MULTILEVEL MODELLING NEWSLETTER

Vol. 8 No. 2   **December, 1996**

Workshop in Norwich, England A three day workshop on multilevel modelling will be held at the University of East Anglia from 8-10 January 1997. It will be assisted by a team from the Multilevel Models Project and will give participants the opportunity to see a preliminary version of *MLn* for Windows. For further information contact *Anne-Lise McDonald at Health Policy and Practice Unit, UEA, Norwich, NR4 7TJ*. Email: *a.cox@uea.ac.uk*. Tel +44 (0)1603 593631.

Conference and Course in The Netherlands A one-and-a-half-day conference on Multilevel Analysis will be held in Amsterdam on April 1-2, 1997, followed on April 3 by a one-day course taught by *Donald Hedeker* (*University of Illinois at Chicago*) on Multilevel Analysis of Categorical Outcomes. For a detailed information to contact *Tom Snijders* at *ICS, Department of Statistics & Measurement Theory, University of Groningen, Grote Kruisstraat 2/1, 9712 TS Groningen. multi.level@ppsw.rug.nl.* Tel: +31 50 3636304.

Conference of ALCD To mark the end of Phase I of the ESRC funded ALCD (*The Analysis of Large and Complex Datasets in the Social Sciences)* research programme a conference will be held at the University of Warwick on April 10/11, 1997.

The aim of the conference will be to disseminate the ideas and results of Phase I to applied researchers in substantive fields who are interested in recent advances in quantitative analysis. Presentations will include overviews of important areas such as*: hierarchical (multilevel) models; handling missing data; measurement errors* and *the analysis of*

longitudinal data.

The cost of attendance at the conference for ESRC students and researchers will be subsidised from ALCD funds. For further details to contact the *Director of the ALCD programme, Professor TMF Smith, Department of Mathematics, University of Southampton, SO17 1BJ. Email: tmfs@maths.soton.ac.uk*

Continued support for newsletter, a new project and workshops

The Economic and Social Research Council has agreed to fund the continued production of the multilevel newsletter. This will be done under the auspices of further ESRC funding for an 18 month project on the application of multilevel modelling in meta analysis. This project is jointly directed by Professor *Harvey Goldstein* at the Institute of Education and Professor *Simon Thompson* at the Royal Postgraduate Medical School (Hammersmith Hospital).

The ESRC has also agreed to fund a series of five advanced training workshops in multilevel modelling. The following are the likely areas of application: *Education: Spatial data analysis: Health services research: Demography: Political science*. Further details will be announced later.

Also In This Issue

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Review of HLM 4 for Windows

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Previously I have used VARCL on a mainframe, and MLN and its earlier manifestations on a PC. I was looking forward to using this software because of its reputed ease of use. In particular I was hoping that a Windows-based software would make it much easier for students to begin multilevel modelling, and would prevent me from making mistakes.

I received a book, 3 discs for installing under Windows 95 or NT, and two discs for installing under Windows 3.1. I choose the latter and installed in a few minutes without any problems on 486 PC. Installation requires 5110kb on the hard disk, about half of which was the TRANSYS software which is optional (see below). The book, **HLM: hierarchical linear and nonlinear modelling with the HLM/2L and HLM/3L Programs** by Bryk, Raudenbush and Congdon is 170 pages long, provides a guide to two and three-level models with a number of worked examples. For the normal-theory models it provides minimal background as it refers to the companion volume (**Hierarchical linear models: applications and data analysis methods**, Sage). For the non-linear models (response variables that are binary, proportions or counts) more details are provided about estimation and specification, as well as detailed worked examples. The Windows version is surprisingly not covered in this book beyond the reader being referred to the 'help screen'. I found that there were few problems if I read the book, then the help screen, and worked through the examples, modifying as I went to conform to the Windows version.

Using HLM requires the production of a number of files, and the process can be seen as 5 steps.

Step 1   is the preparation of input files, one at each level. Any preliminary data manipulations (such as editing, sorting, transforming, creating dummy variables and interactions) have to be done outside HLM. The software can however readily input files from SAS, STATA, SPSS, SYSTAT,and ASCII. The included TRANSYS software takes virtually any spreadsheet and turns into SYSTAT format which can be read by HLM; TRANSYS operates 'manually' under DOS.

Step 2   involves the creation of sufficient statistics matrices which are used in the estimation of the models. That is HLM operates like VARCL but unlike MLN which holds all the data in main memory. Due to this SSM approach, large-scale modelling can be undertaken in a highly efficient manner. This stage can be undertaken in Windows by filling in pre-set boxes, interactively by answering questions, or by creating a batch file if the user is very familiar with the software. Information must be provided on: whether a 2 or 3 level model is to be fitted, file names, variable labels, a FORTRAN-like format to input the data files, and whether 'sampling weights' are to be used. Neither the interactive mode nor Windows deal with the HLM programs directly, they create a batch file which is then processed to produce the SSM file. A summary of results from the SSM file can be checked to see that all is well.

Step 3   requires the creation of a command file which is then used to control the estimation of the models. Again this can be done by

creating a batch file, interactively or through Windows. In the latter, specifying the name of the already-created SSM file brings up the variable labels at each level. These can then be included in the model or not. Specification begins by choosing the variables for the micro model, first the response, then the predictors. For the predictors there is a choice of 'no centering'; 'centering around the group mean', or 'centering around the grand mean'. This is followed by the specification of the macro models in which variables included at a lower level can have coefficients random at a higher level, and higher-level variables can be included un- or grand- centered. At this stage it is possible to select the number of iterations, choose between restricted and full maximum likelihood for the two level model, define the required multivariate hypothesis testing, constrain the random terms and test for homogeneity of level-1 variance. It is also possible to choose a non-linear analysis. Overdispersion is allowed for counts and proportions, but not binary outcomes. Another option is an exploratory procedure whereby the higher-level residuals are related to selected higher-level variables to provide an indication of whether any of these should be included in a revised model. Once the command file has been saved it can be used to run the analysis; this creates two further files: the results of the model fitting, and (optionally) a file of residuals.

Step 4   The results of the model fitting can be read into a word processor or text editor. The view output button in Windows invokes the notepad and automatically loads the results file. This contains starting values, OLS results derived from treating each higher-level as a separate entity, as well as multilevel estimates.

Step 5   The residual file can be read directly into one of three software package(SYSTAT, SPSS and SAS) so that graphical procedures can be used to diagnose non-linearity, heterogeneity, and non-normality.
In addition to Windows, the interface with a wider variety of packages at step 1, and the

non-linear models, new features in this version include:

- estimation of population-average models using Generalized Estimating Equations in the manner of Zeger and Liang;

- improved speed of estimation and convergence by coupling the underlying EM algorithm with a Fisher-scoring algorithm;

- the use of penalized quasi-likelihood in the manner of Breslow and Clayton for estimating the non-linear models;

- plausible value analysis for multiply-imputed data for the 2-level model.

Some of the favourable features that require comment are:

- the professionally-produced manual with plenty of detailed worked examples;

- the specification of the models under Windows generates a graphic box containing the micro and macro equations in the same Greek symbolism as in the books;

- the residual file for the two-level model contains dispersion estimates for exploring level-1 heterogeneity, and distance measures for assessing multivariate normality;

- sample weights which can be specified at levels 1 and 2 for 2-level models, but only at level 1 for 3-level models, and not for non-linear models;

- the speed of the software; although the EM algorithm requires many iterations (typically 100), these are accomplished rapidly due to the sufficient statistics approach. However, estimating non-linear models took a great deal longer than I expected. This is because a double set of

iterations are required, and at each macro iteration the raw level-1 data has to be read anew. When convergence took 106 macro iterations as it did in my problem, this is a lot of file handling.

To be honest, however, I am disappointed with the overall product. I see two main drawbacks: the failure to develop a full Windows version; and the lack of flexibility in model specification. In relation to the Windows interface, the package is really a set of stand-alone programs only loosely coupled via a set of boxes to be filled in. Windows is simply being used as a front-end. I would have expected, at least, inbuilt graphical output to see what is happening to convergence and to help me assess model assumptions, and much greater control over estimation as its is happening. I am not impressed when after a 100 iterations I discover in the output file that convergence has not been achieved and I would appear to have to start iterations from the beginning. I would also have liked more safeguards against inappropriate model choices. Does it make sense, for example, to centre on categorical predictors?

The lack of flexibility focuses on the random part. As far as I can see it is only possible to fit models that are quadratic at the higher levels and not the more parsimonious linear form. Most problematically it is not possible to specify complex heterogeneity at level 1 (a level 1 variable allowed to vary at level 1) nor is it possible to specify that a higher-level variable is random at its own level and at a lower level. Yet all these models can have important substantive interpretations, and what may appear to be higher-level variation may in fact be complex lower-level variation. Taking one of the data sets supplied with the package in which the response is a maths score, I found that: minority pupils have a lower average score, greater variability between schools, but less variability within schools; females have a lower average score, lower variability between schools and lower variability between individuals within schools; while Catholic schools are more variable in their performance than non Catholic. Overall, there is a sense of an unfinished Windows product with remarkably honest remarks in the helpfile such as '*Print SSM files : ahem, I never got around to making this one work*' and '*unfortunately this feature is not implemented in this release*'.

Response to Kelvyn Jones' review of HLM4 for Windows

Stephen W. Raudenbush, Michigan State University

Professor Jones' review provides, for the most part, a detailed and accurate description of HLM version 4, covering most of its new features and aptly describing the basic steps of an analysis using the software. Although a reading of the details of his account would appear to suggest that many will find the software uniquely useful, he expresses a disappointment with the product, and naturally, I am disappointed that he is disappointed.

Happily, however, hundreds of persons who have had a chance to use the software in classes and workshops have responded considerably more favorably. Indeed, reactions have verged on euphoria, especially among those experienced in using a variety of other software packages for hierarchical models, including earlier versions of HLM. While learning how to coax statistical software to produce results often diverts attention from conceptual issues, many have expressed satisfaction that the graphical interface in the Windows version of HLM actually helps consolidate understanding. Not only does the ease of use minimize the technical distraction; the "intelligence" with which the

program aids one in specifying models at each level clarifies the logic of the approach, and for that we can thank Richard Congdon.

I did not understand some of comments in the review ("a variable allowed to vary at level 1;").......("a higher-level variable that is random at its own level and at a lower level"). New terminology associated with new methodology can become cumbersome, to say the least. Nevertheless, the review makes several useful suggestions; we have already taken several to heart and thank Professor Jones for the care with which he has examined HLM.

Multilevel Analysis in Social Science

The *Fourth International Social Science Methodology Conference* was held in University of Essex, Colchester, UK, in 1-5 July 1996. There were five sessions for the topic on multilevel modelling. We have selected some of the study for the references.

Specifying the Random Part of the Multilevel Model (*Berkhof, J.*, University of Groningen, The Netherlands.
Email: j.berkhof@ppsw.rug.nl).

Two Methods for Jackknifing Two-level Models (*Busing, F., Leeden, R. & Meijer, E.*, Leiden University, PO Box 9555, 2300 RB Leiden, The Netherlands).

The IAB-Establishment Panel: Multilevel Analyses of Structural and Firm-Specific Determinants (*Blien, Uwe & Bellmann, L.*, IAB, Regensburger Str. 104, D90327, Nuernberg, Germany).

Hierarchical Models Behavior and Estimation (*Chance, B.*, University of the Pacific, USA.
Email: bchance@legendre.cop.uop.edu).

Trade Union membership Resignation: a Multilevel Analysis (*Daalder, A.*, Motivaction Amsterdam B.V, Vondelstraat 26, 1054 GD Amsterdam, The Netherlands).

Multilevel Modelling of Mortality in England and Wales: Does Place Affect Mortality Given Personal Circumstances? (*Ecob, R. and Jones, K.*, MRC Medical Sociology Unit, University of Glasgow, UK. Email: russell@msoc.mrc.gla.ac.uk).

Structural Change Analysis using Panel Data (*Engel, U. & Bentz, J.*, University of Potsdam, Germany.
Email:engel@rz.uni-potsdam.de).

Modelling Highly Structured Survey Data (*Franconi, L. & Pallara, A.*, ISTAT, Via A. Depretis 74/B, 00184 Roma, Itali).

Using Multilevel Models to Produce Small Area Estimates of Psychiatric Health (*Heady P.& Ruddock, V.*, Office of Population Censuses and Surveys, UK. Email: vera.ruddock@opcs.btx400.co.uk).

Linear Models for Unreliable Dependent Variables (*Hoijtink, H.* University of Groningen, The Netherlands).

Multilevel Models for Panel Data; Comparison and Synthesis (*Hox, J. J.*, University of Amsterdam, The Netherlands. Email: hox@educ.uva.nl).

Multilevel Modelling and Achievement /Proficiency Testing (*Lee, T. & Mok, M.*, Griffith University, Australia.
Email: t.lee@ais.gu.edu.au).

The Hierarchical Linear Model for Repeated measures with Missing Data (*Maas, C. & Snijders, T.A.B.*, University of Utrete, The Netherlands.
Email: T.A.B.Snijders@ppsw.rug.nl).

Taking a Year Off and Going Overseas
(*Parr N. & Mok, M*., University of Macquarie, Australia. Email: nparr@oral.efs.mq.edu.au).

A Multi-level Perspective on the Design and Analysis of Intervention Studies (*Plewis, I. & Hurry, J*., Institute of Education, University of London, UK. Email: tesp102@ioe.ac.uk).

Evaluating the Impact of Youth Credits: A multilevel Approach (*Surridge, P*., Centre for Educational Sociology, University of Edinburgh, UK. Email: p.surridge@ed.ac.uk).

Multilevel Methods for Relations Within Groups (*Snijders, T. & Kenny, D*., University of Groningen, The Netherlands. Email: T.A.B.Snijders@ppsw.rug.nl).

Exploring the Effects of Sparsity on Extra-Binomial Variation (*Wright, D.* University of Bristol, UK. Email: psdbw@ssa.bristol.ac.uk).

Application : Using *MLn* for repeated measures with missing data

Tom A.B. Snijders and Cora J.M. Maas

Introduction

Repeated measures, which is the same as longitudinal data measured at fixed occasions, are a common type of data in psychological and other research. Such data can be described as follows: for each subject j ($j = 1, ..., n$), and for each measurement occasion i ($i = 1, ..., p$), a measurement Y_{ij} is obtained. (In discussions of repeated measures, it is usual to indicate subjects by i and occasions by j; we adhere, instead, to the multilevel usage of indices.) Subjects may be divided into groups, and there can be covariates. Multivariate analysis of variance (MANOVA) and covariance (MANCOVA) are widely used methods for analysing such data, as described in Stevens (1992) and many other textbooks. Software packages containing MANOVA modules, such as *SPSS* and *SAS*, require complete data: for each subject, the entire vector ($Y_{1j}, ..., Y_{pj}$) should be available.

Repeated measures can also be regarded as multilevel data, with measurements defining the first, and subjects the second level of the nesting structure. This is indicated in Longford (1993) and Goldstein (1995).

Completeness of data is not a requirement in the multilevel formulation, which provides an important advantage over the traditional approach. It must be assumed, of course, that missingness of data is at random (cf. Little and Rubin, 1987); if missingness is not random, the fact that certain data are missing may be informative in itself and part of the modelling effort should be directed at this. Advantages of the multilevel approach are the flexibility in handling incomplete data without the necessity of imputation, the generality in model building provided by the multilevel approach, and the fact that the multilevel formulation unifies the random effects approach with the multivariate approach to analysing repeated measures.

This note indicates how *MLn* (Rasbash & Woodhouse, 1995) can be used to obtain estimates and tests for the MANOVA model with complete or incomplete data, provided that missingness is at random. We focus on the test of multivariate homogeneity (used for testing the effect of a within-subject factor). Other tests can be obtained from the multilevel approach in a similar way.

Testing homogeneity of means

$$Y_{ij} = \mu_i + u_{ij}$$

$$= \sum_{h=1}^{p} \mu_h z_{hij} + \sum_{h=1}^{p} u_{hj} z_{hij} . \qquad (1)$$

Consider a single population and p treatments being tested in a repeated measures design, where the null hypothesis is that the population means of the responses to the p treatment do not differ. Denoting the population mean of Y_{ij} by μ_i , this null hypothesis is expressed by

$$\text{H}_0\text{: } \mu_1 = \mu_2 = ... = \mu_p .$$

When the multivariate approach is followed, the usual procedure is to transform the p dependent variables to $p-1$ contrasts, e.g., difference contrasts $D_{ij} = Y_{i+1,j}-Y_{ij}$, combined into the vector $\boldsymbol{D}_j = (D_{1j}, ..., D_{p-1,j})$. The null hypothesis is that the population mean of $\boldsymbol{D}_j$ is $\boldsymbol{0}$. This hypothesis is usually tested by means of Hotelling's T^2 test (Stevens, 1992, section 13.3).

The multilevel formulation of repeated measures data

In the multilevel analysis of repeated measures data, the measurements are the units at level 1 and the subjects the units at level 2. In the data format for analysis by *MLn*, each line in the worksheet will contain the three values

$$j , i , Y_{ij} ,$$

and - if relevant - group membership variables and covariates. The multivariate model for repeated measures can be specified by using an empty random part at level 1 (this may seem strange, but *MLn* makes no complaints), and a fixed part as well as a random part at level 2 consisting of p dummy variables z_h ($h=1, ..., p$), one for each of the measurement occasions. The dummy variables are defined by $z_{iij} = 1$, and $z_{hij} = 0$ for all $h \neq i$. They can be calculated by *MLn* using the command DUMMy.

The formula for the unrestricted multivariate repeated measures model is The second expression in (1) is the usual split of Y_{ij} into its mean fixed part value and the deviation from the mean. The third expression follows from the definition of the dummy variables Z_h , and indicates the split of the model into its fixed and random parts. The formula indicates that the p dummy variables Z_h have random slopes u_{hj} at level 2. The random slopes must be allowed to be correlated. No constant is involved in the fixed or random part. This expression yields an arbitrary covariance matrix for the vector of p measurements. It applies to complete as well as to incomplete data.

As an example, we use the data on salsolinol excretion listed in Hand & Taylor (1987), p. 125 (data provided by Dr. A. Topham), after a logarithmic transformation. There are $n =14$ cases and $p=4$ variables. After the input into *MLn* of a conventional $n{\times}p$ data matrix, columns `c3-c6` of the worksheet contain the 4 repeated measures, while `c1` contains the subject numbers. All columns have length 14. The commands

```
VECT 4 c3-c6 c7 c8
REPEAT 4 c1 c9
NAME c7 'salso' c8 'occ' c9 'subj'
DUMM 'occ' c11-c14
IDEN 1 'occ'
IDEN 2 'subj'
RESP 'salso'
```

are used to disaggregate the 4 variables to a single dependent variable $Y_{ij}=$`salso` of length 56 with an occasion (level-1) identifier $i=$`occ`, a subject (level-2) identifier $j=$`subj`, and 4 dummy variables $z_1=$`c11` to $z_4=$`c14`.

Starting with empty fixed and random parts, the model can be defined by

```
EXPL c11-c14
SETV 2 c11-c14
```

The null hypothesis of homogeneity of means is represented in (1) by the restriction that all μ_i are equal, or equivalently by the formulation

$$Y_{ij} = \mu_1 + \sum_{h=1}^{p} u_{hj} z_{hij}. \qquad (2)$$

Models (1) and (2) have the same random parts. The only variable with a fixed effect in (2) is the constant (equal to 1 for each case). Continuing the example, and assuming that a "variable" `cons` has been defined with a constant value of 1, model (2) can be specified by the commands

```
FPAR c11-c14
EXPL 'cons'
```

Models (1) and (2) can be straightforwardly estimated by *MLn*. The transformation to the contrasts D_{ij} is superfluous. For the purpose of estimating the covariance matrix, the REML (RIGLS) estimates for model (1) provide the usual unbiased estimates. Likelihood ratio tests can be based on deviances obtained from the ML (IGLS) estimation method. The deviance difference between models (1) and (2) has, under the null hypothesis defined by (2), an asymptotic χ^2 distribution with $p-1$ degrees of freedom. Another possibility for testing the null hypothesis is the Wald test that is calculated in *MLn* by the `FTEST` command. with degrees of freedom (number of contrasts) as $p-1$. For the complete data case, the deviance test can be viewed is an asymptotic version of Hotelling's test while the χ^2 statistic given by the `FTEST` command after RIGLS estimation is equal to Hotelling's T^2. The latter statistic can be transformed to an exact F distribution by $F = (n-p+1)T^2/((n-1)(p-1))$.

For several complete data sets, we found close to perfect correspondence between *MLn* and MANOVA software (provided that $n \geq p+2$). The salsolinol excretion example yielded IGLS deviances of 128.994 and 133.931 for models 1 and 2, respectively, so the likelihood ratio test of homogeneity of means has $\chi^2 = 4.937$ (*d.f.*=3). The `FTEST` command (issued after RIGLS estimation to use unbiased variance estimates)

yielded $\chi^2 = 5.50$. Neither result is significant at α=0.10.

Conclusion

The MANOVA model for repeated measures analysis can be implemented in *MLn* by using the nesting structure of measurements within subjects, an empty random part at level 1, and a random part at level 2 consisting of correlated random slopes of dummy variables for the measurement occasions. The advantage of *MLn* is that incomplete data, where some subjects might even provide only one measurement, can be handled without any problem, provided that missingness is at random. Indeed, the model can also deal with completely arbitrary sets of occasions as in the fitting of growth curves. Indeed the model can also deal with completely arbitrary sets of occasions as in the fitting of growth curves. This contrasts sharply with the imputing of missing values, usually carried out to "make data complete" when working with traditional MANOVA software. Another useful extension possible in *MLn* is that the heteroscedasticity assumption needs not be made. Further, in *MLn* it is possible to employ various specifications of the random part, and thus model covariance matrices for the repeated measures that are not completely unrestricted (as in the multivariate approach elaborated in this note), but nevertheless more complicated than the compound symmetry model of the traditional random effects approach to repeated measures.

The authors are preparing a more extensive paper on this subject, which is available on request.

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