Chapter IV: OLAP

Knowledge Discovery in Databases

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Chapter IV: Data warehousing and online analytical processing

Data warehouse: basic concepts.

Data-warehouse modeling: data cube and OLAP.

Data-warehouse design and usage.

Data-warehouse Implementation.

Data generalization by attribute-oriented induction.

Summary.

What is a data warehouse?

Defined in many different ways, but not rigorously:

A **decision-support** database that is **maintained separately** from the organization’s operational database.

Supports information processing by providing a solid platform of **consolidated, historical data** for analysis.

Famous:

A data warehouse is a subject-oriented, integrated, time-variant, and nonvolatile collection of data in support of management’s decision-making process.

– W. H. Inmon.

Data warehousing: The process of constructing and using data warehouses.

Data warehouse – subject-oriented

Organized around major subjects.

Such as customer, product, sales.

Focusing on the modeling and analysis of data for decision makers.

Not on daily operations or transaction processing.

Provide a simple and concise view around particular subject issues.

By excluding data that are not useful in the decision-support process.

Data warehouse – integrated

Constructed by integrating multiple heterogeneous data sources.

Relational databases, flat files, online transaction records, . . .

Data-cleaning and data-integration techniques are applied.

Ensure consistency in naming conventions, encoding structures, attribute measures, etc. among different data sources.

E.g., hotel price: currency, tax, breakfast covered, etc.

When data is moved to the warehouse, it is converted.

ETL – Extraction, Transformation, Loading, see below.

Data warehouse – time variant

The time horizon for a data warehouse is significantly longer than that of operational systems.

Operational database: current-value data.

Data warehouse: provide information from a historical perspective, e.g. past 5 — 10 years.

Every key structure in the data warehouse contains an element of time, explicitly or implicitly.

The key of operational data may or may not contain a "time element."

Data warehouse – nonvolatile

- **A physically separate store of data.**
  - Transformed from the operational environment.
  - By copying.
- **No operational update of data:**
  - Hence, does not require transaction processing,
  - i.e. no logging, recovery, concurrency control, etc.
  - Requires only three operations:
    - Initial loading of data.
    - Refresh (update, often periodically, e.g. over night).
    - Access of data.

OLTP vs. OLAP

	OLTP	**OLAP**
users	clerk, IT professional	knowledge worker
function	day-to-day operations	decision support
DB design	application-oriented	decision support
data	current, up-to-date; detailed, flat relational; isolated	historical; summarized, multidimensional, integrated, consolidated
usage	repetitive	ad-hoc
access	read/write; index/hash on primary key	lots of scans
unit of work	short, simple transaction	complex query
#-records accessed	10	10^6
#-users	1000	100
DB size	100 MB to GB	100 GB to TB
quantification	transaction throughput	query throughput, response

Why a separate data warehouse?

High performance for both systems:

DBMS: tuned for OLTP; Access methods, indexing concurreny control, recovery.

Warehouse: tuned for OLAP; Complex OLAP queries, multidimensional view, consolidation.

Different functions and different data:

Missing data:

Decision support (DS) requires **historical data** which operational DBs do not typically maintain.

Data consolidation:

DS requires **consolidation** (aggregation, summarization) of data from heterogeneous sources.

Data quality:

Different sources typically use inconsistent data representations, codes and formats which have to be reconciled.

Note: There are more and more systems which perform OLAP analysis directly on relational databases.

Three data-warehouse models

Enterprise Warehouse:

Collects all of the information about subjects spanning the entire organization.

Data mart:

A **subset** of corporate-wide data that is of value to a **specific group of users.**

Its scope is confined to specific, selected groups, such as marketing data mart.

Independent vs. dependent (directly from warehouse) data mart.

Virtual warehouse:

A set of **views** over operational databases.

Only some of the possible summary views may be materialized.

Extraction, transformation, and loading (ETL)

Extraction:

Get data from multiple, heterogeneous, and external sources.

Cleaning:

Detect errors in the data and rectify them if possible.

Transformation:

Convert data from legacy or host format to warehouse format.

Loading:

Sort, summarize, consolidate, compute views, check integrity, and build indexes and partitions.

Refresh:

Propagate only the updates from the data sources to the warehouse.

Metadata repository

Metadata: the data defining data-warehouse objects.

Description of the structure of the data warehouse:

- Schema, view, dimensions, hierarchies, derived-data definition, data-mart locations and contents.

Operational metadata:

- **Data lineage** (history of migrated data and transformation path).
- Currency of data (active, archived, or purged).
- Monitoring information (warehouse-usage statistics, error reports, audit trails).

Algorithms used for summarization.

Mapping from operational environment to data warehouse.

Data related to system performance:

- Warehouse schema, view and derived-data definitions.

Business data:

- Business terms and definitions, ownership of data, charging policies.

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From tables and spreadsheets to data cubes

Data warehouse: basic concepts.

- Based on a **multidimensional data model** which views data in the form of a **data cube**.

Data cube.

- Allows data (here: sales) to be modeled and viewed in multiple dimensions.
  - **Dimension tables:** such as: `item (item_name, brand, type)`, or: `time (day, week, month, quarter, year)`.
  - **Fact table:** Contains **measures** (such as `dollars_sold`) and references (`foreign keys`) to each of the related dimension tables.

***n*-dimensional base cube.**

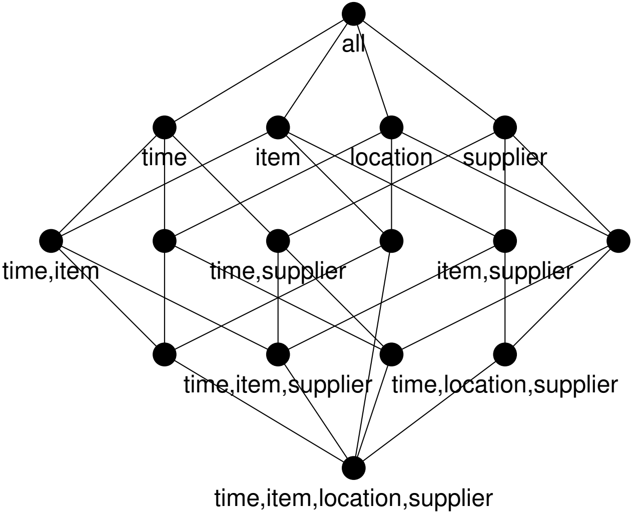
- Called a base cuboid in data-warehousing literature.

Top most 0**-dimensional cuboid.**

- Holds the highest-level of summarization.
- Called the apex cuboid.

Lattice of cuboids. (Forms a data cube)

Cube: a lattice of cuboids



all

time

item

location

supplier

time,item

time,supplier

item,supplier

time,item,supplier

time,location,supplier

time,item,location,supplier

0-dimensional (apex) cuboid

1-dimensional cuboid

2-dimensional cuboid

3-dimensional cuboid

4-dimensional (base) cuboid

Conceptual modeling of data warehouses

Star schema:.

A fact table in the middle connected to a set of dimension tables.

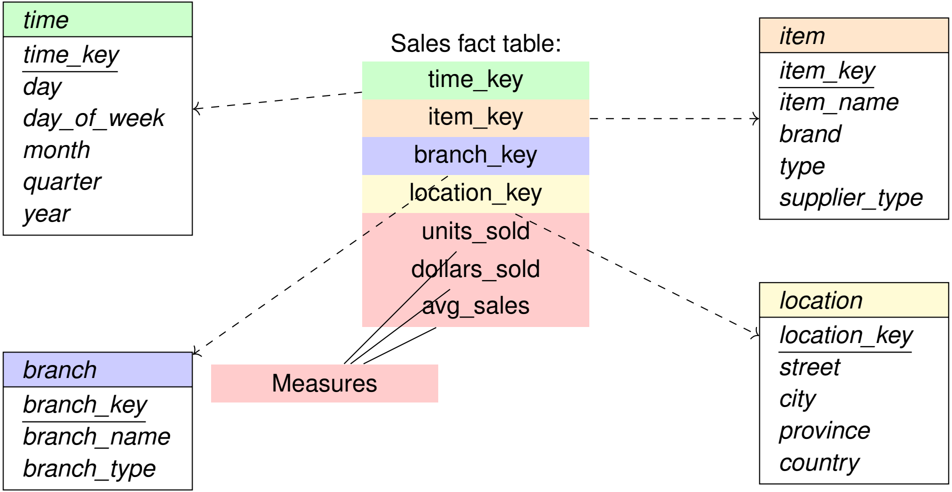
Snowflake schema:.

A refinement of the star schema where some dimensional hierarchy is **normalized** into a set of smaller dimension tables, forming a shape similar to a snowflake.

Fact constellations:.

Multiple fact tables sharing dimension tables, viewed as a collection of stars, therefore called **galaxy schema** or fact constellation.

Example of star schema



time

time_key

day

day_of_week

month

quarter

year

Sales fact table:

time_key

item_key

branch_key

location_key

units_sold

dollars_sold

avg_sales

item

item_key

item_name

brand

type

supplier_type

location

location_key

street

city

province

country

branch

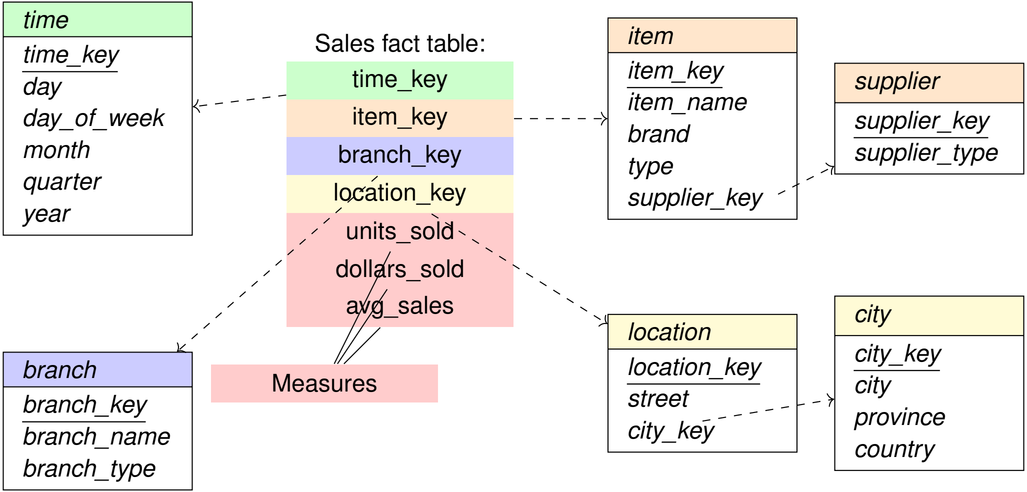
branch_key

branch_name

branch_type

Measures

Example of snowflake schema



Sales fact table:

time_key

item_key

branch_key

location_key

units_sold

dollars_sold

avg_sales

Measures

time

time_key
day
day_of_week
month
quarter
year

item

item_key
item_name
brand
type
supplier_key

supplier

supplier_key
supplier_type

branch

branch_key
branch_name
branch_type

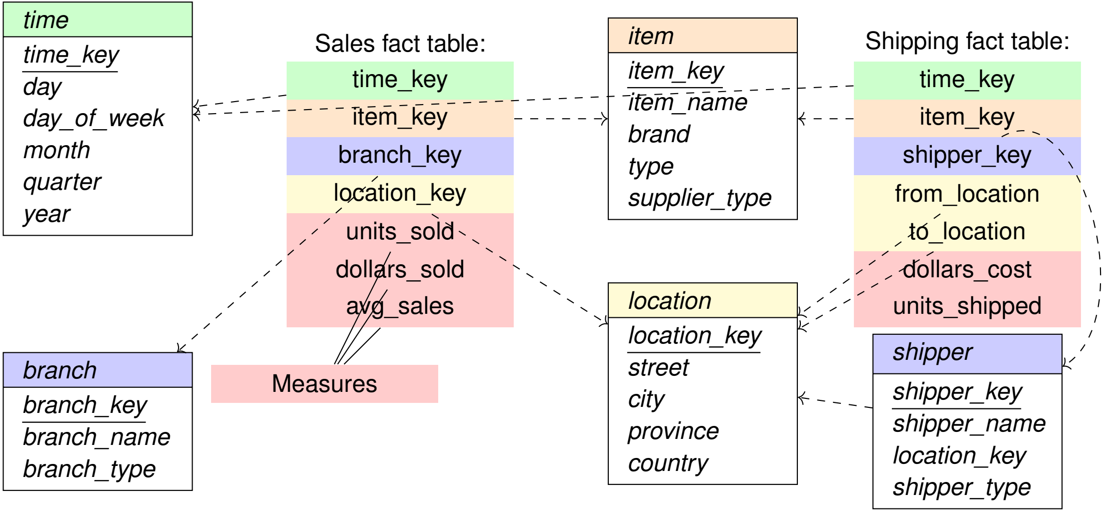
location

location_key
street
city_key

city

city_key
city
province
country

Example of fact constellation



time

time_key
day
day_of_week
month
quarter
year

Sales fact table:

time_key
item_key
branch_key
location_key
units_sold
dollars_sold
avg_sales

item

item_key
item_name
brand
type
supplier_type

Shipping fact table:

time_key
item_key
shipper_key
from_location
to_location
dollars_cost
units_shipped

branch

branch_key
branch_name
branch_type

Measures

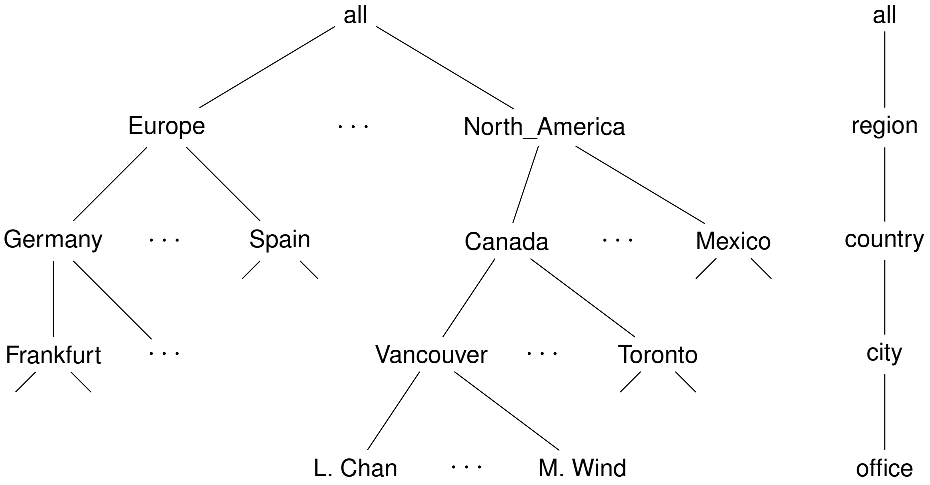
location

location_key
street
city
province
country

shipper

shipper_key
shipper_name
location_key
shipper_type

A concept hierarchy: dimension (location)



Data-cube measures: three categories

Distributive:

If the result derived by applying the function to the *n* aggregate values obtained for *n* partitions of the dataset is the same as that derived by applying the function on all the data without partitioning.
E.g. `COUNT`, `SUM`, `MIN`, `MAX`.

Functional:

If it can be computed by an algebraic function with *M* arguments, each of which is obtained by applying a distributive aggregate function.
E.g. `AVG`, $\mathtt{MIN}_N$, `STD`.

Holistic:

If there is no constant bound on the storage size needed to describe a subaggregate.
E.g. `MEDIAN`, `MODE`, `RANK`.

Aggregation type

Non-trivial property.

Next to name and value range.

Defines the set of aggregation operations that can be executed on a measure (a fact).

FLOW:

Any aggregation.

E.g. sales turnover.

STOCK:

No temporal aggregation.

E.g. stock, inventory.

VPU (Value per Unit:

No summarization.

E.g. price, tax, in general factors.

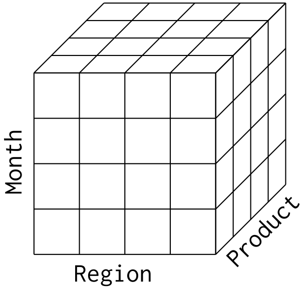
(Always applicable: `MIN`, `MAX` and `AVG`).

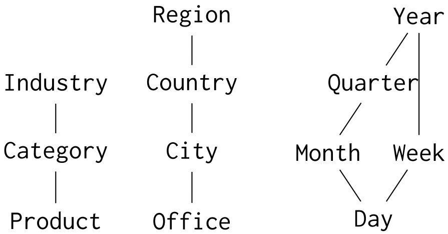
Aggregation type

Sales volume as a function of product, month, and region.

Dimensions: `Product`, `Location`, `Time`.

Hierarchical summarization paths.





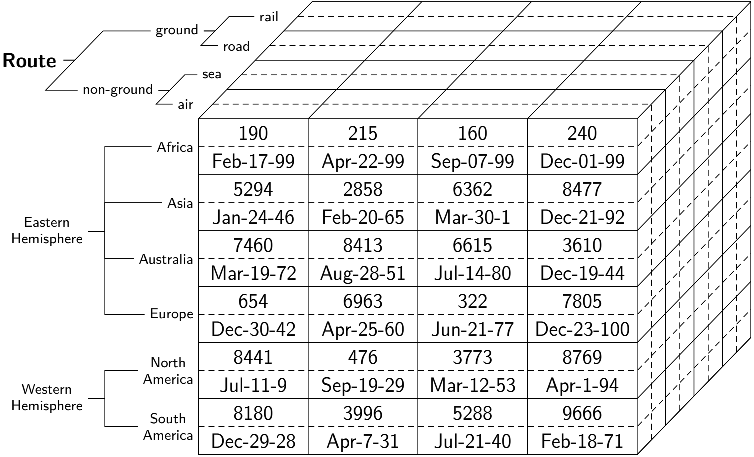
Industry – Category – Product

Region – Country – City – Office

Year – Quarter – Month – Day

Year – Week – Day

Data cube sample



Eastern Hemisphere	Africa	190 Feb-17-99	215 Apr-22-99	160 Sep-07-99	240 Dec-01-99
	Asia	5294 Jan-24-46	2858 Feb-20-65	6362 Mar-30-1	8477 Dec-21-92
	Australia	7460 Mar-19-72	8413 Aug-28-51	6615 Jul-14-80	3610 Dec-19-44
	Europe	654 Dec-30-42	6963 Apr-25-60	322 Jun-21-77	7805 Dec-23-100
Western Hemisphere	North America	8441 Jul-11-9	476 Sep-19-29	3773 Mar-12-53	8769 Apr-1-94
	South America	8180 Dec-29-28	3996 Apr-7-31	5288 Jul-21-40	9666 Feb-18-71

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Data generalization

Summarize data:

- **By replacing relatively low-level values**
  e.g. numerical values for the attribute `age`
  with higher-level concepts
  e.g. `young`, `middle-aged` and `senior`.
- **By reducing the number of dimensions**
  e.g. removing `birth_date` and `telephone_number`
  when summarizing the behavior of a group of students.
- Describe concepts in concise and succinct terms at generalized (rather than low) levels of abstractions:
  - Facilitates users in examining the general behavior of the data.
  - Makes dimensions of a data cube easier to grasp.

Attribute-oriented induction

Proposed in 1989 (KDD’89 workshop).

Not confined to categorical data nor to particular measures.

How is it done?

- Collect the **task-relevant data** (initial relation) using a relational database query.
- Perform **generalization** by attribute removal or attribute generalization.
- Apply **aggregation** by merging identical, generalized tuples and accumulating their respective counts.
- Interaction with users for knowledge presentation.

Attribute-oriented induction: an example

Example: Describe general characteristics of graduate students in a University database.

Step 1: Fetch relevant set of data using an SQL statement, e.g.

```
SELECT name, gender, major, birth_place, birth_date, residence, phone#, gpa)
FROM student
WHERE student_status IN ”Msc”, ”MBA”, ”PhD”;
```

Step 2: Perform attribute-oriented induction.

Step 3: Present results in generalized-relation, cross-tab, or rule forms.

Class characterization: an initial relation (I)

Name	Gender	Major	Birth place	Birth date	Residence	Phone number	GPA
Jim	M	CS	Vancouver, BC, Canada	08-21-76	3511 Main St., Richmond	687-4598	3.67
Scott Lachance	M	CS	Montreal, Que, Canada	28-07-75	345 1st Ave., Richmond	253-9106	3.70
Laura Lee	F	Physics	Seattle, WA, USA	25-08-70	125 Austin Ave., Burnaby	420-5232	3.83
Removed	Retained	Sci, Eng, Bus	Country	Age range	City	Removed	Excl, Vg,. . .

Class characterization: prime generalized relation (II)

Gender	Major	Birth region	Age range	Residence	GPA	Count
M	Science	Canada	20-35	Richmond	Very good	16
F	Science	Foreign	25-30	Burnaby	Excellent	22
...	...	...	...	...	...	...

Class characterization: an example (III)

Cross-table of birth region and gender:

	Canada	Foreign	Total
M	16	14	30
F	10	22	32
Total	26	36	62

Basic principles of attribute-oriented induction

Data focusing:

Task-relevant data, including dimensions
The result is the **initial relation**.

Attribute removal:

Remove attribute A, if there is a large set of distinct values for A,
but (1) there is no generalization operator on A,
or (2) A's higher-level concepts are expressed in terms of other attributes.

Attribute generalization:

If there is a large set of distinct values for A,
and there exists a **set of generalization operators** on A,
then select an operator and generalize A.

Attribute-threshold control:

Typical 2-8, specified/default.

Generalized-relation-threshold control:

Control the final relation/rule size.

Attribute-oriented induction: basic algorithm

InitialRel:

Query processing of task-relevant data, deriving the initial relation.

PreGen:

Based on the analysis of the number of distinct values in each attribute, determine generalization plan for each attribute: removal? Or how high to generalize?

PrimeGen:

Based on the PreGen plan, perform generalization to the right level to derive a "prime generalized relation", accumulating the counts.

Presentation:

User interaction:

1. Adjust levels by drilling.
2. Pivoting.
3. Mapping into rules, cross tabs, visualization presentations.

Presentation of generalized results

Generalized relation:

Relations where some or all attributes are generalized, with counts or other aggregation values accumulated.

Cross tabulation:

Mapping results into cross-tabulation form (similar to contingency tables).
Visualization techniques: pie charts, bar charts, curves, cubes, and other visual forms.

Quantitative characteristic rules:

Mapping generalized result into characteristic rules with quantitative information associated with it, e.g.

$$\begin{aligned} \text{grad}(x) \wedge \text{male}(x) \implies & \text{birth\_region}(x) && (1)\\ & = \text{"Canada"}[t : 53\%] \vee \text{birth\_region}(x) && (2)\\ & = \text{"foreign"}[t : 47\%]. && (3) \end{aligned}$$

Mining-class comparisons

Comparison: Comparing two or more classes.

Method:

- Partition the set of relevant data into the **target class** and the **contrasting class(es)**.
- Generalize both classes to the same high-level concepts (i.e. AOI).
  - Including aggregation.
- Compare tuples with the same high-level concepts.
- Present for each tuple its description and two measures.
  - Support – distribution within single class (counts, percentage).
  - Comparison – distribution between classes.
- Highlight the tuples with strong discriminant features.

Relevance Analysis:

- Find attributes (features) which best distinguish different classes.

Concept description vs. cube-based OLAP

Similarity:

Data generalization.

Presentation of data summarization at multiple levels of abstraction.

Interactive drilling, pivoting, slicing and dicing.

Differences:

OLAP has systematic preprocessing, query independent, and can drill down to rather low level.

AOI has automated desired-level allocation and may perform dimension-relevance analysis/ranking when there are many relevant dimensions.

AOI works on data which are not in relational forms.

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Data warehousing: multi-dimensional model of data.

A data cube consists of dimensions and measures.

Star schema, snowflake schema, fact constellations.

OLAP operations: drilling, rolling, slicing, dicing and pivoting.

Data-warehouse architecture, design, and usage.

Multi-tiered architecture.

Business-analysis design framework.

Information processing, analytical processing, data mining, OLAM (Online Analytical Mining).

Implementation: efficient computation of data cubes.

Partial vs. full vs. no materialization.

Indexing OALP data: Bitmap index and join index.

OLAP query processing.

OLAP servers: ROLAP, MOLAP, HOLAP.

Data generalization: attribute-oriented induction.

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Thank you for your attention.
Any questions about the fourth chapter?

Ask them now, or again, drop me a line:
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