Generalisation of spatial layouts

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Abstract

Generalisation of past spatial layouts provides designers with flexibility to apply the generalised knowledge for a new layout design problem. There are a number of existing approaches to generalising layouts which, in most cases, carry out limited generalisation based on symbolic and sub-symbolic concepts. In this paper, we present two *new* approaches to generalising layouts based on geometry and topology and raise a number of *key* issues.

1 Introduction

In the context of design re-use not only do designers directly re-use specific past designs and experiences to solve a new design problem (e.g. case based reasoning (Maher et al[1])) but they can also learn from the past designs and subsequently re-use the generalised knowledge to solve the problem. In the realm of spatial design, learning past spatial layouts involves generalising or abstracting the layouts into different levels of abstractions based on particular criteria. Generalisation of past spatial layouts provides designers with flexibility to apply the generalised knowledge for a new layout design problem. That is, it reduces the complexity of the knowledge of the layouts, enabling designers to use the generalised knowledge according to their needs. In addition, when searching for past layout solutions, this generalisation supports efficient search as it provides a reduced search space of the past layout solutions.

There are a number of existing approaches to generalising spatial layouts. In most cases, they generalise the layouts based on symbolic and sub-symbolic concepts (see Section 2). In this paper, we present two *new* approaches to generalising layouts based on geometry (similarities in shape) and on topology (similarities in spatial adjacencies), respectively. Realisation of these two approaches raises a number of general questions: (i) *how is the clustering of geometric and topological patterns of layouts, respectively, to be carried out?*, (ii) *how are hierarchical abstractions of these patterns to be generated?* and (iii) *how are these hierarchical abstractions to be used?*. The two presented approaches will be briefly discussed in Section 3. Furthermore, there are a number of *key* issues that should be taken into account if either of these two approaches is to be pursued. These *key* issues will be briefly discussed in Section 4.

2 Existing approaches to generalising spatial layouts

Generalisation of spatial layouts is an important part of human-based processes involved in spatial design. It is a process by which layout design knowledge is organised in a multi-level structure of knowledge from specific precedents (design cases) to higher levels of knowledge (Oxman[2]). This structure of knowledge can be utilised for a new design process in that it supports efficient knowledge search and retrieval. For example, Oxman[2] presents a formal

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typification (a form of generalisation) of precedents of architectural buildings into a number of levels of abstraction. In the first level of abstraction the precedents are typified into their *functional types* (the functionalities of the buildings), such as church, library and villa types. In the next abstraction level, these *functional types* are then typified into *typological types* (the forms or shapes of the buildings), such as the "central type" and "nine square". These initial *typological types* can further be typified into higher level *typological types*, such as the "centralised type", and so on.

Oxman's formal typification forms the classes of formal types which include syntactic classes of design solution types as higher level knowledge than *functional types* or precedents. The syntactic classes represent the formal and typological knowledge which is relevant knowledge for design generation. An example of such knowledge is a shape grammar. For example, sets of rules of a parametric shape grammar, developed by Stiny & Mitchell[3], are defined based on the generalisation of the patterns of Palladio's villa plans. These sets therefore can be used to generate new villa plans of the Palladian style.

The concepts of generalising layouts, such as those proposed by Oxman[2] and Stiny & Mitchell[3], provide theoretical bases upon which the existing approaches to generalising spatial layouts may be based. These existing approaches can be classified as *symbolic* and *sub-symbolic*.

- **Symbolic**. The approaches belonging to this class use symbolic representation of layouts. They use symbolic reasoning to generate symbolic representations of the generalised layouts. The generalisation, in most cases, takes the form of sets of generic rules, symbolic typifications and numerical ranges. For example, Guena & Zreik[4] propose a system architecture for knowledge-based architectural design systems based on symbolic reasoning through analogy with past building cases. A type of frame, referred to as *scheme* [4], is used to represent the generalisation of past cases or situations. It includes performance, structural and topological attributes of this generalisation, which are represented as text and numerical ranges. In the FABEL project (Voβ et al[5]) specially developed machine learning techniques are used to acquire knowledge from layout design cases. The main focus of this project is to develop methods for case retrieval of similar layouts and for case adaptation in different representations.

- **Sub-symbolic**. Coyne & Postmus[6] explore the application of neural networks to simple spatial reasoning. The neural network system is able to generalise features which describe spatial layouts. Examples of these features are adjacencies between the spaces, sizes and orientations, which are represented as neural network patterns. Given a partial input pattern to match against a set of previously learned patterns, the system can produce an output pattern which is a generalisation of the learned features. However, one of the major drawbacks of using the standard neural network model for pattern matching is that the model is sensitive to the locally changed pattern (Manfaat et al[7]). That is, once a network has "learned" to match specified input values with particular outputs, then a change to the input, due to say rotation, scaling, etc., would result in a mismatch of the output.

There are different viewpoints upon which generalisation of spatial layouts is based. In relation to this, we believe that designers should be allowed to generalise layouts according to their particular needs. As pointed out by Kerr[8] in her "Customised Viewpoint" approach, generalisation of specific experiential design knowledge, into appropriate viewpoints, according to designers' needs, makes the generalised knowledge *applicable* for use. In this paper, whilst the existing computer-based approaches *do not* generalise layouts into different levels of abstractions, we propose this kind of generalisation based on the viewpoints of geometry and topology and raise a number of *key* issues which arise. We argue that if we can support designers by providing them with learning techniques which can generalise geometric and topological patterns of layouts into different levels of abstraction, designers can have opportunities to use such patterns and their abstractions. In addition, when searching for a particular layout(s), each of these kinds of generalisation supports efficient search as it provides a reduced search space of the layouts. That is, given an input geometric or topological pattern of a layout, to search for similar layouts, it is not necessary to match the input directly with the geometric and topological patterns of layouts, respectively, but to match the input with abstractions of the layouts. Once they are matched, either partially or completely, relevant layouts and/or their abstractions can then be retrieved.

3 Generalisation of spatial layouts based on geometry and topology

This section discusses two layout generalisation approaches based on geometry and topology.

3.1 Geometric generalisation

Generalisation of spatial layouts based on geometry entails generalising the layouts based on the shape of each of the spaces. To generalise, it is necessary to match the shapes of the spaces of one layout to another. This is regardless of the functionalities of the spaces. Thus, generalisation is obtained by clustering the layouts and their abstractions, respectively, based on their similarities in shape. As an example, consider a set of six spatial layouts of the catering decks of passenger ships given in Figure 1. When generalising this set based on shape, we may have a hierarchy of generalised layouts as shown in Figure 2. With geometry, designers are

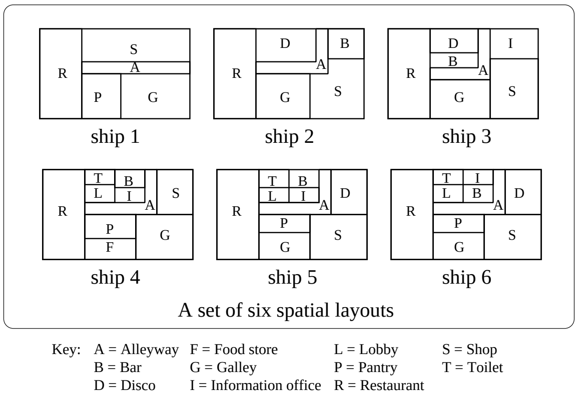

Figure 1: A set of six spatial layouts of the catering decks of passenger ships.

provided with a hierarchical abstraction of geometric patterns of the layouts with which they can directly match an input geometric pattern they prefer to have. That is, designers can directly represent an image of what they have in mind and find a match of it in the hierarchical abstraction of the geometric patterns.

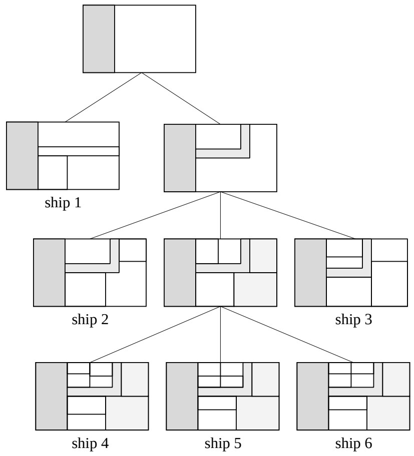

Figure 2: Generalisation of the spatial layouts based on shape.

3.2 Topological generalisation

Topology, here, refers to adjacencies between the spaces of a layout. The topology of a layout can be represented as an adjacency graph. Thus, if the layouts in Figure 1 are generalised based on this kind of representation, a hierarchy of adjacency graphs given in Figure 3 may represent the result of this generalisation. The grouping of the layouts and their abstractions, respectively, are based on similarities in these graphs, i.e. the number of similar spatial adjacencies between the graphs. This kind of generalisation supports efficient search and retrieval of the layouts, because the topology itself represents the abstraction of a layout in terms of adjacencies between its spaces.

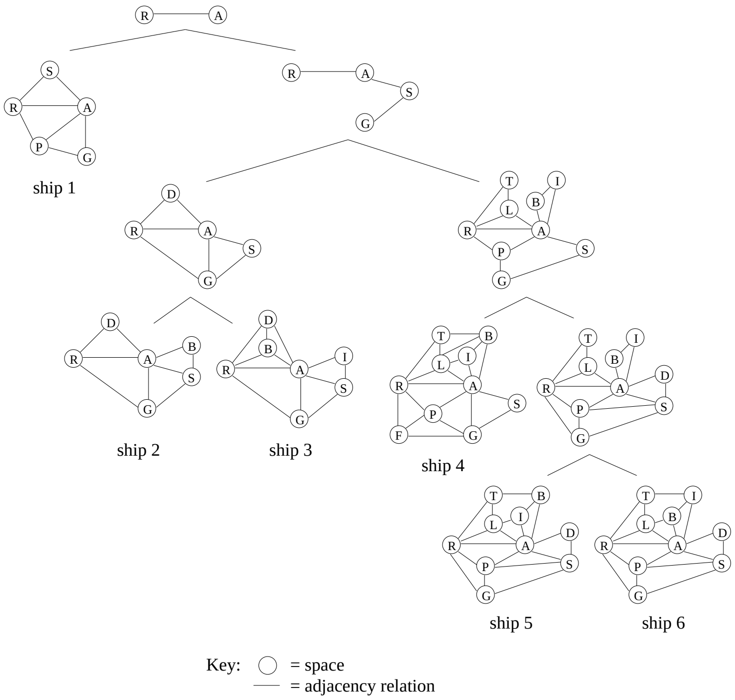

Figure 3: Generalisation of graphs of spatial adjacencies of the layouts of Figure 1.

4 Key issues

Two feasible approaches to generalising layouts have been briefly discussed in Section 3. These give rise to a number of *key* issues which can be briefly discussed as follows:

- **How to represent the layouts?** Representations of the layouts should support the processes involved, such as pattern matching, clustering, abstraction and retrieval of the layouts and their abstractions. For example, closed polygons may be used to represent the shape or geometric pattern of a layout. These polygons may be transformed into a different representation in order for a process, e.g. pattern matching, to be carried out.

- **How to pattern-match the layouts?** To generalise the layouts we need to cluster them into groups. To cluster them, we need to pattern-match one layout to another. For example, given two geometric patterns to match, the pattern matching process should be carried out in such a way that the result of matching is as accurate as possible. Further, if there is a change to either or both of the patterns (e.g. due to rotation, scaling, translation, etc.), the accuracy of matching should not be affected. That is, the matching process should be robust.

- **How to measure similarities between the layouts?** Matching layouts results in a degree of similarity, such as an overall or a part similarity, between them. It is carried out by comparing the parts and/or attributes of one layout with those of another. For example, in matching two graphs representing two topological patterns of layouts, the measuring of similarities between the graphs is carried out by finding the correspondences between the nodes of one graph and those of another graph, which preserve the correspondences between the links of the graphs.

- **How to cluster similar layouts?** Based on the measures of similarities between the layouts, the layouts can be clustered into groups with each group representing the generalisation of its layout elements. The clustering should be done in such a way that the layouts, which have a higher degree of similarity, should be clustered in the same group. The groups of the layouts should further be able to be clustered into higher level groups representing abstractions of the layouts.

- **How to generate hierarchical abstractions of the layouts?** Based on the clustering of the layouts and their abstractions, it should be possible that hierarchical abstractions of the layouts can be generated. In each level of abstractions, the abstraction process is carried out by preserving the common parts and/or attributes of the layouts and merging or dropping the other parts and/or attributes which are significantly different. For example, in abstracting geometric patterns, the similar shapes of the parts of the patterns are preserved, whilst the other parts whose shapes are different are merged to form the new abstract shapes.

- **How to search, match and retrieve similar layouts given an input layout?** To retrieve layouts similar to a given input layout we need to search the layouts and their abstractions and match the input against them. The input given by designers should be represented in such a way that these searching and matching processes can be carried out. Once the matching layouts or abstractions are found, it should be possible to retrieve the layouts and/or abstractions.

- **How to update the hierarchical abstractions of layouts when new layouts are added?** This involves augmenting the hierarchical abstractions of layouts by adding new layouts. Will the added layouts be accommodated into particular clusters of layouts/abstractions as the new instances of these clusters, or will these hierarchical abstractions be regenerated by including the added layouts?

5 Conclusion

In this paper, we have presented two *new* approaches to generalising spatial layouts based on geometry and topology. It has been shown that whilst the existing symbolic and sub-symbolic approaches *do not* generalise layouts into different levels of abstractions, the two presented approaches provide abilities to do this kind of generalisation. This is a creative process which generates a hierarchical structure of past layout design knowledge. It generates and makes explicit patterns and generalisations of previously implicit knowledge. The knowledge structure supports efficient search and retrieval of past layout design knowledge and solutions. Furthermore, a number of *key* issues, arising from the suggested two approaches, have been briefly discussed. One of these key issues is pattern matching. It is thought that if we can properly deal with the pattern matching problem, we can establish effective learning techniques which support designers with efficient clustering and abstraction of layouts.

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