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**CHAPTER NUMBER**

# Geographic Activity Models

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## 1.1 MOTIVATION

The main impediment to a widespread use of geographic information using a geographic information system (GIS) is the gap between the user's expression of a task within the context of an activity and the sequence of operations within a GIS needed to successfully perform that task. Users express their intentions and supporting activities in a high level language, usually in natural language. This level corresponds to the knowledge level (Newell 1982). 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 GIS or a Spatial Decision Support System. Depending on the complexity of the activity, more intermediate levels of tasks might be needed, creating sub-tasks.

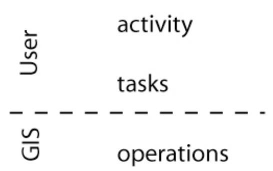


**Fig.1: Division of work between user and GIS**

The high-level language is part of the user or application domain, whereas the low-level operations are part of the system domain (Fig. 1). At the moment the user is in charge of translating between the three levels and creating the intermediate levels. In our opinion at least part of this translation can be done automatically with the help of geographic activity models. Instead of having to deal with operations, the user should deal with the methods needed to carry out the task within the framework of the activity (Fig.2).

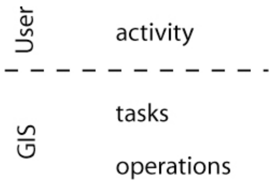


**Fig.2: Desired division of work between user and GIS**

We propose to research geographic activities and corresponding methods in geographic information processing (Table 1). We will discuss questions such as: 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? We argue that the analytical potential of GIS can better be exploited once the user is provided with significant choices to adapt the computing environment to the activity at hand.

| **Geographic Activities** | **Methods** |
|---|---|
| Site location | spatial analysis, visualization |
| Wayfinding | planning, simulation |
| Utility management | inventory, decision-support |
| emergency management | decision-support, inventory |
| landscape conservation | inventory, monitoring |
| urban planning | decision-support, planning |
| environmental monitoring | monitoring, visualization |
| … | |

**Table 1: Some geographic activities and possible associated methods**

We propose to describe problem-solving methods, task ontologies and sequencing in geographic activity models (GAM). This work is a discussion of such models, what they are, how they are supposed to work, and how they should be derived. Geographic activity models should be 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.

Chapter 2 reviews previous and related work. Chapter 3 introduces Geographic Activity models in detail. Chapter 4 discusses geographic activity models in the context of three different research perspectives (usability, interoperability, semantics). Finally, chapter 5 concludes and presents future work.

## 1.2 PREVIOUS AND RELATED WORK

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. 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 this categorization provides a first grouping of operations into tasks. However, the phrase "analyzing data" hides the application–specific knowledge necessary to extract meaning from data.

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 | Patterns/ Dispersion | Centrality/ Connectedness | Shape |
| **Measurements** | Measurement | | | |

**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.

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.

Kuhn criticises that GISs do not support human activities (Kuhn, 2001). His "domain theories are based on the assumption that the increasing complexity of human conceptualizations of the environment results from […] increasingly complex activities, rather than the other way round" (p.28). Along the same lines Camara (2000) promotes the idea of action driven ontologies. Both authors appear to adopt the paradigm that activities (or actions) drive the conceptualization of the domain of study. We infer from their work that more knowledge about geographic activities is necessary in order to study the influence of activities (actions) on human conceptualizations of the geographic world and problem-solving behavior.

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 activity models provide a framework in which to encode knowledge about GIS tasks, their goals, constraints, and their users.

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 medical 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. We believe that for certain geographic activities similar generic methods exist. Geographic activity models are a means to store those methods such that they can be used by expert and novice GIS users alike.

Bucher (2002, 2001, 2000) is working on a geographic task server to provide users with additional knowledge on how to manipulate data. The information is structured according to a task-method-tool model. This work relies on the CommonKADS framework (Schreiber et al. 1994) for describing problem-solving knowledge. The goal of Bucher's work is an expert system that stores patterns of manipulation of geographic data. There is but a small step from patterns to problem-solving knowledge and from there to geographic activity models.

## 1.3 GEOGRAPHIC ACTIVITY MODELS

A Geographic activity 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 activity models can be 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. This classification corresponds to the distinctions between types of task-chaining: opaque task chaining does not disclose detail to the user, translucent task chaining requires user interaction at certain points, whereas transparent task chaining leaves the chaining of tasks up to the user.

Geographic activity 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.

There are four ways to derive geographic activity 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 2001). 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 results from knowledge engineering research to geographic tasks.

### 1.3.1 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 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 difference between a geographic activity model (GAM) and a problem-solving model is that GAMs provide the user with a choice of methods to solve her problem. The choice might depend on the type and quality of available geographic data and a GAM will present criteria for the user to decide which method to use with which data.

### 1.3.2 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)?

### 1.3.3 A simple informal example

This example is taken from an introductory course on GIS. The task is to derive ideal sites for a villa, where the ideal site is determined by several criteria. The task chain including subtasks and operations is given in Tables 2 and 3. In general the task chain is as follows (see also Fig.3):

- determine criteria 1..n (user input)
- determine locations for criterion 1 – n (spatial analysis)
- determine joint locations (spatial analysis)
- map locations (visualization)

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 2). 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).

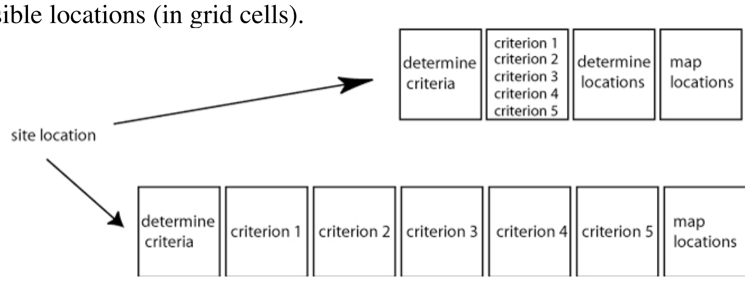


**Fig.3: Task chain for Site Location**

As shown in Fig. 3 there are two possible ways to determine a site from a list of criteria. In the upper task chain we assume that the criteria are independent from each other. Thus they can be computed in parallel. In the lower task chain the criteria are applied sequentially to the result set of the previous computation. This results in less data to hand over to the next task step and reduces the time for computation drastically. Both methods have drawbacks and advantages. It may depend on system resources which solution is chosen.

| ***Activity: Site Location (Part 1)*** | | | |
|---|---|---|---|
| Determine criteria | Determine locations above fog boundary | Determine locations with evening sun | Determine locations with slopes <= 25 degrees |
| Get user determined criteria | Enter arcview | select dtm25 in view | select dtm25 in view |
| Get data: dtm and ground cover | New view | Surface, Derive aspect | Surface, Derive slope |
| | View, view properties: give the view a name | look for number interval southwest-west: 202.5 – 292.5 | MC slope_dtm25 <=25 |
| | Load spatial analyst | MC aspect_dtm25 >= 202.5 and aspect_dtm25 <= 292.5 | |
| | Add theme: grid dtm25 | | |
| | Select in view dtm25 | | |
| | 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; |
| | 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 |

**Table2: Task and operation chains of the activity site location**

| *Activity: Site Location (Part 2)* | | | |
|---|---|---|---|
| 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 |
| View, new theme, points | add theme, ground_cover | MC, villaLocations = notfog and eveningSun and flatSlope and goodView and groundCover | add theme, topographic map |
| select given locations | open table, identify classes | | select villaLocations, legend: color red |
| stop editing, save theme | Query Builder, dxf=other (not forest, not built-up, not vineyards, not lake) | | print or show on screens |
| open table, deselect points | Theme, convert to grid | | |
| select dtm25 and locations in view | | | |
| Surface, calculate Viewshed | | | |
| | | | |
| 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 | |

**Table3: Task and operation chains of the activity site locations**

## 1.4 DISCUSSION

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

### 1.4.1 Improving the usability of GIS

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. A geographic information system is to the users, for example,

- a visualization 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 GIS operations 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 (Krek and Frank 2000).

The list given above presents 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 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 activity models.

### 1.4.2 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 of 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 (Timpf 2001) 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 Activity model. Geographic activity 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 Activity model.

### 1.4.3 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.

## 1.5 CONCLUSIONS: A NEW PARADIGM?

The main impediment to a widespread use of geographic information using a geographic information system (GIS) is the gap between the user's expression of a task within the context of an activity and the sequence of operations within a GIS needed to successfully perform that task. This corresponds to the gap between what Newell (1982) calls the knowledge level and the symbolic (computational) level. It is our conviction that GISs need to communicate with the user at the knowledge level. One possibility to do so is to include information about problem-solving methods, user activities and task chains within a geographic information system, thus making the system more intelligent and usable. The idea is to provide the user as often as possible with knowledge level information in the form of generic tasks and methods instead of requiring her to learn specific GIS operations.

Tasks are the units of work in which people think, activities provide the motive behind a task chain, and sequences of operations carry out the tasks without being themselves goal-directed. Within a distributed, interoperable environment tasks need to be coordinated and then chained for completion. The idea is to reuse knowledge and problem-solving methods as often as possible. Knowledge about task chaining is inherent in problem-solving methods. Unfortunately, we do not have a formalized body of knowledge about geographic problem-solving methods and task chaining.

This research presents a model called geographic activity model to store information about user activities, task chains and corresponding operations, and problem-solving knowledge. Geographic activity models will:

- Adapt user interface to a specific task
- Choose and plug in the problem-solving knowledge i.e. the task chain
- Enable interoperability: knows about the location and quality of necessary methods (subtasks included)
- Disambiguate the semantics of the domain knowledge (i.e. data).

We have shown using a simple site location example how problem-solving knowledge can be extracted and how different methods arrive at the same result. Bucher (2002) has created a framework in which to store this knowledge. More analysis of problem-solving methods and associated activities, tasks, and operations is necessary to complete this knowledge base. This endeavour cannot be the task of a single research group. Therefore, we are proposing to deal with problem-solving knowledge with the same intensity as we have been dealing with data issues in the past. This requires a shift of paradigm from emphasizing what-knowledge to emphasizing how-and why-knowledge.

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