

Representational affordances and creativity in association-based systems

Kazjon Grace

Faculty of Architecture, Design and Planning
Sydney University
NSW, Australia
kazjon@arch.usyd.edu.au

John Gero

Krasnow Institute
for Advanced Study
George Mason University
Fairfax, VA, US
john@johngero.com

Rob Saunders

Faculty of Architecture, Design and Planning
Sydney University
NSW, Australia
rob.saunders@sydney.edu.au

Abstract

This paper describes ongoing research into association-based computational creative systems. The necessary components for developing association-based creative systems are outlined, and the challenges in measuring the creativity of such a system are discussed. An approach to operationalising creativity metrics for association-based systems based on representational affordances is described. This approach is then demonstrated through an analysis of results produced by a system for constructing associations between visual designs.

Association-based creative systems

Association, or the construction of a new relationship between two concepts or ideas, is a cognitive process at the heart of many creative endeavours. Its presence is most obviously felt in analogy and metaphor, but associative reasoning is also a component of complex similarity judgement, recognition and simplification tasks (Markman and Gentner 1993; Balazs and Brown 1998; Goel 2008) that are critical to the appreciation of creative works. Given the creative potential of analogical processes (Goel 1997; Hofstadter and the FARG 1995; Kuhn 1962) and the importance of understanding and appreciating creative works (Jennings 2010; Wiggins 2006; Colton 2008) to a computational creative system, it is clear that an operationalised understanding of the process of association that underlies these and other acts is of value to the field of computational creativity. Furthering that understanding is a twofold endeavour: computational models of association that are general, extensible and powerful must be developed, and metrics by which the creativity of those models can be assessed must be devised.

Association involves representing objects in a manner that enables a new relationship between them. A mapping is then constructed between the objects which embodies that relationship. These two component processes - representation and mapping - cannot be modelled serially or discretely, as representation depends on mapping and mapping depends on representation (Kokinov 1998). This complex relationship between the mapping and the representations used in mapping creates a 'chicken-or-egg' problem that must be addressed by any computational model. Not only must a computational model of association possess representational

flexibility, but the search for representations must be informed by feedback from the ongoing search for mappings, just as the search for mappings is influenced by the construction of new representations.

Notably the process of association does not incorporate the use or evaluation of the relationships that it constructs. This is the primary addition of processes like analogy that extend association - analogy adds the transfer of knowledge between the associated object, the use of that knowledge to achieve some goal, and the evaluation of the analogy in terms of its utility at achieving that goal (French 2002). Association-based similarity judgement also extends association, in this case by evaluating mapped and unmapped attributes to construct a notion of similarity between the objects and then using that similarity in some categorisation or comparison task (Markman and Gentner 1993). Models of association must be capable of supporting this variety of applications.

This research has developed the notion of interpretation-driven search as a general framework for computational association. We investigate this approach for its potential to exhibit creative behaviours.

Interpretation-driven association

Donald Schön (1983) proposed a theory, 'reflection-in-action', to explain the cyclical interactions of evaluation and synthesis processes that had been observed in studies of designers. Schön suggests that designers change the design representations with which they are working, then observe and reflect on the effects of those changes. As a result of that reflection, the designer again acts to change the emerging design representation. This iterative interaction is enabled by the designer's ability to interpret a representation in a new way after it has been produced. Schön posits that the designer's ability to see things in an emerging design that were not consciously put there is the core of the creative design process.

The framework for computational association developed in this research draws a parallel between Schön's theory of creative design and Boden's (1990) notion of creativity as exploring (and potentially transforming) a conceptual space. The actions taken by a designer to modify their design may translate that design to a new position within the designer's conceptual space, or they may transform the space itself, re-

formulating the designer’s understanding of the problem and producing a novel and surprising design. The genesis of both exploratory and transformative reformulations is the reconceptualisation of the representation the designer had constructed previously. This produces a new interpretation of the design on which previously impossible actions are rendered possible.

Schön sees the process of reflection-in-action as itself being based on analogical reasoning (Schön and Wiggins 1992), but this research inverts that relationship, putting forward a framework for association that is based on Schön’s iterative cycle of reflection and action. This framework is referred to as interpretation-driven search. While inspired by the design process, the interpretation-driven search approach can be generalised beyond design tasks to any domain in which potentially creative associations are constructed.

Interpretation-driven association uses iterative transformation and exploration of the objects being associated to produce a representation that enables a new mapping to be constructed. An interpretation is a transformation of the representation of the objects being associated. These transformations affect the object representations and enable potential mappings between them to be explored. In this approach, interpretations are explicitly represented elements of system knowledge, allowing them to be constructed, evaluated, stored and retrieved. The interpretation process iteratively interacts with the process of searching for mappings and operates in parallel with it. Interpretation influences mapping search and mapping influences the construction, application and evaluation of interpretations.

A model of association that implements these principles can broadly be viewed as consisting of three processes: Representation, Interpretation and Mapping. Representation produces the ‘original’ representations of the objects that are then iteratively searched, transformed and mapped by the Interpretation and Mapping cycle. This framework can be seen in Figure 1. The benefits of this parallel, interactive approach are discussed in Grace et. al. (2012), along with a more detailed elaboration of the framework.

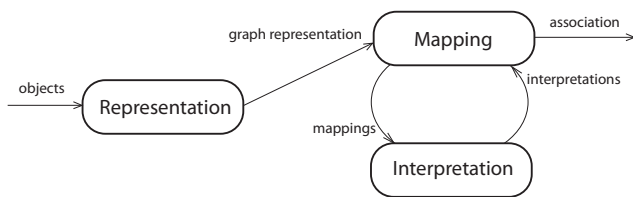


Figure 1: Interpretation-driven search, a high-level framework for computational association.

The creativity of associations

The definition of, and criteria for, creativity have been the subject of considerable debate. One broad definition that has attained some consensus is that of creativity as the union of *novelty* and *value* (Sternberg and Lubart 1999). Novelty is a metric based on the difference between the artefact and

other, existing artefacts in the same domain. Value is a metric based on the artefact’s performance at whatever tasks to which it is applied, when compared to the performance of existing artefacts. Both of these qualities are highly contextualised, as novelty can only be assessed from the perspective of a viewer and usefulness can only be assessed in the context of an application.

Some challenges arise in applying this pair of creativity criteria to the domain of computational association. Firstly, the novelty of an association is on some level guaranteed, as by definition an association must be a new relationship that did not exist previously. Recalling a relationship of which a system was already aware is a memory task, not an association one. This makes an association always at least P-novel (novel to the system itself, as defined by Boden (1990)).

A significant challenge in applying the “novelty and value” framework for evaluating creativity to a model of association is in assessing an association’s value. Association does not necessarily incorporate an evaluative component and it is not necessary that an association be constructed to serve some purpose. We refer to this goal-agnostic form of association as ‘free’ association, which may incorporate evaluative components but in which the associations are not used to accomplish some purpose. Evaluation and purposefulness are instead features of association-derived processes that incorporate additional components. This does not mean, however, ‘free’ association has no effect on the system that constructed it, and therefore an alternative assessment for value can be derived. Different associations produce different transformed and mapped representations of the associated objects, and their value can be assessed based on the degree to which those representations go on to affect the system. This research focusses on this representational affordance model of association value as a way by which the model of association that has been developed could be further developed into an association-based creative system.

Representational affordance as a utility metric

The “affordances” of an object or environment were first defined by the psychologist James Gibson (1979), referring to the opportunities it offers to a user. As applied to the design of objects (Norman 2002) affordances refer to the possibilities for action that a user perceives when interacting with an object. Affordances do not require instruction, they emerge implicitly from the interaction of an object, its user and the situation (Maier and Fadel 2009).

A representation is an internal surrogate that encapsulates knowledge about an entity, enabling the agent or system to reason about that thing (Davis, Shrobe, and Szolovits 1993). In any system that permits the construction of different representations of an object, those representations will facilitate the performance of different actions by that system. Different representations of objects within a system open up different action possibilities for that system. Gero and Kannengeisser (2012) refer to this as representational affordance: the cognitive actions that are enabled by a representing an object in a particular way. During the design process a representation may afford the construction of a new representation with its own, different set of affordances. Gaver

(1991) refers to this as “sequential affordance” and it is consistent with the notion of reflection-in-action (Schön 1983).

Representations can provide affordances based on their syntax or based on their semantics. The structure of a graph representation can provide syntactic affordances, such as path following or matching. However, a representation can also provide semantic affordances based on how its content can interact with other system knowledge. This paper focusses on semantic representational affordances.

In modelling the creativity of an association, a key question arises: what is the value of a new mapping and the representations that underlie it? We define an association’s value in terms of what activities the possession of that association enables the system to do. An association can be said to be of value if the interpretation of the associated objects it contains provides the system with different representational affordances than it previously possessed. Furthermore, associations can be compared and contrasted by the affordances they provide.

Value can be defined using representational affordances in the absence of any specific objectives or purpose of the association construction process, making it apt for use in a general model of creative association. In the case of an analogy-making system built on a model of association, the affordances that would be most relevant would be those that enable acts of knowledge transfer between the object domains. By contrast, in a model of design style the most relevant affordances would be those that permitted the detection of new patterns that connect stylistically similar objects.

A model of ‘free’ association that does not extend the process to incorporate a use for the mappings it constructs can also be assessed using the representational affordance metric for value. If the goal of a free association system is to construct as many different associations as possible, then valuable associations are those that afford the possibility of future, different associations. This kind of sequential affordance of association is made possible by association models that incorporate the effects of a system’s past experiences in constructing associations into new association tasks.

In this research we use the notion of representational affordances as a value metric for association models to discuss the potential creativity of results from a computational model of association.

Experimenting with interpretation-driven association

A computational model based on the interpretation-driven framework for association has been developed. An implementation of that model which constructs ‘free’ associations (in that the associations it constructs are not used for any explicit goals) between ornamental designs is described here. The structure of the model and its prototypical implementation are presented here, along with selected association results produced by the system. The potential representational affordances of the results presented are discussed as a first step towards extending this model towards an association-based creative system.

Computational model

Interpretation-driven search builds on the model of analogy as Structure Mapping (Gentner 1983), in which the relationships within two objects are mapped, rather than their features. The search for these relationship mappings is integrated with an iterative process of re-representation.

The model of interpretation-driven association (see Grace et. al. (2012) for a detailed description) is comprised of five processes. The first three processes: concept formation, relation formation and graph construction collectively form the “representation” process of the interpretation-based framework, while the latter two processes, mapping and interpretation, are direct implementations of that framework.

The system begins with an image-based representation of the objects, extracts a set of features to describe them and then categorises those features into concepts. Relationships between these features within each object are then constructed based on both topological information (such as relative size, bearing or symmetry) from the feature sets and topological information from the conceptual categorisation (such as conceptual similarity or conceptual sameness). The features and relationships are then compiled into a graph representation that serves as the basis for the iterative mapping and interpretation. The mapping process then searches these graphs for subgraphs that contain common edge labels. These subgraphs represent regions of the two images that possess a consistent relational structure.

The transformations that are applied by the interpretation process affect the structure or content of the object graph representations. Implementations of this model could utilise a variety of transformational approaches, such as transforming the graph objects directly, transforming the features or concepts directly and then re-constructing the graphs, or even transforming the process by which one or more representational stages are constructed.

At any given time, a single transformation is applied to the graph representations, this is referred to as the ‘current’ interpretation. This interpretation changes the structure of the graphs, altering the trajectory of the mapping search operating on those graphs. The mapping search process produces candidate mappings as it searches, and these are used to construct new interpretations. New interpretations are constructed by examining what features-to-feature mappings in those candidates cannot currently be successfully mapped, and extrapolating what transformations would be necessary to cause those to be successful.

Implementation

The implementation of the model uses vector images as its input, calculating object features from the minimal closed shapes formed by vector lines. The kinds of relationship implemented in the system are ‘same concept’, ‘similar concept’, ‘relative scale’, ‘linear distance’, ‘horizontal distance’, ‘vertical distance’, ‘relative orientation’, ‘bearing’, ‘contains’, ‘reflection of’, ‘shared vertex’ and ‘shared edge’. The implementation is provided with the knowledge necessary to detect these relationships and categorise them into groups such as “slightly smaller than” or “120 degrees of

difference in orientation”. Instantiations of these relationships form the edge labels on the graph representations of each object being associated.

Mapping search is implemented as a genetic algorithm that searches for subgraph isomorphisms between the graph representation of each object. Each individual in the population of the genetic algorithm is a set of mappings between a feature in one object and a feature in the other. The fitness for this algorithm is the largest contiguous subgraph that can be constructed out of those feature-to-feature mappings in both objects. This use of a powerful, general search algorithm reflects the fact that we are not attempting to implement association in a biologically or cognitively plausible way, rather we are demonstrating the feasibility of the interpretation-driven approach.

The interpretation process is implemented as the substitution of relationships between features. Replacing relationships effectively causes the system to perceive two disparate relationships as being alike. Interpretations in this system can be expressed as “in this situation, relationship X in the first object is the same as relationship Y in the second object”. An interpretation is therefore a set of rules for replacing relationships, where relationships are represented as edge labels in the graphs. Which interpretation is being applied to the objects is able to change every iteration, providing the parallelism between mapping and interpretation that characterises the interpretation-based framework.

Methodology

A total of 31 ornamental designs were inputted into the system as part of a series of experiments to demonstrate the application of interpretation-based association. Objects were drawn from a broad variety of design domains, including symbols, architectural ornamentation and decorations and object designs. These objects were drawn from a variety of cultures and historical periods. From this library of designs a subset of objects were selected for which interesting associations could be produced and the capabilities of the system could be documented.

A set of associations constructed by repeatedly associating a single pair of objects is presented. These associations are presented as a demonstration of the interpretation-based model, but also as a starting point from which the use of representational affordances as a metric for utility in association-based creative systems can be discussed.

The two objects associated here are presented in Figure 2. Object 1, on the left, is a Hittite sun symbol, while Object 2, on the right, is a Japanese floral symbol. Both are vector line drawings produced manually from black and white images by the authors. For the purposes of this experiment the system has been restricted so that the only type of relationship which connects the features of these two objects is relative orientation.

Results

Three associations between the two objects in Figure 2, along with the interpretations used to produce them, are shown in Figures 3, 4 and 5. All three associations constructed between these two objects utilised the ‘relative ori-

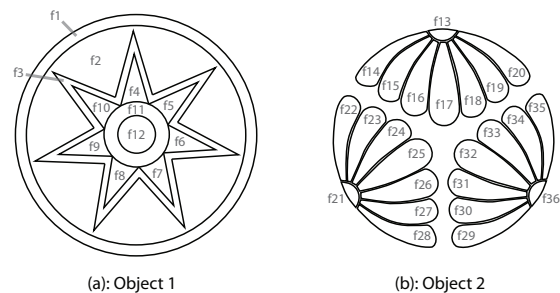


Figure 2: The two objects used in the example associations. The minimal closed shapes extracted from the images by the system are numbered. The relative orientations of these features are the relationships relevant to these examples. Designs sourced from (Humbert 1970).

entation’ relationship type, but each involved a different interpretation. These differing interpretations permitted the construction of different mappings.

In each of these figures the associated objects are presented side by side, with the features involved in the mapping being highlighted. The mapping between features in one object and features in the other is shown as solid lines joining the two images. The common set of relationships between the features within each object is shown as thick dashed lines. Only the relationships that are used in the mapping are shown, pairs of features can have many relationships connecting them. Each of these relationships is labelled with its uninterpreted description. Interpretations are an imposed equality between different labels and are shown at the bottom of each image. Mappings can be constructed between sets of features that share patterns of relationships after this interpretation is applied.

The first association, seen in Figure 3, is constructed without the use of an interpretation. Within the representations of the two objects there exists a pattern of seven nodes in each that share a consistent pattern of relationships. All seven objects in both objects, in the order indicated by the thick dashed lines, are consecutively separated by approximately 150 degrees of orientation. This relationship is present between every second point in the seven-pointed star in Object 1, starting from Feature f_4 and proceeding twice around the star to Feature f_9 . The same relationship of relative orientation is present between every eighth petal in Object 2 - that is between each petal and the petal one spot to its left in the floret to its left, starting from Feature f_{35} and proceeding in a spiralling pattern twice around the design to f_{29} . The ‘null’ interpretation i_0 is shown as this mapping can be constructed from the base representations produced by the system without any transformation.

This association is included to demonstrate the capability of the representation construction and mapping search elements of our model of association. Without the use of interpretations the system is capable of producing representations of visual objects comprised of networks of abstract

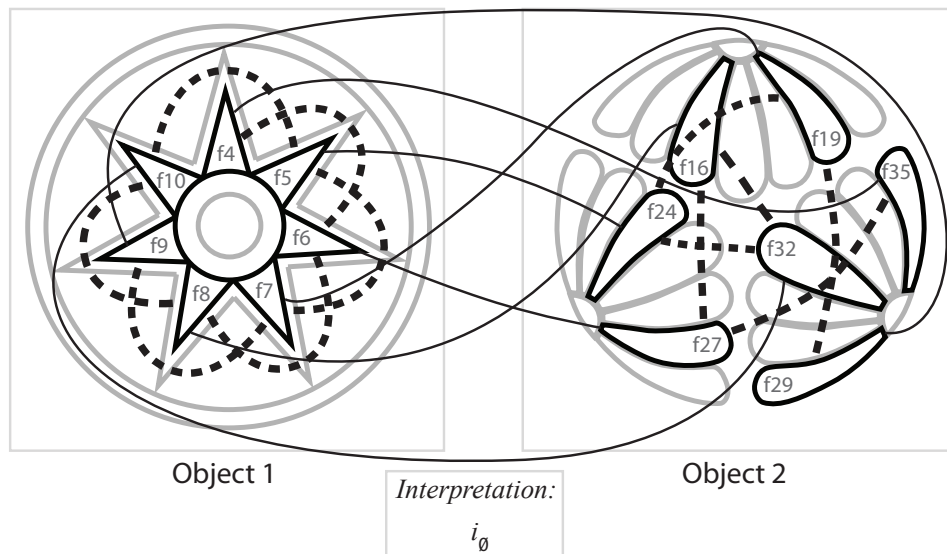


Figure 3: An association constructed between the two objects without the use of an interpretation. All the relationships incorporated into this mapping (depicted by thick dashed lines) are of the type “~150 degrees of difference of orientation”. These relationships join the seven points of the star in Object 1 (by traversing the star twice) and seven of the petals in Object 2 (in a spiral pattern joining each eighth petal). The empty or “null” interpretation means that these relationships are present in the default object representations the system constructs.

relationships and features. These representations can then be searched for common patterns of relationships, allowing the features which those relationships join to be mapped.

Without the ability to transform representations, this association (and others trivially different from it) are all that the system can construct. With mappings limited to those relationships already present in both objects, the potential for constructing an association with relevant affordances is slim. The only way to give a system with a single representation of each object the ability to construct additional associations is to incorporate more information into those representations. In this case that information would take the form of additional types of relationship between features other than differences of orientation.

Utilising the capacity to reinterpret object representations, the system is not limited to “literal” associations as seen in Figure 3. Figure 4 shows the mapping produced by an association between the same two objects that was produced through interpretation-driven search. During the search for mappings between the objects, the system constructed (initially by chance) some fragment of a mapping similar to the one shown in Figure 4. This mapping candidate would not have been successful in the absence of an interpretation. The mapping was selected by the interpretation construction process, which reverse-engineered one or more interpretations from it. Interpretations are generated that would improve the size of the largest common subgraph of the mapping specified by the candidate. That interpretation is then likely to become the “active” one if the mapping search reaches a point where the current interpretation is significantly outperformed by the new interpretation. The search for map-

pings influences the construction of interpretations and then those interpretations in turn influence mapping.

The mapping expressed in Figure 4 is based on an interpretation that effectively treats the orientation difference between adjacent points on the star in Object 1 the same as the orientation difference between adjacent points on the star in Object 2. Thick dashed lines are shown representing the “approximately 50 degrees of orientation difference” relationship in Object 1 and the “approximately 20 degrees of orientation difference” relationship in Object 2. The resultant mapping connects each feature in the star in Object 1, starting with f_4 and proceeding sequentially to f_{10} with each feature in a floret in Object 2, starting with f_{14} and proceeding sequentially to f_{20} . This mapping was constructed from low-level relationships extracted from a visual representation of these objects and then interpreted to make those relationships situationally alike.

The notion of representational affordances as a tool for assessing value in association models can be applied to the association shown in Figure 4. The interpreted representations of the two objects are useful to the extent that the new interpretations more aptly afford actions to the system. In the case of a free association model like this implementation, the only actions available are the construction of different associations, and therefore the value of an association can only be defined by the degree to which it enables that. In this system interpretations are remembered and re-used, which causes the system’s past experiences to affect future interpretations. This provides a mechanism by which this association can guide the system’s future actions.

Representational affordances provided by the association

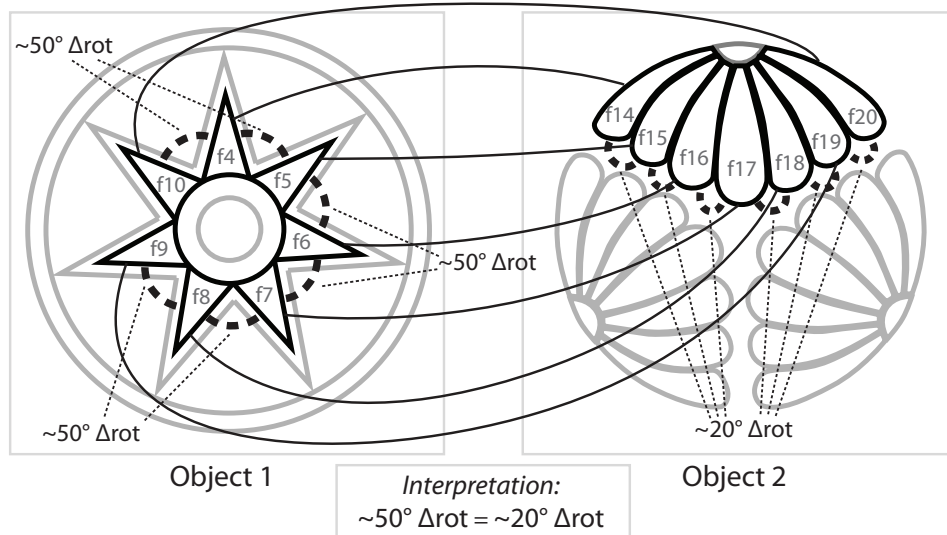


Figure 4: An association constructed between the two objects through the application of an interpretation which equates the relationship “~50 degrees of difference of orientation” in Object 1 to the relationship “~20 degrees of difference of orientation” in Object 2. These relationships join the adjacent points of the star in Object 1 with eight adjacent petals in one of the florets in Object 2. The interpretation that enabled this association is shown in the box beneath the objects.

in Figure 4 could be used to define the value of that association if the system were extended to perform purposeful association construction. If associations were being constructed for use by an ornamental design classification system, then the transformed representation may afford the possibility of classifying Object 2 as being based on radial adjacency, which a naive classification system would have been able to do. If instead associations were being constructed for use in an analogy-based design system, then the mapping of f_4 through f_{10} to f_{14} through f_{20} may afford the transfer of knowledge about f_{11} (the centre circle which all of the mapped features in Object 1 touch) to f_{13} , which could then be considered the “centre” of Object 2. The actions permitted by the representational affordances of the association are used by the system to achieve its goals, so those affordances can be said to be of value because of that use.

Figure 5 shows a different association constructed by the system. This time the interpretation equates the difference in orientation between every third point in the star in Object 1 with the difference in orientation between the edge petals in Object 2. Viewing the “edges” of a compound object such as Object 2 as being part of a rotating sequence may be a valuable affordance for a creative system. The association system implemented in this research was able to find a broad variety of such associations using just two objects and considering just one type of relationship. Different combinations of the relationships that were mapped in Figures 4 and 5 were also found, such as mapping every adjacent point on the star in Object 1 to the outermost petals of the three florets in Object 2. Interpretation construction provided the system with the ability to produce a variety of divergent mapping from a single association problem.

Discussion

The experiments described here demonstrate that it is possible to use the interpretation-driven search approach to construct associations between real-world design objects. The representation construction processes used to produce the graphs on which the iterative mapping and interpretation processes operate have been shown to be viable. Associations were produced based on interpretations that were constructed by the system that transformed graph representations that had also been constructed by the system from features and concepts that had been extracted from low-level visual input. These results serve as an initial proof of concept of the interpretation-driven model of association.

The associations presented in this paper could not have been constructed from the information that was provided to the system without the ability of the system to transform its representations through the interpretation process. These associations could be constructed without the use of interpretation if the system were provided with additional information about the relationships between the objects, but this reduced representational autonomy would have a deleterious effect on novelty. As assessed in the context of a hypothetical society of individuals with access to the same information and possessed of comparable perceptual abilities, associations produced using interpretation will be P-novel to any individual that has not constructed the same interpretation, while associations produced using additional information would be apparent to any other individual with access to that information.

The P-novelty of an association is guaranteed as the system by definition did not know of the relationship expressed in an association before its construction. However, the inter-

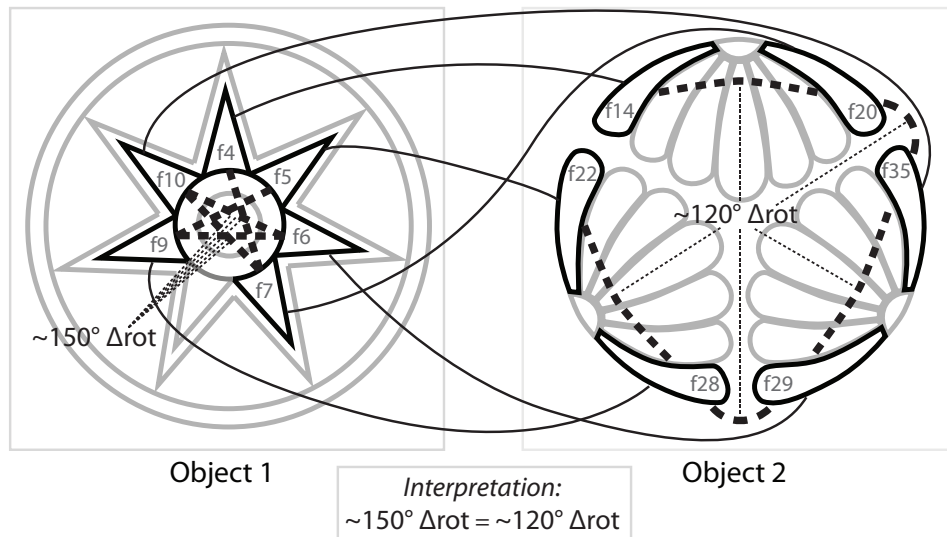


Figure 5: An association constructed between the two objects through the application of an interpretation which equates the relationship “~150 degrees of difference of orientation” in Object 1 with the relationship “~120 degrees of difference of orientation” in Object 2. These relationships join every third point of the star in Object 1 with the two outermost petals in each floret in Object 2. As there are only six such petals in Object 2, only six of the seven points in Object 1 have been mapped. The interpretation that enabled this association is shown in the box beneath the objects.

pretations used in the model of association described in this research may not themselves be novel as they can be learnt and re-used. It is possible to apply a known interpretation to a different object and still produce a novel representation, as a known transformation can produce a novel result.

It is also possible that a P-novel association can be constructed from a representation that has been used before. For example, if the representation of Object 1 present in 4 (and the interpretation used to produce it) were associated with some other, different object, then the resulting association would be P-novel. The known representation of Object 1 is novel in the current circumstances, but is not novel to the system as a whole. This is referred to as “situational” or “S” novelty, after the definition of “S-creativity” in Suwa et al. (1999).

Figure 3 demonstrates an inherent weaknesses of a model of creative association that does not incorporate the ability to reinterpret its object representations. The mapping it expresses is quite likely H-novel, in that it is not expected that the majority of human observers would have identified that mapping. However, any sufficient pattern matching system provided with the two graph representations used by the system would come to the exact same conclusion. The mapping used in this association may be H-novel in a society composed of individuals with human perceptual biases, but to a hypothetical society composed of individuals with a perceptual system like that of this model, the mapping is obvious.

The use of an interpretation in the construction of associations acts to redress the weakness present in models of creative association based on static representations. The association expressed in Figure 4 could not be constructed from

the graph representations the system built without the use of a representation transformation process. In a hypothetical society of individuals with the same perceptual biases as this system, the mapping used in this association would be P-novel to any individual that had not constructed the same interpretation. If this same mapping were to be constructed by incorporating a new relationship type in the default representations that made the mapping possible without interpretation - “radial adjacency” for example - then the resultant mapping would, like the one in Figure 3, be trivially deducible by any other pattern matching system with access to the same information.

The utility component of evaluating creativity can be aided by the use of representational affordances. In the interpretation-driven approach to association, mappings are produced between transformed representations that can reveal structures and connections that were not apparent in the original representations. The utility of those mappings can then be assessed by what actions those new structures enable the system to take. For example, the view of the outermost petals in Object 2 as a sequence of rotated features seen in Figure 5 was not expressed in the uninterpreted representation. The notion of representational affordance also allows the value of an association to be defined in the abstract for models of association that do not use the associations they construct to accomplish any objectives.

Maher (2010) frames the evaluation of a creative artefact as requiring three criteria; not just novelty and value but also unexpectedness. Unexpectedness (also referred to as ‘surprisingness’) is a metric based on how different the artefact is to what was expected to be the next artefact produced.

Unexpectedness, writes Maher, differs from novelty in that it relates to the expected trajectory of the domain or field in which the artefact is being produced, which is distinct from the existing set of artefacts within that domain.

Assessing the unexpectedness of an association using Maher's criteria requires identifying abstract patterns in the sequence of recently constructed associations that can be used to project a trajectory of expected associations. Associations can certainly be surprising in a variety of ways - much humour depends on setting the recipient up to expect that a certain association is being proposed, then subverting that expectation and instead constructing a very different association. However, unexpectedness as defined by Maher specifically refers to identifying emerging trends in the output of a system over multiple iterations. This is a challenging task in the domain of association as it is difficult to define a similarity metric that could then be used to find patterns in association output.

The interpretation-based model of association could provide a method by which the unexpectedness of associations could be assessed. Interpretation-based associations could be characterised by the interpretations used to construct them, which are significantly more generalisable than the mappings that comprise those associations. The explicit representation of interpretations permits further investigation of expectation and unexpectedness in computational models of association. This would address a challenging issue in the development of creative models of association and methods by which they can be evaluated.

The representational affordance framework for assessing the value of an association allows us to consider the associations constructed by an interpretation-based system as a creative artefact. The utility of that artefact is the degree to which it has an effect on the system that constructed it. In a "free" association system where experience plays a role in future associations then that effect can be defined as the influence an association has on the construction of future associations.

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