

OLAP Databases

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Overview

- Data Warehousing & Decision Support
- Datacubes, Dimension Hierarchies
- ROLAP & MOLAP
- ETL
- Summary

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Decision Support Systems (DSS)

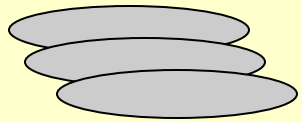
- Support business decisions
 - OLAP vs OLTP
- Examples of high-level analytical questions:
 - *What products have been most profitable for the company this year?*
 - *Is it the same group of products that were most profitable last year?*
 - *How is the company doing this quarter versus this same quarter last year?*
- Examples of data used for making decisions
 - Retail sales transaction details
 - Customer profiles (income, age, sex, etc.)
 - logs



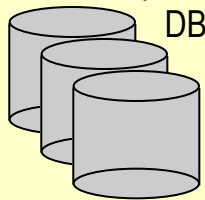
DSS: Architecture

Information Sources

Semistructured
Sources



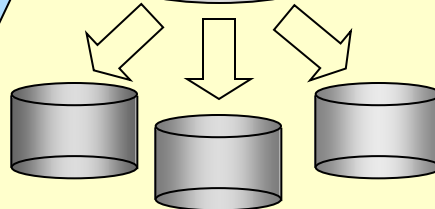
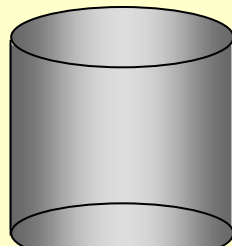
Operational
DB's



*extract
transform
load
refresh
etc.*

Data Warehouse Server

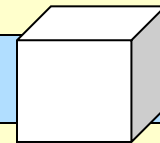
Data
Warehouse



Data Marts

OLAP Servers

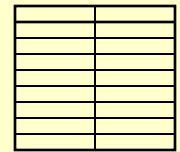
serve



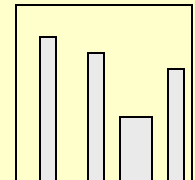
e.g., ROLAP

Clients

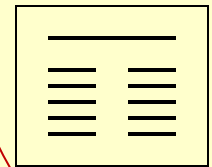
OLAP



Query/Reporting



Data Mining



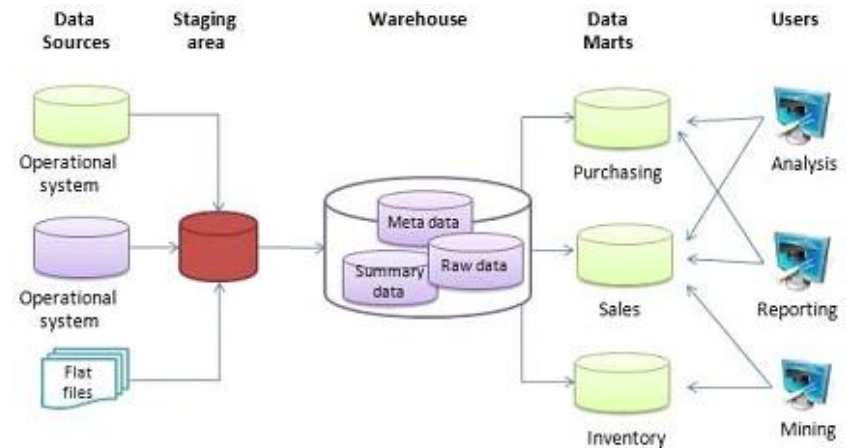
Data Warehousing: Informal

- Problem: critical enterprise information disparate, unavailable
 - locations, representations, storage, accessibility, completeness, ...

- **Data Warehouse**

= system for reporting & data analysis

- one or more disparate sources
→ **central, integrated** repository
- current + historical data
- creating analytical reports
→ core component of business intelligence



[soha jamil / Wikipedia]

- **data cleansing:** extract, transform, load (ETL)

Data Warehousing: Definition

- “A warehouse is a subject oriented, integrated, time-variant, and non-volatile collection of data in support of management decision making process”
 - Bill Inmon, 1990
- Key features:
 - **Subject Oriented:** particular subject instead of company ongoing operations
 - **Integrated:** gathered from a variety of sources, merged into a coherent whole
 - **Time Variant:** particular time period
 - **Non-Volatile:** data, never removed

OLAP

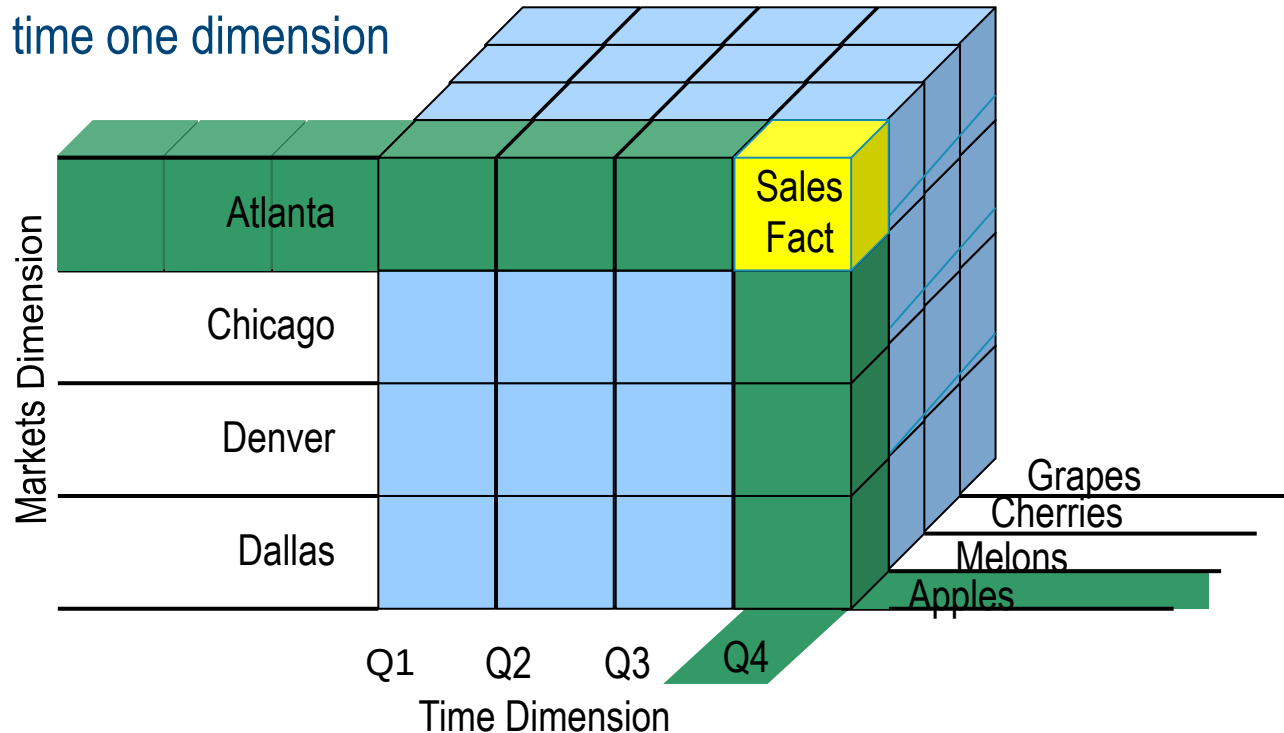
- **OLAP** = Online Analytical Processing
 - Edgar Codd, 1994
 - Differentiated against OLTP = Online Transaction Processing
- software category motivated by industry, introducing advanced data analysis
 - decision making, business modeling, operations research, ...
- enables analysts to extract & view business data from **different points of view**
 - dimensions
- OLAP Characteristics
 - multidimensional data analysis techniques
 - Strong use of aggregate functions for summarizing large volumes of data
 - advanced database support
 - easy-to-use end-user interfaces (spreadsheet type)
 - client/server architecture

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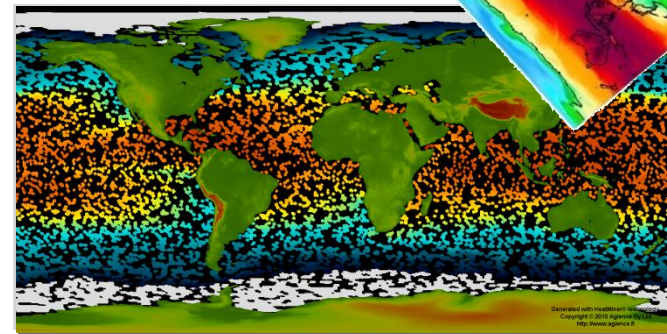
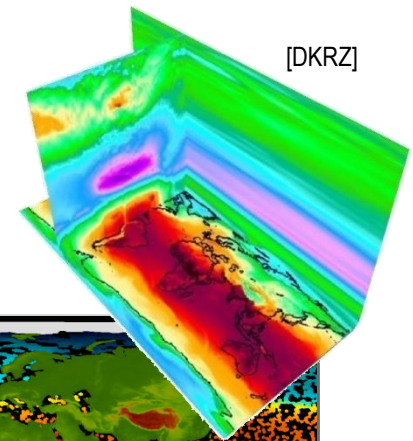
Datacubes

- Data structure for fast **analysis along different views** („dimensions“), on **all levels of detail**
 - Technically: multi-dimensional **array** + metadata
 - Typically, time one dimension

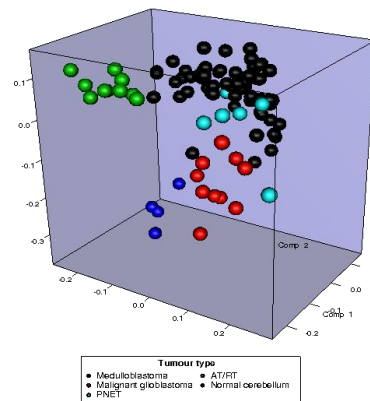
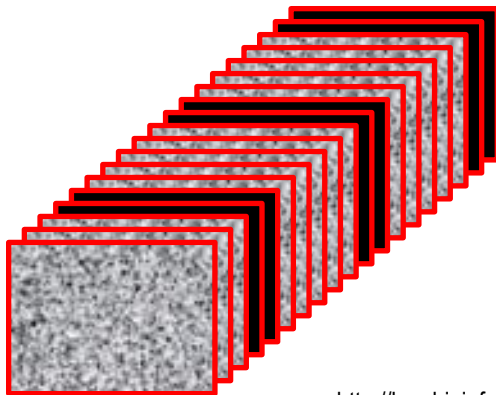


Dense vs Sparse Datacubes

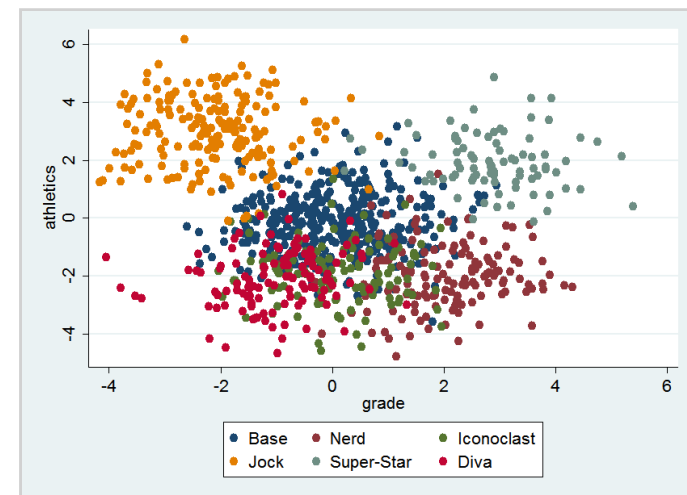
- Dense = every cell has meaningful value
 - Ex: climate simulation
- Sparse = some values null
 - Clustered data
 - Empty regions
 - Ex: retail – open Mon thru Fri



[www.agencie.fi]

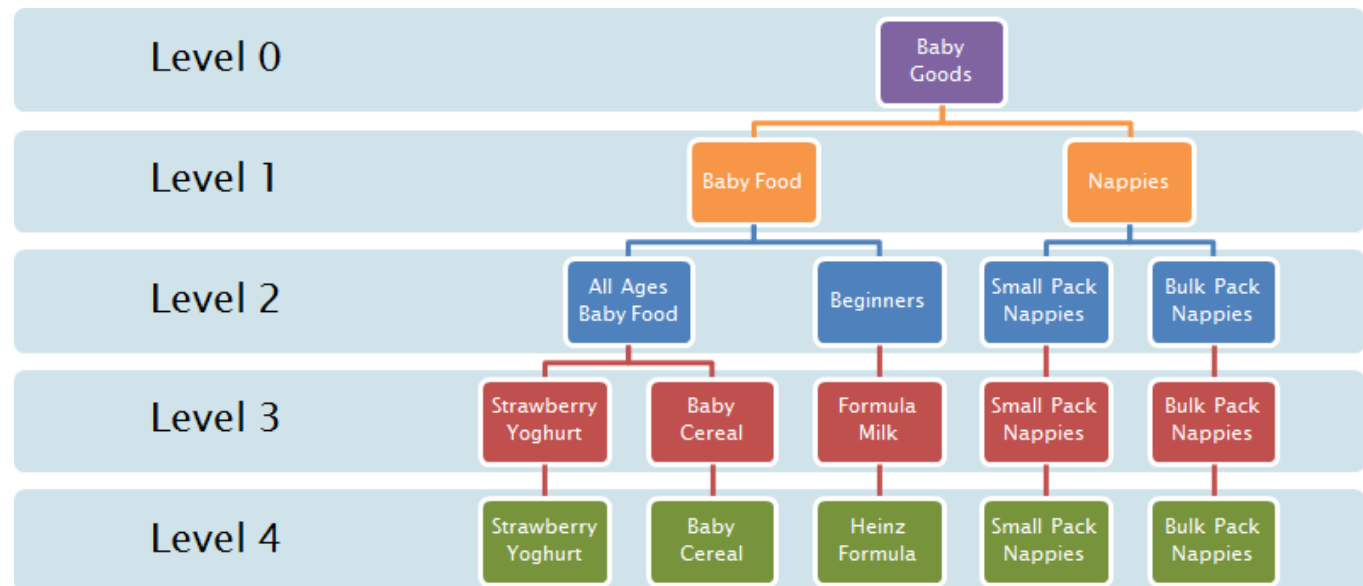


<http://bmcbioinformatics.biomedcentral.com/articles/10.1186/1471-2105-12-253>



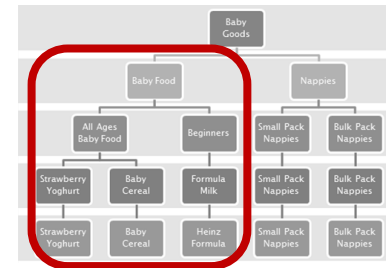
Dimension Hierarchies

- Dimension enumerates values along an axis
 - Ex: time (predefined, ordered), product (custom, unordered)
- Dimension hierarchy = generalization levels of a dimension
 - „zoom levels“ into datacube



Dimension Hierarchies

- Dimension enumerates values along an axis
 - Ex: time (predefined, ordered), product (custom, unordered)
- Dimension hierarchy = generalization levels of a dimension
 - „zoom levels“ into datacube
 - Roll-up done based on hierarchies
- Strict nesting:
Lower bins roll up neatly into higher bins
 - Not always strict! ex: week vs month



location:

city ← region ← country

time:

day ← month
day ← week
month ↔ year
week ↔ year

Datacubes

- Normalizing dimensions
→ dimension hierarchies

- **Datacube** = collection of fact &

location:

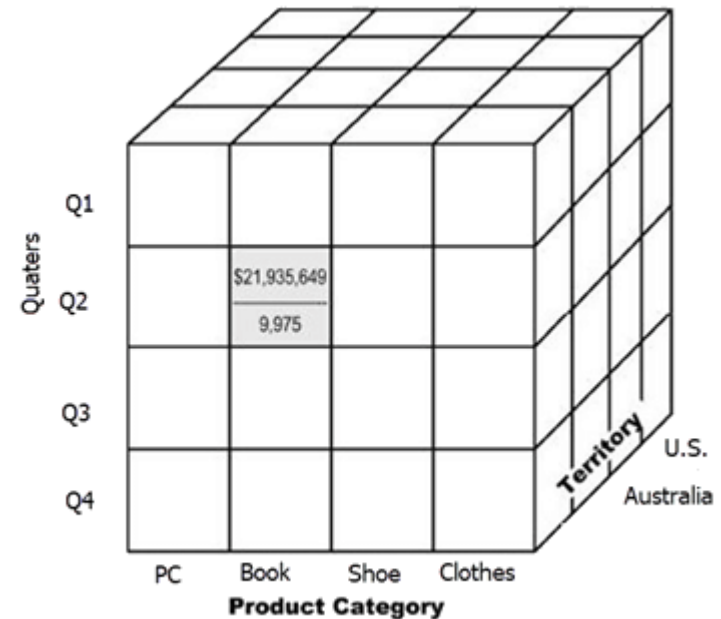
city ← region ← country

time:

day ← month
← week ← year

Datacube Operations

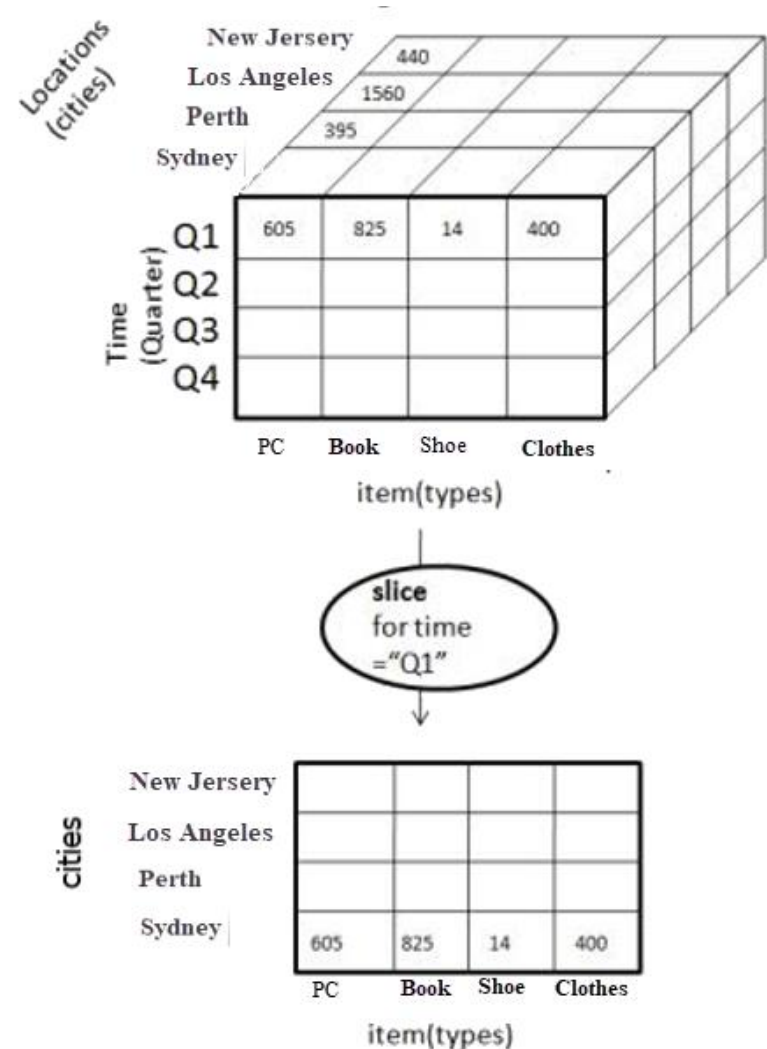
- Extraction + aggregation + combinations:
 - Slice
 - Dice
 - Roll-Up
 - Drill Down
 - Pivot
- Later, with arrays,
we will want to do more



[guru99.com]

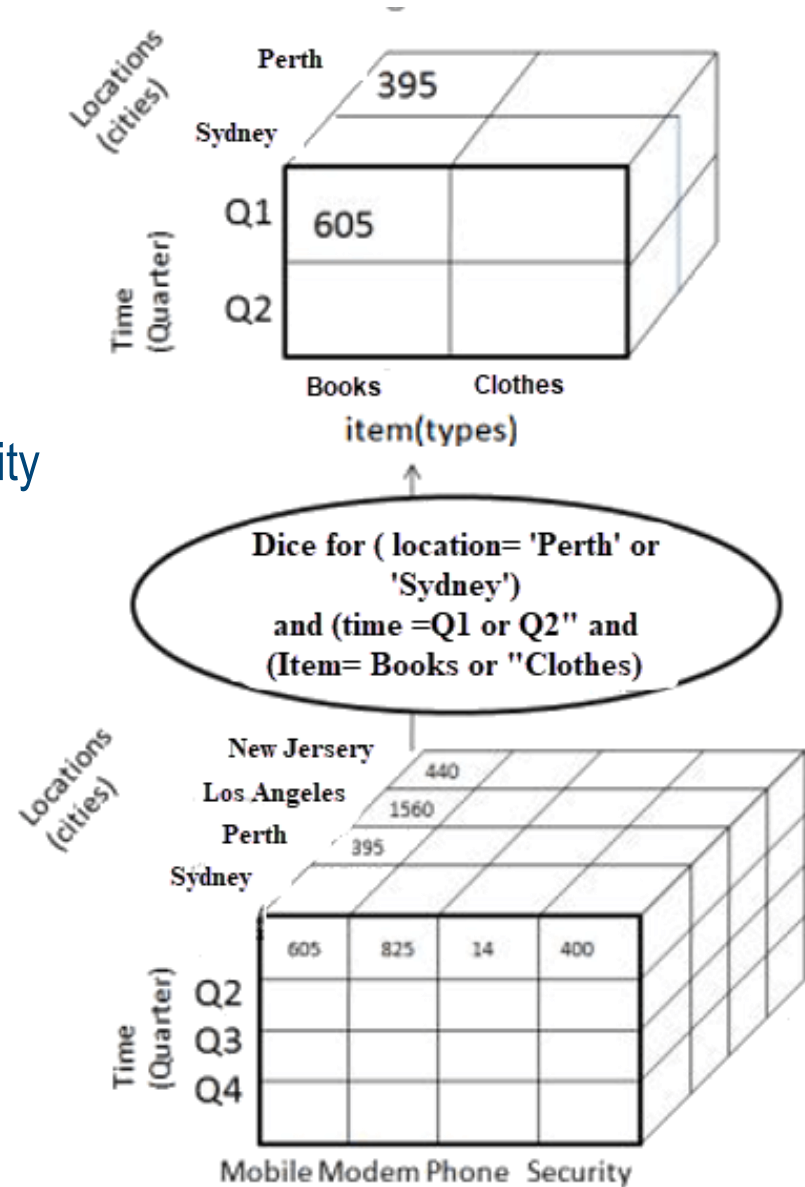
Operations: Slicing

- **Slicing** = Select sub-cube by selecting dimension values to fewer points
 - Result cube has less dimensions
- Ex: select particular time slice



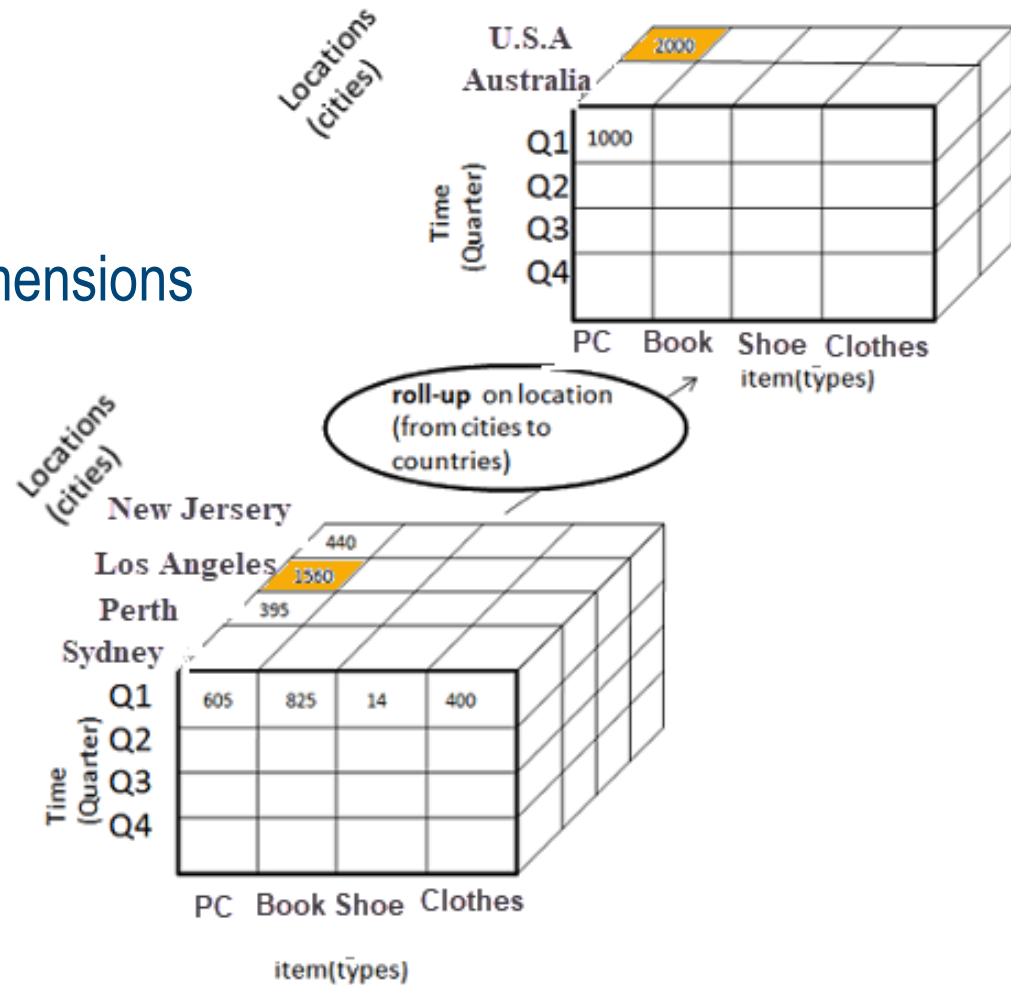
Operations: Dicing

- **Dicing** = subsetting
 - „thicker slices“, not reducing dimensionality
- Ex: derive subcube
by selecting along location, time, item
simultaneously



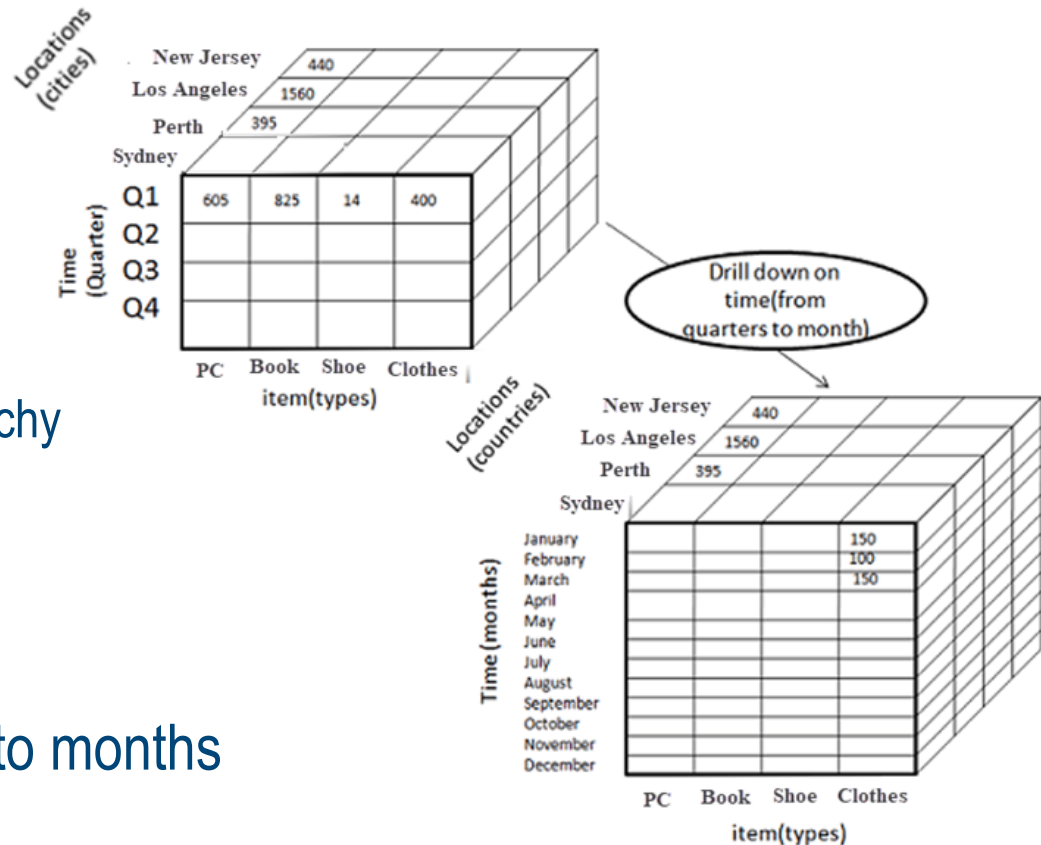
Operations: Roll-Up

- **Roll-Up** = aggregation along dimensions
 - also: „consolidation“
 - collapsing a dimension hierarchy
 - „climbing up“ concept hierarchy
- Ex: consolidating from cities to countries



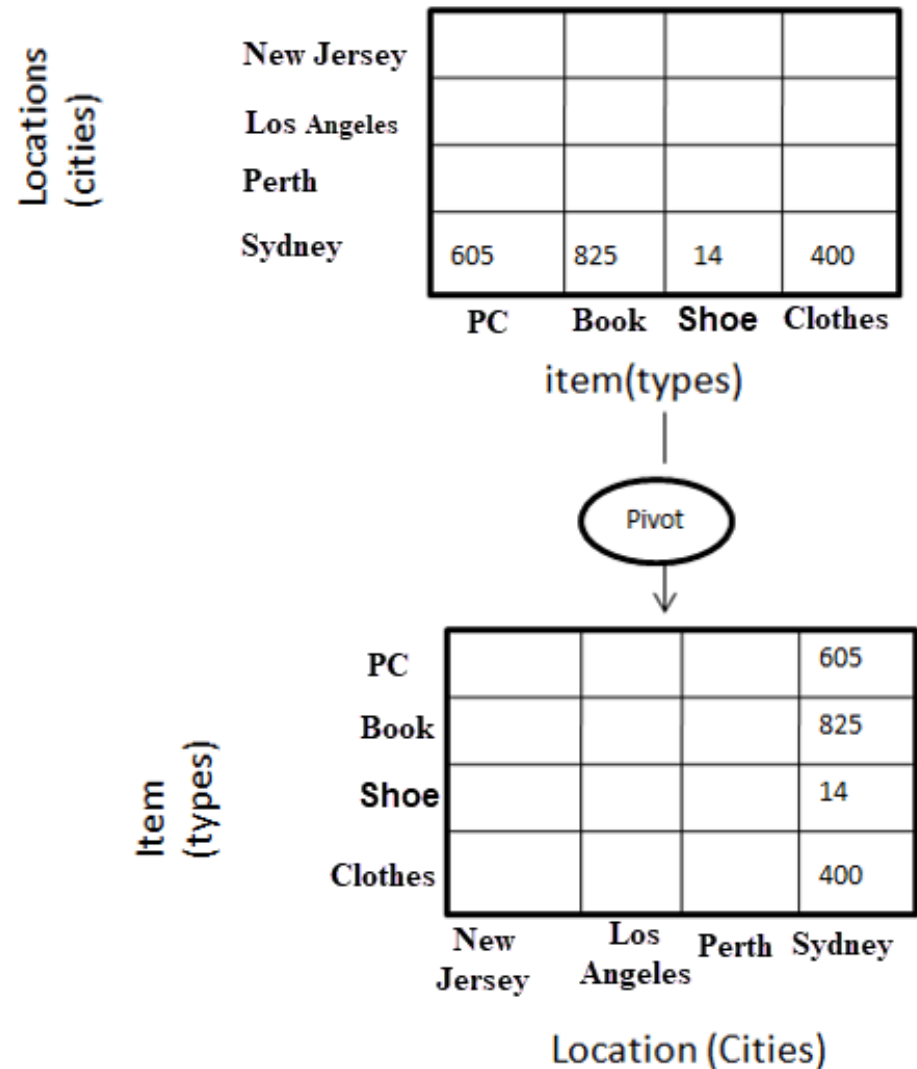
Operations: Drill-Down

- **Drill-Down** = fragment data into smaller parts
 - Moving down concept hierarchy
 - Expanding some dimension
- Inverse of roll-up
- Ex: detailing from quarters to months

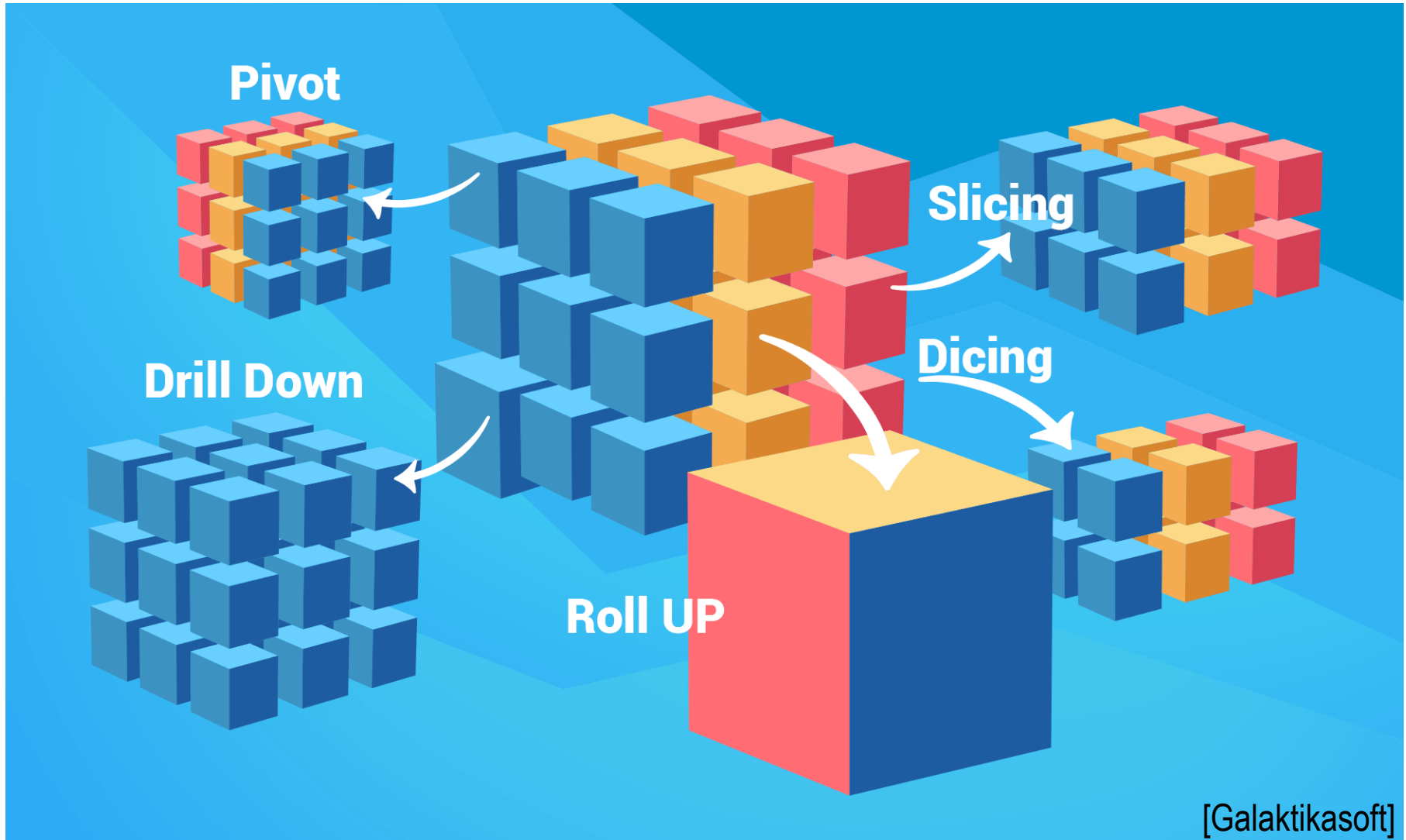


Operations: Pivot

- **Pivot** = rotate axes
 - show another view
 - Ex: swap rows & columns
- Ex: swap cities $\leftrightarrow$ product types



Visual Summary: Datacube Ops



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OLAP Datacube Querying

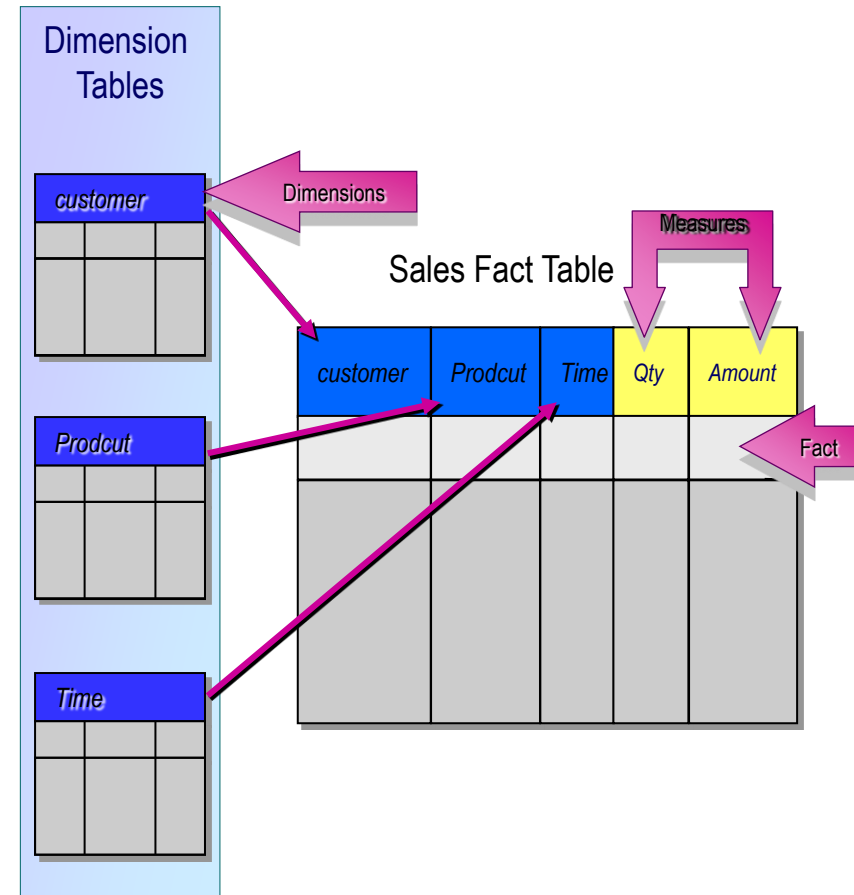
- ISO SQL does not directly support cubes
 - changing with SQL/MDA
- Multidimensional Expressions (MDX) = query language for OLAP
 - Microsoft 1997, also adopted by other vendors
 - <https://docs.microsoft.com/en-us/sql/mdx/multidimensional-expressions-mdx-reference?view=sql-analysis-services-2017>

• Ex:

```
SELECT
  { [Measures].[Store Sales] } ON COLUMNS,
  { [Date].[2002], [Date].[2003] } ON ROWS
FROM Sales
WHERE ( [Store].[USA].[CA] )
```

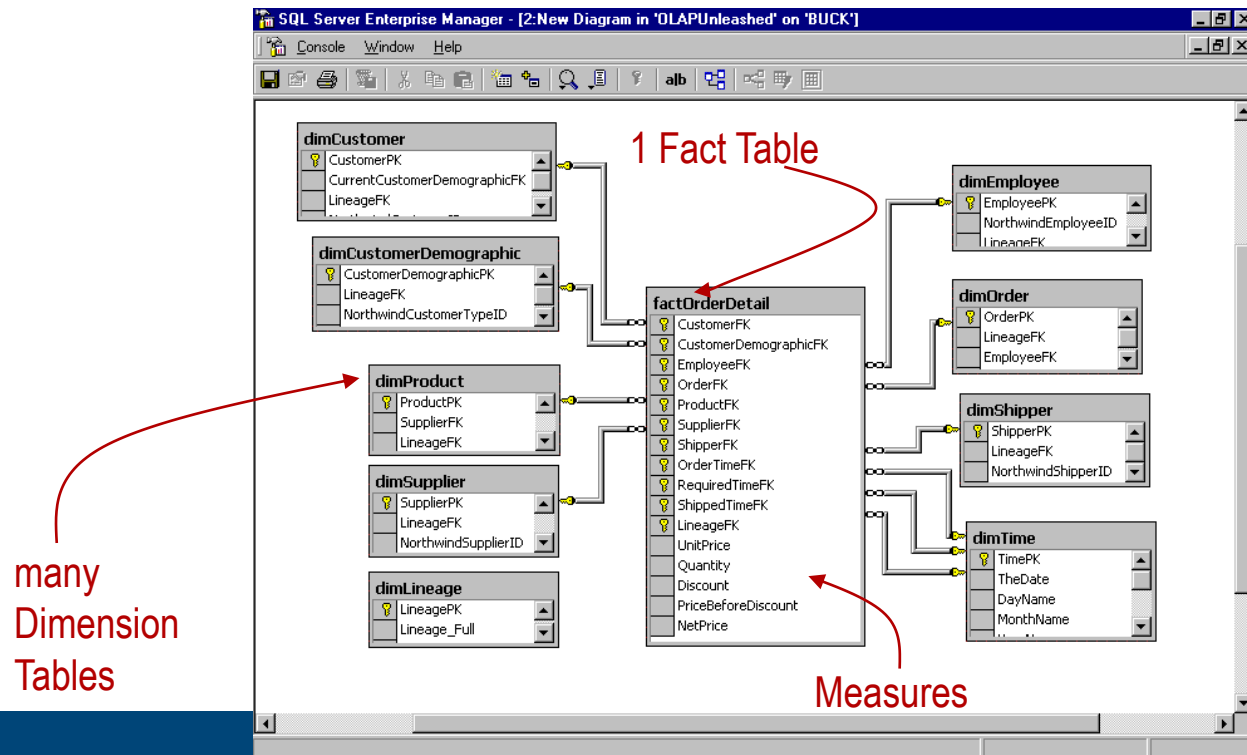
Datacubes in ROLAP: Facts & Dimensions

- Mapping datacubes to relational table schema ?
- Central **fact table**
= tuples + n-D “coordinate” attributes
 - foreign keys
 - non-keys = **measure**
- **Dimension** = table(s)
 - with coordinates
+ descriptions („metadata“)
- One step of normalization:
keys → dimension tables



Star Schema

- **star schema** = multidimensional data structure in relational database
 - Dimension hierarchies = aka lookup tables around fact table
- MS SQL Server Enterprise Manager:



Snowflake Schema

- **snowflake schema** = refinement of star schema

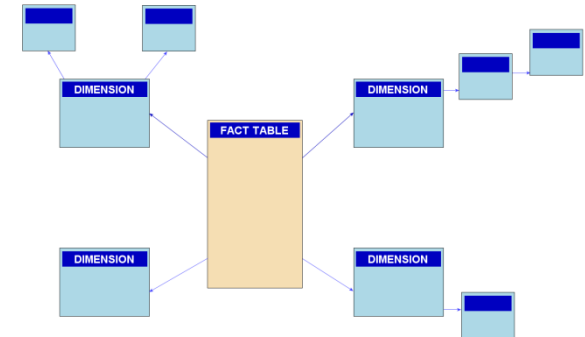
- Normalizing dimension tables

- Ex:

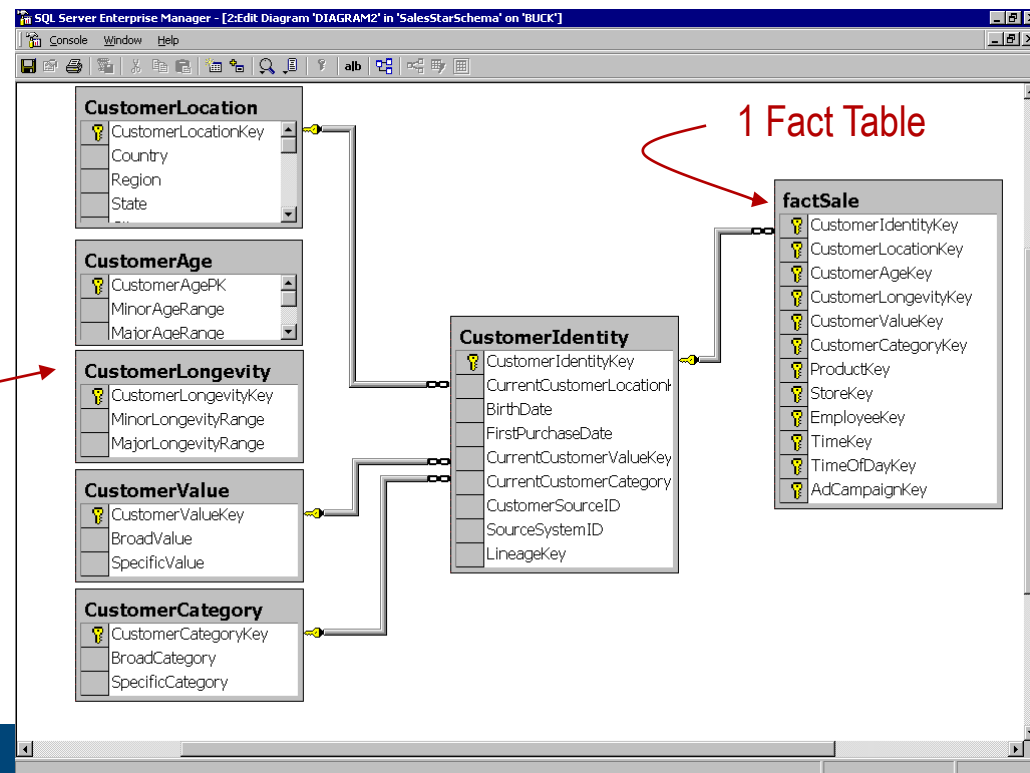
- *Year → Month → Day*
- *Week → Day*

- MS SQL Server Enterprise Manager:

normalized
Dimension
Tables

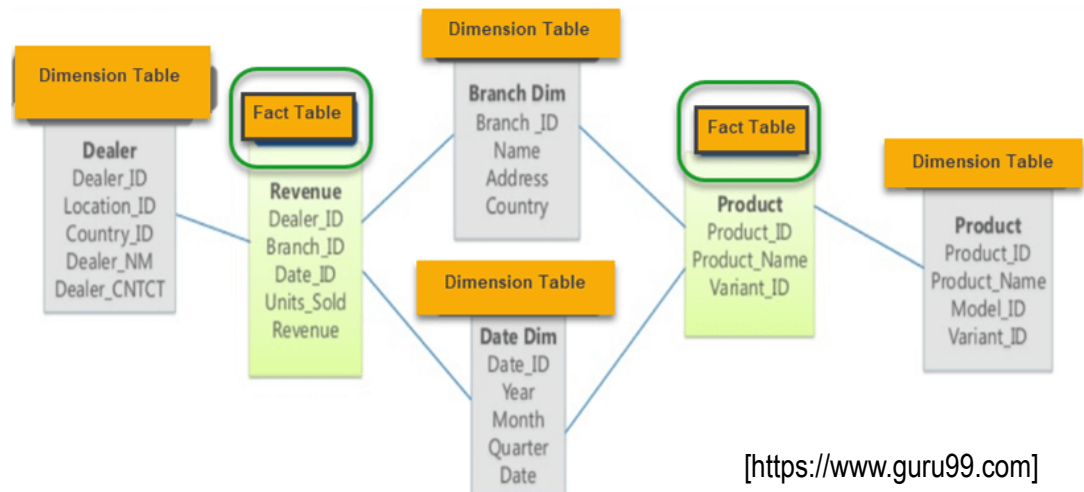


[SqlPac @ Wikipedia]



Galaxy Schema

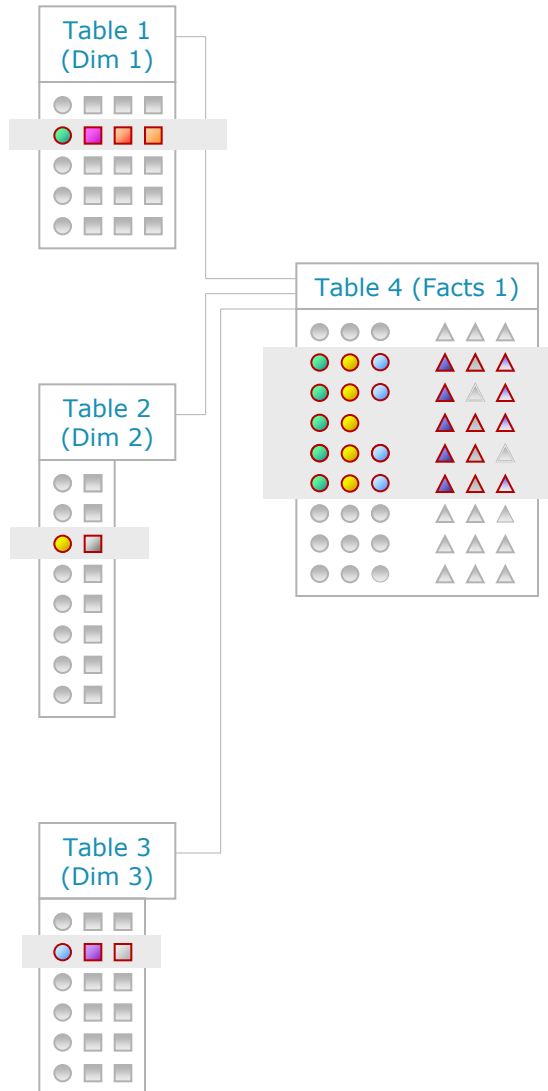
- **Galaxy schema** = Constellation schema = linked datacubes
 - Sharing dimension(s)



[<https://www.guru99.com>]

- helpful for aggregating fact tables

A Query in ROLAP



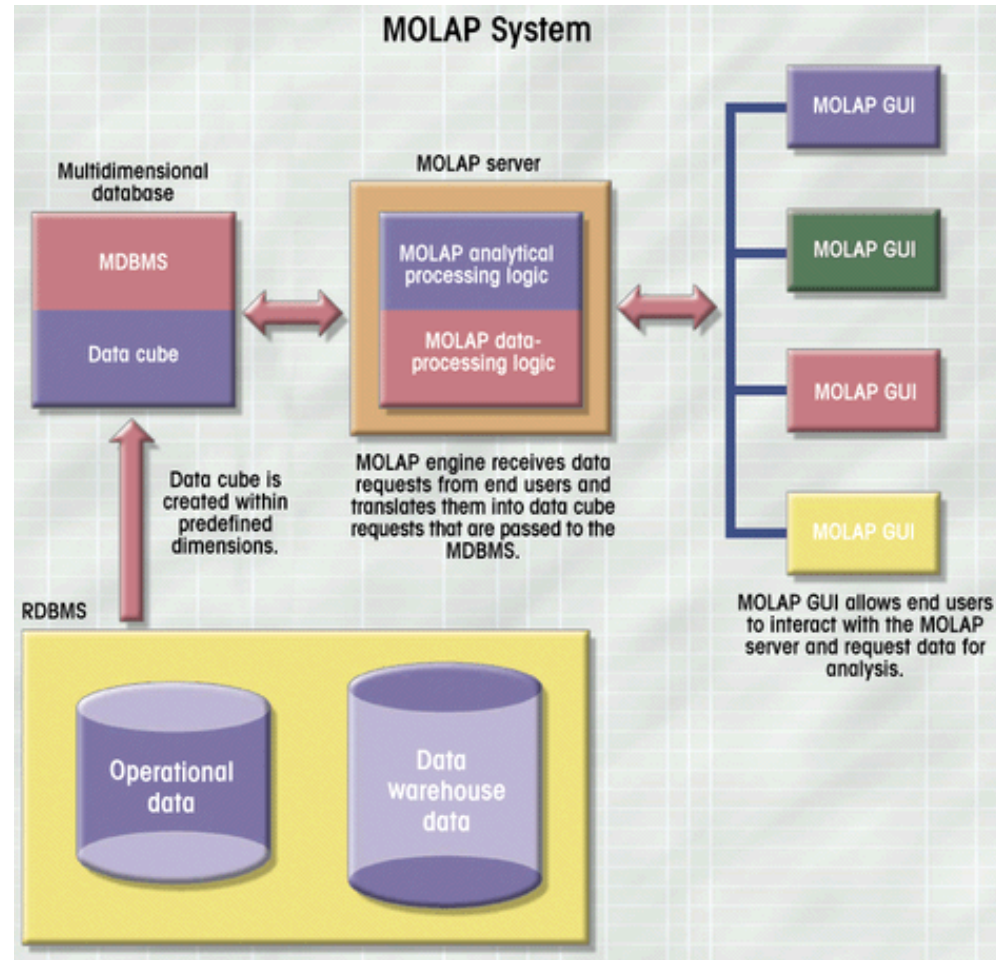
```
SELECT Fact_Column_1
      ,Fact_Column_2
FROM Table 4      T4  -- Fact
      ,Table 1    T1  -- Dim 1
      ,Table 2    T2  -- Dim 2
      ,Table 3    T3  -- Dim 3
WHERE T4.Dim_Col_1 = T1.Dim_Col_1
      AND T4.Dim_Col_2 = T2.Dim_Col_1
      AND T4.Dim_Col_3 = T3.Dim_Col_1
      AND T1.Dim_Property_2 = 'Product 1'
      AND T2.Dim_Property_1 = 'City 1'
      AND T3.Dim_Property_1 = 'Salesman 1'
```

Performance of ROLAP methods

- ~ 70% of the time spent on CPU, rest on I/O
- Most of the CPU time spent in sorting intermediate results
 - ~ 10-20% is spent on copying data
- I/O composed of read/write into large tables

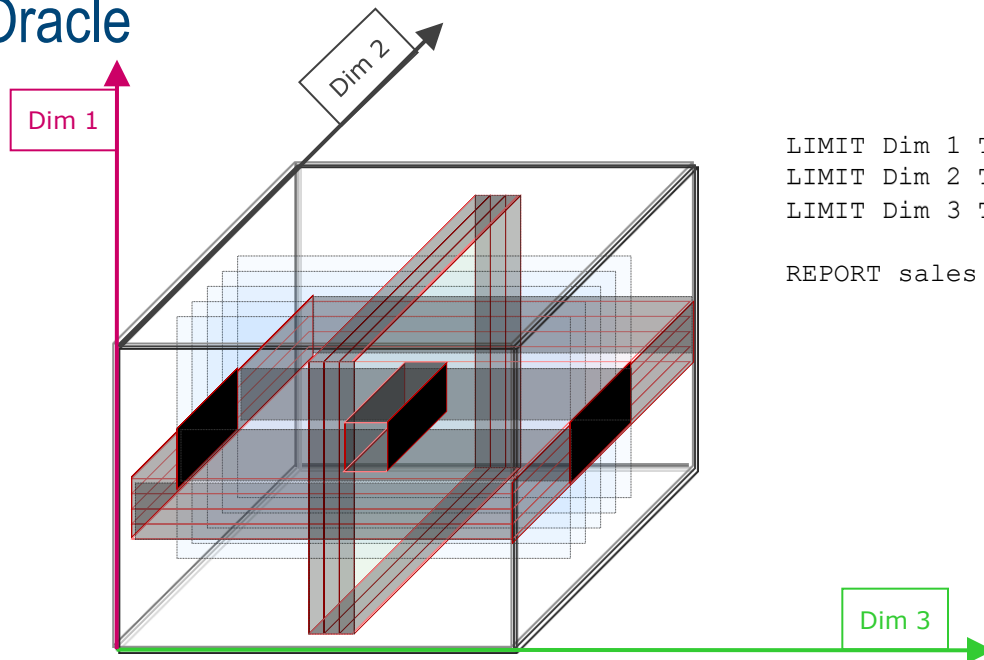
The MOLAP Approach

- Native datacube
= multidimensional array
 - plus metadata
- Fast position-based computation
 - cell values stored in fixed positions determined by dimension values
- Often used for data marts



A Query in MOLAP

- Proprietary QLs
- Ex: Oracle



```
LIMIT Dim 1 TO 'Soap'  
LIMIT Dim 2 TO 'Bremen'  
LIMIT Dim 3 TO 'John Doe'  
  
REPORT sales
```

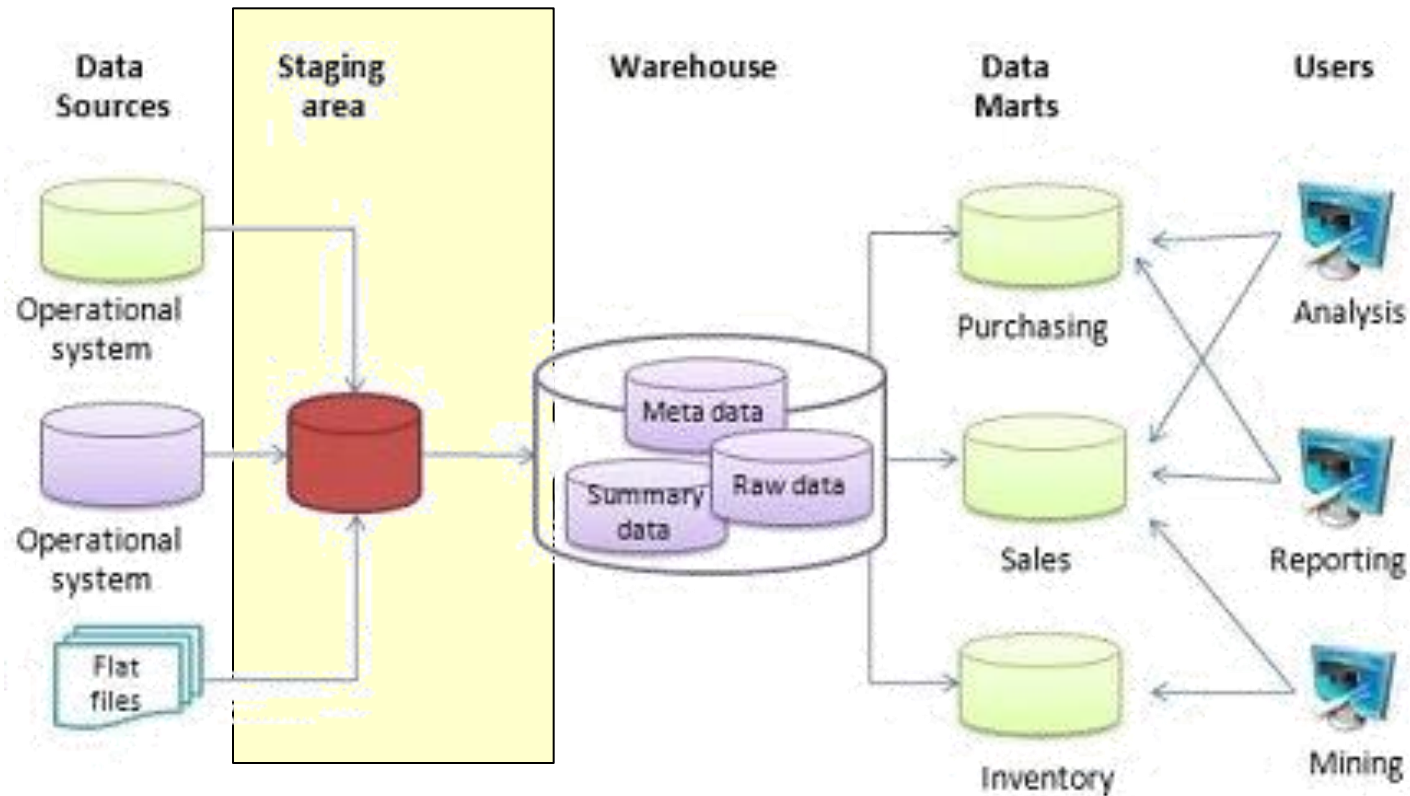
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ETL

- Extract
 - Extract relevant data
 - Transform
 - Transform data to DW format
 - Build keys, etc.
 - cleaning of data
 - Load
 - Load data into DW
 - Build aggregates, etc.
- most underestimated process in DW development
 - most time-consuming process in DW development
 - 80% of development time spent on ETL!

ETL in Data Warehouse Architecture



[soha jamil / Wikipedia]

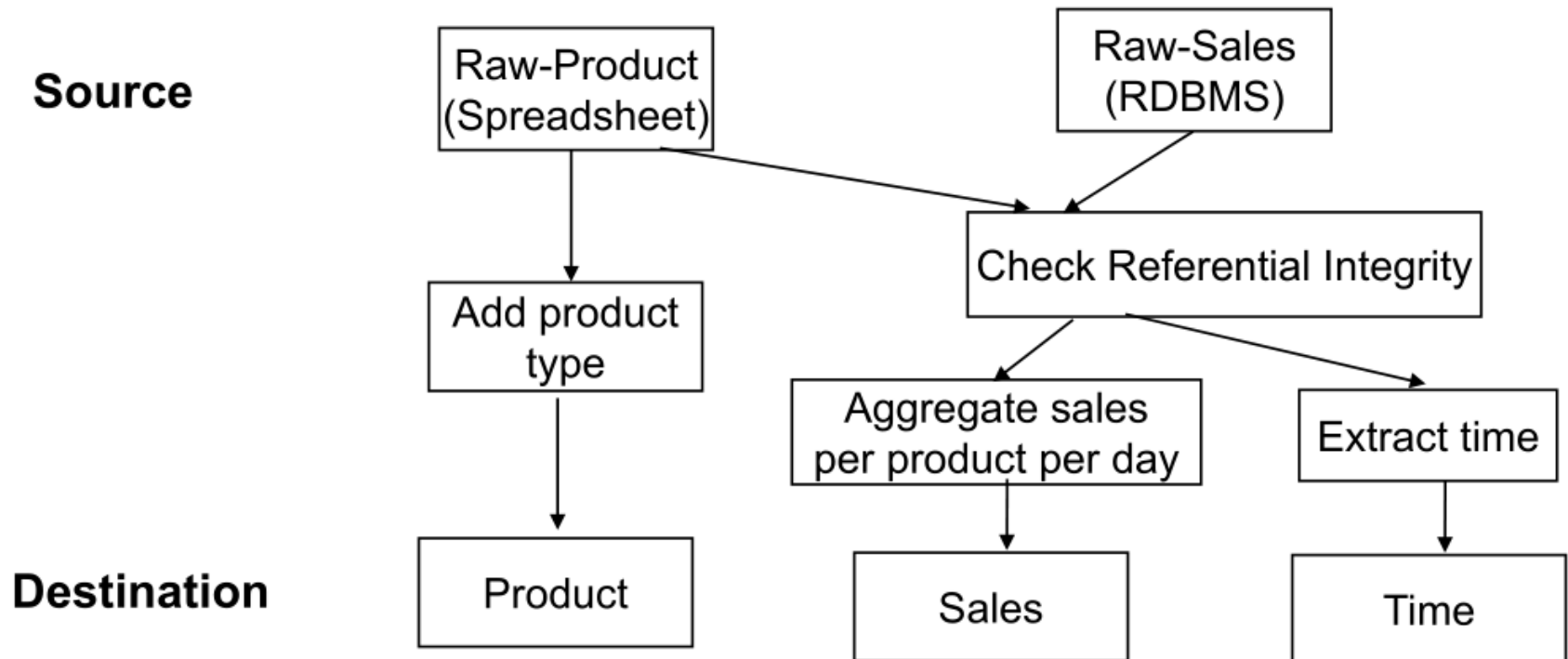
Common Transformations

- Data type conversions
 - EBCDIC → ASCII/UniCode
 - String manipulations
 - Date/time format conversions
 - *Ex: unix time 1201928400 = what time?*
- Normalization/denormalization
 - To desired DW format
 - Depending on source format
- Building keys
 - Table matches production keys to surrogate DW keys
 - Correct handling of history - especially for total reload

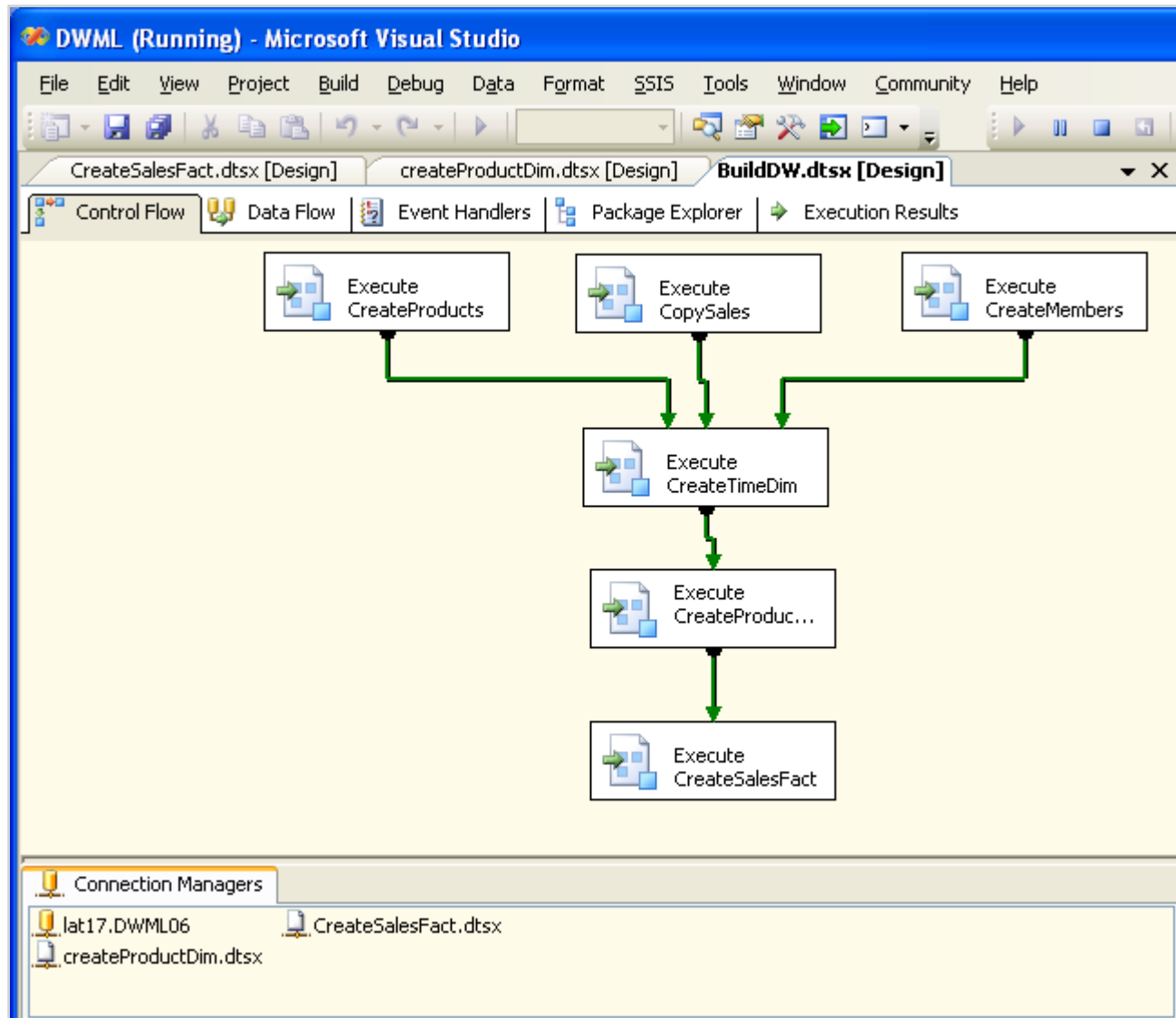
Data Cleansing: Why?

- Garbage In - Garbage Out
- BI does not work on “raw” data
 - Pre-processing necessary for BI analysis
- Handle inconsistent data formats: Spellings, codings, ...
- Remove unnecessary attributes: Production keys, comments,...
- Replace codes with text (Why?)
 - City name instead of ZIP code, e.g., Aalborg Centrum vs. DK-9000
- Combine data from multiple sources with common key
 - E.g., customer data from customer address, customer name, ...

Sample High-Level Extract Diagram



Ex: Microsoft BI Dev Studio

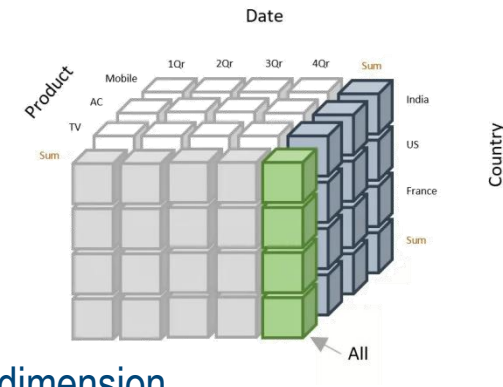


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Summary: Data Warehousing Terminology

- Typically, warehouse data is **multidimensional**, resembling large **datacubes**
- **Datacube**: a structure containing values of same type, each identified by a coordinate tuple along the dimensions of the cube
 - Ex: Cube of sales figures with 3 dimensions region, product, time
- **Fact**: The subject of analysis
 - Ex: sales revenues
- **Measures**: The coordinates of the specific data points, one taken from each dimension
 - Ex: (“Bremen”, “Apples”, “2025-12-01”) might identify the fact containing the revenues made from selling apples that day
- **Dimension**: a set of values providing coordinates that can act as measures for locating facts
 - Ex: region, product, time
- **Hierarchies**: Nested grouping of values within dimensions, used for aggregation (“roll-up”) etc.
 - Ex: time = day / week / year; region = Bremen / Germany / Europe



Summary

- Data warehouse $\neq$ software product or application, but information processing **system architecture** geared at decision making
 - OLAP vs OLTP
- OLAP
 - Multi-dimensional, timeline, integrated, aggregated
 - ROLAP vs MOLAP
 - Star vs Snowflake vs Galaxy schema
- Part of bigger BI plot
 - ETL, Data Warehousing, OLAP, Data Mining, ...
- Recently: Data Lakes