Analogy as Exploration

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Abstract. Theorists have often emphasized the role of analogy in creativity, particular in scientific or intellectual contexts. But in Boden's model, creative processes are assumed to be mediated by acts of exploration and transformation. There is a need to understand how these two perspectives fit together and to clarify whether analogy is mediated by transformation, exploration, or both of those processes. Analogy is often viewed as a form of transformation. But the demonstration that transformation can be understood as meta-level exploration calls that view into question. The present paper shows that analogy can in fact be mediated by exploration alone. A task analysis is used to delineate the prototypical strategies of concept construction. It is then shown that analogical functionality can emerge as a natural result of conceptual-space exploration.

Keywords: Analogy, exploration, transformation, creativity, theoretical cognitive science, concepts, representation.

1 Introduction

Many theorists identify analogy as fundamental for creativity, e.g., [1; 2; 3; 4; 5; 6]. However, the transformational model of creativity [7; 8; 9; 10] emphasizes the role of search-like operations applied to concepts. Creativity on this latter view is understood to involve heuristically-guided exploration of existing conceptual spaces and *transformation*, development of new conceptual spaces. The question then arises as to how analogy fits into this scheme. Is it that analogy should be understood as being an ingredient of conceptual space transformation? Or is it better to think of it as a part of exploration? Using a task analysis of conceptualization [11], the present paper shows that analogical functionality is an emergent property of ordinary conceptual-space exploration.

2 Conceptualization prototypes

For purposes of the analysis, it is assumed that exploration of conceptual spaces can be understood to involve the construction of new concepts from given constituents. On the basis that these are themselves concepts (or can be viewed as such) the task can be accomplished in one of two ways. The constituents man be treated as independent entities. Or they may be treated as a related ensemble.

In the former case, the result is necessarily one in which a set of independent entities are treated as a single entity. It is a generalization or abstraction, i.e., a category which includes all the constituents. In the latter case, the nature of the result depends on the relationship which is deemed to tie the constituents together as an ensemble.

On analytic grounds, then, we can divide the task of concept-combination into two basic forms:

- *categorical* construction in which the constituents are deemed to be independent, and
- ensemble or *compositional* construction, in which the constituents are deemed to be tied together by a relationship.

Where a concept-combining agent is able to introduce relationships, then, there are two ways of accessing new concepts. For any given combination, a categorical construct can be formed. The constituents come to be viewed as instances of a category. For the same combination, each way of superimposing a relationship produces a distinct compositional construct. In this case the constituents come to be viewed as part of the superimposed relationship. This provides us with a provisional account of the possibilities of conceptual space exploration.

In order to identify the concepts which can be generated in a particular case, we need to know what concepts are assumed to be given, what relationships are assumed to be given, and how they can be applied. It simplifies matters if we treat given concepts and given relationships the same way, i.e., if we assume that among given concepts, some are relational and some non-relational. Assuming no restrictions on how such relational concepts can be applied (i.e., taking them to be unordered relations of arbitrary arity), the number of concepts which can be formed by combination can then be ascertained straightforwardly. For each combination of given non-relational concepts, there is

- one categorical construct, and
- for each given relational concept, one compositional construct.

Fig. 1 illustrates how things work out when there are three non-relational and two relational constituents. The given concepts are represented here as circles in the bottom row. The non-relational concepts x, y and z are in the middle. The relational concepts r_1 and r_2 are on the outside. Circles in the top row represent the possible combinatorial constructs with the arcs denoting constituency. The three circles on the left are the categorical constructs. In this case, arcs are brought together indicating the way in which the constituents are combined into a single entity by the construction. Next to these we have the three constructs obtained by applying relationship r_1, followed by the three that can be formed by applying r_2. The connecting arcs here connect to a horizontal bar labeled with the relation applied. This indicates the way in which the relational concept is applied to schematize the ensemble's relationship. The figure shows precisely how many conceptual structures can be formed in this scenario. With three

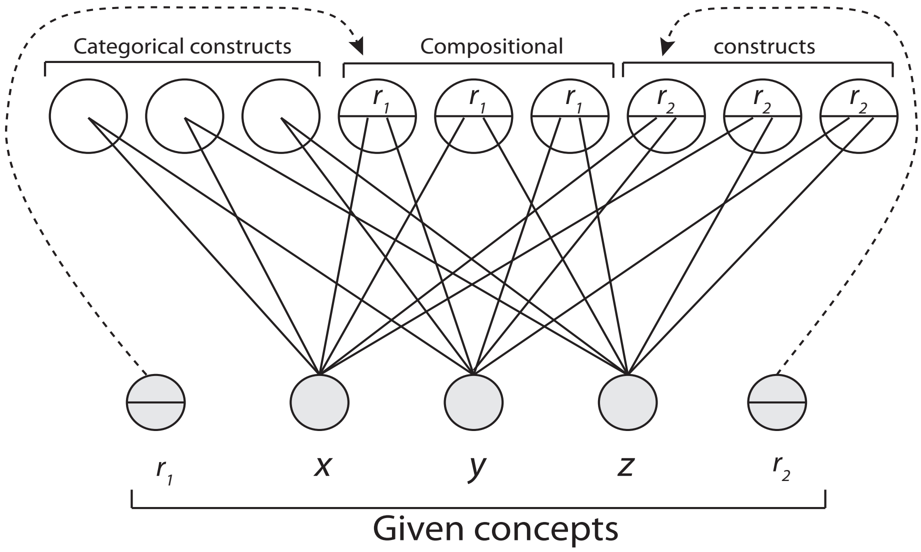

Fig. 1. Categorical and compositional concept-combination.

non-relational and two relational givens, there are nine conceptual structures in all.

3 Hierarchical development

We can map out the contents of the conceptual space defined by some givens, then, by looking at the possibilities for categorical and compositional construction. But Fig. 1 merely shows the concepts which can be obtained directly. We also need to consider the concepts which can be obtained indirectly, i.e., by pursuing constructive possibilities in which previous constructions are used as constituents.

The possibilities are illustrated in Fig. 2. Here, the given and constructed concepts are taken from a domain of vehicles and a domain of animals. However, the concept names should not be taken too seriously: the intention is simply to show syntactic/combinatorial possibilities as before. The given non-relational concepts are BICYCLE, POLICE-CAR, LION, ZEBRA1 etc. The given relational concepts are BETWEEN, STOPPING, CLOSE-TO etc. In this diagram, however, the relational concepts only shown where they are *applied*.

The schematic on the far-left represents the simplest situation. Here the constructed, first-order[1] concept POLICE-ESCORT is used as a constituent in the construction of a 2nd-order compositional construction based on the STOPPING relation. Note that, here, the relation applied at the second level is different to

[1] The term 'order' is used to denote hierarchical level.

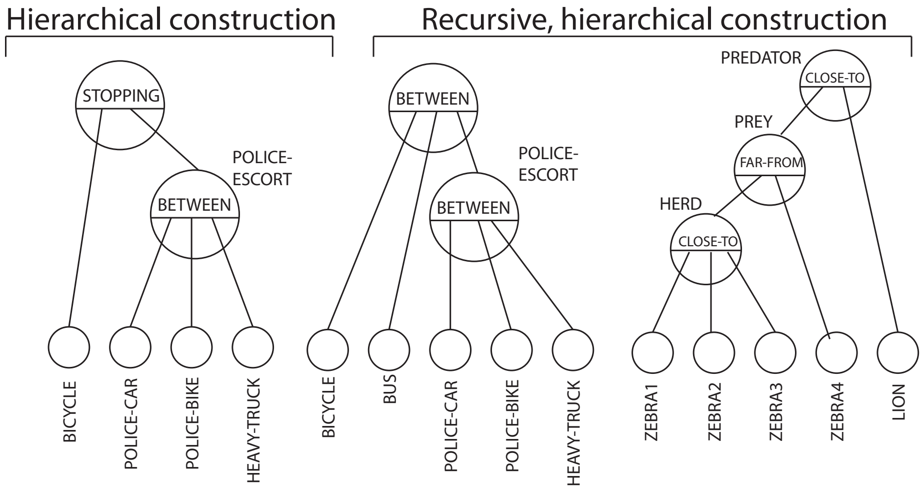

Fig. 2. Hierarchical and recursively hierarchical construction.

the one used at the first level. But re-using a relation is also possible. This leads to the recursive forms of construction illustrated in the middle and right schematics. In the middle schematic, the BETWEEN relation is used to produce a compositional construction on constituents which include one constructed using the same relation. The right schematic also illustrates recursive use of a relation (CLOSE-TO) but here there is an intermediate compositional construct based on the FAR-FROM relation.

4 Analogy as conceptualization

In Gentner's structure-mapping theory [12; 13; 14], analogy is understood to be the exploitation of a mapping between two conceptual structures. The mapping allows details in one structure (the 'target') to be inferred from details in the other (the 'source'). Gentner posits the *abstractness* principle — the notion that the strength of the analogy depends on the degree to which relations rather than attributes are preserved in the mapping. She also proposes the *systematicity principle*, which is the idea that strength also depends on the degree to which 'systems of relations' are carried across from source to target [12, p. 158].

Gentner treats analogy formation as a special operation. However, bringing to bear the analysis of concept combinatorics, we can understand it to be a natural consequence of conceptual-space exploration. What Gentner describes as an 'analogical mapping' can be understood to be a categorical construct combining two compositional constituents, which themselves embody structures of constructs exhibiting corresponding relations.

Figure-shown contrasts a conceptual construction which embodies an 'analogical mapping' with one that does not. In the left schematic, the correspondence

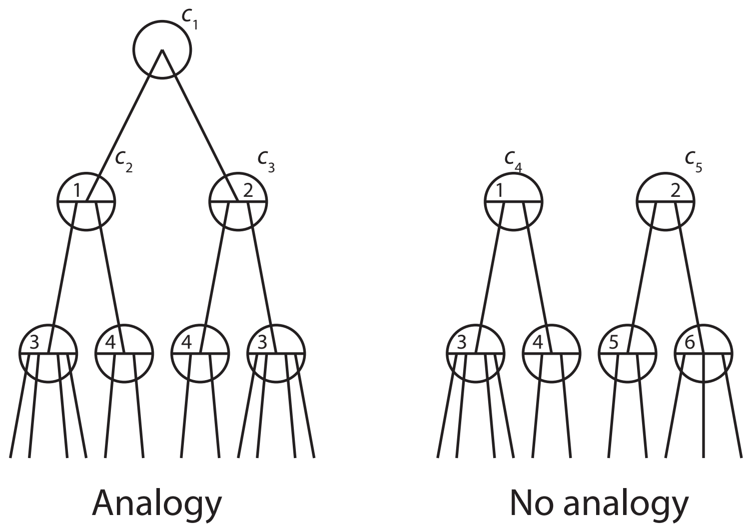

Fig. 3. Formation of analogical mapping through conceptual-space exploration.

between the relations used in the construction of the 1st-order constituents of c_2 and c_3 implies the existence of an analogical mapping between them. The construction of the categorical construct c_1 then places c_2 and c_3 into a single category, implicitly realizing the analogy. In the right schematic, there is no relational corresondence at the level of 1st-order constituents and therefore no analogy.

The formation of such analogical mappings is a natural consequence of conceptual-space exploration. But Gentner also posits abstractness/systematicity, i.e., a *preference* for the formation of such mappings. While this principle is not itself inherent in conceptual-space exploration, it is not hard to envisage how it might emerge from it. For example, a preference for the formation of a categorical construct on c_2 and c_3 (rather than c_4 and c_5) might be based on recognition that, in using a smaller number of relational concepts, the former has a lower representational cost.

5 Analogical transfer

An important feature of Gentner's structure-mapping model is the way in which it accounts for analogical transfer, i.e., the filling-in of relations in the target on the basis of features observed in the source. This is often illustrated using the case of the 'Rutherford' analogy. Fig. 4 is Gentner's own schematic which shows how the structure of relations affecting planetary motion are related to those affecting electrons orbiting a nucleus. On Gentner's analysis, the strength of the analogy depends on the correspondence between the relations (ATTRACTS,

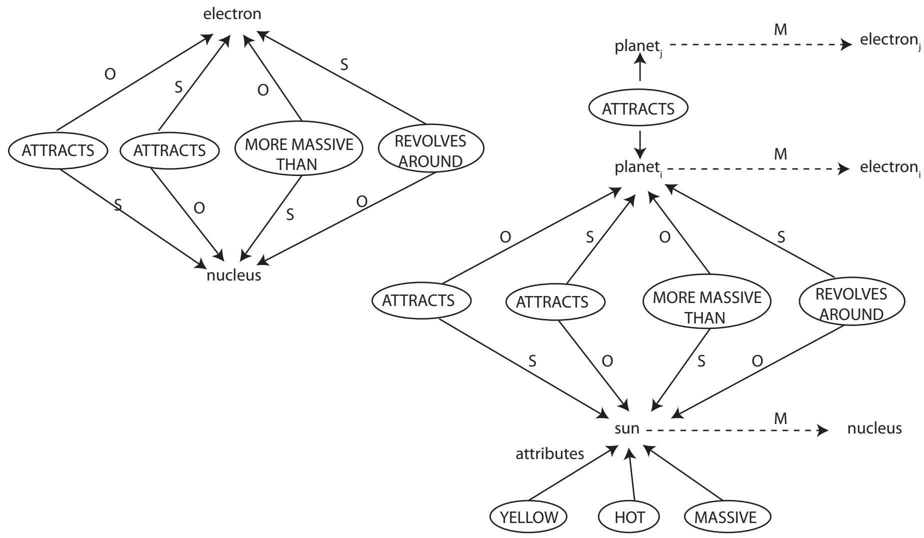

Fig. 4. Gentner's structure-mapping model of the Rutherford analogy.

REVOLVES-AROUND etc.); its formation allows the ATTRACTS relation in the planetary structure to be transferred, effectively filling-in an unknown property of the electron structure.

Reproduction of this functionality in conceptual-space exploration is illustrated by Fig. 5. In forming the top-level, categorical construct c_1, the structures subsumed by c_2 and c_3 are generalized, implicitly filling-in the missing ATTRACTS relation in c_3. Conceptual-space exploration can thus serve to 'transfer' relations subsumed in c_2 to c_3, thus reaping the benefit of the analogical correspondence.

6 Copycat analogy as conceptualization

Gentner's structure-mapping theory has influenced a broad range of work. Analogy models such as the ACME system of Holyoak and Thagard [15] aim to extend Gentner's account by showing how the mapping processes can be implemented or applied. Other models may model analogy without treating SMT as a foundation. An interesting case from the present perspective is the Copycat system of Melanie Mitchell and Douglas Hofstadter, [3; 4]. This is a pseudo-parallel[2] stochastic system which constructs analogical mappings in a data structure called the 'workspace'.

The formation of constructs in Copycat is carried out by 'codelets' (also described as 'micro-processes'). An agenda structure termed the 'coderack' is

[2] In Hofstadter's term, the system executes a 'parallel terraced' scan [3, p. 33].

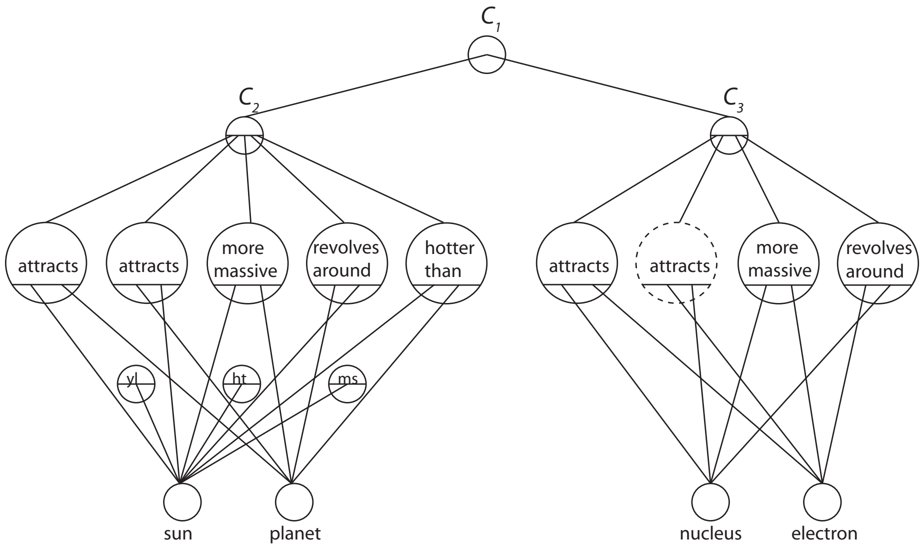

Fig. 5. Transfer of relations in conceptual-space exploration (yl, ht and ms represent the properties of yellow, hot and massive here).

used to mediate the task of scheduling constructive operations. These attempt to achieve 'conceptual slippage' by exploiting relationships in a data structure termed the 'slipnet'. Behind this terminology, however, Copycat pursues a relatively familiar constructive protocol. It builds six types of construct, one being the universal categorical construct *group* and the other five being different types of compositional construct [3, p. 40]. In terms of the present framework, we would say that it utilizes five compositional relations which, figuring in categorical/group construction, allows construction of six types of construct in all.

The constructive processes pursued by Copycat in forming an analogical mapping can also be reproduced by conceptual-space exploration. Consider Fig. 6. This is a screenshot of the final workspace generated by Copycat[3] in solving the letter analogy problem:

if 'abc' goes to 'abd' what does 'ijk' go to?

The way in which the system constructs this analogy involves the construction of various types of linking construct. The most critical of these are represented in the screenshot using directed arcs and labeled boxes. The letter-groups 'abc' and 'ijk' are placed into 'group', 'whole' and 'successor-group' constructs. The final 'd' in 'abd' is placed into a successor relation with the final 'k' in 'ijk'. A construct is then built to represent the higher-order relation in which

[3] The public domain applet version of the system from `http://www2.psy.uq.edu.au/CogPsych/Copycat/` was used to generate this screenshot.

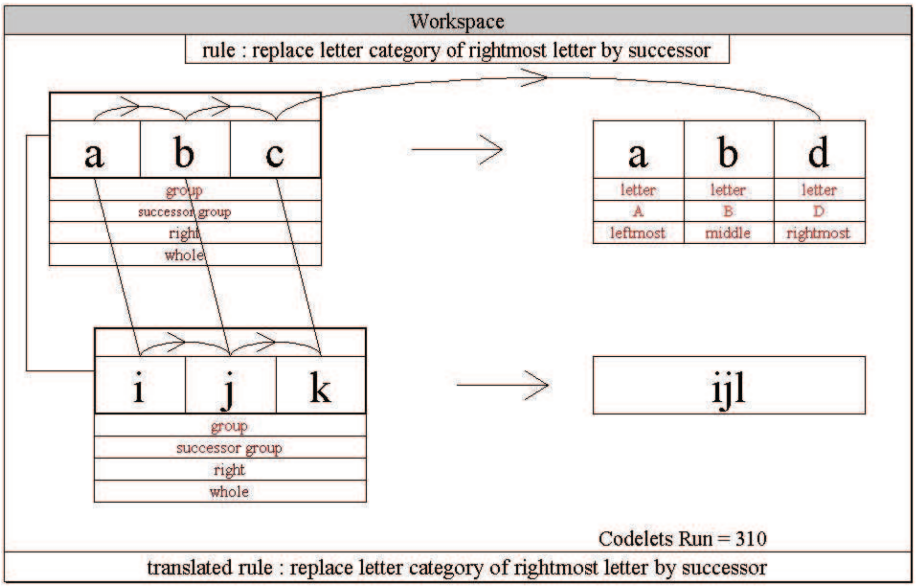

Fig. 6. Construction of a letter-sequence analogy in Copycat.

'abd' is derived by replacing the rightmost letter in 'abc' with its successor. By these means, the system discovers the possibility of there being an analogical relationship between 'abc->abd' and 'ijk' thereby generating 'ijl' as a solution to the problem. (For further details on this and related examples see [3].)

The situation depicted in Fig. 6 is recast as conceptual-space exploration in Fig. 7. Here the critical constructive operations are shown as the formation of categorical and compositional constructs. But the formation of constructs consolidating the analogy (only implicitly represented in the Copycat screenshot) is now explicitly represented. Two, third-order compositional constructs are shown. One of these applies the relation 'succ-group-right-advance' to the relevant constituents which mutually indicate the replacement within a successor-group of the rightmost letter by its successor. The other applies the relation 'whole-right-advance' to the constituents which *would* indicate the (analogous) replacement within a 'whole' gropup of the rightmost letter by its successor. Also shown explicitly is the fourth-order categorical construct which consolidates the root of the analogical match.

7 Concluding comment

While theorists have often viewed analogy as playing a fundamental role in creativity, Boden's model is constructed in terms of operations in/on conceptual spaces. The question then raised is how the process of analogy fits in to Boden's scheme. Boden herself has stressed the way in which the formation of

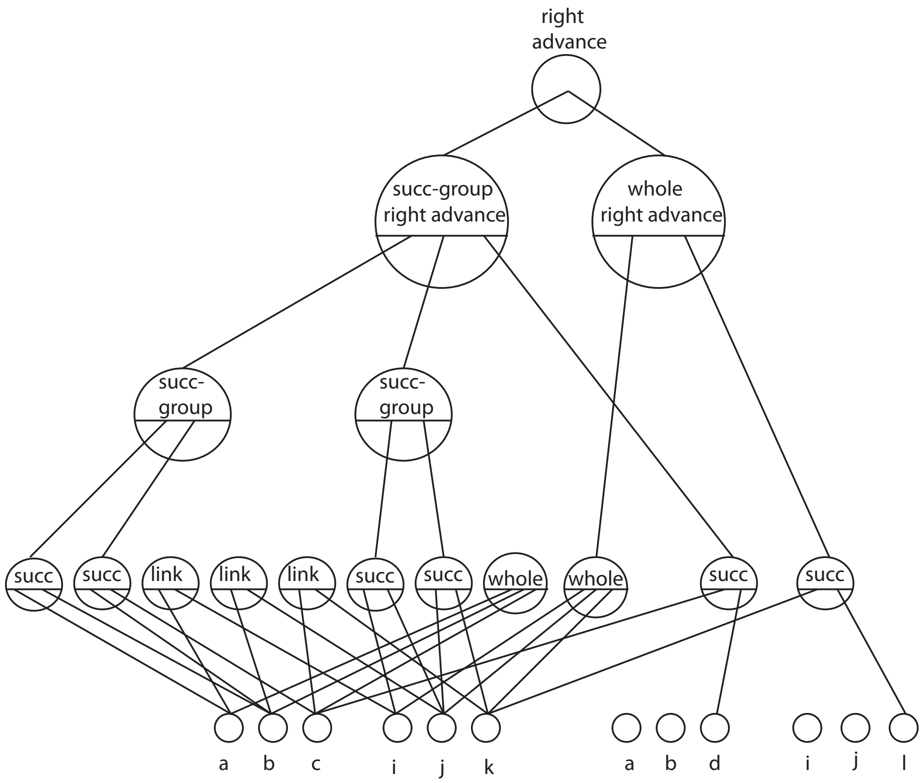

Fig. 7. Copycat construction interpreted as conceptualization.

analogy can be a key element of transformation, i.e., the means by which the constituents of a new conceptual space are formed. This poses some problems in view of the way in which transformation has been shown to be essentially the operation of exploration carried out at the meta-level [16; 10]. However, using an analysis of conceptualization prototypes, the present paper has shown how basic processes of exploration can suffice. Analogy formation may be seen as the formation of a third-order categorical construct built in terms of second-order compositional constructs, which are themselves built in terms of first-order compositional constructs. The potential for analogy-formation is thus inherent in ordinary, explorative functionality.

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