Temporal and Spatial Data Management
Fall 2017

Introduction
SL01

- Course setup and administration
- New requirements for database systems
- Motivation for temporal database functionality

About me

- My employment history:

<table>
<thead>
<tr>
<th>University</th>
<th>Where</th>
<th>When</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETH Zürich</td>
<td></td>
<td>[1990, 1994)</td>
</tr>
<tr>
<td>University of Arizona</td>
<td></td>
<td>[1994, 1995)</td>
</tr>
<tr>
<td>University of Bolzano</td>
<td></td>
<td>[2003, 2009)</td>
</tr>
<tr>
<td>University of Zürich</td>
<td></td>
<td>[2009, now)</td>
</tr>
</tbody>
</table>

- Since more than twenty years I have been an active researcher in the area of temporal database systems.
- I have been working on research issues related to temporal, spatial, and spatio-temporal database systems.

This Course/1

- Pre-conditions (what I assume you know/handle yourself):
  - Read, write and reflect about SQL statements
  - Read, use, and write relational algebra and calculus expressions
  - Work with PostgreSQL
  - Algorithms

- What we do:
  - Work out concrete solutions (SQL, relational calculus, algorithms)
  - Reflect about solutions (identify and understand pros and cons)

- What is not good enough:
  - General/abstract knowledge about the topic
  - Memorizing solutions without understanding details
Course page

http://www.ifi.uzh.ch/dbtg

The course is taught every second year (odd years)

Syllabus

1. Introduction, new requirements, motivation
2. Time domain, timestamps, granularity, calendar
3. Temporal data models and extensions of SQL
4. Sequenced semantics
5. Algorithms for temporal aggregation and joins
6. Spatial databases
7. Query processing in spatial network databases

Location: BIN 2.A.01

Time: Monday 14:00 - 15:45

The course is an advanced course in the area of database systems.

I assume you have followed an introductory database course before (relational model; algebra; SQL; query processing; etc).

The course is research based. In some cases there is no consensus about the best approach. World is not black and white.

The reading material consists of selected research papers or book chapters.

Reading such research papers is important and difficult.

The time-related problems that we discuss are present in many applications

The ANSI/ISO SQL:2011 Standard includes temporal features:

http://dl.acm.org/ft_gateway.cfm?id=2380786&ftid=1294657&down-id=1aCFID=8103256924CFTOKEN=16987313

Basic infrastructure for the time is being incorporated into commercial systems.


Oracle: Workspace Database Manager, total recall
http://download.oracle.com/docs/cd/B28359_01/appdev.111/b28396.pdf

Teradata: current, sequenced, and non-sequenced statements
http://www.info.teradata.com/edownload.cfm?itemid=102320064

PostgreSQL: PGTemporal, time travel, transaction time
http://www.postgresql.org/docs/devel/static/rangetypes.html

Microsoft Research: Immortal DB

A number of database systems support spatial functionality (spatial measurements, spatial functions, spatial predicates, geometry constructors, observer functions):

PostgreSQL DBMS uses the spatial extension PostGIS to implement the standardized datatype geometry and corresponding functions.

Oracle Spatial: functions and procedures that enables spatial data to be stored, accessed, and analyzed

IBM DB2 Spatial Extender can be used to enable any edition of DB2 with support for spatial types

Microsoft SQL Server has support for spatial types since 2008

geometry type for Euclidean coordinates

graphy type for earth coordinates

Rasdaman provides support for raster images.
Exercises

- During the lectures we will solve representative examples that help to understand the material.
- Bring a laptop with PostgreSQL client, shell, vpn, and possibly pgadmin.
- There will be an implementation exercise with an extension of PostgreSQL that supports the processing of time intervals. Requires install and compilation or vpn.
- Solving the exercises is not mandatory but highly recommended since it is a good preparation for the exam.

Exam

- The exam takes place January 8, 2018.
- The exam is oral.
- The oral exam lasts 20-30 minutes in total.
- There will be a couple of questions about selected topics from the course.
- The questions are drawn randomly.
- It is important that you illustrate the answer to your question through an appropriately chosen example.

Schedule (tentative)

<table>
<thead>
<tr>
<th>Date</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.09</td>
<td>Introduction and motivation</td>
</tr>
<tr>
<td>25.09</td>
<td>Time domain, granularities</td>
</tr>
<tr>
<td>02.10</td>
<td>Time domain, granularities</td>
</tr>
<tr>
<td>09.10</td>
<td>Temporal data models</td>
</tr>
<tr>
<td>16.10</td>
<td>Temporal extensions of SQL</td>
</tr>
<tr>
<td>23.10</td>
<td>Temporal extensions of SQL</td>
</tr>
<tr>
<td>30.10</td>
<td>— (no lecture)</td>
</tr>
<tr>
<td>06.11</td>
<td>Sequenced semantics</td>
</tr>
<tr>
<td>13.11</td>
<td>Sequenced semantics</td>
</tr>
<tr>
<td>20.11</td>
<td>Temporal aggregation</td>
</tr>
<tr>
<td>27.11</td>
<td>Temporal joins</td>
</tr>
<tr>
<td>04.12</td>
<td>Spatial database systems</td>
</tr>
<tr>
<td>11.12</td>
<td>Spatial database systems</td>
</tr>
<tr>
<td>18.12</td>
<td>Summary</td>
</tr>
</tbody>
</table>

Literature (tentative)

Basic Definitions/1

- **Mini-world**: The part of the real world we are interested in
- **Data**: Known facts about the mini-world that can be recorded
- **Database (DB)**: A collection of related data
- **Database Management System (DBMS)**: A software package to facilitate the creation/maintenance of databases
- **Database System**: DB + DBMS
- **Meta Data**: Information about the structure of the DB
  - Meta data is organized as a DB itself

Basic Definitions/2

- A DBMS provides two kind of languages
  - A **data definition language** (DDL) for specifying the database schema
    - the database schema is stored in the data dictionary
    - the content of data dictionary is called metadata
  - A **data manipulation language** (DML) for updating and querying databases, i.e.,
    - retrieval of information
    - insertion of new information
    - deletion of information
    - modification of information
- SQL, the intergalactic data speak [Stonebraker], provides DDL and DML statements.

The Relational Data Model/1

- Data are stored in relations/tables
  - employee
    - Name | Dept | Salary
    - Tom  | SE   | 23K
    - Lena | DB   | 33K
  - department
    - DName | Manager | Address
    - SE    | Tom     | Boston
    - DB    | Lena    | Tucson
  - project
    - ProjID | Dept | From    | To
    - 14     | SE   | 2005-01-01 | 2005-12-31
    - 201    | DB   | 2005-04-15 | 2006-03-31
The Relational Data Model/2

- A **domain** $D$ is a set of atomic data values.
  - phone numbers, names, grades, birthdates, departments
  - each domain includes the special value **null** for unknown or missing value
- With each domain a **data type** or format is specified.
  - 5 digit integers, yyyy-mm-dd, characters
- An **attribute** $A_i$ describes the role of a domain in a relation schema.
  - PhoneNr, Age, DeptName
- A **relation schema** $R(A_1, ..., A_n)$ is made up of a relation name $R$ and a list of attributes.
  - $employee(Name, Dept, Salary)$,
  - $department(DName, Manager, Address)$

The Relational Data Model/3

- A **tuple** $t$ is an ordered list of values $t = (v_1, ..., v_n)$ with $v_i \in dom(A_i)$.
  - $t = (\text{Tom, SE, 23K})$
- A **relation** $r$ of the relation schema $R(A_1, ..., A_n)$ is a set of $n$-ary tuples.
  - $r = \{(\text{Tom, SE, 23K}), (\text{Lene, DB, 33K})\}$
- A **database** $DB$ is a set of relations.
  - $DB = \{r, s\}$
  - $r = \{(\text{Tom, SE, 23K}), (\text{Lene, DB, 33K})\}$

Properties of Relations

- A relation is a **set of tuples**, i.e.,
  - **no ordering** between tuples and
  - **no duplicates** (identical tuples) exist.
- A table (in contrast to a relation) allows duplicates.
- Attributes within tuples are **ordered**.
  - At the logical level it is possible to have unordered tuples if the correspondence between values and attributes is maintained
  - e.g., $\{\text{Salary/23K, Name/Tom, Dept/SE}\}$
  - versus $(23K, \text{Tom, SE})$
- Query languages:
  - Relational algebra (RA)
  - Domain relational calculus (DRC), tuple relational calculus (TRC)
  - SQL

Table of Contents

- Course setup and administration
  - Lectures
  - Exercises
  - Exam
  - Literature
  - Database field
- **New requirements for database systems**
  - Motivation for temporal database functionality
    - What is a temporal database
    - The need for temporal databases
    - Case study
New Requirements for Database Systems/1

- **Insurance**: In how many accidents at Rigiplatz was the left side damaged and the driver was less than 25 years? Show all available pictures and sketches of such accidents. [unstructured data]
- **Product management**: Which were the three most profitable products during the past 3 months? [entity resolution]
- **Transport/logistics**: Determine the cheapest transport routes between Bolzano and Zürich and display alternative routes on a map. [shortest path]
- **Finance**: Find all high-tech stock with a risk/profit assessment that is below the one of my current portfolio and add to each the most recent analysis reports. [external information, data integration]
- **Production**: Mark each produced chip that deviates from the provided template chip. [complex data types]

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New Requirements for Database Systems/2

- Highly structured information
  - arbitrarily assembled units
  - assemble/disassemble
  - arbitrary relations between parts
  - uses, derived from, involved in
  - versions
  - alternatives, revisions, variants, configurations
  - nonstandard attribute values
  - vectors, matrices, geometry
- Unstructured information
- Semistructured information

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New Requirements for Database Systems/3

Problems with standard DB technology for nonstandard applications:
- Modeling becomes complex (along with subsequent SQL statements)
- Frequent joins (to construct entities)
- Redundancy (because of 1NF representation)
- Unnecessary inspection of irrelevant tuples during join processing

Standard database technology:
- We can do everything with a relational database systems (+ a simple programming language)
- In many cases we can do much better if the modeling of data and behavior is improved.

Key issue:
- Which extension make a real difference (are important enough) and should become part of DBMSs?

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New Requirements for Database Systems/4

VLSI: managing VLSI designs with a database system is difficult.

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New Requirements for Database Systems/5
XML: standard database systems were not prepared to deal with XML data; today they improved a lot.

<TD>XML</TD>

New Requirements for Database Systems/6
GIS: standard database systems were not prepared to deal with geographical maps; GIS systems had to be used; today database systems improved a lot.

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▶ Course setup and administration
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▶ New requirements for database systems
▶ Motivation for temporal database functionality
  ▶ What is a temporal database
  ▶ The need for temporal databases
  ▶ Case study

Temporal Databases
▶ A temporal database supports the management of time-varying information.
▶ It is difficult to identify applications that do not involve time-referenced data.
▶ Two kinds of temporal aspects are of general interest.
▶ When the data is true in reality, termed valid time. Example: When was an employee in a certain department.
▶ When the data is recorded in the database, termed transaction time. Example: When was it recorded that the employee is in the department.
▶ Existing technology provides little or no support for these.
▶ The main challenge addressed by temporal database systems is that of providing general-purpose built-in support for temporal concepts.
The Need for Temporal Databases/1

- Time is an important aspect of all real-world phenomena, e.g.,
  - Record-keeping applications (e.g., medical records, inventory)
  - Financial applications (e.g., banking, stock market data, trend analysis)
  - Scheduling applications (e.g., airline, train, hotel reservation)
  - Scientific applications (e.g., physics, astronomy, weather monitoring)

Temporal Database Research History/1

- Four overlapping phases
  - 1956–1985: Concept development, considering the multiple kinds of time and conceptual modeling
  - 1978–1994: Design of query languages
    - 1978–1990: Relational temporal query languages
  - 1988–present: Implementation aspects, including storage structures, operator algorithms, and temporal indexes.
  - 1993–present: Consolidation phase
    - Consensus glossary of temporal database concepts
    - Query language test suite

The Need for Temporal Databases/2

- Limited support for temporal data management in DBMSs
  - Conventional (non-temporal) DBs represent a snapshot of the mini-world
  - Management of temporal aspects is implemented by the application program (and not by DBMS)
  - Some time data types and functions are available in SQL, e.g., DATE, TIME, DATEADD(), DATEDIFF(), NOW()

- A temporal database provides built-in support for the management of temporal data/time
  - Representation of various temporal aspects, e.g., valid time, transaction time
  - Support for temporal indeterminacy, including qualitative temporal relations
  - Support for multiple calendars and granularities
  - Easy formulation of complex queries over time
  - Queries over and modification of previous states

Temporal Database Research History/2

- An active research area today
  - Over 2000 papers produced over the past two decades
  - New application domains with the need for new operations
    - spatio-temporal and moving-object databases (e.g., mobile-phone tracking to monitor employees, company cars, and equipment)
    - data streams
    - data warehousing
  - During recent years lots of efforts from companies:
    - Oracle 10g, 2003: temporal extensions through workspace manager, time travel
    - SAP HANA, 2010: history tables
    - IBM DB2 10, 2010: Current and history tables, business (= valid) time, system (= transaction) time, time travel
    - Teradata 13.10, 2010: time travel, parts of ANSI SQL/Temporal
    - SQL:2011 standard with temporal extensions
**A Case Study/1**

Example: Consider a company that stores the following information about the employees: name, salary, and position.

- **No temporal data**
  - Schema: `Employee (Name, Salary, Job)`
  - Query: *What is Bob's salary?*
    
    ```sql
    SELECT Salary 
    FROM Employee 
    WHERE Name = 'Bob'
    ```

- **Additionally store the date of birth (DoB)**
  - SQL provides a data type `DATE`
  - Schema: `Employee (Name, Salary, Job, DoB DATE)`
  - Query: *What is Bob's date of birth?*
    
    ```sql
    SELECT DoB 
    FROM Employee 
    WHERE Name = 'Bob'
    ```

  - Finding the date of birth is analogous to determining the salary.

---

**A Case Study/2**

- **Storing history information**
  - Now the employment history shall be stored
  - Store for each tuple the time period when the tuple was/is valid
  - Schema:
    
    ```sql
    Employee (Name, Salary, Job, Start DATE, End DATE)
    ```

<table>
<thead>
<tr>
<th>Name</th>
<th>Salary</th>
<th>Job</th>
<th>Start</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bob</td>
<td>60000</td>
<td>Assistant Provost</td>
<td>1995-01-01</td>
<td>1995-05-31</td>
</tr>
<tr>
<td>Bob</td>
<td>70000</td>
<td>Assistant Provost</td>
<td>1995-06-01</td>
<td>1995-09-30</td>
</tr>
<tr>
<td>Bob</td>
<td>70000</td>
<td>Provost</td>
<td>1995-10-01</td>
<td>1995-11-30</td>
</tr>
<tr>
<td>Bob</td>
<td>70000</td>
<td>Professor</td>
<td>1995-12-01</td>
<td>1997-12-31</td>
</tr>
</tbody>
</table>

- To the data model, these new columns are identical to `DoB`, but they have far-reaching consequences for queries.
- The Start and End columns model the time during which the fact is valid in the real world.

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**A Case Study/3**

- **Temporal projection**
  - Query: *What is Bob's current salary?*
    
    ```sql
    SELECT Salary 
    FROM Employee 
    WHERE Name = 'Bob' 
    AND Start <= CURRENT_DATE 
    AND CURRENT_DATE <= End
    ```

  - The query is more complicated (but still simple enough; and we agree on the result!).
**A Case Study/4**

- **Coalesce the salary history for employees**
  - **Query:** What is Bob’s salary history?

<table>
<thead>
<tr>
<th>Employee Name</th>
<th>Salary</th>
<th>Job</th>
<th>Start</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bob</td>
<td>60000</td>
<td>Assistant Provost</td>
<td>1995-01-01</td>
<td>1995-05-31</td>
</tr>
<tr>
<td>Bob</td>
<td>70000</td>
<td>Assistant Provost</td>
<td>1995-06-01</td>
<td>1995-09-30</td>
</tr>
<tr>
<td>Bob</td>
<td>70000</td>
<td>Provost</td>
<td>1995-10-01</td>
<td>1995-11-30</td>
</tr>
<tr>
<td>Bob</td>
<td>70000</td>
<td>Professor</td>
<td>1995-12-01</td>
<td>1997-12-31</td>
</tr>
</tbody>
</table>

**Intended answer:**

- **Result relation**

<table>
<thead>
<tr>
<th>Name</th>
<th>Salary</th>
<th>Start</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bob</td>
<td>70000</td>
<td>1995-06-01</td>
<td>1997-12-31</td>
</tr>
</tbody>
</table>

**A Case Study - Coalescing/1**

- **Original query:** What is Bob’s salary history?
- **Refined query:** Longest possible periods during which Bob’s salary remained constant?
- **Thus, the maximal periods of time for each salary need to be determined.**
- **Example:**

<table>
<thead>
<tr>
<th>Input</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
</tr>
</tbody>
</table>

**Computing the salary history is difficult in SQL and requires the coalescing of consecutive, value-equivalent tuples.**

**A Case Study - Coalescing/2**

**Task 1.1**

- **Coalescing – Solution 1**: Iterative approach where pairs of tuples that are overlapping/adjacent and value-equivalent are coalesced (similar to the computation of transitive closure in graphs).
  1. Find time periods with the same salary that overlap or are adjacent.
  2. Merge these periods (either inserting new tuples or updating existing tuples).
  3. Repeat step 1 and 2 until maximal periods are constructed.
  4. Remove the non-maximal periods.

**Input**

<table>
<thead>
<tr>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
</tr>
<tr>
<td>9</td>
</tr>
<tr>
<td>9</td>
</tr>
<tr>
<td>9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1st iteration</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2nd iteration</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>

**Output**

<table>
<thead>
<tr>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
</tr>
<tr>
<td>9</td>
</tr>
<tr>
<td>9</td>
</tr>
</tbody>
</table>

**A Case Study - Coalescing/3**

**Task 1.2**

- **Coalescing – Solution 2**: Entirely in SQL using multiple nested `not exists` clauses
  - Search for two (possibly the same) value-equivalent tuples, \( F \) (first) and \( L \) (last)
  - Ensure that there are no holes between \( F.\text{Start} \) and \( L.\text{End} \), i.e., all start points \( M.\text{Start} \) of value-equivalent tuples \( M \) are extended (towards \( F.\text{Start} \)) by another value-equivalent tuple \( T_1 \)
  - Ensure that only maximal periods result

```
M
T1
F
L
```
Coalescing – Solution 3: Using a loop and cursor
- Use the sorting of the DBMS to fetch tuples ordered according to name, salary and start point
- When a new tuple is fetched
  - either modify the current tuple
  - or return current tuple as a result tuple and start a new tuple
- Only a single tuple buffer is needed
- Below is a skeleton of a table function that can be called with

```sql
CREATE OR REPLACE FUNCTION r_coal()
RETURNS TABLE (X INTEGER, S INTEGER, E INTEGER) AS
$$
BEGIN
...
END;
$$
```

Language PLPGSQL

Use the sorting of the DBMS to fetch tuples ordered according to name, salary and start point.
When a new tuple is fetched, either modify the current tuple or return current tuple as a result tuple and start a new tuple. Only a single tuple buffer is needed. Below is a skeleton of a table function that can be called with

```sql
CREATE OR REPLACE FUNCTION r_coal()
RETURNS TABLE (X INTEGER, S INTEGER, E INTEGER) AS
$$
BEGIN
...
END;
$$
```

Language PLPGSQL

Coalescing – Solution 4: SQL window functions
- Use the SQL window functions (introduced to support OLAP) to coalesce a table.
- SQL window functions:

```sql
<window function> OVER (PARTITION BY <expression list>)
[ORDER BY <expression [ASC|DESC] list>]
[ROWS|RANGE <window frame>]
```

- Window functions are evaluated as the very last part of an SQL statement. Below are some examples.

```sql
SELECT d, n, s, AVG(s) OVER (PARTITION BY d) FROM e;
SELECT d, n, s, RANK() OVER (PARTITION BY d ORDER BY s) FROM e;
SELECT n, s, SUM(s) OVER (PARTITION BY n ROWS UNBOUNDED PRECEDING) FROM e;
SELECT d, s, LAG(s) OVER (PARTITION BY d ORDER BY s) FROM e;
```

Coalescing – Solution 5: Reorganization of the schema
- Separate salary and position information in different relations
  - EmpSalary(Name, Salary, Start DATE, End DATE)
  - EmpJob(Name, Job, Start DATE, End DATE)

<table>
<thead>
<tr>
<th>Name</th>
<th>Salary</th>
<th>Start</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bob</td>
<td>70000</td>
<td>1995-06-01</td>
<td>1997-12-31</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>Job</th>
<th>Start</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bob</td>
<td>Ass Prov</td>
<td>1995-01-01</td>
<td>1995-09-30</td>
</tr>
<tr>
<td>Bob</td>
<td>Provost</td>
<td>1995-10-01</td>
<td>1995-11-30</td>
</tr>
<tr>
<td>Bob</td>
<td>Professor</td>
<td>1995-12-01</td>
<td>1997-12-31</td>
</tr>
</tbody>
</table>
**A Case Study - Coalescing/8**

**Solution 5**: Reorganization of the schema

- Computing Bob's salary history becomes trivial

```sql
SELECT Salary, Start, End
FROM EmpSalary
WHERE Name = 'Bob'
```

- Coalescing is not needed for the salary history, but introduces the need for **temporal joins** for more complex queries.

---

**A Case Study - Join/1**

**Temporal join**

- Query: **Provide the salary and position history for all employees?**

<table>
<thead>
<tr>
<th>Name</th>
<th>Salary</th>
<th>Job</th>
<th>Start</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bob</td>
<td>70000</td>
<td>Ass Prov</td>
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<td>1997-12-31</td>
</tr>
</tbody>
</table>

- Case analysis on how each tuple of EmpSalary overlaps each tuple of EmpJob is required
  - EmpJob tuple entirely contained in the EmpSalary tuple
  - EmpJob tuple overlaps the EmpSalary tuple
  - etc.

---

**A Case Study - Join/2**

- Formulation of the join query in SQL

```sql
SELECT E1.Name, Salary, Job, E1.Start, E1.End
FROM EmpSalary AS E1, EmpJob AS E2
WHERE E1.Name = E2.Name
UNION
SELECT E1.Name, Salary, Job, E1.Start, E1.End
FROM EmpSalary AS E1, EmpJob AS E2
WHERE E1.Name = E2.Name
AND E1.Start > E2.Start
UNION
SELECT E1.Name, Salary, Job, E1.Start, E1.End
FROM EmpSalary AS E1, EmpJob AS E2
WHERE E1.Name = E2.Name
AND E2.Start > E1.Start
UNION
SELECT E1.Name, Salary, Job, E1.Start, E1.End
FROM EmpSalary AS E1, EmpJob AS E2
WHERE E1.Name = E2.Name
AND E2.Start <= E1.Start
```

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**A Case Study - Join/3**

- Do the same but do not return start and end time.
- No union is required

```sql
SELECT E1.Name, Salary, Job
FROM EmpSalary AS E1, EmpJob AS E2
WHERE E1.Name = E2.Name
AND E1.End >= E2.Start
AND E1.Start <= E2.End
```
A Case Study - Join/4

▶ Use of CASE statement

```sql
SELECT E1.Name, Salary, Job,
    CASE WHEN E2.Start < E1.Start
        THEN E1.Start
        ELSE E2.Start
    END,
    CASE WHEN E2.End < E1.End
        THEN E2.End
        ELSE E1.End
    END
FROM EmpSalary AS E1, EmpJob AS E2
WHERE E1.Name = E2.Name
  AND E1.End >= E2.Start
  AND E1.Start <= E2.End
```

Summary

▶ Non-temporal DBMSs and their query languages provide inadequate support for temporal aspects.
▶ Understand and illustrate the limitations of relational database systems for modeling time-varying information:
   ▶ coalescing
   ▶ join
   ▶ aggregation
▶ Formulation of the queries must be simple.
   ▶ What is the average salary for each type of position? should syntactically be (very) similar to
     ```sql
     SELECT AVG(Salary), Job
     FROM Employee
     GROUP BY Job
     ```
▶ In a temporal DBMS
   ▶ the data model more accurately reflects the reality (captures changes)
   ▶ temporal attributes have a specific semantics
   ▶ with support through a temporal DBMS queries shall become simpler