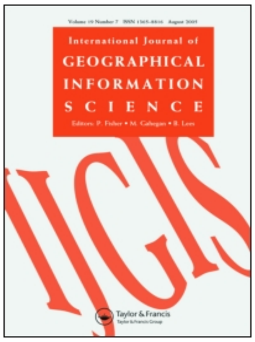

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Patrick McHaffie

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Surfaces: tacit knowledge, formal language, and metaphor at the Harvard Lab for Computer Graphics and Spatial Analysis

PATRICK McHAFFIE

Department of Geography, DePaul University, 990 West Fullerton, Parkway, Chicago, IL60614, USA
e-mail: pmchaffi@wppost.depaul.edu

Abstract. The Harvard Lab for Computer and Spatial Analysis was one of several sites in the early development of GIS where seminal innovations in the processing and display of geographically referenced data took place. An early area of concern at the lab were the mathematical and technical problems associated with the modelling of 'surfaces'. This term, 'surface', came to take on new and sometimes abstract meanings. The language used to describe 'surfaces' was rooted in tacit knowledge and more formal mathematics. The mixing of different forms of language, both verbal and written, allowed the passing of abstract and sometimes difficult meanings. It may be that universal history is the history of a handful of metaphors ... It may be that universal history is the history of the different intonations given a handful of metaphors (Borges 1964, p. 189 and 192).

1. Introduction

Recent writings in the history of science have stressed the importance of language, both written and spoken, formal and informal, as the principal vehicle for transmitting and transforming ideas, understandings, explications and explanations between individuals and communities involved in the production of scientific knowledge (see for example Kuhn 1970; Lakatos 1976, 1978, Bloor 1991, Barnes *et al.* 1996). Within language communities (Galison 1987, 1997) translations of meanings occur in many ways including denotation, connotation, metaphor, metonymy, simile, allusion, encoding, decoding, and intertextuality. Semiotics seeks to understand the ways that these translations occur in communities that are both mundane and extraordinary. Only recently have we come to recognize that scientists, engineers, and technicians engage in constructive word play (written and spoken) as part of their day to day work and, claims of detached objectivity notwithstanding, language in the scientific workplace serves as a powerful marker of the human character of research. Language also can be the site of interchange and the synthetic forging of new understandings and ideas for scientists and others engaged in processes of research and discovery.

One of the fundamental ways that language is used in communities of researchers is to create new linkages between that which is broadly known of things in the world (tacit knowledge) and new or unconventional understandings of these things.

> We often surprise ourselves and others with what we know. We play a song at the piano quite fluently even though we thought we had long ago forgotten the right chords; we suddenly know that Kant died in 1804 though we have just denied having any detailed knowledge of pertinent dates in the history of philosophy... This is an innocent sense of the term tacit, and taken in this way it is uncontroversially true that some of our knowledge is tacit. (Samet 1980: p. 2).

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In the field of geography, where the object of knowledge *is* the world and everything in it, any subject necessarily arrives in the research setting with layers of pre-interpretation draped over its supposed true essence. Whether we speak or write of terrain (hills, valleys, slopes, etc.), the atmosphere (winds, temperatures, precipitation), or populations (crowds, workers, children, the aged); all of these come with pre-formed notions about their character and quality. Also, in the dynamics of day-to-day life within research laboratories personnel change, bringing new understandings of theoretical and practical entities into play as work progresses. This is one way that new language can be brought into a particular localized setting, sometimes producing what Galison (1997) has called 'trading zones' in describing the interaction of experimental and theoretical physicists over the past several decades. In these places 'two dissimilar groups can find common ground', reaching local agreement on theoretical or experimental differences allowing work to go forward, while disagreeing on the significance of results or programmes within the broader discipline itself (Galison 1997, p. 46). One such community was found at the Lab for Computer Graphics and Spatial Analysis (LCGSA) in the Graduate School of Design at Harvard University in the 1960s and 1970s. Here architects, planners, geographers, and others concerned with producing representations of the physical and human world came into close contact through their participation in practical and theoretical work.

Many types of phenomena present themselves to us as ways of knowing the world... sounds, smells, tastes, etc. Perhaps no other, however, has the 'master' character of the surface. It is the 'thing' that separates material from immaterial, made available to us through sight and touch, giving *form* to the world and all things in it. We become adept at an early age in judging the many possible characteristics of this type of thing, the *surface*, its smoothness or roughness, colours or shades, temperatures, its relation to the pull of the Earth, transparent or opaque, fixed or in motion, hard or soft. As a phenomenon it has a strong although not necessary relationship to the *gaze*, the sense of sight, and when combined with our experience of surfaces through the sense of touch it becomes the master piece of evidence in our making sense of the world. Something seen (given form through the illumination of its surfaces) and touched (a test to make certain that the eyes do not deceive) becomes real, irrefutable, incontrovertible, and ultimately believed. It serves as the boundary between the real and the not real and, in its infinite variety, an understanding of it and an ability to describe and model it becomes a principal objective of those who seek to understand the world, geographers included.

Not only do we use surfaces as direct indications of things themselves, but also we extend our knowledge of things sensed as surfaces to include that which lies behind the surface, a certain indirect knowledge, intuited from our understanding of forms in other contexts. Judgements about the interior character of forms, made material through our experience of their surfaces, follow from our *readings* of the surface characteristics of things. This tacit knowledge of surfaces, both simple and complex, is made manifest through a rich set of verbal and written codes, passed from one context to the next. In this paper I ask the question of the surface that Barthes (1985: p. 22) asks of the image: how does meaning come to the surface, in particular the surface as represented through the cartography of human and machine and the descriptions of the researchers producing and explaining those representations. And how does our tacit knowledge of surfaces, real and virtual, colour our understandings and our descriptions of these renderings.

Metaphor and its use in the practice of explanation (scientific and otherwise) has recently become of interest to scholars in the sociology of scientific knowledge (SSK) and the history of science and technology. In particular, economic geographers such as Barnes (1996) have begun to explore the ontological function of metaphor in defining the landscape of major subdisciplinary areas such as economic and social geography over the past several decades. Barnes draws on the work of philosopher Richard Rorty to develop more fully the notion of metaphor as a powerful linguistic device, useful in the construction of explanatory arguments:

> Metaphors, precisely because they are patently false and absurd (truths), cause us to stop and think and thereby possibly lead us to do different things than we have done in the past. Furthermore, the reason that metaphors surprise us is not because they have some special cognitive status but because they have none at all; if they had that status they would not be surprising. (Barnes 1996: p.154).

A language community exists wherever local understandings of words and their meanings become shared in a useful way between individuals and groups in particular institutional or place-bounded settings. Focusing on metaphor alone may be seen as reductive of the rich complex of meanings that evolve in any language community, however here this example is intended to show the workings of a particular type of speech and to consider how it 'works', i.e. how it serves as a conveyor of meaning. To the extent that the use of metaphor and other syncretic linguistic forms go beyond what Dalia Varanka has called scientific 'plain-speak', then some indication of the importance of language in constructing scientific explanation is given. In scientific settings metaphor may often be deployed as exemplars within conversations as different types of explanatory language are utilized to explain particular phenomena. Barnes gives an example of this happening on a broad scale in the ways that William Warntz, an early luminary at the Harvard LCGSA, imported concepts from physics into the social sciences in a wholesale fashion.

> By metaphorically redescribing geographical things in terms of physical models, they (*Stewart, Warntz, and Carrothers*) found that they could use statistical methods, make predictions, publish in scientific journals, speak authoritatively about scientific explanation, and more besides. The more general point is that in hindsight the gravity model metaphor was pragmatic, not cognitive. It did not reveal the Truth, but it enabled economic geographers to look at the world in a different way and do many things that they could not have done before (Barnes, 1996: p. 158).

I will show in this paper that both Howard Fisher, first director of the LCG (and his associates) and William Warntz used metaphor to great effect while they were affiliated with the lab. To the extent that the work produced there was influential and acclaimed is at least in part due to the successful mixing of formal and tacit understandings of real and conceptual surfaces and their representations.

2. Setting the stage: histories of science

I will use a reading of parts of a correspondence course on SYMAP that was promulgated by Fisher and his associates to explore the notion of metaphor, explanation, and the surface. I am also interested in the addition of William Warntz to the LCGSA staff and the effects that his addition had on the ongoing work there. In particular Warntz's use of the surface construct and his way of speaking and writing about that will serve as a major example of the effective use of metaphor in scientific geography during the 1960s. In many ways this paper was conceived as part of a complement to the collection of essays recently compiled by Tim Foresman as a history of GIS technology (Foresman 1998). Several of the chapters from this text have proven useful and indeed the book itself makes a strong case for the importance of histories of technology. While the Foresman book, in general, focused on the technology and institutions involved in the early development of GIS, this work explores the language that was used to explain work that was ongoing at the LCGSA, as well as the context of this language and its use. This approach falls within the mainstream of current research on the history of science and technology.

This has implications for me as an interpreter of historical things, as well as for my interpretation of the events that produced those artefacts. In other words, if our senses are open to penetration by previous experience, then scientists and researchers, when viewed historically, must be considered to have been subject to the same sort of influence. The tacit understandings of things like maps, charts, terrains, or surfaces must have conditioned the interpretations of representations such as these at the lab. Without prior experience of topographic maps, contour mapping, the interpretation of terrain, etc., then the mess of line printed characters (figure 1) will make little sense. Hence, events and the objects that resulted from those events at the LCGSA must be considered as the product of a complex mixing of understandings.

I cannot stress enough the importance of language and local systems of language in the construction of scientific and technical explanation and knowledge. In post-Kuhnian writing on the history of science and SSK, particularly that emanating from the 'strong program' in SSK at the University of Edinburgh, what is most clear is that scientific technical practice, when concerned with the production of credible truth claims, is 'neither determined by rational rules nor the facts but is the result

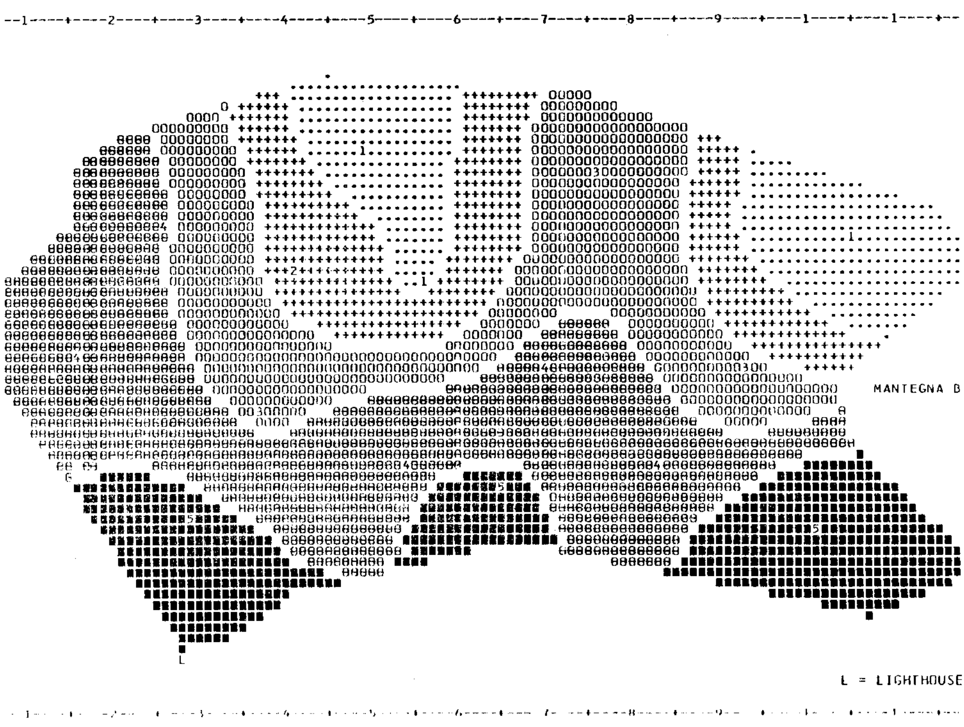

Figure 1. Illustration from the correspondence course mailed by the LCG to hundreds of users at the beginning in 1967.

of specific local conditions that take the form of particular metaphors and analogues and various vested social interests' (Barnes 1996: p. 118). In other words, scientists move from 'case to case, mediated by complex judgments of similarity and difference, (Bloor 1991: p. 164) carrying out classifications of observation and experience through the creative application of language. One of the most widely read historians of science, Thomas Kuhn, in fact wrote that scientists infer theoretical relationships neither inductively nor deductively but by metaphorical leaps (Kuhn 1970). Established relationships, both those established scientifically or accepted as social knowledge, become exemplars to be used as illustrations of general and generalizable principles in new and different circumstances. The well-known case of the development of spatial interaction theories through the application of Newtonian physical models and other physical theories to the interaction of human bodies (Stewart's Social Physics Project and its influence on Warntz and his work, detailed in Barnes 1996) is perhaps the best example of this principal at work in geography.

Perhaps the work of Fisher and others in creating the SYMAP program (as well as the later programs produced by the LCGSA) then should be viewed as an attempt to produce a system for visually recognizing similarities between renderings of points, lines, polygons, and surfaces that were meant to represent vastly different phenomena. In effect, the renderings become visual metaphors that allow the translation of one understanding of a particular kind of surface into another context. The master cases that exist as tacit currency (terrain, hydrology) appear time and again as examples of how particular abstract surfaces work or how they should be interpreted. I would argue that this work (that of Fisher and Warntz) carries immense importance in quantitative geography for it tended to facilitate the passing of metaphorical systems from one context to another by allowing the early visualization and reification within a common visual reference system of what were then merely theoretical objects. To the extent that the marks on the paper made by the fast line printers driven by SYMAP code resembled renderings of other phenomena seen before, then the more acceptable was the system of classification that Fisher had produced. Even though Fisher was an architect by training, and was by the mid 1960s housed in the Graduate School of Design at Harvard University, theoretical and numerical geographers, as well as urban and regional planners quickly grasped the significance and power of his system, and began putting it to use mapping human and physical phenomena with a fervent zeal.

I move now to a discussion of two instances where the use of a particular metaphorical example facilitated their easy understanding. By instances I mean concepts and their deployment, classification systems, texts and textual strategies, maps and graphics, institutions and their social context, and people and their active practices in a particular historical-geographical context. I use a discussion of the SYMAP program to illustrate several metaphors embodied within the documentation and explanations of its operation. This will be followed by a discussion of William Warntz and his work during the 1960s, in particular a metaphor-laden explanation that was given in an early paper in the influential 'Harvard Papers in Theoretical Geography' series.

3. Howard Fisher and the SYMAP program

SYMAP was one of the earliest examples of a computer-mapping program that was widely used in the developed world to produce thematic maps of diverse phenomena. The program was the brainchild of Howard Fisher, a distinguished architect who, in 1963 while at the Northwestern Technical Institute at Northwestern University in Evanston Illinois, worked with a programmer, Mrs. O. G. Benson, to complete the design. According to Chrisman (1988), Fisher, upon retirement from Northwestern, became interested in developing a laboratory for the investigation of practical ways of applying computers to problems of graphical representation. He made inquiries to both Northwestern and the University of Chicago but eventually returned to his *alma mater*, Harvard and the Graduate School of Design (GSD) with his proposal. The Department of City and Regional Planning in the GSD established the LCG in the spring of 1965. After the lab was established a proposal was made to the Ford Foundation for funding which was granted in December 1965. From the beginning he received help from a number of talented students, staff, and faculty in the completion and testing of the program, in particular Carl Steinitz, Robert Russell, and Donald Shepard. The initial version of the program produced crude (by today's standards) thematic maps using punched cards (or perhaps rarely magnetic tape or disk) as input and high-speed line printers as output devices. The program was written in FORTRAN IV. By 1967 the source deck consisted of 3000 cards—in later versions this would expand to over 5000. The initial version of the program that was made available to the public (1966) carried the warning:

> In general, without extensive revision and curtailment of options, computers of less than large scale capacity cannot be successfully used. (LCG 1967b)

By 1971 technology and the recommendations had changed significantly:

> The program uses approximately 200-k bytes of core storage and assumes availability of a full operating system. Other users have devised means for modifying the program to run on systems as small as an IBM 360-40, 128k, and DOS. (LCGSA 1971)

In order to use the program the user typically punched job control statements that caused the machinery to produce one of three types of map. Boundaries were coded using either primitive digitizing tablets or more commonly, engineering graph paper overlain on paper maps or manuscripts (figure 2).

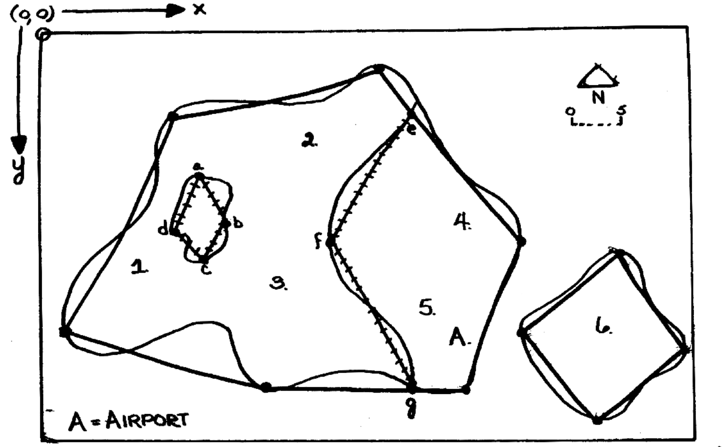

Figure 2. Illustation from the 1971 edition of the SYMAP manual (LCG 1971).

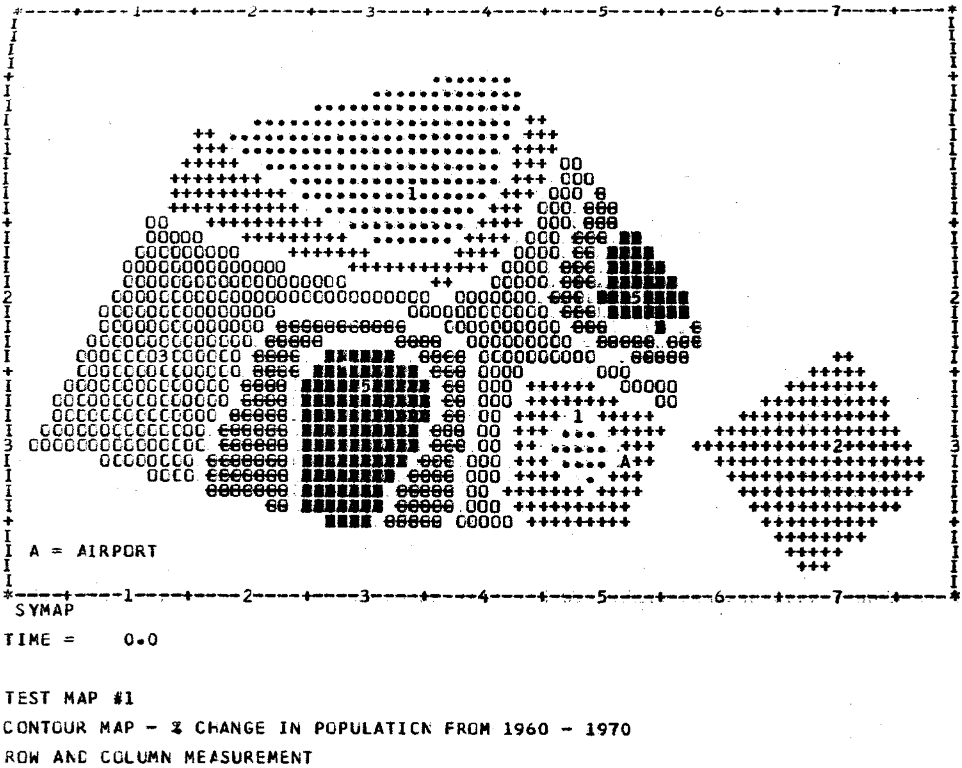

Figure 3. Illustration from the 1971 edition of the SYMAP manual (LCG 1971).

By 1967 the program had been modified to allow the production of three types of maps:

Contour Map (figure 4)
Proximal Map (figure 5)
Conformant Map (figure 6).

A typical SYMAP job might contain several packages in the stack of punched cards. These cards would contain co-ordinate locations of the map outline, the locations of data points, legends, locations of barriers to interpolation, and the values to be assigned to conformal regions or data points for surface interpolation. The F-MAP module specified the type of map to be produced as well as several electives such as size, content, number of class intervals, etc.

Many geographers and cartographers were trained in the use of the program through a correspondence course sent out by the LCG beginning in 1967. The lessons included several worked examples of mapping. The correspondence course was intended by Fisher and his associates to present working models of how the program might be applied to other spatial phenomena, and the examples that were used give some sense of the developer's perception of their clientele. They included representations of corn production in the fictional Abbott County, Iowa, the estimated percentage of coconut acreage suffering from blight in Mantegna Bay (a mythical place?) (figure 1), and the percentage of houses deteriorating in Lawrence Conservation Area in the City of Chicago (figure 4). Correspondence courses came

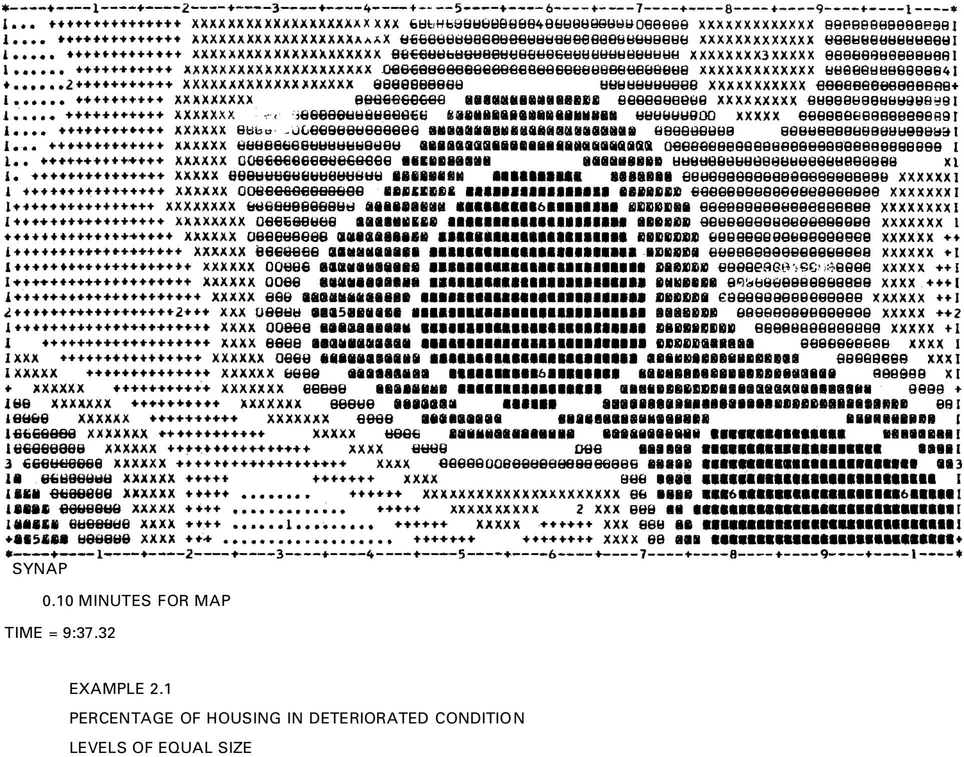

Figure 4. Contour map which purports to show the condition of deteriorated housing in Chicago's Uptown neighbourhood (Dudnik 1971).

with a brief cover letter ('Here is your first lesson. We trust you will find the course interesting and challenging'), a material list, instructions, sample punched cards, coding forms, and an envelope for the return of the materials to the LCG. The instructions and manuals for SYMAP are written in a straightforward technical style—a style well suited to their purpose—ease of use by a non-technical clientele of geographers, cartographers, architects, and planners. That the program was intended to be used in support of scientific and other data intensive investigations, however, was clear from the start:

> SYMAP is a computer program for producing maps which graphically depict spatially disposed quantitative and qualitative information. It is suited to a broad range of applications, and is provided with numerous options to meet widely varying requirements ... Raw data of every kind (physical, social, economic, etc.) when given to the computer may be related, manipulated, weighted, and aggregated in any manner desired (LCG 1967b).

Of the three types of maps that might be produced by the system, the Contour map was anticipated to be the most widely applied. The contouring problem was computationally intensive, and the manual solution of the problem was time consuming and tedious. In case users were unfamiliar with the symbolic usage of contours to delineate a surface, however, further explanation was needed:

> Imagine that a model has been carved out of some solid heavy material—with the area of its flat base corresponding to the study area, and with the height of its upper variable surface at every point proportional to the value or magnitude of the data. (LCG 1967a)

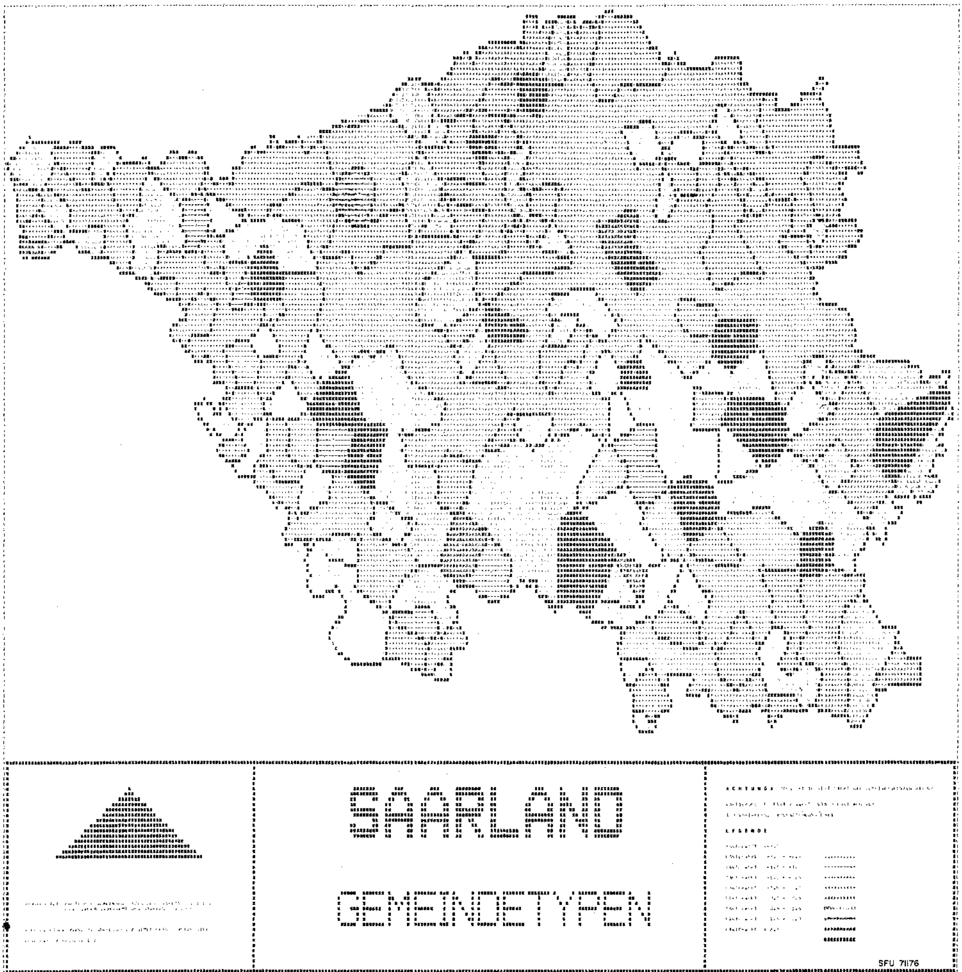

Figure 5. A proximal map (Peucker 1972).

Since the user's imagination might not have been active enough to ensure the understanding of the analogy—perhaps she was unfamiliar with vast carvings from solid heavy materials (mahogany? marble?) and might not understand the need for sculpture of this size—the explanation is supplemented with more vivid imagery:

> By way of further explanation: Imagine the model is placed in a tank filled with water just up to its highest point. If water were then removed from the tank until it was at 80% of its original height, the level surface of the water would meet the variable surface of the model along an uneven 'shore-line'. This shore-line would conform to the highest contour line on the map, that adjacent to the area formed out of black rectangles. (LCG 1967a)

The explanation goes on to remove successively more and more water from the tank—eventually leaving the model high and dry.

> By thinking of the contour lines as a series of shore-lines—or high water marks left by a retreating tide—it is possible (with a little practice and experience) to visualize quite accurately the shape of the statistical or quantitative surface represented by the symbolism printed on the map. (LCG 1967a)

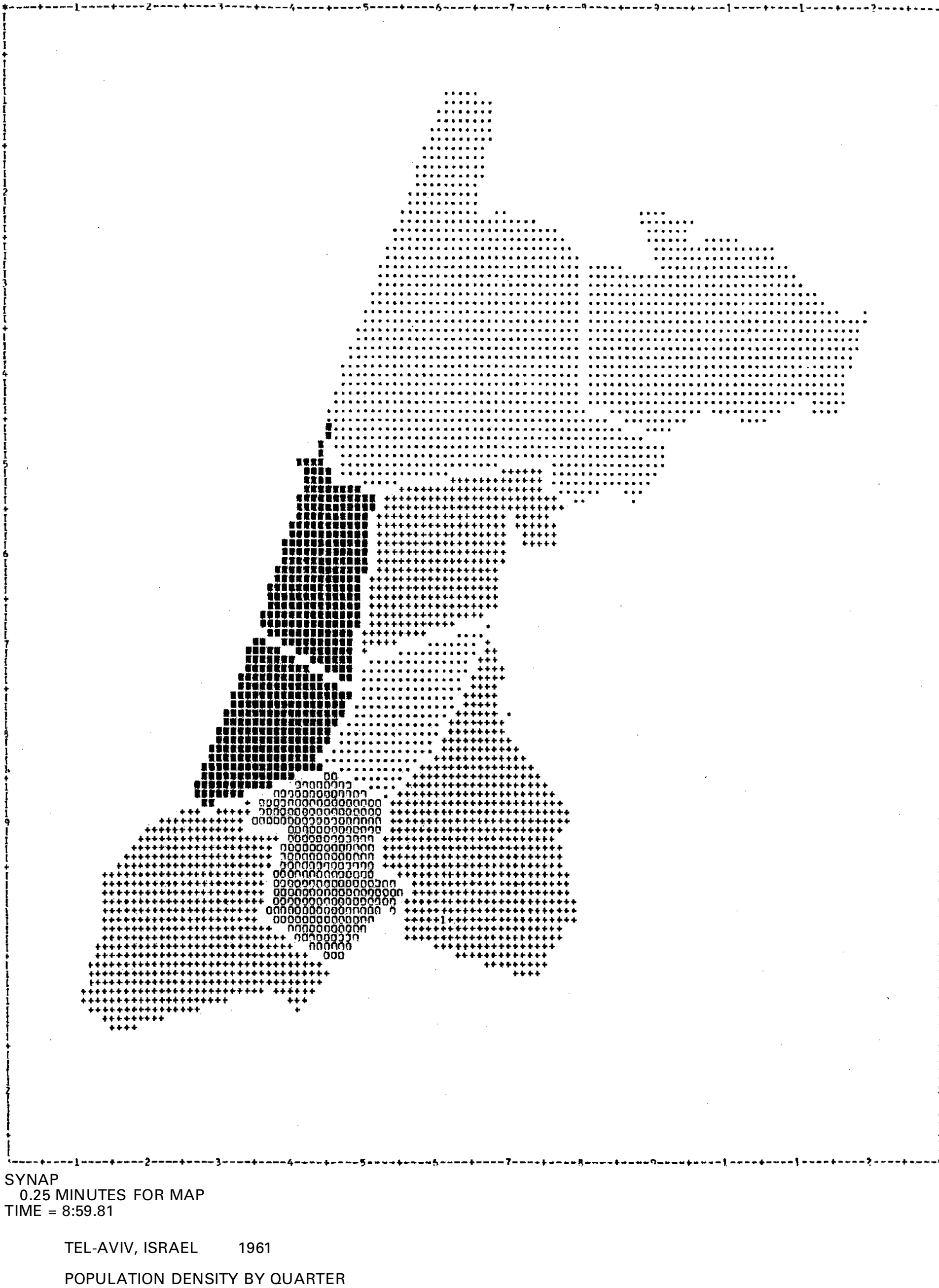

Figure 6. A conformant map of Tel Aviv, Israel (Dudnik 1971).

Never mind that the ‘contour lines’ in the line-printed SYMAP graphic were not lines at all but were blocky voids left between different classes of composite symbols produced by the overprinting of alphanumeric characters. Returning to the exercise at hand concludes the metaphorical explanation:

> Thus, in the case of Abbott County, for the particular subject specified in the title, there are 'peaks' of high value at the upper left and lower right—with the latter peak somewhat less steep than the former. (LCG 1967a)

The use of scare quotes at the introduction of the term 'peaks' refers the reader back to the recent flood, dropping the quotes later in the same sentence normalizes the metaphor. One perhaps is left wondering if the corn crop was affected by the unusually high water of recent times. The explanation goes on to discuss further interpretation of the problem in more formal language that related directly to the data and its representation by the computer system. This mixing of metaphorical explanation here and the drawing upon tacit understandings of common objects like carvings, basins of water, and peaks allows an unsophisticated user to rapidly grasp the contour concept. Fisher's previous professional background and his academic training was in the field of architecture—perhaps his explanations were sensitive to the untrained users who might benefit most from the program. By some accounts his understanding of cartography was unsophisticated at this time, although he did go on to write extensively on maps and mapping. Woldenberg described Fisher's cartographic knowledge during the 1960s:

> He (Fisher) was completely ignorant ... it's easy to say he was ignorant of cartography because he made up, he didn't refer, he made up all these terms like proximal ... and by the way he made up all those terms and that's why I say he invented cartography again ... in his own mind. (Woldenberg 1997)

As you will see later, this particular extended metaphor might have been derived from an explanation of a similar concept used frequently by William Warntz. Metaphorical explanations such as that given above allowed the normalization of this technology in a sense—particularly for users who had little experience with maps, cartography, or contouring. At about the same time that the correspondence courses were being circulated through the community of scholars, William Warntz had joined the lab and initiated a new, more scientific focus for the work that was going on there.

4. William Warntz and the LCGSA

William Warntz came to the LCG with impeccable credentials in the small community of scientific and theoretical geographers and regional scientists. He made no secret of his desire to come to Harvard as a way of beginning the 'reintroduction (of geography) as a discipline into the prestigious universities where it had been strongly represented in two earlier "cycles" of geographic thought' (Warntz 1983: p. 147). It was shortly after his arrival that the decision was made to change the name of the Lab to the Laboratory for Computer Graphics and Spatial Analysis (LCGSA), reflecting an expanded vision that his addition brought with it. His writings on 'macrogeography' and social energy had been recently published (Warntz 1965) and he had served a year (1965–66) as the President of the Regional Science Association. His presidential address gives some hint of his views of geography, science, and the discipline's role in society:

> Space is a tyrant and distances enforce his rule. He militates against us, often disposing of what we propose if our plans ignore his influence. The revolution against him is already well begun, however. Among the most disloyal of his subjects are geographers and regional scientists. Their attack on space is premeditated, calculating and unremitting. They aim to understand him completely the better to channel his influences to their own ends, and are willing to study long hours and hold frequent conferences to achieve this. They know

> the rule of space is not whimsical or capricious. That it is systematic and orderly has been glimpsed. When thoroughly understood, advantage will redound to mankind (Warntz 1966: p.1).

In this instance the 'space is a tyrant' metaphor establishes the context for a cluster of related word usages. For example:

he militates against us
if our *plans* ignore his *influence*
the *revolution* against *him*
the most *disloyal* of his *subjects*
the *rule* of space

Warntz was a visionary and a master of metaphorical explanation. In the same address he used a brilliant example of a global scale prison to explain the ambiguity of the spatial abstractions of 'inside' and 'outside' on a globe and described a system of gravity-driven subterranean intercontinental trains in order to stress the importance of always accounting for the spherical nature of the Earth. The point here is that while Warntz was certainly part of the vanguard of the quantitative revolution in geography, and has been treated perhaps unfairly by other historians of science, his visions of the discipline, and logical extension the world, were often thought provoking.

When he reached Harvard after an extended period at the American Geographical Society in New York Warntz set about continuing his work in spatial science and the establishment of a presence for scientific geography at the nation's premier university, where geography had been terminated as a program some time before. He began an ambitious teaching program including a graduate course on 'The Theory of the Region', and a team-taught course on 'Physical Geographical Systems'. His greatest satisfaction, in a teaching sense, came from a freshman seminar he offered, titled 'Geography, Geometry, and Graphics' (Warntz 1983).

During the winter of 1966–67 Warntz initiated what was to be his most influential contribution at the LCGSA, The Harvard Papers in Theoretical Geography. This series, funded by the Office of Naval Research, was a continuation of work begun at the American Geographical Society in New York prior to his move to Harvard. Carrying the subtitle 'Geography and the Properties of Surfaces' and running from 1966 to 1971, it served as a vehicle for the theoretical and empirical writings of Warntz and others that were associated with the LCGSA in some way. Of the 47 papers in the series, Warntz, Michael Woldenberg, or C. E. Lindgren authored 29.

The first paper in the series, published in the spring of 1966 and co-authored by Warntz and Woldenberg, bore the broad title 'Concepts and Applications—Spatial Order' and it was divided into two sections. The first, by Warntz, was an extension of a discussion he had begun in his monograph *Macrogeography and Income Fronts* (1965) that dealt with the topology of surfaces in a terrestrial context. The second section, by Woldenberg, dealt with hierarchical systems and their growth. The preface set the context for the series:

> We intend that all of the papers taken together represent a discipline of geography that is at once respectful and mindful of the remarkable tradition of that discipline and receptive to and perhaps a moving force behind the grand advances currently being made within geography that permit us now to attempt not only 'explanations' of particular spatial patterns, be they of social and economic or of physical phenomena, but also of the 'patterns of patterns'. (Warntz and Woldenberg 1967, p. iii)

Whether the contribution hoped for by the authors was achieved or not is an open question. Certainly the papers were widely read in geography and regional science in the 1960s and 1970s. Perhaps because of their theoretical focus, their practical application has been limited, although I would argue that they set a legitimizing and scientific tone for the applied work that was occurring at the time such as that evidenced at the early conferences facilitated by Roger Tomlinson and others.

Warntz set the goal of this first piece to begin a discussion of the theoretical foundations of surface modelling and representation:

> It is, in part, the purpose of this first report to treat explicitly certain parts of the theory of contouring land forms that have remained neglected through the years not only with the hope of removing that confusion but especially with the aim of developing pertinent ideas concerning certain properties of surfaces generally and demonstrating their significance for a theoretical geography of spatial structure and spatial process, that is to say, spatial form and spatial movement. The theory of surfaces is equally applicable in many cases to phenomena generally acknowledged otherwise to be significantly different in terms of their non-spatial properties. (Warntz and Woldenberg 1967, pp. 1–2)

This is the ontological leap that allows the extension of mathematical and representational logics, developed in one context, to be linked to others in a decontextualized fashion. In effect the representational logic of terrain mapping becomes metaphorically connected to more abstract mathematical models meant to describe ephemeral socio-economic phenomena that were capable of being represented in a similar fashion. As shown later, this technique becomes legitimized in part through the creative use of language. Warntz continues, setting the stage for what is to follow:

> We now look upon maps not only as stores for spatially ordered information, but also as a means for the graphical solution of certain spatial problems for which the mathematics proves to be intractable, and to produce necessary spatial transformations for hypothesis testing ... The modern geographer conceives of spatial structures and spatial processes as applying not only to such things as land forms, drainage patterns, temperatures, and the like in physical geography alone but also to social, economic, and cultural phenomena portraying not only conventional densities but other things such as field quantity potentials, probabilities, refractions, costs, times, etc. Always, however these conceptual patterns may be regarded as overlying the surface of the real earth and the geometrical and topological characteristics of these patterns, as transformed mathematically or graphically, thus describe aspects of the geography of the real world (Warntz and Woldenberg 1967, pp. 2–3).

So scientific geography, combined with the computing power available at the LCG, was poised to make the kinds of contributions to society dreamed of by the spatial scientists since the early 1950s.

> Of considerable promise here is the possibility of developing a logical computing program for producing meaningful and operationally significant geographical regionalizations for particular uses (planning, administration, etc.) based on mappings effecting programmed compromises between spatial and non-spatial variances (Warntz and Woldenberg 1967, p. 4).

Warntz seems here to hope for the construction of something much more applied from the outcome of theoretical research being carried out at the LCG and at other places.

After the programmatic statements of the first few pages Warntz returns to the object of his concern, the surface. He is very careful initially to establish its meaning in a formal, mathematical sense:

> Surface is a geometrical construct dealing with kind of space that may be regarded as deriveable (sic) from a plane by a transformation that is reversible. If m and n are taken as the two independent variables over the intervals $a<m<b$, $c<m<d$ (sic) and $u(m, n)$, $v(m, n)$ and $w(s, t)$ are taken as three continuous functions of m and n in their given intervals, there exists a point of space corresponding to each pair of values (m, n) as a consequence of the equations $x=u(m, n)$, $y=v(m, n)$, and $z=w(m, n)$. All of these points considered at once constitute a continuous surface and the three equations immediately above are called a parametric representation of the surface. This totality is regarded as a surface-segment if, in the above definition, the intervals are bounded (Warntz and Woldenberg 1967, pp. 6–7).

This mathematical-logical definition of surface is consistent with understandings of physical surfaces—those that can be observed, touched, or walked upon and might even serve to describe more ephemeral physical surfaces such as continuous atmospheric or hydrological phenomena. But to extend this understanding to non-continuous human phenomena such as population, incomes, deteriorated housing, or even corn production requires the case-by-case suspension of 'that which is known' about virtually any of these things. To extend the status of continuous surface to discrete or even stepped things in the world, things that might even have been measured at particular places that might be locationally identifiable as a point in some co-ordinate system, just because it is mathematically possible to interpolate values for all of those locations in between might be viewed as an act of intellectual fraud. The application of contour mapping to social data was—at this time—well established in geography and cartography. The advent of high-speed computers and the creation of programs like SYMAP, with its interpretation algorithm written by Donald Shepard at the LCGSA (Shepard 1968), made simple continuous surface mapping of any thing that could be measured and assigned to a Cartesian location. Following Haggett (1966), Warntz gave a thumbs up to the use of this technique for virtually any type of data, regardless of our understanding of process or pattern—not without noting, however that 'The history of the origin and development of such conceptualization and its cartographic presentation is an interesting and involved one' (Warntz and Woldenberg 1967, p. 7).

Warntz went on to demonstrate some general properties of closed surfaces. Almost immediately he launched into an extended allegorical description of a spherical system that would illustrate a point:

> Imagine in space any closed surface ... Describe, with the point G as its center, a sphere with a radius large enough to envelop the surface entirely. In order to represent these things better, let us imagine that the sphere is formed from a mass of water surrounding the surface, and that the water be submitted afterwards to continuous evaporation which makes the volume of the sphere decrease progressively ... If we conceive the given surface as the exterior surface of a solid body of stone plunged into the interior of a liquid, the point S (shown in an illustration) will be like the summit of an island which will rise and grow in proportional increases. (Warntz and Woldenberg 1967, pp. 11–12).

The use of this example went on for some time. The liquid sphere gradually evaporated entirely (one would assume creating an atmosphere, weather, climate) eventually exposing the entire surface of the solid stone body inside, illustrating various characteristics of contour lines (described as a 'coast line') along the way. There were several important and interesting points to be made here, including the possibility of crossing contour lines and a generalizable characteristic of the number of pits, peaks, pales, and passes that describe the irregular stone object. At certain points Warntz dips back into the description of the surface using formal mathematics, only to return to the sphere and the flood of biblical proportions. All through the illustration (10 pages long) he moves back and forth between flood and drought, and formal mathematical language. While the demonstration would have most certainly been possible without appealing to the scriptural imagination of the reader, it would most certainly have not been as understandable, convincing, or readable.

Warntz follows the discussion above with a long, graphic illustration of his diluvian world, meant to reveal the coastlines as they emerge from the all-encompassing ocean:

> This figure and subsequent ones are meant to be regarded as geographical maps, in particular as one point equi-distant azimuthal projections to the plane of the entire sphere to the plane with that point being mapped as the center of the circle and with its antipodal point on the sphere being depicted as the boundary circle of the map. (Warntz and Woldenberg 1967, pp. 23–24)

The series of thirty figures, when thumbed through like a flipbook, reveals the emergence of a rectilinear continent with peaks, plains, valleys, and passes. Warntz maps the contours of his continent (figure 7) but lest we think this is intended as a dry theoretical exercise he reminds us:

> Keep in mind that the features exposed by the diminution of the liquid sphere can be taken literally as geomorphological features or as on a three dimensional surface model (with an arbitrary but convenient vertical scale) of some phenomenon, real or conceptual, geographically distributed, pertaining to social, economic, or physical realms. (Warntz and Woldenberg 1967, p. 24).

Once again we see that, while not wholly relying on the use of metaphor and allegorical description, these writings suggest that the researchers at the LCGSA, like scientists everywhere, did build allegorical and metaphorical arguments that helped to explain the abstract mathematical concepts they were constructing during the ascendant period of scientific and theoretical spatial science. Warntz, and his work while at the LCGSA, served to underpin more practical work done by other researchers at Harvard and at other locations through the late 1960s and the 1970s with an aura of scientism and epistemological legitimization. Whether it was used or not by workers at the 'grand enterprise' that has come to be GIScience in the 1990s, it is remembered as being part of the fabric, woven during the 1950s and 1960s, establishing the conditions for the development of modern GIS.

5. Final thoughts

My observations here, and what I've written about them are the more permeable kind, drawn from my reflection on what I've seen, read, and discussed over the course of this work. At several points in this paper I have used materials that were produced by workers at the LCGSA during the 1960s as a way of explaining the new techniques and technologies that were being developed there, in particular the SYMAP program and the paper series on theoretical geography. They also served as a source of income for the lab during these years where at Harvard research was expected to 'float it's own boat'. These were the materials that many GIS practitioners of the present generation used as an introduction to what was then known broadly as 'computer cartography'. As we use the descriptions of our early experiences with SYMAP, SYMVU, and similar applications to illustrate to current students and younger GIS users the progress that has been made over the past several decades,

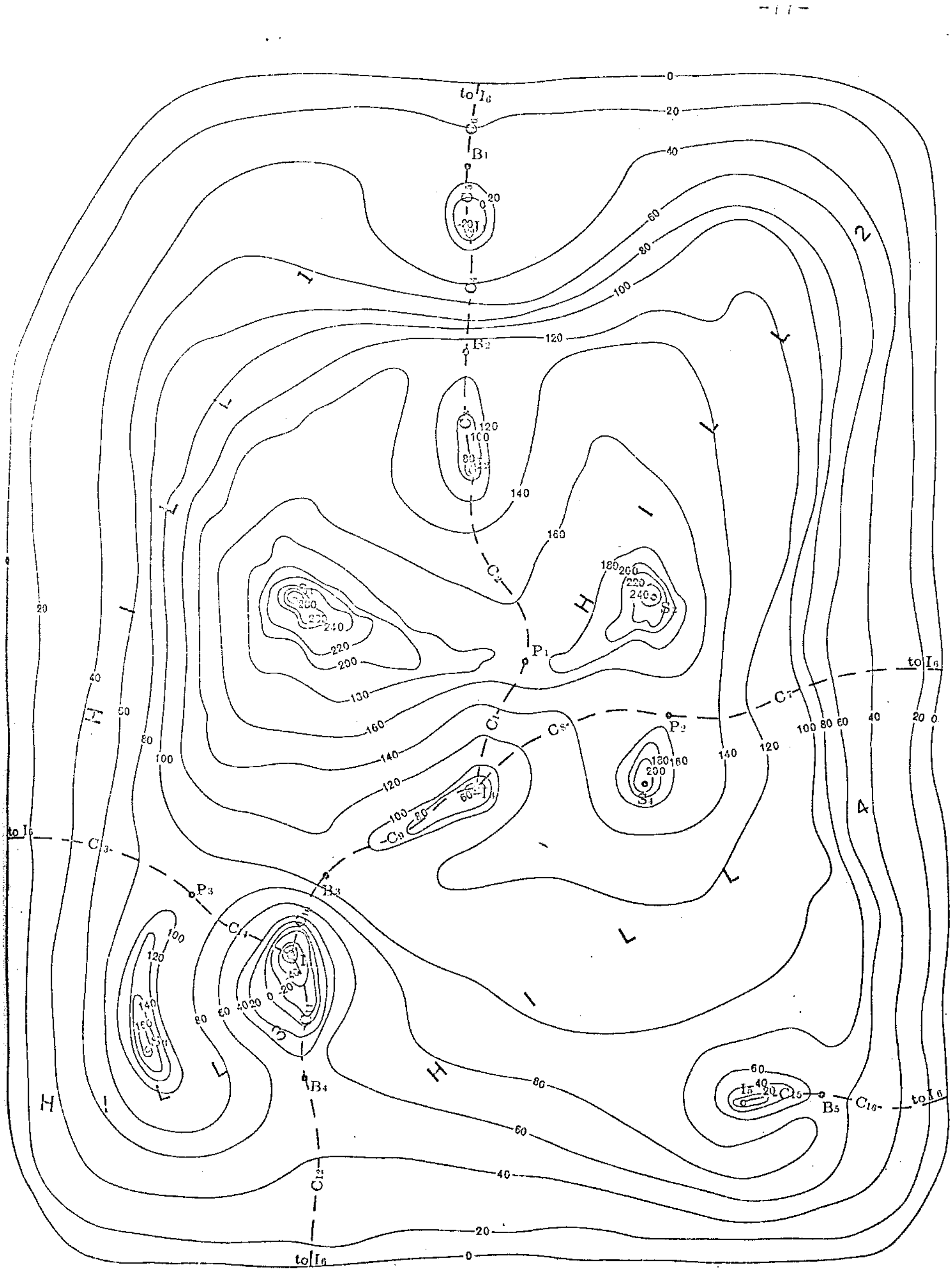

Figure 7. The contours of an unnamed surface/form described by William Warntz (Woldenberg and Warntz 1967).

the story of this early application and the works of Fisher, Warntz, and others is reproduced, albeit as something of a straw man. To the extent that metaphors such as the 'solid object in water' story allowed the easy understanding of abstract SYMAP renderings, or the theoretical writings of Warntz and others then it is relevant to the evolving historiography of GIS.

The work of Fisher and others at the LCGSA combined the emerging epistemology of quantitative geography, championed by Warntz and others, with the practical technologies that were readily available through university research computing centres. The application of the surface interpolation algorithm through the SYMAP package's CONTOUR module to practical and theoretical problems allowed geographers, planners, and other social scientists to visualize abstractions from the physical and social worlds that had never been seen before. To the extent that these renderings *looked like* other renderings of terrain surfaces, better known but *not* derived through mathematical interpolation but rather analogical photogrammetric modelling or field mapping, the system was a success. The researchers at the LCGSA, Warntz in particular, were prepared to extend the status of 'surface' to practically any phenomena, so long as it was capable of being measured and fixed to a point.

This work is a small part of an emerging literature that seeks to flesh out the ways that what we currently know as Geographical Information Science or Geographical Information Systems came about. Examining disciplinary change in core concepts such as surfaces and their properties raises epistemological and ontological questions. What counts as acceptable technique or knowledge in GIScience and how these things came to be embraced will always be relevant for practitioners, as well as historians of science and technology. The work of Keith Clarke and John Cloud on the CORONA program, supported by NSF, indicates the breadth of topics that geographers and historians are beginning to examine. Another strand of interesting work in this vein comes from the intersections of science and technology studies and critical appraisals of GIS technology from within the disciplines of geography, sociology, and the history of science and technology. This volume is a reflection of the growing importance and relevance of this work. If GIS is to become GIScience then we can expect (and welcome) an outpouring of richer and more complete investigations of the intellectual genealogy of our discipline's core concepts.

Several questions have been raised here and (at least) partial answers have been proposed. At least two bear repeating:

- How do renderings of surfaces such as those produced by computer applications such as SYMAP take on meaning?

It should be clear from the examples given here that, at the critical moment when computer mapping of continuous surfaces was placed within the grasp of a large community of scholars, the interpretations of these renderings were aided by creative uses of descriptive, metaphorical explanations. Because metaphor relies on the existence of broadly held, tacit understandings of things then tacit knowledge comes into play as being an important facilitator of the transfer of scientific knowledge. And this moment is historically significant because for many this was our first experience of computer mapping technology.

- How are proposed theoretical explanations of cartographic renderings (such as those given by Warntz) of surfaces made understandable?

Again, and interestingly in the same institutional context, they were normalized at least in part through the creative use of language and the reliance on metaphorical explanation (and hence the existence of broad tacit knowledge regarding particular kinds of surfaces) in the writings of William Warntz. This is important for its location in close institutional juxtaposition with the other more practical works being produced at the LCGSA, and for the legitimizing role that the Harvard Papers played in the early development of GIScience. I hope that this work will spur reconsideration of the role of language in the development of scientific knowledge within GIScience and the mapping disciplines in general.

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References

Barnes, B., Bloor, D., and Henry, J., 1996, *Scientific knowledge: a sociological analysis.* (London: Athlone).

Barnes, T. J., 1996, *Logics of Dislocation: Models, Metaphors, and Meanings of Economic Space* (New York: Guilford).

Barthes, R., 1985, *The Responsibility of Forms: Critical Essays on Music, Art, and Representation,* translated by R. Howard (Berkeley: University of California Press).

Bloor, D., 1991, *Knowledge and Social Imagery,* Second Edition (Chicago: University of Chicago Press).

Borges, J. L., 1964, *Labyrinths: Selected Stories and Other Writings* (New York: New Directions).

Chrisman, N., 1988, The risks of software innovation: a case study of the Harvard Lab. *The American Cartographer*, **13**, 291–300.

Dudnik, E. E., 1971, SYMAP user's reference manual (Chicago: University of Illinois—Chicago Circle).

Foresman, T.,editor, 1998, *History of Geographic Information Systems: Perspectives From the Pioneers* (Upper Saddle River, NJ.: Prentice Hall).

Galison, 1987, *How experiments end* (Chicago: University of Chicago Press).

Galison, 1997, *Image and logic: a material culture of microphysics* (Chicago: University of Chicago Press).

Haggett, P., 1966, *Locational Analysis in Human Geography* (New York: St Martin Press).

Kuhn, T., 1970, *The structure of scientific revolutions,* Second edition (Chicago: University of Chicago Press).

LCG (Laboratory for Computer Graphics), 1967a, SYMAP correspondence course (Cambridge: Harvard University).

LCG (Laboratory for Computer Graphics), 1967b, *Introductory Manual for Synagraphic Computer Mapping 'SYMAP'* (Cambridge: Harvard University).

LCG (Laboratory for Computer Graphics), 1971, *SYMAP manual* (Cambridge: Harvard University)

Lakatos, I., 1976, *Proofs and Refutations: The Logic of Mathematical Discovery* (London: Cambridge University Press).

Lakatos I., 1978, *The Methodology of Scientific Research Programmes, Philosophical Papers,* Volume 1 (Cambridge: Cambridge University Press).

Peucker, T., 1972, *Computer Cartography, Commission on College Geography Resource Paper,* No. 17, (Washington: Association of American Geographers).

Samet, J., 1980, Tacit Knowledge. Unpublished Ph.D. Dissertation (New York: City University of New York).

SHEPARD, D., 1968, A two-dimensional interpolation function for computer mapping of irregularly spaced data. Paper Number Fifteen, *Harvard Papers in Theoretical Geography, Geography and the Properties of Surfaces Series* (Cambridge: Laboratory for Computer Graphics).

WARNTZ, W., 1965, *Macrogeography and Income Fronts* (Philadelphia: Regional Science Research Institute)

WARNTZ, W., 1966, *Global Science and the Tyranny of Space*, Presidential Address, Regional Science Association.

WARNTZ, W., 1983, Trajectories and coordinates. In *Recollections of a Revolution: Geography as Spatial Science*, edited by M. Billinge, D. Gregory, and R. Martin (New York: St. Martin Press).

WARNTZ, W., and WOLDENBERG, M., 1967, Concepts and applications—spatial order. Paper Number One, *Harvard Papers in Theoretical Geography, Geography and the Properties of Surfaces Series*, In Conjunction with the American Geographical Society (Cambridge: Laboratory for Computer Graphics),

WOLDENBERG, M., 1997, Transcript of interview conducted 8 November, 1997 in Buffalo, New York.