing
OLAP … Online Analytical Processing
ETL … Extract, Transform, Load

- **Enterprise DBMS**
  - **Heavy investment in research and development** ➔ adoption
  - Oracle, IBM DB2, Informix, Sybase, MS SQL, PostgreSQL, MySQL
  - **Other technologies:** OODBMS, Multimedia, Spatiotemporal, Web, XML
- **Information/Data Warehousing (DWH)**
  - **Workload separation into OLTP and OLAP**
  - **Classical DWH architecture:** operational, staging, DWH, data marts + mining
  - **ETL Process** (Extract, Transform, Load)



- **Different Personas**
  - Domain Experts (e.g., BI Tools, SAP R/3)
  - DB Application Developers (e.g., ABAP)
  - DB Developers and DB Admins



History 2000s / Early 2010s

- **Specialized Systems**
  - **Column stores + compression** for OLAP
  - **Main memory systems** for OLTP and OLAP
  - Data streaming, scientific and graph databases
  - Information extraction / retrieval, and XML

[M. Stonebraker, S. Madden, D. J. Abadi, S. Harizopoulos, N. Hachem, P. Helland: **The End of an Architectural Era** (It's Time for a Complete Rewrite). **VLDB 2007**]

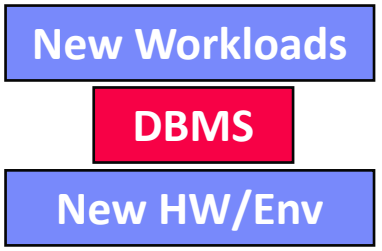
- **Other Research Trends**
  - Approximate QP / **Adaptive QP** / tuning tools
  - **Large-scale data management** (DFS, MR) / **cloud computing**

- **Toward Flexible, Large-Scale Data Management** (DWH … a bygone era)
  - **MAD Skills (magnetic, agile, deep)**, MADlib
  - Integration of R, Python in data analysis
  - Open data and its integration
  - Query processing over raw data files

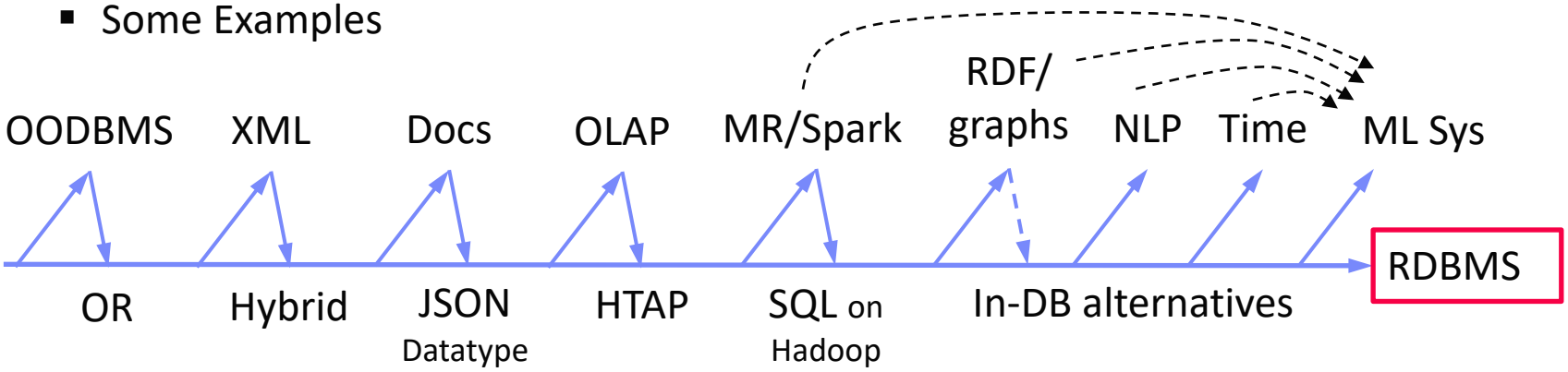
[J. Cohen, B. Dolan, M. Dunlap, J. M. Hellerstein, C. Welton: **MAD Skills**: New Analysis Practices for Big Data. **PVLDB 2(2) 2009**]

History 2010s – Present

- **Two Key Drivers of DB Research**
  - **New analysis workloads** (NLP, key/value, RDF/graphs, documents, time series, ML) and applications
  - **New HW/infrastructure** (multi-/many-core, cloud, scale-up/ scale-out, NUMA/HBM, RDMA, SSD/NVM, FPGA/GPU/ASIC)



- **Excursus: A retrospective view of specialized systems**
  - **Goal #1**: Avoid boundary crossing ➔ **General-purpose**
  - **Goal #2**: New workload + Performance ➔ **Specialized systems**
  - Some Examples



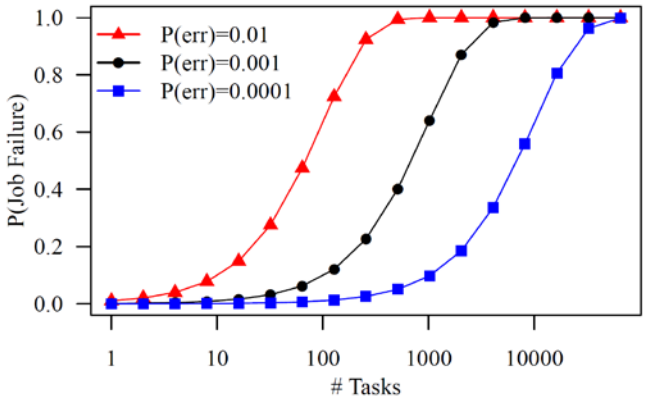
History 2010s – Present, cont.

- **Motivation NoSQL Systems**
  - **Flexible schema** (no upfront costs), **scalability**, or specific data types
  - Relaxed **ACID** (atomicity, consistency, isolation, durability) requirements
    ➔ **BASE** (basically available, soft state, eventual consistency)

- **Example NoSQL Systems** (local and distributed)**:**
  - **Key/Value-Stores:** simple put/get/delete, massive scalability
  - **Document-Stores:** store nested documents (tree)
  - **RDF Stores:** store subject-predicate-object triples
  - **Graph DBs:** store nodes/edges/attributes, vertex-centric
  - **Time Series DBs:** store sequences of observations

History 2010s – Present, cont.

- **Motivation Large-Scale Data Management**
  - **Massive scalability** (data/compute) on demand, **fault tolerance**, flexibility
  - Example Facebook 2014: **300PB** DWH, **600TB** daily ingest
  - Cost-effective commodity hardware
  - Error rate increases with increasing scale



- **Examples Large-Scale Data Management**
  - Distributed file systems w/ replication (e.g., GPFS, HDFS)
  - **Cloud object storage** (e.g., Amazon s3, OpenStack Swift)
  - Data-parallel data analysis with Spark/Flink, incl streaming
  - Automatic cloud resource elasticity (pay as you go)

Data Lake

Summary and Q&A

- **#1 Database Systems**
  - Mature and established technology ➔ broadly applicable & eco system
  - **General concepts:** abstraction, data modeling, query optimization & processing, transaction processing and recovery, physical design and tuning
- **#2 Modern Data Management**
  - Multiple specialized systems for specific scale / data types
  - General trend toward less upfront cost, flexibility, and higher scalability

➔ **Variety of data management tools → Course meta goals**

- **Understand, use, debug**, and evaluate data management systems
- **Fundamental concepts** as basis for advanced courses and other areas

- **Next Lectures**
  - **02 Conceptual Architecture and Design** [Mar 14] (ER Diagrams)
  - **03 Data Models and Normalization** [Mar 21] (ERD → Relational Model)