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CONSTRUCTING COMPUTATIONAL ASSOCIATIONS BETWEEN ORNAMENTAL DESIGNS

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Abstract. This paper presents the application of a computational model of association to the domain of real-world ornamental designs. The driving principle of the model, interpretation-driven association, is discussed with respect to its suitability to design applications. An implementation of the model is presented, in which associations are constructed based on topological and typological relationships within each design's structure, rather than based on literal similarities. Results are presented which demonstrate that the implementation and the model from which it was derived are capable of associating between real-world design objects.

Keywords. Design association; design interpretation; computational modelling; ornamental designs.

1. Computational association in design

Association, in this paper, refers to the process of constructing new relationships between different ideas, objects or situations. This is a similar definition to that of computational analogy-making (French 2002), but without the requirement that the relationship so constructed be then used to transfer knowledge between the domains of the two analogues. Association can be considered a foundational component of analogy-making, which is considered an important cognitive process in designing (Qian and Gero 1996).

In a design context the representations of the objects to be associated will change before, during and after the association is made. In this way design is unlike many problem-solving domains to which computational models of association have been applied. Designers modify their representations of both the design problem and the emerging design solution while they are designing. They act to further the design, reflect on that action, and act again (Schön 1983). These representational modifications are not necessarily gradual or incremental, they are often deliberate reinterpretations that construct new design situations (Gero 1998).

An important question in the computational modelling of association is how to re-represent and transform the representations of objects in such a way as to enable the construction of new associations (Kokinov 1998). Re-representation in association research is complicated by a recursive question: How can the representation that enables a new mapping be constructed before the mapping itself? And how can a mapping be constructed before the relationship that enables it? These questions parallel those raised in the computational modelling of design. This research approaches these problems by using iterative and parallel processes of transformation and search to construct new representations and associations.

The model of association described in Grace et al. (2011) is well suited to the representational dynamism of design contexts, as it does not require an extensive knowledge base about the domain(s) it is associating. Additionally, the representations used in this model need not possess identical relational lexicons, as associations are found based on similar structures of relationships rather than identically labelled representations. These characteristics arise from the notion of interpretation-driven search. This paper describes an implementation of that model and presents its output.

2. Interpretation-driven association

Grace et al. (2011) define an interpretation as a transformation applied to a representation of an object. These interpretations change the structure and/or content of the representations to which they are applied. This in turn changes the relationships that can be constructed from them. An interpretation-driven approach to computational association involves an iterative, parallel interaction between reinterpretation of object representations and searching those representations for mappings. In this framework, Figure 1, potential interpretations are constructed from the search for mappings, based on what transformations could enable new mappings. Additionally, the search for mappings is affected by what interpretations have been applied to the objects, as each transformation changes the search space. This iterative feedback between searching and transforming parallels the notion of reflection-in-action described by Schön (1983) as central to design thinking.

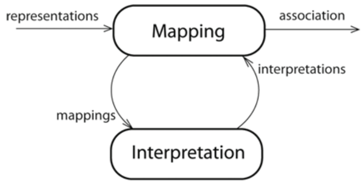

Figure 1. The interpretation-driven framework for computational association.

Models of association-based processes propose that associated objects share patterns of relationships, but not necessarily the attributes connected by those relationships (Gentner 1983). The model used in this research extends this principle to an additional level of abstraction, positing that associated objects need not share patterns of identically labelled relationships, only that the structure of those patterns be similar. The system constructs an interpretation of the objects in which similar structures of disparate relationships can be viewed as alike. This is the basis of the interpretation-driven model of association detailed in Grace et al. (2011) of which an implementation is described in this paper.

The implementation described in this paper will be first assessed for its compliance with the principles of the interpretation-driven approach to association. In order to be judged a complete implementation of the model, the implementation must construct interpretations during the search for mappings, apply those interpretations to affect the trajectory of the search for mappings, and produce associations between interpreted representations. Once it has been demonstrated that the implementation exhibits these behaviours, it will be possible to demonstrate the effectiveness of the model through the results produced by the implementation.

3. Implementation

The computational model of interpretation-driven association was implemented in the domain of ornamental visual designs. This domain permitted the use of vector-based line drawings for which representation construction processes could be efficiently developed. This implementation and the experiments performed using it serve as a proof of concept of the capabilities of the model.

The model begins with the process of representation construction, in which features are extracted from low-level visual representations and organised into conceptual categories. Relationships between these features and concepts are automatically constructed, and then a graph representation is constructed from these features and relationships. These graphs provide the representations that can be iteratively transformed and searched.

The implementation of the model developed in this research begins with vector representations of ornamental designs and constructs a set of minimal closed shapes from them. These shapes became the features used in the system, each of which was described by the contours of its outline. Outline descriptions are produced by casting rays from the polygon centroid and measuring the distances to their intersection with the polygon's edge. This is similar to the centroid-radii method proposed by Tan et al. (2003). Five example features and their descriptions can be seen in Figure 2. Features were then placed into concepts using a clustering algorithm.

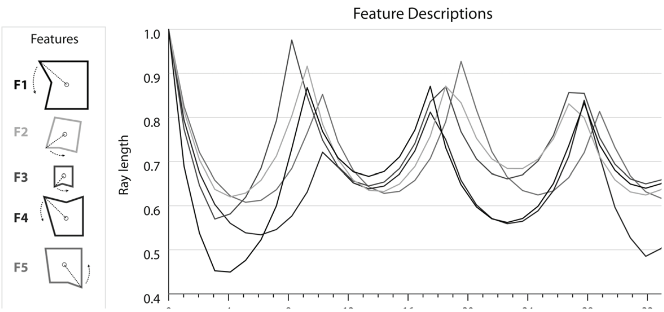

Figure 2. Five example features (on left) produced by the implementation of our model of association. A plot of their descriptions (on right) shows the outlines produced, with the y axis as the normalised side length and the x axis as the point on the outline.

The relationship formation process searched the feature representations for a wide variety of both topological and typological relationships, including relative scale, relative position, relative orientation, same concept and similar concept. These relationships were then converted into graph edge labels, categorising continuous-valued representations where necessary. The resulting graph representations were then used by the system to construct associations in the manner described by the model.

The mapping search process was implemented using a genetic algorithm-based approximation of subgraph isomorphism. The genotype for each individual mapping candidate was which features in one object would be mapped to which features in the other object. The fitness function was then based on the size of the largest contiguous subgraph of identically labelled edges that each mapping produced.

Interpretation in this implementation involved the substitution of edge labels. When an interpretation was applied the edges in one object's graph with a particular label, along with the edges in the other object's graph with a different label were replaced with a third, unique label. This represented the idea that those two relationships were considered equivalent in the context of the interpretation. These interpretations transformed the fitness function being used by the genetic algorithm during the search, affecting the search trajectory as required to satisfy the description of the model.

4. Experiments in association with designs

In order to demonstrate the capability of the implementation – and accordingly the model – to produce associations between designs, a large number of ornamental design objects were given as input and the results were investigated. A subset of those results is presented here.

The six designs with which the association-construction behaviours of the implementation are to be demonstrated are shown in Figure 3. These design objects were gathered from a variety of sources, shown in Table 1.

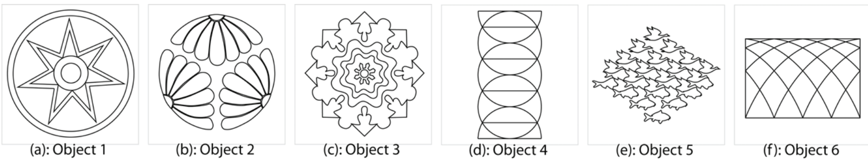

Figure 3. The six designs that are used in associations constructed by our implementation. These vector image representations were manually constructed from source images.

TABLE 1. Sources for the six designs shown in Figure 3.

Obj.	**Description**	**Source**
1	Hittite sun symbol.	Humbert (1970)
2	Japanese floral symbol.	Humbert (1970)
3	French empire motif.	Humbert (1970)
4	Ironwork pattern for a gate, fence or balcony.	Cottingham (1824) via Cliff (1998)
5	'Sky and Water I', oil painting.	Escher (1938)
6	Ironwork pattern for a gate, fence or balcony.	Cottingham (1824) via Cliff (1998)

From these six objects three trials were performed, with each trial consisting of constructing associations between two objects. The trials are as follows:

- *Trial 1* associates Object 1 and Object 2.
- *Trial 2* associates Object 3 and Object 4.
- *Trial 3* associates Object 5 and Object 6.

Multiple associations were constructed in each trial as the system can produce different output depending on its historical context – see Grace et al. (2011) for details. Each trial was repeated until 10 consecutive associations were constructed that had already been produced. All unique mappings were recorded, along with the interpretations under which they were constructed. A selection of the results from each trial is presented here.

5. Results

The results images presented in this section use the following formatting:

- Each of the two objects is bounded by a light grey box.
- The outlines of unmapped object features are drawn in grey stroke.
- The outlines of mapped object features are drawn in a black stroke.
- Thin black lines between the two objects join mapped features.
- Thick dashed lines between features of an object show the relationships on which the mapping was based. These mappings are labelled with their respective relationships.
- The interpretation used to construct the association, referred to as *i* in the model, is shown in a box below the two objects.

5.1. RESULTS OF TRIAL 1: OBJECTS 1 AND 2

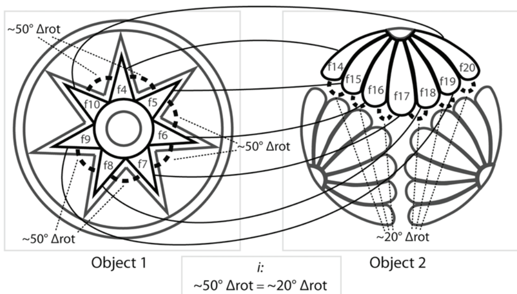

Figure 4. A result from Trial 1 showing an association between Objects 1 and 2. The seven points in the star on the left have been mapped to seven petals in a floret on the right.

Figure 4 shows one of the associations constructed by the implementation during Trial 1. The star-shaped pattern central to Object 1 has been mapped to one of the three florets in Object 2. This mapping was enabled by an interpretation that equates the difference in orientation between adjacent triangles in Object 1 with the difference in orientation between adjacent petals in Object 2. Specifically this interpretation situationally equates a 50° difference with a 20° difference. These relationships are treated as interchangeable while the interpretation is applied, enabling the association.

5.2. RESULTS OF TRIAL 2: OBJECTS 3 AND 4

Figure 5 shows one association constructed by the implementation during Trial 2. The eight arrow-headed objects surrounding the perimeter of Object 3 have been mapped to the eight circular segments in the centre of Object 4. This mapping was enabled by an interpretation that equates the difference in orientation between adjacent arrow-features with the difference in horizontal position between the segments. Unlike the interpretation used in Figure 3 this interpretation is heterogeneous with respect to relationship type.

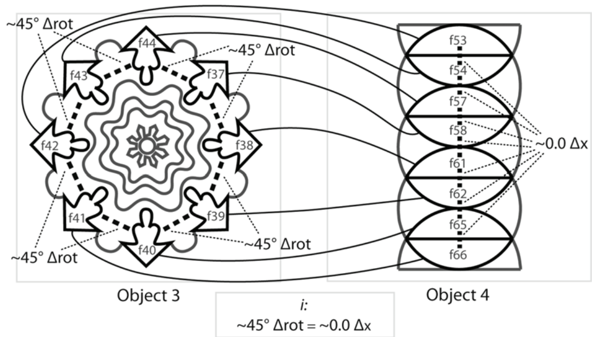

Figure 5. A result from Trial 2 showing an association between Objects 3 and 4. The eight features surrounding the design on the left have been mapped to the eight segments in the design on the right.

Figure 6 shows a different association that was constructed by the system during Trial 2, this time connecting the six concentric shapes that form the body of Object 3 with the six curve-sided triangles that adjoin the centre of Object 4. This mapping interprets a set of "contains" relationships in Object 3 – relationships based on one feature being entirely inside another – to be like a set of orientation difference relationships in Object 4. These two sets of very different relationships share a common structure and were able to be associated through interpretation by our implementation.

5.3. RESULTS OF TRIAL 3: OBJECTS 5 AND 6

Figure 7 shows one of the two associations constructed by the system during Trial 3, in which the four rows of fish-shaped features, thirteen in total, are mapped to the four rows of four-sided shapes, also thirteen in total. The other association that was constructed in this trial had the same overall structure but mapped the triangular structure of the fence in Object 6 to the birds in the upper half of Object 5 instead of the fish. This association demonstrates that visually complex patterns can be represented as graph structures with simple underlying structural commonalities. Associations can then be constructed based on those commonalities using interpretation-driven search.

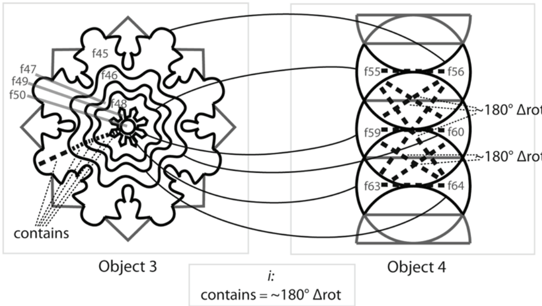

Figure 6. A result from Trial 2 showing an association between Objects 3 and 4. The six concentric shapes in the design on the left have been mapped to the six three-sided curved objects in the design on the right.

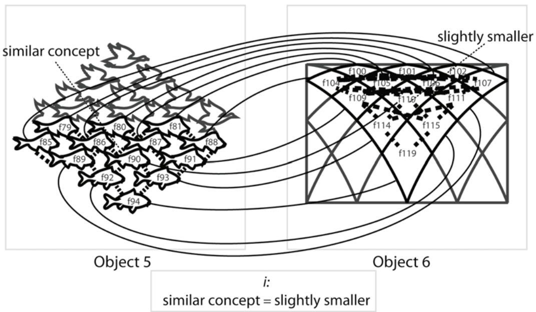

Figure 7. A result from Trial 3 showing an association between Objects 5 and 6. The rows of gradually more abstract fish on the left have been mapped to the rows of gradually smaller quasi-rectilinear shapes on the right.

6. Discussion

The challenge of applying computational association to design tasks is that the act of designing possesses qualities that differ significantly from the well-structured problem-solving domains to which computational associative reasoning is typically applied. Design is a sequence of situated acts (Gero 1998) that is characterised by iterative cycles of reflection and action (Schön 1983) and intended to solve a wicked problem (Rittel 1988). The model described in Grace et al. (2011) can be shown to address each of these characteristics, and the implementation described in this paper demonstrates the feasibility of that model. This approach to computational association is both possible and demonstrably suited to design, which will enable a furtherance of association in design research.

The model incorporates the effects of experience on both object representation and interpretation construction, making these processes dependent on the historical context of the system performing them. This is a significant step towards the modelling of association in design as a situated process. The associations shown in Figures 4 through 7 are the product of a system for which the output is dependent not only on the current inputs but also on what has come before. If the system has successfully used a particular kind of interpretation on a past association problem it can attempt to re-use it again, leading to ‘priming’ effects of past input on results.

The interpretation process that enabled all of the results presented in this paper involves the iterative construction of potential mappings, the investigation of those mappings for avenues for interpretation, and the generation of interpretations that transform those mappings. This process is an analogue of the reflection-in-action process described by Schön (1983), in which the critical role of the seeing-as process is performed by interpretation. In formulating association as being based on this iterative, reflective approach, the model described in Grace et al. (2011) renders the association process more compatible with design thinking.

The classification of design, particularly creative design, as a wicked problem prohibits the specification of a complete solution space before or during the design process. This means that the space of possible designs can change – often dramatically – during design itself, and that any computational model to be applied to design must be capable of operating in an environment of representational dynamism. The results presented in this paper were generated using representations that were developed by the system during operation. These graph representations of object features and the typological and topological relationships between those features were constructed from low-level visual input by the system itself. These representations were then transformed by constructed interpretations.

The development of a computational model of association that is demonstrably suitable for application in design opens up opportunities for future research. With the incorporation of a knowledge transfer process, the model could be used to construct analogies. Computational analogy-making can be used in design for proposing or modifying candidate design solutions, although Goel (1997) suggests it could also be used for elaboration, decomposition and problem-framing tasks.

The process of association could also be used as the basis for a computational model of design style. The factors that influence design style do not typically lead to style descriptions that can be simply delineated in most computational design representations (Jupp and Gero 2006). Association has been used to judge similarity by mapping what features of two objects are similar and what features are different but structurally comparable. This is referred to as 'alignable difference' and has been found to strongly predict human similarity judgements (Markman and Gentner 2005). An interpretation-driven approach could use the interpretations on which associative similarity judgements were based to characterise how objects were related. These characterisations of the kind of transformations necessary to relate two objects could form a description of design styles.

The results presented in this paper serve as a proof-of-concept of the interpretation-driven search framework for computational association in design. It has been demonstrated that the model presented in Grace et al. (2011) can be used to produce interesting associations between representations of real-world design objects that it has constructed.

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