

ISIT312 Big Data Management

# Data Warehouse Concepts

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# 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

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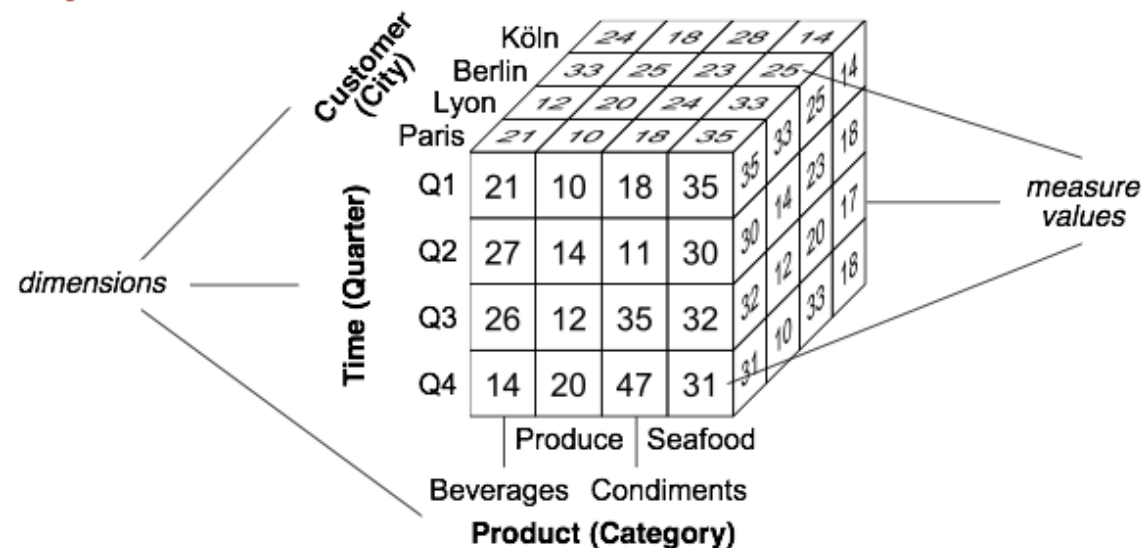
# The Multidimensional Model

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

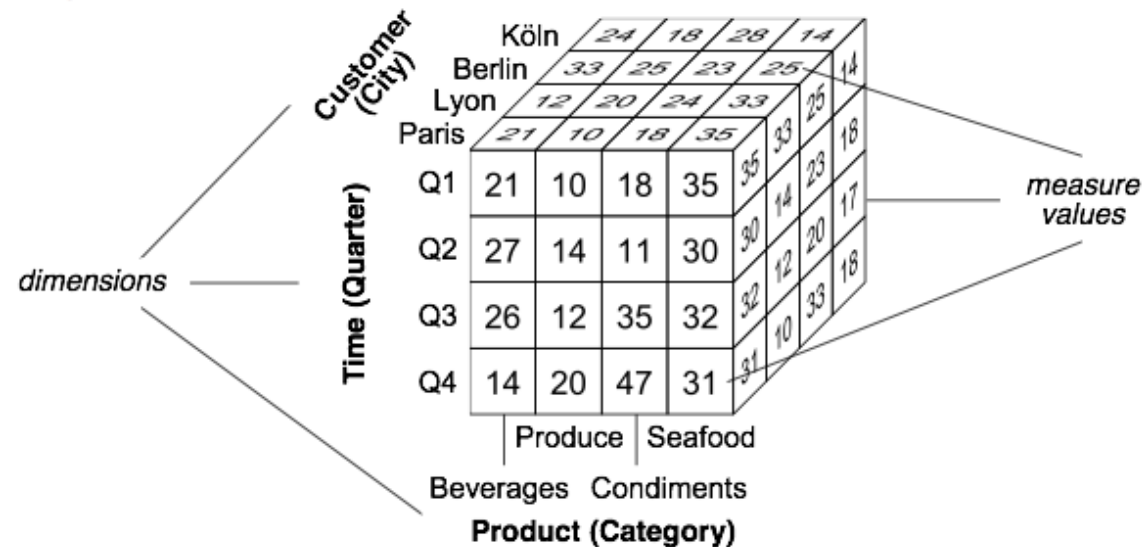
- Example: A three-dimensional cube for sales data with dimensions **Product**, **Time**, and **Customer**, and a measure **Quantity**



**Attributes** describe dimensions

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

# The Multidimensional Model



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

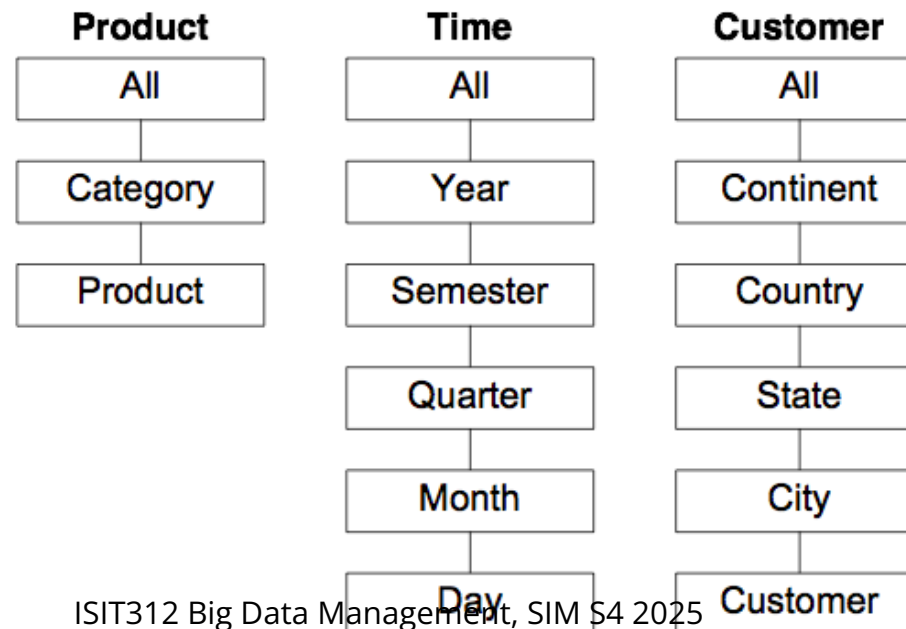


# The Multidimensional Model

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

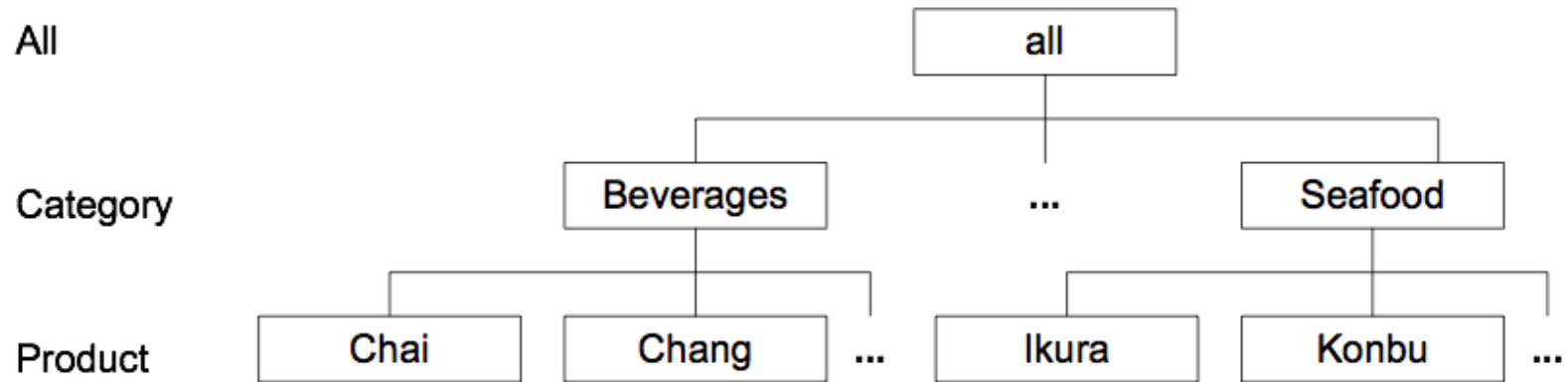
We may want sales figures at a finer granularity (**Month**), or at a coarser granularity (**Country**)

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

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# OLAP Operations

Customer (City)	Köln	24	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 (Country)	Germany	57	43	51	39
	France	33	30	42	68
	Q1	33	30	42	68
	Q2	39	26	41	44
Time (Quarter)	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	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 (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

Product (Category)	Seafood	35	30	32	31
	Condiments	18	11	35	47
	Produce	10	14	12	20
	Beverages	21	27	26	14
		14	20	47	31
Customer (City)	Paris	21	27	26	14
	Lyon	12	14	11	13
	Berlin	33	28	35	32
	Köln	24	23	25	18
		18	19	47	31
		Q1	Q2	Q3	Q4
		Time (Quarter)			

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)			

Pivot

Slice on City='Paris'

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

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

OLAP

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

OLAP

- **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, X<sub>1</sub>, Y<sub>1</sub>, Z<sub>1</sub>, ... }.

```
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

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# 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