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Publication Date

Peer reviewed

Can a real distinction be made between cognitive theories of analogy and categorisation?

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Abstract

Analogy has traditionally been defined by use of a contrast definition: analogies represent associations or connections between things distinct from the 'normal' associations or connections determined by our 'ordinary' concepts and categories. Research into analogy, however, is also distinct from research into concepts and categories in terms of the richness of its process models. A number of detailed, plausible models of the analogical process exist (Forbus, Gentner and Law, 1995; Holyoak and Thagard, 1995): the same cannot be said of categorisation.

In this paper we argue that in the absence of an acceptable account of categorisation, this contrast definition amounts to little more than a convenient fiction which, whilst useful in constraining the scope of cognitive investigations, confuses the relationship between analogy and categorisation, and prevents models of these processes from informing one another. We present a study which addresses directly the question of whether analogy can be distinguished from categorisation by contrasting categorisational and analogical processes, and following from this, whether theories of analogy, notably Gentner's structure mapping theory (Gentner, 1983; Forbus et al, *ibid.*), can also be used to model parts of the categorisation process.

Introduction

Ordinarily one accepts a distinction between category membership and analogy according to realist terms. In categorical judgements, relating a new representation of an object to some kind of stored category representation, objects are felt to be similar to one another in a way in which those objects in judgements of analogical association are not. If two objects are considered to be members of a category, the classification is real; if they are considered to be analogous, it is not. Consider, for example an analogy between a theory and a building (Lakoff and Johnson 1980): we might talk of "the *foundations* of a theory"; "we might wish to *buttress* a theory with more facts"; "theories that we *construct* can also *collapse*". From an everyday, psychologically realist viewpoint, an igloo and a castle and a skyscraper really are similar in a way that similarities between buildings and theories are not.

Research into analogy and metaphor has accepted this tacit realism. Holyoak and Thagard (1995) describe a world in which "we think we see things as they really are", and analogy is used in order to recycle our existing knowledge of the real world to formulate new bits of 'real' knowledge. Similarly, in the case of metaphor, Ortony (1979) makes a distinction between literal and non-literal similarities: 'encyclopaedias are like dictionaries' is true in a literal (real) way, whereas 'encyclopaedias are like goldmines' is only true in a metaphorical (non-real) way. Whether the notion of literal similarity might be problematic or not is barely examined, since the real problem to be addressed is metaphor. Holyoak and Thagard (1995) offer the comment "A metaphor always connects two domains in a way that goes beyond our normal category structure" (pp 217), whilst giving little indication as to what might constitute this 'normal category structure'. Analogies are defined as being distinct from categories, the nature of which are left unexamined, presumed real.

Once the difficulties of giving an account of categorisation are admitted into the picture, distinctions between analogy and metaphor reliant upon a contrast with categorisation cease to distinguish at all. Analogy is consistently defined in contrast to categorisation (Clement and Gentner, 1991; Holyoak and Thagard, 1995); yet in order to make a contrast definition one needs an account of at least one of the contrasting elements. This we don't have. An analogy is defined as an associative judgement between two things that are in different categories, yet an account of what constitutes an association between two things such that they are members of the same category rather than different categories is not available (Medin, Goldstone and Gentner, 1993)[1]. Moreover, on the best accounts of categorisation, the question of whether two things are members of the same category may not be amenable to any straightforward answer (Medin and Ortony, 1989; Ramscar, 1996). Thus analogy

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[1] Similarly, Glucksberg and Keysar (1990) argue that metaphorical judgements are the *same* as categorisational judgements ("metaphors are understood as they are as class inclusion statements", pp17). It is hard to see how categorisation is to illuminate metaphor, since they conclude: "The central problem is to understand categorization." (pp 17).

tends to be defined in contrast to what is in itself a largely undefined process. In the light of this, a definition such as:

"In an analogy, a familiar domain is used to understand a novel domain in order to highlight important similarities between the domains, or to predict new features of the novel domain." *[We interpret domain here to be equivalent to category]* (Clement and Gentner, 1991)

might be more accurately reformulated along the lines of: 'in analogy, a stored representation is used in order to highlight important similarities between it and a new representation of an object or concept, or to predict new features in the new representation of an object or concept'. None of this would be out of place in a definition of categorisation. The distinction between categorisation and analogy is difficult to draw: here we explore the hypothesis that at cognitive levels of description there may no clear distinction to be made at all.

Models of analogy and categorisation

Another factor which favours the abandoning of traditional distinctions between categorisation and analogy are the strong parallels which can be drawn between theories of analogy and the most plausible models of categorisation. It is becoming more widely accepted that structure plays a major role in category formation (Boyd, 1984; Goldstone, 1994; Kiel, 1989; Medin and Ortony, 1989): analogical reasoning research directly addresses a process which reasons amongst structural networks (Falkenhainer, Forbus and Gentner, 1989; Holyoak and Thagard, 1995). Forbus, Gentner and Law (1995; pp 145-6) propose the following theoretical model of analogical reasoning:

- initial selection dependant upon surface similarity
- analogical similarity is determined by deeper structures

this is strikingly similar to Medin and Ortony's (1989; pp 185-6) knowledge representation scheme for categorisation:

- identification procedure based upon surface features
- classification is determined by deeper structures.

Where research into analogy differs from research into categorisation is in the richness of its process models. A number of detailed, plausible models of the analogical process exist (Forbus, Gentner and Law, 1995; Holyoak and Thagard, 1995): the same cannot be said of categorisation. Medin and Ortony offer little detail as to the mechanisms by which surface identification is governed by deeper structures, or indeed the composition of these deeper structures. In the current study we address directly the question discussed above, of whether analogy can be distinguished from categorisation by contrasting categorisational and analogical processes, and following from this, whether theories of analogy can also be used to model parts of the categorisation process.

Gentner's structure mapping theory

Gentner's (1983) Structure Mapping Theory is an attempt to explain how it is that two domains can be considered analogous, and in particular how it is that correspondences between analogues from two domains can be mapped. Structure mapping proposes that the mapping and inference between two domains can be achieved by assigning correspondences between objects and attributes and then mapping predicates with identical names. In order to do this,

Gentner assumes a predicate like representation distinguishing between *objects, object-attributes* and *relations*. Object-attributes are those predicates that have one argument and describe object properties, e.g. RED(lobster). Relations are divided into a hierarchy of orders, with those predicates with two or more arguments which are used to describe relations between objects, for example UPSETS(stomach,lobster) forming the lowest order, and those predicates describing different levels of relationships between relations forming the higher orders e.g.: CAUSE(UPSETS(stomach,lobster),DRINKS(seltzer,diner)).

The theory itself comprises two parts: *mapping rules*, and the *systematicity principle*. Mapping rules state that (a) attributes of objects are not mapped and (b) relations between objects are preserved. The systematicity principle requires that higher order relations (e.g. CAUSE above) are mapped preferentially, followed by the relations that constitute the higher order arguments.

The question of how analogies are accessed, i.e. how representations are selected in order to allow analogical mapping to take place, was addressed experimentally by Gentner, Ratterman and Forbus (1993). Their study showed that analogical access relied primarily upon surface (feature) matches, and they propose that judgements of analogical similarity can be decomposed into two sub-processes:

- *Accessing* a similar (*base*) situation from memory, based primarily on surface similarity
- Creating a *mapping* from base to target using structural commonalities.

Structural systematicity and categorisation

Since the Gentner, Ratterman and Forbus (1993) studies did not directly address categorisation, a tacitly realist position was adopted in respect of the categories amongst which subjects were to analogise (Ramscar, 1996). The most obvious way in which this realist assumption manifests itself is in the classification of match items (the individual stories within the "Karla the hawk" story sets (Gentner, Ratterman and Forbus 1993)). The question of the categorical status of match items is determined in advance, thus story 1 in figure 1 is classified as a base story, whilst story 3 is defined as its analogue. It is tacitly assumed that the two stories are members of distinct and separate categories, and that they share some kind of analogous link. Whilst the study aimed to explore a wider range of determinants of similarity, the particular correspondences determined by structural systematicity were considered to be indicative of analogous similarities (similarities *between* rather than *within* categories). These assumptions determined the predictions that Gentner *et al* made for their experiments, and the evidence they sought with which to test them.

Gentner *et al*'s study explored criteria of similarity, and discovered that the preferred determinant of analogical similarity in subjects was shared structural systematicity. As a consequence of our hypothesis we predicted that if we were to use Gentner et al's methods and materials to explore categorisation rather than analogy, structural systematicity might also serve as a criterion for the determining category membership. Story 3 in figure 1 was assumed by Gentner et al to be an analogue of story 1. Analogues, as posited in

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traditional accounts of analogy, are defined in contrast to category members. If subjects were to use structural systematicity as a categorisation determinant, then definitions of analogy which rely on shared structure to contrast analogy with categorisation might need some refinement. If both analogy and categorisation produce the same results, then this might imply some shared, structure based mechanism, or that one process is supervenient upon the other. Accordingly, we experimented by presenting subjects with Gentner *et al*'s materials and asking them to categorise them. Given that Gentner *et al* define the analogical mechanism in terms of structure mapping, we accordingly expected structure mapping to determine categorisation: i.e. Gentner *et al* assume that match items with only structural similarities (i.e. analogues) belong to different categories: we predict that they will be categorised together.

The Experiment

Subjects

The subjects were 20 volunteers, a mixture of postgraduate and undergraduate students from the Artificial Intelligence Department at the University of Edinburgh.

Materials

The basic materials used in this study were the 20 sets of "Karla the hawk" stories (Gentner, Ratterman and Forbus, 1993).[2]

Gentner defines the following taxonomy of similarity relationships between the stories:
- *Literal similarity* matches include both common relational structure and common object descriptions;
- *Surface matches*: based upon common object descriptions, plus some first order relations;
- *Structural similarity*, a match based upon a common system of internal relations;
- *First order matches*, where the only common feature is first order relations;
- *Object only matches*, where stories have only object matches in common.

Each set consists of a base (B), a literally similar story (LS), an analogue (TA - with only structural similarities with the base), a mere-appearance story (MA with surface and first order commonalities with the base), a false analogy (FA an analogue of MA), and an object only match story (OO - with only surface commonalities with the base). This allowed for a number of potential groupings according to the classification strategy adopted. Our prediction was that subjects would use structural similarity as their categorical similarity determinant, putting analogues and bases into the same categories (i.e. B, LS and TA together), rather than grouping match items at the object level (i.e. grouping B, LS, MA and OO together).

The sets were modified slightly: in Gentner et al's analogy research questions of the asymmetry and direction of comparisons were clearly fixed (all comparisons were in

relation to the base story). Extra features (a varied mix of objects, attributes and relationships) were added to (or removed from) the base story representations (Figure 1, bold face) which did little to affect analogical similarity judgements. In categorisation judgements, aspects such as symmetry and directionality may be more fluid. As we predicted that structure would be an important determinant of categorical similarity judgements, and noting that the directionality of similarity judgements cannot be fixed in

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Story 1 - Base story

Once there was a teacher named Mrs Jackson who wanted a salary increase. One day, the principal said that he was increasing his own salary by 20 percent. However, he said there was not enough money to give the teachers a salary increase.

When Mrs Jackson heard this she became so angry that she decided to take revenge. The next day, Mrs Jackson used gasoline to set fire to the principal's office.

Then she went to a bar and got drunk.

Story 2 - Literal similarity

Professor Rosie McGhee very much wanted a raise. One day the provost announced that he was giving himself a raise. However, he said that since money was short, no one else would get a raise this year.

After Professor McGhee heard this she became so upset that she decided to get even. One hour later, Professor McGhee blew up the administration building with dynamite.

Story 3 - True Analogy

McGhee was a sailor who wanted a few days of vacation on land. One day, the captain announced that he would be taking a vacation in the mountains. However, he said everyone else would have to remain on the ship.

After McGhee heard this he became so upset that he decided to get revenge. Within an hour McGhee blew up the captain's cabin with dynamite.

Story 4 - Mere appearance: (First order commonalities)

Professor McGhee very much wanted a raise. One day she became so impatient that she used kerosene to burn down the administration building.

After the fire, the provost announced that he was giving himself a raise. However, he said that due to the fire, there was not enough money to give one to anyone else.

Story 5 - False Analogy

McGhee was a sailor who wanted a few days of vacation on land. One day McGhee became so impatient that he tried to blow up the captain's cabin using dynamite.

After this incident, the captain announced that he would be taking a vacation in the mountains. However, he said everyone else would have to remain on board to repair the ship.

Story 6 - Mere appearance: (Object commonalities only)

A teacher once thought that she deserved a pay rise. She asked the principal when her rise was due. She was wearing her best suit. The principal told her that rises were decided by the governors.

Figure 1: Sample stories from Gentner, Ratterman and Forbus (1993) - the text in bold type illustrates extra structure added by Gentner at al to the base stories only.

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[2] Many thanks to Dedre Gentner for providing the story sets.

categorisation, we accordingly removed Gentner et al's extra features from 65% of the story sets (G- sets: in these, for example, the base / literal similarity relationship were symmetrical), and retained the extra features (and any attendant asymmetries) in 35% of stories (G+ sets).

Procedure

Subjects were given 10 mixed sets of 6 stories[3] and asked to work through them a set at a time. Both sets and stories were presented in randomised order. For each set, they read through each story a number of times in order to familiarise themselves with its content. Subjects were then asked to "Group the stories into the categories that seemed most natural and appropriate to you. These groups can range from putting every member of the story set into the same group, to putting each story into a group on its own." When subjects had made their categorisation decisions, they physically grouped each set of stories by pasting them onto a large sheet of paper and encircling each group in ink. Subjects were then re-presented with their groupings a set at a time, asked to give each group with two or more members

Classification Criterion			% of Total
Systematic network of relations in common - Type 1			79.5 %
1 B LS TA	2 FA MA	3 OO	
Systematic network of relations in common - Type 2 *(Base classified separately)*			8 %
1 LS TA	2 FA MA	3 B 4 OO	
First order relations in common - Type 3			4 %
1 B LS TA FA MA	2 OO		
Only object similarities in common - Types 6 & 7			5 %
1 MA LS B OO	2 FA MA		
1 B OO	2 LS MA	3 TA FA	
No classification possible - Types 4, 5, 8 , 9 10			3.5 %
1 B LS MA	2 FA TA	3. OO	
1 B TA	2 FA MA	3 LS 4 OO	
1 B MA FA	2 LS TA	3 OO	
1 B LS TA OO	2 FA MA		
1 FA B TA MA	2 LS		

Figure 2: Output patterns from the categorisation task, showing the groups formed and criteria established. The stories are labelled according to Gentner's taxonomy of similarity (defined above): B = Base; LS = Literal Similarity; TA = True Analogy; FA = False Analogy; MA = Mere Appearance; OO = Object Only match.

a simple descriptive name, and then to write a few sentences explaining what caused them to classify each named group of stories together[4].

Results

For each story set the groups formed by each subject's classifications were analysed. The pattern of groupings which emerged fell broadly into 5 types (figure 2). Similarities across groupings (i.e. similarity shared by every member of a two or more member group across a categorised story set) according to Gentner et al's taxonomy of similarities could be identified in 96.5% of groupings. Of these, in 5% of cases the stories were grouped according to types 6 and 7. The only similarities across groupings in these types are that the stories in the individual groups had only objects in common. In 4% the stories were classified according to type 3, where the across grouping similarity was shared first order relations. In 79.5% of cases subjects grouped using type 1. Here the only similarity across groupings was a network of systematic causal relations. The full output and incidence of the types is given in Table 1.

Story Set Type			
Grouping Type	*G+*	*G-*	*% of total*
Type 1	68 %	86.5%	79.5%
Type 2	20 %	0.5%	8%
Other	12%	13%	12.5%

Figure 3: Classification strategies according to set type.

8% of groupings were according to type 2, where the base was put into a category on its own, with the only similarity across other groupings being shared structure. This type was only found once amongst those sets from which Gentner *et al*'s extra features had been removed (0.5% of G- sets; figure 3). The G+ sets, those with added features in the base, were sets 5; 7; 10; 12; 15; 17; and 20. Of these: in set 5 and set 20 the extra features involved higher order relations; in sets 7 10, 15 they involved first order relations; and in sets 12 17 the extra features were objects. 20% of these sets were classified as type 2, with the bulk of these classifications being in the sets with extra higher order relations (figure 4).

	Higher-order relations Sets		*Objects only Sets*		*1st order relations Sets*		
	5	**20**	**12**	**17**	**7**	**10**	**15**
Type 1	7	2	7	7	11	9	5
Type 2	9	2	1		2		
Type 3	1	1			1	2	
Types 6 & 7	2						
Types 4, 5, 8, 9 & 10							1
Totals	19	5	8	7	14	11	6

Figure 4: Classification data for the G+ sets.

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[3]Given the sample size, we concentrated on sets 1   10; sets 11   20 were used to a more limited extent to check for any marked variations in the data being produced.

[4]This data is currently being analysed, and will not be considered here.

	1	2	3	4	5+	6	7+	8	9	10+	11	12+	13	14	15+	16	17+	18	19	20+
A					1	1		1	1	1		1	1	1			1	1		
B	3	3	1	1	2	1	1	1	1	1										
C	1	1	1	1	2	1	1	1	1	1										
D	1	1	1	1	2		1				1	2							1	2
E	1	1	1	1	2	1	2	1	1	3										
F	4	1	1	1	2	1	1				1	1					5			
G		8			6	7		1	1				1	6	1		1	1		
H	5	1	1	1	2		1				1	1							1	1
I	1	1	1	1	1		1				1	1							1	2
J	1		1		8	1		1	1		1				1		1	1		
K							1	1	1	1		1	1	1		1	1			1
L	7	1	1	1	2	1	1	1	1	1										
M	1	1	1	1	1	1	1				1	1						1		
N	1	1	1	1	5	2	2				1	1						1		
O					1	1		1	1	1			1	1	1		1		1	
P	6	3	1	1	1		3				7	1							1	3
Q					2	1		1	1	1			2	1	1		1	1		
R	1	10	1	1	1	1	1	1	1	1										
S	1	1	1	1	1	1	1	1	1	1										
T					3	7		9	1	3			7			7	7	1	1	

Table 1: Output incidence of subject groupings. Each subject was given 10 story sets (each row represents one subject): the type of grouping is indicated by the type number in the story set column (see also figure 2).
Subject T produced some rather strange results: this was explained by examining the reasons T gave for her groupings, in which she explained that she was exploring a different heuristic for each story set.

Discussion

Our study explored the hypothesis that mechanisms normally considered to be analogical could in fact support categorisation tasks. The most important finding here is the role that shared structure plays in categorisation judgements. 79.5% of the groupings formed by our subjects had only shared systematic structure (traditionally defined as analogy) as a common feature amongst members of the categories formed. In contrast, only 5% of groupings produced had common object descriptions as the common similarity across categories. Traditionally categorisation models have concentrated on object descriptions, making use of very representationally-simple attribute-value lists (Murphy and Medin, 1985), whereas analogy research has examined relationships between highly structured representations (considering the influence of attributes, relations and higher-order relations in judgements of similarity).

The argument for abandoning the current de facto distinction between categorical and analogical associations of objects is twofold: firstly, that the standard distinctions (Clement and Gentner, 1991; Holyoak and Thagard, 1995) between analogy and categorisation actually failed to distinguish between them; and secondly, that by removing the distinction, understanding of the factors which govern mappings between representations that have been gleaned from analogy research might help illuminate categorisation questions (Ramscar, Lee and Pain, *in press*). Our results provide evidence that structures, and more pertinently Gentner's structural systematicity, rather than features, are the key to categorical similarity in this instance: this tallies with other evidence, such as Rips (1989) who found that subjects were reluctant to change classifications as a result of feature changes alone.

Our argument is supported not only by the proportion of categorisations that were determined by commonalities between internal structures in the stories, but also by the effects of added structure in the G+ sets where the added structure was a higher-order structure. These might at first appear to present a problem for our attempt to use a structure mapping analysis to model these categorisation judgements. In these cases, Gentner's base stories were put into separate categories from stories to which they were supposed to be literally similar, which were in turn categorised alongside their supposed analogues (both of which were supposed to share structures with the base).

These results can be attributed to the effects of directionality and symmetry upon similarity judgements. Whilst Gentner, Ratterman and Forbus (1993) found that subjects judged literally similar (LS) stories to be very similar to bases, and analogues less so, they did not consider the effect of reversing the directionality and symmetry of the

comparisons, for example comparing the base and analogue stories similarity to the LS. Neither did they consider the judging of cumulative similarity, where dissimilarities are also taken into account. During this process, the structural dissimilarities of the base versus the LS and analogue appear from our results to be clearly relevant, whereas the object differences of the analogue versus the LS and base do not. This maximisation of important similarities (i.e. structure matches) relative to lesser dissimilarities (i.e. object matches) amongst groupings appears to play a crucial role in categorisation in this study. Whilst it might be argued that all we have shown here is that subjects will form categories of analogies, such an interpretation (in so far as we can make sense of it) does not affect our argument that it is structure that determines the content of these categories.

All of this strengthens our dubiety with respect to the separation of analogy from categorisation. We should note, however, that asserting that analogy cannot be distinguished from categorisation at a cognitive level is not the same thing as arguing that analogy is the same thing as categorisation. Categorisation is such a central cognitive process that it is hard to see how it can be reduced to a single process (c.f. Goldstone, 1994). It may well be that any given manifest reasoning process - such as rule following or metaphor - might be able to illuminate some aspect of categorisation: i.e. can provide the constraints necessary to determining certain categorical similarities. We argue that the analogical process cannot be distinguished from the 'categorisation process' at a cognitive level. Our hypothesis is that analogy is supervenient upon an important part of the classification process, and that as such analogy research is capable of illuminating[5] some categorisation tasks, for instance, the way in which structural systematicity can determine both analogical and category judgements.

Acknowledgements

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[5]For example, one problem faced by all cognitive theories of categorisation is explaining typicality effects (e.g. Rosch, 1978); how they occur, or even, how the existence of typicality effects can be accommodated by a given model. Gentner et al (1993) have shown how differing aspects of similarity structural versus surface affect recall, soundness ratings and judgements of similarity. By showing that judgements of categorical similarity and the recall of category members can be reliant upon different representational features (surface attributes for recall, structural systematicity for similarity and typicality), we might be able to begin to present a model of the categorisation process which can explain and account for at least some typicality effects.

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