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Putting spatial statistics (back) on the map

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ABSTRACT

The literature in Geographical Information Science and Statistical Science often contains calls for analysts to "think spatially" and to "think statistically", respectively, in order to gain better insight into proposed hypotheses. A central element of these calls involves the development of a *spatial* intuition or a *statistical* intuition, i.e., conceptual ways of framing questions, incorporating available data, calculating quantitative summaries, interpreting outcomes, and providing empirical answers from either a spatial or a statistical perspective. In this paper, I draw on past experience to identify and illustrate the potential for "spatial statistical thinking", that is, the development of a *spatial statistical* intuition. Several examples illustrate the potential for a more explicit development of such intuition drawing simultaneously from both spatial analysis and statistics. As a step in this direction, I stress the importance of maintaining a spatial conceptual framework in the application and interpretation of spatial statistical methods, i.e., the importance of *spatial* interpretation of spatial statistics.

1. Introduction: I have in my possession a map...

Maps play a key component in human thought, and history is filled with stories wherein a newly revealed map sets events in motion. Fictional characters including Jim Hawkins in *Treasure Island*, Indiana Jones in *Raiders of the Lost Ark*, Nancy Drew, and Harry Potter all benefit from timely reference to maps. Similarly, the history of science is filled with breakthroughs motivated by insight provided by maps of various types of data. Examples abound including:

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- Heinrich Wilhelm Brandes' maps to understand weather patterns in the late 1800s (Monmonier, 2000 describes his own valiant attempt to identify the first such map);
- John Snow's famed maps revealing the impact of water systems on the spread of cholera in London (Snow, 1855);
- Alfred Wallace's "Wallace Line" contributing to the theory of evolution by identifying geographic borders between dominant species (Wallace, 1863, with similar maps circulating even earlier, see (Camerini, 1993));
- Alfred Wegener's maps linking the visual similarity of continental coastlines with matched fossil records to support his theory of continental drift (Wegener, 1915, 1966);
- Walter Christaller's recognition of the relatively regular distribution of mapped German towns motivating the development of central place theory (Christaller, 1933, Trans. 1966); and
- Torsten Hägerstrand's logarithmic distance-based "fish eye" maps of Asby, Sweden seeding his theory of spatial diffusion of innovations (Hägerstrand, 1967).

In each case, the spatial representations of data in maps offer insight not readily available through numerical or textual summaries. Such spatial curiosity led directly to new ideas, hypotheses, and understanding. However, all too often, similar spatial inquisitiveness is lacking in the modern application, interpretation, and communication of spatial statistics.

In the sections below, I briefly review highlights from the literature addressing "spatial thinking" and "statistical thinking", with the goal of identifying elements common to both. The full literature on modes of analytic thinking is vast, even within these two particular fields, and the interested reader is referred to existing reviews (e.g., Creswell, 2003) for a fuller discussion. My goal is to use results from past research collaborations to illustrate my own developing intuition in spatial statistics, admittedly, often developed in hindsight via trial and error. This evolving intuition views both statistical problems in a spatial setting and spatial problems in a statistical setting. While I cannot claim to have achieved final balance in these areas myself, I have learned to see results in a broader perspective. I argue that this evolving problem-solving mindset reveals new assumptions, new default questions, and new analytic skills relating to something beyond simply viewing spatial problems statistically or viewing statistical problems spatially. For the sake of discussion, I refer to these skills as "spatial statistical thinking", and illustrate the concept in several examples below. While the examples certainly do not fully define the concept, I argue they illustrate important elements of a developing idea and motivate further discussion and development of the issue.

2. Thinking spatially: geographic information science

The development of Geographic Information Systems (GISs) greatly facilitated ready access to geographically referenced data in a wide variety of fields. Increased access to spatial data increased the opportunities for spatial visualization and analysis of geographic data thereby motivating increased calls to "think spatially", i.e., calls to use spatial associations, patterns, linkages, and visualization to synergize the development and assessment of *spatial* theories and hypotheses within any discipline. These new analytic frameworks build on a broad base of fundamental geographic concepts, as illustrated through Napoleon and Brook's (2008) use of the National Geography Standards from the Geography Education Standards Projects (1994) to motivate introductory instruction in Geographic Information Systems. Together, the synthesis of geographic concepts, georeferenced data, and spatial conceptualization form the basis of the field of *Geographic Information Science* (GIScience, Goodchild (1992)).

Goodchild's (2010) review of the first 20 years of GIScience outlines the development of its key concepts: the recognition and representation of complexity in spatial data, the explicit consideration of the scale of observation, and a deliberate focus on spatial data acquisition and integration. Goodchild (2010, pp. 13–15) notes that the field of GIScience continues to evolve and outlines a short list of current "grand challenges". These include: application of broadly accessible location information, incorporation of volunteered geographic information, analysis of temporal variations in spatiotemporal data, modeling uncertainty in GIScience, and education of the general public in GIScience concepts. All of these further expand the need to think spatially in an increasingly georeferenced world.