The intuitive literature on segregation is reviewed and a segregation measure, S, is constructed to embody existing intuitions. S measures segregation over a network of symmetrical social relations. Distributional problems are explored and two kinds of applications are illustrated.

SEGREGATION IN SOCIAL NETWORKS

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The word segregation is widely used both in everyday conversation and in the discourse of the social sciences. Many social scientists talk about segregation in the same loose intuitive sense that characterizes its use in ordinary discourse (Berry, 1958; van den Berghe, 1960; Tillman, 1961; Clark, 1965, van der Zanden, 1972; Hunt and Walker, 1974; Rose, 1974; Berry et al., 1976). Others, however, have attempted to explicate its meaning and to specify precise conditions for its use by developing measures of segregation (Hornseth, 1947; Williams, 1948; Jahn et al., 1948; Jahn, 1950; Cowgill and Cowgill, 1951; Bell, 1954; Duncan and Duncan, 1955; Cowgill, 1956; Bell and Willis, 1957; Taeuber, 1965; Campbell, et al., 1966; Beauchamp, 1966; Freeman and Sunshine, 1970; Schelling, 1971).

It is obvious that much is to be gained by developing measures of segregation. The use of measures, in contrast to the use of intuitive natural language statements, provides explicit rules that facilitate precise thought and communication about segregation. Moreover, the existence of measures permits the systematic collection and assessment of data.

On the other hand, the existence of precise measures tends to "freeze" data collection and analysis into a more or less standardized mold. This is certainly the case with segregation. The sort of segregation that has been studied empirically using the various measures has very little to do with the phenomenon described by those who have worked intuitively in the natural language (Duncan and Duncan, 1955; Freeman and Sunshine, 1970; Schelling, 1971).

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Progress has been made in the refinement of measurement concepts and procedures in order to bring them into closer correspondence with intuitive ideas about segregation. But much remains undone. It is the purpose of this paper to move along toward the goal of bringing measures and intuitive ideas closer together. A new and more general index of segregation will be introduced that is closely tied to the intuitive foundations of the concept. It is hoped that this index will provide the precision and utility of measurement without sacrificing the conceptual richness of the natural language concept.

SEGREGATION: INTUITIVE BACKGROUND

As it is used in the natural language, the term segregation refers to restrictions on the access of people to one another. People are partitioned into two or more classes or "kinds" and techniques are devised to limit the interaction between members of differing classes.

Nearly 20 years ago, Berry (1958: 273) defined segregations as a "form of isolation which places limits upon contact, communication, and social relations." Hunt and Walker (1974: 6) spoke of restriction of contacts between various "groups," Rose (1974: 139) talked in terms of maintaining physical and social distance, and van der Zanden (1972: 185) said, "*Segregation* may be thought of as a process or state whereby people are separated or set apart. As such it serves to place limits on social interaction."

Without exception, however, existing measures of segregation refer not to limitations on interaction but to restrictions on access to some physical space. They are designed to measure physical separation in housing, for example, or in seating in a classroom.[1] Although such physical separation is undoubtedly a form of segregation, it is segregation of a very limited and special sort. There is, as a matter of fact, considerable opinion (Berry et al., 1976; Clark, 1965; Tillman, 1961; van der Berghe, 1960) that spatial segregation is simply a device for maintaining status differences, Given a dominant group, spatial segregation is imposed by that group as a device for maintaining their higher status vis-à-vis others through limiting interaction. If lower status persons are kept spatially isolated, they can be prevented from interacting with higher status persons in ways that might imply and perhaps ultimately lead to equality.

From this perspective, spatial segregation is seen as only one of several social devices that can be used to protect status. Van den Berghe (1960) has suggested that in traditional stable social settings spatial segregation is unnecessary. In such settings the "etiquette" of status is explicit and shared and status differences can be maintained without keeping people apart. Live-in servants, for example, are traditionally "kept in their social place" despite their physical proximity to their employers by the appeal to traditional values and by the use of special status symbols like uniforms and stereotyped modes of address that continually call attention to the differences (Frazer, 1935).

It is also possible that limitations on interaction, whether they involve spatial separation or not, may be built with the support or even at the initiative of less powerful persons. Typically, such persons cannot *impose* segregation in the same sense that those in dominant positions can. But they can, either through retreat to unoccupied places or through the development of special symbols, limit interaction between themselves and others. According to Rose (1974: 141) this is particularly likely when the more powerful persons exhibit hostility or pile abuse on those they consider undesirable; he cites the formation of the ghetto of Cologne as an example of this sort of process.

All restrictions on interaction, whether they involve physical space or not, are forms of segregation—in social space. Any social device that results in restrictions on some form of social contact between persons who possess different socially relevant characteristics fosters segregation and at the most fundamental level such a restriction is the most basic form of segregation.

The study of segregation at this level requires the examination of the networks of social contacts and relations that bind individuals together. In these terms, segregation is one kind of structured order that can be exhibited in a network.[2]

To have segregation we must be able to differentiate two or more classes of persons according to their personal attributes. Typically, persons are differentiated for this purpose according to their race, ethnicity, social class, gender, age, occupation, education or any of the hundreds of other characteristics people seem to find essential in stereotyping one another. Then, given this partition, classes of persons are segregated to the degree that their social relations are restricted to members of their own class and do not "cross over" to members of other classes.

From this perspective a social network displays an extreme of segregation when all the members of one class of persons are cut off from all relationships with all members of other classes. At the opposite extreme is the situation in which all members of a class have relationships only with members of other classes—never with their fellow class members. Freeman and Sunshine (1970: 35-36) have characterized this latter situation as systematic or "formula" integration. Like segregation, systematic integration is an ordered arrangement of relations among persons. It is a different kind of order, but it is, nonetheless, ordered.

Obviously such systematic integration implies a complete lack of segregation. It is not, however, the only way that a lack of segregation may be displayed. Segregation is absent whenever relations are established without respect to the class memberships of the persons involved. In this latter case, social ties are established as if they were made by persons who were unable to perceive the characteristics that led to the classification; the several classes are well-mixed or randomly linked.

Thus, the intuitive literature on segregation suggests that the term refers to a phenomenon that takes place in social space. It implies a continuum with total separation or segregation at one end and either systematic integration or the random establishment of relations with respect to the partition on the other. In the next section an attempt will be made to embody these ideas in a measure.

MEASURING SEGREGATION

In the general case, any social network may be represented by a directed graph consisting of a set of points and a set of directed lines connecting ordered pairs of points. Points represent persons and directed lines represent relations or links from one person to another.

In studying segregation, however, we are concerned only with symmetrical relations between pairs of persons. Segregation limits those relations or interactions that might imply status equality; it protects status inequalities. But as Davis (1970) has pointed out, asymmetrical relations, as a consequence of their asymmetrical form, already embody status inequality. Only symmetrical relations can possibly imply equality of status, so it is these that must be restricted or cut off in order to maintain status inequality. Segregation, then, should be expressed as a limitation in symmetrical relations.

Thus, the sort of network appropriate for the study of segregation may be represented by a symmetrical graph consisting of a set of points,

$$A = \{a_i\},$$

and a set of edges or unordered pairs,

$$R = \{r_k\} = \{(a_i, a_j)\}.$$

Points represent persons and edges represent symmetrical social relations linking pairs of persons.

For the examination of segregation in such a network, the set of points must be partitioned into two or more subsets, A_g. This partitioning defines classes of persons according to some criterion that is potentially relevant to limiting their interaction.

Let

$$m = \text{the number of points in } A,$$
$$m_g = \text{the number of points in } A_g,$$
$$n = \text{the number of edges in } R.$$

Now we can define a random variable,

$$e_k^* = \begin{cases} 1 \text{ if and only if } r_k \text{ is an edge that cross-links} \\ \quad \text{a point in } A_g \text{ with an outsider, and} \\ 0 \text{ otherwise.} \end{cases}$$

Then

$$e^* = \sum_{k=1}^{n} e^*_k$$

is the number of edges that cross-link points in A_g with outsiders. It is this sum, e*, that forms the basis for a general measure of segregation.

If e* is small, there are few relations linking members of the critical subclass, A_g, with outsiders and segregation is indicated. If e* is large, there are many cross-class relations and the two classes are systematically integrated. By itself, however, e*, is not a satisfactory measure of segregation. It is dependent upon the total number of persons involved and on the proportion who fall in the designated subclass. We must establish a zero point or baseline and a unit of measurement or yardstick that are independent of these factors and will permit comparisons.

A natural baseline may be developed from the idea of the random generation of edges introduced above. If the individuals involved were, in effect, "color blind," if they were unaware of and unresponsive to the criterion used to designate subgroups, edges would be generated at random with respect to subclasses of A. The expected value, E(e*), under these conditions provides the baseline we seek. Segregation, then, may be defined as some function of the degree to which the expected value of e* exceeds its observed value. Thus, let

$$s = \begin{cases} E(e^*) - e^* \text{ if and only if } E(e^*) \geqslant e^* \text{ and} \\ 0 \text{ otherwise.} \end{cases}$$

Then, s is simply a count of the number of cross-class edges that are missing in the observed graph as compared with a graph where edges are generated at random. It is a natural measure of segregation, but since it depends on the number of points and number of edges in the graph it still does not permit comparison between graphs of differing sizes. It is useful, therefore, to express it as a proportion of its maximum possible value for a graph of the observed size. Thus, the proposed measure of segregation, S, is

$$S = \frac{s}{E(e^*)}.$$

The segregation measure, S, varies between 0 and 1. A value of 0 indicates a complete lack of segregation: the number of links between subclass members and outsiders is greater than or equal to the number expected by chance under the random choice assumption. A value of 1 indicates that there are no cross-class links—segregation is complete. Any value of S may be interpreted simply as the ratio of the number of missing cross-class links to the expected number of such links; thus it is the proportion by which the expected number of cross-class links is reduced in observation.

S, then, is a general measure of segregation. It embodies the intuitive ideas outlined above and provides an explicit definition of the concept. Undoubtedly it will need elaboration and refinement when a process model of segregation is developed; it may in fact be replaced completely by a measure or measures defined in terms of such a model. But in the meantime, S provides a foundation upon which a segregation model can be developed.[3]

DETERMINING THE EXPECTATION

The expected value of e* under the condition of the random generation of edges depends upon the number of points in the graph. Given m points, the total possible number of edges is

$$N = \binom{m}{2} = \frac{m(m-1)}{2}$$

and the total possible number of cross-class edges is

$$m_g(m-m_g).$$

If edges are generated at random, the probability of a given edge being a cross-class edge is therefore

$$p = \frac{m_g(m-m_g)}{N}$$

$$= \frac{2m_g(m-m_g)}{m(m-1)}$$

and the probability that a given edge links two points within either class is of course,

$$q = 1 - \frac{2m_g(m-m_g)}{m(m-1)} = 1-p.$$

Moreover, given the number of edges, n, the expected number of cross-class edges is

$$E(e^*) = \frac{n2m_g(m-m_g)}{m(m-1)} = np.$$

This expression may be used to determine the expectation of e* under any and all conditions.[4]

THE DISTRIBUTION PROBLEM

Direct calculation of the distribution of S is cumbersome and, fortunately, unnecessary. Instead, it is satisfactory and relatively simple to determine the distribution of e*.

The distribution of e* depends, in part, upon the nature of the application. If relations (both within and between subclasses) can be established without distributional constraints—if each point can, in principle, be connected to every other point—e* is hypergeometrically distributed. It is hypergeometrical because each cross-class link "uses up" a part of the potential of each of its points to establish links with any other points at all. This is analogous to sampling without replacement, and the probability that e* takes a particular value, y, is

$$pr(e^* = y) = H(y \mid p, n, N),$$

with variance,

$$Var(e^*) = \left[\frac{2nm_g(m-m_g)}{m(m-1)}\right]\left[1-\frac{2m_g(m-m_g)}{m(m-1)}\right]\left[\frac{m(m-1)-2n}{m(m-1)-2}\right]$$
$$= npq\frac{N-n}{N-1}.$$

This means that we can test the significance of observed measures of segregation by referring to a table of the hypergeometric distribution.[5] Unfortunately, however, published tables of the hypergeometric distribution are fairly uncommon and usually quite small. The largest is that produced by Lieberman and Owen (1961). However, computer calculation of the hypergeometric probability distribution for a given application is simple and straightforward. The probability of observing e* or fewer cross-links under the assumption that links are established at random is:

$$\sum_{i = \max[0, n+k-N]}^{e^*} \left[\frac{k!\, n!}{(k-i)!\,(n-i)!\, i!}\right]\left[\frac{(N-k)!\,(N-n)!}{N!\,(N-k-n+i)!}\right]$$

All this applies to networks that are unrestricted. Unfortunately, however, most actual networks are constrained. Limitations are imposed that restrict the generation of links to some particular distribution form. In this case we can let

d_i = the degree of the i^{th} point and

$$d = \sum_{i=1}^{m} d_i(d_i-1).$$

and

q_k = the sum of the degrees of the two points linked by the k^{th} edge and

$$q = \sum_{k=1}^{n} (q_k-2).$$

Moran (1948) proved that the variance of e* under these conditions is

$$\mathrm{Var}(e^*) = \frac{2nm_g(m-m_g)}{m(m-1)} + \frac{dm_g(m-m_g)}{m(m-1)} + \frac{4[n(n-1)-q]\, m_g(m_g-1)(m-m_g)(m-m_g-1)}{m(m-1)(m-2)(m-3)} - \left[\frac{2nm_g(m-m_g)}{m(m-1)}\right]^2$$

The exact distribution of e* under these conditions is unknown. It may be approximated, however, by use of the standard normal distribution.

APPLICATIONS

To illustrate the utility of the segregation measure, S, two applications will be presented here. An example involving the analysis of unrestricted networks is provided by reexamination

TABLE 1
Symmetrical Incidence Matrix of Nonavoidance Diads in the Effective Kinship Networks

	M	S	BW	SD	BD	F	B	SH	BS	SS	Σ
Mother	0	1	0	1	1	1	1	0	1	1	7
Sister	1	0	0	1	1	1	0	0	0	1	5
Brother's Wife	0	0	0	0	1	0	0	0	0	0	1
Sister's Daughter	1	1	0	0	0	1	0	0	0	0	3
Brother's Daughter	1	1	1	0	0	1	1	0	0	0	5
Father	1	1	0	1	1	0	1	0	1	1	7
Brother	1	0	0	0	1	1	0	0	1	1	5
Sister's Husband	0	0	0	0	0	0	0	0	1	1	2
Brother's Son	1	0	0	0	0	1	1	1	0	0	4
Sister's Son	1	1	0	0	0	1	1	1	0	0	5

of White's (1975) data. White dealt with the problem of segregation among social positions rather than among individual persons. He specified a set of ten standard kinship positions that he called the "effective kinship network."

Traditional analysts (e.g., Murdock, 1971) have argued that societies sometimes proscribe interaction among some kinship positions as an extension of incest taboos. Thus, given this reasoning, kinship positions should be segregated according to the gender of their occupants. White's data provide the possibility of a test of this hypothesis.

White collected data on the rules governing various kinds of interaction among occupants of his ten standard kinship positions for a sample of 219 societies. For every pair of positions for was able to specify whether or not interaction between their occupants was *ever* restricted in any society in the sample.

White's data are shown in Table 1. They allow us to determine the degree to which these kinship positions are segregated with respect to gender.

For this case, the number of points is

$$m = 10.$$

We may designate the females as A_g, the number of females is

$$m_g = 5,$$

and the number of symmetrical edges is

$$n = 22.$$

Moreover, the observed number of cross-gender links is

$$e^* = 9.$$

Then assuming edges were generated at random with respect to gender, the expected number of cross-gender edges is

$$E(e^*) = \frac{2nm_g(n-m_g)}{m(m-1)}$$

$$= \frac{(2)(22)(5)(5)}{(10)(9)}$$

$$= 12.22,$$

and

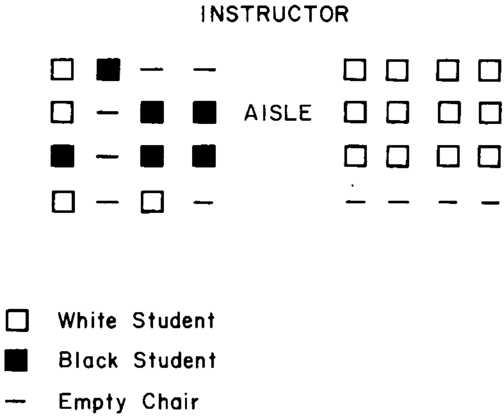
$$= \frac{12.22-9}{12.22}$$

$$= .26$$

The idea that communicative avoidance is based entirely on gender then, seems unlikely. The fact that cross-gender links are reduced from their random expectation by only 26% suggests that other factors must be operating in this phenomenon.

Under the assumption that edges were generated at random with respect to gender, we can determine the probability that $e^* \leqslant 9$. The hypergeometric probability of $e^* \leqslant 9$ is .051. Therefore, from these data we cannot strictly rule out the notion that gender is irrelevant to rules for social access in kinship networks.

Another example may be used to illustrate the study of segregation under conditions where there are restrictions on the distri-



SOURCE: Campbell, Kruskal, and Wallace (1966)

Figure 1: Sample Seating Chart

bution of edges. Campbell et al. (1966) reported a study of racial segregation of seating among students in a college classroom. Data on voluntary seating arrangements were collected in classrooms in a teachers' college in 1964. The data show actual seating arrangements of students by race (black and white). A sample data set is shown in Figure 1.

The authors reasoned that only side-by-side adjacent seating was socially significant in linking students and, moreover, that the students were limited to the observed pattern of occupied and unoccupied seats. Obviously then, there are physical restrictions on the number of adjacencies that any student can establish under these conditions. Here we have a case of strong constraints on the distribution of edges in a network.

For these data the number of persons,

$$m = 22,$$

and the number of blacks,

$$m_g = 6.$$

There were

$$n = 12$$

adjacencies in seating out of which

$$e^* = 1$$

was a black-white adjacency.

The expected number of cross-race adjacencies under the assumption of random-seating choice with respect to race is

$$E(e^*) = \frac{2nm_g(n-m_g)}{m(m-1)}$$

$$= \frac{(2)(12)(6)(16)}{(22)(21)}$$

$$= 4.987,$$

and the index of segregation is

$$S = \frac{4.99-1}{4.99}$$

$$= .80,$$

indicating that there are 80% fewer cross-race adjacencies than would be expected if seating choice were independent of race.

We can estimate the significance of this value by referring to a one-tailed table of the normal distribution. For these data,

$$d = 12$$

and

$$q = 12.$$

Therefore, the variance of e* is

$$Var(e^*) = \frac{2nm_g(m-m_g)}{m(m-1)} + \frac{dm_g(m-m_g)}{m(m-1)} + \frac{4[n(n-1)-q]\,m_g(m_g-1)(m-m_g)(m-m_g-1)}{m(m-1)(m-2)(m-3)} - \left[\frac{2nm_g(m-m_g)}{m(m-1)}\right]^2$$

$$= \frac{(2)(12)(16)(6)}{(22)(21)} + \frac{(12)(6)(16)}{(22)(21)} +$$

$$\frac{(4)[(12)(11)-12](6)(5)(16)(15)}{(22)(21)(20)(19)} - \left[\frac{(2)(12)(16)(6)}{(22)(21)}\right]^2$$

$$= \frac{2304}{462} + \frac{1152}{462} + \frac{3456000}{175560} - \left[\frac{2304}{462}\right]^2$$

$$= 4.987 + 2.495 + 19.686 - 24.870$$

$$= 2.296, \text{ and}$$

the standard deviation of e* is therefore 1.515.

Then, given

$$e^* = 1$$

and

$$E(e^*) = 4.987,$$

we can estimate the chance of value of observing an e* less than or equal to 1 by calculating a standard Z-ratio with a correction for continuity. Since the distribution of e* is discrete, we must correct for continuity by raising the observed value of e* half the interval between its observed value and its next observable value. The corrected value of e*, therefore, is 1.5. Then,

$$Z = \frac{1.5-4.987}{1.515}$$

$$= -2.301$$

for which the one-tailed area is .01. Thus, we may conclude that if seats were chosen without respect to race, repeated observations would show as much or more segregation as that observed here approximately one time in every 100 trials.

SUMMARY AND CONCLUSIONS

In this paper an attempt has been made to derive a measure of segregation that is consistent with current intuitive ideas about how segregation works. Segregation is viewed here as a restriction on the mutual access of people to one another in terms of some characteristic of the persons involved. Thus, segregation is defined as one kind of bias on what might otherwise be viewed as a random network of interpersonal ties.

The proposed measure is applicable to a broad range of phenomena. Two applications have been illustrated, but the measure could also easily be used in studying segregation in housing, lunch room seating, dating, marriages, mutual best-friend sociometric choice, work groups, recreational patterns, communication patterns or any set of social relations that might conceivably be restricted according to race, ethnicity, gender, religion, class, education or any of the large number of personal attributes people use to stratify themselves. The measure presents a perfectly general way of thinking about and measuring segregation in social space.

Problems of sampling distribution have been discussed. In the free-choice situation the sampling distribution of cross-class choices is hypergeometric. With constraints on choice the sampling distribution is unknown but may be estimated by the methods described.

NOTES

1. This concern with spatial separation seems to be the result of a desire to produce segregation measures that may be used on available census data. The result is a set of measures that are easy to apply using existing data but that lose sight of the intuitive concept.

2. This is almost identical to the conception proposed by Blau (1977) who refers to this phenomenon as "discrimination." This writer prefers the word segregation because discrimination has come to have an explicit meaning in the context of economic exchange.

3. The measure, S, is related to Geary's (1954) measure of contiguity, c; specifically,

$$S = \begin{cases} 1\text{-}c \text{ if } c \leqslant 1 \\ 0 \text{ otherwise.} \end{cases}$$

4. This suggests another way of looking at the reasoning underlying the measure, S, in terms of some of the more established measures. This same information used to calculate S may be expressed in an ordinary contingency table (see Table 2).

TABLE 2

	Unlinked Pair	Linked Pair	Sum
Cross-Class Pair	$m_g(m-m_g)-e^*$	e^*	$m_g(m-m_g)$
Within-Class Pair	$\frac{m(m-1)}{2} - [m_g(m-m_g) + n-e^*]$	$n-e^*$	$\frac{m(m-1)}{2} - m_g(m-m_g)$
Sum	$\frac{m(m-1)}{2} - n$	n	$\frac{m(m-1)}{2}$

Table 2 is a perfectly standard contingency table and possesses all the usual properties of such tables except that the frequencies recorded in its cells are frequencies of *pairs*. All this suggests that we might use a standard measure of association (or nonindependence) to measure segregation. Indeed, we might use gamma, for example, because gamma yields a P.R.E. interpretation. The interpretation in this case involving pairs of pairs is, perhaps, somewhat strained but gamma is nonetheless a standard measure with an established interpretation.

There are, however, two drawbacks to the use of gamma in contrast to S in the present context.

(1) Consider a shifting operation. Marginal totals are held constant and segregation is increased by shifting cases, one by one, from the cell containing cross-class links to the cell containing within-class links as shown in Table 3. Obviously this shifting operation results in a step-by-step increase in segregation. This step-by-step increase is reflected in the values taken by S for these tables. For a, S = .6, for b, S = .8, and for c, S = 1.0. Gamma shows a similar pattern of increase. For a, gamma = .72, for b, gamma = .88, and for c, gamma = 1.0. The important fact, however, is that while S increases as a linear function of step-by-step growth of segregation, gamma does not. S, therefore, seems to be the preferred measure.

(2) When all possible cases are shifted out of the cell containing cross-class links, in the manner shown above, gamma will always take a value equal to one. S, however, will reach 1.0 only if that cross-class linked cell contains no cases at all. In effect, this suggests that gamma takes the marginals as fixed parameters and leads to the conclusion that there is maximum segregation whenever the number of cross-class links is at its minimum. S, on the other hand, treats the marginals as random variables. It finds maximum segregation only when there are *no* cross-class links at all, regardless of the marginals.

Similar objections can be made to each of the other standard statistical measures of association (i.e., phi, the contingency coefficient, lambda, the uncertainty coefficient, tau, Sommers' D, and eta). Except for the symmetric version of Sommers' D statistic, none is a linear function of the shift of cases described above. Moreover, none of the others, including D_{sym}, necessarily reaches a value of one in the case where the observed number of cross-class links is zero. Many of these standard measures are useful but they are simply not designed to perform the task of measuring segregation.

5. This is, of course, exactly equivalent to the use of Fisher's Exact Test on the two-by-two table described in note 4, since Fisher's test is based on the hypergeometric distribution. Furthermore, it indicates that unless any of the expectations are extremely small, the chi-square test for independence may be used as an appropriate approximation.

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TABLE 3

	23	2	25
a	13	7	20
	36	9	45
	24	1	25
b	12	8	20
	36	9	45
	25	0	25
c	11	9	20
	36	9	45

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