TDA357/DIT621 – Databases

Lecture 14 – Repetition & History of databases

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A history of databases

A.k.a. The ghost of databases past

These are the shadows of things that have been.
That they are what they are, do not blame me!

History of databases

- In this lecture we will look at the (relatively short) history of databases
- While doing so, we will re-visit topics we have seen throughout the course
- You do <u>not</u> have to memorize any of the names or years, they are merely a way of giving context to how the subject of this course developed

Epoch Timestamp -1E10 to -3E8

Pre-modern times(by computer scientist standards)

- Early 1600's René Descartes formulates analytic geometry
  - Later, work derived from this I called Cartesian, e.g. Cartesian product
- The mathematical concept of a relation is credited De Morgan in the 1860s
- It is later expanded by other mathematicians like Frege, Cantor and Russel
- I doubt any of them had applications in databases in mind…

Timestamp -3E8 to 0

1960s

- The first digital databases appear around the time storage technology develops from tape stations to more HDD-like devices
  - Turns out running queries on tapes that take minutes to rewind is no fun
  - Computers are now undeniably faster than humans at information retrieval
- The first databases are a mess of data and pointers back and forth
- Querying databases requires knowledge of how the data is laid out on disk
- Altering the design of the database typically requires modifying the software that accesses it

The birth of the relational model

Timestamp ca. 0

- Unlike many discoveries, it is easy to pinpoint when databases started
- This is the first line from Edgar F. Codd's 1970 paper titled "A Relational Model of Data for Large Shared Data Banks":

That's you! $\rightarrow$ *"Future users of large data banks must be protected from having to know how the data is organized in the machine* [...]*"*

- In a single paper, Codd outlines much of what we teach in this course today
- Codd's contributions to database research landed him a Turing Award in 1981
- As you may have realized, he is the 'C' in BCNF

Timestamp 0 – 10^8

Early 1970s

- Relational databases are proposed by E. F. Codd
- The term schema is coined, to describe the design of a database
- Schemas are logical descriptions of data organization, disconnected from the physical layout of data in storage devices
  - This became a guiding principle in the field of databases
- First, second and third normal form were all introduced by Codd
  - Later also Boyce-Codd Normal Form
- The process of normalization is intended to address various anomalies that may occur in a relational databases with data redundancies
  - Most notably update and deletion anomalies

Quiz

- Give an example of a deletion anomaly on this schema

Employees(<u>empId</u>, name, officeNumber, officeFloor)

  - Answer: Removing an employee removes the information of which floor its office is on
  - Note that update anomalies are a bit more contrived here: If the floor of an office is changed(?), it needs to be changed for all its occupants
- Give an example of a functional dependency that we would expect to hold in this domain, but which violates BCNF
  - officeNumber→officeFloor seems like a reasonable FD for this domain
  - It is a BCNF-violation <u>if we assume multiple employees can share an office</u>
  - Seen as determination: From an officeNumber we can determine officeFloor
  - Seen as constraint: An office can never reside in more than one floor

Even more from the early 1970s

- Codd also (in the same paper) elevated relational algebra from a mathematical curiosity into a basis for database query languages
- Introduced most of the relational algebra operators you have seen in this course

Quiz

- Given the same (flawed) schema as before
  Employees(<u>empId</u>, name, officeNumber, floor)
- Write an expression for the floor(s) with the highest number of employees

Quiz

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  Employees(<u>empId</u>, name, officeNumber, floor)
- Write an expression for the floor(s) with the highest number of employees

$R1 = \gamma_{\text{floor, COUNT(*)} \rightarrow \text{number}}(\text{Employees})$

Each floor with its number of employees

$R2 = \gamma_{\text{MAX(number)} \rightarrow \text{maxNumber}}(R1)$

Always a single row

$\text{Result} = \pi_{\text{floor}}(\sigma_{\text{number=maxNumber}}(R1 \times R2))$

Sanity check: ***(floor, number, maxNumber)***

Quiz

Given this data, compute the result of the expression on the previous slide

Table: Employees

empId	office	floor
e1	5113	5
e2	5128	5
e3	6128	6
e4	6142	6
e5	4111	4

$R1 = \gamma_{\text{floor, COUNT(*)}\rightarrow\text{number}}(\text{Employees})$

$R2 = \gamma_{\text{MAX(number)->maxNum}}(R1)$

$\text{Result} = \pi_{\text{floor}}(\sigma_{\text{number=maxNumber}}(R1 \times R2))$

Quiz

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e4	6142	6
e5	4111	4

$R1 = \gamma_{\text{floor, COUNT(*)}\rightarrow\text{number}}(\text{Employees})$

floor	number
4	1
5	2
6	2

$R2 = \gamma_{\text{MAX(number)->maxNum}}(R1)$

maxNum
2

$\text{Result} = \pi_{\text{floor}}(\sigma_{\text{number=maxNumber}}(R1 \times R2))$

floor
5
6

floor	number	maxNum
5	2	2
6	2	2

floor	number	maxNum
4	1	2
5	2	2
6	2	2

Timestamp 1.5E8-3.0E8

Mid/late 1970s

- The first relational database systems were developed in the later half of the 1970s: *INGRES* (UC Berkeley) and *System R* (IBM)
  - INGRES used a query language called QUEL
  - IBM called their query language SEQUEL
    - Later changed to SQL due to intellectual property issues
    - Developed by R. F. Boyce (The 'B' in BCNF)
  - Later, the INGRES project had a spinoff called Post Ingres
    - The name was contracted to simply "Postgres"
- The term Relational Database Management System (RDBMS) is coined to describe these emerging systems

1976

- P. Chen proposed a new model for databases: Entity-Relationships
- Abstracts further away from storage layout, allowing designers to focus on data application instead of table structure

Quiz

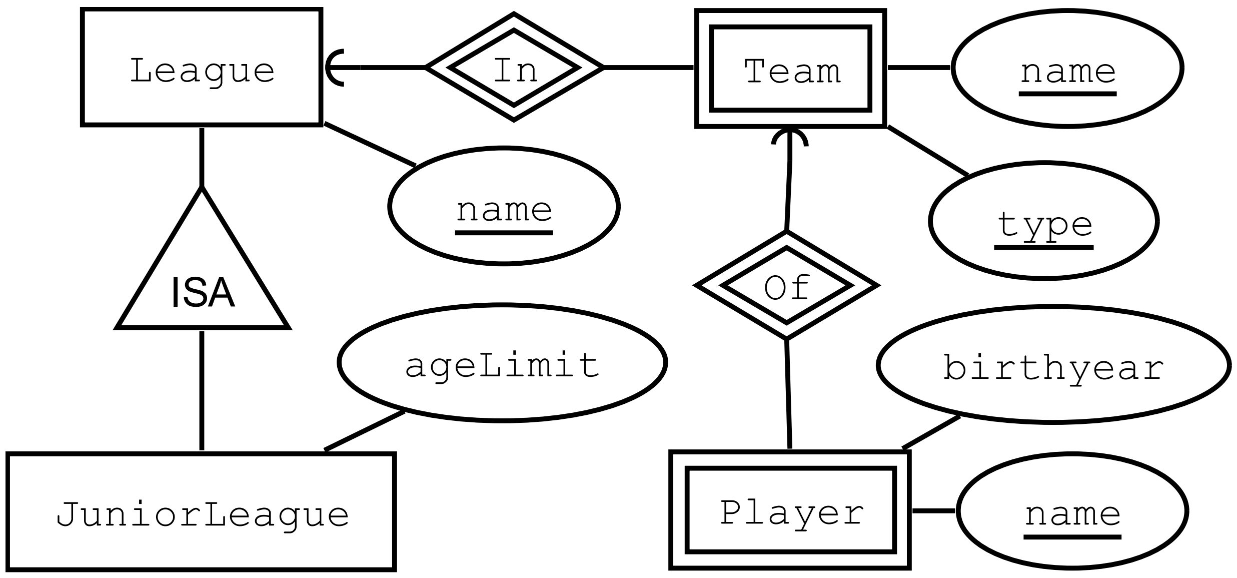
- What is the difference between a weak entity and a subentity?

Quiz

- What is the difference between a weak entity and a subentity?
  - Answer: A weak entity can have additional identifying attributes, also weak entities can be supported from multiple entities (but inheriting from multiple entities does not make sense)
  - If a weak entity would have no identifying attributes of its own and just a single supporting entity, it would essentially be a subentity (using a subentity is the correct choice here)

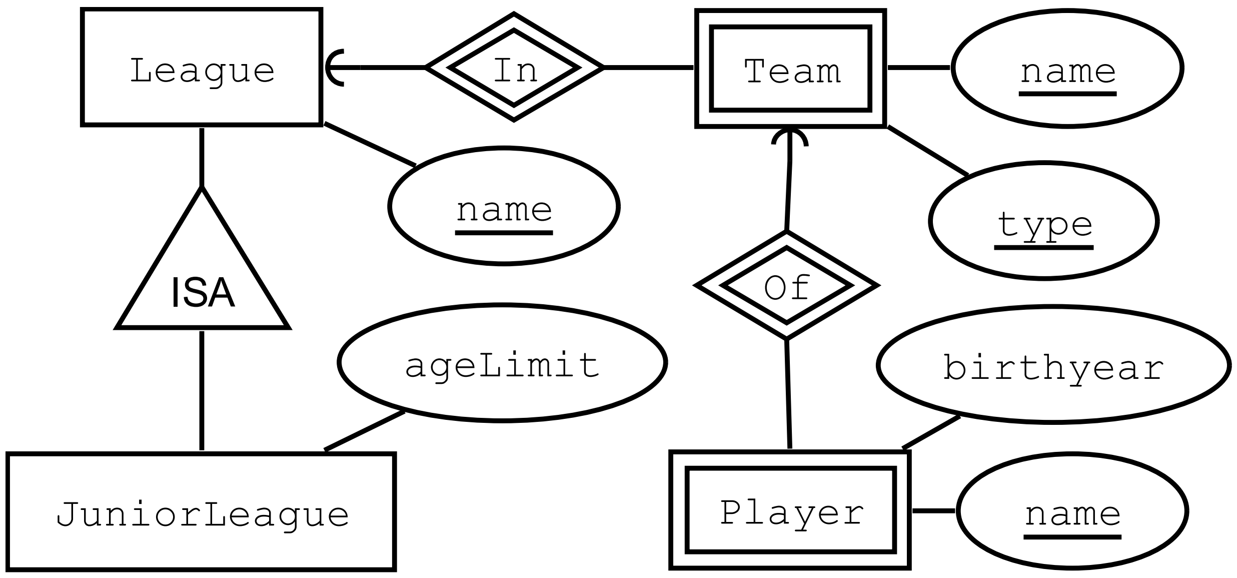
Quiz

Translate this ER-diagram to a relational schema



Quiz

Translate this ER-diagram to a relational schema



League(<u>name</u>)

JuniorLeague(<u>name</u>, ageLimit)

  name -> League.name

Team(<u>name</u>, <u>type</u>, <u>league</u>)

  league-> League.name

Player(<u>name</u>, <u>team</u>, <u>type</u>, <u>league</u>, birthYear)

  (team,league,type) -> Team.(name,league,type)

Timestamp 3.0E8-6.0E8

1980s

- The database market explodes
- IBM is the leading DBMS vendor (with a system called DB2)
  - Remains leading well into the 2000s
- In 1986, SQL is accepted as an ANSI standard, and in 1987 as an ISO
- In 1983, ACID (Atomicity, Consistency, Isolation, Durability) is coined as a golden standard for Database transaction properties

Quiz

- Explain the concept of a non-repeatable read in terms of isolation, and give an example of a problem this can cause

Quiz

- Explain the concept of a non-repeatable read in terms of isolation, and give an example of a problem this can cause
- Answer: A non-repeatable read occurs when a transaction reads a data item, and some other transaction modifies it while the first transaction is still running (so if it re-reads it, it would get different data)
- Example: Read a value from the database, compute a new value in your application based on the old value, and write the new value back
  - The last step assumes the value has not been modified (or it will overwrite those modifications)

Quiz

- A booking application uses transactions that lists available seats, allows the user to choose one, then books the selected one
- Two schemas are proposed, and two booking SQL statements:
  - Book using insert:
    Seats(<u>seatNum</u>)
    BookedSeats(<u>seat</u>)
    seat -> Seats.seatNum

```
INSERT INTO BookedSeats VALUES (?)
```

  - Book by changing boolean attribute:
    Seats(<u>seatNum</u>, isBooked)

```
UPDATE Seats
  SET isBooked=true
  WHERE seatNum=?
```

- Which phenomena are they vulnerable to? Which design is better?

Quiz

- A booking application uses transactions that lists available seats, allows the user to choose one, then books the selected one
- Two schemas are proposed, and two booking SQL statements:
  - Book using insert:
    Seats(seatNum)
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INSERT INTO BookedSeats VALUES (?)
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  - Book by changing boolean attribute:
    Seats(seatNum, isBooked)

```
UPDATE Seats
  SET isBooked=true
  WHERE seatNum=?
```

- Which phenomena are they vulnerable to? Which design is better?
  - The first is vulnerable to non-repeatable reads (seat is removed) and phantoms (seat is booked), the second only to non-repeatable reads
  - The first one is still better, because it will never double book a seat (prevented by primary key constraint: Insert will fail, update will not)

Timestamp 6.0E8-1.0E9

1990s

- The World Wide Web emerges
- Database Driven Web pages become popular
- The first publicly known SQL injection attacks occur ☹
- A standard called ODBC (Open Database Connectivity) is developed to provide an API of functions for applications to interact with databases
  - JDBC is a variant of ODBC specifically for Java

Quiz

- Convert this JDBC code into one that is less vulnerable to injection attacks

```
try (Statement s = conn.createStatement());){
  ResultSet rs = s.executeQuery(
    "SELECT * FROM Grades WHERE student='"+student+"'");
```

Quiz

- Convert this JDBC code into one that is less vulnerable to injection attacks

```
try (Statement s = conn.createStatement());){
  ResultSet rs = s.executeQuery(
    "SELECT * FROM Grades WHERE student='"+student+"'");
```

- Solution:

```
try (PreparedStatement ps = conn.prepareStatement(
       "SELECT * FROM Grades WHERE student=?");){
  ps.setString(1,student);
  ResultSet rs = ps.executeQuery();
```

Quiz

- Suggest how this JDBC code could be simplified/optimized:

```
try (PreparedStatement ps1 = conn.prepareStatement(
       "SELECT student FROM Grades WHERE course='TDA357'");
      PreparedStatement ps2 = conn.prepareStatement(
       "SELECT name FROM Students WHERE id=?");){
   ResultSet rs1 = ps1.executeQuery();
   while(rs1.next()){
      ps2.setString(rs1.getString(1));
      ResultSet rs2 = ps2.executeQuery();
      rs2.next();
      System.out.println(rs2.getString(1));
   }
}
```

Students(<u>id</u>,name)
Grades(<u>student</u>,<u>course</u>,grade)
student -> Students.id

Quiz

- Suggest how this JDBC code could be simplified/optimized:

```
try (PreparedStatement ps1 = conn.prepareStatement(
       "SELECT student FROM Grades WHERE course='TDA357'");
      PreparedStatement ps2 = conn.prepareStatement(
       "SELECT name FROM Students WHERE id=?");){
   ResultSet rs1 = ps1.executeQuery();
   while(rs1.next()){
      ps2.setString(rs1.getString(1));
      ResultSet rs2 = ps2.executeQuery();
      rs2.next();
      System.out.println(rs2.getString(1));
   }
}
```

- Solution: Use a single query with a join of Grades/Students on id=student

```
Students(id,name)
Grades(student,course,grade)
   student -> Students.id
```

1997

- XML is introduced as a universal data language
  - A subset of a previous standard called SGML
  - Intended to be readable by both humans and machines

Quiz

- What is wrong with this XML document?

```
<e><inner><br x="Jonas"/></e></inner>
```

Quiz

- What is wrong with this XML document?

```
<e><inner><br x="Jonas"/></e></inner>
```

Uses </e> to close <inner>

Timestamp 1.0E9-1.3E9

2000s

- More powerful programming features are used in databases
  - Most notably triggers, but also cascading updates etc.
  - A general trend of moving logic into the Database

- NoSQL is introduced as a concept
- The JSON format is specified and quickly gains momentum

Quiz

- Which ones are <u>not</u> valid JSON documents?
  1. `{"answer":42}`
  2. `["answer",42]`
  3. `["answer":"42"]`
  4. `[{}]`
  5. `{"Jonas"}`
  6. `false`

Quiz

- Which ones are not valid JSON documents?
    1. `{"answer":42}`
    2. `["answer",42]`
    3. `["answer":"42"]`
    4. `[{}]`
    5. `{"Jonas"}`
    6. `false`

These ones!

Quiz

```
{"type":"array",
 "items":{"oneOf":
     [{"$ref":"#"},
      {"type":"integer"}
     ]}}
```

- Which JSON documents matches this schema:

```
1. 5
2. []
3. [[]]
4. [{}]
5. [3,["5"]]
6. [3,[4],5]
7. [[1],[2,[5]]]
```

Quiz

```
{"type":"array",
 "items":{"oneOf":
     [{"$ref":"#"},
      {"type":"integer"}
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- Which JSON documents matches this schema:

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1. 5
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5. [3,["5"]]
6. [3,[4],5]
7. [[1],[2,[5]]]
```

These

Timestamp 1.3E9-1.6E9

2010s

- Gathering and processing data is a booming business
- Technical aspects of databases are evolving at a high pace
- Data becomes a commodity. Ethical and legal concerns around handling user data is wildly debated.

2016

- A new revision of the SQL ISO is released
- It standardizes lots of new optional features, several of them related to JSON in some way
- Includes a large part of the JSON Path query language

Quiz

- Write a Postgres JSON Path query that collects the grades of all students named Jonas. Expected result for this test data (two objects):
  `{"TDA357":"5"}   {"TDA143":"5"}`

```
{  "s1":{"name":"Jonas",
         "grades":[{"TDA357":"5"}]},
   "s2":{"name":"Jonas",
         "grades":[{"TDA143":"5"}]},
   "s3":{"name":"Sanoj",
         "grades":[{"XYZ123":"4"},{"ABC111":"3"}]},
   "s4":{"name":"Jonas",
         "grades":[]} }
```

Quiz

- Write a Postgres JSON Path query that collects the grades of all students named Jonas. Expected result for this test data (two objects):
  `{"TDA357":"5"}   {"TDA143":"5"}`

- Solution: **`$.**?(@.name=="Jonas").grades[*]`**

```
{  "s1":{"name":"Jonas",
         "grades":[{"TDA357":"5"}]},
   "s2":{"name":"Jonas",
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   "s3":{"name":"Sanoj",
         "grades":[{"XYZ123":"4"},{"ABC111":"3"}]},
   "s4":{"name":"Jonas",
         "grades":[]} }
```

Analyzing JSON Paths

```
{  "s1":{"name":"Jonas",
         "grades":[{"TDA357":"5"}]},
   "s2":{"name":"Jonas",
         "grades":[{"TDA143":"5"}]},
   "s3":{"name":"Sanoj",
         "grades":[{"XYZ123":"4"},{"ABC111":"3"}]},
   "s4":{"name":"Jonas",
         "grades":[]}  }
```

```
$.**?(@.name=="Jonas").grades[*]
```

$\underbrace{\texttt{\$.**?(@.name=="Jonas")}}_{\text{Gives 3 objects}}$

Gives 3 arrays

Gives all individual elements in those arrays (2 total)

Timestamp 1670923000

The ghost of databases present

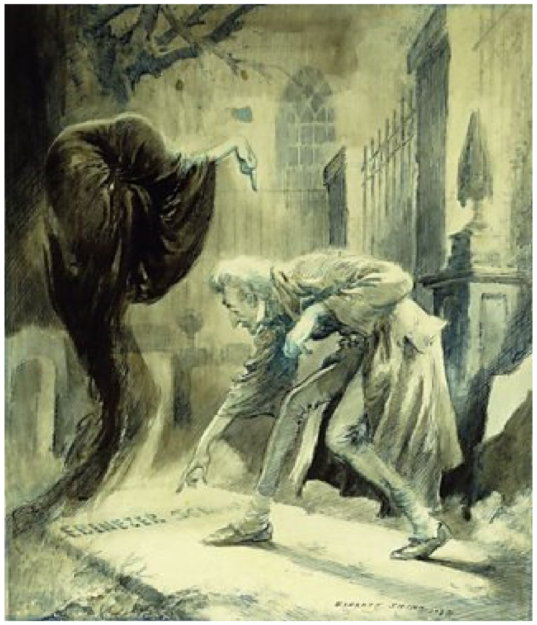
Look upon me! You have never seen the like of me before!

Current challenges in databases

- Dealing with big data: Making systems that can manage petabytes of data for the Web, for bioinformatics, for autonomous vehicles etc.
- Distributed databases: Making databases that are split up or mirrored across lots of machines across the world, and still maintaining a level of consistency
- Handling data from multiple sources with a mix of structured/unstructured data.
- People are still enabling SQL injection attackers. Why?!
  - Maybe a question better suited for a behavioral scientist…

Timestamp 1670925000 +

The ghost of databases yet to come



Why show me this, if I am past all hope!

The (very) near future: Finish up Assignments

- Please try to demonstrate tomorrow if you have not already demonstrated
- Note: if you demonstrate on Friday, there is a very real risk that your demo is unsuccessful, and you will not have time to re-do it
- If you submit any task tomorrow or later, you may not have time to resubmit it before the final deadline if it is rejected

The still pretty near future: Exam

- The exam is on January 11
  - Make sure you are registered!
- You are allowed to bring one **handwritten** double sided A4 sheet to the exam
  - You can draw or write anything you want (within the confines of the law) on the paper
  - I can not promise that I won't give bonus points for epic poetry or art
- Use the Slack to ask questions about previous exams, and help each other out

The more distant future(?)

- The future is always the hardest thing to predict
- Next year, I hope the best and brightest of you will work as my TAs
- Perhaps your generation will be the first to stop enabling SQL injection?
- Maybe in a few years, one of you will have solved some of the challenges I presented earlier?
- If you do, I will be sure to update my slides, adding your name to them

This is the end of the last lecture

Thank you for listening!