DIPARTIMENTO DI ECONOMIA E GIURISPRUDENZA
UNIVERSITÀ DI CASSINO E DEL LAZIO MERIDIONALE

UNICAS 1979>2019
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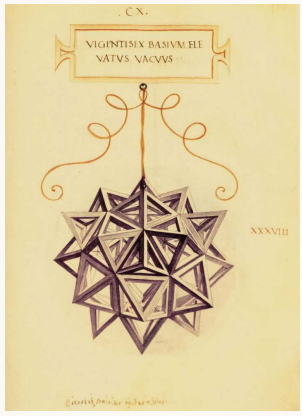
UNIVERSITÀ DI CASSINO E DEL LAZIO MERIDIONALE

12-TH SCIENTIFIC MEETING
CLASSIFICATION AND DATA ANALYSIS

CLADAG 2019

11-13 SEPTEMBER 2019
CASSINO



Book of Short Papers

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SIS Società Italiana di Statistica

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This book collects the short papers presented at CLADAG 2019, the 12th Scientific Meeting of the Classification and Data Analysis Group (CLADAG) of the Italian Statistical Society (SIS).

The meeting has been organized by the Department of Economics and Law of the University of Cassino and Southern Lazio, under the auspices of the SIS and the International Federation of Classification Societies (IFCS). CLADAG is a member of the IFCS, a federation of national, regional, and linguistically-based classification societies. It is a non-profit, non-political scientific organization, whose aims are to further classification research.

Every two years, CLADAG organizes a scientific meeting, devoted to the presentation of theoretical and applied papers on classification and related methods of data analysis in the broad sense. This includes advanced methodological research in multivariate statistics, mathematical and statistical investigations, survey papers on the state of the art, real case studies, papers on numerical and algorithmic aspects, applications in special fields of interest, and the interface between classification and data science. The conference aims at encouraging the interchange of ideas in the above-mentioned fields of research, as well as the dissemination of new findings.

CLADAG conferences, initiated in 1997 in Pescara (Italy), were soon considered as an attractive information exchange market and became a most important meeting point for people interested in classification and data analysis. One reason was certainly the fact that a selection of the presented papers is regularly published in (post-conference) proceedings, typically by Springer Verlag.

The Scientific Committee of CLADAG2019 conceived the Plenary and Invited Sessions to provide a fresh perspective on the state of the art of knowledge and research in the field. The scientific program of CLADAG 2019 is particularly rich. All in all, it comprises 5 Keynote Lectures, 32 Invited Sessions promoted by the members of the Scientific Program Committee, 16 Contributed Sessions, a Round Table and a Data Competition. We thank all the session organizers for inviting renowned speakers, coming from 28 countries. We are greatly indebted to the referees, for the time spent in a careful review.

The editors would like to express their gratitude to the Rector of the University of Cassino and Southern Lazio and the Director of the Department of Economics and Law for having hosted the meeting. Special thanks are finally due to the members of the Local Organizing Committee and all the people who with their abnegation and enthusiasm have worked for CLADAG 2019.

Special thanks go to Alfiero Klain and Livia Iannucci for the editorial and administrative support.

Last but not least, we thank all the authors and participants, without whom the conference would not have been possible.

Cassino, September 11, 2019

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COPULA-BASED NON-METRIC UNFOLDING ON AUGMENTED DATA MATRIX

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ABSTRACT: A multidimensional unfolding technique that is not prone to degenerate solutions and is based on multidimensional scaling of a complete data matrix is proposed. We adopt the strategy of augmenting the data matrix, trying to build a complete dissimilarity matrix, by using Copulas-based association measures among rankings (the individuals), and between rankings and objects (namely, a rank-order representation of the objects through tied rankings). The proposed technique leads to acceptable recovery of given preference structures.

KEYWORDS: copulas, unfolding, multidimensional scaling.

1 The copulas function

Copulas are functions that join multivariate distribution functions to their marginal distribution functions (Nelsen, 2013). They describe the dependence structure existing across pairwise marginal random variables. In this way we can consider bivariate distributions with dependency structures different from the linear one that characterizes the multivariate normal distribution.

A bivariate copula $C : I^2 \to I$, with $I^2 = [0,1] \times [0,1]$ and $I = [0,1]$, is the cumulative bivariate distribution function of a random variable (U_1, U_2) with uniform marginal random variables in [0,1]

$$C(u_1, u_2; \theta) = P(U_1 \leq u_1, U_2 \leq u_2; \theta), \quad 0 \leq u_1 \leq 1 \quad 0 \leq u_2 \leq 1 \qquad (1)$$

where θ is a parameter measuring the dependence between U_1 and U_2.

The following theorem by Sklar (Nelsen, 2013) explains the use of the copula in the characterization of a joint distribution. Let (Y_1, Y_2) be a bivariate random variable with marginal cdfs $F_{Y_1}(y_1)$ and $F_{Y_2}(y_2)$ and joint cdf $F_{Y_1,Y_2}(y_1, y_2; \theta)$, then there always exists a copula function $C(\cdot, \cdot; \theta)$ with $C : I^2 \to I$ such that

$$F_{Y_1,Y_2}(y_1, y_2; \theta) = C\big(F_{Y_1}(y_1), F_{Y_2}(y_2); \theta\big), \quad y_1, y_2 \in \mathbb{R}. \qquad (2)$$

Conversely, if $C(\cdot,\cdot;\theta)$ is a copula function and $F_{Y_1}(y_1)$ and $F_{Y_2}(y_2)$ are marginal cdfs, then $F_{Y_1,Y_2}(y_1,y_2;\theta)$ is a joint cdf.
If $F_{Y_1}(y_1)$ and $F_{Y_2}(y_2)$ are continuous functions then the copula $C(\cdot,\cdot;\theta)$ is unique. Moreover, if $F_{Y_1}(y_1)$ and $F_{Y_2}(y_2)$ are continuous the copula can be found by the inverse of (2):

$$C(u_1,u_2) = F_{Y_1,Y_2}(F_{Y_1}^{-1}(u_1),F_{Y_2}^{-1}(u_2)) \tag{3}$$

with $u_1 = F_{Y_1}(y_1)$ and $u_2 = F_{Y_2}(y_2)$. This theorem states that each joint distribution can be expressed in term of two separate but related issues, the marginal distributions and the dependence structures between them. The dependence structure is explained by the copula function $C(\cdot,\cdot;\theta)$. Moreover the (2) provides a general mechanism to construct new multivariate models in a straightforward manner. By changing the copula function we can construct new bivariate distributions with different dependence structures, with the association parameter indicating the strength of the dependence, also different from the linear one that characterizes the multivariate normal distribution.

Each copula is related to the most important measures of dependency: the Pearson correlation coefficient and the Spearman grade correlation coefficient. The Spearman grade correlation coefficient (see Nelsen, 2013 pp. 169-170 for the definition of the grade correlation coefficient for continuous random variables) measure the association between two variables and can be expressed as a function of the copula. More precisely, if two random variables are continuous and have copula C with parameter θ, then the Spearman grade correlation is

$$\rho_s(C) = 12\int_{I^2} C_\theta(u_1,u_2)du_1du_2 - 3. \tag{4}$$

For continuous random variables it is invariant with respect to the two marginal distributions, i.e. it can be expressed as a function of its copula. This property is also known as 'scale invariance'. Note that not all measures of association satisfy this property, e.g. Pearson's linear correlation coefficient (Embrechts *et al.* , 2002).

In the following, we focus on observations Y_{ik} of the latent continuous random variable Y_{ik}^*, describing the preference of the consumer i ($i \in N = \{1,...,n\}$) for the object k. Let $y_i = (y_{i1},...,y_{ik})$ be the vector of ranks of consumer i for the k objects, where y_{ik} is the rank of object k for the subject $i-th$. Be $U = F(Y_{ik}^*)$ and $V = F(Y_{jk}^*)$ the marginal cumulative distributions (cds). We assume that (Y_{ik},Y_{jk}) correspond to the bivariate discrete random variable obtained by a discretization of the continuous latent variable $(U = F(Y_{ik}^*), V = F(Y_{jk}^*))$ with support $[0,1]\times[0,1]$ and cdf given by $C_\theta(\cdot,\cdot)$.

Let $A_{r,s} = [u_{r-1}, u_r] \times [v_{s-1}, v_s]$ $r,s = 1,...,k$ be rectangles defining the discretization. Let $p_{k,k}$ be the joint probabilities corresponding to the rectangle $A_{r,s}$ for $r,s = 1,...,k$ with value $1/k$ if the pair (y_{ik}, y_{jk}) is observed and 0 otherwise. Let $V_{C_\theta}(A_{11}), \ldots, V_{C_\theta}(A_{kk})$ be the volumes of the rectangles under the copula C_θ, then there exists a unique element in the family of copula for which the following relationship holds true:

$$(V_{C_\theta}(A_{11}), \ldots, V_{C_\theta}(A_{kk})) = (p_{11}, \ldots, p_{kk}). \tag{5}$$

Given the ranking of two subjects i and j, a $k \times k$ contingency table K_{rs} $(r,s = 1,...,k)$ is defined. A cell in this table takes value $1/k$ if (y_{ik}, y_{jk}) is observed and 0 otherwise. This contingency table provides the basis for our estimation procedure.

Fixed the copula C_θ and defined the Spearman grade correlation coefficients $\rho_s(C_\theta)$ (Nelsen, 2013) to each pair (Y_{ik}, Y_{jk}), $i \neq j$ with $i, j \in N$, we define the dissimilarity coefficient d_{ij}:

$$d_{ij} = \sqrt{1 - \frac{\rho_s + 1}{2}} \tag{6}$$

where ρ_s performs well in measuring the agreement between two rankings Y_{ik} Y_{jk}.

Notice that other ways of findings a correlation-type distance matrix have been provided in the literature (Kaufman & Rousseeuw, 2009). For instance, one may consider $d_{ij} = 1 - \rho$ or $d_{ij} = 1 - |\rho|$.

The parameter θ can be estimated via maximum likelihood. Estimating the value of the copula dependence parameter θ we obtain the grade of association between two rankings.

2 Unfolding as a special case of multidimensional scaling on Copulas based association between rankings

Unfolding applies multidimensional scaling (Cox & Cox, 2000) to an off-diagonal $n \times m$ matrix, usually representing the scores (or the rank) assigned to a set of m items by n individuals or judges (Borg & Groenen, 1997). The goal is to obtain two configuration of points representing the position of the judges (X) and the items (Y) in a reduced geometrical space. Each point representing the individuals is considered as an ideal point so that its distances to the object points correspond to the preference scores (Coombs, 1964). Unfolding can be seen as a special case of multidimensional scaling because the off-diagonal

matrix is considered as a block of an ideal distance matrix in which both the within judges and the within items dissimilarities are missing. The presence of blocks of missing data causes the phenomenon of the so-called degenerate solutions, i.e., solutions that return excellent badness of fit measures but not graphically interpretable at all. To tackle the problem of degenerate solutions, several proposals have been presented in the literature (Borg & Groenen, 1997). By following the approach introduced by Van Deun *et al.* , 2007, we adopt the strategy of augmenting the data matrix, trying to build a complete dissimilarity matrix, and then applying any MDS algorithms. In order to augment the data matrix, we use Copulas-based association measures among rankings (the individuals), and between rankings and objects (namely, a rank-order representation of the objects through tied rankings). Both experimental evaluations and applications to well-known real data sets show that the proposed strategy produces non-degenerate non-metric unfolding solutions.

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CLADAG 2019
Cassino (ITALY)
11-13 September, 2019

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The CLAssification and Data Analysis Group of the Italian Statistical Society (SIS) promotes advanced methodological research in multivariate statistics with a special vocation in Data Analysis and Classification.

CLADAG supports the interchange of ideas in these fields of research, including the dissemination of concepts, numerical methods, algorithms, computational and applied results.

CLADAG is a member of the International Federation of Classification Societies (IFCS).

Among its activities, CLADAG organizes a biennial international scientific meeting, schools related to classification and data analysis, publishes a newsletter, and cooperates with other member societies of the IFCS to the organization of their conferences.

Founded in 1985, the IFCS is a federation of national, regional, and linguistically-based classification societies. It is a non-profit, nonpolitical scientific organization, whose aims are to further classification research.