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STRUCTURE-MAPPING: A THEORETICAL FRAMEWORK FOR ANALOGY AND SIMILARITY

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This paper describes a theoretical framework in which analogies and other comparisons are defined in terms of structure-mappings between domains (Gentner, 1979, 1980). Different kinds of mappings correspond to analogies, metaphors, literal similarity statements, applications of general laws, and simple chronologies. The chief focus is on explanatory analogies, such as are used in scientific modelling (Gentner, 1981, 1982; Gentner & Gentner, 1982). Such analogies are fundamentally assertions that partly identical relational structures apply to dissimilar objects across different domains.

It is generally accepted that the degree of literal similarity perceived between two objects depends on the degree of overlap among their components. In Tversky's (1977) elegant contrast model, the similarity between A and B is greater the greater the size of the intersection ($A \cap B$) and the less the size of the two complement sets[1] ($A - B$) and ($B - A$). This account works well for literal similarity, but the mere relative number of shared and non-shared predicates appears to be an inadequate basis for a general account of relatedness.

For example, consider a simple arithmetic analogy. The analogy 3:6::2:4 is no better than the analogy 3:6::200:400, even though 3 has more features in common with 2 than with 200. It is not the overall number of shared versus nonshared features that counts here, but only the relationship "twice as great as." I will argue that a general theory of relatedness between domains must be based on the relational structure of the overlapping information. The structure of the shared versus nonshared predicates determines whether a given comparison is thought of as analogy, as literal similarity, or as the application of a general law.

In this paper I first lay out some representational preliminaries; second, provide definitions and examples of each kind of relatedness; and finally, discuss some psychological implications of the framework. To give a brief preview: If both the relationships and the object descriptions correspond, the comparison is one of literal similarity; if the relationships correspond, but the objects do not, the comparison is analogical. The third possibility, that the objects correspond but the relationships do not, represents neither literal nor analogical similarity. Such comparisons arise chiefly in chronologies, in which the same entities pass from one configuration into another over time. The place of general laws in this framework will also be discussed.

Preliminary Assumptions

1. Domains and situations are psychologically viewed as systems of objects, object-attributes and relations between objects. These "objects" may be coherent conceptual bundles or component parts of a larger object, rather than separate concrete objects; the important point is that they function as wholes at a given level of organization.

2. Domains and situations are represented propositionally. The format used here is a propositional network of nodes and predicates (cf. Miller & Johnson-Laird, 1979; Rumelhart & Norman, 1975; Rumelhart & Ortony, 1977; Schank & Abelson, 1977). The nodes represent concepts treated as wholes and the predicates express propositions about the nodes.

3. The distinction between object attributes and relationships is important. In a propositional representation, the distinction can be made explicit in the predicate structure: <u>attributes</u> are predicates taking one argument, and <u>relations</u> are predicates taking two or more arguments. For example, COLLIDE (x,y) is a relation, while RED (x) is an attribute.

4. The distinction between first-order predicates (taking objects as arguments) and second- and higher-order predicates (taking propositions as arguments) is important. For example, if COLLIDE (x,y) and FALL (y) are first-order predicates, CAUSE [COLLIDE(x,y), FALL(y)] is a second-order predicate.

5. These representations, including the distinctions between different kinds of predicates, are intended to reflect the way people construe a situation, rather than what is logically possible.[2]

[1] The negative effects of the two complement sets are not equal: if we are asked "How similar is A to B?", the set (B - A)--features of B not shared by A--counts much more than the set (A - B).

6. Finally, it is assumed that a comparison "An X is (like a) Y." conveys that knowledge is to be mapped from Y to X. X will be called the target, since it is the domain being explicated. Y will be called the base, since it is the (presumably more familiar) domain that serves as the source of knowledge.

Structure-mapping: Interpretation Rules

Assume that the hearer's representation of the base domain B can be stated in terms of object nodes b_1, $b_2,\ldots,b_n$ and predicates such as A, R, R'. The hearer knows, or is told, that the target domain has object nodes t_1, $t_2,\ldots,t_m$. A structure-mapping comparison maps the nodes of B onto the nodes of T:

$$M: b_i \dashrightarrow t_i$$

The hearer derives inferences about T by applying predicates valid in the base domain B, using the node substitutions dictated by the mapping:

$$M: [R(b_i,b_j)] \dashrightarrow [R(t_i,t_j)]$$

Here $R(b_i,b_j)$ is a relation that holds in the base domain B. Attributes (one-place predicates) from B can also be mapped into T:

$$[A(b_i)] \dashrightarrow [A(t_i)].$$

Finally, higher-order relations, such as $R'(R_1, R_2)$, can also be mapped:

$$M: [R'(R_1(b_i, b_j), R_2(b_k, b_l)] \dashrightarrow$$

$$[R'(R_1(t_i, t_j), R_2(t_k, t_l)]$$

Kinds of Structure-Mappings

(1) A literal similarity statement is a comparison in which a large number of predicates is mapped from base to target, relative to the number of nonmapped predicates (Tversky, 1979). The mapped predicates include both object-attributes and relational predicates.

EXAMPLE(1): The X12 star system in the Andromeda nebula is like our solar system.

INTERPRETATION: Intended inferences include both object characteristics--e.g., "The X12 star is YELLOW, MEDIUM-SIZED, etc., like our sun." and relational characteristics, such as "The X12 planets REVOLVE AROUND the X12 star, as in our system." Figure 1 shows a representation of our solar system; most or all of the predicates shown would be mapped in a literal similarity comparison.

(2) An analogy is a comparison in which relational predicates, but not many object attributes, can be mapped from base to target.

EXAMPLE(2): The hydrogen atom is like our solar system.

INTERPRETATION: Intended inferences concern chiefly the relational structure: e.g., "The electron REVOLVES AROUND the nucleus, just as the planets REVOLVE AROUND the sun." but not "The nucleus is YELLOW, MASSIVE, etc., like the sun." (see Figure 1). If higher-order relations are present on the base they can be mapped as well: e.g., The hearer might map "The fact that the nucleus ATTRACTS the electron CAUSES the electron to REVOLVE around the nucleus." from "The fact that the sun ATTRACTS the planets CAUSES the planets to REVOLVE AROUND the sun." (This relation is not shown in Figure 1.)

(3) A general law is a comparison in which the base domain is a named abstract relational structure. Such a structure would resemble Figure 1, except that the object nodes would be generalized physical entities, rather than particular objects like "sun" and "planet". Predicates from the abstract base domain are mapped into the target domain; there are no nonmapped predicates.

EXAMPLE(3): The hydrogen atom is an example of a central force system.

INTERPRETATION: Intended inferences include "The nucleus ATTRACTS the electron."; "The electron REVOLVES AROUND the nucleus." These are mapped from base propositions such as "The central object ATTRACTS the peripheral object."; or "The less massive object REVOLVES AROUND the more massive object."

(4) A chronology is a comparison between two time-states of the same domain. The objects at time 1 map onto the objects at time 2. This is the only interesting case in which objects are shared but relational structure need not be. The two time-states share object-attributes, but in general not relational predicates.

EXAMPLE(4): Two hydrogen atoms and an oxygen atom will combine to form water.

INTERPRETATION: The intended inferences that can be mapped from time state 1 to time state 2 concern enduring characteristics of the component objects: "Oxygen HAS ATOMIC WEIGHT 16."

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[2] Logically, a relation R(a,b,c,) can perfectly well be represented as Q(x), where Q(x) is true just in case R(a,b,c) is true. Psychologically, the representation must be chosen to model the way people think.

Neither configurational relations nor dynamic relations of the initial system can be mapped into the final system. Note that overlap among component objects is not sufficient to produce similarity between systems: Two isolated hydrogen atoms and an oxygen atom do not resemble water, either literally or analogically.

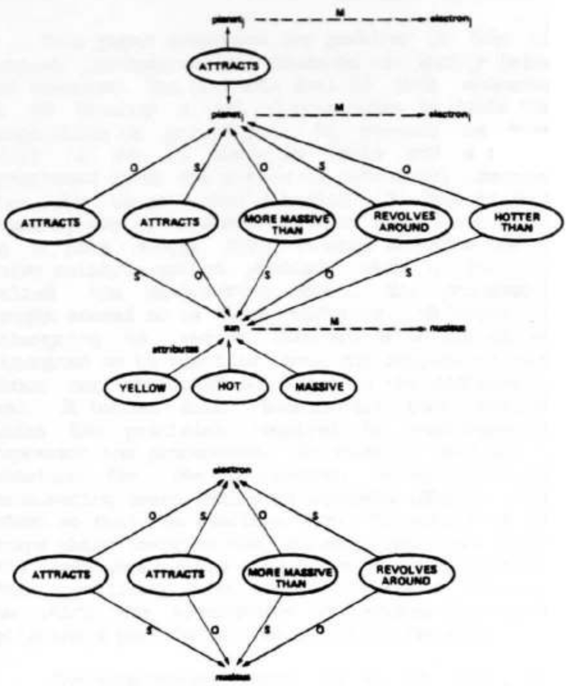

Figure 1. Structure-mapping between solar system and hydrogen atom.

To summarize, overlap in relations is necessary for any strong perception of similarity between two domains. Overlap in both object attributes and inter-object relationships is seen as literal similarity, and overlap in relationships but not objects is seen as analogical relatedness. Overlap in objects but not relationships may be seen as temporal relatedness, but not as similarity.

According to this analysis, the contrast between analogy and literal similarity is a continuum, not a dichotomy. Given that two domains overlap in relationships, they are more literally similar to the extent that their object-attributes also overlap. A different sort of continuum applies between analogies and general laws: In both cases, a relational structure is mapped from base to target. If the base representation includes concrete objects that must be left behind, the comparison is an analogy. As the object nodes of the base domain become more abstract and variable-like the comparison is seen as a general law.

Psychological speculation: The Analogical Shift Conjecture. People learning a new domain often make spontaneous comparisons with other domains. The speculation is that the earliest comparisons are chiefly literal-similarity matches, followed by analogies, followed by general laws. For example, Ken Forbus and I have observed a subject trying to understand the behavior of water flowing through a constricted pipe. His first comparisons were similarity matches, e.g., water coming through a constricted hose. Later, he produced analogies such as a train speeding up or slowing down, and iron balls banging into one another and transferring momentum. Finally, he was able to state a version of the Bernoulli principle, that velocity increases and pressure decreases in a constriction.

Literal similarity matches are highly accessible but not very useful in deriving causal principles, because there is too much overlap. Analogies are harder to generate, since they require searching the data base for relational matches, not object matches. However, once found, an analogy should be more useful in deriving the key principles, especially if the set of overlapping predicates includes higher-order relations such as CAUSE (see Winston, 1981). Finally, by comparing two or more analogies, the common subparts of the relational structure can be isolated and a general law derived. [See Gick and Holyoak (in press) for relevant studies.]

In summary, no treatment of domain relatedness can be complete without distinguishing between object features and relational features: that is, between relational predicates and one-place attributive predicates. Careful analysis of the predicate structures being mapped is central to modelling the inferences people make in different kinds of comparisons.

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