1. INTRODUCTION

If two raters independently classify N items into the same set of k nominal or ordinal categories, one wishes to develop a measure of agreement between the raters. The data can be presented in the format of a two-way contingency table, where the cell entry, $X_{ij}$, $i=1, \ldots, k, j=1, \ldots, k$, denotes the number of items classified into the jth category by rater A that were classified into the ith category by rater B. The row and column totals, $X_i$ and $X_j$, respectively, denote the total number of items classified into the ith category or the jth category by rater A, respectively.

Agreement can be regarded as a special kind of association: perfect association implies the ability to perfectly predict the category of one rater from knowledge of the category of the other rater, while perfect agreement implies that both raters classify the same items into the same categories. Intuitively, a high level of agreement implies that the diagonal cell entries $X_{ii}$, $i=1, \ldots, k$, would be larger than the off-diagonal cell entries $X_{ij}$, $i,j=1, \ldots, k, i \neq j$.

Cohen (1960) proposed the kappa statistic,

$$\kappa = \frac{\sum_{i=1}^{k} \sum_{j=1}^{k} X_{ij} - \frac{1}{k} \sum_{i=1}^{k} X_{i}X_{i}}{N - \frac{1}{k} \sum_{i=1}^{k} X_{i}X_{i}},$$

where $n_i = \sum_{j=1}^{k} X_{ij}$ and $n_j = \sum_{i=1}^{k} X_{ij}$, are the marginal totals of the contingency table. The kappa statistic's values range from -1 to 1. The range of values can be seen to depend on the observed marginal totals. The kappa statistic's values are intuitively interpreted as follows:

- If $\kappa < 0$, there is agreement smaller than expected due to chance alone; if $\kappa = 0$, there is agreement only as expected due to chance alone; if $\kappa > 0$, there is agreement beyond what is expected due to chance alone; and if $\kappa = 1$, there is perfect agreement.

The kappa statistic has enjoyed widespread popularity and has been generalized in various ways. Cohen (1968) and others have extended the statistic to a "weighted kappa," which takes into account the off-diagonal terms as indicators of "partial agreement." All of the kappa-like statistics have as drawbacks their constraint of the marginal totals. The motivation for the statistic is the "agreement chart" developed by Bangdiwala (1985) to display the information contained in the contingency table. A description of the agreement chart is presented in Section 2. In Section 3, the SAS® software features utilized to automate drawing the agreement chart are described. Finally, the techniques are illustrated with two examples in Section 4.

2. DESCRIPTION OF THE AGREEMENT CHART

The motivation for developing a new measure of agreement was to provide a visual representation of the contingency table as well as have a statistic with an intuitive interpretation. Few graphical representations are available to represent cross-classifying variables, and interpret results for up to a maximum of six cross-classifying variables. The concept of utilizing rectangles to represent counts is adapted by Bangdiwala (1985) in producing another graphical display, the "agreement chart," for the specific purpose of assessing observer agreement and investigating other relevant hypotheses such as observer bias.

Figure 1b displays the information from the hypothetical data displayed in the contingency table shown in Figure 1a. N=50 items classified into k=3 classification categories. It is constructed as follows:

1. Draw an NxN square.
2. Draw k rectangles of dimensions $X_{i} \times X_{i}$, $i=1, \ldots, k$, within the N x N square. The rectangles are positioned such that the first rectangle of dimension $X_{1} \times X_{1}$ is in the lower left corner of the N x N square, the second rectangle's lower left corner touches the first rectangle on the first one's upper right corner, and so on until the kth rectangle is in the upper right corner of the N x N square. These rectangles contain the information on the marginal totals of the contingency table.
3. The $X_{ij}$, diagonal entry, $i=1, \ldots, k$, will determine a square of perfect agreement of dimension $X_{i} \times X_{i}$, which will be blackened and positioned within the ith marginal total rectangle such that $\sum_{j=1}^{k} X_{ij}$ spaces are to the left of it, $\sum_{j=i+1}^{k} X_{ij}$ spaces are to the right of it, $\sum_{i=1}^{j-1} X_{is}$ spaces are below it, and $\sum_{i=j+1}^{k} X_{is}$ spaces are above it.

A descriptive measure for agreement between the observers that naturally arises from such a chart is the proportion of the sum of the areas of the squares of perfect agreement to the sum of the areas of the rectangles of the marginal totals. The statistic

$$\kappa = \frac{\sum_{i=1}^{k} \sum_{j=1}^{k} X_{ij}^2 - \frac{1}{k} \sum_{i=1}^{k} X_{i} \sum_{j=1}^{k} X_{j}}{N - \frac{1}{k} \sum_{i=1}^{k} X_{i} \sum_{j=1}^{k} X_{j}},$$

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is a measure of agreement ranging from 0 to +1, with zero being "no agreement" and one "perfect agreement." Thus, the range of values of $B_k$ does not depend on the cell frequency counts. The $B_k$ statistic does utilize the information contained in the marginal totals, and thus accounts for chance agreement.

The choice of ordering of the categories in the contingency table will affect the visual interpretation of the agreement chart. This is not a concern for ordinal categories or for nominal categories with a preferred ordering, but a reasonable choice of ordering categories, say, in descending order by the size of the diagonal entries, can eliminate any arbitrariness in the visual impact encountered for nominal categories. Finally, note that when $k=N$, the agreement chart provides a graphical display of the rank scores comparison between two raters.

Tests of hypotheses and the properties of the $B_k$ statistic are examined in Bangdiwala (1987). Similar to the notions of a "weighted kappa" as discussed in Cohen (1968), the $B_k$ statistic can be generalized to a "weighted $B_k$" statistic by meaningfully incorporating the information contained in the off-diagonal cell entries. In the agreement chart, "partial agreement" can be visualized as successively lighter shaded areas the further away one is from the perfect agreement diagonal entries. Thus, if $i=1,\ldots,k$, cell entries $X_{i,i}, X_{i,i+1}, X_{i+1,i}, X_{i+1,i+1}$, and $X_{s,s}$ would determine a shaded rectangle surrounding the $X_{s,s}$ determined square of perfect agreement which would represent an area $A_{s,s}$ of "close to perfect agreement." Successively lighter shaded areas from the diagonal cells will determine successively lighter shaded areas (see Figure 9, for example). These concepts are especially appropriate for ordinal categories, where aggregate bias would be related to the shaded areas and a "weighted $B_k$" statistic constructed as follows:

$$B_k = \sum_{i=1}^{k} \sum_{b=1}^{q} \left( X_{i,i} - \frac{q}{k} \sum_{b=1}^{q} X_{i,i} \right)^2$$

where $w_b$ is the weight for $A_{i,i}$, the shaded area $b$ level away from the $i$th diagonal entry, $b=1,\ldots,q$, where $q$ is the furthest level of "partial agreement" wishing to be considered, $q=1,\ldots,k-1$. The advantage of such a statistic would again be its graphical interpretation. Of course, the choice of weights can be appropriate for specific alternatives one is wishing to detect.

The concept of observer bias can be studied utilizing the agreement chart as well. Observer bias refers to the tendency of one rater to classify items more into certain categories than the other rater, and is thus a measure of the difference in the observers' marginal distributions. A common case of observer bias is either an increasing or decreasing preference for categories by one of the observers if the categories are ordinal. This concept can be easily visualized in the agreement chart (see Figure 9, for example) by noting the deviation of the path of marginal totals rectangles from the diagonal line of marginal homogeneity. The closer to the diagonal the path is, the closer in agreement the raters' marginal distributions are. This concept is useful only for ordinal categories, since the rearrangement of the rectangles possible for nominal categories, makes the path of rectangles an arbitrary criterion.

3. AUTOMATED DRAWING OF THE AGREEMENT CHART USING SAS® SOFTWARE

For the computer construction of the agreement chart, the procedure needed to be able to produce the rectangles determined by the marginal and individual cell frequencies, the appropriate pattern of shading for assessing partial agreement, the diagonal line to examine observer bias and to take into account empty cell entries in the contingency table.

For a $k \times k$ contingency table with $N$ items being classified by observers $A$ and $B$, the agreement chart is an $N \times N$ square with $k$ large rectangles placed along the diagonal and from 1 to $k-1$ small rectangles within each large one. Each large rectangle $i$, $i=1$ to $k$, is defined by the marginal totals of row $i$ and column $i$. The small rectangles within are defined by the cells of this row and column. Matching row cells with column cells produces a pair of numbers which can be manipulated to produce a set of ordered pairs, with the row coordinates and the column coordinates and the column cells determining the $y$ coordinates. This set of ordered pairs positions the upper right corner of each small rectangle. The upper left corner either coincides with that of the encompassing large rectangle or is offset from it. These two corners are sufficient to define each small rectangle.

The SAS® PROC FREQ/LIST output dataset for a two-way frequency table of observer $A$ by observer $B$ has a variable defining categories for observer $A$, one defining categories for observer $B$, and one defining cell counts for each combination of categories of observer $A$ and observer $B$ (Figure 1a). If sorted by observer $A$, the counts are ordered across each row, row 1 to $k$ (Figure 2). An observation with the cell counts for each row is outputted. Each observation includes the variable BOX to identify the row in the table and thus which large rectangle the cells will define (Figure 3).

If the same dataset is sorted by observer $B$, the counts are ordered down each column, column 1 to $k$ (Figure 4). Observations for each column, numbered 1 to $k$, are outputted with the variable BOX to identify the column (Figure 5). Merging the two datasets of Figures 3 and 5 by BOX matches row 1 to column 1 (Figure 6).

To compute the actual coordinates from these sets of pairs, each $x$ or $y$ value is added to the sum of the $x$ or $y$ values for previous points within the same large rectangle. This provides the upper right corner coordinates of the small rectangles. The origin of the enclosing $N \times N$ square forms the lower left corner for the first large rectangle and all the small ones inside (BOX=1). The other large rectangles have their lower left corners at the upper right corner of the preceding large rectangle. The lower left
corners and upper right corners of the small rectangles within may or may not coincide with a corner of a large rectangle. If they do not, an offset from the corner is computed. Coordinates are also computed to center labels within each large rectangle along the x and y axes. (See Figure 7 for coordinates for rectangles with BOX=1.)

From similar datasets of coordinate pairs, an ANNOTATE dataset is created. An ANNOTATE dataset has x and y coordinate variables to indicate what is to be done at that point. Variables also define the coordinate system used in referencing x and y values (Figure 8).

Variables XOFFSET and YOFFSET are assigned a value of 3 to define the coordinate system to be "screen percentage" in which the value of the x and y coordinates represent percentages of the entire plot area. The origin of the graph is offset from the screen origin in order to allow space for labels and titles. Taking into account this offset, a scaling variable is computed based on N, the total number of items in the contingency table. Each point, when multiplied by the scaling value, thus represents a percentage.

The ANNOTATE functions MOVE and BAR are used to move to the lower left corner of each rectangle and draw a box to the upper corner. Each rectangle thus requires two observations in the ANNOTATE dataset. The STYLE variable is assigned a value, when function equals BAR, to produce degrees of shading for the small interior rectangles. The innermost rectangle is solid and outermost is empty (Figure 8). To label axes, observations with the function LABEL are outputted with variables giving x and y coordinates, style and size of text. Two additional variables XSYS and YSYS are outputted, one with function MOVE, and one with function DRAW. This produces the diagonal line from the innermost rectangle of the first large rectangle to the innermost box of the last large rectangle.

To display the chart, FROC GOLDS is run using this ANNOTATE dataset. Hard copy plots are produced on a TERTRONIX plotter and screen plots on an IBM 3179C terminal using interactive SAS® software and PROC GPRELAY.

The main problems occur when there are many classification categories. Charts with as many as six categories were produced, but axis labels would not fit if the rectangles were small (i.e. the marginal totals were small). Distinguishing levels of shading is a problem with too many categories. One solution is to draw only the large rectangles and the innermost small squares which represent the diagonal cell entries. Marginal totals or cell counts of zero are not a problem.

4. ILLUSTRATIVE EXAMPLES

Table 1 displays the information on independent diagnostic classification by New Orleans and Winnipeg neurologists of multiple sclerosis patients from the two cities. Data from this table is presented in the agreement charts of Figures 9(a) and 9(b), where shading denotes partial agreement as discussed in Section 2. By examining the path of rectangles in Figure 9, it seems that the Winnipeg neurologist tends to classify patients into worse diagnostic classes than the New Orleans neurologist. Closer examination of the relative sizes of the large rectangles seems to indicate that the Winnipeg neurologist is more certain about his own patients than he is about the New Orleans patients. The pattern of disagreement noted in the partial shading areas is similar for both sets of patients.

A practical example of the technique is in comparing the reliability of classification of causes of death by a trained nosologist with classification by a panel of physicians. In elderly cases, the presence of a multitude of factors at death may make the selection of the underlying cause difficult. Relying solely on the death certificate may not provide sufficient information to properly classify the death. Table 2 presents information on 155 nonelderly deaths (age at death 66 years) among participants of the Lipid Research Clinics Prevalence Follow-up Study, a mortality follow-up study focused primarily on cardiovascular reasons for death. Table 2(b) is the 268 elderly deaths in the same cohort of subjects. Examining Figures 10(a) and 10(b) confirms the high level of reliability between the two different measures of classification. The graphical technique provides a visual test of the belief that classifying deaths in the elderly is especially difficult. Death certificate tend to emphasize cardiovascular-related causes of death. The panel of cardiologists examine additional information and is better able to rule out cardiovascular as an underlying cause while the nosologist, relying solely on the death certificate, may not. In Figure 10(b) for elderly deaths, the upper right-hand rectangle in the chart has a large area of disagreement indicating that a large number of elderly deaths are classified as "Other noncardiovascular" by the panel of physicians but not so (and thus as cardiovascular of some type) by the nosologist. This phenomenon is not seen to occur in Figure 10(a) for the nonelderly deaths.

ACKNOWLEDGEMENTS

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REFERENCES


For further information, and a copy of the computer program, contact: Shrikant I. Bangdiwala, Collaborative Studies Coordinating Center, Department of Biostatistics, Suite 203, NCNB Plaza, 137 E. Franklin St., Chapel Hill, NC 27514. (919) 962-3266.

TABLES AND FIGURES

Figure 1a. Example of a contingency table with N=50 items being classified by observers A and B

\[
\begin{array}{ccc|c}
\text{class} & 1 & 2 & 3 & \text{total} \\
\hline
\text{Observer A} & 10 & 6 & 4 & 20 \\
2 & 9 & 3 & 7 & 16 \\
3 & 5 & 1 & 4 & 14 \\
\text{column total} & 25 & 10 & 15 & 50 \\
\end{array}
\]

Figure 1b. Agreement Chart for data of Figure 1a

\[
\begin{array}{c|c}
\text{Observer B} & \text{row} \\
1 & 10 \\
2 & 6 \\
3 & 9 \\
\end{array}
\]

\[
\begin{array}{c|c|c}
\text{class} & 1 & 2 & 3 \\
\hline
\text{total} & 20 \\
\end{array}
\]

Figure 2. Output dataset from PROC FREQ with LIST option for contingency table of Figure 1a, sorted by OBSERVA, OBSERVB

\[
\begin{array}{c|c|c|c|c|c|c}
\text{OBSERVA} & \text{OBSERVB} & \text{COUNT} \\
1 & 1 & 10 \\
1 & 2 & 6 \\
1 & 3 & 4 \\
2 & 1 & 6 \\
2 & 2 & 3 \\
2 & 3 & 7 \\
3 & 1 & 9 \\
3 & 2 & 1 \\
3 & 3 & 4 \\
\end{array}
\]

Figure 3. Output dataset with observations containing cell counts for each row of contingency table of Figure 1a

\[
\begin{array}{c|c|c|c|c|c|c}
\text{BOX} & \text{Y1} & \text{Y2} & \text{Y3} \\
1 & 10 & 6 & 4 \\
2 & 6 & 3 & 7 \\
3 & 9 & 1 & 4 \\
\end{array}
\]

Figure 4. Output dataset from PROC FREQ with LIST option for contingency table of Figure 1a, sorted by OBSERVB, OBSERVA

\[
\begin{array}{c|c|c|c|c|c|c|c}
\text{OBSERVA} & \text{OBSERVB} & \text{COUNT} \\
1 & 1 & 10 \\
2 & 1 & 6 \\
3 & 1 & 9 \\
1 & 2 & 6 \\
2 & 2 & 3 \\
3 & 2 & 2 \\
1 & 3 & 4 \\
2 & 3 & 7 \\
3 & 3 & 4 \\
\end{array}
\]

Figure 5. Output dataset with observations containing cell counts for each column of contingency table of Figure 1a

\[
\begin{array}{c|c|c|c|c|c|c|c}
\text{BOX} & \text{X1} & \text{X2} & \text{X3} \\
1 & 2 & 3 & 4 \\
2 & 6 & 3 & 1 \\
3 & 4 & 7 & 4 \\
\end{array}
\]

Figure 6. Merged dataset with observations matching cell counts for each row and column of contingency table of Figure 1a

\[
\begin{array}{c|c|c|c|c|c|c|c}
\text{BOX} & \text{X1} & \text{Y1} & \text{X2} & \text{Y2} & \text{X3} & \text{Y3} \\
1 & 10 & 10 & 6 & 6 & 4 & 9 \\
2 & 6 & 6 & 3 & 7 & 1 \\
3 & 9 & 4 & 1 & 7 & 4 & 4 \\
\end{array}
\]

Figure 7. X and Y coordinates for rectangles within first large rectangle and small ones within, for contingency table of Figure 1a

\[
\begin{array}{c|c|c|c|c|c}
\text{BOX} & \text{ORGINX} & \text{ORGINY} & \text{PTX} & \text{PTY} & \text{FUNCT} \\
1 & 0 & 0 & 10 & 10 & \text{BOX} \\
1 & 0 & 0 & 16 & 16 & \text{BOX} \\
1 & 0 & 0 & 20 & 25 & \text{BOX} \\
\end{array}
\]

Figure 8. ANNOTATE dataset created with observations for first large rectangle and small ones within, for contingency table of Figure 1a

\[
\begin{array}{c|c|c|c|c|c|c|c}
\text{FUNCTION} & \text{XSYS} & \text{YSYS} & \text{X} & \text{Y} & \text{TEXT} & \text{SIZE} & \text{STYLE} & \text{LINE} \\
\text{MOVE} & 3 & 3 & 17 & 17 & \text{BAR} & 3 & . & \text{S} \\
\text{MOVE} & 3 & 3 & 30.2 & 30.2 & \text{BAR} & 3 & . & \text{R} \\
\end{array}
\]
### Table 1. Diagnostic Classification Regarding Multiple Sclerosis [Landis and Koch (1977)]

<table>
<thead>
<tr>
<th>New Orleans Neurologist</th>
<th>(a) New Orleans Patients</th>
<th>(b) Winnipeg Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Diagnostic Class</strong></td>
<td><strong>Winnipeg Neurologist</strong></td>
<td><strong>Winnipeg Neurologist</strong></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Certain MS</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Probable MS</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Possible MS</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Doubtful or No MS</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 2. Nosological Coding* By Mortality Classification Panel for Underlying Cause of Death. Lipid Research Clinics Prevalence Follow-Up Study

#### (a) Nonelderly (Age at Death Less than 65 Years)

<table>
<thead>
<tr>
<th>Nosological Classification</th>
<th>MCP Classification</th>
<th>440.2,445.0</th>
<th>441-442</th>
<th>437</th>
<th>410-414</th>
<th>390-458</th>
<th>Other Non-CVD</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atherosclerosis of</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>peripheral arteries with</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>gangrene (440.2, 445.0)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>aneurysm with rupture</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>(441-442)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atherosclerotic cerebrovascular disease (437)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>84</td>
<td>5</td>
<td>3</td>
<td>92</td>
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<tr>
<td>Atherosclerotic coronary heart disease (410-414)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>7</td>
<td>1</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Other cardiovascular disease (390-458)</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>4</td>
<td>18</td>
<td>28</td>
<td></td>
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<tr>
<td>Other noncardiovascular disease</td>
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<td>1</td>
<td>6</td>
<td>100</td>
<td>24</td>
<td>23</td>
<td>155</td>
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<td>1</td>
<td>6</td>
<td>100</td>
<td>24</td>
<td>23</td>
<td>155</td>
</tr>
</tbody>
</table>

#### (b) Elderly (Age at Death 65 Years and Over)

<table>
<thead>
<tr>
<th>Nosological Classification</th>
<th>MCP Classification</th>
<th>440.2,445.0</th>
<th>441-442</th>
<th>437</th>
<th>410-414</th>
<th>390-458</th>
<th>Other Non-CVD</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atherosclerosis of</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>peripheral arteries with</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>gangrene (440.2, 445.0)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>107</td>
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*Eighth Revision ICDA.