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Adaptive grids then and now

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ABSTRACT. The adaptive grid (now called the uniform grid), an algorithm for efficiently finding intersections in large geometric databases was introduced in this 1983 paper. The cross-fertilization from computer graphics and geometry to GIS and automated cartography has continued to be useful in the 30 years since, and indeed is even more relevant with current large databases and fast computers.

KEYWORDS. Adaptive grid, uniform grid, efficient automated cartography algorithms, large databases

A. Title of AutoCarto Six paper. Adaptive grids for geometric operations

B. Reason for paper.

The intent of the 1983 presentation was to introduce a new efficient geometric data structure to facilitate certain important spatial operations on large (for that time) GIS datasets. One such operation was to find all intersections among a large set of small line segments. A second was to find which polygon of a large planar graph contained a test point. These operations are necessary components of common operations such as map overlays. The broader goal was to link the computer graphics and computational geometry communities to the GIS and automated cartography communities, and to show that each community had something of use to the other.

C. Thoughts shaping the design of the 1983 paper.

This paper was driven by my non-geographer's perspective on GIS and automated cartography. Although I had worked with geographers such as David Douglas (Douglas 1982) at the University of Ottawa since about 1969 (during summer jobs while I was a high school student), my own background was in computer science and computer graphics, based on a love of classical geometry. The beauty of classical geometry lies in the multitude of implicit relations between points and lines that follow from a few Euclidean axioms. Indeed, my current longterm unsolved problem of trying to find a mathematics for terrain rests on that philosophy.

In the summer of 1972, between college and grad school, I worked with Douglas in Tom Poiker's lab at Simon Fraser University. There, I designed and implemented the first Triangulated Irregular Network program in geography. (Unfortunately, being an undergrad, I knew nothing about publishing. I gave the lab my documented Pl/1 code with examples and even a primitive animation of the triangulation being incrementally refined as new points were inserted. However I didn't write a paper for publication.) Next, as a grad student at Harvard, while enrolled in the computer science program in Applied Mathematics in the Division of Applied Science, I worked in the Lab for Computer Graphics and Spatial Analysis in the Graduate School of Design (the architecture school) in Gund Hall. After graduation, and while writing this paper, I was on the faculty of an electrical engineering department at Rensselaer Polytechnic Institute. Indeed, I'm still there.

All this gave me a liking for solving geometry problems. A research theme in computer science, then as now, was to find techniques (algorithms) to solve problems on larger datasets in less time. However, the exact time used was not of interest, but only the rate of growth of the time as the dataset got larger. (The reason is that exact times shrink as hardware gets faster, but the rate of growth stays the same, and so the rate of growth expresses something more fundamental about the algorithm.) However, computer scientists sometimes carried this theme too far, because actual times are important in the real world. Here, solving a problem in half the time or space, although of no theoretical interest, is quite practically important. Indeed, computer scientists have more than once ignored cartographers' practical solutions to real problems, because those solutions were not sufficiently theoretically interesting. The exceptions that do exist benefit both fields.

Likewise, in GIS and automated cartography there is a contrast between theory and practice. Grand system designs are all well and good. However, taking them from abstract exercises to concrete useful implementations requires expertise in computer science on how to create efficient algorithms and data structures. Conversely, GIS and automated cartography give computer science a set of important problems to solve.

My paper was intended to extend the bridge between these separate communities, by providing an efficient solution from computer science to an important problem in automated cartography.

D. Derivative attributions.

In computer science, there was the new field of computational geometry, first named by Michael Ian Shamos. His unpublished PhD thesis (Shamos 1978) was inspirational to many, and resulted in the influential book (Preparata 1978). (The term *computational geometry* has also been used to name two other fields in computer science, which are irrelevant to this paper). There was also efficient computational geometry work by Franco Preparata, and Jon Bentley (1979), whose work was both inspirational and practical.

The group at the Harvard Lab for Computer Graphics and Spatial Analysis, led by Alan Schmitt, and including Nick Chrisman, Jim Little, James Dougenick, Geoff Dutton, Scott Morehouse and others, was also busy designing new algorithms and producing useful SW, (Harvard 1976). Interestingly, no one had a PhD, and the lab, situated in the Graduate School of Design for want of a better place, seemed to be unwanted by Harvard, (Chrisman 2006). In the late 1970s and early 1980s, the LCGSA hosted several influential conferences, whose proceedings are almost impossible to find today, (Harvard 1979, 1980, 1982, 1983).

While enrolled in computer science but working in the LCGSA, I basically created my own research theme, developing the ideas presented in my paper for my PhD work, (Franklin 1978). I am grateful to Harry Lewis, my advisor, for permitting such an unusual arrangement.

E. Original contribution.

The original contribution was of a data structure that is so simple that people cannot believe that it can be useful. On first seeing it, the common reaction is that it's nice, but to be useful has to be complexified into something like a quadtree. That's wrong! Both theoretical analysis and experiments on real data support this.

F. Impacts.

The adaptive grid technique, now called the uniform grid technique, has stood the test of time well, and is increasingly useful today. Applications can use it to process hundreds of millions of objects. It also utilizes parallel computers quite well. That ability was apparent from the start; it's just taken awhile for the available hardware to catch up to the technique. Now, every computer with an NVIDIA graphics card can do useful parallel programming. Uniform grids have been used to solve problems such as the following, (Akman 1989), (Franklin 1984, 1988, 1989a, 1989b, 1990a. 1990b, 1994, 1999, 2000, 2005a, 2005b).

1. Preprocess millions of fixed points so that the closest fixed point to a new query point can be found fast.

2. Preprocess a large planar graph (i.e., a map) so that the polygon containing a query point can be located fast.

3. Overlay two maps to find the areas of all the nonempty intersections between a polygon of the first map and a polygon of the second. One application is the cross-area problem, to interpolate some statistic that is known for each polygon of the first map onto each polygon of the second.

4. Find the volume of the union of many polyhedra. One application is object collision detection. (If the union volume changes as the objects move, then they just collided.)

The general philosophy of simple and efficient solutions has been successfully applied to other problems such as the following.

1. Siting multiple observers on terrain so as to maximize the union of their viewshed polynomials, (Franklin 2011).

2. Interpolating from contour lines to raster elevation data, (Gousie 2005).

3. Computing the hydrography on massive raster terrains, (Magalhães 2012).

4. Filling gaps in incomplete hydrography in a geologically reasonable way, (Lau 2013).

G. What was new in the paper?

The novel aspect of the paper was the publication of a technique that had been devised to solve a problem in computer graphics, but which could also solve important problems in automated cartography.

H. Conclusions/Findings/Next Steps.

Bridging computer science and GIS / automated cartography to devise efficient algorithms is as important as always. New problems needing efficient solutions on the new faster parallel computers continually appear because of the ever larger databases of geographic data that need to be processed.

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