Database Management Systems
Chapter 11: Big Data and Analytics

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Objectives

- Define terms
- Database management extends beyond RDBs and DWs
- List the main NoSQL DBMS categories
- Choose between relational and NoSQL databases
- Describe meanings and demands of big data
- List and describe components of Hadoop environment
- Compare descriptive, predictive, and prescriptive analytics
- Describe impact of analytics on data management technologies

Introduction

- **Big Data**: Data that exist in:
  - Very large **volumes**
  - Many different **varieties** (data types)
  - That need to be processed at a very high **velocity** (speed)

- **Analytics**: Systematic analysis and interpretation of data to improve our understanding of a real-world domain.

Characteristics of Big Data

- The Five **V**s of Big Data:
  - **Volume**: much larger quantity of data than relational databases
  - **Variety**: lots of different data types and formats
  - **Velocity**: data comes at very fast rate (e.g. mobile sensors, web click stream)
  - **Veracity**: traditional data quality methods don't apply; how to judge the data's accuracy and relevance?
  - **Value**: big data is valuable to the bottom line, and for fostering good organizational actions and decisions

Characteristics of Big Data

- Schema on Read, rather than Schema on Write
  - **Schema on Write**: preexisting data model, how traditional databases are designed (relational databases)
  - **Schema on Read**: data model determined later, depends on how you want to use it (XML, JSON)
  - Capture and store the data, and worry about how you want to use it later
- **Data Lake**
  - A large integrated repository for internal and external data that does not follow a predefined schema
  - Capture everything, dive in anywhere, flexible access

Figure 11-1: Examples of JSON and XML

JSON Example JavaScript Object Notation

```
{"products": [
        {"number": 1, "name": "Zoom X", "Price": 10.00},
        {"number": 2, "name": "Wheel Z", "Price": 7.50},
        {"number": 3, "name": "Spring 10", "Price": 12.75}
]}
```

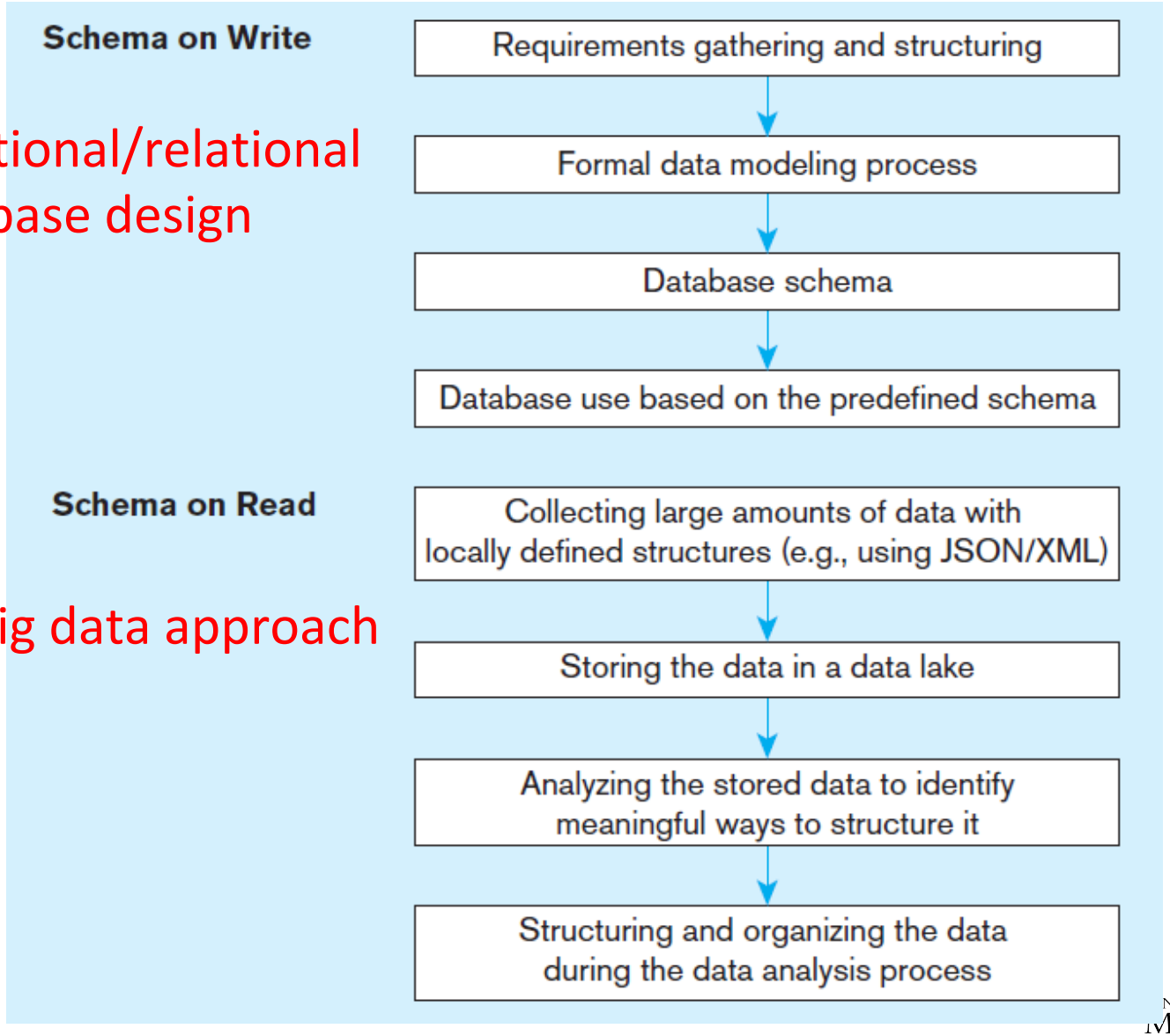
XML Example eXtensible Markup Language

```
<products>
        <product>
                <number>1</number> <name>Zoom X</name> <price>10.00</price>
        </product>
        <product>
                <number>2</number> <name>Wheel Z</name> <price>7.50</price>
        </product>
        <product>
                <number>3</number> <name>Spring 10</name> <price>12.75</price>
        </product>
</products>
```

Figure 11-2: Schema on Write versus Schema on Read

traditional/relational database design

big data approach



NoSQL

- **NoSQL** = Not Only SQL
- A category of recently introduced data storage and retrieval technologies not based on the relational model
- Scaling out rather than scaling up
- Natural for a cloud environment
- Supports schema on read
- Largely open source
- Not ACID compliant!
- BASE (basically available, soft state) eventually consistent

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NoSQL Classifications

- **Key-value stores**
  - A simple pair of a key and an associated collection of values.
  - Key is usually a string.
  - Database has no knowledge of the structure or meaning of the values.
- **Document stores**
  - Like a key-value store, but “document” goes further than “value”.
  - Document is structured so specific elements can be manipulated separately.
- **Wide-column stores**
- **Graph**-oriented database

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NoSQL Classifications

- **Key-value stores**
- **Document stores**
- **Wide-column stores**
  - Rows and columns.
  - Distribution of data based on both key values (records) and columns, using “column groups/families”
- **Graph**-oriented database
  - Maintain information regarding the relationships between data items.
  - Nodes with properties, Connections between nodes (relationships) can also have properties.

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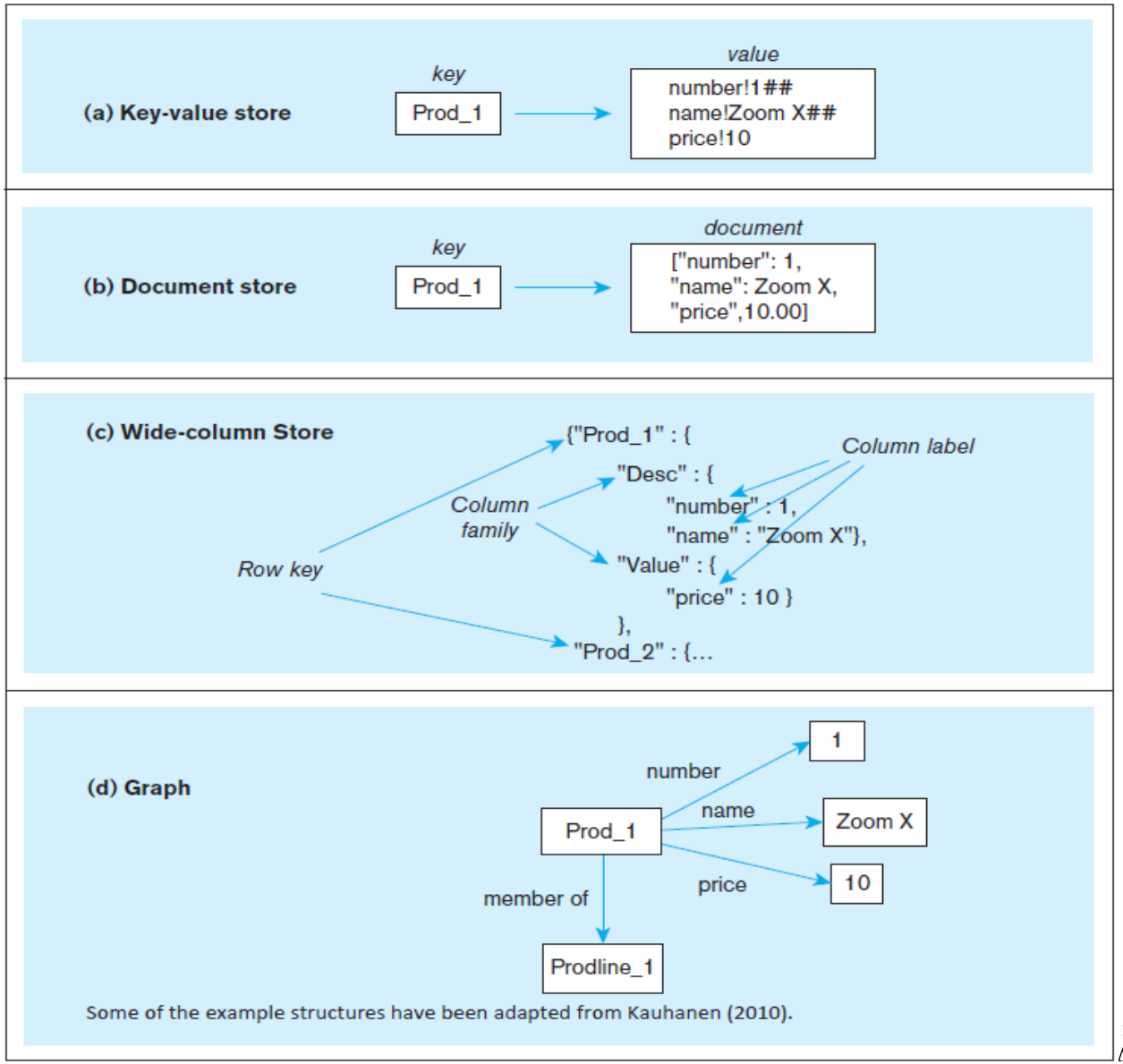
Figure 11-3: Four-Part Illustrating NoSQL Databases



Some of the example structures have been adapted from Kauhanen (2010).

Table 11-2: NoSQL Comparison

TABLE 11-2 Comparison of NoSQL Database Characteristics (Based on Scofield, 2010)

	Key-Value Store	Document Store	Column Oriented	Graph
Performance	high	high	high	variable
Scalability	high	variable/high	high	variable
Flexibility	high	high	moderate	high
Complexity	none	low	low	high
Functionality	variable	variable (low)	minimal	graph theory

Source: http://www.slideshare.net/bscofield/nosql-codemash-2010
Courtesy of Ben Scofield.

- NoSQL Examples:
  - Redis: Key-value store DBMS
  - MongoDB: document store DBMS
  - Apache Cassandra: wide-column store DBMS
  - Neo4j: graph DBMS

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Hadoop

- **Hadoop** is an open source implementation framework of MapReduce
- **MapReduce** is an algorithm for massive parallel processing of various types of computing tasks
- **Hadoop Distributed File System (HDFS)** is a file system designed for managing a large number of potentially very large files in a highly distributed environment
- Hadoop is the most talked about Big-Data data management product today
- Hadoop is a good way to take a big problem and allow many computers to work on it simultaneously

Hadoop Distributed File System (HDFS)

- A file system, not a DBMS, not relational
- Breaks data into **blocks** and distributes them on various computers (**nodes**) throughout a Hadoop **cluster**
- Each cluster consists of a **NameNode** (master server) and some **DataNodes** (slaves)
- Overall control through **YARN** ("yet another resource allocator")
- No updates to existing data in files, just appending to files
- "Move computation to the data", not vice versa

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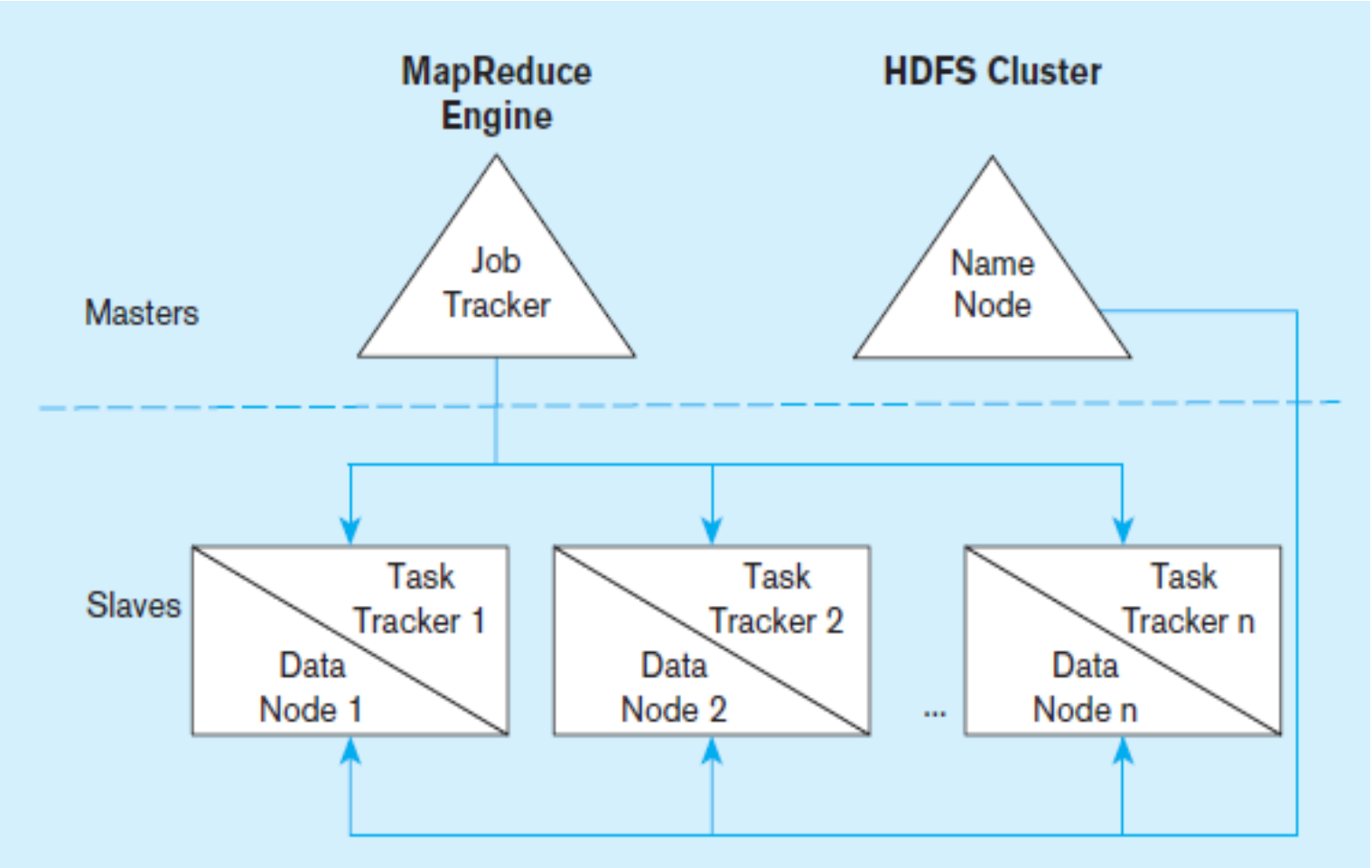
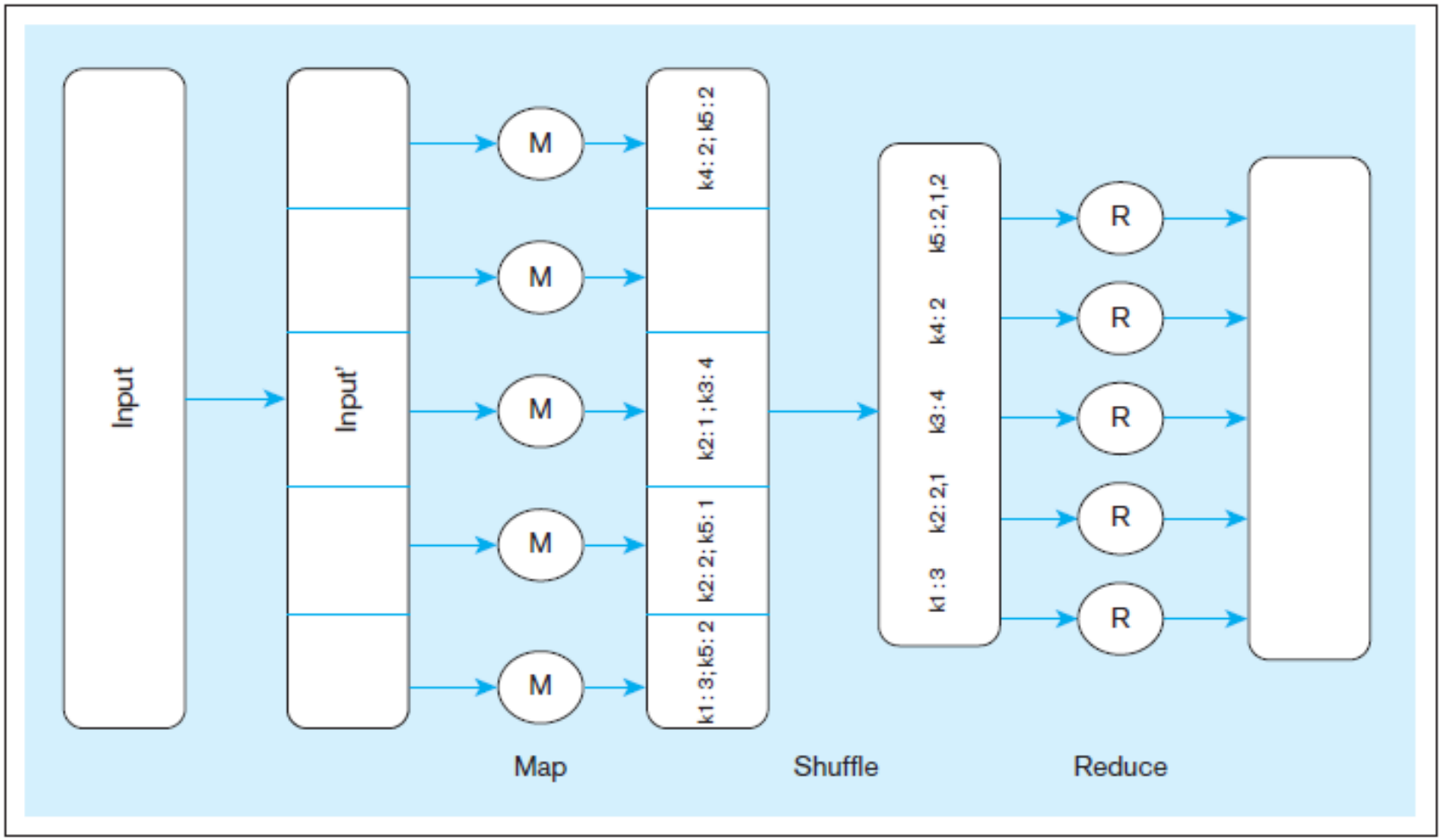
Figure 11-5: MapReduce and HDFS



MapReduce

- Enables parallelization of data storage and computational problem solving in an environment consisting of a large number of commodity servers
- Programmers don't have to be experts at parallel processing
- Core idea: divide a computing task so that a multiple nodes can work on it at the same time
- Each node works on local data doing local processing.
- Two stages:
  - **Map** stage: divide for local processing
  - **Reduce** stage: integrate the results of the individual map processes

Figure 11-6: Schematic Representation of MapReduce



MapReduce: Simplified Data Processing on Large Clusters, Jeff Dean, Sanjay Ghemawat, Google, Inc.,http://research.google.com/archive/mapreduce-osdi04-slides/index-auto-0007.html.Courtesy of the authors.

Other Hadoop Components

- **Pig**
  - A tool that integrates a scripting language and an execution environment intended to simplify the use of MapReduce
  - Useful development tool
- **Hive**
  - An Apache project that supports the management and querying of large data sets using HiveQL, an SQL-like language that provides a declarative interface for managing data stored in Hadoop.
  - Useful for ETL tasks
- **HBase**
  - A wide-column store database that runs on top of HDFS
  - Not as popular as Cassandra

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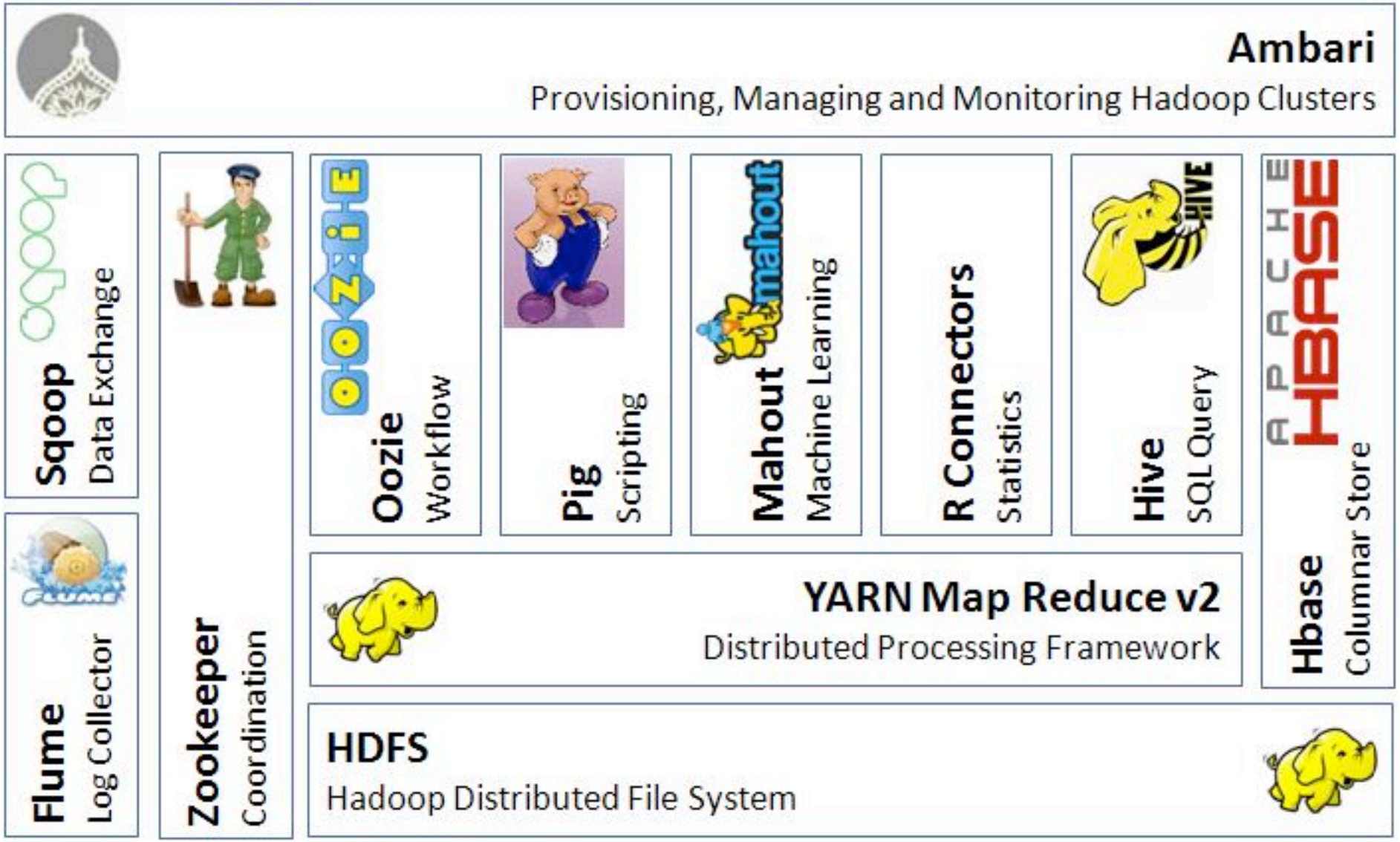
Apache Hadoop Ecosystem



Integrated Analytics and Data Science Platforms

- Some vendors are bringing together traditional data warehousing and big data capabilities
- Examples:
  - **HP HSAVEn**: Hewlett Packard technologies combined with Hadoop open source and an analytics engine
  - **Teradata Aster**: integrate SQL, graph analysis, MapReduce, R
  - **IBM Big Data Platform**: combine IBM technologies with Hadoop, JSON Query Language (JAQL), DB2, Netezza

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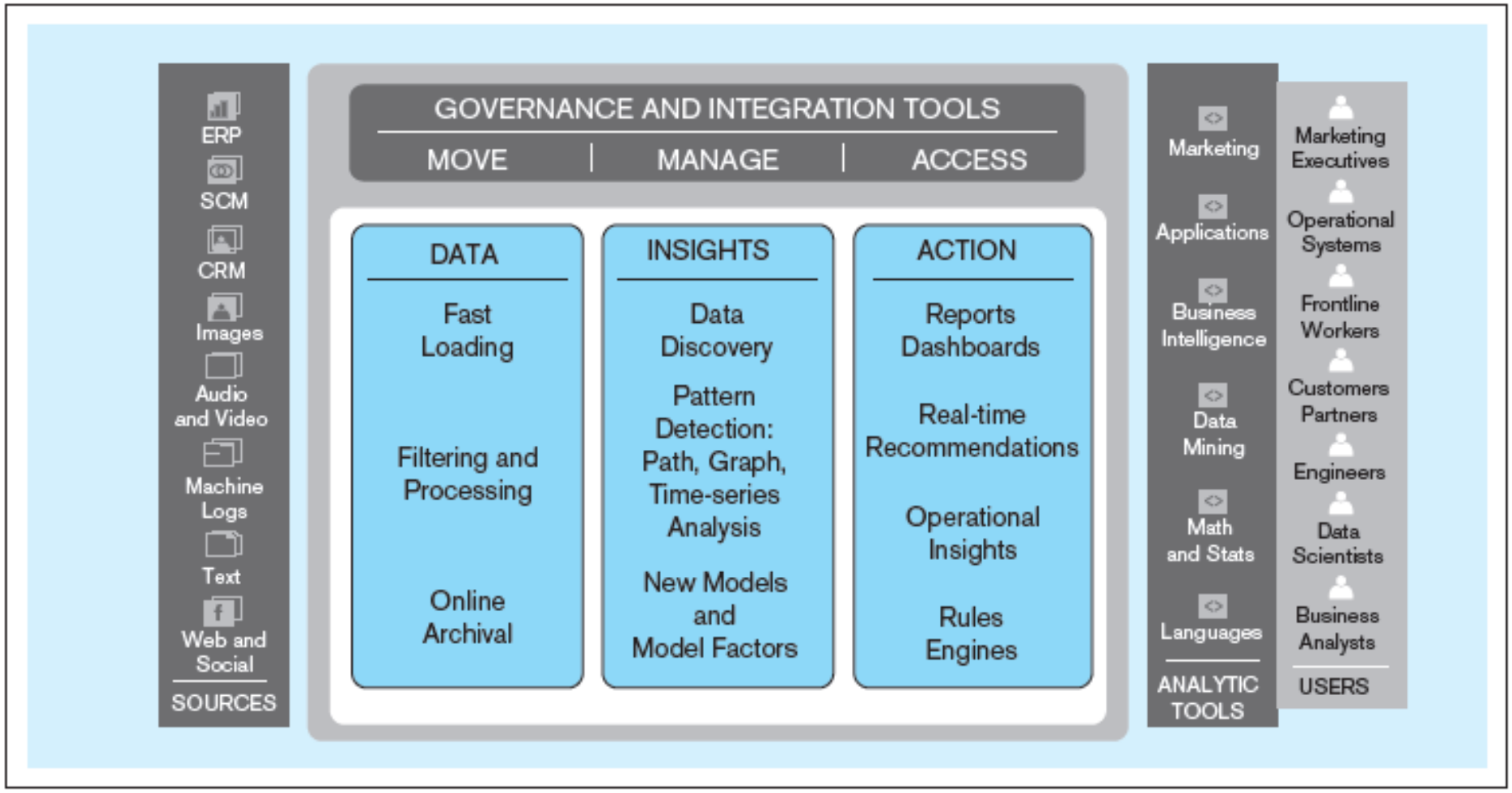
Figure 11-8: Teradata Unified Data Architecture – Logical View



UNIFIED DATA ARCHITECTURE, 10.14, EB 7805,http://www.teradata.com/Resources/White-Papers/Teradata-Unified-Data-Architecture-in-Action. Courtesy of Teradata Corporation

Figure 11-9: Teradata Unified Data Architecture – System Conceptual View

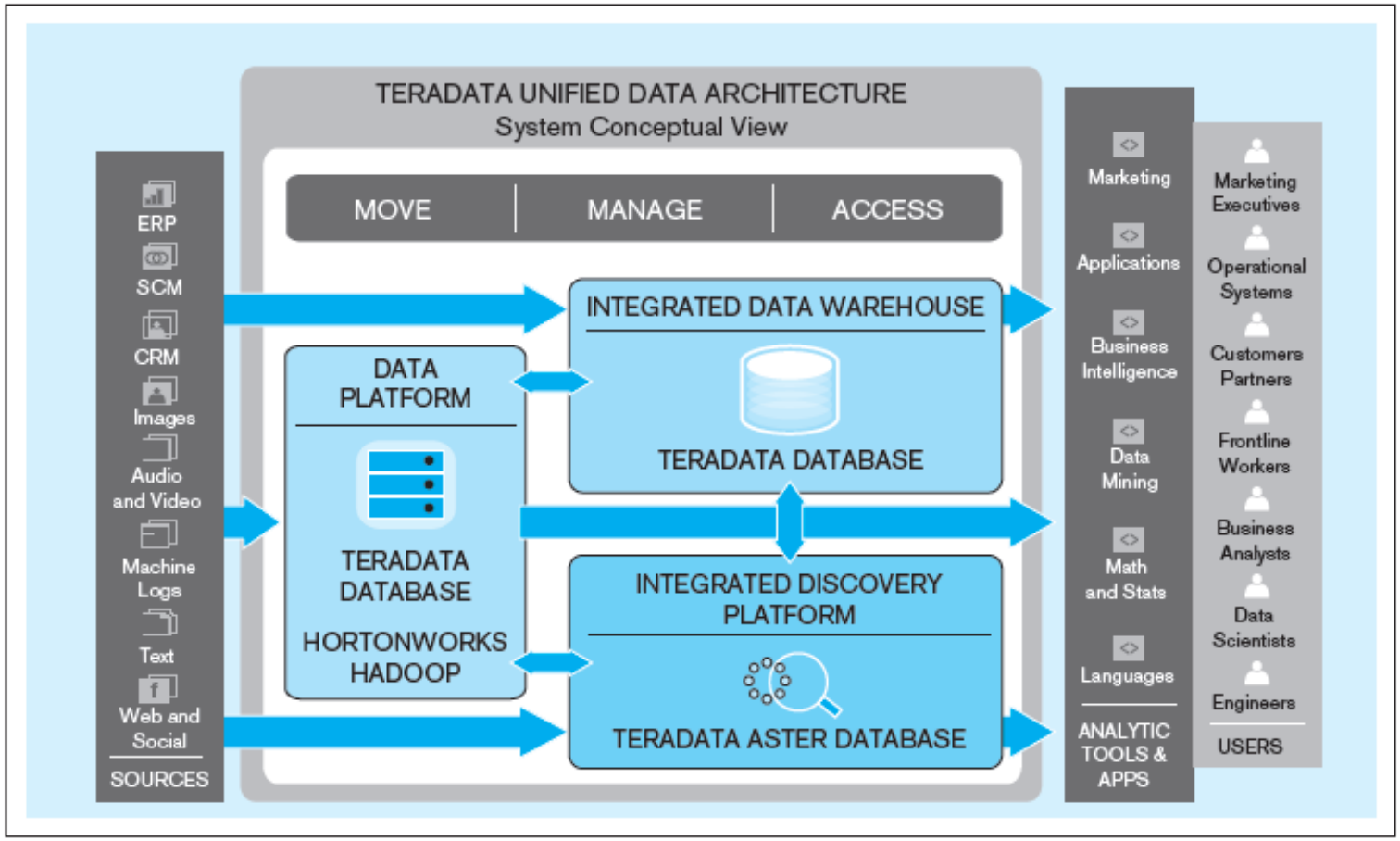


FIGURE 11-9 **Teradata Unified Data Architecture – system conceptual view**

UNIFIED DATA ARCHITECTURE, 10.14, EB 7805,http://www.teradata.com/Resources/White-Papers/Teradata-Unified-Data-Architecture-in-Action. Courtesy of Teradata Corporation

Analytics

- Historical precedents to **analytics**:
  - Management information systems (MIS) → Decision Support Systems (DSS) → Executive Information Systems (EIS)
  - DSS idea evolved into Business Intelligence (BI)
- **Business Intelligence**: a set of methodologies, processes, architectures, and technologies that transform raw data into meaningful and useful information.

Figure 11-10: Moving from Decision Support Systems to Analytics

- Analytics encompasses more than BI
  - Umbrella term that includes BI
  - Transform data to useful form
  - Infrastructure for analysis
  - Data cleanup processes
  - User interfaces

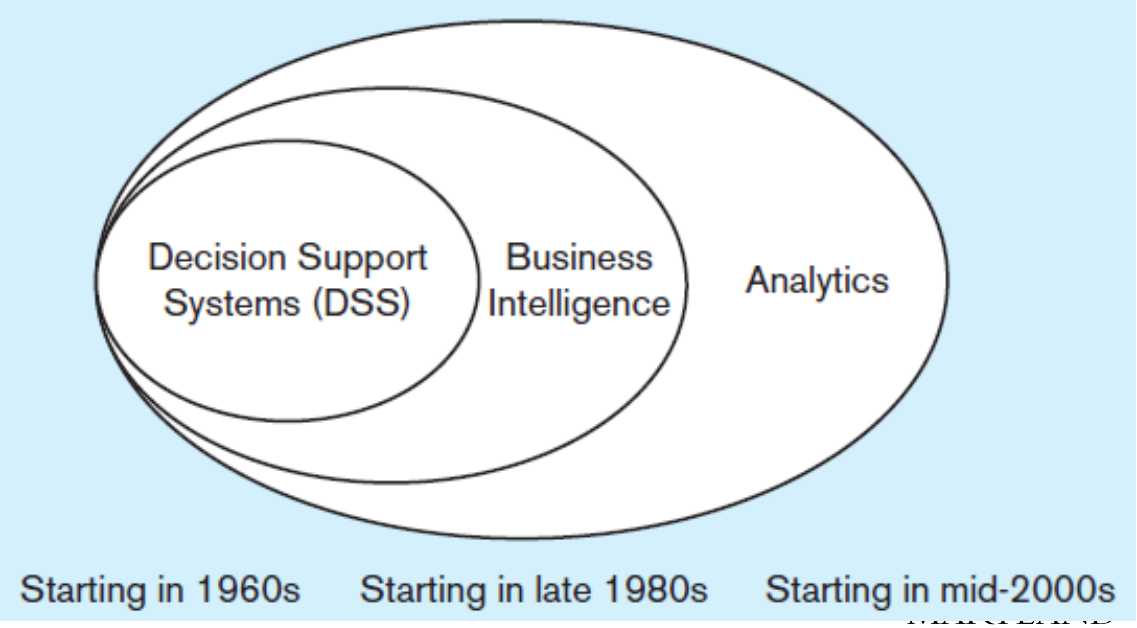
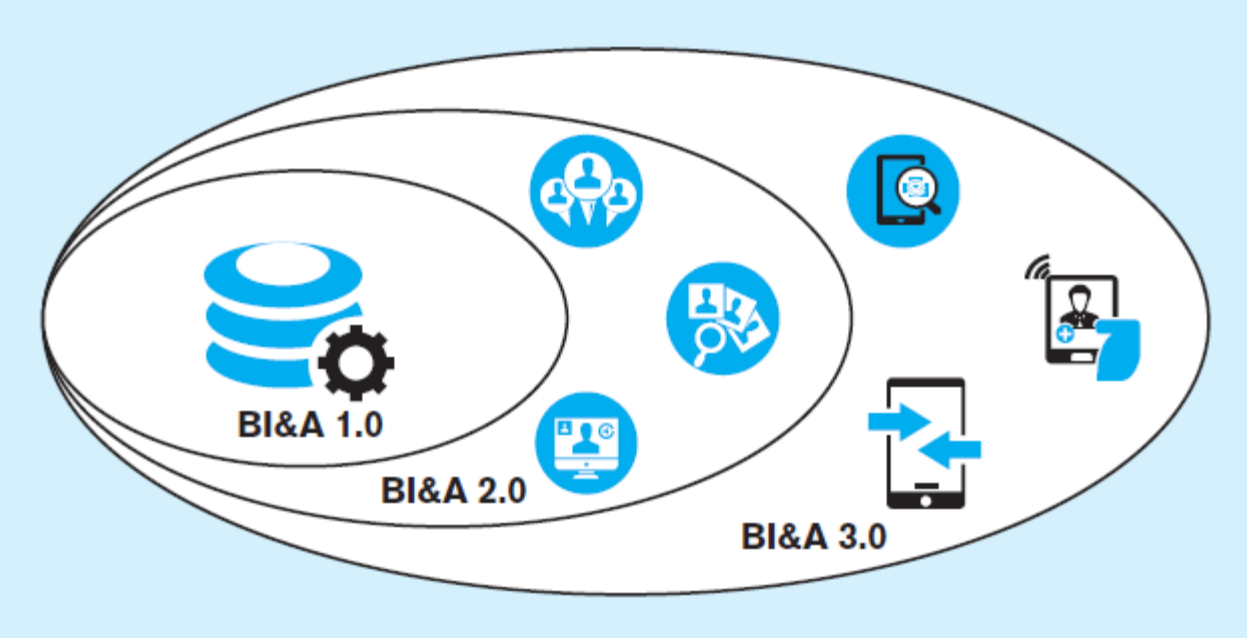


Figure 11-11: Generations of Business Intelligence and Analytics



BI&A 1.0
Focus on structured quantitative data largely from relational databases

BI&A 2.0
Include data from the Web (web interaction logs, customer reviews, social media)

BI&A 3.0
Include data from mobile devices, (location, sensors, etc.) as well as Internet of Things

Types of Analytics

- **Descriptive analytics**: describes the past status of the domain of interest using a variety of tools through techniques such as reporting, data visualization, dashboards, and scorecards
- **Predictive analytics**: applies statistical and computational methods and models to data regarding past and current events to predict what might happen in the future
- **Prescriptive analytics**: uses results of predictive analytics along with optimization and simulation tools to recommend actions that will lead to a desired outcome

Use of Descriptive Analytics

- **Descriptive analytics** was the original emphasis of BI
- Reporting of aggregate quantitative query results
- Tabular or data visualization displays
- **Dashboard**: a few key indicators
- **Scorecard**: like a dashboard, but broader range
- **OLAP**: online analytical processing

Predictive Analytics

- Statistical and computational methods that use data regarding past and current events to form models regarding what might happen in the future
- Examples:
  - classification trees
  - linear and logistic regression analysis
  - machine learning
  - neural networks
  - time series analysis
  - Bayesian modeling

Example of Predictive Analytics

- Credit scoring
  - Takes past financial data to produce a credit score
  - Starts with decision trees, neural networks, and support vector machine (SVM) algorithms for initial model
  - Next uses Predictive Modeling Markup Language (PMML)
- Marketing
  - Churn analysis: predicting which customers will leave using clustering via k-means algorithm
  - Social media analysis using association rules

Use of Prescriptive Analytics

- Use of optimization and simulation tools for prescribing the best action to take
- Example applications
  - Making trading decisions in securities and stock market
  - Making pricing decisions for airlines and hotels
  - Making product recommendations (e.g. Amazon and Netflix)
- Often requires predictive analytics and game theory

Online Analytical Processing (OLAP) Tools

- **Online Analytical Processing (OLAP)**
  - the use of a set of graphical tools
  - that provides users with multidimensional views of their data and
  - allows to analyze the data using simple windowing techniques
- **Relational OLAP (ROLAP)**
  - view the database as a traditional relational database.
- **Multidimensional OLAP (MOLAP)**
  - load data into an intermediate structure using Cube structure.
- **Hybrid OLAP (HOLAP)**
  - Storage mode combines both MOLAP and ROLAP.

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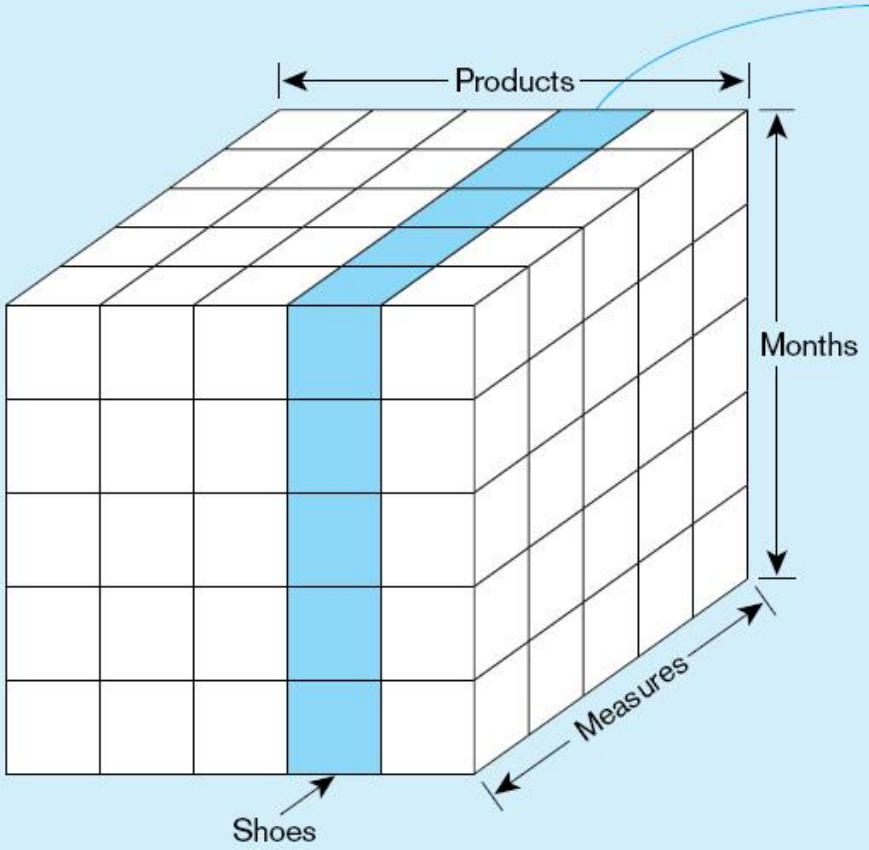
Cube Operations

- **Slicing**: select one dimension.
- **Dicing**: select two or more dimensions.
- **Pivoting**: rotate dimensional orientation of the cube.
- **Drill-down**: navigates from less detailed data to more detailed data.
- **Roll-up**: reduce dimension.

Figure 11-12: Slicing a Data Cube



	Measure		
	Units	Revenue	Cost
January	250	1564	1020
February	200	1275	875
March	350	1800	1275
April	400	1935	1500
May	485	2000	1560

Product: Shoes

Figure 11-13: Example of Drill-Down

Summary report

Brand	Package size	Sales
SofTowel	2-pack	$75
SofTowel	3-pack	$100
SofTowel	6-pack	$50

Starting with summary data, users can obtain details for particular cells.

Drill-down with color added

Brand	Package size	Color	Sales
SofTowel	2-pack	White	$30
SofTowel	2-pack	Yellow	$25
SofTowel	2-pack	Pink	$20
SofTowel	3-pack	White	$50
SofTowel	3-pack	Green	$25
SofTowel	3-pack	Yellow	$25
SofTowel	6-pack	White	$30
SofTowel	6-pack	Yellow	$20

Figure 11-14: Sample Pivot Table

four dimensions: Country (pages)
Resort Name (rows)
Travel Method, No. of Days (columns)

Country	(All)

Average of Price	Travel Method	No. of Days												
	Coach			Coach Total	Plane									Plane Total
Resort Name	4	5	7		6	7	8	10	14	16	21	32	60	
Aviemore			135	135										
Barcelona														
Black Forest	69			69										
Cork							269							269
Grand Canyon													1128	1128
Great Barrier Reef												750		750
Lake Geneva							699							699
London														
Los Angeles						295			375					335
Lyon									399					399
Malaga										234				234
Nerja					198				255					226.5
Nice						289								289
Paris–Euro Disney														
Prague		95		95										
Seville								199						199
Skiathos											429			429
Grand Total	69	95	135	99.66666667	198	292	484	199	343	234	429	750	1128	424.5384615

SQL OLAP Querying

- SQL is generally not an analytic language, but it can be used for analysis.
- However, OLAP extensions to SQL make this easier.
- OLAP queries should support:
  - **Categorization** – e.g. group data by dimension characteristics
  - **Aggregation** – e.g. create averages per category
  - **Ranking** – e.g. find customer in some category with highest average monthly sales

Regular SQL Query

TOP 1

```
SELECT P1.ProductId, ProductDescription, C1.CustomerId,
   CustomerName, SUM(OL1.OrderedQuantity) AS TotOrdered
   FROM Customer_T AS C1, Product_T AS P1, OrderLine_T
      AS OL1, Order_T AS O1
   WHERE C1.CustomerId = O1.CustomerId
      AND O1.OrderId = OL1.OrderId
      AND OL1.ProductId = P1.ProductId
   GROUP BY P1.ProductId, ProductDescription,
      C1.CustomerId, CustomerName
   HAVING TotOrdered >= ALL
   (SELECT SUM(OL2.OrderedQuantity)
   FROM OrderLine_T AS OL2, Order_T AS O2
   WHERE OL2.ProductId = P1.ProductId
      AND OL2.OrderId = O2.OrderId
      AND O2.CustomerId <> C1.CustomerId
   GROUP BY O2.CustomerId)
ORDER BY P1.ProductId;
```

OLAP SQL Query

- SalesHistory (TerritoryID, Quarter, Sales) and the desire to show a three-quarter moving average of sales.

```
SELECT TerritoryID, Quarter, Sales,
   AVG(Sales) OVER (PARTITION BY TerritoryID
      ORDER BY Quarter ROWS 2 PRECEDING) AS 3QtrAverage
FROM SalesHistory;
```

TerritoryID	Quarter	Sales	3QtrAverage
Atlantic	1	20	20
Atlantic	2	10	15
Atlantic	3	6	12
Atlantic	4	29	15
East	1	5	5
East	2	7	6
East	3	12	8
East	4	11	10
…			

OVER (also called WINDOW) is a special clause that provide a "sliding view" of rows from a query.

PARTITION BY is like a GROUP by for OVER.

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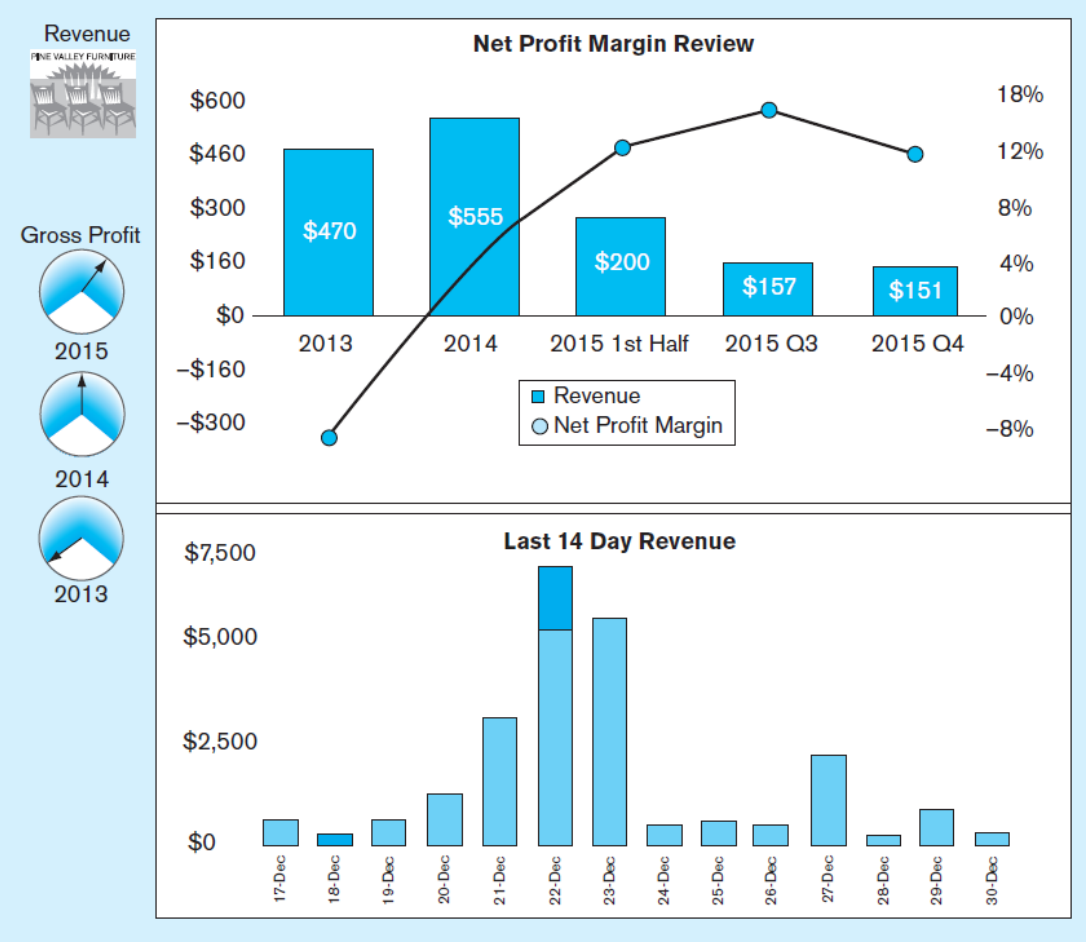
Data Visualization

- Representation of data in graphical and multimedia formats for human analysis
- "A picture tells a thousand words"
- Without showing precise values, graphs and charts can depict relationships in the data
- Often used in dashboards, as shown in next slide

Figure 11-16: Sample Dashboard

Business Performance Management (BPM)

BPM systems allow managers to measure, monitor, and manage key activities and processes to achieve organizational goals. Dashboards are often used to provide an information system in support of BPM.



Charts like these are examples of **data visualization**, the representation of data in graphical and multimedia formats for human analysis.

Data Mining

- Knowledge discovery using a blend of statistical, AI, and computer graphics techniques.
- Goals:
  - **Explanatory**: Explain observed events or conditions.
  - **Confirmatory**: Confirm hypotheses.
  - **Exploratory**: Explore data for new or unexpected relationships

- **Text mining** – Discovering meaningful information algorithmically based on computational analysis of unstructured textual information

Table 11-4: Data Mining Techniques

TABLE 11-4 Data-Mining Techniques

Technique	Function
Regression	Test or discover relationships from historical data
Decision tree induction	Test or discover if…then rules for decision propensity
Clustering and signal processing	Discover subgroups or segments
Affinity	Discover strong mutual relationships
Sequence association	Discover cycles of events and behaviors
Case-based reasoning	Derive rules from real-world case examples
Rule discovery	Search for patterns and correlations in large data sets
Fractals	Compress large databases without losing information
Neural nets	Develop predictive models based on principles modeled after the human brain

Table 11-5: Typical Data Mining Applications

TABLE 11-5 Typical Data-Mining Applications

Data-Mining Application	Example
Profiling populations	Developing profiles of high-value customers, credit risks, and credit-card fraud.
Analysis of business trends	Identifying markets with above-average (or below-average) growth.
Target marketing	Identifying rustomers (or customer segments) for promotional activity.
Usage analysis	Identifying usage patterns for products and services.
Campaign effectiveness	Comparing campaign strategies for effectiveness.
Product affinity	Identifying products that are purchased concurrently or identifying the characteristics of shoppers for certain product groups.
Customer retention and churn	Examining the behavior of customers who have left for competitors to prevent remaining customers from leaving.
Profitability analysis	Determining which customers are profitable, given the total set of activities the customer has with the organization.
Customer value analysis	Determining where valuable customers are at different stages in their life.
Upselling	Identifying new products or services to sell to a customer based upon critical events and life-style changes.

Source: Based on Dyché (2000).

Table 11-6: Analytics Data Management Infrastructure

- Important criteria: scalability, parallelism, low latency, and data optimization
- These criteria ensure speed, availability, and access

TABLE 11-6 Technologies Enabling Infrastructure Advances in Data Management

Massively parallel processing (MPP)	Instead of relying on a single processor, MPP divides a computing task (such as query processing) between multiple processors, speeding it up significantly.
In-memory DBMSs	In-memory DBMSs keep the entire database in primary memory, thus enabling significantly faster processing.
In-database analytics	If analytical functions are integrated directly to the DBMS, there is no need to move large quantities of data to separate analytics tools for processing.
Columnar DBMSs	They reorient the data in the storage structures, leading to efficiencies in many data warehousing and other analytics applications.

Big Data and Analytics Impact

- Applications:
  - Business
  - E-government and politics
  - Science and technology
  - Smart health and well-being
  - Security and public safety
- Social Implications:
  - Personal privacy vs. collective benefit
  - Ownership and access
  - Data/algorithm quality and reuse
  - Transparency and validation
  - Demands for workforce capabilities and education