# A CONSTRAINT BASED APPROACH TO HUMAN COMPUTER INTERACTION IN AUTOMATED CARTOGRAPHY

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**Abstract**
Automated cartography has tended to focus on the geometric at the expense of a holistic view which includes consideration of the over arching mechanisms by which a cartographic solution is reached. The use of computer technology has itself altered the methodology of design yet little effort has been spent on supporting the actual process of design - something that should be creative and exploratory. There is little that is endearing about machines that offer high functionality which empower the user to travel round in recursive circles in search of a solution (and a way out!). This paper looks at methods by which the user can feel more in control, can explore and navigate among alternate designs, while still moving towards some acceptable solution. A constraint based system is proposed: one that views the problem from a user centered perspective, asking the questions: What objectives is the user trying to satisfy?, What decisions do we control which affect these objectives? What items dictate constraints on our range of choices? What decision provides us with the most satisfactory outcome with respect to the criteria we have established? Ideally the design of such systems should implicitly support the user's opportunistic sense-making efforts.

## 1. Introduction

GIS continues to reach a larger and more diverse proportion of computer users. Users who have varying levels of computer literacy, geographical knowledge, experience and cartographic training. Developments in automated cartography now mean that the user of a GIS might typically be presented with a menu of generalization operators (such as displace, simplify, classify, amalgamate etc.). But this functionality and flexibility in the handling and manipulation of GIS data is both its attraction and its Achilles' heel because 1) the terms and effect of their application are unfamiliar, 2) the 'optimal' sequence or combination is unknown, and 3) the appropriateness of one operator over another is not apparent. Of cartography it is said 'You can't tell the truth without telling a few lies' (for example see Monmonier 1991). The question seems to be, 'how best to lie'. Without various guiding mechanisms, users often complain of getting lost in this information space - not knowing what they have just done, what needs to be done next, and why! This is because the complex associative structure that reflects the interdependence and potential substitution of various generalization operators (and the interdependence of the geographic phenomenon itself) cannot be fully visualized. This paper looks at techniques that might give the user a greater sense of control; techniques that constrain the user according to their own actions but enables them to navigate away from those constraints. What this paper tries to illustrate is that automated design requires a range of techniques to support both learning and experimentation in the search for a solution. It begins with a brief discussion of the driving forces underpinning map design.

## 2. Map Design - Creative Thinking, Scientific Investigation, Navigation

Many cartographers would agree that map design is both a creative process and an investigative one. But attempts to automate cartographic design have focused on copying the various manual components of the map production process and have thereby failed to look at how best to support, in a holistic sense, the complex decision making process of design. While automated cartographic (expert?) systems are beginning to provide an equivalent to the cartographer's toolbox, they are not supporting the essential ingredient to design - that of experimentation. The result is that GIS (and indeed most CAD package) are seen variously as being uninviting, deplorably complex to use, and that after climbing the steep learning curve, an end product that leaves much to be desired. It is a poor reflection on GIS that users tend to port the data away to graphics packages for the design phase (for example that some of the most aesthetically pleasing maps have been done using Corall draw). But before addressing some these issues, it is worth commenting on why design is such a complex task to automate.

Cartography is both creative and investigative in nature. Wallas (1926) identified four stages in creative thinking: preparation, incubation, illumination, and verification. In simple terms, the processes of incubation and illumination are viewed as mental processes (Osland 1992) leaving any cartographic system to support the processes of preparation and verification. In addition (and intuitively woven among the idea of it being a creative process), is the idea that it is also an investigative process. The idea being that the user is exploring alternate solutions, and selecting between them based on a set of often conflicting desires. For example to be abstract (the very essence of effective graphics), yet to convey complex information in a coherent, 'truthful' and efficient manner.

In an automated environment, this investigative process is cyclic, sometimes recursive, involving human and computer based activities, the sharing of results impacting on subsequent decisions. Watson (1990) proposed a model of scientific investigation which finds parallel in this view of the map design process. Namely that we start with some hazy thumbnail sketch of what we want, we then source the data (in terms of its geographical extent and intended theme), apply some set of generalization operators (for description of typical sets of operators see McMaster and Barnett 1993), view the result and repeat and refine subsequent application of generalization operators in a cycle until a satisfactory solution is found (Figure 1).

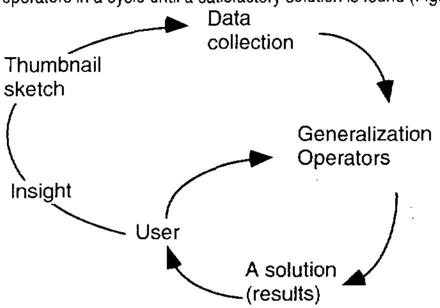


Figure 1: Map design as a process of scientific investigation (adopted from Watson 1990).

Figure 1 highlights two problems, however. First, what is a satisfactory solution? Since any solution is a compromise between multiple perspectives, the design process can be viewed as a search merely for a *workable* solution (rather than an optimum one)- an idea suggested by Simon (1969) as 'satisficing'. Secondly, how does the user get to one of these workable solutions? - or rather, how do we end the map design process? Experimentation is not simply about offering infinite permutations yet many users complain of being lost in a maze of colour options, functions, symbol libraries, and sub windows, moving from one data layer to another, trying to experiment with different mixes and changes. Some combinations of operators are synergistic and complimentary, others are not. Since the screen allows limited viewing there is a risk that some changes produce radical changes elsewhere on the map but few on the currently viewed section, and vice versa. Elm and Wood (1985) suggest that when users become lost among a set of open windows and boxes, it reflects a poor conception of the relationships within the system. Thus for the cartographically illiterate, learning and finding the constraints in the 'design envelope' can only be determined by exploring the boundaries of bad design. But in order to retreat back from those ghastly solutions, we need to be able to navigate through the solution space - back to previous designs. The idea being that for systems to support both creative thinking and scientific visualization, we need effective means of navigating between alternate designs. Navigation through an application is defined as 1) knowing where you have been, 2) where the user is currently, and, 3) as a result of where the user is, the choice of routes available at that point).Furthermore, that since intermediate results will affect consequent operations in the design of alternate solutions, it is imperative that the effect of an operation is conveyed to the user (both at the local level, and across the map as a whole). Fitter (1979) suggests that by enabling such navigation, the user feels in control of the system.

## 3. Supporting Structures

The challenge in the design of systems for automated cartography appears to require a user centered perspective (Medyckyj-Scott and Hearnshaw 1993); one that supports creative thinking (through comparison among alternate experimental designs), but allows the user to steer themselves towards satisficing solutions. With respect to map design, this can be achieved in a number of ways - through navigation of design choices, conveying of outcomes and improved interface design. Techniques for assessing the amount of design effort required, for conveying choice of operators, for navigating among designs, and an overarching constraint based approach are now discussed.

### *3.1 Initial Assessment of the Effort Required*

The first stage in the map design process is the selection of data. Potentially a user may select excessive amounts of data (of highly variable spatial complexity), and have in mind a scale that is simply too small. This then requires a great deal of effort in the design phase to reduce and simplify the content. What is required is a way of conveying the amount of effort required so that the user will see the need to reduce the selected set and/or choose a larger scale. Figure 2 is a suggested solution to this problem. It is an isoline map based on the density of features on the map and provides a range of information. The 'altitude' of the isolines(proportional to the density of map objects) is an indicator of how much effort is required to find a solution. The variation in topography indicates how widespread or localized dense regions are. This information is used to determine whether a 'local' operator should be applied (such as displacement) or whether certain features should be removed wholesale from the entire map.

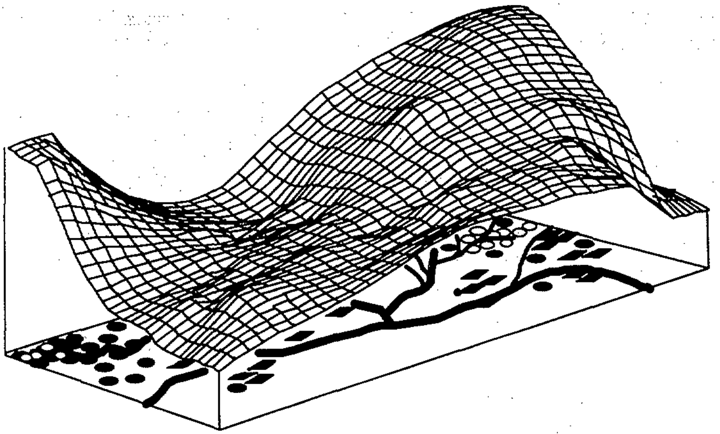

Figure 2: Isolines of feature density: greater the altitude, greater the effort required in the design phase.

### *3.2 Conveying Choice of Generalization Operators*

There are various graphical and textual cues that can be used to convey the choice of techniques available to resolve design problems. At its simplest, users can be shown a list of generalization operators, with a footprint or highlighted box over the one in current use (Figure 3a). But we know that at varying times, one generalization operator is more appropriate than another, and that the sequence of application can affect the final product (Mackaness 1994). Figure 3b illustrates a simple method for showing the sequence of operators applied to an object. Such a list could appear against objects selected in the map image in order to show its provenance in terms of operators applied. Figure 3c shows the grouping of operators according to effect (derived from McMaster and Barnett's list 1994). These types of structures support 'chunking' of information (Miller 1965), and help the user to choose appropriately by aiding the understanding of their effect.

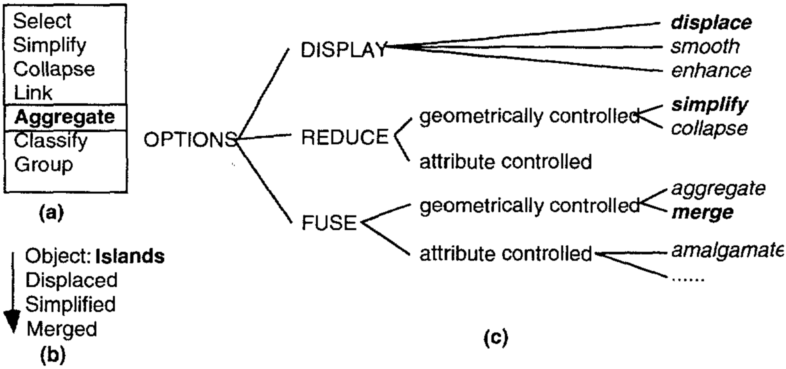


Figure 3:a)Selecting from a list, b) conveying sequence, and c) Structured choices..

By highlighting those operators that have been applied to a particular map object, it is possible to show what choices remain. Thus Figure 3c, for the object 'Islands', indicates that they have been displaced, simplified and merged.

Generalization operators can be applied in varying amounts; a classic example being that of displacement. Thus the *degree of application* of an operator is another factor influencing the outcome of a map. It is rare that only one operator is applied to an object, and operators are applied in varying amounts and combinations (Mackaness 1994). One technique is to use 'thermometers' to indicate the degree and mix of application. This can be done both at a general level (as in Figure 4), but also for individual ojects once they are selected (using the mouse). Figure 4 attempts to convey the idea that by applying different combinations of operators (in varying amounts) to the same data set, one can generate maps of different themes.

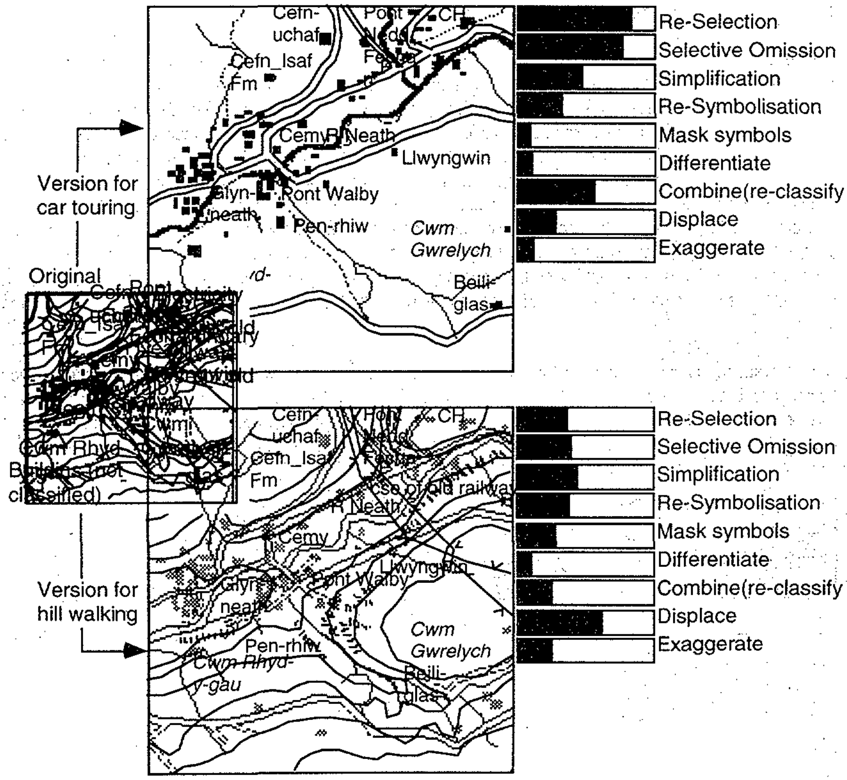

Figure 4: Conveying the degree of application (after Mackaness 1991).

### *3.3 Techniques to support navigation among alternate designs*

The selection and application of generalization is made based on the designer's expectations of the outcomes of their synthesis. These expectations are formed by induction from observations of previous designs and experience (Maher and Zhao 1987), and the constraints are created through unsatisfactory outcomes, driven by those expectations. In turn, these constraints govern future design expectations. It is therefore important to provide an experimental environment, one that is capable of undoing a succession of operations. In other words the making of mistakes is a natural and critical activity of the design process. If a user is not satisfied with a design choice or the effect of a generalization operation or simply wishes to experiment, the system should be capable of undoing a succession of operations. Since one of the goals of the interface is to minimize the burden on user memory, the progress through a map design session should be tracked and presented to the user. To support this functionality, users should have access to all actions which were performed along with information on the objects the operations were applied to. Lynch (1960) proposed that people form mental maps of the environment in which they live which is then used to navigate through it, and that since an equivalent process can be observed with respect to the interpretation of documents (Simpson 1990), it is likely that it is equally true of maps and the map design process. Indeed many of the navigation techniques used to support interpretation in hypermedia documents can be applied in the map design process.

Just as path finding in a wood involves leaving markers at critical junctions, so too in design; we can leave 'return-to' markers either at points of major change, or at points when the user moved to a new location on the map. A key event is defined in three ways: 1) when the user moves to a new part of the map to resolve a spatial conflict, 2) when a generalization operator had been applied at a global level, 3) when an accumulation of operations had occurred at a local level. The user would set a number of operations before a 'save scene' prompt came to the screen. Whenever any of these instances occurred, the scene would be saved. Thus as the 'play' progressed, a series of scenes would be paved out in sequential order. The user at any time could then view the play and return to a given scene (Figure 5). The user can overview the design process and return to a previous map state by clicking the pertinent scene. The more convoluted manner by which the user alters the design, the more scenes would be stored. The scenes would need to have sufficient detail that the user could associate a scene with a particular state, and therefore it is likely that the scenes would be 'details' of the map, as a way of triggering the flashback.

Such a system requires that each scene store sufficient information so that when the user selects a scene, each object in that scene is able to return to its former state. This could be achieved in one of two ways: either the objects could keep a record of their state for each scene, thus all they would need as information was the scene number, or the scene could keep track of what the attributes of the object were at that time, so that the object would ask the scene how it should display itself.

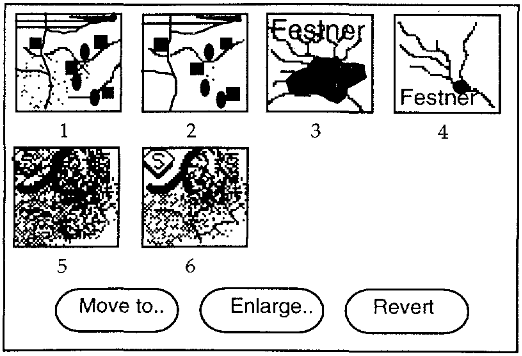


Figure 5: Just six scenes from the 'play' of generalization.

By providing the user with a 'map' of progress, the system can provide 1) the flexibility required to explore, 2) an ability to navigate through the decision space, 3) guidance on task sequence and design task parameters. This provides a model for organizing design tasks that support logical steps toward a solution as well as reversal if required.

### *3.4 Constraint based Approach to Design*

With respect to an overarching mechanism, the idea of a constraint based approach is suggested - the idea here, is that the user's actions impose constraints on their consequent choices. Thus the user's actions can either expand the choice of operations available or constrain them. By advising the user with a set of non-binding constraints, coupled with the visualization/ navigation techniques previously mentioned, it is possible for the system to funnel the user towards a solution.

But what of an overarching structure that helps the user guide themselves towards a solution? The process of design is complicated by the fact that 1) it occurs iteratively, at many different conceptual and physical levels, 2) it is not a logical or deterministic activity (Cathaine 1982), and 3) the user may not have complete knowledge of how the final map will look. Indeed because design problems are complex, and inevitably under-specified, there are likely to be 'a range of acceptable solutions rather than a single optimum solution' (Whitefield 1990 14). The fact that a number of solutions may be appropriate coupled with 'unconstrained' choice of operators makes the whole process overwhelming. What is needed in the human/machine interaction is a method of informing the user of changing constraints based on the choices made during the design phase. That constraints variously arise as a result of scale, varying complexity and density of data and purpose. For example spatial accuracy is constrained by resolution, and content is constrained by complexity of data.

Automated design can be described as a search problem characterized by an initial state which evolves into a goal state via a suitable sequence of operators (Newell and Simon 1972). This view mirrors Caplan's definition of design as being 'the process of making things right' (Caplan 1982 9) - the interplay of two entities - 'the process' and 'the getting it right' requiring interaction, exploration and experimentation.

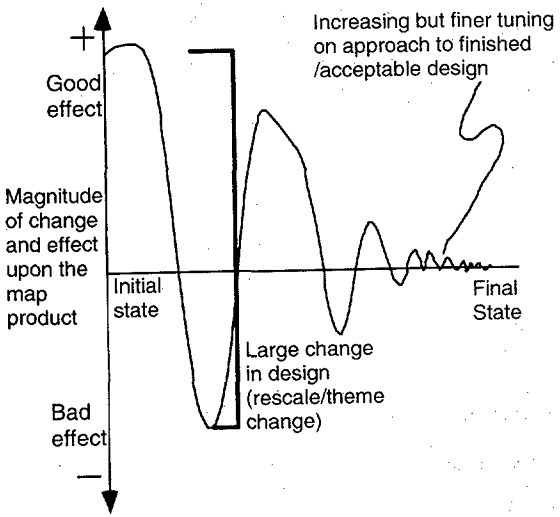


Figure 6: Honing in on the final design.

As an *initial step in an automated environment*, heuristics (rules of thumb) can be used to constrain the search space in map design, and during the compilation phase the choice of generalization operators can also constrain subsequent choices. The idea that design constraints are needed in the design process is not a new one (Gross et al. 1978); indeed design constraints play a crucial role in any design process principally because 'constraint knowledge is the main method of detecting design failures' (Horner and Brown 1990, 165). In map design we can say that from an initial, almost speculative state, the cartographer moves through a series of stages that are principally distinguished by the degree and extent of application of a particular technique. Therefore operations that produce wholesale effects tend to be applied early in design (for example scaling or selection of whole classes of *objects for inclusion on a map), while fine tuning occurs towards the end (for example selectively* omitting or *marginally displacing objects). Figure 6 graphically conveys the conceptual nature of this 'honing'* effect. The initial state starts with a large (potentially infinite) number of options and operations with global or large scale effects. With progression along a design process line, options are constrained and operators become progressively more subtle, but nevertheless essential to the final outcome.

Two points are worthy of mention: First, large effect operators tend to be used early in the map creation process (such as selection, classification) while small effect operators (such as displacement and individual object omission) become the potential choices in the closing stages. In any given situation, any number of operators may resolve a design problem, however an operator which has a global effect on the map (involving wholesale map changes) and wide implications for subsequent design alterations may not be desirable later in the design process. Small effect operators tend to group together as potential choices; i.e. the choices for resolving a single symphysis (some objects sharing very similar space) would **not** be: displace or rescale map. Whilst both would resolve the problem, rescaling would have a major wholesale effect over the entire map.

The second point is that as the user approaches an acceptable solution, one can envisage' 'micro' operations being applied. Thus a class of features may be resymbolized or reclassified, but their new 'values' might only be marginally different or subtle in color tone, in order to achieve a more aesthetic solution. Choices become more limiting both in degree and extent, as the user approaches a solution; thus users are in essence constrained by their previous actions. If, for some reason, at a later stage, the user wishes to re-scale the whole map, this effectively moves the design back along the design process line towards the initial state, and once again to a broader choice of options (Figure 7).

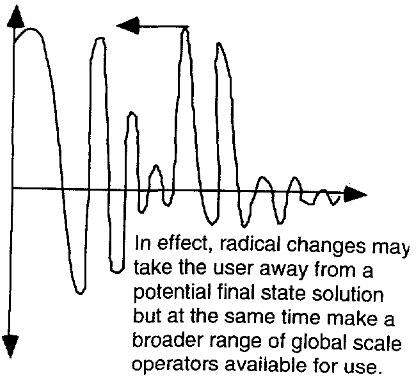


Figure 7: Moving 'back' along the design line, where radical / global operators are again appropriate.

By advising the user based on a set of non-binding constraints, it is possible for the system to funnel the user towards a solution based on their own actions, rather than those of the system.

## 4. Conclusion

Comprehension of the data and the impact of applying generalization operators can only evolve through active engagement and experimentation. It is only by this means that users will come to learn the intrinsic rules that govern the map design process. Working on the basis that design is a mix of both creative thinking and scientific investigation, this paper has tried to address the question: what human activities should the system provide in order to encourage and support the map design process. These are:

- Methods for conveying the amount of work required in order to reach a solution (given the initial set of data and a target scale);
- Methods for presenting choice, but only those tools appropriate to a given stage of the design;
- Methods for indicating the range of generalization operators applied to an object and their degree of application;
- Methods to navigate back and forth among candidate designs (and to build on those designs)
- Methods for showing the logical sequence between generalization operators (in terms of their effect at the local and global level);

The design of any cartographic (expert) system should implicitly support the user's opportunistic sense-making efforts, and their investigative and creative senses.

Study of traditional cartography has revealed methods by which maps are generalized but the overall/collective approach is not applicable in the automated environment and alternative paradigms need to be considered in the context of automated map design. Decisions are being made both in front of the screen and behind it (Turk 1992). It is therefore no longer sufficient to demand that these system be user friendly - they must be user intimate - to convey the consequences of our actions as well as be able to anticipate both our foibles and the 'errs' that define us as human!

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