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The Application of Agents in Automated Map Generalisation

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Abstract

This paper reports on current research utilising agent based methodologies in order to provide solutions in autonomous map generalisation. The research is in pursuit of systems able to support the derivation of multi scaled products from a single detailed database with minimal human intervention in the map compilation process. Such research has important implications for automated conflation (multiple database integration),and is in response to the huge growth in provision of digital map data over the Internet, coupled with a broadening community of map users who wish to visualise information in a variety of ways but who have little cartographic skill.

Introduction

This research is driven by a desire to be able to automatically derive multi-scaled multi-themed maps from a single detailed database. The research is of direct relevance to National Mapping Agencies (in the management and value added reselling of national series) and in access and retrieval of information over the Internet (Buttenfield 1997; Davies 1997). The derivation of smaller scaled maps from a detailed source is figuratively shown in Figure 1. The idea being that Figure 1b and 1c could be automatically derived from Figure 1a. In theory this can be achieved using a mix of generalisation techniques (such as selection, merging, displacing, symbolising, simplification).

Getting the right 'mix' of methods has revealed map design to be a complex spatial decision making process that operates at a number of design levels - coupling broad scale objectives such as the overall homogeneity of the map with fine detail refinement such as the small displacement of two objects to improve their legibility. The challenges in providing autonomous generalisation systems are many. We require methods to analyse map

Figure 1: 1:25 000 1: 100 000 1: 250 000 (Copyright of the IGN).

content and to measure the patterns inherent among a set of geographic objects (analysis). We require generalisation methods that enable us to manipulate objects in the map space in order to create candidate solutions (synthesis), and we require methods to evaluate the solutions in order to refine and measure the success of the design (evaluation). Most critically we require a framework that enables us to model design at various levels of granularity, from the map as a whole (the macro level) through to the fine detail (the micro level). It is the absence of this framework that has stymied progress in autonomous systems and why existing systems typically require intensive interaction with the user. This paper discusses the use of multi-agent systems for providing such a framework. In simple terms an agent is a self contained program capable of controlling its own decision making and acting, based on its perception of its environment and itself, in pursuit of one or more objectives. With respect to cartography, the map is the environment, and the objective is to resolve design problems at a number of scales and resolutions.

The paper discusses various qualities of agents that provide a better way of modelling the complex decision making process of design and goes on to consider the information requirements in order for agents to act autonomously. The paper begins by exploring the current context of research in map generalisation before providing an overview of agents and multi-agent systems. Agents are not considered to be a utopia that obviates the need to tackle many of the problems identified by recent research in map generalisation. However they do offer a more transparent means by which we can model the complexities of map generalisation, in particular the often competing goals of map design and the complexities of grouping phenomena in a meaningful way.

Why Agents?

Generalisation in its epistemological sense, is a process that attempts to establish the universality of a statement (Hawkins 1983). In other words, generalisation is all about answering the question - 'how may the phenomena being studied be ordered or grouped?' (Harvey 1967, 82). The objectives of 'Map generalisation' precisely mirror this question but with the added challenge of visualising these generalised phenomena in an effective and efficient manner. Whilst we can point to many interesting developments in automated cartography, it is the failure of vendors and researchers to acknowledge the importance of <u>strategy</u> in design that has led to the development of map production systems that are complex and tedious to use, and require user intensive interaction and guidance during the design process. In short these systems have attempted to automate the <u>movement</u> of the cartographic hand, they have done nothing to model the thinking <u>behind</u> the movement of that hand. This research on multi-agent systems in cartography is driven by a desire to address such shortcomings whilst offering a framework in which to address a number of critical issues in map generalisation research (Table 1).

Table 1: ‘Needs’ in generalisation research.

Specifically contemporary research in map generalisation has highlighted the need:

- to understand the underlying philosophy and objectives of map generalisation
- to view the map as a system of relationships rather than points, lines and areas
- to model the interdependence that exist naturally between geographic objects
- to model the sequence and degree of application of generalisation methods
- to define goal states and model the competing nature of goal states
- to understand the links between goal states and the application of a toolbox of generalisation methods
- to understand the context (spatial and thematic) in which generalisation takes

Where did the idea of agents come from?

Ant colonies are an example of a large society with apparently co-ordinated and co-operative behaviour that results in rather complex space time events, namely the building and maintenance of an ant hill, gathering of food, defence, the survival of the community and its colonisation of new sites. That such simple folk should be capable of such sophisticated co-operative events is intriguing. It is this concept of a society of co-operation among simple folk within a shared environment that has led to the study of ‘agents’ - a collection of simple operations, operating in a co-ordinated manner to achieve a cohesive collective goal. Their use is driven by a motivation to improve computer systems and to make them easier to design and implement, more robust, and less error prone. There is no precise agreement on what constitutes an agent, but one definition proposed by Luck is that an agent is ‘a self contained program capable of controlling its own decision making and acting, based on its perception of its environment, in pursuit of one or more objectives.’ (Luck 1997, 309). Where more than one agent exists, we can define what are called multi-agent systems (MAS): Multi-agent systems are ones in which several computational entities, called agents, interact with one another. The concept of an agent implies a problem solving entity that both perceives and acts upon the environment in which it is situated, applying its individual knowledge, skills, and other resources to accomplish high-level goals. Agents thus integrate many of the algorithms and processes that have been independently studied by researchers in artificial intelligence and more widely in computer science. Much of the conceptual power of this exciting new paradigm arises from the flexibility and sophistication of the interactions and organisations in which agents participate. Because an agent is relatively self-contained, it has a considerable degree of freedom in how it interacts with other computational and human agents. The study of multi-agent systems concentrates on the opportunities and pitfalls afforded by this freedom. Agents can communicate, co-operate, co-ordinate, and negotiate with one another, to advance both their individual goals and the good (or otherwise) of the overall system in which they are situated. Agent societies can be structured and mechanisms instituted to encourage particular kinds of interactions among the agents. Populations of agents acting on their individual perspectives can converge to systemic properties. Teams of agents, each providing a particular suite of capabilities needed by one another, can be constructed and deployed to collectively solve problems that are beyond their individual abilities. This teaming can even be done on the fly, and can include humans as well as heterogeneous computational agents (Demazeau 98).

With respect to cartography, this is translated into the goal of wishing to resolve design problems at both the local and community (or global) level. The various compromises between the local and global elements of a society of agents means that a sub-optimal but acceptable solution can often be reached. Using a multi-agent approach enables us to model: the roles of autonomy, communication, operation, co-ordination, and negotiation.

A Brief Comment On the Complexities of Map Design

Before discussing the application of agents to the cartographic domain, it is worth reminding ourselves of the essential qualities of design. Map design is essentially a decision making process and broadly includes three stages: intelligence gathering (analysis), design of solutions (synthesis), and choice and review of solution (evaluation). The human achieves this collectively/cohesively through an encompassing strategy that involves working at multiple scales/resolutions (localized design and broad overview design), manipulating complex object types that have multiple, scale dependent geometries, in order to reach an acceptable design solution. The objective of map generalization is to both conserve and convey the essence of the relationships among a set of geographic phenomena. This process takes place in a dynamic environment - at any instant there may be a large number of possible solutions, the chosen solution influencing consequent choices and actions. At any one stage during the design, there exists a large number of candidate solutions which can be created by applying generalization operators to a mix of objects, in vary degree and in varying sequence. Each solution is constrained by a desire to achieve certain goals. During generalisation we wish to achieve a set of goals:

- maintain clarity and legibility (defined as a minimum separation between objects, a minimum size, a minimum difference in symbology utilizing the 6 variables defined by Bertin(1983))
- to retain the quality of the objects (their defining characteristics in terms of location, shape/distribution/ homogeneity, and defining qualities such as location, connectivity, orthogonality, association)
- to retain a level of information content commensurate with scale

Why apply agents to cartography?

When viewed in this manner, it is clear that map design lends itself to the application of agent methodologies. Indeed this research is premised on the idea that there is something in the process of map design that is analogous to our ant community. Similar to the ants, there appears to be a one to one mapping between the description of agents and the objectives of automated cartography. The agent paradigm in artificial intelligence is based upon the notion of reactive, autonomous, internally motivated entities embedded in changing, uncertain worlds which they perceive and in which they act. With respect to automated cartography, that world is the evolving map space to which objects are added, merged, symbolised and taken away. We have

1) a (hierarchical) set of competing goals or tasks (defined above),

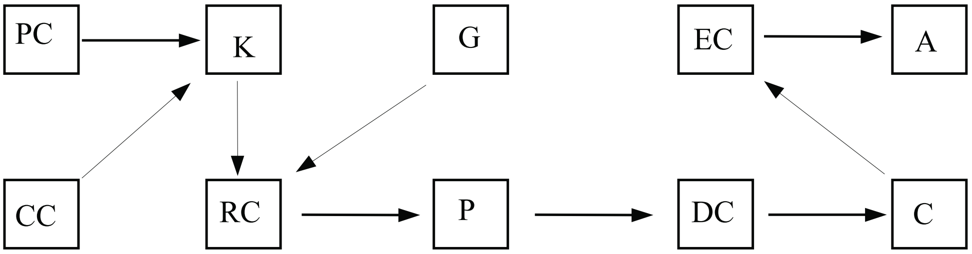
2) we understand the importance of sequence and believe there are heuristics (rules of thumb) governing sequence (Ruas and Mackaness 1997)

3) the need for compromise across scales - resolving localised / autonomous solutions whilst at the same time considering the map as a whole.

For this we can define a set of agents whereby each agent is capable of performing a specific task pertinent to map design. The operations of each agent are constrained by the protocols of what is ‘acceptable design’. Acceptable design born from the idea of a ‘design policy’ at a number of conceptual levels, constraining/ modifying the activities of the individual - defining what is acceptable. The agents work together, collectively, sharing in their successes and failures, the goal is a distributed set of activities that results in the construction of a map, having specified scale and theme. The essential components to support this process are 1) a capacity to perceive and communicate between agents, 2) a knowledge based on which to draw heuristic design information, 3) reasoning and design capabilities, 4)a capacity to create a set of choices, achievable through a set of plans, 4) driven by a desire to achieve a set of goals. These essential elements are summarised in Figure 2.

The sequence by which the agents act is summarised in Figure 3, which encompasses the processes of analysis, synthesis (proposals for solving a given design problem), and evaluation in assessing the success of the chosen proposal.

A large number of techniques are now being developed to support the analysis phase and include measures of shape, pattern, topology, and distribution. Implicit in the development of these techniques is the idea that if you wish to preserve some quality of the map or any object in the map, you first need to characterise it. Various research has highlighted the need to characterise the phenomena in order to 1) drive the solution and 2) to ensure that the solution is recognisable as being a generalised form of the source data. Research has focused on modelling qualities such as connectivity, sinuosity, alignment, relative size, and compactness (Regnauld1996). Cartometric techniques will also be required to model distributions in order to maintain the homogeneity of the map content. Such information will also play an important role in the provision of information for co-operation among agents.



PC	perception capabilities (first hand)	DC	decision capabilities
CC	communication capabilities (second hand)	EC	executive capabilities
K	Knowledge	G	Goals
RC	Reasoning capabilities	P	Possible plans
A	Actions	C	Choices
INPUT	perception stimuli	OUPUT	action on agents or environments

Figure 2: The various components of an agent based methodology (Demazeau 1990, 6).

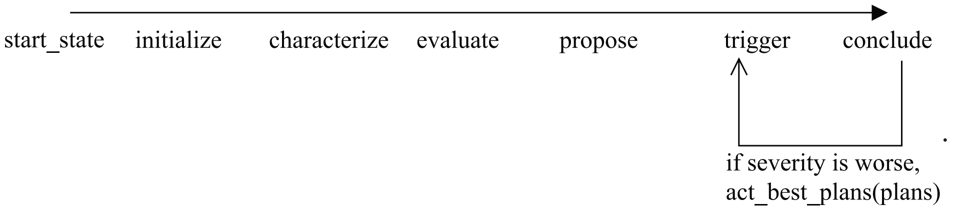


Figure 3: Agent state diagram (simplified) (Ruas 1999)

Development of Methods For Generalising Geographic Phenomena

The classification and description of geographic phenomena is central to the generalisation process. From a pragmatic point of view, we require meaningful ways of generalising phenomena whilst retaining their distinguishing characteristics and their interdependencies with other phenomena. We know that it is necessary to prioritise certain qualities and characteristics that define the phenomenon being represented. Their description is a prerequisite to this abstraction process. Furthermore if we are to observe notions of homogeneity, then by definition we need to prescribe the regions we intend to compare. It is therefore apparent that we need to define agents in terms of their overall tasks and the scale dependent nature of their activities. It is proposed that micro agents be created to manage the generalisation of individual geographic phenomenon. That meso agents be devised to manage groups of objects, and that macro objects are at a coarser scale still, involved in the broadscale issues of map design. The challenge is in deciding the most appropriate level at which to group phenomena together.

It is important that when considering the grouping of phenomena, we not only consider it at the geometric level but at the semantic and topological level (Ormsby and Mackaness 1999). For example a residential suburb is a geographic phenomenon. It is made up of houses, of relatively high density, roads, small shops, and is away from a city centre. And by way of a further example, a city is a phenomenon made up of suburbs, industrial sectors, shopping precincts, schools and transportation infrastructure. These examples clearly illustrate that phenomena can easily be complex collections of other phenomena. It is important to stress that the composition of these phenomenon may vary - perhaps driven by the thematic intent, or the intended scale transition and that one element or phenomenon might contribute/be part of more than one other phenomenon. Precisely how these phenomena might be formalised or prescribed is an important part of the research and is critical to the success of applying the agent paradigm in the map generalisation process. There is a close link between the generalisation of such phenomena and the way in which we partition the map space. The partitioning of the map space is required in order to allocate tasks and responsibilities between the different types of agents. One could partition based on some geographical distinction, such as the rural/urban divide, or a mountain/ valley divide. You could partition based on some geographic function such as the river catchment zone that defines the region into which a river flows. Alternatively one could partition on the basis of some anthropogenic feature. Popular among these has been the use of road networks to partition the map space. For the agent project it is likely that partition will occur using a mix of these partitioning mechanisms, depending on the task in hand. For example some generalisation techniques are more appropriately applied to urban regions that rural ones, and being able to partition the map space along some urban/rural divide might therefore be required (Mackaness 1995). Figure 4 shows one such (hierarchical) arrangement of agents across the building/district/ town divide, and Figure 5 shows how the roads can be used to partition the map space into meaningful chunks.

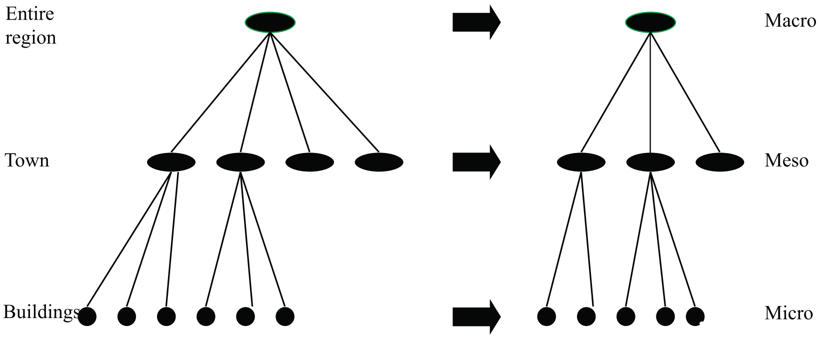


Figure 4: A Hierarchical structure of micro, meso and macro agents (adapted from Ruas 1999).

Figure 5: Using the road network to partition the map space in terms of responsibilities and activities between meso agents. Each 'smiley' represents one meso agent.

A Worked Example

Having devised a structure for agents, and identified the tasks associated with each agent type, we require a way of modelling the competing goals of design at each of these three levels. In the example below, we consider the activities of a micro agent, and show how a constraint based approach can be used to find compromise between a set of (competing) goals.

The methodology is centred around a constraint based approach to generalisation (Harrie 1999; Ruas 1998; Weibel 1996).

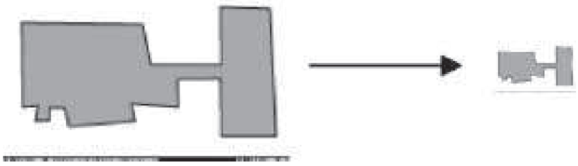


Figure 6: Scaling a building generates noise in the detail, and narrow sections are indiscernible.

In the following example we consider the constraints associated with a micro agent which represents an individual building. In the analysis phase, various qualities of the building are measures. These measures include size, minimum width, how square it is, its orientation, position, compactness. All these measures will influence how the object is generalised. Certain characteristics we wish to conserve (such as overall shape, its angular nature, location, and size relative to other buildings), and other characteristics we wish to alter in order to maintain legibility, and to support ease of interpretation. Some of these tasks are handled at the meso level (such as separation, or common/relative orientation). Collectively the result is a compromise among these constraints, at the micro, meso and macro level. In the figure below, various characteristics have been measured and an assessment is made as to whether the object will be discernible at the target scale. The narrow width will become illegible at reduced scale, and the fine detail in the boundary will not be visible at coarser scales. These qualities therefore need to be altered by applying methods to the agent building which will alter its form.

Table 2: A set of measures associated with the building agent.

Goal	Required value	Measure	Current value	State
Size	> 300 m^2	Poly_area	318m^2	Goal satisfied
Minimum width	> 20 m	Min_width	11m	**Goal unsatisfied**
Square_Angle_Dev	< 3 deg	Angle_Deviation	5.2 deg	**Goal unsatisfied**
D_Orientation	< 0.1 rad	Orientation_MBR	0.0 rad	Goal satisfied
D_Position	< 20m	Hausdorff_Distance	0.0m	Goal satisfied
………..				

Figure 7: Squaring and selective enlargement leading to changes in constraint values (adapted from Ruas 1999).

From table 2 we see that two goals are unsatisfied. The narrow section of the building is indiscernible and the fine detail cannot be preserved - the building has lost its anthropogenic feel (squareness). The resulting generalisation methods are first to square the building, and then to enlarge the width of the narrow section. This results in changes in the total area of the footprint of the building. These changes are figuratively illustrated in Figure 8, in which just three of the goal states have been normalised against each other. Provided any changes don't have an untoward effect on other constraints (raising a bar of the histogram above the line) then we can essentially define 'an acceptable solution' whereby the changes are sufficient for the object to be legible (Figure 7), but not sufficiently great to alter the general image of the footprint of the building.

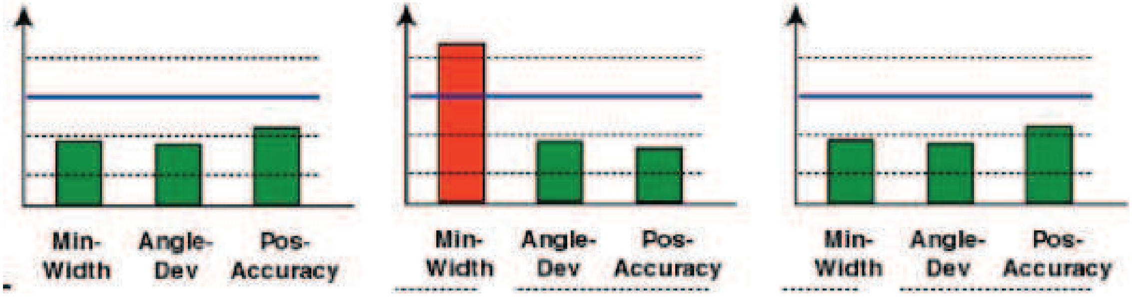


Figure 8: Modelling compromise between a competing set of design constraints (adapted from Ruas 1999).

The idea proposed for a micro agent is equally applicable for meso and macro agents, though different criteria would form the bars of the graphs.

Issues in the Use of Agents

Agent methodologies can be viewed as a natural progression to solving issues of automated map design (Baeijs et al. 1996). The development of object oriented techniques and the ideas of reactive databases are symptomatic of attempts to build greater intelligence into databases and to provide the functionality to model explicitly the relationships that exists between map objects. But there are many issues that still need to be addressed. Werner () warns us of believing that by throwing together a few ants, we can build anthills and by analogy that by throwing together a few cartographic agents that we can build maps. In particular current research is trying to understand:

- What are the levels of cooperation achievable betweeen a set of agents?
- What is the finest level of detail at which agents are defined?
- What information is shared between agents?
- How do we model sequence in activities of agents?
- How do we model an agent’s autonomy?

Such questions and more will need to be addressed during the lifetime of the project. The emphasis of these research questions is reflected in the composition of the agent consortium. The five institutions comprising the consortium have expertise ranging from a knowledge of the map user community, the agent methodology, research in map generalisation and R&D in commercial OO based GIS. The AGENT project is eighteen months into a three year research contract. The lead institution is the IGN, the national mapping agency of France. The collaborators are: INPG, Grenoble; Laser Scan in Cambridge; the Department of Geography, University of Zurich; and the Department of Geography, University of Edinburgh, Scotland. Collectively the teams are working in five critical areas:

- development of cartometric techniques
- definition of behavioural constraints of agents
- implementation/ prototyping of generalisation methods
- methods for partitioning of the map space for workflow decomposition
- methods for the meaningful grouping of phenomena

Conclusion

Agents are all about managing complexity and provide a fundamentally new way of considering complex distributed systems, containing societies of autonomous cooperating components. One should not infer that by utilising multi-agent systems (MAS) that the current impediments to automated map generalisation will easily be addressed or that MAS is a better approach than procedural approaches, OO, XS, neural networks or other approaches previously adopted (Muller 1993). Indeed the use of the MAS paradigm has highlighted the fact that these needs must be addressed. What MAS does offer is a new perspective on the problem - the 'right' framework in which to understand and model the generalisation process.

Mistakenly map generalisation has, in the past, been seen simply as a set of geometric manipulations. It is true that generalization manifests itself as the manipulation of geometry, but it is fundamentally driven by the need to convey specific meaning with respect to a particular map purpose. In reality the process of design has been shown to be complex, necessitating the modelling of geographic phenomena sufficient to support both the generalisation of that phenomenon, exploratory design, and effective visualisation (conveying meaning).

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