Integrated land evaluation: Story of a track not taken[1]

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Abstract

Many cite CGIS and Tomlinson as the origin of GIS, yet it is instructive to examine the community of practice into which this idea was presented in 1967. A group of practitioners in CSIRO Lands Directorate had evolved a scheme for integrated land evaluation. This paper considers the track not taken, and the delicate connection between technology and conceptual frameworks. This story has particular relevance to spatial data integration. The prior technology dealt with a deeper kind of integration than we manage with current approaches.

1 Preamble

The first round of GIS History was written by the winners, often as a tale of great feats of dare-doing (Foresman, 1998, for example). Recently much more nuanced accounts focus on the interaction of society, organizations, and GIS technology (Harvey and Chrisman, 2004; Chrisman, 2006a, 2006b). History requires careful reading of the contemporaneous documents, not what the actor comes to think later on. But that remains the history of the victors, in the sense that we focus on the developments leading to the current day. What happens to the tendencies that disappear? How do we remember the tracks not taken, the technological developments that do not lead to vibrant industries with gigantic conferences? This paper will consider this more speculative form of history.

But this is not merely a return to a parallel world that might have been. The lost approaches have much to offer in the realm of spatial data integration. It is crucial to look back to history to enrich the current strategies.

1.1 Before the beginning

The game of origins can get quite convoluted. After all, every event occurs in some circumstances, and thus there is literally nothing new under the sun. Rather than a simple branching tree, leading back to a unitary root, the history of technology may reach a level of "rhizomes" where lateral connections link lillies in a complex maze (Deleuze and Guatari, 1976; Harvey and Chrisman, 2004).

Roger Tomlinson (1998) claims to have built the "first GIS", a claim that many accept at face value (despite multiple origins such as Garrison and others, 1965). Certainly Tomlinson and his colleagues at the Canada Land Inventory in Ottawa did build a functioning system that included many innovations. I do not seek to minimize these advances. But Tomlinson's first published paper indicates the community into which this GIS development contributed. It brings us to this city, Canberra 46 years ago. Tomlinson brought his first paper to a conference (26-31 August 1968) hosted by CSIRO, which assembled a collection of professionals engaged in "terrain evaluation," an integrative practice of natural resource survey (Stewart, 1968). This group (Stewart, 1952; Mabutt and Stewart 1963; Mabutt 1968) understood what Tomlinson wanted to achieve, since that was the kind of work they already performed—with different technologies.

This article will consider the quite Australian paradigm of terrain evaluation as it was practiced by the CSIRO Lands Directorate for a few decades, and what that practice has to offer in a world of linked data, spatial information integration, cloud computing and volunteered geographic information.

2 Integrated terrain evaluation

In the review article that led off the collected proceedings of the conference in 1968, Mabutt (1968) divided land inventory into three general approaches: genetic, parametric and landscape. According to this classification, geological

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maps are the classic example of 'genetic' maps, being classified according to their origins. Any attributes are derived from the historical sequence. Beyond geology, and certain soils surveys, the genetic approach is not the primary technique for land evaluation and measurement. These sciences played a key role in early land surveys, but track of process is harder to trace for many other concerns. Most of our current GIS is filled with 'parametric' information – where the maps are structured to present a particular variable, with spatial units to depict various attribute values. This is a measurement framework termed categorical coverage, and in wide use. The lines on the map are determined by a particular level of the attribute. This parametric view of a map is so dominant that genetic maps are often presented in these terms.

By contrast, Mabutt's landscape approach considered many attributes at once. "The land complex as a whole is the object of study, even where a particular attribute may be of prime interest to a land classifier." (Mabutt, 1968, p. 16) In certain academic literature, this approach is presented as 'gestalt' (Hopkins, 1977), implying a connection to a branch of cognitive psychology from the previous century. Certainly the landscape approach is interested in the whole, not each item. Yet, the motivation is not based on psychology. Mabutt argues for a synthesis of various viewpoints on the landscape, thus the integration is very much the issue. It was accomplished by various forms of fieldwork and collaboration by a group of specialists representing the parametric disciplines. My anonymous sources (uncited to protect the informants) who worked in these teams tell of the force of personality playing perhaps more of a factor than it should in the purity of the method. This was a method profoundly connected to human elements, and professional training. In a modern era when we think of technical factors, we often undervalue the influence of these human factors.

The landscape approach, as developed by CSIRO in Australia, involved sending an interdisciplinary team into the field together. They would not produce distinct layers, but one single final interpretation. Figure 1 and Table 1 present one of these "land systems" defined on the basis of geology, vegetation, and soils (Story and others, 1963).

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%.

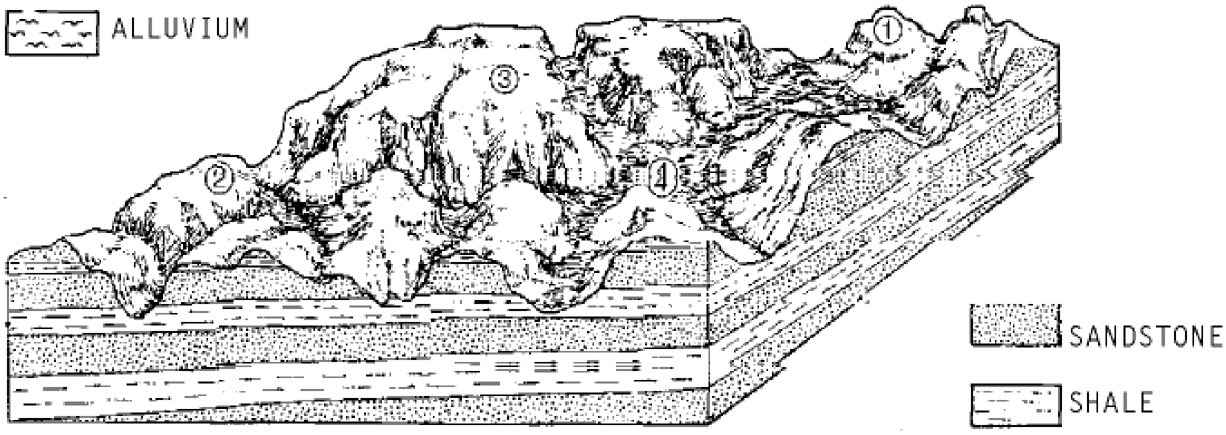

Figure 1: Lee's Pinch Land System *Source: (Story and others, 1963).*

Table 1: Explanation the four land units of Lee's Pinch Land System *(Note 1 foot = 0.3 m)*

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 4080 ft high, iron-barks 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 observations; 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

Source: *General report on the lands of the Hunter Valley.* (Story and others, 1963)

This "Lee's Pinch" land 'system' in the Hunter Valley had four 'units', each in relationship to each other and to the distribution of soils, vegetation and topography. The underlying geology had shale and sandstone in interleaved beds, nearly horizontal. This geology formed the basis for the soils, and thence the vegetation. This multi-faceted landscape system was portrayed on a single map, produced out of negotiation among the various specialists sent into the field, and then delineated on airphoto surveys (Christian, 1952; Mabutt and Stewart, 1963; Christian and Stewart, 1968). The various elements of the landscape were to be handled together as an integrated whole, not through separate maps and separate layers. Attributes would be assigned to the land system and the units, not to specific polygons.

The techniques developed at CSIRO led to a major effort of the Food and Agriculture Organization of the United Nations (FAO 1976), and a whole community of practice with developments in Netherlands and elsewhere. Practitioners in this form of land inventory were trained around the World, including a substantial number at ITC in the Netherlands (Zonneveld, 1972). The popularity of this approach did not diminish in the 1970s as GIS and remote sensing began to develop. For example, one researcher from USGS travelled to Australia to work with the landscape approach, and attempted to derive landscape (integrated) units from the parametric measurements of the early Landsat imagery (Robinove, 1979). The experiment ran into some difficulties matching what the satellite can detect to the land units scheme. By this time, the technique was termed "integrated terrain unit mapping" (ITUM) at least in North America. One of the greatest proponents of this technique in the United States was Jack Dangermond (1979). ESRI's President championed ITUM (presenting a case study in the Zulia region of Venezuela at the first Harvard Computer Graphics Week in 1979) at the very time his company was developing software packages based on a different (parametric) model. At that point, Aerial Information Systems (a company related to ESRI), specializing in air photo interpretation, had more employees than ESRI. This company continues to work with ITUM concepts, for example in a long-term contract with the State of New Jersey (http://www.aisgis.com/projects/NewJersey.html).

The ITUM method, as implemented by ESRI and its sister company in the Zulia case, Alaska and New Jersey at about the same time, involved making one coverage of polygons that could be reclassified without additional linework to portray a number of variables. So, it could present something that looked like each parametric map, but from a common database. The attraction of this approach was quite apparent at that time, for technical reasons. Polygon overlay procedures were inefficient and unable to deal with imprecisions in borders (Goodchild, 1978; Dougenik, 1980; Chrisman and others, 1992). The experience of CGIS had established the terminology of 'slivers' to refer to small thin areas created by the overlay of lines intended to be the same but that differed by small amounts. These slivers enlarged the database, creating a flood of spurious entities that could not be treated with the algorithms of the day.

3 Competitors and fellow-travellers

In 1968, when CSIRO ran its seminar, there were other efforts going in with more or less communication. In 1967 (essentially simultaneously), the Landscape Architecture Research Office (1967) at the Graduate School of Design, Harvard University hosted a series of speakers on the subject of 'environmental resource analysis' – much the same topic as landscape evaluation. Harvard did this under contract with the Washington-based Conservation Foundation, but with a clear goal to develop strategic directions in research (Chrisman, 2006, p. 42-43).

This event occurred before Tomlinson's announcement to the World, but it concentrated on the content and analytical procedures not the technology. The three experts invited were Ian McHarg (University of Pennsylvania), Philip Lewis (University of Wisconsin) and Angus Hills (Ontario).

Angus Hills was a mapping expert, quite connected to the CSIRO group from the Ontario forestry agency. Hills (1966) presented his version of terrain assessment, which had been adopted as the basis for the Canada Land Inventory (CLI), the project that had created the requirement for Tomlinson's computer system CGIS. In a variant of the Australian land systems approach, Hills set up CLI with the concept of mixtures in each polygon. Figure 2 presents the descriptive legend to decipher the CLI maps. Each polygon could be coded with one (or many) capability classes, calibrated in tenths. The example shows a polygon that is 60% class 1 and 40% class 3. In addition it is coded with additional subclasses that may occur in some part of the polygon.

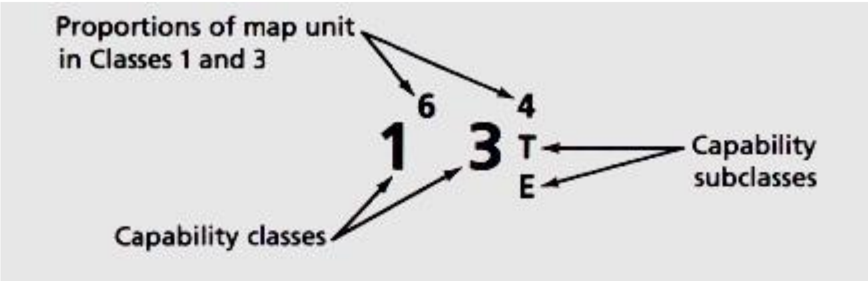

Figure 2: Legend from Canada Land Inventory *Source: CLI map sheet Ville Marie.*

Clearly any software written to handle CLI would have to be rather delicate to ensure that it could handle these mixture codes and the logical issues raised by a variable number of attributes attached to each polygon. These complications have not been included in the story about CGIS as the first GIS. While the group from Harvard listened to Hills, they were more attracted to the presentations of McHarg and Lewis.

Phil Lewis presented his analytical framework for environmental analysis, largely based on connectivity and 'corridors' (Lewis, 1963). Lewis's vision of the environment was interconnected and systematic, much as the views of Mabutt. Most of Lewis's work started with points connected by lines, though some masses of polygons were used to define the background and the connectivity. This was tricky stuff along the line of pattern recognition that would be hard to automate in the first instance. Lewis presented a way to integrate based on a human interpreter. While perhaps more scientifically valid, simpler technical fixes could be more attractive.

Ian McHarg presented the work that he was doing that later appeared in his massively popular book (McHarg, 1969). McHarg used simple map layers, mostly black and white, to exclude areas from the analysis. He stacked them up, looking for the least threatened areas, or the most suitable sites. A confirmed showman, McHarg made it all look easy and direct. No need to integrate the maps, on the light table they were all seen together. McHarg was presenting the basic overlay approach, where each map presented on parameter.

4 Overlay-based organization

The parametric mapping approach has venerable origins, and equally contested history (Manning, 1913, Steinitz and others, 1976; Cloud, 2005). 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 1990). This software capability became a kind of litmus test to separate mere mapping from GIS (Boyle and Tomlinson, 1981). Certainly, this centrality has diminished as the capabilities have had to expand to respond to many different marketplaces and user communities. Yet, the metaphor of map layers (Figure 3) 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.

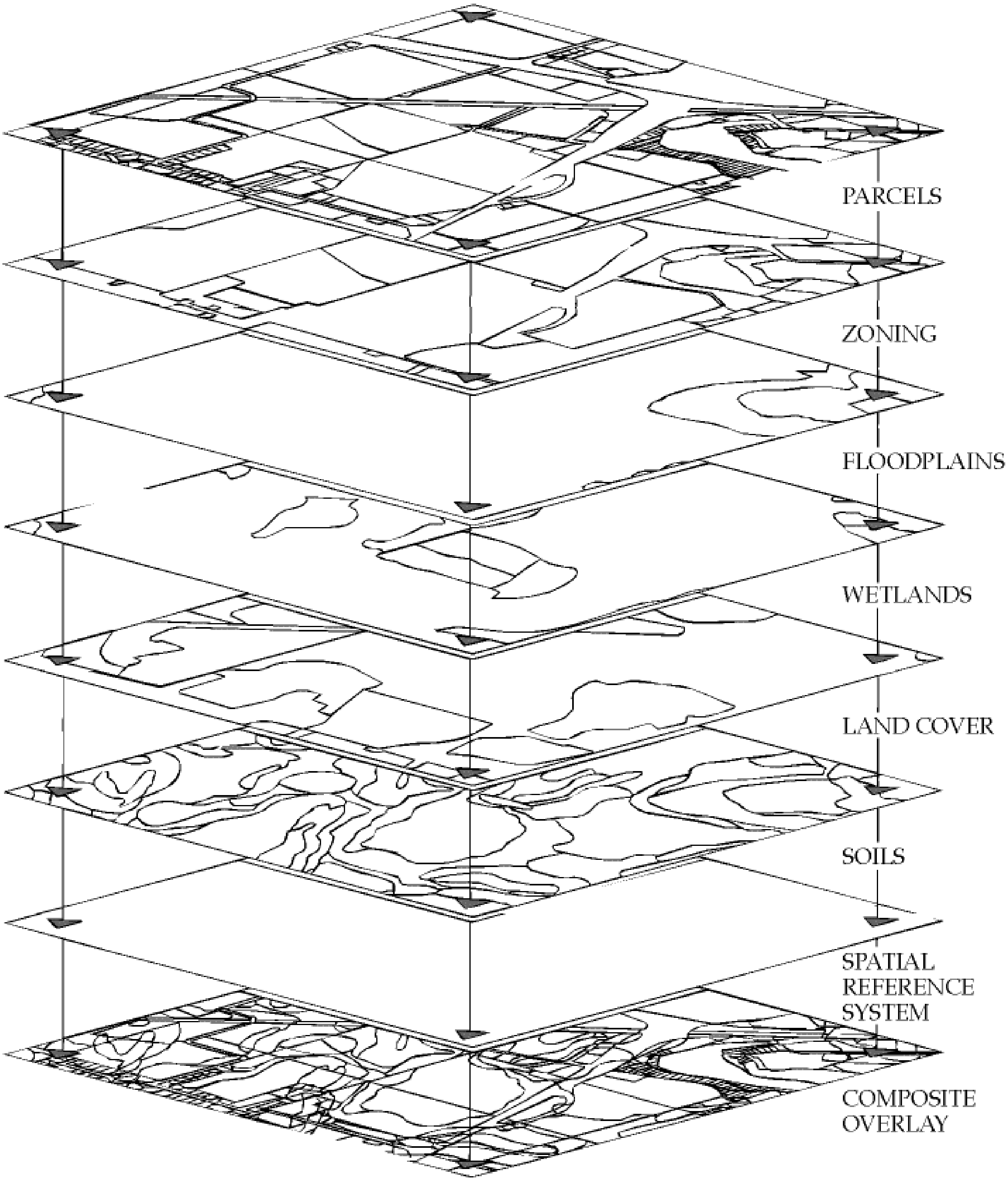

Figure 3: Concept for a Multi-Purpose Land Information System (1984)
Source: Sullivan, Chrisman and Niemann (1984)

The layer cake diagram presented in Figure 3 is one of many produced in approximately the same period (1984), and copied again and again ever since. This particular one was perhaps the first produced with actual data layers, in this case, Section 12 (one square mile) in Westport Wisconsin. It was originally produced in a press run of 20,000 on card stock to be handed out at the Wisconsin 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 highbrow 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.

At that time, a certain element in the community was proposing a multipurpose cadastre as the primary direction for implementation (National Research Council, 1980). That concept emphasized the property parcel as the base unit, much as the ITUM also relied on a single base polygon- but one that was derived to fit the circumstances. The NRC panel proposed to make all other variables simply an attribute of parcels. Thus, land use: attribute of parcel; floodplains:

attribute of parcel; wetlands: attribute of parcel; agricultural productivity: attribute of parcel and so on. They demonstrated this with a layer cake diagram showing the parcel layer as the base on which everything was built. The alternative layer cake presented in Figure 3 was part of an attempt to demonstrate that one particular layer did not need to be the base. The geodetic framework (blank!) was provided as the means to integrate. The diagram was constructed in the first years of the GPS constellation, then just a few satellites with a few hours of observation a day. The potential was already clear.. Viewed from 2014, the geodetic underpinning is even more important.

Thus, this diagram may look obvious now, but it was contentious when constructed. The land systems concept from CSIRO had much more to offer than simply selecting one layer like the parcels. Land ownership is important, but it does not define all map boundaries so that everything is an attribute of parcels. The land units, however, were refined and tuned to suit the situation by the domain experts. Originally developed for rapid appraisal in an overview of huge areas, it developed into a niche tool for expert photointerpreters to develop many internally consistent land inventories without needing the polygon overlay tool. It was actually technically superior to use ITUM technology up to 1979.

5 Discussion

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 is too common to ascribe the reasons to a simple technological march of progress where the past is simply a prologue to the age of enlightenment.

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. This procedure introduced a division of labor, and a division of knowledge. While ITU kept the compilation phase under disciplinary control, the polygon overlay software displaced this effort to the user and the uncontrolled vagaries of software packages. 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. Software packages took charge and resolved complex issues with simplistic heuristics. The multiple tolerance overlay has been discussed in the research literature for a number of years (Dougenik 1980; Pullar 1991; 1993; Harvey 1994), without breaking into the mainstream of user software.

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 3) represents the organizations currently making the maps, and accepted their several responsibility. The concept of ‘mandates’ and ‘custodians’ derived from this project (Chrisman, 1987b). The overlay procedure is presented as a final step simply to produce the analytical product. Data quality issues would not be apparent until you ask certain questions.

This contrasts with ITU were the expert compilation will alter all sources to bring them into coherence with each other in the preparation phase, upfront. 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. 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.

In a study of an early computer company building a new model, Woolgar (1991) saw a particular set of social relationships where the developers did not particularly design the computer, rather they attempted to configure the user. The layer-cake model takes the overlay algorithm as the base, and then configures the administrative and professional world around that capability. In much the same way, the integrated survey set the goal as a single map, and made all the activity fall around that choice.

6 Conclusion

This paper therefore concludes by evoking social factors that often determine the nature of the GIS and GIS products. In particular, a layer-based design has strong support from the administrative divisions of labor and knowledge. This may not be particularly surprising, but it continues the demonstration that the divisions between GIS and society are perhaps not drawn in the right places, and might be impossible to draw at all.

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.

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