Temporal Data Warehouses: Logical Models and Querying

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Type of Changes in External Data Sources

External data sources change in their:

1. **Content**
   - Daily operations

2. **Structure**
   - Changes in business requirements
   - Changes in the modeled reality
   - Adaptation of new technologies
   - Simulation scenarios
   - Changes in legislation
Propagate Changes in EDS into Data Warehouses

• As a result of changes in EDSs, DWs also change in their:
  1. Content
     • products always change their prices
  2. Structure
     • Splitting the hierarchy Product → Category to Product → Sub-Category → Category

• The user may be interested in keeping the history of changes in the content and structure
  • to reconstruct the state of the business world in the past
  • to simulate the effect of future changes
  • for audit and accountability purposes

• In this paper, we consider the changes in the content
1. Introduction

2. Available Approaches

3. Running Example

4. Temporal Queries

5. Conclusion
Available Approaches to Keep the Content History

- Two available approaches to keep the history of content changes in a DW
  1. Slowly Changing Dimensions (SCDs) Type 2
  2. Temporal Data Warehouses (TDWs)
Outline

1. Introduction
2. Available Approaches
3. Running Example
4. Temporal Queries
5. Conclusion
An Example Sales DW

Temporal Requirements

- Product life-cycle
- Product price
- Product-category assignment
- Category description
- Employee life-cycle
- Employee-supervisor assignment
- Employee-city assignment
SCD Type 2 Schema of Sales DW

- **Customer**
  - CustomerKey
  - CustomerID
  - CompanyName
  - Address
  - PostalCode
  - CityKey

- **Category**
  - CategoryKey
  - CategoryID
  - CategoryName
  - Description
  - FromDate
  - ToDate

- **Time**
  - TimeKey
  - Date
  - DayNbWeek
  - DayNameWeek
  - DayNbMonth
  - DayNbYear
  - MonthNumber
  - MonthName
  - Quarter
  - Year

- **Territories**
  - EmployeeKey
  - CityKey
  - FromDate
  - ToDate

- **Employee**
  - EmployeeKey
  - EmployeeID
  - FirstName
  - LastName
  - BirthDate
  - HireDate
  - Address
  - City
  - State
  - PostalCode
  - Country
  - SupervisorKey
  - FromDate
  - ToDate

- **Sales**
  - CustomerKey
  - EmployeeKey
  - OrderDateKey
  - DueDateKey
  - ProductKey
  - UnitPrice
  - Quantity
  - Discount
  - SalesAmount

- **City**
  - CityKey
  - CityName
  - StateKey

- **State**
  - StateKey
  - StateName
  - StateCapital
  - CountryKey

- **Country**
  - CountryKey
  - CountryName
  - CountryCapital
  - Population
SCD Type 2 Implementation

Time line of the evolution of unit price and category of product \( p_1 \)

<table>
<thead>
<tr>
<th>ProductKey</th>
<th>ProductID</th>
<th>UnitPrice</th>
<th>CategoryKey</th>
<th>FromDate</th>
<th>ToDate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>p1</td>
<td>10</td>
<td>c1</td>
<td>( T_1 )</td>
<td>( T_2 )</td>
</tr>
<tr>
<td>2</td>
<td>p1</td>
<td>15</td>
<td>c1</td>
<td>( T_2 )</td>
<td>( T_3 )</td>
</tr>
<tr>
<td>3</td>
<td>p1</td>
<td>15</td>
<td>c2</td>
<td>( T_3 )</td>
<td>( T_4 )</td>
</tr>
<tr>
<td>4</td>
<td>p1</td>
<td>18</td>
<td>c2</td>
<td>( T_5 )</td>
<td>Now</td>
</tr>
</tbody>
</table>

SCD Type 2 implementation
Temporal DW schema of Sales DW
Temporal Data Warehouse Implementation

Time line of the evolution of unit price and category of product **p1**

<table>
<thead>
<tr>
<th>ProductLifespan</th>
<th>FromDate</th>
<th>ToDate</th>
</tr>
</thead>
<tbody>
<tr>
<td>ProductKey</td>
<td>FromDate</td>
<td>ToDate</td>
</tr>
<tr>
<td>p1</td>
<td></td>
<td>T4</td>
</tr>
<tr>
<td>p1</td>
<td>T1</td>
<td>T6</td>
</tr>
<tr>
<td>p1</td>
<td>T1</td>
<td>Now</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ProductUnitPrice</th>
<th>UnitPrice</th>
<th>FromDate</th>
<th>ToDate</th>
</tr>
</thead>
<tbody>
<tr>
<td>ProductKey</td>
<td>UnitPrice</td>
<td>FromDate</td>
<td>ToDate</td>
</tr>
<tr>
<td>p1</td>
<td>10</td>
<td>T1</td>
<td>T2</td>
</tr>
<tr>
<td>p1</td>
<td>15</td>
<td>T2</td>
<td>T4</td>
</tr>
<tr>
<td>p1</td>
<td>18</td>
<td>T6</td>
<td>Now</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ProductCategory</th>
<th>CategoryKey</th>
<th>FromDate</th>
<th>ToDate</th>
</tr>
</thead>
<tbody>
<tr>
<td>ProductKey</td>
<td>CategoryKey</td>
<td>FromDate</td>
<td>ToDate</td>
</tr>
<tr>
<td>p1</td>
<td>c1</td>
<td>T1</td>
<td>T3</td>
</tr>
<tr>
<td>p1</td>
<td>c2</td>
<td>T3</td>
<td>T4</td>
</tr>
<tr>
<td>p1</td>
<td>c2</td>
<td>T6</td>
<td>Now</td>
</tr>
</tbody>
</table>
Outline

1. Introduction
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# Classes of temporal queries

<table>
<thead>
<tr>
<th>No.</th>
<th>Class</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>Temporal roll-up</td>
<td>Total quantity per category and month.</td>
</tr>
<tr>
<td>Q2</td>
<td>Temporal-roll-up (with window)</td>
<td>Monthly year-to-date sales per category.</td>
</tr>
<tr>
<td>Q3</td>
<td>Temporal roll-up (recursive)</td>
<td>Total sales amount made by an employee and her subordinates during 1997.</td>
</tr>
<tr>
<td>Q4</td>
<td>Temporal selection</td>
<td>For each employee, total sales amounts of products she sold with unit price greater than $30 at the time of the sale.</td>
</tr>
<tr>
<td>Q5</td>
<td>Temporal projection</td>
<td>Total sales amount for supervisors.</td>
</tr>
<tr>
<td>Q6</td>
<td>Temporal union</td>
<td>Total sales amounts for products assigned to categories beverages or dairy products.</td>
</tr>
<tr>
<td>Q7</td>
<td>Temporal join</td>
<td>Name, unit price, and total sales amount by month for products.</td>
</tr>
<tr>
<td>Q8</td>
<td>Temporal difference</td>
<td>Total sales amount for employees assigned to only one city.</td>
</tr>
<tr>
<td>Q9</td>
<td>Temporal aggregation</td>
<td>For each month, give the total quantity of products sold per category.</td>
</tr>
<tr>
<td>Q10</td>
<td>Temporal aggregation (for a many-to-many relationship)</td>
<td>For each employee, total sales amount, number of cities, and number of states to which she is assigned.</td>
</tr>
<tr>
<td>Q11</td>
<td>Temporal aggregation (duration of interval)</td>
<td>For each pair of employee and supervisor, total number of days when the supervision lasted.</td>
</tr>
<tr>
<td>Q12</td>
<td>Temporal universal quantifier</td>
<td>Total sales for categories in which all products have a price greater than $15</td>
</tr>
<tr>
<td>Q13</td>
<td>Time slice</td>
<td>Average unit price by category as of January 1st, 1997.</td>
</tr>
</tbody>
</table>

**Table:** Classes of temporal business queries and example queries
 Temporal Roll-up

- Total quantity per category and month

<table>
<thead>
<tr>
<th>Time</th>
<th>01/14</th>
<th>02/14</th>
<th>03/14</th>
<th>04/14</th>
<th>05/14</th>
<th>06/14</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C1</td>
<td>C2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>P2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C1</td>
<td>C2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>5</td>
<td>4</td>
<td>8</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>P3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C2</td>
<td>C1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1</td>
<td>3</td>
<td>7</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>C1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>7</td>
<td>9</td>
<td>9</td>
<td>3</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>C2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>4</td>
<td>10</td>
<td>12</td>
<td>12</td>
<td>10</td>
</tr>
</tbody>
</table>
• Total sales per category in which all products have price greater than $15
Comparing the Queries

- Name, unit price, and total sales amount by month for products

**In Query for SCD Type 2**

- Month must be split according to unit price variations
- Temporal projection (with coalescing) is required to compute the Product’s unit price with the period of its applicability
- A temporal join of the computed product unit price with the month from the sales table, and traditional join with the other tables
SQL Query for SCD Type 2

- Name, unit price, and total sales amount by month for products

```
WITH ProdUnitPrice (ProductID, UnitPrice, FromDate, ToDate) AS (
    SELECT ProductID, UnitPrice, FromDate, ToDate
    FROM Product
),
ProdUnitPriceCoalesced AS (  
    -- Coalescing the table ProdUnitPrice above ... ),
SELECT P.ProductName, U.UnitPrice, SUM(SalesAmount) AS SalesAmount,
    dbo.MaxDate(M.FromDate, U.FromDate) AS FromDate,
    dbo.MinDate(M.ToDate, U.ToDate) AS ToDate
FROM Sales S, Time T, Product P, ProdUnitPriceCoalesced U, Month M
WHERE S.OrderDateKey = T.TimeKey AND S.ProductKey = P.ProductKey AND
    P.ProductID = U.ProductID AND dbo.MaxDate(M.FromDate, U.FromDate) <
    dbo.MinDate(M.ToDate, U.ToDate) AND
    dbo.MaxDate(M.FromDate, U.FromDate) <= T.Date AND
    T.Date < dbo.MinDate(M.ToDate, U.ToDate)
GROUP BY P.ProductName, U.UnitPrice, M.FromDate, U.FromDate,
    M.ToDate, U.ToDate
ORDER BY P.ProductName, dbo.MaxDate(M.FromDate, U.FromDate)
```
Comparing the Queries (cont.)

- Name, unit price, and total sales amount by month for products

In Query for TDW

- Temporal projection with coalescing is not needed as product unit price is directly available
- A temporal join of the product unit price with the month from the sales table, and traditional join with the other tables
- No projection and coalescing needed, hence simplified query
SQL Query for TDW

- Name, unit price, and total sales amount by month for products

```sql
SELECT P.ProductName, U.UnitPrice, SUM(SalesAmount) AS SalesAmount,
dbo.MaxDate(M.FromDate, U.FromDate) AS FromDate,
dbo.MinDate(M.ToDate, U.ToDate) AS ToDate
FROM Sales S, Time T, Product P, ProductUnitPrice U, Month M
WHERE S.OrderDateKey = T.TimeKey AND S.ProductKey = P.ProductKey AND
P.ProductKey = U.ProductKey AND dbo.MaxDate(M.FromDate, U.FromDate) <
dbo.MinDate(M.ToDate, U.ToDate) AND
dbo.MaxDate(M.FromDate, U.FromDate) <= T.Date AND
T.Date < dbo.MinDate(M.ToDate, U.ToDate)
GROUP BY P.ProductName, U.UnitPrice, M.FromDate, U.FromDate, M.ToDate, U.ToDate
ORDER BY P.ProductName, dbo.MaxDate(M.FromDate, U.FromDate)
```
Comparing the Queries (cont.)

- Average unit price by category as of January 1st, 1997.

Product schema in SCD Type 2

In Query for SCD Type 2

- Product evolution exists in the single table
- Query would need join of two table i.e. Product and Category
SQL Query for SCD Type 2

- Average unit price by category as of January 1st, 1997.

```
SELECT C.CategoryName, AVG(UnitPrice) AS AvgUnitPrice
FROM Product P, Category C
WHERE P.CategoryKey = C.CategoryKey AND
P.FromDate <= '1997-01-01' AND '1997-01-01' < P.ToDate AND
C.FromDate <= '1997-01-01' AND '1997-01-01' < C.ToDate
GROUP BY C.CategoryName
```
Comparing the Queries (cont.)

- Average unit price by category as of January 1st, 1997.

In Query for TDW

- Product evolution is stored in multiple tables
- Query would need join of four tables i.e. Product, ProductUnitPrice, ProductCategory, and Category
SQL Query for TDW

- Average unit price by category as of January 1st, 1997.

```sql
SELECT C.CategoryName, AVG(UnitPrice) AS AvgUnitPrice
FROM Product P, ProductUnitPrice PU, ProductCategory PC, Category C
WHERE P.ProductKey = PC.ProductKey AND
  PC.CategoryKey = C.CategoryKey AND
  P.ProductKey = PU.ProductKey AND
  PC.FromDate <= '1997-01-01' AND '1997-01-01' <= PC.ToDate AND
  PU.FromDate <= '1997-01-01' AND '1997-01-01' <= PU.ToDate AND
  C.FromDate <= '1997-01-01' AND '1997-01-01' <= C.ToDate
GROUP BY C.CategoryName
```
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Conclusion

• Keeping the history of changes in content enables users to query various states of the business world

• Slowly Changing Dimensions Type 2 and Temporal Data Warehouses are two approaches to keep content history

• It is important to know which of these two approaches is most suitable for time-related business questions
Future Work

• Generate temporal data set based on statistics from the real world data
• Run the representative queries from identified classes on the benchmark data
• Determine which approach is suitable for each class of queries
• Consider changes in the structure
• Combine the approaches to manage changes in the content and structure in a single solution