A 3D GEOVISUALIZATION APPROACH TO CRIME MAPPING

Markus Wolff, Hartmut Asche
3D-Geoinformation Research Group
Department of geography
University of Potsdam
Markus.Wolff@uni-potsdam.de, gislab@uni-potsdam.de

Abstract

This contribution presents an approach to visualize crime scene analysis results with three-dimensional geovirtual environments. Commonly, the results of those crime data analyses are published trough thematic maps. Therefore cartographic visualizations can be considered as a key element to communicate the outcomes of crime analysis. Those visualizations produced by crime analysts both in operational and academia are predominantly presented in form of traditional two-dimensional, static maps. According to defined task and analysed crime, these maps vary in subject, purpose, audience and map quality. Depending on the map topic and anticipated audience, these maps can be difficult to comprehend. A common issue, for instance, deals with the question how to define adequate threshold values for choropleth maps of certain hotspots. Against this background it is often rather ambiguous from which value precisely hot-spots can be considered "hot" (*Chainey and Ratcliffe, 2005*).

Against this background this contribution tries to explore innovative methods of visualizing the outcomes of geospatial crime scene analysis. Therefore the main objective of this paper is to facilitate an instant grasp of complex spatial information by using three-dimensional geovisualization techniques. For this purpose crime data analysis is combined with methods from the field of 3D geovisualization.

According to this concept, methods of geospatial crime scene analysis are applied using geographic information systems (GIS). By applying kernel density estimation (KDE) techniques areas are identified where robbery scenes tend to cluster. Once identified, these hotspots provide the basis for further analysis. For instance, further geovisual analysis uses a three-dimensional city model to determine the minimum distances of each building to the closest crime scene. This allows for classifying the buildings of the city model according to robbery exposure.

For visualization purposes an interactive three-dimensional geovirtual environment is created. Besides the analytical power of GIS, a specialised 3D visualization system is required for this kind of interactive visualizations. The findings of crime scene analysis are integrated into this virtual environment.

Consequently taking advantage of the third dimension, this contribution identifies benefits for a cartography oriented design of three-dimensional landscapes of security and insecurity by outlining several methods and functions for analysing and visualizing crime data by using three-dimensional geovirtual environments. Although demonstrated for the specific example of a German city, the presented methodology is transferable to any other region.

Summarised, GIS based crime scene analysis is combined with selected approaches from 3D geovisualization. This result in calculating and visualizing statistical surfaces based on kernel density estimation. Afterwards the analysis scale is increased by focussing on particular hotspots and by including the urban landscape via integrating a three-dimensional city model. This combination of analysing crime data and visualizing the results with methods from the field of 3D geovisualization might provide an instant grasp of complex spatial phenomena – to both, the public and responsible decision makers.

1 Introduction

Within the discipline of crime mapping geographic information systems (GIS) are widely used. Because crime scenes can virtually almost be localised in space – inside or outside of a building – a GIS can be considered as an adequate tool for managing and analysing crime data. Both, in academic research and in practical law enforcement GIS is applied for the analysis and the mapping of crime data (*Murray et al. 2001*). Digital analysis and mapping of crime offers a number of benefits, particularly in the following fields of applications: operational policing purposes, crime prevention, informing and interaction with the community, change monitoring changes in the distribution of crime over time and evaluation of efficiency of crime prevention initiatives (*Hirschfield and Bowers, 2001*).

Subsequent to geospatial analysis of crime scene datasets, the results have to be communicated to a broader audience. For this purpose thematic maps are created. Therefore, cartographic visualizations can be considered as a key element to communicate the outcomes of crime analyses. However, those crime maps are predominantly presented in form of two-dimensional static maps. Frequently these maps show pattern- or feature distributions, for instance the spatial variation of crime hotspots related to certain offences. Depending on the maps topic and advised anticipated audience, these maps can be difficult to read. A common issue related to 2D crime visualizations, for instance, deals with the issue of how to define adequate threshold values for choropleth maps regarding certain hotspots. Often it is rather ambiguous from what value precisely a certain hotspot can be considered as to be “hot” (*Chainey and Ratcliffe, 2005*). Taking methods of 3D geovisualization into account, the presented approach aims at visualizing crime related issues by using interactive three-dimensional geovirtual environments. The following workflow is applied in this study: at first we process and analyse geocoded crime scene data with GIS methods. In this context kernel density estimation (KDE) techniques are applied to identify certain robbery hotspots. For visual analysis these hotspots are combined with a three-dimensional city model. Subsequently, this city model is used to determine the minimum distances of each building to the closest crime scene. The findings of these spatial analyses are integrated and combined into the three-dimensional geovirtual environment. This interactive environment is modelled outside the GIS. For this purpose a specialised 3D visualization system is used.

Consequently taking advantage of the third dimension, this contribution tries to identify benefits for a cartographic oriented design of three-dimensional landscapes of security and insecurity. This combination of analysing crime data and visualizing the results with methods from the field of 3D geovisualization might provide an instant grasp of complex spatial phenomena – to both, the public and responsible decision makers.

2 Three-dimensional mapping of robbery scenes using geovirtual environments

This paper focuses on analysis, integration and visualization of crime data into three-dimensional geovirtual urban environments. Therefore a three-dimensional geovirtual environment is created for the study area. This 3D environment builds a basis for urban crime data visualization and consists of a digital terrain model, a 3D city model, high resolution aerial photography (25 cm/pixel), a digital cadastral map and further vector based datasets including rivers, administrative boundaries and many more. Figure 1 shows a screenshot of this 3D environment. Concerning the presented figures, however, we underline that the underlying environment is completely interactive. A commercial GIS (ArcGIS) is used to process these datasets and to design specific visualization styles for the subsequent 3D visualization. With the LandXplorer application, a software system is used that provides a common platform for 3D geovisualization techniques (*Döllner et al., 2006*).

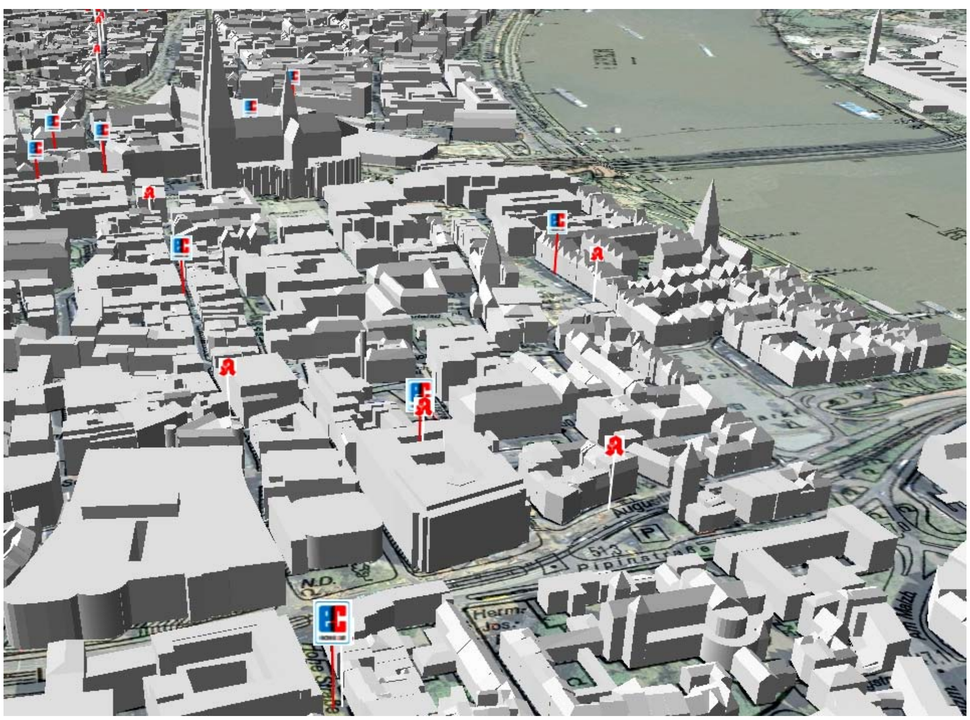

Figure 1. Virtual three-dimensional environment of the city of Cologne

2.1 Exploring robbery clusters

The base dataset for analysis is obtained from the police headquarters of the German city of Cologne. The dataset represents robbery crime scenes for the year 2007 whereas each robbery scene is represented as an individual point, geocoded by x and y co-ordinates. Beyond these co-ordinates each point has further attributes describing the time of the offence.

Mapping those robbery scenes with the purpose of creating first overview maps on relative small scales, one has to consider, that basic positional-based point maps do not show all of the recorded crimes since several robberies can have the same coordinates (several robberies at the same registered position at different times). However, using graduated symbols, those point maps visualize the overall distribution of crime scenes.

The distribution of offences in space and time is one of the cardinal purposes of crime maps. Analysing hotspots is therefore of substantial interest for security agents as well as for decision makers in urban planning. A commonly used method for identifying and visualizing hotspots is based on calculating a continuous surface that transforms the discrete crime scene distribution into a density surface. Unlike other point based data (as precipitation data for instance), crime data can not be interpolated to a continuous surface by implication. Therefore density mapping techniques using kernel density estimations (KDE) can be applied to identify and map crime hotspots. Applying this technique leads to a grid whose cell values represent density values. For this purpose KDE-algorithms first overlay a study area with a grid of user definable cell size. In a second step, density values for each cell are calculated – depending on the implemented kernel density function (cf. Smith et al. 2006). For analysing the robbery scenes of Cologne we use the quadratic kernel density function that is implemented in ArcGIS.

Here, the value at each grid location g_j with distance d_{ij} from each event point *i* is calculated as the sum of all applications of the kernel function over all event points in the crime scene dataset. Therefore the resulting grid shows density values of crimes sites related to a surface measure (for instance number of crimes sites per square kilometre).

For this study a hotspot grid for the robberies 2007 is calculated. For our study region we consider a bandwidth parameter (search radius) of 400 meters and a cell size of 50 meters as appropriate. The 400 meter bandwidth value produces the most reasonable output as hotspots are visualised as well as the overall distribution of crime scenes.

For visual analysis the resulting hotspot grid is integrated into the 3D geovirtual environment. Using a colourless continuous surface instead of the 2D classified and coloured grid provides an alternative representation of the KDE grid: to allow for a visual differentiation of regions with higher crime densities from regions with lower densities, predominantly traditional two-dimensional choropleth or isopleth maps are created on the basis of the hotspot grid. This requires defining adequate thresholds for the class breaks. That, in turn, finally leads to the issue that different maps result from different threshold definitions. However, using a three-dimensional surface no thresholds have to be defined for initial visualization. Integrated into the 3D environment this visualization facilitates an intuitive exploration and interactive visual analysis of crime site densities. Apart from this, the surface can be overlaid with additional textures – for instance with a (classified) choropleth map of the hotspot grid

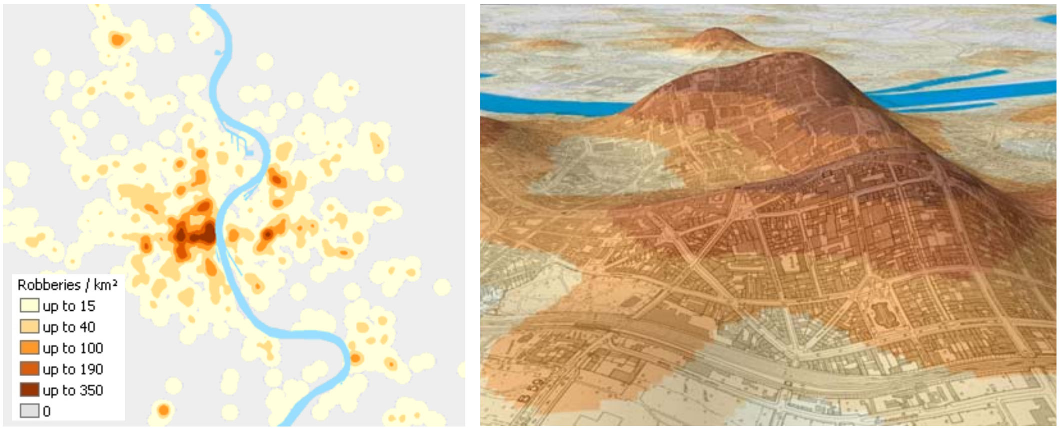

Figure 2. 2007 hotspot grid with robbery densities defined as number of incidents per square kilometre – represented in form of a 2D thematic map (left image) and in form of a three-dimensional "information landscape" (right image)

or with further georeferenced maps (cf. figure 2).
This double coding of crime site densities can be considered as an effective visualization method for focussing on certain hotspot regions – for instance to brief decision makers.
The presented techniques illustrate how to detect and map hotspots while its application to 3D geovisualization demonstrates the potential to facilitate an instant grasp of complex geospatial information for decision makers.

2.3 Adding the 3D city model

For further analysis the virtual environment is extended by a 3D city model. The use of a 3D city model facilitates visualizations of spatial relationships at the building level in an easy to comprehend way. This analytical and geovisual potential of 3D city models can be instrumental for decision makers working in security agencies for an intuitive communication of spatial phenomena related to urban security issues. However, city models vary in semantic and graphic detail from those with reduced level of detail (LOD1) to completely textured LOD3 models. The latter are often complemented by interior models of single rooms to complete buildings (*Gröger et al., 2005, Döllner et al., 2006*). In this study we use a city model that consists of 23,330 buildings. To facilitate visual analysis of each building the city model is overlaid with the KDE-hotspot grid. Figure 3 shows the central Cologne hotspot area with a corresponding 3D city model.
To broaden this visual approach and to facilitate further analysis, we calculate for each building the minimum distance to the closest robbery scene. Based on the crime scene dataset, an Euclidean-distances-grid with a cell size of two meters is calculated. Each pixel of this grid represents the distance to the closest crime scene. This grid is

combined with the city model: for each of the 22,000 buildings those pixels are detected that fall within the respective building footprint. From this set of pixels we determine that one with the lowest value – which is the minimum distance of the building to the closest crime site. This value is added to the building database as a new attribute.

Finally, the building dataset is classified and coloured according to these minimum distance values. The subsequent 3D visualization allows for exploring particular buildings of urban districts affected by a high number of robberies (cf. figure 4). Since the distance values are stored in the buildings database further selection tasks are supported. This visualization facilitates an intuitive geo-communication relating the distances of each building from the closets crime scene.

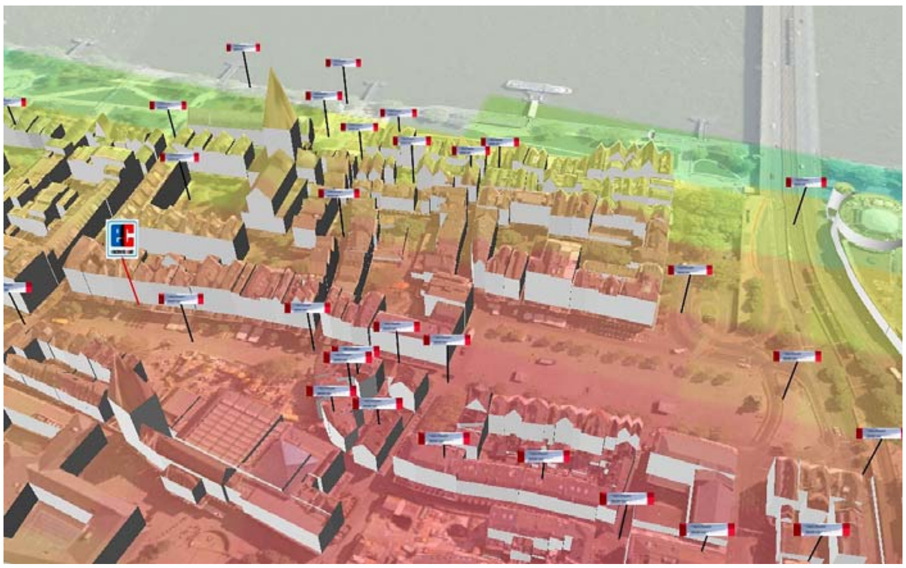

Figure 3. 3D city model with additional hotspot texture and crime scene positions

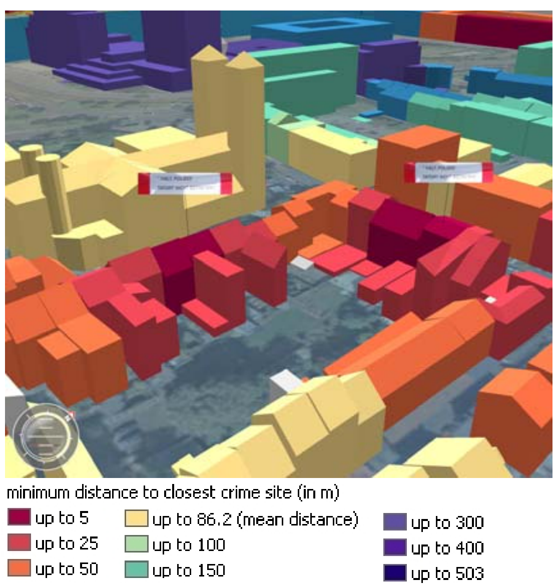

Figure 4. Minimum distances of each building to the closest robbery crime scene

3 Conclusion

This paper presents several methods and functions for analysing and visualizing crime scene data with three-dimensional geovirtual environments by the example of the city of Cologne. For this purpose we combined methods of analysing crime scenes data with innovative 3D geovisualization techniques. As a first step, we calculated statistical surfaces based on kernel density estimation techniques. Afterwards we increased the analysis scale by focussing on particular hotspots and by including the urban landscape via integrating a three-dimensional city model into the virtual environment.

However, for further studies the underlying population has to be considered. Furthermore the 4th dimension should be included in further analysis. Therefore next steps in this project will comprehend population and time related analysis of crime patterns. Further innovative three-dimensional visualization styles will have to be developed for displaying these issues in a cartographic yet appealing way.

Acknowledgements

Funding of this study by the German Federal Ministry of Education and Research (BMBF) within the framework of the InnoProfile research group '3D Geoinformation' (www.3dgi.de) is gratefully acknowledged. The authors also like to thank the police headquarters of the metropolis of Cologne for providing extensive crime datasets. Furthermore we like to thank Virtual City Systems GmbH for providing the 3D city model and 3D Geo GmbH (now: Autodesk, Inc.) for supplying the LandXplorer system.

References

Bowers, K. J., Johnson, S. D., Pease, K., (2004), Prospective Hot-Spotting The Future of Crime Mapping?, The British Journal of Criminology 44(5): 641-658

Chainey, S., Ratcliffe, J. (2005), GIS and Crime Mapping. Chichester, John Wiley & Sons Inc

Döllner, J., Baumann, K., Buchholz, H. (2006), Virtual 3D City Models as Foundation of Complex Urban Information Spaces. CORP, Vienna

Getis, A., Ord, J. K. (1992), The Analysis of Spatial Association by Use of Distance Statis-tics, Geographical Analysis 24: 189-206

Gröger, G., Benner, J., Dörschlag, D., Drees, R., Gruber, U., Leinemann, K., Löwne M. O, (2005), Das interoperable 3D-Stadtmodell der SIG 3D, Zeitschrift für Vermessungswesen 130: 1-11

Hirschfield, A., Bowers, K. (2001), Mapping and analysing crime data. London and New York, Taylor & Francis

Murray, A. T., McGuffog, I., Western, J. S., Mullins, P. (2001), Exploratory Spatial Data Analysis Techniques for Examining Urban Crime Implications for Evaluating Treatment, British Journal of Criminology 41(2): 309-329

Ord, J. K., Getis, A. (1995), Local Spatial Autocorrelation Statistics: Distributional Issues and an Application, Geographical Analysis 27: 286-306

Smith, de M.J., Goodchild, M. F., Longley, P.A. (2006), Geospatial Analysis, Troubador Publishing