

Mental-model-based Similarity in Interactive Layout

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In interactive layout a drawing is repeatedly modified either by the user or by the assistance system. A usability requirement states that the assistance system should alter the layout such that the user's *mental map* is preserved. This work concretises mental map preservation from a cognitive science perspective. A notion of similarity that is based on the idea of transforming spatial mental models serves to measure the user's cognitive effort needed for orientation in the changed layout.

1 Mental Map Preservation

In recent years *graph-like* diagrams such as concept or topic maps, UML class diagrams or entity relationship diagrams have gained increasing importance in professional as well as educational contexts.

The layout of graph-like diagrams poses not only algorithmic but also complex usability problems. One still unsolved problem is the system-side re-layout of diagrams. Most layout algorithms fail to *preserve the user's mental map* [8]. They do not take into account previous layouts and thereby often produce layouts that unnecessarily force the user to reorientate himself in the new layout with the effect of reduced working efficiency and satisfaction.

Despite many efforts to develop algorithms preserving the mental map of a diagram (e.g. [9, 3]) there still exists no general solution to this problem. Therefore it was proposed, to develop difference metrics measuring mental map preservation [1]. The use of such measures is twofold. They can be used to evaluate existing algorithms with respect to their ergonomic adequacy and can provide concrete hints for design principles layout algorithms should follow. In [1, 2] several measures were evaluated for their capability to measure mental map preservation. The evaluated measures relied on well known concepts such as Euclidean distance. Due to shortcomings in the evaluation method that was mainly based on similarity judgements the results of the investigation are questionable.

2 Mental-model-based Approach

This work presents a framework of similarity measures for two-dimensional spatial configurations such as graph-like diagrams. It concretises mental map preservation in cognitive science terms. The argument starts with the intuition underlying the notion mental map, that only some layout information is relevant for layout changes while other is not. In cognitive science, this intuition is covered by the notion *spatial mental model*, a mental representation of a real or imaginary spatial configuration. In the context of spatial reasoning, findings in Mental Model Theory [7] suggest an approach where the ease of navigation in a changed layout is considered as the cognitive effort needed to transform the mental model of one layout into the mental model of a changed layout: ease,

formalized as similarity measure, decreases with increasing spent cognitive effort.

The proposed similarity concept makes some key assumptions that rely on findings about the nature of spatial mental models and how they are transformed:

Finite relational structure. When a user is presented with a layout, he perceives visual information. While detailed metrical information like precise position, distance, or angle fades away in short-term visual memory within splits of seconds, only vague and incomplete information remains afterwards. This remaining information forms the basis of a spatial mental model, which can be seen as a finite relational structure [11].

Hierarchy. Human short-term memory is characterized by its capacity limitations. A reasoning strategy to reduce working memory load is *chunking*, the process of integrating separate pieces of information into units of higher order. The resulting hierarchical structure is more compact and thereby allows keeping in memory more pieces of information.

Neighbourhood. Results about one-dimensional mental models indicate that mental models of spatial configurations encode explicitly only relations between neighbored elements [11]. There is also first evidence that in two dimensional mental models the relational structure with the represented spatial relations constitutes a planar graph [12].

Local transformations. According to Mental Model Theory, a basic reasoning strategy is the subsequent consideration of alternative models of a given situation. In the context of spatial reasoning, empirical results indicate, that the subsequent generation of alternative models consists in the creation of a first model and then subsequently changing this model by performing certain structural transformation operations [11]. But spatial mental models are no random access structures. Access is mediated by a focus which rests on an element of a mental model. If the mental model needs to be accessed (or modified) elsewhere, the focus must be shifted from this element step-wise to immediately neighbored elements until it reaches the element in question. Structural transformations as well as focus shifts cause cognitive costs.

3 Similarity Concept

These findings are integrated into a formal concept of similarity. The mental model is represented as an annotated

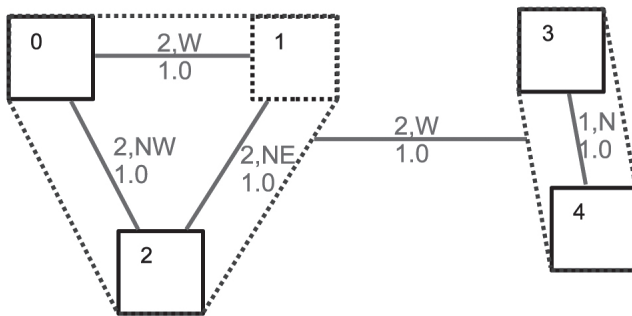


Figure 1: Representation format

graph (see figure 1. Two types of nodes, primitive objects representing layout objects (in the figure square boxes each identified by a unique number) and groups of primitive objects (boxes within dashed bordered areas) represent elements in two hierarchical levels. Edges either assign primitives to groups or relate neighbored objects (continuous annotated lines). Neighbourhood-edges represent explicitly encoded spatial relations. They connect two neighbored nodes of the same hierarchical level and are annotated with information about the spatial relationship between the connected nodes (upper annotations for directional information (e.g. *West*) and distance) and a degree of *prominence* (lower annotation). For a more detailed description of the representation format see [4].

Similarity is defined on the basis on the "transformation distance between representations" [5]. A representation is transformed into another by applying subsequently one of a set of basic transformations such as deleting or inserting an edge, renaming an edge or changing the focus position. The usual computationally expensive approach to determine the minimal transformation costs is replaced by a concept that is motivated by this idea but compares two graphs directly with respect to structural differences and required focus steps in an efficient way.

The similarity concept is realized as a framework that is adaptable to different types of two-dimensional spatial configurations. Thereby, it can capture domain-specific requirements such as those posed by different types of diagrams. A suitable domain-specific similarity measure is created by parameterizing elements of the representation and the costs for specific types of transformations such as edge deletions or insertions. The most important configurable elements of the representation format are the outline of the represented layout objects, the grouping mechanism, the relevant types of spatial relations, and the prominence of spatial relations.

4 Application to Graph-like Diagrams

Graph-like diagrams basically consist of two types of layout objects, nodes and edges. A basic assumption made for applying the framework to the domain of class diagrams is that memory traces essentially encode the positions of the boxes. Spatial neighbourhood relations, not functional relations are relevant for preserving the user's mental map. This is not surprising, if one takes into account that a good layout of graph-like diagrams tries to satisfy limitations of human perceptive

faculty by placing functionally related objects close to each other.

Class diagrams lack a natural hierarchical structure with respect to groups of layout objects. We propose a simple interactive grouping mechanism that allows the user to partition the layout himself: Elements are grouped together according to the law of proximity. Each group is a connected graph with respect to the neighbourhood relations, and the distance between two neighbored group members falls below a predefined threshold.

Because this simple mechanism does not guarantee a layout containing well perceptible groups, it must be complemented either with a suitable visualisation of the groups or a layout algorithm ensuring sufficient large distances between groups.

5 Coarse-fine Localisation

A typical element of navigation in graph-like diagrams is searching for specific nodes. In general, layouts where layout objects are arranged in easily perceptible groups offer an efficient search strategy provided that the user has in mind the group memberships, i.e. what nodes belong to the same group. Then he can embark on an *coarse-fine-localisation-strategy*: Firstly he locates the group containing the layout element of interest. If it is found, he can restrict further search on this group.

Under the idealized assumption that grouping is the only available information, one can quantify the use of this strategy. If the number of groups is approximately the same as the number of the elements of each group, the needed average effort amounts to $O(\log(N))$ with grouping instead of $O(N)$ without. Note, that this argument is only based on the existence of a hierarchy but independent from its specific properties.

6 Experiment

In theory, users navigating a grouped diagram could profit from the coarse-fine-localisation-strategy, but it is not self-evident that it is easy to use, although in the other context of route searching in an environment, grouping of semantically related neighbored landmarks has proved to support efficient navigation with this strategy [13].

For the navigation in diagrams, an experiment should verify whether participants 1) recognize preserved group memberships in modified layouts and 2) are spontaneously able to exploit this knowledge for the described search strategy. A group-based measure was compared with another similarity measure relying on Euclidean distance [2] that does not account for proximity based grouping. Instead of graphs with edges, configurations of named square boxes served as diagrams. At first, participants learned one layout of such a box configuration. After viewing the learned layout, they were presented with another layout of the same box configuration where all names except one were hidden. Participants could click with the mouse into a box in order to make its name visible. Using this type of interaction, they had to locate the box of a given name with a minimum number of clicks while

working in a speedy manner. The effort to find a box was operationalized with the number of clicks and the time needed to find the box in question. The layouts were constructed in a way that both measures returned contradicting predictions about the participant's efforts.

The results of the experiment confirmed the hypotheses that users spontaneously use the coarse-fine-localisation strategy while Euclidean distance seems not have a causal effect on their behaviour.

7 Conclusion

The presented framework of similarity provides a formalisation of the intuitive notion mental map preservation.

It provides concrete hints layout algorithms should follow. While small changes of metrical information do not prevent the user from efficient navigation in a changed layout, changed group memberships of layout elements or changes in neighbourhood do.

Another suggested design principle is the use of group based layout: layout objects are grouped according to the Gestalt principle of proximity. This principle contradicts commonly accepted aesthetical design principles for graph layout algorithms stating that edges should have all the same length and that nodes should be evenly distributed [6, 10]. Layouts created with such algorithms do not arrange layout objects in well perceivable proximity-based groups and thereby prevent the user from efficiently locating layout objects using the *coarse-fine-localisation strategy*. Because the sketched experimental findings indicate the use of this strategy, grouping should be taken into account as additional design principle for future layout algorithms and user interfaces.

On the other hand, there remain open questions. The presented notion of similarity itself needs further empirical evaluation. In general, developing a suitable experimental framework for investigating mental map preservation would be helpful for further research. Here, the type of search task used in the presented experiment seems to be a promising part of such a framework. All in all, these open questions give cause for further extending the cooperation between computer scientists and cognitive psychologists.

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