Data Warehousing

Outline

- Overview of data warehousing
- Dimensional Modeling
- Online Analytical Processing

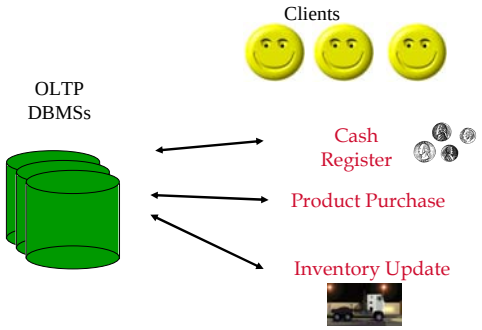
From OLTP to the Data Warehouse

- Traditionally, database systems stored data relevant to current business processes
  - Old data was archived or purged
- A database stores the current snapshot of the business:
  - Current customers with current addresses
  - Current inventory
  - Current orders
  - Current account balance

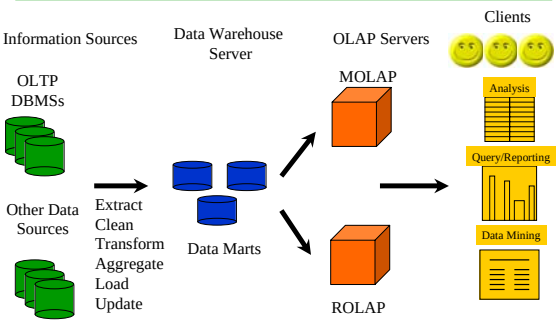
The Data Warehouse

- The data warehouse is a historical collection of all relevant data for analysis purposes
- Examples:
  - Current customers versus all customers
  - Current orders versus history of all orders
  - Current inventory versus history of all shipments
- Thus the data warehouse stores information that might be useless for the operational part of a business

OLTP Architecture



DW Architecture



Building a Data Warehouse

- Data warehouse is a collection of data marts
- Data marts contain one dimensional star schema that captures one business aspect
- Notes:
  - It is crucial to centralize the logical definition and format of dimensions and facts (political challenge; assign a dimension authority to each dimension). Everything else is a distributed effort throughout the company (technical challenge)
  - Each data mart will have its own fact table, but dimension tables are duplicated over several data marts

OLTP Versus Data Warehousing

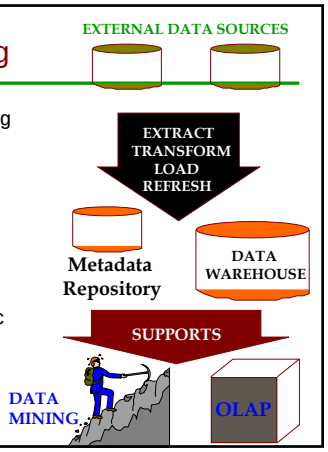
	OLTP	Data Warehouse
Typical user	Clerical	Management
System usage	Regular business	Analysis
Workload	Read/Write	Read only
Types of queries	Predefined	Ad-hoc
Unit of interaction	Transaction	Query
Level of isolation required	High	Low
No of records accessed	<100	>1,000,000
No of concurrent users	Thousands	Hundreds
Focus	Data in and out	Information out

Three Complementary Trends

- Data Warehousing: Consolidate data from many sources in one large repository
  - Loading, periodic synchronization of replicas
  - Semantic integration
- OLAP:
  - Complex SQL queries and views
  - Queries based on spreadsheet-style operations and "multidimensional" view of data
  - Interactive and "online" queries
- Data Mining: Exploratory search for interesting trends and anomalies (Another lecture!)

Data Warehousing

- Integrated data spanning long time periods, often augmented with summary information
- Several gigabytes to terabytes common
- Interactive response times expected for complex queries; ad-hoc updates uncommon



Warehousing Issues

- Semantic Integration: When getting data from multiple sources, must eliminate mismatches, e.g., different currencies, schemas
- Heterogeneous Sources: Must access data from a variety of source formats and repositories
  - Replication capabilities can be exploited here
- Load, Refresh, 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

Terminology

- OLTP (Online Transaction Processing)
- DSS (Decision Support System)
- DW (Data Warehouse)
- OLAP (Online Analytical Processing)

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Dimensional Data Modeling

- Recall: The relational model

The dimensional data model:

- Relational model with two different types of attributes and tables
- Attribute level: Facts (numerical, additive, dependent) versus dimensions (descriptive, independent)
- Table level: Fact tables (large tables with facts and foreign keys to dimensions) versus dimension tables (small tables with dimensions)

Dimensional Modeling (contd.)

- Fact (attribute): Measures performance of a business
- Example facts:
  - Sales, budget, profit, inventory
- Example fact table:
  - Transactions (timekey, storekey, pkey, promkey, ckey, units, price)
- Dimension (attribute): Specifies a fact
- Example dimensions:
  - Product, customer data, sales person, store
- Example dimension table:
  - Customer (ckey, firstname, lastname, address, dateOfBirth, occupation, ...)

OLTP versus Data Warehouse

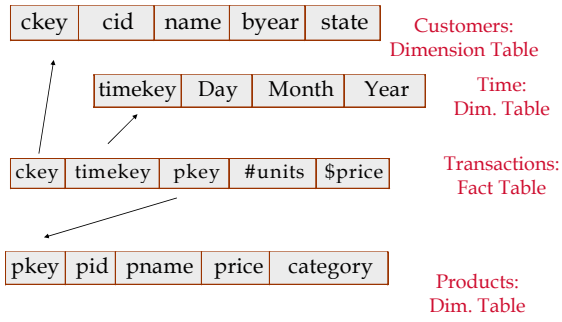
OLTP

- Regular relational schema
  - Normalized
- Updates overwrite previous values: One instance of a customer with a unique customerID
- Queries return information about the current state of affairs

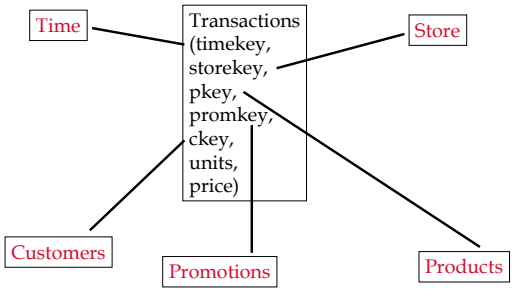
Data warehouse

- Dimensional model
  - Fact table in BCNF
  - Dimension tables not normalized: few updates, mostly queries
- Updates add new version: Several instances of the same customer (with different data, e.g., address)
- Queries return aggregate information about historical facts

Example: Dimensional Data Modeling



Another View: Star Schema



Fact versus Dimension Tables

- Fact tables are usually very large; they can grow to several hundred GB and TB
- Dimension tables are usually smaller (although can grow large, e.g., Customers table), but they have many fields
- Queries over fact tables usually involve many records

Grain

- The grain defines the level of resolution of a single record in the fact table.
- Example fact tables:
  - Transactions (timekey, storekey, pkey, promkey, ckey, units, price); grain is individual item
  - Transactions (timekey, storekey, ckey, units, price); grain is one market basket

Typical Queries

- SQL:

```
SELECT      D1.d1, ..., Dk.dk, agg1(F.f1,)
FROM        Dimension D1, ...,
            Dimension Dk, Fact F
WHERE       D1.key = F.key1 AND ... AND
            Dk.keyk = F.keyk AND
            otherPredicates
GROUP BY    D1.d1, ..., Dk.dk
HAVING      groupPredicates
```

- This query is called a “Star Join”.

Example Query

- "Break down sales by year and category for the last two years; show only categories with more than $1M in sales."
- SQL:

```
SELECT T.year, P.category, SUM(X.units * X.price)
FROM Time T, Products P, Transactions X
WHERE T.year = 1999 OR T.year = 2000
GROUP BY T.year, P.category
HAVING SUM(X.units * X.price) > 1000000
```

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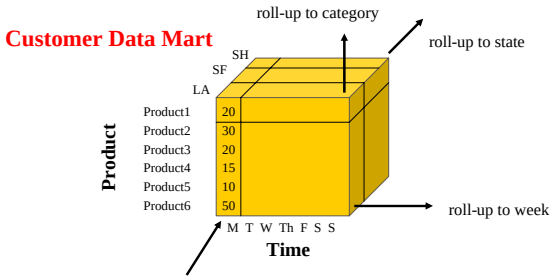
Online Analytical Processing (OLAP)

- Ad hoc complex queries
- Simple, but intuitive and powerful query interface
  - Spreadsheet influenced analysis process
- Specialized query operators for multidimensional analysis
  - Roll-up and drill-down
  - Slice and dice
  - Pivoting

Visual Intuition: Cube



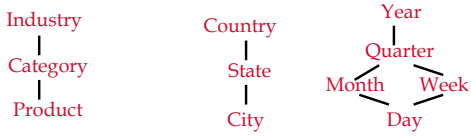
50 Units of Product6 sold on Monday in LA

Multidimensional Data Analysis

Data warehouse:

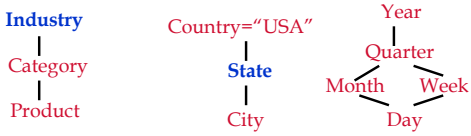
- Transactions(ckey, timekey, pkey, units, price)
- Customers(ckey, cid, name, byear, city, state, country)
- Time(tkey, day, month, quarter, year)
- Products(pkey, pname, price, pid, category, industry)

Hierarchies on dimensions:



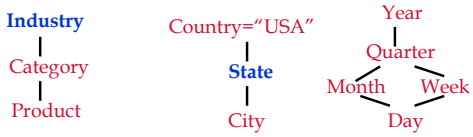
Multidimensional Data Analysis

	NY	CA	WI
Industry1	$1000	$2000	$1000
Industry2	$500	$1000	$500
Industry3	$3000	$3000	$3000



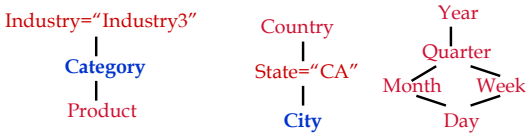
Corresponding Query in SQL

- SELECT SUM(units)
  FROM Transactions T, Products P, Customers C
  WHERE T.pkey = P.pkey AND T.ckey = C.ckey
  AND C.country = "USA"
  GROUP BY P.industry, C.state
- We think that Industry3 in CA is interesting.



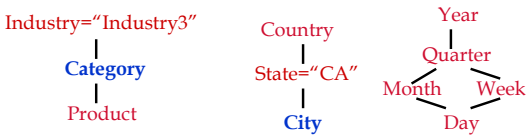
Slice and Drill-Down

	San Francisco	San Jose	Los Angeles
Category1	$300	$300	$400
Category2	$300	$300	$400
Category3	$100	$800	$100



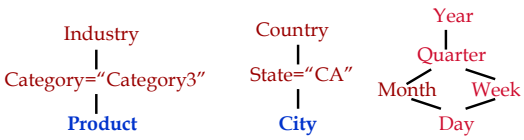
Corresponding Query in SQL

- SELECT SUM(units)
  FROM Transactions T, Products P, Customers C
  WHERE T.pkey = P.pkey AND T.ckey = C.ckey
  AND P.industry = "Industry3" AND C.state = "CA"
  GROUP BY P.category, C.city
- We think that Category3 is interesting.



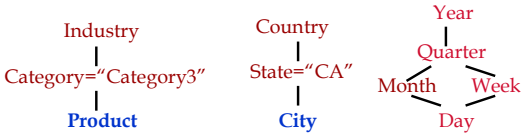
Slice and Drill-Down

	San Francisco	San Jose	Los Angeles
Product1	$20	$160	$20
Product2	$20	$160	$20
Product3	$60	$480	$60



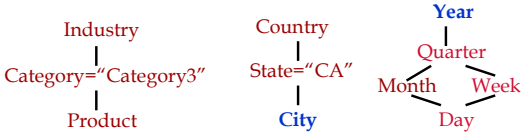
Corresponding Query in SQL

- SELECT SUM(units)
  FROM Transactions T, Products P, Customers C
  WHERE T.pkey = P.pkey AND T.ckey = C.ckey
  AND C.state = "CA" AND P.category = "Category3"
  GROUP BY P.product, C.city
- Nothing new in this view of the data.



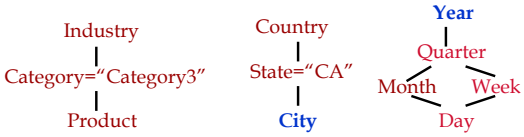
Pivot To (City, Year)

	San Francisco	San Jose	Los Angeles
1997	$20	$100	$20
1998	$20	$600	$20
1999	$60	$100	$60



Corresponding Query in SQL

- SELECT SUM(units)
  FROM Transactions T, Products P, Customers C
  WHERE T.pkey = P.pkey AND T.ckey = C.ckey
  AND C.state = "CA" AND P.category = "Category3"
  GROUP BY **C.city, T.year**



Multidimensional Data Analysis

Set of data manipulation operators

- Roll-up: Go up one step in a dimension hierarchy (e.g., month -> quarter)
- Drill-down: Go down one step in a dimension hierarchy (e.g., quarter -> month)
- Slice: Select a value of a dimension (e.g., all categories -> only Category3)
- Dice: Select range of values of a dimension (e.g., Year > 1999)
- Pivot: Select new dimensions to visualize the data (e.g., pivot to Time(quarter) and Customer(state))

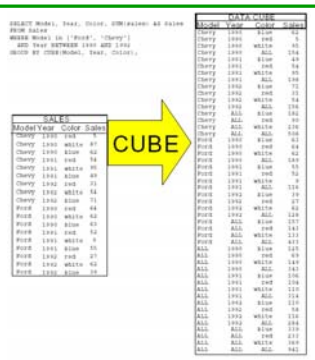
The CUBE Operator

- Generalizing GROUP BY and aggregation
  - 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.
- CUBE pid, locid, timeid BY SUM Sales
  - Equivalent to rolling up Sales on all eight subsets of the set {pid, locid, timeid}; each roll-up corresponds to an SQL query of the form:

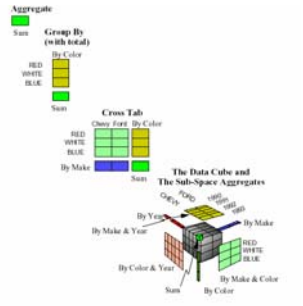
Lots of recent work on optimizing the CUBE operator!

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

Example



Multidimensional View Of CUBE



OLAP Server Architectures

- Relational OLAP (ROLAP)
  - Relational DBMS stores data mart (star schema)
  - OLAP middleware:
    - Aggregation and navigation logic
    - Optimized for DBMS in the background, but slow and complex
- Multidimensional OLAP (MOLAP)
  - Specialized array-based storage structure
- Desktop OLAP (DOLAP)
  - Performs OLAP directly at your PC
- Hybrids and Application OLAP

Summary: Multidimensional Analysis

- Spreadsheet style data analysis
- Roll-up, drill-down, slice, dice, and pivot your way to interesting cells in the CUBE
- Mainstream technology