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Lecture Notes
Week 05

INFS3200 Advanced Database Systems
Semester 1, 2021

Data Warehouse Design

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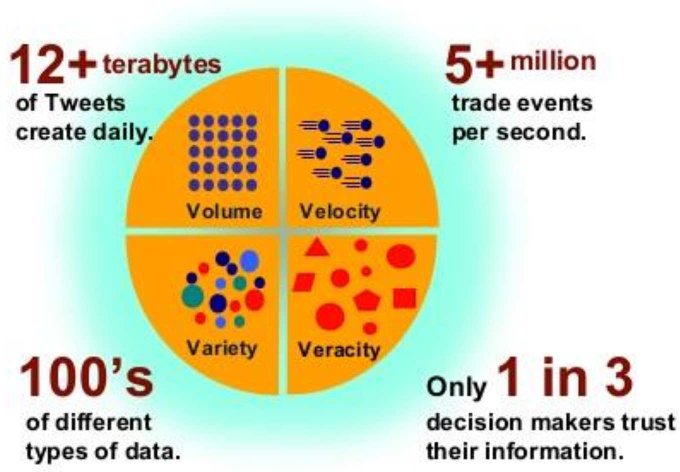
+ Last Week

- Distributed Transaction Management
  - A review of TM in centralized DB
    - ACID, serializability, 2PL, log-based recover
  - Two key issues in DDB
    - Updating distributed data – replication strategies
    - Distributed transactions – 2PC

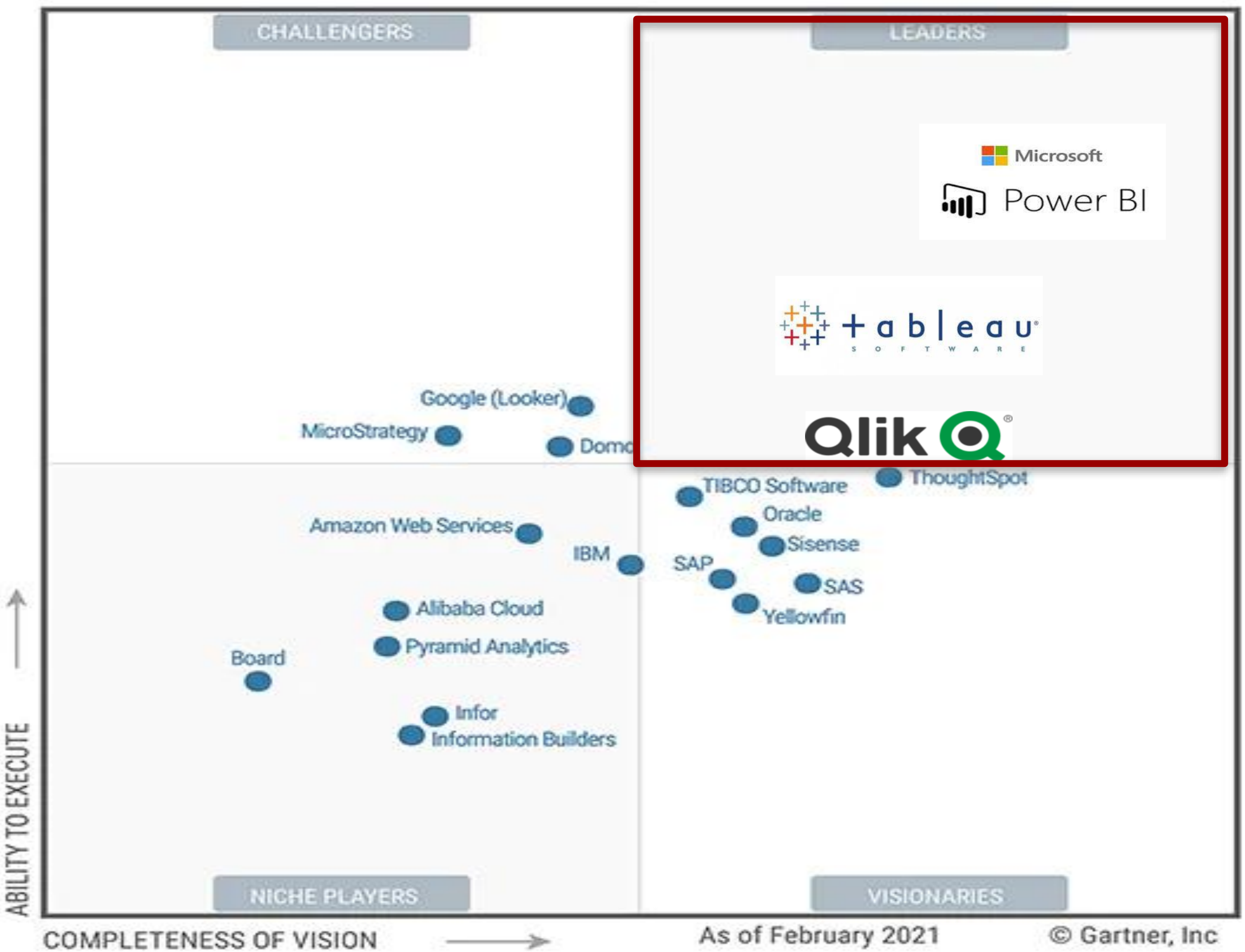
+ Background



- Big Data Era
  - 4V property
  - Value
    - Large-scale e-commerce system
    - Decision making driven by large-scale data
    - Data sharing and crowd-sourcing
- Big Data Techniques
  - Distributed DBMS: Volume, Velocity
  - Data Warehousing: Variety, Veracity, Volume
    - Data integration & Quality management
  - Data privacy & security

+ Data Warehousing Products

Figure 1: Magic Quadrant for Analytics and Business Intelligence Platforms

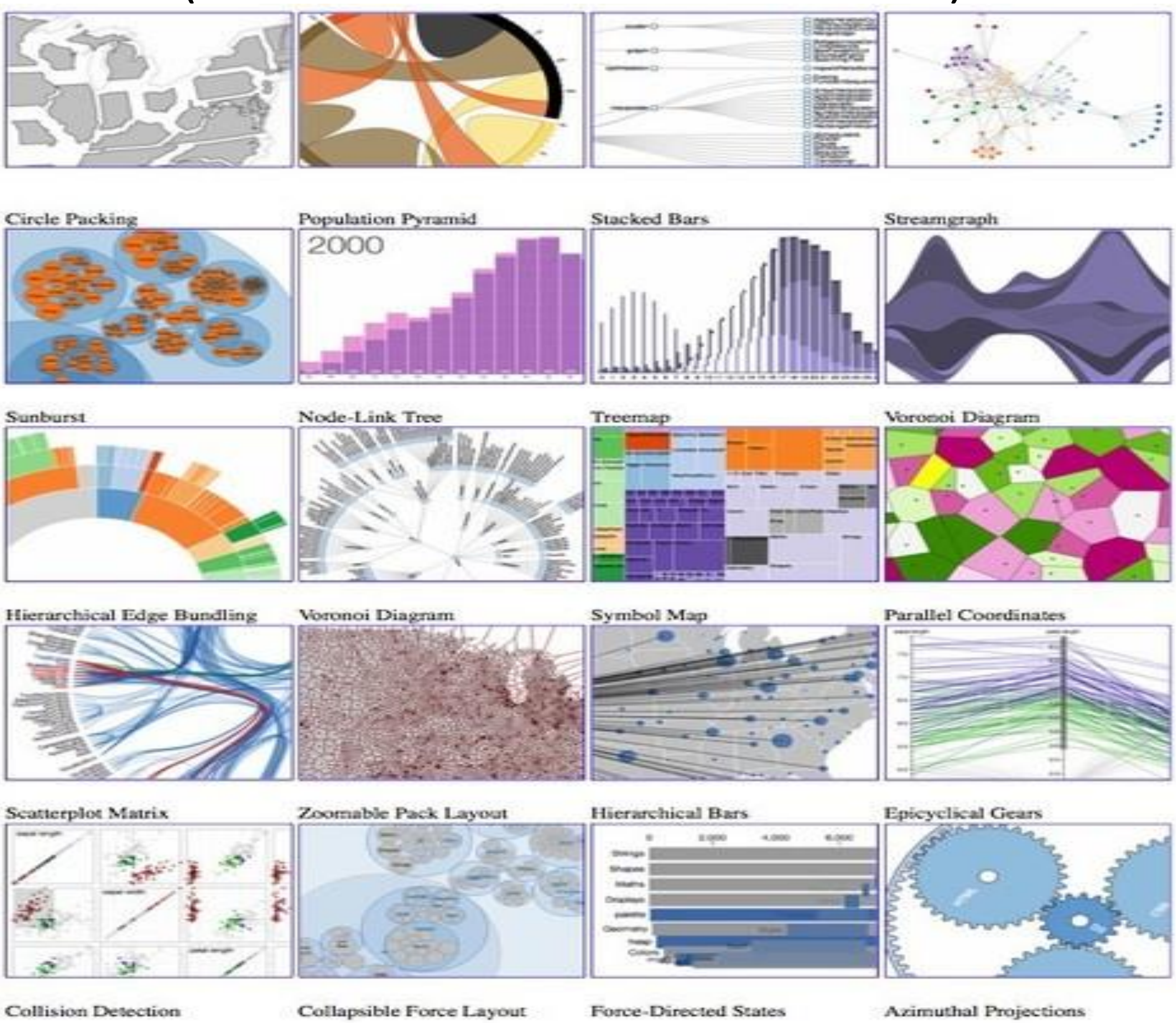


Source: Gartner (February 2021)

Source: Gartner © 2021data warehouse Magic Quadrant

https://www.qlik.com/us/lp/sem/gartner-magic-quadrant-2021-b

Language for big data visualization:
D3 (Data-Driven Documents)

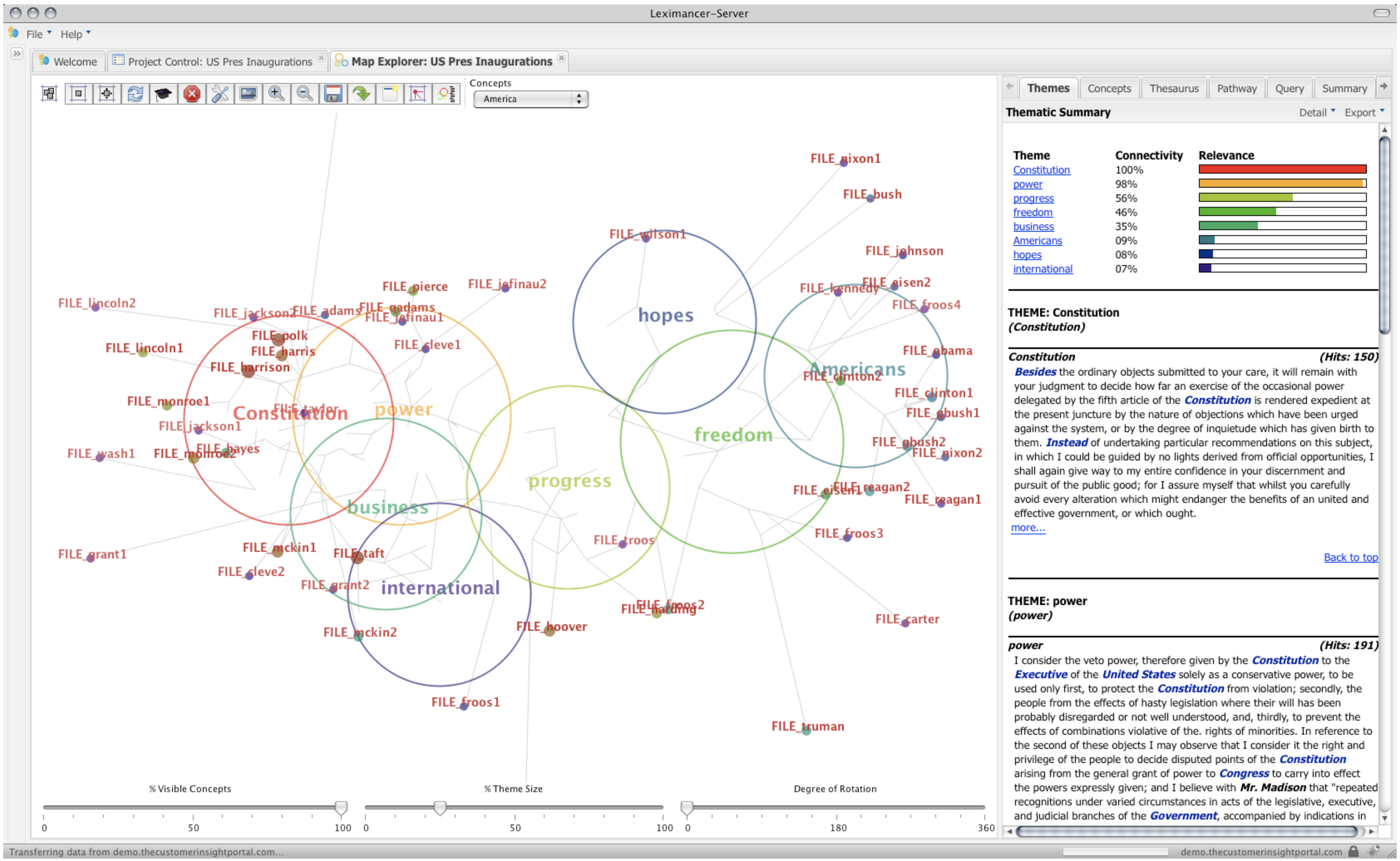


http://d3js.org/

Big machine data - Splunk

http://www.splunk.com/?r=header

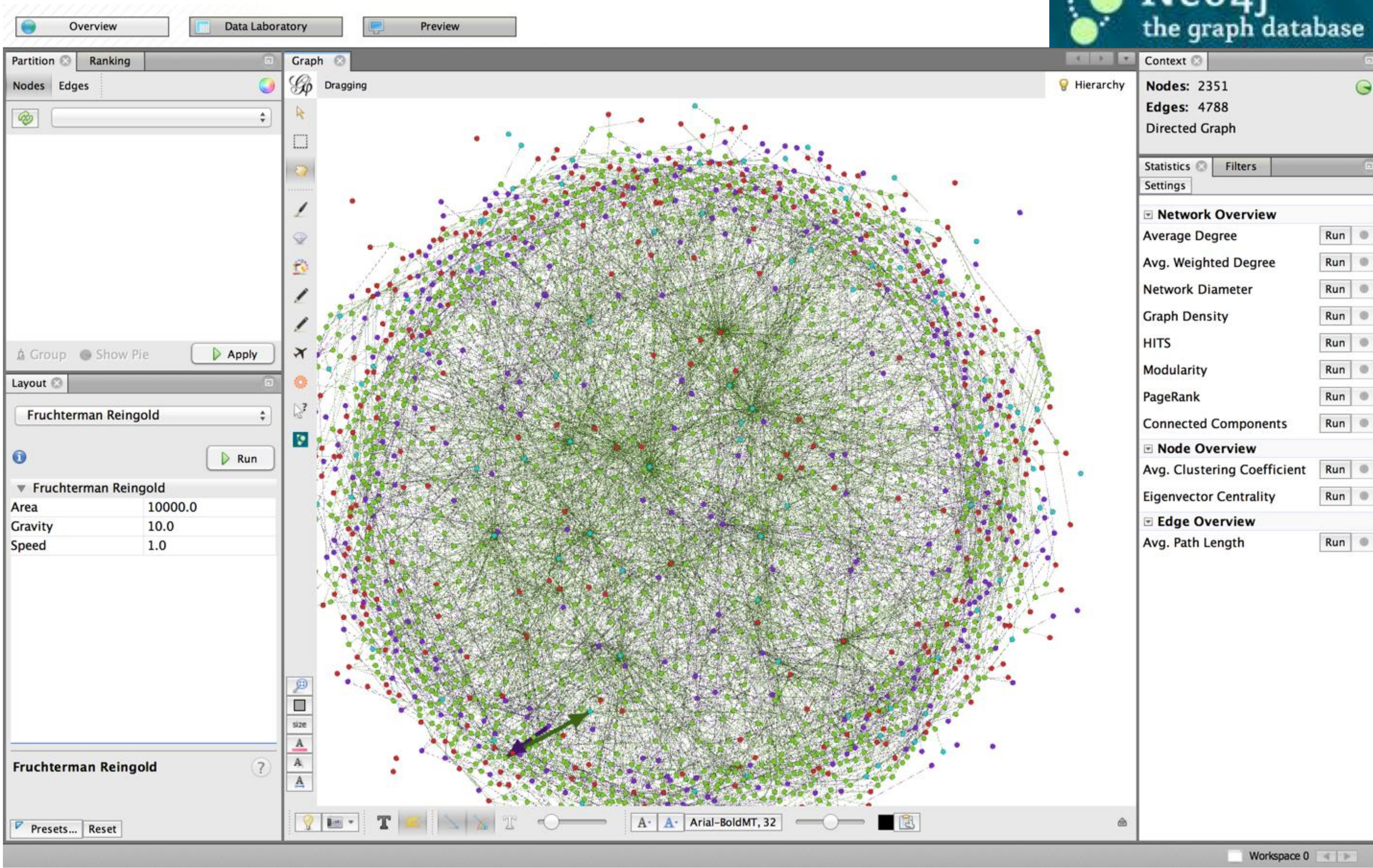
Big text data: Leximancer



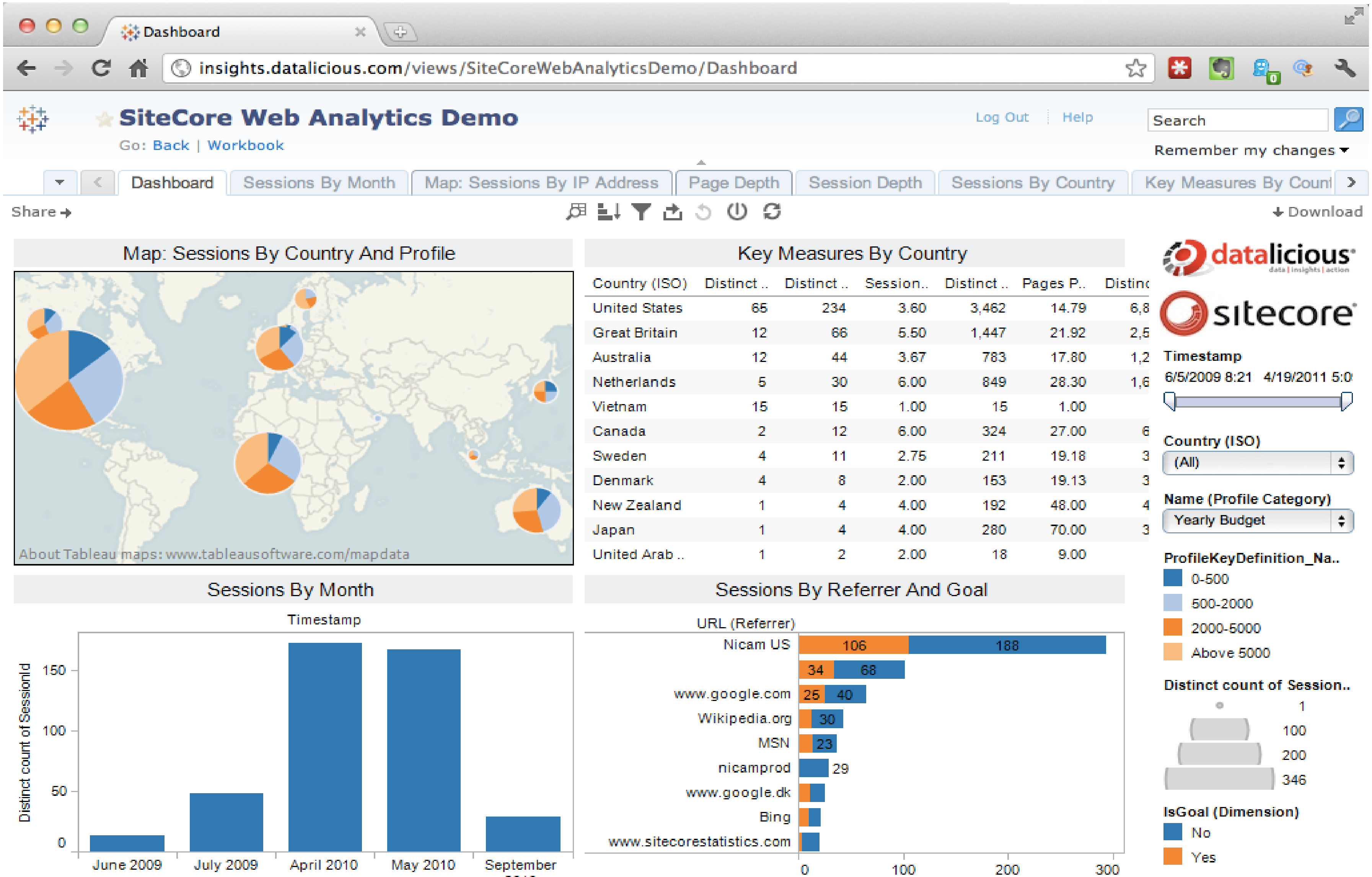
https://www.leximancer.com/

Big graph-structured data: Neo4j

Neo4j
the graph database

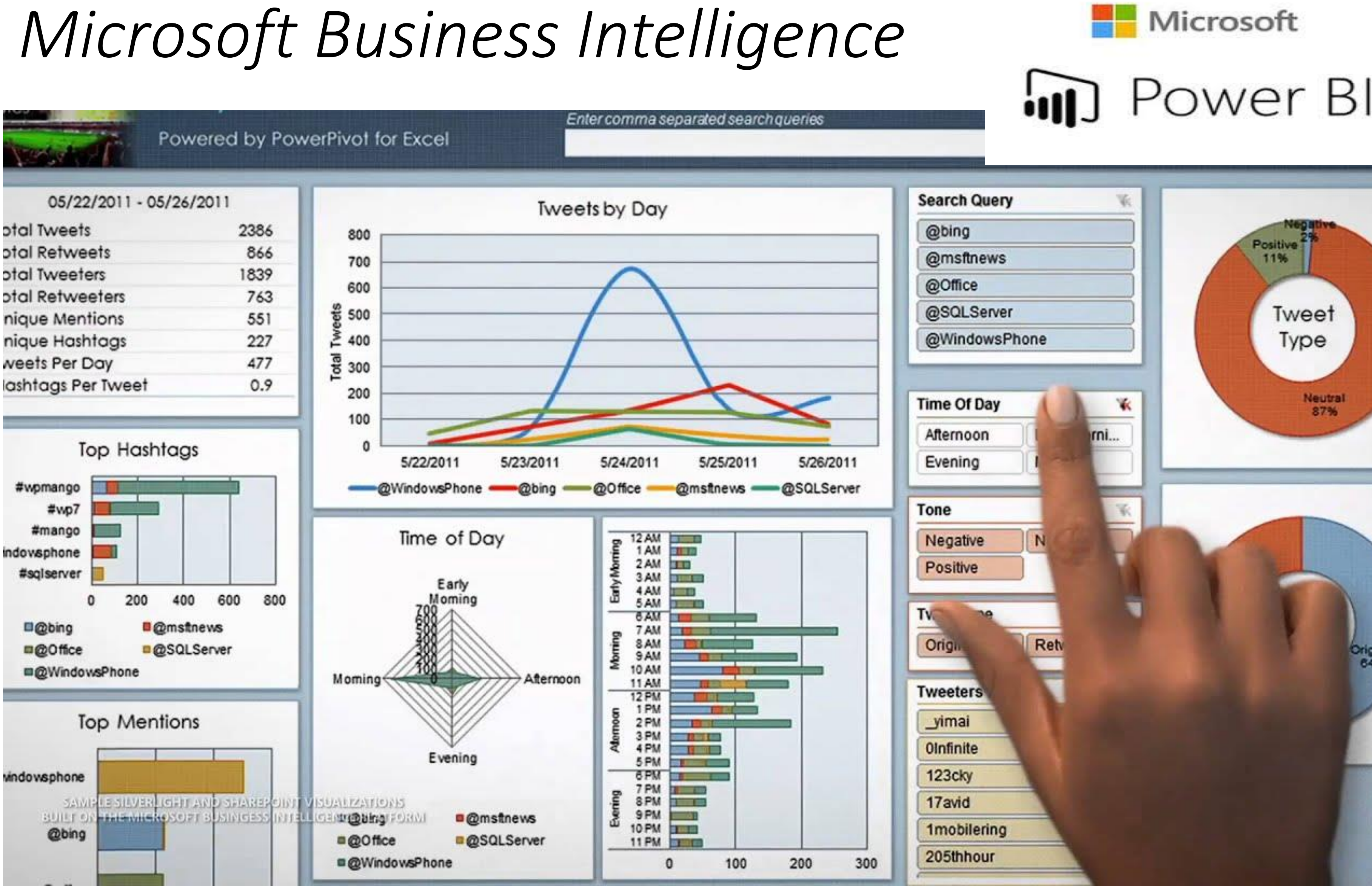


Big Tabular data: Tableau



http://blog.datalicious.com/sitecore-raw-data-analysis-tableau/

Microsoft Business Intelligence



https://www.youtube.com/watch?v=N8FbarXC0Og

+ Outline

- Data Warehousing
  - Data warehousing concepts
  - Data warehousing design
  - Data warehousing operations
  - Data warehousing implementation (week 06)
- Data Integration (week 07)
- Date Quality Management (week 08 - 09)
- Data Security and Privacy (week 10)

OLTP (Online Transaction Processing) vs. OLAP (Online Analytical Processing)

- OLTP system is a database system used to record current **Update, Insertion** and **Deletion** transactional operations.
  - Queries are simpler and short ,
  - Time-critical in processing, and requires less space.
- OLAP database stores historical data that has been collected from OLTP databases.
  - view different summaries of multi-dimensional data
  - extract information from a large database
  - analyse data for **decision making**

https://techdifferences.com/difference-between-oltp-and-olap.html#:~:text=OLAP

+ OLTP vs. OLAP (count.)

- OLTP is an online **transaction** system whereas, OLAP is an online **data retrieval and analysis** system.
- **Transactional data** is the source of OLTP, whereas different OLTP databases are the source of OLAP.
- OLTP's main operations are **insert, update** and **delete** whereas, OLAP's main operation is to **extract multidimensional data for analysis**.
- OLTP has **short but frequent** transactions whereas, OLAP has **long and less frequent** transaction.
- Processing time for the OLAP's transaction is more as compared to OLTP.
- OLAPs queries are more complex with respect OLTPs.
- The tables in OLTP database must be **normalized** (**3NF**) whereas, the tables in OLAP database **may not be normalized**.
- As OLTPs frequently executes transactions in database, in case any transaction fails in middle it may harm data's integrity and hence it must take care of data integrity. While in OLAP the transaction is less frequent hence, it does not bother much about data integrity.

https://techdifferences.com/difference-between-oltp-and-olap.html#:~:text=OLAP

+ Decision Support Systems

- Data warehousing is for Decision Support Systems (DSS) (also known as EIS, Executive Information Systems)
  - DSS provides decision makers in organizations with information (*data-driven decisions*)
  - Queries are less well structured (for under-specified problems faced by most senior managers)
  - Used by non-IT professionals (i.e., managers) interactively (*data exploration*)
  - Flexible enough to accommodate changes in the environment and decision-making approaches

+ DBMS? Data Warehousing?

Day	Product	Store	Sales ($)
9/2/2014	Milk	Toowong	3412
10/2/2014	Bread	Toowong	3445
9/2/2014	Milk	Kenmore	5440
10/2/2014	Bread	Kenmore	3067
…	…	…	…

- What is the total sale in each store?
- How about milk sold on Monday?
- Which item is the most popular one?

Aggregated result

Day	Product	Store	Qty	Price
9/2/2014	A2 milk	Toowong	1	3.3
9/2/2014	Grape green	Toowong	2	7.9
9/2/2014	Lindt choc	Kenmore	1	8.4
9/2/2014	Coles coke	Kenmore	2	3.2
…	…	…		…

- Change the Price of “A2 milk” to $4 each.
- Delete the “Grape green” sold on “9/2/2014” in “Toowong”

+ Why do we need Data Warehouses?

- Traditional database applications consist of both updates and queries
  - While, some queries are large scale aggregation reports which can take long time to generate on-the-fly
- Database updates and queries must lock data resources
  - Large scale aggregation reports lock many resources for a long time
- If high frequency of database updates coincides with high frequency of reports, there is **competition** for computing resources
  - For example, student enrolment transactions at beginning of semester coincide with high report demand for checking if room sizes, tutor allocations etc are adequate

…these are problems with the traditional DBMS

+ Data Warehouse is Useful

- Organizations are analysing current and historical data to identify useful patterns and support business strategies
- Emphasis is on complex, interactive, exploratory analysis of very large datasets created by integrating data from across all parts of an enterprise
- Resource competition solved by making periodic replicas of data from operational data into separate system for analytics
  - Data snapshots are acceptable
  - Pre-processing for common aggregations are desirable
  - Efficient support for common analytics operations
  - OLAP vs. OLTP

+ What is Data Warehouse?

- A storage architecture designed to hold data extracted from transaction systems, operational data stores and external sources
  - Data are combined in an aggregate, summary form suitable for enterprise-wide data analysis and reporting for predefined business needs

- Four main characteristics (Inmon 1992)
  - Subject oriented (vs application oriented): the data is organized around subjects (such as Sales), rather than operations applications (such as order processing).
  - Nonvolatile: not usually subject to changes
  - Integrated: data is consistent
  - Time variant: historical data is recorded

+ Data Warehouse is very different from Transactional Database

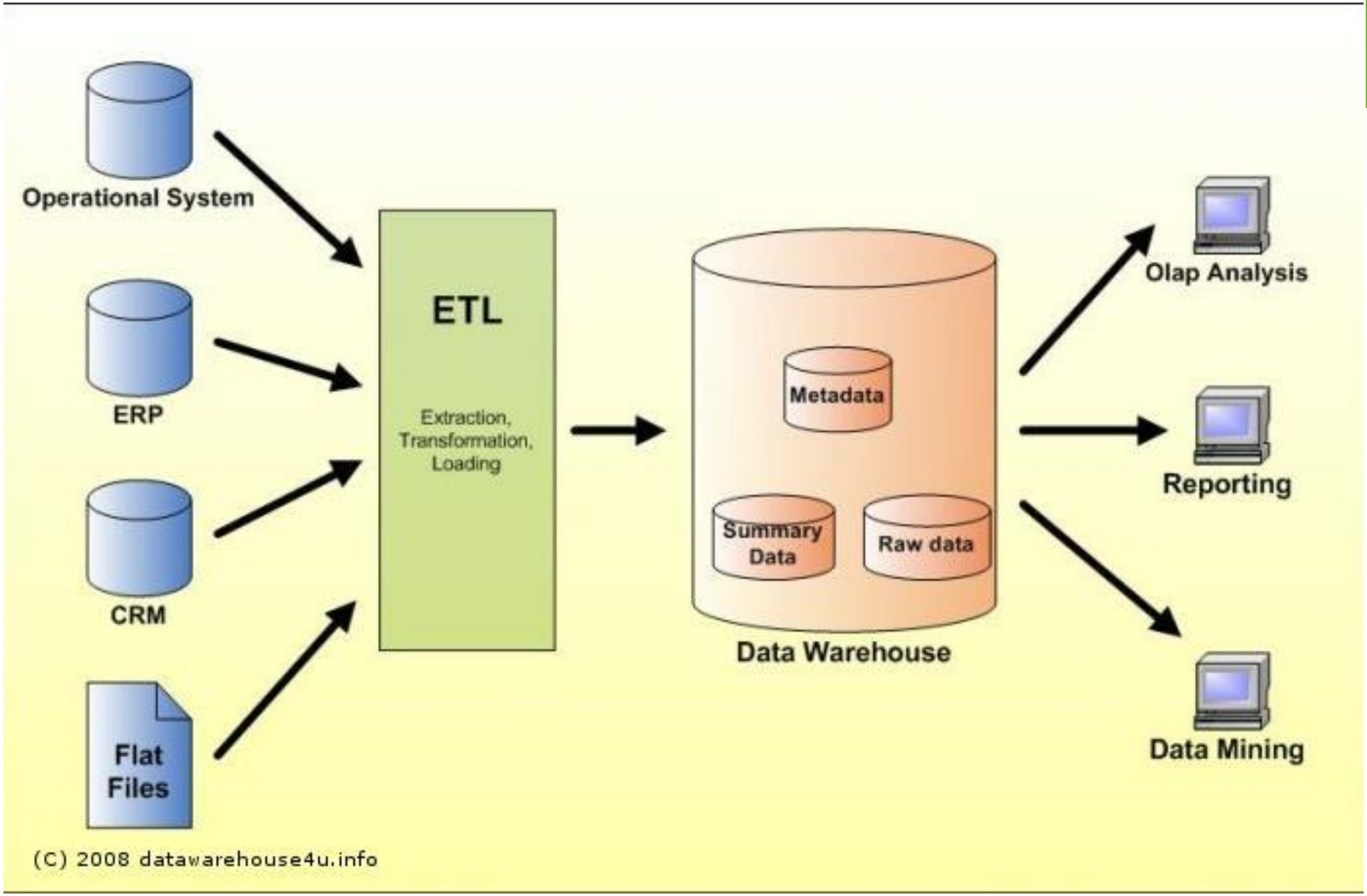
- Integrated data spanning long time periods, often augmented with summary information
- Very large volume: several Terabytes (TB) common
- Interactive response times expected for complex queries
- Ad-hoc updates uncommon (***Write-once* and *Read-forever***)

Responding times: simple query: <1s, complex query: <3s, really complex query: <6s

+ Data Warehousing Environments

- In Data Warehouse (DW), data is decoupled from its generation source
- Information in DW is organized to be easily used for DSS applications (i.e., a variety of visualization charts)
  - Database views are used to organize data
- Information is available independently from the availability of the source
  - The views are materialized
- Information is structured and stored in order to optimize processing of DW queries
- Only a small cooperation is required with the source to keep the warehouse in sync of time periods

+ Data Warehouse Overview



+ Building a Data Warehouse

- The data must be extracted from multiple, heterogeneous sources (i.e., from OLTP databases)
- The data must be formatted for consistency of multiple sources
- The data must be cleaned to ensure validity
- The data must be fitted to the DW data model (pre-processed for summary data)
- The data must be loaded into the DW

+ Data Warehousing Issues

- Syntactic data integration
  - Must access data from a variety of source formats and repositories
- Semantic data integration
  - When getting data from multiple sources, must eliminate mismatches, e.g., different currencies
- Load, refresh and purge
  - Must load data, periodically refresh it, and purge too-old data
- Metadata management
  - Must keep track of source, loading time, and other information for all data in the warehouse

+ Data Warehouse Types

- Virtual Data Warehouses
  - Provide views of operational DBs that are materialized for efficiency
- Data Marts
  - Targeted to a subset of the organization
  - Also called department-level data warehouse
  - Low-risk, low-cost, but hard to evolve
- Enterprise-wide Data Warehouses
  - Large projects with massive investment of time and resources

+ Outline

- Data Warehousing
  - Data warehousing concepts
  - Data warehousing design
  - Data warehousing operations
  - Data warehousing implementation

+ Example Fact Table

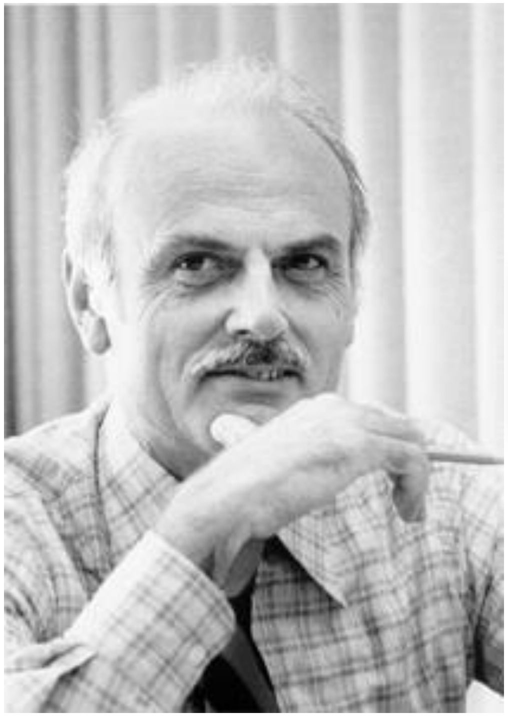
Consider a table of transactions:

Day	Product	Store	Sales (AUD)
…	…	…	…
9/2/2014	Milk	Toowong	3412
10/2/2014	Milk	Toowong	2918
9/2/2014	Bread	Toowong	2918
10/2/2014	Bread	Toowong	3445
9/2/2014	Milk	Kenmore	5440
10/2/2014	Milk	Kenmore	4992
9/2/2014	Bread	Kenmore	2918
10/2/2014	Bread	Kenmore	3067
…	…	…	…

- Can these **facts be automatically summarized** (aggregated) in order to answer analytical queries?
  - ✓ How many different locations of Stores?
  - ✓ What kinds of Products sold well?
  - ✓ Can we get the monthly report on sales?

+ Multidimensional Data Model

"There are typically a **number of dimensions** from which a given pool of data can be analyzed. This plural perspective, or **multidimensional conceptual view**, appears to be the way most business persons naturally view their enterprise." - Codd 1993



Codd, Edgar Frank (June 1970). "A Relational Model of Data for Large Shared Data Banks". Communications of the ACM. 13 (6): 377–387.

Edgar Frank Codd
19/08/1923 - 18/04/2003
(aged 79)

+ The Fact Table

- The core of a data warehouse is a fact table
- The facts are the values for the object of interest
  - A fact about that data entity
  - Raw data to be aggregated
  - There are lots of instances of these facts
- Associated with each fact is a key that is used for identifying, for example, which day, which product and which store.

A fact is described an a proposition which can be announced by a complete sentence.

…facts vs dimensions

+ Example Fact Table

Keys			Facts
Day	**Product**	**Store**	**Sales (AUD)**
…	…	…	…
9/2/2014	Milk	Toowong	3412
10/2/2014	Milk	Toowong	2918
9/2/2014	Bread	Toowong	2918
10/2/2014	Bread	Toowong	3445
9/2/2014	Milk	Kenmore	5440
10/2/2014	Milk	Kenmore	4992
9/2/2014	Bread	Kenmore	2918
10/2/2014	Bread	Kenmore	3067
…	…	…	…

Facts can be verified as true or false.

+ # Dimensions

- Each key is a dimension – the example has three
- Dimensions can have hierarchical organization
  - Days grouped into weeks, months, quarters, years
  - Product groups **aggregated hierarchically**
    - Milk ➔ dairy ➔ perishable ➔ food
    - Bread ➔ baked goods ➔ perishable ➔ food
  - Stores grouped into regions hierarchically
    - Toowong ➔ West Brisbane ➔Brisbane ➔ QLD ➔ Australia ➔ Oceania
- Dimensions organized by dimension tables

+ Dimension Tables

- Each dimension is a projection of the fact table onto one of its keys

Day
9/2/2012
10/2/2012
…

Product
Milk
Bread
…

Store
Toowong
Kenmore
…

+ Design for General Dimension Tables

Time-Period

Day	Month	Qtr	Year
9/2/2012	Feb	1	2012
10/2/2012	Feb	1	2012

Region

Store	District	Region
Toowong	West	Brisbane
Kenmore	West	Brisbane

Product

Product	Kind	Type	Class
Milk	Dairy	Perishable	Food
Bread	Bakery	Perishable	Food

+ The Star Schema

Time-Period

Day	Month	Qtr	Year
9/2/2012	Feb	1	2012
10/2/2012	Feb	1	2012

Region

Store	District	Region
Toowong	North	Brisbane
Kenmore	West	Brisbane

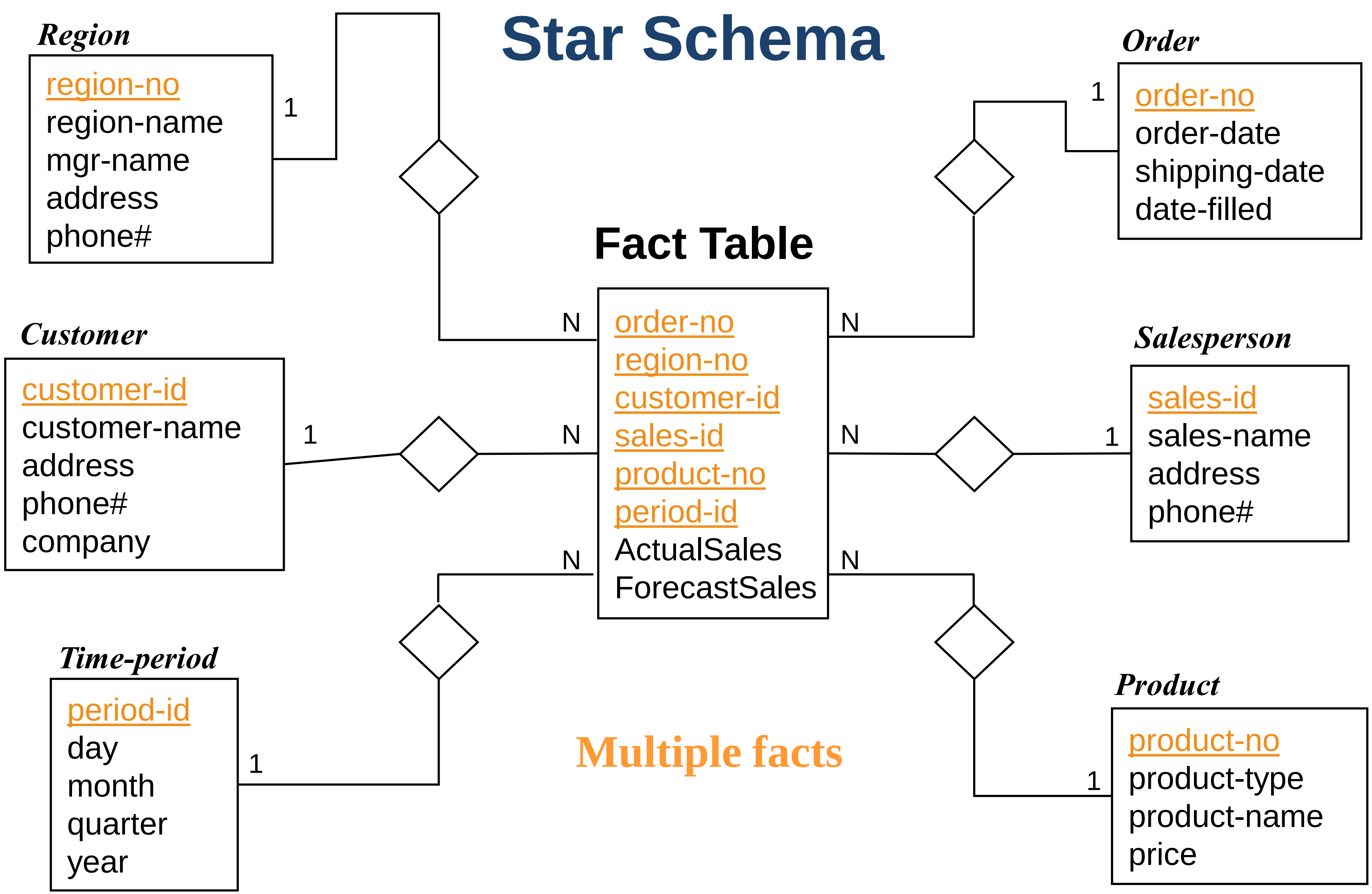
Facts

Product

Product	Kind	Type	Class
Milk	Dairy	Perishable	Food
Bread	Bakery	Perishable	Food

The fact table is much larger than dimension tables

+ Logical Schema (Entity Relationship)



+ Containment in Star Schemas

- Much information stored in a containment situation
  - February is in first quarter
  - First quarter is in 2012, 2013…
  - Dairy products are perishable
  - Baked goods are perishable
  - Perishable goods are food
  - West is in Brisbane…

Day	Month	Qtr	Year
9/2/2012	Feb	1	2012
10/2/2012	Feb	1	2012

Facts

Day	Month
9/2/2012	Feb
10/2/2012	Feb
…	…

Month	Qtr
Feb	1
Mar	1
…	…

Qtr	Year
1	2012
2	2012
1	2013

+ Normalization

- Many identifiers are weak
  - There is a February in every year
  - There is a first quarter in every year
  - West in Brisbane must be distinguished from west in Sydney…
- Replace weak identifiers by global identifiers in scope
  - Month ID, so that Feb 2012 is M002, Feb 2013 is M014, etc
  - Quarter ID, so that Q1 2012 is Q001, Q1 2013 is Q005, etc
  - Brisbane West is District D13, Brisbane South D22, Sydney North is D45, etc

…weak ID: must be used with another attribute (e.g. a foreign key) in order to be able to uniquely identify an entity

+ Normalized Dimension Tables

Day	Month ID
9/2/2012	M002
10/2/2012	M002
…	…

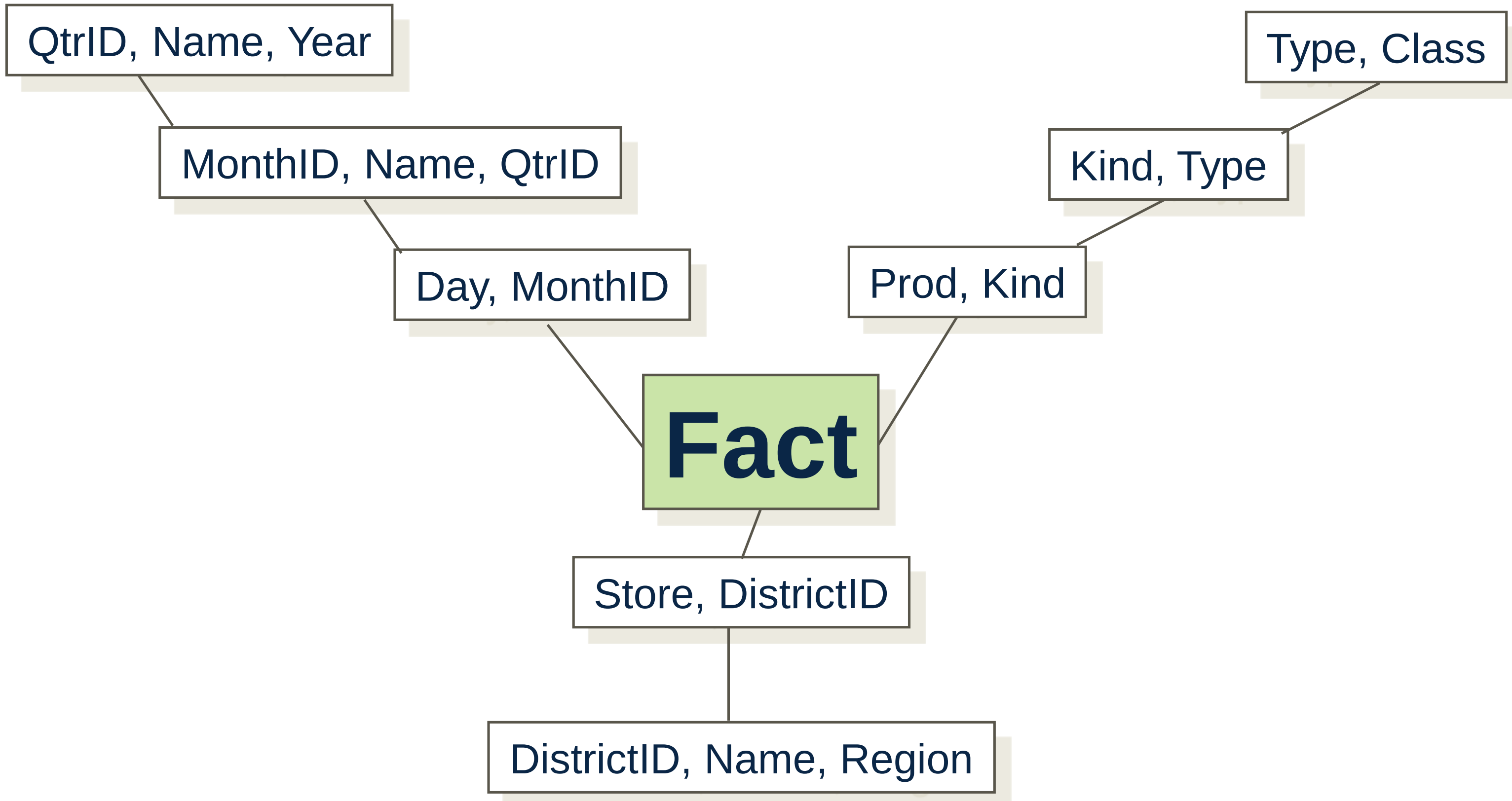
MonthID	Name	Quarter ID
M002	February	Q001
M014	February	Q005
M026	February	Q009
…	…	…

Quarter ID	Name	Year
Q001	1	2012
Q005	1	2013
Q009	1	2014
…	…	…

Original Table:

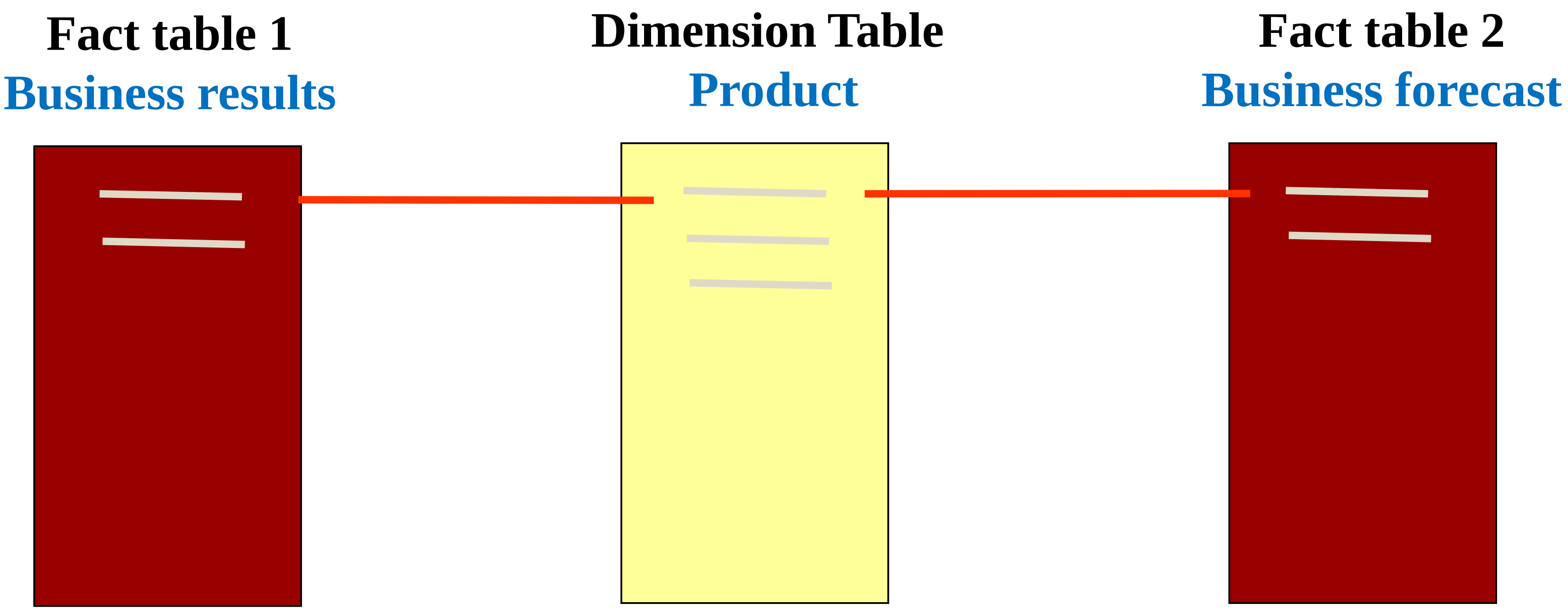
Day	Month	Qtr	Year
9/2/2012	Feb	1	2012
10/2/2012	Feb	1	2012
…	…	…	…

+ The Snowflake Schema



+ Fact Constellation

- A set of fact tables that share some dimension tables



+ Outline

- Data Warehousing
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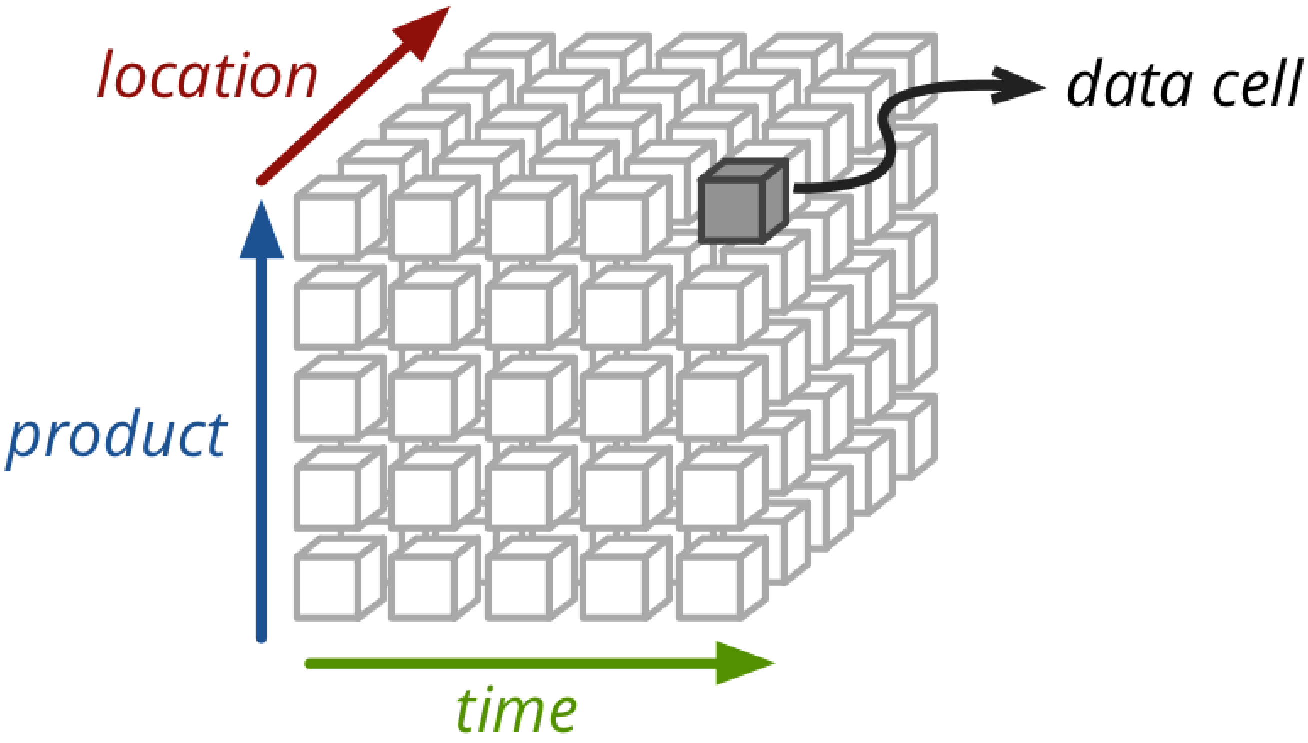
  - Data warehousing operations
  - Data warehousing implementation

+ Data Cube

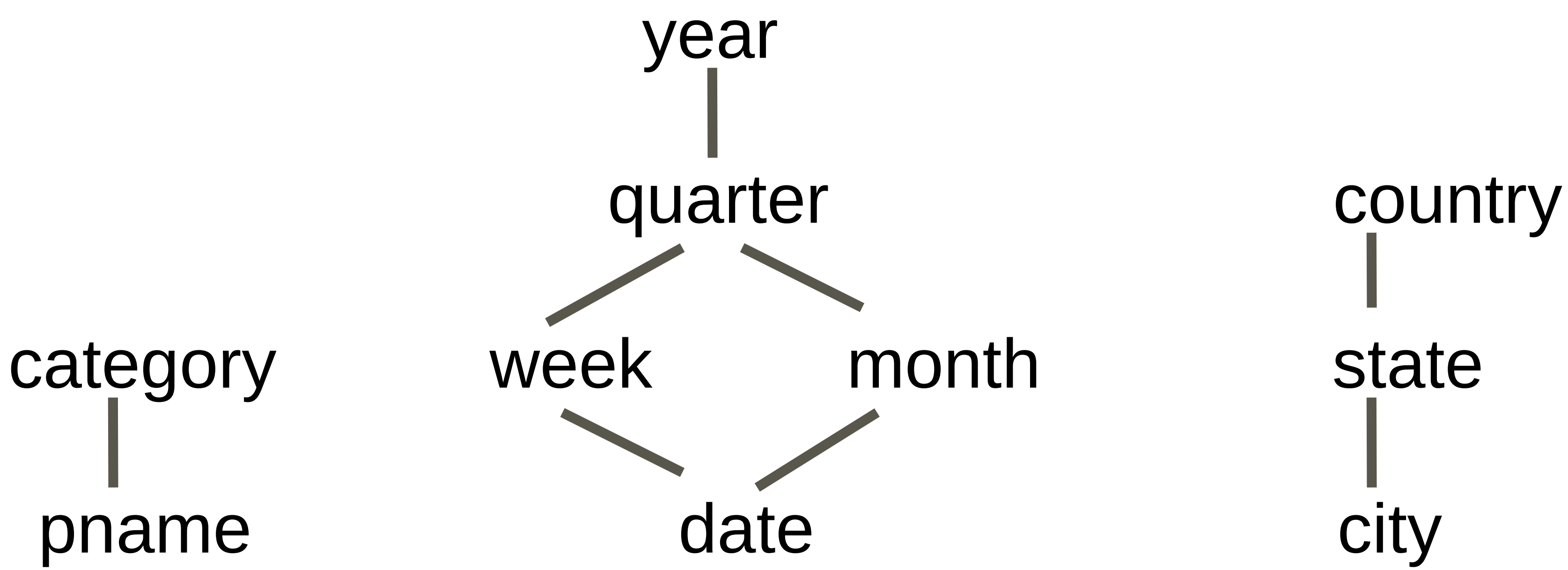
- Sales data with three dimensions: location, product and time



Hypercubes if there are more than 3 dimensions

+ Dimension Hierarchies

PRODUCT **TIME** **LOCATION**

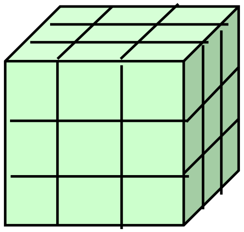


+ OLAP Queries

- Most OLAP queries can be expressed in SQL – this is difficult for general end users
- The goal is to give non SQL experts some tools for selected class of queries
- Examples;
  - find the total sales,
  - find the top five products ranked by total sales,
  - find total sales by month for each city,
  - find % change in the total monthly sales
  - for each product…

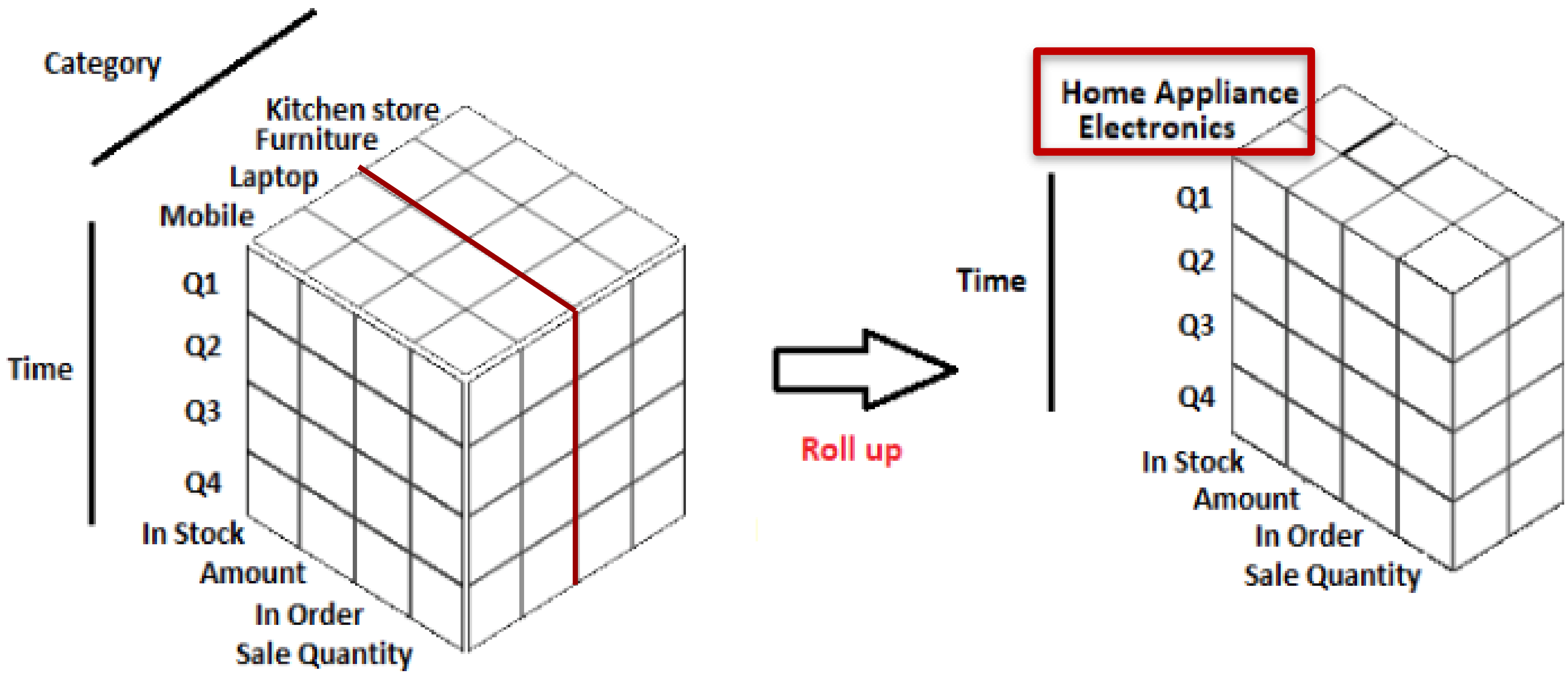
+ Typical Functionality of DW

- Pivoting (cross-tabulation)
  - Rotate data cube to show a different orientation of axes
- Roll-up
  - Move up concept hierarchy, grouping into larger units along a dimension with more generalization
- Drill-down
  - Disaggregate to a finer-grained view to show more details
- Slice and dice
  - Perform projection operations on the dimensions



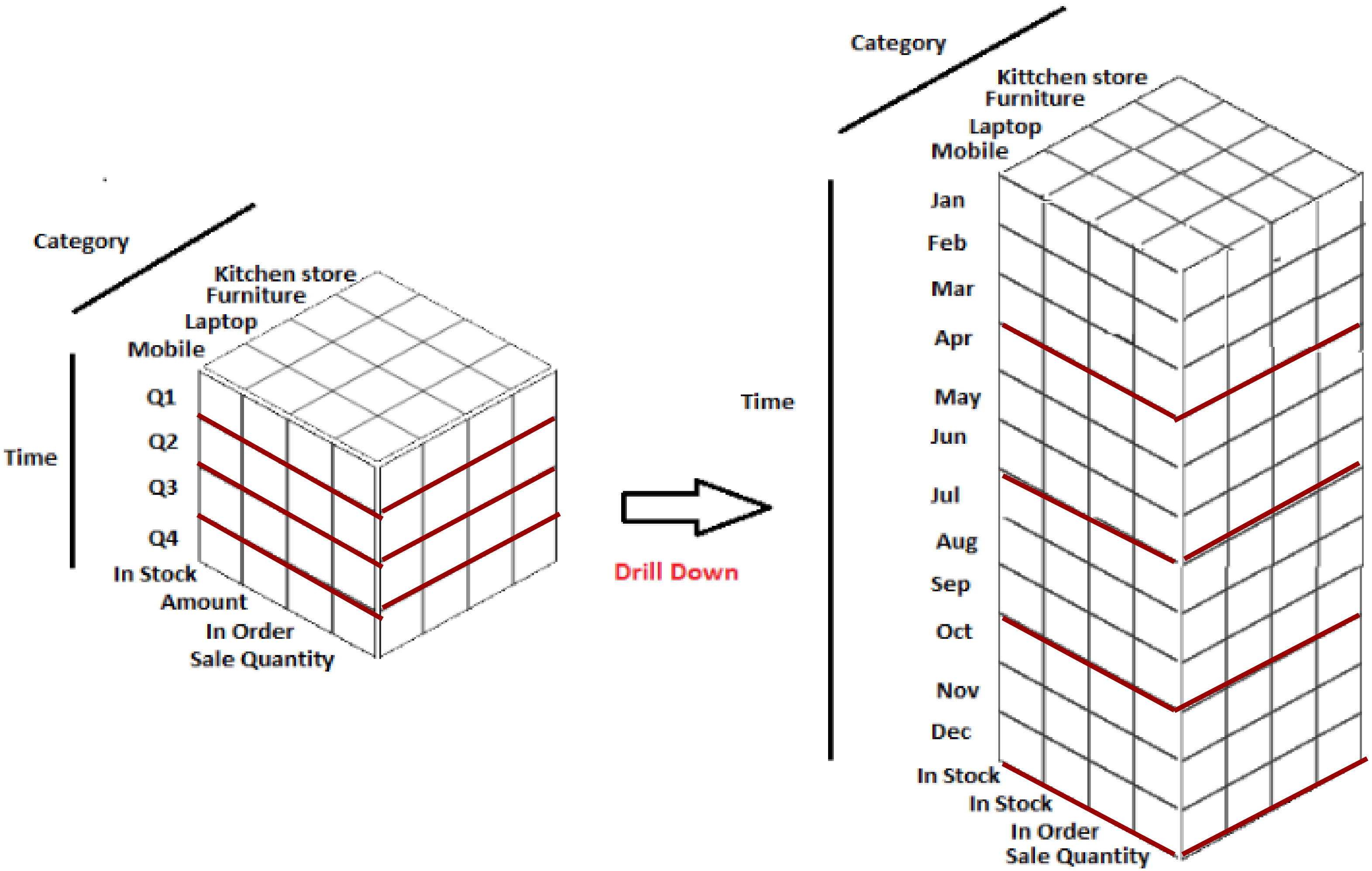
- Other operations, such as arithmetic (to get derived values), sorting, selection…

+ An Example of Rollup



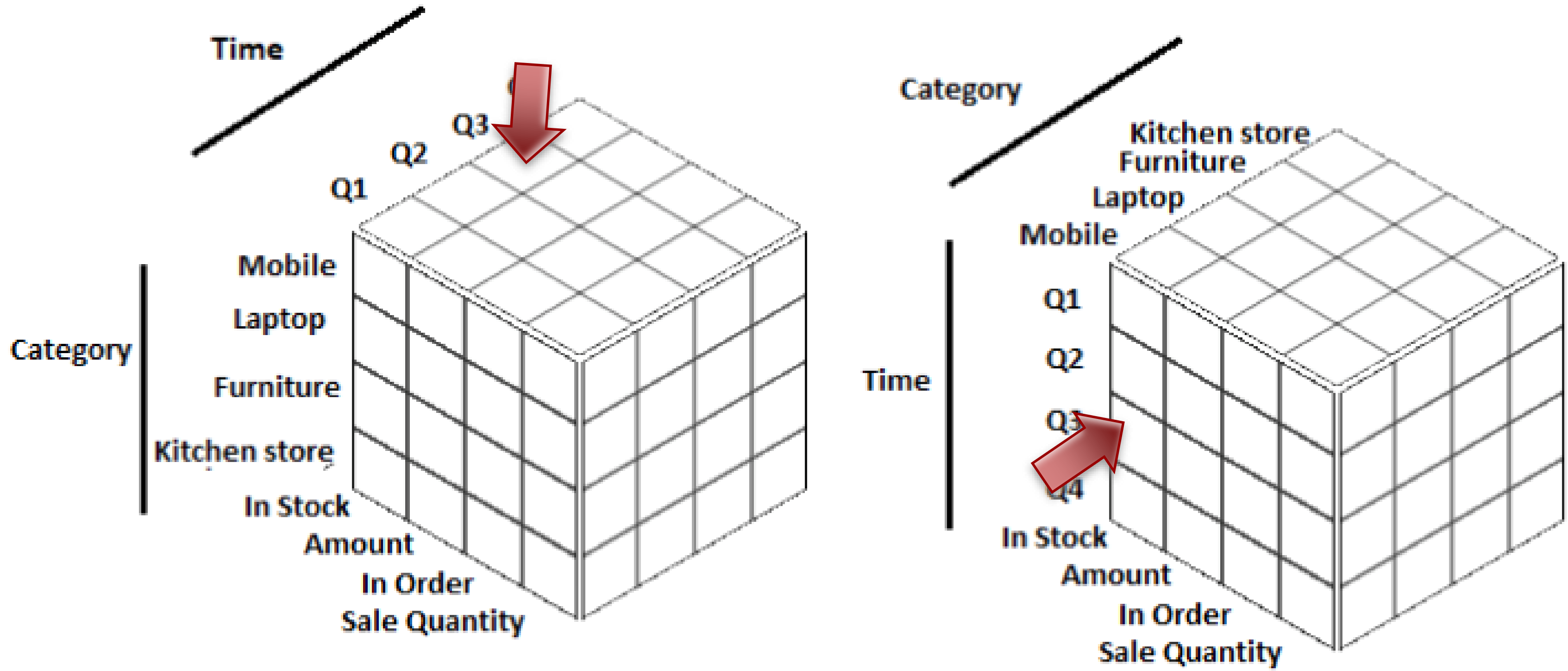
Page 147, Figure 4.12 Examples of typical OLAP operations on multidimensional data., Jiawei Han Book

+ An Example of Drill-down



Page 147, Figure 4.12 Examples of typical OLAP operations on multidimensional data., Jiawei Han Book

+ An Example of Pivoting



Page 147, Figure 4.12 Examples of typical OLAP operations on multidimensional data., Jiawei Han Book

+ Example of Pivot Query

Pivot Query (in SQL Server)

```
SELECT [Year], Pankaj,Rahul,Sandeep FROM
(SELECT Name, [Year] , Sales FROM Employee )Tab1
PIVOT
(
SUM(Sales) FOR Name IN (Pankaj,Rahul,Sandeep)) AS Tab2
ORDER BY [Tab2].[Year]
```

Employee

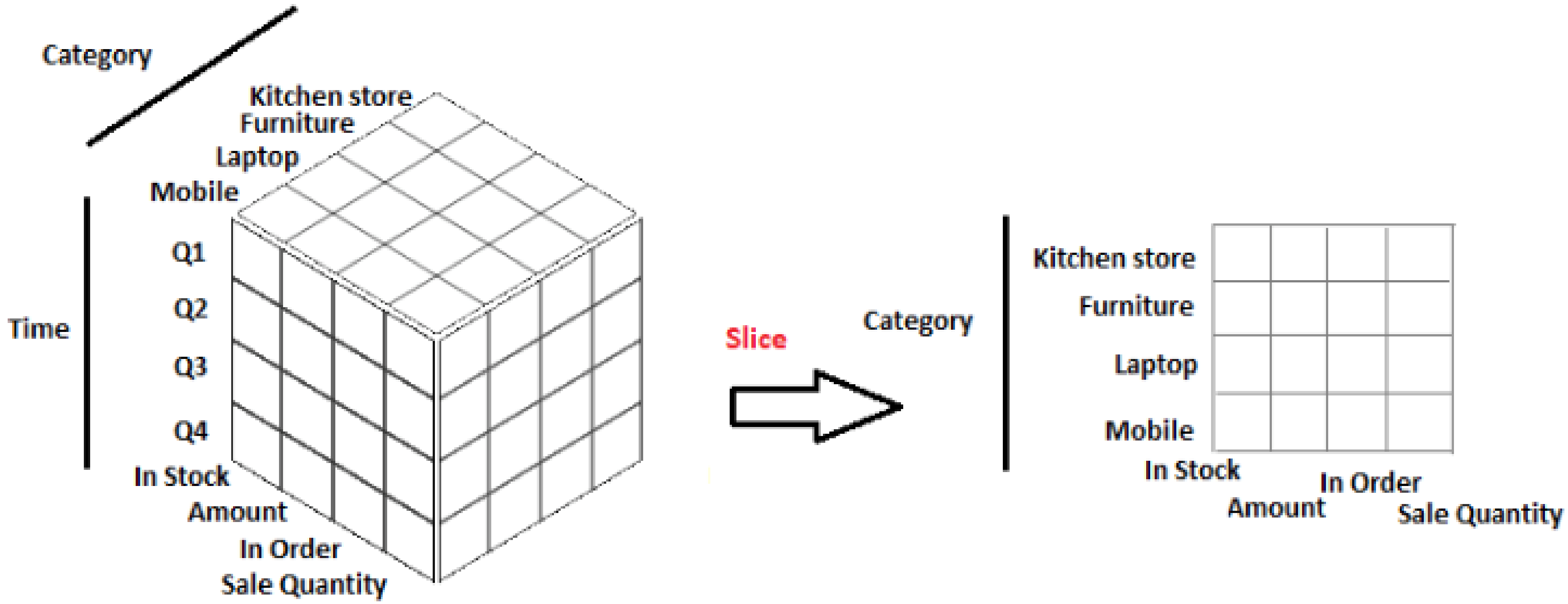
	Name	Year	Sales
1	Pankaj	2010	72500
2	Rahul	2010	60500
3	Sandeep	2010	52000
4	Pankaj	2011	45000
5	Sandeep	2011	82500
6	Rahul	2011	35600
7	Pankaj	2012	32500
8	Pankaj	2010	20500
9	Rahul	2011	200500
10	Sandeep	2010	32000

Output

	Year	Pankaj	Rahul	Sandeep
1	2010	93000	60500	84000
2	2011	45000	236100	82500
3	2012	32500	NULL	NULL

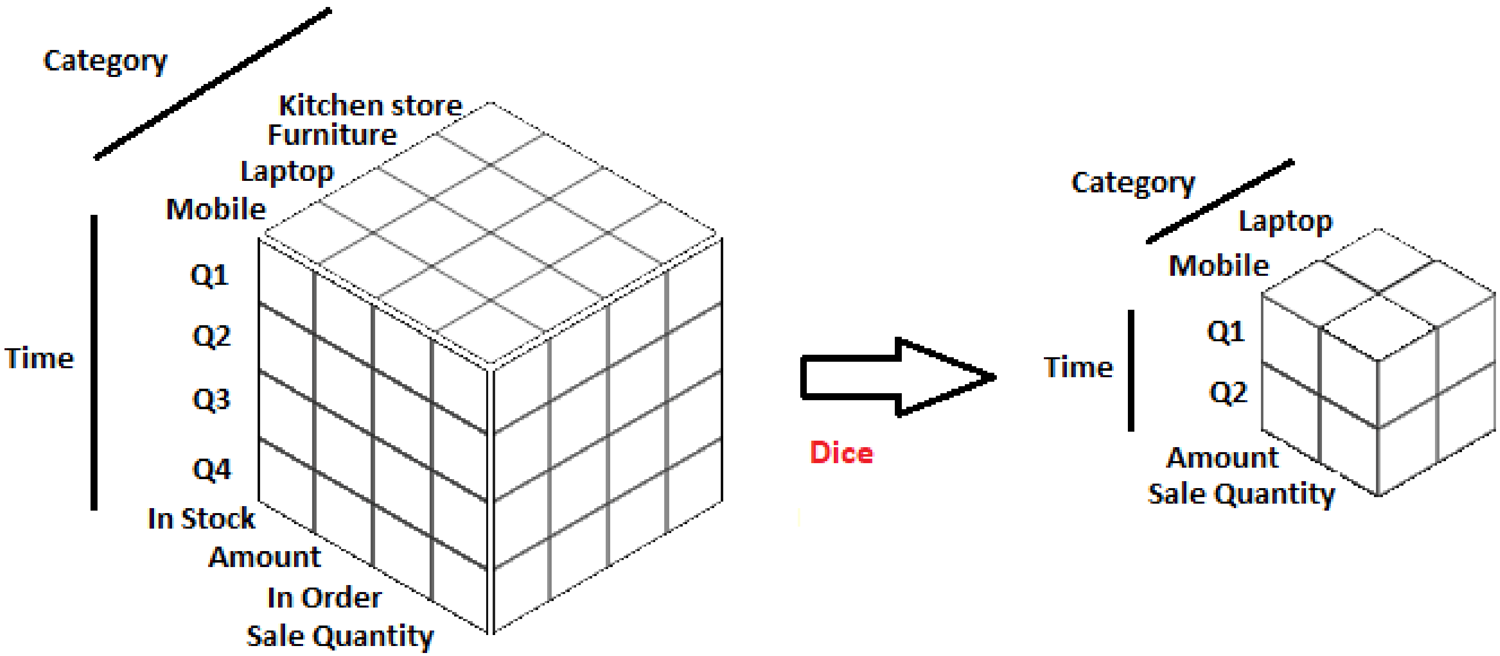
https://www.c-sharpcorner.com/UploadFile/f0b2ed/pivot-and-unpovit-in-sql-server/#:~:text=PIVOT%20relational%20operator%20converts%20data,operation%20where%20we%20need%20them.

+ An Example of Slicing



Page 147, Figure 4.12 Examples of typical OLAP operations on multidimensional data., Jiawei Han Book

+ An Example of Dicing



Page 147, Figure 4.12 Examples of typical OLAP operations on multidimensional data., Jiawei Han Book

+ OLAP Queries

- Influenced by SQL + spreadsheets
- A common operation is to aggregate a measure over one or more dimensions
  - Find total sales
  - Find total sales for each city, or for each state
  - Find top five products ranked by total sales
- Roll-up: Aggregating at different levels of a dimension hierarchy
  - Given total sales by *city*, we can roll-up to get sales by *state*
- Drill-down: The inverse of roll-up
  - Given total sales by *state*, can drill-down to get total sales by *city*
  - Can also drill-down on different dimension to get total sales by *product* for *each state*

+ Example Roll-up

	Product		Total
Day	**Milk**	**Bread**	**Perishables**
9/2/2012	8952	5836	14788
10/2/2012	7910	8059	15969
	Product Group		Total
Day	**Perishables**	**Canned Goods**	**All Groups**
9/2/2012	14788	55621	206771
10/2/2012	15969	68123	310885

Roll-up milk, bread to compare perishables with other product groups

+ Example Drill-down

	Product Group		Total
Day	**Perishables**	**Canned Goods**	**All Groups**
9/2/2012	14788	55621	206771
10/2/2012	15969	68123	310885
	Product		Total
Day	**Milk**	**Bread**	**Perishables**
9/2/2012	8952	5836	14788
10/2/2012	7910	8059	15969

Drill-down perishables to constituent products

+ OLAP Queries

- **Slicing** and **Dicing**: Equality and range selections on one (slice), or more (dice) dimensions
  - Total now only of selected data behind pivot
  - Similar to HAVING clause in SQL

- **Pivoting**: Aggregation on selected dimensions.
  - E.g., Pivoting on Location and Time yields this cross-tabulation: Cells contain sums of data from other dimensions (data behind pivot)
  - Metaphor of *rotating* data cube

Q1 Q2 Q3

	WI	CA	Total
1995	63	81	144
1996	38	107	145
1997	75	35	110
Total	176	223	339

+ Pivoting by Multiple SQL Queries

- The cross-tabulation obtained by pivoting can also be computed using a collection of SQL queries:

Q1:

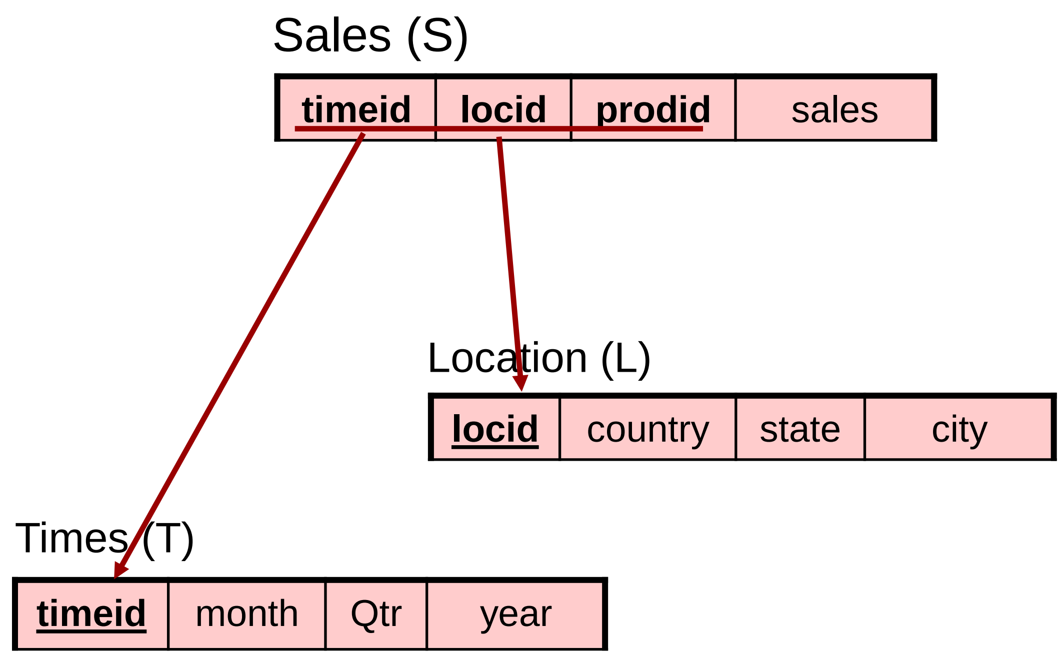
SELECT SUM(S.sales)
FROM Sales S, Times T, Location L
WHERE S.timeid=T.timeid **AND** S.locid=L.locid
GROUP BY T.year, L.state

Q2:

SELECT SUM(S.sales)
FROM Sales S, Times T
WHERE S.timeid=T.timeid
GROUP BY T.year

Q3:

SELECT SUM(S.sales)
FROM Sales S, Location L
WHERE S.locid=L.locid
GROUP BY L.state



+ The CUBE Operator

- Generalizing the previous example, if there are *k* dimensions, we have 2^k possible SQL **GROUP BY** queries that can be generated through pivoting on a subset of dimensions.

```
SELECT SUM(S.sales)
FROM    Sales S, …
GROUP BY grouping-list
```

- CUBE pid, locid, timeid BY SUM Sales
  - Equivalent to rolling up Sales on all eight subsets of the set {**pid, locid, timeid**}

Sales (S)

Day	Product	Store	Sales ($)

The CUBE operator has been implemented in most data warehousing products, and often used together with SQL statements following GROUP_BY. It basically creates a cube using the listed dimensions for the required aggregations (in the SUM part). For example, if CUBE(a, b, c) is used, where a, b and c are dimensions (attributes with their hierarchies), it will **generate aggregates for all the following combinations: (a, b, c), (a, b), (a, c), (b, c), (a), (b), (c) and (null)**. That is, for k dimensions in the CUBE list, 2^k types of group-bys will be generated. Therefore, once CUBE(a, b, c) is used, aggregates based on all these 2^k dimension combinations are generated.

+ Conclusions

- Decision support by OLAP is an emerging, rapidly growing subarea of databases technology.
- OLAP involves the creation of large, consolidated data repositories called **Data Warehouses (DW).**
- DW concepts include Star Schema, Snowflake Schema, Fact table, Hierarchical dimensions; OLAP queries include Roll-up, Drill-down, Pivoting, Slicing and Dicing, Cube, etc.
- Warehouses exploited using sophisticated analysis techniques: complex SQL queries and OLAP "multidimensional" queries (influenced by both SQL and spreadsheets).
- New techniques for database design, indexing, view maintenance, and interactive querying need to be supported.

Next week: Data Warehouse Implementation

+ Reading Materials

- Paulraj Ponniah, **Data Warehousing Fundamentals for IT Professionals**, 2nd edition
  - Chapter 10: Principles of Dimensional Modeling
  - Chapter 11: Dimensional Modeling: Advanced Topics
  - Chapter 15: OLAP in the Data Warehouse
- Jiawei Han, **Data Mining Concepts and Techniques**, 3rd edition
  - Chapter 4.1: Data Warehouse Basic Concepts
  - Chapter 4.2: Data Warehouse Modeling
  - Chapter 4.3: Data Warehouse Design and Usage

- Oracle **Database Data Warehousing Guide**
- Elmasri & Navathe, 7th edition
  - Chapter 29: Overview of Data Warehousing and OLAP

The PDF Files are downloadable from the following links:

https://docs.oracle.com/database/121/DWHSG/toc.htm

http://business.baylor.edu/gina_green/teaching/dw/spr16/Ponniah_data-warehousing-fundamentals-for-it-professionalsSecondEdition.pdf

http://myweb.sabanciuniv.edu/rdehkharghani/files/2016/02/The-Morgan-Kaufmann-Series-in-Data-Management-Systems-Jiawei-Han-Micheline-Kamber-Jian-Pei-Data-Mining.-Concepts-and-Techniques-3rd-Edition-Morgan-Kaufmann-2011.pdf