Item analysis of single-peaked response data : the psychometric evaluation of bipolar measurement scales

Polak, M.G.

Appendix A

The Mathematics of Correspondence Analysis

In the following we give the computational details and rationale of correspondence analysis (CA) of item response data. The formulation is adapted from Greenacre (1993).

Let **Z** denote the original data matrix, where the entries z_{ij} indicate the observed response of subject i ($i = 1, ..., n$) to item j ($j = 1, ..., k$). The responses are considered measures of association strength between the row entry (here: subject i) and column entry (here: item j). The association measure is assumed to be some non-negative quantity, where lack of association (for instance a *strongly disagree* response to an attitude item with a graded response scale) is indicated by a zero entry.

It is algebraically simpler to work with the so-called correspondence matrix **P**, with elements $p_{ij} = z_{ij}/z_{++}$, where the index + indicates the sum over the omitted index. From **P** we compute the matrix **D**, with standardized deviations from independence, d_{ij}, where

$$d_{ij} = (p_{ij} - p_{i+}p_{+j})/\sqrt{p_{i+}p_{+j}}. \tag{A.1}$$

Note that if the subjects and items are independent (which means that the subjects' ratings of the various items cannot be explained from their mutual distances on one or only a few latent scales(s)), an element p_{ij} equals the product $p_{i+}p_{+j}$. By weighing the deviations from independence with the respective marginals p_{i+} and p_{+j} as in (A.1), we obtain the matrix **D** of standardized deviations from independence. A rationale for this approach is that the weighing is "variance-standardizing", which compensates for the larger variance in relatively popular items and the smaller variance in relatively "rare" items. If no such standardization is performed, the differences between larger proportions, would tend to be large compared to the differences between smaller proportions, and hence dominate the solution. The weighing factors are used to equalize these differences.

For $\mathbf{D}$ we compute the singular value decomposition: $\mathbf{D} = \mathbf{U}\Delta\mathbf{V}^T$, where $\mathbf{U}$ is the matrix of left singular vectors, with elements u_{is}, $s = 1,...,q$, with $q = \min(n$-$1,k$-$1)$; Δ is a diagonal matrix with positive singular values l_s, in descending order along the diagonal; and $\mathbf{V}$ is the matrix with right singular vectors, with elements v_{js}.
The aim of CA is to find a lower-dimensional representation of $\mathbf{D}$. The CA estimated subject location $\hat{\theta}_{is}$ and estimated item location $\hat{\delta}_{js}$ on dimension s can be expressed as, respectively,

$$\hat{\theta}_{is} = l_s^{1-a} \cdot u_{is}/\sqrt{p_{i+}}, \quad \text{(A.2)}$$

and

$$\hat{\delta}_{js} = l_s^{a} \cdot v_{js}/\sqrt{p_{+j}}. \quad \text{(A.3)}$$

There are three choices for a in (A.2) and (A.3) in common usage, namely $a =$ 0, 1, or 1/2 (also referred to as, respectively, row principal, column principal, and symmetrical normalization). With a=0 the subject locations $\hat{\theta}_i$ are weighted averages of the sample locations $\hat{\delta}_j$ (which is called by Benzécri, 1973, "le principe barycentrique"), which is the choice of normalization in the current thesis, as it corresponds to the notion of the subject scaling in Thurstone's (1928) method (where each subject's scale score is the weighted average of the item scale scores, with the ratings used as weights). In the unfolding literature this representation of subject locations is also referred to as the ideal point representation (cf. Heiser, 1981).

Note that the current thesis focuses on one-dimensional data, in which case only the first left and right singular vectors and the first singular value are used to determine respectively, the subject and item location estimates.

The quality of the lower-dimensional representation of the data is derived from the singular values l_s and is expressed as the percentage of the total inertia that is explained by each dimension. The total inertia of the data table is the chi-square statistic divided by n, which can be written as

$$\chi^2/n = \sum_{i=1}^{n} p_{i+} \sum_{j=1}^{k} (z_{ij}/z_{i+} - p_{+j})^2/p_{+j}. \quad \text{(A.4)}$$

The total inertia of the data table can be regarded as the weighted average of the squared deviations between the subjects' profiles (the subjects' scores proportional

to their total score) and the average score profile. Hence, it can be thought of the amount of variation among the subjects' score patterns (See Greenacre, 1993, p. 28-29, for a more thorough explanation of the concept of inertia).
The total inertia of the data table is identical to

$$\sum_{s=1}^{q} l_s^2, \tag{A.5}$$

where l_s^2 (which equals the eigenvalue λ_s) is referred to as the principal inertia of dimension s. The percentage of inertia explained by dimension s is

$$100 \times l_s^2 / \sum_{s=1}^{q} l_s^2. \tag{A.6}$$

The contribution of item point $\hat{\delta}_{js}$ to the inertia of dimension s is

$$p_{+j} \hat{\delta}_{js}^2 / l_s^2, \tag{A.7}$$

or, equivalently, of subject point $\hat{\theta}_{is}$, the contribution to the inertia of dimension s is

$$p_{i+} \hat{\theta}_{is}^2 / l_s^2. \tag{A.8}$$

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