INTRODUCTION: A GENERAL FRAMEWORK FOR ERROR ANALYSIS IN MEASUREMENT-BASED GIS

Michael F. Goodchild, University of California, Santa Barbara[1]

In science generally, the analysis of the errors inherent in continuous-scaled measurements of quantities is well developed, and numerous textbooks are available (e.g., Taylor, 1982). It is possible, for example, to predict the errors that result when individual measurements are combined arithmetically, based on differentiation of the combination equation with respect to the measurements, and based on knowledge of the error distributions of the measurements. The Gaussian distribution is frequently assumed as the error distribution of measurements, based on sound theory.

We do not normally consider mapping a measurement science, largely because of the complex transformations, generalizations, and partially subjective interpretations that occur in data acquisition. Instead, it is common to remove any information that might link GIS layers to original measurements, and thus to present data in a way that makes any conventional error analysis impossible. The science of error modeling for such layers has developed rapidly over the past 15 years (see, for example, Zhang and Goodchild, 2002), but it is fundamentally constrained by a lack of formal characterization of the measurement and compilation process; instead, error models must be "retrofitted" to data, and key information such as error covariance structure is frequently missing. This is in sharp distinction to the fields of surveying and geodesy, where error analysis based on known measurement error distributions is routine, based on well-developed theory.

In a paper prepared for a conference in 1999 (Goodchild, 1999, 2002) I argued that GIS could take a leaf from the surveying and geodesy books, by rethinking its fundamental assumptions regarding uncertainty. If one assumed that it was never possible to know location on the Earth's surface perfectly (no measurement of a continuous quantity can ever be exact), then one would logically adopt a very different approach to GIS architecture, in which positions were established not in some absolute Earth coordinate system, but by a hierarchy of relative measurements, anchored to the Earth only at well-defined points. By preserving the measurements, and the transformations that convert them to positions (and the inverses of such transformations), a *measurement-based GIS* would solve several long-standing problems. First, it would be capable of partial update, the process whereby positions of some features can be made more accurate without at the same time replacing the entire database. Second, it would support comprehensive analysis of the propagation of error, and thus of the errors in results of GIS analysis.

In this series of four papers we show the implications of such an approach (see Leung, Ma, and Goodchild, 2003 for an earlier preview of this work). We are very grateful to the

[1] Department of Geography and National Center for Geographic Information and Analysis, University of California, Santa Barbara, CA 93106-4060, USA. Email good@geog.ucsb.edu, voice +1 805 893 8049, FAX +1 805 893 3146

editors of *JGS* for agreeing to publish all four papers in one issue, preserving the integrity of the whole. The mathematics is not easy, but we have endeavored to make the presentation as accessible as possible. We hope that the collection reinforces the case for measurement-based GIS by demonstrating the significant advances in understanding that result from taking this approach. We also hope that it stimulates further research on the topic, and further steps towards a practical implementation.

REFERENCES

Goodchild, M.F., 1999. Measurement-based GIS. In W. Shi, M.F. Goodchild, and P.F. Fisher, editors, *Proceedings, International Symposium on Spatial Data Quality, Hong Kong*. Hong Kong: Hong Kong Polytechnic University, pp. 1–9.

Goodchild, M.F., 2002. Measurement-based GIS. In W. Shi, P.F. Fisher, and M.F. Goodchild, editors, *Spatial Data Quality*. New York: Taylor and Francis, pp. 5–17.

Leung, Y., J.-H. Ma, and M.F. Goodchild, 2003. A general framework for error analysis in measurement-based GIS: a summary. In W. Shi, M.F. Goodchild, and P.F. Fisher, editors, *Proceedings of the Second International Symposium on Spatial Data Quality*. Hong Kong: Hong Kong Polytechnic University, pp. 23–33.

Taylor, J.R., 1982. *An Introduction to Error Analysis: The Study of Uncertainties in Physical Measurements*. Mill Valley, CA: University Science Books.

Zhang, J.X. and M.F. Goodchild (2002) *Uncertainty in Geographical Information*. New York: Taylor and Francis.