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Book review

Spatial Tessellations-Concepts and Applications of Voronoi Diagrams. By ATSUYUKI OKABE, BARRY BOOTS and KOKICHI SUGIHARA (Chichester: John Wiley and Sons, 1992) [Pp. 532.) Price: £49·95/US$ 112, ISSN 047 I 93430-5.

This book is absolutely necessary reading for anyone concerned with the likely future directions of the spatial sciences. I think it indicates the arrival, or coming of age, of something of a revolution that has been developing for several years within GIS and related disciplines.

In their simplest form. Voronoi diagrams of point data sets partition space into a series of tiles, one for each point, containing all locations closer to that point than to any other. The common boundaries of these 'bubbles' express the spatial adjacency relationships between the points, and connecting adjacent point pairs gives the Delaunay triangulation. This book explores the applications and variations of this simple concept.

The structure has been well known for many years-indeed the authors show a figure by Descartes (1 644) that appears to be a Voronoi diagram, although Dirichlct (1850) and Voronoi (1908) were the first to define it formally, as did Delaunay (1934) for the associated triangulation. Theseconcepts entered the natural and social sciences by the 196Os.and Shamos and Hoey(1975) probably initiated the modern computer science field ofcomputational geometry with their work on efficient computer algorithms, showing that the method was applicable to a variety of geometric problems.

The field of GIS developed quite indcpcndcntly, developing its own rules of spatial structure based on global co-ordinate systems and the detection of the intersections of polygon boundaries. Thus the introduction of another, and in many ways more general, spatial model poses a variety of challenges to the 'usual way of doing things'. Before this book information about the Voronoi approach was scattered through a wide variety ofjournals and disciplines-indeed, the authors give an amusing account of its frequent rcdiscovcry. Their motivation has been to bring together into one coherent account as much as possible of the scientific literature, for those whose concern is theoretical, practical, or both. In this they have succeeded beyond reasonable expectations and the impact of their work should be felt for many years.

It is a beautiful book, not least for its many diagrams-fascinating to anyone who has whiled away an afternoon attempting to sketch the spatial relationships implicit in some problem in geography, geology, astronomy of molecular physics. (The authors cite examples from the structure of the universe to the atomic arrangement in crystals.) It is also a very helpful book, providing useful tutorials on sets, matrices, geometry, calculus, graph theory, probability, point processes and non-linear programming for those somewhat deficient in those topics. They derive the properties of the common Voronoi diagram, (an extremely useful review), and then move on into the slightly disorienting world of its many generalizations-weighted, higher-order, farthest-point, diagrams with obstacles, diagrams with line segments or solid objects, diagrams with different metrics, diagrams on spheres, cylinders or cones, diagrams on networks. There is much meat here that should be thoroughly chewed over and digested by anyone concerned with the whole question of spatial queries. A simple example involves determining the urban region where fire station B would be the closest if fire station A was temporarily unavailable, and vice versa. This uses the order-2 Voronoi diagram to resolve the problem for all fire stations in the city, perhaps as a disaster planning exercise.

This chapter is followed by a relatively brief (60 page) section on algorithms for generating these diagrams. Those not in computational geometry will find this a sufficient introduction. I think the authors were correct not to try to cover in detail this rapidly expanding and specialist field, but to give the philosophy of the basic methods and refer to the literature for those interested in implementation details. Nevertheless, it should be recognized that this field is expanding to the extent of several hundred articles a year, and it is inevitable that this expertise will in the end spill over into the world of GIS.

The rest of the book is concerned with applications of these various forms of Voronoi diagrams, with a particular emphasis on spatial analysis. Diagrams generated from point Poisson processes are examined in some detail, both for use as a model of some empirical process and as a normative model to be used for comparison with observed point distributions. Various types of interpolation are discussed, both those based on the Voronoi diagram and on the dual

Delaunay triangulation. A very well-organized section covers models of spatial processes, starting with simple assignment and growth models and describing in detail spatial competition models where the generating points are able to migrate over time, as well as techniques for recognizing whether a particular tessellation is in fact a Voronoi diagram. Point pattern analysis is then discussed using both Voronoi and Delaunay methods, as well as nearest-neighbour distance methods. The last section is an excellent and detailed coverage of locational optimization problems using Voronoi diagrams, giving the development of appropriate objective functions. Most of these applications clearly come from the field of geographical analysis rather than from the natural sciences or other disciplines.

This book is an impressive synthesis-about 700 articles are cited, for example, and many of them are described in some detail. Nevertheless, it is inevitable that the authors chose to concentrate on certain application fields rather than others. There is, for example, recent work in progress by various authors on dynamic Voronoi diagrams-for moving point sets and for topological data structures. There are applications in computer graphics where the 3-D version provides the structure for efficient ray-tracing algorithms for realistic image illumination. There are applications of the medial axis transform or skeleton (a subset of the Voronoi diagram for complete polygons) for image analysis and robotics, and for terrain reconstruction from contours. There are finite clement, finite difference and free-Lagrange methods for modelling fluid flow. There are techniques for point cluster analysis. But the list could go on-it would be nearly impossible to keep up to date. Be assured, however, that this book is, and will remain for a long time, the standard reference on an extremely important and rapidly expanding subject.

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Computer modelling in the Environmental Sciences. Edited by D. G. Farmer and M. J. Rycroft (Oxford: Clarcndon Press, 1991.) [Pp. 379.] Price: Hard bound £45·00.

This collection of 29 papers, covering a wide range of fields, has been published as the proceedings of a conference hosted by the British Geological Survey in 1990. Topics span the range of the environmental sciences, including oceanography, hydrology, geology and geophysics, atmospheric sciences and meteorology, life sciences and ecology, coastal and sedimentary processes. From the title. it is clear that the only common ground lies in the use of computer modelling, on platforms ranging from PC's to the Cray Y-MP.

The first five papers arc on oceanic to estuarinc processes. Preliminary runs of the FRAM model (D. J. Webb) for circulation in the Southern Ocean show the main features of the circumpolar circulation, including significant steering by the land masses. While deliberately simplifying tidal responses, it is able to resolve features as small as 30 km, although there is still a discrepancy of 50 per cent in estimating the total transport through the Drake Passage. On a more local scale, R. Flather et al. have used a 35 km grid to forecast storm surge elevations around Britain using the POL model, implcmcntcd on a PC. although finer resolution (4 km) versions are also being developed for the Cray X-M P. A. M. Davies and R. B. Grzonka illustrate how critical good algorithm design is for simulating turbulent velocity profiles on a similar (35 km) grid around Britain. Coming still further down in scale, A. M. Riddle describes a two-dimensional advection-diffusion model related to possible spills from ICI Grangemouth in the Forth Estuary, with verification using dye patches. C. M. Allen discusses approaches to this problem through Lagrangian particle tracking and the aggregated dead zone (ADZ), which offer some advantages over the standard advection-diffusion method.

Four papers are concerned with catchment hydrology. A. M. Binley and K. J. Beven present their Bayesian GLUE method for selecting optimal forecasts from a distribution of simulation forecasts, obtained by Monte-Carlo sampling from the range of parameter uncertainties. Although the example given perhaps underlines errors in the model structure, both the power of the method and the advantages of parallel processes are clear. A. J. Jakeman *et* al. describe a general method for developing rainfall runoff relationships, which in an example consists of separating the hydrograph for a small (O-72 km") catchment into quickflow and delayed flow