

# A Geographic Visualization Approach to Multi-Criteria Evaluation of Urban Quality of Life

CLAUS RINNER

Department of Geography, Ryerson University, Toronto, Canada

crinner@ryerson.ca

This paper proposes to use geographic visualization principles in conjunction with multi-criteria evaluation methods to support spatial decision-making. Interactive maps can be combined with analytical tools to explore various settings of multi-criteria evaluation parameters that define different decision-making strategies. In a case study, the analytical hierarchy process (AHP) is used to calculate composite measures of urban quality of life (QoL) in Toronto. The AHP allows for an interactive blending between different QoL models, while offering a view on spatial patterns in the processed QoL indicators. This feature is used in interviews with domain experts to gather their feedback on the utility of geographic visualization in urban QoL assessment.

*Keywords:* Geographic Visualization, Multi-Criteria Evaluation, Spatial Decision Support, Urban Quality of Life

## 1. Introduction

Geographic visualization (GeoVis) draws on the goals of *information visualization*, namely presenting complex scientific data in graphical forms in order to facilitate the analyst's understanding of the phenomena underlying those data. In GeoVis, the data being analyzed are spatial in nature and represent problems of geographic scale. The utility of the GeoVis approach was shown for the exploratory analysis of spatial and spatio-temporal data. Fewer attempts have been made to apply GeoVis techniques to processed data – data that represent the results of an analytical process rather than directly representing the characteristics of geographic features. While GeoVis from its beginning was conceived as a visual *analysis* approach, the term “visual analytics” makes this goal more explicit while at the same time suggesting to combine visualization tools with specialized analysis tools.

In this paper, I propose to use GeoVis principles in conjunction with multi-criteria evaluation (MCE) methods to support spatial decision-making. MCE was introduced to spatial decision-making and geographic information systems (GIS) in the 1990s. MCE methods such as *simple additive weighting* provide simple analytical tools that can be made more useful through a combination with interactive cartographic and graphic displays. Based on previous work, I will demonstrate how a specific problem in urban quality of life (QoL) assessment can be addressed by this approach, and describe our methods for gathering feedback from domain experts about the utility of this approach.

In the next section, I will review MCE methods in GIS and introduce GeoVis support for MCE to provide map-centred, exploratory decision support. Then, I will discuss common steps in evaluating the usefulness of GeoVis tools. Next, I will present the assessment of urban QoL as a spatial decision-making problem. Using a case study of QoL assessment across neighbourhoods of the City of Toronto, I will describe the use of the *analytic hierarchy process* (AHP) to define a classical and a contemporary model of QoL, and interactively blend between these two models. Finally, I will summarize our guide for interviews with urban geography and planning experts to elicit the utility of the geo-visual MCE approach.

## 2. Map-Centred Exploration of Multi-Criteria Decision Strategies

MCE was introduced to GIScience in a variety of applications using different calculation methods (Malczewski 1999). In essence, a multi-criteria method creates summary evaluation scores for each decision alternative (e.g. location, area) based on their combined performance in the multiple criteria. In the MCE framework described by Malczewski (1999), there are various choices to be made by the decision analyst, including the following:

- decision criteria
- standardization method for criteria
- multi-criteria decision rule
- criterion importance weights.

The former parameters relate to the *problem definition*, the latter to *method uncertainty*. Different choices with respect to these parameters can lead to different evaluation results. Therefore, we can use a GeoVis approach to support a visual sensitivity analysis for decision parameters. This would let the analyst assess differences in evaluation scores with a view on their spatial patterns. GeoVis capitalizes on the power of human image processing to support the discovery of patterns in spatial data and the development of ideas for scientific investigation of geographic phenomena. Interactive functionality for the visual-analytical approach to spatial decision support ranges from map navigation and modifiable symbolization of MCE score maps to multiple, dynamically linked displays of geographic space and criterion space, and highlighting of data subsets across these interfaces.

The GeoVis approach to MCE was introduced by Jankowski et al. (2001) extending earlier work on exploratory spatial decision support (Heywood et al. 1994) and “decision research” (Densham and Armstrong 1995). Andrienko and Andrienko (2001) describe interactive visual tools and map symbols to support decision-making. Andrienko and Andrienko (2002) call for highly interactive tools to visualize the consequences of variations in MCE parameters. The same authors implement an automatic sensitivity analysis based on the variation of criterion weights. Rinner and Malczewski (2002) focus

on the exploration of multi-criteria *decision strategies* using GeoVis principles and techniques. Decision strategies in a narrower sense are defined by the settings of the *ordered weighted averaging* (OWA) decision rule. In a wider sense, we can interpret any combination of the above-listed decision-making parameters as a decision strategy. Malczewski and Rinner (2005) extend the OWA with linguistic quantifiers, a modification of the underlying conceptual framework that subsequently allows for an improved user interface design.

The *analytic hierarchy process* (AHP) (Saaty 1980) is a widely used MCE method, which is particularly effective in eliciting user preferences (Malczewski 1999). AHP assists the decision-maker in simplifying the decision problem by creating a hierarchy of decision criteria. Subsequent operations take place independently at different hierarchy levels with a smaller number of factors to take into account. Furthermore, the method is usually offered with the pairwise comparison technique that simplifies preference ratings among decision criteria. Rinner and Taranu (2006) describe a map-centred interactive AHP implementation to support spatial decision-making.

### 3. Evaluating the Usefulness of Geographic Visualization Tools

The increasing popularity of GeoVis tools brings with it a need to evaluate their usefulness for supporting users to solve certain tasks. In transferring design principles from human-computer interaction (HCI) research, GeoVis researchers have become aware of the difficulty in *measuring* the success of GeoVis tools (Fuhrmann et al. 2005). The HCI community defines the usefulness of software products through their utility and usability. *Utility* refers to the ability of a tool to address a task and, thus, is bound by the tool's functionality. *Usability* refers to the user's effort in using the tool and is composed of the following aspects:

- Learnability
- Efficiency
- Memorability
- Low frequency and severity of errors
- User satisfaction

Usability, thus, is mainly determined by the presentation of the tool's functionality in its user interface. Various procedures are currently adopted from HCI to increase the usability of GeoVis tools. Fuhrmann and Pike (2005) review the user-centred design method and apply it to the development of collaborative GeoVis tools. The authors use effectiveness, efficiency, and satisfaction as measurements for usability. Similarly, Koua et al. (2006) use effectiveness (task performance), usefulness (appropriateness of functionality), and user reactions as their test measures.

GeoVis however may provide particular challenges to usability engineering methods. Tobon (2005) provides an example where high values in the usability measure of "time

required to perform a task”, in GeoVis, may be as indicative of high user involvement in the task as it may signal difficulties in using the tool. It must also be noted that the usability measures are based on a complete description of the tasks to be solved. Fuhrmann et al. (2005) acknowledge that in GeoVis user goal achievement is often difficult to measure since a data exploration process usually cannot be pre-structured, even in a usability test environment.

Therefore, an important aspect in evaluating the usefulness of GeoVis tools is to assess their *utility* early in the development process. This might include testing the utility of GeoVis principles in a new domain before appropriate task descriptions become available and may require evaluation methods that can more easily distinguish between the underlying theoretical framework of a GeoVis tool and user interface concerns.

Robinson et al. (2005) adapt a design process from HCI to include user input at various stages of GeoVis tool development. The *work domain analysis* “represents the initial communication of ideas and requirements between the client ... and developers”. While this scenario still requires a “client” to be determined, it acknowledges that a rather informal, developer-driven initial design phase may exist. In the present paper, qualitative feedback from potential users of a GeoVis method is sought based on a prototype demonstration in order to estimate whether the method might be worthwhile introducing to a new domain, urban QoL assessment.

#### **4. Assessment of Urban Quality of Life**

Urban centres worldwide are in a competition concerning the QoL they offer to their residents. QoL rankings are not only a matter of prestige but one of attracting and retaining an economically productive workforce. In particular, highly educated and creative people have been shown to be ready to move to high-quality places across boundaries of countries and continents (Arora et al. 2000).

A difficulty in reacting to urban QoL deficits has been the lack of an agreed-upon definition and measure of QoL. QoL is a multi-faceted problem that has drawn considerable attention in the urban geography and planning literature (Massam 2002). Among its multiple dimensions, the QoL of individual persons or groups can be distinguished from the QoL of places. QoL can refer to personal health and well-being or to the residential environment.

Beyond the personal level, QoL often has been determined by assessing sets of demographic and socio-economic indicators. Traditionally, wealthy places with educated and employed populations have been considered high-quality (GC 1978, FCM 1999). More recently, indicators such as the cultural and artistic workforce, diversity of origin and sexual orientation, and housing diversity have been taken into account (Florida 2002, Gertler et al. 2002). While most studies discuss these indicators individually (Murdie et al. 1992, van Kamp et al. 2003), MCE offers a distinct option for composite QoL measures (Massam 2002).

While comparisons of QoL between cities are more common than between neighbourhoods within a city, the latter become increasingly important to maintain similar levels of QoL in our growing urban centres. The methodological challenges with assessing urban QoL include the definition of neighbourhoods, the selection of QoL indicators, and the processing of these indicators. The assessment of neighbourhood QoL is not a decision problem per se, but the MCE-based composite QoL scores could inform subsequent political decision-making. With respect to the selection of indicators, a classical and a contemporary model of QoL are suggested that are based on the aggregation of different indicator lists. MCE methods further allow to weight individual QoL indicators.

## 5. Case Study: Quality of Life by Toronto Census Tracts

Based on Canadian QoL studies (GC 1978, FCM 1999, Massam 2002) and data availability, the variables shown in Table 1 have been selected as QoL indicators for a classical model of QoL. Similarly, the set of variables in Table 2 was selected to build a contemporary model of QoL.

Table 1: Classical QoL indicators.

<b>Benefit criteria (to be maximized)</b>	<b>Cost criteria (to be minimized)</b>
Population change	Population density
Ownership of dwellings*	Lone-parent families*
Average household income	Spending 30% or more of income on housing*
Owned dwellings*	Unemployment rate*
Immigrants*	Population without a highschool diploma*

\* denotes variable as a proportion of an appropriate total population.

Table 2: Contemporary QoL indicators.

<b>Benefit criteria (to be maximized)</b>	<b>Cost criteria (to be minimized)</b>
Arts and culture workforce*	Incidence of low income
People between the age of 20 and 29*	
Bachelor's degree or higher*	
Employment rate*	
Average individual income	
Diversity of Housing (Rented dwellings)	
Immigrants*	

\* denotes variable as a proportion of an appropriate total population.

QoL indicators are taken from socio-economic and demographic characteristics of neighbourhoods. The AHP method in CommonGIS (Rinner and Taranu 2006) allows the analyst to establish a hierarchy of indicators. On the top level, we split the hierarchy by the two QoL models. Within each model, the indicators were partially grouped by subject (e.g. income) as shown in the left panel of Figure 1.

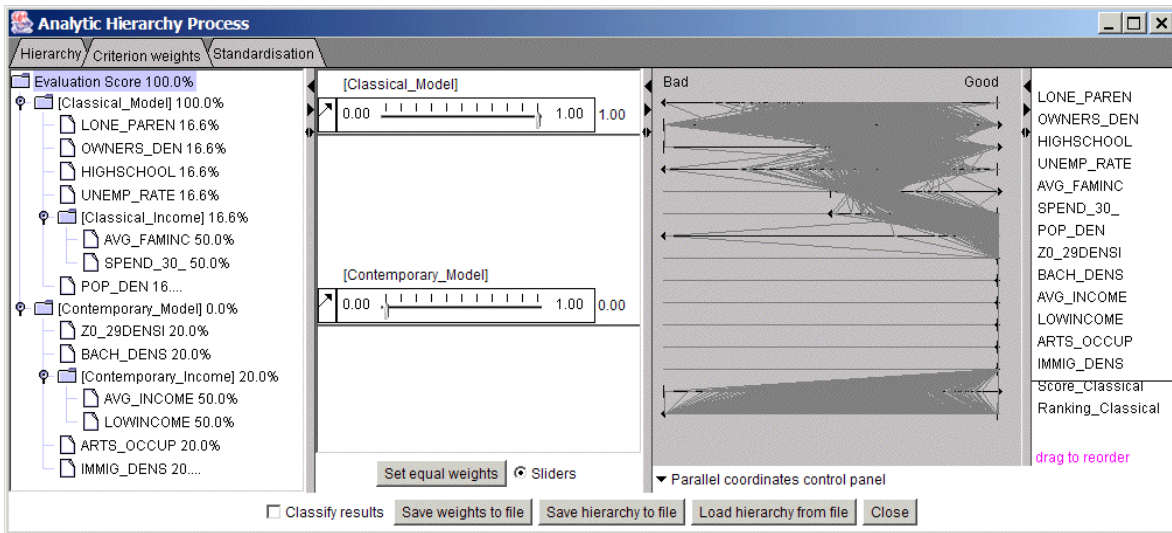


Figure 1: Dialog for setting AHP parameters. Hierarchy shown on the left; weighting of the two models on the top-level shown in centre panel (full weight given to classical model); CommonGIS' parallel coordinate plot for all QoL indicators shown in right-hand panel.

Figure 2 shows the ranks of Census Tracts in the City of Toronto based on multi-criteria evaluation of the QoL indicators with equal weights on the second hierarchy level. The left choropleth map in the figure shows the classical QoL model, the right map shows the contemporary model. According to the classical QoL model, the City of Toronto is characterised by a U-shaped pattern of low QoL (dark colour) reaching from the northwest down to the lakeshore at the Toronto Island and harbour areas and up to the northeast. This U shape is known anecdotally to have a larger proportion of disadvantaged population with respect to social and health-related characteristics. High QoL is found in the wealthy central part of the city and towards the western suburbs.

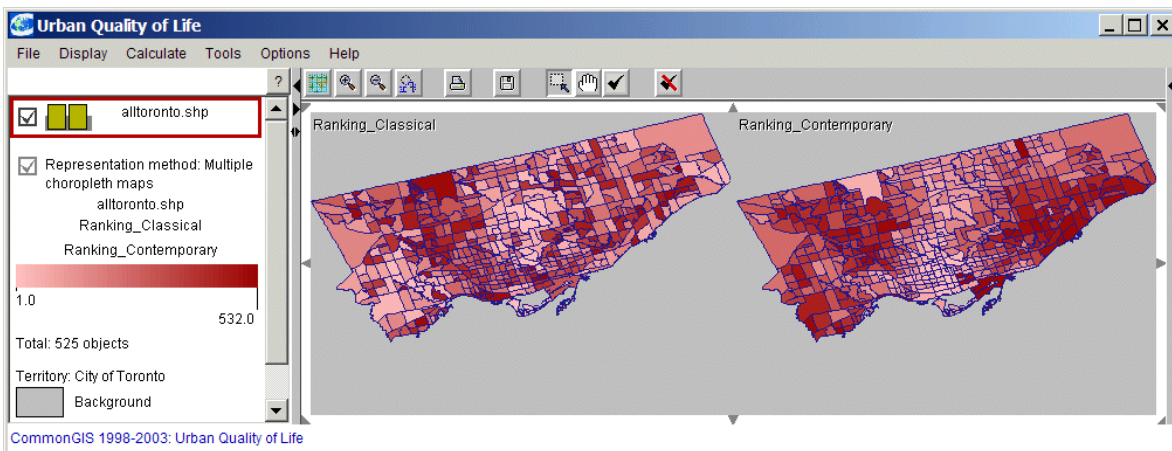


Figure 2: Multiple choropleth maps showing ranks of the 532 Census Tracts in the City of Toronto when applying the two QoL models. Higher ranks are shown in bright colour.

In the second map, the contemporary QoL model yields a significantly different picture characterised by higher QoL in the south-central (downtown) area and lower QoL towards the western suburbs. The central part of the city is still assessed at high QoL and the eastern part at low QoL. This pattern reflects the attractiveness of the urban core through its younger and diverse population and higher level of occupation in creative businesses.

## **6. Interviews with Domain Experts**

The complex nature of both, the assessment of urban QoL and the use of the CommonGIS-based GeoVis tool led us to develop interviews with domain experts in which the GeoVis tool is operated by an experienced user and the domain expert is questioned about urban QoL assessment. Three test interviews were run successfully based on the following interview guide. Interviews with urban geography and planning faculty as well as planning graduate students are planned for August 2006. Subsequently, this analysis process will be examined to understand typical tasks that were intuitively performed by our experts and can be used to further structure subsequent user tests. Expert feedback on the utility of the geo-visualization approach to multi-criteria QoL assessment will also be obtained through questionnaires.

The interviewer will briefly introduce the basic tenets of urban QoL assessment, multi-criteria decision-making with the AHP method, and the CommonGIS software. The Toronto neighbourhood application described above will be started and a pre-defined AHP hierarchy with the two QoL models be loaded. The socio-demographic variables used as QoL indicators will be reviewed. Then, the interactive manipulation of weights for QoL indicators and immediate feedback on the cartographic display of resulting evaluation ranks will be demonstrated. Focusing on the weight balance at the top of the indicator hierarchy, i.e. between the two distinct QoL models, the interviewer will ask the first question:

1. What weighting between the contemporary and classical models do you see as useful on a city-wide scale, based on the existing hierarchy?

Next, the interviewer provides the opportunity to identify a neighbourhood of interest and to re-assess their previously preferred weighting scheme:

2. Is there any particular area of interest you'd like to examine? If so, how well does the representation reflect your perceptions on a neighbourhood scale?

Next, the expert's opinions on the composition of the indicator hierarchy will be collected. This includes the hierarchy structure separated by QoL models, the weighting of indicators within each model, and a question for missing or unnecessary indicators in the default hierarchy.

The final set of open-ended questions relates to the usefulness of the map-centred QoL assessment method and suggestions for improvement:

3. What are your impressions on the usefulness of this interactive mapping method within a decision support framework?
4. Are there any areas in which the concept of using interactive maps for subjective assessments could be improved?

In summary, we hope that the demonstration of the map-centred approach to urban QoL assessment will spark the expert's imagination so that they will ask the interviewer to run them through various settings in the AHP method, in particular with respect to the blending between the classical and contemporary model. This interview context of visually analysing data which the expert will know already, but which are presented to them in a novel way, should yield insight into the possible tasks in urban QoL assessment that could then be more formally structured and evaluated for GeoVis support.

## **7. Conclusion and Outlook**

This paper discusses the application of geographic visualization principles to spatial decision support. GeoVis allows for the exploration of geographic space and decision space in MCE. When interactively manipulating MCE settings, analysts can observe the resulting changes in the decision outcome and compare them to their knowledge of the study area. Through this process, a fine-tuning of MCE settings such as criterion weights can be achieved.

An application of interactive map-based MCE to urban QoL assessment was suggested, in which a specific property of the AHP method is exploited. AHP allows the analyst to blend between different models for QoL thus allowing for a visual comparison of QoL patterns across the study area. This feature is going to be used in interviews with domain experts in urban geography and planning in order to elicit the utility of the GeoVis approach to urban QoL assessment.

More generally, this paper aims at contributing to the development and validation of novel GeoVis tools with (simple) analytical decision support functionality. Results from this research will inform further development of tools and processes for decision-centred GeoVis, and aid in designing case studies to test the usability and utility of such tools.

## **Acknowledgements**

Contributions by William Hong, Angela Brinklow, and Jordan Katz to the review of urban QoL concepts, and the data collection and preparation for the two QoL models are gratefully acknowledged. Comments by two anonymous reviewers were helpful in expanding the scope of this manuscript. Partial funding was provided by the Natural Sciences and Engineering Research Council of Canada and the GEOIDE Network of Centres of Excellence.

## References

- Andrienko, N., and Andrienko, G., 2001, Intelligent Support for Geographic Data Analysis and Decision Making in the Web. *Journal of Geographic Information and Decision Analysis* 5(2):115-128
- Andrienko, N., and Andrienko, G., 2002, Informed Spatial Decisions through Coordinated Views. *Information Visualization* 2(4): 270-285
- Andrienko, G., Andrienko, N., Bernardo, F., Hipolito, J., Kretschmer, U., and Voss, H., 2002, Testing the usability of interactive maps in CommonGIS. *Cartography and Geographic Information Science* 29(4): 325-342
- Arora, A., Florida, R., Gates, G.J., and Kamlet, M., 2000, Human Capital, Quality of Place and Location. Report prepared on behalf of Heinz Endowments and Sustainable Pittsburgh. September 2000. Available online at <http://www.pittsburgh-region.org/public/cfm/library/reports/humancapital.pdf> [last access: 14 May 2006]
- Densham, P., and Armstrong, M.P., 1995, Human-computer interaction: considerations for visual interactive locational analysis. In T.L. Nyerges, D.M. Mark, R. Laurini, and M.J. Egenhofer: *Cognitive Aspects of Human-Computer Interaction for GIS*. Kluwer
- FCM (Federation of Canadian Municipalities) (1999) The FCM Quality of Life Reporting System: Quality of Life in Canadian Communities. Ottawa
- Florida, R., 2002, The Economic Geography of Talent. *Annals of the Association of American Geographers* 92(4):743-755
- Fuhrmann, S., Ahonen-Rainio, P., Edsall, R.M., Fabrikant, S.I., Koua, E.L., Tobon, C., Ware, C., and Wilson, S., 2005, Making Useful and Usable Geovisualization: Design and Evaluation Issues. In J. Dykes, A.M. MacEachren, and M.-J. Kraak, *Exploring Geovisualization*. Amsterdam: Elsevier
- Fuhrmann, S., and Pike, W., 2005, User-centred Design of Collaborative Geovisualization Tools. In J. Dykes, A.M. MacEachren, and M.-J. Kraak, *Exploring Geovisualization*. Amsterdam: Elsevier
- Gertler, M.S., Florida, R., Gates, G., and Vinodrai, T., 2002, Competing on Creativity: Placing Ontario's Cities in North American Context. A report prepared for the Ontario Ministry of Enterprise, Opportunity and Innovation and the Institute for Competitiveness and Prosperity, November 2002. Available online at [http://www.utoronto.ca/progris/Competing%20on%20Creativity%20in%20Ontario%20Report%20\(Nov%202002\).pdf](http://www.utoronto.ca/progris/Competing%20on%20Creativity%20in%20Ontario%20Report%20(Nov%202002).pdf) [last access: 14 May 2006]
- GC (Government of Canada) (1978) Urban Indicators: Statistical Profiles of Quality of Life for Canadian Cities. Revised ed., Ottawa: Ministry of State of Urban Affairs
- Heywood, I., Oliver, J., and Tomlinson, J., 1994, Building and Exploratory Multi-Criteria Modelling Environment for Spatial Decision Support. In Proceedings of the EGIS'94 conference. Paris
- van Kamp, I., Leidelmeijer, K., Marsman, G., and de Hollander, A., 2003, Urban Environmental Quality and Human Well-Being Towards a Conceptual Framework and Demarcation of Concepts; a Literature Study. *Landscape and Urban Planning* 65:5-18

- Jankowski, P., Andrienko, N., and Andrienko, G., 2001, Map-centered exploratory approach to multiple criteria spatial decision making. *International Journal of Geographical Information Science* 15(2):101-127
- Jankowski, P., and Nyerges, T., 2001, GIS-Supported Collaborative Decision Making: Results of an Experiment. *Annals of the Association of American Geographers* 91(1):48-70
- Koua, E.L., MacEachren, A.M., and Kraak M.-J., 2006, Evaluating the usability of visualization methods in an exploratory geovisualization environment. *International Journal of Geographical Information Science* 20(4): 425-448
- MacEachren, A.M., Brewer, I., 2004, Developing a conceptual framework for visually-enabled geocollaboration. *International Journal of Geographical Information Science* 18(1):1-34
- Malczewski, J., 1999, *GIS and Multicriteria Decision Analysis*. New York: John Wiley
- Malczewski, J., Rinner, C., 2005, Exploring Multicriteria Decision Strategies in GIS with Linguistic Quantifiers: A Case Study of Residential Quality Evaluation. *Journal of Geographical Systems* 7(2):249-268.
- Massam, B.H., 2002, Quality of life: public planning and private living. *Progress in Planning* 58(3):141-227.
- Murdie, R., Rhyne, D., and Bates, J., 1992, Modeling Quality of Life Indicators in Canada: A Feasibility Analysis. Ottawa: Centre for Future Studies in Housing and Living Environments.
- Rinner, C., and Malczewski, J., 2002, Web-enabled spatial decision analysis using Ordered Weighted Averaging (OWA). *Journal of Geographical Systems* 4(4):385-403.
- Rinner, C., and Taranu, J., 2006, Map-Based Exploratory Evaluation of Non-Medical Determinants of Population Health. *Transactions in GIS* 10(4):633-649
- Saaty, T.L., 1980, *The Analytic Hierarchy Process*. New York: McGraw-Hill
- Tobon, C., 2005, Evaluating Geographic Visualization Tools and Methods: An Approach and Experiment Based upon User Tasks. In J. Dykes, A.M. MacEachren, and M.-J. Kraak, *Exploring Geovisualization*. Amsterdam: Elsevier