

ISIT312 Big Data Management

Data Warehouse Concepts

Dr Fenghui Ren

School of Computing and Information Technology -
University of Wollongong

Data Warehouse Concepts

Outline

OLAP versus OLTP

The Multidimensional Model

OLAP Operations

Data Warehouse Architecture

OLAP versus OLTP

Traditional database systems designed and tuned to support the day-to-day operation:

- Ensure fast, concurrent access to data
- Transaction processing and concurrency control
- Focus on online update data consistency
- Known as **operational databases** or **online transaction processing (OLTP)**

OLTP database characteristics:

- Detailed data
- Do not include historical data
- Highly normalized
- Poor performance on complex queries including joins and aggregation

Data analysis requires a new paradigm: **online analytical processing (OLAP)**

- Typical **OLTP** query: pending orders for a customer
- Typical **OLAP** query: total sales amount by a product and by a customer

OLAP versus OLTP

OLAP characteristics

- OLTP paradigm focused on transactions, OLAP focused on analytical queries
- Normalization not good for analytical queries, reconstructing data requires a high number of joins
- OLAP databases support a heavy query load
- OLTP indexing techniques not efficient in OLAP: oriented to access few records; OLAP queries typically include aggregation

The need for a different database model to support OLAP was clear: led to **data warehouses**

Data warehouse: (usually) large repositories that consolidate data from different sources (internal and external to the organization), are updated offline, follow the **multidimensional data model**, designed and optimized to efficiently support OLAP queries

Data Warehouse Concepts

Outline

OLAP versus OLTP

The Multidimensional Model

OLAP Operations

Data Warehouse Architecture

The Multidimensional Model

A view of data in n-dimensional space: a **data cube**

A **data cube** is composed of **dimensions** and **facts**

Dimensions: Perspectives used to analyze the data

- Example: A three-dimensional cube for sales data with dimensions **Product**, **Time**, and **Customer**, and a measure **Quantity**

The diagram illustrates a 3D data cube with dimensions labeled along its axes. The vertical axis is labeled 'Time (Quarter)' with categories Q1, Q2, Q3, and Q4. The horizontal axis is labeled 'Customer (City)' with categories Köln, Berlin, Lyon, and Paris. The depth axis is labeled 'Product (Category)' with categories Produce, Seafood, Beverages, and Condiments. Lines from the text 'dimensions' and 'measure values' point to the respective axes and the numerical data cells.

Köln	24	18	28	14
Berlin	33	25	23	25
Lyon	12	20	24	33
Paris	21	10	18	35
Q1	21	10	18	35
Q2	27	14	11	30
Q3	26	12	35	32
Q4	14	20	47	31

Attributes describe dimensions

[TOP](#) - Product dimension may have attributes **ProductNumber** and **UnitPrice** (not 6/26

The Multidimensional Model

The diagram illustrates a 3D data cube with three dimensions: Customer (City), Time (Quarter), and Product (Category). The Customer dimension has four cities: Köln, Berlin, Lyon, and Paris. The Time dimension has four quarters: Q1, Q2, Q3, and Q4. The Product dimension has four categories: Produce, Seafood, Beverages, and Condiments. The cube contains numeric values representing sales quantities. A line labeled "dimensions" points to the vertical axis of the cube. Another line labeled "measure values" points to one of the numerical entries in the cube.

Köln	24	18	28	14	
Berlin	33	25	23	25	14
Lyon	12	20	24	33	25
Paris	21	10	18	35	33
Q1	21	10	18	35	35
Q2	27	14	11	30	30
Q3	26	12	35	32	32
Q4	14	20	47	31	31
	Produce	Seafood			
	Beverages	Condiments			
	Product (Category)				

The **cells** or **facts** of a data cube have associated numeric values called **measures**

Each **cell** of the **data cube** represents **Quantity** of units sold by **category**, **quarter**, and **customer's city**

Data granularity: level of detail at which measures are represented for each dimension of the cube

TOP - Example: sales figures aggregated to granularities **Category**, **Quarter**, and **City**

The Multidimensional Model

Instances of a dimension are called **members**

- Example: **Seafood** and **Beverages** are **members** of the **Product** at the granularity **Category**

A **data cube** contains several measures, e.g. **Amount**, indicating the total sales amount (not shown)

A **data cube** may be **sparse** (typical case) or **dense**

- Example: not all customers may have ordered products of all categories during all quarters

Hierarchies: allow viewing data at several granularities

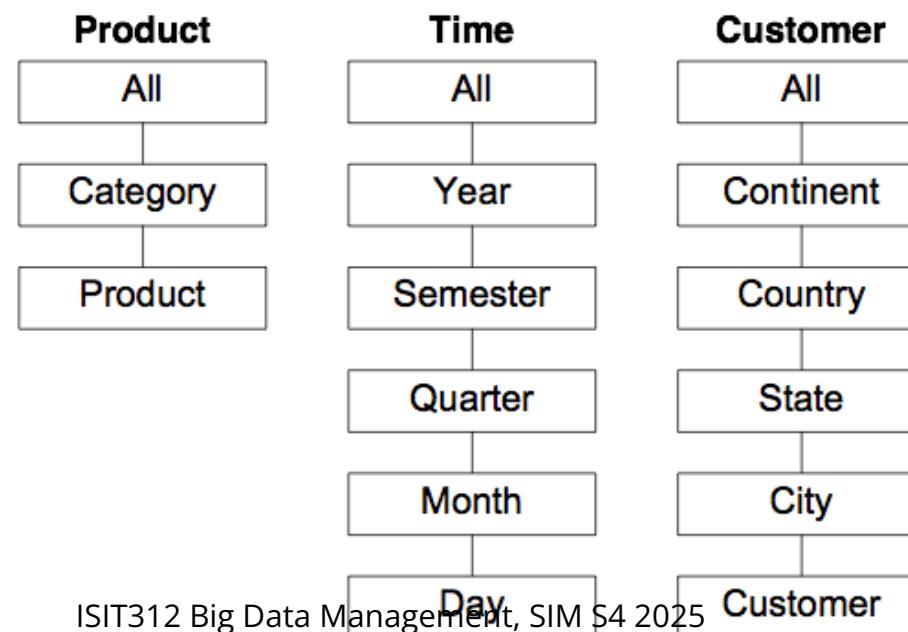
- Define a sequence of mappings relating lower-level, detailed concepts to higher-level ones
- The lower level is called the **child** and the higher level is called the **parent**
- The hierarchical structure of a dimension is called the dimension **schema**
- A dimension **instance** comprises all members at all levels in a dimension

The Multidimensional Model

In the previous figure, granularity of each dimension indicated between parentheses: Category for the **Product** dimension, Quarter for **Time**, and City for **Customer**

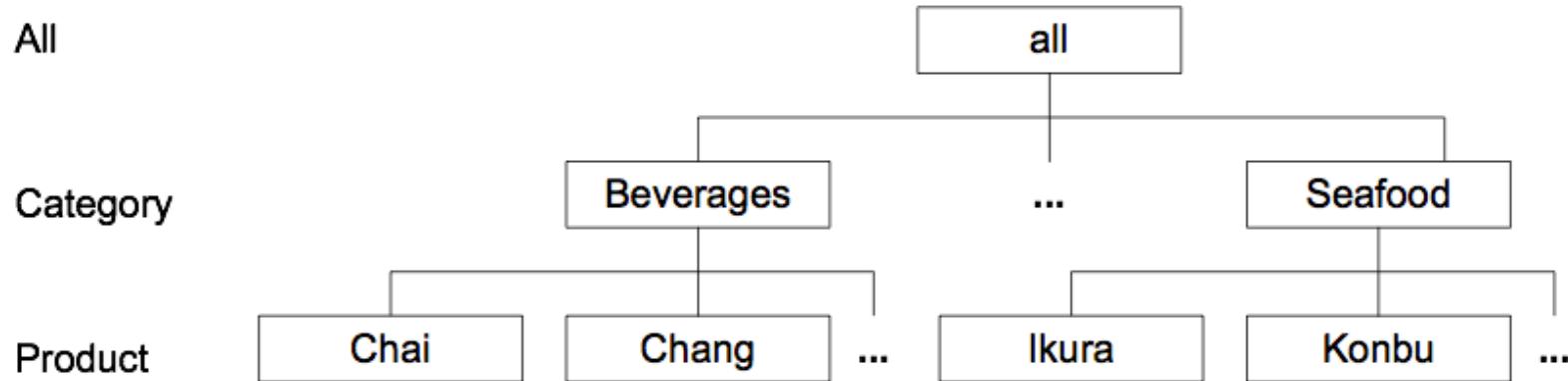
We may want sales figures at a finer granularity (**Month**), or at a coarser granularity (**Country**)

Hierarchies of the **Product**, **Time**, and **Customer** dimensions



The Multidimensional Model

Members of a hierarchy **Product - Category**



The Multidimensional Model: Measures

Aggregation of measures changes the abstraction level at which data in a cube are visualized

Measures can be:

- **Additive**: can be meaningfully summarized along all the dimensions, using addition; The most common type of measures
- **Semiadditive**: can be meaningfully summarized using addition along some dimensions; Example: inventory quantities, which cannot be added along the Time dimension
- **Nonadditive measures** cannot be meaningfully summarized using addition across any dimension; Example: item price, cost per unit, and exchange rate

The Multidimensional Model: Measures

Another classification of measures:

- **Distributive**: defined by an aggregation function that can be computed in a distributed way; Functions `count`, `sum`, `minimum`, and `maximum` are distributive, `distinct count` is not; Example: $S = \{3, 3, 4, 5, 8, 4, 7, 3, 8\}$ partitioned in subsets $\{3, 3, 4\}, \{5, 8, 4\}, \{7, 3, 8\}$ gives a result of 8, while the answer over the original set is 5
- **Algebraic measures** are defined by an aggregation function that can be expressed as a scalar function of distributive ones; example: `average`, computed by dividing the sum by the count

Data Warehouse Concepts

Outline

OLAP versus OLTP

The Multidimensional Model

OLAP Operations

Data Warehouse Architecture

OLAP Operations

		Customer (City)				
		Köln	18	28	14	
		Berlin	33	25	23	25
		Lyon	12	20	24	33
		Paris	21	10	18	35
Time (Quarter)		Q1	21	10	18	35
		Q2	27	14	11	30
		Q3	26	12	35	32
		Q4	14	20	47	31
			Produce	Seafood		
			Beverages	Condiments		
			Product (Category)			

Original cube

		Customer (City)				
		Köln	8	6	9	5
		Berlin	10	8	11	8
		Lyon	4	7	8	14
		Paris	7	2	6	20
Time (Quarter)		Jan	7	2	6	20
		Feb	8	4	8	8
		Mar	6	4	4	7
	
		Dec	4	4	16	7
			Produce	Seafood		
			Beverages	Condiments		
			Product (Category)			

Drill-down to the Month level

		Customer (Country)				
		Germany	57	43	51	39
		France	33	30	42	68
Time (Quarter)		Q1	33	30	42	68
		Q2	39	26	41	44
		Q3	30	22	46	44
		Q4	25	29	49	41
			Produce	Seafood		
			Beverages	Condiments		
			Product (Category)			

Roll-up to the Country level

		Customer (City)				
		Köln	24	28	18	14
		Berlin	33	23	25	25
		Lyon	12	24	20	33
		Paris	21	18	10	35
Time (Quarter)		Q1	21	18	10	35
		Q2	27	11	14	30
		Q3	26	35	12	32
		Q4	14	47	20	31
			Condiments	Seafood		
			Beverages	Produce		
			Product (Category)			

Sort product by name

OLAP Operations

Starting cube: quarterly sales (in thousands) by product category and customer cities for 2012

We first compute the sales quantities by country: a **roll-up** operation to the **Country** level along the **Customer** dimension

Sales of category Seafood in France significantly higher in the first quarter

- To find out if this occurred during a particular month, we take cube back to **City** aggregation level, and **drill-down** along **Time** to the **Month** level

To explore alternative visualizations, we **sort** products by name

To see the cube with the **Time** dimension on the x axis, we rotate the axes of the original cube, without changing granularities → **pivoting** (see next 2 slides)

OLAP Operations

To visualize the data only for Paris → **slice** operation, results in a 2-dimensional sub-cube, basically a collection of time series (see next slide)

To obtain a 3-dimensional sub-cube containing only sales for the first two quarters and for the cities Lyon and Paris, we go back to the original cube and apply a **dice** operation

OLAP Operations

Pivot

Customer (City)		Product (Category)				Time (Quarter)
		Seafood	Condiments	Produce	Beverages	
Customer (City)	Paris	21	10	18	35	Q1
	Lyon	12	14	11	13	Q2
	Berlin	33	28	35	32	Q3
	Köln	24	23	25	18	Q4
		35	30	32	37	

Slice on City='Paris'

Customer (City)		Product (Category)				Time (Quarter)
		Seafood	Condiments	Produce	Beverages	
Customer (City)	Paris	21	10	18	35	Q1
	Lyon	12	14	11	13	Q2
	Berlin	33	28	35	32	Q3
	Köln	24	23	25	18	Q4
		35	30	32	37	

Customer (City)		Product (Category)				Time (Quarter)
		Seafood	Condiments	Produce	Beverages	
Customer (City)	Paris	21	10	18	35	Q1
	Lyon	12	20	24	33	Q2
	Berlin	33	28	35	32	Q3
	Köln	27	14	11	30	Q4
		35	30	32	37	

Dice on City='Paris' or 'Lyon' and Quarter='Q1' or 'Q2'

OLAP Operations

The operations in the previous slides can be defined using the following algebraic operators.

Roll-up: aggregates measures along a dimension hierarchy (using an aggregate function) to obtain measures at a coarser granularity

```
ROLLUP(CubeName, (Dimension → Level)*, AggFunction(Measure)*)
ROLLUP(Sales, Customer → Country, SUM(Quantity))
```

OLAP

Extended roll-up: similar to rollup, but drops all dimensions not involved in the operation

```
ROLLUP*(CubeName, [(Dimension → Level)*], AggFunction(Measure)*)
ROLLUP*(Sales, Time → Quarter, SUM(Quantity))
ROLLUP*(Sales, Time → Quarter, COUNT(Product) AS ProdCount)
```

OLAP

Recursive roll-up: aggregates over a recursive hierarchy (a level rolls-up to itself)

```
REROLLUP(CubeName, Dimension → Level, AggFunction(Measure)*)
```

OLAP

OLAP Operations

Drill-down moves from a more general level to a more detailed level in a hierarchy

```
DRILLDOWN(CubeName, (Dimension → Level)*)
```

OLAP

```
DRILLDOWN(Sales, Time → Month)
```

Sort returns a cube where the members of a dimension have been sorted according to the value of Expression

```
SORT(CubeName, Dimension, Expression [ASC | DESC])
```

OLAP

```
SORT(Sales, Product, NAME)
```

- **NAME** is a predefined keyword in the algebra representing the name of a member

OLAP Operations

Pivot

`PIVOT(CubeName, (Dimension → Axis)*)`

OLAP

- where the axes are specified as {X, Y, Z, X₁, Y₁, Z₁, ... }.

`PIVOT(Sales, Time → X, Customer → Y, Product → Z)`

OLAP

Slice:

`SLICE(CubeName, Dimension, Level = Value)`

OLAP

- Dimension will be dropped by fixing a single Value in the Level, other dimensions unchanged

`SLICE(Sales, Customer, City = 'Paris')`

OLAP

- Slice supposes that the granularity of the cube is at the specified level of the dimension

OLAP Operations

Dice:

DICE(CubeName, ?)

OLAP

- where ? is a Boolean condition over dimension levels, attributes, and measures.

DICE(Sales, (Customer.City = 'Paris' OR Customer.City = 'Lyon') AND
(Time.Quarter = 'Q1' OR Time.Quarter = 'Q2'))

OLAP

Data Warehouse Concepts

Outline

OLAP versus OLTP

The Multidimensional Model

OLAP Operations

Data Warehouse Architecture

Typical Data Warehouse Architecture

Data Warehouse Architecture

General data warehouse architecture: **several tiers**

Back-end tier composed of:

- The **extraction, transformation, and loading (ETL)** tools: Feed data into the data warehouse from operational databases and internal and external data sources
- The **data staging area**: An intermediate database where all the data integration and transformation processes are run prior to the loading of the data into the data warehouse

Data warehouse tier composed of:

- An **enterprise data warehouse** and/or **several data marts**
- A **metadata repository** storing information about the data warehouse and its contents

OLAP tier composed of:

- An **OLAP server** which provides a multidimensional view of the data, regardless the actual way in which data are stored

Data Warehouse Architecture

Front-end tier is used for data analysis and visualization

- Contains client tools such as OLAP tools, reporting tools, statistical tools, and data-mining tools

References

A. VAISMAN, E. ZIMANYI, Data Warehouse Systems: Design and Implementation, Chapter 3 Data Warehouse Concepts, Springer Verlag, 2014