DOCUMENT RESUME

ED 267 408 CS 209 587

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TITLE Relation Definition Theory.
PUB DATE 10 Nov 84
NOTE 20p.; Paper presented at the Annual Meeting of the Psychonomic Society (25th, San Antonio, TX, November 10, 1984).
PUB TYPE Viewpoints (120) -- Speeches/Conference Papers (150)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS Cognitive Processes; *Definitions; Language Acquisition; *Language Processing; Language Research; *Linguistic Theory; *Models; Perception; *Semantics; Vocabulary Development
IDENTIFIERS *Relation Definition Theory

ABSTRACT

The relation definition theory proposed in this paper is explicitly different from previous semantic memory theories since it is the first to make a relation's definition the basis of semantic processing. The paper suggests that this relation definition theory successfully predicts relation similarity on the basis of one key primary assumption: that people perform and comprehend relations by processing some or all of the simple relation elements defining the task relation. The paper concludes by observing that since the relation definition theory makes the logic of relations central, it promises to account for a wider range of relation phenomena than addressed by previous models. (HOD)

Presented at the Twenty-fifth Annual Meeting of the Psychonomic Society, San Antonio, 11/10/84

Relation Definition Theory

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Abstract

This paper proposes a theory of relation comprehension. First, semantic relations (e.g., antonymy, class incluson, part-whole inclusion, synonymity) are uniquely defined by simple relations (e.g. opposition, overlap, symmetry). Second, relation processing is based on the definitions of semantic relations involved in a task. Thus, relation comprehension can be accounted for by the simple relations involved by relation definition.

Relation Definition Theory

Relations between words (e.g., antonymy, class inclusion, part-whole inclusion, synonymity), are commonly regarded as important language phenomena - in anthropology, artificial intelligence, lexicography, linguistics, philosophy, and psychology (Bierwisch, 1970, Bolinger & Sears, 1981; Evens, Litsowitz, Markowitz, & Werner, 1983; Katz, 1972; Kempson, 1977; Lyons, 1968, 1977; Palmer, 1976). Performance on relation tasks is taken to reflect verbal ability, dimensions of intelligence (Sternberg, 1977; Whitely, 1976), and mental processes as they pertain to language (Clark & Clark, 1970; Rosch, 1978; Smith & Medin, 1981) and to thought (Deese, 1965, 1970). Thus it would be helpful to several research areas in psychology to develop an adequate psychological account of how relations are processed in language tasks.

Semantic relations differ in logical properties (Bar-Hillel, 1967; Hampton, 1973; Johnson-Laird, 1975; Katz, 1972). These properties exist because of the particular definition of a relation. The essence of the theory proposed here, Relation Definition Theory is that language users are aware to varying degrees of relation definitions, and that people perform relation tasks primarily by application of the relation definition (or definitions) to the demands for processing imposed by a task.

The definitions of semantic relations are built out of one or more simpler relations or relational elements. For example, the relation of similarity involves just one relation element: that some aspect of the meaning of one word be shared by another. An example of a relation that involves more than one element is that of contrary antonymy. The first element required by this semantic relation is the sharing of dimensional meaning; e.g., the dimension of _temperature states_ is shared by _hot_ and _cold_. The second element is opposition on the dimension; e.g., _hot_ and _cold_ are clearly opposed where _hot_ and _warm_, also both temperature states, are not. The third element is that opposition be symmetric, e.g., hot and cold are opposed symmetrically whereas hot and cool are not. Thus, contrary antonymy is defined as two words 1) sharing a common dimension, 2) with opposed meanings on this dimension such that 3) opposition is symmetrical.

A recent study (Stasio, Herrmann, & Chaffin, in press) illustrates the predictive power of relation definitions. This study modelled judgments of similarity between relations as reported in a previous study (Chaffin & Herrmann, 1984). The judgments of relation similarity were made by subjects in a sorting task. Each subject sorted cards where each card represented a different relation as illustrated by five pairs. The names of these 31 relations, and two pairs representing each relation are presented in the first two columns of Table 1. The sorting frequencies indicated

Insert Table 1 about here

three aspects of subjects' perceptions of relation similarity. First, subjects perceived relations as similar when they originated from the same family grouping, e.g., contrasts, similar, class inclusion, case relations, and part-whole inclusion. The relations that were sorted into a family by Chaffin and Herrmann's subjects are shown in Table 1. Second, families were perceived to vary in relation similarity to each other (e.g., similars and class inclusion relations were occasionally sorted together; case relations and part-whole inclusion relations were occasionally sorted together; contrasts were almost never sorted with the other four families). Third, subjects' perceptions of relations similarity varied within a family, e.g., opposites like hot-cold were sorted more frequently together with opposites like alive-dead than either were with opposites like frank-hypocritical.

The three ways that relation similarity varied in Chaffin and Herrrmann's (1984) study may be explained as being due to agreement in the elements that define relations. For example, subjects frquently sorted pairs like alive-dead with hot-cold because both pairs represent the antonym elements of (1) a common dimension on which word meanings are represented (2) bilaterally and (3) symmetrically about the dimensions midpoint; however, neither pair was sorted with synonyms (car-auto) since synonymity is not defined by a common dimension with symmetric opposition. However, Chaffin and Herrmann's explanantion was only speculative; consequently, it seemed appropriate to test whether agreement in relation elements might actually account for the relation similarity data.

In order to provide an explicit test of the element agreement hypothesis of relation similarity, it is necessary to develop a precise linguistic account of the relational elements required by the 31 relations in the Chaffin and Herrmann (1984) study. Table 2 presents such a list of relational

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Insert Table 2 about here

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elements and Table 1 presents in its third column the way in which these elements enter into each of the 31 relations (Tables 1 and 2 are drawn from a manuscript by Stasio, Herrmann, & Chaffin, in press). The present accounts of relation definitions and their elements were derived from detailed analyses given in standard linguistic sources (Lyons, 1968, 1977; Leech, 1974; Evens, Litowitz, Markowitz, Smith, & Werner, 1983) and in other sources cited in Chaffin & Herrmann (1984). We wish to point out that linguistic analysis of some of these relations is new; thus, some of these definitions represent only a first approximation to the definitions that will eventually be settled on. The definitions in Table 1 may be interpreted with the aid of Table 2 in the following manner. For example, the definition of contrary antonymy includes the elements of dimensional meaning, continuous dimension, and symmetreic bilateral position on a dimension (Herrmann, Chaffin, Conti, Peters, & Robbins, 1979).

Comparison of the definitions in Table 1 suggests that relation element agreement accounts for the salient results of Chaffin and Herrmann's study. First, it may be seen that the relational elements defining relations differ markedly between families, consistent with the finding that sorting was most frequent within families. Second, the overlap in relational elements across families is partially consistent with the sorting data. For example, the similars and class inclusion families share approximately two elements and were occasionally sorted together. Alternatively, the part whole relations and syntactic relations were occasionally sorted together but share no relational elements. Third, the agreement in elements between relations within a family appears to be consistent with the sorting data, e.g. the definitions of necessary and invited attribution agree more with each other than either of these relations agree with synonymity.

Table 1, besides allowing a qualitative evluation of the relation element explanation of relation similarity, permits quantitative tests of this explanation. Two equations were formed to yield relation similarity estimates from relation element agreement. (Many other equations are clearly possible; it is beyond the scope of this article to provide a comprehensive analysis of possible math models of relation similarity). One equation represents similarity as bidirectional (i.e. Relation 1 is a similar to Relation 2 as vice versa). The other equation represents similarity as the mean of unidirectional similarities (where the similarity of Relation 1 to Relation 2 may differ from that of Relation 2 to Relation 1: cf. Chaffin & Herrmann, 1981). If relation similarity is based on the number of shared relational elements, then there should be a significant correlation between the sorting data reported by Chaffin & Herrmann (1984) and each of the relation similarity estimates.

Method

Relation Similarity Sorting Frequencies. The sorting data collected by Chaffin and Herrmann (1984) were represented in a matrix (31 relations by 31 relations) in which each cell of the matrix contained the number of subjects who sorted into the same pile the two relations defining a cell. Since sorting data do not separate directional differences in similarity (i.e. Relation 1 to Relation 2 versus Relation 2 to Relation 1), these data fill only half of the matrix (which included 465 cells). The Chaffin and Herrmann report does not present this matrix directly but instead the Hierarchical Clustering Solution (HICLUS) that was derived from the matrix.

Estimates of Relation Similarity from Relation Definitions. Two kinds of estimated similarity co-efficients were derived from alternative mathematical expressions of agreement in definitional elements. The bidirectional similarity of two relations (R_1 and R_2) was computed from the number of elements (A) that were in agreement between the given relations over the mean number of elements that defined both relations, i.e. similarity = $A/((R_1 + R_2)/2)$. The unidirectional similarity of two relations was the mean of the overall number of elements that were in agreement between the relations over each relation's elements, i.e. similarity = $(A/R_1 + A/R_2)/2$. Each kind of similarity estimate was computed for each cell in the matrix that was identical to the empirically based sorting matrix. It should be noted that neither equation took account of the hierarchical structure of elements defining relations (e.g. that two words must share a dimension before they can be opposed) in order to simplify the analysis.

Results

The correlation of the sorting data with the bidirectional similarity estimate was .685, df = 463, p <.001. The correlation for the unidirectional similarity estimate was .707, df = 463, p < .001. Since the two kinds of similarity estimates were essentially the same, all further statistics reported here will be for the unidirectional similarity estimate.

Additional analyses were carried out to determine how well relation element agreement correlates with the three specific aspects of the clustering analysis reported by Chaffin and Herrmann (1984): that relations were perceived to be most similar within a family, that families varied in similarity to one another, and that relations within a family varied in similarity to each other. To assess how much of the variance was accounted for by the defining elements of a family, a family similarity matrix was computed. Similarity estimates were assigned a value of 1 when a pair of relations came from the same family as defined by relation definitions (family elements are underlined in Table 1). Estimates were assigned a value of 0 when the pair came from different families. The family-based correlation was, as expected from the HICLUS solution in Chaffin and Herrmann (1984), substantial: r = .691, df = 463, p < .001. A partial correlation of relation similarity and relation element agreement with family element agreement held constant was .355, df = 461, p < .001, showing that some of the variance in the sorting data cannot be accounted for by agreement of family elements within a family.

To assess how well relation element agreement accounts for the similarity of families to each other, the sorting frequencies were correlated with element agreement for relations from different families, r = .399, df = 378, p < .001. Inspection of Table 1 indicates that this correlation is due to interfamily agreement for similars and class inclusion, as well as to agreement on general inclusion between part-whole inclusion and class inclusion.

In order to assess how well relation element agreement accounts for relation similarity within families, the sorting data and similarity estimates were correlated for each of the five families separately. These correlations by family were: contrasts, $r = .751$, $df = 28$, $p < .001$; similars, $r = .517$, $df = 10$, $p < .07$; class inclusion, $r = .535$, $df = 15$, $p < .05$; case relations, $r = .445$, $df = 10$, $p < .10$; and part-whole relations, $r = .329$, $df = 21$, $p < .08$. Although three of these correlations were not significant ($p \leq .05$), the general pattern of results indicates that sorting within families may be accounted for by relation element agreement. It seems likely that a more powerful sorting study (e.g. such as one which used more subjects) would obtain significant correlations for all of the families.

It might be argued that the present analyses are not valid because the relation elements used here are not genuine components of relation definitions. For example, the elements, may have been developed ad hoc to explain the Chaffin and Herrmann (1984) study. However, careful examination of the semantic-relations literature will show that the definitions in Table 1 coincide closely with current linguistic accounts of relation definitions (Apresyan, Mel'Cuk, & Zolkovsky, 1981; Leech, 1974; Lyons, 1968, 1977; see also Evens et al., 1983); relation element agreement does predict relation similarity data.

Even if the present correlations are valid, it may be argued that other models exist that generate better accounts of relation similarity data. Network theories, it might be supposed, could do so. However, these theories are totally incapable of accounting for relation similarity because the links representing relations in networks are assumed to be unanalyzable and unique (Johnson-Laird et al., 1984). But a variant of network models could be assumed that can generate relation similarity estimates. This variant assumes that relation links represent just the family relation between words. Thus, related words in each family (e.g. antonymy, part-whole inclusion) would be linked by associations representing the appropriate family. If a maximal similarity of one is assigned to pairs of relations having the same family marker, and zero otherwise, it is possible to generate similarity estimates for the Chaffin and Herrmann study. These estimates are equivalent to that discussed above concerning family elements. As was also pointed out above, the partial correlation holding family influences constant showed that neither family elements nor marked links will be sufficient. Instead specific relational elements must be assumed as well to fully account for the sorting data.

It might be argued that a variant of a feature comparison model can generate a better account of the sorting data than that done from relation elements. These models assume that relations are apprehended merely from the computation of overlap of meanings in a word pair (Smith & Medin, 1981). Obviously, overlap alone cannot indicate the degree to which relations resemble one another; e.g. the meanings of car-engine have nothing in common with the meanings of house-kitchen, yet these pairs clearly possess similar relation definitions. In order to account for these data, these models will have to be modified to explicitly process the elements defining relations.

Thus, the best account of relation similarity is provided by a model in which relation similarity is derived from the agreement in the elements that define relations. This conclusion coincides with evidence that relation similarity ratings and the latency and accuracy of relation judgements rest on processing stimuli according to how well their relational properties conform to the elements defining task relations (Johnson-Laird, et al., 1984).

In summary, Relation Definition Theory successfully predicts relation similarity on the basis of one key primary assumption: that people perform comprehend relations by processing some or all of the simple relation elements defining the task relation. That semantic relations differ is obvious; that their definitions differ is obvious. However, it must be noted that Relation Definition Theory is explicitly different from previous semantic memory theories since it is the first theory to make a relation's definition the basis of semantic processing. Semantic relations constitute units of meaning whose purpose is to enable a person to logically manipulate and evaluate verbal ideas. Until the logical nature of semantic relations is made the central focus of semantic-memory theories, these theories will provide an inadequate performance of language tasks involving relations. Relation Definition Theory makes the logic of relations central; consequently, this theory promises to account for a wider range of relation phenonema than addressed by previous models.

Footnotes

The authors thank Teresa Staslo, Jonathan Vaughan, and Alan Searleman for helpful comments on an earlier draft of this paper. Requests for reprints should be sent to Douglas J. Herrmann, Department of Psychology, Hamilton College, Clinton, NY 13323.

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Table 1

Semantic Relations and Their Relational Elements[a]

Relations by Families	Examples	Relational Elements[b]
I. CONTRASTS		
Pseudoantonyms	Popular-Shy, Generous-Poor	Dim, BiP, Con
Contradictory	Alive-Dead, Remember-Forget	Dim, BiP, Dich, Sym
Contrary	Old-Young, Smooth-Rough	Dim, BiP, Cont, Sym
Directional	Front-Back, Left-Right	Dim, BiP, Dich, Spa
Reverse	Buy-Sell, Attack-Defend	Dim, BiP, Dich, Vec
Asymmetric Contrary	Hot-Cool, Large-Tiny	Dim, BiP, Cont
Incompatible	Frank-Hypocritical, Happy-Morbid	Dim, BiP,
Attribute Similarity	Rake-Fork, Valley-Gutter	Over, Int, Att, Dis,
II. SIMILARS		
Action Subordinate	Cook-Fry, Clean-Scrub	Inc, Int, UniI
Dimensional Similarity	Smile-Laugh, Hungry-Starving	Over, Int, Dim, UniP,
Synonymity	Purchase-Buy, Car-Auto	Inc, Int, BiI
Necessary Attribution	Bachelor-Unmarried, Tower-High	Over, Int, Att, Poss,
Invited Attribution	Food-Tasty, Bed-Comfortable	Inc, Con, Att, Poss
III. CLASS INCLUSION		
State Subordinate	Disease-Polio, Emotion-Fear	Inc, Int, UniI
Functional Subordinate	Furniture-Chair, Vehicle-Car	Inc, Int, UniI
Activity Subordinate	Game-Chess, Crime-Theft	Inc, Int, UniI
Perceptual Subordinate	Animal-Horse, Flower-Rose	Inc, Int, UniI
Place	Germany-Hamburg, Asia-China	Inc, Poss, Partive, Loc
Geographical Subordinate	Country-Russia, Continent-America	Inc, Int, UniI

IV. CASE RELATIONS		
Action-Recipient	Sit-Chair, Hunt-Prey	Evt, Act, Obj
Action-Instrument	Drink-Cup, Cut-Knife	Evt, Act, Inst
Agent-Action	Dog-Bark, Artist-Paint	Evt, Act, Agent
Agent-Instrument	Farmer-Tractor, Soldier-Gun	Evt, Agent, Inst
Agent-Object	Baker-Bread, Carpenter-Lumber	Evt, Agent, Obj
V. PART-WHOLES		
Measure	Mile-Yard, Hour-Minute	Inc, Homo, Partive
Ingredients	Pizza-Cheese, Table-Wood	Inc, Prop, Poss, Comp, Loc, Partive
Collection	Forest-Tree, Fleet-Ship	Inc, Prop, Homo, Poss, Partive
Group	Choir-Singer, Faculty-Professor	Inc, Prop, Soc, Homo, Poss, Partive
Functional-Object	Car-Engine, House-Roof	Inc, Prop, Attach, Poss, Comp, Partive
Functional Location	House-Dining Room, Kitchen-Refrigerator	Inc, Attach, Prop, Poss, Comp, Partive
Organization	Army-Supply Corps, Government-Executive Branch	Inc, Prop, Soc, Attach Poss, Comp, Partive

[a] The relations in this table are those used in Chaffin and Herrmann's (1984) sorting study. The table presents these relations according to family and in the order of presentation in the Hierarchical Clustering solution of the sorting data.

[b] All relations in the table involve the element of denotative agreement inaddition to the elements shown. For the definitions of the relation elements, see Table 2.

Table 2

Relation Elements and Their Definitions

Relation Elements	Definition	Description
I. Concerning Orientation of Meaning		
Denotative (Den)	Wi & Wj share denotative meaning	referential sense
Connotative (Con)	Wi connotes Wj	affective sense
II. Concerning Substance of Meaning		
Attributive (Att)	Wi "is" Wj	must (can) be like
Property (Prop)	Wi "has" Wj	property of
Componential (Comp)	Wi is a component of Wj	partial make-up of
Social (Soc)	Wi is socially committed to Wj	social contract
Homogeneous (Homo)	Wi's referent is indistinguishable from Wj's referent	indistinguishable
Attachment (Attach)	Wi's referent is attached to Wj's referent	is attached to
Possession (Poss)	Wi belongs to Wj	owned/possessed by
Agentive (Agent)	Wi acts on/to/for Wj	agentive power
Objective (Obj)	Wi is an object of/to/for Wj	object status
Instrumental (Inst)	Wi acts as an instrument for Wj	instrumental power
Action (Act)	Wi is action bearing to/for/on Wj	action bearing
Event (Evt)	Wi pertains to an event involving Wj	event bearing
III. Concerning Qualification of Meaning		
Dimension (Dim)	Wi & Wj share a single dimension	dimensional commonality
Unilateral (UniP) Position	Wi & Wj are on the same sides of the midpoint	same side of midpoint
Bilateral (BiP) Position	Wi & Wj are on opposite sides of the midpoint	opposing magnitudes

Symmetrical (Sym) Position	Wi is of = magnitude to Wj	equidistant from midpoint
Continuous (Cont)	Wi & Wj can be qualified	gradable
Discrete (Dis)	Wi & Wj can not be qualified	non-gradable
Dichotomous (Dich)	If Wi then not Wj	mutually exclusive
Spatial (Spa)	Wi is spatially opposite Wj	opposed in space
Vector (Vec)	Wi is directionally opposed to Wj	directionally oriented

IV. <u>Concerning Amount of Meaning</u>

Inclusion (Inc)	Wi is included in Wj	general inclusion
Overlap (Over)	Wi is partially included in Wj	overlap in meaning
Intersection (Int)	Wi is semantically included in Wj	semantic inclusion
Unilateral (UniI) Inclusion	Wj includes all of Wi, but Wi does not include all of Wj	partial inclusion
Bilateral (BiI) Inclusion	Wi = Wj	total inclusion
Locative (Loc) Inclusion	Wi's referent is dependent on Wj's referent	locational restraint
Partive (Partive) Inclusion	Wi is literally part of Wj	parts of