Lecture Notes
in Geoinformation and Cartography

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Manfred Buchroithner *Editor*

# True-3D in Cartography

## Autostereoscopic and Solid Visualisation of Geodata

Springer

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## Autostereoscopic and Solid Visualisation of Geodata

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*Editor*
Manfred Buchroithner
TU Dresden
Helmholtzstrasse 10
01062 Dresden
Germany
manfred.buchroithner@tu-dresden.de

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# Preface

Over the past fifteen years the city of Dresden in Germany has been gaining international reputation in the autostereoscopic depiction of geodata. Hardcopy and softcopy displays are currently being developed and produced by the Dresden University of Technology and three other Dresden-based commercial companies, all spin-offs of the university.

This recent increase in interest and the principally intuitive appeal of "True-3D" in geodata presentation fuelled our motivation to compile a textbook about the present technical status and recent innovative developments.

As a primary step towards attaining this goal a first international symposium was organized in close cooperation with the Executive Committee of the International Cartographic Association (ICA), with several of its Commissions as well as with the support of SPIE Europe and on behalf of the German Cartographic Society (DGfK). The symposium covered almost all aspects of autostereoscopic representations of both topographic and thematic geodata, be they haptic or not, and took place in Dresden between 24th and 28th August 2009.

Displays for large audiences were under discussion along with special single-user applications, and well-established technologies contrasted strongly with cutting-edge developments. This attracted experts from the international cartographic "true-3D community" who exchanged opinions and knowledge about the state-of-the-art in various fields.

Most of the information conveyed during this international symposium has been compiled to form the present volume. Although being far from all-embracing, it represents a first "anthology" treating the rapidly evolving complex field of "True-3D in Cartography".

The contributions contained in this book were reviewed at least twice by an international group of scientists (in alphabetical order): Manfred F. Buchroithner (Dresden, Germany), Arzu Coltekin (Zurich, Switzerland), Harold Moellering (Columbus, Ohio/USA), and Wolf-Dieter Rase (Bonn, Germany). As editor, I am very thankful for the critical remarks of my colleagues with regard to both the articles' contents and the authors' phrasing.

The production of this book would not have been possible without the professional and formidable efforts of Steffi Sharma, Jana Simmert, Ulrike Schinke and Rebecca Dittmann. I also extend my thanks and gratitude to them.

Manfred F. Buchroithner

# List of Contributors

Armstrong, Robert W.
NERC, British Geological Survey
Kingsley Dunham Centre, Keyworth, NG12 5GG, Nottingham
United Kingdom

Ascencio Escamilla, Maria Guadalupe
CUCEI, Universidad de Guadalajara
Blvd. Marcelino García Barragán #1421, JAL 44430 Guadalajara
Mexico

Bektaş, Kenan
Department of Geography, University of Zurich – Irchel
Winterthurerstr. 190, CH-8057 Zurich
Switzerland

Boulos, Maged N. Kamel
Faculty of Health, University of Plymouth
Drake Circus, Plymouth, Devon PL4 8AA
UK

Bruhm, Katharina
Institute for Cartography, Dresden University of Technology
Helmholtzstr. 10, 01062 Dresden
Germany

Buchroithner, Manfred F.
Institute for Cartography, Dresden University of Technology
Helmholtzstr. 10, 01062 Dresden
Germany

Büyükbayrak, Hakan
General Command of Mapping
Tip Fakültesi Caddesi, 06100 Ankara
Turkey

Çöltekin, Arzu
Department of Geography, University of Zurich – Irchel
Winterthurerstr. 190, CH-8057 Zurich
Switzerland

Dalkiran, H. Polat
General Command of Mapping
Tip Fakültesi Caddesi, 06100 Ankara
Turkey

Doležal, Jan
Department of Geoinformatics, Palacký University Olomouc
tř. Svobody 26, 771 46 Olomouc
Czech Republic

Döllner, Jürgen
Hasso-Plattner-Institut, University Potsdam
Postfach 900460, 14440 Potsdam
Germany

Dolz, Wolfram
State Art Collections Dresden, Mathematical-Physical Salon,
Zwinger Palace
Theaterplatz 1, 01067 Dresden
Germany

Eisfelder, Christina
German Remote Sensing Data Center (DFD),
German Aerospace Center (DLR) Oberpfaffenhofen
Münchner Straße 20, 82234 Wessling
Germany

El Nabbout, Khaled
Chair of the Geosciences Department,
European Arabic Engineers Union
Am Kuesterland 18, 44892 Bochum
Germany

Finková, Dita
Institute of Special Education Studies, University Olomouc
Žižkovo nám. 1, 771 00 Olomouc
Czech Republic

Fritsche, Niels-Christian
Institute of Foundations of Design and Architectural Delineation,
Dresden University of Technology
01062 Dresden
Germany

Gede, Mátyás
Department of Cartography and Geoinformatics,
Eötvös Loránd University
Egyetem tér 1-3., 1053 Budapest
Hungary

Gindele, Matthias
ACADIS GmbH
Boelckestrasse 26, 55252 Wiesbaden
Germany

Götzelmann, Timo
Department of Research and Development, PreDevelopment,
NAVIGON AG
Berliner Platz 11, 97070 Hamburg
Germany

Gründemann, Thomas
mbmSystems GmbH
Lingnerallee 3, 01069 Dresden
Germany

Habermann, Klaus
mbmSystems GmbH
Lingnerallee 3, 01069 Dresden
Germany

Hahmann, Thomas
German Remote Sensing Data Center (DFD),
German Aerospace Center (DLR) Oberpfaffenhofen
Münchner Straße 20, 82234 Wessling
Germany

Hetze, Bernd
Center of Information Services and High Performance Computing,
Dresden University of Technology
01062 Dresden
Germany

Jobst, Markus
Hasso-Plattner-Institut, University Potsdam
Postfach 900460, 14440 Potsdam
Germany

Katzer, Jochen
Department of Research and Development, PreDevelopment,
NAVIGON AG
Berliner Platz 11, 97070 Hamburg
Germany

Knust, Claudia
Institute for Cartography, Dresden University of Technology
01062 Dresden
Germany

Koch, Wolf Günther
Institute for Cartography, Dresden University of Technology
01062 Dresden
Germany

Kolecka, Natalia
Institute of Geography and Spatial Management, Jagiellonian University
ul. Gołębia 24, 31-007 Krakow
Poland

Kozáková, Magdaléna
Department of Geoinformatics, Palacký University Olomouc
tř. Svobody 26, 771 46 Olomouc
Czech Republic

Ledesma Tello, Ismael Luis
CGTI, Universidad de Guadalajara
Juárez #976, JAL 44100 Guadalajara
Mexico

Lorenz, Haik
Hasso-Plattner-Institut, University Potsdam
Postfach 900460, 14440 Potsdam
Germany

Ludíková, Libuše
Institute of Special Education Studies, University Olomouc
Žižkovo nám. 1, 771 00 Olomouc
Czech Republic

Mahmud, Ahmad Rodzi
Department of Civil Engineering, Universiti Putra Malaysia
43400 UPM Serdang, Selangor
Malaysia

Mair, Toni
Geomodelia, Landscape relief models studio
Rainstrasse 24, 6314 Unteraegeri
Switzerland

Márquez Azúa, Bertha
DGOT, Universidad de Guadalajara
Guanajuato #1045, JAL 44260 Guadalajara
Mexico

Menounos, Brian
Natural Resources and Environmental Studies Institute,
University of Northern British Columbia
3333 University Way, V2N 4Z9 Prince George
Canada

Moellering, Harold
Department of Geography, Ohio State University
Enarson Hall 154 W 12th Avenue, 43210 Columbus
USA

Nausner, Ben
Department of Geography and Regional Research, University of Vienna
Universitaetstr 7, 1010 Wien
Austria

Němcová, Zuzana
Department of Geoinformatics, Palacký University Olomouc
tř. Svobody 26, 771 46 Olomouc
Czech Republic

Oksanen, Juha
Department of Geoinformatics and Cartography,
Finnish Geodetic Institute
P.O. Box 15, FIN-02431 Masala
Finland

Özağaç, Servet
Head of Relief Map Section, General Command of Mapping
Tip Fakültesi Caddesi, 06100 Ankara
Turkey

Pradhan, Biswajeet
Institute of Cartography, Dresden University of Technology
01062 Dresden
Germany

Rase, Wolf-Dieter
Federal Office for Building and Regional Planning
Deichmanns Aue 31-37, 53179 Bonn
Germany

Regec, Vojtěch
Institute of Special Education Studies, University Olomouc
Žižkovo nám. 1, 771 00 Olomouc
Czech Republic

Riedl, Andreas
Department of Geography and Regional Research, University of Vienna
Universitaetsstrasse 7, 1010 Wien
Austria

Robinson, Larry R.
Geospatial Sciences and Technologies Branch,
USGS-BRD-Upper Midwest Environmental Sciences Center
2630 Fanta Reed Road, La Crosse, Wisconsin 54603
USA

Růžičková, Veronika
Institute of Special Education Studies, University Olomouc
Žižkovo nám. 1, 771 00 Olomouc
Czech Republic

Ruzinoor, Che Mat
Department of Biological & Agricultural Engineering,
Universiti Putra Malaysia
43400 UPM, Serdang, Selangor Darul Ehsan
Malaysia

Sanchez, Conrado
Sigrid S.L.
Ronda de Poniente n° 3, 28760 Tres Cantos (Madrid)
Spain

Sánchez, Javier González
Tecnológico de Monterrey, Campus Guadalajara
General Ramón Corona #2514, JAL 45201 Zapopan
Mexico

Sarjakoski, L. Tiina
Department of Geoinformatics and Cartography,
Finnish Geodetic Institute
P.O. Box 15, 02431 Masala
Finland

Sarjakoski, Tapani
Department of Geoinformatics and Cartography,
Finnish Geodetic Institute
P.O. Box 15, 02431 Masala
Finland

Schwarzbach, Friederike
Department of Geoinformatics and Cartography,
Finnish Geodetic Institute
P.O. Box 15, 02431 Masala
Finland

Schwarzbach, Friederike
Institute for Cartography, Dresden University of Technology
01062 Dresden
Germany

Shariff, Abdul Rashid Mohamed
Department of Biological & Agricultural Engineering,
Universiti Putra Malaysia
43400 UPM Serdang, Selangor
Malaysia

Stendel, Dirk
ILaUP, Technische Universität Berlin
Straße des 17. Juni 145, 10623 Berlin
Germany

Straumann, Ralph K.
Department of Geography, University of Zurich – Irchel
Winterthurerstr. 190, 8057 Zurich
Switzerland

Suter, Martin
ESRI Schweiz AG
Josefstrasse 218, 8005 Zurich
Switzerland

Trapp, Matthias
Hasso-Plattner-Institut, University Potsdam
Postfach 900460, 14440 Potsdam
Germany

Ungvári, Zsuzsanna
Department of Cartography and Geoinformatics,
Eötvös Loránd University
Egyetem tér 1-3., 1053 Budapest
Hungary

Vondráková, Alena
Department of Geoinformatics, Palacký University Olomouc
tř. Svobody 26, 771 46 Olomouc
Czech Republic

Voženílek, Vít, Prof.
Department of Geoinformatics, Palacký University Olomouc
tř. Svobody 26, 771 46 Olomouc
Czech Republic

Weckman, Suvi
Department of Geoinformatics and Cartography,
Finnish Geodetic Institute
P.O. Box 15, 02431 Masala
Finland

Weiss, Gunter, Prof.
Institute of Geometry, Technische Universität Dresden
01062 Dresden
Germany

Wheate, Roger
Natural Resources and Environmental Studies Institute,
University of Northern British Columbia
3333 University Way, V2N 4Z9 Prince George
Canada

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# Introduction

## Perspectives on 3-D Visualization of Spatial Geodata and Future Prospects

*Moellering, H.*

# Perspectives on 3-D Visualization of Spatial Geodata and Future Prospects

Harold Moellering

Department of Geography, Ohio State University, Columbus, Ohio, U.S.A.

## Abstract

*For more than a century spatial scientists have sought to mathematically describe, illuminate, and visualize various forms of spatial surfaces, and other 3-D and higher dimensional spatial data. In the early years these were mostly physical terrain surfaces illustrated under the rubric of hill shading. In the first half of the 20th century rapid developments in 3-D visualization occurred largely in air photo and analogue photogrammetry.*

*Beginning in the 1960s it became feasible to implement quantitative formulations in computing machines. This provided the opportunity to operationalize the mathematical theory in a digital virtual environment that was much more flexible than before. At about that time the use of homogeneous coordinate transformations provided a major breakthrough for digital 3-D object visualization. The involvement of interactive control and visualization techniques soon followed. Spatial surfaces, and especially topographic surfaces, were among the more popular objects. Since that time the theory of spatial surfaces and objects, spatial data structure designs, and the technology of display hardware have continued to develop and enhance the 3-D spatial visualization processes.*

*This presentation will reflect on these conceptual and technical developments in spatial 3-D visualization from the perspective of four decades of involvement in the field. Comments and suggestions will be offered for suggestions of future developments.*

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*Keywords:* Analytical Cartography, 3-D Stereoscopic Vision, Lenticular Vision, Virtual Maps, Perceptual Color Spaces, History of Visualization.

## 1 Introduction

Today a wide range of individuals – also outside the field of cartography proper - is working with cartographic and spatial visualization, and with the hardware technology of 3-D displays. Many of them are using these concepts and technologies in interesting and effective ways.

The present paper strives to present some historical background coming initially from the field of cartography and then from Analytical Cartography, and then later from some of the more scientific and technical topics that will provide more insight and enrich the discussion. It focuses on some broader spatial visualization topics, outside of the excellent visualization research conducted by Prof. Buchroithner and colleagues that will be discussed in individual papers in this volume.

The article has a North American perspective. Much of the analytical theory is discussed by Harold Moellering (2000) in a review of the concepts in Analytical Cartography.

## 2 A look at some history of analytical visualization

One can begin with the traditional hard copy map used over more than 3,000 years of human history. These 2-D hard copy maps served civilization well through the centuries for mapping and navigation purposes. Well known examples are Babylonian clay tablets, Egyptian maps on papyrus, Chinese imperial maps, down through the ages to European portolan charts that were used for navigation at the beginning of the Age of Discovery. One exotic example is the 2 1/2-D wood navigation models made by the Polynesian Islanders for sailing across the Pacific Ocean.

Beginning in the 19th Century, one began to see the rise of Analytical Visualization where one began to use mathematical concepts to understand spatial surfaces and visualize them. One of the earlier was Cayley (1859) where he picked up on some of the concepts of continuous surfaces from mathematics. He also began to look at the critical points and lines on a surface where the mathematical derivatives change, and explore how those relate to surface contours and slope lines. Now spatial surfaces could be conceptualized analytically beyond just description.

A couple of decades later, Wiechel (1878) began to use the concepts from what we now call the Cosine Law to calculate the illumination of a light source at a point on a topographic surface as shown in Fig. 1. This was a cumbersome effort because the angle between the light ray and the normal to the slope had to be derived indirectly with equations as shown in Fig. 2. This calculation using the normal to the slope, vertical of the topographic datum, azimuth to the light ray and azimuth to the surface normal is still used today in such computations. The irony is that at the time one could only make individual illumination calculations for individual points on a surface. It is only with a computer more half a century later did such calculations and surface illuminations become practical in the spatial sciences.

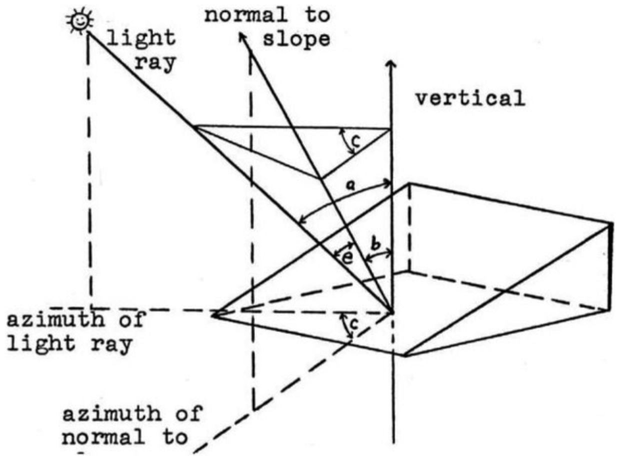
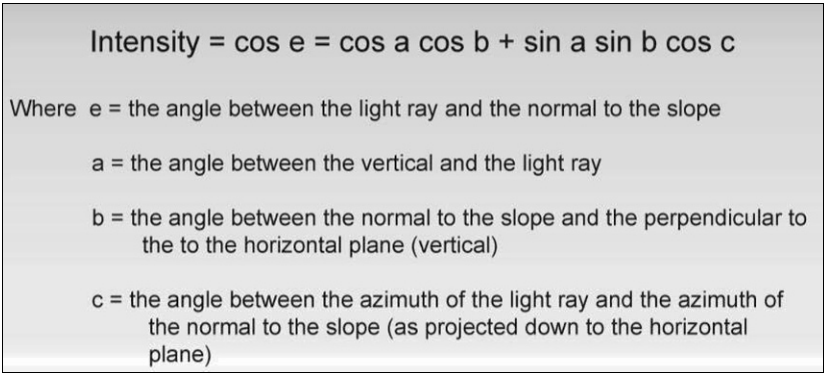


**Fig. 1.** Wiechel Aalytical Point Illumination 1878 (after Webster)



Intensity = cos e = cos a cos b + sin a sin b cos c

Where e = the angle between the light ray and the normal to the slope

a = the angle between the vertical and the light ray

b = the angle between the normal to the slope and the perpendicular to the to the horizontal plane (vertical)

c = the angle between the azimuth of the light ray and the azimuth of the normal to the slope (as projected down to the horizontal plane)

**Fig. 2.** Wiechel Illumination on a Surface (1878)

Beginning in the 1950s one began to see the rise of computer technology in a systematic way that begins to provide digital approaches to spatial visualization. This provided the beginnings of spatial data base files, and the development of new hard copy technologies. Later as the 1970s dawned did one see the development of several key conceptual and technical innovations in computer graphics which greatly benefited spatial visualization. They were: 1) Homogeneous Coordinate axes, which provided for more robust calculations of nearly parallel coordinate axes, 2) Homogeneous Matrix Transformations, which provided 3-D "straight space" orthogonal axis transformations such as translation, rotation, scaling, and perspective, 3)More effective and efficient visible surface algorithms based on the "straight space" coordinate axes. These led to many new strategies in spatial visualization.

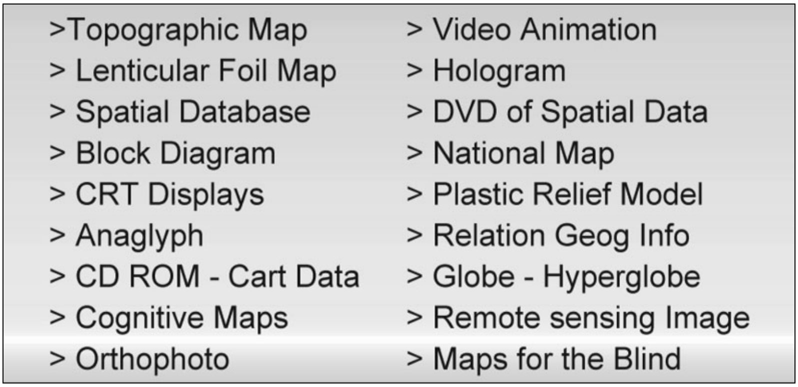
Also in the 1970s one began to see a host of conceptual innovations in spatial visualization that benefited from the earlier innovations in computer and computer graphics concepts and technologies. Examples include:

- Effective Square Cell Structures
- Raster-Vector Conversions
- Topological Spatial Data Structures
- Invention of the Triangulated Irregular Network - TIN Model
- Development of the Warntz Network on a Surface
- Development of "Pfaltz" surface networks
- Creative uses of reorienting sun angle on a surface
- Topological Surface Generalization.

There is a rich literature on these and many other conceptual innovations in spatial visualization during this period. One further example is that by Horn (1982) which reviews the concepts of computer graphics and shading, and integrates that with existing concepts of Analytical Hill Shading from the spatial visualization literature. He managed to bring the concepts from these different fields together into one publication.

## 3 Real and virtual maps and their transformations

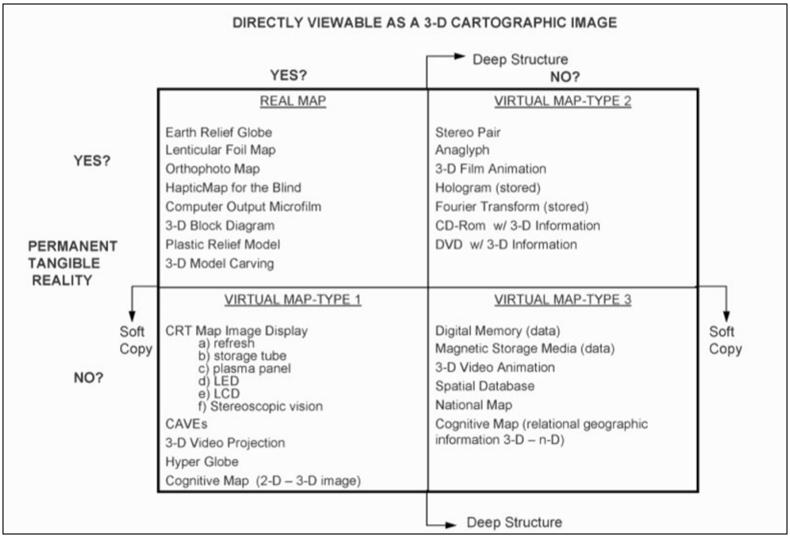
One can now turn to the rich variety of 2-D and 3-D maps that have been developed in spatial visualization. They range from the lowly topographic map to the sophisticated 3-D lenticular displays. Some are hard copy real maps, and some are various forms of virtual maps. Fig. 3 shows a selected list of such products. The primary question is how can one understand them on a conceptual basis?



- >Topographic Map
- > Lenticular Foil Map
- > Spatial Database
- > Block Diagram
- > CRT Displays
- > Anaglyph
- > CD ROM - Cart Data
- > Cognitive Maps
- > Orthophoto
- > Video Animation
- > Hologram
- > DVD of Spatial Data
- > National Map
- > Plastic Relief Model
- > Relation Geog Info
- > Globe - Hyperglobe
- > Remote sensing Image
- > Maps for the Blind

**Fig. 3.** Many Kinds of Map Products

One approach is to look at the two fundamental conceptual characteristics of such a display, and then to classify them. The first characteristic is whether the product is hard copy or not. The second is whether the product is directly visible as a spatial/cartographic image, or not. From there on can construct a four class table of Real and Virtual Maps as shown in Fig. 4. This particular Table of Real and Virtual Maps contains 3-D examples that are in harmony with the theme of the conference. Now one can better understand the kind of spatial product and its characteristics that one is working with. This fourfold classification helps one to more systematically understand these products and how they relate to each other.



DIRECTLY VIEWABLE AS A 3-D CARTOGRAPHIC IMAGE

| PERMANENT TANGIBLE REALITY | YES? | NO? |
|---|---|---|
| YES? | REAL MAP<br>Earth Relief Globe<br>Lenticular Foil Map<br>Orthophoto Map<br>HapticMap for the Blind<br>Computer Output Microfilm<br>3-D Block Diagram<br>Plastic Relief Model<br>3-D Model Carving | VIRTUAL MAP-TYPE 2<br>Stereo Pair<br>Anaglyph<br>3-D Film Animation<br>Hologram (stored)<br>Fourier Transform (stored)<br>CD-Rom w/ 3-D Information<br>DVD w/ 3-D Information |
| NO? | VIRTUAL MAP-TYPE 1<br>CRT Map Image Display<br>a) refresh<br>b) storage tube<br>c) plasma panel<br>d) LED<br>e) LCD<br>f) Stereoscopic vision<br>CAVEs<br>3-D Video Projection<br>Hyper Globe<br>Cognitive Map (2-D – 3-D image) | VIRTUAL MAP-TYPE 3<br>Digital Memory (data)<br>Magnetic Storage Media (data)<br>3-D Video Animation<br>Spatial Database<br>National Map<br>Cognitive Map (relational geographic information 3-D – n-D) |

**Fig. 4.** The Scientific Definition of 3-D Real and Virtual Maps

When one is working with such spatial visualization products, one typically begins with spatial data, a Virtual type 3 product and transform it into a product that is visible, a Real Map if it is hard copy, and a Type 1 virtual display if it is not hard copy. It turns out that when working with spatial data and generating spatial displays one typically makes many of these kinds of Real/Virtual map transformations in the process. Fig. 5 shows the 16 possible Real/Virtual map transformations that are possible. If one considers these 16 transformations carefully, it becomes clear that they define all of the processing steps one could make while processing spatial data.

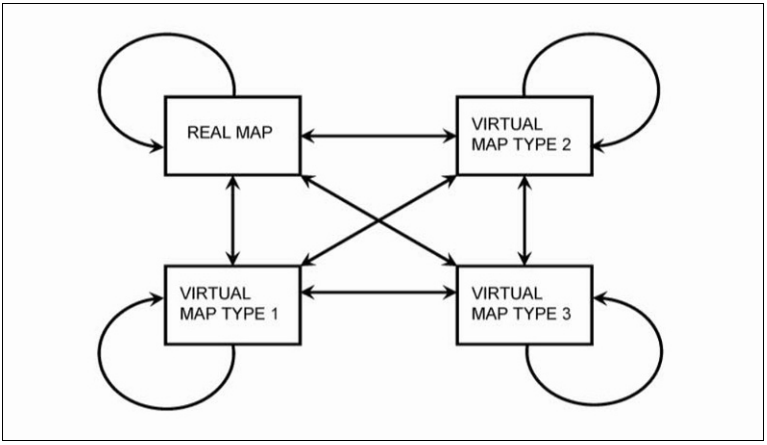


**Fig. 5.** 16 Transformations Between Real and Virtual Maps Defines all Operations in Spatial Data Sciences

One straightforward example shown in Fig. 6 is a Real Time Interactive Spatial Analysis System at a very general level. Most spatial data display systems are configured like this at this level of generality. One could then go in and define these processes at a much greater level of detail in terms of the Real/Virtual transformations taking place in such a system. This means that any kind of spatial data processing or display system can be conceptually understood as working with a host of sequential Real/Virtual map transformations as it operates. One can also use such transformations to help design such a system and the functionalities it contains.

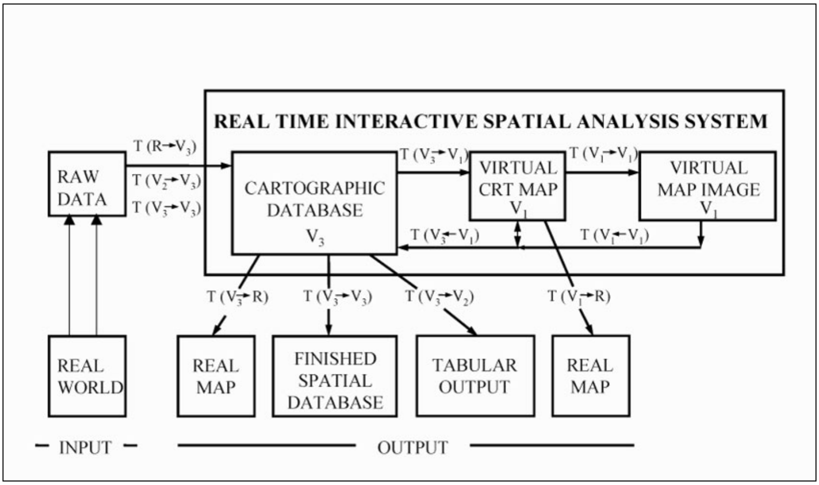


**Fig. 6.** Real Time Spatial Analysis and Display System Conceptualized With Real and Virtual Map Transformations

## 4 Deep and Surface Spatial Structure

While examining the spatial characteristics of spatial data, one can also consider the concept of Deep Structure. Nyerges (1980) adapted the concept of deep structure over from the discipline of structural linguistics to serve this purpose with spatial data. Fig. 7 illustrates the concept of Deep and Surface spatial structure in the spatial sciences. Here Surface Structure is spatial data that is in spatial products that are visible to the observer. These are Real Maps and Virtual Map Type 1.

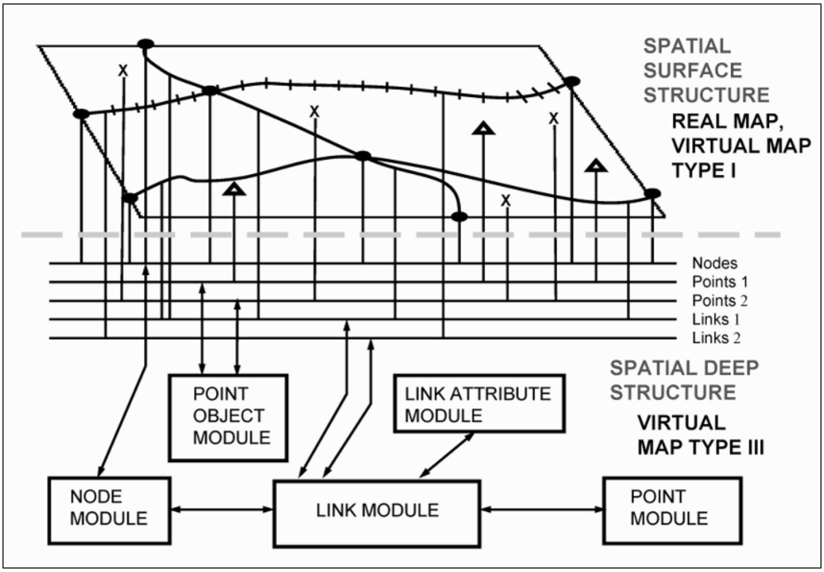


**Fig. 7.** Representation of Deep and Surface Spatial Structure

Then Deep Structure is the characteristic of spatial data that is not directly visible, say data deeper in a spatial data structure in a system. Virtual Maps Type 3 fall into this category. Please also refer to Fig. 4. In an interactive spatial data processing system, the computational processing of the data takes place in the deep structure level, and then when it is visualized, it emerges into the surface structure. Spatial metadata is a good example of Deep Structure information about a spatial feature.

The concept of Deep and Surface Spatial structure helps the researcher to more fully understand the characteristics of the spatial data with which one is dealing. The concepts of Deep and Surface Structure and Real/Virtual Maps complement each other conceptually and scientifically to yield a better understanding of the spatial data one is processing and visualizing.

## 5 Nyerges Spatial Data Levels

A third major concept that helps us understand the concepts of spatial data more completely is that of Nyerges Data Levels (1980). One begins with:

- Real World Entities
  1. Data Reality - Geographic entities in the Real World;
  2. Information Structure - A formal model of geographic entities and their relationship in the Real World.

Real World Entities are things that exist in the real world such as buildings, roads and lakes. The Information Structure contains the spatial relationships between these various Real World Entities.

- Spatial Object Model
  3. Canonical Model - A formal model of the spatial data objects in the deep structure;
  4. Spatial Data Structure - An operational spatial data model used for spatial analysis and visualization.

The Canonical Model takes the same relationships from the Information Structure and now relates those relationships to the defined spatial data objects. These are then organized into the Spatial Data Structure to produce a working spatial database.

- System Hardware & Architecture
  5. Storage Structure - The file structures of how the spatial data structures are stored in the computer system.
  6. Machine Encoding - A machine representation of the file structures in the computer system hardware, e.g. bits and bytes.

Most spatial scientists work with the first four levels of data, while only computer specialists would deal with levels 5 and 6. This conceptual organization of data levels is distinctive in that it separates the spatial relationships into two levels: the Information Structure which points up to the Real World entities, and the Canonical Model which deals with the spatial objects such as nodes, links and polygons. Many approaches lump those two levels together, but in the spatial sciences it is very helpful to specify them separately as Nyerges has done. This improves the conceptual understanding of how one is treating the spatial data involved in the system.

## 6 Early 3-D digital stereoscopic visualization

Stereoscopic visualization has been a part of civilization for millennia as ordinary human 3-D analogue vision. In the last few decades mechanical analogue approaches to stereoscopic vision has been developed with the use of analogue stereo pairs in air photo analysis. This was enhanced with the later development of analogue photogrammetric instruments. However,