Data Management
01 Introduction and Overview

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Last update: Oct 07, 2019

Announcements/Org

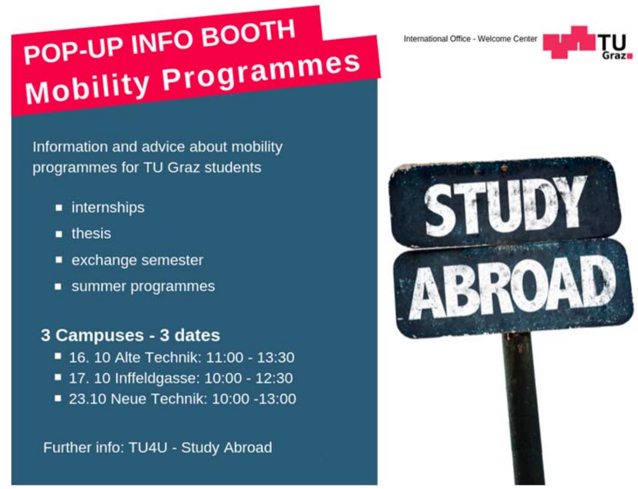
- **#1 Video Recording**
  - Link in TeachCenter & TUbe (lectures will be public)
- **#2 CS Talks x5** (Oct 15, 5pm, Aula Alte Technik)
  - Margarita Chli (ETH Zurich)
  - Title: How Robots See – Current Challenges and Developments in Vision-based Robotic Perception

- **#3 Course Intro International Entrepreneurship**
  - Understanding of intern. business, markets, and people
  - Lecturer: Univ.-Prof. Dr. techn. Hongying Foscht
  - Beginning Oct 9, 2019; 4 ECTS, 706.319

- **#4 Master Thesis – JOANNEUM RESEARCH Health**
  - **Thesis topic:** Development and validation of a hybrid decision model to identify frailty in older adults with care needs in geriatric care facilities
  - 60% part-time employment JOANNEUM RESEARCH, 8 months, € 831

Announcements/Org, cont.

- **#5 Study Abroad Info**
  - **Oct 17, 10am** @ Inffeldgasse
  - Internships, master theses, study courses, summer programs



- **#6 Workshop - Focus on FAIR**
  - **Nov 7**, **9.30am – 4pm** (all day)
  - Student reach-out BS, MS, PhD
  - Invited speakers from EGI, TU Delft, Uni. Vienna, Uni. Barcelona, UCL, and TU Graz/Know-Center

Agenda

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

Data Management Group

About Me

- **09/2018 TU Graz**, Austria
  - BMVIT endowed chair for data management
  - **Data management for data science**
    (ML systems internals, end-to-end data science lifecycle)

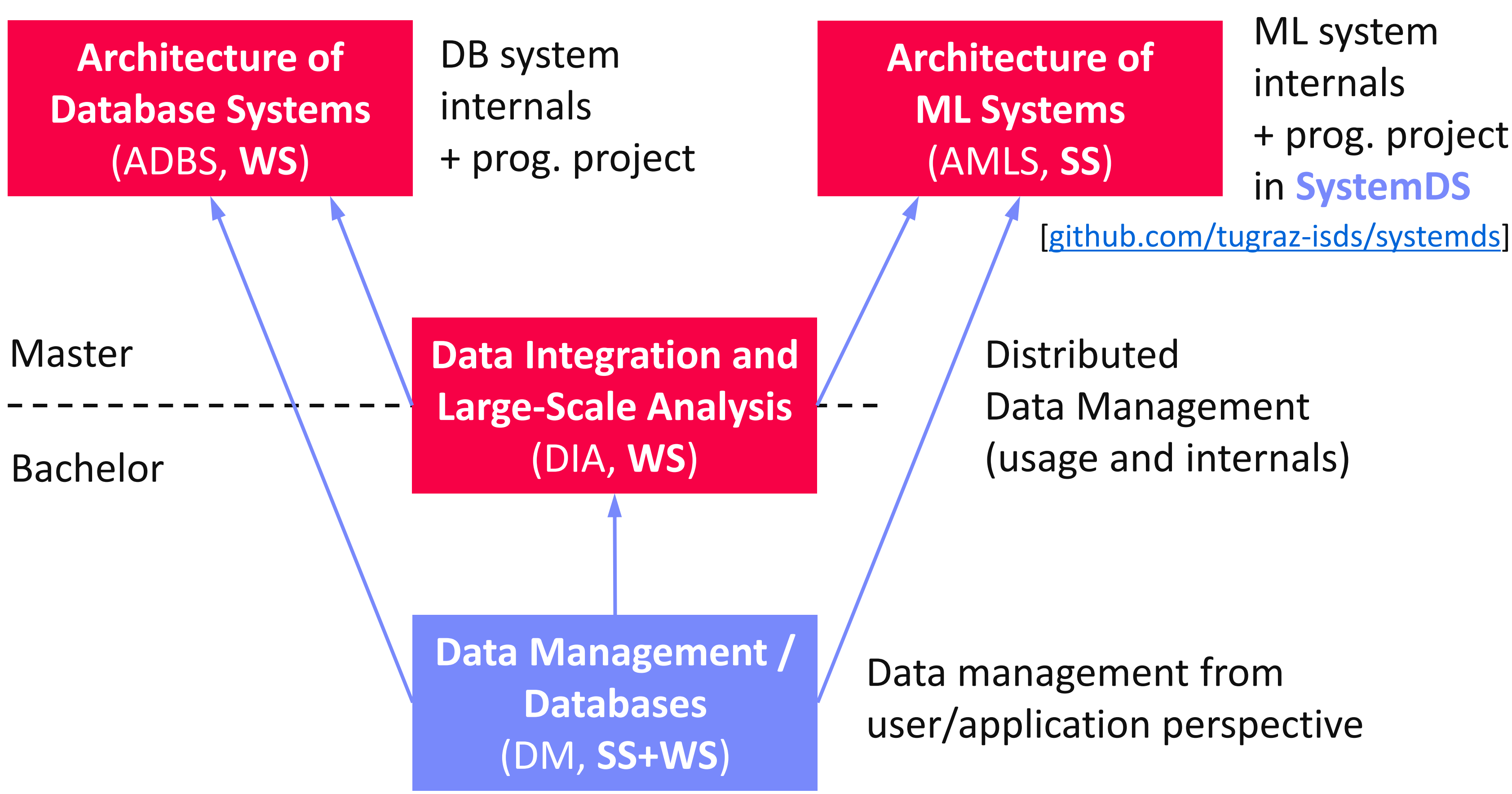
https://github.com/tugraz-isds/systemds

- **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

DB group

Data Management Courses

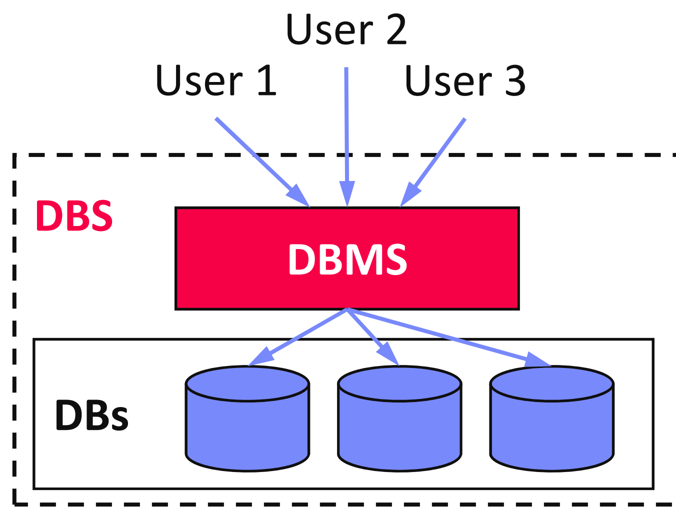


Course Motivation, Goals, and Outline

Database Systems and Modern Data Management

Definition and Impact

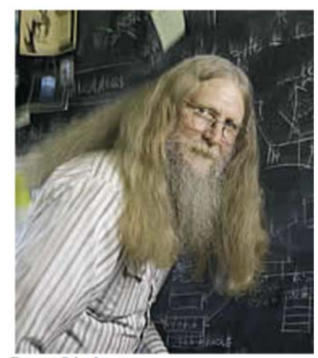
- **Def: Database System**
  - Overall system of DBMS + DBs
  - DBMS: Database Management System (SW to handle DBs)
  - DBs: Database (data/metadata collection of conceptual mini-world)
  - Note: DB also a short for DBS/DBMS



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

"Relational databases are the foundation of western civilization"

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



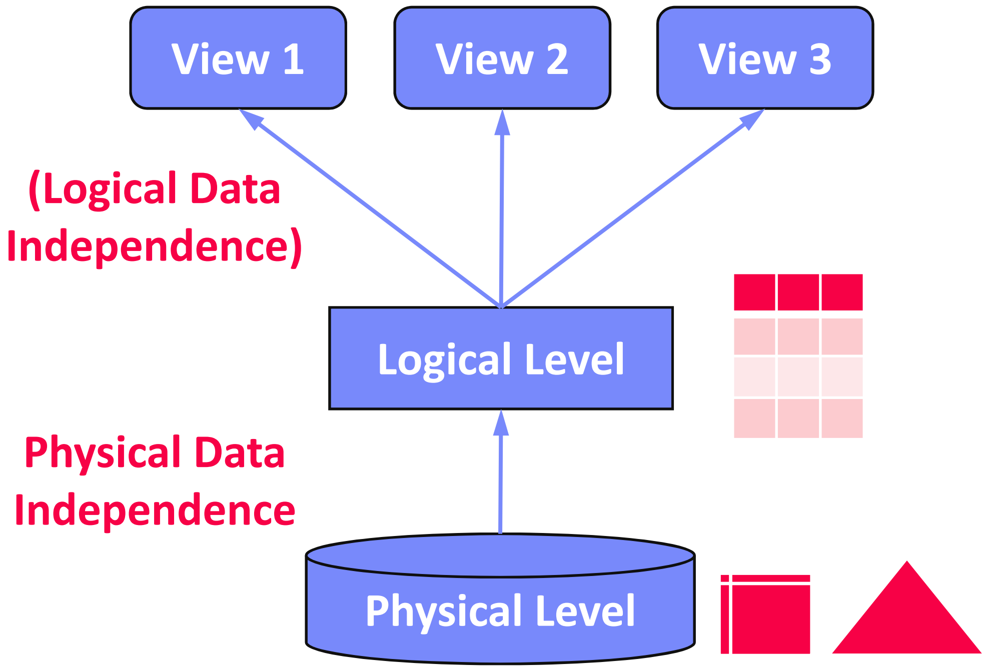
Bruce Lindsay

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

Data Independence

- **Three Layer ANSI-SPARC Architecture**
  - External schemas (external level)
  - Conceptual schema (logical level)
  - Internal schema (physical level)



- **Types of Data Independence**
  - Logical data independence (external views and applications independent of logical data model)
  - Physical data independence (logical data model independent of underlying data organization)

Goals

- **Course Goals**
  - **A:** Understanding of database systems **from user perspective**
  - **B:** Understanding of modern means of 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** [Oct 07]
- **02 Conceptual Architecture and Design** [Oct 14]
- **03 Data Models and Normalization** [Oct 21]

→ Exercise 1: Data Modeling **[Nov 05]**

- **04 Relational Algebra and Tuple Calculus** [Oct 28]
- **05 Query Languages (SQL)** [Nov 04]
- **06 APIs (ODBC, JDBC, OR frameworks)** [Nov 11]

→ Exercise 2: Queries **[Nov 26]**

- **07 Physical Design and Tuning** [Nov 18]
- **08 Query Processing** [Nov 25]
- **09 Transaction Processing and Concurrency** [Dec 02]

→ Exercise 3: Tuning **[Dec 20]**

Part B: Modern Data Management

- **10 NoSQL (key-value, document, graph)** [Dec 09]
- **11 Distributed file systems and object storage** [Jan 13]
- **12 Data-parallel computation (MapReduce, Spark)** [Jan 13]
- **13 Data stream processing systems** [Jan 20]

→ Exercise 4: Spark **[Jan 21]**

- **14 Q&A and exam preparation** [Jan 27]
- **Final written exam** [Jan 30 5.30pm, Jan 31 5.30pm]

Course Organization

Basic Course Organization

- **Staff**
  - **Lecturer:** Univ.-Prof. Dr.-Ing. Matthias Boehm, ISDS
  - **Teaching Assistants:** Dardan Dermaku, Olga Ovcharenko, Oliver Nikolic, Melanie Willfurth

- **Language**
  - Lectures and slides: **English**
  - Communication and examination: **English**/**German**
- **Course Format**
  - DM VO + KU 2/1 (**3+1 ECTS**), DB VU 1/1 (**3(2) ECTS**)
  - **Weekly lectures** (**start 6.10pm**, including **Q&A**), **attendance optional**
  - **4/3 exercises** (introduced in lecture) as individual assignments
  - **Recommended papers** for additional reading on your own

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 hours: **Mo 3pm**, or after lecture

- **Website**
  - https://mboehm7.github.io/teaching/ws1920_dbs/index.htm
  - All course material (lecture slides, exercises) and dates

- **Exam**
  - **Completed mandatory exercises** (Nov 05, Nov 26, Dec 20, [Jan21])
  - **Final written exam** (Jan 30 5.30pm, Jan 31 5.30pm, HS i13)
  - **DB Grading** (30% exercises, 70% final)

Course Logistics, cont.

- **Exercises**
  - Written and programming assignments, submitted through **TeachCenter**
  - Assignments have **25 points + 5 bonus points**
  - Assignment **completed if >50% points in total** (**vs last semester**)
  - 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: e.g., C, C++, **Java**, **Scala** or **Python**

Exercises: Airlines and Flights

New

- **Dataset**
  - Public-domain, derived (parsed, cleaned) from the **OpenFlights Dataset**
  - Clone or download your copy from https://github.com/tugraz-isds/datasets.git

- **Exercises**
  - **01** Data modeling (relational schema)
  - **02** Data ingestion and SQL query processing
  - **03** Tuning, query processing, and transaction processing
  - **04** Large-scale data analysis (distributed data ingestions and query processing)

Airlines.csv: The Airlines file contains the airlines informatior

```
#Name, IATA, ICAO, Country, Active
Austrian Airlines,OS,AUA,Austria,Y
Turkish Airlines,TH,THY,Turkey,Y
Lufthansa,MH,DLH,Germany,Y
```

Airports.csv: The Airports file contains the airports informati

```
#Name, City, Country, IATA, ICAO, Latitude, Logtitude,
Goroka Airport,Goroka,Papua New Guinea,GKA,AYGA,-6.0816
Kaduna Airport,Kaduna,Nigeria,KAD,DNKA,10.6960000991821
Brussels Airport,Brussels,Belgium,BRU,EBBR,50.90140151
```

Routes.csv: The Routes file contains the flights information. I

```
#Airline, Departure, Arrival, Plane
NF,NUS,VLI,YN2;DHT;BNI
Y9,IFN,MRX,TU3
6R,MJZ,YKS,TU3;AN4
3R,ASF,DME,SU9
```

Planes.csv: The Planes file contains the planes information. I

```
#Name, IATA, ICAO
Aerospatiale SN.601 Corvette,NDC,S601
Airbus A380-800,388,A388
Antonov AN-12,ANF,AN12
Boeing 737-400,734,B734
```

Literature

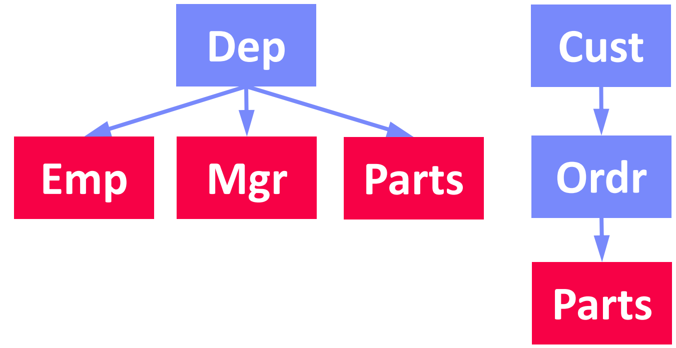
- **Not needed for lectures / exercises** (course is self-contained), **but second perspective on covered topics of first part**
- Raghu Ramakrishnan, Johannes Gehrke: Database Management Systems (3. ed.). McGraw-Hill 2003, ISBN 978-0-07-115110-8, pp. I-XXXII, 1-1065
- Jeffrey D. Ullman, Jennifer Widom: 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

History of Data Management

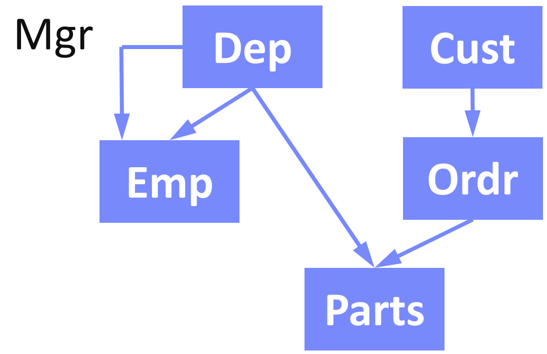
History 1960/70s (pre-relational)

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)

SQL Standard (SQL-**86**)

↑

SEQUEL

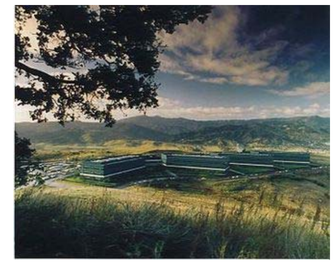
Oracle, IBM DB2, Informix, Sybase → MS SQL

QUEL - - - → **SEQUEL**

↑ QUEL | ↑ SEQUEL

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

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



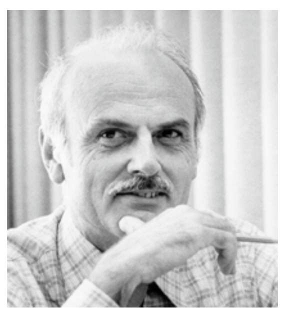
Tuple Calculus

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**]

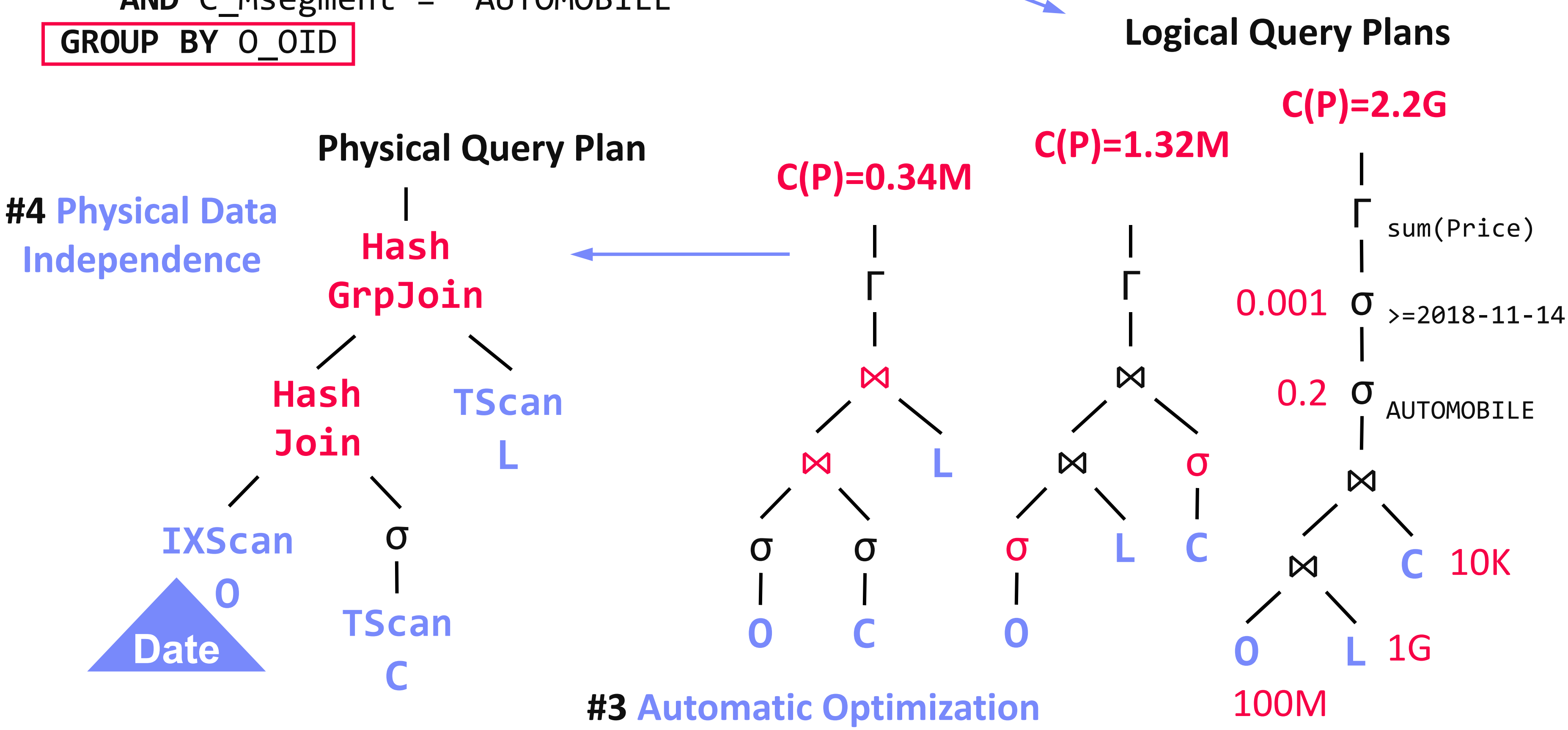
Success of SQL / Relational Model

Query:

```
SELECT O_OID, sum(O_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



Excursus: PostgreSQL

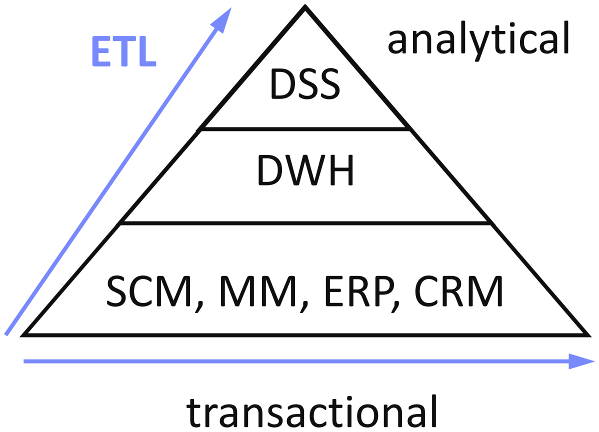
- **History of PostgreSQL** (used in the exercises)
  - Postgres is the successor project of commercialized Ingres
  - Focus on abstract data types, commercialized as Illustra
  - Prototype w/ SQL open sourced as **Postgres95** → **PostgreSQL**
  - Heavily used as **basis for research projects / startups**

- **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

→ SQL

History 2000s / Early 2010s

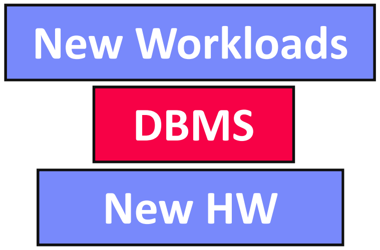
[M. Stonebraker, S. Madden, D. J. Abadi, S. Harizopoulos, N. Hachem, P. Helland: **The End of an Architectural Era** (It's Time for a Complete Rewrite). **VLDB 2007**]


- **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
- **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

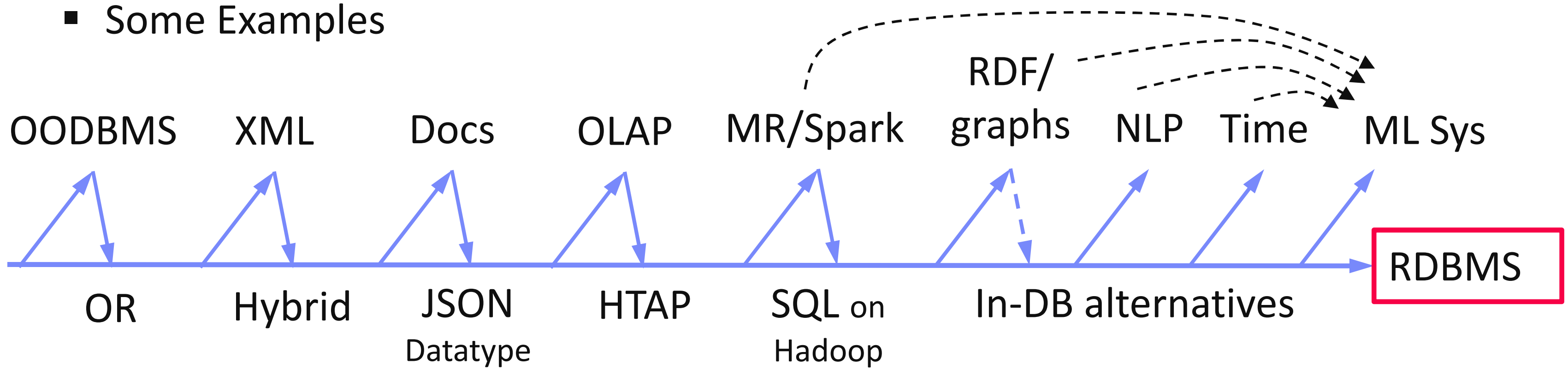
[J. Cohen, B. Dolan, M. Dunlap, J. M. Hellerstein, C. Welton: **MAD Skills**: New Analysis Practices for Big Data. **PVLDB 2(2) 2009**]


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



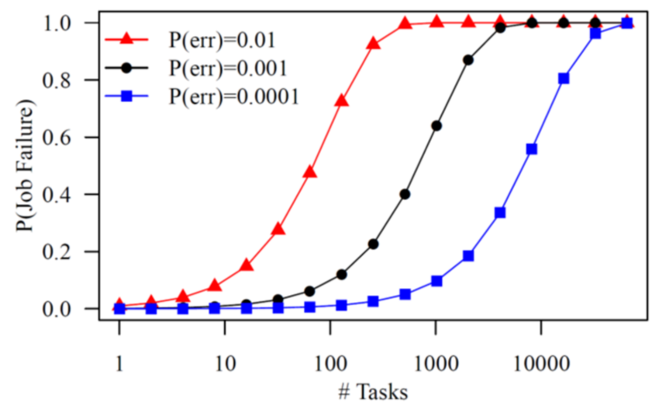
History 2010s – Present (2)

- **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 (3)

- **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

- **Upcoming**
  - **02 Conceptual Architecture and Design** [Oct 14] (ER Diagrams)
  - **03 Data Models and Normalization** [Oct 21] (ERD -> Relational Model)