Configuring the User:

Social Divisions of Labor in GIS Software

Nicholas Chrisman
chrisman@u.washington.edu
Department of Geography Box 353550, University of Washington
Seattle WA 98195-3550 USA

ABSTRACT

Research on "Society and GIS" has fallen into a trap to the extent that it separates these two realms. As an antidote to rampant technological determinism, this paper demonstrates how the highly technical decisions inside GIS software have a distinctly social flavor, in particular they specify a division of labor (and thus of knowledge). In the case of map registration, the software adopts an optimal least-squares model that requires protection from "blunders", while a more robust technique would shift the division of labor. In the case of coordinate geometry, the software has been structured around the two-dimensional planar coordinates of traditional maps. While this is certainly easier on the programmer, it delays the introduction of global three-dimensional geometry. Overall, these examples demonstrate the aphorism of Woolgar: configuring the user. The practice of GIS is social to its very core.

Society and GIS

Over the past few years, a number of geographers, inspired by social theory of various derivations, attempted to recenter the focus of research about GIS. In place of a technical agenda, they sought to make space for studies of the implications of GIS for society at many scales and through many processes. While much of their critique serves useful purposes, the focus on implications adopts a model of GIS as an inexorable, implacable force.

Proponents often acclaim geographic information technology as the means to make more efficient and socially equitable decisions. These proponents hope to clear away subjective issues and rationalize the process of establishing consensus, so that decisions can be made objectively (Dobson 1983; Cowen 1988; Openshaw 1991; Dobson 1993; Morrison 1994). Most of this literature aligns itself with the "March of Progress" metaphor, an attitude about history with limited utility to detect the choices and inconsistencies involved in technological change (Chrisman 1993). The idea of an automated geography implies that the technology is somehow independent of the people, operating on its own internal logic. Critics of GIS are quite justified in calling attention to flaws in the proponents' claims.

Arguments about GIS technology often slip into a discourse of technological determinacy. GIS-proponents and critics alike assert, consciously or unconsciously, that technology is intrinsically independent from the social world. This perpetuates the two major tenets of technological determinism:

1) technology engages unilinear progress from less to more advanced systems;

2) technology is an imperative to which social institutions and people must adapt

(Bijker et al. 1987; Woolgar 1987; Bijker and Law 1992; Feenberg 1995). Technological determinism leads to the belief that the technology can be studied solely by itself, outside of the context of its construction or use. As a consequence, "implications" remain as the sole issue in studies of technology and society written from this perspective. This paper will present an alternative.

Use of the Progress Myth by proponents

Technological determinism suffuses the debate surrounding the development of GIS. The belief in the "march of progress" dominates the new industry’s self-representation (Dangermond and Freedman 1984; Tomlinson 1984; 1989; Antenucci et al. 1991). These heralds of progress create the impression that improvement is inexorable and assured. The GIS bandwagon suggests that jumping aboard is the way to success; technology can fulfill every demand, and bring you the world. Dobson (1983; 1993) places GIS technology on a clear rational path towards a better tomorrow, arguing that "GIS has become a *sine qua non* for geographic analysis and research ... the beginning stage of a technological, scientific, and intellectual revolution" (Dobson 1993, p. 431). The authors of *Ground Truth* made much of the claims of GIS proponents (Pickles 1995b) as well as the advertising of GIS vendors (Goss 1995; Roberts and Schein 1995). The more arrogant the claim, the better it seems to serve the critics.

The dominant approach to GIS methodology emphasizes the abstract nature of geometry and mathematics as the basis for GIS tools (Goodchild 1987; Goodchild 1992, for example). This view relies upon a form of abstract essentialism (rendered for illustration in its most extreme form): geometric concepts reside in a Platonic world of forms; researchers simply discover eternal truths; technology can rely on iterative approximation to move closer and closer to the ideal essential truth. In this view, issues of society hold low priority, because the only way that society can impede progress is in delaying the inexorable and inevitable. There has developed a counter-current of meetings, research agendas, and some papers that treat "Society and GIS" as a two-way interaction. However, most of this work still deals with "implications" of the GIS technology, it studies applications of the technology, not the technology itself.

Role of the critics

The critics (Curry 1991; Smith 1992; Lake 1993; Pickles 1995a; Sheppard 1995) have also focused on the impacts of technology. They often portray the technology as a force out of social control, something external to the social discourse. They use a somewhat sophisticated form of C.P. Snow's (1959) "two cultures" argument, saying that technologists are not connected to the same literature and not engaged in the same bases of theory. The gap between two discourses does not mean that technology and technologists do not respond to their own versions of social forces. Both proponent and critic alike need to see where exactly the social comes into GIS. It may not be in the places they are watching.

Technological determinism, proclaimed by proponents or implied by critics, obscures the relationships between GIS technology and society largely by neglecting linkages. The contention between progress-believing technologists and humanistic-orientated social theorists omits the people involved with the technology and the complex interactions required to maintain it. GIS technology serves to extend human capabilities by other means, not a superorganic force in itself. The people who use GIS are not mere instruments of progress towards better information systems nor are they simply victims of its social consequences. The systems now in place reflect many layers of negotiation between social goals and technical capacity to respond. The simplistic metaphors must be replaced with more nuanced understanding of interactions between people and technology.

Rather than a vast superhuman realm, GIS technology is the result of localized social construction. This construction occurs when the technology is created, and continues as it is configured for each application. The march of progress myth must be replaced with a careful examination of the social divisions created and maintained by geographic information technologies.

Society and a variety of social structures influence the nature of geographic information representations. In turn, certain characteristics of geographic information can influence society. Research in GIS rarely takes account of this two-directional flow of influence. Most research on GIS has taken an instrumentalist approach, trying to improve the technology to fulfill defined purposes. Originally, GIS research was conceived without overt consideration of social factors. GIS principles are still presented as universals, derived from abstract laws of geometry. Social, cultural and historical contingencies of GIS use are considered aberrations, deflecting the logical trajectory of the technology. Many use a "barrier" model in which the seemingly natural and predetermined spread of GIS technology is impeded by some irrational social factors (Croswell 1991; Onsrud and Pinto 1991). Technological innovation is not some hydrostatic force, but a much more complex interaction of economic, institutional, political, social and cultural components.

This paper will not attempt to demonstrate all forms of interaction between society and technology. It will focus on how the seemingly technical details of programming embed certain choices that are, at their root, social. It will consider the case of coordinate registration and the case of coordinate representation in separate sections below. First, it will introduce the origins of the catch-phrase that serves as the title for this paper.

Technology studies: origins of "configure the user"

There is a large emerging literature on technology. This paper draws specifically on recent theoretical insights from a number of interlocking literatures including the sociology of scientific knowledge (SSK), studies of technology and science (STS), philosophy of science, and related fields.

Studies of science and technology (Barnes 1974; Bloor 1976; Latour and Woolgar 1986, for example) provide strong documentation of complex networks linking social organization, political structure, economic interaction, and cultural foundations to the development of a technology. The sociology of scientific knowledge developed a "strong program" of researchers (Bloor 1976; Collins 1981) who argued that social relationships underpin the development of science and technology. This strong program argues against the study of "impacts" from technology to society, but ends up asserting that the social dominates everything else. The constructivist literature (Latour and Woolgar 1986; Bijker, Hughes et al. 1987; Latour 1987; Woolgar 1987; Latour 1988; Bijker and Law 1992; Latour 1993), though inherently quite diverse and far from unambiguous, modified the unidirectional direction providing a more complex dynamic of mutual constitution. Latour (1993) argues that the division between “nature” – a realm of scientific enquiry – and “society” – a realm for human creation – obscures intricate interactions required to sustain the hybrid networks of current technology.

This literature argues that science and technology are constructed from a multiplicity of viewpoints, and that this construction is distinctly local, not universal. Multiple social forces interact in the process of developing a complex technology such as GIS. Implementation of any technology depends on the specific local environment that strongly constrains how actors interact with the artifacts they construct. This literature digs deeper than the argument of ‘inherent logic’; any logic in a technology was put there by developers through some process and adopted by users for another set of reasons.

As the specific resource for this paper, I am borrowing the phrase "configure the user" from a paper written by Steven Woolgar (1991), a British sociologist of technology and science. In the days when the IBM XT was the dominant PC, he observed how a microcomputer manufacturing organization decided how to design their next model. He argues that the group did not configure a machine to suit a specific body of users, but rather that they built the machine that they could and attempted to configure the users to suit the machine. He was contributing to a literature about the role of technical artifacts (Latour and Woolgar 1986; 1987, for example). This theme has recently been extended (in a more interactive form) to the study of software developments (Mackay et al. 2000). This specific literature gives a theoretical basis for this paper, but the core of the observations are empirical ones, drawn from the practice of GIS, the technical details themselves. Yet, these facts do not speak for themselves. There is no guarantee that the facts will self-organize to support one view or another. They only make sense due to deliberate sense-making.

Blunders as a division of labor

Much as Caesar divided all Gaul in three parts, the science of photogrammetry divides all error into random error, systematic error and blunders (Mikhail and Ackermann 1976; Wolfe 1983). Along with importing the mathematical procedures into the practice of GIS, this division came as an unheralded axiom of GIS practice. As in many situations where the basic theoretical work comes from outside the discipline, some of the details get hazy over time. It is worthwhile returning to first principles here (at the risk of offending those who remember).

If the central commonality of GIS is the integration of different sources, almost every application requires some form of geometric registration. To connect the measurements obtained on a digitizer, the device units are transformed into map coordinates by solving the correspondence for a set of known points. To transform a remotely sensed image to other layers, a set of known features are located on the image. In either case, a set of "tic points" serve as the Rosetta Stone, being measured in two systems. This procedure is critical to the whole GIS enterprise, yet the tools presented to users are considered so simple that they are rarely called into question. Like many elements of technology, once the decisions are made, it becomes a "black box" whose internal structure is not worth considering (Latour 1987).

Registration software, as currently embedded in GIS packages, uses least-squares estimation – a well-established standard in the realm of applied mathematics. It is this choice that generates the tripartite division of error. Least-squares is indeed the most efficient estimator to solve for the parameters of a coordinate transformation between two coordinate systems, under a particular set of assumptions. Least-squares minimizes the random error and gives the best estimate of the systematic error under the condition that there are no blunders. So, what is a blunder? A blunder is an error that does not behave according to the expectations of the least-squares technique. If this all sounds rather circular, it is.

Photogrammetric research gives substantial attention to blunders, largely in the detection and elimination of blunders (Kavouras 1982; Kubik et al. 1988). Users of the least-squares model were meant to recognize the signs of the dread blunder then purify the input so that the least-squares procedure could do its Best Linear Unbiased Estimation. This choice is somewhat analogous to buying a cow because she would have the best possible milk production, but then having to sort through every bit of hay you fed this cow because she couldn't eat one particular species of grass that is endemic to your pasture. The care and feeding of the least-squares model moves some of the effort from the mathematical model to the "user".

Now, if this situation were unavoidable, then there would be little to complain about. If all cows required careful sorting of the hay, then that would just be the way things are for dairy production. Similarly, the least-squares view of the world gives the impression that blunders are a different kind of error. They do not obey the mathematical behavior required by the estimation procedure. One lesson from the sociology of scientific knowledge rings the alarm bells right here. Users, being regular people, do not know when they are making errors and when they are doing the right thing. In fact, they will think that they are not making errors at all. Errors are not different from "correct" answers (Bloor 1976; Latour 1993), they come from the same work practices. There are indeed, alternatives to least-squares discussed in photogrammetric research (Kubik et al. 1987; Shyue 1989), particularly in the adaptation of robust statistics (Rousseeuw 1984; Hampel et al. 1986; 1987) to the estimation of coordinate transformations. Rather than dividing the blunder detection off into a pre-processing step requiring manual intervention, the robust techniques like least-median squares estimate nearly the same parameters as the optimal least-squares does by pruning off blunders using an iterative procedure.

This last revelation is critical. Iterative procedures work much better on a computer with programming control. Least-squares has a closed numerical form and could be calculated directly in the fewest possible steps using hand calculators or even earlier technology. The division of error into three parts thus depends on the affordances of a computing technology available. It is historical and contingent, not universal and inescapable.

But why do I characterize these highly numerical decisions as social? Certainly I am not adopting some connection between least-squares and global capitalism, or between robust statistics and the class struggle. I am focusing on the social processes that divide labor and knowledge. The software designers maintained an established division where the numerical model did its job as long as the user kept blunders out. The software manuals deepened the division by leaving out some of the critical elements of photogrammetry practices on which the technique was based. The market leader in GIS software suggests four points (ESRI 1991, p. 5-13): "Select 4 widely spaced points common to maps A and B to be used as tics for A." ESRI software will handle many more points, but four are considered adequate. Some other systems only allow four, no more (Planet One Corp. 1997). In the translation from the research community to the world of practice, the number of points was cut back to a bare minimum. The random error is estimated with virtually no degrees of freedom and any blunders might pass unnoticed. It would make much more sense to expect sixteen or twenty points, not just four. In the case of Planet One, it seems to be a drive for a simple, minimal interface that led to a fixed number of control points. Also, they are simply following the lead of their Business Partner, ESRI. This software choice devolves responsibility onto the user, but at the same time the user is not being trusted. The result leads to a much less optimal result.

The user has been configured by the software and the software producer. Responsibility has been transferred without sufficient notification. Since the software companies mostly develop new features to respond to user demand (not research frontiers), the user will not even know to demand coordinate registration software based on robust statistics. The software company is blameless, they were following best practices in the industry and after all, the user should avoid blunders (that are only retrospectively defined). In the end everyone ends up losing. The researchers who develop new solutions that do not require blunder detection will not be able to crack the self-fulfilling practices that sustain the use of least-squares. The division of knowledge works against innovation. The division of labor means that the accuracy of GIS datasets are lower than they could be.

Overlay mirrors division of knowledge

The second example moves from the internal details of choice of numerical algorithm to the architecture of data models and procedures. Polygon overlay played a key role in making GIS software viable (Burrough 1986). Most academic research on GIS in the early phase placed the overlay function at the core (Tomlinson 1974; Chrisman 1982; Tomlin 1983; 1990). This software capability became a kind of litmus test to separate mere mapping from GIS. Certainly, the centrality has altered as the capabilities have had to expand to respond to many different marketplaces and user communities. Yet, the metaphor of map layers (Figure 1) remains a central element of the graphic interface, even using software that no longer is as strongly tied to the topological coverage model. The logic for placing overlay at the core deserves some reexamination.

The layer cake diagram presented in Figure 1 is one of many produced in approximately the same period (1984). This particular one was perhaps the first produced with actual data layers, in this case, Section 12 Westport Wisconsin. It was originally produced in a press run of 20,000 on card stock to be handed out at the State Fair to explain multipurpose land information systems to the farming community and the general public. The text on the reverse was titled "Conceptual Model of a Multipurpose Land Information System", perhaps a bit high brow for the average State Fair booth, but received with substantial interest when I served my stint at the booth handing them out. The text did make some mention of computing technology, after all, the state motto is "Progress". However, the primary emphasis was on the independence of the sources of various layers of information. This layer-cake diagram was about the institutional relationships as much as it was about the overlay procedure.

The first point is that this diagram is not entirely obvious; there are alternatives. At the very conference where Roger Tomlinson first published a paper about CGIS, the dominant approach to land information was an integrated form of evaluation practiced by some Australians (Christian and Stewart 1968; Mabbutt 1968), that developed into a major effort of the Food and Agriculture Organization of the United Nations (FAO 1976). According to the approach, the various elements of the landscape were to be handled together in a form of gestalt, not through separate maps and separate layers. One of the greatest proponents of this technique in the United States was Jack Dangermond (1979). ESRI championed the Integrated Terrain Unit Mapping (ITUM) at the very time he was developing software packages based on a different model. To some extent, these models did not seem all that different, but they required totally incompatible infrastructure.

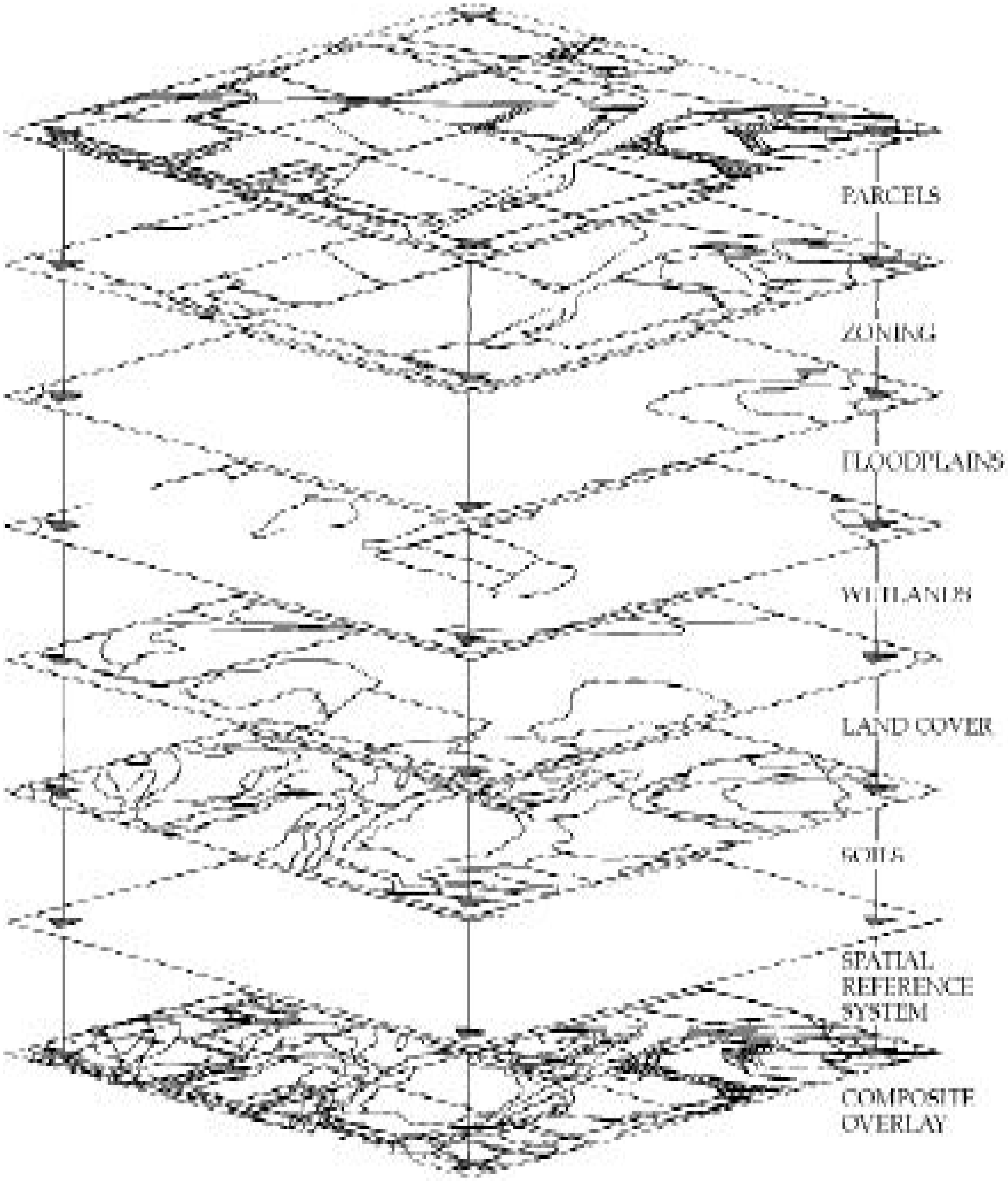
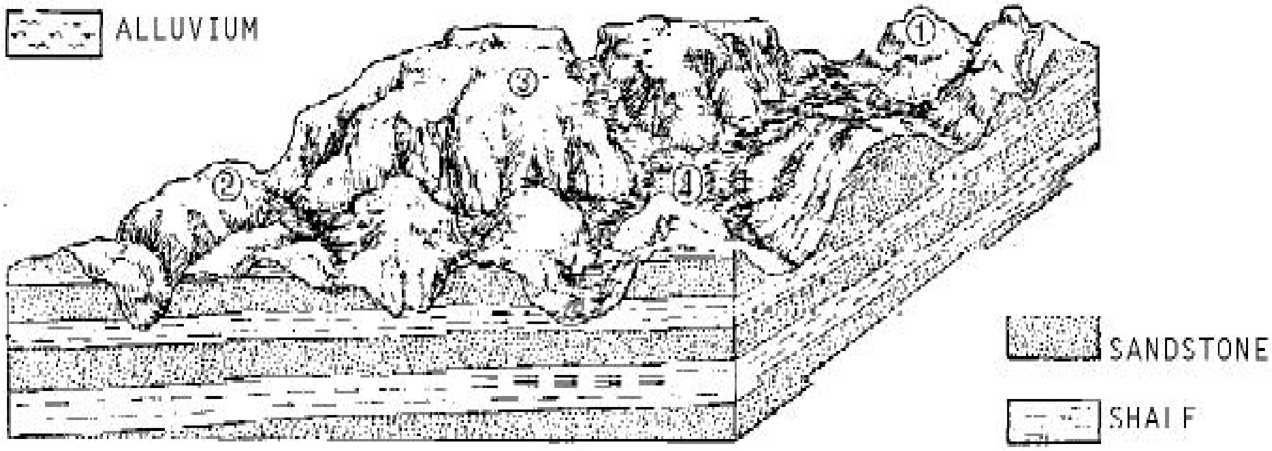


Figure 1: Concept of a Multipurpose Land Information System (Chrisman, Niemann and Sullivan, 1984)

The integrated terrain mapping technique as practiced in Australia involved sending an interdisciplinary team into the field together. They would not produce distinct layers, but one single final interpretation. Figure 2 shows the diagram explaining one of these "land systems" defined on the basis of geology, vegetation, and soils as they interact.

Lee's Pinch Land System (1386 Sq. Miles)

Geology.—Triassic sandstone and minor shale.
Rainfall.—22-30 in.
Locality.—Southern mountains.
Elevation.—500-3300 ft. Local Relief.—Up to 2500 ft.
Wooded Area.—100%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	30	Rugged hills with rounded summits; irregularly benched slopes often littered with boulders and with very frequent sandstone outcrops including low cliffs up to 30 ft. high; fairly narrow flat-floored valleys 400–1000 ft deep	Mainly shallow coarse-textured skeletal soils and bare rock; in moist cool sites humic surface-soils; infrequently on interbedded shales or arkosic sandstones shallow podzolic soils (Binnie, Pokolbin); in stable sites coarse-textured earths	Shrub woodland of ironbark and gum 40–80 ft high, ironbarks common, with *E. punctata* *E aggiomerata*, and *E. oblonga,* and with scattered or dense *Callitris endlicheri, Casuarina torulosa,* and *Persoonia spp.* below; shrubs usually abundant and mixed, *Leguminosae* common; ground cover poor, of grasses and herbs
2	30	Rugged hills margined by sandstone cliffs 50–500 ft high usually overlooking steep shaly slopes littered with boulders; cavernous weathering of the cliffs; narrow inaccessible valleys 500–2500 ft deep	Similar to unit 1; predominantly coarse-textured non-humic skeletal soils; probably more bare rock	As for unit 1, but with more herbs, shrubs, and non-eucalypt trees in ravines and at bases of cliffs
3	35	Stony, hilly plateaux with ridges and escarpments up to 200 ft high; very steep margins including cliffs up to 100 ft high; narrow gorges along the major rivers	Restricted obsevations; similar to units 1 and 2; deep yellow earth (Mulbring) in level, stable site on plateau	Shrub woodland of ironbark and gum 30 ft high, including *E. punctata, E. trachyphola,* and stringybarks; ground cover poor; many non-eucalypts in ravines and at bases of cliffs
4	<5	Sandy alluvium occupying valley floors in unit 1; liable to frequent flooding and deposition of sand in middle and upper reaches	Restricted observations; deep sandy stratified alluvial regosols (Rouchel); sedimentation in valley bottoms frequent and calamitous owing to low soil stability on sandstone hills	Shrub woodland or ironbark and gum with an admixture of non-eucalypt trees, sometimes cleared and under pioneer grasses

Figure 2: Lee's Pinch Land System from (Story et al. 1963)

Playing the origins game is hardly very fruitful in this case. Both overlay and integrated terrain units (ITU) have deep historical roots. Both contributed to the emergence of the current digital technology. Yet, it is clear that the integrated terrain unit mapping technique did not become dominant. There are complex reasons why layer-based logic and polygon overlay procedures took the lead.

It would be hard to argue that polygon overlay procedures are more "accurate". Since the earliest days of CGIS, it became apparent that overlay produces a flood of slivers [small objects induced by slight differences between two boundaries] (Goodchild 1978; Chrisman 1987a). The ITU requires all such disparities to be resolved in the compilation phase, a phase which engages experts and human interpretation. Here is where the division of labor comes in. While ITU kept the compilation phase under disciplinary control, the polygon overlay software displaced this effort to the user. This user was meant to resolve the disagreements between the various source layers as a part of their analysis. Of course, the user typically has little knowledge that such slivers are even there, and does not understand the procedures that would have to be applied to resolve each kind of sliver appropriately. Only in this year has a commercial package actually implemented a version of the multiple tolerance overlay algorithms discussed in the research literature for a number of years (Dougenik 1980; Pullar 1991; 1993; Harvey 1994).

The strongest reason for the overlay approach is that it matched administrative hierarchy, with its implicit divisions of labor and responsibility, and the divisions of knowledge between disciplines and communities of practice. The Dane County layer cake (Figure 1) represents the organizations currently making the maps, and accepted their several responsibility. The overlay procedure is presented as a final step simply to produce the analytical product. This contrasts with ITU were the expert compilation will alter all sources to bring them into coherence with each other. Agencies are much more likely to associate with a federation in which they retain autonomy and control over the parts they consider to be theirs. The concept of "custodians" of data layers came from this administrative logic, not any particular technical merit (Chrisman 1987b). There are lots of strong reasons to support ITU, but they are likely to lose to the impressive solidity of the administrative reasoning behind custodians managing their individual layers. The division of labor and the division of knowledge is exactly the center of the design process.

CONCLUSION

This paper set out to demonstrate that inside the most technical issues, there are social factors that often determine the nature of the GIS and the GIS products. It demonstrated that the use of least-squares for coordinate registration places the task of removing blunders directly in the "user's" lap. It demonstrated that a layer-based design has strong support from the administrative divisions of labor and knowledge. Each of these factors may not be particularly surprising, but they provide the basis to argue that the divisions between GIS and society are perhaps not drawn in the right places, and might be impossible to draw at all.

It provides some solid examples of how this amorphous social category of "user" is constrained and configured by the choices of software designers. Drawing the lines between what is the "technical" part and what is the responsibility of the less-sophisticated user is a frontier of substantial interest for future research. In study of another kind of software, Rachel and Woolgar (1995) noted that the key element in locating what was considered "technical" was who got to make their decisions first. In their business software organization, the programmers decided things then told the documentation team that the decisions were "technical", meaning mostly that they were already made. In the GIS situation, the roles may be somewhat more subtle, but the effect of time and priority of decision-making still will be important.

ACKNOWLEDGEMENTS

Supported by a grant from National Science Foundation Grant SBR 98-10075.

REFERENCES

Antenucci, J. C., Brown, K., Croswell, P. L., Kevany, M. J. and Archer, H. 1991: *Geographic Information Systems: A Guide to the Technology*. New York: Van Nostrand Reinhold.

Barnes, B. 1974: *Scientific Knowledge and Sociological Theory*. London: Routledge & Kegan Paul.

Bijker, W. E., Hughes, T. P. and Finch, T. J., eds. 1987: *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*. Cambridge MA: MIT Press.

Bijker, W. E. and Law, J., eds. 1992: *Shaping Technology/Building Society*. Cambridge MA: MIT Press.

Bloor, D. 1976: *Knowledge and Social Imagery*. London: Routledge & Kegan Paul.

Burrough, P. A. 1986: *Principles of Geographical Information Systems for Land Resource Assessment*. Oxford: Clarendon Press.

Chrisman, N. R. 1982: Methods of spatial analysis based on error in categorical maps. unpublished Ph.D. thesis, University of Bristol.

Chrisman, N. R. 1987a: Accuracy of map overlays: a reassessment. *Landscape and Urban Planning* **14**: 427-439.

Chrisman, N. R. 1987b: Design of information systems based on social and cultural goals. *Photogrammetric Engineering and Remote Sensing* **53**: 1367-1370.

Chrisman, N. R. 1993: Beyond spatio-temporal data models: A model of GIS as a technology embedded in historical context. *Proceedings Auto-Carto 11* 23-32.

Christian, C. S. and Stewart, G. A. 1968: Methodology of integrated surveys. *Aerial Surveys and Integrated Studies* 233-280.

Collins, H. M. 1981: Understanding science. *Fundamentals of Science* **2**: 367-380.

Cowen, D. J. 1988: GIS versus CAD versus DBMS: what are the differences? *Photogrammetric Engineering and Remote Sensing* **54**: 1551-1555.

Croswell, P. 1991: Obstacles to GIS implementation and guidelines to increase the opportunities for success. *Journal of the Urban and Regional Information Systems Association* **3**(1): 43-56.

Curry, M. R. 1991: On the possibility of ethics in geography: writing citing and the construction of intellectual property. *Progress in Human Geography* **15**: 125-147.

Dangermond, J. 1979: A case study of the Zulia Regional Planning Study, describing work completed. In *Harvard Library of Computer Graphics*, 3 , ed. P. J. Moore, p. 35-62. Cambridge MA: Harvard Laboratory for Computer Graphics.

Dangermond, J. and Freedman, C. 1984: Findings Regarding a Conceptual Model of a Municipal Data Base and Implications for Software Design. *Proceedings of the International Symposium on Spatial Data Handling* **2**: 479-496.

Dobson, J. 1983: Automated geography. *Professional Geographer* **35**: 135-143.

Dobson, J. 1993: The geographic revolution: A retrospective on the age of automated geography. *Professional Geographer* **45**: 431-439.

Dougenik, J. A. 1980: WHIRLPOOL: a geometric processor for polygon coverage data. *Proceedings, AUTO-CARTO IV* 304-311.

ESRI 1991: *Map Projections and Coordinate Management: Concepts and Procedures*. Redlands CA: Environmental Systems Research Institute.

FAO 1976: *A Framework for Land Evaluation*. Rome: Food and Agriculture Organization.

Feenberg, A. 1995: Subversive Rationalization: Technology, Power, and Democracy. In *Technology and the Politics of Knowledge*, eds. A. Feenberg and A. Hannay, p. 3-22. Bloomington: Indiana University Press.

Goodchild, M. F. 1978: Statistical aspects of the polygon overlay problem. In *Harvard Papers on Geographic Information Systems*, 6 , ed. G. Dutton. Reading MA: Addison Wesley.

Goodchild, M. F. 1987: A spatial analytical perspective on geographical information systems. *International Journal of Geographical Information Systems* **1**(4): 327-334.

Goodchild, M. F. 1992: Geographical information science. *International Journal of Geographical Information Systems* **6**(1): 31-45.

Goss, J. 1995: Marketing the new marketing: the strategic discourse of geodemographic information systems. In *Ground Truth: Social Implications of Geographic Information Systems*, ed. J. Pickles, p. 130-170. New York: Guilford.

Hampel, F. R., Ronchetti, E. M., Rousseeuw, P. J. and Stahel, W. A. 1986: *Robust Statistics: the approach based on influence functions*. New York: John Wiley.

Harvey, F. 1994: Defining unmovable nodes/segments as a part of vector overlay: the alignment overlay. *Spatial Data Handling 94* **1**: 159-176.

Kavouras, M. 1982: On the detection of outliers and the determination of reliability in geodetic networks. *Technical Report 87.* Department of Surveying Engineering, University of New Brunswick.

Kubik, K., Lyons, K. and Merchant, D. 1988: Photogrammetric work without blunders. *Photogrammetric Engineering and Remote Sensing* **54**: 167-169.

Kubik, K., Merchant, D. and Schenk, T. 1987: Robust estimation in photogrammetry.

Photogrammetric Engineering and Remote Sensing **53**: 167-169.

Lake, R. W. 1993: Planning and applied geography: postivisim, ethics, and geographic information systems. *Progress in Human Geography* **17**: 404-413.

Latour, B. 1987: *Science in Action*. Cambridge MA: Harvard University Press.

Latour, B. 1988: *The Pasteurization of France*. Cambridge MA: Harvard University Press.

Latour, B. 1993: *We Never Were Modern*. Cambridge MA: Harvard University Press.

Latour, B. and Woolgar, S. 1986: *Laboratory Life: The Construction of Scientific Facts*. Princeton NJ: Princeton University Press, 2nd edition.

Mabbutt, J. A. 1968: Review of concepts of land classification. In *Land Evaluation*, ed. G. A. Stewart, p. 11-28. Melbourne: Macmillan.

Mackay, H., Carne, C., Beynon-Davies, P. and Tudhope, D. 2000: Reconfiguring the User: Using Rapid Application Development filing cabinet. *Social Studies of Science* **30**: 737 - 757.

Mikhail, E. M. and Ackermann, F. 1976: *Observations and least squares*. New York: IEP-Dunn-Donnely.

Morrison, J. L. 1994: Cartography and organization. *ACSM Bulletin* **148**: 38-45.

Onsrud, H. J. and Pinto, J. K. 1991: Diffusion of geographic information innovations. *International Journal of Geographical Information Systems* **5**: 447-467.

Openshaw, S. 1991: A view on the crisis in geography, or using GIS to put Humpty-Dumpty back together again. *Environment and Planning A* **23**: 621-628.

Pickles, J., ed. 1995a: *Ground Truth: Social Implications of Geographic Information Systems.* New York: Guilford.

Pickles, J. 1995b: Representations in an electronic age: geography, GIS and democracy. In *Ground Truth: Social Implications of Geographic Information Systems*, ed. J. Pickles, p. 1-30. New York: Guilford.

Planet One Corp. 1997:*Image Registration and Reference Point Tools*.

Pullar, D. V. 1991: Spatial overlay with inexact numerical data. *Proceedings, AUTO-CARTO 10* 313-329.

Pullar, D. V. 1993: Consequences of using a tolerance paradigm in spatial overlay. *Proceedings, AUTO-CARTO 11* 288-296.

Rachel, J. and Woolgar, S. 1995: The discursive structure of the socio-technical divide: the example of information systems development. *The Sociological Review* **43**: 251-273.

Roberts, S. M. and Schein, R. H. 1995: Earth shattering: Global imagery and GIS. In *Ground Truth: Social Implications of Geographic Information Systems*, ed. J. Pickles, p. 171-195. New York: Guilford.

Rousseeuw, P. J. 1984: Least median squares regression. *Journal of the American Statistical Association* **79**: 871-880.

Rousseeuw, P. J. and Leroy, A. M. 1987: *Robust Regression and Outlier Detection*. New York: John Wiley.

Sheppard, E. 1995: GIS and society: towards a research agenda. *Cartography and Geographic Information Systems* **22**: 5-16.

Shyue, S. W. 1989: High breakdown point robust estimation for outlier detection in photogrammetry. unpublished PhD dissertation, University of Washington.

Smith, N. 1992: History and philosophy of geography: real wars, theory wars. *Progress in Human Geography* **16**: 257-271.

Snow, C. P. 1959: *The Two Cultures and the Scientific Revolution*. Cambridge: Cambridge University Press.

Story, R., Galloway, R. W., van de Graaf, R. H. M. and Tweedie, A. D. 1963: General report on the lands of the Hunter Valley. *Australian Land Research series 8.* CSIRO.

Tomlin, C. D. 1983: Digital Cartographic Modeling Techniques in Environmental Planning. unpublished Ph.D., Yale University.

Tomlin, C. D. 1990: *Geographic Information Systems and Cartographic Modeling*. Englewood Cliffs NJ: Prentice Hall.

Tomlinson, R. F. 1974: The application of electronic computing methods to the storage, compilation and assessment of mapped data. unpublished Unpublished Ph.D., University of London.

Tomlinson, R. F. 1984: Geographic information systems - a new frontier. *Proceedings of the International Symposium on Spatial Data Handling* **2**: 1-14.

Tomlinson, R. F. 1989: Presidential Adress: Geographic information systems and geographers in the 1990s. *Canadian Geographer* **33**: 290-298.

Wolfe, P. R. 1983: *Elements of Photogrammetry*. New York: McGraw Hill, second edition edition.

Woolgar, S. 1987: Reconstructing man and machine: A note on sociological critiques of cognitivism. In *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, eds. W. E. Bijker, T. P. Hughes and T. J. Finch, p. 311-328. Cambridge MA: MIT Press.

Woolgar, S. 1991: Configuring the user: the case of usability trials. In *A Sociology of Monsters: Essays on Power, Technology and Domination*, ed. J. Law, p. 58-97. London: Routledge.