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Abstract

What are the activities we use GIS for? What are the tasks that we need to solve a specific problem within an activity? What are the methods that we use to accomplish a task? Which are the operations that we need within a GIS for a specific method. Can we describe those methods (not the operations within a GIS) such that they can be re-used by others automatically?

Geographic task models are conceived of as plug-in modules that adapt an information system to a specific task. They represent a fundamental change in the way to operate an information system. They offer problem-solving knowledge to the information system and thus can transform the vocabulary of the generic information system to that of an application-specific information system. The idea is to make current geographic information systems more intelligent, i.e., to include knowledge about common problem-solving processes, and to enable the reuse of problem-solving methods.

Keywords: method reuse, geographic task models, interoperability, usability of GIS, semantics of data

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1. Motivation

> Sharing digital geographic information is in principle possible, but in practice it is severely impeded by the lack of appropriate methods and tools for describing data. (Goodchild in Foreman, p.377)

Examination of the functionality of GISs (Maguire and Dangermond 1991, Albrecht 1997) has shown that current GISs are designed to handle data and enable reuse of data. In the future, GISs will include knowledge about geographic tasks and facilitate method reuse. This has been proposed in the context of intelligent GIS (Birkin et al. 1996). The system can be more intelligent and thus more usable if knowledge about geographic tasks is available.

At the NCGIA specialist meeting on user interfaces the need for research on typology of users, use types and GIS tasks to improve usability of GIS was identified (Mark et al. 1992, Mark 1994). Geographic task models provide a framework in which to encode knowledge about GIS tasks, their goals, constraints, and their users.

Users express their intentions and supporting activities in a high level language, usually in natural language. To be carried out those activities need to be broken down into a sequence of tasks that exist in the head of the user and are part of her training as expert in the field. Each task has to be performed as a sequence of operations (according to a specific method), which can be carried out (mostly) by the commands and functions of an information system, e.g., a Geographic Information System (GIS) or a Spatial Decision Support System (SDSS). Depending on the complexity of the activity, more intermediate levels of tasks are needed, creating sub-tasks.

The high-level language is part of the user or application domain, whereas the low-level operations are part of the system domain. At the moment the user is in charge of translating between the two levels and creating the intermediate levels. In our opinion at least part of this translation can be done automatically with the help of geographic task models. We propose to research problem-solving methods and corresponding tasks in geographic information processing and to describe them formally in geographic task models. This paper is a discussion of such models, what they are, how they are supposed to work, their benefits, and their drawbacks (yet to come). We also propose how to derive geographic task models.

Chapter 2 reviews previous and related work. Chapter 3 introduces Geographic Task Models in detail. Chapter 4 lists the current hypotheses and presents arguments in favor of geographic task models. Finally, chapter 5 concludes.

2. Previous and Related Work

Within the GIScience community there has been research done on functionalities of GIS. Maguire and Dangermond (1991) analyzed high level generic tasks in Geographic Information Systems. They identified data capture, data transfer, data validation and editing, storing and structuring data, restructuring data, generalizing data, transforming data, querying data, analyzing data, and presenting data as generic tasks of a GIS. Those tasks are generic data handling tasks and in my opinion do not characterize a GIS but all data handling systems.

Albrecht (1996, 1997) presents 20 universal GIS operations derived from questionnaires out of a compiled list of 144 GIS analytical operations and functions from diverse GISystems. The operations are listed in table 1.

Search	Interpolation	Spatial Search	Thematic Search	Reclassification
Locational Analysis	Buffer	Corridor	Overlay	Thiessen/Voronoi
Terrain Analysis	Slope/Aspect	Watershed	Drainage/Network	Viewshed
Distribution/ Neighborhood	Cost/Diffusion/ Spread	Proximity	Nearest Neighbor	
Spatial Analysis	Multivariate Statistics	Patters/Dispersion	Centrality/ Connectedness	Shape
Measurements	Measurements			

Table 1: Universal GIS operations (Albrecht 1997)

Those operations are derived from the user perspective although heavily influenced by the available operations in GISystems. Those operations are not the tasks we are looking for. Research will show if those 20 operations indeed represent the building blocks of all geographic tasks within a certain application area. As Albrecht (1997) remarked, a good GIS user interface needs to adjust to the field of application, i.e., the categorization of the operations depends on the application. This is expressed, for example, in the group heading and the names of operations within the groups, which should conform to the commonly accepted knowledge within the user group of a specific application. There need to be more research carried out to derive this kind of knowledge. In part this knowledge can be taken from accounts of customization procedures of GIS.

Within the Knowledge engineering community Chandrasekaran (1986) has brought up the concept of universality with the idea of generic tasks. His aim was to model the problem-solving process in medial diagnosis. He showed that diagnosis consists of several generic methods and defined those methods formally. Subsequent work dealt with the application of those generic problem-solving methods to other domains.

Within the domain of GIS Kuhn proposes ontologies in support of geographic activities (Kuhn, in press). Along the same lines Camara (2000) promotes the idea of action driven ontologies. The difference is that Kuhn tries to mediate between domain ontologies and task ontologies, whereas Camara prefers an action–driven approach.

The incorporation of domain-specific problem-solving knowledge has been promoted by research on Intelligent GIS (Birkin et al. 1996). The authors discuss a combination of conventional GIS and model-based analysis. The incorporation of reasoning mechanisms and knowledge bases into current GIS to make GIS more intelligent is also subject to research by Yuan (Yuan in ouucgis.ou.edu/nima_abs.html). The aim in this project is to support spatiotemporal queries, analysis, and modeling in hydrology.

3. Geographic task models

A Geographic task model contains a (formal) description of a task and states its goal or goals. It names the data requirements (input) and the results (output) of the task. It also contains a description of its parameters in the space of task, i.e. an indication of its standing in relation to other tasks. It lists possible methods to carry out the task. It gives an account of the necessary subtasks, i.e., the task chain. It describes how the information flows between the subtasks in the task chain. Finally, it defines possible constraints (e.g., quality) on data, methods, input, and results.

Geographic task models are conceived of as plug-in modules that adapt an information system to a specific task. For example, the user interface is adapted by showing under a specific command the necessary steps (or subtasks) to carry out the task. Depending on the skill of the user more or less detail on the subtasks (information on operations, methods, constraints, and data requirements) is given. Even the sequence of those steps could be subject to change, i.e., an expert user can modify the list of subtasks (Brazier et al. 2000), whereas a novice user will operate with a given sequence. But geographic task models are more than an adaptation of the user interface. They represent a fundamental change in the way to operate an information system. They plug problem-solving knowledge into the information system and thus transform the vocabulary of the generic Information System to that of an application-specific Information System. This changes the possible interpretations of the data, which might contribute to the solution of the semantics problem. At the same time necessary methods for the solution of the task are identified which can be accessed over the Internet. A feasibility check of the data is executed to derive possible problems with in- or output of the subtasks and to check if the constraints of the task are fulfilled.

3.1. A simple informal example

This example is taken from an introductory course on GIS. The task is to derive ideal sites for a building, where the ideal site is determined by several criteria. The task chain including subtasks and operations is given in Table1. In general the task chain is as follows:

- determine criteria 1..n
- determine locations for criterion 1 - n
- determine joint locations
- map locations

The spatial data used are raster data with the information for each criterion. The data flow in this example is rather simple. For each criterion possible locations are determined independently and later combined (for specific operation chains please refer to table 1). The base data is a digital terrain model, information on ground cover (vector transformed to raster), and three locations that should be seen. As special input the criteria are given. The output of the task is a set of possible locations (in grid cells). The method used is divide-and-recombine.

Activity: locate building site

Determine criteria	Determine locations above fog boundary	Determine locations with evening sun	Determine locations with slopes <= 25 degrees	Determine locations with a view on the three given locations	Determine locations not in forest and not built-up	Determine locations that satisfy all those criteria	Map possible locations
Get user determined criteria	Enter arcview	select dtm25 in view	select dtm25 in view	View, new theme, points	add theme, ground_cover	MC, villaLocations = notfog and eveningSun and flatSlope and goodView and groundCover	add theme, topographic map
Get data: dtm and ground cover	New view	Surface, Derive aspect	Surface, Derive slope	select given locations	open table, identify classes		select villaLocations, legend: color red
	View, view properties: give the view a name	look for number interval southwest-west: 202.5 – 292.5	MC slope_dtm25 <=25	stop editing, save theme	Query Builder, dxf=other (not forest, not built-up, not vineyards, not lake)		print or show on screens
	Load spatial analyst	MC aspect_dtm25 >= 202.5 and aspect_dtm25 <= 292.5		open table, deselect points	Theme, convert to grid		
	Add theme: grid dtm25			select dtm25 and locations in view			
	Select in view dtm25			Surface, calculate Viewshed			
	Map calculator (MC) dtm25<550						
	Legend of calc1: change foreground and background color of class 0=False, do not show NoData;	legend of calc1: change foreground and background color of class 0=False, do not show NoData;	legend of calc1: change foreground and background color of class 0=False, do not show NoData;	legend of calc1: change foreground and background color of class 0=False, do not show NoData;	legend of calc1: change foreground and background color of class 0=False, do not show NoData;	legend of calc1: change foreground and background color of class 0=False, do not show NoData;	
	Theme, theme properties: change name in legend; theme, save dataset as: give it a proper name	theme, theme properties: change name in legend; theme, save dataset as: give it a proper name	theme, theme properties: change name in legend; theme, save dataset as: give it a proper name	theme, theme properties: change name in legend; theme, save dataset as: give it a proper name	theme, theme properties: change name in legend; theme, save dataset as: give it a proper name	theme, theme properties: change name in legend; theme, save dataset as: give it a proper name	

Table1: task and operation chains of the activity site location

3.2. How can Geographic Task Models be derived?

There are four ways to derive geographic task models. The first one is a task-analysis, i.e., an analysis of the subtasks, operations, and data used in solving a specific problem (see for example Raubal 1997, Timpf et al. 1992, Timpf under review). Secondly, information on past task-analyses should be available in the literature on GIS applications. During this literature search it would be beneficial to classify tasks per application. This would help in extracting the methods used to solve certain tasks and to identify domain-independent strategies. Thirdly, customized products should show an alteration of the user interface and an adaptation of the methods and operations used, which are observable and attributable to specific tasks. Finally, we can apply knowledge from the scientific Knowledge Engineering groups to geographic tasks.

3.3. Geographic problem-solving methods

A Problem-Solving Method (after McDermott 1988) is an abstract model of problem-solving with the following components:

- Actions that accomplish tasks, expressed in a behavioral way
- Recursive decomposition into subtasks, solved by another method until mechanisms.
- Selected w.r.t. factors (e.g. availability of data; time, space and quality requirements)

Typically problem-solving methods are specified in a task-specific fashion, using modeling frameworks which describe their control and inference structures as well as their knowledge requirements and competence (Fensel et al. 1997). Describing problem-solving methods in the style of CommonKADS (Schreiber et al., 1994) requires to specify much of the internal reasoning process of a problem-solving method. In particular, the following descriptions need to be given:
1) the internal reasoning steps of the problem-solving method;
2) the data flows between the reasoning steps;
3) the control that guides the dynamic execution of the internal reasoning steps;
4) the knowledge requirements of a problem-solving method;
5) the goals that can be achieved by a problem-solving method.
However, most of these aspects have to do with understanding how a problem-solving method achieves its goals. To assess the applicability of a problem-solving method one only needs knowledge about its competence and domain requirements - i.e. (4) and (5) above.

The method – hyperspace

The method-hyper-space (MHS) is a formal description of the problem solving methods used in geographic information processing. It is in fact an n-dimensional space where the axes denote the parameters that determine which method to use when. At the moment it is a hypothesis that such a set of independent parameters, determining the use of a method, exists.

Each method occupies a region within this hyperspace. Those regions can overlap, meaning that both methods can be used for at least one specific problem type. If those regions are disjoint, then the two methods cannot solve the same problem type. Perhaps more topological relations are meaningful.

Given a specific problem/task the method-hyperspace shows which methods or combination of methods can possibly be used to solve this problem. The final decision is also dependent on the available data and on performance and optimization criteria.

Some methods might be independent of the application domain (example), others are clearly dependent on the domain (example). Can we make a difference, are independent methods more generic than dependent methods? Can both types of methods be described in the same framework, e.g., the one as a specialization or instantiation of the other (as in, e.g., Brazier 1995)?

4. Hypotheses

Geographic task models have three main objectives: provide the context for data (i.e., semantics issue), enable geographic information brokering (i.e., the interoperability issue), and make GIS more usable and adaptable (i.e., the UI issue).

4.1. Tasks provide context for data

A task guides cognition and perhaps even perception of objects in a given situation. The reason for a task and the way we perform this task guide which parts of reality we look at and perceive. For example, we give different route directions to a pedestrian than to a truck driver: our cognitive model of the route changes with the specific task. The task influences the types of objects and the parts of objects that we consider important, i.e., object ontology and its level of abstraction: The directions for a pedestrian yield different objects (sidewalks, foot-paths, stairs, etc.) than the directions for the truck driver (highways, stop lights, one-way streets etc.).

Tasks produce partitions of reality (Smith 2000), where reality is composed of those things that are interesting (the smaller part but very detailed) and of those things that are not interesting for the task at hand (the larger part). *Domain Ontologies* (in the sense of Guarino 1998) describe those parts of partitions, i.e. concepts, which are interesting for a certain domain. These concepts are used for all tasks that occur within that domain. *Problem-solving methods* describe the reasoning concepts and their relationships occurring for a specific task (see above).

Any time we use data for a specific purpose, data is metamorphosed into information. The emphasis in GI science research so far has been on data – how to represent, how too measure, visualize geographic data. We do not know much about the tasks this data is used for although tasks seem to play a big role in determining the meaning of data. From this observation we infer a need to do research about geographic tasks.

The current hypothesis is that tasks provide context for data and thus solve the semantic ambiguity problem of data. If we were able to describe data sets in combination with associated tasks and knew formal relations between tasks, we would be able to tell if the data used for task 1 can also be used for task 2. If task 2 is more specific, we will need additional or more detailed data to solve it. If the task 2 is more generic, then we need abstraction mechanisms to abstract from the existing data. If the tasks are at the same level of abstraction, then the question is if they share a common generic task. If they do, the likelihood increases that the knowledge used for the first task can be re-used for the second.

4.2. Interoperability: Sharing information – sharing methods

Interoperability deals with sharing information that is distributed over different platforms, geographic locations, and database systems (Goodchild et al. 1999). But it also deals with sharing and accessing distributed services, i.e., methods or programs. One of the main challenges for interoperable GIS is the sharing of semantic information and the intelligent reuse of services. GISs now deal with the management and storage of data for reuse, in the future they will also have to deal with the reuse methods and tasks descriptions.

In recent years two main technologies for knowledge sharing and reuse have emerged: *ontologies* (Gruber 1993) and *problem solving methods*. Ontologies specify reusable conceptualizations, which can be shared by multiple reasoning components communicating during a problem solving process. problem-solving methods describe in a domain-independent way the generic reasoning steps and knowledge types needed to perform a task (Fensel et al. 1997).

Scenarios in interoperability (Kottmann 1999) rely on the existence of software that can deal with redirecting queries to appropriate addresses for handling or computing and sending the compiled answer back to the inquirer. This software is called the information broker. The information broker is in charge of *task chaining*, i.e., breaking the query down into a sequence of tasks and sending tasks or subtasks off for computation (see also Fensel 1997). Task chaining requires knowledge about possible task decompositions of the query (Yang 1997, Brazier et al. 1995), i.e., exactly that knowledge which we intend to provide with a Geographic Task Model. Geographic task models contain knowledge about the task sequence, the task hierarchy, and constraints to the computation process. Thus an information broker would directly benefit from the knowledge embedded in a Geographic Task Model.

4.3. Improving the usability of GIS – adaptable UI

Users of current Geographic Information Systems (GIS) are experts in their own domain. They are interested in solving their problem, planning and designing, simulating future scenarios, assessing a risk, mapping, or getting help in making a decision. An information system is to the users, for example,

- a mapping tool,
- an inventory tool, (acquire and present)
- a decision-support tool,(all types)
- a spatial analysis tool, (cover and differentiate)
- a simulation tool, (propose and revise, extrapolate from a similar case

- an intelligent planning tool,(propose and revise, extrapolate)
- a design tool
- or a combination of the above.

(For a similar list see also Breuker 1994.)

The current generation of GIS does not live up to this image. Users must have knowledge about the intricacies of dealing with geographic data in addition to their own field of expertise. They cannot concentrate on 'doing their job' wielding a powerful tool. This greatly reduces the usability of GISs and also the value of GIS, because value is only derived from geodata by use.

The list given above lists user activities in increasing complexity although no total order is implied. But it suggests that a spatial problem solver might be more complex than a spatial decision-support tool, which in turn is more complex than a mapping tool. This has implications for the organization of a GIS. If the activities can be described such that each step or combination of steps can be represented by a module in a GIS, then the GIS can be tailored to the activity by providing exactly those modules that allow the user to carry out their activity. A 'good' GIS should also be adaptable. Depending on the knowledge and skill of the user it will present more or less functions, apart from tailoring the shown functions to the application at hand (Davies and Medyckyj-Scott 1994).

The current GIS functionality has two distinct markets with similar consequences for the 'inner working' of the GIS. Within the mass market (e.g., location-based services), a user will be completely unaware that she just processed spatial information. Within the expert market, the GIS will blend into the background and put the focus on the task at hand. The expert might be more interested in the methods and algorithms that are used for her specific application area. To satisfy this user need a greater transparency in the use of tasks and methods is needed. However, in both cases the non-task-essential computing processes become invisible (Norman 1998), leaving the focus to the task at hand. We believe that this invisibility of non-task-related computing processes can be achieved by using geographic task models.

5. Conclusions: a new paradigm?

(yet to be done properly)

Summary: geographic task model, method-hyperspace, more tasks, less data

If we want to improve the usability of GISystems, and if we want to be able to provide interoperable services to the GIS community, then we need knowledge about how we solve problems in and with GIS. This includes the methods we use, the sequence of operations that constitute a task, and the circumstances (constraints) in which a specific method is picked to solve a problem. geographic task models will provide a framework to put that knowledge into:

- Adapts user interface to a specific task
- Plugs in the problem-solving knowledge: task chain

- Enables interoperability: knows about the location and quality of necessary methods (subtasks included)
- Makes feasibility check with data
- Changes the use and interpretations (semantics) of the vocabulary (domain (from data) and task knowledge)

The big view: we should change the paradigm – not modeling the data but modeling the tasks

The small view: usability is increased if system is more intelligent – can be more intelligent through knowledge about tasks

Another hypothesis: Tasks are the units of work in which people think – HCI and cognitive science research necessary to prove this hypothesis. Activities provide the motive behind a sequence of tasks

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