## JAN LA VAN BUCKEVORSEL JAN DE LEEUW

COMPONENT AND CORRESPONDENCE ANALYSIS

DIMENSION REDUCTION BY FUNCTIONAL APPROXIMATION





# Component and Correspondence Analysis

Dimension Reduction by Functional Approximation

Edited by

JAN L.A. VAN RIJCKEVORSEL

Department of Statistics, TNO Institute for Preventive Health Care Leiden, The Netherlands

JAN DE LEEUW

Department of Psychology and Mathematics UCLA, Los Angeles, USA

#### **JOHN WILEY & SONS**

Chichester · New York · Brisbane · Toronto · Singapore

Copyright © 1988 by John Wiley & Sons Ltd.

All rights reserved.

No part of this book may be reproduced by any means, or transmitted, or translated into a machine language without the written permission of the publisher

#### Library of Congress Cataloging in Publication Data:

Component and correspondence analysis: dimension reduction by functional approximation/edited by Jan L. A. van Rijckevorsel, Jan de Leeuw.

cm. — (Wiley series in probability and mathematical statistics) Bibliography: p.

Includes index.

ISBN 0 471 91847 4

1. Principal components analysis. 2. Correlation (Statistics)

I. Rijckevorsel, Jan L. A. van H. Leeuw, Jan de. HI. Series. QA278.5.C657 1988

519.5'354-dc19

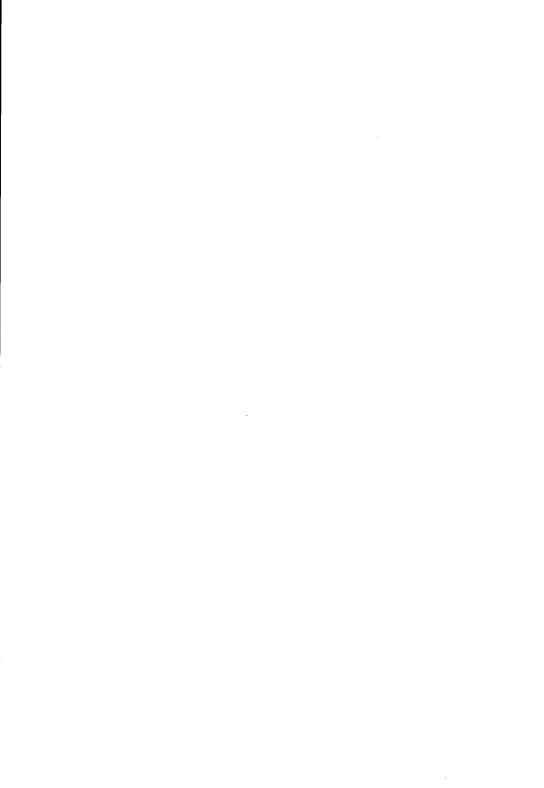
87-33981 CIP

#### British Library Cataloguing in Publication Data Available

Typeset by Cotswold Typesetting Ltd., Gloucester Printed and bound in Great Britain by Anchor Brendon Ltd, Tiptree, Essex

# Contents

List	of Contributors	vii	
Pref	ace	ix	
The	Editors		
	Relations between Variants of Non-linear Principal Component Analysis P. Bekker and J. de Leeuw	1	
2.	Fuzzy Coding and B-Splines  J.L.A. van Rijckevorsel	33	
3.	Beyond Homogeneity Analysis  J. de Leeuw and J.L.A. van Rijckevorsel	55	
4.	Spline Functions and Optimal Metric in Linear Principal Component Analysis  P. Besse	81	
5.	On Probability Coding  JF. Martin	103	
6.	Two Techniques: Monotone Spline Transformations for Dimension Reduction in PCA and Easy-to-Generate Metrics for PCA of Sampled Functions S. Winsberg	115	
Ref	References		
Inday			



## List of Contributors

**Dr Paul Bekker**, Dept of Econometrics, Nettelbosje 2, University of Groningen, 9747 AE Groningen, The Netherlands.

**Dr Philippe Besse**, Laboratoire de Statistique et Probabilités, Université Paul Sabatier, 118 Route de Narbonne, 31062 Toulouse Cedex, France

**Dr Jan de Leeuw**, Dept of Psychology and Mathematics, UCLA, 405 Hilgard Avenue, Los Angeles, CA 90024, USA.

**Dr J.-F. Martin**, Centre de Mathematiques, INSA, bâtiment 403, 20 Avenue Albert Einstein, 69621 Villeurbanne Cedex, France.

Dr Jan L.A. van Rijckevorsel, Dept of Statistics, TNO NIPG, Wassenaarseweg 56, 2333 AL Leiden, The Netherlands.

Dr Suzanne Winsberg, 18 rue Visconti, Paris 75006, France.



#### References

- Agarwal, G.G. and Studden, W.J. (1978). Asymptotic design and estimation using linear splines, Commun. Statist.-Simula. Computa B7, 4, 309-319.
- Andrews, D.F., Gnanadesikan, R. and Warner, J.L. (1971). Transformation of multivariate data, *Biometrika*, 27, 825-40.
- Aronszajn, N. (1950). Theory of reproducing kernel, Transactions of the American Mathematical Society, 68, 337-404.
- Bartlett, M.S. (1953). Factor Analysis in Psychology as a Statistician Sees it. Uppsala Symposium on Psychol. Factor Analysis. Uppsala: Almqvist & Wicksell.
- Bekker, P. (1983). Relationships Between Versions of Nonlinear Principal Component Analysis. Leiden: Department of Data Theory.
- Besse, P. (1979). Etude descriptive des processus: Approximation et interpolation. Thèse de 3ème Cycle. Toulouse: Université Paul Sabatier.
- Besse, P. (1980). Deux exemples d'Analyse en Composantes Principales filtrantes, Statistique et Analyse des Données, 3, 5-15.
- Besse, P. (1986). Choice of a metric or choice of a model. The case of discrete events data. In F. de Antoni et al. (eds), COMPSTAT. Proceedings in Computational Statistics. Vienna: Physica-Verlag.
- Besse, P. (1987). Choix de la métrique pour l'a.c.p. de séries d'évènements discrets, Statistique et Analyse des données, to appear.
- Besse, P., Caussinus, H., Ferre, L. and Fine, J. (1987). Principal components analysis and optimization of graphical displays, submitted to *Statistics*.
- Besse, P. and Ramsay, J.O. (1986). Principal component analysis of sampled functions, *Psychometrika*, **51**, 2, 285–311.
- Besse, P. and Vidal, C. (1982). Analyse des correspondances et codage par une Probabilité de transition, Statistique et Analyse des Données, 7, 3.
- Benzécri, J.P. et al. (1973). Analyse des données (2 vols). Paris: Dunod.
- Benzécri, J.P. (1980). Pratique de l'analyse des données 1. Paris: Dunod.
- Bezdek, J.C. (1987). Some nonstandard clustering algorithms. In P. Legendre and L. Legendre (eds), *Developments in Numerical Ecology*. New York: Springer.
- Boneva, L., Kendall, D. and Stefanov, I. (1971). Spline transformations: three new diagnostic aids for the data analyst, *JRSS Ser B.*, 33, 1–70.
- Bordet, J.P. (1973). Etudes de données geophysiques. Thèse de 3ème Cycle. Paris: Université de Paris VI.
- Bowman, A.W. (1980). A note on consistency of the kernel method for the analysis of categorical data. *Biometrika*, 67, 3.
- Box, G.E.P. and Cox, D.R. (1964). Analysis of transformations (with discussion), *Journal* of the Royal Statistical Society, Series B, 26, 211-52.
- Breiman, L. and Friedman, J.H. (1985). Estimating optimal transformations for multiple regression and correlation. *JASA*, **80**, 580-598.

- Burt, C. (1950). The factorial analysis of qualitative data, British Journal of Statistical Psychology, 3, 166-85.
- Carroll, J. D. (1968). A generalization of canonical correlation analysis to three or more
- sets of variables, *Proc.* 76th Conv. APA, 227-8.

  Cattell, R. B. (1966). The scree test for the number of factors. J. Multiv. Behav. Res., 1,
- 245-76.
   Chang, J.C. and Bargmann, R.E. (1974). Internal Multidimensional Scaling of Categorical Variables. Department of Statistics and Computer Science. Technical Report, University of Georgia.
- Cliff, N. (1966). Orthogonal rotation to congruence, *Psychometrika*, 31, 33-42. Cogburn, R. and Davis, H.T. (1974). Periodical splines and spectral estimation, *Annals of* 
  - Statistics, 2, 1108–26.
- Conte, S. and De Boor, C. (1980). Elementary Numerical Analysis. 2nd edition. New York: McGraw-Hill.
- Coolen, H., Van Rijckevorsel, J. and De Leeuw, J. (1982). An algorithm for nonlinear principal components analysis with B-splines by means of alternating least squares. In H. Caussinus *et al.* (eds), *COMPSTAT* 1982, part II. Vienna: Physika-Verlag.
- Craddock, J.M. and Flood, C.R. (1969). Eigenvectors for representing the 500 mb. geopotential surface over the Northern Hemisphere. Q.J.R. Met. Soc., 95, 576-93.
- Daudin, J.J., Duby, C. and Trecourt, P. (1987). Stability of principal components analysis studied by the bootstrap method, *Statistics*, to appear.
- Dauxois, J. and Pousse, A. (1976). Les analyses factorielles en calcul de probabilités et en statistique: Essai d'étude synthetique. Thèse d'Etat. Toulouse: Université de Toulouse III.
- De Boor, C. (1978). A Practical Guide to Splines. New York: Springer.
- De Leeuw, J. (1973). Canonical Analysis of Categorical Data. Leiden: Psychological Institute. Reissued by DSWO Press, Leiden, 1984.
- De Leeuw, J. (1976). HOMALS. Paper presented at the Psychometric Society meeting, Murray Hill, NJ.
- De Leeuw, J. (1982). Nonlinear principal component analysis. In H. Caussinus et al. (eds), COMPSTAT 82. Proceedings in Computational Statistics, part I. Vienna: Physika-Verlag.
- De Leeuw, J. (1983). On the prehistory of correspondence analysis, *Statistica Neerlandica*, 37, 161–164.
- De Leeuw, J. (1984a). The Gifi-system of non-linear multivariate analysis. In E. Diday, M. Jambu, L. Lebart, J. Pages and R. Tomassone (eds), *Data Analysis and Informatics*, volume III. Amsterdam: North-Holland.
- De Leeuw, J. (1984b). Statistical properties of multiple correspondence analysis. Submitted for publication.
- De Leeuw, J. (1984c). Models of Data, Kwantitatieve Methoden, 5, 17-31.
- De Leeuw, J. and Tijssen, R. (1984). Multivariate Analysis with Optimal Scaling. Leiden: Department of Data Theory.
- De Leeuw, J., Van Rijckevorsel, J. and Van der Wouden, H. (1981). Nonlinear principal component analysis with B-splines, *Methods of Operations Research*, 33, 379-93.
- De Leeuw, J. and Walter, J. (1977). Optimal Scaling of Continuous Numerical Data.
- Leiden: Department of Data Theory.

  De Leeuw, J. and Van Rijckevorsel, J. (1980). Homals en Princals. In E. Diday et al. (eds),

  Data Analysis and Informatics. Amsterdam: North-Holland.
- De Leeuw, J., Young, F.W. and Takane, Y. (1976). Additive structure in qualitative data: an alternating least squares method with optimal scaling features, *Psychometrika*, 41, 471–503.

REFERENCES 139

- De Vore, R. (1977). Monotone approximation by splines, SIAM J. Math. Anal., 8, 891-905.
- Deville, C. (1977). Un exemple catastrophique d'analyse factorielle et son explication. In E. Diday (ed), *Premières Journées Internationales*, *Analyse des Données et Informatique*. Versailles: Inria, pp. 557-65.
- Duc-Jacquet, M. (1973). Approximation des fonctionnelles linéaires sur des espaces hilbertiens auto-reproduisants, unpublished doctoral dissertation, Grenoble.
- Eagle, A. (1928). On the relation between the fourier constants of a periodic function and the coefficients determined by harmonic analysis. *Phil. Mag.*, 5, 113–32.
- Eckart, C. and Young, G. (1936). The approximation of one matrix by another of lower rank. *Psychometrika*, 1, 211–18.
- Fischer, G.H. (1974). Einführung in die Theorie psychologischer Tests, Grundlagen und Anwendungen. Berne: Verlag Hans Huber.
- Gallego, F.J. (1980). Un codage flou pour l'analyse des correspondances. Thèse de 3ème Cycle. Paris: Université de Paris VI.
- Gautier, J.M. and Saporta, G. (1982). About fuzzy discrimination. In H. Caussinus et al. (eds), Compstat 1982. Proceedings in Computational Statistics. Vienna: Physica-Verlag.
- Ghermani, B.M., Roux, C. and Roux, M. (1977). Sur le codage logique des données héterogènes, Les Cahiers de l'Analyse des Données, 1, 115-18.
- Gifi, A. (1981a). Non-linear Multivariate Analysis. Leiden: Department of Data Theory.
- Gifi, A. (1981b). HOMALS User's Guide. Leiden: Department of Data Theory.
- Gifi, A. (1982). PRINCALS User's Guide. Leiden: Department of Data Theory.
- Gifi, A. (1988). Non-linear Multivariate Analysis. Leiden: DSWO Press.
- Good, I.J. and Gaskins, R.A. (1971). Non-parametric roughness penalties for probability densities, *Biometrika*, **58**, 255-77.
- Greenacre, M.J. (1981). Practical correspondence analysis. In V. Barnett (ed), *Interpreting Multivariate Data*. New York: Wiley.
- Greenacre, M.J. (1984). Theory and Applications of Correspondence Analysis. New York: Academic Press.
- Guitonneau, G.G. and Roux, M. (1977). Sur la taxinomie du genre erodium, Les Cahiers de l'Analyse des Données, 1, 97-113.
- Guttman, L. (1941). The quantification of a class of attributes: A theory and method of scale construction. In P. Horst et al. (eds), The Prediction of Personal Adjustment. New York: Social Science Research Council.
- Harman, H.H. (1976). *Modern Factor Analysis*. Chicago: University of Chicago Press (revised edn).
- Hayashi, C. (1952). On the prediction of phenomena from qualitative data and the quantification of qualitative data from the mathematico-statistical point of view. *Ann. Inst. Statist. Math.*, 5, 121-143.
- Holmquist, N.D., McMahan, C.A. and Williams, O.D. (1967). Variability in classification of carcinoma in situ of the uterine cervix, *Arch. Path.*, **84**, 334–45.
- Horst, P. (1965). Factor Analysis of Data Matrices. New York: Holt, Rinehart & Winston.
- Hudson, D.J. (1966). Fitting segmented curves whose join points have to be estimated, JASA, 61, 1097-1129.
- Jambu, M. and Lebeaux, M.O. (1983). Cluster Analysis and Data Analysis. Amsterdam: North-Holland.
- Jolliffe, I. T. (1986). Principal Component Analysis. New York: Springer-Verlag.
- Kettenring, J.R. (1971). Canonical analysis of several sets of variables, *Biometrika*, 58, 433-60.
- Koyak, R. (1985). Optimal Transformations for Multivariate Linear Reduction Analysis. Unpublished PhD thesis. University of California, Berkeley, California: Dept. of Statistics.

- Kruskal, J.B. (1965). Analysis of factorial experiments by estimating monotone transformations of the data, Journal of the Royal Statistical Society, series B, 27, 251-63.
- Kruskal, J.B. and Shepard, R. N. (1974). A nonmetric variety of linear factor analysis,
- Psychometrika, 39, 123-57.

  Lafaye de Michaux, D. (1978). Approximations d'analyses canoniques nonlineaires de variables aléatoires et analyses factorielles privelégiantes. Thèse de Docteur-Ingenieur. Nice: Université de Nice.
- Lancaster, H.O. (1969). The Chi-squared Distribution. New York: Wiley. Lebart, L., Morineau, A. and Warwick, K.M. (1984). Multivariate Descriptive Statistical
- Analysis. New York: Wiley.

  Le Foll, V. (1979). Sur les propriétés de l'analyse des correspondances pour diverses formes.
- Le Foll, Y. (1979). Sur les propriétés de l'analyse des correspondances pour diverses formes complètes de données. Thèse de 3ème Cycle. Paris: Université de Paris VI.
- Mallet, J.L. (1982). Propositions for fuzzy characteristics functions in data analysis. In H. Caussinus et al. (eds), Compstat 82. Proceedings in Computational Statistics. Vienna: Physica-Verlag
- Physica-Verlag.

  Martin, J.F. (1980) Le codage flou et ses applications en statistique. Thèse de 3ème Cycle.

  Pau: Université de Pau et des Pays de l'Adour.
- Martin, J.F. (1981). Formalisation et étude de codages flous, C.R. Acad. Sci. Paris, 292, 299-301.
- Maung, K. (1941). Measurement of association in a contingency table with special reference to the pigmentation of hair and eye colors of Scottish school children. *Ann. Eugen.*, 11, 189–223.
- McDonald, R.P. (1968). A unified treatment of the weighting problem, *Psychometrika*, 33, 351–81.
- Munoz-Perez, F. (1982). L'évolution de la fécondité dans les pays industrialisés dépuis 1971, *Population*, 37iéme année, 3, 483-512.
- Nishisato, S. (1980). Analysis of Categorical Data: Dual Scaling and its Applications. Toronto: University of Toronto Press.
- Park, S.H. (1978). Experimental designs for fitting segmented polynomial regression models, *Technometrics*, 20, 2, 151-4.
- Poirier, D.J. (1973). Piecewise regression using cubic splines. JASA, 68, 515-24.
- Poirier, D.J. (1976). The Econometrics of Structural Change. Amsterdam: North-Holland. Quade, W. and Collatz, L. (1938). Zur Interpolationstheorie der Reelen Periodischen Funktionen, Aka, Wiss. (Math-Phys. Kl), 30, 383-429.
- Rao, C.R. (1964). The use and interpretation of Principal Component Analysis in applied research, Sankhyā, 26(A), 329-58.
- Ramsay, J.O. (1977). Monotonic weighted power transformations to additivity, *Psychometrika*, **42**, 83-109(a).
- Ramsay, J.O. (1982). When data are functions, Psychometrika, 47, 379-96.
- Runge, C. (1901). Uber Die Darstellung Willkürlichen Funktionen und die Interpolation zwischen Aquidistanten Ordinaten, Z. Angew, Math. Phys., 46, 224-43.
- Ruspini, E. (1969). A new approach to clustering, Inf. and Control, 15, 22-32.
- Saporta, G. (1985). Data analysis for numerical and categorical individual time-series. Applied Stochastic Models and Data Analysis, 1, 109-119.
- Schoenberg, I.J. (1946a). Contributions to the problem of approximation of equidistant data by analytic functions, Part A, Quart. Appl. Math., 4.
- Schoenberg, I.J. (1946b). Contributions to the problem of approximation of equidistant data by analytic functions, Part B, Quart. Appl. Math., 4.
- Schriever, B.F. (1986). Order Dependence, CWI-Tract 20. Amsterdam: Centre for Mathematics and Computer Science.
- Schumaker, L. (1981). Spline Functions: Basic Theory. New York: Wiley.

141

- Shapiro, H.S. (1971). Topics in Approximation Theory. New York: Springer-Verlag.
- Smith, P. (1979). Splines as a useful statistical tool, The American Statistician, 33, 57-62.
- Styan, G.P. (1973). Hadamard products and multivariate statistical analysis, *Linear Algebra and its Applications*, 6, 217-240.
- Takane, Y., Young, F.W. and De Leeuw, J. (1978). The principal components of mixed measurement level multivariate data: an alternating least squares method with optimal scaling features, *Psychometrika*, **43**, 278-81.
- Tenenhaus, M. (1977). Analyse en composantes principales d'un ensemble de variables nominales et numériques, Revue de Statistique Appliqué, 25, 39-56.
- Tenenhaus, M., and Young, F.W. (1985). An analysis and synthesis of multiple correspondence analysis, optimal scaling, dual scaling, homogeneity analysis and other methods for quantifying categorical multivariate data, *Psychometrika*, **50**, 91–119.
- Thurstone, L.L. (1947). Multiple Factor Analysis. Chicago: University of Chicago.
- Tijssen, R. (1984). A New Approach to Nonlinear Canonical Correlation Analysis. Leiden: Department of Data Theory.
- Van de Geer, J.P. (1986). Introduction to Linear Multivariate Analysis. (2 Vols). Leiden: DSWO Press.
- Van der Heijden, P.G.M. (1987). Correspondence Analysis of Longitudinal Categorical Data. Leiden: DSWO Press.
- Van Rooij, P.L.J. and Schurer, F. (1974). A bibliography on spline functions. In K. Böhmer et al. (eds), Tagung über Spline Funktionen. Mannheim: Bigliographisches Institut, pp. 315-415.
- van Rijckevorsel, J.L.A. (1982). Canonical analysis with B-splines. In H. Caussinus et al. (eds), Compstat 1982. Proceedings in Computational statistics. Vienna: Physica-Verlag, pp. 393-8.
- van Rijckevorsel, J.L.A. (1987). The Application of Horseshoes and Fuzzy Coding in Multiple Correspondence Analysis. Leiden: DSWO Press.
- van Rijckevorsel, J.L.A. and van Kooten, G. (1985). Smooth PCA of economic data, Computational Statistics Quarterly, 2, 143-72.
- Wahba, G. (1971). A polynomial algorithm for density estimation, Annals of Mathematical Statistics, 42, 1870-86.
- Wahba, G. (1978). Improper priors, spline smoothing and the problem of guarding against model errors in regression, *JRSC*, Ser. B, 40, 364-72.
- Wegman, E.J. and Wright, I. (1983). Splines in statistics, JASA, 78, 351-65.
- Winsberg, S. and Kruskal, J.O. (1986). Easy to generate metrics for use with sampled functions. In F. De Antoni et al. (eds), COMPSTAT 86. Proceedings in Computational Statistics. Vienna: Physica-Verlag.
- Winsberg, S. and Ramsay, J.O. (1980). Monotonic transformations to additivity using splines. *Biometrika*, 67, 669-74.
- Winsberg, S. and Ramsay, J.O. (1981). Analysis of pairwise preferences data using integrated B-splines, *Psychometrika*, **46**, 171–86.
- Winsberg, S. and Ramsay, J.O. (1982). Monotone splines: a family of transformations useful for data analysis. In H. Caussinus et al. (eds), Compstat 82. Proceedings in Computational Statistics. Vienna: Physica Verlag, pp. 451-6.
- Winsberg, S. and Ramsay, J.O. (1983). Monotone spline transformations for dimension reduction, *Psychometrika*, 48, 575-95.
- Wold, S. (1974). Spline functions in data analysis, Technometrics, 16, 1-11.
- Wold, H. and Lyttkens, E. (1969). Nonlinear iterative partial least squares (Nipals) estimation procedures, Bulletin of the International Statistical Institute, 43, 29-51.
- Wright, I.W. and Wegman, E.J. (1980). Isotonic, convex and related splines, *Annals of Statistics*, 8, 1023-35.

- Young, F.W., De Leeuw, J. and Takane, Y. (1976). Regression with qualitative variables: an alternating least squares method with optimal scaling features, *Psychometrika*, 41, 505-529.
- Young, F.W., Takane, Y. and De Leeuw, J. (1978). The principal components of mixed measurement level multivariate data: an alternating least squares methods with optimal scaling features, *Psychometrika*, 43, 279-81.
- Young, F.W. (1981). Quantitative analysis of qualitative data, Psychometrika, 46, 357-88. Young, F.W., De Leeuw, J. and Takane, Y. (1980). Quantifying qualitative data. In E. D. Lantermann and H. Feger (eds), Similarity and Choice. Papers in Honour of Clyde Coombs. Berne: Hans Huber.
- Zadeh, L.A. (1965). Fuzzy sets, Inf. and Control, 8, 338-53.

# Index

analysis	barycentric coordinates, see triangle
analyse des correspondances 26, 27	property
multiple correspondence analysis 1,	basis 24, 35, 68, 86, 117
2, 6, 37, 55	bivariate coding, see coding
theoretical non-linear analysis, see	blockwise rank one approximation, see
semi-linear analysis	approximation
non-linear generalized canonical	bootstrap 89
analysis 76	breakpoint 34
non-linear continuous analysis, see	Burt table 18, 25
semi-linear analysis	B-spline, see spline
semi-linear analysis 33, 36, 76, 82	-
non-linear multivariate analysis 16,	category quantification, see
17, 52, 115	quantification
applications	centroid property 60
in medicine	centre of gravity 10
fecundity rates 96	principe barycentrique 10, 68
flow-volume curves 91	chi-square 8, 31, 104
pathology data 30	codage flou, see fuzzy coding
in economics	codages complets 75
public spending in the	coding
Netherlands 41, 42	bivariate coding 45
spirits data 127–129	crisp coding 33, 38, 76, 82
in marketing	codage par la mesure de Dirac 38,
automobile data from the	103, 106
Consumer's Report 57, 123–127	codage flou, see fuzzy coding
in meteorology	fuzzy coding 36, 66, 74, 103
temperatures of French cities	local coding 37
129–135	(piecewise) linear coding 47, 75
approximation	quadratic coding 44, 47
approximation of a model vector 33,	semi-exponential 43, 47
49	semi-discrete 38, 47, 106
blockwise rank one approximation	trapezoidal 39, 47, 106
20, 21, 30	polynomial coding 37
global approximation 49	probability coding 76, 103-105, 108
least squares approximation, see least	components, see principal components
squares	cone 17, 56, 62
spline approximation, see spline	continuous 27, 28
	continuous space, see space
bandwidth 46 68 77, 78	continuous option, see process

1 77

piecewise function 34, 86 continuous—(cont.) piecewise polynomial (function) continuous function, see function 117-119 continuous scaling, see process piecewise linear function, see coding continuous variables, see process polynomial spline function, see spline contingency table 26, 33, 56 quadratic function, see coding convergence semi-discrete coding function, see in discretization 37, 50 coding in sample size 37, 50 semi-exponential function, see coding copies 65 spline function, see spline correspondence analysis, see analysis step function 28, 34, 118 trapezoidal coding function, see data coding data reduction 2, 11

data reduction 2, 11
data fitting 49
dédoublement 42
degenerate solution, see trivial solution
density 108
diagonally dominant 36
dichotomous variables 27
differential operator 83, 132
difference operator 133
dimension
dimension of the coding function 35,
68
dimension reduction 81, 115–117
how many to retain 88
of the spline function 52, 118
Dirac measure, see coding
discrimination measure 9, 11, 12

Eckart-Young approximation,
-decomposition 13, 116, 122
Economics, see applications
EY-T model 116, 122

factor analysis 3, 115
fecundity rates, see applications in medicine
fixed factor scores model 116
filter 87, 132–133
flow-volume curves, see applications in medicine
function
basis function 68, 117
continuous function 28, 87
dimension of, see dimension
hat function 40
indicator function, see indicator
interpolated function 86, 132
likelihood function 82, 120, 122

periodic function 129, 132, 133

null function 133

geometry 9, 16, 55, 68 global approximation, see approximation

Holmquist data, see applications in medicine: pathology data
Homogeneity analysis 2, 55, 61
fuzzy homogeneity analysis, see
smooth homogeneity analysis
smooth homogeneity analysis 67, 71,
74
horseshoe 29, 60

indicator matrix, -function 6, 24, 28, 33, 56, 104
inner product, see scalar product isotone regression, see regression interpolation spline interpolation, see spline

kernel
reproducing kernel 84, 132
kernel estimation 108
knots
exterior knots 34
interior knots 34, 118
knot sequence 34, 87
knot placement 53, 118

least squares
1.s. estimation 35, 53
1.s. loss function 57, 119-121
likelihood function, see function
linear differential operator, see
differential operator
linear PCA, see PCA
1.e.v. diagram 89

MCA, see analysis measurement levels 65 nominal 1, 24 ordinal 1, 24, 116 numerical 1 interval, see numerical maximum likelihood (estimation) 116, 119-122 medicine, see applications metric 84, 88, 98, 110 metric scaling, see numerical measurement level MN - T model 117, 122 monotone spline, see monotone transformation monotone regression, see regression multidimensional scaling 2, 55, 77 multiple, see quantification multiple correspondence analysis, see analysis

NCA, see non-metric PCA nominal, see measurement level norm 85, 132 numerical, see measurement level normalization 3, 13 normal distribution 27, 119

optimal scaling 16, 76 order dependence 31 ordinal, see measurement level overlap, overlapping functions 35

pathology data, see applications PCA, see principal component analysis Principal Component Analysis 62, 90, classical PCA, see linear PCA conventional PCA, see linear PCA linear PCA 5, 87, 115 non-linear PCA 1, 115-117 non-linear continuous PCA, see semilinear PCA non-metric PCA 1, 12, 77, 78, 115-117 ordinary PCA, see linear PCA semi-linear PCA 82 periodic function, see function piecewise, see function and see coding polynomial spline function, see spline P-coding, see probability coding

principe barycentrique, see centroid property
principal components 88, 115
probability coding, see coding
process 78
continuous 55, 75, 76, 103
continuous ordinal 77
primary approach to ties 77
projection operator 133
pseudo-indicator 35, 65, 77
public spending in the Netherlands, see applications

quantification category quantification 9, 10, 16, 57 multiple quantification 14, 61 single quantification 61

rating scale type data 30 random factor scores model 117 rank one restriction, see restrictions reciprocal averages 10 regression isotone, see monotone regression

monotone regression 15, 52, 127 non-linear regression 25 non-parametric regression 52 regression spline, see spline restrictions

additivity restrictions 56 cone restrictions, see cone measurement, see measurement levels rank one restriction 56, 61 single, see rank one restrictions

sampled functions 87, 129
scalar product 83
scores
factor scores 116
observation scores 3, 49, 59
object scores, see observation scores
scree graph 89
single, see quantification
singular value decomposition 4, 122,
133
simultaneous diagonalization, see
blockwise rank one
approximation
smoothness, smoothing 34, 46, 53, 64,

88, 110, 112

Sobolev, see space

finite-dimension approach of the Sobolev inner product space 45, 46, 85 Hilbert space, see  $L_2$  $L_2$  space of square integrable functions 34, 50, 83, 132 spline approximating spline 28, 82, 85, 117 basis of spline functions 85, 117 I-spline 81, 117–119 B-spline 28, 35, 40, 44, 66, 81, 117-119 M-spline 117–119 interpolating spline 85, 132 polynomial spline function 17, 47, regression spline 52 tensor product B-spline 45 stability 79

space

c

С

С

¢

¢

(

SVD, see Singular Value Decomposition

transformation admissible transformation 2 fuzzy transformation 46 global transformation 46, 70 linear transformation 3, 87 monotone transformation 81 non-linear transformation 6. ordinal transformation 116 quadratic transformation 29 spline transformation function spline triangle of reference 68 barycentric coordinates 68 regular polygon 68 triangular coordinates 68 triangle inequality 57 trivial solutions 3, 5, 7, 26, 90



