# Chapter VII
# Spatial Data in Multidimensional Conceptual Models

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## INTRODUCTION

Data warehouses (DWs) are used for storing and analyzing high volumes of historical data. The structure of DWs is usually represented as a star schema consisting of fact and dimension tables. A fact table contains numeric data called measures (e.g., quantity). Dimensions are used for exploring measures from different analysis perspectives (e.g., according to products). They usually contain hierarchies required for online analysis processing (OLAP) systems in order to dynamically manipulate DW data. While traversing hierarchy, two operations can be executed: the roll-up operation, which transforms detailed measures into aggregated data (e.g., daily into monthly sales); and the drill-down operation, which does the opposite.

Current DWs typically include a location dimension (e.g., store or client address). This dimension is usually represented in an alphanumeric format. However, the advantages of using spatial data in the analysis process are well known, since visualizing data in space allows users to reveal patterns that are otherwise difficult to discover. Therefore, spatial databases (SDBs) can give in-

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sights about how to represent and manage spatial data in DWs.

SDBs provide mechanisms for storing and manipulating spatial objects. These databases typically are used for daily business operations (e.g., to indicate how to get to a specific place from the current position given by a GPS). SDBs are not well suited for supporting the decision-making process (Bédard, Rivest & Proulx, 2007) (e.g., to find the best location for a new store). This is how the field of spatial data warehouses (SDWs) emerged.

SDWs combine SDB and DW technologies for managing significant amounts of historical data that include spatial location. To better represent users' requirements for SDW applications, a conceptual model should be used. The advantages of using conceptual models are well known in database design. Nevertheless, the lack of a conceptual approach for DW and OLAP system modeling in addition to the absence of a commonly accepted conceptual model for spatial applications make the modeling task difficult. Existing conceptual models for SDBs are not adequate for DWs since they do not include the concepts of dimensions, hierarchies, and measures. Therefore, there is a need for extending multidimensional models by including spatial data to help users have a better understanding of the data to be analyzed.

## BACKGROUND

To the best of our knowledge, very few proposals address the issue of conceptual modeling for SDWs (Ahmed & Miquel, 2005; Bimonte, Tchounikine & Miquel, 2005; Jensen, Klygis, Pedersen & Timko, 2004; Pestana, Mira da Silva & Bédard, 2005). Some of these models include the concepts presented in Malinowski and Zimányi (2004), as explained in the next section; other models extend nonspatial multidimensional models with different aspects such as imprecision in location-based data (Jensen et al., 2004) or continuous phenomena (e.g., temperature or elevation) (Ahmed & Miquel, 2005).

Other models for SDWs use the logical relational representation based on the star/snowflake schemas. These proposals introduce concepts of spatial dimensions and spatial measures (Fidalgo, Times, Silva & Souza, 2004; Rivest, Bédard & Marchand, 2001; Stefanovic, Han & Koperski, 2000); however, they impose some restrictions on the model, as discussed in the next section.

We consider that a conceptual multidimensional model with spatial support should not only include dimensions, hierarchies, and measures, but should also refer to various aspects that are not present in conventional multidimensional models related to particularities of spatial objects.

Spatial objects correspond to real-world entities for which the application needs to keep their spatial characteristics. Spatial objects consist of a thematic (or descriptive) component and a spatial component. The thematic component describes general characteristics of spatial objects (e.g., name) and is represented using traditional DBMS data types (e.g., integer, string, date). The spatial component includes its geometry that can be of type point, line, surface, or a collection of them.

Spatial objects can relate to each other forming topological relationships. Various topological relationships have been defined (Egenhofer, 1993). They allow determining, for example, whether a store is located within city limits or whether bus and tramway lines intersect in some location.

Pictograms are typically used for representing spatial objects and topological relationships in conceptual models, such as the ones shown in Figure 1 (Parent, Spaccapietra & Zimányi, 2006).

Even though the experience gained in SDBs can be useful for SDWs, the inclusion of spatial objects in a multidimensional model requires additional analysis with respect to topological relationships existing between various elements of the multidimensional model or aggregations of spatial measures, among others. While some of

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