The Nature of Analytical Cartography: An Introduction

Harold Moellering

Guest Editor

Since its auspicious beginnings in the early 1960s by Prof. Waldo Tobler (1961), analytical cartography has grown and flourished scientifically, analytically, and intellectually. Analytical cartography has added a new dimension to cartography with its goal of developing a scientific base of analytical and mathematical theory as the fundamental underpinning of cartographic research. This focus on theory is in stark contrast with the traditional focus of cartography on artistry and technology in map design and production that has been practiced for more than four thousand years. Analytical cartography is also very different from the other major cartographic theme—map communication and representation—, which dates back to Robinson's (1952) seminal research that established the "Communication School" of cartography.

An earlier issue of this journal dedicated to analytical cartography (Moellering 1991) contained five research articles reflecting a variety of philosophical, mathematical, technical and applied aspects of analytical cartography. These papers were carefully selected to show the breadth and depth of research going on at that time in analytical cartography. This issue systematically explores the nature of analytical cartography, defining the scope and conceptual content of the field with all of its richness, diversity, and research opportunities. Apart from theory, we examine some of the applications of analytical theory in cartographic practice, highlighting major computational limitations to such work. The discussions also identify linkages to related cognate fields of research, especially the emerging area of geographic information science. One such link between analytical cartography and other fields is through the Mathematical Mode of Inquiry (MMOI) advocated by Casetti (1999) for human geography.

Analytical cartography was the topic of two sessions organized at the 1999 Association for American Geographers (AAG) meeting in Honolulu, Hawaii: "The Nature of Analytical Cartography" and "The Future of Analytical Cartography." The outcome of those sessions was very positive, and the organizer was invited to serve as the Guest Editor for this issue of *Cartography and Geographic Information Science.* Four out of the five session presenters expanded their papers into full journal articles. All manuscripts received full peer review. The result is a set of articles by some of the leading figures in the field of analytical cartography.

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Professor Waldo Tobler, Professor Emeritus from the University of California, Santa Barbara, was the one who, by the power of his penetrating spatial/analytical insights and phenomenal theoretical grasp of the field, brought analytical cartography into being. His pioneering research and subsequent scientific leadership attracted many other researchers to the field of analytical cartography. We dedicate this issue to him as a tribute to his long and distinguished record in the development of analytical cartography as a science.

The first article, ironically, is by Tobler himself. In it he recounts some of his personal academic and research history and development. As one reads the article, one begins to understand the inner workings of a truly brilliant spatial mind. Tobler points that "Geographers use maps more as analytical tools...," suggesting that both analog map (i.e. hard-copy) and digital (virtual map) data can be used to solve cartographic problems. Tobler reviews work he has conducted since the mid-1970s in an orderly analytical perspective. Looking back at his predictions for the future, he notes that some have already come to pass. Examples in point are wristwatch latitude and longitude which he had predicted in the late 1960s, and which have come into existence as part of the GPS wristwatch. Although an eminent theoretist, many of Tobler's predictions relate to practical technology, perhaps because Tobler has always tried to find an application for his theories. An example of this is presented in the appendix to his paper where he

Cartography and Geographic Information Science, Vol. 27, No. 3, 2000, pp.187-188

describes an N-dimensional extension to the resel resolution formula for the irregular cellular version of the sampling theorem, an extension that is scientifically provocative as well as of great potential for practical application.

The second article, by Clarke and Cloud, examines some of the developments in analytical cartography and Tobler's major contributions to these developments. According to Clarke and Cloud, analytical cartography's roots go as far back as World War II and the Cold War. The authors review work coming out of the academic, industry, government, and intelligence communities from the 1960s (e.g., Project CORONA) through to the 1990s (e.g., the World Wide Web) and suggest that "The next generational shift in the center of the discipline may occur in networks that even Waldo Tobler did not anticipate."

Moellering, in the third article, examines the scope and conceptual content of analytical cartography using a number of selected topics. Among them are such fundamental concepts as Tobler's transformations, real and virtual maps, deep and surface structure, Nyerges' data levels, spatial dimensional object primitives, and the sampling theorem. More specific theory is also included. Moellering gives brief definitions of spatial frequencies, neighborhood operators, Fourier theory, fractals, Warntz networks, and polygon operations, to name just a few of the topics. Recent concerns such as map generalization, shape analysis, spatial data models and structures, analytical visualization, and spatial data standards are discussed as well. The discussions are well referenced, and geared toward reenforcing future directions for research, e.g., research in the spatial regular and irregular cellular domain, the spatio-temporal domain, and in associated analytical areas of work. Judging from the specific research needs emerging from these future directions, the discipline of analytical cartography has a bright research future ahead.

The fourth article by Franklin focuses on selected applications of analytical cartography and the computational and implementation challenges these applications may be facing. Franklin examines terrain visibility, map overlay, mobility, approximation of curves, and terrain smoothing. He is concerned about the simplicity, robustness, and the tradeoffs between various data types, and looks at future applications from this same perspective.

Saalfeld contributes the final article in which he examines the tractability and complexity of algorithms and computer processing. He points out that there are significant limitations to the computational solving of spatial problems. Saalfeld believes that NP-complete problems, and especially those that are classed NP-hard, are not likely to be solved by more computer power. Map labeling and map generalization are two problems that reside in the domain where the need for better analytical spatial theory could not be greater.

A Suggestion

As was already mentioned, Tobler provides in this issue an extension of his irregular cellular resel resolution approximation to the regular form of the sampling theorem originally presented in 1984 (Tobler 1984). He has extended the approximation into *N*-dimensional space that results in Average Spatial Resolution given in units of length. Currently there is no known name for such units of spatial resolution. In the time domain the units of cycles/second are named Hertz, after the famous 19th century physicist. Now we have units of cycles per unit distance, probably kilometers. It is proposed here that we begin using the term "Toblers" for irregular spatial resolution measured in cycles per unit of distance. This would be a wonderful way to commemorate the powerful influence of Prof. Waldo Tobler on the spatial data sciences. Your comments are invited.

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