

Geovisualization of Retail Structural Change in Canada

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Introduction

Geovisualization research has gained considerable momentum over recent years within the fields of GIS, cartography and spatial statistics. The aim of geovisualisation is to turn large heterogeneous data into information (interpreted data) and subsequently, into knowledge (understanding derived from information). As MacEachren and Kraak (2001: 3) define, "*geovisualisation* integrates approaches from visualization in scientific computing, cartography, image analysis, information visualization, exploratory data analysis and geographic information systems to provide theory, methods and tools for visual exploration, analysis, synthesis and presentation of geospatial data". Figure 1 provides a conceptual framework for geovisualization system use, defined along three axes: (i) the nature of the tasks performed – from knowledge construction to the sharing and dissemination of information; (ii) the type of users – ranging from domain experts to the general public; and, (iii) the level of interaction with the data – referring to the extent to which the user will have control over the system and the underlying geospatial data (i.e., open source versus black-box). The four primary functions of geovisualization can be placed along the central diagonal of the geovisualization use space: explore, analyze, synthesis and present (MacEachren et al 2003; MacEachren 1994). A defining element of geovisualization is the role and emphasis placed on human cognitive visual processing. Geovisualization techniques are geared to exploit visual-cognitive abilities: such as, pattern recognition, ordering, and

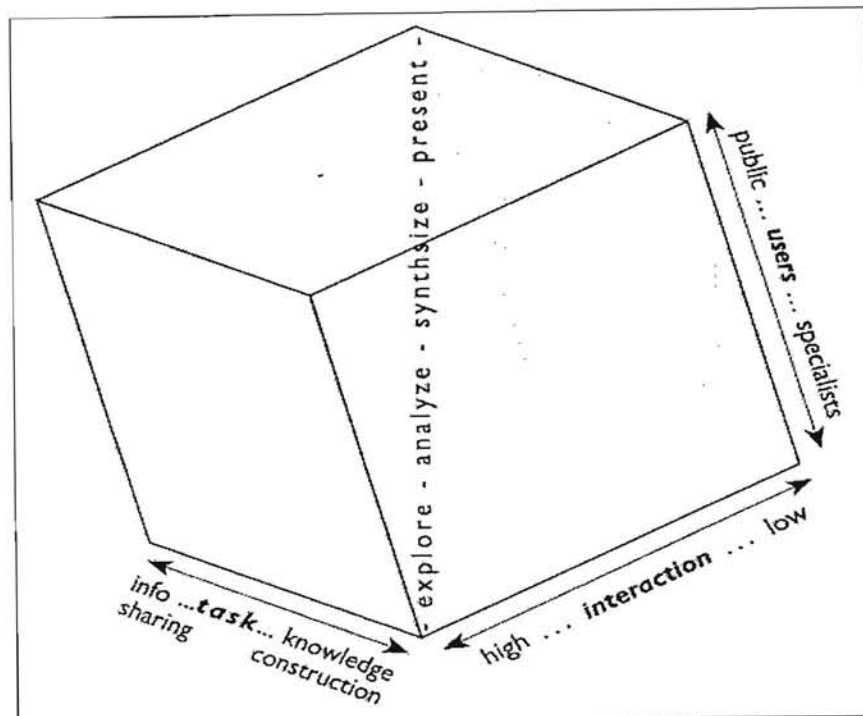


FIGURE 1 Functions of Geovisualization
Source: MacEachren et al 2003

interpretation of visual cues. Based on the contentious premise that humans learn more effectively and efficiently within a visual as opposed to textual or numerical setting (Tuft 1997, 1990; Lloyd 1997; Bertin 1981), geovisualization aims to transform decision support from static uni- or bi-dimensional space into a highly dynamic and visual environment that facilitates interactive exploration of multi-dimensional space.

The traditional focus of visualization research has been within the hard sciences, in fields such as biotechnology, engineering and medical science. Interest amongst geographers and cartographers in visualization since the 1980s has resulted in the emergence of the *geovisualization* field of research (Brown et al 1995; Hearnshaw and Unwin 1994). This has provided opportunities for businesses to build on parallel developments in the areas of GIS, data warehousing, data mining and business intelligence, in providing techniques and technologies to unlock through *visual* means previously hidden spatial-temporal dimensions of their data sets. The increasing availability of time-series data within the retail industry coupled with the addition of temporal and spatial elements within data structures has allowed retail analysts and decision makers to move away from simply generating *static* snap-shots to undertaking *dynamic* temporal analysis and visualization of change (e.g., animation of spatially related data over a number of

time periods). The application of geovisualization within business geomatics¹ are many and varied, ranging from visualizing retail sales performance metrics (e.g., sales per square foot, market share and penetration) to monitoring changes in commercial structure over time (e.g., the changing ethnic composition of retail businesses in a given urban market).

The paper is divided into four sections. First, the paper provides the research context by focusing on the tradition of retail location decision support, geovisualization is placed within the context of the widespread use and evolution of GIS within the retail industry. The second section details the development of a prototype geovisualization system that has been designed to enable visualization of spatial-temporal change of retail-related data. The third section presents a number of examples of potential analysis, examined at four different scales of analysis: national, regional, market and micro-level. The final section highlights both the challenges and potential to enhancing retail decision support by integrating geovisualization techniques and technology within existing decision support activities.

Tradition of Retail Location Decision Support

GIS are used by the vast majority of major retail chains across North America and Europe to provide decision support for a range of location-based decisions (see Hernandez and Biasiotto 2001). The widespread adoption of GIS within retail is hardly surprising given the spatial nature of the retail business. Retail demand (customers) and supply (stores), and the interaction between them, is spatially constrained (i.e., the existence of distance decay). Retail organizations typically have access to substantial reserves of spatially-related data, with such data ranging from demographic variables, store sales data, customer transaction and loyalty data to competitor store data and land-use planning data (Byrom et al 2001; Hernandez 1995). The most common retail GIS applications include customer spotting, trade area analysis (e.g., demographic reporting for given trade areas), customer profiling, competitor analysis, hot-spotting, sales forecasting and consumer behaviour modeling. These can be applied to a number of decision events, from relatively low-risk store openings, renovations and merchandising decisions to major high-risk decisions, such as, corporate acquisition of competing chains or international expansion through merger activities (Hernandez and Biasiotto 2002). The vast majority of these decisions are supported by relatively rudimentary GIS-based inventory mapping and analysis, with a smaller number of retailers pursuing more sophisticated and complex modeling applications (Hernandez and Biasiotto 2001). The prevailing decision style of retail organizations has been characterized by

1. Geomatics defined as "...the science and technology of gathering, analyzing, interpreting, distributing and using geographic information. Geomatics encompasses a broad range of disciplines that can be brought together to create a detailed but understandable picture of the [human] and physical world and our place in it" (Geomatics Canada 2004).

Clarke (1995) as knee-jerk and cavalier, a mix of both 'art' and 'science' (Hernandez and Bennison 2000). Typically, retail location decisions have been supported by a range of static maps, for example, a trade area demographic map and associated data, such as existing store sales and the number of competitors within the trade area. The decision stakeholders (e.g., members of the capital investment board, CEO, CFO) are presented with static views of the retail landscape. Change in markets conditions, such as sales trends, the entry and growth of new competitors, or change in customer demand profiles in a given market have been represented as snap-shots in time (e.g., separate maps for each year) or relative changes (e.g., percentage change between time periods). To date, managing, analyzing and visualizing the most fundamental element of retail – change over time and space – has been extremely difficult within a conventional GIS framework (Andrienko et al 2003). The lack of such decision support capability (temporal, spatial and visual) presents a significant hurdle, and conversely, source of potential competitive advantage, to retail organizations in developing understanding and creating organizational knowledge of the environment in which they operate.

Geovisualization Prototype Development

This section provides a brief overview of the development of the geovisualization system prototype – the 4D Geovisualizer. The section is divided into two parts. First, the combined use of 3D mapping and spatial-temporal animation techniques is outlined (4D mapping), illustrating the type of decision support functionality that can be provided by geovisualization systems. Second, the development environment and system design is detailed. The purpose has not been to create new decision support software *per se*, but instead to develop a geovisualization system prototype as a vehicle for testing the geovisualization approach to retail decision support.

Geovisualization Techniques: 3D Mapping and Spatial-Temporal Animation

The majority of maps used by retail organization show data depicted from an abstract 2D plan view, such as a choropleth map that is viewed from directly overhead and represents data values through colour or shading. Vision has been the primary means of acquiring spatial knowledge (Slocum and Egbert 1993). Three-dimensional mapping allows the user to effectively visualize data values by scaling the Z axis of each object to highlight intensity and variation in data. (e.g., polygon objects representing customer spend for a given postal geography or point objects representing store location and sales volume). There have been a number of studies that have focused on the utilization and potential for 3D mapping (Haberling 1999; Ledbetter 1999; Kraak 1994). In order to convert 2D maps into 3D maps a number of geometric objects need to be created. As is common practice in computer graphics programming, 2D polygons need to be triangulated, with each polygon divided into the minimum set of triangles that define the area – to

create a base triangulated map layer. O'Rourke (2001) provides an excellent primer to polygon triangulation algorithms. It should be noted that the creation of 3D objects creates significant computational overheads, specifically, processing and graphics memory loads – in part explaining why geovisualization has traditionally taken place on high-end scientific workstations. For most geovisualization applications it is appropriate to generalize the polygons, i.e., simplify the geometric shapes, prior to translating the files into 3D objects. Numerous algorithms are available, and a number of these are available within standard GIS packages. The challenge with generalization is in minimizing geometric complexity, whilst maintaining the integrity of the geographical shape and the topology of the entire dataset. An approach that has worked effectively is to use a detailed geometric shape file as a cosmetic map layer and generalize the file that will be used to create the 3D objects. In this way, the user is able to view the detail of original boundaries as a background map with the simplified 3D objects placed above.

By animating the display across user-defined independent variables, users can easily observe trends in extremely complex data sets. With the addition of temporal-animation, the user has the ability to discover trends, patterns, and anomalies in spatial data. The term dynamic representation refers to displays that change continuously, either with or without user control. Dynamic data representation has changed the way users obtain and interact with information across the full range of display technologies (Andrienko and Andrienko 1999; DiBiase et al 1992). One form of dynamic representation is the animated map (see for example, Bishop et al 1999; Koussoulakou and Styliandis 1999). An argument for utilizing animation is that it is natural for depicting temporal data (Dorling 1992; Acevedo and Masuoka 1997; Blok et al 1999; Morrison et al 2000). This is because changes in real world time can be reflected by changes in display time. In addition to enabling animated maps, dynamic representations also permit users to explore geospatial data by interacting with mapped displays, a process sometimes referred to as direct manipulation (Slocum 1999).

However, in order to create smooth animation, it is often necessary to interpolate a number of virtual values between actual values. For example, a user wants to display a map of store sales for 30 outlets, covering 10 years of annual sales data. If the user created an annual sequence of this data, there would be 10 time snapshots. It is likely that such a sequence would not appear particularly smooth, i.e., the data would change abruptly 10 times, an alternative approach is to create an additional sequence of interim virtual snapshots between each actual time snapshot – e.g., creating 9 additional sequences (linear smoothing) between each time period that would result in the map window updating 100 times. The ability to produce animations of data sequences and produce digital movie files is particularly important in terms of the sharing of information between different departments or individuals within a given company. For example, an analyst may produce an animated data movie showing the growth of their store network and the changing level of customer penetration measured on a monthly basis over a three year time frame for use within a capital investment board meeting.

Dynamic legends are often used with animated maps (Buziek 2000; Peterson 1999; Kraak et al 1997). In the case of the static map, one only requires a

single legend for the single array of data values. When visualizing a series of time periods, multiple arrays of data values are being displayed; therefore a legend with a minimum and maximum value for time period t_1 may not cover the range of data in time period t_2 to t_n . There are two approaches that can be adopted to address this problem. First, the legend is updated for every new time period (dynamic) – this can be very difficult for the end-user to interpret as the objects on the map are changing shape and color while the legend is also changing, which clearly creates difficulties for the user (particularly if the data are only displayed for a short period of time). Simply, the user has little time to make sense of the map. The second approach is to take the minimum and maximum values of the data values across all of the data arrays, and keep the legend static (fixed). In this case, if the data range is large, or there is sporadic or dramatic change in the data values, the fixed legend may not provide useful information across a number of the time periods. An issue with displaying a number of variables simultaneously is that the user requires a legend or some other means of assessing the range and intensity of the values being displayed, e.g., simultaneously displaying four variables require four associated legends – this again can become overwhelming for the user (MacEachren 1995). Studies to date on merits of 3D mapping and temporal-animation vary significantly, some advocate such techniques, while others highlight their limitations (see for example, Morrison et al 2000; Slocum et al 2001, 2000, 1990; Robertson et al 1999; Openshaw et al 1993).

Geovisualization Development Environment

The 4D Geovisualizer system outlined in this paper has been developed within the Iris Explorer Visualization programming environment. The visualization tasks are conceptualized as a series of objects, and these objects communicate with one another via information flows, with pipelines between the objects being able to accommodate a range of data and parameter types (Figure 2), e.g. objects to read in spatial data, to create 3D symbols, to create animations of data. The final flow of data is typically into a render object or some form of data output through which a variety of information can be displayed (including maps, tables, graphs and multi-media files). The benefit of modular design is in the ability to be able to modify existing modules in order to create customized packaged applications, e.g. providing retail analyst users with access to the entire set of modules, and restricting retail executives to a small subset of 'black-box' widget and display modules. An overview of the modules integrated within the 4D Geovisualizer system are provided in Table 1.

TABLE 1 4D GeoVisualizer – Core Functions

MODULE	PRIMARY FUNCTION
<i>GEOREADER</i>	This module reads in data from a number of GIS formats and converts these into the spatial-temporal data structures used within the 4D Geovisualizer package. Underlying this module is a series of data translators that unpack GIS data and restructure the spatial, temporal and data attributes dimensions into a customized data format for use in Iris Explorer.
<i>GGEOWORKBENCH</i>	The workbench is the primary user interface that provides menus, widgets and associated controls for the user to select variable, time periods, the type of legend, temporal interpolation, dynamic or fixed legends. The module includes simple video-recorder style features to allow the user to choose the variables to display, navigate the temporal dimensions of the data set, and to run and record animations.
<i>GGEPOINTS</i>	This module provides tools for the user to select the way in which point data will be represented. For example, the user can choose to represent point data of store sales with 3D proportional spheres or cubes.
<i>GGEOPOLYGONS</i>	The geopolygons module provides 3D choropleth mapping capabilities, allowing the user to translate 2D polygon data into 3D shapes. A number of generalizations routines are currently being integrated within the module to allow the user to alter the level of geometric complexity of the polygons (i.e., simplifying the shape of boundaries to reduce graphic processing)
<i>GGEOBARS</i>	The geobars module allows the user to create a 3D spatial bar graph, with the bars located at actual locations in space (as opposed to arbitrarily on a given axis). The module allows the user to use different variables to represent the height, width (radius), color, geometric complexity and opacity of the 3D bar. A number of different 3D shapes allow the user to, for example, show one set of stores with 3D cylinders, and competitor stores using 3D pyramids.
<i>GGEOSURFACES</i>	This module (currently under development) will allow the user to view data represented as surfaces. For example, allowing the user to visualize probabilistic trade areas for a number of stores or retail sales surfaces across a given market area.
<i>GGEOMAP</i>	The geomap module provides the user with very basic GIS layering functionality this allows the user to add cosmetic layers, e.g., roads, rivers, towns, administrative boundaries. The user can label these layers and offset layers on the x,y z-axis, i.e. to manipulate the ordering the layers.
<i>GGEOQUERY</i>	This module provides the user with information on objects that have been selected in the geoview window. At present this module provides simple inventory-type information and basic statistical summary information, a geostats module is being developed to provide the user with the ability to create multi-linked windows with scatterplots, histograms, etc.
<i>GGEVIEW</i>	The data is rendered (displayed) within the geoview module. A number of standard GIS display functions allow the user to zoom-in and -out, pan across the display, select objects, change the rotation axis, fly-to given locations, change the lighting of objects, etc.

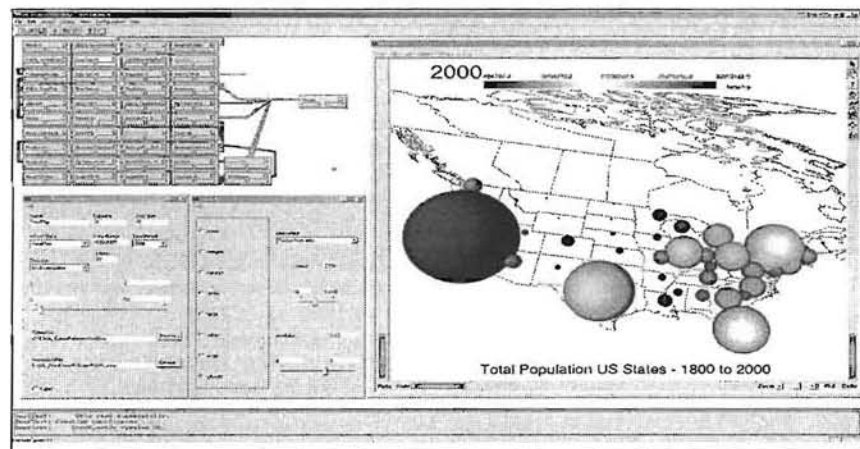


FIGURE 2 Geovisualization Development Environment

Note: Top-left - linked modules that feed into the final render window. Bottom-left - example of two widgets that allow the user to change the data displayed. Right - basic render window to display data.

Retail Applications of Geovisualization

This section provides a number of examples of geovisualization at four scales of analysis: national, regional, market and micro. The *national-level* analysis provides an example of using geovisualization to explore trends in retail sales data across Canada, using the Small Area Retail Trade Estimate (SARTRE) data set collected by the Canadian Government. The *regional-level* example uses data provided by a retail partner, illustrating the use of geovisualization to examine sales trends across a portfolio of stores in the Province of Ontario. Data from the CSCA's Greater Toronto Area database is used at the *market-level* of analysis, with an application of geovisualization to analyzing ethnic retail structural change detailed. Finally, at the *micro-level*, data provided by a shopping centre developer of retail performance of tenants within a shopping mall is presented to highlight the potential of using geovisualization to understand the dynamics of mall operations. It should be noted that the applications forwarded are indicative of the type of geovisualization system that can be developed, further details are available on the research project website (CSCA 2004).

National-level: Geovisualizing Small Area Retail Trade Estimate Data

As Pearce et al (1999: 53) note "the retail industry in Canada is large and exceedingly diverse" -- with retail sales approaching \$CDN 330 billion in 2003 (Statistics Canada 2004). Identifying the fastest growing areas (hot-spotting) in terms of retail sales and ranking the 'top' locations for development against an existing portfolio of stores is an important aspect of strategic planning for most retailers operating

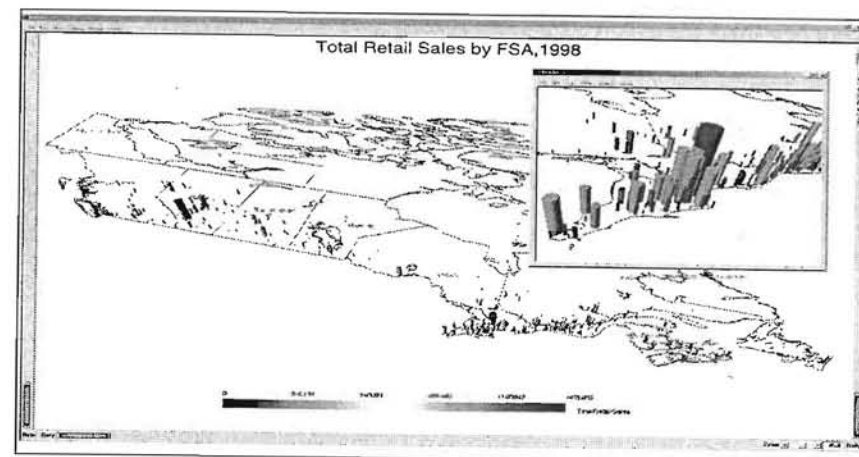


FIGURE 3 National-level: Canadian Retail Sales Data, 1998

Note: Height, colour and radius of bars represent total retail sales by FSA centroid. Inset view shows Southern Ontario data.

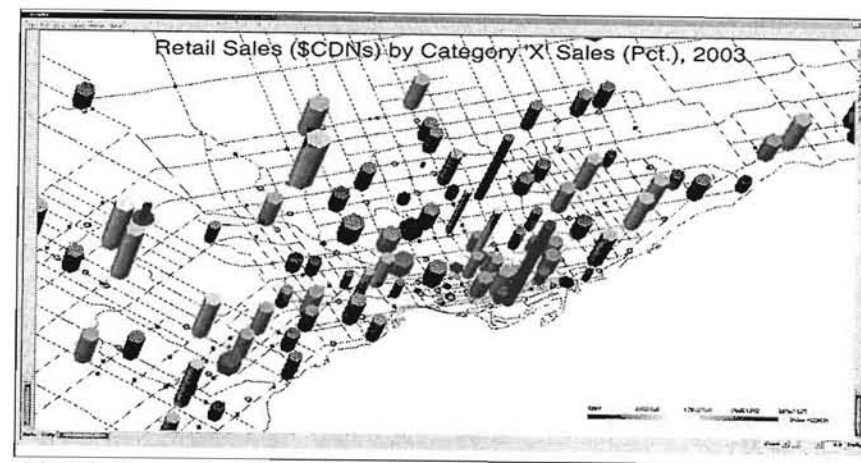


FIGURE 4 Regional-level: Total Retail Sales by Percentage Category 'X' Sales, 2003

Note: Height and colour of the bars represent total sales, radius of bars represent the percentage sales for category 'x' merchandise. Spheres and cubes show the location of competing firms.

in Canada. Statistics Canada has annually collected data on retail sales and locations at a fine level of geography since 1989. The data disseminated to the public, subject to suppression rules, as the SARTRE data set. As Statistics Canada (2002: 2) details, "it combines data from survey and taxation sources to give a picture of all incorporated retailers in Canada". Figure 4 provides a snap-shot from a geovisualization application that facilitates analysis of the SARTRE data set from 1989 to 1998. The application developed allows users to select data from 70 retail-related standard industrial classification (SIC) codes to map retail sales, the num-

ber of retail locations, sales per location or percentage sales. This retail sector visualization covers the 10-year time frame of the SARTRE data set. The basic visualization shown in Figure 3 illustrates the dominant metropolitan markets of Toronto, Montreal, Vancouver, Calgary, Edmonton and Ottawa. In the example, the colour, height and radius of the 3D bars represent total retail sales. This application allows a given retailer to map their existing network of stores to highlight the parallel growth of total retail sales against own-store and/or competitor locations. This could be used to support decisions relating to targeting areas for future development or to assess opportunities to develop merchandise mix in specific markets.

Regional-level: Retail Sales Performance Analysis for a Major Retail Chain

Retail sales performance analysis is central to network planning for major retail chains. The need to comparatively assess the performance of a portfolio of stores operating across a number of markets is a common decision support task for a retail organization. Figure 4 provides a snap-shot of sales performance for a given retail chain operating across the Province of Ontario, with the active display focused on the GTA. In the example, the height and colour of the bars represent total annual sales, whereas the radius of bars represent the percentage sales for category 'x' merchandise. The geovisualization application facilitates the spatial-temporal analysis of retail sales by category across the entire regional portfolio of stores. The diverse population across the Ontario region, with over 11 million residents, is reflected in variations in category sales within the region's sub-markets. In addition, the main competitor stores are visualized as spheres and cubes, these could similarly be coloured and sized (height, radius) according to retail selling space, competitive index, estimated sales or market share/penetration. While the data in Figure 4 shows annual sales, analysis of weekly sales reveals the seasonality of retail performance across Ontario, with summer and winter flows of sales into the 'cottage' country and 'northern community' areas of Ontario. This application can be used to support a range of decisions relating to merchandise planning, store type clustering, advertising, and seasonal staffing.

Market-level: Structural Retail Change in the Greater Toronto Area

The CSCA have annually collected data on more than 50,000 commercial businesses operating in the GTA since 1993. This extensive database of free-standing locations, retail strips, shopping malls and power centre businesses enables the spatial-temporal analysis of structural change. This includes, for example: analyzing the location of large format retailers across the GTA, visualizing fluctuations in retail vacancy rates for shopping malls, assessing business opening to closure rates along retail strips, and examining the changing mix of retailers in a given neighbourhood. Figure 5 provides a snap-shot of a geovisualization application

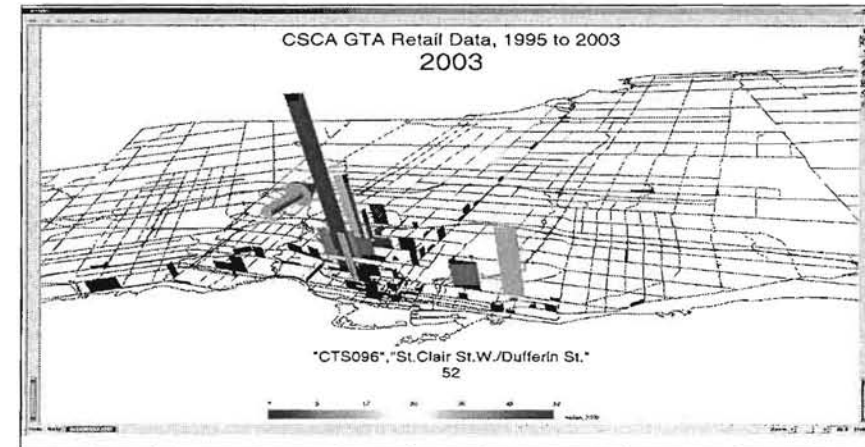


FIGURE 5 Market-level: Ethnic Commercial Structure of the GTA (Italian Businesses), 2003
 Note: Height of polygon represents number of Italian businesses situated along the given retail strip. The St. Clair West and Dufferin Street retail strip in the centre of the 'Little Italy' area is highlighted.

that focuses on the ethnic composition of businesses along the GTA's retail strips. The figure shows the number of Italian businesses by retail strip, with the highest concentration found in the 'Little Italy' neighbourhood centred on St. Clair West and Dufferin Street. An animation of the data over the 1993 to 2003 period clearly illustrates the decreasing number of Italian businesses in 'Little Italy' – a result of the suburbanization of the Italian community to Vaughan in the north-west of Toronto. The ethnic retail geovisualization provides a simple interface to visualize change in the GTA's ethnic retail structure. For example, identifying dominant ethnic clusters of retail and visualizing their growth or decline over time (e.g., Chinese, Italian, East Indian, Portuguese, Vietnamese, Korean, etc.). The structural analysis could include visualizing the extensive development of power centres across the GTA, the changing mix of retail strips (e.g., the transition from retail to business/personal services), the development of particular retail chains or sectors, and the impact of big-box retailers on shopping mall vacancy rates. These geovisualization applications could be used by retailers, developers and city planners to support decisions ranging from new development opportunity to revising land-use planning regulations.

Micro-level: The Operation of a Shopping Mall

Shopping mall managers are concerned with the profitable operation of leased retail space. This can be measured in a number of ways, including, vacancy rates, lease rates, business turnover and sales performance of tenants. The shopping mall industry collects a large amount of highly detailed spatial-temporal data relating to the performance of the leaseable mall floor area. Figure 6 shows a simple

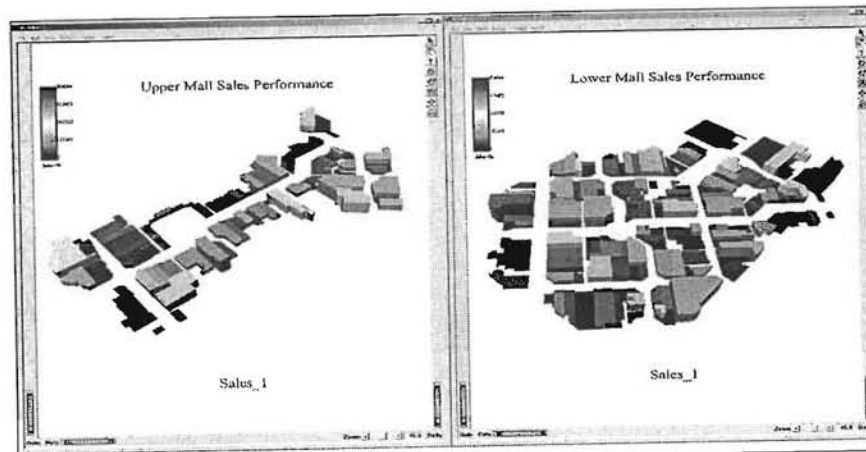


FIGURE 6 Micro-level: Shopping Mall Sales Performance, 2003

Note: Height and colour of polygons represent total sales, change in sales over monthly time periods can be viewed simultaneously.

example of a two-level mall map with the height and colour of the polygons representing sales revenue for the tenants for a one-month period in 2003. The display is split between the upper-level and lower-level floors with the displays linked allowing simultaneous animation of monthly sales performance over the two year sales data set – providing an easy way of viewing the seasonal flow in mall sales. In this example, shopping mall management could choose to colour the polygons according to the type of tenant or lease profitability and the height of the polygons according to sales per square foot or lease rate per square foot. If monthly pedestrian footfall through the entrances (on both levels, including internal access points) were available this could also be included to examine the influence of variations in the flow of mall shoppers. The mall management may also want to focus on critical areas in the mall, for example, the food court, anchor tenants, marginal stores next to anchors, or stores at the entrances. As more malls externalize their retail environment, and open up their tenants via external store entrances, visualizing the increasingly complex flow of customers becomes more critical to understanding how the mall operates. The changing dynamic of mall space, in particular, the increasing number of large format retailers within malls could also benefit from geovisualization applications, for example, assessing the performance over time of leased units adjoining large format stores. These types of application could be used to support decisions relating to, for example, lease renewals, anchor tenant subsidies, mall access planning and optimizing tenant mix.

Future Prospects

This paper has provided an overview of the development and application of geovisualization to retail location decision support. The benefits of the geovisualization approach have been outlined, including for example, the ability to dynamically explore spatial-temporal data, the multi-dimensional display of complex data sets, the sequencing and animation of spatial-temporal data to visually uncover trends and identify anomalies. There are many potential application areas for retail geovisualization systems. Applications at four different scales of analysis have been detailed, providing the scope for geovisualization enabled decision support.

To date, the GIS industry has been slow to integrate spatial-temporal functionality within mainstream GIS decision support products (e.g., current products provide animated 3D fly-through of static data and limited non-interactive animation of temporal data). This presents a significant barrier to enhancing decision support within retail organizations. As the technical barriers become less significant, the future development of geovisualization, and specifically, the speed and diffusion of system development within the mainstream will be largely a function of the level of demand for such systems and the ability to provide generic 'off-the-shelf' systems (in terms of data portability and functionality). The research team is currently undertaking evaluations of the geovisualization system prototype with a number of major Canadian retailers. The findings will provide further insight into the nature, extent and viability of developing geovisualization functionality within retail decision support systems. As technical barriers erode, advances in computational and graphical processing capabilities will continue to provide analysts and decision makers with new opportunities to develop understanding, create knowledge and enhance decision support systems. The challenge is to provide functionality that meets the needs of users and enables analysts and decision makers to think visually. It is envisaged that the applications detailed in this paper will be representative of the next generation in retail decision support with advanced GIS-based systems that enable spatial-temporal analysis of change in the retail landscape.

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