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Cos and Cosmos

Considerations on Patrick Slater's Monograph *The Principal Components of a Repertory Grid**

By K. HOPE

The reviewer here outlines the theory behind Patrick Slater's technique for the analysis of Repertory Grids. He then presents an analysis of a very simple Grid. The clinical possibilities of the method are assessed, and it is put into its context as a research design by a comparison with other multivariate methods.

In a short article published in 1958, Patrick Slater clarified the relations between what factor analysts call Q and R techniques. He showed that the results of the two methods bear a simple relation to one another. Following Burt, Slater analysed a p x t (person by test) matrix M and showed that the latent root λ_i of the p x p matrix MM′ is the same as the ith latent root of the t x t matrix M′M. If c_i is the latent vector associated with λ_i in MM′ then $M'c_i$ is the latent vector associated with λ_i in M′M. The relation between the two analyses holds as long as M is identical in the two cases. If M is centred by rows but not by columns for one analysis, and centred by columns but not by rows for the other analysis then the relationship does not hold. M can be centred (or centred and normalized) by one or both types of array so long as it remains the same in the two analyses.

The following arithmetic example of the analysis of a 7 x 2, person by test, matrix may help the reader to appreciate the generality of these relationships. The matrix M (below) is quite unlike any matrix which the psychologist has to analyse in that it is not centred, that is, the values in it are not expressed as deviations from the means of either rows or columns. Nevertheless the relations shown algebraically in the first paragraph of this review hold for M.

M

	t_1	t_2
p_1	6	8
p_2	4	0
p_3	6	8
p_4	0	6
p_5	6	8
p_6	0	1
p_7	6	6

The "variance-covariance" matrix of M for tests is:

M′M

	t_1	t_2
t_1	160	180
t_2	180	265

And the matrix of components, T, and the diagonal matrix of latent toots, λ, are:

T

	c_1	c_2
t_1	12	4
t_2	16	−3

λ

	c_1	c_2
c_1	400	0
c_2	0	25

The "variance-covariance" matrix of M for persons is MM′ and may be calculated by the reader, who may easily verify that its component matrix P is:

P

	c_1	c_2
p_1	10·0	0·0
p_2	2·4	3·2
p_3	10·0	0·0
p_4	4·8	−3·6
p_5	10·0	0·0
p_6	0·8	−0·6
p_7	8·4	1·2

Components three to seven are all zero. It may readily be verified that

* *The Principal Components of a Repertory Grid.* By Patrick Slater, Ph.D. 1964. London: Vincent Andrews & Co. (obtainable only from the author). Pp. 55. Price 15*s*.

$$P = MT\lambda^{-\frac{1}{2}}$$
$$T = M'P\lambda^{-\frac{1}{2}}$$
$$M = P\lambda^{-\frac{1}{2}}T'$$

In the monograph under review, Slater extends his investigations of the relation between the two possible ways of analysing a two-dimensional matrix. Although he limits the discussion to the analysis of Repertory Grids, that is to the analysis of element by construct matrices, the technique he suggests is quite general and applies to the usual person by test score matrix and to an object by judge matrix of discriminations.

Slater's Theoretical Approach

The extension of the investigation is illustrated in the following two-dimensional diagram:

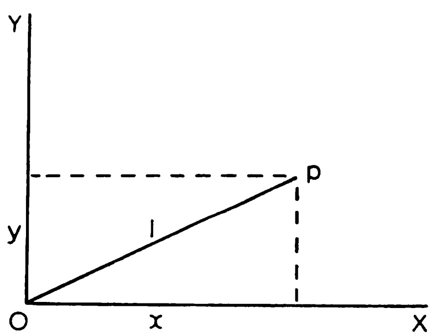


FIG. 1.

x and y are the co-ordinates of the point P with respect to the axes OX and OY. The vector OP is assumed to be of unit length and so the cosine of angle XOP is x and the cosine of angle YOP is y. By Pythagoras' theorem $x^2+y^2=OP^2=1$. We may regard x as specifying both a length and the cosine of an angle. It is a co-ordinate of a point, but also a direction cosine of a vector.

Factor analysts, having extracted a factor, component or vector, often plot it as an axis and indicate its relation to the tests by plotting the tests as points. Suppose we have two vectors, a and b, and two tests, t_1 and t_2:

		a	b		a	b
t_1	..	x	w	=	·8	−·6
t_2	..	y	z		·6	·8

This is plotted as follows:

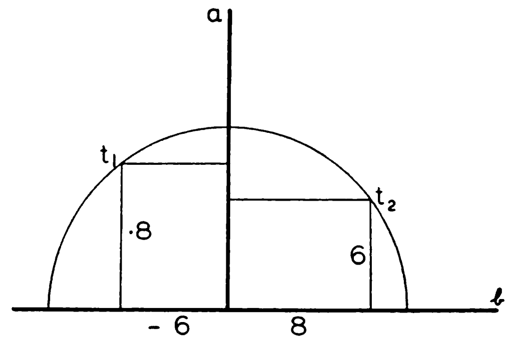


FIG. 2.

The mode of representation ignores the fact that the tests are in fact vectors, not points. In the example this does not matter too much, because in each case the distance from the origin to the test is unity $((\cdot 8)^2+(\pm\cdot 6)^2)$ and the tests can be regarded as points on the circumference of a circle with unit radius. It is reasonable to specify a vector by the point where it cuts a surface, just as we specify the South Pole as a point on the surface of the earth. It is only rarely, however, that a factor analyst concerns himself with all the factor saturations (x, w, etc.) of a test. Usually he extracts the first two or three factors and ignores the rest (that this neglect is not always justified has been argued by Slater (1964) and by the present writer, (1963)). The test vector is then left, like the jib of a wrecked crane, sticking up in the air and ending at nothing in particular.

Slater proposes to represent the test vectors by points on the surface of a sphere which has as many dimensions as there are non-zero lambdas. The space through which the test vectors pass on their way to the surface is the person space, that is, the space which is obtained by extracting the principal components of MM′. Thus, if we imagine a three-dimensional analysis as a terrestrial globe, each person is represented by a point somewhere inside the earth (very few will be on the surface) and the tests are points on the surface. How do we calculate the point at which a test vector meets the surface of the earth? This is done by establishing an arbitrary origin where the Greenwich line of longitude crosses the Equator. If a test is wholly accounted for by the first component, then that test is assumed to cut the surface at zero longitude and zero latitude. Angles of longitude and latitude are calculated for each test. If the component saturations for a test are x, y, and z for the first, second and third components respectively, then the cosine of the first angle is given by

$$\cos \alpha = \sqrt{\frac{x_2}{x_2 + y_2}}$$

and the cosine of the second angle is given by

$$\cos \beta = \sqrt{\frac{x_2 + y_2}{x_2 + y_2 + z_2}}$$

Continuing to follow the same patterning of the saturations enables us to calculate any number of angles. Their number will be one less than the number of non-zero latent roots. The sum of the squared saturations will be unity. With three non-zero roots, the relations between the tests can be represented by marking them on the surface of a sphere. With four roots we require a four-dimensional hypersphere and no physical representation is possible.

An Example

The following simple and (rather simple-minded) example may serve to clarify the geometry and algebra. Let us suppose that we are investigating a woman's attitudes to male members of her family and we invite her to suggest the sort of terms she uses to describe them. She suggests four adjectives: strong, sympathetic, aggressive and excitable. She supplies these terms with their opposites: weak, unsympathetic, pacific and calm. Taking each construct in turn we ask the woman to give a rating on a five-point scale to each man on that construct. The ratings are reported in Table I, which corresponds to Slater's Grid G. A numerically high value means that the woman attributes the first-named end of the construct to the element.

We now centre the matrix for constructs, that is, we express each rating as a deviation from the mean for that construct. The resulting matrix (Table II) is equivalent to Slater's matrix D. In the terms of this review it is the transpose of matrix M, i.e. it has persons (elements) in the columns rather than in the rows as in the previous arithmetic example.

The present example differs from Slater's in that he uses rankings, rather than ratings; thus his matrix D is standardized, i.e. every construct has the same variance. In our example, the variance-covariance matrix for constructs, M′M, is shown (Table III).

It seems that the woman is particularly discriminating in her attribution of strength or weakness to her menfolk, but does not differentiate them greatly on excitability. We may suppose that this is a reflection of the true nature

TABLE I

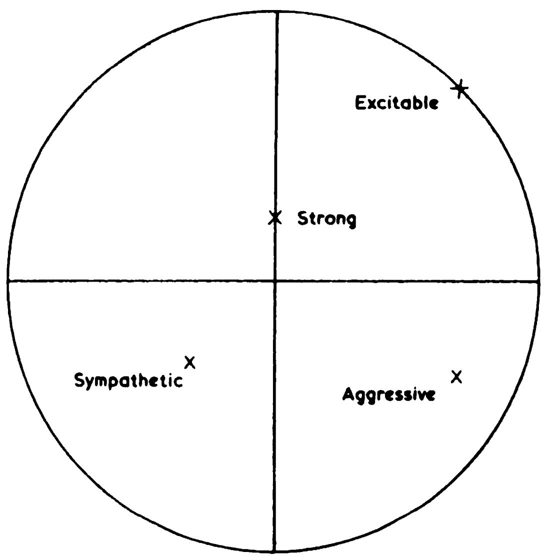
	Husband	Uncle	Brother	Father	Son	Mean
Strong	4	3	1	2	5	3
Sympathetic	4	3	3	1	4	3
Aggressive	4	2	1	2	1	2
Excitable	1	1	0	2	1	1

TABLE II

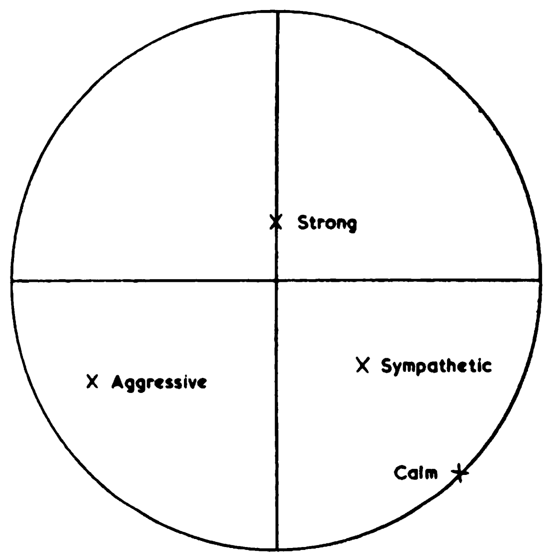
	Husband	Uncle	Brother	Father	Son
Strong	1	0	−2	−1	2
Sympathetic	1	0	0	−2	1
Aggressive	2	0	−1	0	−1
Excitable	0	0	−1	1	0

TABLE III

	Strong	Sympathetic	Aggressive	Excitable
Strong	10	5	2	1
Sympathetic		6	1	−2
Aggressive			6	1
Excitable				2



MAP 1—Plot of four constructs on the surface of a sphere (Projection: Lamberts Equivalent Azimuthal)



MAP 2.—Plot of the same four constructs as in Map 1 but with the signs of the second component and the fourth construct reflected.

of the relation between the woman and her family and so we may decide not to distort the reflection by standardizing or normalizing the ratings. The principal components (matrix T) of the variance-covariance matrix are reported below in non-normalized form. The sum of squares of each vector is equal to the associated latent root. One root disappears.

Components

	c_1	c_2	c_3	c_4
Strong	3	0	1	0
Sympathetic ..	2	−1	−1	0
Aggressive ..	1	2	−1	0
Excitable ..	0	1	1	0
Latent Root ..	14	6	4	0

If we normalize* these vectors and use them to weight the deviation ratings in matrix M we obtain the orthogonal components (matrix P):

Components

	c_1	c_2	c_3
Husband ..	1·87	1·22	−1·00
Uncle	0	0	0
Brother	−1·87	−1·22	−1·00
Father	−1·87	1·22	1·00
Son	1·87	−1·22	1·00
Latent Root ..	14·00	6·00	4·00

**i.e.* divide each element by the square root of the latent root so that the sum of squares of the elements becomes unity. Alternatively, we may use the elements as they stand and then divide by $\lambda^{\frac{1}{2}}$. For example, the position of the husband on the first component is given by $1\cdot87 = ((1 \times 3) + (1 \times 2) + (2 \times 1) + (0 \times 0))/\sqrt{14}$.

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Owing to the artificiality of the data it happens that every person except the uncle has the same proportion of the total variance. The uncle has none at all.

The husband appears in M as a strong character whose aggressiveness is mitigated by sympathy. The son is also seen as a strong character; he is sympathetic but not aggressive. With the aid of the woman's introspections we might interpret the first component as a dimension of strength of character, giving rather more weight to sympathy than to aggressiveness. The second component contrasts pacific persons, who tend to be sympathetic (son) or calm (brother), with persons who are aggressive (husband) or unsympathetic and excitable (father). It might represent an irascibility dimension. The third component throws together the sympathetic and aggressive husband and the calm and weak brother on the one hand, while on the other are the unsympathetic and excitable father and the strong, pacific son. It would be rash to suggest a name for this dimension solely on the evidence of the principal component analysis.

In order to represent the constructs geographically, we calculate their polar co-ordinates, that is we represent them as vectors springing from the centre of a sphere such as a terrestrial globe. Taking the elements of the non-normalized weighting vectors of each construct in turn we calculate

$$\cos\theta = \sqrt{\frac{c_1^2 + c_2^2 \ldots\ldots + c_k^2}{c_1^2 + c_2^2 + \ldots\ldots + c_k^2 + c_{k+1}^2}}$$

Thus for the construct Strong we calculate

$$\cos\alpha = \sqrt{\frac{3^2}{3^2 + 0^2}} = 1\cdot00$$

$$\cos\beta = \sqrt{\frac{3^2 + 0^2}{3^2 + 0^2 + 1^2}} = \cdot95$$

Performing these calculations for each construct we arrive at the following table of cosines:

	α	β
Strong	1·00	·95
Sympathetic	−·89	−·91
Aggressive	·45	−·91
Excitable	0	·71

Some care must be taken when inserting positive and negative signs in this table and the investigator must have a good grasp of what he is about. He is faced with a blank globe on which he draws, quite arbitrarily, a Greenwich line of 0° longitude, and another line, at right angles to the first, which represents the equatorial line of 0° latitude. One or other of the points of intersection of these lines is nominated the origin 0°, 0°. A construct which has a negative weight in the first weighting vector, c_1, will have a positive cosine with the radius which cuts the surface of the globe at 180°, 0° (the point where the equator meets the International Date Line). However, if a construct has a negative loading on the first component it is customary to reverse all the signs in that row of the component matrix. This is equivalent to measuring the construct from the other end—as weakness, for example, rather than strength. If this has been done then we are relieved of the need to employ one hemisphere of the globe. The signs of the cosines can be filled in by reference to weighting vectors other than the first. If a construct has a positive weight on c_2 we may, arbitrarily, assign it to the region East of 0° longitude, and if it has a positive weight on c_3 we may, arbitrarily, assign it to the region North of the Equator. Adopting these conventions we can convert the cosines into degrees of arc by reference to a cosine table:

	Longitude	Latitude
Strong	0°	18°N
Sympathetic	27°W	24°S
Aggressive	63°E	24°S
Excitable	90°E	45°N

Plotting Tests

The constructs in this example have different variances, that is to say they are vectors of varying lengths. We might make a wire model in which each wire represented a construct and the wires all crossed at a common origin. The lengths of the wires would be made proportional to the square roots of the variances of the constructs.

In Slater's own example the constructs all have the same variance, and so he is able to give each construct a length of one diameter. He then plots the point at which the positive end of each diameter meets the surface of a globe. These points may be examined to see if the constructs are grouped or strung out in any meaningful way. The more constructs there are the easier it becomes to identify their structure.

If there are more than three positive latent roots, we can either neglect the smaller roots, in which case some or all of the construct vectors stop short of the surface of the globe, or we can add more dimensions to our model and work with a hypersphere. Unfortunately this latter course deprives us of one of the main advantages of the technique, which is the ability to have all relations among the constructs under simultaneous scrutiny.

Plotting Persons

In Slater's model the components, like the constructs, are diameters of the globe, but, as befits reference axes, they are at right-angles to one another. The first component is the diameter whose positive end meets the surface at 0°, 0°. The second component emerges at 90° East on the equator, and the third emerges at the North Pole. The position of a person or element within the globe can be plotted as a point in the three-dimensional system defined by the three orthogonal component-diameters. Alternatively, the person can be plotted as a vector by applying the same calculations to P as have previous been applied to T. (Of course it is much simpler to plot a person as a point. The line joining that point to the centre of the sphere is the required vector.) A person who has no loading on any but the first component is represented by a vector which coincides with the diameter emerging at 0°, 0°. The length of this vector is the square root of his (one and only) loading.

It is possible that Slater might not approve of this mode of representation, since he has a preference (though not an exclusive preference) for referring to constructs as vectors and to elements as points. However, in psychological testing the person and the test are unknowable things-in-themselves. The material which we have to work with is the shadow which they cast in the form of a set of scores, and each score is related to both a test and a person. The reviewer can see no objection to representing the arrays in both rows and columns as vectors. Such a representation is particularly appropriate to a Repertory Grid in that the elements are there to illuminate the constructs and the constructs are there to illuminate the elements. But even in the analysis of the more usual person by test matrix we are not primarily interested in the measurement of persons. Rather, we are looking for the structure of interactions between persons and tests. The space to be mapped is not primarily a person space or a test space; it is a component space. Although the number of persons or the number of tests set limits to the dimensionality of the space, they do not determine how many dimensions it shall have. On the other hand it must be admitted that a certain asymmetry is introduced before the analysis proper has begun, in that the scores are centred for one set of arrays but not for the other. The analysis is therefore an analysis of a matrix compounded of two parts: the general factor of persons and the interaction of persons and tests. It is arguable that a Repertory Grid should be centred for both constructs and elements. In order to ensure that, in centring for elements, we are removing the general factor and not some dimension orthogonal or oblique to it, it would be necessary to ensure that each construct was scored in an appropriate direction.

The Polar Co-ordinate Technique

In the analysis of psychological data it is only too easy to achieve simplicity at the expense of accuracy and insight. So often an analysis of a person by test matrix terminates in a set of test vectors which are so remote from the original scores that no amount of ingenuity could enable us to re-thread the maze and determine the nature of the original score matrix. The method of polar co-ordinates makes explicit the interrelation between constructs and elements in a Repertory Grid. Slater has written a Fortran programme for the analysis of grids which performs all the calculations illustrated above, and which also prints out useful information such as the amount of interaction between constructs and elements and the distances between elements expressed as points in the construct space.

One of the great merits of representing reference axes as polar co-ordinates is that it does not tempt us to reify factors. It is obvious that geographers' reference lines, for all their convenience, are quite arbitrary. Burt (1940) explicitly adopted the imagery of latitude and longitude in order to emphasize the arbitrariness of psychological axes.

Polar Co-ordinates and Other Techniques

After outlining the analysis of an actual grid and demonstrating the richness of clinical interpretation which becomes available by the use of the method, Slater discusses briefly the possibility of comparing grids obtained from different persons. Of course, the great advantage of the method is that it can be meaningfully applied to the individual person. It is, in fact, a sophisticated and improved means of answering the sort of questions which Bannister's (1960) coefficients of thought disorder are supposed to answer. Nevertheless, having analysed a grid, the psychologist is tempted to compare it with other grids in order to see whether it is unusual, richer or more diversified. Slater, quite rightly, emphasizes that such questions can be answered only by imposing rigidities on the Repertory Grid technique, and since an advantage of the technique in the study of a single person is its flexibility, we may lose more than we gain by introducing rigidities. However, a consideration of the kinds of rigidity which might be introduced, and the kinds of analysis which they entail, serves to set the polar co-ordinate method in its context and to clarify its peculiar virtues and limitations.

Suppose that we wish to compare the Repertory Grids of two persons, A and B. The most rigid approach would be to constrain A and B to employ the same constructs and the same elements. Such a method might be appropriate to showing, for example, that twins are more similar in their thought patterns than non-twin sibs, or that members of a primitive culture are more similar to one another than members of an advanced culture. The appropriate technique of analysis is the three-dimensional method illustrated by Burt (1955) and Mahmoud (1955) for the analysis of p persons who have completed t tests on two (or more) occasions. The elements correspond to persons, the constructs to tests, and A and B are the first and second "occasions" respectively. Burt suggests a coefficient which measures the extent to which A and B share a general factor running through all the constructs. The reviewer (Hope, 1964) has suggested a coefficient which measures the similarity of patterning of elements irrespective of any general factor. For example, both A and B may prefer Aunt Flo to Uncle Jim, although A likes them on the whole while B dislikes them. A and B shows high pattern similarity but low agreement on the general factor of liking-disliking.

A second, less rigid, method of comparing Repertory Grids involves imposing identity on only one set of arrays, either constructs or elements. One might ask a husband and wife each to form their own constructs but to apply these constructs to the same set of friends and relations. An appropriate form of analysis would be a canonical correlation analysis. One might then find, for example, that the friends and relations were ranked in very similar order along two dimensions, one defined by a linear combination of husband's constructs, and the other defined by a linear combination of wife's constructs. (Would there be any advantage in expressing each set of canonical variates in terms of polar co-ordinates and mapping them on a common sphere?) If the husband's constructs were nominally very different from those of his wife, or if they were nominally similar but differently weighted, there would exist a tension between the semantic differences and the pragmatic similarity. Resolution of the tension would be simple in the case, let us say, of an alcoholic whose affection diminishes as it passes from his drinking companions to his in-laws, while the affection of the wife shows an opposite trend.

The technique of polar co-ordinates requires no constraint on either of the dimensions of the

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grid, and it is this flexibility which makes it so appropriate to the study of the individual case. The reviewer is of the opinion that it is of little value, and may be misleading, to analyse two grids separately and then to compare them. One important objection to this practice may be illustrated by an analysis of two persons by test correlation matrices, one derived from a sample of neurotics and the other from a sample of normals. Each sample completed the same five tests. The components of the two matrices were compared by normalizing them and multiplying the transpose of one component matrix by the other component matrix in order to arrive at the cosine matrix which relates each neurotic component to each normal component (Hope, 1963; Slater (1964) quotes this table of cosines in another context). The cosines show that each of the neurotic components is similar to a normal component, but there is one reversal in that the fourth neurotic component is equivalent to the third normal component and *vice versa*. The polar co-ordinates (in degrees) of the two samples as they stand are shown in Table IV.

Only the first and fourth columns reveal any degree of similarity between the two samples. If, however, we reverse the order of the third and fourth normal components the polar co-ordinates of the normal sample become:

		Normals			
		α	β	γ	δ
Tests	AH	3	−33	−25	− 8
	CO	−43	− 9	20	15
	PH	−21	31	−17	−12
	SC	25	− 1	34	−18
	G	33	10	− 6	26

The similarity between the two matrices is now much more obvious.

Although he is not aware of any explicit statement on this subject, the reviewer suspects that there exists a tacit opinion that, if two latent roots are so similar in size that they tend to appear in reverse order in different samples, then the components associated with those roots cannot be stable. The evidence of the above analysis tells against such a view.

Clinical Use

Clinicians should not allow the fearsome statistics to deter them from the employment of the technique of polar co-ordinates. Within a very few years many hospitals will have direct access to a computer and the analysis of a patient's grid will be a ten minute job: five minutes teleprinting and five minutes waiting for results. No doubt many grids will be quite useless, but it seems very probable that some at least will yield most useful clues to a patient's values and perceptions, always providing that the clinician is sufficiently skilled and thoughtful.

It may be that the method will throw light on that type of causation which seems to be peculiar to psychology, that is, idiosyncratic causation. In a particular patient's history one sometimes sees a very definite and specific cause for the patient's condition even though one makes no claim that this cause would produce this condition in any other person. One possible explanation of idiosyncratic causation is that the patient sees the cause as a sufficient reason for his condition. A skilfully manipulated Repertory Grid might reveal the patient's perceptions of his illness.

However, both the clinician and the reader of research articles must be warned never to believe anything they are told about a map of

TABLE IV

		Neurotics				Normals			
		α	β	γ	δ	α	β	γ	δ
Tests	AH	−27	−29	−14	−12	3	−29	30	− 8
	CO	−29	− 0	33	8	−43	20	9	15
	PH	−14	34	−12	− 9	−21	−20	−30	−12
	SC	54	− 4	14	−15	25	34	0	−18
	G	26	− 4	−15	23	33	− 6	−10	26

a person's constructs until they have considered the projection which has been employed in order to reduce the spherical surface of a globe to the flat plane of a sheet of paper. All projections involve distortion. For example, Mercator's projection, which Slater employs, exaggerates the distances between constructs at the top and bottom of the map. The map of a grid should never be presented without a statement of the projection employed.

The user of the technique should be aware of the disconcerting consequences of a property which is inherent in the method of principal components. A matrix of normalized principal components is an orthogonal matrix. A property of orthogonal matrices is that the signs of all the values in any row or any column may be "reflected" (reversed) without affecting the other properties of the matrices. To take a psychological example: the fourth construct of the above example is excitable-calm, and this may be considered from the opposite point of view as the construct calm-excitable. The second, irascibility, component may be seen from the opposite end to be a component of easy-going good nature. The first of the above maps shows the constructs and components as they appear in the preceding tables. The second map shows them after reflecting the signs of component 2 and construct 4. Reflecting the second component has turned East into West and West into East for all constructs. Reflecting the signs of the fourth construct has similarly switched *both* dimensions for that construct, and so the new East has gone back to being the old West (a double reversal) and North has become South.

Some psychologists will see such reversals as a source of exciting metaphysical possibilities; others will see them as a nuisance. They can be controlled to some extent by imposing the condition that every construct shall have a positive sign on the first component. While the condition is usually reasonable, there are some cases where the first component saturation of a test is near-zero and its sign is determined by error. There is no good reason for reversing all the signs of such a construct simply because the first saturation is negative.

It is not easy to formulate any reasonable rule to determine the appropriate sign pattern of a component. There is not likely to be one construct which is *primus inter pares*. However, in his example, Slater shows that certain persons may act as norms by which the subject judges other elements. These persons tend to occupy one extreme of a component. If such persons can be identified, then it seems appropriate to ensure, by reflection of signs if necessary, that they occupy the positive end of a component. It is conceivable that, say, the child of separated parents may see one parent as all good and the other as wholly bad. Presumably the good parent should be allowed to occupy the positive end of the component.

Misprints

There are a number of misprints in the text of the monograph, including a cube instead of a square in the formula for VL on page 30 and incorrect values in the table on page 33.

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