History of the Harvard Laboratory for Computer Graphics: a Poster Exhibit

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Abstract
Howard Fisher founded the Laboratory for Computer Graphics with a grant from Ford Foundation to develop computer mapping techniques based on SYMAP, a program for mapping on a line printer. Joined by William Warntz, the second Director, research at the Laboratory expanded in the direction of spatial analysis while others developed tools for environmental planning. The staff expanded to around forty by 1970. These initial grants finished, and the staff dispersed. By 1972, the staff was barely six. With a renewed direction, the Laboratory found new sources of support and grew back to over forty staff members in 1981. Again, the direction shifted, this time due to changes in policy about software distribution. the Laboratory trailed off in size and was dissolved in 1991. This history of boom and bust captures the pulse of a growing field that did not know its boundaries.

This exhibit samples some of the themes addressed by this fertile interdisciplinary collaboration. It includes some of the early computer mapping software and experimentation in cartography, the spatial analysis research, and applications to environmental planning. Around the edges are glimpses of some of the key figures involved in this exploration.

1. Howard Fisher founds a Laboratory

There are many stories about the origins of geographic information systems technology, and a few of them are true. No matter which story you hear, if you probe a little bit, you will find a connection to the Harvard Laboratory for Computer Graphics and Spatial Analysis. At this Laboratory, beginning in 1965, a varied collection of planners, geographers, cartographers, mathematicians, computer scientists, artists and many other fields converged to rethink thematic mapping, spatial analysis, and what we would now call geographic information systems.

The motive force behind the Laboratory was Howard Fisher, who graduated from Harvard College in 1926 and studied architecture at the Harvard Graduate School of Design. He practiced architecture in Chicago, working on curtain wall construction for high-rise buildings, shopping centers, and prefabricated housing during World War II. While teaching in the Technological Institute at Northwestern University, Fisher attended a workshop on computer mapping organized by Edgar Horwood from University of Washington. Fisher conceived of an improved computer mapping program that he called SYMAP.

Howard Fisher served as Director of the Laboratory for its first two years. He continued his research on thematic cartography until his death in 1979.

While Howard Fisher was prime mover in creating the institution of the Laboratory for Computer Graphics, he did this work in a web of interactions involving many others. This paper provides a text introduction to some of the important aspects of the history of the Laboratory (see also Chrisman 2005). The posters of the accompanying exhibit provide a richness of graphic expression which the text cannot.

2. SYMAP: packaging thematic mapping

From the perspective of today, it is entirely unremarkable for software to be seen as a product. In the early 1960s, even the largest vendors were bundling software with computers simply as a way to sell more hardware. There was very little idea about how to disseminate software or who would want it. Howard Fisher envisioned software packaged so that it could be used by planning professionals with a few weeks training by correspondence. He underestimated how long it would take to develop a polished program ready for broad use, but that is not the first time that the author of a prototype thought the problem had been solved.

At Northwestern, the original programmer, Betty Benson generated a few distinct versions. Her last version came to Harvard with the mistaken idea it was her third, and work started on a version IV. Principal programmers at Harvard were Richard Russell, Marion Manos and Kathleen Reine. Version IV was transitional, real distribution came with an overhaul required to move onto the IBM 360 called version V. As the maintenance continued, version numbers became decimal, rising through to 5.20 for the definitive version distributed for many years until the line printer was no longer attractive as an output vehicle.

From the start, Howard Fisher wanted to improve on the interpolation as performed in Horwood's program. Fisher's early versions used linear interpolation with a network of neighbors that had to separately input. On arrival at Harvard, Fisher conducted seminars for Harvard College freshmen. He showed them his work on SYMAP, and many of them participated in Laboratory events, particularly the conference in 1967. One freshman, Donald Shepard, decided to overhaul the interpolation in SYMAP, using a mathematical framework that we now call Inverse Distance Weighting. He conducted a number of experiments with the exponent of distance, deciding on something closer to the gravity model (exponent of -2). Shepard's (1968) algorithm was also influenced by the theoretical approach of William Warntz and others at the Lab who worked with spatial analysis. Shepard implemented not just basic inverse distance weighting, but also he allowed *barriers* (permeable and absolute) to interpolation. The 'proximal' map was a side-effect of setting the number of neighbors to 1 in the interpolation algorithm, yielding an approximation of Voronoi/Thiessen polygons.

Shepard's algorithm also downgraded the influence of a point if there was a closer point between it and the location being interpolated. While this complicates the computation, it makes for much more realistic surfaces. Other research centers were working on interpolation at this time, particularly University of Kansas and their SURFACE II program. Still, the features of SYMAP were state-of-the-art, even though programmed by an undergraduate.

2.1 Early dynamic cartography

In March of 1967, just before becoming Assistant Director of the Laboratory, Allan Schmidt produced a motion picture generated from SYMAP output. This may be the earliest attempt to use automated cartography to display dynamic spatial information. Waldo Tobler's movie of the urban expansion of Detroit, often described as the first such, was produced two years later.

Schmidt's movie portrays the urban expansion of Lansing, Michigan, where he was working at the Michigan State University, Urban Regional Research Institute. Every property transaction from 1850 to 1965 was coded by square-mile section of the Public Land Survey System. To produce the SYMAP output, a thematic attribute was generated of the percent of land developed during each five year period.

Each annual SYMAP output formed a square about two feet by two feet. Hung in front of a movie camera, a set of frames were photographed. The sequence starts with a slow version of two minutes forty-five seconds. Then it repeats the sequence more rapidly in forty-five seconds, and finally in five seconds. The production values may not be great (the maps fade in and out of focus), but the film represents a milestone in the development of thematic cartography.

3. Environmental planning and grid analysis software

One group at the Laboratory, led by Carl Steinitz, applied computer mapping to issues of environmental planning, closely coordinating their work with the instructional program of the Department of Landscape Architecture and other research projects. In 1967, a major regional study was conducted for the Delmarva Peninsula, a project pivotal to understanding early GIS.

In 1967, both City Planning and Landscape Architecture chose to work on the Delmarva Peninsula (Delaware, Eastern Maryland, and a tip of Virginia). Carl Steinitz applied the Laboratory's toolkit (SYMAP) to this enterprise. The project had all the components of any GIS enterprise: base layers, computer-generated intermediaries, and results. The base layers included topographic maps, soil maps, airphotograph interpretation, and the census for county-level statistics. (In 1960, there were not many tabulations for fine geographic detail outside cities.) The fourteen counties, the shoreline, and the roads were entered as vector objects, but most of the environmental sources were coded according to grid cells two miles by two miles. The land use was recorded as the percentage of the cell that was forest or agriculture. The topographic relief was recorded as an 'average' elevation in this flat terrain. In SYMAP, these grid cells were treated as points, and the maps were interpolated to show a smoother rendition than the grid cells would allow. The main results were produced by map overlay of all the factors. Suitability for a range of different uses were assessed using the weighted sum of the factor scores.

Technically, the overlay was produced by generating an attribute value for each point that represented a grid cell center, leading Steinitz and his student assistant, David Sinton, to question the need for the vector model. Simple grid cells would be easier to conceptualize and manage. Sinton pulled the map production capability from SYMAP IV and spliced on a simple, grid-based input system. The result was called (somewhat unoriginally) GRID. Sinton's GRID was rewritten as IMGRID for Landscape Architecture projects in the 1970s, becoming the springboard for early software from ERDAS and the MAP Analysis software written by Dana Tomlin. These packages have had a strong influence on the grid-based spatial analysis tools in current commercial products.

4. Spatial Analysis

In the 1950s and 60s, 'social science', disciplines that studied people, including sociology, anthropology, geography, and economics, became embroiled in becoming more 'scientific,' interpreted as a need for demonstrable theory, and more mathematical treatment of quantitative data. A new generation of geographers took up these challenges in the 1950s. One cluster at University of Washington led what came to be called the 'Quantitative Revolution'. At the American Geographical Society, William Warntz worked on the application of the mathematics of surfaces to macrogeography. When Fisher founded the Laboratory at Harvard, he invited University of Washington graduates Waldo Tobler and Brian Berry in his first series of lunch speakers as well as William Warntz. Warntz came to Harvard and became Director of the Laboratory in 1968. He added ‘and Spatial Analysis’ to the name.

To Warntz, spatial analysis meant the study of surfaces and the mathematical structure of spatial distributions. He obtained funding from the Office of Naval Research for this highly theoretical enterprise, and hired a number of research assistants, postdoctoral fellows, and staff. In short order, this group produced research reports. The ‘Harvard Papers on Theoretical Geography’ includes fifty-seven papers, most produced in the ‘Geography and the Properties of Surfaces’ series, though some were placed in a ‘Geography of Income’ series. Some papers were abstruse mathematical theory (like the ‘sandwich theorem’: about the topology of entities); some were morphological (like ‘Law and Order in the Human Lung’ which applied stream ordering to a wide set of branching networks).

While others saw surfaces as cellular, the development at the Laboratory emphasized a topological approach that was fundamental in developing Triangular Irregular Networks (TIN) and other surface-oriented software. Warntz was primarily interested in thematic surfaces, such as population potential (human viewed as gravitational fields), income, and continentality (proximity to other land masses). All these surfaces had ridges, passes, hills and dales just like the 3D terrain of elevation above sea-level.

As a bomber navigator during World War II, Warntz (1961) had learned ‘pressure pattern flying’, taking winds into account to find the fastest path. Current software capabilities that construct least cost paths over surfaces can be traced back to this experience and the theoretical work at the Laboratory that followed.

5. Experimental cartography

For decades, the Laboratory's work involved experiments in new techniques for thematic cartography. Although Howard Fisher’s (1982) book, *Mapping Information, the Graphic Display of Quantitative Information,* did not appear until after Fisher's death, it was around, in some form or other, from the early days, as were many examples of experimental cartography.

5.1 Surface display

One well-established problem for cartography is how to depict a topographic surface. Surfaces were a central concern for the Laboratory, and as technology developed the experiments became more serious. The best known surface display package was SYMVU, a plotter-oriented package first distributed in 1969. As graphics hardware evolved, and the computing environment changed from batch to interactive, ASPEX replaced SYMVU. ASPEX used a keyword interface and emphasized interactive display on vector CRTs, though it could generate plotter commands as well. Two later examples are the programs SEURAT and IMAGO.

As the name implies, Geoff Dutton (1982) applied a pointillist approach to terrain display in the program SEURAT. For each pixel in a terrain matrix, he produced four pixels of output in four hues, red for elevation, yellow for northwest illumination hillshading, and blue and green for slope and inverse slope.

This approach came about because of the limited number of colors available on early color displays. The Laboratory had an AED 512 that allowed 256 colors. By halving the spatial resolution (displaying each pixel as four), the spectral resolution was increased enormously, demonstrating that principles from art can apply to the analytical field of thematic cartography.

Denis White (1985) developed a technique for combining a two-dimensional thematic map and its three-dimensional surface in a program called IMAGO.. Hillshading provides a scale from dark to light, and the attribute provides the hue. As with the SEURAT program, the color devices of the period limited the number of colors displayed. With some care in constructing the color table, a typical land use map could be shown with hillshaded relief.

5.2 American Graph Fleeting: a thematic hologram

In 1978, Geoffrey Dutton made what may be the first thematic spatio-temporal hologram, apparently the only example of holographic four-dimensional cartographic display. The hologram is a cylinder sixteen inches in diameter that shows the changes in population over time as it turns.

The hologram was produced by the program ASPEX from a sequence of images showing the US population by county from 1790-1970. Each annual surface is based on interpolation from the decennial census data, smoothed onto a grid of 82 by 127 cells. Cells with fewer than 500 people are shown as blank. The viewpoint starts over the Caribbean and shifts two degrees with each year, rotating full circle as you move one turn around the image. The view also moves upward from 30 degrees at the start to 60 at the end. The images were produced on paper then shot with 16 mm high contrast film using a pin-registered animation stand, five frames per image. With the titles and credits, the movie is 1080 frames, and, if played through a projector, would take only 45 seconds to run.

Each frame of the movie was then exposed onto successive vertical strips of the holographic film, projected through one beam of a laser, and merged with a reference beam so that the interference pattern is recorded on the film. The resulting hologram can be displayed with an ordinary light bulb.

6. ODYSSEY

Development towards a package to process geographic information began with POLYVRT, a program released in 1974 that converted between various data structures and formats, moving attention from producing a display to producing the database. In 1975, the Laboratory contracted with the Census Bureau to restructure some Urban Atlas files (scanned using a line-following laser scanner in isolated polygons). That project revealed the weaknesses of POLYVRT. Nick Chrisman, the designer of POLYVRT, and Denis White were waiting around one December night for turnaround on batch editing jobs. In the clarity of late night work, they saw that the solution to the Urban Atlas problem was a system of processors to manage large geographic files, or ODYSSEY. This package became a prototype geographic information system.

It took three years of programming to build ODYSSEY by a team that expanded to five (with the addition of Jim Dougenik, Scott Morehouse, and Randolph Franklin) then to eight, then more. The 1982 version had seven programs:

PROTEUS	editing, projections, generalization, aggregation, simple display
CYCLONE	topological checking of nodes, error correction
CYCLOPS	topological checking of polygons, produce graphics shape files
WHIRLPOOL	planar enforcement: overlay, error detection of input
CALYPSO	attribute manipulations (areal interpolation)
POLYPS	planar choropleth display
PRISM	raised 3d prisms

ODYSSEY was held together by common modules to manage files and to manage the user interface. The GLIB program compiled languages to be operated by LINGUIST, the run-time system. As a system, not just a program, ODYSSEY demonstrated many crucial functions of a modern GIS, like the overlay processor, which had advanced capabilities to treat fuzzy tolerances (Dougenik, 1980; Chrisman and others 1993).

ODYSSEY gave the Laboratory some grand moments but also led to some difficult decisions. It was not at all clear how Harvard would handle the commercial potential of a major software product. Between 1979 and 1983, there were contracts signed and broken, agreements negotiated and breached, money spent, and bad feelings all around. In 1981, the Laboratory had over forty employees preparing ODYSSEY for its commercial debut. When the decisions changed, the budget for the Laboratory collapsed. The team dispersed and attempts to sell ODYSSEY on the SYMAP model were limited.

7. A search for future directions

At each conference he organized, Allan Schmidt would hold a final session under some title related to 'Future Directions'. Often the participants who had detailed ideas of current technology would stumble in projecting into the future. Allan Schmidt's (1979, 16) view of the future, from twenty-five years ago, shows how much of the cutting edge could already be discerned by those who cared to look..

> "Personal uses of computing will undoubtedly include the ability to generate computer maps using a new technology known as Mapavision. Mundane applications will include preparation of route maps at home or en route for the journey to work, play, shopping, picking up the kids, etc., taking into account existing traffic conditions and a minimum travel path (especially for those families with many children!). Shopping for a particular product will be facilitated by preparation of a map showing the locations of all stores having that product in stock. Vacation trips can be planned and updated during the trip to take into account weather, road conditions, changing interests of the travelers (including those kids), and accomodations available. Cross country travelers will have the novel opportunity of not being able to get lost due to the constant availability of a map on their TV screen which pinpoints their current location. Of greatest importance, however, will be everyone's ability and right as a free citizen to display information related to recent and forthcoming public policy issues on the national, regional, and local level....
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> "The medium of computer graphics may prove to be the messenger (if not the message) by which all people will most effectively benefit from the emergence of computer technology."

Acknowledgements
This work was generously supported by ESRI, Redlands CA. The author acknowledges conversations and materials generously offered by many colleagues, including Brian Berry, Jack Dangermond, Kenneth Dueker, Geoffrey Dutton, William Garrison, Scott Morehouse, Thomas Poiker, Allan Schmidt, David Sinton, Carl Steinitz, Eric Teicholz, Anne Hunt White and Denis White. Harvard University Archives provided access to their collection of the papers of Howard Fisher. The views expressed are those of the author.

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