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Web-Based Virtual Models for the Earth Science Community

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Abstract

Optimized agricultural management depends on reliable and detailed information describing the spatial distribution of soils, geology (parent material), and topography. Subsurface attributes (earth data) have in common that they vary through three-dimensional (3-D) space and through time. Our goal was to overcome current limitations of geographic information systems to manage, analyze, and visualize geographic data in two dimensions (2-D). In this paper we present an approach to reconstruct and visualize soil-landscapes with focus on web-based dissemination of model output. Our approach is multi-dimensional, multi-variate, spatially object-oriented, transferable, scalable, and expandable. We used geo-referenced subsurface and topographic attributes from several sites in southern Wisconsin and northwestern Ohio to demonstrate the capabilities of our approach. Reconstruction was based on 2-D and 3-D ordinary kriging utilizing Environmental Visualization System (EVS) software and implemented in Virtual Reality Modeling Language (VRML). Three different types of soil-landscape models were distinguished: (i) Models representing subsurface attributes as points (ii) Models representing subsurface objects as polyhedrons or "volume models" and (iii) Block models consisting of voxels (volume cells). A server hosts the virtual soil-landscape models, which are accessible by multi-clients via an interface coded in HTML. These models are interactive, platform independent and enable users to analyze, explore and gain insight into the spatial distribution of topographic and subsurface attributes in 3-D geographic space. Numerous agricultural tasks are supported using our approach including 3-D soil surveys, informed decision-making, assessment of environmental quality, farm management, land use planning, and many more. Virtual soil-landscape models are beneficial in disseminating geo-referenced earth data to educators, researchers, government agencies, and the general public.

Keywords

Data communication, geographic distribution, information systems

1. Introduction

Optimized agricultural management depends on reliable and detailed information describing the spatial distribution of soils, geology (parent material) and topography. This is challenging because soil and geologic features are invisible from the surface. All subsurface (or earth) attributes have in common that they vary through 3-D space and through time. Earth attributes are usually anisotropic, i.e., they exhibit an uneven spatial distribution in geographic space. Usually, observations and measurements collected with drills, boreholes or excavated pits are limited to specific locations. For many of these attributes, the quantity of input information is not exhaustive. Therefore, powerful interpolation methods were developed to describe the spatial distribution of subsurface attributes continuously. However, most of these interpolation methods are applicable in a 2-D plane only (Goovaerts, 1997).

Currently, geographic information systems (GIS) are still the most common tools to store, analyze, and visualize digital geographic data including soil and landscape data. However, GIS lack the functionality to handle and display 3-D and four-dimensional (4-D) multi-variate geo-data. Commonly, 2-D maps or digital layers are used to visualize the spatial distribution of soil and landscape patterns (Pennock and Acton, 1989; Osher and Buol, 1998). Other soil-landscape representations use a 2½-D design, where soil or land use data are draped over a digital elevation model (DEM) (Su et al., 1996; Hogan and Laurent, 1999) to produce a 3-D view. Since this technique describes patterns on 2-D landscape surfaces rather than the spatial distribution of subsurface attributes (e.g., soil texture, soil horizons) it fails to address three-dimensional soil-landscape reality. Numerous sketches of soil-landscapes can be found in Soil Survey Manuals and other publications (e.g., Dane County Soil Survey; Mickelson, 1983). These hypothetical sketches are three-dimensional but neither utilize real data nor interpolation methods. Few studies used reconstruction and 3-D visualization techniques to portray subsurface attributes at landscape-scale. For example, the Cooperative Research Center for Landscape Evolution and Mineral Exploration constructed a 3-D regolith model of the Temora study area in Central New South Wales, Australia (CRCLEME, 1999) and a 3-D soil horizon model in a Swiss floodplain was created by Mendonça Santos et al. (2000) using a quadratic finite-element method. Sirakow and Muge (2001) developed a 3-D Subsurface Objects Reconstruction and Visualization System (3-D SORS) in which 2-D planes are used to assemble 3-D subsurface objects. Even fewer studies use reconstruction along with virtual reality techniques to portray soil data in 3-D space (Barak and Nater, 2001; Grunwald et al., 2000).

To provide a more holistic, multi-dimensional view of soil-landscapes, several issues needs to be addressed. First, subsurface attributes and processes in natural environments often vary at granularities ranging from pedons, hillslopes, watersheds, and regions. This suggests the development of a nested hierarchical and spatially object-oriented (SOO) approach, which integrates over a spectrum of scales. Secondly, soil-landscapes can be represented by many different constituents ranging from categorical (e.g., soil horizons, drainage classes), discrete (e.g., soil texture) and continuous (e.g., bulk density) attributes, which suggest using a multi-variate generic model. Thirdly, usually subsurface attributes are derived from sparse observations and measurements. Therefore, we propose to use a robust geostatistical method to interpolate subsurface attributes in 3-D geographic space to create a geo-data model portraying soil-landscapes. Fourthly, interactive, computer-generated, 3-D representations enrich our perception, which enable clients to comprehend soil-landscapes intuitively and gain insight into complex environmental systems. Therefore, we suggest employing a web-based virtual environment to disseminate models. In this paper, we present an approach to reconstruct and visualize soil-landscapes with focus on web-based dissemination of model output. Though in this paper we highlight soil attributes, the same principles apply to other subsurface attributes.

2. Methodology

2.1. Multi-Variate Geo-Data

We represented subsurface attributes using points, voxels and polyhedrons consisting of arcs. A multi-variate dataset comprising soil horizons, soil color, texture, bulk density, water content, and cone index was collected to demonstrate the capabilities of our approach. Topographic data were derived from U.S. Geological Survey DEM 7.5-min, orthophotos and field surveys conducted with a differential global positioning system, respectively. Our study areas were located in southern Wisconsin (site descriptions at: http://www.soils.wisc.edu/soils/3D_SL_models/3Dsoils.html) and northwestern Ohio (site descriptions at: http://www.soils.wisc.edu/~barak/wmc2001/sl_vrml.htm).

2.2. Reconstruction

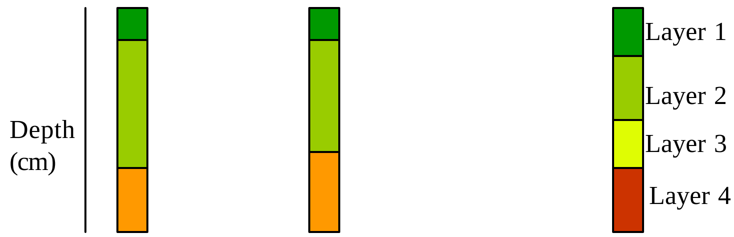
Reconstruction soil-landscapes were implemented and visualized utilizing Virtual Reality Modeling Language (VRML) (Ames et al., 1997; Lemay et al., 1999), which is a 3-D object-oriented graphics language. Object-oriented programming models real-world objects with software counterparts and it encapsulates data (attributes) and methods (behavior, communication, and interaction) into objects. Attributes such as geometry (shape, size), content (value), and appearance characterize objects. Objects interact with each other and with their environment, i.e., they exhibit behavior (e.g., algorithms to calculate percolation or erosion), communicate with other objects (e.g., routing of soil particles from one object to an adjacent object), and interact with users (e.g., a mouse click triggers the rotation of an object). Object-oriented programming takes advantage of class relationships, where objects of a certain class share the same characteristics, attribute types, and operations. It also takes advantage of inheritance relationships where newly created classes of objects inherit characteristics of existing classes yet contain unique characteristics of their own. These characteristics make object-oriented code portable and increase the flexibility of changing code. We used a SOO approach geo-referencing each object. Models implemented in VRML are portable across platforms and deliverable across the Internet. Within the VRML-capable browser, the user can interact with objects, e.g., move around these VRML worlds, scale and rotate objects, and view virtual worlds from different viewpoints – e.g., bird's eye view or immersive world view where the user moves through a landscape (Fairbairn and Parsley, 1997; Moore et al., 1999).

We distinguished three different model types. The first type describes (i) models representing subsurface attributes as points. These are the simplest type of virtual soil-landscape models. For example, soil samples collected at fixed depth increments of 5-cm were analyzed for bulk densities and represented as virtual points. The *PointSet* VRML class (node) created point geometry. The input datasets to create more complex models comprised x, y, and z (depth) coordinates, elevations and subsurface attribute values. Spatial modeling was used to create (ii) models representing subsurface attributes as polyhedrons or "volume objects" and (iii) block models consisting of voxels (Figure 1 and 2). The *IndexedFaceSet* VRML class was employed to render polyhedrons (e.g., representing soil horizons) where the *Normal* VRML class specified a list of normal vectors calculated from the face coordinates of objects. This normal indicates the

(1) Input geo-data (boreholes)

Boreholes: B-1 B-2 B-3

Elevation (m): 328.6 325.2 327.4



(2) Data structure

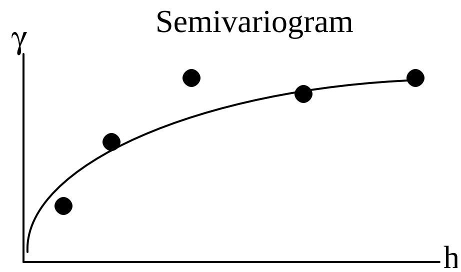
x	y	elevation	depth1	depth2	depth3	depth4	boreholes
293668.5	4771376.3	328.6	22.0	51.0	-	130.0	B-1
293678.5	4771376.3	325.2	24.0	48.0	-	130.0	B-2
293708.5	4771376.3	327.4	25.0	39.0	62.0	130.0	B-3
etc.							

(3) Interpolation

Method: 2-D ordinary kriging in the horizontal plane

$$g(h) = \frac{1}{2N(h)} \sum_{(i,j)|h_{ij}=h} (v(x)_i - v(x)_{i+h})^2$$

γ: semivariance
v_i: variable value
x: location
h: distance
N: pairs of data



Method: Linear interpolation in the vertical plane

(5) VRML implementation (classes or nodes)

Shape
IndexedFaceSet
Normal
Appearance
Material
Color

(6) Visualization

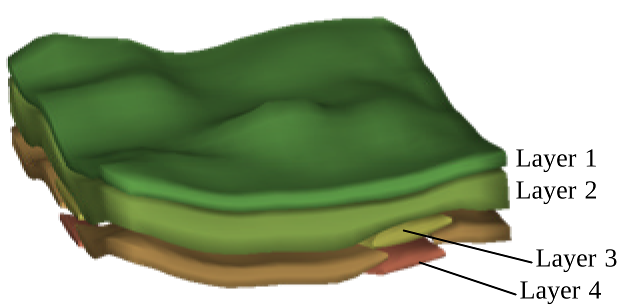
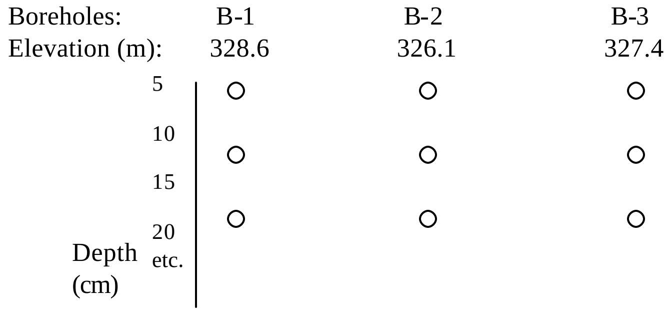


Fig. 1. Steps to create models representing subsurface attributes as polyhedrons or "volume objects".

(1) Input geo-data (boreholes)



(2) Data structure

x	y	z	value	name	elevation
293678.5	4771376.3	5.0	1.23	B-1	328.6
293678.5	4771376.3	10.0	1.40	B-1	328.6
293678.5	4771376.3	15.0	1.61	B-1	328.6 etc.
293668.5	4771376.3	5.0	1.35	B-2	326.1
293668.5	4771376.3	10.0	1.33	B-2	326.1
293668.5	4771376.3	15.0	1.72	B-2	326.1

etc.

(3) Interpolation

Method: 3-D ordinary kriging

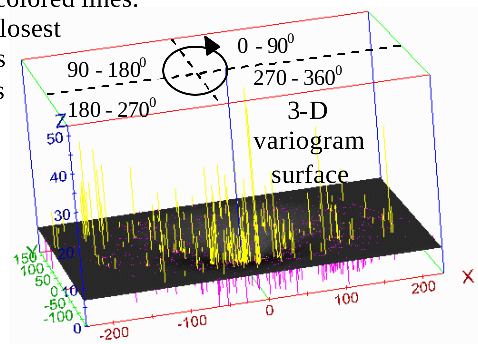
Multi-dimensional variogram

Representations of data pairs are displayed as colored lines. Lines are drawn from the pair location to the closest point on the semivariogram surface. Directions of datapairs are represented as vector distances (range from 0^o to 360^o clockwise)

x-axis : distance (h) between data pairs in the x-y plane (horizontal)

y-axis: distance (h) between data pairs in the z-plane (vertical)

z-axis : semivariance



(5) VRML implementation (classes or nodes)

Shape
IndexedFaceSet
Normal
Appearance
Material
Color

(6) Visualization

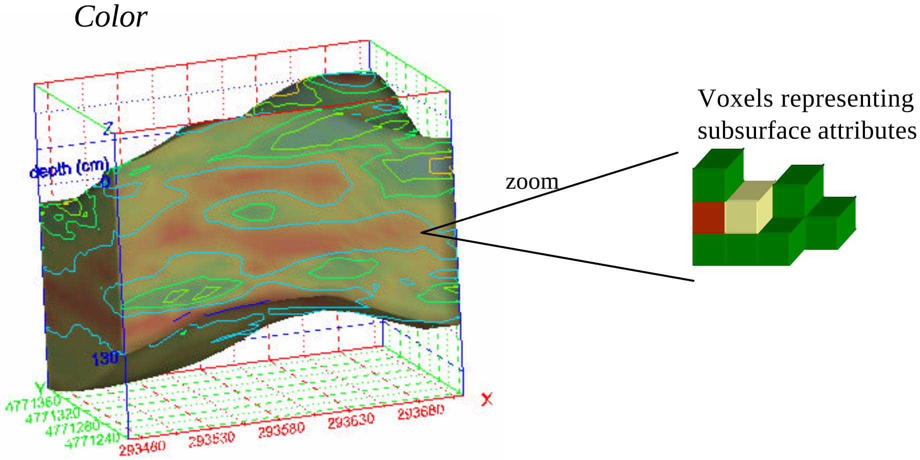


Fig. 2. Steps to create block models consisting of voxels.

direction the entire polygon faces. These subsurface objects were computed utilizing 2-D ordinary kriging to create horizontal surfaces and linear interpolation to create vertical surfaces. Voxel-based models were created utilizing 3-D ordinary kriging that is an innovative 3-D geostatistical method interpolating attributes in the horizontal and vertical dimension simultaneously (software: EVS-PRO, Environmental Visualization System; CTech Development Corporation, Huntington Beach, CA).

2.3. Visualization

Our models visualize the 3-D spatial distribution of subsurface and topographic attributes. Colors and surface textures were used to specify the appearance of objects. Subsurface attributes were portrayed using the red-green-blue (RGB) color specification system and topographic attributes were portrayed on the z-axis. The VRML capable browser automatically computes shading to give objects a 3-D appearance. Users can specify reflection and diffusivity parameters.

2.4. Architecture

Currently, a server hosts an HTML-coded interface to facilitate access to VRML soil-landscape models. Models are accessible either with web-browsers (e.g., Netscape Communicator, Microsoft Internet Explorer) equipped with VRML-capable plug-ins or with standalone software such as GLView 3D (available at: http://home.snafu.de/hg/). Viewers capable of interpreting VRML syntax have been coded in a number of computer languages for numerous operating systems. By design, the computational effort of 3-D calculations is shifted from the server to the client to reduce bandwidth requirements. Many VRML viewers are further optimized to utilize the high-end gaming capabilities of 3-D video cards (e.g., OpenGL or Direct3D drivers) thereby transferring some of the computational load from the client CPU central processing unit to the video card RAM (random access memory). Legend and metadata enhance the information content disseminated to end-users. Information transfer is by intention primarily in one direction, from the virtual model (server) to the user (client), to inhibit manipulation of reconstructed soil-landscapes by clients.

3. Results

Reconstructed soil-landscape models are accessible at:
http://www.soils.wisc.edu/soils/3D_SL_models/3Dsoils.html
http://www.soils.wisc.edu/~barak/wmc2001/sl_vrml.htm
http://www.crosswinds.net/~sabwql/ and http://www.earthit.com.

4. Discussion and Conclusions

The results presented illustrate the capabilities of an object-oriented, multi-variate, and multi-dimensional approach to reconstruct and visualize virtual soil-landscape models implemented in VRML. Reconstructed soil-landscape models are:

- Based on a realistic geo-data model using 2-D and 3-D ordinary kriging, respectively
- Multi-variate: A variety of different subsurface attributes can be used for geo-data modeling and visualization (e.g., taxonomic classes, texture, soil horizons, drainage classes, etc.)
- Multi-dimensional: Reconstructed soil-landscape models are emulated in 3-D geographic space

- Transferable: Our spatially object-oriented modeling approach is not limited to a specific geographic location
- Scalable: Models can be developed at small and large scale (e.g., pedons, catenas, and soil regions)
- Expandable: As new data become available the 3-D soil landscape models can be updated with new data
- Interactive: Users can interact and communicate with models (e.g., scale, rotate, access subsurface data and metadata)

Virtual reality (VR) is a way for humans to visualize, manipulate, and interact with virtual environments and extremely complex data. Desktop VR uses computer monitors and the World Wide Web (WWW) to display virtual models. Our virtual soil-landscape models implemented in VRML are disseminated via the WWW, which is an inexpensive way to distribute information to a wide variety of users. Clients can interact with virtual models and scale, move, and explore objects.

Limitations of the presented approach are largely those due to the availability of subsurface and landscape data used to reconstruct models and complexity and size of soil-landscapes. Complex models extending over large areas with great detail slow down loading times and interactivity functions in web-browsers.

GIS vendors are developing pseudo virtual reality environments such as Environmental Systems Research Institute's (ESRI Inc., Redlands, CA) 3D Analyst extension to ArcView GIS. These are tools to visualize geo-data in 3-D view; however, they are not able to manipulate and visualize three- and four-dimensional, multi-variate soil and landscape data. The upcoming release of ESRI's ArcGIS 8.1 software will have the potential to export GeoVRML format, which enables the dissemination of models via the WWW. The spatial modeling software EVS provides functionality for interpolation and visualization of geo-data, while action streaming is limited to one direction – from the ASCII input geo-dataset to graphical output (client). Currently, seamless bi-directional action streaming from the geo-dataset to graphical output (client) and vice versa is not available.

New tools are needed to explore high-dimensional data spaces representing soil-landscapes enabling users to gain insight into the underlying geo-processes. Until quite recently, little attempt has been made to manage geographic information using true 3-D or 4-D representations. Innovative research studies demonstrate the development of 3-D and/or 4-D GIS prototypes, which can manage multi-variate and multi-dimensional datasets and output 3-D models, and/or animations (Raper et al., 1998; Doellner and Hinrichs, 2000; Edsall et al., 2000; Kreuseler, 2000; Morris et al., 2000) and virtual reality applications (Haase et al., 2000).

5. Outlook

We presented a web-based approach to reconstruct and visualize soil-landscapes in 3-D format. Reconstruction and geographic visualization facilitate the exploration, analysis, synthesis and presentation of geo-referenced information. Numerous agricultural tasks are supported using our approach including 3-D soil surveys, informed decision-making, assessment of environmental quality, farm management, land use planning, and many more. Shiffer (1992) argues that users gain an improved understanding by viewing information from several different graphical perspectives. Krygier (1999) notes that combining multimedia elements (e.g., WWW, 3-D visualization, interactivity) can produce insight that would not arise from using of the elements alone. In the realm of education, Freundschuh and Hellevik (1999) note that students can be encouraged to become active participants, rather than passive learners, by appealing to their multi-sensory learning ability with interactive media. Virtual soil-landscape models are beneficial in disseminating geo-referenced earth data to educators, researchers, government agencies, and the general public.

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