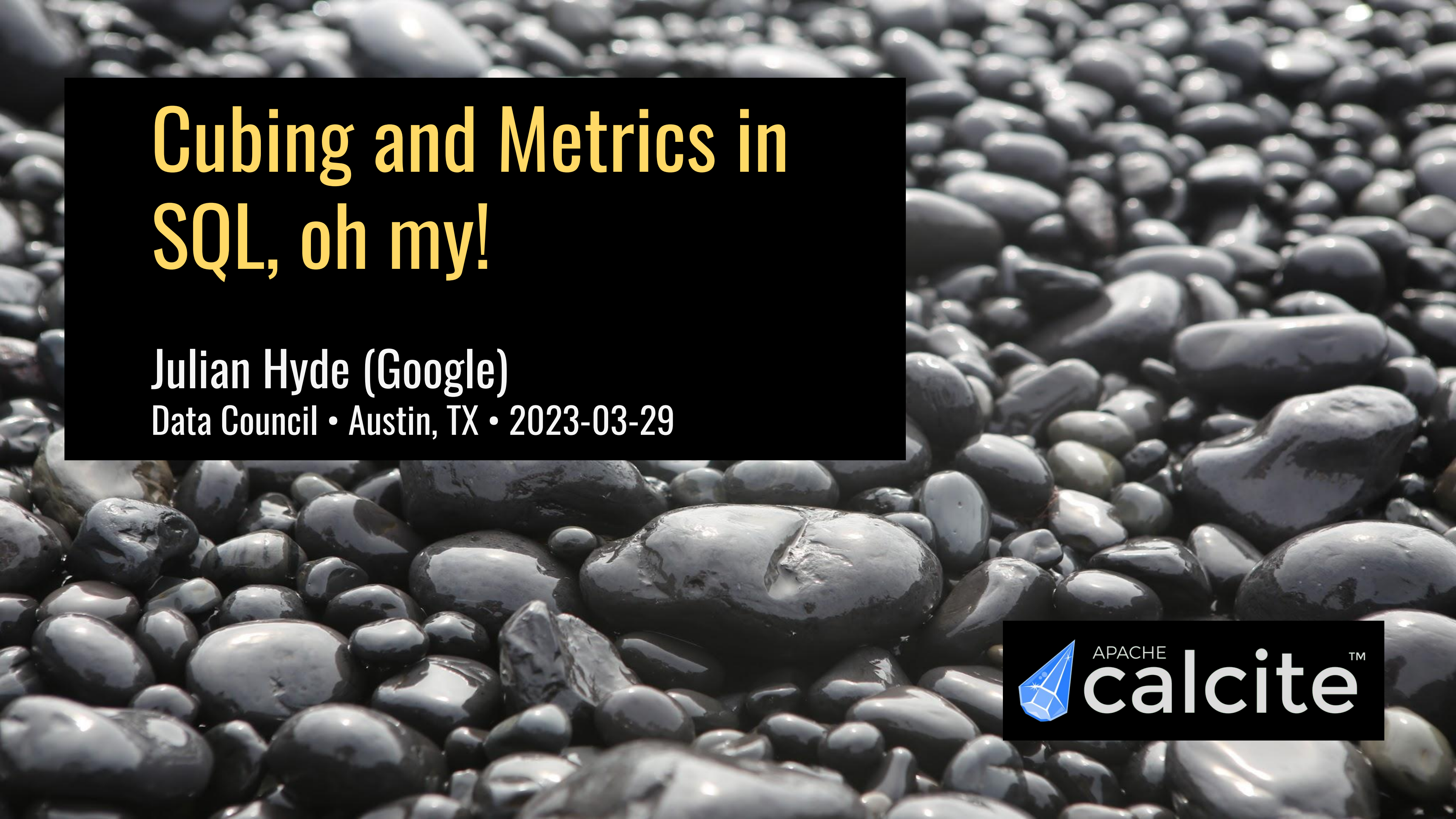


Cubing and Metrics in SQL, oh my!

Julian Hyde (Google)

Data Council • Austin, TX • 2023-03-29

APACHE calcite™

SQL vs BI

BI tools implement their own languages on top of SQL. Why not SQL?

Possible reasons:

- Semantic Model
- Control presentation / visualization
- Governance
- Pre-join tables
- Define reusable calculations
- Ask complex questions in a concise way

Processing BI in SQL

Why we should do it

- Move processing, not data
- Cloud SQL scale
- Remove data lag
- SQL is open

Why it's hard

- Different paradigm
- More complex data model
- Can't break SQL

What’s this talk about?

Extensions to Apache Calcite’s SQL dialect

Adoption by other SQL engines?

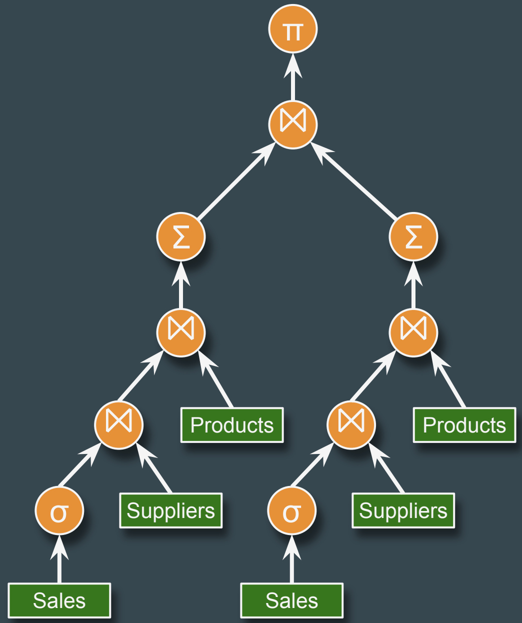
Rethinking the “semantic model” and “metrics layer”

An API for data?

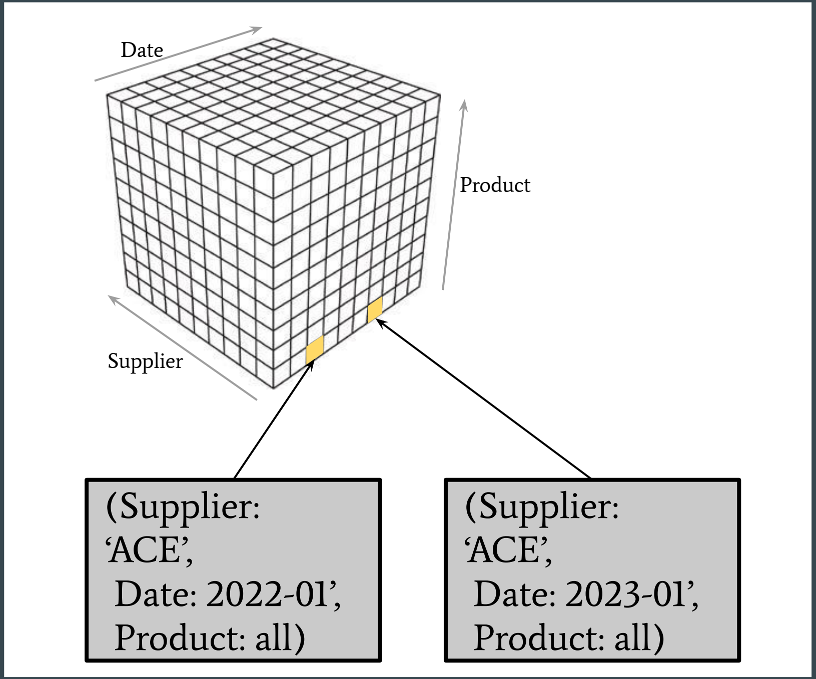
Pasta machine vs Pizza delivery

Bottom-up vs Top-down query

Relational algebra (bottom-up)



Multidimensional (top-down)


Date
Product
Supplier
(Supplier: ‘ACE’, Date: 2022-01’, Product: all)
(Supplier: ‘ACE’, Date: 2023-01’, Product: all)

A multidimensional query #1

Select top 5 suppliers for each product category for last year, based on total sales.

A multidimensional query #2

For each product category, select total sales this month of the product that had highest sales in that category last month.

A multidimensional query #3

For supplier “Ace” and for each product, give the fractional increase in the sales in January 2023 relative to the sales in January 2022.

Query:

- For supplier “Ace” and for each product, give the fractional increase in the sales in January 2023 relative to the sales in January 2022.

SQL

```
SELECT p.prodId,
  s95.sales,
  (s95.sales - s94.sales) / s95.sales
FROM (
  SELECT p.prodId, SUM(s.sales) AS sales
  FROM Sales AS s
    JOIN Suppliers AS u USING (suppId)
    JOIN Products AS p USING (prodId)
  WHERE u.name = ‘ACE’
  AND FLOOR(s.date TO MONTH) = ‘2023-01-01’
  GROUP BY p.prodId) AS s95
LEFT JOIN (
  SELECT p.prodId, SUM(s.sales) AS sales
  FROM Sales AS s
    JOIN Suppliers AS u USING (suppId)
    JOIN Products AS p USING (prodId)
  WHERE u.name = ‘ACE’
  AND FLOOR(s.date TO MONTH) = ‘2022-01-01’
  GROUP BY p.prodId) AS s94
USING (prodId)
```

MDX

```
WITH MEMBER [Measures].[Sales Last Year] =
    ([Measures].[Sales],
     ParallelPeriod([Date], 1, [Date].[Year]))
  MEMBER [Measures].[Sales Growth] =
    ([Measures].[Sales]
        - [Measures].[Sales Last Year])
      / [Measures].[Sales Last Year]
SELECT [Measures].[Sales Growth] ON COLUMNS,
  [Product].Members ON ROWS
FROM [Sales]
WHERE ([Supplier].[ACE], [Date].[1995].[Jan])
```

Query:

- For supplier “Ace” and for each product, give the fractional increase in the sales in January 2023 relative to the sales in January 2022.

SQL

```
SELECT p.prodId,
  s95.sales,
  (s95.sales - s94.sales) / s95.sales
FROM (
  SELECT p.prodId, SUM(s.sales) AS sales
  FROM Sales AS s
    JOIN Suppliers AS u USING (suppId)
    JOIN Products AS p USING (prodId)
  WHERE u.name = ‘ACE’
  AND FLOOR(s.date TO MONTH) = ‘2023-01-01’
  GROUP BY p.prodId) AS s95
LEFT JOIN (
  SELECT p.prodId, SUM(s.sales) AS sales
  FROM Sales AS s
    JOIN Suppliers AS u USING (suppId)
    JOIN Products AS p USING (prodId)
  WHERE u.name = ‘ACE’
  AND FLOOR(s.date TO MONTH) = ‘2022-01-01’
  GROUP BY p.prodId) AS s94
USING (prodId)
```

SQL with measures

```
SELECT p.prodId,
   SUM(s.sales) AS MEASURE sumSales,
   sumSales AT (SET FLOOR(s.date TO MONTH)
                = ‘2022-01-01’)
     AS MEASURE sumSalesLastYear
FROM Sales AS s
  JOIN Suppliers AS u USING (suppId)
  JOIN Products AS p USING (prodId))
WHERE u.name = ‘ACE’
AND FLOOR(s.date TO MONTH) = ‘2023-01-01’
GROUP BY p.prodId
```

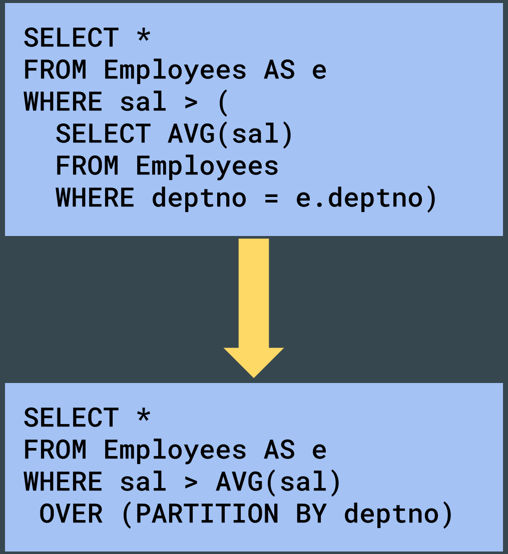
Self-joins, correlated subqueries, window aggregates, measures

Window aggregate functions were introduced to save on self-joins.

Some DBs rewrite scalar subqueries and self-joins to window aggregates [Zuzarte2003].

Window aggregates are more concise, easier to optimize, and often more efficient.

However, window aggregates can only see data that is from the same table, and is allowed by the `WHERE` clause. Measures overcome that limitation.



```
SELECT *
FROM Employees AS e
WHERE sal > (
  SELECT AVG(sal)
  FROM Employees
  WHERE deptno = e.deptno)
```

```
SELECT *
FROM Employees AS e
WHERE sal > AVG(sal)
 OVER (PARTITION BY deptno)
```

A measure is...

… a column with an aggregate function.

… a column that, when used as an expression, knows how to aggregate itself.

… a column that, when used as expression, can evaluate itself in any context.

Its value depends on, and only on, the predicate placed on its dimensions.

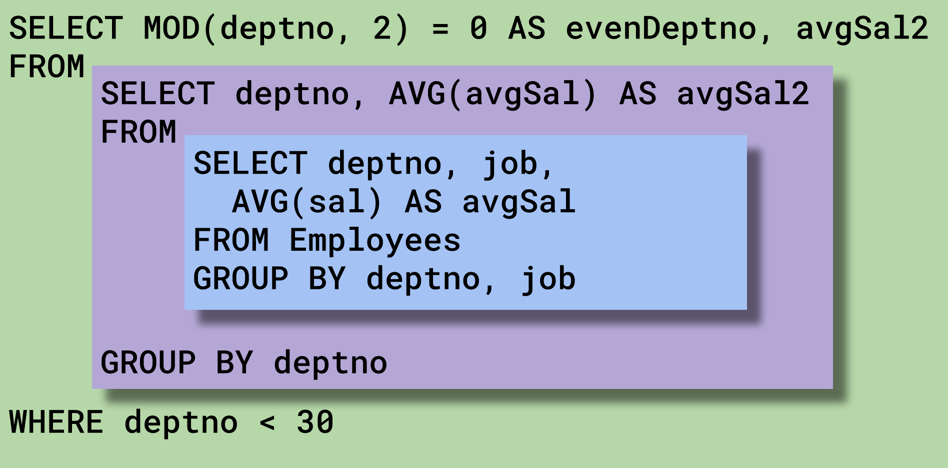
```
SUM(sales)

(SUM(sales) - SUM(cost))
   / SUM(sales)

(SELECT SUM(forecastSales)
  FROM SalesForecast AS s
  WHERE predicate(s))

ExchService$ClosingRate(
  ‘USD’, ‘EUR’, sales.date)
```

Table model

Tables are SQL's fundamental model.

The model is closed – queries consume and produce tables.

Tables are opaque – you can't deduce the type, structure or private data of a table.



```
SELECT MOD(deptno, 2) = 0 AS evenDeptno, avgSal2
FROM
     SELECT deptno, AVG(avgSal) AS avgSal2
     FROM
          SELECT deptno, job,
            AVG(sal) AS avgSal
          FROM Employees
          GROUP BY deptno, job

     GROUP BY deptno

WHERE deptno < 30
```

Table model with measures

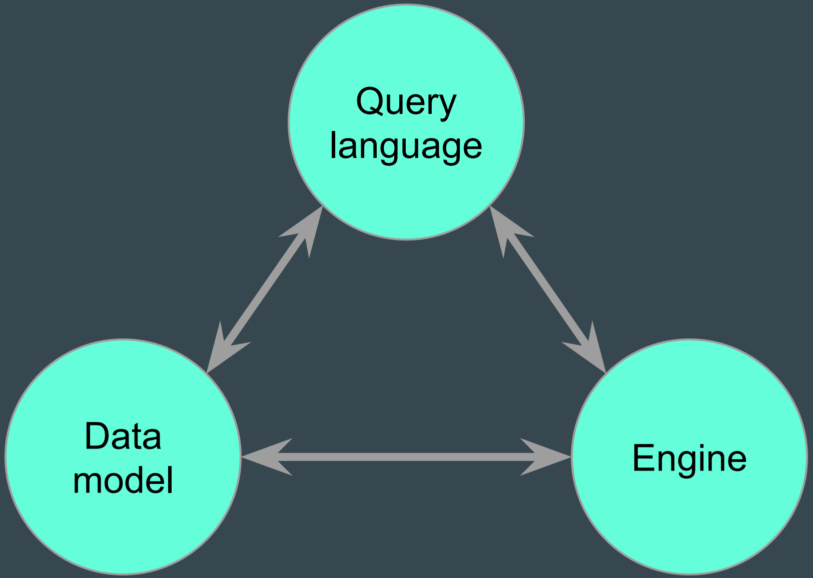
We propose to allow any table and query to have measure columns.

The model is closed – queries consume and produce tables-with-measures.

Tables-with-measures are semi-opaque – you can’t deduce the type, structure or private data, but you can evaluate the measure in any context that can be expressed as a predicate on the measure’s dimensions.

```
SELECT e.deptno, e.job, d.dname, e.avgSal / e.deptAvgSal
FROM SELECT *,
       avgSal AS MEASURE avgSal,
       avgSal AT (CLEAR deptno) AS MEASURE deptAvgSal
     FROM SELECT *,
            AVG(sal) AS MEASURE avgSal
          FROM Employees

  AS e
JOIN Departments AS d USING (deptno)
WHERE d.dname <> ‘MARKETING’
GROUP BY deptno, job
```

Model + Query + Engine = Data system



Syntax

expression `AS MEASURE` *name* – defines a measure in the `SELECT` clause

`AGGREGATE(`*measure*`)` – evaluates a measure in a `GROUP BY` query

expression `AT` (*contextModifier…*) – evaluates expression in a modified context

contextModifier ::=

  `CLEAR` *dimension* [, *dimension…*]

| `CLEAR ALL` [`EXCEPT` *dimension* [, *dimension…*]]

| `SET` *dimension* = [`CURRENT`] *expression*

| `VISIBLE`

| `ALL`

aggFunction(*aggFunction*(*expression*) `PER` *dimension*) – multi-level aggregation

Plan of attack

1. Add measures to the table model, and allow queries to use them
   - Measures are defined only via the Table API
2. Define measures using SQL expressions (`AS MEASURE`)
   - You can still define them using the Table API
3. Context-sensitive expressions (`AT`)

Semantics

0. We have a measure *M*, value type *V*, in a table *T*.

1. System defines a row type *R* with the non-measure columns.

2. System defines an auxiliary function for *M*. (Function is typically a scalar subquery that references the measure's underlying table.)

```
CREATE VIEW AnalyticEmployees AS
  SELECT *, AVG(sal) AS MEASURE avgSal
  FROM Employees
```

```
CREATE TYPE R AS
  ROW (deptno: INTEGER, job: VARCHAR)
```

```
CREATE FUNCTION computeAvgSal(
    rowPredicate: FUNCTION<R, BOOLEAN>) =
  (SELECT AVG(e.sal)
    FROM Employees AS e
    WHERE APPLY(rowPredicate, e))
```

Semantics (continued)

3. We have a query that uses *M*.

```
SELECT deptno,
  avgSal
   / avgSal AT (CLEAR deptno)
FROM AnalyticEmployees AS e
GROUP BY deptno
```

4. Substitute measure references with calls to the auxiliary function with the appropriate predicate

```
SELECT deptno,
  computeAvgSal(r → (r.deptno = e.deptno))
    / computeAvgSal(r → TRUE))
FROM AnalyticEmployees AS e
GROUP BY deptno
```

5. Planner inlines `computeAvgSal` and scalar subqueries

```
SELECT deptno, AVG(sal) / MIN(avgSal)
FROM (
  SELECT deptno, sal,
    AVG(sal) OVER () AS avgSal
  FROM Employees)
GROUP BY deptno
```

Calculating at the right grain

Example	Formula	Grain
Computing the revenue from units and unit price	units * pricePerUnit AS revenue	Row
Sum of revenue (additive)	SUM(revenue) AS MEASURE sumRevenue	Top
Profit margin (non-additive)	(SUM(revenue) - SUM(cost)) / SUM(revenue) AS MEASURE profitMargin	Top
Inventory (semi-additive)	SUM(LAST_VALUE(unitsInStock) PER inventoryDate) AS MEASURE sumInventory	Intermediate
Daily average (weighted average)	AVG(sumRevenue PER orderDate) AS MEASURE dailyAvgRevenue	Intermediate

Subtotals & visible

```
SELECT deptno, job,
  SUM(sal), sumSal
FROM (
  SELECT *,
    SUM(sal) AS MEASURE sumSal
  FROM Employees)
WHERE job <> ‘ANALYST’
GROUP BY ROLLUP(deptno, job)
ORDER BY 1,2
```

deptno	job	SUM(sal)	sumSal
10	CLERK	1,300	1,300
10	MANAGER	2,450	2,450
10	PRESIDENT	5,000	5,000
10		8,750	8,750
20	CLERK	1,900	1,900
20	MANAGER	2,975	2,975
20		4,875	10,875
30	CLERK	950	950
30	MANAGER	2,850	2,850
30	SALES	5,600	5,600
30		9,400	9,400
		20,750	29,025

Measures by default sum ALL rows;
Aggregate functions sum only VISIBLE rows

Visible

Expression	Example	Which rows?
Aggregate function	`SUM(sal)`	Visible only
Measure	`sumSal`	All
AGGREGATE applied to measure	`AGGREGATE(sumSal)`	Visible only
Measure with VISIBLE	`sumSal AT (VISIBLE)`	Visible only
Measure with ALL	`sumSal AT (ALL)`	All

Measures don’t require GROUP BY

Evaluating a measure on each row

```
SELECT deptno,
  avgSal
FROM AnalyticEmployees AS e
```

Evaluating a measure on a window of several rows

```
SELECT deptno,
  avgSal OVER (PARTITION BY job
               ORDER BY hiredate
               RANGE ‘1’ YEAR PRECEDING)
FROM AnalyticEmployees AS e
```

Semantic models versus databases

Shouldn't the semantic model be *outside* the database?

(I don't want to be tied to one DBMS vendor.)

I have a great semantic model already. Why do I need a query language? My users don't want to write SQL.

What even ***is*** a semantic model?

In my opinion, a semantic model...

- ... is the place to share data and calculations
- ... needs a really good query language
  - (So you don't have to change the model every time someone has a new question)
- ... doesn't become a database just because it speaks SQL
- ... should do other things too
  - (Access control, governance, presentation defaults, guide data exploration, transform data, tune data, ...)

Summary

Top-down evaluation makes queries concise

Measures make calculations reusable

Measures don’t break SQL

References

Papers

- [Agrawal1997] “Modeling multidimensional databases” (Agrawal, Gupta, and Sarawagi, 1997)
- [Zuzarte2003] “WinMagic: Subquery Elimination Using Window Aggregation” (Zuzarte, Pirahash, Ma, Cheng, Liu, and Wong, 2003)

Issues

- [CALCITE-4488] WITHIN DISTINCT clause for aggregate functions (experimental)
- [CALCITE-4496] Measure columns ("SELECT … AS MEASURE")
- [CALCITE-5105] Add MEASURE type and AGGREGATE aggregate function
- [CALCITE-5155] Custom time frames
- [CALCITE-xxxx] PER
- [CALCITE-xxxx] AT

Thank you!
Any questions?

@julianhyde
@ApacheCalcite
https://calcite.apache.org

Slides and recording will be posted at @julianhyde

Appendix

Abstract

If SQL is the universal language of data, why do we author our most important data applications (metrics, analytics, business intelligence) in languages other than SQL? Multidimensional databases and languages such as MDX, DAX and Tableau LOD solve these problems but introduce others: they require specialized knowledge, complicate the data pipeline and don't integrate well. Is it possible to define and query business intelligence models in SQL?

Apache Calcite has extended SQL to support metrics (which we call 'measures'), filter context, and analytic expressions. With these concepts you can define data models (which we call Analytic Views) that contain metrics, use them in queries, and define new metrics in queries.

In this talk by the original developer of Apache Calcite, we describe the SQL syntax extensions for metrics, and how to use them for cross-dimensional calculations such as period-over-period, percent-of-total, non-additive and semi-additive measures. We describe how we got around fundamental limitations in SQL semantics, and approaches for optimizing queries that use metrics.

ABOUT THE SPEAKER

Julian Hyde is the original developer of Apache Calcite, an open source framework for building data management systems, and Morel, a functional query language. Previously he created Mondrian, an analytics engine, and SQLstream, an engine for continuous queries. He is a staff engineer at Google, where he works on Looker and BigQuery.

Some multidimensional queries

- Give the total sales for each product in each quarter of 1995. (Note that quarter is a function of date).
- For supplier “Ace” and for each product, give the fractional increase in the sales in January 1995 relative to the sales in January 1994.
- For each product give its market share in its category today minus its market share in its category in October 1994.
- Select top 5 suppliers for each product category for last year, based on total sales.
- For each product category, select total sales this month of the product that had highest sales in that category last month.
- Select suppliers that currently sell the highest selling product of last month.
- Select suppliers for which the total sale of every product increased in each of last 5 years.
- Select suppliers for which the total sale of every product category increased in each of last 5 years.

From [Agrawal1997]. Assumes a database with dimensions {supplier, date, product} and measure {sales}.)