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MULTIDIMENSIONAL DYNAMIC CARTOGRAPHY

Mitasova, Helena - Brown, William M. - Hofierka, Jaroslav: Multidimensional dynamic cartography. Kartograficke listy, 1994, 2, 6 figs., 12 refs.

Abstract: New approach to cartographic modeling based on integration of scientific visualization and computer cartography is presented. This approach moves cartography from 2D static maps to cartographic modeling of landscape as a complex dynamic system in 3D space and time.

Key words: geographic information systems, computer aided cartography, scientific visualization

INTRODUCTION

As the result of a revolution in technologies for collection of information about the Earth, large volumes of geospatial data are now available in digital form [7]. Increasing volume of these data is being measured in three dimensional (3D) space and time for studies of spatial and temporal relationships of landscape phenomena. Every component of natural landscape is 3D varying more or less through time and realistic landscape modeling requires methods and tools working in 3 dimensions and time. 3D GIS can provide an appropriate environment for study of objects and processes in real landscape. Reflecting needs of the future 3D GIS systems, new approach to cartographic modeling is emerging from the integration of computer cartography and scientific visualization [3]. This approach is based on viewing the data in 3D space and modeling the dynamics of geospatial processes using animation, as pioneered by Tobler [12]. Another important difference is the high level of interaction with data. Cartographic modeling is approached as a creative process, requiring a cartographer to browse through data, looking at various attributes and spatial layers before deciding how to best represent the phenomena being studied.

Radical changes in communication of information stimulate the development of multidimensional dynamic cartography (MDC). More information is now being distributed *via* computer networks in the form of text, image, animation and sound. An excellent example of the future of information communication is NCSA Mosaic - "a networked information discovery, retrieval, and collaboration tool and World Wide Web browser", available from the ftp site ftp.ncsa.uiuc.edu.

MULTIDIMENSIONAL CARTOGRAPHIC MODELING IN GRASS GIS

GRASS(Geographic Resources Analysis Support System) [2] is a public domain open system designed as a standard GIS with basic raster and vector capabilities as well as a programming environment for development of new methods and approaches for GIS technology. This system has provided a sound basis for the development and testing of MDC as both an analytical and communication tool. GRASS tools for MDC enable users to view all formats of currently supported geographic data (raster, point, vector) in the same 3D space and allows scripting for producing dynamic visualizations *via* animation [1]. The support for the volumetric visualization of 3D raster, point, and vector data sets is being implemented along with the development of the new d-dimensional data structures for GRASS GIS.

The following capabilities are designed for standard 2D data, but enhance cartographic modeling beyond the traditional cartography:

1. 2D raster data are displayed as surfaces in 3D space, using one data set for surface topography and a second one for surface color. This is especially useful for terrain modeling when surface represents elevations, and color can be either a derived terrain parameter like curvature (Figure 3, [5]) or a map related to land cover (soils, vegetation *etc.*). This combination enhances the study of relationships between topography and natural or socio-economic phenomena. Display of abstract surfaces, e.g. population densities (Figure 1a,b) enhance the perception of surface structure. In general, surface structure is suitable for display of quantitative differences while qualitative data (e.g. vegetation or soil types) are better represented by color.
2. A graphical user interface provides a means for interactively changing input, positioning, zooming, z-scaling, and defining the method and resolution of data display. These capabilities are crucial for the efficient use of MDC in the analysis of results of spatial models and for finding the optimal view for communication of studied phenomenon.
3. Fast querying capabilities are provided for retrieving the numerical values of spatial coordinates as well as values of categories for both surface and color raster maps.
4. Interactive lighting enables users to choose the proper light position, color, intensity and surface reflectivity. Lighting and shading is a powerful tool for detecting noise or small errors in data or models, invisible when standard 2D methods are used. It also significantly enhances the 3D perception of surface topography (Figure 2a,b).
5. Vector and point data can be draped over the surface incorporating the line and point features into the cartographic model. Point data can be displayed in their 3D position which enables users to evaluate the spatial relations between the data points and the displayed surface. Point data can be displayed also as glyphs sized proportionally to the value associated with this point, representing, for example, an error (Figure 3).

Besides the features for the visualization of data measured and stored in planar (x,y) coordinates, GRASS tools for MDC support visualization of data in spherical (latitude/longitude) coordinates and 3D datasets:

1. Raster maps in a spherical coordinate system can be rendered as surfaces draped over the globe or its part along with vector and point data. This option simulates the 3D globe on the 2D screen and thus creates more realistic cartographic models for global studies. (Figure 4.)
2. 3D data sets can be visualized in the same 3D space as the standard 2D data using the following options: - isosurfaces calculated at user specified intervals or values (Figure 5), - user specified crossections (slices), - solids defined by selected isosurfaces and slices. Data from two or more 3D raster data sets can be displayed in one cartographic model, using various combinations of the previous options and/or by draping the color from one data set on isosurfaces from the second one, an option useful e.g. for

displaying the results of 3D topographic analysis.

Animation is an important tool for exploring large and complex data sets, especially when they involve more than 2 dimensions, with one dimension representing some kind of change. Animation may be used in visualization to represent a) change in time (data changes), b) change in a modeling parameter (data changes), or c) change in viewer position (no change in data).

Two methods are used to automatically generate animations:

1. Scripting is used to load a new data set for each frame, producing series of images animated as a dynamic surface. For example: a) surfaces interpolated from a time series of measured data such as monthly precipitation or temperature as they change during the year; b) surfaces generated from the same point data set using spline interpolation with gradually increasing tension (useful for better understanding the method); c) surfaces produced as a result of models of landscape processes. For complex spatial dynamic models, when it is necessary to visualize changing input parameters and several changing modeled variables, it is useful to use multiple dynamic surfaces. Three dynamic surfaces representing rainfall, water depth draped over terrain and soil infiltration may be visualized simultaneously as they change in time during a rainfall. Scripting is also used with 3D data to generate animations showing a series of isosurfaces using different threshold values or a series of slices moving through the data, enhancing the perception of volume and leading to better data exploration and understanding.
2. Keyframe animation is used to generate each frame along a path which represents changing viewer position. The user specifies a few "key" positions where they want the viewpoint to be at a relative time in the animation, then a user-defined number of total frames is automatically rendered as the viewer position and view direction are interpolated along a 3D path. Keyframe animation is useful to explore large data sets where much of the surface data is hidden behind other data when viewing from any single position. When translucent surfaces are used, viewer movement adds to the perception of depth. Keyframe animation is also used to animate the rotation of the Earth when using data in a spherical coordinate system draped over the globe.

APPLICATIONS TO ENVIRONMENTAL MODELING

MDC requires the development of sophisticated tools for processing of raw data and their transformation to a form suitable for visualization. These tools include multivariate interpolation from point to raster data [9],[11], surface and hypersurface geometry analysis [4], programs for spatial dynamic modeling [6] and a lot more. The following two examples show the role of MDC in environmental modeling - the main field of applications for GRASS GIS.

1. Spatial dynamic modeling of water flux.

Overland flow is an important phenomenon influencing various landscape processes such as water erosion or spatial distribution of chemical pollutants. This highly dynamic phenomenon varying rapidly through time during a rainfall event, can be modeled in GRASS at various levels of complexity using e.g. programs r.mapcalc [2], r.flow [8],[9], r.flow.time, or r.hydro [11]. For example, a new GRASS program r.flow.time computes the direction and velocity of water flux during each time step from a new dynamic surface of water layer on relief. The trajectories representing water flux are constructed using a modified raster-vector approach for flowtracing, presented in [8], [13]. The output is a time series of raster maps representing the spatial distribution of water flux as it develops during the rainfall event. The results of these models can be displayed as animated series of surfaces representing the water flux (Figure 6a-d, output of r.flow) or as a color map draped over terrain.

2. Modeling of spatio-temporal distribution of chemicals from measured data.

As a part of environmental monitoring programs concentrations of various chemicals are being measured in water bodies. To evaluate these data it is necessary to create a cartographic model representing both spatial and temporal distribution of measured values. The distribution of chemicals in space and time can be modeled by a function $u = S(x_1, x_2, x_3, x_4)$ where the fourth variable x_4 is proportional to time. The 4-variate regularized smoothing spline with tension was used to model both spatial and temporal distribution of chemicals measured in irregularly distributed sampling stations during the one year cycle. The time step of measured data was variable - 2 to 4 weeks, the resulting model was interpolated at 7 days time step. GRASS MDC tools were used to create the animations from the results of 4-variate interpolation (Figure 5. shows one frame from the animation). The resulting excellent animation proved the importance of using time as a 4-th independent variable when processing the time series of data measured in 3D space and time.

DISCUSSION AND CONCLUSIONS

We have successfully developed and tested the functionality of MDC as a tool for cartographic modeling based on GIS technology. MDC increases the power of cartography for modeling landscapes as complex dynamic systems and enables users to better understand modeled phenomena. This approach radically changes the ways a cartographer processes the data and opens the world of new cartography for scientists without cartographic background. This represents a new challenge for the theory of cartography - tools for creation of cartographic models are much richer now, besides the standard cartographic variables like shape, orientation, color, texture etc., cartographers have to learn how to work with light, variable scales, and animations. At the same time, the production of cartopgraphic models is much more efficient and faster.

We did not try to build a new cartography, nor even attempt to define the proper terminology, but we hope that our contribution will stimulate the discussions and research in the area of cartographic language [10] and cartographic modeling and will help to incorporate the new approaches into theory of cartography. This should help to formalize the MDC tools and design them as an easy to use language which will enhance the possibilities for the GIS users (even without cartographic background or only with the background in 2d static cartography) to use the MDC properly end effectively.

Note: Images, animations and scientific papers can be viewed via NCSA Mosaic under GRASS visualization at www.cecer.army.mil.

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Resume

Multidimenzionalna dynamicka kartografia

V suvislosti s revolucnym vyvojom technologie na zber informacii o Zemi dochadza k vzrastu mnozstva udajov o priestorovych a dynamickych javoch. Integraciou pocitacovej kartografie a pocitacovej vizualizacie vznika novy smer v kartografickom modelovani, ktory sa stava sucastou modernych 3D geoinformacnych systemov (GIS). Tento smer je zalozeny predovsetkym na vizualizacii dat v 3D priestore a animacii.

GRASS je otvoreny, volne dostupny GIS poskytujuci standarne nastroje na analyzu priestorovych dat a sucasne vybudovany ako prostredie pre vyvoj novych GIS programov.

Jeho sucastou sa stava aj subsystem pre multidimenzionalnu dynamicku kartografiu (MDC). MDC umoznuje zobrazovat priestorove data vo vsetkych GIS formatoch v 3D priestore a tiez dynamicku vizualizaciu prostrednictvom animacie. V sucasnosti sa moznosti vizualizacie 3D dat doplnuju o dalsie multidimenzionalne datove struktury.

GRASS subsystem pre MDC umoznuje pre standardne 2D data:

1. zobrazovat rastrove data ako farebne povrchy v 3D priestore (obr. 3, 6a-d);

2. interaktivne menit vstupne udaje, miesto pozorovatela, zvacsovanie a zmensovanie obrazu, prevysenie, metodu a rozlisenie zobrazovania;

3. rychle zistenie suradnic a zobrazovanych hodnot;

4. interaktivne menit poziciu, farbu a intenzitu osvetlenia a odrazivost modelovaneho povrchu;

5. nalozit liniove a bodove prvky na povrch, bodove data mozu byt zobrazene ako glyfy velkost ktorych vyjadruje numericke hodnoty javu v tomto bode (obr. 3);

6. zobrazovat udaje v sferickych zemepisnych suradniciach na guli (obr. 4);

3D data mozu byt vizualizovane v 3D priestore tymito sposobmi: - izoplochami definovanymi intervalmi alebo hodnotami (obr. 5) - definovanymi rezmi - telesami definovanymi izoplochami a rezmi

Animacia je vyznamny nastroj na studium komplexnych priestorovo-casovych dat. Moze byt pouzita pre vyjadrenie 1. zmeny v case (datove zmeny), 2. zmien v hodnotach parametra modelu (datove zmeny), 3. zmeny v polohe pozorovatela (ziadne datove zmeny).

Ulohu kartografickeho modelovania a MDC mozno ilustrovat na prikladoch z oblasti environmentalneho modelovania:

1. Dynamicke modelovanie povrchoveho odtoku vody.

Novy program r.flow.time umoznuje modelovat povrchovy odtok v case a konstruovat trajektorie pohybu latok na zaklade analyzy meniaceho sa povrchu vody na reliefe (obr. 6a-d).

2. Modelovanie priestorovych a casovych zmien chemickych latok

Tieto zmeny mozu byt modelovane prostrednictvom 4D interpolacnej funkcie $u = S(x_1, x_2, x_3, x_4)$ kde x_4 je casova premenna. MDC umoznuje z vysledkov interpolacie vytvorit animacie a potvrdzuje dolezitost pouzivania casu ako 4. nezavislej premennej pri skumani priestorovych dynamickych javov.

MDC v GRASSe predstavuje uzitocny nastroj pre modelovanie krajiny ako dynamickeho systemu a umoznuje lepsie pochopit uzivatelom modelovane javy a procesy. Preto pochopitelne vznika potreba rozpracovania tychto otazok v ramci teorie a terminologie kartografie.

Poznamka: Obrazky, animacie a vedecke clanky si zaujemci mozu pozriet prostrednictvom NCSA Mosaic softwaru pod heslom GRASS Visualization (ftp site ncsa.uiuc.edu)

obr. 1 Hustota obyvatelstva v Juznej a Juhovychodnej Azii zobrazena ako a) farebna mapa nalozena na teren b) ako povrch a farebna mapa

obr. 2 3D pohlad na digitalny model reliefu Vysokych Tatier a) bez osvetlenia b) s osvetlenim

obr. 3 Digitalny model reliefu regionu Trnavy s nalozenou krivostou a datovym bodmi zobrazenymi ako glyfy vyjadrujucimi 10x zvacsenu odchylku interpolovaneho povrchu od dat.

obr. 4 Globalny digitalny model reliefu (ETOPO5) nalozeny na povrch globu ako povrch s vhodnym osvetlenim reliefu

obr. 5 Koncentracia dusika v Chesapeake bay vyjadrena izoplochami

obr. 6 Casove rezy z animacie reprezentujuce kartograficky model akumulovania povrchoveho odtoku vody pocas zrazkovej udalosti

Text pod ciarou

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Texty pod obrazy:

Figure 1. Population densities in South-, South-East Asia (data courtesy Anatha Prasad) displayed a) as color map draped over terrain, b) as surface and color map.

Figure 2. 3D view of the High Tatras digital elevation model (data courtesy Milan Koren) a) without light, b) with light.

Figure 3. Digital elevation model of Trnava region with draped curvatures and data points displayed as glyphs, representing the deviations of interpolated surface from the data points 10 times exagerated.

Figure 4. Global digital elevation model (ETOPO5) draped over the globe as surface with appropriate lighting and shading to enhance the perception of surface topography.

Figure 5. Concentrations of nitrogen in the Chesapeake bay represented by isosurfaces

Figure 6. Frames from an animation representing a cartographic model of flow accumulation during rainfall.