Naming Topological Operators at GIS User Interfaces

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SUMMARY

User interfaces of geospatial information systems (GIS) are endowed with natural language terms describing topological operators in spatial queries. Thus, users do not have to learn underlying models and their formal languages in order to communicate with the system. Nevertheless, we have observed difficulties with identifying the appropriate operator for a given task. This work examines if the natural language terms contribute to these difficulties. In a test, 34 human subjects were presented with the natural language terms of two GIS for relations between two regions and asked to select graphical stimuli with spatial situations fitting to these terms. It turned out that nine out of 15 operator names are only understood by significantly less than half of the people in the way they are implemented in the products. Apart from appropriate names the results raise the question if all system concepts match human concepts.

KEYWORDS: *Topological operators, topological relations, formal models, natural language, user interface, GIS, human subject testing*

INTRODUCTION

In student GIS courses we have observed that often the wrong topological operator is selected for a given task. We assume that naming plays an important role in conveying the meaning of operators and examine in this work which concepts people associate with names. We consider relations between two regions, because they are the simplest case with fewest relations. Furthermore, they are often seen as ontological primitives (Cohn & Hazarika, 2001), like in the theory of region connection calculus (RCC) (Randell et al., 1992). Studying regions avoids the debate if humans have concepts of lines or points. The fact that the author is a native speaker of German suggests studying German terms, because you can understand subtleties only in your native language.

The vocabulary problem with software objects and commands is not new (Ledgard et al., 1980; Landauer et al., 1983; Furnas et al., 1987). (Furnas et al., 1987) found that only 10-20 percent of unfamiliar users will hit the term chosen by a system designer when they have to enter a term to invoke a command. By eliciting terms with real users and choosing the one applied most often as "best possible name" the hit rate could be doubled. Today, commands are usually not invoked by entering terms any more, but by selecting from a list of given terms. This avoids the risk of entering a term unknown to the system. It does not prevent, however, selecting wrong commands due to misunderstanding of terms. Therefore, it is not surprising that speaking the user's language is on the list of usability heuristics propagated by (Nielsen, 1993). Also in the context of GIS the importance of terminology has been emphasised (Frank, 1993), and adaptation to user language has been demanded (BEST-GIS Project, 1998).

Formal mathematical models have abstracted the infinite number of possible topological relations on specific levels and resulted in finite numbers. The nine-intersection model of (Egenhofer & Herring, 1990) is the one usually employed in GIS. It looks at the intersections of interiors, boundaries, and exteriors of two objects and results in eight different relations between two simple two-dimensional regions, i.e. connected regions without holes. Formal definitions need not correspond to human cognition. (Mark & Egenhofer, 1994b) have shown that humans do not only use atomic relations but also more abstract and overlapping groups of them. Research has been conducted to find out how human concepts map to formal definitions. A well-known approach is that of Mark and Egenhofer who examined human concepts of the relation between a road and a park with various tests. They started with a grouping task in which human subjects had to group various depictions of a road and a park and finally describe the groups (Mark & Egenhofer, 1994b). In an agreement task reported in the same article the subjects were presented with graphics of spatial situations and the two phrases "the road crosses the park" and "the road goes into the park". They had to indicate to which degree they agree that each phrase corresponds to each spatial situation. In (Mark & Egenhofer, 1994a) four English terms have undergone the road/park agreement task with partly modified graphical stimuli. According to (Mark et al., 1995), four additional English terms and one Spanish term have been tested subsequently (no references given), and (Abrahamson, 1994) has tested five sentences in Norwegian. Another approach was taken with a drawing task in (Mark & Egenhofer, 1995). Subjects had to draw examples for sentences. The results were used in (Shariff et al., 1998) where the nine-intersection model was refined by introducing metrics. The grouping task was also applied to relations between two regions (Knauff et al., 1997; Renz et al., 2000).

The author is not aware of a study focusing on terms actually used in GIS. GIS terms would only accidentally appear studies like those mentioned above. Existing studies have one of two focuses: either they try to prove the validity of formal models, which is independent of terminology, or they try to define natural language terms. The aspect of finding the best possible name for a concept has been neglected. Most tests have been done for relations between a line and a region. For relations between two regions only the grouping task has been applied. As already noted this does not allow the detection of overlapping concepts which is essential when examining GIS concepts. Furthermore, the obtained German results are not applicable, because their underlying samples are too small or they stem from grouping tasks (and besides they are not published).

TOPOLOGICAL RELATIONS IN GIS

The eight atomic nine-intersection relations yield 255 combinations (2^8-1, from atomic combinations consisting only of one relation to the combination of all eight relations, leaving aside the combination containing no relation), of which GIS typically present only a small subset (Riedemann, 2004). A reduced set of such combinations denoted "suitable for end-user interaction" (which was not tested) has been presented by (Clementini et al., 1993) and was incorporated in the international standard for simple features access (ISO, 2000). It consists of eight operators: *equals*, *disjoint*, *intersects*, *touches*, *crosses* (not applicable to two regions), *within*, *contains*, *overlaps*. This set has been roughly adopted by GIS products.

In this study the operators of ArcGIS[1] and GeoMedia[2] are used. Their selection followed feasibility: these two products were readily available and the author is familiar with them. The choice in particular does not mean that we expected an especially fruitful situation in terms of discrepancy between system designer and user concepts. As research results are missing, we assume that every GIS product is more or less afflicted with the same problems, at most to a different degree.

Table 1 and ***Table 2*** show the operator sets for spatial queries of ArcGIS and GeoMedia. The first column contains the operator names, first in German and then in English (in brackets). The following eight columns represent the eight relations between two simple regions as defined by the nine-intersection model. The relations are identified by a prototypical graphical representation in the header of each column (graphics taken from Egenhofer & Herring, 1990). For each operator it is

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[1] ArcGIS 8.3 of Environmental System Research Institute (ESRI)
[2] GeoMedia Professional 5.1 of Intergraph Corporation

marked which relations it comprises: a cross means that the relation is contained in the operator combination. The GeoMedia *meet* operator, for example, is an atomic combination, while the ArcGIS *intersect* operator combines all relations except the disjoint relation.

The information presented in the two tables is not completely and unambiguously available to the user via the documentation of the two GIS products. It was obtained by creating objects according to the nine-intersection relations and running the topological operations against them.

Table 1: ArcGIS operators and their nine-intersection definitions

Nine-intersection relation / **Operator name**[3]	1	2	3	4	5	6	7	8
Gekreuzt werden durch den Umriss von (are crossed by the outline of)			x					
Sich überschneiden (intersect)		x	x	x	x	x	x	x
Vollständig enthalten sind in (are completely within)								x
Vollständig enthalten (completely contain)							x	
Ein Linien-Segment gemeinsam benutzen mit (share a line segment with)						x		
Die Umrandung berühren von (touch the boundary of)		x		x	x	x		
Identisch sind zu (are identical to)						x		
Enthalten (contain)				x		x	x	
Enthalten sind von (are contained by)					x	x		x

Table 2: GeoMedia operators and their nine-intersection definitions

Nine-intersection relation / **Operator name**[4]	1	2	3	4	5	6	7	8
berührt (touch)		x	x	x	x	x	x	x
enthält (contain)				x		x	x	
ist enthalten in (are contained by)					x	x		x
enthält vollständig (entirely contain)							x	
ist vollständig enthalten in (are entirely contained by)								x
überlappt (overlap)			x	x	x	x	x	x
trifft auf (meet)		x						
ist räumlich identisch mit (are spatially equal)						x		

[3] Original terms used in the German and English versions of ArcGIS
[4] Original terms used in the German and English versions of GeoMedia

HUMAN SUBJECTS TEST

Research Question and Hypothesis

The question underlying our research is if users understand the natural language terms naming topological operators in GIS in the way intended by the system designers and implemented in the software. We assume that an appropriate operator name should be understood by the majority of users in the intended way. But based on our observations our hypothesis is that most operator names in ArcGIS and GeoMedia are understood in the intended way only by a minority of users.

Experiment

Ideally, we would like to make a statement about the population of native German speakers. 34 native German speaking subjects (13 female, 21 male; average age 34, standard deviation 11) were recruited at the Institute for Geoinformatics and among the author's friends. They participated gratuitously in the test. 17 of them had GIS experience; the other half had no GIS experience. GIS experience need not mean a specifically well understanding of topological operators. It is taken as an indicator for general spatial awareness and training here. The subjects had a variety of educational and professional backgrounds. As we have a quota and not a random sample, the picture of the target population will be distorted.

Each subject got a printed questionnaire that could be completed in any place. The natural language terms of the two GIS products had to be compared to graphics of the eight nine-intersection relations and each graphics had to be marked if it fits to the term or not in the subject's mind. At least one graphics had to be chosen as fitting, but more or even all graphics could be chosen. The terms in the questionnaire were formulated according to the schema "A *relation* B", for example "A *berührt* B" for the first GeoMedia operator (see ***Table 2***). For the ArcGIS operators the phrases had to be adapted in order to be grammatically correct, but the terms remained, for example "A *wird gekreuzt durch den Umriss von* B" for the first operator (see ***Table 1***). The two operators for complete containment have identical definitions and - apart from grammatical differences - identical names in the German versions of ArcGIS and GeoMedia. They appeared only once in the questionnaire, so that 15 terms had to be tested. There were 33 more natural language terms not stemming from GIS, but they are not regarded in this article. The order of terms and the order of graphics were determined randomly. To facilitate recognition of the regions they were hatched and coloured differently, and these colours were also used for the identifiers "A" respectively "B" in the phrases. ***Figure 1*** shows a page of the questionnaire. The instruction was printed on the first page. The subjects were instructed not to ask other people for help. It took about half an hour to answer all questions.

Results

The following two tables present the results of the test separately for the two GIS products. They show for each subject (S 1 to S 34) the combination of nine-intersection relations associated with a natural language term naming a GIS operator. The combinations are represented by combinations of numbers. The numbers are the same as in ***Table 1*** and ***Table 2*** where they refer to the nine-intersection relations depicted there. The combination 236 would then mean that the graphics representing *touch*, *overlap*, and *equal* have been found appropriate for a term. As mentioned before, combinations can also consist of only one relation, for example combination 6 denoting equality. The lines titled "ArcGIS" respectively "GeoMedia" contain the combinations implemented in the GIS products.

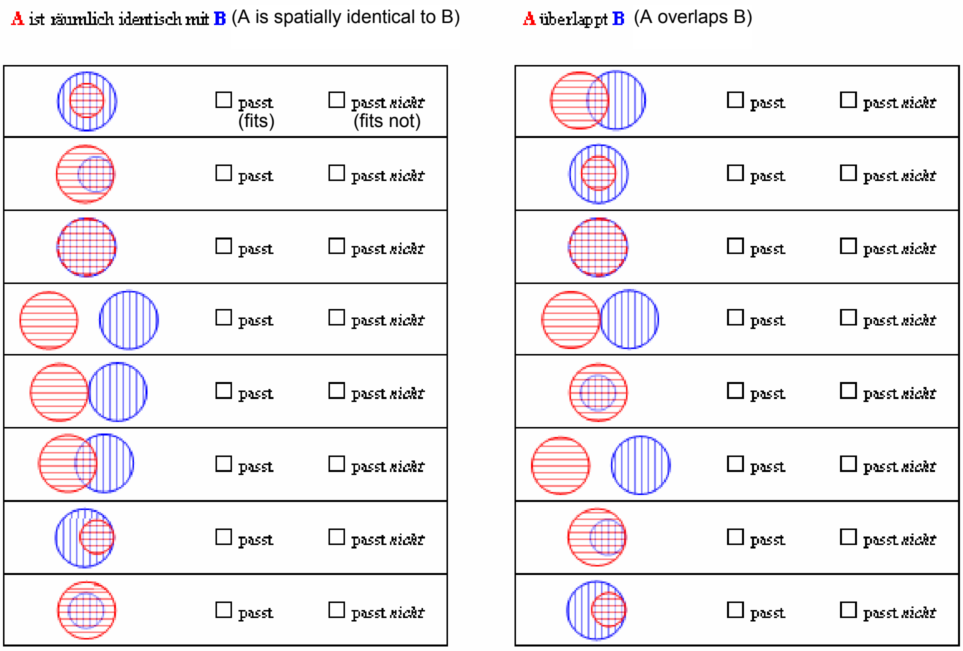

Figure 1: A page of the questionnaire (translations in brackets added)

Table 3 contains the results for the ArcGIS operators. It shows that in the worst case an operator is recognised by three percent of the subjects[5]. In the best case an operator is recognised by 56 percent of the subjects. Eight of nine operators are recognised by less than 50 percent of the subjects. The results for the GeoMedia operators are presented in ***Table 4***. An operator recognized by nine percent of the subjects is the worst case; the best case is an operator recognised by 65 percent of the subjects. Six of eight operators are recognised by less than 50 percent of the subjects. Thus, GeoMedia shows somewhat higher recognition rates in the sample than ArcGIS.

The hypothesis formulated above translates into the following statistical hypothesis about a proportion in the population:

H_0: Π_{hits}>=0.5
H_1: Π_{hits}<0.5

For each operator separately, the proportion of subjects understanding it in the intended way is tested. It is not possible to test the proportion of "good" operators across the individual operators, because the probabilities of choosing the intended interpretations in all likelihood are not equal for all operators. Proportions are tested against reference values with the binomial test, or, in the case of a sample size greater than 30 like in our study, with the approximate binomial test. The prerequisite of independent Bernoulli variables is fulfilled: the selection of one subject does not influence the selection of another subject and the outcome of a selection is either a hit, i.e. it corresponds to the system implementation, or not.

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[5] All percentages have been calculated based on the valid answers only. Three answers are invalid (marked with a dash).

The significance test yields the results depicted by the stars in ***Table 3*** and ***Table 4***. One star means that the result is significant with an error probability of ten percent. Two stars correspond to an error probability of five percent, and three stars denote one percent error probability, which is the most reliable result.

Table 3: Results for the ArcGIS operators

	are crossed by the outline of	*intersect*	*are completely within*	*completely contain*	*share a line segment with*	*touch the boundary of*	*are identical to*	*contain*	*are contained by*
ArcGIS	3	2345678	8	7	6	2456	6	47	58
S 1	23456	3	58	47	2456	23456	1236	47	58
S 2	234567	3	568	467	23456	23456	6	467	568
S 3	3	36	568	467	456	2456	126	467	568
S 4	37	3467	568	467	2456	23456	1236	467	568
S 5	34	345678	8	7	245	245	-	7	8
S 6	36	345678	568	467	2456	23456	6	467	568
S 7	3	36	568	467	23456	23456	6	467	-
S 8	36	36	568	467	23456	2456	6	467	568
S 9	3	3	58	47	6	245	6	47	58
S 10	2345	3	568	3467	23456	2345	6	3467	345678
S 11	3	47	568	467	2456	23456	1236	345678	345678
S 12	347	345678	8	7	2456	23456	6	467	568
S 13	3	345678	568	467	6	23456	6	47	58
S 14	23456	345678	568	467	232456	23456	1236	3467	3568
S 15	3	345678	568	467	2456	23456	6	345678	345678
S 16	34567	3	568	467	2456	2456	1236	345678	345678
S 17	3	3	568	467	2345	23456	6	467	568
S 18	3568	345678	58	58	345678	2345678	123	345678	1234568
S 19	3	3	6	6	3	26	12	6	6
S 20	3	3	8	7	2456	256	1236	467	568
S 21	3	345678	58	47	23456	23456	123	47	358
S 22	3	345678	568	467	2456	23456	1236	467	568
S 23	23456	234	68	47	23456	23456	1236	347	3568
S 24	3	345678	568	467	3	25	6	467	568
S 25	3456	36	5678	6	23456	23456	1236	345678	345678
S 26	3	3568	568	467	6	2456	1236	467	58
S 27	3	345678	568	467	2456	2456	6	467	1
S 28	3	347	568	467	2456	23456	1236	345678	568
S 29	3	2345678	568	467	34578	2	6	467	58
S 30	3	3	568	467	2456	2345678	1236	467	568
S 31	23456	345678	568	467	345678	23456	1236	467	568
S 32	3	345678	5678	467	345678	234567	6	467	568
S 33	3	345678	568	467	2456	2456	6	467	568
S 34	23456	345678	568	467	12345678	23456	1236	345678	345678
hits abs.	**19**	**1**	**3**	**3**	**3**	**6**	**15**	**4**	**5**
hits [%]	**56**	**3*****	**9*** **	**9*** **	**9*** **	**18*** **	**46**	**12*** **	**15*** **

Table 4: Results for the GeoMedia operators

	touch	*contain*	*are contained by*	*entirely contain*	*are entirely contained by*	*overlap*	*meet*	*are spatially equal*
GeoMedia	2345678	467	568	7	8	345678	2	6
S 1	23456	47	58	47	58	3	2	6
S 2	2	467	58	467	568	345678	2	6
S 3	23456	467	568	467	568	3467	245	6
S 4	2	467	568	467	568	345678	23568	6
S 5	2	7	8	7	8	3467	2	6
S 6	2	467	345678	467	568	345678	2	6
S 7	2	467	568	467	568	3	2345678	6
S 8	23456	467	58	467	568	345678	23	6
S 9	245	47	58	47	58	345678	345678	6
S 10	2345678	3467	345678	3467	568	345678	2345678	6
S 11	2345678	345678	345678	467	568	345678	2	678
S 12	2345678	467	568	7	8	345678	23456	6
S 13	2	47	568	467	568	345678	25	6
S 14	2356	3467	3568	467	568	345678	23	6
S 15	23456	345678	345678	467	568	345678	236	6
S 16	2	345678	345678	467	568	345678	345678	6
S 17	23456	467	568	467	568	3	2345678	1236
S 18	2345678	345678	-	58	58	34567	2	123
S 19	236	6	6	6	6	36	6	126
S 20	25	467	68	7	8	47	2	126
S 21	23456	47	58	47	58	345678	2345678	1236
S 22	2345678	467	568	467	568	345678	2345678	6
S 23	2345678	347	3568	47	68	23456	2345678	1236
S 24	2	467	568	467	568	3	2	1236
S 25	23456	345678	345678	6	5678	3467	2345678	1236
S 26	2	467	568	467	568	3	23	6
S 27	2456	467	345678	467	568	3	2	6
S 28	23	345678	345678	467	568	3	2	678
S 29	23	467	568	467	568	3	2345678	6
S 30	2345678	467	568	467	568	3	2	1236
S 31	2	467	345678	467	568	2345678	2	6
S 32	345678	467	568	467	5678	345678	2	6
S 33	2345678	467	568	467	568	34678	2345678	6
S 34	2345	345678	568	467	568	347	245	1236
hits abs.	**8**	**18**	**14**	**3**	**3**	**15**	**13**	**22**
hits [%]	**24*** **	**53**	**42**	**9*** **	**9*** **	**44**	**38***	**65**

With ArcGIS, the sample data support the alternative hypothesis (H_1) that less than 50 percent of the population understand the operator in the intended way for seven operators, in each case on the highest significance level. For GeoMedia, the alternative hypothesis is supported for three operators on the highest and for one operator on the lowest significance level. For the remaining operators, the sample data do not speak against recognition by the majority of the population.

In detail, this means that neither *intersect* nor *touch* seem to be appropriate names for the combination 2345678. Furthermore, the terms indicating complete containment do not seem to fit to the combinations 7 respectively 8. The combinations 467 respectively 568 show much better recognition rates. They are also preferred with the terms *contain* respectively *are contained by*, like implemented in GeoMedia, whereas the ArcGIS combinations 47 respectively 58 do not seem to match people's understanding. The two equality operators achieve good recognition results, with the GeoMedia term working obviously better. Good results are also reached with *are crossed by the outline of* (ArcGIS term for combination 3) and *overlap* (GeoMedia term for combination 345678). In contrast, the ArcGIS terms *share a line segment with* and *touch the boundary of* as well as the GeoMedia term *meet* are interpreted only by less than half of the people in the intended way.

DISCUSSION AND OUTLOOK

This work asked if the names found at GIS user interfaces are appropriate for the underlying implementations of topological operators. It could be shown that there are operator names that work better than others. It is an interesting question which recognition rate should be required in order to make an operator name acceptable. We have assumed that a good operator name should point to the implemented combination for more than 50 percent of users. Maybe the expectation should be higher. Of course topological operators usually are not only represented by names, but also by graphics. Good graphics can surely support and compensate weak names. However, how good can graphics be? Topological relations are not portrayable without adding metrical and directional aspects which are not inherent in the notion of topology and consequently can disguise the original meaning. Therefore, wording and graphics should be taken seriously and acceptable recognition rates for both representation forms should be striven for.

As to the test procedure, a computer-based questionnaire would prevent invalid answers and speed up analysis, which allows larger samples. The problem of a non-probabilistic sample has already been mentioned. It is possible that there are variables having a systematic influence on the topic of the study. Random selection, however, is impractical facing the population of all native German speakers.

Because most of the operator names have low recognition rates, alternative names with better rates should be looked for. As mentioned above, the human subjects test reported here included terms beyond those used in the two GIS products. The next step will be to evaluate the results of these terms and see if better alternatives can be proposed. In addition, research is needed for graphical depictions of topological relations and for the combination of names and graphics. Until the research results lead to revised user dialogues, more detailed documentation would be a helpful immediate measure.

Even if more appropriate operator names are found, this approach leaves open the question if the combinations implemented in GIS are suitable for human task solving. In this respect the results for the combinations 7 and 8 are interesting. As atomic combinations they are only very rarely associated with any of the containment terms. It would be interesting to see if this can be reproduced in actual applications, like for example planning. The more general suggestion is that the appropriateness of the combinations implemented in GIS is doubtful. On the one hand, combinations like 7 and 8 may be dispensable. On the other hand, combinations could be missing, which cannot be detected by the current approach either.

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