Progress and Missed Opportunities in Spatial Analysis for Digital Earth

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***Abstract*— The development of spatial data technologies has been spotty, with certain topics getting much more attention than others. This paper returns to an assessment of limitations written in 1986 by Professor Peter Burrough and finds a few of his observations that remain important. More recent calls for Digital Earth are reconsidered in terms of spatial analysis capabilities.**

***Keywords*— Analytical techniques, Uncertainty, GIS,**

I. Introduction

The recurring theme at meeting after meeting over four decades has been a revolution of analytical techniques and digital technologies [1]. After a few decades of this effort we find ourselves with warehouses of spatial data infrastructures, an advance, but hardly as revolutionary as desired. Many important advances have been made; some of them indeed may count as revolutionary. Yet, the present is not entirely the future we had imagined. The current situation depends much more on the mass market, and therefore less on science and advanced analytics. Major opportunities to advance land resource assessment and management have been missed. Major scientific issues remain unresolved.

II. Five Reasons (1986)

This paper uses a short article written by Peter Burrough in 1986 [2] as a starting point to reflect on the developments over the past 25 years. Burrough set out 'five reasons why GISs are not being used effectively in land resource assessment' (paraphrased):

1. uncertainty and fuzziness in resource data
2. reliance on sample points for assessment
3. GIS inaccessible due to cost
4. lack of training and workforce
5. remote sensing has diverted attention from 'more direct methods of land resource assessment'

The first is most fundamental. Recent years have seen great effort in understanding alternatives to sharp categorical boundaries in natural landscape data. While much remains to do, we can point to advances [3]. This paper will return to this issue later on.

The second deals with the incompatibility of traditional methods of resource survey in forests, soils and other circumstances where great detail is obtained at specific sampled sites, then estimates are generated to cover much larger territories. This approach is not entirely compatible with the spatially exhaustive coverage of mapping technologies. Since 1986, the relative costs of mapping technologies have diminished compared to the sampling technique. Much of this is due to higher resolution remote sensing imagery, enhanced digital airphotos, and LiDAR scanners. The incompatibility remains an issue in how estimates are derived.

The third and fourth are transitional, dependent on Burrough's position in 1986. At that time, the minicomputers and workstations to operate a reasonable GIS installation would cost $100,000 (pre-inflation), and software licences were quite expensive. Similarly, training had yet to be implemented, so the workforce for GIS was scarce. For this concern, we can point to huge strides, particularly in the area of the cost of computing. Speed and capacity of computers have increased according to Moore's Law without a break [4]. Software licenses are still costly, but less of a barrier due to competition from open-source alternatives in part. Similarly, the training issue has become less crucial. Over 25 years, GIS has moved from a tiny academic curiosity to the mainstream. Professional training has filled the gaps, and employment numbers are quite substantial. DiBiase

and coauthors [5] reference estimates of the geospatial sector employment in just the United States at 315,000 or 857,000 in 2008. In either case, Burrough's concerns about training and available workforce have been remedied to some extent.

The last concern of Professor Burrough will be the most troubling to an IGARSS audience. His 1986 paper contended that "remote sensing and image analysis have diverted much finance and brain power away from more direct methods of land resource assessment" [2, p. 138]. He noted that remote sensing had (at least at that time) functioned as an independent discipline. He called for some balance of the technical developments of image classification with fundamental studies of patterns of distribution and natural processes at work in the environment.

For whatever reason, it has only been cited nine times (on Google Scholar, the most open-minded of citation counters), so if you have not yet read it, you are not alone. While much of Burrough's short paper can be dismissed as one person's opinion from many decades ago, it raises some important issues that remain quite valid. In particular, the issue of uncertainty remains a topic a great concern. A substantial element of the IGARSS symposium deals with exactly these topics, as do specialized symposia. Burrough's call for treatment of propagation of errors remains unfulfilled, and the issue of transformation between measurement frameworks remains difficult at best.

Burrough's commentary about fuzziness and uncertainty relates closely to his views about remote sensing. Viewed in 1986, the production of sharp classifications was the primary direction of image processing. Tools such as mixture models and other forms of less sharp classifications are the product of research into better adapted models [6].

Yet, this is not the only issue of importance. The 1986 viewpoint saw a field of technical workstations, and a highly skilled work force. The current world still has that element, but now joined by a substantially different set of actors.

III. Current Realities

The field has to come to terms with a reality different from the one we imagined originally. The first massive shift comes from opening the field to many more users – and contributors. The initial 1999 vision of a Digital Earth [7] presumed a centralized infrastructure to deliver spatially referenced images and materials to a broad public, starting with a public library model.

In a very short eight years, the vision had shifted to new resources generated by that very public, a form a citizen sensor [8]. This time the covert authorship of Gore's vision was more overt (M. Goodchild). Volunteered geographic information has been given substantial coverage, perhaps beyond its actual ability to contribute to the bureaucratically bound and authoritatively obsessed centralized spatial data infrastructures that persist to control the industry.

The tools are changing too. Spatial analysis is a part of the consumer toolkit openly available to web users, but the tools are different from the ones that Burrough expected. Many of them are limited, placing much more emphasis on visual interpretation than analytical reports and queries. Others, like route planning functions and shortest path algorithms, are computationally quite demanding. Consider the computational power to take a whole continent's road network and recalculate the shortest path as the user drags a point to another road segment. Inside a city, this function is not very demanding, but over thousands of kilometres, it is a sign that computing speed is no longer an issue. Everyone's browsers now provide access to all kinds of services and data portals. Imagery of a fairly detailed nature is often just a backdrop without any attempt at interpretation (or effective metadata).

Despite this raw power, odd decisions have conditioned the capacities available. For example, the projections available on web cartography engines are pretty poor, with continued reliance on versions of the Mercator even in the northern regions where huge distortions reign. What passes for projection is a form of fly-over video game that zooms in from global view to imagery in greater detail. Much is precomputed and cached, out in vast warehouses of queries past and future. Did we ever imagine this?

Yes, of course, the dream of a "Digital Earth" foreshadowed certain of these elements, including greater citizen engagement as users (consumers of

information). In 2008, a Vespucci-aligned group led by Craglia [9] reported on progress towards Digital Earth and what remains to be done to bring forth a next generation. Their vision runs to a two pages, followed by three pages of required research. They give substantial space to GEOSS, the Global Earth Observation System of Systems [10], even if it remains in the world of government infrastructure. At least GEOSS is designed to respond to societal needs and pressing world problems.

Certain key elements in the Vespucci group report recognize that the world has become less centralized. Rather than a single monolith, we can expect multiple views, even multiple resources. The group called for many initiatives that are unlikely to succeed in obtaining sufficient support for the next millennium, from ontologies for global poverty, to better tiling for global dynamic models. Many of the issues are directed towards the social impacts, the development of trust in data sources, and support for integration and sharing between institutions. Curiously, Burrough's demand for greater attention to uncertainty and fuzziness did not make the list. Their earnest list of research priorities show how far we are from any realistic implementation of the dream of Digital Earth.

In the original formulation, a young child would magically become empowered by a "Magic carpet ride" produced by the Digital Earth, through a head-mounted display and a data glove (in the backwards days of 1999). This undelivered "speech" did place the emphasis quite correctly on integrating information from different sources. This was also the focus at the heart of Burrough's concern about data models. Thus from time to time we return to the big challenge in spatial data handling.

The great advantages arise from combining disparate sources, but this is exactly what we cannot yet automate. It takes great restraint and sensitivity to figure out what value resides in each data source. Combining sources takes judgement and wisdom. While our collective attention focuses often on the most flashy potential of the moment, sometimes the old issues are left unresolved.

IV. Conclusions

Over the decades, we never seem to tire in calling for more research. Often these calls overlap the earlier calls. We spend less time considering the missed opportunities, and the things we left undone.

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