NCGIA

National Center for Geographic Information and Analysis

Selected Annotated Bibliography On Visualization of the Quality of Spatial Information

Research Initiative 7

by

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Preface

This bibliography has been prepared in conjunction with NCGIA Research Initiative 7, "Visualization of Spatial Data Quality," as an aid to research. The bibliography lists those researchers whose work falls within Initiative 7 and contains over 200 references. Issues of uncertainty, quantitative and qualitative descriptions of quality, management and quality control, and impact of quality on decision making are just a few of the areas included in this bibliography. For this bibliography to be as useful as possible, the authors have included comprehensive citations and for most entries, the abstracts are also included.

Visualization of the quality of spatial data is a critical tool for the effective use of GIS, a tool which has become more urgently needed with the growing reliance on GIS, particularly in the decision making environment. Visualization tools potentially provide the GIS users with powerful insight capabilities into the nature of data. Two issues are central to the visualization of spatial data quality: 1) how to model, assess, and represent quality information in a digital database and 2) how to provide users with effective access and display methods for the communication of quality information. Given this intrinsic link between the modeling of quality and its visualization, the authors thought it beneficial to classify the citations under three broad categories: 1) Issues pertaining to the modeling, quantitative and qualitative description of quality in spatial data, and 2) visualization techniques and 3) the visualization of spatial data quality.

The authors of this report have attempted to include very current, accessible articles to be found in conference proceedings, reports, journals and books. Completeness can never be guaranteed, despite a comprehensive and systematic search of various GIS proceedings and journals. For any omissions, the authors apologize profusely. Please feel free to submit additional bibliographic material for consideration of updated versions of this report.

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BIBLIOGRAPHY

ISSUES OF DATA QUALITY

Amhein C G and Griffith, D A 1991 A Model for Statistical Quality Control of Spatial Data in GIS. Proceedings of The Canadian Conference on GIS '9 1, Ottawa 1: 91-103.

Altman D 1994 Fuzzy Set theoretic approaches for handling imprecision in spatial analysis International Journal Of Geographical Information Systems, 8 (3): 271-289. Abstract: This paper presents methodologies for modeling imprecision in the definition, analysis and synthesis of two-dimensional features. The imprecision may arise through incomplete information, the presence of varying concentrations of attributes, or the use of qualitative descriptions of spatial features or their relationships. The work is intended to have applications in geographical information systems (GIS), but is equally applicable to other types of spatial information systems or spatial database applications. Fuzzy sets are used as a representational and reasoning device. The paper contains definitions of an imprecisely defined spatial feature or fuzzy region; definitions of distance and directional metrics between two such regions; a methodology for analysis of the spatial relationship between two regions; and a methodology for synthesis of new regions that are subject to the presence of imprecise spatial constraints.

Angwin G T 1991 Quality Control of Digital Map Generation. Proceedings GIS/LIS '91, 2: 715723. Atlanta. Abstract: Statistical methods for quality control and inspection of product have been used since the 1920's to enhance the quality of manufactured products. Applying these methods to the production of digital maps presents some new challenges such as the definition of a lot and random sampling of appropriate map elements. This paper surveys the issues involved in applying statistics to controlling the quality of data capture and inspecting the resulting digital maps, then illustrates the ideas by describing the approach taken at Etak.

Baker K 1991 Positional Accuracy Considerations for a Digital Cadastral Database. Proceedings of the Symposium on Spatial Database Accuracy, 1:36-48. Melbourne: University of Melbourne. Abstract: The existence of large cadastral databases which are derivatives of paper based systems present spatial accuracy problems to users. The user base of these systems is ever growing and due to merging with other data, spatial accuracy problems are being highlighted. Many organisations are now addressing the need to effectively resolve this problem. This paper outlines current initiatives underway at the Department of Lands in Queensland. These include an innovative method of attaching positional accuracy indicators.

Bartakovich A 1994 Quality Assurance Of National Topographic System Paper Products Proceedings of the Canadian Conference on GIS, Ottawa, Canada June 6-10. 2: 879-890. Abstract: Recently the Canada Centre for Mapping has developed and implemented a system for assuring the quality of National Topographic System (NTS) paper products. The QA System examines each of the four parameters of map quality (integrity accuracy process precision and lineage) and reports on the effectiveness of the Centre in meeting predetermined quality standards. In the case of recurring deficiencies the Quality Assurance Section may be called upon to recommend corrective actions which will contribute to the improvement of the quality of the product. Using the key elements of the ISO definition of quality assurance and statistical sampling methods as outlined in the MIL-STD-1051) sampling scheme the QA System consists of a series of independent and organized procedures that provides management with feedback on the quality of the NTS products regarding existing standards and specifications. This paper describes the four parameters and outlines the procedures and the techniques used to evaluate the quality of each parameter.

Beard M K 1989 Use Error: The Neglected Error Component. Proceedings of AUTO-CARTO 9, 808-817. Abstract: Commonly recognized map errors include those associated with data collection (source error) and the processing of data for map compilation (process error). Another error component, use error is defined and added to this typology. This paper argues that without attention to use error, large investments to reduce source and process error may be wasted. Traditional representation of spatial information on paper maps has limited our ability to control this form of error in any significant way. While the misuse of maps cannot be entirely avoided, computer technology offers a possibility for limiting the opportunities for misuse. This idea is explored by examining ways in which maps are misused, and from this exploration, formulating geographic information system design strategies that may counteract the potential for use error.

Bedard Y 1987 Uncertainties in Land Information Systems Databases. Proceedings of AUTOCARTO 8,175-184. Abstract: Based on the communication paradigm of Land Information Systems, this paper presents (1) how uncertainty is inevitably introduced in LIS databases, (2) four resulting types of uncertainty, and (3) different means to deal with uncertainty. Finally, the paper suggests that there exist two classes of land data with regards to their reliability.

Bell K C 1991 Data Quality And Spatial Data Integration: The Australian Geographic Data Base Program. Proceedings AURISA'91, 1: 569-575. Wellington: Australasian Urban and Regional Information Systems. Abstract: Ile Australian Geographic Data Base (AGDB) Program reflects a change in emphasis in the Australian Surveying and Land Information Group's (AUSLIG) national mapping and adas programs. Digital data have previously been a spin off from the production of printed maps. The AGDB, as part of

Australia's national spatial data infrastructure, will provide digital spatial data to meet the needs of land/geographic information systems (LIS/GIS) and other users and will improve the efficiency of AUSLIG's map production. The development of the AGDB is AUSLIG's response to user demand for high quality digital spatial data suitable for use in land/geographic information systems (LIS/GIS) and mapping. The implementation of the AGDB will lift the quality of AUSLIG's digital data products and through a truth in labeling approach these data will offer a product that can be confidently integrated with other spatial data. The AGDB program will address issues such as data quality, data structuring, import into LIS/GIS and more efficient and reliable data transfer. This paper describes the AGDB and examines issues related to data quality and transfer of national digital spatial data sets.

Bolstad P V, Gessler P, Lillesand, T M 1990 Positional Uncertainty in Manually Digitized Map Data International Journal of Geographical Information Systems 4 (4): 399-412 Abstract: Digital map coordinates represent the locations of real world entities. As such, differences can exist between the 'true' and digital database coordinates of those entities. This paper reports on a statistical characterization of positional error in manually-digitized and map-registered point data, the relative contribution of point type and operator to digitization error, and the effects of map media type on the positional uncertainty associated with registration. Manually-digitized point data were collected by four operators from mylar and paper maps. Point locations for a number of different feature types were sampled from United States Geological Survey (USGS) 1: 24 000 scale maps. Linear models were used to estimate the variance components due to among-operator, map media, point type and registration effects. The statistical distribution of signed distance deviations for manually-digitized data was leptokurtic relative to a random normal variate. Unsigned deviations averaged 0.054 mm. Squared distance **deviations were not different from** a Chi-square random variate. Variance components indicate that among-operator differences in positional uncertainty were large and statistically significant, while differences among point type were small and nonsignificant. Signed distance deviations associated with a first-order affine followed a normal distribution.

Bolstad, P V 1991 Positional Uncertainty in Natural Resource Spatial Data: The Contribution of Camera Tilt and Terrain Relief. Proceedings of GIS/LIS '91, 2: 874-881. Atlanta. Abstract: Errors were estimated for GIS spatial data derived via monoscopic interpretation of 230 (9-inch) aerial photographs. Positional and area error were observed for a range of photo scales, camera tilts, and relief. Average positional error was observed between 4 and 104 meters and varied positively with tilt and terrain range and inversely with scale. Maximum average errors were approximately 3 to 4 times overall averages. Average errors in polygon area were observed over a range of polygon sizes, from 40 to 600 meters. Average percent area error ranged from 1.3 to 10.7 percent and was positively related to tilt and terrain range and not related to scale or polygon size. The magnitude of these errors and the available cost of correction technologies suggest analytical methods for removing relief and tilt distortion should be used where possible.

Brimicombe A J 1993 Combining Positional And Attribute Uncertainty Using Fuzzy Expectation In A GIS Proceedings GIS/LIS 93 Nov 2-4,1993 Minneapolis Minnesota 1: 72-81 Abstract: Spatial data of natural resources and other aspects of the environment are frequently inexact with levels of inherent and perceived uncertainty. The literature mostly treats positional and attribute uncertainty separately. A model has been developed which provides the basis for recording uncertainty, for propagation of uncertainty during data transformation and for assessing fitness-for use of outcomes. In the context of this model, a metric fuzzy expectation - has been developed as an extension of fuzzy sets and fuzzy numbers into a coordinate system and linguistic uncertainty descriptor. Using this metric, thematic uncertainty can be modeled over vague boundaries.

Bruegger B 1994 A Spatial Theory for the Integration of Resolution Limited Space. Unpublished PhD thesis, Department of Surveying Engineering, University of Maine. Abstract: This thesis presents a major contribution to the understanding of how to integrate data sets of different levels of resolution and format (i.e., raster or vector). The results are possible due to an approach that (i) explicitly models how sensor resolution limits spatial knowledge in GIS representations, and (ii) uses format-independent representations that can be finitely implemented in either raster or vector models (with minor extensions). The thesis objective is to develop a GIS architecture that allows a comprehensive treatment of resolution and format issues. The backbone of this architecture is a consistent spatial theory consisting of (i) representations, (ii) meta-data that include resolution, format, and uncertainty, and (iii) transformations that convert data sets across levels of resolution and formats.

Brunsdon C, Carver S, Charlton M and Openshaw S 1990 A Review of Methods for Handling Error Propagation in GIS Proceedings EGIS '90 106-116.

Burrough P 1987 Multiple Sources Of Spatial Variation And How To Deal With Them. Proceedings Auto Carto 8 145-154. Abstract: Conventional methods of thematic mapping often assume implicitly that only one major pattern can be recognized at any given scale of mapping. Conventional thematic map representations model spatial units by 'homogeneous' units or polygons representing the various components of the pattern being mapped. Interpolation methods allow gradual variation within spatial units to be mapped but they commonly also ignore the problems that arise from multiscale sources of variation. Observed natural variation may be caused by a number of separate spatial processes operating with various weights (intensities) over a range of scales. This paper reviews some ways in which theoretical multiscale models, complex semivariograms, robust methods and sampling strategies can be applied to the problem of multiple sources of spatial variation.

Campbell W G and Mortenson D C 1989 Ensuring the Quality of Geographic Information System Data: A Practical Application of Quality Control. Photogrammetric Engineering and Remote Sensing, 55(11): 1613-1618.
Abstract: Errors within GIS data can limit the usefulness of GIS technology. To control and document the error introduced during data entry, we have instituted a series of Quality Control (QC) procedures for use within the U.S. Environmental Protection Agency's Direct/Delayed Response Project (DDRP). Central to our approach has been the use of formalized log sheets detailing the steps necessary for validating and digitizing mapped data. Additionally, we have evaluated the accuracy and precision of the data at specific stages of the data entry process. At critical stages, these formalized evaluations were independently repeated. We believe that the establishment of QC procedures within the DDRP has lead to very low error rate associated with GIS data entry. Our procedures and techniques described within this paper have other applications within the GIS community.

Carver S 1991 Adding error handling functionality to the GIS toolkit. Proceedings of EGIS '9 1, 1: 187-196. Brussels: EGIS Foundation. Abstract: Accurately representing complex coastlines and boundaries by means of a dense raster database can be costly in terms of storage overheads. Similarly, the representation of terrain surfaces as a large sample digital elevation model can also be very inefficient, especially in areas of mixed relief Defining the tolerances and sampling strategies used in determining the trade-off position between accuracy and economy of storage/processing time in both 2D and 3D GIS can be a rather arbitrary process. Mis-specification can seriously affect the ultimate results gained from GIS analyses and make the difference between efficient and inefficient use of storage space and processing time. Important factors influencing the decisions regarding sampling strategy and relevant tolerances are line and terrain complexity, storage overheads and the accuracy required. The relationships between these factors are investigated in 2D and 3D using simulated landscapes of varying complexity. Particular attention is paid in the paper to the use of quadtree data structures to store 2D polygon information and the use of very important point (VIP) algorithms for reducing the storage requirements of digital terrain models.

Carver S and Brunsdon C 1992 Accuracy and Sampling Strategy in Second and Third GIS Databases: A Study by Simulation. Proceedings of EGIS '92 1: 244-253. Munich: EGIS Foundation. Abstract: Accurately representing complex coastlines and boundaries by means of a dense raster database can be costly in terms of storage overheads. Similarly, the representation of terrain surfaces as a large sample digital elevation model can also be very inefficient, especially in areas of mixed relief Defining the tolerances and sampling strategies used in determining the trade-off position between accuracy and economy of storage/processing time in both 2D and 3D GIS can be a rather arbitrary process. This is usually left to the judgement of the user and mis-specification can seriously affect the ultimate results gained from GIS analyses and make the difference between efficient and inefficient use of storage space and processing time.

Caspary W and Scheuring R 1992 Error-Bands as A Measure of Geometrical Accuracy. Proceedings of EGIS '92, 1:226-233. Munich. Abstract: Generally, there is a lack of concepts expressing the accuracy of the digital data base of spatial information systems. Usually some point measures of positional accuracy, for example the root mean square positional error (RMS) or the circular error probable (CEP), are the only information available on geometrical accuracy. But the user is rather interested in measures for accuracy of objects such as lines, parcels and polygons. The purpose of this paper is to propose a method of describing the accuracy of lines and polygons derived from positional errors of points. The uncertainty of the digital representation of a line is often visualized by a band which is an area defined by two parallels of the most probable position of the line. The constant width of this band is usually interpreted as the diameter of the error circles of all points of the line. This, however, is a simplification. By the law of error propagation it is easily demonstrated, that points in the middle of the line possess smaller RMS values than the end points. Because of this the correct error-band is not a rectangle but a band bordered by sagging rather than by straight lines. Further investigations have been carried out to determine the shape of the band at the end of a line and at comer and junction points of polygons.

Chrisman N R 1983 The Role of Quality Information in the Long-term Functioning of a Geographic Information System. Proceedings of Auto Carto 6, 1: 303-312. Abstract: A geographic information system requires a method to maintain its contents over the longterm. This process must handle quality components along with the data directly depicted on a map. Quality information includes lineage records, accuracies of position and classification, integrity of data structure and temporal reference, among other things. The quality component informs users of suitability for their applications, and it also offers distinct advantages to data producers with responsibility for long-term maintenance. Quality information is not currently maintained by most available software. New data structures and algorithms will be required to meet this need.

Chrisman N R 1984 The role of Quality Information in the Long- Term Functioning of a Geographical Information System Cartographica 21: 79-87.

Chrisman N R 1986 Obtaining Information on Quality of Digital Data Proceedings Auto Carto London 1: 350-385. Abstract: Quality information has been recognized as an important component of geographic information systems, at least in theory. This paper expands on the definitions of quality information with particular reference to sources. Many system developers believe that quality information will make enormous demands, and that the user may be unwilling to pay for such extravagance. This paper provides a counter

argument, maintaining that quality information is currently processed and maintained. Digital cartography usually proceeds on the presumption that the manual system is hopelessly outdated and encrusted with peculiar rites of dubious importance. This paper argues that quality information is a continual concern in the traditional practice of cartography. Examination of a few diverse cases reveals a broad range of quality information maintained by producers which can be fully integrated into current spatial databases. Better exploitation of quality information can improve communication with users and it can also cut costs inside the producing agency.

Chrisman N R 1987 The Accuracy of Map Overlays: A Reassessment. Landscape and Urban Planning, 14: 427-439.

Chrisman N R 1989 Error in Categorical Maps: Testing versus Simulation. Proceedings of Auto Carto 9, 521-529. Abstract: Understanding error in maps requires a combination of theory (new models) and practice (understanding how error can be measured in real applications). While other research emphasizes mathematical models to simulate error, a practical test provides a more useful judge of cartographic data quality. A comprehensive test, overlaying two categorical maps intended to be the same, can provide an estimate of separate components of error including positional and attribute accuracy along with scale effects.

Chrisman N R 1989 Modeling Error in overlaid categorical maps. Accuracy of Spatial Databases. London, Taylor and Francis. 21-34. Abstract: A model for error in geographic information should take high priority in the research agenda to support the recent explosion in use of GIS. While the treatment of surfaces and spatial autocorrelation is more mathematically tractable, much of the GIS layers consist of categorical coverages, analyzed through polygon overlay. This paper provides a basic taxonomy of forms of error in this type of information and provides some questions for future research.

Chrisman N R 1991 The error component in spatial data. In Geographical Information Systems: principles and applications D J Maguire, M F Goodchild and D W Rhind (Eds.), 1: 165-174. Essex: Longman Scientific and Technical. Abstract: Although most data gathering disciplines treat error as an embarrassing issue to be expunged, the error inherent in spatial data deserves closer attention and public understanding. This chapter presents a review of the components of error in spatial data, based on Sinton's scheme of roles in the measurement process and also on the categories in the US Proposed Standard for Digital Cartographic Data Quality.

Chrisman N R and Lester M 1991 A Diagnostic Test for Error in Categorical Maps. Proceedings Auto-Carto 10: Technical Papers of the 1991 ACSM-ASPRS Annual Convention, 6: 330-348. Baltimore: ACSM-ASPRS. Abstract: A test based on exhaustive overlay of two categorical maps provides a description of error distinguished into the likely sources of that error (a diagnosis of the error). The results of the overlay are characterized by geometric, topological and attribute criteria to separate the most likely positional errors from the attribute errors. This paper applies the proposed test to a simple land cover map, which was replicated by a second interpreter. Results diagnose the positional inaccuracy and misidentifications common in such a GIS layer. Adopting this test will target the efforts of a producer's quality control functions, and it will also clarify fitness for the particular uses contemplated by others.

Clarke A 1991 Data Quality Reporting in the Proposed Australian Spatial Data Transfer Standard. Proceedings of the Symposium on Spatial Database Accuracy, 1: 252-259. Melbourne: University of Melbourne. Abstract: Standards Australia proposes to clone the U.S. Spatial Data Transfer Standard (SDTS) to supersede the current Australian spatial data standard, AS 2482. SDTS adopts a 'truth in labeling' approach to data quality, requiring users to report what is known about the lineage, positional accuracy attribute accuracy, logical consistency and completeness of the data being transferred. The AS 2482 and SDTS data quality reporting requirements are described, and the implications for data producers are discussed. It is proposed that spatial data users critically review the quality of the SDTS quality reports supplied by data producers, and that they specify their data quality requirements within the SDTS report structure.

Couclelis H, Beard M K and Mackaness W A 1992 Two Perspectives on Data Quality NCGIA Technical Report 92-12 Dec, NCGIA, University of California, Santa Barbara. The first report discusses the impediments to effective quality control, and proposes a conceptual model to monitor GIS product quality at any state of deriving an application; the second outlines a research agenda based on the identification of impediments to data quality.

Coward P and Heywood 11991 Aspects of uncertainty in spatial decision making. Proceedings of EGIS '91, 1: 233-242. Brussels: EGIS Foundation.

Coward P and Heywood 11992 Multiple Criteria Decision Analysis as a Method for Quality Assurance in GIS. Proceedings The Canadian Conference on GIS , 1: 643-653). Ottawa. Abstract: Quality assurance is an area of applied GIS which is growing in importance. At present much of the current research involves the use of complex statistical techniques which require large amounts of processing power and are difficult to comprehend by potential users. This paper will outline research underway at the University of Salford towards developing a hierarchical structure for assigning significance and weights to error sources in spatial information. This approach forms the basic building blocks for a user centered approach to quality assurance. The techniques employed draw upon Multiple Criteria Decision Analysis (MCDA) as a working methodology. The model described here is implemented using procedures which already exist in the SPANS GIS.

Deichmann U, Ansel L and Goodchild M F 1992 Estimation Issues In The Areal Interpolation Of Socioeconomic Data Proceedings of EGIS 92 254-263 Abstract: Spatial data are collected and represented as attributes of spatial objects embedded in the plane. We define basis change as the transfer of attributes from one set of objects to another. Methods of basic change for socioeconomic data are reviewed, and are seen to differ in the assumptions they make about underlying density surfaces. We extend these methods to more general cases, and provide an illustration using California data. The implementation of this framework within a GIS is discussed.

Detrekoi A 1994 Data Quality Management In GIS Systems. Computers Environment And Urban Systems, 1994 Mar-Apr, 18 (2):81-85.

Dillard R 1992 Using Data Quality Measures In Decision-Making Algorithms. IEEE Eaert, 1992 Dec, 7 (6):63-72.

Dunn R, Harrison A R and White J C 1990 Positional accuracy and measurement error in digital databases of land use: an empirical study. International Journal of Geographic Information Systems 4(4): 385-398. Abstract: This paper discusses the issues of positional accuracy and measurement error in the context of a large empirical study of landscape change in England and Wales. The epsilon band model of digitizing accuracy is used to make estimates of the levels of positional uncertainty and measurement error that is due to digitizing polygon outlines. The degree of error expected had the same polygons been captured in raster format is then detem-iined. These results prompt a general discussion of the nature of error in spatial databases

Dutton G 1992 Handling Positional Uncertainty in Spatial Databases. In P. Bresnahan, E. Corwin and D. Cowen (Ed.), Proceedings of the 5th International Sy=osium on Spatial Data Handling, 2: 460-469. Charleston: IGU Commission of GIS. Abstract: Many inaccuracies in digitized map features derive from circumstances of data capture, others from the ways in which features are represented in a database, and others stem from how data are manipulated, particularly when datasets are merged or graphic scales change. This paper describes one way in which vector representation of digitized map features limits their reliability, and by implication, the quality and usability of databases of digitized maps. It describes how locational uncertainty about punctiform, linear and areal cartographic features derives from mislocation of the coordinates that define them regardless of what causes these mislocations in the first place - such as hardware error or operator blunders during digitizing, line widths on source maps and numerical instability in computations - and goes on to specify an approach to handling this inevitable source of error in a systematic way.

Dutton G and Buttenfield BP 1993 Scale Cbange Via Hierarchical Coarsening: Cartographic Properties of Quaternary Triangular Meshes. Proceedings. 16th Conference of the International Canographic Association 3-8 May 1993, Cologne, Germany, vol. 2: 847-862. Abstract: A data model and coordinate system for global spatial data is described: called quaternary triangular mesh (QTM), this model identifies geographic locations as a nested hierarchy of triangles created by subdividing the faces of an octahedron embedded in a planet. At each successive level of subdivision, each facet begets four children, each blossoming forth to occupy slightly more than one-fourth its parent's area. After 16 levels of subdivision, facets are roughly the size of Landsat pixels. By the 30th level, the planet is covered by millions of trillions of facets, each about one square centimeter in area. Once coordinates of puncti form, linear and polygonal digital cartographic features are encoded into hierarchical addresses, they may be retrieved at any level of detail (doublings of scale), as desired. QTM addresses can be retransformed into geographic coordinates by selecting centers of triangular facets or at other locations within them (no unique mapping from QTM to latitude and longitude exists). The paper concludes with a discussion of cartographic problems that QTM encoding of map features can address, perhaps even solve.

Edwards G 1992 The Integration of Remotely Sensed Data Analysis into GIS: Time and Uncertainty Management Needs. In The Canadian Conference on GIS Proceedin , 1: 432-440. Ottawa Abstract: The integration of remote sensing image analysis with GIS technology requires, among other issues, the development of automated and efficient time-management capabilities in GIS software. Remotely sensed images are obtained at intervals ranging from a few minutes to many years, and hence the time management of these data is often more exacting than that of typical cartographic data. Furthermore, effective means of handling uncertainty must be introduced if the results of temporal analyses are to be meaningful. These issues are discussed in some detail, along with research being carried out to put such a capability together.

Eginton D W 1992 Achieving Consensus on GIS Map Accuracy. In D. M. Freund (Ed.), URISA 1992 Annual Conference Proceedings, 1: 12-23. Washington, D. C.: Urban and Regional Information Systems Association. Abstract: Coordination among a multiplicity of local government agencies and public service providers is often critical to the success of a GIS program. Failure to carefully consider accuracy standards can limit the usefulness of the GIS, preclude efficient sharing of data, limit options for cost sharing, and result in costly duplication of efforts. Geodetic and survey control, land parcel and street centerline data are strategic components of a GIS database, since they provide a basis for registration or creation of other sets of thematic data. Plans for development of these three components of the database should be coordinated and should address several key issues, including: future GIS application requirements, database design, sources of data, alternative approaches to establishment of control coordinates, potential uses of aerial photogrammetry, and alternative parcel conversion procedures.

Elmes G A 1992 Data Quality Issues in User Interface Design for a Knowledge-Based Decision Support System. In P. Bresnahan, E. Corwin and D. Cowen (Ed.), Proceedings of the 5th International Symposium on Spatial Data Handling, 1: 303-312. Charleston: IGU Commission of GIS. Abstract: An 'intelligent' geographic information system (IGIS) is being developed as part of a spatial decision support expert system to advise on the management of gypsy moth, a serious pest of deciduous forests in North America. The gypsy moth expert system (GypsES) has three primary knowledge-based components: hazard rating and risk assessment; insect monitoring and prediction; and treatment. Each component is embedded in a GIS designed to have certain aspects of intelligent functionality. The objectives of the development of IGIS for GypsES are to: define a conceptual framework of intelligent functions for spatial data handling; identify the nature of information provided by IGIS components; identify the sources, nature and content of knowledge necessary to develop intelligent functionality; and evaluate IGIS under GypsES test conditions.

Fain M A 1991 Quality Through Conversion Process Management. Proceedings GIS/LIS '9 1, 1: 137-141. Atlanta. Abstract: The quality of the data destined for Geographic Information Systems continues to be a topic of debate and an area that requires serious scrutiny. Quality is first defined in a measurable manner and the costs of poor quality data are discussed. The way to achieve data quality is to view conversion as a process. Process management makes a project-by-project approach obsolete and is used to implement a "Zero defect" philosophy. High quality throughout the process then becomes less expensive than a final quality review phase that requires re-routing and re-working after the fact. The process itself ends up assuming a great deal of the responsibility for the quality of the end product, in effect eliminating opportunities for human error.

Fenstermaker L K 1991 A Proposed Approach for National to Global Scale Error Assessments. Proceedings GIS/LIS '91, 1: 293-300. Atlanta. Abstract: The error assessment of large area classified imagery presents unique problems to the remote sensing scientist. The primary problem is usually a lack of resources to collect sufficient ground information. This paper proposes a field verification and accuracy assessment approach that uses field, aerial and existing data from a representative area. The proposed approach has three phases. The first phase partitions the large area in relatively homogeneous strata. For example the United States may be partitioned into ecoregion types. Then within those strata representative areas that contain most of the classes of interest are selected. The third phase is the stratified random sampling by class, ensuring at least 50 points per class or 100 percent representation of small area resources.

Firns P and Benwell G 1991 ER on the Side of Spatial Accuracy. Proceedings of the Symposium on Spatial Database Accuracy, 1: 192-202. Melbourne: University of Melbourne. Abstract: There are two main issues pertaining to the accuracy of spatial databases. They are defined here as: (a) Spatial accuracy - or the ability of the database to accurately represent the position of objects in space and relative to each other, (b) Descriptive accuracy - or the ability of the database to accurately represent the state of objects in terms of attribute values and non-spatial relationships between each other. This paper is concerned with descriptive accuracy and specifically examines the implications for descriptive accuracy of inappropriate database structures. The entity-relationship (ER) model is used as a framework for analyzing appropriateness of alternative database structures for a specific application and it is shown that an inappropriate database structure as specified by an ER model can preclude the production of accurate information.

Fisher P F 1993 Conveying Object Based Meta Information Proceedings of Auto Carto 11, Minneapolis, Minnesota, Oct 30 - Nov 1, 113-122. Abstract: Metadata and lineage are two related areas of research which have received considerable recent attention from the GIS community, but that attention has largely focused on meta-information at the level of the image, coverage, or data layer. Researchers working in other areas such as error and uncertainty handling, have focused on a lower level within the spatial data, but can also be considered to have been working on metadata. Users require access to the whole set of metadata from the level of the mapset to the elemental object, i.e. the point, line, polygon or pixel. This paper attempts to draw these different research strands together and suggests an umbrella framework for metadata which can be translated to a number of different flavors of metadata for which accuracy, lineage, statistics and visualization are exemplified. This leads to discussion of an interface design which enables rapid access to the metadata.

Fisher P F 1991 First Experiments in Viewshed Uncertainty: Ile accuracy of the viewshed area. Photoganimetric Engineering and Remote Senain LVII(10): 1321-1328. Abstract: Digital elevation models are computer representations of a portion of the land surface. The elevations recorded in the DEM are not, however, without error, and the United States Geological Survey publish a root mean squared error for each DEM. The research reported here examines how that error propagates into derivative products resulting from geographic information system type operations. One product from a DEM, the focus of this paper, is the viewshed. The viewshed is the area observable from a viewing location versus that which is invisible. In this research, repeated error fields with varying parameters are added to the original DEM, and the viewshed is determined in the resulting noisy DEM. Results show that the are of the viewshed calculated in the original DEM may significantly over estimate the viewshed area.

Fisher P F 1987 The Nature of Soil Data in GIS: Error or Uncertainty. Proceedings of the International Geo=phic Information Systems (IGIS) Sympgsium: The Research A3: 307318.

Fisher P F 1991 Simulation of the Uncertainty of a Viewshed. In Auto-Carto 10: Technical Papers of the 1991 ACSM-ASPRS Annual Convention, 6: 205-218. Baltimore: ACSM-ASPRS. Abstract: One of the most widely available procedures packaged with GIS for the analysis of a Digital Elevation Model (DEM) is the identification of the viewable area, or the viewshed. The elevations recorded in the DEM do, however, contain error, and the USGS, for example, publishes a Root Mean Squared Error (RMSE) for each DEM. Research reported here assesses the uncertainty of locations being within a viewshed, given the published error for the DEM. In this research, repeated error fields are simulated with variable spatial autocorrelation, and added to the original DEM. The viewshed is then determined in the resulting noisy DEM. Results show that using the basic assumption of spatial independence in the error which is implicit in the RMSE remarkably few points are reliably within the viewshed. With spatially autocorrelated noise, the reliability is higher, but still should be cause for concern to many using viewshed procedures.

Foote-Lennox, Thom 1992 The Need For Coordinate Quality Metrics In Predicting Accuracy In GIS Queries Proceedings of The 13 Annual ESRI User Conference, 121-127. Abstract: A coordinate pair defines the center of some object (example: a ZIP-code, fire district, address) in a GIS database. The coordinates alone provide little information that can be used to determine the quality of placement. The user must assume that the accuracy is the same for each coordinate and trust that accuracy is sufficient. This paper calls for a new standard in which additional metrics would be included with each coordinate pair. These additional metrics allow the measurement of positional error, and in the context of a specific geographic query, allow a confidence metric to be calculated.

Fox C, Levitin A. Redman T. 1994 The Notion Of Data And Its Quality Dimensions. Information Processing and Management, 1994 Jan-Feb, 30 (1):9-19.

Ganter John H 1993 Metadata Management In An Environmental GIS For Multidisciplinary Users Proceedines GIS/LIS 93, Nov 2-4,1993 Minneapolis Minnesota 1: 233-245. Abstract: A GIS interface to support non-specialists must collect and maintain metadata, describing iterative work sessions and interim or final products such as maps and analyses. These capabilities, which are not yet part of commercial software, allow the user to confidently navigate underlying databases and quickly return to previous maps and analyses with minimal effort. The same interface would assist organizations that manage growing collections of derivative products (e.g., maps with source data, views, layouts, legends, etc. require storage and future retreivability). Metadata is a significant topic in the GIS literature because it is linked to data interchange, compatibility, accuracy, and quality. There has been little emphasis on tracking derivative datasets, analyses, and dynamic map compositions once data is within an organization. A prototype interface addressing these needs was developed at the Los Alamos National Laboratory (LANL) environmental restoration program. The interface uses a metaphor wherein the user can manage a collection of Snapshots that, with outward simplicity, describe data themes, storage locations, parameters, and map layout.

Garza R J and Foresman T W 1991 Embedding Quality Into County-Wide Data conversion. Proceedings GIS/LIS '91, 1:130-136. Atlanta. Introduction: Through careful planning and attention to detailed process control design, efficient and automated database construction can be performed with embedded quality control for a geographic information system. Establishing the appropriate quality control for data conversion efforts requires formalization of data handling procedures, conversion techniques, documentation standards, and product specifications. While planning, implementation, and enforcement of these methodologies are major components of a quality assurance approach, group commitment and vigilant monitoring effort are required to fulfill the ultimate strategic goals prescribed.

Gong, Peng and Jun Chen 1992 Boundary Uncertainties In Digitized Maps I: Some Possible Determination Methods Proceedings GIS/LIS 92, 1: 274-28 1. Abstract: In traditional thematic mapping, errors or uncertainties are not associated with the final map product. When such maps are used in a map compilation or a map overlay process to generate derivative maps, the lack of error or uncertainty estimates makes it difficult to study how errors or uncertainties are propagated. In this paper, we report an on-going research project regarding methods on how to determine, represent, and display boundary uncertainties in categorical (areaclass) maps. Selective sampling, curve fitting and blending functions can be used for determining boundary uncertainties and their distributions. An experiment was designed to illustrate the different levels of boundary uncertainties and uncertainty determination methods.

Gonzalez M 1994 Improving Data Quality Awareness In The United-States Federal Statistical Agencies. American Statistician, 1994 Feb, 48 (1):12-17.

Goodchild M F 1990 Modeling Error in Spatial Databases Proceedings GIS/LIS '90 Anaheim, California, 1: 154-162. Abstract: Geographic Information Systems process spatial data to generate information products through such operations as overlay, area measurement and buffer zone generation. Ile paper reviews the techniques available for modeling error in the various data models commonly used in GIS, and the relationships between them. Methods are **discussed for incorporating error** model parameters in the database, for tracking the propagation of error through computational processes and for reporting uncertainty in system products. The paper provides a general introduction to the research completed under the NCGIA's Initiative 1: Accuracy of Spatial Databases.

Goodchild M and S Gopal 1989 Accuracy of Spatial Databases. London: Taylor and Francis. Abstract: The subject of the NCGIA research initiative might well be summed up in a single anecdote. GIS technology is now widely used in forestry, often to make estimates of timber yield. A forester was asked how he dealt with the problem of inaccuracy in yield estimates, and answered that the accuracy was known to be 10%. Given the problems of making such estimates based on poorly delimited stands, the natural spatial heterogeneity of forest species, and the dubious accuracy of the conversion tables used to compute board feet from tree counts, we asked for the basis of the accuracy estimate. It's very simple - we take the estimate from the GIS and subtract 10% to be safe. The chapters of the book represent a number of different perspectives on the accuracy problem from efforts to simulate and model error to techniques for accommodating to it. We have chosen to organize the 23 chapters into seven sections, and to provide a brief introduction to each. The papers in Section Two through Four look at error in GIS with increasing technical complexity and generality. Section Five groups together four papers on various aspects of error in the spatial analysis of socio-economic data, and Section Six contains four papers on more fundamental approaches to the particular problems of aggregation and reporting zone effects which underlie much modeling in human geography and related disciplines.

Goodchild M F 1978 Statistical aspects of the polygon overlay problem. In G. H. Dutton (Eds.), Harvard PaMrs on Geographic Information System Reading, MA: Addison-Wesley.

Goodchild M F 1982 Accuracy and Spatial Resolution: Critical Dimensions for Geoprocessing. In D. H. Douglas and A. R. Boyle (Eds.), Cartography and Geogrgphic Information Processing: Heart and Realism (87-90). Ottawa Canadian Cartographic Association.

Goodchild M F 1988 The Issue of Accuracy in Global Databases. In H. Mounsey and R. F. Tomlinson (Eds.), Building Databases for Global Science (31-48). London: Taylor and Francis. Abstract: Very few procedures exist for estimating the uncertainty or accuracy of products of spatial databases. Point objects can be treated by direct extension of the theory of measurement errors, but no suitable models exist for more complex spatial objects. The paper reviews the available techniques and describes work in progress. The prospects for error evaluation and reporting will improve if objects are tagged with relevant information, and if the data stored in the system can be obtained earlier in the chain of abstraction and generalization. It is argued that the cartographic representation of data should be regarded as a product rather than an input. The final section of the paper reviews available techniques for global spatial analysis, and identifies areas where further research is needed.

Goodchild M F 1989 Modeling Error in Objects and Fields. Accuracy of Spatial Databases. London, Taylor and Francis. 107-114. Introduction: The current interest in spatial databases stems largely from their role in supporting geographic information systems, and the rapidly growing GIS industry. GISs are powerful systems for handling spatial data, and in recent years they have found application in fields as different as transportation, forestry and archaeology. Yet the power of a GIS to input, store, analyze and output geographic information of all kinds is at the same time a major liability. To the database, the structure used to store a polygon or pixel has almost no connection to the real meaning of the polygon, as a parcel of land, object on a topographic map or stand of timber. The analyst making use of a polygon overlay operation has similarly little pressure to be sensitive to the interpretation of the data layers being overlaid. In reality a GIS may encourage poor analysis by separating the data collection, compilation and analysis functions, and failing to make the user aware of the possible dangers of indiscriminate use of such functions as scale change, reclassification and overlay.

Goodchild, M F 1991 Issues of Quality and Uncertainty. In J. C. Muller (Eds.), Advances in Cartog=hy 113-140. London: Elsevier Applied Science.

Goodchild M F 1991 Keynote Address: Symposium on Spatial Database Accuracy. Proceedings the SymRgsium on Spatial Database Accuracy, 1: 1-16. Melbourne: University of Melbourne. Ile accuracy of spatial databases has been the focus of NCGIA's Research Initiative 1. Uncertainty is a particularly significant problem in GIS because spatial data tend to be used for purposes for which they were never intended, and because the accuracy problem in GIS requires consideration of both object-oriented and field-oriented views of geographic variation. The paper defines the relevant terms, and provides a review of the current state of knowledge in the area of error models for spatial data. Efforts to build data quality standards are also reviewed.

Goodchild M F and Dubuc 0 1987 A Model of Error for Choropleth Maps with Applications to Geographic Information Systems. Proceedings of AUTO-CARTO 8,165-174. Abstract: The precision of geographic information systems is in sharp contrast to the accuracy of much spatial data, and requires a more objective approach than is conventional in cartography. Existing models of the error of cartographic lines are inappropriate for topological data for various reasons. We propose a model of error in choropleth data, with specific application to the data types found in natural resource inventories. One or more spatially autocorrelated continuous variables are generated, and mapped through a number of domains into a choropleth map with nominal attributes. Fractional Brownian surfaces are convenient sources of the continuous variables. The choropleth boundaries are subject to additional smoothing. Although the model is probably too complex to calibrate, it can be used to simulate choropleth images under a wide range of conditions, in order to investigate effects of error and accuracy in a variety of GIS functions.

Goodchild M F 1994, Integrating GIS and remote sensing for vegetation analysis and modeling: methodological issues. Journal of Vegetation Science, (in press). Abstract: GIS and remote sensing have emerged as distinct spatial data handling technologies with their own methods of data representation and analysis. Combining them as tools to support vegetation analysis and modeling thus presents a number of challenges. The paper begins by describing the major data sources, applications, and software characteristics of each technology, and then compares them within a consistent terminological framework that emphasizes the digital representation of continuously varying spatial data. Because the spatial continuum can be discretized in many different ways, and because each can only approximate the truth, both GIS and remote sensing are subject to error and uncertainty. Integration, and subsequent analysis and modeling, require that explicit attention be directed to uncertainty. The paper reviews the models of error that have been developed in recent years for spatial data and examines their use in the interface between GIS and remote sensing. The paper looks at the functional requirements of modeling, and includes discussion of error propagation.

Grady R 1988 Data Lineage in Land and Geographic Information Systems. Proceedings GIS/LIS '88, 2: 722-730. Abstract: The issue of data lineage in LIS/GIS is a critical one to ascertain the validity and suitability of the data to support decision-making. When setting up a data model to support decision-making, one must bear in mind the nature of decisions to be made. It is imperative that data not be assumed to be more accurate than it is. As basic as this point is, it is often violated in the use of LIS/GIS technology. Much like one should not derive a large-scale map fron small scale base materials, one should not make decisions that impact large-scale phenomena based on a data model built from small-scale data. An important (but often overlooked) aspect of LISJGIS therefore, is data lineage. This paper will explore the inclusion of data lineage as a vital part of data collection in building a relaible LIS/GIS database.

Greenland A Socher R M Thompson, M R 1985 Statistical Evaluation of Accuracy for Digital Cartographic Databases, Proceedings Auto-Carto 7, Washington DC. 212 - 221. Abstract: The major statistical techniques used by cartographers to measure accuracy in digital cartographic databases, namely linear and circular probable errors, were derived for application to analog cartographic products. Digital products because of their use, application, and construction do not necessarily fit in the accuracy model of paper products. This paper documents the application of a relatively new measure, the Kappa statistic, for analyzing the accuracy of digital geographic feature databases. The specific application was the comparison of two digital cartognaphic databases provided by the defense mapping agency.

Guptill S C 1993 Describing spatial data quality Proceedings Of the 16 International Cartographic Conference Cologne Germany 1: 552-558. Introduction: As cartographers have accepted the use of computer technology in their field, they have been forced to reexamine many of the processes that they have traditionally performed on spatial information. It is becoming increasingly apparent that this reexamination is pronounced with respcct to data used to make cartographic products. The structuring of digital data bases, which is required by automated cartography, is a new and vital process. A necessary part of the digital data base is metadata, information required for the efficient access and use of the data. This paper outlines the need and suggests potential categories for the content of a comprehensive statement of data quality that must be imbedded in the metadata that accompanies a digital spatial data file.

Hawkes, A G D 1992 Total Quality Management of AM/FM/GIS Data Conversion. In W. Mumbleau and M. J. Salling (Ed.), Proceedings URISA 1992 Annual Conference Proceedings 2: 122-128. Washington, D. C.: Urban and Regional Information Systems Association.

Heuvelink G B M, Burrough P A, Stein A 1989 Propagation of errors in spatial modelling with GIS International Journal Of GeoUQhical Information Systems 3: 303-322. Abstract. Methods are needed for monitoring the propagation of errors when spatial models are driven by quantitative data stored in raster geographical information systems. This paper demonstrates how the standard stochastic theory of error propagation can be extended and applied to continuously differentiable arithmetic operations (quantitative models) for manipulating gridded map data. The statistical methods have been programmed using the Taylor series expansion to approximate the models. Model inputs are (a) model coefficients and their standard errors and (b) maps of continuous variables and the associated prediction errors, which can be obtained by optimal interpolation from point data. The model output is a map that is accompanied by a map of prediction errors. The relative contributions of the errors in the inputs (model coefficients, maps of individual variables) can be determined and mapped separately allowing judgments to be made about subsequent survey optimization. The methods are illustrated by two case studies.

Hirst W G and Masters E 1992 Recording Graphical Data Accuracy. Proceedings of the 20th Annual AURISA Conference, 1: 436. Gold Coast: AURISA. Abstract: This paper discusses the need for more detailed and usable form of reporting on digital data integrity. A dual approach to data accuracy recording is proposed. A brief indication of positional accuracy closely linked to the feature tag, and a far more throrough report available through a relational textual database.

Hootsmans Rob M, Wouter M de Jong and Frans J M van der Wel 1993 Knowledge-Supported Generation Of Meta-Information On Handling Crisp And Fuzzy Datasets Proceedings Auto Carto 11470-479. ;Astract: In 1991 The Dutch National Physical Planning Agency and Utrecht University initiated a research program to develop knowledge modules for the generation and application of

metainformation on quality characteristics of datasets and data manipulation methods, which enables the prediction of the quality of a newly generated dataset. The project forsees in an expert system for planning environments, which should offer reliable and effective decision support, by means of efficient and uniorm meta-information. This paper reported on the first stages of the project, illustrated with simulated prototype experiences.

Huang Shabai, David Douglas and Aining Zhang 1992 A Logic-Based Approach For GIS Error Handling Proceedings GIS/LIS 92, 1: 343-359. Introduction: GISs are powerful systems for handling spatial data. They provide a wide range of operations to be applied to spatial data in the production of both tabular and graphic output products. In the recent years, they have found increasing applications in fields as different as forestry, urban planning, transportation, archaeology, etc. Too frequently, however, GISs are applied with little regard for types and levels of errors and uncertainties that may result, and for error handling if errors exist in GIS databases. In numerous published articles detailing GIS products and applications are presented without any associated estimate of their quantitative or qualitative reliability on their data analysis and output. Unfortunately, in most cases, these omissions do not imply that errors are of a sufficiently low magnitude that they may safely be ignored.

Huh Y U, Keller F R, Redman T C and Watkins A R 1990 Data Quality Information and Software Technology_ 32 (8): 559-565.

Hunter G 1991 Processing Error in Spatial Databases: The Unknown Quantity. Proceedings of the SympQsium on Spatial Database Accuracy, 1: 203-214. Melbourne: University of Melbourne. Abstract: It is clear that the creation of spatial databases is now passing from the exclusive domain of cartographic/geographic experts into the hands of a far larger section of the community. This includes many users who may not have an understanding of either the inherent errors in spatial datasets or those that might be subsequently propagated. It is suggested that processing errors incurred after data collection and compilation remain perhaps the least understood of all the errors that may occur in spatial data. And as such, they represent a major unknown quantity in assessing the accuracy of spatial databases. The purpose of this paper is to overview the causes and forms of error that may reside in spatial databases, and to examine the nature of processing errors so that they might be better understood and managed.

Hunter G and Goodchild M F 1993 Managing Uncertainty in Spatial Databases: Putting Theory into Practice. Proceedings URISA. 1: 1- 14. Abstract: Users of spatial databases face three fundamental questions when dealing with the error or uncertainly in their product. Viz, What error is present? (definition) How can it be visualized? (communication) and How can the results be used in practice? (management). While researchers have spent considerable effort examining the first to questions, the results of their labour will not be recognized until users start applying the technique in practice. With tools for error visualization now becoming available, the research agenda must be widened to determine how and when these aids can best be applied. Accordingly the purpose of this paper is to discuss the techniques available and present a strategy for managing uncertainty in spatial databases.

Hunter G and Goodchild M F 1993 Managing Uncertainty in Spatial Databases: Putting Theory into Practice. URISA Journal. 5 (2): 55-63. Abstract: Users of spatial databases face three fundamental questions when dealing with the error or uncertainly in their products. What error is present? (definition) How can it be visualized? (communication) and How can the results be used in practise? (management). While researchers have spent considerable effort examining the first to questions, the results of their labour will not be recognized until users start applying the technique in practise. With tools for error visualization now becoming available, the research agenda must be widened to determine how and when these aids can best be applied. Accordingly the purpose of this paper is to discuss the techniques available and present a strategy for managing uncertainty in spatial databases.

Jessip M B 1991 Systematic Horizontal Adjustment of Positional Error in Digital Line Graphs. Technical Papers of the 1991 ACSM-ASPRS Annual Convention 2: 130-139. Baltimore: ACSMASPRS.

John S 1993 Data Integration In A GIS - The Question Of Data Quality. Proceedings of ASLIB, 1993 Apr, 45 (4):109-119.

John S and Lewis S 1992 Compiling a GIS Database Jigsaw: The Question of Data Quality. Proceedings of EGIS'92 1: 521-531. Munich: EGIS Foundation. Abstract: The vast array of data available from different sources, in different formats, and at different scales, likens the development of a GIS database to the compilation of a multi-layered jigsaw puzzle. We can consider GIS technology as the table-top on which the data pieces are compiled, considered, manipulated and located. the complexity of compiling such a database puzzle is increased when a number of different pictures must be pieced together. Maintaining the integrity of the database is then dependent on the quality of the source data. With reference to the development of a geographic database for a loosely defined sub-region of the South East of England - the East Thames Corridor, we consider the problems associated with obtaining data of an appropriate standard from within institutional restraints, and the data quality problems inherent in the development of an integrated database.

Kennedy-Smith G M 1986 Data Quality- A Management Philosophy Proceedings Auto-Carto London RICS 1: 381-390. Abstract: Military Survey is developing a 2nd generation digital production system known as the Military Survey Geographic Database. The system will use multi-product data sets. In such an environment it is essential that data integrity is maintained to the highest possible

standards. To meet this requirement, Military Survey is developing a concept known as the Source ID database. Although the origins of the concept are rooted in data integrity, it is proposed that the Source ID database is developed as a tool for the management of both data integrity and quality. The Moellering Committee recommendations for data quality have been adopted as the design criteria for the Geographic Database. This paper outlines the status of development and describes proposals for an implementation of the Moellering recommendations.

Kiernan B D 1991 Effective Quality Control In The Conversion Process. Proceedings of AM/FM Conference XIV, 1: 245-256. San Diego: AWM International.

Kottman C A and Buttenfield B P 1994 Standards for Spatial Data Use: Similes Improve Our Understanding. Cartography and GIS (in press).

Kummert A,Csillag F and Kertesz M 1992 Quality Descriptor in a Soil Database. Proceedings of EGIS'92,1: 722-731. Munich: EGIS Foundation. Abstract: A varying resolution tiling strategy is proposed to construct optimal region quadtrees to represent responses of a geographical information system. In principle, optimization is locally controlled by spatial variability. Traditional measures of spatial variability are generally applied to mapping as global characteristics, and tend to define one best resolution, range, or other representation. Instead of this, we adopt i divergence, and apply it for multiple resolution representations; i.e. two dimensional discrete distributions. For each tile information content is measured as distance from other representations, or from uniform distribution; in this latter case it equals to entropy. Although this information measure is not spatial in itself, its change with resolution locally accounts for pattern of heterogeneity. Decomposition of variability can be guided by minimizing local maximum of divergence, or thresholding, which will thus serve as a stopping rule for quadtree construction. Model calculations and preliminary results of a natural grassland mapping project are presented to illustrate how this approach can be utilized to measure quality in terms of effort/accuracy.

Lanter D P 1990 Lineage in GIS: The Problem and a Solution NCGJA Technical Report 90-6. Santa Barbara, CA: NCGIA.

Lanter D P 1991 Design of a Lineage Meta-Database for GIS. Cartogwhy and GIS. 18(4): 255261. Abstract: A conceptual design is presented for a lineage meta-data base system that documents data sources and geographic information system (GIS) transformations applied to derive cartographic products. Artificial intelligence techniques of semantic networks are used to organize input-output relationships between map layers, and frames are used for storing lineage attributes characterizing source, intermediate, and product layers. An example indicates that a lineage meta-data base enables GIS users to determine the fitness for use of spatial data sets.

Lanter D P 1993 A Lineage Meta-Database Approach Towards Spatial Analytic Database Optimization. Carto Why and GIS. 20(2): 112-121. Abstract: This work demonstrates how increasing levels of intelligence can be added to commercial geo graphic information systems. The lineage-knowledge representation introduced in an earlier article (Lanter 1991) provides a basis for encoding the logic applied within specific spatial analytic applications. This knowledge is general, reusable and extendible to solving many significant problems in geographic information processing. In this study, the lineage-knowledge representation is applied to automatically differentiate between source and derived layers, pick an optimal spatial analytic database configuration, and generate applications tailored to the contents of the spatial analytic database.

Lanter D P and Veregin H 1990 A Lineage Meta-Database for Propagating Error in Geographic Information Systems Proceedings GIS/LIS 90 Anahiem, California, 1: 144-153 Abstract: This paper presents a research paradigm for exploring the formulation of source accuracy indices and functions to propagate such indices to document the quality of derived GIS data products. Error propagation functions are defined by their association with a particular GIS transformation and a particular accuracy index. These resulting associations and indices are metadata manipulatable by a Lineage Information Program (LIP) to propagate measures of spatial, thematic, and temporal error through GIS applications. The result is a way in which users can experiment with measures that document the accuracy of GIS derived spatial data products.

Lanter D P and Veregin H 1992 A research paradigm for propogation error in layer based GIS. Photogrammetric Engineering and Remote Sensing 58(6): 825-833. Abstract: This paper focuses on the nature of error in spatial databases and the implications of this error for spatial data transformations in GIS applications. It describes an error propagation research paradigm as an information flow linking successively more formal components of error propagation in a GIS context. These components include development of conceptual models of error, creation of formal indices to measure error in spatial databases, implementation of mathematical functions to transform to transform error indices and model the propagation of error as it is processed, and evaluation of the indices gain insight into the utility of conceptual models used in error measurement and propagation.

Lankowski P 1991 On a Mixed Local-Global Error Measure for a Minimum Distortion Projection. In Technical Papers of the 1991 ACSM-ASPRS Annual Convention 2: 181-186. Baltimore: ACSM-ASPRS.

Lester M and Chrisman N R 1991 Not All Slivers Are Skinny: A Comparison of Two Methods for Detecting Positional Error in Categorical Maps. Proceedings GIS/LIS '91, 2: 648-658. Atlanta. Abstract: The polygons produced by some GIS overlay operations may represent areas of no error, attribute error or positional error. Two polygon characteristics, compactness and source of perimeter, are tested for their ability to correctly classify known positional error. It is found that there is a counterintuitive relationship between compactness and polygon area, and that compactness is an unreliable indicator of positional error. The relative amounts of a polygon's perimeter derived from each source is found to be a relatively reliable indicator of positional error.

Lodwick W 1989 Developing Confidence Limits on Errors of Suitability Analyses in Geographical Information Systems Chapter 6. Accuracy of Spatial Databases by Goodchild, M F. Gopal, S. Taylor and Francis, London 69-80. Abstract: Confidence limits based on measures of sensitivity are developed for two of the most widely used types suitability analyses, weighted intersection overlay and weighted multidimensional scaling. Some underlying types of sensitivity analyses associated with computer map suitability analyses are delineated as a way to construct measures of these delineated sensitivities that in turn become the means by which confidence limits are obtained.

Lolonis Panagiotis, Armstrong Marc P, Pavlik Claire E and Lin Sidan 1992 Accuracy Of A GISBased Small-Area Population Projection Method Used In Spatial Decision Support Systems Proceedings GISALIS 92, San Jose California 2: 473-483. Abstract: This paper describes a recently developed GIS-based population projection method for small spatial units, known as the Modifiable Spatial Filter (MSF) method, and evaluates the accuracy of its projections with respect to a parameter that controls the sample size of the data that are used to estimate projection parameters. This assessment is made with respect to average absolute error, average relative error, distribution of absolute error and absence of bias for subgroups. Results show that MSF projections appear to be stable when the parameter is greater than fifteen.

Lowell K E 1992 Probability based spatial-temporal modeling for natural forests sampling techniques, model development, accuracy assessment, and residual evaluation. Proceedings GIS '92 Symposium, I (N. pag.). Vancouver: Forestry Canada.

Lowell K E 1992 On the Incorporation of Uncertainty into Spatial Data Systems. Proceedings GISALIS '92, 2: 484-493. San Jose. Abstract: Existing digital spatial systems function under the implicit assumption that boundaries are real, identifiable, locatable, and width less, and that new boundaries may appear or old ones disappear, but existing boundaries do not change position. This may be true in socio-political geography, in those subjects involving natural phenomena, this model of space is inappropriate. In these subjects, there may be a considerable amount of uncertainty associated with each boundary and each map category. Thus a new model of space which shows transition zones for boundaries, and polygon attributes as indefinite, is required. The use of uncertainty in digital representations of the real world will impact two areas directly: map representations and spatial operators. To address these issues, uncertainty based cartographic representations and spatial operators are discussed.

Lundin B 1991 Accuracy of Points, Lines, Polygons and Other Geographic Information. Proceedings The Canadian Conference on GIS '91, 1: 104-115. Ottawa

Mackay B and McKenney D W 1992 Quality control in data base development and spatial analysis. Proceedings GIS '92 Symposium, I (N. pag.). Vancouver: Forestry Canada.

Masters E 1991 Defining Spatial Accuracy. Proceedings Of the S3=osium on S12atial Database Accuracy, 1: 215-224. Melbourne: University of Melbourne. Abstract: This paper examines the sections of the proposed Australian Spatial Data Transfer Standard, which deal with documenting the quality of spatial data. Specifically, the sections which
deal with lineage and positional accuracy are examined in terms of the information they will provide for spatial analysis and display. Positional accuracy is a term derived from conventional mapping accuracy standards and must be re assessed in terms of the functionality of Geognaphical Information System technology and applications and also in terms of the information requirements of organisations.

Masters E 1992 Digitization and Database Accuracy. Proceedings GIS/LIS '92, 2: 522-53 1. San
Jose. Abstract: As organizations endeavor to come to grips with new digital mapping products, aspects of accuracy and database quality are recurring themes. This paper investigates the many processes that drive database development and how these fit in with **the** typical GISYLIS vision of cormnunity accessible data. A few problems with defining spatial database accuracy are also examined.

McGuire K C and Estes J C 1988 Interpolation and Uncertainty in GIS Modeling. Proceedings the First International Symposium on GIS 2: 229-242.

Meyer N V and Fletcher, D 1992 Parcel Mapping Accuracy - Some Wisconsin Experiences. URISA 1992 Annual Conference Proceedings, 1: 39-45. Washington, D. C.: Urban and Regional Information Systems Association. Abstract: The Wisconsin Land Information Program has identified four categories of parcel information that relate to parcel mapping. WLIA Technical Issues

committee is identifying guidelines recommendations and standards to support these parcel mapping requirements. The WLIA efforts are evolving and this paper presents a summary of work in progress.

Middlestead J A 1991 Am/Fm/GIS And Ile Landbase Accuracy Dilemma - One Utility's Perspective. Proceedings of AM/FM Conference XIV, 1: 75-86. San Diego: AM/FM International.

Millsorn R 1991 Accuracy Moves from Maps to GIS - Has Anything Changed? Proceedings of the Sympgsium on Spatial Database Accuracy, 1: 17-22. Melbourne: University of Melbourne. Abstract: In this paper presents the map-maker's view on mapping accuracy. The standards for the positional accuracy of mapping in Victoria are set out - both the national IGACSM standard and those of the Survey Co-ordination Regulations. Accuracy to map-makers is scale dependent but scale is less relevant in the GIS/LIS application. Whilst the inherent imprecision in traditional mapping may be an impediment for those establishing GIS/LIS, economics and time dictate that there is no other course than to digitise existing mapping. As with printed map users, completeness and current information in the map base is still of critical importance and there must he a compromise between high positional accuracy and these other qualities. The new systems will need to live with the inherent positional uncertainty and develop procedures accordingly. The education of users and data quality stamping are recommended.

Monette B and MacDonald K B 1992 Standards of Accuracy for Digital Soil Resource Data Stored in the National Soils Data Base (NSDB). Proceedings Canadian Conference on GIS, 1: 282-288 Ottawa. Abstract: The Land Resource Research Centre is responsible for the development and implementation of standards for digital soil inventory maps stored in the NSDB. These developments required, among other things, the definition of standards relating to two aspects of map accuracy. The first standard defines the fidelity with which the digital data represents the manuscript lines. It represents the development of a digital standard to replace a publication "cartographic" standard. The second involves measuring and documenting the positional accuracy of the map with respect to the earth's surface. It represents a new standard which was not part of the published product but is required to define the expected precision with which these data can be combined with data from other sources. (In published maps, the soil thematic boundaries were registered to base map information). In absolute terms, both of these standards are dependent on the scale of the original manuscript. This presentation documents a project in LRRC to adapt and
develop appropriate standards of accuracy for digital soil maps. It defines the standards which apply to data in the National Soils Data Base (NSDB).

Montgomery R J 1992 Total Quality Management. Proceedings of AM/FM Conference XV, 1: 837846. San Antonio: AM/FM International.

Nanna S 1991 The use of multiplying effect of ancillary data in erosion severity classification: a method for improving data quality of multispectral classification. Proceedings of EGIS '91, 2: 1046-1057. Brussels: EGIS Foundation.

Nijpels K and Laan F v d 1991 The Vectorization Of Topographical Map: Accuracy and Efficiency. Proceedings of EGIS '91, 2: 747-755. Brussels: EGIS Foundation.

Openshaw S 1989 Learning to Live with Errors in Spatial Databases. in Goodchild M F and S Gopal. Accuracy of Spatial Databases. 263-276. Introduction: Error and uncertainty have always been a feature of cartographic information so it hardly surprising that these aspects are also present in digital versions of analogue maps. Neither should it be imagined that any map-related spatial data exist which are error-free. Errors and uncertainty are facts of life in all information systems. There are many different causes of uncertainty and those explicitly due to GIS-based manipulations of mappable information are merely a more recent problem. However, it is also obvious that GIS has the potential to dramatically increase both the magnitude and importance of errors in spatial databases. Urgent action is needed to minimise the potential worst case consequences and also to provide a methodology for coping with the effects of processing uncertain data.

Openshaw S, Charlton M and Carver S 1991 Error propagation: a Monte Carlo simulation. In Handling Geog=hical Information I Masser and M Blakemore (Eds.), 78-101. Essex: Longman Scientific and Technical.

Paller A 1988 Why Some People Don't Listen to Statisticians. Chance: New Directions for Statistics and Computing, l(l): 58-61.

Parameter B M 1992 Total Quality Management In Data Conversion. Proceedings of AMIFM Conference XV, 1: 847-858. San Antonio: AM/FM International.

Peng Z and Dueker K J 1993 Error and Accuracy in Spatial Data Allocation Proceedings IS/LIS 93, Nov 2-4, 1993 Minneapolis Minnesota 2: 592-602 Abstract: Ile major function of GIS is its capability of integrating different types of spatial data. However, there are errors associated with the analysis process of data integration, especially for the allocation of counts of objects in areas, when the objects are not uniformly distributed. Several methods are available to allocate count data. This paper discusses the error and accuracy

associated with these methods. An index of population density distribution has been developed to measure the extent to which the population is distributed in an area.

Price A 1991 Information System Quality Costs And Quality Implementation. In AURISA'91 Proceedinga, 1: 501-505. Wellington: Australasian Urban and Regional Information Systems. Abstract: IS professionals need to be aware of the potential for quality improvement in IS. This presentation will show the principles of quality costing, detailing the New Zealand IS averages, before focusing on IS quality implementation.

Pullar D and Beard M K 1990 Specifying and Tracking Errors from Map Overlay Proceeding GIS '90 Anaheim, California 1: 79-87. Abstract: This paper presents tools to treat spatial uncertainty for representing and combining the geometry for map layers. As a speculative approach, we adopt an error model for geometrical
objects based upon a normal probability distribution. The error model is used to track error in two applications, line simplification and map overlay.

Ries T 1991 Data Quality in the Geographic Data Base Creation Process: Guidelines and Recommendations. In D. D. Moyer and B. L. Larson (Ed.), Proceedings of the 1991 Geographic Information Systems (GIS) for Transportation Symposium, 1: 59-76. Orlando: American Association of State Highway and Transportation Officials.

Robinson V B and Frank A U 1985 About different kinds of uncertainty in collections of spatial data. Proceedings of AUTO-CARTO 7 440-449.

Robinson V B, Miller R and Klesh L 1988 Issues in the Use of Expert Systems to Manage Uncertainty in Geographic Information Systems. Proceedings of the First International Symposium on GIS 2: 89- 100.

Rose D 1992 Data Quality In Longitudinal Research - MagnussonD, Bergman,l-x. Pro=ss In Human Geogaphy, 1992 Oct, 16 (4):636-637.

Schalla R, Lewis A K and Bates, D J 1992 Accuracy and Precision of Wen Casing Surveys and Water-Level Measurements and Their Impact on Water-Level Contour Maps. In Geouvhic Information Systems (GIS) and Mapping - Practices and Standards A. 1. Johnson, C. B. Petterson and J. L. Fulton (Eds.), 295-312. Philadelphia: ASTM.

Skidmore A and Turner B 1991 A Measure of Vector Map Accuracy. Proceedings of the Symposium on Spatial Database Accuracy, 1: 161-174. Melbourne: University of Melbourne. Abstract: It is relatively easy for an operator with minimal training to derive, and print, high quality map products using a geographic information system (GIS). However, few quantitative techniques exist for assessing the accuracy of derived maps, or indeed the accuracy of the primary data layers in the GIS. A methodology is presented for calculating map accuracy based on line intersect sampling. Line intersect sampling is used to estimate the length of cover class boundaries on a map that coincide with the actual boundaries of the cover classes on the ground. A ratio of coincident boundary to total boundary is proposed as one measure of map accuracy. Initial field trials indicate the technique is efficient for estimating the accuracy of forest type boundaries interpreted from aerial photographs.

Sorensen P and D Lanter 1993 Two Algorithms for Determining Partial Visibility and Reducing Data Structure Induced Error in Viewshed Analysis. Photogmmmetric Engineering and Remote Sensing. 59 (7): 1149-1160. Abstract: In geographic information systems, viewshed analysis is used to calculate the areas on a topographic map that can be seen from a specified set of locations. Grid cell ("raster") based viewshed routines typically create maps, in which each cell is listed as being entirely visible or entirely not visible. Prior research has shown that sampling errors in elevation data can reduce the accuracy of the resulting visibility maps. This study demonstrates that for the errors may be introduced in binary viewshed maps by the geometry of the raster data structure itself. Two techniques are illustrated for reducing data-structure induced en-or in viewshed analysis.

Stanek Heinz and Frank A U 1993 GIS Based Decision Making Must Consider Data Quality Proceedings EGIS 93. 29 March - April 1685-692. Abstract: The great benefit of GIS is that it simplifies the process of decision-making. The availability of data quality parameters improves decisions in GIS applications. Besides the economic aspects, questions of liability will have to be considered in the future. In order for data quality to be a useful tool it is not sufficient that the necessary information be supplied to the decision-maker. In a second step, an appraisal of the quality of the information provided must be carried out. This applies to all aspects of spatial decision making, from real estate acquisition to environmental protection measures. There is, however, the problem of differentiating between the constituent elements of data quality, re positional accuracy, attribute accuracy, temporal update level, or scale. The goal must be to provide an analytical description of data quality, which is practically "independent" of the processes used.

Stephan E M, Bucher F and Vckovski A1993 Virtual Data Set - An Approach for the Integration of Incompatible Data. Proceedings. AUTO-CARTO 11. Minneapolis, MN, October, 93-102. Abstract: Data integration within GIS is made difficult by the incompatibility

of source data. Here both, traditional approaches are discussed and an enhanced strategy for data integration is proposed. The concept of a virtual data set is presented, which allows more flexible and - due to quality information - more reliable integrated analysis. As a conclusion implementation issues are discussed, including the benefits of object-oriented techniques, comprehensive data quality modeling and visualization.

Switzer P 1975 Estimation of the Accuracy of Qualitative Maps. In Display and Analysis of Spatial Data J.C. Davis And M Mccullagh, London, Wiley 1-13.

Turner H 1988 Real-time data collection quality assurance models in two-dimensional spatial information systems International Journal Of Geographical Information 5 m 2):295-306. y~ (4 Abstract: Databases used in GIS must be supplied with current data. Maps are usually out of date when they are published. Satellite imagery and aerial photographs supply up to date 3D data. Three different models of real time quality assurance control in 3D data collection for GIS are discussed. Emphasis is placed on the visual detection of blunders in 3D data. One data collection quality assurance model has been implemented in the Photogrammetric Analysis Lab at Purdue University. An example from this system is given and the precision and speed of digitization of 3D data are discussed.

Veregin H 1993 Design Of An Error Handling Capability For Inexact Data In Geographic Information Systems Proceedings GISALIS 93, Nov 2-4, 1993 Minneapolis Minnesota 2: 691-700. Abstract: One of the main strengths of GIS lies in the facilitates it provides for merging, transforming and manipulating data. However, these operations tend to modify the error characteristics of input data, which complicates the assessment of error for derived data products. The ability to model the modification of input errors through the course of GIS based analysis is referred to as error propagation modeling. This study examines the issue of error propagation in the context of the buffer operation. Previous work on error propagation for this operation focuses on conventional raster databases. The present study extends this work into the realm of fuzzy raster databases. Results of this study indicate that there is a strong positive relationship between error levels in input and buffer layers. The strength of the relationship is affected by the degree to which input data tend to be under- or over-estimated, and the interaction between buffer size and spatial covariation in input data.

Veregin H 1989 Accuracy of Spatial Databases: Annotated Bibliography Technical Pawr 89-9, NCGIA, Santa Barbara. Prepared in conjunction with Initiative 1 as an aid to research: Includes references to articles papers, reports, and chapters.

Veregin H 1989 A Taxonomy of Error in Spatial Databases Technical Paper 89-12, NCGIA, Santa Barbara. Discusses types of error which occur in spatial databases and methods for dealing with inaccuracies. A companion paper to the annotated bibliography 89-9 in conjunction with initiative 1.

Walsh S J, Lightfoot D R, Butler D R 1987 Recognition and Assessment of Error in Geographic Information Systems Photogrammetric Engineering and Remote sensin& 53(10):1423-1430.

Wel F J M v d 1991 The integration or remote sensed data into a GIS: estimation of the accuracy. Proceedings of EGIS '91, 2: 1219-1227. Brussels: EGIS Foundation.

Wesseling C G and Heuvelink, G B M 1991 Semi-automatic evaluation of error propagation. Proceedings of EGIS '91~ 2: 1228-1237. Brussels: EGIS Foundation.

Wortman K C and Buttenfield B P 1994 (eds.) Current Developments and Use of the Spatial Data Transfer Standard. Special Issue of Cartography and GIS (in press).

Wu C Victor 1993 Object-Based Queries on Spatial Data Quality. Unpublished Ph.D. thesis, Department of Geography, SUNY-Buffalo.

Wu C V and Buttenfield B P 1994 Spatial Data Quality and its Evaluation. Computers Environment and Urban Systems (in press). Abstract: This paper reviews recent concepts of data quality assessment and presents a model for data quality evaluation. Data quality may be acquired in a static state by quantitative or qualitative testing, or in an operational state by tracking what processing steps have been applied. The complexity and variety of spatial data attests to the reconsideration of data quality evaluation: as one goal for evaluating spatial data quality is to determine fitness for use, representation of quality information should be based on capabilities for decision support. Four steps in the evaluation process are described, with specific tasks outlined for each step. Computer tools for evaluation in both static and operational states may improve the amount and detail of data quality information archived with digital data.

Young J 1988 Reassessing the Quality of Geographic Databases. Proceedings of the First International GIS Symposium 1: 339-344.

Zhang G 1991 Estimating the accuracy of areas in simultaneous multilayer spatial overlay. Proceedings of EGIS '91, 2: 1281-1290. Brussels: EGIS Foundation.

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Armenakis C and Siekierska E M 1991 issues on the Visualization of Time-Dependent Geographical Information. Proceedings The Canadian Conference on GIS '91, 1: 584-595. Ottawa

Armstrong M P, Densham P J and Lolonis P 1991 Cartographic Visualization and User Interfaces in Spatial Decision Support Systems. Proceedings GIS/LIS '91, 1: 321-330. Atlanta. Abstract: Spatial decision support systems enable decision-makers to analyze complex locational problems. When such systems are used, problems often undergo reconceptualization as the effects of altering criteria and model specifications become known. Model results, however, must be placed in a geographical context for decision makers to understand key spatial relationships among components of their problem. Several distinct tasks typically must be accomplished during locational decision-making, and the interface presented to the user must adapt to different display requirements. Decision-makers also must be allowed to interactively visualize the effects of making adjustments to parameters in the solution space. We present a model of an interface that relies on the establishment of linkages between database entities and displays to support visualization requirements.

Berris C 1992 Design and simulations of harvesting by visual quality objectives class. Proceedings GIS '92 Symposium, I (N. pag.). Vancouver: Forestry Canada.

Bishop 11994 Ile Role Of Visual Realism In Communicating And Understanding Spatial Change And Process In Visualization in GeoUaphical Information Systems. H M Heamshaw and D J Unwin (eds) John Wiley and Sons Chichester UK 60-64.

Bitz F J and Zabusky N J 1989 DAVID and Visiometrics: Visualizing. diagnosing and quantif)jng evolving am=hous objects. Dept. of Mechanical and Aerospace Engineering, Rutgers University, Piscataway NJ 08855.

Brodhe K 1994 A Typology For Scientific Visualization in Visualization in Geog=hical Infon-nation Systems. H M Hearnshaw and D J Unwin (eds) John Wiley and Sons Chichester UK 34-41 Introduction: The growth of scientific visualization has been one of the most striking features of computing over the past five years. The twin developments of, first, increasing computing power for simulation and, second, increasing band-width of sensing equipment have led to vast increases in data collection in almost all fields of basic and applied science. Visual techniques are an important element both in analysing and presenting these large volumes of data. Modem soft ware systems, such as AVS (Upson et al., 1989) and his Explorer (Edwards, 1992), are based on a dataflow paradigm in which the system presents the user with a library of modules. Using a visual programming editor, the user extracts modules from this library and connects them together in a network that will process and display a given dataset in the manner intended. These systems are extremely flexible and powerful, providing an environment under which the user can manage the visualization process. To support this way of working, it is crucial that there is a sound underlying methodology such as that provided by Haber and McNabb (1990). In the first part of this chapter, we review their work, considering the particular case of interpolating a contour map from a set of scattered data, a common application in geography and other areas. This provides the framework from which to look at various forms of classification in scientific visualization. 'Me aim is to increase the theoretical underpinning of the subject.

Brown A and Elzakker C P J M van 1993 The use of colour in the cartographic representation of information quality generated by a GIS Proceedings 16 International CartoUUhic Conference 2: 707-720 Cologne Germany Abstract: Bertin's systematic approach to symbol design is reviewed with special reference to its possible use in communicating to the user of a GIS quality information at the same time as attribute information, in cartographic form. The discussion leads to the hypothesis that the visual variables of colour can be used in the case of categoric area information, with the variable hue used to represent the category and the variable saturation to represent the quality of the information. Experiments were carried out for a particular combination of a GIS and an inkjet printer. It was found to be much easier to vary saturation independently on a display screen than on printer output. On the printer output, however, lightness value could be made to vary to reinforce variations in saturation. With the help of colour charts, it is concluded that the simultaneous representation of attribute and quality is possible for categoric area information, for both screen display and printer output, but for a limited number of categories and quality levels.

Buttenfield B P and Ganter J H 1990 Visualization and GIS: What Should We See? What Might We Miss? Proceedings. 4th International Symposium on Spatial Data Handling, Zurich Switzerland, July 1990, 1: 307-316. Abstract: The ease with which visualization tools may be integrated within GIS packages varies considerably depending on the domain of the phenomena to be studied, and the purpose or intent of the user. We argue for a coordinated effort to formalize study of visualization with GIS. We suggest that GIS requirements for visualization include conceptual, technological, and evaluatory solutions, which may be seen to vary over three broad domains: analysis, illustration, and decisionmaking. Each presents a challenge to the integration of appropriate visualization tools in GIS. The issue here is graphical validity and its impact on data manipulation, maintenance and presentation. We

examine and classify graphics from the three domains and offer applications of these framework to the system designer and to the user of GIS graphics and visual tools.

Buttenfield B P and Mackaness W A 1991 Visualization. In Geogaphical Information Systems: principles and applications Maguire D J, Goodchild M F and Rhind D W (Eds.), 1: 427-443. Essex: Longman Scientific and Technical. Abstract: Visualization is an important component of any effort to understand, analyse or explain the distribution of phenomena on the surface of the earth, and will become increasingly important as volumes of digital spatial data become more unmanageable. Although the principles of designing displays of spatial data have been investigated for centuries, very little use has been made of such principles in GIS. It is argued here that GIS needs to pay much more attention to visualization research and to the principles of good map design. The chapter begins with a history of visualization research in the context of GIS and then presents an overview of the major areas of visualization and cartographic design.

Carr Daniel B, Olsen Anthony R, White Denis 1992 Hexagon Mosaic Maps for Display of Univariate and Bivariate Geographical Data Cartography And Geographic Information Systems 19(4): 228-236, 271. Abstract: This paper presents concepts that motivate the use of hexagon mosaic maps and hexagonbased ray-glyph maps. The phrase hexagon mosaic map refers to maps that use hexagons to tessellate major areas of a map, such as land masses. Hexagon mosaic maps are similar to colorcontour (isarithm) maps and show broad regional patterns. The ray glyph, an oriented line segment with a dot at the base, provides a convenient symbol for representing information within a hexagon cell. Ray angle encodes the local estimate for the hexagon. A simple extension adds upper- and lower-confidence bounds as a shaded arc bounded by two rays. Another extension, the bivariate ray glyph, provides a continuous representation for showing the local correlation of two variables. The theme of integrating statistical analysis and cartographic methods appears throughout this paper. Example maps show statistical surnmaries of acidic deposition data for the eastern United States. These maps provide useful templates for a wide range of statistical summarization and exploration tasks. Correspondingly, the concepts in this paper address the incorporation of statistical information, visual appeal, representational accuracy, and map interpretation.

Cleveland W S and McGill R 1985 Graphical Perception and Graphical Methods for Analyzing Scientific Data. Science pp. 828-833. Abstract: The subject of graphical methods for data analysis and for data presentation needs a scientific foundation. In this article we take a few steps in the direction of establishing such a foundation. Our approach is based on graphical perception - the visual decoding of information encoded in graphs-and it includes both theory and experimentation to test the theory. The theory deals with a small but important piece of the whole process of graphical perception. The first part is an identification of a set of elementary perceptual tasks that are carried out when people extract quantitative information from graphs. The second part is an ordering of the tasks on the basis of how accurately people perform diem. Elements of the theory are tested by experimentation in which subjects record their judgments of the quantitative information on graphs.

Csillag F 1987 A Cartographer's Approach to Quantitative Mapping of Spatial Variability from Ground Sampling to Remote Sensing of Soils. Proceedings of AUTO-CARTO 8,155-164. Abstract: Data collection and the handling of spatial information inherent in the data for natural resource mapping is cumbersome and particularly problematic in large area surveys for which remote sensing provides an excellent tool in resource assessment and process monitoring. In this case ground sampling is used not only to produce maps but also to calibrate remotely sensed data, therefore the statistical and physical relationships between them should be treated quantitatively as well as the features of the resulting thematic maps. This approach can be extensively used in both ways: in sampling design and in accuracy testing.

DiBiase David, LeRoy Sloan J, Paradis T 1994 Weighted Isolines: An Alternative Method for Depicting Statistical Surfaces The Professional Geography May. 46(2): 218-228 Abstract: Weighted isolines is a method of isoline symbolization in which isolines vary in width in proportion to the data values they represent. Results of a map interpretation experiment demonstrate that the weighted isolines method is an effective alternative to conventional labeled isolines of uniform width and shadowed isolines (which thicken uniformly along southeastward slopes) for prompting rapid and accurate interpretation of statistical surfaces.

DiBiase D, MacEachren A M, Krygier J B , Reeves C 1992 Animation and the Role of Map Design in Scientific Visualization Cartography And Geogaphic Information Systems 19(4): 201-214, 265266 Abstract: As the supply of numerical environmental data has increased, so has the need for effective visual methods, especially for exploratory data analysis. Map animation is particularly attractive to earth system scientists who typically study large spatio-temporal data sets. In addition to the visual variables of static maps, animated maps are composed of three basic design elements or dynamic variables-scene duration, rate of change between scenes, and scene order. The dynamic variables can be used to emphasize the location of a phenomenon, emphasize its attributes, or visualize change in its spatial, temporal, and attribute dimensions. In combination with static maps, graphs, diagrams, images, and sound, animation enhances analysts' ability to express data in a variety of complementary forms.

Dorling D 1994 Cartograms For Visualizing Human Geography In Visualization In Geographical Information Systems. H M Hearnshaw and D J Unwin (eds) John Wiley and Sons Chichester UK 85-102.

Dorling Daniel 1992 Stretching Space and Splicing Time From Cartographic Animation to Interactive Visualization Cartography And Geographic Information Systems 19 (4): 215-227, 267270. Abstract: Animation and cartography present very different traditions to combine. This paper offers some ideas about the directions such a combination might take and presents a series of cartographic animation and visualization case studies involving several unusual representations. These examples range from the interactive exploration of high-resolution, two-dimensional images, to the use of animation in understanding temporal data and three-dimensional structure. Some of the conventional wisdom about the appropriate software applications and visual representations to use is questioned. Exploratory analysis, presenting facts to an interested audience and creating a dramatic image, are seen as distinct tasks, requiring distinctly different animation methods.

Evans, J D, Joseph Ferreira, Jr., Philip R Thompson 1992 A Visual Interface To Heterogeneous Spatial Databases Based On Spatial Metadata Proceedings 5th International Symposium on Spatial Data Handling Aug 3 - 7 1992 2: 282-293. Abstract: The burgeoning availability of digital spatial data presents GIS users with **new demands** for managing and accessing heterogeneous information in a timely and direct manner. We present a scheme for cataloging and browsing through large numbers of diverse data files using metadata representations. We have implemented this approach in a workstation-based browsing tool which provides an intuitive and interactive graphic interface to the metadata. The metadata describes the characteristics of each spatial-data item: data type, history, spatial extent, etc. By performing simple transformations on these characteristics, the browser provides an integrated view of available spatial data, while leaving data items in their native formats and coordinate systems.

Foley J D, Wallace V L and Chan P 1984 The Human Factors of Computer Graphics Interaction Techniques. IEEE Computer G=hics and Applications, Nov, 13-48.

Gatrell A 1994 Density Estimation And The Visualization Of Point Patterns in Visualization in Geogmj2hical Information Systems. H M Heamshaw and D J Unwin (eds) John Wiley and Sons Chichester UK 65-75.

Heamshaw H 1994 Psychology And Displays In GIS in Visualization in Geographical Information Systems. H M Hearrishaw and D J Unwin (eds) John Wiley and Sons Chichester UK 193-199

Heamshaw H M and D J Unwin 1994 Visualization in Geographical Information Systems. John Wiley and Sons Chichester UK

Hunter G J 1992 Techniques for Assessing the Effect of Processing Errors in Spatial Databases. In D. M. Freund (Ed.), URISA 1992 Annual Conference Proceedings, 1: 24-33. Washington, D. C.: Urban and Regional Information Systems Association. Abstract: Of the three causes of error which may affect spatial data viz. data collection and compilation, data misuse and data processIng, the lack of understanding of the latter is delaying efforts to ultimately define and quantify error in spatial database products - a problem compounded by the variety of operations now available in processing software packages. Examples of these operations Include coordinate transformation, line generalization, surface modeling, polygon overlay, and data display and analysis. While detailed mathematical study of error propagation within the algorithms used to effect these operations is one way of approaching the problem, it is argued that there are other techniques whlch can provide an equally effective means of understanding error which may occur during spatial processing. This paper discusses how various alternative approaches may be applied by users to assess processing error induced during spatial operations.

Koverman H C 1961 How and When Should We Visualize? The Professional Geographer Vol X111 (4)2634.

La Brecque M 1989 The Scientific Use of Visualization American Scientist 77: 525- 527.

Lee J and Snyder P K 1991 Modeling Spatial Patterns of Digital Elevation Errors for Drainage Network Analysis. Proceedings GIS/LIS '91 Atlanta. 1: 71-79. Introduction: In recent decades digital elevation models have been developed and provided to users for performing a wide variety of terrain analyses. The DEM can take the form of a regular matrix of elevations in which elevations are spaced evenly apart in two orthogonal directions. Published DEMs are usually supplied with reports of accuracy levels as reference for the users. But how realistic or accurate is it to perform terrain analysis functions from a DEM with a stated accuracy?

MacDougall E Bruce 1992 Exploratory Analysis, Dynamic Statistical Visualization, and Geographic Information Systems Cartography and GIS 19 (4): 237-246. Abstract: This paper investigates how concepts from exploratory data analysis, dynamic graphics, and statistical visualization may be applied to the study of geo-referenced data. The first part describes the use of commercially available computer programs with data stored as irregularly spaced points or in raster (grid) format. The second part presents results from an operational prototype that operates on data stored as polygons and includes some novel features that extend cluster analysis into the spatial domain.

MacEacheren A M 1994 Some truth with Maps: a Primer on Symblization and Design. Resource Publications in Geography. Washington DC: American Association of Geographers. Preface: This primer provides an introduction to mapping principles with an emphasis on maps used in the context of environmental research, policy formulation, monitoring and management. Some truths about maps details a process for systematically considering cartographic symbolization and design issues so that scientists and or policy analysts will be equipped to deal with the inevitably unique problems with which they are faced in the course of their activities.

MacEachren A, Bishop 1 Dykes J, Dorling D, Gatrell A 1994 Introduction To Advances In Visualizing Spatial Data In Visualization in GeoaUhical Information Systems. H M Heamshaw and D J Unwin (eds) John Wiley and Sons Chichester UK 51-59.

MacEachren A E, Buttenfield B P, Campbell J C, DiBiase D and Monmonier M S 1992 Visualization. In: Abler, R. A., Olson, J. M. and Marcus, N. G. Geography's Inner World. New Brunswick, NJ: Rutgers University Press: 99-137.

McAbee I James 1991 Spatial modeling and visualization: methodologies for integration pathways to understanding. Proceedings of EGIS '91, 2: 707-716. Brussels: EGIS Foundation.

McCleary G F 1983 An Effective Graphic 'Vocabulary' IEEE Computer Graphics and Applications, March/April, 46-53.

McCormick B H, DeFanti T A, Brown M D 1987 Visualization of Scientific Computing Report to the National Science Foundation by the Panel on Graphics, Image Processing, and Workstations. Baltimore Maryland,: ACM SIGGRAPH.

Medyckyj-Scott D 1994 Visualization And Human-Computer Interaction In GIS in Visualization in Geographical Information Systems. H M Heamshaw and D J Unwin (eds) John Wiley and Sons Chichester UK 200-211.

Monmonier Mark 1992 Authoring Graphic Scripts Experiences and Principles Cartography And Geographic Information Systems 19 (4): 247-260, 272. Abstract: Two prototype graphic scripts illustrate a variety of design principles useful in composing narrative sequences of dynamic maps, statistical graphics, and text blocks. The correlation script examines the variation and covariation of two variables in both geographic and bivariate attribute space, and the historical script uses complementary measurements to explore spatial-temporal change in a single variable. Both scripts are organized into acts and scenes, like a stage play, and progress from simple to more complex representations. A unique signature hue identifies each variable. Motion and juxtaposition link maps with scatterplots, bar graphs, and other non cartographic displays, and blinking symbols emphasize important features and support the sequential joint examination of maps and graphs by category or region. Text is a key element for
describing the purpose or strategy of short graphic sequences, called graphic phrases, as well as for identifying variables, categories, or regions.

Monmonier Mark and MacEachren Alan M (eds) 1992 Special Issue on Geographic Visualization Cartography And Geographic Information Systems 19 (4).

Neisser U and Kerr N 1973 Spatial and Mnemonic Properties of Visual Images. Cognitive PsychologY, 5: 138-150.

Onodera T and Kawai S 1990 A Formal Model of Visualization in CQm ut Graphics Berlin: Springer Verlag.

Openshaw S, D Waugh and A Cross 1994 Some Ideas About The Use Of Map Animation As A Spatial Analysis Tool in Visualization in Geographical Information Systems. H M Heamshaw and D J Unwin (eds) John Wiley and Sons Chichester UK131-138.

Petch J 1994 Epistemological Aspects Of Visualization in Visualization in Geographical Information Systems. H M Heamshaw and D J Unwin (eds) John Wiley and Sons Chichester UK 212-219.

Reilly S S and Roach I W 1984 Improved Visual Design for Graphics Display. IEEE Computer Graphics and Applications, Feb, 42-5

Robertson P K 1988 Choosing Data Representations for the Effective Visualization of Spatial Data. Proceedings of the Third Intemational Symposium on Spatial Data Handling, Sydney, Australia, 243-253.

Thalman D 1990 Scientific Visualization and Graphic Simulation Chichester: John Whiley

Tobler W R 1994 Bidimensional Regression Geographical Analysis 26 (3): 187 - 212 Abstract: Regression analysis has been found useful in almost all disciplines. In a computer implementation a nonparametric approach allows visualization of the regression by automatically plotting the pair of scatter diagrams, drawing of the displacement field, differentiable smooth interpolation of the warped coordinates and predicted image, by a diagram of the principal strains, and with contour maps of the estimated local angular, areal, and total distortion.

Tang Q 1992 A Personal Visualization System for Visual Analysis of Area-Based Spatial Data. Proceedings GIS/LIS '92 San Jose. 2: 767-776. Abstract: The wide use of digital technology has produced a large mount of spatial data in computer compatible format. Effective methods are needed to explore the data to find interesting pattems or structures that are unknown to us. Current GISs lack the capability of exploring or hypothesis generating. Their strength in spatial data handling can provide a dependable ground for developing new techniques that facilitate the exploration of digital spatial data and provide an effective approach to hypothesis generating. Developing a visualization system that encourages the exploratory analysis of spatial data is one of these techniques. This paper describes the design of a personal visualization system for exploring area based spatial temporal information. Conceptual discussion on combining visualization and spatial data analysis is presented. The system features, requirements and components and structure are discussed. The research illustrates how to develop a visualization system through enhancing traditional cartographic methods for visual spatial data analysis.

Tobler W R 1994 Bidimensional Regression Geographical Analysis 26 (3): 187 - 212.

Tukey J W 1980 We Need Both Exploratory and Confirmatory. The American Statistician, 34:1, Feb, 23-25.

Turk A 1994 Cogent GIS Visualizations in Visualization in Geographical Information Systems. H M Hearnshaw and D J Unwin (eds) John Wiley and Sons Chichester UK 26-33.

Turk A 1993 Designing advanced GIS visualisations using cognitive ergonomics theories, models and procedures Proceedings 16 International Cartog=hic Conference Cologne Germany 1: 460467. Introduction: Much useful and interesting information about the **world** contains aspects which draw their significance from the spatial distribution of phenomena. Since the earliest days of civilisation such information has been presented in the form of maps and diagrams. The manner of representation has changed exceedingly slowly until recent times. The ability to encode maps digitally has evolved into geographic information systems (GIS) with powerful analysis functionality and display capabilities. Traditional cartographic educational, decision-support and entertairment objectives can now be achieved via a multitude of interactive multimedia products. While this (technology led) revolution has greatly enhanced the potential to fulfill these objectives, it has not eliminated the basic question: what is a good map? Indeed the problem of design has become considerably more complex. The map designer could be said to be left with a choice between: the easy solution - giving users what you have; the popular solution - giving users what they want; the complex solution giving users what they need. The paper discusses these choices in the light of technology advances.

Verplank W L 1988 Graphic challenges in designing object orientated user interfaces. In: Helender, M. (ed.) Handbook of Human Computer Interfaces. North Holland Elsevier Science Publishers, Chapter 17.

Visvalingam M 1994 Visualisation In GIS, Cartography And Vision Visualization in Geographical Information Systems. H M Heamshaw and D J Unwin (eds) John Wiley and Sons Chichester UK 18-25.

Williams B 1991 The Definition and Description of Data Quality Through Truth in Labeling. Proceedings of the Symposium on Spatial Database Accuracy, 1: 240-251. Melbourne: University of Melbourne. Abstract: A geographic information system requires a method to maintain and manage its contents and processes over the long-term. Unfortunately, up until just a few years ago, the description of data quality and associated issues have been neglected topics. Even now emphasis is still predominately concentrated in two areas, these being cartographic aspects of source maps and statistical analysis of data. The real quality of data cannot be quantified using simple descriptive labels. Accuracy requirements are different for specific applications and it seems that the recording of 'quality' is best defined under the concept of truth-in-'labelling'. The goal of this concept is to communicate information on 'fitness for use rather than fixing thresholds of quality. This paper addresses methodologies for incorporating such statements into geographic databases.

Winslett C and Pearsall R J 1991 GIS - The Visualization of Tomorrow. In Technical Papers of the 1991 ACSM-ASPRS Annual Convention, 2: 333-335. Baltimore: ACSM-ASPRS.

Wood J D and Fisher P F 1993 Assessing Interpolation Accuracy in Elevation Models IEEE Computer Graphics and Applications March 1993 48 - 56.

Wood M 1994 Ile Traditional Map As A Visualization Technique in Visualization in Geog=hical Information System . H M Heamshaw and D J Unwin (eds) John Wiley and Sons Chichester UK 9-17

Wood M and K Brodlie 1994 Visc And GIS: Some Fundamental Considerations in Visualization in Geographical Information Systems. H M Heamshaw and D J Unwin (eds) John Wiley and Sons Chichester UK 3-8

Xiong D 1992 Traffic Flow Modeling with Visualization Tools. Proceedings GIS/LIS '92, 2: 844853. San Jose. Abstract: Recently, transportation studies in the area of intelligent vehicle highway systems have been directed mainly toward the development of new types of traffic flow models and the technology necessary to communicate with and guide drivers. The present research however, is conducted with a GIS perspective that places emphasis upon the development of methods to integrate modeling and visualization techniques in order to analyze traffic flows in more effective ways. This paper first introduces a conceptual framework which can be used to integrate various procedures for effective and efficient traffic flow modeling and visualization. Then techniques to carry on model calculation with user equilibrium modeling as a specific example will be presented.

THE VISUALIZATION OF SPATIAL DATA QUALITY

Beard M K 1991 Position Statement on the visualization of data quality Coleaders: Beard M K and

Buttenfield B, NCGIA Specialist Meeting of 17 - Visualisation of the Quality of Spatial Data June 8-12 Castine, ME, USA. Introduction: The historic meaning of quality is associated with fitness for use. This implies some direct interaction on the part of a particular user in the specification of quality or the institutionalization of a common definition or specification of quality by some group of users and/or producers. This position paper will briefly cover characteristics of spatial data which could be considered as contributing to fitness for use. There is both some general agreement about what constitutes spatial data's fitness for use as well as some individual specifications or requirements. Another important consideration for spatial data is its life span and the ways in which fitness for use can change over this life span. The life span and multiple use of data within a geographic information system will generally require that quality is assessed repeatedly and from different perspectives.

Beard M K 1994 Accommodating Uncertainty in Query Response. Proceedings 6th International Symposium on Spatial Data Handling. Edinburgh Sept 5-9. Abstract: No GIS currently presents users with information on confidence limits for data in the database or products derived from the database. As uncertainty is inherent in geographic data, estimates of uncertainty should be made available with any routine inquiry of the database. Standard query processing generates a single deterministic result using standard logic and arithmetic. This paper examines how uncertainty could be accommodated in one of the most basic queries to a spatial database: what is the value of a variable at a specified location. The answer to this question requires a prediction for the variable at unmeasured locations and the uncertainty response requires a measure of reliability of that prediction. The paper examines variations in the form of this query in terms of the measurement scale of the variable, the nature of the underlying distribution and the specificity of the requested location. Data, error descriptions, and error models needed to estimate the reliability of the prediction are discussed.

Beard M K and Mackaness W A 1993 Visual Access to Data Quality in Geographic Information Systems. Cartographica 30(2/3): 37-46. Abstract: Visualization encompasses the display of measured quantities or qualities of visible or invisible phenomena through the combined use of points, lines, a coordinate system, numbers, symbols, words, shading, color, and animation. The objectives of visualization are to provoke insights and expand comprehension of information by revealing complex relationships among data. As Tufte (1983) suggests the special power of visualization hes in the display of large complex data sets. Geographical information is complex information which we have been visualizing for centuries in the form of maps. Recent concern over the accuracy and reliability of spatial information in geographic information systems have raised an interest in extending visualization to help comprehend and communicate the reliability and uncertainty of GIS information and information products. This paper develops design requirements for visualization of spatial data quality based on characterizations of quality, a range of quality assessment tasks, and different contexts under which data quality might be investigated.

Beard M K, Buttenfield B P and Clapharn S B 1992 Scientific Report on Specialist Meeting on Visualizing the Quality of Spatial Information. NCGIA Technical Rel2ort 91-26. 170 pp. Summarises the specialist meeting discussions and development of research topics in connection with the visualization of spatial data quality.

Bregt A K 1991 Mapping uncertainty in spatial data. Proceedings of EGIS '911 1: 149-154. Brussels: EGIS Foundation. Buttenfield B P and Beard M K 1991 Visualizating the Quality of Spatial Information. Proceedings Auto-Carto 10: Technical Papers of the 1991 ACSM-ASPRS Annual Convention, 6:423-427. Baltimore: ACSM-ASPRS. Scope: Effective use of this information for analysis and decision making presupposes that the information is correct or reasonably reliable. Information on the quality of data is essential for effective use of GIS data: it affects the fitness of use of data for a particular application, the credibility of data representation and interpretation, and the evaluation of decision alternatives. The credibility of spatial decision support using GIS may indeed depend on the incorporation of quality information within the database and the display. As Goodchild (1990) states the best insurance will be to sensitize the GIS user community to accuracy issues and to develop tools which allow spatial data handling systems to be sensitive to error propagation. Visualization should be explored as a method for capturing, interpreting and communicating quality information to users of GIS. Clearly, the quality of information varies spatially, and visual tools for display of data quality will improve and facilitate use of GIS. At present, those tools are either unavailable (in existing GIS packages) or not-well developed (error models and the process of visualization are only recently beginning to be addressed directly as research topics).

Buttenfield B P and Beard M K 1993 Graphic and Geographic Components of Data Quality. In Heamshaw, H. and Unwin, D. (Eds.) Visualization in Geographic Information Systems. London: Belhaven Press 150-157. Abstract: Ibis chapter reports development of a conceptual framework within which to address research topics associated with visualization of data quality. The framework refines previous work. A brief review of other efforts to report data quality prefaces discussion about the framework.

Buttenfield B P and Beard M K 1992 Spatial, Statistical, and Graphical Dimensions of Data Quality. Proceedings 24th Symposium on the Interface-Graphics and Visualization Conference, College Station Texas, March 19-21, 1992 408-415. Abstract: The meaning of data quality is associated with the fitness for use. The life span and multiple use of data within a Geographic Information System (GIS) generally requires that quality be assessed repeatedly and from the varying perspectives mandated by varying types of analysis. Collection and maintenance of data quality information has been a goal for producers of digital data, however its incorporation into digital data files only recently has become a priority. The well-known advantage of analyzing data in a GIS is that data can be composited in both numerical and visual fashion, to provide facile interpretation of patterns of spatial autocorrelation, covariance, and similar measures. The intention of integrating data quality with data is to provide numerical and visual interpretation of certainty and reliability of interpreted pattern. The paper presents the current federal standards for categorizing and evaluating data quality, taken from the Spatial Data Transfer Standard, and discusses implications for using data quality displays in spatial analysis. Use of data quality information in GIS modeling will be summarized with examples of graphical design methods appropriate for measures associated with discrete, categorical and continuous data.

Buttenfield B P 1993 Representing Data Quality. Cartographica.30(2/3): 1-7.

Clapharn S B 1992 A Formal Approach to the Visualization of Spatial Data Ouality. Unpublished MA thesis, Department of Surveying Engineering, University of Maine. Abstract: Visualization of the quality of spatial data is a critical tool for the effective use of GIS, a tool which has become more urgently needed with the growing reliance on GIS in the decision making environment. Visualization tools potentially provide the GIS users with powerful insight capabilities into the nature of data. Two issues are central to the visualization of spatial data quality: 1) how to model, assess, and represent quality information in a digital database in a manner responsive to changes in data, as well as in application; and 2) how to provide users with effective access and display methods for the communication of quality information. This thesis is focused on the second of these issues - on the development of a formal basis for the visualization of data quality information.

Clapham S B 1992 A Formal Approach to the Visualization of Spatial Data Quality. Proceedings GIS/LIS '92 ~ 1: 138-149. San Jose. Abstract: Visualization of the quality of spatial data is a critical tool for the effective use of geographic information systems (GIS), a tool which has become more urgently needed with the growing reliance on computer information systems in the decision-making environment. Two issues are central to the visualization of spatial data quality: (I) how to model, assess, and represent quality information in a digital database in a manner responsive to changes in data, as well as in application and (2) how to provide users with effective access and display methods for the communication of quality information. This paper focuses on the second of these issues - on the development of a formal basis for the visualization of data quality information. Using the tools of formal algebraic specification, the domains of data quality and visualization will be logically defined. The paper will discuss spatial data quality, focusing on a small subset of quality components as defined by the Proposed Standards for Digital Cartographic Data. The paper will conclude with a discussion of the implication for GIS design and the integration of visualization tools within geographic information systems.

Clapharn S B and Beard M K 1991 The Development of an Initial Framework for Visualization of Spatial Data Quality. Proceedings Technical Papers of the 1991 ACSM-ASPRS Annual Convention, Annual Meeting American Congress on Surveying and Mapping, Baltimore, Maryland, March, 19912: 73-82. Baltimore: ACSM-ASPRS. Abstract: Knowledge of the quality of data within Geographic Information Systems is a critical factor in spatial decision-making determining not only the fitness-for-use of data for a particular application but also influencing the evaluation of decision alternatives. Current systems lack the capability to adequately assign, track, and communicate quality information. This paper describes preliminary work on the development of a formal basis for the graphic design of visual variables depicting data quality. The approach involves the formal specification of two problem domains -data quality elements and the visual variables which encode information to the graphic interface. The goal of formal specification is to develop a clear, rigorous, implementation-independent definition of the problem components, establish a basis for the evaluation of graphic products, and provide a framework for the integration of visualization tools through automatic synthesis or selection of the graphic representations of quality information within Geographic Information Systems.

Coseir R A and Dalton D R 1988 Presenting information under conditions of uncertainty and availability: Some recommendations. Behavioural Science, 33: 272 - 28 1.

Costanza R, Funtowicz S, Ravetz Jr. 1992 Assessing And Communicating Data Quality In PolicyRelevant Research. Environmental Mana2ement, 1992 Jan-Feb, 16 (1):121-131.

Drummond J and Ramlal B 1992 A Prototype Uncertainty Subsystem Implemented in ITC's IOLWIS PC-Based GIS, and Tested in a Dutch Land Re allotment Project. Proceedings of EGIS '92 1: 234-243. Munich: EGIS Foundation. Abstract: In the context of developing an Uncertainty Sub-system for ILWIS, this paper first proposes some components for a standard GIS error processing capability. It then outlines a practical exploration of a Dutch Land Consolidation Project, where the quality parameters of several soil and grazing potential characteristics relating to land parcels were processed. Then some resulting cartographic products are described, which show both grazing potential information and the quality of that information. Finally, future tasks to be carried out in this Uncertainty Subsystem project are outlined.

Fisher P F 1992 Real-Time Randomization For The Visualization Of Uncertain Spatial Information Proceedings of 5th International Symposium on Spatial Data Handling IGU Commission on GIS, Aug 3 - 7 1992, Charleston South Carolina 491-494. Abstract: Much spatial information is presented to users as if its location were precisely determined when in reality it is only imprecisely known, and other information, which is imprecisely known, is not presented at all. This paper explains how the visualization of these types of data may be made possible by using real-time randomization as part of the computer-screen display. The paper does not contain any illustrations because the resulting displays contain continuous change, and so any displays are inherently dynamic and static displays can only give a partial representation.

Fisher P F 1994 Animation And Sound For The Visualization Of Uncertain Spatial Information in Visualization in Geographical Information Systems. H M Heamshaw and D J Unwin (eds) John Wiley and Sons Chichester UK 181-186. Abstract: In this chapter two methods for visualizing error are presented. In the first, error terms are integrated with the display by animation, where the locations of features are revised by random selection as the map is displayed, and it is believed that the uncertainty in the locations and attributes are communicated to the user at the same time as the information in the original map is retained. The second method uses sound to convey the error by highlighting a location and sounding either tone or rhythm in proportion to that error. The discussion considers the effectiveness of these methods. A systematic experimental testing of the effectiveness of the displays is essential but is not without problems.

Fisher P F 1993 Visualizing Uncertainty in Soil Maps by Animation. Cartographica. 30(2/3): 2027.

Frank S 1993 Using Visualization Techniques to Examine the Effects of Random Control Points on Grid Interpolation. Proceedings GIS/LIS '93. Minneapolis, MN. 1: 226-232. Abstract: Rectangular grids are often interpolated from random data points in an effort to more easily manipulate spatial data. Data with spatial components are often easier to sample in random spatial patterns while the manipulation of such data is easier accomplished using uniform spatial sampling patterns. Grid interpolation attempts to bridge these two problems by making spatial data both easy to collect and easy to manipulate. While the merits of different approaches are widely discussed in GIS literature, methods to visualize what effects the placement of the random sampling points on the interpolation of values at derived grid points has bee rarely, if ever, approached. We examine a method of visualizing the effects of grid interpolation by distorting the grid at points where the randomly sampled control points have differing effects on the interpolated grid. While the exact method of our research is focused on the Interpolation methods used to compute dissolved inorganic nitrogen levels in Chesapeake Bay, the method is extensible and can be applied to other interpolation methods.

Goodchild M F, Buttenfield B P and J Wood 1994 Introduction To Visualizing Data Validity in Visualization in Geographical Information Systems. H M Hearnshaw and D J Unwin (eds) John Wiley and Sons Chichester UK 141-149. Abstract: The need for tools to facilitate description, storage and representation of such information has been recognised by the US National Center for Geographic Information and Analysis (NCGIA). Priorities for the initiative include development of frameworks linking spatial data quality components with visualization methods, implementation of prototype displays, and database management to support error tracking and to facilitate graphical depiction of error propagation during GIS operations. This section reports research in all three areas.

Goodchild M F, Chih-Chang L and Leung Y 1994 Visualizing Fuzzy Maps in Visualization in Geographical Information Systems. H M Heamshaw and D J Unwin (eds) John Wiley and Sons Chichester UK 158-167 Introduction: Increasing emphasis on analysis, modeling and decision support within the GIS applications community in recent years has led to a general concern for issues of data quality. If the purpose of spatial data handling is to make maps, then perhaps it is sufficient to require merely that the output map product be as accurate as the input and to present visualizations of the data as if they
were perfectly accurate and certain. But the detailed analytic and modeling applications that underlie much of the recent literature of GIS demand much more stringent and robust approaches. If the input is known to be inaccurate, uncertain or error-prone, then it is important that the effects of such inaccuracies on the output also be known. Without such knowledge, the apparent value of GIS in supporting spatial decision-making may be illusory.

Hassen K M 1993 Visualization of Soil Boundaries in a Cell Based Model. Proceedings GIS/LIS'9a. Minneapolis, MN. 1: 292-301. Abstract: A consequence of internal variations in soil properties is that the boundaries between mapping units on soil maps are inherently indeterminate. Uncertainties in soil boundaries are pervasive in soil maps. Thus, the effective and proper use of any soil

maps is a function of the users' awareness of these uncertainties and the users' ability to interpret such uncertainties. Visualization tools offer the promise of easy and efficient methods for conveying soil map quality components to soil map users. This paper acknowledges that raster or grid-cell models have greater suitability for representing not only inherent continuous polygon variations but also transition zones between soil classes. This project uses a grid-cell model to characterize and visualize the uncertainty in soil boundary transition zones. The paper begins with a discussion of the representation of the soil boundary uncentainties in a grid-cell based model. The paper describes in details the methodologies used in the current project.

Hootsmans R and van der Wel, F 1993 Detection and visualization of ambiguity and fuzziness in composite spatial databases. Proceedings of EGIS '93, 2: 1035-1046.

Jaakkola 0 and Sarjakoski T 1993 Visualization of the Quality of Satellite Based Land Use Classification Surveying Science in Finlan 11 (1-2) 61 - 81. Abstract: Pixel based supervised satellite image classifiers produce results with varying quality. There is a need for a measure of quality in the use of land-use classifications derived from satellite image classifiers. The article proposes a method for showing the quality of a supervised classifier and summarizes the results of the research, described in Finnish, in Jaakkola and Sarjakoski (1991).

The Mahalanobis distance, available from the classification procedure itself, was taken as a quality measure. From this measure we have derived the distance ratio of one class to another and the distance ratio of one class to the minimum of the other classes, as well as the minimum distance itself. The distance images are combined with a classification using a user oriented HSB - colour mode. In the combination we have used the theory of graphics which suggests the use of hue for qualitative land-use classes and saturation intensity for quantitative Mahalanobis distances and derivations of it. The resulting combination images show the different aspects of classification quality and give the answer to questions concerning the spatial variation of the quality of one class, to classes or the whole classification.

Kraus K 1992 Analysis of geographical data and visualisation of their quality. XVth Congress. International Society for Photogrammetry and Remote Sensing, 741-747.

Kraus K 1994 Visualization of the quality of surfaces and their derivatives. Photogrammetric Engineering and Remote Sensing 60 (4): 457-462.

Kress T 1991 Visualization of Spatial Data Quali1y. Unpublished MA thesis, Department of Geography, SUNY-Buffalo.

Leung Y, Goodchild M F and Lin C-C 1992 Visualization of Fuzzy Scenes and Probability Fields. In P. Bresnahan, E. Corwin and D. Cowen (Ed.), Proceedings of the 5th International Symposium on Spatial Data Handliiig, 2: 480-490. Charleston: IGU Commission of GIS. Abstract: Fuzzy classification has the potential to yield richer information from remotely sensed images, but there have been few efforts to deal with the issues involved in working with fuzzy classifications in GIS. Analogous data are also obtained when the multinomial classification given to land is treated as mixed, fuzzy or probabilistic. The paper reports on a series of efforts to develop visualization techniques for such data. To support visualization of the inherent variability in such data, and to propagate uncertainty effectively through GIS operations, it is necessary to introduce the concept of an error model as a stochastic process, and to define a method for creating individual realizations of that process.

MacEachren Alan M, Howard David, Von Wyss Martin, Askov David, Taormino, Tiln 1993 Visualizing The Health Of Chesapeake Bay: An Uncertain endeavor Proceedings GIS/LIS 93, Nov 2-4, Minneapolis Minnesota 1: 449-458 Abstract: This paper reports on a prototype exploratory spatial data analysis (ESDA), environment designed to facilitate incorporation of uncertainty estimates. The prototype is directed particularly to analysis of dissolved inorganic nitrogen in the Chesapeake Bay. Emphasis is placed on spatial, temporal, and attribute uncertainty issues inherent in collection and processing of space-time data (e.g., sampling, categorization, interpolation, spatial filtering, etc.). The development platform for the ESDA project is IMSLADL, running under UNIX on Sun Sparcstations. IDL allows a wide range of data manipulation possibilities and provides flexible tools for designing custom interactive user interfaces. Two important questions related to uncertainty representation have been identified in previous research: (a) which graphic variables are appropriate for showing different kinds of uncertainty and (b) what kind of user interface is most effective. IDL provides a dynamic environment for addressing both of these questions and for extending the first to dynamic as well as static variables.

Mackaness W A and Beard M K 1993 Visualization of Interpolation Accuracy Proceedings of Auto Carto 11, Minneapolis, Minnesota, Oct 30 - Nov 1, 228-237. Abstract: Spatial interpolation is a valuable and now more frequently used function within GIS. A number of data sources for GIS include interpolated values (e.g. DEM's) and a number of the output products from GIS are the results of some form of interpolation. Since interpolated results in one way or another play a role in GIS analysis, users can benefit from some assessment of the reliability of interpolated values. The accuracy of an interpolation depends on several factors including: sampling scheme, number of sample points, interpolation method, measurement error in the observed x, y, z values and the nature and

complexity of the observed phenomena. Most interpolation methods provide no information on the reliability of the estimated values. Kriging is one exception which produces estimates of values at unrecorded places without bias and with minimum and known variance. Results of kriging reported in the literature typically show kriged values and error estimates as separate isarithmic maps making assessment of the results difficult. This paper describes visualization techniques for examining the reliability of interpolated values. Visual displays are presented which account for the number and distribution of sampling points, the interpolation method, and measurement error in observed values. Additionally, the paper addresses displays for kriged results which combine kriged values and error estimates.

McGranaghan M 1993 A Cartographic View of Spatial Data Quality. Cartographica. 30(2/3): 8-19.

Miri B 1993 Visualization of Soil Map Inclusions with Change in Scale. Proceedings GIS/LIS '93. Minneapolis, MN. 2: 540-549. Abstract: Internal variation within mapping units is an inevitable characteristic of soil maps. Scale limitations, cartographic legibility, and the natural variation of soil properties prevent the delineation of areas that are 100 percent pure; but soil maps and their digital representations imply homogeneous units to the non soil scientists. To avoid misinforming users, GIS should be capable of displaying the presence of impurities or foreign inclusions within soil map units. This paper describes methods for presenting the existence of soil inclusions at different resolutions so that the users can be better informed on the reliability of soil maps.
Mitasova H, Brown W, Gerdes D P, Kosinovsky I and Baker T 1993 Multidimensional Interpolation, Analysis And Visualization For Environmental Modeling. Proceedings GISYLIS '93 2: 550-556. Abstract: To support the needs of environmental modeling using GIS, a new system for multidimensional interpolation, analysis and visualization has been developed. The interpolation is based on multivariate regularized spline with tension and smoothing. It allows the user to transform the point data to 2D, 3D and 4D grids, and compute the geometric parameters like gradient sand curvatures. Cross validation procedures is used to find the optimal tension and smoothing and evaluate the predictive error. Visualization tools support the visualization of multiple dynamic surfaces with draped color, vector or point data and point data attributes for bivariate cases. Similar capabilities are being developed for dynamic volumetric visualization using animated isosurfaces, slices and solids. System is integrated or linked with GRASS GIS.

Monmonier M 1993 Exploring the Quality of Enumeration-Area Data With Graphic Scripts. Cartographic . 30(2/3): 28-36.

Niemann Brand L 1993 Integration Of Metadata And Space-Time-Depth Variabilities And Uncertainties In Chesapeake Bay Monitoring Data For Improved Visualization And Spatial Analysis Proceedings GIS/LIS 93, Nov 2-4, 1993 Minneapolis Minnesota 2: 567-576. Abstract: An entry to the Visualization Challenge was created which communicates multiple aspects of geographic data quality and uncertainties in a hypertext-hypermedia run-time stand alone software package, Folio Views, that can be used with GIS and Desktop Mapping software packages. The U.S. EPA data set from the Chesapeake Bay Program Office consisting of concentrations of dissolved inorganic nitrogen (DIN) measured at 49 stations in the main stem of the Chesapeake Bay during the period October, 1985 through September, 1991, was used to develop a visualization and metadata retrieval system to supplement the conventional spatial displays from a GIS. The database contains changes in sampling frequency and detection limits, seasonal oscillations, and possible trends due to variations in sampling depth, riverine flow and pollution loads that render simple GIS displays of spatial patterns of median concentrations or total mass incomplete and potentially misleading. The Folio Views infobase and LOTUS worksheets will be made available on diskettes and the Internet.

Paradis J and Beard M K 1994 Visualization of Spatial Data Quality for the Decision Maker. A Data Quality Filter URISA Joumal (in press). The lack of effective communication of data quality (fitness for use) is a key issue hampering the successful utilization of geographic information systems (GIS). Current GISs do not explicitly address quality information and provide few or primitive means by which to communicate it. This work proposes a "data quality filter" to efficiently organize and communicate data quality to a decision maker. The filter relates data quality information directly to the visualization of data, providing an implicit yet precise portrayal of the datas fitness for use. To apply the filter, the user defines a set of quality requirements with respect to accuracy, resolution, consistency and lineage. As the user retrieves and processes one or more data sets, only data meeting the specified criteria pass through the "filter." The visualization technique simply displays the data meeting the user's specifications. The application of the filter to a cadasu-al data set of heterogeneous quality illustrates the effectiveness and utility of this approach. The filter directly relates quality and its communication and encourages users to become intimately involved with their actual data requirements, contemplate trade-offs, define a realistic error budget and participate in comprehending the effects of a GIS function on a data set.

Schweizer D M 1992 Visualizing Data Qualily for Chorppleth MWs. Unpublished MA thesis, Department of Geography, University of California-Santa Barbara.

Schweizer D M and Goodchild M F 1992 Data Quality and Choropleth Maps: An Experiment with the Use of Color. Proceedings GIS/LIS '92. 2: 686-99. San Jose. Abstract: Thematic attribute uncertainty is an inherent feature of maps produced from Geographic databases since all spatial data are of limited accuracy. To minimize the incorrect interpretation of GIS output, accuracy information needs to be readily available. The purpose of this research is to determine if the connotative implications of gray are effective in displaying data uncertainty. The Hue Saturation Value (HSV) color model is tested for its ability to simultaneously map data attributes

and corresponding data uncertainty. Saturation is used to symbolize data attributes. Value is used to symbolize uncertainty rankings as the value scale corresponds to the gray scale. An experiment designed using this color theory was administered to 101 students. Results of the experimentation indicate that value, when correlated to grayness, is not an effective means of displaying data uncertainty. The authors suggest the inability of value to represent data uncertainty may be attributable to the relationship between grayness and the value scale defined for this experiment. As a result, the authors further suggest maximum grayness occurs towards the center of the gray scale rather than at an endpoint.

Veregin H, Paul Krause, Robin Pandya Rebecca Roethlisberger 1993 Design And Development Of An Interactive Geiger Counter For Exploratory Analysis Of Spatial Data Quality Proceedings GIS/LIS 93, Nov 2-4, Minneapolis Minnesota 2:701-7 10. Abstract: This paper discusses the design and development of an automated system to facilitate interactive exploration of data quality for spatial databases. 'Me system is implemented in a windows-based graphical environment. This environment allows map information (i.e. soil mapping units) to be displayed independently from data quality information. Separate windows displaying map and data quality information are linked dynamically, such that actions carried out in one window have effects in the other. Animation techniques provide the user with direct, immediate feedback on the actions undertaken. The design of the system encourages the user to adopt an exploratory approach and test hypotheses in an informal manner. Another important characteristic of the system is the use of auditory variables to complement the visual portrayal of data quality information. The system is also designed around a flexible data model that allows different data quality models to be examined. This characteristic reflects the multidimensional nature of data quality in the context of soil maps and other spatial databases.

Veregin H 1994 Exploratory analysis of error in geographic information systems Proceedings 16 International Cartographic Conference, Cologne Germany 1: 561-570. Introduction: A frequent but often overlooked problem in map-based spatial analysis is the use of data for which the magnitude and spatial distribution of error is unknown. Although some maps conform to known accuracy standards (e.g., the US Geological Survey's National Map Accuracy Standard), many maps contain undocumented errors and many map producers do not consistently apply procedures for assessing map accuracy. Reliance on data of low quality can have serious repercussions in decision-making, especially if these data are used in policy enforcement and litigation, where data quality standards are high. The replacement of traditional cartographic techniques with GIS has exacerbated rather than diminished this problem. One of the advantages of GIS is that it provides a convenient environment in which source map layers can be transformed to derive new map layers. GIS data transformation functions induce modifications in the error characteristics of source layers and pass these modified characteristics on to derived layers. This process is referred to as error propagation. As a result of error propagation, derived layers may contain significantly higher levels of error than the sources from which they were derived, making them unfit for certain applications.

Ward M 0 and J Zheng 1993 Visualization Of Spatio-Temporal Data Quality Proceedings GIS/LIS 93, Nov 2-4, 1993 Minneapolis Minnesota 2: 727-737. Project Summary: Maps and other forms of geographic visualization rarely convey to users the quality or reliability of the information being presented. However, decisions are made based on the analysis of spatio-temporal data may be seriously flawed if the quality of the data is not taken under
consideration. This paper presents a technique for visualizing the quality of data which has both spatial and temporal attributes. We use a model of quality which incorporates both characteristics of the data gathering equipment as well as the model used to interpolate data at arbitrary locations in space and time. The resulting visualization system allows users to map five-dimensional data to five graphical attributes, where each attribute may be displayed in one of three modes continuous, sampled, or constant. We show examples using US EPA data on dissolved inorganic nitrogen (DIN) concentrations in the Chesapeake Bay over a several year period.

Wood J 1994 Visualizing Contour Interpolation Accuracy In Digital Elevation Models in Visualization in Geographical Information Systems. H M Heamshaw and D J Unwin (eds) John Wiley and Sons Chichester UK 168-180

Wel F J M v d 1993 Visualization of quality informations as an indispensable part of optimal information extraction from a GIS. Proceedings. International Cartographic Association Conference, Koln, 3-9 May 2: 881-897. Abstract: Results of geographical analyses often lack any indication of the fitness for a certain application. This quality information is becoming indispensible in order to guide the inexperienced GIS user who is faced with an increasing amount of digitally available data. Visual support during the selection, processing, presentation and interpretation of data is considered an effective and efficient means to communicate quality information. Two projects, being performed at Utrecht University, illustrate the shifting role of cartography in the handling of spatial data quality in a GIS environment.

Zhou F Q and Lee Y C 1994 Polygon Uncertainty Modelling And Representation Proceedings of the Canadian Conference on GIS Ottawa, Canada June 6-10. 1: 185-194. Abstract: Uncertainly modeling and representation for area features are important to the management of spatial data. Traditionally, uncertainty indicators are not attached to polygons, thus causing the loss of valuable information. This paper discusses the problems of deriving uncertainty information from raw data and their efficient representation in geographic databases. We will consider two sources of uncertainty in this study: those inherent in the data as results of measurement and interpretation, and those introduced by spatial operators. For the latter case, we will concentrate on uncertainty related to the

classification process. A representation of uncertainty for area features based on polygons has been developed. It assumes that the area has a homogenous core of no uncertainty surrounded by a fuzzy boundary. We will address the issues of determining the uncertainty function for the boundary, and the representation of the core and fuzzy boundary for a polygon.