Piet: a GIS-OLAP Implementation

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Outline

- GIS-OLAP motivation
- Query Language
- Data Model
- Implementation Details
- Experimental Results
- Conclusion
GIS Systems

1. Organize geometric objects in thematic layers
2. Spatial objects can be annotated with numerical and categorical information
3. Two kinds of queries: pure geometric queries and geometric aggregation queries.
4. Queries use some indexing technique like R-tree or its variation
GIS Systems

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GIS Systems

Example: Map of Belgium organized in 5 layers with demographic and economic information
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- regions (polygons)
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- regions (polygons)
- provinces (polygons)
GIS Systems

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- regions (polygons)
- provinces (polygons)
- districts (polygons)
GIS Systems

Example: Map of Belgium organized in 5 layers with demographic and economic information

- regions (polygons)
- provinces (polygons)
- districts (polygons)
- cities (points)
GIS Systems

**Example:** Map of Belgium organized in 5 layers with demographic and economic information

- regions (polygons)
- provinces (polygons)
- districts (polygons)
- cities (points)
- rivers (polylines)
**GIS Systems**

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GIS Systems - Queries

Pure Geometric Queries

“Districts and their cities, only for districts crossed by rivers”
GIS Systems - Queries

Geometric Aggregation Queries

“For each district crossed by at least one river, show the total number of its cities”
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2. Spatial objects can be annotated with numerical and categorical information
3. Two kinds of queries: pure geometric queries and geometric aggregation queries.
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1. We assume that non-spatial information resides in data warehouses.
2. Data perceived as a cube, where the dimensions provide contextual information and the cells contain measures of facts.
3. OLAP tools used to exploit multidimensional databases.
OLAP & Multidimensional Databases

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OLAP & Multidimensional Databases

1. We assume that non-spatial information resides in **data warehouses**.

2. *Data perceived as a cube, where the dimensions provide contextual information and the cells contain **measures** of facts.*

3. OLAP tools used to exploit **multidimensional databases**.
1. We assume that non-spatial information resides in data warehouses.
2. Data perceived as a cube, where the dimensions provide contextual information and the cells contain measures of facts.
3. OLAP tools used to exploit multidimensional databases.
OLAP & Multidimensional Databases

Example: Information about stores and sales in Belgium

OLAP Queries

“Unit Sales, Store Cost and Store Sales for products and promotion media offered by stores in provinces, during 1997”
Motivation for GIS-OLAP

• Data aggregation marginally present in commercial GIS

• Light integration between spatial and non-spatial data

• A single framework for GIS and OLAP is needed.

• This requires a formal data model and query language
GIS-OLAP: Our Proposal

- Based on a solid formal model (see “Spatial aggregation: Data model and implementation” [Gomez, Haesevoets, Kuijpers, and Vaisman]).

- Allows expressing a wide range of aggregation queries over a GIS map and a data warehouse.

- Implements a novel query evaluation technique, called “sub-polygonization” that go beyond the typical R-tree-based strategies

**Classical Solution:**

*For Geometric Queries* => database spatial extenders, such as R-trees

*For Geometric Aggregation Queries* => techniques not implemented in commercial DBMS like aR-trees
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Query Language

Pure Geometric Queries *(SQL Approach)*

“*Districts and their cities, only for districts crossed by rivers*”
Query Language

Pure Geometric Queries (SQL Approach)

“Districts and their cities, only for districts crossed by rivers”

SELECT layer.bel_dist, layer.bel_city;
FROM PietSchema;
WHERE intersection(layer.bel_river,layer.bel_dist) AND
   contains(layer.bel_dist,layer.bel_cities)
Query Language

Geometric Aggregation Queries (SQL Approach)

“For each district crossed by at least one river, show the total number of its cities”
Query Language

Geometric Aggregation Queries (SQL Approach)

“For each district crossed by at least one river, show the total number of its cities”

SELECT layer.bel_dist, measure.CitiesQuantity;
FROM PietSchema;
WHERE intersection(layer.bel_river,layer.bel_dist) AND
  contains(layer.bel_dist,layer.bel_city)
**Query Language**

**OLAP Queries (MDX)**

“Browse Unit Sales, Store Cost and Store Sales for products and promotion media offered by stores in provinces, during 1997”

```
SELECT
{{[Measures].[Unit Sales], [Measures].[Store Cost], [Measures].[Store Sales]} ON columns,
{{([Promotion Media].[All Media], [Product].[All Products])} ON rows
FROM [Sales]
WHERE [Time].[1997]
```
Query Language

GIS-OLAP Queries *(SQL Approach + MDX)*

“Browse Unit Sales, Store Cost and Store Sales for products and promotion media offered by stores in provinces crossed by rivers, during 1997”

SQL Approach

| MDX

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Query Language

GIS-OLAP Queries *(SQL Approach + MDX)*

SELECT layer.bel_prov;
FROM PietSchema;
WHERE intersection(layer.bel_river,layer.bel_prov);

| SELECT
| SELECT
{{[Measures].[Unit Sales], [Measures].[Store Cost], [Measures].[Store Sales]} ON columns,
{{[Promotion Media].[All Media], [Product].[All Products]}} ON rows
FROM [Sales]
WHERE [Time].[1997]
The first part is a “geometric query”. Once solved, the province IDs are passed to the MDX part.
Query Language

```
SELECT
{[Measures].[Unit Sales], [Measures].[Store Cost], [Measures].[Store Sales]} ON columns,
Crossjoin(Hierarchize(Union(Union(
{[Store].[All Stores].[BEL].[ANT].Children},
{[Store].[All Stores].[BEL].[LIE].Children}),
{[Store].[All Stores].[BEL].[LUX].Children})),
{([Promotion Media].[All Media], [Product].[All Products])} ON rows
FROM [Sales]
WHERE [Time].[1997]
```

Suppose that these province IDs correspond to “ANT”, “LIE” and “LUX” then the MDX is rewritten as:

```
SELECT
{[Measures].[Unit Sales], [Measures].[Store Cost], [Measures].[Store Sales]} ON columns,
Crossjoin(Hierarchize(Union(Union(
{[Store].[All Stores].[BEL].[ANT].Children},
{[Store].[All Stores].[BEL].[LIE].Children}),
{[Store].[All Stores].[BEL].[LUX].Children})),
{([Promotion Media].[All Media], [Product].[All Products])} ON rows
FROM [Sales]
WHERE [Time].[1997]
```
PIET Test Query uses GIS data and Mondrian OLAP (MDX)

<table>
<thead>
<tr>
<th>Store</th>
<th>Promotion Media</th>
<th>Product</th>
<th>Measures</th>
<th>Unit Sales</th>
<th>Store Cost</th>
<th>Store Sales</th>
</tr>
</thead>
<tbody>
<tr>
<td>Store 2</td>
<td>-All Media</td>
<td>All Products</td>
<td></td>
<td>67,659</td>
<td>56,772.50</td>
<td>142,277.07</td>
</tr>
<tr>
<td>Store 11</td>
<td>-All Media</td>
<td>All Products</td>
<td></td>
<td>26,079</td>
<td>21,948.94</td>
<td>55,058.79</td>
</tr>
<tr>
<td></td>
<td>Bulk Mail</td>
<td>All Products</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cash Register Handout</td>
<td>All Products</td>
<td></td>
<td>1,625</td>
<td>1,476.69</td>
<td>3,699.69</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Drink</td>
<td>173</td>
<td>140.16</td>
<td>351.29</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Food</td>
<td>1,184</td>
<td>1,031.82</td>
<td>2,572.49</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Non-Consumable</td>
<td>328</td>
<td>304.71</td>
<td>775.91</td>
</tr>
<tr>
<td>Daily Paper</td>
<td>All Products</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daily Paper, Radio</td>
<td>All Products</td>
<td></td>
<td></td>
<td>1,446</td>
<td>1,225.38</td>
<td>3,058.22</td>
</tr>
<tr>
<td>Daily Paper, Radio, TV</td>
<td>All Products</td>
<td></td>
<td></td>
<td>400</td>
<td>340.58</td>
<td>828.67</td>
</tr>
<tr>
<td>In-Store Coupon</td>
<td>All Products</td>
<td></td>
<td></td>
<td>385</td>
<td>342.59</td>
<td>852.65</td>
</tr>
<tr>
<td>No Media</td>
<td>All Products</td>
<td></td>
<td></td>
<td>17,709</td>
<td>14,858.85</td>
<td>37,212.87</td>
</tr>
<tr>
<td>Product Attachment</td>
<td>All Products</td>
<td></td>
<td></td>
<td>2,150</td>
<td>1,779.88</td>
<td>4,914.04</td>
</tr>
<tr>
<td>Radio</td>
<td>All Products</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Street Handout</td>
<td>All Products</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sunday Paper</td>
<td>All Products</td>
<td></td>
<td></td>
<td>417</td>
<td>357.56</td>
<td>892.44</td>
</tr>
<tr>
<td>Sunday Paper, Radio</td>
<td>All Products</td>
<td></td>
<td></td>
<td>1,011</td>
<td>841.73</td>
<td>2,130.39</td>
</tr>
</tbody>
</table>

DOLAP 2007
Outline

• GIS-OLAP motivation

• Query Language

• *Data Model*

• Implementation Details

• Experimental Results

• Conclusion
A **GIS dimension** is a set of graphs, each one describing a set of geometries in a thematic layer. The dimension is composed of schema and instances.

The **GIS dimension schema** has three parts.
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The **GIS dimension schema** has three parts:

The algebraic part contains the infinite points in a layer and could be described by means of linear algebraic equalities and inequalities.
Data Model Overview

A **GIS dimension** is a set of graphs, each one describing a set of geometries in a thematic layer. The dimension is composed of schema and instances.

The **GIS dimension schema** has three parts:

- The geometric part stores the finite identifiers of certain geometries (elements of the layers in the GIS).
Data Model Overview

A GIS dimension is a set of graphs, each one describing a set of geometries in a thematic layer. The dimension is composed of schema and instances.

The GIS dimension schema has three parts

The OLAP part stores non-spatial data
At the **GIS dimension instance** we have **rollup relations** between geometries and **association functions**.
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Data Model Overview

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At the GIS dimension instance we have rollup relations between geometries and association functions.
Data Model Overview

Piet processing technique

1) The *sub-polygonization strategy*

Decomposes each thematic GIS layer into sub-geometries (open convex polygons, open line segments and points) using the concept of carrier lines.
Data Model Overview

Example
Data Model Overview
Data Model Overview

Piet processing technique

1) The *sub-polygonization strategy*

Decomposes each thematic GIS layer into sub-geometries (open convex polygons, open line segments and points) using the concept of carrier lines.

2) *Preoverlay of layers*

All geometries in common are pre-computed and stored in the database.

3) *Evaluate queries using the pre-computed geometries in common*

These shared geometries between layers are used to solve queries.
Data Model Overview

Summable Queries

If we have an aggregate function uniformly distributed over the space, we can easily compute its total value by adding the partial values of the sub-geometries involved.

For example, to calculate the total population of cities crossed by the ‘Lis’ river we can use the following formula

\[ \sum_{g_{id} \in Region} \text{population}(g_{id}) \]

where the set Region contains the identifiers of the geometries that verify the condition.

In the case the Region contains the IDs of geometries of cities crossed by ‘Lis’ river. Formally

\[ Region = \{ g_{id} | (\exists x)(\exists y)(\exists pol_{river}\rightarrow pol_{line})(x, y, pol) \land \]
\[ (\exists pol_{city}\rightarrow node)(x, y, g_{id}) \land pol_{river}\rightarrow pol_{line}(\text{‘Lis’})=pol \} \]
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**Implementation Details**

- PostgreSQL 8.2.3 database with Postgis 1.2 spatial extensions
- Java 1.5
- OLAP Mondrian (MDX query language)
- Xerces
- Castor
- Tomcat Apache 5.5 WebServer (for Web version)
- Jump 1.2 (for stand-alone version)
Implementation Details

Scalability

Real-world maps present irregularities: holes, bays, gulfs
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Scalability

Real-world maps present irregularities: holes, bays, gulfs

The number of carrier lines induced would become huge, and their interaction become unnecessary as they produce irrelevant partitions and increase the computational cost of algorithms
Implementation Details

Partitioning
Benefits of Partitioning

1) Reduce the density of carrier lines, and database volume.
2) Partitions that contain no geometries, would not have carrier lines, therefore they do not produce unnecessary storage.
3) The algorithm can easily run in a parallelized environment.
4) Only zones with high density of carrier lines can be further divided into smaller partitions, instead of dividing the entire map in more zones.
5) If some zone changes over time, it can be re-computed without affecting the calculated previous zones.
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Experimental Results

Q1: Districts crossed by at least one river

Q2: Districts and the cities within them

Q3: Districts and the cities within them only for districts crossed by at least one river

Q4: Districts crossed by at least five rivers
Experimental Results

Q5: List each region with the total number of rivers that crossed it

Q6: List each region with the total number of rivers that crossed it, only for regions that contains at least 20 cities

Q7: List each district with the total number of rivers that crossed it and the total number of cities that contains

Q8: For each region show the total length of the part of rivers which intersects it, only for regions with at least an area under cereal cultivation equal or higher than 1000 Km2.
Experimental Results

Q9: List each region with the total number of rivers that crossed it, considering only the part of the river that lies within the query region.

Q10: For each district show the total number of cities, for cities within the query region.

Q11: For each region show the total length of the part of each river which intersects it, only for regions containing at least area under cereal cultivation equal or higher than 1000 Km2, considering only the part of the river that lies within the query region.
Experimental Results

Geometric Aggregation Queries with Query Region 1

Geometric Aggregation Queries with Query Region 2
Outline

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Conclusion

1) The data model provides a unified view of GIS and OLAP data

2) This data model can be efficiently implemented

3) The GIS-OLAP Query Language introduced is simple and uses well-known sub-query syntax.

4) Our experiments show that summable queries can be solved without using special indexing techniques.

   We can implement all these features, without waiting for extenders to be incorporated in databases. Using tables and B-trees we can reach very good performance

5) Visit our site  [http://piet.exp.dc.uba.ar/piet](http://piet.exp.dc.uba.ar/piet)
Not only integrating OLAP and GIS, but also spatio-temporal data, in the form of trajectories of moving objects.

We are developing specific techniques to reduce the huge volume of the data obtained by sensors without losing relevant information (‘Aggregation Languages for Moving Object and Places of Interest Data’ [Leticia Gomez, Haesevoets, Bart Kuijpers, and Alejandro Vaisman]).