
ASReml User Guide

Release 2.0

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ASReml is a statistical package that fits linear mixed models using Residual Maximum Likelihood (REML). It is a joint venture between the Biometrics Program of NSW Department of Primary Industries and the Biomathematics Unit of Rothamsted Research. Statisticians in Britain and Australia have collaborated in its development.

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Preface

New

ASReml is a statistical package that fits linear mixed models using Residual Maximum Likelihood (REML). It has been under development since 1993 and is a joint venture between the Biometrics Program of NSW Department of Primary Industries and the Biomathematics and Bioinformatics Division (previously the Statistics Department) of Rothamsted Research. This guide relates to Release 2 of ASReml, completed in December 2005. Changes in this version are indicated by the word **New** in the margin. A separate document, *ASReml Update. What's new in Release 2.00*, is available to highlight the changes from Release 1.00.

Linear mixed effects models provide a rich and flexible tool for the analysis of many data sets commonly arising in the agricultural, biological, medical and environmental sciences. Typical applications include the analysis of (un)balanced longitudinal data, repeated measures analysis, the analysis of (un)balanced designed experiments, the analysis of multi-environment trials, the analysis of both univariate and multivariate animal breeding and genetics data and the analysis of regular or irregular spatial data.

ASReml provides a stable platform for delivering well established procedures while also delivering current research in the application of linear mixed models. The strength of ASReml is the use of the Average Information (AI) algorithm and sparse matrix methods for fitting the linear mixed model. This enables it to analyse large and complex data sets quite efficiently.

One of the strengths of ASReml is the wide range of variance models for the random effects in the linear mixed model that are available. There is a potential cost for this wide choice. Users should be aware of the dangers of either overfitting or attempting to fit inappropriate variance models to small or highly unbalanced data sets. We stress the importance of using data-driven diagnostics and encourage the user to read the examples chapter, in which we have attempted to not only present the syntax of ASReml in the context of real analyses but also to indicate some of the modelling approaches we have found useful.

ASReml is one of several user interfaces to the underlying computational engine. Genstat in its REML directive and the `asrem1` class of S language functions (Butler *et al.* 2007) available for S-Plus (ASReml-S) and R (ASReml-R) use the same engine. These are available from VSN (<http://www.vsnl.co.uk>) and have good data manipulation and graphical facilities.

The focus in developing ASReml has been on the core engine and it is freely acknowledged that its user interface is not to the level of these other packages. Nevertheless, as the developers interface, it is functional, it gives access to everything that the core can do and is especially suited to batch processing and running of large models without the overheads of other systems. Feedback from users is welcome and attempts will be made to rectify identified problems in ASReml.

The guide has 15 chapters. Chapter 1 introduces ASReml and describes the conventions used in this guide. Chapter 2 outlines some basic theory while Chapter 3 presents an overview of the syntax of ASReml through a simple example. Data file preparation is described in Chapter 4 and Chapter 5 describes how to input data into ASReml. Chapters 6 and 7 are key chapters which present the syntax for specifying the linear model and the variance models for the random effects in the linear mixed model. Chapters 8 and 9 describe special commands for multivariate and genetic analyses respectively. Chapter 10 deals with prediction of linear functions of fixed and random effects in the linear mixed model and Chapter 11 presents the syntax for forming functions of variance components. Chapter 12 demonstrates running an ASReml job features available and Chapter 13 gives a detailed explanation of the output files. Chapter 14 gives an overview of the error messages generated in ASReml and some guidance as to their probable cause. The guide concludes with the most extensive chapter which presents the examples.

Briefly, the improvements in Release 2.00 include more robust variance parameter updating so that 'Convergence Failure' is less likely, extensions to the syntax, inclusion of the Matérn correlation model, ability to plot predicted values, improvements to the Analysis of Variance procedures, improvements to the handling of pedigrees and some increases in computational speed.

The data sets and ASReml input files used in this guide are available from <http://www.vsnl.co.uk/products/asrem1> as well as in the `examples` directory of the distribution CD-ROM. They remain the property of the authors or of the original source but may be freely distributed provided the source is acknowledged. The authors would appreciate feedback and suggestions for improvements to the program and this guide.

Proceeds from the licensing of ASReml are used to support continued development to implement new developments in the application of linear mixed models. The developmental version is available to supported licensees via a website upon request to VSN. Most users will not need to access the developmental version unless they are actively involved in testing a new development.

Acknowledgements

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We sincerely thank Ari Verbyla, Sue Welham, Dave Butler and Alison Smith, the other members of the ASReml ‘team’. Ari contributed the cubic smoothing splines technology, information for the Marker map imputation, on-going testing of the software and numerous helpful discussions and insight. Sue Welham has overseen the incorporation of the core into Genstat and contributed to the `predict` functionality. Dave Butler has developed the `asreml` class of functions for S-plus and R. Alison contributed to the development of many of the approaches for the analysis of multi-section trials. We also thank Ian White for his contribution to the spline methodology, and Simon Harding for the licensing and installation software and for his development of the ASReml-W environment for running ASReml. The Matérn function material was developed with Kathy Haskard, a PhD student with Brian Cullis, and the denominator degrees of freedom material was developed with Sharon Nielsen, a Masters student with Brian Cullis. Damian Collins contributed the PREDICT !PLOT material. Greg Dutkowski has contributed to the extended pedigree options. The `asremload.dll` functionality is provided under license to VSN. Alison Kelly has helped with the review of the XFA models. Finally, we especially thank our close associates who continually test the enhancements.

Arthur Gilmour acknowledges the grace of God through Jesus Christ who enables this research to proceed. *Be exalted O God, above the heavens: and Thy glory above all the earth.* Psalm 108:5.

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What ASReml can do

Installation

User Interface

How to use the guide

Help and discussion list

Typographic conventions

1.1 What ASReml can do

ASReml (pronounced *A S Rem el*) is used to fit linear mixed models to quite large data sets with complex variance models. It extends the range of variance models available for the analysis of experimental data. ASReml has application in the analysis of

- (un)balanced longitudinal data,
- repeated measures data (multivariate analysis of variance and spline type models),
- (un)balanced designed experiments,
- multi-environment trials and meta analysis,
- univariate and multivariate animal breeding and genetics data (involving a relationship matrix for correlated effects),
- regular or irregular spatial data.

The engine of ASReml forms the basis of the REML procedure in GENSTAT and the `asreml` class of S language functions (Butler *et al.* 2007) available for S-Plus (ASReml-S) and R (ASReml-R)¹. Both of these have good data manipulation and graphical facilities. and will be adequate for many analyses, some large problems will need to use ASReml. The ASReml user interface is terse. Most effort has been directed towards efficiency of the engine. It normally operates in a batch mode.

Problem size depends on the sparsity of the mixed model equations and the size of your computer. However, models with 500,000 effects have been fitted successfully. The computational efficiency of ASReml arises from using the Average Information REML procedure (giving quadratic convergence) and sparse matrix operations. ASReml has been operational since March 1996 and is updated periodically.

1.2 Installation

Installation instructions are distributed with the program. If you require help with installation, please email support@asreml.co.uk.

¹These are available from VSN (<http://www.vsnl.co.uk>).

1.3 User Interface

New

ASReml is essentially a batch program with some optional interactive features. The typical sequence of operations when using ASReml is

- Prepare the data (typically using a spreadsheet or data base program)
- Export that data as an ASCII file (for example export it as a `.csv` (comma separated values) file from Excel)
- Prepare a job file with filename extension `.as`
- Run the job file with ASReml
- Review the various output files
- revise the job and re run it, or
- extract pertinent results for your report.

So you need an ASCII editor to prepare input files and review and print output files. We directly provide two options.

ASReml-W

ASReml-W is a graphical tool distributed by VSN (<http://www.vsnl.co.uk>) allowing the user to edit and run ASReml programs, and then view the output. It is available on the following platforms:

- Windows 32-bit,
- Windows 64-bit,
- Linux 32-bit,
- Linux 64-bit, and
- Sun/Solaris 32-bit

ASReml-W has a built-in help system explaining its use.

ConTEXT

ConTEXT is a third-party freeware text editor, with programming extensions which make it a suitable environment for running ASReml under Windows. The ConTEXT directory on the CD-ROM includes installation files and instructions for configuring it for use in ASReml. Full details of ConTEXT are available from <http://www.context.cx/>.

1.4 How to use this guide

- Theory** The guide consists of 15 chapters. Chapter 1 introduces ASReml and describes the conventions used in the guide. Chapter 2 outlines some basic theory which you may need to come back to.
- Getting started** New ASReml users are advised to read Chapter 3 before attempting to code their first job. It presents an overview of basic ASReml coding demonstrated on a real data example. Chapter 15 presents a range of examples to assist users further. When coding your first job, look for an example to use as a template.
- Examples**
- Data file** Data file preparation is described in Chapter 4, while Chapter 5 describes how to input data into ASReml. Chapters 6 and 7 are key chapters which present the syntax for specifying the linear model and the variance models for the random effects in the linear mixed model. Variance modelling is a complex aspect of analysis. We introduce variance modelling in ASReml by example in Chapter 7.
- Linear model**
- Variance model**
- Prediction** Chapters 8 and 9 describe special commands for multivariate and genetic analyses respectively. Chapter 10 deals with prediction of fixed and random effects from the linear mixed model and Chapter 11 presents the syntax for forming functions of variance components.
- Output** Chapter 12 discusses the operating system level command for running an ASReml job. Chapter 13 gives a detailed explanation of the output files. Chapter 14 gives an overview of the error messages generated in ASReml and some guidance as to their probable cause.

1.5 Help and discussion list

- The ASReml help accessible through ASReml-W can also be accessed directly (ASReml.chm).
- Supported users of ASReml may email support@asrem1.co.uk for assistance. When requesting help for a job that is not working as you expect, please send the input command file, the data file and the corresponding primary output file along with a description of the problem.
- New** There is an ASReml discussion list. If you would like to join, change your email address or be removed from the list, email arthur.gilmour@dpi.nsw.gov.au with your request. The address for messages to the list is ASRem1-L@dpi.nsw.gov.au.

There is a User Area on the website (<http://www.VSNi.co.uk> select ASReml and then User Area) which contains contributed material that may be of assistance. It includes an ASReml tutorial in the form of sixteen sets of slides with audio (.mp3) discussion. The sessions last about 20 minutes each.

1.6 Typographic conventions

A hands on approach is the best way to develop a working understanding of a new computing package. We therefore begin by presenting a guided tour of ASReml using a sample data set for demonstration (see Chapter 3). Throughout the guide new concepts are demonstrated by example wherever possible.

In this guide you will find framed sample boxes to the right of the page as shown here. These contain ASReml command file (sample) code. Note that

- the code under discussion is highlighted in bold type for easy identification,
- the continuation symbol (:) is used to indicate that some of the original code is omitted.

An example ASReml code box

bold type highlights sections of code currently under discussion

remaining code is not highlighted

: indicates that some of the original code is omitted from the display

Data examples are displayed in larger boxes in the body of the text, see, for example, page 42. Other conventions are as follows:

- keyboard key names appear in SMALLCAPS, for example, TAB and ESC,
- example code within the body of the text is in **this size and font** and is highlighted in bold type, see pages 33 and 49,
- in the presentation of general ASReml syntax, for example
`[path] asrem1 basename [.as] [arguments]`
 - **typewriter font** is used for text that must be typed verbatim, for example, `asrem1` and `.as` after *basename* in the example,
 - *italic font* is used to name information to be supplied by the user, for example, *basename* stands for the name of a file with an `.as` filename extension,
 - square brackets indicate that the enclosed text and/or arguments are not always required.
- ASReml output is in **this size and font**, see page 35,
- **this font** is used for all other code.

2

Some theory

The linear mixed model

- Introduction
- Direct product structures
- Variance structures for the errors: R structures
- Variance structures for the random effects: G structures

Estimation

- Estimation of the variance parameters
- Estimation/prediction of fixed and random effects

What are BLUPs?

Combining variance models

Inference: Random effects

- Tests of hypotheses: variance parameters
- Diagnostics

Inference: Fixed effects

- Introduction
- Incremental and Conditional Wald Statistics
- Kenward and Roger Adjustments
- Approximate stratum variances

2.1 The linear mixed model

Introduction

If \mathbf{y} denotes the $n \times 1$ vector of observations, the linear mixed model can be written as

$$\mathbf{y} = \mathbf{X}\boldsymbol{\tau} + \mathbf{Z}\mathbf{u} + \mathbf{e} \quad (2.1)$$

where $\boldsymbol{\tau}$ is the $p \times 1$ vector of fixed effects, \mathbf{X} is an $n \times p$ design matrix of full column rank which associates observations with the appropriate combination of fixed effects, \mathbf{u} is the $q \times 1$ vector of random effects, \mathbf{Z} is the $n \times q$ design matrix which associates observations with the appropriate combination of random effects, and \mathbf{e} is the $n \times 1$ vector of residual errors.

The model (2.1) is called a linear mixed model or linear mixed effects model. It is assumed

$$\begin{bmatrix} \mathbf{u} \\ \mathbf{e} \end{bmatrix} \sim N \left(\begin{bmatrix} \mathbf{0} \\ \mathbf{0} \end{bmatrix}, \theta \begin{bmatrix} \mathbf{G}(\boldsymbol{\gamma}) & \mathbf{0} \\ \mathbf{0} & \mathbf{R}(\boldsymbol{\phi}) \end{bmatrix} \right) \quad (2.2)$$

where the matrices \mathbf{G} and \mathbf{R} are functions of parameters $\boldsymbol{\gamma}$ and $\boldsymbol{\phi}$, respectively. The parameter θ is a variance parameter which we will refer to as the scale parameter. In mixed effects models with more than one residual variance, arising for example in the analysis of data with more than one section (see below) or variate, the parameter θ is fixed to one. In mixed effects models with a single residual variance then θ is equal to the residual variance (σ^2). In this case \mathbf{R} must be a correlation matrix (see Table 2.1 for a discussion).

Direct product structures

To undertake variance modelling in ASReml you need to understand the formation of variance structures via direct products (\otimes). The direct product of two matrices $\mathbf{A}^{(m \times p)}$ and $\mathbf{B}^{(n \times q)}$ is

$$\begin{bmatrix} a_{11}\mathbf{B} & \dots & a_{1p}\mathbf{B} \\ \vdots & \ddots & \vdots \\ a_{m1}\mathbf{B} & \ddots & a_{mp}\mathbf{B} \end{bmatrix}$$

Direct products in R structures

Consider a vector of common errors associated with an experiment. The usual least squares assumption (and the default in ASReml) is that these are independently and identically distributed (IID). However, if \mathbf{e} was from a field experiment

laid out in a rectangular array of r rows by c columns, we could arrange the residuals as a matrix and might consider that they were autocorrelated within rows and columns. Writing the residuals as a vector in field order, that is, by sorting the residuals rows within columns (plots within blocks) the variance of the residuals might then be

$$\sigma_e^2 \boldsymbol{\Sigma}_c(\rho_c) \otimes \boldsymbol{\Sigma}_r(\rho_r)$$

where $\boldsymbol{\Sigma}_c(\rho_c)$ and $\boldsymbol{\Sigma}_r(\rho_r)$ are correlation matrices for the row model (order r , autocorrelation parameter ρ_r) and column model (order c , autocorrelation parameter ρ_c) respectively. More specifically, a two-dimensional separable autoregressive spatial structure ($\text{AR1} \otimes \text{AR1}$) is sometimes assumed for the common errors in a field trial analysis (see Gogel (1997) and Cullis *et al.* (1998) for examples). In this case

$$\boldsymbol{\Sigma}_r = \begin{bmatrix} 1 & & & & \\ \rho_r & 1 & & & \\ \rho_r^2 & \rho_r & 1 & & \\ \vdots & \vdots & \vdots & \ddots & \\ \rho_r^{r-1} & \rho_r^{r-2} & \rho_r^{r-3} & \dots & 1 \end{bmatrix} \quad \text{and} \quad \boldsymbol{\Sigma}_c = \begin{bmatrix} 1 & & & & \\ \rho_c & 1 & & & \\ \rho_c^2 & \rho_c & 1 & & \\ \vdots & \vdots & \vdots & \ddots & \\ \rho_c^{c-1} & \rho_c^{c-2} & \rho_c^{c-3} & \dots & 1 \end{bmatrix}.$$

See Chapter 8 for further details. Alternatively, the residuals might relate to a multivariate analysis with n_t traits and n units and be ordered traits *within* units. In this case an appropriate variance structure might be

$$\mathbf{I}_n \otimes \boldsymbol{\Sigma}$$

where $\boldsymbol{\Sigma}^{(n_t \times n_t)}$ is a general or *unstructured* variance matrix.

Direct products in G structures

Likewise, the random terms in \mathbf{u} in the model may have a direct product variance structure. For example, for a field trial with s sites, g varieties and the effects ordered varieties *within* sites, the model term *site.variety* may have the variance structure

$$\boldsymbol{\Sigma} \otimes \mathbf{I}_g$$

where $\boldsymbol{\Sigma}$ is the variance matrix for sites. This would imply that the varieties are independent random effects within each site, have different variances at each site, and are correlated across sites. **Important** Whenever a random term is formed as the interaction of two factors you should consider whether the IID assumption is sufficient or if a direct product structure might be more appropriate.

Variance structures for the errors: \mathbf{R} structures

The vector \mathbf{e} will in some situations be a series of vectors indexed by a factor or factors. The convention we adopt is to refer to these as *sections*. Thus $\mathbf{e} = [\mathbf{e}'_1, \mathbf{e}'_2, \dots, \mathbf{e}'_s]'$ and the \mathbf{e}_j represent the errors of *sections* of the data. For example, these sections may represent different experiments in a multi-environment trial (MET), or different trials in a meta analysis. It is assumed that \mathbf{R} is the direct sum of s matrices \mathbf{R}_j , $j = 1 \dots s$, that is,

$$\mathbf{R} = \oplus_{j=1}^s \mathbf{R}_j = \begin{bmatrix} \mathbf{R}_1 & 0 & \dots & 0 & 0 \\ 0 & \mathbf{R}_2 & \dots & 0 & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \dots & \mathbf{R}_{s-1} & 0 \\ 0 & 0 & \dots & 0 & \mathbf{R}_s \end{bmatrix},$$

so that each section has its own variance structure which is assumed to be independent of the structures in other sections.

A structure for the residual variance for the spatial analysis of multi-environment trials (Cullis *et al.*, 1998) is given by

$$\begin{aligned} \mathbf{R}_j &= \mathbf{R}_j(\phi_j) \\ &= \sigma_j^2(\boldsymbol{\Sigma}_j(\boldsymbol{\rho}_j)). \end{aligned}$$

Each section represents a trial and this model accounts for between trial error variance heterogeneity (σ_j^2) and possibly a different spatial variance model for each trial.

In the simplest case the matrix \mathbf{R} could be known and proportional to an identity matrix. Each component matrix, \mathbf{R}_j (or \mathbf{R} itself for one section) is assumed to be the direct product (see Searle, 1982) of one, two or three component matrices. The component matrices are related to the underlying structure of the data. If the structure is defined by factors, for example, replicates, rows and columns, then the matrix \mathbf{R} can be constructed as a direct product of three matrices describing the nature of the correlation across replicates, rows and columns. These factors must completely describe the structure of the data, which means that

1. the number of combined levels of the factors must equal the number of data points,
2. each factor combination must uniquely specify a single data point.

These conditions are necessary to ensure the expression $\text{var}(\mathbf{e}) = \theta\mathbf{R}$ is valid. The assumption that the overall variance structure can be constructed as a direct

product of matrices corresponding to underlying factors is called the assumption of separability and assumes that any correlation process across levels of a factor is independent of any other factors in the term. Multivariate data and repeated measures data usually satisfy the assumption of separability. In particular, if the data are indexed by factors **units** and **traits** (for multivariate data) or **times** (for repeated measures data), then the R structure may be written as $units \otimes traits$ or $units \otimes times$. This assumption is sometimes required to make the estimation process computationally feasible, though it can be relaxed, for certain applications, for example fitting isotropic covariance models to irregularly spaced spatial data.

Variance structures for the random effects: **G** structures

The $q \times 1$ vector of random effects is often composed of b subvectors $\mathbf{u} = [\mathbf{u}'_1 \ \mathbf{u}'_2 \ \dots \ \mathbf{u}'_b]'$ where the subvectors \mathbf{u}_i are of length q_i and these subvectors are usually assumed independent normally distributed with variance matrices $\theta \mathbf{G}_i$. Thus just like **R** we have

$$\mathbf{G} = \oplus_{i=1}^b \mathbf{G}_i = \begin{bmatrix} \mathbf{G}_1 & 0 & \dots & 0 & 0 \\ 0 & \mathbf{G}_2 & \dots & 0 & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \dots & \mathbf{G}_{b-1} & 0 \\ 0 & 0 & \dots & 0 & \mathbf{G}_b \end{bmatrix}.$$

There is a corresponding partition in **Z**, $\mathbf{Z} = [\mathbf{Z}_1 \ \mathbf{Z}_2 \ \dots \ \mathbf{Z}_b]$. As before each submatrix, \mathbf{G}_i , is assumed to be the direct product of one, two or three component matrices. These matrices are indexed for each of the factors constituting the term in the linear model. For example, the term *site.genotype* has two factors and so the matrix \mathbf{G}_i is comprised of two component matrices defining the variance structure for each factor in the term.

Models for the component matrices \mathbf{G}_i include the standard model for which $\mathbf{G}_i = \gamma_i \mathbf{I}_{q_i}$ and direct product models for correlated random factors given by

$$\mathbf{G}_i = \mathbf{G}_{i1} \otimes \mathbf{G}_{i2} \otimes \mathbf{G}_{i3}$$

for three component factors. The vector \mathbf{u}_i is therefore assumed to be the vector representation of a 3-way array. For two factors the vector \mathbf{u}_i is simply the vec of a matrix with rows and columns indexed by the component factors in the term, where vec of a matrix is a function which stacks the columns of its matrix argument below each other.

A range of models are available for the components of both **R** and **G**. They include correlation (*C*) models (that is, where the diagonals are 1), or covariance

(V) models and are discussed in detail in Chapter 7. Some correlation models include

- autoregressive (order 1 or 2)
- moving average (order 1 or 2)
- ARMA(1,1)
- uniform
- banded
- general correlation.

Some of the covariance models include

- diagonal (that is, independent with heterogeneous variances)
- antedependence
- unstructured
- factor analytic.

There is the facility within ASReml to allow for a nonzero covariance between the subvectors of \mathbf{u} , for example in random regression models. In this setting the intercept and say the slope for each unit are assumed to be correlated and it is more natural to consider the two component terms as a single term, which gives rise to a single G structure. This concept is discussed later.

2.2 Estimation

Estimation involves two processes that are closely linked. They are performed within the ‘engine’ of ASReml. One process involves estimation of $\boldsymbol{\tau}$ and prediction of \mathbf{u} (although the latter may not always be of interest) for given θ , $\boldsymbol{\phi}$ and $\boldsymbol{\gamma}$. The other process involves estimation of these variance parameters. Note that in the following sections we have set $\theta = 1$ to simplify the presentation of results.

Estimation of the variance parameters

Estimation of the variance parameters is carried out using residual or restricted maximum likelihood (REML), developed by Patterson and Thompson (1971). An historical development of the theory can be found in Searle *et al.* (1992). Note firstly that

$$\mathbf{y} \sim N(\mathbf{X}\boldsymbol{\tau}, \mathbf{H}). \quad (2.3)$$

where $\mathbf{H} = \mathbf{R} + \mathbf{ZGZ}'$. REML does not use (2.3) for estimation of variance parameters, but rather uses a distribution free of $\boldsymbol{\tau}$, essentially based on error contrasts or *residuals*. The derivation given below is presented in Verbyla (1990).

We transform \mathbf{y} using a non-singular matrix $\mathbf{L} = [\mathbf{L}_1 \ \mathbf{L}_2]$ such that

$$\mathbf{L}'_1 \mathbf{X} = \mathbf{I}_p, \quad \mathbf{L}'_2 \mathbf{X} = \mathbf{0}.$$

If $\mathbf{y}_j = \mathbf{L}'_j \mathbf{y}$, $j = 1, 2$,

$$\begin{bmatrix} \mathbf{y}_1 \\ \mathbf{y}_2 \end{bmatrix} \sim N \left(\begin{bmatrix} \boldsymbol{\tau} \\ \mathbf{0} \end{bmatrix}, \begin{bmatrix} \mathbf{L}'_1 \mathbf{H} \mathbf{L}_1 & \mathbf{L}'_1 \mathbf{H} \mathbf{L}_2 \\ \mathbf{L}'_2 \mathbf{H} \mathbf{L}_1 & \mathbf{L}'_2 \mathbf{H} \mathbf{L}_2 \end{bmatrix} \right).$$

The full distribution of $\mathbf{L}'\mathbf{y}$ can be partitioned into a *conditional distribution*, namely $\mathbf{y}_1|\mathbf{y}_2$, for estimation of $\boldsymbol{\tau}$, and a *marginal distribution* based on \mathbf{y}_2 for estimation of $\boldsymbol{\gamma}$ and $\boldsymbol{\phi}$; the latter is the basis of the **residual likelihood**.

The estimate of $\boldsymbol{\tau}$ is found by equating \mathbf{y}_1 to its conditional expectation, and after some algebra we find,

$$\hat{\boldsymbol{\tau}} = (\mathbf{X}'\mathbf{H}^{-1}\mathbf{X})^{-1}\mathbf{X}'\mathbf{H}^{-1}\mathbf{y}$$

Estimation of $\boldsymbol{\kappa} = [\boldsymbol{\gamma}' \ \boldsymbol{\phi}']'$ is based on the log residual likelihood,

$$\begin{aligned} \ell_R &= -\frac{1}{2}(\log \det \mathbf{L}'_2 \mathbf{H}^{-1} \mathbf{L}_2 + \mathbf{y}'_2 (\mathbf{L}'_2 \mathbf{H} \mathbf{L}_2)^{-1} \mathbf{y}_2) \\ &= -\frac{1}{2}(\log \det \mathbf{X}'\mathbf{H}^{-1}\mathbf{X} + \log \det \mathbf{H} + \mathbf{y}'\mathbf{P}\mathbf{y}) \end{aligned} \quad (2.4)$$

where

$$\mathbf{P} = \mathbf{H}^{-1} - \mathbf{H}^{-1}\mathbf{X}(\mathbf{X}'\mathbf{H}^{-1}\mathbf{X})^{-1}\mathbf{X}'\mathbf{H}^{-1}.$$

Note that $\mathbf{y}'\mathbf{P}\mathbf{y} = (\mathbf{y} - \mathbf{X}\hat{\boldsymbol{\tau}})'\mathbf{H}^{-1}(\mathbf{y} - \mathbf{X}\hat{\boldsymbol{\tau}})$. The log-likelihood (2.4) depends on \mathbf{X} and not on the particular non-unique transformation defined by \mathbf{L} .

The log residual likelihood (ignoring constants) can be written in terms of the mixed model equations (see equation 2.11) with $\mathbf{W} = [\mathbf{X} \ \mathbf{Z}]$ as

$$\ell_R = -\frac{1}{2}(\log \det \mathbf{C} + \log \det \mathbf{R} + \log \det \mathbf{G} + \mathbf{y}'\mathbf{P}\mathbf{y}) \quad (2.5)$$

where $\mathbf{C} = \mathbf{W}'\mathbf{R}^{-1}\mathbf{W} + \mathbf{G}^*$, $\mathbf{G}^* = \begin{bmatrix} \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{G}^{-1} \end{bmatrix}$ and

$$\mathbf{P} = \mathbf{R}^{-1} - \mathbf{R}^{-1}\mathbf{W}\mathbf{C}^{-1}\mathbf{W}'\mathbf{R}^{-1}$$

Letting $\boldsymbol{\kappa} = (\boldsymbol{\gamma}, \boldsymbol{\phi})$, the REML estimates of κ_i are found by calculating the score

$$U(\kappa_i) = \partial \ell_R / \partial \kappa_i = -\frac{1}{2} [\text{tr}(\mathbf{P}\mathbf{H}_i) - \mathbf{y}'\mathbf{P}\mathbf{H}_i\mathbf{P}\mathbf{y}] \quad (2.6)$$

and equating to zero. Note that $\mathbf{H}_i = \partial \mathbf{H} / \partial \kappa_i$.

The elements of the observed information matrix are

$$\begin{aligned} -\frac{\partial^2 \ell_R}{\partial \kappa_i \partial \kappa_j} &= \frac{1}{2} \text{tr}(\mathbf{P}\mathbf{H}_{ij}) - \frac{1}{2} \text{tr}(\mathbf{P}\mathbf{H}_i\mathbf{P}\mathbf{H}_j) \\ &\quad + \mathbf{y}'\mathbf{P}\mathbf{H}_i\mathbf{P}\mathbf{H}_j\mathbf{P}\mathbf{y} - \frac{1}{2} \mathbf{y}'\mathbf{P}\mathbf{H}_{ij}\mathbf{P}\mathbf{y} \end{aligned} \quad (2.7)$$

where $\mathbf{H}_{ij} = \partial^2 \mathbf{H} / \partial \kappa_i \partial \kappa_j$.

The elements of the expected information matrix are

$$\mathbb{E} \left(-\frac{\partial^2 \ell_R}{\partial \kappa_i \partial \kappa_j} \right) = \frac{1}{2} \text{tr}(\mathbf{P}\mathbf{H}_i\mathbf{P}\mathbf{H}_j). \quad (2.8)$$

Given an initial estimate $\boldsymbol{\kappa}^{(0)}$, an update of $\boldsymbol{\kappa}$, $\boldsymbol{\kappa}^{(1)}$ using the Fisher-scoring (FS) algorithm is

$$\boldsymbol{\kappa}^{(1)} = \boldsymbol{\kappa}^{(0)} + \mathbf{I}(\boldsymbol{\kappa}^{(0)}, \boldsymbol{\kappa}^{(0)})^{-1} \mathbf{U}(\boldsymbol{\kappa}^{(0)}) \quad (2.9)$$

where $\mathbf{U}(\boldsymbol{\kappa}^{(0)})$ is the score vector (2.6) and $\mathbf{I}(\boldsymbol{\kappa}^{(0)}, \boldsymbol{\kappa}^{(0)})$ is the expected information matrix (2.8) of $\boldsymbol{\kappa}$ evaluated at $\boldsymbol{\kappa}^{(0)}$.

For large models or large data sets, the evaluation of the trace terms in either (2.7) or (2.8) is either not feasible or is very computer intensive. To overcome this problem ASReml uses the AI algorithm (Gilmour, Thompson and Cullis, 1995). The matrix denoted by \mathcal{I}_A is obtained by averaging (2.7) and (2.8) and approximating $\mathbf{y}'\mathbf{P}\mathbf{H}_{ij}\mathbf{P}\mathbf{y}$ by its expectation, $\text{tr}(\mathbf{P}\mathbf{H}_{ij})$ in those cases when $\mathbf{H}_{ij} \neq 0$. For variance components models (that is those linear with respect to variances in \mathbf{H}), the terms in \mathcal{I}_A are exact averages of those in (2.7) and (2.8). The basic idea is to use $\mathcal{I}_A(\kappa_i, \kappa_j)$ in place of the expected information matrix in (2.9) to update $\boldsymbol{\kappa}$.

The elements of \mathcal{I}_A are

$$\mathcal{I}_A(\kappa_i, \kappa_j) = \frac{1}{2} \mathbf{y}'\mathbf{P}\mathbf{H}_i\mathbf{P}\mathbf{H}_j\mathbf{P}\mathbf{y}. \quad (2.10)$$

The \mathcal{I}_A matrix is the (scaled) residual sums of squares and products matrix of

$$\mathbf{y} = [\mathbf{y}_1, \dots, \mathbf{y}_k]$$

where \mathbf{y}_i is the ‘working’ variate for κ_i and is given by

$$\begin{aligned}\mathbf{y}_i &= \mathbf{H}_i \mathbf{P} \mathbf{y} \\ &= \mathbf{H}_i \mathbf{R}^{-1} \tilde{\mathbf{e}} \\ &= \mathbf{R}_i \mathbf{R}^{-1} \tilde{\mathbf{e}}, \quad \kappa_i \in \phi \\ &= \mathbf{Z} \mathbf{G}_i \mathbf{G}^{-1} \tilde{\mathbf{u}}, \quad \kappa_i \in \gamma\end{aligned}$$

where $\tilde{\mathbf{e}} = \mathbf{y} - \mathbf{X} \hat{\boldsymbol{\tau}} - \mathbf{Z} \tilde{\mathbf{u}}$, $\hat{\boldsymbol{\tau}}$ and $\tilde{\mathbf{u}}$ are solutions to (2.11). In this form the AI matrix is relatively straightforward to calculate.

The combination of the AI algorithm with sparse matrix methods, in which only non-zero values are stored, gives an efficient algorithm in terms of both computing time and workspace.

Estimation/prediction of the fixed and random effects

To estimate $\boldsymbol{\tau}$ and predict \mathbf{u} the objective function

$$\log f_{\mathbf{Y}}(\mathbf{y} | \mathbf{u}; \boldsymbol{\tau}, \mathbf{R}) + \log f_{\mathbf{U}}(\mathbf{u}; \mathbf{G})$$

is used. This is the log-joint distribution of (\mathbf{Y}, \mathbf{u}) .

Differentiating with respect to $\boldsymbol{\tau}$ and \mathbf{u} leads to the mixed model equations (Robinson, 1991) which are given by

$$\begin{bmatrix} \mathbf{X}' \mathbf{R}^{-1} \mathbf{X} & \mathbf{X}' \mathbf{R}^{-1} \mathbf{Z} \\ \mathbf{Z}' \mathbf{R}^{-1} \mathbf{X} & \mathbf{Z}' \mathbf{R}^{-1} \mathbf{Z} + \mathbf{G}^{-1} \end{bmatrix} \begin{bmatrix} \hat{\boldsymbol{\tau}} \\ \hat{\mathbf{u}} \end{bmatrix} = \begin{bmatrix} \mathbf{X}' \mathbf{R}^{-1} \mathbf{y} \\ \mathbf{Z}' \mathbf{R}^{-1} \mathbf{y} \end{bmatrix}. \quad (2.11)$$

These can be written as

$$\mathbf{C} \tilde{\boldsymbol{\beta}} = \mathbf{W} \mathbf{R}^{-1} \mathbf{y}$$

where $\mathbf{C} = \mathbf{W}' \mathbf{R}^{-1} \mathbf{W} + \mathbf{G}^*$, $\boldsymbol{\beta} = [\boldsymbol{\tau}' \ \mathbf{u}']'$ and

$$\mathbf{G}^* = \begin{bmatrix} \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{G}^{-1} \end{bmatrix}.$$

The solution of (2.11) requires values for γ and ϕ . In practice we replace γ and ϕ by their REML estimates $\hat{\gamma}$ and $\hat{\phi}$.

Note that $\hat{\boldsymbol{\tau}}$ is the best linear unbiased estimator (BLUE) of $\boldsymbol{\tau}$, while $\hat{\mathbf{u}}$ is the best linear unbiased predictor (BLUP) of \mathbf{u} for known γ and ϕ . We also note that

$$\tilde{\boldsymbol{\beta}} - \boldsymbol{\beta} = \begin{bmatrix} \hat{\boldsymbol{\tau}} - \boldsymbol{\tau} \\ \hat{\mathbf{u}} - \mathbf{u} \end{bmatrix} \sim N \left(\begin{bmatrix} \mathbf{0} \\ \mathbf{0} \end{bmatrix}, \mathbf{C}^{-1} \right).$$

2.3 What are BLUPs?

Consider a balanced one-way classification. For data records ordered r repeats within b treatments regarded as random effects, the linear mixed model is $\mathbf{y} = \mathbf{X}\boldsymbol{\tau} + \mathbf{Z}\mathbf{u} + \mathbf{e}$ where $\mathbf{X} = \mathbf{1}_b \otimes \mathbf{1}_r$ is the design matrix for $\boldsymbol{\tau}$ (the overall mean), $\mathbf{Z} = \mathbf{I}_b \otimes \mathbf{1}_r$ is the design matrix for the b (random) treatment effects u_i and \mathbf{e} is the error vector. Assuming that the treatment effects are random implies that $\mathbf{u} \sim N(\mathbf{A}\boldsymbol{\psi}, \sigma_b^2 \mathbf{I}_b)$, for some design matrix \mathbf{A} and parameter vector $\boldsymbol{\psi}$. It can be shown that

$$\tilde{\mathbf{u}} = \frac{r\sigma_b^2}{r\sigma_b^2 + \sigma^2}(\bar{\mathbf{y}} - \mathbf{1}\bar{y}_{..}) + \frac{\sigma^2}{r\sigma_b^2 + \sigma^2}\mathbf{A}\boldsymbol{\psi} \quad (2.12)$$

where $\bar{\mathbf{y}}$ is the vector of treatment means, $\bar{y}_{..}$ is the grand mean. The differences of the treatment means and the grand mean are the estimates of treatment effects if treatment effects are fixed. The BLUP is therefore a weighted mean of the data based estimate and the ‘prior’ mean $\mathbf{A}\boldsymbol{\psi}$. If $\boldsymbol{\psi} = \mathbf{0}$, the BLUP in (2.12) becomes

$$\tilde{\mathbf{u}} = \frac{r\sigma_b^2}{r\sigma_b^2 + \sigma^2}(\bar{\mathbf{y}} - \mathbf{1}\bar{y}_{..}) \quad (2.13)$$

and the BLUP is a so-called shrinkage estimate. As $r\sigma_b^2$ becomes large relative to σ^2 , the BLUP tends to the fixed effect solution, while for small $r\sigma_b^2$ relative to σ^2 the BLUP tends towards zero, the assumed initial mean. Thus (2.13) represents a weighted mean which involves the prior assumption that the u_i have zero mean.

Note also that the BLUPs in this simple case are constrained to sum to zero. This is essentially because the unit vector defining \mathbf{X} can be found by summing the columns of the \mathbf{Z} matrix. This linear dependence of the matrices translates to dependence of the BLUPs and hence constraints. This aspect occurs whenever the column space of \mathbf{X} is contained in the column space of \mathbf{Z} . The dependence is slightly more complex with correlated random effects.

2.4 Combining variance models

The combination of variance models within G structures and R structures and between G structures and R structures is a difficult and important concept. The underlying principle is that each \mathbf{R}_i and \mathbf{G}_i variance model can only have a single scaling variance parameter associated with it. If there is more than one scaling variance parameter for any \mathbf{R}_i or \mathbf{G}_i then the variance model is overspecified, or *nonidentifiable*. Some variance models are presented in Table 2.1 to illustrate this principle.

While all 9 forms of model in Table 2.1 can be specified within ASReml only models of forms 1 and 2 are recommended. Models 4-6 have too few variance parameters and are likely to cause serious estimation problems. For model 3, where the scale parameter θ has been fitted (univariate single site analysis), it becomes the scale for \mathbf{G} . This parameterisation is bizarre and is not recommended. Models 7-9 have too many variance parameters and ASReml will arbitrarily fix one of the variance parameters leading to possible confusion for the user. If you fix the variance parameter to a particular value then it does not count for the purposes of applying the principle that there be only one scaling variance parameter. That is, models 7-9 can be made identifiable by fixing all but one of the nonidentifiable scaling parameters in each of \mathbf{G} and \mathbf{R} to a particular value.

Table 2.1 Combination of models for G and R structures

model	G_1	G_2	R_1	R_2	θ	comment
1.	V	C	C	C	y	valid
2.	V	C	V	C	n	valid
3.	C	C	V	C	y	valid, but not recommended
4.	*	*	C	C	n	inappropriate as R is a correlation model
5.	C	C	C	C	y	inappropriate, same scale for R and G
6.	C	C	V	C	n	inappropriate, no scaling parameter for G
7.	V	V	*	*	*	nonidentifiable, 2 scaling parameters for G
8.	V	C	V	C	y	nonidentifiable, scale for R and overall scale
9.	*	*	V	V	*	nonidentifiable, 2 scaling parameters for R

* indicates the entry is not relevant in this case

Note that G_1 and G_2 are interchangeable in this table, as are R_1 and R_2

2.5 Inference: Random effects

Tests of hypotheses: variance parameters

Inference concerning variance parameters of a linear mixed effects model usually relies on approximate distributions for the (RE)ML estimates derived from asymptotic results.

It can be shown that the approximate variance matrix for the REML estimates is given by the inverse of the expected information matrix (Cox and Hinkley, 1974, section 4.8). Since this matrix is not available in `ASReml` we replace the expected information matrix by the AI matrix. Furthermore the REML estimates are consistent and asymptotically normal, though in small samples this approximation appears to be unreliable (see later).

A general method for comparing the fit of nested models fitted by REML is the REML likelihood ratio test, or REMLRT. The REMLRT is only valid if the fixed effects are the same for both models. In `ASReml` this requires not only the same fixed effects model, but also the same parameterisation.

If ℓ_{R2} is the REML log-likelihood of the more general model and ℓ_{R1} is the REML log-likelihood of the restricted model (that is, the REML log-likelihood under the null hypothesis), then the REMLRT is given by

$$D = 2 \log(\ell_{R2}/\ell_{R1}) = 2 [\log(\ell_{R2}) - \log(\ell_{R1})] \quad (2.14)$$

which is strictly positive. If r_i is the number of parameters estimated in model i , then the asymptotic distribution of the REMLRT, under the restricted model is $\chi_{r_2-r_1}^2$.

The REMLRT is implicitly two-sided, and must be adjusted when the test involves an hypothesis with the parameter on the boundary of the parameter space. In fact, theoretically it can be shown that for a single variance component, say, the asymptotic distribution of the REMLRT is a mixture of χ^2 variates, where the mixing probabilities are 0.5, one with 0 degrees of freedom (spike at 0) and the other with 1 degree of freedom. The approximate P-value for the REMLRT statistic (D), is $0.5(1 - \Pr(\chi_1^2 \leq d))$ where d is the observed value of D . The distribution of the REMLRT for the test that k variance components are zero, or tests involved in random regressions, which involve both variance and covariance components, involves a mixture of χ^2 variates from 0 to k degrees of freedom. See Self and Liang (1987) for details.

Tests concerning variance components in generally balanced designs, such as the

balanced one-way classification, can be derived from the usual analysis of variance. It can be shown that the REMLRT for a variance component being zero is a monotone function of the F-statistic for the associated term.

To compare two (or more) non-nested models we can evaluate the *Akaike Information Criteria* (AIC) or the *Bayesian Information Criteria* (BIC) for each model. These are given by

$$\begin{aligned} \text{AIC} &= -2\ell_{Ri} + 2t_i \\ \text{BIC} &= -2\ell_{Ri} + t_i \log \nu \end{aligned} \quad (2.15)$$

where t_i is the number of variance parameters in model i and $\nu = n - p$ is the residual degrees of freedom. AIC and BIC are calculated for each model and the model with the smallest value is chosen as the preferred model.

Diagnostics

In this section we will briefly review some of the diagnostics that have been implemented in ASReml for examining the adequacy of the assumed variance matrix for either R or G structures, or for examining the distributional assumptions regarding e or u . Firstly we note that the BLUP of the residual vector is given by

$$\begin{aligned} \tilde{e} &= \mathbf{y} - \mathbf{W}\tilde{\beta} \\ &= \mathbf{R}\mathbf{P}\mathbf{y} \end{aligned} \quad (2.16)$$

It follows that

$$\begin{aligned} \text{E}(\tilde{e}) &= \mathbf{0} \\ \text{var}(\tilde{e}) &= \mathbf{R} - \mathbf{W}\mathbf{C}^{-1}\mathbf{W}' \end{aligned}$$

The matrix $\mathbf{W}\mathbf{C}^{-1}\mathbf{W}'$ is the so-called ‘extended hat’ matrix. It is the linear mixed effects model analogue of $\mathbf{X}(\mathbf{X}'\mathbf{X})^{-1}\mathbf{X}'$ for ordinary linear models. The diagonal elements are returned in the .yht file by ASReml .

The variogram has been suggested as a useful diagnostic for assisting with the identification of appropriate variance models for spatial data (Cressie, 1991). Gilmour *et al.* (1997) demonstrate its usefulness for the identification of the sources of variation in the analysis of field experiments. If the elements of the data vector (and hence the residual vector) are indexed by a vector of spatial coordinates, $\mathbf{s}_i, i = 1, \dots, n$, then the ordinates of the sample variogram are given by

$$v_{ij} = \frac{1}{2} [\tilde{e}_i(\mathbf{s}_i) - \tilde{e}_j(\mathbf{s}_j)]^2, \quad i, j = 1, \dots, n; \quad i \neq j$$

New

The sample variogram reported by ASReml has two forms depending on whether the spatial coordinates represent a complete rectangular lattice (as typical of a field trial) or not. In the lattice case, the sample variogram is calculated from the triple $(l_{ij1}, l_{ij2}, v_{ij})$ where $l_{ij1} = s_{i1} - s_{j1}$ and $l_{ij2} = s_{i2} - s_{j2}$ are the displacements. As there will be many v_{ij} with the same displacements, ASReml calculates the means for each displacement pair l_{ij1}, l_{ij2} either ignoring the signs (default) or separately for same sign and opposite sign (!TOWAY), after grouping the larger displacements: 9-10, 11-14, 15-20, The result is displayed as a perspective plot (see page 205) of the one or two surfaces indexed by absolute displacement group. In this case, the two directions may be on different scales.

Otherwise ASReml forms a variogram based on polar coordinates. It calculates the distance between points $d_{ij} = \sqrt{l_{ij1}^2 + l_{ij2}^2}$ and an angle θ_{ij} ($-180 < \theta_{ij} < 180$) subtended by the line from $(0, 0)$ to (l_{ij1}, l_{ij2}) with the x-axis. The angle can be calculated as $\theta_{ij} = \tan^{-1}(l_{ij1}/l_{ij2})$ choosing $(0 < \theta_{ij} < 180)$ if $l_{ij2} > 0$ and $(-180 < \theta_{ij} < 0)$ if $l_{ij2} < 0$. Note that the variogram has angular symmetry in that $v_{ij} = v_{ji}$, $d_{ij} = d_{ji}$ and $|\theta_{ij} - \theta_{ji}| = 180$. The variogram presented averages the v_{ij} within 12 distance classes and 4, 6 or 8 sectors (selected using a !VGSECTORS qualifier) centred on an angle of $(i - 1) * 180/s$ ($i = 1, \dots, s$). A figure is produced which reports the trends in \bar{v}_{ij} with increasing distance for each sector.

ASReml also computes the variogram from predictors of random effects which appear to have a variance structures defined in terms of distance. The variogram details are reported in the .res file.

2.6 Inference: Fixed effects

Introduction

New

Inference for fixed effects in linear mixed models introduces some difficulties. In general, the methods used to construct F -tests in analysis of variance and regression cannot be used for the diversity of applications of the general linear mixed model available in ASReml. One approach would be to use likelihood ratio methods (see Welham and Thompson, 1997) although their approach is not easily implemented.

Wald-type test procedures are generally favoured for conducting tests concerning τ . The traditional Wald statistic to test the hypothesis $H_0 : \mathbf{L}\tau = \mathbf{l}$ for given

\mathbf{L} , $r \times p$, and \mathbf{l} , $r \times 1$, is given by

$$\mathcal{W} = (\mathbf{L}\hat{\boldsymbol{\tau}} - \mathbf{l})' \{ \mathbf{L}(\mathbf{X}'\mathbf{H}^{-1}\mathbf{X})^{-1}\mathbf{L}' \}^{-1} (\mathbf{L}\hat{\boldsymbol{\tau}} - \mathbf{l}) \quad (2.17)$$

and asymptotically, this statistic has a chi-square distribution on r degrees of freedom. These are marginal tests, so that there is an adjustment for all other terms in the fixed part of the model. It is also anti-conservative if p -values are constructed because it assumes the variance parameters are known.

The small sample behaviour of such statistics has been considered by Kenward and Roger (1997) in some detail. They presented a scaled Wald statistic, together with an F -approximation to its sampling distribution which they showed performed well in a range (though limited in terms of the range of variance models available in ASReml) of settings.

In the following we describe the facilities now available in ASReml for conducting inference concerning terms which are the in dense fixed effects model component of the general linear mixed model. These facilities are not available for any terms in the sparse model. These include facilities for computing two types of Wald statistics and partial implementation of the Kenward and Roger adjustments.

Incremental and Conditional Wald Statistics

The basic tool for inference is the Wald statistic defined in equation 2.17. ASReml produces a test of fixed effects, that reduces to an F -statistic in special cases, by dividing the Wald test, constructed with $\mathbf{l} = 0$, by r , the numerator degrees of freedom. In this form it is possible to perform an approximate F test if we can deduce the denominator degrees of freedom. However, there are several ways \mathbf{L} can be defined to construct a test for a particular model term, two of which are available in ASReml. For balanced designs, these Wald F -statistics are numerically identical to the F -tests obtained from the standard analysis of variance.

The first method for computing Wald statistics (for each term) is the so-called “incremental” form. For this method, Wald statistics are computed from an incremental sum of squares in the spirit of the approach used in classical regression analysis (see Searle, 1971). For example if we consider a very simple model with terms relating to the main effects of two qualitative factors A and B, given symbolically by

$$y \sim 1 + A + B$$

where the 1 represents the constant term (μ), then the incremental sums of

squares for this model can be written as the sequence

$$\begin{aligned} R(1) \\ R(A|1) &= R(1, A) - R(1) \\ R(B|1, A) &= R(1, A, B) - R(1, A) \end{aligned}$$

where the $R(\cdot)$ operator denotes the reduction in the total sums of squares due to a model containing its argument and $R(\cdot|\cdot)$ denotes the difference between the reduction in the sums of squares for any pair of (nested) models. Thus $R(B|1, A)$ represents the difference between the reduction in sums of squares between the so-called maximal “model”

$$y \sim 1 + A + B$$

and

$$y \sim 1 + A$$

Implicit in these calculations is that

- we only compute Wald statistics for *estimable* functions (Searle, 1971, page 408),
- all variance parameters are held fixed at the current REML estimates from the maximal model

In this example, it is clear that the incremental Wald statistics may not produce the *desired* test for the main effect of A, as in many cases we would like to produce a Wald statistic for A based on

$$R(A|1, B) = R(1, A, B) - R(1, B)$$

The issue is further complicated when we invoke “marginality” considerations. The issue of marginality between terms in a linear (mixed) model has been discussed in much detail by Nelder (1977). In this paper Nelder defines marginality for terms in a factorial linear model with qualitative factors, but later Nelder (1994) extended this concept to functional marginality for terms involving quantitative covariates and for mixed terms which involve an interaction between quantitative covariates and qualitative factors. Referring to our simple illustrative example above, with a full factorial linear model given symbolically by

$$y \sim 1 + A + B + A.B$$

then A and B are said to be marginal to A.B, and 1 is marginal to A and B. In a three way factorial model given by

$$y \sim 1 + A + B + C + A.B + A.C + B.C + A.B.C$$

the terms A, B, C, A.B, A.C and B.C are marginal to A.B.C. Nelder (1977, 1994) argues that meaningful and interesting tests for terms in such models can only be conducted for those tests which respect marginality relations. This philosophy underpins the following description of the second Wald statistic available in ASReml, the so-called “conditional” Wald statistic. This method is invoked by placing !FCON on the datafile line. ASReml attempts to construct conditional Wald statistics for each term in the fixed dense linear model so that marginality relations are respected. As a simple example, for the three way factorial model the conditional Wald statistics would be computed as

Term	Sums of Squares	M code
1	R(1)	.
A	R(A | 1,B,C,B.C) = R(1,A,B,C,B.C) - R(1,B,C,B.C)	A
B	R(B | 1,A,C,A.C) = R(1,A,B,C,A.C) - R(1,A,C,A.C)	A
C	R(C | 1,A,B,A.B) = R(1,A,B,C,A.B) - R(1,A,B,A.B)	A
A.B	R(A.B | 1,A,B,C,A.C,B.C) = R(1,A,B,C,A.B,A.C,B.C) - R(1,A,B,C,A.C,B.C)	B
A.C	R(A.C | 1,A,B,C,A.B,B.C) = R(1,A,B,C,A.B,A.C,B.C) - R(1,A,B,C,A.B,B.C)	B
B.C	R(B.C | 1,A,B,C,A.B,A.C) = R(1,A,B,C,A.B,A.C,B.C) - R(1,A,B,C,A.B,A.C)	B
A.B.C	R(A.B.C | 1,A,B,C,A.B,A.C,B.C) = R(1,A,B,C,A.B,A.C,B.C,A.B.C) - R(1,A,B,C,A.B,A.C,B.C)	C

Of these the conditional Wald statistic for the 1, B.C and A.B.C terms would be the same as the incremental Wald statistics produced using the linear model

$$y \sim 1 + A + B + C + A.B + A.C + B.C + A.B.C$$

The preceding table includes a so-called M (marginality) code reported by ASReml when conditional Wald statistics are presented. All terms with the highest M code letter are tested conditionally on all other terms in the model, i.e. by dropping the term from the maximum model. All terms with the preceding M code letter, are marginal to at least one term in a higher group, and so forth. For example, in the table, model term A.B has M code B because it is marginal to model term A.B.C and model term A has M code A because it is marginal to A.B, A.C and A.B.C. Model term mu (M code .) is a special case in that its test is conditional on all covariates but no factors. Following is some ASReml output from the .aov table which reports the terms in the conditional statistics.

Model Term	DF	Marginality pattern for F-con calculation							
		-- Model terms --							
		1	2	3	4	5	6	7	8
1 mu	1	*	.	.	.	.	.	.	.
2 water	1	I	*	C	C	.	.	c	.
3 variety	7	I	I	*	C	.	c	.	.
4 sow	2	I	I	I	*	C	.	.	.
5 water.variety	7	I	I	I	I	*	C	C	.

```

6 water.sow          2  I  I  I  I  I  *  C  .
7 variety.sow       14  I  I  I  I  I  I  *  .
8 water.variety.sow 14  I  I  I  I  I  I  I  *

```

F-inc tests the additional variation explained when the term (*) is added to a model consisting of the **I** terms. **F-con** tests the additional variation explained when the term (*) is added to a model consisting of the **I** and **C/c** terms. Any **c** terms are ignored in calculating DenDF for **F-con** using *numerical* derivatives for computational reasons. The **.** terms are ignored for both **F-inc** and **F-con** tests.

Consider now a nested model which might be represented symbolically by

$$y \sim 1 + \text{REGION} + \text{REGION.SITE}$$

For this model, the incremental and conditional Wald tests will be the same. However, it is not uncommon for this model to be presented to **ASReml** as

$$y \sim 1 + \text{REGION} + \text{SITE}$$

with **SITE** identified across **REGION** rather than within **REGION**. Then the nested structure is hidden but **ASReml** will still detect the structure and produce a valid conditional Wald F-statistic. This situation will be flagged in the **M** code field by changing the letter to lower case. Thus, in the nested model, the three **M** codes would be **.**, **A** and **B** because **REGION.SITE** is obviously an interaction dependent on **REGION**. In the second model, **REGION** and **SITE** appear to be independent factors so the initial **M** codes are **.**, **A** and **A**. However they are not independent because **REGION** removes additional degrees of freedom from **SITE**, so the **M** codes are changed from **.**, **A** and **A** to **.**, **a** and **A**.

We strongly recommend, if you are in any doubt about the “maximal conditional” model (MCM) for the conditional Wald F-statistic, that you consult the **.aov** file which spells out the “maximal conditional” model for each term. We also advise users that the aim of the conditional Wald statistic is to facilitate inference for fixed effects. It is not meant to be prescriptive nor is it foolproof for every setting.

The Wald statistics are collectively presented in a summary table in the **.asr** file. The basic table includes the numerator degrees of freedom (ν_{1i}) and the incremental Wald F-statistic for each term. To this is added the conditional Wald F-statistic and the **M** code if **!FCON** is specified. A conditional F-statistic is not reported for **mu** in the **.asr** but is in the **.aov** file (adjusted for covariates).

Kenward and Roger Adjustments

In moderately sized analyses, ASReml will also include the denominator degrees of freedom (`DenDF`, denoted by ν_{2i} , Kenward and Roger, 1997) and a probability value if these can be computed. They will be for the conditional Wald F-statistic if it is reported. The `!DDF i` (see page 68) qualifier can be used to suppress the `DenDF` calculation (`!DDF -1`) or request a particular algorithmic method: `!DDF 1` for numerical derivatives, `!DDF 2` for algebraic derivatives. The value in the probability column (either `P_inc` or `P_con`) is computed from an $F_{\nu_{1i}, \nu_{2i}}$ reference distribution. An approximation is used for computational convenience when calculating the `DenDF` for Conditional F statistics using numerical derivatives. The `DenDF` reported then relates to a maximal conditional incremental model (MCIM) which, depending on the model order, may not always coincide with the maximal conditional model (MCM) under which the conditional F statistic is calculated. The MCIM model omits terms fitted after any terms ignored for the conditional test (I after . in marginality pattern). In the example above, MCIM ignores `variety.sow` when calculating `DenDF` for the test of `water` and ignores `water.sow` when calculating `DenDF` for the test of `variety`. When `DenDF` is not available, it is often possible, though anti-conservative to use the residual degrees of freedom for the denominator.

Kenward and Roger (1997) pursued the concept of construction of Wald-type test statistics through an adjusted variance matrix of $\hat{\tau}$. They argued that it is useful to consider an improved estimator of the variance matrix of $\hat{\tau}$ which has less bias and accounts for the variability in estimation of the variance parameters. There are two reasons for this. Firstly, the small sample distribution of Wald tests is simplified when the adjusted variance matrix is used. Secondly, if measures of precision are required for $\hat{\tau}$ or effects therein, those obtained from the adjusted variance matrix will generally be preferred. Unfortunately the Wald statistics are currently computed using an unadjusted variance matrix.

Approximate stratum variances

ASReml reports approximate stratum variances and degrees of freedom for simple variance components models. For the linear mixed-effects model with variance components (setting $\sigma_H^2 = 1$) where $\mathbf{G} = \bigoplus_{j=1}^q \gamma_j \mathbf{I}_{b_j}$, it is often possible to consider a natural ordering of the variance component parameters including σ^2 . Based on an idea due to Thompson (1980), ASReml computes approximate stratum degrees of freedom and stratum variances by a modified Cholesky diagonalisation of the average information matrix. That is, if \mathbf{F} is the average information matrix for σ , let \mathbf{U} be an upper triangular matrix such that $\mathbf{F} = \mathbf{U}'\mathbf{U}$.

We define

$$\mathbf{U}_c = \mathbf{D}_c \mathbf{U}$$

where \mathbf{D}_c is a diagonal matrix whose elements are given by the inverse elements of the last column of \mathbf{U} ie $d_{cii} = 1/u_{ir}, i = 1, \dots, r$. The matrix \mathbf{U}_c is therefore upper triangular with the elements in the last column equal to one. If the vector $\boldsymbol{\sigma}$ is ordered in the “natural” way, with σ^2 being the last element, then we can define the vector of so called “pseudo” stratum variance components by

$$\boldsymbol{\xi} = \mathbf{U}_c \boldsymbol{\sigma}$$

Thence

$$\text{var}(\boldsymbol{\xi}) = \mathbf{D}_c^2$$

The diagonal elements can be manipulated to produce effective stratum degrees of freedom Thompson (1980) viz

$$\nu_i = 2\xi_i^2/d_{cii}^2$$

In this way the closeness to an orthogonal block structure can be assessed.

3

A guided tour

Introduction

Nebraska Intrastate Nursery (NIN) field experiment

The ASReml data file

The ASReml command file

- The title line
- Reading the data
- The data file line
- Specifying the terms in the mixed model
- Tabulation
- Prediction
- Variance structures

Running the job

Description of output files

- The .asr file
- The .sln file
- The .yht file

Tabulation, predicted values and functions of the variance components

3.1 Introduction

This chapter presents a guided tour of ASReml, from data file preparation and basic aspects of the ASReml command file, to running an ASReml job and interpreting the output files. You are encouraged to read this chapter before moving to the later chapters;

- a real data example is used in this chapter for demonstration, see below,
- the same data are also used in later chapters,
- links to the formal discussion of topics are clearly signposted by margin notes.

Note that some aspects of ASReml, in particular, pedigree files (see Chapter 9) and multivariate analysis (see Chapter 8) are only covered in later chapters.

ASReml is essentially a batch program with some optional interactive features. The typical sequence of operations when using ASReml is

- Prepare the data (typically using a spreadsheet or data base program)
- Export that data as an ASCII file (for example export it as a `.csv` (comma separated values) file from Excel)
- Prepare a job file with filename extension `.as`.
- Run the job file with ASReml
- Review the various output files
- revise the job and re run it, or
- extract pertinent results for your report.

You will need a file editor to create the command file and to view the various output files. On unix systems, `vi` and `emacs` are commonly used. Under Windows, there are several suitable program editors available such as ASReml-W and ConText described in section 1.3.

New

3.2 Nebraska Intrastate Nursery (NIN) field experiment

The yield data from an advanced Nebraska Intrastate Nursery (NIN) breeding trial conducted at Alliance in 1988/89 will be used for demonstration, see Stroup *et al.* (1994) for details. Four replicates of 19 released cultivars, 35 experimental wheat lines and 2 additional triticale lines were laid out in a 22 row by 11

column rectangular array of plots; the varieties were allocated to the plots using a randomised complete block (RCB) design. In field trials, complete replicates are typically allocated to consecutive groups of *whole* columns or rows. In this trial the replicates were not allocated to groups of whole columns, but rather, overlapped columns. Table 3.1 gives the allocation of varieties to plots in field plan order with replicates 1 and 3 in *ITALICS* and replicates 2 and 4 in **BOLD**.

3.3 The ASReml data file

See Chapter 4 for details. The standard format of an ASReml data file is to have the data arranged in space, TAB or comma separated columns/fields with a line for each sampling unit. The columns contain covariates, factors, response variates (traits) and weight variables in any convenient order. This is the first 30 lines of the file `nin89.asd` containing the data for the NIN variety trial. The data are in field order (rows within columns) and an optional heading (first line of the file) has been included to document the file. In this case there are 11 space separated data fields (`variety...column`) and the complete file has 224 data lines, one for each variety in each replicate.

```
variety id pid raw repl nloc yield lat long row column
LANCER  1 1101 585 1 4 29.25 4.3 19.2 16 1
BRULE   2 1102 631 1 4 31.55 4.3 20.4 17 1
REDLAND 3 1103 701 1 4 35.05 4.3 21.6 18 1
CODY    4 1104 602 1 4 30.1 4.3 22.8 19 1
ARAPAHOE 5 1105 661 1 4 33.05 4.3 24 20 1
NE83404 6 1106 605 1 4 30.25 4.3 25.2 21 1
NE83406 7 1107 704 1 4 35.2 4.3 26.4 22 1
NE83407 8 1108 388 1 4 19.4 8.6 1.2 1 2
CENTURA 9 1109 487 1 4 24.35 8.6 2.4 2 2
SCOUT66 10 1110 511 1 4 25.55 8.6 3.6 3 2
COLT    11 1111 502 1 4 25.1 8.6 4.8 4 2
NE83498 12 1112 492 1 4 24.6 8.6 6 5 2
NE84557 13 1113 509 1 4 25.45 8.6 7.2 6 2
NE83432 14 1114 268 1 4 13.4 8.6 8.4 7 2
NE85556 15 1115 633 1 4 31.65 8.6 9.6 8 2
NE85623 16 1116 513 1 4 25.65 8.6 10.8 9 2
CENTURAK78 17 1117 632 1 4 31.6 8.6 12 10 2
NORKAN 18 1118 446 1 4 22.3 8.6 13.2 11 2
KS831374 19 1119 684 1 4 34.2 8.6 14.4 12 2
:
```

optional field labels
data line sampling unit 1
data line sampling unit 2

Note that in Chapter 7 these data are analysed using spatial methods of analysis, see model **3a** in Section 7.3. For spatial analysis using a separable error structure

Table 3.1: Trial layout and allocation of varieties to plots in the NIN field trial

row	1	2	3	4	5	6	7	8	9	10	11
1	-	NE83407	BUCKSKIN	NE87612	VONA	NE87512	NE87408	CODY	BUCKSKIN	NE87612	KS831374
2	-	CENTURA	NE86527	NE87613	NE87463	NE83407	NE83407	NE87612	NE83406	BUCKSKIN	NE86482
3	-	SCOUT66	NE86582	NE87615	NE86507	NE87403	NORKAN	NE87457	NE87409	NE85556	NE85623
4	-	COLT	NE86606	NE87619	BUCKSKIN	NE87457	REDLAND	NE84557	NE87499	BRULE	NE86527
5	-	NE83498	NE86607	NE87027	ROUGH RIDER	NE83406	KS831374	NE83712	CENTURA	NE86507	NE87451
6	-	NE84557	ROUGH RIDER	-	NE86527	COLT	COLT	NE86507	NE83432	ROUGH RIDER	NE87409
7	-	NE83432	VONA	CENTURA	SCOUT66	NE87522	NE86527	TAM200	NE87512	VONA	GAGE
8	-	NE85556	SIOUXLAND	NE85623	NE86509	NORKAN	VONA	NE87613	ROUGH RIDER	NE83404	NE83407
9	-	NE85623	GAGE	CODY	NE86606	NE87615	TAM107	ARAPAHOE	NE83498	CODY	NE87615
10	-	CENTURAK78	NE83712	NE86582	NE84557	NE85556	CENTURAK78	SCOUT66	-	NE87463	ARAPAHOE
11	-	NORKAN	NE867666	NE87408	KS831374	TAM200	NE87627	NE87403	NE867666	NE86582	CHEYENNE
12	-	KS831374	NE87403	NE87451	GAGE	LANCOTA	NE867666	NE85623	NE87403	NE87499	REDLAND
13	-	TAM200	NE87408	NE83432	NE87619	NE86503	NE87615	NE86509	NE87512	NORKAN	NE83432
14	-	NE86482	NE87409	CENTURAK78	NE87499	NE86482	NE86501	NE85556	NE87446	SCOUT66	NE87619
15	-	HOMESTEAD	NE87446	NE83712	CHEYENNE	BRULE	NE87522	HOMESTEAD	CENTURA	NE87513	NE83498
16	LANCER	LANCOTA	NE87451	NE87409	NE86607	NE87612	CHEYENNE	NE83404	NE86503	NE83712	NE87613
17	BRULE	NE86501	NE87457	NE87513	NE83498	NE87613	SIOUXLAND	NE86503	NE87408	CENTURAK78	NE86501
18	REDLAND	NE86503	NE87463	NE87627	NE83404	NE867666	NE87451	NE86582	COLT	NE87627	TAM200
19	CODY	NE86507	NE87499	ARAPAHOE	NE87446	-	GAGE	NE87619	LANCER	NE86606	NE87522
20	ARAPAHOE	NE86509	NE87512	LANCER	SIOUXLAND	NE86607	LANCER	NE87463	NE83406	NE87457	NE84557
21	NE83404	TAM107	NE87513	TAM107	HOMESTEAD	LANCOTA	NE87446	NE86606	NE86607	NE86509	TAM107
22	NE83406	CHEYENNE	NE87522	REDLAND	NE86501	NE87513	NE86482	BRULE	SIOUXLAND	LANCOTA	HOMESTEAD

(see Chapter 2) the data file must first be augmented to specify the complete 22×11 column array of plots. These are the first 20 lines of the augmented data file `nin89aug.asd` with 242 data rows.

variety	id	pid	raw	repl	nloc	yield	lat	long	row	column
LANCER	1	NA	NA	1	4	NA	4.3	1.2	1	1
LANCER	1	NA	NA	1	4	NA	4.3	2.4	2	1
LANCER	1	NA	NA	1	4	NA	4.3	3.6	3	1
LANCER	1	NA	NA	1	4	NA	4.3	4.8	4	1
LANCER	1	NA	NA	1	4	NA	4.3	6	5	1
LANCER	1	NA	NA	1	4	NA	4.3	7.2	6	1
LANCER	1	NA	NA	1	4	NA	4.3	8.4	7	1
LANCER	1	NA	NA	1	4	NA	4.3	9.6	8	1
LANCER	1	NA	NA	1	4	NA	4.3	10.8	9	1
LANCER	1	NA	NA	1	4	NA	4.3	12	10	1
LANCER	1	NA	NA	1	4	NA	4.3	13.2	11	1
LANCER	1	NA	NA	1	4	NA	4.3	14.4	12	1
LANCER	1	NA	NA	1	4	NA	4.3	15.6	13	1
LANCER	1	NA	NA	1	4	NA	4.3	16.8	14	1
LANCER	1	NA	NA	1	4	NA	4.3	18	15	1
LANCER	1	NA	NA	2	4	NA	17.2	7.2	6	4
LANCER	1	NA	NA	3	4	NA	25.8	22.8	19	6
LANCER	1	NA	NA	4	4	NA	38.7	12.0	10	9
LANCER	1	1101	585	1	4	29.25	4.3	19.2	16	1
BRULE	2	1102	631	1	4	31.55	4.3	20.4	17	1
REDLAND	3	1103	701	1	4	35.05	4.3	21.6	18	1
CODY	4	1104	602	1	4	30.1	4.3	22.8	19	1
:										
:										

optional field labels
file augmented by
missing values for first
15 plots and 3 buffer
plots and variety coded
LANCER to complete
 22×11 array

buffer plots
between reps

original data

Note that

- the `pid`, `raw`, `repl` and `yield` data for the missing plots have all been made NA (one of the three missing value indicators in ASReml, see Section 4.2),
- `variety` is coded LANCER for all missing plots; one of the variety names must be used but the particular choice is arbitrary.

3.4 The ASReml command file

See Chapters 5, 6 and 7 for details

- a title line to describe the job,
- labels for the data fields in the data file and the name of the data file,
- the linear mixed model and the variance model(s) if required,
- output options including directives for tabulation and prediction.

Below is the ASReml command file for an RCB analysis of the NIN field trial data highlighting the main sections. Note the order of the main sections.

title line →	NIN Alliance trial 1989
data field definition →	variety !A
	id
	pid
	raw
	repl 4
	nloc
	yield
	lat
	long
	row 22
	column 11
data field definition →	nin89.asd !skip 1
data file name and qualifiers →	tabulate yield ~ variety
tabulate statement →	yield ~ mu variety !r repl
linear mixed model definition →	predict variety
predict statement →	0 0 1
variance model specification →	repl 1
	repl 0 IDV 0.1

The title line

The first non-blank line in an ASReml command file is taken as the title for the job and is used to identify the analysis for future reference.

```
NIN Alliance trial 1989
variety !A
id
:
```

Reading the data

The data fields are defined before the data file name is specified. Field definitions must be given for all fields in the data file and in the order in which they appear in the data file. **Data field definitions must be indented.** In this case there are 11 data fields (`variety ... column`) in `nin89.asd`, see Section 3.3.

The `!A` after `variety` tells ASReml that the first field is alphanumeric and the `4` after `repl` tells ASReml that the field called `repl` (the fifth field read) is a numeric factor with 4 lev-

```
NIN Alliance trial 1989
variety !A
id
pid
raw
repl 4
nloc
yield
lat
long
row 22
column 11
nin89.asd !skip 1
:
```

els. Similarly for `row` and `column`. The other data fields include variates (`yield`) and various other variables.

The data file line

The data file name is specified immediately after the last data field definition. Data file qualifiers that relate to data input and output are also placed on this line if they are required.

[See Section 5.7](#) In this example, `!skip 1` tells ASReml to read the data from `nin89.asd` but to ignore the first line in this file, the line containing the field labels.

[See Section 5.8](#) The data file line can also contain qualifiers that control other aspects of the analysis. These qualifiers are presented in Section 5.8.

```
NIN Alliance trial 1989
  variety !A
  id
  pid
  :
  :
  row 22
  column 11
nin89.asd !skip 1
tabulate yield ~ variety
yield ~ mu variety !r repl
predict variety
0 0 1
repl 1
repl 0 IDV 0.1
```

Tabulation

[See Chapter 10](#) Tabulate statements provide a simple way of exploring the structure of a data file. They appear immediately before (or after) the model line. In this case the 56 simple variety means for yield are formed and written to a `.tab` output file. See Chapter 10 for a discussion of tabulation.

```
:
:
  column 11
nin89.asd !skip 1
tabulate yield ~ variety
yield ~ mu variety !r repl
predict variety
:
```

Specifying the terms in the mixed model

[See Chapter 6](#) The linear mixed model is specified as a list of model terms and qualifiers. All elements must be space separated. ASReml accommodates a wide range of analyses. See Section 2.1 for a brief discussion and general algebraic formulation of the linear mixed model. The model specified here for the NIN data is a simple random effects RCB model including fixed variety effects and random replicate effects. The reserved word `mu` fits a constant term (inter-

```
NIN Alliance trial 1989
  variety !A
  :
  :
  column 11
nin89.asd !skip 1
tabulate yield ~ variety
yield ~ mu variety !r repl
predict variety
0 0 1
repl 1
repl 0 IDV 0.1
```

cept), `variety` fits a fixed variety effect and `repl` fits a random replicate effect. The `!r` qualifier tells ASReml to fit the terms that appear after this qualifier as random effects.

Prediction

See Chapter 10 Prediction statements appear after the model statement and before any variance structure lines. In this case the 56 variety means for yield would be formed and returned in the `.pvs` output file. See Chapter 10 for a detailed discussion of prediction in ASReml.

```
NIN Alliance trial 1989
variety !A
:
column 11
nin89.asd !skip 1
tabulate yield ~ variety
yield ~ mu variety !r repl
predict variety
0 0 1
repl 1
repl 0 IDV 0.1
```

Variance structures

See Chapter 7 The last three lines are included for expository purposes and are not actually needed for this analysis. An extensive range of variance structures can be fitted in ASReml. See Chapter 7 for a lengthy discussion of variance modelling in ASReml. In this case independent and identically distributed random replicate effects are specified using the identifier IDV in a *G structure*. G structures are described in Section 2.1 and the list of available variance structures/models is presented in Table 7.3. Since IDV is the default variance structure for random effects, the same analysis would be performed if these lines were omitted.

```
NIN Alliance trial 1989
variety !A
:
column 11
nin89.asd !skip 1
tabulate yield ~ variety
yield ~ mu variety !r repl
predict variety
0 0 1
repl 1
repl 0 IDV 0.1
```

3.5 Running the job

See Chapter 12 An ASReml job is often run from a command line. The basic command to run an ASReml job is normally

```
asreml basename[.as]
```

where *basename[.as]* is the name of the command file. For example, the com-

mand to run `nin89.as` is

```
asreml nin89.as
```

However, if the path to ASReml is not specified in your system's PATH environment variable, a *path* to this program must also be given. In this case the command to run the ASReml job in a PC/Windows environment is

```
[path] asreml basename[.as]
```

Make a habit of giving command files the .as extension

where *path* is typically `C:\Program Files\ASReml2\bin\` pointing to the location of the ASReml program. In this guide we assume the command file has a filename extension `.as`. ASReml also recognises the filename extension `.asc` as an ASReml command file. When these are used, the extension (`.as` or `.asc`) may be omitted from *basename.as* in the command line if there is no file in the working directory with the name *basename*. The *options* and *arguments* that can be supplied on the command line to modify a job at run time are described in Chapter 12.

Forming a job template

New

Notice that the data files `nin89.asd` and `nin89aug.asd` commenced with a line of column headings. Since these headings do not contain embedded blanks, we can use ASReml to make a template for the `.as` file by running ASReml with the datafile as the command argument (see Chapter 12). For example, running the command

```
asreml nin89aug.asd
```

writes a file `nin89aug.as` (if it does not already exist) which looks like

```
Title: nin89aug.
#variety id pid raw rep nloc yield lat long row column
#LANCER 1 NA NA 1 4 NA 4.3 1.2 1 1
#LANCER 1 NA NA 1 4 NA 4.3 2.4 2 1
#LANCER 1 NA NA 1 4 NA 4.3 3.6 3 1
#LANCER 1 NA NA 1 4 NA 4.3 4.8 4 1
  variety !A
  id *
  pid
  raw
  rep *
  nloc *
  yield
  lat
  long
  row *
  column *
# Check/Correct these field definitions.
nin89aug.asd !SKIP 1
```



```

column ~ mu ,          # Specify fixed model
      !r              # Specify random model
# 1 2 0
# column column AR1 0.1
# row row AR1 0.1

```

This is a template in that it needs editing (it has nominated an inappropriate response variable) but it displays the first few lines of the data and infers whether fields are factors or variates as follows: Missing fields and those with decimal points in the data value are taken as covariates, integer fields are taken as simple factors (*) and alphanumeric fields are taken as !A factors.

3.6 Description of output files

A series of output files are produced with each ASReml run. Running the example as above, the primary output is written to `nin89.asr`. This file contains a summary of the data, the iteration sequence, estimates of the variance parameters and an analysis of variance (ANOVA) table. The estimates of all the fixed and random effects are written to `nin89.sln`. The residuals, predicted values of the observations and the diagonal elements of the hat matrix (see Chapter 2) are returned in `nin89.yht`, see Section 13.3. Other files produced by this job include the `.aov`, `.pvs`, `.res`, `.tab`, `.vvp` and `.veo` files, see Section 13.4.

The `.asr` file

Below is `nin89.asr` with pointers to the main sections. The first line gives the version of ASReml used (in square brackets) and the title of the job. The second line gives the build date for the program and indicates whether it is a 32bit or 64bit version. The third line gives the date and time that the job was run and reports the size of the workspace. The general announcements box (outlined in asterisks) at the top of the file notifies the user of current release features. The remaining lines report a data summary, the iteration sequence, the estimated variance parameters and an ANOVA table. The final line gives the date and time that the job was completed and a statement about convergence.

```

job heading  ASReml 1.63o [01 Jun 2005]  NIN alliance trial 1989
              Build: j [01 Jul 2005]   32 bit
              11 Jul 2005 13:55:21.504  32.00 Mbyte Windows  nin89
notices      Licensed to: Arthur Gilmour
              *****

```

```

* SYNTAX change: A/B now means A A.B *
*
* Contact support@asreml.co.uk for licensing and support *
***** ARG *

Folder: C:\data\asr\UG2\manex
variety !A
QUALIFIERS: !SKIP 1
data summary Reading nin89.asd FREE FORMAT skipping 1 lines

Univariate analysis of yield
Using 224 records of 224 read
Model term          Size #miss #zero  MinNon0  Mean  MaxNon0
1 variety           56    0    0      1  28.5000    56
2 id                0    0    0  1.000    28.50   56.00
3 pid              0    0    0 1101.    2628.   4156.
4 raw              0    0    0  21.00    510.5  840.0
5 repl             4    0    0    1    2.5000    4
6 nloc             0    0    0  4.000    4.000   4.000
7 yield            Variate  0    0  1.050    25.53   42.00
8 lat              0    0    0  4.300    27.22   47.30
9 long             0    0    0  1.200    14.08   26.40
10 row             22    0    0    1  11.7321    22
11 column          11    0    0    1   6.3304    11
12 mu              1
4 identity         0.1000
Structure for repl          has 4 levels defined
Forming 61 equations: 57 dense.
Initial updates will be shrunk by factor 0.316
NOTICE: 1 singularities detected in design matrix.
iteration sequence 1 LogL=-454.807 S2= 50.329 168 df 1.000 0.1000
2 LogL=-454.663 S2= 50.120 168 df 1.000 0.1173
3 LogL=-454.532 S2= 49.868 168 df 1.000 0.1463
4 LogL=-454.472 S2= 49.637 168 df 1.000 0.1866
5 LogL=-454.469 S2= 49.585 168 df 1.000 0.1986
6 LogL=-454.469 S2= 49.582 168 df 1.000 0.1993
7 LogL=-454.469 S2= 49.582 168 df 1.000 0.1993
Final parameter values 1.0000 0.19932

Source          Model terms  Gamma  Component  Comp/SE  % C

```

```
parameter      Variance          224    168    1.00000      49.5824      9.08    0 P
estimates      repl              identity    4  0.199323      9.88291      1.12    0 U
```

```
ANOVA          Analysis of Variance          NumDF    DenDF    F_inc          Prob
12 mu          1          3.0    242.05          <.001
1 variety      55         165.0    0.88           0.708
Notice: The DenDF values are calculated ignoring fixed/boundary/singular
        variance parameters using algebraic derivatives.
5 repl          4 effects fitted
Finished: 11 Jul 2005 13:55:25.309  LogL Converged
```

The .sln file

The following is an extract from `nin89.sln` containing the estimated variety effects, intercept and random replicate effects in this order (column 3) with standard errors (column 4). Note that the variety effects are returned in the order of their first appearance in the data file, see replicate 1 in Table 3.1.

```
variety        LANCER          0.000      0.000
variety        BRULE           -2.487      4.979
variety        REDLAND        1.938      4.979
variety        CODY            -7.350      4.979
variety        ARAPAHOE        0.8750     4.979
variety        NE83404         -1.175     4.979
variety        NE83406         -4.287     4.979
variety        NE83407         -5.875     4.979
variety        CENTURA        -6.912     4.979
variety        SCOUT66         -1.037     4.979
variety        COLT            -1.562     4.979
variety        NE83498         1.563      4.979
variety        NE84557         -8.037     4.979
variety        NE83432         -8.837     4.979
:
variety        NE87615         -2.875     4.979
variety        NE87619         2.700     4.979
variety        NE87627         -5.337     4.979
mu              1              28.56     3.856
repl            1              1.880     1.755
repl            2              2.843     1.755
```

```

repl          3      -0.8713      1.755
repl          4      -3.852       1.755

```

The .yht file

The following is an extract from `nin89.yht` containing the predicted values of the observations (column 2), the residuals (column 3) and the diagonal elements of the hat matrix. This final column can be used in tests involving the residuals, see Section 2.5 under Diagnostics.

```

Record      Yhat      Residual      Hat
  1      30.442      -1.192      13.01
  2      27.955       3.595      13.01
  3      32.380       2.670      13.01
  4      23.092       7.008      13.01
  5      31.317       1.733      13.01
  6      29.267       0.9829     13.01
  7      26.155       9.045      13.01
  8      24.567      -5.167      13.01
  9      23.530       0.8204     13.01
  ⋮
222      16.673       9.877      13.01
223      24.548       1.052      13.01
224      23.786       3.114      13.01

```

3.7 Tabulation, predicted values and functions of the variance components

It may take several runs of `ASReml` to determine an appropriate model for the data, that is, the fixed and random effects that are important. During this process you may wish to explore the data by simple tabulation. Having identified an appropriate model, you may then wish to form predicted values or functions of the variance components. The facilities in `ASReml` to form predicted values and functions of the variance components are described in Chapters 10 and 11 respectively. Our example only includes tabulation and prediction.

The statement

```
tabulate yield ~ variety
```

in `nin89.as` results in `nin89.tab` as follows:

```
NIN alliance trial 1989                                11 Jul 2005 13:55:21

                               Simple tabulation of yield

variety
LANCER                        28.56
BRULE                         26.07
REDLAND                       30.50
CODY                          21.21
ARAPAHOE                     29.44
NE83404                       27.39
NE83406                       24.28
NE83407                       22.69
CENTURA                     21.65
SCOUT66                      27.52
COLT                          27.00
:
NE87522                      25.00
NE87612                      21.80
NE87613                      29.40
NE87615                      25.69
NE87619                      31.26
NE87627                      23.23
```

The

`predict variety`

statement after the model statement in `nin89.as` results in the `nin89.pvs` file displayed below (some output omitted) containing the 56 predicted variety means, also in the order in which they first appear in the data file (column 2), together with standard errors (column 3). An average standard error of difference among the predicted variety means is displayed immediately after the list of predicted values. As in the `.asr` file, date, time and trial information are given the title line. The `Ecode` for each prediction (column 4) is usually `E` indicating the prediction is of an estimable function. Predictions of non-estimable functions are usually not printed, see Chapter 10.

```

title line      nin alliance trial                      11 Jul 2005 13:55:21
                                                    nin893

Ecode is E for Estimable, * for Not Estimable

----- 1 -----
Predicted values of yield
repl          is ignored in the prediction (except where specifically included

variety      Predicted_Value Standard_Error Ecode
predicted variety effects
LANCER              28.5625      3.8557 E
BRULE               26.0750      3.8557 E
REDLAND            30.5000      3.8557 E
CODY                21.2125      3.8557 E
ARAPAHOE           29.4375      3.8557 E
NE83404             27.3875      3.8557 E
NE83406             24.2750      3.8557 E
NE83407             22.6875      3.8557 E
CENTURA           21.6500      3.8557 E
SCOUT66            27.5250      3.8557 E
COLT                27.0000      3.8557 E
:
NE87613             29.4000      3.8557 E
NE87615             25.6875      3.8557 E
NE87619             31.2625      3.8557 E
NE87627             23.2250      3.8557 E
SED: Overall Standard Error of Difference  4.979

```

4

Data file preparation

Introduction

The data file

- Free format
- Fixed format
- Preparing data files in Excel
- Binary format

4.1 Introduction

The first step in an ASReml analysis is to prepare the data file. Data file preparation is described in this chapter using the NIN example of Chapter 3 for demonstration. The first 25 lines of the data file are as follows:

```

variety id pid raw repl nloc yield lat long row column
BRULE 2 1102 631 1 4 31.55 4.3 20.4 17 1
REDLAND 3 1103 701 1 4 35.05 4.3 21.6 18 1
CODY 4 1104 602 1 4 30.1 4.3 22.8 19 1
ARAPAHOE 5 1105 661 1 4 33.05 4.3 24 20 1
NE83404 6 1106 605 1 4 30.25 4.3 25.2 21 1
NE83406 7 1107 704 1 4 35.2 4.3 26.4 22 1
NE83407 8 1108 388 1 4 19.4 8.6 1.2 1 2
CENTURA 9 1109 487 1 4 24.35 8.6 2.4 2 2
SCOUT66 10 1110 511 1 4 25.55 8.6 3.6 3 2
COLT 11 1111 502 1 4 25.1 8.6 4.8 4 2
NE83498 12 1112 492 1 4 24.6 8.6 6 5 2
NE84557 13 1113 509 1 4 25.45 8.6 7.2 6 2
NE83432 14 1114 268 1 4 13.4 8.6 8.4 7 2
NE85556 15 1115 633 1 4 31.65 8.6 9.6 8 2
NE85623 16 1116 513 1 4 25.65 8.6 10.8 9 2
CENTURK78 17 1117 632 1 4 31.6 8.6 12 10 2
NORKAN 18 1118 446 1 4 22.3 8.6 13.2 11 2
KS831374 19 1119 684 1 4 34.2 8.6 14.4 12 2
TAM200 20 1120 422 1 4 21.1 8.6 15.6 13 2
NE86482 21 1121 560 1 4 28 8.6 16.8 14 2
HOMESTEAD 22 1122 566 1 4 28.3 8.6 18 15 2
LANCOTA 23 1123 514 1 4 25.7 8.6 19.2 16 2
NE86501 24 1124 635 1 4 31.75 8.6 20.4 17 2
NE86503 25 1125 840 1 4 42 8.6 21.6 18 2
:

```

4.2 The data file

The standard format of an ASReml data file is to have the data arranged in columns/fields with a single line for each sampling unit. The columns contain variates and covariates (numeric), factors (alphanumeric), traits (response variables) and weight variables in any order that is convenient to the user. The data file may be free format, fixed format or a binary file.

Free format data files

The data are read free format (SPACE, COMMA or TAB separated) unless the file name has extension `.bin` for real binary, or `.dbl` for double precision binary (see

below). Important points to note are as follows:

- files prepared in Excel must be converted to comma or tab-delimited form.
- blank lines are ignored,
- column headings, field labels or comments may be present at the top of the file provided that the `!skip` qualifier (Table 5.2) is used to skip over them,
- NA,* and . are treated as coding for *missing values* in free format data files;
 - if missing values are coded with a unique data value (for example, 0 or -9), use `!M` to flag them as *missing* or `!D` to drop the data record containing them (see Table 5.1),
- comma delimited files whose file name ends in `.csv` or for which the `!CSV` qualifier is set recognise empty fields as missing values,
 - a line beginning with a comma implies a preceding missing value,
 - consecutive commas imply a missing value,
 - a line ending with a comma implies a trailing missing value,
 - if the filename does not end in `.csv` or the `!CSV` qualifier is not set, commas are treated as white space,
- characters following `#` on a line are ignored so this character may not be used in alphanumeric fields,
- blank spaces, tabs and commas must not be used (embedded) in alphanumeric fields unless the label is enclosed in quotes, for example, the name `Willow Creek` would need to be appear in the data file as `'Willow Creek'` to avoid error,
- the `$` symbol must not be used in the data file,
- alphanumeric fields have a default size of 16 characters. Use the `!LL` qualifier to extend the size of factor labels stored.
- extra data fields on a line are ignored,
- if there are fewer data items on a line than `ASReml` expects the remainder are taken from the following line(s) except in `.csv` files were they are taken as missing. If you end up with half the number of records you expected, this is probably the reason,
- all lines beginning with `!` followed by a blank are copied to the `.asr` file as comments for the output; their contents are ignored,
- a data file line may not exceed 2000 characters; if the data fields will not fit in 2000 characters, put some on the next line.

New

New

Fixed format data files

The format must be supplied with the `!FORMAT` qualifier which is described in (Table 5.5). However, if all fields are present and are separated, the file can be read free format.

Preparing data files in Excel

Many users find it convenient to prepare their data in Excel or Access. However, the data must be exported from these programs into either `.csv` (Comma separated values) or `.txt` (TAB separated values) form for ASReml to read it. ASReml can convert an `.xls` file to a `.csv` file. When ASReml is invoked with an `.xls` file as the filename argument and there is no `.csv` file or `.as` with the same basename, it exports the first sheet as a `.csv` file and then generates a template `.as` command file from any column headings it finds (see page 178). It will also convert a Genstat `.gsh` spreadsheet file to `.csv` format. The data extracted from the `.xls` file are labels, numerical values and the results from formulae. Empty rows at the start and end of a block are trimmed, but empty rows in the middle of a block are kept. Empty columns are ignored. A single row of labels as the first non-empty row in the block will be taken as column names. Empty cells in this row will have default names C1, C2 etc. assigned. Missing values are commonly represented in ASReml data files by `NA`, `*` or `..`. ASReml will also recognise empty fields as missing values in `.csv` (`.xls`) files.

Binary format data files

Conventions for binary files are as follows:

- binary files are read as unformatted Fortran binary in single precision if the filename has a `.bin` or `.BIN` extension,
- Fortran binary data files are read in double precision if the filename has a `.dbl` or `.DBL` extension,
- ASReml recognises the value `-1e37` as a missing value in binary files,
- Fortran binary in the above means all real (`.bin`) or all double precision (`.dbl`) variables; mixed types, that is, integer and alphabetic binary representation of variables is not allowed in binary files,
- binary files can only be used in conjunction with a pedigree file if the pedigree fields are coded in the binary file so that they correspond with the pedigree file (this can be done using the `!SAVE` option in ASReml to form the binary file, see Table 5.5), or the identifiers are whole numbers less than 9,999,999 and the `!RECODE` qualifier is specified (see Table 5.5).

5 Command file: Reading the data

Introduction

Important rules

Title line

Specifying and reading the data

Data field definition syntax

Transforming the data

Transformation syntax

Other rules and examples

Special note on covariates

Other examples

Datafile line

Datafile line syntax

Datafile qualifiers

Job control qualifiers

5.1 Introduction

In the code box to the right is the ASReml command file `nin89a.as` for a spatial analysis of the Nebraska Intrastate Nursery (NIN) field experiment introduced Chapter 3. The lines that are highlighted in bold/blue type relate to reading in the data. In this chapter we use this example to discuss reading in the data in detail.

```
NIN Alliance Trial 1989
variety !A
id
pid
raw
repl 4
nloc
yield
lat
long
row 22
column 11
nin89aug.asd !skip 1
yield ~ mu variety
1 2
11 column AR1 .424
22 row AR1 .904
```

5.2 Important rules

In the ASReml command file

- all characters following a # symbol on a line are ignored,
- all blank lines are ignored,
- lines beginning with ! followed by a blank are copied to the .asr file as comments for the output,
- a blank is the usual separator; TAB is also a separator,
- maximum line length is 2000 characters,
- a comma as the last character on the line is used to indicate that the current list is continued on the next line; a comma is not needed when ASReml knows how many values to read,
- reserved words used in specifying the linear model (Table 6.1) are case sensitive; they need to be typed exactly as defined: they may not be abbreviated.
- a qualifier is a particular letter sequence beginning with an ! which sets an option or changes some aspect of ASReml;
 - some qualifiers require arguments,
 - qualifiers must appear on the correct line,
 - qualifier identifiers are not case sensitive,
 - qualifier identifiers may be truncated to 3 characters.

New

5.3 Title line

The first 40 characters of the first nonblank line in an ASReml command file are taken as a title for the job. Use this to identify the analysis for future reference.

```
NIN Alliance Trial 1989
variety !A
id
pid
:
:
```

5.4 Specifying and reading the data

Typically, a data record consists of all the information pertaining to an experimental unit (plot, animal, assessment). We distinguish the fields which exist in the data file and are read into ASReml from the fields that are saved in ASReml and are available for analysis. They coincide only if no transformations are performed. Similarly, we sometimes discard some records so that there are fewer records available for analysis than appear in the data file.

The data fields to be saved for analysis are defined immediately after the job title. The definitions control how each field in the data file is handled as it is read into ASReml. ASReml deduces how many of them are read from the data file from the associated transformation information (override with the !READ qualifier described in Table 5.5). No more than 1000 variables may be read or formed.

Data field definitions

- should be given for all fields in the data file; fields (on the end of a data line) without a field definition are ignored; if there are not enough data fields on a data line, the remainder are taken from the next line(s),
- must be presented in the order in which they appear in the data file,
- must be indented one or more spaces,
- can appear with other definitions on the same line,
- Data fields can be transformed (see below):
 - transformation qualifiers should be listed after the data field labels for the fields being modified/created.
 - additional data fields can be created by transformation qualifiers.

Important

```
NIN Alliance Trial 1989
variety !A
id
pid
raw
repl 4
nloc
yield
lat
long
row 22
column 11
nin89aug.asd !skip 1
yield ~ mu variety
:
:
```

Data field definition syntax

Data field definitions appear in the ASReml command file in the form

```
SPACE label [field_type] [transformations]
```

- SPACE
 - is a required space
- *label*
 - is an alphanumeric string to identify the field,
 - has a maximum of 31 characters of which only 20 are printed; the remaining characters are not displayed,
 - must begin with a letter,
 - must not contain the special characters ., *, :, /, !, #, — or (,
 - reserved words (Table 6.1 and Table 7.3) must not be used,
- *field_type* defines how a variable is interpreted if specified in the linear model,
 - for a variate, leave *field_type* blank or specify 1,
 - for a model factor, various qualifiers are required depending on the form of the factor coding where *n* is the number of levels of the factor and *s* is a list of labels to be assigned to the levels:
 - * or *n* is used when the data field has values 1...*n* directly coding for the factor unless the levels are to be labelled (see !L),
 - !A [*n*] is required if the data field is alphanumeric,
 - !I [*n*] is required if the data is numeric but not 1...*n*; !I must be followed by *n* if more than 1000 codes are present,
 - !L *s* is used when the data field is numeric with values 1...*n* and labels are to be assigned to the *n* levels, for example
Sex !L Male Female
 If there are many labels, they may be written over several lines by using a trailing comma to indicate continuation of the list.
 - !P indicates the special case of a pedigree factor; ASReml will determine the levels from the pedigree file, see Section 9.3,

A warning is printed if the nominated value for *n* does not agree with the actual number of levels found in the data and if the nominated value is too small the correct value is used.

New

- !DATE specifies the field has one of the date formats *dd/mm/yy*, *dd/mm/ccyy*, *dd-Mon-yy*, *dd-Mon-ccyy* and is to be converted into a Julian day where *dd* is a 1 or 2 digit day of the month, *mm* is a 1 or 2 digit month of the year, *Mon* is

a three letter month name (Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec), *yy* is the year within the century (00 to 99), *cc* is the century (19 or 20). The separators '/' and '-' must be present as indicated. The dates are converted to days starting 1 Jan 1900. When the century is not specified, *yy* of 0-32 is taken as 2000-2032, 33-99 taken as 1933-1999.

- New - !DMY specifies the field has one of the date formats *dd/mm/yy* or *dd/mm/ccyy* and is to be converted into a Julian day.
- New - !MDY specifies the field has one of the date formats *mm/dd/yy* or *mm/dd/ccyy* and is to be converted into a Julian day.
- New - !TIME specifies the field has the time format *hh:mm:ss.* and is to be converted to seconds past midnight where *hh* is hours (0 to 23), *mm* is minutes (0-59) and *ss* is seconds (0 to 59). The separator ':' must be present.

- for a group of *m* variates

!G *m* is used when *m* contiguous data fields are to be treated as a factor or group of variates. For example

longhand	shorthand
:	:
X1 X2 X3 X4 X5 y	X !G 5 y
data.dat	data.dat
y ~ mu X1 X2 X3 X4 X5	y ~ mu X

so that the 5 variates can be referred to in the model as X by using X !G 5

- *transformations*
 - see below

Storage of alphabetic factor labels

- New Space is allocated dynamically for the storage of alphabetic factor labels with a default allocation being 2000 labels of 16 characters long. If there are large !A factors (so that the total across all factors will exceed 2000), you must specify the anticipated size (within say 5%). If some labels are longer than 16 characters and the extra characters are significant, you must lengthen the space for each label by specifying !LL *c* e.g.

```
cross !A 2300 !LL 48
```

indicates the factor **cross** has about 2300 levels and needs 48 characters to hold the level names although only the first 20 characters of the names are ever printed.

- New !PRUNE on a field definition line means that if fewer levels are actually present

in the factor than were declared, `ASReml` will reduce the factor size to the actual number of levels. Use `!PRUNALL` for this action to be taken on the current and subsequent factors up to (but not including) a factor with the `!PRUNEOFF` qualifier. The user may overestimate the size for large ALPHA and INTEGER coded factors so that `ASReml` reserves enough space for the list. Using `!PRUNE` will mean the extra (undefined) levels will not appear in the `.s1n` file. Since it is sometimes necessary that factors not be pruned in this way, for example in pedigree/GIV factors, pruning is only done if requested.

Reordering the factor levels

New

`!SORT` declared after `!A` or `!I` on a field definition line will cause `ASReml` to sort the levels so that labels occur in alphabetic/numeric order for the analysis. By default, `ASReml` orders factor levels in the order they appear in the data so that for example, the user cannot tell whether `SEX` will be coded `1=Male, 2=Female` or `1=Female, 2=Male` without looking at the data file to see whether `Male` or `Female` appears first in the `SEX` field. With the `!SORT` qualifier, the coding will be `1=Female, 2=Male` regardless of which appears first in the file.

`!SORTALL` means that the levels for the current and subsequent factors are to be sorted.

Skipping input fields

New

`!SKIP f` will skip *f* data fields BEFORE reading this field. It is particularly useful in large files with alphabetic fields which are not needed as it saves `ASReml` the time required to classify the alphabetic labels. For example

```
Sire !I !skip 1
```

would skip the field before the field which is read as 'Sire'.

5.5 Transforming the data

Transformation is the process of modifying the data (for example, dividing all of the data values in a field by 10), deriving new forms of the data for analysis (for example, summing the data in two fields) or creating temporary data (for example, a test variable used immediately to discard some records from analysis). Occasional users may find it easier to use a spreadsheet to calculate derived variables than to modify variables using `ASReml` transformations.

Transformation qualifiers are listed after data field labels. They define an operation (e.g. +), often involving an argument (a constant or another variable), which is performed on a *target* variable. The *target* is usually implicit but can be changed to a new variable. Note that

- there may be up to 1000 variables and these are internally labeled V1, V2 ... V1000,
- values from the data file are read into the leading variables,
- alpha (!A), integer (!I), pedigree (!P) and date (!DATE) fields are converted to real numbers (level codes) as they are read and before any transformations are applied,
- transformations may be applied to any variable (since every variable is numeric), but it may not be sensible to change factor level codes,
- transformations are performed in the order of appearance for each record in turn,
- after completing the transformations for each record, the values in the record for variables associated with a label are held for analysis, (or the record (all values) is discarded; see !D transformation and Section 6.10),

Thus variables form three classes: those read from the data file (possibly modified, normally labelled and available for subsequent use in analysis), those created and labelled (available for subsequent use in the analysis) and those created but not labelled (intermediate calculations not required for subsequent analysis).

The first variables contain the values read from the data file for each record. The number of variables read can be explicitly set using the !READ qualifier described in Table 5.5. Otherwise ASReml reads values from the data file for each variable/factor defined unless the variable/factor and all subsequent labelled variables are created (using transformations). For example,

```
A B C !=A !-B
```

reads two fields (A and B), and constructs C as A-B. All three are available for analysis.

Variables that have an explicit label, may be referenced by their explicit label or their internal label. Therefore, to avoid confusion, do not use explicit labels of the form Vi, where i is a number, for variables to be referred to in a transformation. Vi always refers to field/variable i in a transformation statement.

Variables that are not initialized from the data file, are initialized to *missing value* for the first record, and otherwise, to the values from the preceding record

(after transformation). Thus

```
A B LagA !=V4 !V4=A
```

reads two fields (A and B), and constructs `LagA` as the value of A from the previous record by extracting a value for `LagA` from working variable `V4` before loading `V4` with the current value of A.

Transformation syntax

Transformation qualifiers have one of six forms, namely

<code>!operator</code>	to perform an operation on the current field, for example, <code>!ABS</code> to take absolute values,
<code>!operator value</code>	to perform an operation involving an argument on the current field, for example, <code>!+3</code> to add 3 to all elements in the field,
<code>!operator Vfield</code>	to perform an operation on the current field using the data in another field, for example, <code>!-V2</code> to subtract field 2 from the current field
<code>!Vtarget</code>	to reset the focus for subsequent transformations to field number <i>target</i> ,
<code>!Vtarget = value</code>	to change all of the data in a target field to a given value,
<code>!Vtarget = Vfield</code>	to overwrite the data in a target field by the data values of another field; a special case is when <i>field</i> is 0 instructing <code>ASReml</code> to put the record number into the <i>target</i> field.

- `!` flags the presence of the transformation
- *operator* is one of the symbols defined in Table 5.1,
- *value* is the argument required by the transformation,
- `V` is the literal character and is followed by the number (*target* or *field*) of a data field; the data field is used or modified depending on the context,
- *Vfield* may be replaced by the label of the field if it already has a label,
- in the first three forms the operation is performed on the *current* field; this will be the field associated with the label unless the focus has been reset by specifying a new *target* in a preceding transformation,
- the next three forms change the focus for subsequent transformations to the field *target*,

- in the last two forms a value is assigned to the *target* field. For example, `... !V22=V11 ...` copies (existing) field 11 into field 22. Such a statement would typically be followed by more transformations. If there are fewer than 22 variables labelled then V22 is used in the transformation stage but not kept for analysis.

Table 5.1: List of transformation qualifiers and their actions with examples

qualifier	argument	action	examples
!=, !+, !-, !*, !/ ! ^v	<i>v</i>	usual arithmetic meaning; note that, 0/0 gives 0 but <i>v</i> /0 gives a missing value where <i>v</i> is not 0.	<code>yield !/10</code> <code>half !=0.5</code> <code>zero !=0.</code>
! ^v	<i>v</i>	raises the data (which must be positive) to the power <i>v</i> .	<code>yield</code> <code>SQRyld !=yield !^{0.5}</code>
! ⁰	0	takes natural logarithms of the data (which must be positive).	<code>yield</code> <code>LNyld !=yield !⁰</code>
! ⁻¹	-1	takes reciprocal of data (data must be positive).	<code>yield</code> <code>INVyld !=yield !⁻¹</code>
!>, !<, !<>, !==, !<=, !>=	<i>v</i>	logical operators forming 1 if true, 0 if false.	<code>yield</code> <code>high !=yield !>10</code>
!ABS		takes absolute values - no argument required.	<code>yield</code> <code>ABSyld !=yield !ABS</code>
!ARCSIN	<i>v</i>	forms an ArcSin transformation using the sample size specified in the argument, a number or another field. In the side example, for two existing fields Germ and Total containing counts, we form the ArcSin for their ratio (ASG) by copying the Germ field and applying the ArcSin transformation using the Total field as sample size.	<code>Germ Total</code> <code>ASG !=Germ !ARCSIN Total</code>
!COS, !SIN	<i>s</i>	takes cosine and sine of the data variable with period <i>s</i> having default 2π; omit <i>s</i> if data is in radians, set <i>s</i> to 360 if data is in degrees.	<code>Day</code> <code>CosDay !=Day !COS 365</code>
!D, !D<>, !D<, !D<=, !D>, !D>=	<i>v</i> <i>v</i> <i>v</i>	!D <i>v</i> discards records which have <i>v</i> or 'missing value' in the field; if !D is used after !A or !I, <i>v</i> should refer to the encoded factor level rather than the value in the data file (see also Section 4.2). Use !D * to discard just those records with a missing value in the field.	<code>yield !D<=0</code> <code>yield !D<1 !D>100</code> <code>InitialWt !D *</code>

List of transformation qualifiers and their actions with examples

qualifier	argument	action	examples
New	!DOM	f	copies and converts additive marker covariables (-1, 0, 1) to dominance marker covariables (see below). <code>ChrAdom !DOM ChrAadd</code>
	!EXP		takes antilog base e - no argument required. <code>Rate !EXP</code>
	!Jddm, !Jmmd !Jyyd		!Jddm converts a number representing a date in the form <i>ddmmccyy</i> , <i>ddmmyy</i> or <i>ddmm</i> into days. !Jmmd converts a date in the form <i>ccyyymmdd</i> , <i>yymmdd</i> or <i>mmdd</i> into days. !Jyyd converts a date in the form <i>ccyyddd</i> or <i>yyddd</i> into days. These calculate the number of days since December 31 1900 and are valid for dates from January 1 1900 to December 31 2099; note that if <i>cc</i> is omitted it is taken as 19 if <i>yy</i> > 32 and 20 if <i>yy</i> < 33, the date must be entirely numeric: characters such as / may not be present (but see !DATE).
	!M, !M<, !M< !M<= !M> !M>=	v v v	!M v converts data values of v to missing; if !M is used after !A or !I, v should refer to the encoded factor level rather than the value in the data file (see also Section 4.2). <code>yield !M-9</code> <code>yield !M<=0 !M>100</code>
	!MAX, !MIN, !MOD	v	the maximum, minimum and modulus of the field values and the value v . <code>yield !MAX 9</code>
New	!MM	s	assigns Haldane map positions (s) to marker variables and imputes missing values to the markers (see below). <code>ChrAadd !G 10 !MM 1 ...</code>
	!NA	v	replaces any missing values in the variate with the value v . <code>Rate !NA 0</code>
New	!NORMAL	v	replaces the variate with normal random variables having variance v . <code>Ndat !=0 !Normal 4.5</code> is equivalent to <code>Ndat !=Normal 4.5</code>
New	!REPLACE	$o n$	replaces data values o with n in the current variable. I.e. <code>IF(DataValue.EQ.o) DataValue=n</code> <code>Rate !REPLACE -9 0</code>
New	!RESCALE	$o s$	rescales the column(s) in the current variable (!G group of variables) using $Y = (Y + o) * s$ <code>Rate !RESCALE -10 0.1</code>

List of transformation qualifiers and their actions with examples

qualifier	argument	action	examples	
New	!SEED	v	sets the seed for the random number generator.	<code>... !SEED 848586</code>
	!SET	$vlist$	for $vlist$, a list of n values, the data values $1 \dots n$ are replaced by the corresponding element from $vlist$; data values that are < 1 or $> n$ are replaced by zero. $vlist$ may run over several lines provided each incomplete line ends with a comma, i.e., a comma is used as a continuation symbol (see Other examples below).	<code>treat !L C A B</code> <code>CvR !=treat !SET 1 -1 -1</code> <code>group !=treat !SET 1,</code> <code>2 2 3 3 4</code>
New	!SETN	$v n$	!SETN $v n$ replaces data values $1 : n$ with normal random variables having variance v . Data values outside the range $1 \dots n$ are set to 0.	<code>Anorm !=A !SETN 2.5 10</code>
New	!SETU	$v n$	replaces data values $1 : n$ with uniform random variables having range $0 : v$. Data values outside the range $1 \dots n$ are set to 0.	<code>Aeff !=A !SETU 5 10</code>
	!SUB	$vlist$	replaces data values $= v_i$ with their index i where $vlist$ is a vector of n values. Data values not found in $vlist$ are set to 0. $vlist$ may run over several lines if necessary provided each incomplete line ends with a comma. ASReml allows for a small rounding error when matching. It may not distinguish properly if values in $vlist$ only differ in the sixth decimal place (see Other examples below).	<code>year 3 !SUB 66 67 68</code>
	!SEQ		replaces the data values with a sequential number starting at 1 which increments whenever the data value changes between successive records; the current field is presumed to define a factor and the number of levels in the new factor is set to the number of levels identified in this sequential process (see Other examples below). Missing values remain missing.	<code>plot !=V3 !SEQ</code>
New	!UNIFORM	v	replaces the variate with uniform random variables having range $0 : v$.	<code>Udat !=0. !Uniform 4.5</code> is equivalent to <code>Udat !=Uniform 4.5</code>

List of transformation qualifiers and their actions with examples

qualifier	argument	action	examples
!Vtarget=	value	assigns <i>value</i> to data field <i>target</i> overwriting previous contents; subsequent transformation qualifiers will operate on data field <i>target</i>.	... !V3=2.5
	Vfield	assigns the contents of data field <i>field</i> to data field <i>target</i> overwriting previous contents; subsequent transformation qualifiers will operate on data field <i>target</i> . If <i>field</i> is 0 the number of the data record is inserted.	... !V10=V3 ... !V11=block ... !V12=V0

QTL marker transformations

New

!MM *s* associates marker positions in the vector *s* (based on the Haldane mapping function) with marker variables and replaces missing values in a vector of marker states with expected values calculated using distances to non-missing flanking markers. This transformation will normally be used on a !G *n* factor where the *n* variables are the marker states for *n* markers in a linkage group in map order and coded [-1,1] (backcross) or [-1,0,1] (F2 design). *s* (length *n*+1) should be the *n* marker positions relative to a left telomere position of zero, and an extra value being the length of the linkage group (the position of the right telomere). The length (right telomere) may be omitted in which case the last marker is taken as the end of the linkage group. The positions may be given in Morgans or centiMorgans (if the length is greater than 10, it will be divided by 100 to convert to Morgans).

The recombination rate between markers at s_L and s_R (L is left and R is right of some putative QTL at Q) is

$$\theta_{LR} = (1 - e^{-2(s_R - s_L)})/2.$$

Consequently, for 3 markers (L,Q,R), $\theta_{LR} = \theta_{LQ} + \theta_{QR} - 2\theta_{LQ}\theta_{QR}$.

The expected value of a missing marker at Q (between L and R) depends on the marker states at L and R: $E(q|1, 1) = (1 - \theta_{LQ} - \theta_{QR})/(1 - \theta_{LR})$,

$$E(q|1, -1) = (\theta_{QR} - \theta_{LQ})/\theta_{LR}, \quad E(q|-1, 1) = (\theta_{LQ} - \theta_{QR})/\theta_{LR}$$

$$\text{and } E(q|-1, -1) = (-1 + \theta_{LQ} + \theta_{QR})/(1 - \theta_{LR}).$$

$$\text{Let } \lambda_L = (E(q|1, 1) + E(q|1, -1))/2 = \frac{\theta_{QR}(1 - \theta_{QR})(1 - 2\theta_{LQ})}{\theta_{LR}(1 - \theta_{LR})}$$

and $\lambda_R = (E(q| -1, 1) + E(q| -1, -1))/2 = \frac{\theta_{LQ}(1-\theta_{LQ})(1-2\theta_{QR})}{\theta_{LR}(1-\theta_{LR})}$

Then $E(q|x_L, x_R) = \lambda_L x_L + \lambda_R x_R$. Where there is no marker on one side, $E(q|x_R) = (1 - \theta_{QR})x_R + \theta_{QR}(-x_R) = x_R(1 - 2\theta_{QR})$.

New

`!DOM A` is used to form dominance covariables from a set of additive marker covariables previously declared with the `!MM` marker map qualifier. It assumes the argument `A` is an existing group of marker variables relating to a linkage group defined using `!MM` which represents additive marker variation coded [-1, 0, 1] (representing marker states `aa`, `aA` and `AA`) respectively. It is a group transformation which takes the [-1,1] interval values, and calculates $(|X| - 0.5) * 2$ i.e. -1 and 1 become one, 0 becomes -1. The marker map is also copied and applied to this model term so it can be the argument in a `qt1()` term (page 95).

Other rules and examples

Other rules include the following

- missing values are unaffected by arithmetic operations, that is, missing values in the current or target column remain missing after the transformation has been performed except in assignment
 - `!+3` will leave missing values (`NA`, `*` and `.`) as missing,
 - `!=3` will change missing values to `3`,
- multiple arithmetic operations cannot be expressed in a complex expression but must be given as separate operations that are performed in sequence as they appear, for example, `yield !-120 !*0.0333` would calculate $0.0333 * (\text{yield} - 120)$.

ASReml code	action
<code>yield !M0</code>	changes the zero entries in <code>yield</code> to missing values
<code>yield !^0</code>	takes natural logarithms of the <code>yield</code> data
<code>score !-5</code>	subtracts 5 from all values in <code>score</code>
<code>score !SET -0.5 1.5 2.5</code>	replaces data values of 1, 2 and 3 with -0.5, 1.5 and 2.5 respectively

ASReml code	action
<pre>score !SUB -0.5 1.5 2.5</pre>	replaces data values of -0.5, 1.5 and 2.5 with 1, 2 and 3 respectively; a data value of 1.51 would be replaced by 0 since it is not in the list or very close to a number in the list
<pre>block 8 variety 20 yield plot * !=variety !SEQ</pre>	<p>in the case where</p> <ul style="list-style-type: none"> - there are multiple units per plot, - contiguous plots have different treatments, and - the records are sorted units within plots within blocks, <p>this code generates a <code>plot</code> factor assuming a new plot whenever the code in <code>V2</code> (<code>variety</code>) changes; no field would be read unless there were later definitions which are not created by transformation,</p>
<pre>Var 3 Nit 4 VxN 12 !=Var !-1 !*4 !+Nit</pre>	assuming <code>Var</code> is coded 1:3 and <code>Nit</code> is coded 1:4, this syntax could be used to create a new factor <code>VxN</code> with the 12 levels of the composite <code>Var</code> by <code>Nit</code> factor.
<pre>YA !V98=YA !NA 0 YB !V99=YB !NA 0 !+V98 !DO</pre>	will discard records where both <code>YA</code> and <code>YB</code> have missing values (assuming neither have zero as valid data). The first line sets the focus to variable 98, copies <code>YA</code> into <code>V98</code> and changes any <i>missing values</i> in <code>V98</code> to zero. The second line sets the focus to variable 99, copies <code>YB</code> into <code>V99</code> and changes any <i>missing values</i> in <code>V99</code> to zero. It then adds <code>V98</code> and discards the whole record if the result is zero, i.e. both <code>YA</code> and <code>YB</code> have missing values for that record. Variables <code>98</code> and <code>99</code> are not labelled and so are not retained for subsequent use in analysis.

Special note on covariates

Covariates are variates that appear as independent variables in the model. It is recommended that covariates be centred and scaled to have a mean of zero and a variance of approximately one to avoid failure to detect singularities. This can be achieved either

- externally to ASReml in data file preparation,
- using `!RESCALE` *-mean scale* where *mean* and *scale* are user supplied values, for example, `age !rescale -200 !/10`.

5.6 Datafile line

The purpose of the datafile line is to

- nominate the data file,
- specify qualifiers to modify
 - the reading of the data,
 - the output produced,
 - the operation of ASReml.

```

NIN Alliance Trial 1989
variety !A
:
row 22
column 11
nin89aug.asd !skip 1
yield ~ mu variety
:

```

Data line syntax

The datafile line appears in the ASReml command file in the form

datafile [*qualifiers*]

- *datafile* is the path name of the file that contains the variates, factors, covariates, traits (response variates) and weight variables represented as data fields, see Chapter 4; enclose the path name in quotes if it contains embedded blanks,
- the *qualifiers* tell ASReml to modify either
 - the reading of the data and/or the output produced, see Table 5.2 below for a list of data file related qualifiers,
 - the operation of ASReml, see Tables 5.3 to 5.6 for a list of job control qualifiers
- the data file related qualifiers must appear on the data file line,
- the job control qualifiers may appear on the data file line or on following lines,
- the arguments to qualifiers are represented by the following symbols

f — a filename,
n — an integer number, typically a count,
p — a vector of real numbers, typically in increasing order,
r — a real number,
s — a character string,
t — a model term label,
v — the number or label of a data variable,
vlist — a list of variable labels.

5.7 Data file qualifiers

Table 5.2 lists the qualifiers relating to data input. Use the **Index** to check for examples or further discussion of these qualifiers.

Table 5.2: Qualifiers relating to data input and output

<i>qualifier</i>	action
Frequently used data file qualifier	
<code>!SKIP <i>n</i></code>	causes the first <i>n</i> records of the (non-binary) data file to be ignored. Typically these lines contain column headings for the data fields.
Other data file qualifiers	
<code>!CSV</code>	used to make consecutive commas imply a missing value; this, is automatically set if the file name ends with <code>.csv</code> or <code>.CSV</code> (see Section 4.2)
<code>!FILTER <i>v</i> !SELECT <i>n</i></code>	enables a subset of the data to be analysed; <i>v</i> is the number or name of a data field. When reading data, the value in field <i>v</i> is checked <i>after</i> any transformations are performed. If <code>!select</code> is omitted, records with zero in field <i>v</i> are omitted from the analysis. Otherwise, records with <i>n</i> in field <i>v</i> are retained and all other records are omitted. Warning If the filter column contains a missing value, the value from the previous non-missing record is assumed in that position.
<code>!FORMAT <i>s</i></code>	<p>supplies a Fortran like FORMAT statement for reading fixed format files. A simple example is <code>!FORMAT(3I4,5F6.2)</code> which reads 3 integer fields and 5 floating point fields from the first 42 characters of each data line. A format statement is enclosed in parentheses and may include 1 level of nested parentheses, for example, e.g. <code>!FORMAT(4x,3(I4,f8.2))</code>. Field descriptors are</p> <ul style="list-style-type: none"> • <code>rX</code> to skip <i>r</i> character positions, • <code>rAw</code> to define <i>r</i> consecutive fields of <i>w</i> characters width, • <code>rIw</code> to define <i>r</i> consecutive fields of <i>w</i> characters width, and • <code>rFw.d</code> to define <i>r</i> consecutive fields of <i>w</i> characters width; <i>d</i> indicates where to insert the decimal point if it is not explicitly present in the field, <p>where <i>r</i> is an optional repeat count.</p> <p>In ASReml, the A and I field descriptors are treated identically and simply set the field width. Whether the field is interpreted alphabetically or as a number is controlled by the <code>!A</code> qualifier.</p>

Qualifiers relating to data input and output

<i>qualifier</i>	action
------------------	--------

Other legal components of a format statement are

- the , character; required to separate fields - blanks are not permitted in the format.
- the / character; indicates the next field is to be read from the next line. However a / on the end of a format to skip a line is not honoured.
- BZ; the default action is to read blank fields as missing values. * and NA are also honoured as missing values. If you wish to read blank fields as zeros, include the string BZ.
- the string BM; switches back to 'blank missing' mode.
- the string Tc; moves the 'last character read' pointer to line position *c* so that the next field starts at position *c* + 1. For example T0 goes back to the beginning of the line.
- the string D; invokes debug mode.

A format showing these components is
 !FORMAT(D,3I4,8X,A6,3(2X,F5.2)/4X,BZ,20I1) and is suitable for reading 27 fields from 2 data records such as
 111122223333xxxxxxxxALPHAFxx 4.12xx 5.32xx 6.32
 xxx123 567 901 345 7890

New !MERGE *c f* [!SKIP *n*] [!MATCH *a b*] may be specified on a line following the datafile line.

The purpose is to combine data fields from the (primary) data file with data fields from a secondary file (*f*). The effect is to open the named file (skip *n* lines) and then insert the columns from the new file into field positions starting at position *c*. If !MATCH *a b* is specified, ASReml checks that the field *a* ($0 < a < c$) has the same value as field *b*. If not, it is assumed that the merged file has some missing records and missing values are inserted into the data record and the line from the MERGE file is kept for comparison with the next record. At this stage it is expected that the lines in the MERGE file are in the same order as the corresponding lines occur in the primary data file, and that there are no extraneous lines in the MERGE file. (It is proposed to extend this so the orders do not need to agree and that multiple lines in the primary file could be merged with the same line of the MERGE file.)

Qualifiers relating to data input and output

<i>qualifier</i>	action
	<p>For example, assuming the field definitions define 10 fields, <code>PRIMARY.DAT !skip 1</code> <code>!MERGE 6 SECOND.DAT !SKIP 1 !MATCH 1 6</code> would obtain the first five fields from <code>PRIMARY.DAT</code> and the next five from <code>SECOND.DAT</code>, checking that the first field in each file has the same value. Thus each input record is obtained by combining information from each file, before any transformations are performed.</p>
<code>!READ <i>n</i></code>	formally instructs <code>ASReml</code> to read <i>n</i> data fields from the data file. It is needed when there are extra columns in the data file that must be read but are only required for combination into earlier fields in transformations, or when <code>ASReml</code> attempts to read more fields than it needs to.
<code>!RECODE</code>	is required when reading a binary data file with pedigree identifiers that have not been recoded according to the pedigree file. It is not needed when the file was formed using the <code>!SAVE</code> option but will be needed if formed in some other way (see Section 4.2).
New <code>!RREC [<i>n</i>]</code>	causes <code>ASReml</code> to read <i>n</i> records or to read up to a data reading error if <i>n</i> is omitted, and then process the records it has. This allows data to be extracted from a file which contains trailing non-data records (for example extracting the predicted values from a <code>.pvs</code> file). The argument (<i>n</i>) specifies the number of data records to be read. If not supplied, <code>ASReml</code> reads until a data reading error occurs, and then processes the data it has. Without this qualifier, <code>ASReml</code> aborts the job when it encounters a data error. See <code>!RSKIP</code> .
New <code>!RSKIP <i>n</i> [<i>s</i>]</code>	allows <code>ASReml</code> to skip lines at the heading of a file down to (and including) the <i>n</i> th instance of string <i>s</i> . For example, to read back the third set predicted values in a <code>.pvs</code> file, you would specify <code>!RREC !RSKIP 4 ' Ecode'</code> since the line containing the 4th instance of ' Ecode' immediately precedes the predicted values. The <code>!RREC</code> qualifier means that <code>ASReml</code> will read until the end of the predict table. The keyword <code>Ecode</code> which occurs once at the beginning and then immediately before each block of data in the <code>.pvs</code> file is used to count the sections.

Combining rows from separate files

New

ASReml can read data from multiple files provided the files have the same layout. The file specified as the 'primary data file' in the command file can contain lines of the form

```
!INCLUDE <filename> !SKIP n
```

where <filename> is the (path)name of the data subfile and !SKIP *n* is an optional qualifier indicating that the first *n* lines of the subfile are to be skipped. After reading each subfile, input reverts to the primary data file.

Typically, the primary data file will just contain !INCLUDE statements identifying the subfiles to include. For example, you may have data from a series of related experiments in separate data files for individual analysis. The primary data file for the subsequent combined analysis would then just contain a set of !INCLUDE statements to specify which experiments were being combined.

If the subfiles have CSV format, they should all have it and the !CSV file should be declared on the primary datafile line. This option is not available in combination with !MERGE.

5.8 Job control qualifiers

The following tables list the job control qualifiers. These change or control various aspects of the analysis. Job control qualifiers may be placed on the datafile line and following lines. They may also be defined using an environment variable called ASREML_QUAL. The environment variable is processed immediately after the datafile line is processed. All qualifier settings are reported in the .asr file. Use the Index to check for examples or further discussion of these qualifiers.

Important Many of these are only required in very special circumstances and new users should not attempt to understand all of them. You do need to understand that all general qualifiers are specified here. Many of these qualifiers are referenced in other chapters where their purpose will be more evident.

Table 5.3: List of commonly used job control qualifiers

<i>qualifier</i>	action
<code>!CONTINUE</code>	<p>is used to restart/resume iterations from the point reached in a previous run. This qualifier can alternately be set from the command line using the option letters <code>C</code> (continue) or <code>F</code> (final) (see Section 12.3 on command line options). After each iteration, <code>ASReml</code> writes the current values of the variance parameters to a file with extension <code>.rsv</code> (re-start values) with information to identify individual variance parameters. The <code>!CONTINUE</code> qualifier causes <code>ASReml</code> to scan the <code>.rsv</code> file for parameter values related to the current model replacing the values obtained from the <code>.as</code> file before iteration resumes. If the model has changed, <code>ASReml</code> will pick up the values it recognises as being for the same terms. Furthermore, <code>ASReml</code> will use estimates in the <code>.rsv</code> file for certain models to provide starting values for certain more general models, inserting reasonable defaults where necessary. The transitions recognised are listed and discussed in Section 7.10.</p> <p> <code>DIAG</code> to <code>FA1</code> <code>DIAG</code> to <code>CORUH</code> (uniform heterogeneous) <code>CORUH</code> to <code>FA1</code> <code>FAi</code> to <code>FA$i+1$</code> <code>FAi</code> to <code>CORGH</code> (full heterogeneous) <code>FAi</code> to <code>US</code> (full heterogeneous) <code>CORGH</code> (heterogeneous) to <code>US</code> </p>
<p>New</p> <p><code>!CONTRAST s t p</code></p>	<p>provides a convenient way to define contrasts among treatment levels. <code>!CONTRAST</code> lines occur as separate lines between the datafile line and the model line.</p> <p> s is the name of the model term being defined. t is the name of an existing factor. p is the list of contrast coefficients. For example </p> <pre>!CONTRAST LinN Nitrogen 3 1 -1 -3</pre> <p>defines <code>LinN</code> as a contrast based on the 4 (implied by the length of the list) levels of factor <code>Nitrogen</code>. Missing values in the factor become missing values in the contrast. Zero values in the factor (no level assigned) become zeros in the contrast. The user should check that the levels of the factor are in the order assumed by contrast (check the <code>.ass</code> or <code>.sln</code> or <code>.tab</code> files). It may also be used on the implicit factor <code>Trait</code> in a multivariate analysis provided it implicitly identifies the number of levels of <code>Trait</code>; the number of traits is implied by the length of the list. Thus, if the analysis involves 5 traits,</p> <pre>!CONTRAST Time Trait 1 3 5 10 20</pre>

List of commonly used job control qualifiers

<i>qualifier</i>	action
<p>New !FCON</p>	<p>adds a 'conditional' F-statistic column to the Analysis of Variance table. It enables inference for fixed effects in the dense part of the linear mixed model to be conducted so as to respect both structural and intrinsic marginality (see Section 2.6). The detail of exactly which terms are conditioned on is reported in the <code>.aov</code> file. The principle used in determining this conditional test is that a term cannot be adjusted for another term which encompasses it explicitly (e.g. term <code>A.C</code> cannot be adjusted for <code>A.B.C</code>) or implicitly (e.g. term <code>REGION</code> cannot be adjusted for <code>LOCATION</code> when locations are actually nested in regions although they are coded independently).</p>
!MAXIT <i>n</i>	<p>sets the maximum number of iterations; the default is 10. ASReml iterates for <i>n</i> iterations unless convergence is achieved first. Convergence is presumed when the REML log-likelihood changes less than 0.002* <i>current iteration</i> number and the individual variance parameter estimates change less than 1%.</p> <p>If the job has not converged in <i>n</i> iterations, use the !CONTINUE qualifier to resume iterating from the current point.</p> <p>To abort the job at the end of the current iteration, create a file named <code>ABORTASR.NOW</code> in the directory in which the job is running. At the end of each iteration, ASReml checks for this file and if present, stops the job, producing the usual output but not producing predicted values since these are calculated in the last iteration. Creating <code>FINALASR.NOW</code> will stop ASReml after one more iteration (during which predictions will be formed).</p> <p>On case sensitive operating systems (eg. Unix), the filename (<code>ABORTASR.NOW</code> or <code>FINALASR.NOW</code>) must be upper case. Note that the <code>ABORTASR.NOW</code> file is deleted so nothing of importance should be in it. If you perform a system level abort (CTRL C or close the program window) output files other than the <code>.rsv</code> file will be incomplete. The <code>.rsv</code> file should still be functional for resuming iteration at the most recent parameter estimates (see !CONTINUE).</p> <p>Use !MAXIT 1 where you want estimates of fixed effects and predictions of random effects for the particular set of variance parameters supplied as initial values. Otherwise the estimates and predictions will be for the updated variance parameters (see the !BLUP qualifier below).</p>

List of commonly used job control qualifiers

<i>qualifier</i>	action
<p>New !SUM</p>	<p>If !MAXIT 1 is used and an Unstructured Variance model is fitted, ASReml will perform a Score test of the US matrix. Thus, assume the variance structure is modelled with reduced parameters, if that modelled structure is then processed as the initial values of a US structure, ASReml tests the adequacy of the reduced parameterization.</p> <p>causes ASReml to report a general description of the distribution of the data variables and factors and simple correlations among the variables for those records included in the analysis. This summary will ignore data records for which the variable being analysed is missing unless a multivariate analysis is requested or missing values are being estimated. The information is written to the .ass file.</p>
!X v !Y v !G v !JOIN	<p>is used to plot the (transformed) data. Use !X to specify the x variable, !Y to specify the y variable and !G to specify a grouping variable. !JOIN joins the points when the x value increases between consecutive records. The grouping variable may be omitted for a simple scatter plot. Omit !Y y produce a histogram of the x variable.</p> <p>For example, !X age !Y height !G sex Note that the graphs are only produced in the graphics versions of ASReml (Section 12.3).</p> <p>For multivariate repeated measures data, ASReml can plot the response profiles if the first response is nominated with the !Y qualifier and the following analysis is of the multivariate data. ASReml assumes the response variables are in contiguous fields and are equally spaced. For example</p> <p>Response profiles Treatment !A Y1 Y2 Y3 Y4 Y5 rat.asd !Y Y1 !G Treatment !JOIN Y1 Y2 Y3 Y4 Y5 ~ Trait Treatment Trait.Treatment</p>

Table 5.4: List of occasionally used job control qualifiers

<i>qualifier</i>	action
<code>!ASMV <i>n</i></code>	<p>indicates a multivariate analysis is required although the data is presented in a univariate form. 'Multivariate Analysis' is used in the narrow sense where an unstructured error variance matrix is fitted across traits, records are independent, and observations may be missing for particular traits, see Chapter 8 for a complete discussion.</p> <p>The data is presumed arranged in lots of <i>n</i> records where <i>n</i> is the number of <i>traits</i>. It may be necessary to expand the data file to achieve this structure, inserting a missing value NA on the additional records. This option is sometimes relevant for some forms of repeated measures analysis. There will need to be a factor in the data to code for trait as the intrinsic Trait factor is undefined when the data is presented in a univariate manner.</p>
<code>!ASUV</code>	<p>indicates that a <i>univariate</i> analysis is required although the data is presented in a multivariate form. Specifically, it allows you to have an error variance other than $I \otimes \Sigma$ where Σ is the unstructured (US, see Table 7.3) variance structure. If there are <i>missing values</i> in the data, include <code>!f mv</code> on the end of the linear model. It is often also necessary to specify the <code>!S2==1</code> qualifier on the R-structure lines. The intrinsic factor Trait is defined and may be used in the model. See Chapter 8 for more information.</p> <p>This option is used for repeated measures analysis when the variance structure required is not the standard multivariate unstructured matrix.</p>
<code>!COLFAC <i>v</i></code>	<p>is used with <code>!SECTION <i>v</i></code> and <code>!ROWFAC <i>v</i></code> to instruct ASReml to set up R structures for analysing a multi-environment trial with a separable first order autoregressive model for each site (environment). <i>v</i> is the name of a factor or variate containing column numbers (1 . . . n_c where n_c is the number of columns) on which the data is to be sorted. See <code>!SECTION</code> for more detail.</p>

List of occasionally used job control qualifiers

<i>qualifier</i>	action
<p>New !DDF [<i>i</i>]</p>	<p>requests computation of the approximate denominator degrees of freedom according to Kenward and Roger (1997) for the Analysis of Variance of fixed effects terms in the dense part of the linear mixed model. There are three options for <i>i</i>: <i>i</i> = -1 suppresses computation, <i>i</i> = 1 and <i>i</i> = 2 compute the denominator d.f. using numerical and algebraic methods respectively.</p> <p>If <i>i</i> is omitted then <i>i</i> = 2 is assumed.</p> <p>If !DDF <i>i</i> is omitted, <i>i</i> = -1 is assumed except for small jobs (< 10 parameters, < 500 fixed effects, < 10,000 equations and < 100 Mbyte workspace) when <i>i</i> = 2.</p> <p>Calculation of the denominator degrees of freedom is computationally expensive. Numerical derivatives require an extra evaluation of the mixed model equations for every variance parameter. Algebraic derivatives require a large dense matrix, potentially of order number of equations plus number of records and is not available when MAXIT is 1 or for multivariate analysis.</p>
!DISPLAY <i>n</i>	<p>is used to select particular graphic displays. In spatial analysis of field trials, four graphic displays are possible (see Section 13.4). Coding these</p> <p style="padding-left: 2em;">1=variogram 2=histogram 4=row and column trends 8=perspective plot of residuals,</p> <p>set <i>n</i> to the sum of the codes for the desired graphics. The default is 9. These graphics are only displayed in versions of ASReml linked with Winteracter (that is, LINUX, SUN and PC) versions. Line printer versions of these graphics are written to the .res file. See the G command line option (Section 12.3 on graphics) for how to save the graphs in a file for printing.</p> <p>Use !NODISPLAY to suppress graphic displays.</p>
!EPS	sets hardcopy graphics file type to .eps.
!G <i>v</i>	is used to set a grouping variable for plotting, see !X.

List of occasionally used job control qualifiers

<i>qualifier</i>	action
New !GKRIGE [<i>p</i>]	controls the expansion of !PVAL lists for <code>fac(X,Y)</code> model terms. For kriging prediction in 2 dimensions (X,Y), the user will typically want to predict at a grid of values, not necessarily just at data combinations. The values at which the prediction is required can be specified separately for X and Y using two !PVAL statements. Normally, predict points will be defined for all combinations of X and Y values. This qualifier is required (with optional argument 1) to specify the lists are to be taken in parallel. The lists must be the same length if to be taken in parallel. Be aware that adding two dimensional prediction points is likely to substantially slow iterations because the variance structure is dense and becomes larger. For this reason, ASReml will ignore the extra PVAL points unless either !FINAL or !GKRIGE are set, to save processing time.
!HPGL [2]	sets hardcopy graphics file type to HP GL. An argument of 2 sets the hardcopy graphics file type to HP GL 2
!JOIN	is used to join lines in plots, see !X.
New !MBF <code>mbf(v,n) f [!SKIP k]</code>	specified on a separate line after the datafile line predefines the model term <code>mbf(v,n)</code> as a set of n covariates indexed by the data values in variable v . MBF stands for My Basis Function and uses the same mechanism as the <code>leg()</code> , <code>pol()</code> and <code>spl()</code> model functions but with covariates supplied by the user. The file f should contain $1+n$ fields where the first field contains the values which are in the data variable or at which prediction is required, and the remaining n fields define the corresponding covariate values. !SKIP k is an optional qualifier which requests the first k lines of the file be ignored.
!MVINCLUDE	When missing values occur in the design ASReml will report this fact and abort the job unless !MVINCLUDE is specified (see Section 6.10); then missing values are treated as zeros. Use the !D transformation to drop the records with the missing values.
!MVREMOVE	instructs ASReml to discard records which have missing values in the design matrix (see Section 6.10).
!NODISPLAY	suppresses the graphic display of the variogram and residuals which is otherwise produced for spatial analyses in the PC and SUN versions. This option is usually set on the command line using the option letter N (see Section 12.3 on graphics). The text version of the graphics is still written to the <code>.res</code> file.
!PS	sets hardcopy graphics file type to <code>.ps</code> .

List of occasionally used job control qualifiers

<i>qualifier</i>	action
<code>!PVAL <i>v p</i></code>	is a mechanism for specifying the particular points to be predicted for covariates modelled using <code>fac(<i>v</i>)</code> , <code>leg(<i>v,k</i>)</code> , <code>spl(<i>v,k</i>)</code> and <code>pol(<i>v,k</i>)</code> . The points are specified here so that they can be included in the appropriate design matrices. <i>v</i> is the name of a data field. <i>p</i> is the list of values at which prediction is required. See <code>!GKRIGE</code> for special conditions pertaining to <code>fac(<i>x,y</i>)</code> prediction.
<code>!PVAL <i>f vlist</i></code>	is used to read <code>predict_points</code> for several variables from a file <i>f</i> . <i>vlist</i> is the names of the variables having values defined. If the file contains unwanted fields, put the pseudo variate label <code>skip</code> in the appropriate position in <i>vlist</i> to ignore them. The file should only have numeric values. <code>predict_points</code> cannot be specified for design factors.
<code>!ROWFAC <i>v</i></code>	is used with <code>!SECTION <i>v</i></code> and <code>!COLFAC <i>v</i></code> to instruct ASReml to setup the R structures for multi-environment spatial analysis. <i>v</i> is the name of a factor or variate containing <i>row</i> numbers (1 ... <i>n_r</i> where <i>n_r</i> is the number of rows) on which the data is to be sorted. See <code>!SECTION</code> for more detail.
<code>!SECTION <i>v</i></code>	specifies the factor in the data that defines the data sections. This qualifier enables ASReml to check that sections have been correctly dimensioned but does not cause ASReml to sort the data unless <code>!ROWFAC</code> and <code>!COLFAC</code> are also specified. Data is assumed to be presorted by section but will be sorted on row and column within section. The following is a basic example assuming 5 sites (sections). When <code>!ROWFAC <i>v</i></code> and <code>!COLFAC <i>v</i></code> are both specified ASReml generates the R structures for a standard AR ⊗ AR spatial analysis. The R structure lines that a user would normally be required to work out and type into the <code>.as</code> file (see the example of Section 15.6) are written to the <code>.res</code> file. The user may then cut and paste them into the <code>.as</code> file for a later run if the structures need to be modified.
	<pre> Basic multi-environment trial analysis site 5 # sites coded 1 ... 5 column * # columns coded 1 ... row * # rows coded 1 ... variety !A # variety names yield met.dat !SECTION site !ROWFAC row !COLFAC col yield ~ site !r variety site.variety !f mv site 2 0 # variance header line # asrem1 inserts the 10 lines required to define # the R structure lines for the five sites here </pre>

List of occasionally used job control qualifiers

<i>qualifier</i>	action
<p><code>!SPLINE spl(<i>v</i>,<i>n</i>) <i>p</i></code></p>	<p>defines a spline model term with an explicit set of knot points. The basic form of the spline model term, <code>spl(<i>v</i>)</code>, is defined in Table 6.1 where <i>v</i> is the underlying variate. The basic form uses the unique data values as the knot points. The extended form is <code>spl(<i>v</i>,<i>n</i>)</code> which uses <i>n</i> knot points. Use this <code>!SPLINE</code> qualifier to supply an explicit set of <i>n</i> knot points (<i>p</i>) for the model term <i>t</i>. Using the extended form without using this qualifier results in <i>n</i> equally spaced knot points being used. The <code>!SPLINE</code> qualifier may only be used on a line by itself after the datafile line and before the model line.</p> <p>When knot points are explicitly supplied they should be in increasing order and adequately cover the range of the data or <code>ASReml</code> will modify them before they are applied. If you choose to spread them over several lines use a comma at the end of incomplete lines so that <code>ASReml</code> will continue reading values from the next line of input. If the explicit points do not adequately cover the range, a message is printed and the values are rescaled unless <code>!NOCHECK</code> is also specified. Inadequate coverage is when the explicit range does not cover the midpoint of the actual range. See <code>!KNOTS</code>, <code>!PVAL</code> and <code>!SCALE</code>.</p>
<p><code>!STEP <i>r</i></code></p>	<p>reduces the update step sizes of the variance parameters. The default value is the reciprocal of the square root of <code>!MAXIT</code>. It may be set between 0.01 and 1.0. The step size is increased towards 1 each iteration. Starting at 0.1, the sequence would be 0.1, 0.32, 0.56, 1. This option is useful when you do not have good starting values, especially in multivariate analyses.</p>
<p>New <code>!SUBSET <i>t v p</i></code></p>	<p>forms a new factor (<i>t</i>) derived from an existing factor (<i>v</i>) by selecting a subset (<i>p</i>) of its levels. Missing values are transmitted as missing and records whose level is zero are transmitted as zero. The qualifier occupies its own line after the datafile line but before the linear model. e.g.</p> <pre>!SUBSET EnvC Env 3 5 8 9 :15 21 33</pre> <p>defines a reduced form of the factor <code>Env</code> just selecting the environments listed. It might then be used in the model in an interaction.</p> <p>The intention is to simplify the model specification in MET (Multi Environment Trials) analyses where say Column effects are to be fitted to a subset of environments. It may also be used on the intrinsic factor <code>Trait</code> in a multivariate analysis provided it correctly identifies the number of levels of <code>Trait</code> either by including the last trait number, or appending sufficient zeros. Thus, if the analysis involves 5 traits,</p> <pre>!SUBSET Trewe Trait 1 3 4 0 0</pre>

Table 5.5: List of rarely used job control qualifiers

<i>qualifier</i>	action
<p>New</p> <p>!AISINGULARITIES</p>	<p>can be specified to force a job to continue even though a singularity was detected in the Average Information (AI) matrix. The AI matrix is used to give updates to the variance parameter estimates. In release 1, if singularities were present in the AI matrix, a generalized inverse was used which effectively conditioned on whichever parameters were identified as singular. ASReml now aborts processing if such singularities appear unless the !AISINGULARITIES qualifier is set. Which particular parameter is singular is reported in the variance component table printed in the <code>.asr</code> file.</p> <p>The most common reason for singularities is that the user has overspecified the model and is likely to misinterpret the results if not fully aware of the situation. Overspecification will occur in a direct product of two unconstrained variance matrices (see Section 2.4), when a random term is confounded with a fixed term and when there is no information in the data on a particular component.</p> <p>The best solution is to reform the variance model so that the ambiguity is removed, or to fix one of the parameters in the variance model so that the model can be fitted. For instance, if !ASUV is specified, you may also need !S2=1. Only rarely will it be reasonable to specify the !AISINGULARITIES qualifier.</p>
<p>!BMP</p>	<p>sets hardcopy graphics file type to <code>.bmp</code>.</p>
<p>New</p> <p>!BRIEF [<i>n</i>]</p>	<p>suppresses some of the information written to the <code>.asr</code> file. The data summary and regression coefficient estimates are suppressed. This qualifier should not be used for initial runs of a job until the user has confirmed from the data summary that the data is correctly interpreted by ASReml. Use !BRIEF 2 to cause the predicted values to be written to the <code>.asr</code> file instead of the <code>.pvs</code> file. Use !BRIEF -1 to get BLUE (fixed effect) estimates reported in <code>.asr</code> file. The !BRIEF qualifier may be set with the B command line option.</p>
<p>!BLUP <i>n</i></p>	<p>restricts ASReml to performing only part of the first iteration. The estimation routine is aborted after</p> <ul style="list-style-type: none"> <i>n</i> = 1: forming the estimates of the vector of fixed and random effects, <i>n</i> = 2: forming the estimates of the vector of fixed and random effects, REML log-likelihood and residuals (this is the default), <i>n</i> = 3: forming the estimates of the vector of fixed and random effects, REML log-likelihood, residuals and inverse coefficient matrix.

List of rarely used job control qualifiers

<i>qualifier</i>	action
	<p>ASReml prints its standard reports as if it had completed the iteration normally, but since it has not completed it, some of the information printed will be incorrect. In particular, variance information on the variance parameters will always be wrong. Standard errors on the estimates will be wrong unless $n=3$. Residuals are not available if $n=1$. Use of $n=3$ or $n=2$ will halve the processing time when compared to the alternative of using !MAXIT 1. However, !MAXIT 1 does result in a complete and correct output report.</p>
!DATAFILE <i>f</i>	<p>specifies the datafile name replacing the one obtained from the datafile line. It is required when different !PATHS (see !DOPATH in Table 12.3) of a job must read different files. The !SKIP qualifier, if specified, will be applied when reading the file.</p>
!DENSE <i>n</i>	<p>sets the number of equations solved densely up to a maximum of 5000. By default, sparse matrix methods are applied to the random effects and any fixed effects listed after random factors or whose equation numbers exceed 800. Use !DENSE <i>n</i> to apply sparse methods to effects listed before the !r (reducing the size of the DENSE block) or if you have large fixed model terms and want them included in the ANOVA table. Individual model terms will not be split so that only part is in the dense section. <i>n</i> should be kept small (<100) for faster processing.</p>
!DF <i>n</i>	<p>alters the error degrees of freedom from ν to $\nu + n$. This qualifier might be used when analysing pre-adjusted data to reduce the degrees of freedom (<i>n</i> negative) or when weights are used in lieu of actual data records to supply error information (<i>n</i> positive). The degrees of freedom is only used in the calculation of the residual variance in a univariate single site analysis. The option will have no effect in analyses with multiple error variances (for sites or traits) other than in the reported degrees of freedom. Use !ADJUST <i>r</i> rather than !DF <i>n</i> if <i>r</i> is not a whole number. Use with !YSS <i>r</i> to supply variance when data fully fitted.</p>

List of rarely used job control qualifiers

<i>qualifier</i>	action
<p>New !EMFLAG <i>n</i></p> <p>Caution !PXEM <i>n</i></p>	<p>requests ASReml use Expectation-Maximization (EM) rather than Average Information (AI) updates when the AI updates would make a US structure non-positive definite. This only applies to US structures and is still under development. When !GP is associated with a US structure, ASReml checks whether the updated matrix is positive definite (PD). If not, it replaces the AI update with an EM update. If the non PD characteristic is transitory, then the EM update is only used as necessary. If the converged solution would be non PD, there will be a EM update each iteration even though !EM is omitted.</p> <p>EM is notoriously slow at finding the solution and ASReml includes several modified schemes, discussed by Cullis <i>et al.</i> (2004), particularly relevant when the AI update is consistently outside the parameter space. These include optionally performing extra local EM or PXEM (Parameter Extended EM) iterates. These can dramatically reduce the number of iterates required to find a solution near the boundary of the parameter space but do not always work well when there are several matrices on the boundary. The options are</p> <p>!EMFLAG [1] Standard EM plus 10 local EM steps !EMFLAG 2 Standard EM plus 10 local PXEM steps !PXEM [2] Standard EM plus 10 local PXEM steps !EMFLAG 3 Standard EM plus 10 local EM steps !EMFLAG 4 Standard EM plus 10 local EM steps !EMFLAG 5 Standard EM only !EMFLAG 6 Single local PXEM !EMFLAG 7 Standard EM plus 1 local EM step !EMFLAG 8 Standard EM plus 10 local EM steps</p> <p>Options 3 and 4 cause all US structures to be updated by (PX)EM if any particular one requires EM updates. The test of whether the AI updated matrix is positive definite is based on absorbing the matrix to check all pivots are positive. Repeated EM updates may bring the matrix closer to being singular. This is assessed by dividing the pivot of the first element with the first diagonal element of the matrix. If it is less than 10^{-7} (this value is consistent with the multiple partial correlation of the first variable with the rest being greater than 0.9999999, ASReml fixes the matrix at that point and estimates any other parameters conditional on these values. To proceed with further iterations without fixing the matrix values would ultimately make the matrix such that it would be judged singular resulting the analysis being aborted.</p>

List of rarely used job control qualifiers

<i>qualifier</i>	action
<p>New</p> <p>!EQORDER <i>o</i></p>	<p>modifies the algorithm used for choosing the order for solving the mixed model equations. A new algorithm devised for release 2 is now the default and is formally selected by !EQORDER 3. The algorithm used for release 1 is essentially that selected by !EQORDER 1. The new order is generally superior. !EQORDER -1 instructs ASReml to process the equations in the order they are specified in the model. Generally this will make a job much slower, if it can run at all. It is useful if the model has a suitable order as in the IBD model</p> $Y \sim \mu + r + \{ \text{giv}(\text{id}) \text{id} \}$ <p>giv(id) invokes a dense inverse of an IBD matrix and id has a sparse structured inverse of an additive relationship matrix. While !EQORDER 3 generates a more sparse solution, !EQORDER -1 runs faster.</p>
	<p>!EXTRA <i>n</i></p> <p>forces another $\text{mod}(n,10)$ rounds of iteration after apparent convergence. The default for <i>n</i> is 1. This qualifier has lower priority than !MAXIT and ABORTASR.NOW (see !MAXIT for details).</p> <p>Convergence is judged by changes in the REML log-likelihood value and variance parameters. However, sometimes the variance parameter convergence criteria has not been satisfied.</p>
<p>New</p> <p>Difficult</p> <p>!LAST <factor₁ > <lev₁ > [<fac₂ > <lev₂ > <fac₃ > <lev₃ >]</p>	<p>limits the order in which equations are solved in ASReml by forcing equations in the sparse partition involving the first <lev_{<i>i</i>} > equations of <factor_{<i>i</i>} > to be solved after all other equations in the sparse partition. Is intended for use when there are multiple fixed terms in the sparse equations so that ASReml will be consistent in which effects are identified as singular. The test example had</p> <pre>!r Anim Litter !f HYS</pre> <p>where genetic groups were included in the definition of Anim. Consequently, there were 5 singularities in Anim. The default reordering allows those singularities to appear anywhere in the Anim and HYS terms. Since 29 genetic groups were defined in Anim, !LAST Anim 29 forces the genetic group equations to be absorbed last (and therefore incorporate any singularities). In the more general model fitting</p> <pre>!r Tr.Anim Tr.Lit !f Tr.HYS</pre> <p>without !LAST, the location of singularities will almost surely change if the G structures for Tr.Anim or Tr.Lit are changed, invalidating Likelihood Ratio tests between the models.</p>
	<p>!OWN <i>f</i></p> <p>supplies the name of a program supplied by the user in association with the OWN variance model (page 131).</p>

List of rarely used job control qualifiers

<i>qualifier</i>	action
<code>!PRINT <i>n</i></code>	causes ASReml to print the transformed data file to <i>base-name.asp</i> . If $n < 0$, data fields $1 \dots \text{mod}(n)$ are written to the file, $n = 0$, nothing is written, $n = 1$, all data fields are written to the file if it does not exist, $n = 2$, all data fields are written to the file overwriting any previous contents, $n > 2$, data fields $n \dots t$ are written to the file where t is the last defined column.
New <code>!PVSFORM <i>n</i></code>	modifies the format of the tables in the <code>.pvs</code> file and changes the file extension of the file to reflect the format. <code>!PVSFORM 1</code> is TAB separated: <code>.pvs</code> → <code>.pvs.txt</code> <code>!PVSFORM 2</code> is COMMA separated: <code>.pvs</code> → <code>.pvs.csv</code> <code>!PVSFORM 3</code> is Ampersand separated: <code>.pvs</code> → <code>.pvs.tex</code> See <code>!TXTFORM</code> for more detail.
<code>!RESIDUALS [2]</code>	instructs ASReml to write the transformed data and the residuals to a binary file. The residual is the last field. The file <i>basename.srs</i> is written in single precision unless the argument is 2 in which case <i>basename.drs</i> is written in double precision. The file will not be written from a spatial analysis (two-dimensional error) when the data records have been sorted into field order because the residuals are not in the same order that the data is stored. The residual from a spatial analysis will have the <code>units</code> part added to it when <code>units</code> is also fitted. The <code>.drs</code> file could be renamed (with extension <code>.dbl</code>) and used for input in a subsequent run.
<code>!SAVE <i>n</i></code>	instructs ASReml to write the data to a binary file. The file <code>asrdata.bin</code> is written in single precision if the argument n is 1 or 3; <code>asrdata.dbl</code> is written in double precision if the argument n is 2 or 4; the data values are written before transformation if the argument is 1 or 2 and after transformation if the argument is 3 or 4. The default is single precision after transformation (see Section 4.2).

List of rarely used job control qualifiers

<i>qualifier</i>	action
New	<p><code>!SCREEN [n] [!SMX m]</code></p> <p>performs a 'Regression Screen', a form of all subsets regression. For d model terms in the DENSE equations, there are $2^d - 1$ possible submodels. Since for $d > 8$, $2^d - 1$ is large, the submodels explored are reduced by the parameters n and m so that only models with at least n (default 1) terms but no more than m (default 6) terms are considered. The output (see page 192) is a report to the <code>.asr</code> file with a line for every submodel showing the sums of squares, degrees of freedom and terms in the model. There is a limit of $d = 20$ model terms in the screen. ASReml will not allow interactions to be included in the screened terms. For example, to identify which three of my set of 12 covariates best explain my dependent variable given the other terms in the model, specify <code>!SCREEN 3 !SMX 3</code>. The number of models evaluated quickly increases with d but ASReml has an arbitrary limit of 900 submodels evaluated. Use the <code>!DENSE</code> qualifier to control which terms are screened. The screen is conditional on all other terms (those in the SPARSE equations) being present.</p>
New	<p><code>!SLNFORM [n]</code></p> <p>modifies the format of the <code>.sln</code> file. <code>!SLNFORM -1</code> prevents the <code>.sln</code> file from being written. <code>!SLNFORM 1</code> is TAB separated: <code>.sln</code> becomes <code>_sln.txt</code> <code>!SLNFORM 2</code> is COMMA separated: <code>.sln</code> becomes <code>_sln.csv</code> <code>!SLNFORM 3</code> is Ampersand separated: <code>.sln</code> becomes <code>_sln.tex</code> See <code>!TXTFORM</code> for more detail.</p>
New	<p><code>!SPATIAL</code></p> <p>increases the amount of information reported on the residuals obtained from the analysis of a two dimensional regular grid field trial. The information is written to the <code>.res</code> file.</p>
New	<p><code>!TABFORM [n]</code></p> <p>controls form of the <code>.tab</code> file <code>!TABFORM 1</code> is TAB separated: <code>.tab</code> becomes <code>_tab.txt</code> <code>!TABFORM 2</code> is COMMA separated: <code>.tab</code> becomes <code>_tab.csv</code> <code>!TABFORM 3</code> is Ampersand separated: <code>.tab</code> becomes <code>_tab.tex</code> See <code>!TXTFORM</code> for more detail.</p>
New	<p><code>!TXTFORM [n]</code></p> <p>sets the default argument for <code>!PVSFORM</code>, <code>!SLNFORM</code>, <code>!TABFORM</code> and <code>!YHTFORM</code> if these are not explicitly set. <code>!TXTFORM</code> (or <code>!TXTFORM 1</code>) replaces multiple spaces with TAB and changes the file extension to, say, <code>_sln.txt</code>. This makes it easier to load the solutions into Excel. <code>!TXTFORM 2</code> replaces multiple spaces with COMMA and changes the file extension to, say, <code>_sln.csv</code>. However, since factor labels sometimes contain COMMAS, this form is not so convenient.</p>

List of rarely used job control qualifiers

<i>qualifier</i>	action
	<p>!TXTFORM 3 replaces multiple spaces with Ampersand, appends a double backslash to each line and changes the file extension to say <code>_sln.tex</code> (Latex style). Additional significant digits are reported with these formats. Omitting the qualifier means the standard fixed field format is used. For <code>.yht</code> and <code>.sln</code> files, setting n to -1 means the file is not formed.</p>
New	<p>!TWOWAY modifies the appearance of the variogram calculated from the residuals obtained when the sampling coordinates of the spatial process are defined on a lattice. The default form is based on absolute 'distance' in each direction. This form distinguishes same sign and different sign distances and plots the variances separately as two layers in the same figure.</p>
	<p>!VCC n specifies that n constraints are to be applied to the variance parameters. The constraint lines occur after the G structures are defined. The constraints are described in Section 7.9. The variance header line (Section 7.4) must be present, even if only 0 0 0 indicating there are no explicit R or G structures (see Section 7.9).</p>
New	<p>!VGSECTORS [s] requests that the variogram formed with radial coordinates (see page 18) be based on s (4, 6 or 8) sectors of size $180/s$ degrees. The default is 4 sectors if !VGSECTORS is omitted and 6 sectors if it is specified without an argument. The first sector is centred on the X direction.</p> <p>Figure 5.1 is the variogram using radial coordinates obtained using predictors of random effects fitted as <code>fac(xzca,ysca)</code>. It shows low semivariance in <code>xzca</code> direction, high semivariance in the <code>ysca</code> direction with intermediate values in the 45 and 135 degrees directions.</p>
	<p>!WMF sets hardcopy graphics file type to <code>.wmf</code>.</p>
New	<p>!YHTFORM [f] controls the form of the <code>.yht</code> file !YHTFORM -1 suppresses formation of the <code>.yht</code> file !YHTFORM 1 is TAB separated: <code>.yht</code> becomes <code>_yht.txt</code> !YHTFORM 2 is COMMA separated: <code>.yht</code> becomes <code>_yht.csv</code> !YHTFORM 3 is Ampersand separated: <code>.yht</code> becomes <code>_yht.tex</code></p>
New	<p>!YSS [r] adds r to the total Sum of Squares. This might be used with !DF to add some variance to the analysis when analysing summarised data.</p>

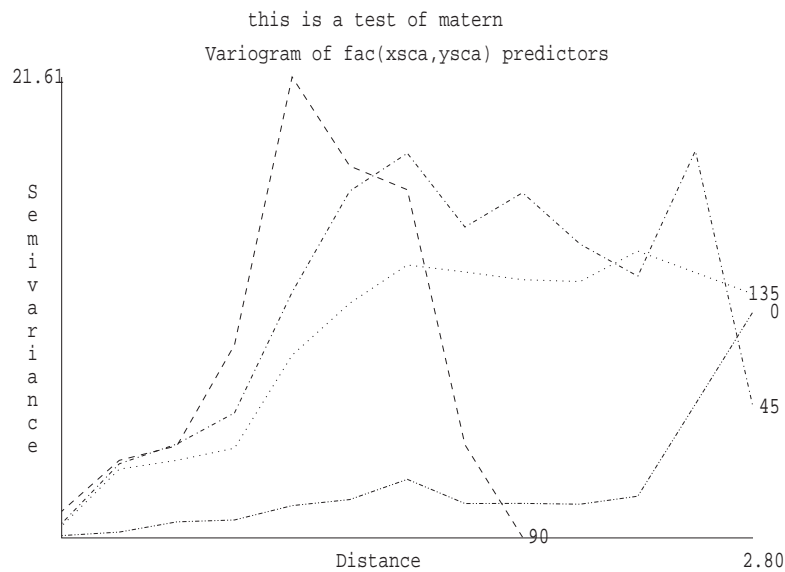


Figure 5.1 Variogram in 4 sectors for Cashmore data

Table 5.6: List of very rarely used job control qualifiers

<i>qualifier</i>	action
<p>New !ALOADINGS <i>i</i></p>	controls modification to AI updates of loadings in factor analytic variance models. After ASReml calculates updates for variance parameters, it checks whether the updates are reasonable and sometimes reduces them. For factor loadings, the default behaviour is to shrink the loadings only in the first iteration if they appear large. This qualifier gives some user control. If it is specified without an argument, no (extra) shrinkage is allowed. Otherwise shrinkage is allowed in the first <i>i</i> iterations.
!CINV <i>n</i>	prints the portion of the inverse of the coefficient matrix pertaining to the n^{th} term in the linear model. Because the model has not been defined when ASReml reads this line, it is up to the user to count the terms in the model to identify the portion of the inverse of the coefficient matrix to be printed. The option is ignored if the portion is not wholly in the SPARSE stored equations. The portion of the inverse is printed to a file with extension .cii The sparse form of the matrix only is printed in the form $i\ j\ C^{ij}$, that is, elements of C^{ij} that were not needed in the estimation process are not included in the file.

List of very rarely used job control qualifiers

<i>qualifier</i>	action
!FACPOINTS <i>n</i>	affects the number of distinct points recognised by the fac() model function (Table 6.1). The default value of <i>n</i> is 1000 so that points closer than 0.1% of the range are regarded as the same point.
!KNOTS <i>n</i>	changes the default knot points used when fitting a spline to data with more than <i>n</i> different values of the spline variable. When there are more than <i>n</i> (default 50) points, ASReml will default to using <i>n</i> equally spaced knot points.
!NOCHECK	forces ASReml to use any explicitly set spline knot points (see !SPLINE) even if they do not appear to adequately cover the data values.
!NOREORDER	prevents the automatic reversal of the order of the fixed terms (in the dense equations) and possible reordering of terms in the sparse equations.
!NOSCRATCH	forces ASReml to hold the data in memory. ASReml will usually hold the data on a scratch file rather than in memory. In large jobs, the system area where scratch files are held may not be large enough. A Unix system may put this file in the /tmp directory which may not have enough space to hold it.
!POLPOINTS <i>n</i>	affects the number of distinct points recognised by the pol() model function (Table 6.1). The default value of <i>n</i> is 1000 so that points closer than 0.1% of the range are regarded as the same point.
!PPOINTS <i>n</i>	influences the number of points used when predicting splines and polynomials. The design matrix generated by the leg() , pol() and spl() functions are modified to include extra rows that are accessed by the PREDICT directive. The default value of <i>n</i> is 21 if there is no !PPOINTS qualifier. The range of the data is divided by <i>n</i> -1 to give a step size <i>i</i> . For each point <i>p</i> in the list, a predict point is inserted at <i>p</i> + <i>i</i> if there is no data value in the interval [<i>p</i> , <i>p</i> +1.1× <i>i</i>]. !PPOINTS is ignored if !PVAL is specified for the variable. This process also effects the number of levels identified by the fac() model term.
!REPORT	forces ASReml to attempt to produce the standard output report when there is a failure of the iteration algorithm. Usually no report is produced unless the algorithm has at least produced estimates for the fixed and random effects in the model. Note that residuals are not included in the output forced by this qualifier. This option is primarily intended to help debugging a job that is not converging properly.

List of very rarely used job control qualifiers

<i>qualifier</i>	action
!SCALE 1	When forming a design matrix for the <code>sp1()</code> model term, ASReml uses a standardized scale (independent of the actual scale of the variable). The qualifier !SCALE 1 forces ASReml to use the scale of the variable. The default standardised scale is appropriate in most circumstances.
New !SCORE	requests ASReml write the SCORE vector and the Average Information matrix to files <i>basename.SCO</i> and <i>basename.AIM</i> . The values written are from the last iteration.
!SLOW <i>n</i>	reduces the update step sizes of the variance parameters more persistently than the !STEP <i>r</i> qualifier. If specified, ASReml looks at the potential size of the updates and if any are large, it reduces the size of <i>r</i> . If <i>n</i> is greater than 10 ASReml also modifies the Information matrix by multiplying the diagonal elements by <i>n</i> . This has the effect of further reducing the updates. This option may help when you do not have good starting values, especially in multivariate analyses.
New !TOLERANCE [<i>s</i> ₁ [<i>s</i> ₂]]	<p>modifies the ability of ASReml to detect singularities in the mixed model equations. This is intended for use on the rare occasions when ASReml detects singularities after the first iteration; they are not expected. Normally (when no !TOLERANCE qualifier is specified), a singularity is declared if the adjusted sum of squares of a covariable is less than a small constant (η) or less than the uncorrected sum of squares $\times \eta$, where η is 10^{-8} in the first iteration and 10^{-10} thereafter. The qualifier scales η by 10^{s_i} for the the first or subsequent iterations respectively, so that it is more likely an equation will be declared singular. Once a singularity is detected, the corresponding equation is dropped (forced to be zero) in subsequent iterations. If neither argument is supplied, 2 is assumed. If the second argument is omitted, it is given the value of the first.</p> <p>If the problem of later singularities arises because of the low coefficient of variation of a covariable, it would be better to centre and rescale the covariable. If the degrees of freedom are correct in the first iteration, the problem will be with the variance parameters and a different variance model (or variance constraints) is required.</p>
New !VRB	requests writing of <code>.vrb</code> file. Previously, the default was to write the file.

6 Command file: Specifying the terms in the mixed model

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Specifying model formulae in ASReml

General rules
Examples

Fixed terms in the model

Primary fixed terms
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Interactions
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Analysis of Variance table

6.1 Introduction

The linear mixed model is specified in ASReml as a series of model terms and qualifiers. In this chapter the model formula syntax is described.

6.2 Specifying model formulae in ASReml

The linear mixed model is specified in ASReml as a series of model terms and qualifiers. Model terms include factor and variate labels (Section 5.4), functions of labels, special terms and interactions of these. The model is specified immediately after the datafile and any job control qualifier and/or tabulate lines. The syntax for specifying the model is

```
NIN Alliance Trial 1989
variety
:
column 11
nin89.asd !skip 1
yield ~ mu variety !r repl,
!f mv
1 2
11 column AR1 .3
22 row AR1 .3
```

response [**!wt** *weight*] ~ *fixed* [**!r** *random*] [**!f** *sparse-fixed*]

- *response* is the label for the response variable(s) to be analysed; multivariate analysis is discussed in Chapter 8,
- *weight* is a label of a variable containing weights; weighted analysis is discussed in Section 6.7,
- ~ separates *response* from the list of fixed and random terms,
- *fixed* represents the list of primary fixed explanatory terms, that is, variates, factors, interactions and special terms for which analysis of variance (ANOVA) type tests are required. See Table 6.1 for a brief definition of reserved model terms, operators and commonly used functions. The full definition is in Section 6.6,
- *random* represents the list of explanatory terms to be fitted as random effects, see Table 6.1,
- *sparse-fixed* are additional fixed terms not included in the ANOVA table.

General rules

The following general rules apply in specifying the linear mixed model

- all elements in the model must be space separated,
- the character ~ separates the response variables(s) from the explanatory variables in the model,

Choose labels that will avoid confusion

- data fields are identified in the model by their labels
 - labels are case sensitive,
 - labels may be abbreviated (truncated) when used in the model line but care must be taken that the truncated form is not ambiguous. If the truncated form matches more than one label, the term associated with the first match is assumed,
 - model terms may only appear once in the model line; repeated occurrences are ignored,
 - model terms other than the original data fields are defined the first time they appear on the model line. They may be abbreviated (truncated) if they are referred to again provided no ambiguity is introduced.
- Important** It is often clearer if labels are not abbreviated. If abbreviations are used then they need to be chosen to avoid confusion.
- if the model is written over several lines, all but the final line must end with a comma to indicate that the list is continued.

In Tables 6.1 and 6.2, the arguments in model term functions are represented by the following symbols

- f — the label of a data variable defined as a model factor,
- k, n — an integer number,
- r — a real number,
- t — a model term label (includes data variables),
- v, y — the label of a data variable,

Parsing of model terms in ASReml is not very sophisticated. Where a model term takes another model term as an argument, the argument must be predefined. If necessary, include the argument in the model line with a leading '-' which will cause the term to be defined but not fitted. For example

```
Trait.male -Trait.female and(Trait.female)
```

Also, `dens` is an abbreviation for `density` but `spl(dens,7)` is a different model term (albiet probably equivalent) to `spl(density,7)` because it does not represent a simple truncation.

Table 6.1: Summary of reserved words, operators and functions

	model term	brief description	common usage	
			fixed	random
reserved	<code>mu</code>	the constant term or intercept	✓	
terms	<code>mv</code>	a term to estimate missing values	✓	
	<code>Trait</code>	multivariate counterpart to <code>mu</code>	✓	
	<code>units</code>	forms a factor with a level for each experimental unit		✓
operators	<code>.</code> or <code>:</code>	placed between labels to specify an interaction	✓	✓
	<code>/</code>	forms nested expansion (Section 6.5)	✓	✓
	<code>*</code>	forms factorial expansion (Section 6.5)	✓	✓
	<code>-</code>	placed before model terms to exclude them from the model	✓	✓
	<code>,</code>	placed at the end of a line to indicate that the model specification continues on the next line		
	<code>+</code>	treated as a space	✓	✓
	<code>!{ ... !}</code>	placed around some model terms when it is important the terms not be reordered (Section 6.4)		✓
commonly used	<code>at(<i>f</i>, <i>n</i>)</code>	condition on level <i>n</i> of factor <i>f</i> . <i>n</i> may be a list of values	✓	✓
functions	<code>at(<i>f</i>)</code>	forms conditioning covariables for all levels of factor <i>f</i>	✓	✓
	<code>fac(<i>v</i>)</code>	forms a factor from <i>v</i> with a level for each unique value in <i>v</i>		✓
	<code>fac(<i>v</i>, <i>y</i>)</code>	forms a factor with a level for each combination of values in <i>v</i> and <i>y</i>		✓
	<code>lin(<i>f</i>)</code>	forms a variable from the factor <i>f</i> with values equal to 1... <i>n</i> corresponding to level(1)...level(<i>n</i>) of the factor	✓	
	<code>spl(<i>v</i> [, <i>k</i>])</code>	forms the design matrix for the random component of a cubic spline for variable <i>v</i>		✓

Summary of reserved words, operators and functions

	model term	brief description	common usage	
			fixed	random
other functions	<code>and(t[,r])</code>	adds r times the design matrix for model term t to the previous design matrix; r has a default value of 1. If t is complex it may be necessary to predefine it by saying <code>-t and(t,r)</code>		
	<code>c(f)</code>	factor f is fitted with <i>sum to zero</i> constraints	✓	
	<code>cos(v,r)</code>	forms cosine from v with period r	✓	
	<code>ge(f)</code>	condition on factor/variable $f \geq r$	✓	
	<code>giv(f,n)</code>	associates the n th <code>.giv</code> G-inverse with the factor f		✓
	<code>gt(f)</code>	condition on factor/variable $f > r$	✓	
	<code>h(f)</code>	factor f is fitted <i>Helmert</i> constraints	✓	
	<code>ide(f)</code>	fits pedigree factor f without relationship matrix		✓
	<code>inv(v[,r])</code>	forms reciprocal of $v + r$	✓	
	<code>le(f)</code>	condition on factor/variable $f \leq r$	✓	
	<code>leg(v,[-]n)</code>	forms $n+1$ Legendre polynomials of order 0 (intercept), 1 (linear)... n from the values in v ; the intercept polynomial is omitted if v is preceded by the negative sign.	✓	
	<code>lt(f)</code>	condition on factor/variable $f < r$	✓	
	<code>log(v[,r])</code>	forms natural logarithm of $v + r$	✓	
	<code>ma1(f)</code>	constructs MA1 design matrix for factor f		✓
	<code>ma1</code>	forms an MA1 design matrix from plot numbers		✓
	<code>out(n)</code>	condition on observation n	✓	
	<code>out(n,t)</code>	condition on record n , trait t	✓	

Summary of reserved words, operators and functions

model term	brief description	common usage	
		fixed	random
<code>pol(v, [-]n)</code>	forms $n+1$ orthogonal polynomials of order 0 (intercept), 1 (linear) . . . n from the values in v ; the intercept polynomial is omitted if n is preceded by the negative sign.	✓	
<code>pow(x, p[, o])</code>	defines the covariable $(x + o)^p$ for use in the model where x is a variable in the data, p is a power and o is an offset.	✓	
<code>qtl(f, p)</code>	impute a covariable from marker map information at position p	✓	
<code>sin(v, r)</code>	forms sine from v with period r	✓	
<code>sqrt(v[, r])</code>	forms square root of $v + r$	✓	
<code>uni(f)</code>	forms a factor with a level for each record where factor f is non-zero		✓
<code>uni(f, n)</code>	forms a factor with a level for each record where factor f has level n		✓
<code>xfa(f, k)</code>	is formally a copy of factor f with k extra levels. This is used when fitting extended factor analytic models (XFA, Table 7.3) of order k .		✓

Examples

ASReml code	action
<code>yield ~ mu variety</code>	fits a model with a constant and fixed variety effects
<code>yield ~ mu variety !r block</code>	fits a model with a constant term, fixed variety effects and random block effects
<code>yield ~ mu time variety time.variety</code>	fits a saturated model with fixed time and variety main effects and time by variety interaction effects
<code>livewt ~ mu breed sex breed.sex !r sire</code>	fits a model with fixed breed, sex and breed by sex interaction effects and random sire effects

6.3 Fixed terms in the model

Primary fixed terms

The *fixed* list in the model formula

- describes the fixed covariates, factors and interactions including special functions to be included in the ANOVA table,
- generally begins with the reserved word `mu` which fits a constant term, mean or intercept, see Table 6.1.

```
NIN Alliance Trial 1989
  variety
:
:
row 22
column 11
nin89.asd !skip 1 !mvinclude
yield ~ mu variety !r repl,
!f mv
1 2
11 column AR1 .3
22 row AR1 .3
```

Sparse fixed terms

The `!f` *sparse_fixed* terms in model formula

- are the fixed covariates (for example, the fixed `lin(row)` covariate now included in the model formula), factors and interactions including special functions and reserved words (for example `mv`, see Table 6.1) for which ANOVA type tests are not required,
- include large (>100 levels) terms.

```
NIN Alliance Trial 1989
variety
:
:
row 22
column 11
nin89.asd !skip 1
yield ~ mu variety !r repl,
!f mv lin(row)
1 2
11 column AR1 .424
22 row AR1 .904
```

6.4 Random terms in the model

The `!r` *random* terms in the model formula

- comprise random covariates, factors and interactions including special functions and reserved words, see Table 6.1,
- involve an initial non-zero variance component or ratio (relative to the residual variance) default 0.1; the initial value can be specified after the model term or if the variance structure is not scaled identity, by syntax described in detail in Chapter 7,
- an initial value of its variance (ratio) may be followed by a `!GP` (keep positive, the default), `!GU` (unrestricted) or `!GF` (fixed) qualifier, see Table 7.4,
- use `!{` and `!}` to group model terms that may not be reordered. Normally ASReml will reorder the model terms in the sparse equations - putting smaller terms first to speed up calculations. However, the order must be preserved if the user defines a structure for a term which also covers the following term(s) (a way of defining a covariance structure across model terms). Grouping is specifically required if the model terms are of differing sizes (number of effects). For example, for traits `weaning_weight` and `yearling_weight`, an animal model with maternal weaning weight should specify model terms


```
!{ Trait.animal at(Trait,1).dam !}
```

 when fitting a genetic covariance between the direct and maternal effects.

```
NIN Alliance Trial 1989
variety
:
:
row 22
column 11
nin89.asd !skip 1
yield ~ mu variety !r repl,
!f mv 1 2
11 column AR1 .424
22 row AR1 .904
```

6.5 Interactions and conditional factors

Interactions

- interactions are formed by joining two or more terms with a ‘.’ or a ‘:’, for example, `a.b` is the interaction of factors `a` and `b`,
- interaction levels are arranged with the levels of the second factor nested within the levels of the first,
- labels of factors including interactions are restricted to 31 characters of which only the first 20 are ever displayed. Thus for interaction terms it is often necessary to shorten the names of the component factors in a systematic way, for example, if `Time` and `Treatment` are defined in this order, the interaction between `Time` and `Treatment` could be specified in the model as `Time.Treat`; remember that the first match is taken so that if the label of each field begins with a different letter, the first letter is sufficient to identify the term,
- interactions can involve model functions,
- `*` indicates factorial expansion (up to 5 way)
 - `a*b` is expanded to `a b a.b`
 - `a*b*c*d` is expanded to
`a b c d a.b a.c a.d b.c b.d c.d a.b.c a.b.d a.c.d b.c.d a.b.c.d`
- `/` indicates nested expansion
 - `a/b` is expanded to `a a.b`
- `a.(b c d) e` is expanded to `a.b a.c a.d e`. This syntax is detected by the string ‘.’ and the closing parenthesis must occur on the same line and before any comma indicating continuation. Any number of terms may be enclosed. Each may have ‘-’ prepended to suppress it from the model. Each enclosed term may have initial values and qualifiers following. For example,

New

```
yield~site site.(lin(row) !r variety),
      at(site,1).(row .3 col .2)
```

expands to

```
yield~site site.lin(row) !r site.variety,
      at(site,1).row .3 at(site,1).col .2
```


Conditional factors

A conditional factor is a factor that is present only when another factor has a particular level.

New

- individual components can be specified using the `at(f, n)` function (see Table 6.2), for example, `at(site, 1).row` will fit `row` as a factor only for site 1,
- a complete set of conditional terms are specified by omitting the level specification in the `at(f)` function provided the correct number of levels of `f` is specified in the field definitions. Otherwise, a list of levels may be specified.
 - `at(f).b` creates a series of model terms representing `b` nested within `a` for any model term `b`. A model term is created for each level of `a`; each has the size of `b`. For example, if `site` and `geno` are factors with 3 and 10 levels respectively, then for `at(site).geno` ASReml constructs 3 model terms `at(site, 1).geno at(site, 2).geno at(site, 3).geno`, each with 10 levels,
 - this is similar to forming an interaction except that a separate model term is created for each level of the first factor; this is useful for random terms when each component can have a different variance. The same effect is achieved by using an interaction (e.g. `site.geno`) and associating a `DIAG` variance structure with the first component (see Section 7.5).

6.6 Alphabetic list of model functions

Table 6.2 presents detailed descriptions of the model functions discussed above. Note that some three letter function names may be abbreviated to the first letter.

Table 6.2: Alphabetic list of model functions and descriptions

model function	action
<code>and(t, r)</code> <code>a(t, r)</code>	overlays (adds) r times the design matrix for model term t to the existing design matrix. Specifically, if the model up to this point has p effects and t has a effects, the a columns of the design matrix for t are multiplied by the scalar r (default value 1.0) and added to the last a of the p columns already defined. The overlaid term must agree in size with the term it overlays. This can be used to force a correlation of 1 between two terms as in a diallel analysis <code>male and(female)</code> assuming the i th male is the same individual as the i th female. Note that if the overlaid term is complex, it must be predefined; e.g. <code>Tr.male -Tr.female and(Tr.female)</code> .

Alphabetic list of model functions and descriptions

model function	action
<code>at(f, n)</code> <code>@(f, n)</code>	defines a binary variable which is 1 if the factor f has level n for the record. For example, to fit a row factor only for site 3, use the expression <code>at(site,3).row..</code> . The string <code>@(</code> is equivalent to <code>at(</code> for this function.
New <code>at(f)</code> <code>@(f)</code>	<code>at(f)</code> is expanded to a series of terms like <code>at(f,i)</code> where i takes the values 01 to the number of levels of factor f . Since this command is interpreted before the data is read, it is necessary to declare the number of levels correctly in the field definition. This extended form may only be used as the first term in an interaction.
<code>at(f, m, n)</code> <code>@(f, m, n)</code>	<code>at(f, i, j, k)</code> is expanded to a series of terms <code>at(f, i) at(f, j) at(f, k)</code> . Similarly, <code>at(f, i).X at(f, j).X at(f, k).X</code> can be written as <code>at(f, i, j, k).X</code> provided <code>at(f, i, j, k)</code> is written as the first component of the interaction. Any number of levels may be listed.
<code>cos(v, r)</code>	forms cosine from v with period r . Omit r if v is radians. If v is degrees, r is 360.
<code>con(f)</code> <code>c(f)</code>	apply <i>sum to zero</i> constraints to factor f . It is not appropriate for random factors and fixed factors with missing cells. ASReml assumes you specify the correct number of levels for each factor. The formal effect of the <code>con()</code> function is to form a model term with the highest level formally equal to minus the sum of the preceding terms. With <i>sum to zero</i> constraints, a missing treatment level will generate a singularity but in the first coefficient rather than in the coefficient corresponding to the missing treatment. In this case, the coefficients will not be readily interpretable. When interacting constrained factors, all cells in the cross-tabulation should have data.
<code>fac(v)</code> <code>fac(v, y)</code>	<code>fac(v)</code> forms a factor with a level for each value of x and any additional points inserted as discussed with the qualifiers <code>!PPPOINTS</code> and <code>!PVAL</code> . <code>fac(v, y)</code> forms a factor with a level for each combination of values from v and y . The values are reported in the <code>.res</code> file.
<code>giv(f, n)</code> <code>g(f, n)</code>	associates the n th <code>.giv</code> G-inverse with the factor. This is used when there is a known (except for scale) G-structure other than the additive inverse genetic relationship matrix. The G-inverse is supplied in a file whose name has the file extension <code>.giv</code> described in Section 9.6

Alphabetic list of model functions and descriptions

model function	action																																																						
New <code>h(f)</code>	<p><code>h(f)</code> requests <code>ASReml</code> to fit the model term for factor f using Helmert constraints. Neither Sum-to-zero nor Helmert constraints generate interpretable effects if singularities occur. <code>ASReml</code> runs more efficiently if no constraints are applied. Following is an example of Helmert and sum-to-zero covariables for a factor with 5 levels.</p> <table border="1"> <thead> <tr> <th></th> <th>H1</th> <th>H2</th> <th>H3</th> <th>H4</th> <th>C1</th> <th>C2</th> <th>C3</th> <th>C4</th> </tr> </thead> <tbody> <tr> <td>F1</td> <td>-1</td> <td>-1</td> <td>-1</td> <td>-1</td> <td>1</td> <td>0</td> <td>0</td> <td>0</td> </tr> <tr> <td>F2</td> <td>1</td> <td>-1</td> <td>-1</td> <td>-1</td> <td>0</td> <td>1</td> <td>0</td> <td>0</td> </tr> <tr> <td>F3</td> <td>0</td> <td>2</td> <td>-1</td> <td>-1</td> <td>0</td> <td>0</td> <td>1</td> <td>0</td> </tr> <tr> <td>F4</td> <td>0</td> <td>0</td> <td>3</td> <td>-1</td> <td>0</td> <td>0</td> <td>0</td> <td>1</td> </tr> <tr> <td>F5</td> <td>0</td> <td>0</td> <td>0</td> <td>4</td> <td>-1</td> <td>-1</td> <td>-1</td> <td>-1</td> </tr> </tbody> </table>		H1	H2	H3	H4	C1	C2	C3	C4	F1	-1	-1	-1	-1	1	0	0	0	F2	1	-1	-1	-1	0	1	0	0	F3	0	2	-1	-1	0	0	1	0	F4	0	0	3	-1	0	0	0	1	F5	0	0	0	4	-1	-1	-1	-1
	H1	H2	H3	H4	C1	C2	C3	C4																																															
F1	-1	-1	-1	-1	1	0	0	0																																															
F2	1	-1	-1	-1	0	1	0	0																																															
F3	0	2	-1	-1	0	0	1	0																																															
F4	0	0	3	-1	0	0	0	1																																															
F5	0	0	0	4	-1	-1	-1	-1																																															
<code>ide(f)</code> <code>i(f)</code>	<p>is used to take a copy of a pedigree factor f and fit it without the genetic relationship covariance. This facilitates fitting a <i>second animal effect</i>. Thus, to form a direct, maternal genetic and maternal environment model, the maternal environment is defined as a second animal effect coded the same as dams. <i>viz.</i> <code>!r !{ animal dam !} ide(dam)</code></p>																																																						
<code>inv(v[,r])</code>	<p>forms the reciprocal of $v + r$. This may also be used to transform the response variable.</p>																																																						
<code>leg(v, [-]n)</code>	<p>forms $n+1$ Legendre polynomials of order 0 (intercept), 1 (linear)... n from the values in v; the intercept polynomial is omitted if n is preceded by the negative sign. The actual values of the coefficients are written to the <code>.res</code> file. This is similar to the <code>pol()</code> function described below.</p>																																																						
<code>lin(f)</code> <code>l(f)</code>	<p>takes the coding of factor f as a covariate. The function is defined for f being a simple factor, <code>Trait</code> and <code>units</code>. The <code>lin(f)</code> function does not centre or scale the variable. Motivation: Sometimes you may wish to fit a covariate as a random factor as well. If the coding is say $1..n$, then you should define the field as a factor in the field definition and use the <code>lin()</code> function to include it as a covariate in the model. Do not centre the field in this case. If the covariate values are irregular, you would leave the field as a covariate and use the <code>fac()</code> function to derive a factor version.</p>																																																						
<code>log(v[,r])</code>	<p>forms the natural log of $v + r$. This may also be used to transform the response variable.</p>																																																						
<code>ma1</code> <code>ma1(f)</code>	<p>creates a first-differenced (by rows) design matrix which, when defining a random effect, is equivalent to fitting a moving average variance structure in one dimension. In the <code>ma1</code> form, the first-difference operator is coded across all data points (assuming they are in time/space order). Otherwise the coding is based on the codes in the field indicated.</p>																																																						
<code>mu</code>	<p>is used to fit the intercept/constant term. It is normally present and listed first in the model. It should be present in the model if there are no other fixed factors or if all fixed terms are covariates or contrasts except in the special case of regression through the origin.</p>																																																						

Alphabetic list of model functions and descriptions

model function	action
<code>mv</code>	<p>is used to estimate missing values in the response variable. Formally this creates a model term with a column for each missing value. Each column contains zeros except for a solitary -1 in the record containing the corresponding missing value. This is used in spatial analyses so that computing advantages arising from a balanced spatial layout can be exploited. The equations for <code>mv</code> and any terms that follow are always included in the sparse set of equations.</p> <p>Missing values are handled in three possible ways during analysis (see Section 6.10). In the simplest case, records containing missing values in the response variable are deleted. For multivariate (including some repeated measures) analysis, records with missing values are not deleted but <code>ASReml</code> drops the missing observation and uses the appropriate unstructured R-inverse matrix. For regular spatial analysis, we prefer to retain separability and therefore estimate the missing value(s) by including the special term <code>mv</code> in the model.</p>
<p><code>out(<i>n</i>)</code> <code>out(<i>n</i>,<i>t</i>)</code></p> <p>New</p>	<p><code>out(<i>n</i>)</code>, <code>out(<i>n</i>,<i>t</i>)</code> establishes a binary variable which is:</p> <p style="padding-left: 2em;"><code>out(<i>i</i>)</code> 1 if data relates to observation <i>i</i>, (trait 1), else is 0 <code>out(<i>i</i>,<i>t</i>)</code> 1 if data relates to observation <i>i</i>, (trait <i>t</i>), else is 0</p> <p>The intention is that this be used to test/remove single observations for example to remove the influence of an outlier or influential point. Possible outliers will be evident in the plot of residuals versus fitted values (see the <code>.res</code> file) and the appropriate record numbers for the <code>out()</code> term are reported in the <code>.res</code> file. Note that <i>i</i> relates to the data analysed and will not be the same as the record number as obtained by counting data lines in the data file if there were missing observations in the data and they have not been estimated. (To drop records based on the record number in the data file, use the <code>!D</code> transformation in association with the <code>!=V0</code> transformation.)</p>
<p><code>pol(<i>v</i>,<i>n</i>)</code> <code>p(<i>v</i>,<i>n</i>)</code></p>	<p>forms a set of orthogonal polynomials of order <code>|n|</code> based on the unique values in variate (or factor) <i>v</i> and any additional interpolated points, see <code>!PPOINTS</code> and <code>!PVAL</code> in Table 5.4. It includes the intercept if <i>n</i> is positive, omits it if <i>n</i> is negative. For example, <code>pol(time,2)</code> forms a design matrix with three columns of the orthogonal polynomial of degree 2 from the variable <code>time</code>. Alternatively, <code>pol(time,-2)</code> is a term with two columns having centred and scaled linear coefficients in the first column and centred and scaled quadratic coefficients in the second column.</p> <p>The actual values of the coefficients are written to the <code>.res</code> file. This factor could be interacted with a design factor to fit random regression models. The <code>leg()</code> function differs from the <code>pol()</code> function in the way the quadratic and higher polynomials are calculated.</p>

Alphabetic list of model functions and descriptions

model function	action
<code>pow(x, p[, o])</code>	defines the covariable $(x + o)^p$ for use in the model where x is a variable in the data, p is a power and o is an offset. <code>pow(x, 0.5[, o])</code> is equivalent to <code>sqr(x[, o])</code> ; <code>pow(x, 0[, o])</code> is equivalent to <code>log(x[, o])</code> ; <code>pow(x, -1[, o])</code> is equivalent to <code>inv(x[, o])</code> .
New <code>qtl(f, r)</code>	calculates an expected marker state from flanking marker information at position r of the linkage group f (see <code>!MM</code> to define marker locations). r may be specified as <code>\$TPn</code> where <code>\$TPn</code> has been previously internally defined with a <code>predict</code> statement (see page 164). r should be given in Morgans.
<code>sin(v, r)</code>	forms sine from v with period r . Omit r if v is radians. If v is degrees, r is 360.
<code>spl(v [, k])</code> <code>s(v [, k])</code>	In order to fit spline models associated with a variate v and k knot points in <code>ASReml</code> , v is included as a covariate in the model and <code>spl(v, k)</code> as a random term. The knot points can be explicitly specified using the <code>!SPLINE</code> qualifier (Table 5.4). If k is specified but <code>!SPLINE</code> is not specified, equally spaced points are used. If k is not specified and there are less than 50 unique data values, they are used as knot points. If there are more than 50 unique points then 50 equally spaced points will be used. The spline design matrix formed is written to the <code>.res</code> file. An example of the use of <code>spl()</code> is <code>price ~ mu week !r spl(week)</code>
<code>sqrt(v[, r])</code>	forms the square root of $v + r$. This may also be used to transform the response variable.
<code>Trait</code>	is used with multivariate data to fit the individual trait means. It is formally equivalent to <code>mu</code> but <code>Trait</code> is a more natural label for use with multivariate data. It is interacted with other factors to estimate their effects for all traits.
<code>units</code>	creates a factor with a level for every record in the data file. This is used to fit the 'nugget' variance when a correlation structure is applied to the residual.
<code>uni(f[, 0[, n]])</code>	creates a factor with a new level whenever there is a level present for the factor f . Levels (effects) are not created if the level of factor f is 0, missing or negative. The size may be set in the third argument by setting the second argument to zero.

Alphabetic list of model functions and descriptions

model function	action
<code>uni(f,k[,n])</code>	creates a factor with a level for every record subject to the factor level of f equalling k , i.e. a new level is created for the factor whenever a new record is encountered whose integer truncated data value from data field f is k . Thus <code>uni(site,2)</code> would be used to create an independent error term for site 2 in a multi-environment trial and is equivalent to <code>at(site,2).units</code> . The default size of this model term is the number of data records. The user may specify a lower number as the third argument. There is little computational penalty from the default but the <code>.sln</code> file may be substantially larger than needed.
<code>xfa(f,k)</code>	Factor analytic models are discussed in Chapter 7. There are three forms, <code>FAk</code> , <code>FACVk</code> and <code>XFAk</code> where k is the number of factors. The <code>XFAk</code> form is a sparse formulation that requires an extra k levels to be inserted into the mixed model equations for the k factors. This is achieved by the <code>xfa(f,k)</code> model function which defines a design matrix based on the design matrix for f augmented with k columns of zeros for the k factors.

6.7 Weights

Weighted analyses are achieved by using `!WT weight` as a qualifier to the response variable. An example of this is `y !WT wt ~ mu A X` where `y` is the name of the response variable and `wt` is the name of a variate in the data containing weights. If these are relative weights (to be scaled by the `units` variance) then this is all that is required. If they are absolute weights, that is, the reciprocal of known variances, use the `!S2==1` qualifier described in Table 7.4 to fix the unit variance. When a structure is present in the residuals the weights are applied as a matrix product. If Σ is the structure and \mathbf{W} is the diagonal matrix constructed from the square root of the values of the variate weight, then $\mathbf{R}^{-1} = \mathbf{W}\Sigma^{-1}\mathbf{W}$. Negative weights are treated as zeros.

caution

6.8 Generalized Linear Models

ASReml includes facilities for fitting the family of Generalized Linear Models (GLMs, McCullagh and Nelder, 1994). GLMs are specified by qualifiers after the name of the dependent variable but before the `~` character. Table 6.3 lists the link

function qualifiers which relate the linear predictor (η) scale to the observation ($\mu = E[y]$) scale. Table 6.4 lists the distributions and other qualifiers.

A second dependent variable may be specified if a bivariate analysis is required but it will always be treated as a normal variate (no syntax is provided for specifying GLM attributes for it). The !ASUV qualifier is required in this situation for the GLM weights to be utilized.

Table 6.3 Link qualifiers and functions

Qualifier	Link	Inverse Link	Available with
!IDENTITY	$\eta = \mu$	$\mu = \eta$	All
!SQRT	$\eta = \sqrt{\mu}$	$\mu = \eta^2$	Poisson
!LOGARITHM	$\eta = \ln(\mu)$	$\mu = \exp(\eta)$	Normal, Poisson, Negative Binomial, Gamma
!INVERSE	$\eta = 1/\mu$	$\mu = 1/\eta$	Normal, Gamma, Negative Binomial
!LOGIT	$\eta = \mu/(1 - \mu)$	$\mu = \frac{1}{(1 + \exp(-\eta))}$	Binomial
!PROBIT	$\eta = \Phi^{-1}(\mu)$	$\mu = \Phi(\eta)$	Binomial
!COMPLOGLOG	$\eta = \ln(-\ln(1 - \mu))$	$\mu = 1 - e^{-e^\eta}$	Binomial

where μ is the mean on the data scale and $\eta = \mathbf{X}\boldsymbol{\tau}$ is the linear predictor on the underlying scale.

Table 6.4: GLM qualifiers

qualifiers	action
Distributions	where μ is the mean on the data scale calculated from $\eta = \mathbf{X}\boldsymbol{\tau}$, n is the count specified by the !TOTAL qualifier, v is the variance expression for the distribution, d is the deviance expression for the distribution, y is the observation and ϕ is a parameter set with the !PHI qualifier. The default link is listed first followed by permitted alternatives.
!NORMAL [!LOGARITHM | !INVERSE]	The model is fitted on the log/inverse scale but the residuals are on the natural scale.

GLM qualifiers

qualifier	action
!BINOMIAL [!LOGIT | !IDENTITY | !PROBIT | !COMPLOGLOG] [!TOTAL n] $v = \mu(1 - \mu)/n$ $d = 2n(y \ln(y/\mu) + (1 - y) \ln(\frac{1-y}{1-\mu}))$	Proportions or counts [r] are indicated if !TOTAL specifies the variate containing the binomial totals. Proportions are assumed if no response value exceeds 1. A binary variate [0, 1] is indicated if !TOTAL is unspecified. The expression for d on the left applies when y is proportions (or binary). The logit is the default link function. The variance on the underlying scale is $\pi^2/3 \sim 3.3$ (underlying logistic distribution) for the logit link.
!POISSON [!LOGARITHM | !IDENTITY | !SQRT] $v = \mu$ $d = 2(y \ln(y/\mu) - (y - \mu))$	Natural logarithms are the default link function. ASReml assumes the Poisson variable is not negative.
!GAMMA [!INVERSE | !IDENTITY | !LOGARITHM] [!PHI ϕ] [!TOTAL n] $v = \mu^2/(\phi n)$ $d = 2n(-\phi \ln(\frac{\phi y}{\mu}) + \frac{\phi y - \mu}{\mu})$	The inverse is the default link function. n is defined with the !TOTAL qualifier and would be degrees of freedom in the typical application to mean-squares. The default value of ϕ is 1.
!NEGBIN [!LOGARITHM | !IDENTITY | !INVERSE] [!PHI ϕ] $v = \mu + \mu^2/\phi$ $d = 2((\phi + y) \ln(\frac{\mu + \phi}{y + \phi}) + y \ln(\frac{y}{\mu}))$	fits the Negative Binomial distribution. Natural logarithms are the default link function. The default value of ϕ is 1.

General qualifiers

!AOD New Caution	requests an Analysis of Deviance table be generated. This is formed by fitting a series of sub models for terms in the DENSE part building up to the full model, and comparing the deviances. An example if its use is <code>LS !BIN !TOT COUNT !AOD ~ mu SEX GROUP</code> !AOD may not be used in association with PREDICT .
!DISP [h]	includes an <i>overdispersion</i> scaling parameter (h) in the weights. If !DISP is specified with no argument, ASReml estimates it as the residual variance of the working variable. Traditionally it is estimated from the deviance residuals, reported by ASReml as Variance heterogeneity . An example if its use is <code>count !POIS !DISP ~ mu group</code>

GLM qualifiers

qualifier	action
<code>!OFFSET [o]</code>	<p>is used especially with binomial data to include an offset in the model where o is the number or name of a variable in the data. The offset is only included in binomial and Poisson models (for Normal models just subtract the offset variable from the response variable), for example</p> <pre>count !POIS !OFFSET base !DISP ~ mu group</pre> <p>The offset is included in the model as $\eta = \mathbf{X}\tau + o$. The offset will often be something like $\ln(n)$.</p>
<code>!TOTAL [n]</code>	<p>is used especially with binomial data where n is the field containing the total counts for each sample. If omitted, count is taken as 1.</p>
<p>Residual qualifiers control the form of the residuals returned in the <code>.yht</code> file. The predicted values returned in the <code>.yht</code> file will be on the linear predictor scale if the <code>!WORK</code> or <code>!PVW</code> qualifiers are used. They will be on the observation scale if the <code>!DEVIANCE</code>, <code>!PEARSON</code>, <code>!RESPONSE</code> or <code>!PVR</code> qualifiers are used.</p>	
<code>!DEVIANCE</code>	<p>produces deviance residuals, the signed square root of d/h from Table 6.4 where h is the dispersion parameter controlled by the <code>!DISP</code> qualifier. This is the default.</p>
<code>!PEARSON</code>	<p>writes Pearson residuals, $\frac{y-\mu}{\sqrt{v}}$, in the <code>.yht</code> file</p>
<code>!PVR</code>	<p>writes fitted values on the response scale in the <code>.yht</code> file. This is the default.</p>
<code>!PVW</code>	<p>writes fitted values on the linear predictor scale in the <code>.yht</code> file.</p>
<code>!RESPONSE</code>	<p>produces simple residuals, $y - \mu$</p>
<code>!WORK</code>	<p>produces residuals on the linear predictor scale, $\frac{y-\mu}{d\mu/d\eta}$</p>

6.9 Generalized Linear Mixed Models

This section was written by Damian Collins

There is the capacity to fit a wider class of models which include additional random effects for non-normal error distributions. The inclusion of random terms in a GLM is usually referred to as a Generalized Linear Mixed Model (GLMM). For GLMMs, ASReml uses what is commonly referred to as penalized quasi-

likelihood or PQL (Breslow and Clayton, 1993). The technique is also known by other names, including Schall's technique (Schall, 1991), pseudo-likelihood (Wolfinger and O'Connell, 1993) and joint maximisation (Harville and Mee, 1984, Gilmour *et al.*, 1985). It is implemented in many statistical packages, for instance, in the GLMM procedure (Welham, 2005) and the IRREML procedure of Genstat (Keen, 1994), in MLwiN (Goldstein *et al.*, 1998), in the GLMMIXED macro in SAS and in the GLMMPQL function in R, to name a few.

The PQL technique is based on a first order Taylor series approximation to the likelihood. It has been shown to perform poorly for certain types of GLMMs. In particular, for binary GLMMs where the number of random effects is large compared to the number of observations, it can underestimate the variance components severely (50%) (e.g. Breslow and Lin, 1995, Goldstein and Rasbash, 1996, Rodriguez and Goldman, 2001, Waddington *et al.*, 1994). For other types of GLMMs, such as Poisson data with many observations per random effect, it has been reported to perform quite well (e.g. Breslow, 2003). As well as the above references, users can consult McCulloch and Searle (2001) for more information about GLMMs.

Most studies investigating PQL have focussed on estimation bias. Much less attention has been given to the wider inferential issues such as hypothesis testing. In addition, the performance of this technique has only been assessed on a small set of relatively simple GLMMs. Anecdotal evidence from users suggests that this technique can give very misleading results in certain situations.

Caution Therefore we cannot recommend the use of this technique for general use. It is included in the current version of ASReml for advanced users. It is highly recommended that its use be accompanied by some form of cross-validators assessment for the specific dataset concerned. For instance, one way of doing this would be by simulating data using the same design and using parameter values similar to the parameter estimates achieved, such as used in Millar and Willis (1999).

Caution The standard GLM Analysis of Deviance (!AOD) should not be used when there are random terms in the model as the variance components are reestimated for each submodel.

6.10 Missing values

Missing values in the response

It is sometimes computationally convenient to estimate missing values, for example, in spatial analysis of regular arrays, see example **3a** in Section 7.3. Missing values are estimated if the model term `mv` is included in the model. Formally, `mv` creates a factor with a covariate for each missing value. The covariates are coded 0 except in the record where the particular missing value occurs, where it is coded -1.

```
NIN Alliance Trial 1989
variety
:
row 22
column 11
nin89.asd !skip 1
yield ~ mu variety !r repl,
!f mv
1 2
11 column AR1 .424
22 row AR1 .904
```

The action when `mv` is omitted from the model depends on whether a univariate or multivariate analysis is being performed. For a univariate analysis, `ASReml` discards records which have a missing response. In multivariate analyses, all records are retained and the `R` matrix is modified to reflect the missing value pattern.

Missing values in the explanatory variables

`ASReml` will abort the analysis if it finds missing values in the design matrix unless `!MVINCLUDE` or `!MVREMOVE` is specified, see Section 5.8. `!MVINCLUDE` causes the missing value to be treated as a zero. `!MVREMOVE` causes `ASReml` to discard the whole record. Records with missing values in particular fields can be explicitly dropped using the `!D` transformation, Table 5.1.

Covariates: Treating missing values as zero in covariates is usually only sensible if the covariate is centred (has mean of zero).

Design factors: Where the factor level is zero (or missing and the `!MVINCLUDE` qualifier is specified), no level is assigned to the factor for that record.

6.11 Some technical details about model fitting in `ASReml`

Sparse versus dense

`ASReml` partitions the terms in the linear model into two parts: a *dense* set and a *sparse* set. The partition is at the `!r` point unless explicitly set with

the `!DENSE` data line qualifier or `mv` is included before `!r`, see Table 5.5. The special term `mv` is always included in sparse. Thus *random* and *sparse* terms are estimated using sparse matrix methods which result in faster processing. The inverse coefficient matrix is fully formed for the terms in the dense set. The inverse coefficient matrix is only partially formed for terms in the sparse set. Typically, the sparse set is large and sparse storage results in savings in memory and computing. A consequence is that the variance matrix for estimates is only available for equations in the dense portion.

Ordering of terms in ASReml

The order in which estimates for the fixed and random effects in linear mixed model are reported will usually differ from the order the model terms are specified. Solutions to the mixed model equations are obtained using the methods outlined Gilmour *et al.*, 1995. ASReml orders the equations in the sparse part to maintain as much sparsity as it can during the solution. After absorbing them, it absorbs the model terms associated with the dense equations in the order specified.

Aliasing and singularities

A singularity is reported in ASReml when the diagonal element of the mixed model equations is effectively zero (see the `!TOLERANCE` qualifier) during absorption. It indicates there is either

- no data for that fixed effect, or
- a linear dependence in the design matrix means there is no information left to estimate the effect.

ASReml handles singularities by using a generalized inverse in which the singular row/column is zero and the associated fixed effect is zero. Which equations are singular depends on the order the equations are processed. This is controlled by ASReml for the sparse terms but by the user for the dense terms. They should be specified with main effects before interactions so that the ANOVA table has correct marginalization. Since ASReml processes the dense terms from the bottom up, the first level (the last level processed) is often singular.

The number of singularities is reported in the `.asr` file immediately prior to the REML log-likelihood (LogL) line for that iteration (see Section 13.3). The effects (and associated standard or prediction error) which correspond to these singularities are zero in the `.sln` file.

Warning

Singularities in the *sparse-fixed* terms of the model may change with changes in the random terms included in the model. If this happens it will mean that changes in the REML log-likelihood are not valid for testing the changes made to the random model. This situation is not easily detected as the only evidence will be in the `.sln` file where different fixed effects are singular. A likelihood ratio test is not valid if the fixed model has changed.

Examples of aliasing

The sequence of models in Table 6.5 are presented to facilitate an understanding of over-parameterised models. It is assumed that `var` is a factor with 4 levels, `trt` with 3 levels and `rep` with 3 levels and that all `var.trt` combinations are present in the data.

Table 6.5: Examples of aliasing in ASReml

model	number of singularities	order of fitting
<code>yield ~ var !r rep</code>	0	<code>rep var</code>
<code>yield ~ mu var !r rep</code>	1	<code>rep mu var</code> first level of <code>var</code> is aliased and set to zero
<code>yield ~ var trt !r rep</code>	1	<code>rep var trt</code> <code>var</code> fully fitted, first level of <code>trt</code> is aliased and set to zero
<code>yield ~ mu var trt, var.trt !r rep</code>	8	<code>rep mu var trt var.trt</code> first levels of both <code>var</code> and <code>trt</code> are aliased and set to zero, together with subsequent interactions
<code>yield ~ mu var trt !r rep, !f var.trt</code>	8	<code>[var.trt rep] mu var trt</code> <code>var.trt</code> fitted before <code>mu</code> , <code>var</code> and <code>trt</code> , <code>var.trt</code> fully fitted; <code>mu</code> , <code>var</code> and <code>trt</code> are completely singular and set to zero. The order within <code>[var.trt rep]</code> is determined internally.

6.12 Analysis of variance table

The ANOVA table has 4 forms:

```

Source   DF          F_inc
Source   DF          F_inc  F_con M
Source   DF  DDF_inc  F_inc          P_inc
Source   DF  DDF_con  F_inc  F_con M  P_con

```

depending on whether conditional F-statistics are reported (requested by the !FCON qualifier) and whether the denominator degrees of freedom are reported. ASReml always reports incremental F-statistics (F_inc) for the fixed model terms (in the DENSE partition) conditional in the order the terms were nominated in the model. Users should study Section 2.6 to understand the contents of this table. The 'conditional maximum' model used as the basis for the conditional F-statistic is spelt out in the .aov file described in section .

The numerator degrees of freedom for each term is easily determined as the number of non-singular equations involved in the term. However, in general, calculation of the denominator degrees of freedom is not trivial. ASReml will by default attempt the calculation for small analyses, by one of two methods. In larger analyses, users can request the calculation be attempted using the !DDF qualifier (page 68). Use !DDF -1 to prevent the calculation.

7

Command file: Specifying variance structures

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Non-singular variance matrices

Variance model specification in ASReml

A sequence of structures for the NIN data

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Rules for combining variance models

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Constraining variance parameters

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Constraints between and within variance models

Model building using the !CONTINUE qualifier

7.1 Introduction

The subject of this chapter is variance model specification in ASReml. ASReml allows a wide range of models to be fitted. The key concepts you need to understand are

- the mixed linear model $\mathbf{y} = \mathbf{X}\boldsymbol{\tau} + \mathbf{Z}\mathbf{u} + \mathbf{e}$ has a residual term $\mathbf{e} \sim N(\mathbf{0}, \mathbf{R})$ and random effects $\mathbf{u} \sim N(\mathbf{0}, \mathbf{G})$,
- we use the terms R structure and G structure to refer to the independent blocks of R and G respectively,
- R and G structures are typically formed as a direct product of particular variance models,
- the order of terms in a direct product must agree with the order of effects in the corresponding model term,
- variance models may be correlation matrices or variance matrices with equal or unequal variances on the diagonal. A model for a correlation matrix (eg. AR1) can be converted to an equal variance form (eg. AR1V) and to a heterogeneous variance form (eg. AR1H),
- variances are sometimes estimated as variance ratios (relative to the residual variance).

These issues are fully discussed in Chapter 2. In this chapter we begin by considering an ordered sequence of variance structures for the NIN variety trial (see Section 7.3). This is to introduce variance modelling in practice. We then present the topics in detail.

Non singular variance matrices

When undertaking the REML estimation, ASReml needs to invert each variance matrix. For this it requires that the matrices be negative definite or positive definite. They must not be singular. Negative definite matrices will have negative elements on the diagonal of the matrix and/or its inverse. The exception is the XFA model which has been specifically designed to fit singular matrices (Thompson *et al.* 2003).

Let $\mathbf{x}'\mathbf{A}\mathbf{x}$ represent an arbitrary quadratic form for $\mathbf{x} = (x_1, \dots, x_n)'$. The quadratic form is said to be nonnegative definite if $\mathbf{x}'\mathbf{A}\mathbf{x} \geq 0$ for all $\mathbf{x} \in \mathbf{R}^n$. If $\mathbf{x}'\mathbf{A}\mathbf{x}$ is nonnegative definite and in addition the null vector $\mathbf{0}$ is the only value of \mathbf{x} for which $\mathbf{x}'\mathbf{A}\mathbf{x} = 0$, then the quadratic form is said to be positive definite. Hence the matrix \mathbf{A} is said to be positive definite if $\mathbf{x}'\mathbf{A}\mathbf{x}$ is positive definite, see Harville (1997), pp 211.

7.2 Variance model specification in ASReml

The variance models are specified in the ASReml command file after the model line, as shown in the code box. In this case just one variance model is specified (for replicates, see model **2b** below for details). `predict` and `tabulate` lines may appear after the model line and before the first variance structure line. These are described in Chapter 10.

```
NIN Alliance Trial 1989
  variety !A
:
column 11
nin89.asd !skip 1
yield ~ mu variety !r repl
0 0 1
repl 1
repl 0 IDV 0.1
```

Table 7.3 presents the full range of variance models available in ASReml. The identifiers for specifying the individual variance models in the command file are described in Section 7.5 under Specifying variance models in ASReml. Many of the models are correlation models. However, these are generalized to homogeneous variance models by appending **V** to the base identifier. They are generalized to heterogeneous variance models by appending **H** to the base identifier.

7.3 A sequence of structures for the NIN data

Eight variance structures of increasing complexity are now considered for the NIN field trial data (see Chapter 3 for an introduction to these data). This is to give a feel for variance modelling in ASReml and some of the models that are possible.

See Section 2.1 Before proceeding, it is useful to link this section to the algebra of Chapter 2. In this case the mixed linear model is

$$\mathbf{y} = \mathbf{X}\boldsymbol{\tau} + \mathbf{Z}\mathbf{u} + \mathbf{e}$$

where \mathbf{y} is the vector of yield data, $\boldsymbol{\tau}$ is a vector of fixed variety effects but would also include fixed replicate effects in a simple RCB analysis and might also include fixed missing value effects when spatial models are considered, $\mathbf{u} \sim N(\mathbf{0}, \mathbf{G})$ is a vector of random effects (for example, random replicate effects) and the errors are in $\mathbf{e} \sim N(\mathbf{0}, \mathbf{R})$. The focus of this discussion is on

- changes to \mathbf{u} and \mathbf{e} and the assumptions about these terms,
- the impact this has on the specification of the **G** structures for \mathbf{u} and the **R** structures for \mathbf{e} .

1 Traditional randomised complete block (RCB) analysis

The only random term in a traditional RCB analysis of these data is the (residual) error term $e \sim N(\mathbf{0}, \sigma_e^2 \mathbf{I}_{224})$. The model therefore involves just one R structure and no G structures ($\mathbf{u} = \mathbf{0}$). In ASReml

- the error term is implicit in the model and is not formally specified on the model line,
- the IID variance structure ($\mathbf{R} = \sigma_e^2 \mathbf{I}_{224}$) is the default for error.

```
NIN Alliance Trial 1989
variety !A
id
pid
raw
repl 4
:
:
row 22
column 11
nin89.asd !skip 1
yield ~ mu variety repl
```

Important The error term is *always* present in the model but its variance structure does not need to be formally declared when it has the default IID structure.

2a Random effects RCB analysis

The random effects RCB model has 2 random terms to indicate that the total variation in the data is comprised of 2 components, a random replicate effect $\mathbf{u}_r \sim N(\mathbf{0}, \gamma_r \sigma_e^2 \mathbf{I}_4)$ where $\gamma_r = \sigma_r^2 / \sigma_e^2$, and error as in **1**. This model involves both the original implicit IID R structure and an implicit IID G structure for the random replicates. In ASReml

- IID variance structure is the default for random terms in the model.

```
NIN Alliance Trial 1989
variety !A
id
pid
raw
repl 4
:
:
row 22
column 11
nin89.asd !skip 1
yield ~ mu variety !r repl
```

For this reason the only change to the former command file is the insertion of **!r** before **repl**. **Important** All random terms (other than error which is implicit) must be written after **!r** in the model specification line(s). [See Section 6.4](#)

2b Random effects RCB analysis with a G structure specified

This model is equivalent to **2a** but we explicitly specify the G structure for `repl`, that is, $\mathbf{u}_r \sim N(\mathbf{0}, \gamma_r \sigma_e^2 \mathbf{I}_4)$, to introduce the syntax.

See Section 7.4

The `0 0 1` line is called the *variance header* line. In general, the first two elements of this line refer to the R structures and the third element is the number of G structures. In this case `0 0` tells ASReml that there are no explicit R structures but there is one G structure (1). The next two lines define the G structure. The first line, a *G structure header line*, links the structure that follows to a term in the linear model (`repl`) and indicates that it involves

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one variance model (1) (a 2 would mean that the structure was the direct product of two variance models). The second line tells ASReml that the variance model for replicates is IDV of order 4 ($\sigma_r^2 \mathbf{I}_4$). The `0.1` is a starting value for $\gamma_r = \sigma_r^2 / \sigma_e^2$; a starting value must be specified. Finally, the second element (0) on the last line of the file indicates that the effects are in standard order. There is almost always a 0 (no sorting) in this position for G structures. The following points should be noted:

```
NIN Alliance Trial 1989
variety !A
id
pid
raw
repl 4
:
:
row 22
column 11
nin89.asd !skip 1
yield ~ mu variety !r repl
0 0 1
repl 1
4 0 IDV 0.1
```

- the 4 on the final line could have been written as `repl` to give

```
repl 0 IDV 0.1
```

This would tell ASReml that the order or dimension of the IDV variance model is equal to the number of levels in `repl` (4 in this case),

- when specifying G structures, the user should ensure that one scale parameter is present. ASReml does not automatically include and estimate a scale parameter for a G structure when the explicit G structure does not include one. For this reason
 - the model supplied when the G structure involves just one variance model must *not* be a correlation model (all diagonal elements equal 1),
 - all but one* of the models supplied when the G structure involves more than one variance model *must* be correlation models; the other must be either an homogeneous or a heterogeneous variance model (see Section 7.5 for the distinction between these models; see also **5** for an example),
- an initial value must be supplied for all parameters in G structure definitions. ASReml expects initial values immediately after the variance model identifier

See Sections 2.1 and 7.5

or on the next line (0.1 directly after IDV in this case),

- 0 is ignored as an initial value on the model line,
- if there is no initial value after the identifier, ASReml will look on the next line,
- if ASReml does not find an initial value it will stop and give an error message in the .asr file,

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- in this case $V = \sigma_r^2 \mathbf{Z}_r \mathbf{Z}_r' + \sigma_e^2 \mathbf{I}_{224}$ which is fitted as $\sigma_e^2 (\gamma_r \mathbf{Z}_r \mathbf{Z}_r' + \mathbf{I}_{224})$ where γ_r is a variance ratio ($\gamma_r = \sigma_r^2 / \sigma_e^2$) and σ_e^2 is the scale parameter. Thus 0.1 is a reasonable initial value for γ_r regardless of the scale of the data.

3a Two-dimensional spatial model with spatial correlation in one direction

This code specifies a two-dimensional spatial structure for error but with spatial correlation in the row direction only, that is, $e \sim N(\mathbf{0}, \sigma_e^2 \mathbf{I}_{11} \otimes \Sigma_r(\rho_r))$. The variance header line tells ASReml that there is one R structure (1) which is a direct product of two variance models (2); there are no G structures (0). The next two lines define the components of the R structure. A structure definition line must be specified for *each* component. For $V = \sigma_e^2 \mathbf{I}_{11} \otimes \Sigma(\rho_r)$, the first matrix is an identity matrix of order 11 for columns (ID), the second matrix is a first order autoregressive correlation matrix of order 22 for rows (AR1) and the variance scale parameter σ_e^2 is implicit. Note the following:

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```
NIN Alliance Trial 1989
  variety !A
  id
  pid
  raw
  repl 4
  :
  row 22
  column 11
  nin89aug.asd !skip 1
  yield ~ mu variety !f mv
  1 2 0
  11 column ID
  22 row AR1 0.3
```

- placing `column` and `row` in the second position on lines 1 and 2 respectively tells ASReml to internally sort the data *rows within columns* before processing the job. This is to ensure that the data matches the direct product structure specified. If `column` and `row` were replaced with 0 in these two lines, ASReml would assume that the data were already sorted in this order (which is not true in this case),
- the 0.3 on line 2 is a starting value for the autoregressive row correlation. Note that for spatial analysis in two dimensions using a separable model, a complete matrix or array of plots must be present. To achieve this we augmented the data with the 18 records for the missing yields as shown on page 30. In the

augmented data file the yield data for the missing plots have all been made NA (one of the missing value indicators in ASReml) and `variety` has been arbitrarily coded `LANCER` for all of the missing plots (any of the variety names could have been used),

See Chapter 13
See Sections 6.3
and 6.11

- `!f mv` is now included in the model specification. This tells ASReml to estimate the missing values. The `!f` before `mv` indicates that the missing values are fixed effects in the *sparse* set of terms,

See Sections 2.1
and 7.5

- unlike the case with G structures, ASReml automatically includes and estimates a scale parameter for R structures (σ_e^2 for $\mathbf{V} = \sigma_e^2 (\mathbf{I}_{11} \otimes \boldsymbol{\Sigma}(\rho_r))$ in this case). This is why the variance models specified for `row` (AR1) and `column` (ID) are correlation models. The user could specify a non-correlation model (diagonal elements $\neq 1$) in the R structure definition, for example, ID could be replaced by IDV to represent $\mathbf{V} = \sigma_e^2 (\sigma_c^2 \mathbf{I}_{11}) \otimes \boldsymbol{\Sigma}(\rho_r)$. However, IDV would then need to be followed by `!S2==1` to fix σ_e^2 at 1 and prevent ASReml trying (unsuccessfully) to estimate both parameters as they are confounded: the scale parameter associated with IDV and the implicit error variance parameter, see Section 2.1 under Combining variance models. Specifically, the code

See Section 7.7

```
11 column IDV 48 !S2==1
```

would be required in this case, where 48 is the starting value for the variances. This complexity allows for heterogeneous error variance.

3b Two-dimensional separable autoregressive spatial model

This model extends **3a** by specifying a first order autoregressive correlation model of order 11 for columns (AR1). The R structure in this case is therefore the direct product of two autoregressive correlation matrices that is, $\mathbf{V} = \sigma_e^2 \boldsymbol{\Sigma}_c(\rho_c) \otimes \boldsymbol{\Sigma}_r(\rho_r)$, giving a two-dimensional first order separable autoregressive spatial structure for error. The starting column correlation in this case is also 0.3. Again note that σ_e^2 is implicit.

```
NIN Alliance Trial 1989
variety !A
id
:
row 22
column 11
nin89aug.asd !skip 1
yield ~ mu variety !f mv
1 2 0
11 column AR1 0.3
22 row AR1 0.3
```

3c Two-dimensional separable autoregressive spatial model with measurement error

This model extends **3b** by adding a random `units` term. Thus

$V = \sigma_e^2 (\gamma_\eta I_{242} + \Sigma_c(\rho_c) \otimes \Sigma_r(\rho_r))$. The reserved word `units` tells ASReml to construct an additional random term with one level for each experimental unit so that a second (independent) error term can be fitted. A `units` term is fitted in the model in cases like this, where a variance structure is applied to the errors. Because a G structure is not explicitly specified here for `units`, the default IDV structure is assumed. The `units` term is often

fitted in spatial models for field trial data to allow for a nugget effect.

```
NIN Alliance Trial 1989
  variety !A
  id
  :
  row 22
  column 11
  nin89aug.asd !skip 1
  yield ~ mu variety !r units,
  !f mv
  1 2 0
  11 column AR1 0.3
  22 row AR1 0.3
```

4 Two-dimensional separable autoregressive spatial model with random replicate effects

This is essentially a combination of **2b** and **3c** to demonstrate specifying an R structure and a G structure in the same model. The variance header line `1 2 1` indicates that there is one R structure (1) that involves two variance models (2) and is therefore the direct product of two matrices, and there is one G structure (1). The R structures are defined first so the next two lines are the R structure definition lines for `e`, as in **3b**. The last two lines are the G structure definition lines for `repl`, as in **2b**. In this case $V = \sigma_e^2 (\gamma_r I_{242} + \Sigma_c(\rho_c) \otimes \Sigma_r(\rho_r))$.

See Section 7.4

```
NIN Alliance Trial 1989
  variety !A
  id
  :
  row 22
  column 11
  nin89aug.asd !skip 1
  yield ~ mu variety !r repl,
  !f mv
  1 2 1
  11 column AR1 0.3
  22 row AR1 0.3
  repl 1
  repl 0 IDV 0.1
```

5 Two-dimensional separable autoregressive spatial model defined as a G structure

This model is equivalent to **3c** but with the spatial model defined as a G structure rather than an R structure. As discussed in **2b**,

See Section 7.7

- *all but one* of the models supplied when the G structure involves more than one variance model must be correlation models,
- the other model must not be a correlation model, that is, the other model must be either an homogeneous or a heterogeneous variance model, and an initial value for the scale parameter must be supplied.

```
NIN Alliance Trial 1989
variety !A
id
:
row 22
column 11
nin89.asd !skip 1
yield ~ mu variety,
!r row.column
0 0 1
row.column 2
row 0 AR1V 0.3 0.1
column 0 AR1 0.3
```

For this reason, the model for rows is now **AR1V** and an initial value of **0.1** has been supplied for the scale parameter. In this case $\mathbf{V} = \sigma_e^2 (\gamma_{rc} \boldsymbol{\Sigma}_c(\rho_c) \otimes \boldsymbol{\Sigma}_r(\rho_r) + I_{224})$. Use of **row.column** as a G structure is a useful approach for analysing incomplete spatial arrays. This approach will often run faster for large trials but requires more memory.

Important

Note that we have used the original version of the data and **!f mv** is omitted from this analysis since **row.column** is fitted as a G structure. If we had used the augmented data **nin89aug.asd** we would still omit **!f mv** and **ASReml** would discard the records with missing yield.

Table 7.1: Sequence of variance structures for the NIN field trial data

	ASReml syntax	extra random terms		residual error term			
		term	G structure models		term	R structure models	
			1	2		1	2
1	<code>yield ~ mu variety repl</code>	-	-	-	error	ID	-
2a	<code>yield ~ mu variety, !r repl</code>	repl	IDV	-	error	ID	-
2b	<code>yield ~ mu variety, !r repl 0 0 1 repl 1 4 0 IDV 0.1</code>	repl	IDV	-	error	ID	-
3a	<code>yield ~ mu variety, !f mv 1 2 0 11 column ID 22 row AR1 0.3</code>	-	-	-	column.row	ID	AR1
3b	<code>yield ~ mu variety, !f mv 1 2 0 11 column AR1 0.3 22 row AR1 0.3</code>	-	-	-	column.row	AR1	AR1
3c	<code>yield ~ mu variety, !r units !f mv 1 2 0 11 column AR1 0.3 22 row AR1 0.3</code>	units	IDV	-	column.row	AR1	AR1
4	<code>yield ~ mu variety, !r repl !f mv 1 2 1 11 column AR1 0.3 22 row AR1 0.3 repl 1 4 0 IDV 0.1</code>	repl	IDV	-	column.row	AR1	AR1
5	<code>yield ~ mu variety, !r column.row 0 0 1 column.row 2 column 0 AR1 .3 row 0 AR1V 0.3 0.1</code>	column.row	AR1	AR1V	error	ID	-

7.4 Variance structures

The previous sections have introduced variance modelling in ASReml using the NIN data for demonstration. In this and the remaining sections the syntax is described formally. However, where appropriate we continue to reference the example.

General syntax

Variance model specification in ASReml has the following general form

```
[variance header line  
[R structure definition lines ]  
[G structure header and definition lines ]  
[variance parameter constraints ]]
```

- *variance header line* specifies the number of R and G structures,
- *R structure definition lines* define the R structures (variance models for error) as specified in the variance header line,
- *G structure header and definition lines* define the G structures (variance models for the additional random terms in the model) as specified in the variance header line; these lines are always placed after any R structure definition lines,
- *variance parameter constraints* are included if parameter constraints are to be imposed, see the !VCC *c* qualifier in Table 5.5 and Section 7.9 on constraints between and within variance structures.

A schematic outline of the variance model specification lines (variance header line, and R and G structure definition lines) is presented in Table 7.2 using the variance model of **4** for demonstration.

Table 7.2: Schematic outline of variance model specification in ASReml

general syntax			model 4
<i>variance header line</i>	[s [c [g]]]		1 2 1

<i>R structure definition lines</i>	S_1	C_1	11 column AR1 0.3
		C_2	22 row AR1 0.3
		⋮	⋮
		C_c	-
	S_2	C_1	-
		⋮	⋮
		C_c	-
	⋮	⋮	⋮
	S_s	C_1	-
		⋮	⋮
		C_c	-

<i>G structure definition lines</i>	G_1		repl 1 4 0 IDV 0.1
	G_2		-
	⋮		⋮
	G_g		-

Variance header line

The variance header line is of the form

`[s [c [g]]]`

- s and c relate to the R structures, g is the number of G structures,
- the variance header line may be omitted if the default IID R structure is required, no G structures are being explicitly defined and there are no parameter constraints (see !VCC and examples **1** and **2a**),
- s is used to code the number of independent sections in the error term
 - if $s = 0$, the default IID R structure is assumed and no R structure definition lines are required (as in examples **2b** and **5**),
 - if $s > 0$, s R structure definitions are required, one for each of the s sections (as in examples **3a**, **3b**, **3c** and **4**),
 - for the analysis of multi-section data s can be replaced by the name of a factor with the appropriate number of levels, one for each section,
- c is the number of component variance models involved in the variance structure for the error term for each section; for example, **3a**, **3b** and **3c** have `column.row` as the error term and the variance structure for `column.row` involves 2 variance models, the first for `column` and the second for `row`,
 - c has a default value of 2 when s is not specified as zero,
- g is the number of variance structures (G structures) that will be explicitly specified for the random terms in the model.

```

NIN Alliance Trial 1989
  variety !A
  id
  :
  row 22
  column 11
nin89aug.asd !skip 1
yield ~ mu variety !r repl,
!f mv
1 2 1
22 row AR1 0.3
11 column AR1 0.3
repl 1
repl 0 IDV 0.1

```

R and G structures are now discussed with reference to s , c and g . As already noted, each variance structure may involve several variance models which relate to the individual terms involved in the random effect or error. For example, a two factor interaction may have a variance model for each of the two factors involved in the interaction. Variance models are listed in Table 7.3. As indicated in the discussion of **2b**, care must be taken with respect to scale parameters when combining variance models (see also Section 7.7).

See Table 7.3
See Section 7.7

R structure definition

For each of the s sections there must be c R structure definitions. Each definition may take several lines. Each R structure definition specifies a variance model and has the form

order [*field model* [*initial_values*] [*qualifiers*]
[*additional_initial_values*]]

- *order* is either the number of levels in the corresponding term or the name of a factor that has the same number of levels as the term, for example,

```
11 column AR1 0.5
```

is equivalent to

```
column column AR1 0.5
```

when `column` is a factor with 11 levels,

```
NIN Alliance Trial 1989
  variety !A
:
row 22
  column 11
nin89aug.asd !skip 1
yield ~ mu variety !r repl,
!f mv
1 2 1
11 column AR1 0.3
22 row AR1 0.3
repl 1
repl 0 IDV 0.1
```

- *field* is the name of the data field (variate or factor) that corresponds to the term and therefore indexes the levels of the term;
 - ASReml uses this field to sort the units so they match the R structure,
 - in the example the data will be sorted internally rows within columns for the analysis but the residuals will be printed in the `.yht` file in the original order (which is actually rows within columns in this case).

Important It is assumed that the joint indexing of the components uniquely defines the experimental units,

- if *field* is a variable, it can be plot coordinates provided the plots are in a regular grid. Thus in this example

```
11 lat AR1 0.3
```

```
22 long AR1 0.3
```

is valid because `lat` gives column position and `long` gives row position, and the positions are on a regular grid. The autoregressive correlation values will still be on an plot index basis (1, 2, 3, ...), not on a distance basis (10m, 20m, 30m, ...),

- if the data is sorted appropriately for the order the models are specified, set *field* to 0,

- *model* specifies the variance model for the term, for example,
`22 row AR1 0.3`
chooses a first order autoregressive model for the row error process,
 - all the variance models available in ASReml are listed in Table 7.3,
 - these models have associated variance parameters,
 - a error variance component (σ_e^2 for the example, see Section 7.3) is automatically estimated for each section,
 - the default *model* is ID,
- *initial_values* are initial or starting values for the variance parameters and must be supplied, for example,
`22 row AR1 0.3`
chooses an autoregressive model for the row error process (see Table 7.1) with a starting value of 0.3 for the row correlation,
- *qualifiers* tell ASReml to modify the variance model in some way; the qualifiers are described in Table 7.4,
- *additional_initial_values* are read from the following lines if there are not enough initial values on the model line. Each variance model has a certain number of parameters. If insufficient non zero values are found on the model line ASReml expects to find them on the following line(s),
 - initial values of 0.0 will be ignored if they are on the model line but are accepted on subsequent lines,
 - the notation *n*v* (for example, 5 * 0.1) is permitted on subsequent lines (but not the model line) when there are *n* repeats of a particular initial value *v*,
 - only in a few specified cases is 0 permitted as an initial value of a non-zero parameter.

G structure header and definition lines

There are g sets of G structure definition lines and each set is of the form

model_term d

order [*key model* [*initial_values*] [*qualifier*]
[*additional_initial_values*]]

order [*key model* [*initial_values*] [*qualifier*]
[*additional_initial_values*]]

⋮

order [*key model* [*initial_values*] [*qualifier*]
[*additional_initial_values*]]

- *model_term* is the term from the linear model to which the variance structure applies; the variance structure may cover additional terms in the linear model, see Section 7.8
- d is the number of variance models and hence direct product matrices involved in the G structure; the following lines define the d variance models,
- *order* is either the number of levels in the term or the name of a factor that has the same number of levels as the component,
- *key* is usually zero but for power models (**EXP**, **GAU**,...) provides the distance data needed to construct the model,
- *model* is the ASReml variance model identifier/acronym selected for the term,
 - variance models are listed in Table 7.3,
 - these models have associated variance parameters,
- *initial_values* are initial or starting values for the variance parameters, the values for initial values are as described above for R structure definition lines,
- *qualifier* tells ASReml to modify the variance model in some way; the qualifiers are described in Table 7.4.

```
NIN Alliance Trial 1989
variety !A
id
:
row 22
column 11
nin89aug.asd !skip 1
yield ~ mu variety !r repl,
!f mv
1 2 1
22 row AR1 0.3
11 column AR1 0.3
repl 1
repl 0 IDV 0.1
```

7.5 Variance model description

Table 7.3 presents the full range of variance models, that is, correlation, homogeneous variance and heterogeneous variance models available in ASReml. The table contains the model identifier, a brief description, its algebraic form and the number of parameters. The first section defines (BASE) correlation models and

in the next section we show how to extend them to form variance models. The second section defines some models parameterized as variance/covariance matrices rather than as correlation matrices. The third section covers some special cases where the covariance structure is known except for the scale.

Table 7.3: Details of the variance models available in ASReml

base identifier	description	algebraic form	number of parameters [†]		
			corr	homo's variance	hetero's variance
Correlation models					
One-dimensional, equally spaced					
ID	identity	$C_{ii} = 1, C_{ij} = 0, i \neq j$	0	1	ω
AR[1]	1 st order autoregressive	$C_{ii} = 1, C_{i+1,i} = \phi_1$ $C_{ij} = \phi_1 C_{i-1,j}, i > j + 1$ $|\phi_1| < 1$	1	2	$1 + \omega$
AR2	2 nd order autoregressive	$C_{ii} = 1,$ $C_{i+1,i} = \phi_1 / (1 - \phi_2)$ $C_{ij} = \phi_1 C_{i-1,j} + \phi_2 C_{i-2,j}, i > j + 1$ $|\phi_1| < (1 - \phi_2), |\phi_2| < 1$	2	3	$2 + \omega$
New AR3	3 rd order autoregressive	$C_{ii} = 1, \Omega = 1 - \phi_2 - \phi_3(\phi_1 + \phi_3),$ $C_{i+1,i} = (\phi_1 + \phi_2 \phi_3) / \Omega,$ $C_{i+2,i} = (\phi_1(\phi_1 + \phi_3) + \phi_2(1 - \phi_2)) / \Omega,$ $C_{ij} = \phi_1 C_{i-1,j} + \phi_2 C_{i-2,j} + \phi_3 C_{i-3,j}, i > j + 2$ $|\phi_1| < (1 - \phi_2), |\phi_2| < 1, |\phi_3| < 1$	3	4	$3 + \omega$
SAR	symmetric autoregressive	$C_{ii} = 1,$ $C_{i+1,i} = \phi_1 / (1 + \phi_1^2 / 4)$ $C_{ij} = \phi_1 C_{i-1,j} - \phi_1^2 / 4 C_{i-2,j},$ $i > j + 1$ $|\phi_1| < 1$	1	2	$1 + \omega$
New SAR2	constrained autoregressive 3 used for competition	as for AR3 using $\phi_1 = \gamma_1 + 2\gamma_2,$ $\phi_2 = -\gamma_2(2\gamma_1 + \gamma_2),$ $\phi_3 = \gamma_1 \gamma_2^2,$	2	3	$2 + \omega$

Details of the variance models available in ASReml

base identifier	description	algebraic form	number of parameters [†]		
			corr	homo's variance	hetero's variance
MA[1]	1 st order moving average	$C_{ii} = 1,$ $C_{i+1,i} = -\theta_1/(1 + \theta_1^2)$ $C_{ji} = 0, j > i + 2$ $|\theta_1| < 1$	1	2	$1 + \omega$
MA2	2 nd order moving average	$C_{ii} = 1,$ $C_{i+1,i} = -\theta_1(1 - \theta_2)/(1 + \theta_1^2 + \theta_2^2)$ $C_{i+2,i} = -\theta_2/(1 + \theta_1^2 + \theta_2^2)$ $C_{ji} = 0, j > i + 2$ $\theta_2 \pm \theta_1 < 1$ $|\theta_1| < 1, |\theta_2| < 1$	2	3	$2 + \omega$
ARMA	autoregressive moving average	$C_{ii} = 1,$ $C_{i+1,i} = (\theta - \phi)(1 - \theta\phi)/(1 + \theta^2 - 2\theta\phi)$ $C_{ji} = \phi C_{j-1,i}, j > i + 1$ $|\theta| < 1, |\phi| < 1$	2	3	$2 + \omega$
CORU	uniform correlation	$C_{ii} = 1, C_{ij} = \phi, i \neq j$	1	2	$1 + \omega$
CORB	banded correlation	$C_{ii} = 1$ $C_{i+j,i} = \phi_j, 1 \leq j \leq \omega - 1$ $|\phi_j| < 1$	$\omega - 1$	ω	$2\omega - 1$
CORG	general correlation CORGH = US	$C_{ii} = 1$ $C_{ij} = \phi_{ij}, i \neq j$ $|\phi_{ij}| < 1$	$\frac{\omega(\omega-1)}{2}$	$\frac{\omega(\omega-1)}{2} + 1$	$\frac{\omega(\omega-1)}{2} + \omega$

One-dimensional unequally spaced

EXP	exponential	$C_{ii} = 1$ $C_{ij} = \phi^{|x_i - x_j|}, i \neq j$ x_i are <i>coordinates</i> $0 < \phi < 1$	1	2	$1 + \omega$
-----	-------------	---	---	---	--------------

Details of the variance models available in ASReml

base identifier	description	algebraic form	number of parameters [†]		
			corr	homo's variance	hetero's variance
GAU	gaussian	$C_{ii} = 1$ $C_{ij} = \phi^{(x_i - x_j)^2}, i \neq j$ x_i are coordinates $0 < \phi < 1$	1	2	$1 + \omega$
Two-dimensional irregularly spaced					
		\mathbf{x} and \mathbf{y} vectors of coordinates $\theta_{ij} = \min(d_{ij}/\phi_1, 1)$ d_{ij} is euclidean distance			
IEXP	isotropic exponential	$C_{ii} = 1$ $C_{ij} = \phi^{|x_i - x_j| + |y_i - y_j|}, i \neq j$ $0 < \phi < 1$	1	2	$1 + \omega$
IGAU	isotropic gaussian	$C_{ii} = 1$ $C_{ij} = \phi^{(x_i - x_j)^2 + (y_i - y_j)^2}, i \neq j$ $0 < \phi < 1$	1	2	$1 + \omega$
IEUC	isotropic euclidean	$C_{ii} = 1$ $C_{ij} = \phi^{\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}, i \neq j$ $0 < \phi < 1$	1	2	$1 + \omega$
New	LVR	linear variance $C_{ij} = (1 - \theta_{ij})$ $0 < \phi_1$	1	2	$1 + \omega$
New	SPH	spherical $C_{ij} = 1 - \frac{3}{2}\theta_{ij} + \frac{1}{2}\theta_{ij}^3$ $0 < \phi_1$	1	2	$1 + \omega$
New	CIR	circular (Webster & Oliver, 2001, p 113) $C_{ij} = 1 - \frac{2}{\pi}(\theta_{ij}\sqrt{1 - \theta_{ij}^2} + \sin^{-1}\theta_{ij})$ $0 < \phi_1$	1	2	$1 + \omega$
AEXP	anisotropic exponential	$C_{ii} = 1$ $C_{ij} = \phi_1^{|x_i - x_j|} \phi_2^{|y_i - y_j|}$ $0 < \phi_1 < 1, 0 < \phi_2 < 1$	2	3	$2 + \omega$

Details of the variance models available in ASReml

base identifier	description	algebraic form	number of parameters [†]		
			corr	homo's variance	hetero's variance
AGAU	anisotropic gaussian	$C_{ii} = 1$ $C_{ij} = \phi_1^{(x_i - x_j)^2} \phi_2^{(y_i - y_j)^2}$ $0 < \phi_1 < 1, 0 < \phi_2 < 1$	2	3	$2 + \omega$
New MATk	Matérn with first $1 \leq k \leq 5$ parameters specified by the user	C_{ij} = Matérn: see text $\phi > 0$ range, ν shape(0.5) $\delta > 0$ anisotropy ratio(1), α anisotropy angle(0), $\lambda(1|2)$ metric(2)	k	k+1	$k + \omega$

Additional heterogeneous variance models

DIAG	diagonal = IDH	$\Sigma_{ii} = \phi_i \Sigma_{ij} = 0, i \neq j$	-	-	ω
US	unstructured general covariance matrix	$\Sigma_{ij} = \phi_{ij}$	-	-	$\frac{\omega(\omega+1)}{2}$
OWNk	user explicitly forms \mathbf{V} and $\partial\mathbf{V}$		-	-	k
ANTE[1] ANTEk	1^{st} k order antedependence $1 \leq k \leq \omega - 1$	$\Sigma^{-1} = \mathbf{U}\mathbf{D}\mathbf{U}'$ $D_{ii} = d_i, D_{ij} = 0, i \neq j$ $U_{ii} = 1, U_{ij} = u_{ij}, 1 \leq j - i \leq k$ $U_{ij} = 0, i > j$	-	-	$\frac{\omega(\omega+1)}{2}$
CHOL[1] CHOLk	1^{st} k order cholesky (banded form) $1 \leq k \leq \omega - 1$	$\Sigma = \mathbf{L}\mathbf{D}\mathbf{L}'$ $D_{ii} = d_i, D_{ij} = 0, i \neq j$ $L_{ii} = 1, L_{ij} = l_{ij}, 1 \leq i - j \leq k;$ $L_{ij} = 0, i - j > k;$	-	-	$\frac{\omega(\omega+1)}{2}$
CHOL[1]C CHOLkC	1^{st} k order cholesky (column form) $1 \leq k \leq \omega - 1$	$\Sigma = \mathbf{L}\mathbf{D}\mathbf{L}'$ $D_{ii} = d_i, D_{ij} = 0, i \neq j$ $L_{ii} = 1, L_{ij} = l_{ij}, 1 \leq j < i;$ $L_{ij} = 0, k + 1 \leq j < i;$	-	-	$\frac{\omega(\omega+1)}{2}$

Details of the variance models available in ASReml

base identifier	description	algebraic form	number of parameters [†]		
			corr	homo's variance	hetero's variance
FA[1] FAk	1 st k th order factor analytic	$\Sigma = DCD,$ $C = FF' + E,$ <i>F</i> contains <i>k</i> correlation factors <i>E</i> diagonal $DD = \text{diag}(\Sigma)$	-	-	$\omega + \omega$ $k\omega + \omega$
FACV[1] FACVk	1 st k th order factor analytic covariance form	$\Sigma = \Gamma\Gamma' + \Psi,$ Γ contains covariance factors Ψ contains specific variance	-	-	$\omega + \omega$ $k\omega + \omega$
XFA[1] XFAk	1 st k th order extended factor analytic covariance form	$\Sigma = \Gamma\Gamma' + \Psi,$ Γ contains covariance factors Ψ contains specific variance	-	-	$\omega + \omega$ $k\omega + \omega$
Inverse relationship matrices[‡]					
AINV	inverse relationship matrix derived from pedigree		0	1	-
GIV1	generalized inverse number 1		0	1	-
⋮	⋮	⋮	⋮	⋮	
GIV6	generalized inverse number 6		0	1	-

[†] This is the number of values the user must supply as initial values where ω is the dimension of the matrix. The homogeneous variance form is specified by appending V to the correlation basename; the heterogeneous variance form is specified by appending H to the correlation basename

[‡] These must be associated with 1 variance parameter unless used in direct product with another structure which provides the variance.

Forming variance models from correlation models

The base identifiers presented in the first part of Table 7.3 are used to specify the correlation models. The corresponding homogeneous and heterogeneous variance models are specified by appending **V** and **H** to the base identifiers respectively. This convention holds for most models. However, no **V** or **H** should be appended to the base identifiers for the heterogeneous variance models at the end of the table (from **DIAG** on).

In summary, to specify

- a correlation model, provide the base identifier given in Table 7.3, for example

`EXP .1`

is an exponential correlation model,

- an homogeneous variance model, append a **V** to the base identifier and provide an additional initial value for the variance, for example,

`EXPV .1 .3`

is an exponential variance model,

- a heterogeneous variance model, append an **H** to the base identifier and provide additional initial values for the diagonal variances, for example,

`CORUH .1 .3 .4 .2`

is a 3×3 matrix with uniform correlations of 0.1 and heterogeneous variances 0.3, 0.4 and 0.2.

Important See Section 7.7 for rules on combining variance models and important notes regarding initial values.

The algebraic forms of the homogeneous and heterogeneous variance models are determined as follows. Let $\mathbf{C}^{(\omega \times \omega)} = [C_{ij}]$ denote the correlation matrix for a particular correlation model. If $\mathbf{\Sigma}^{(\omega \times \omega)}$ is the corresponding homogeneous variance matrix then

$$\mathbf{\Sigma} = \sigma^2 \mathbf{C}.$$

It has just one more parameter than the correlation model. For example, the homogeneous variance model corresponding to the **ID** correlation model has variance matrix $\mathbf{\Sigma} = \sigma^2 \mathbf{I}_\omega$ (specified **IDV** in the **ASReml** command file, see below) and one parameter. The initial values for the variance parameters are listed after the initial values for the correlation parameters. For example, in

AR1V 0.3 0.5

0.3 is the initial spatial correlation parameter and 0.5 is the initial variance parameter value.

Similarly, if $\Sigma_h^{(\omega \times \omega)}$ is the heterogeneous variance matrix corresponding to C , then

$$\Sigma_h = DCD$$

where $D^{(\omega \times \omega)} = \text{diag}(\sigma_i)$. In this case there are an additional ω parameters. For example, the heterogeneous variance model corresponding to ID is specified IDH in the ASReml command file (see below), involves the ω parameters $\sigma_1^2 \dots \sigma_\omega^2$ and is the variance matrix

$$\Sigma_h = \begin{bmatrix} \sigma_1^2 & 0 & \dots & 0 \\ 0 & \sigma_2^2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \sigma_\omega^2 \end{bmatrix}$$

Notes on the variance models

These notes provide additional information on the variance models defined in Table 7.3.

New

- the IDH and DIAG models fit the same diagonal variance structure,
- the CORGH and US models fit the same completely general variance structure parameterized differently,
- in CHOL k models $\Sigma = LDL'$ where L is lower triangular with ones on the diagonal, D is diagonal and k is the number of non-zero off diagonals in L ,
- in CHOL kC models $\Sigma = LDL'$ where L is lower triangular with ones on the diagonal, D is diagonal and k is the number of non-zero sub diagonal columns in L . This is somewhat similar to the factor analytic model.
- in ANTE k models $\Sigma^{-1} = UDU'$ where U is upper triangular with ones on the diagonal, D is diagonal and k is the number of non-zero off diagonals in U ,
- the CHOL k , CHOL kC and ANTE k models are equivalent to the US structure, that is, the full variance structure, when k is $\omega - 1$,
- initial values for US, CHOL k CHOL kC and ANTE k structures are given in the form of a US matrix which is specified lower triangle row-wise, viz

$$\begin{bmatrix} \sigma_{11} & & \\ \sigma_{21} & \sigma_{22} & \\ \sigma_{31} & \sigma_{32} & \sigma_{33} \end{bmatrix},$$

that is, initial values are given in the order, $1 = \sigma_{11}$, $2 = \sigma_{21}$, $3 = \sigma_{22}, \dots$

- the US model is associated with several special features of ASReml. When used in the R structure for multivariate data, ASReml automatically recognises patterns of missing values in the responses (see Chapter 8). Also, there is an option to update its values by EM rather than AI when its AI updates make the matrix non positive definite.
- **New** The Matérn class of isotropic covariance models is now described. ASReml uses an extended Matérn class which accomodates geometric anisotropy and a choice of metrics for random fields observed in two dimensions. This extension, described in detail in Haskard (2006), is given by

$$\rho(\mathbf{h}; \phi) = \rho_M(d(\mathbf{h}; \delta, \alpha, \lambda); \phi, \nu)$$

where $\mathbf{h} = (h_x, h_y)^T$ is the spatial separation vector, (δ, α) governs geometric anisotropy, (λ) specifies the choice of metric and (ϕ, ν) are the parameters of the Matérn correlation function. The function is

$$\rho_M(d; \phi, \nu) = \left\{ 2^{\nu-1} \Gamma(\nu) \right\}^{-1} \left(\frac{d}{\phi} \right)^{\nu} K_{\nu} \left(\frac{d}{\phi} \right), \quad (7.1)$$

where $\phi > 0$ is a range parameter, $\nu > 0$ is a smoothness parameter, $\Gamma(\cdot)$ is the gamma function, $K_{\nu}(\cdot)$ is the modified Bessel function of the third kind of order ν (Abramowitz and Stegun, 1965, section 9.6) and d is the distance defined in terms of X and Y axes: $h_x = x_i - x_j$; $h_y = y_i - y_j$; $s_x = \cos(\alpha)h_x + \sin(\alpha)h_y$; $s_y = \cos(\alpha)h_x - \sin(\alpha)h_y$; $d = (\delta|s_x|^{\lambda} + |s_y|^{\lambda}/\delta)^{1/\lambda}$.

For a given ν , the range parameter ϕ affects the rate of decay of $\rho(\cdot)$ with increasing d . The parameter $\nu > 0$ controls the analytic smoothness of the underlying process \mathbf{u}_s , the process being $[\nu] - 1$ times mean-square differentiable, where $[\nu]$ is the smallest integer greater than or equal to ν (Stein, 1999, page 31). Larger ν correspond to smoother processes. ASReml uses numerical derivatives for ν when its current value is outside the interval [0.2,5].

When $\nu = m + \frac{1}{2}$ with m a non-negative integer, $\rho_M(\cdot)$ is the product of $\exp(-d/\phi)$ and a polynomial of degree m in d . Thus $\nu = \frac{1}{2}$ yields the exponential correlation function, $\rho_M(d; \phi, \frac{1}{2}) = \exp(-d/\phi)$, and $\nu = 1$ yields Whittle's elementary correlation function, $\rho_M(d; \phi, 1) = (d/\phi)K_1(d/\phi)$ (Webster and Oliver, 2001).

When $\nu = 1.5$ then

$$\rho_M(d; \phi, 1.5) = \exp(-d/\phi)(1 + d/\phi)$$

which is the correlation function of a random field which is continuous and once differentiable. This has been used recently by Kammann and Wand (2003). As $\nu \rightarrow \infty$ then $\rho_M(\cdot)$ tends to the gaussian correlation function.

The metric parameter λ is not estimated by `ASReml`; it is usually set to 2 for Euclidean distance. Setting $\lambda = 1$ provides the cityblock metric, which together with $\nu = 0.5$ models a separable $AR1 \times AR1$ process. Cityblock metric may be appropriate when the dominant spatial processes are aligned with rows/columns as occurs in field experiments. Geometric anisotropy is discussed in most geostatistical books (Webster and Oliver, 2001, Diggle *et al.*, 2003) but rarely are the anisotropy angle or ratio estimated from the data. Similarly the smoothness parameter ν is often set a-priori (Kammann and Wand, 2003, Diggle *et al.*, 2003). However Stein (1999) and Haskard (2006) demonstrate that ν can be reliably estimated even for modest sized data-sets, subject to caveats regarding the sampling design.

The syntax for the Matérn class in `ASReml` is given by `MATk` where k is the number of parameters to be specified; the remaining parameters take their default values. Use the `!G` qualifier to control whether a specified parameter is estimated or fixed. The order of the parameters in `ASReml`, with their defaults, is $(\phi, \nu = 0.5, \delta = 1, \alpha = 0, \lambda = 2)$. For example, if we wish to fit a Matérn model with only ϕ estimated and the other parameters set at their defaults then we use `MAT1`. `MAT2` allows ν to be estimated or fixed at some other value (for example `MAT2 .2 1 !GPF`). The parameters ϕ and ν are highly correlated so it may be better to manually cover a grid of ν values.

We note that there is non-uniqueness in the anisotropy parameters of this metric $d(\cdot)$ since inverting δ and adding $\frac{\pi}{2}$ to α gives the same distance. This non-uniqueness can be removed by considering $0 \leq \alpha < \frac{\pi}{2}$ and $\delta > 0$, or by considering $0 \leq \alpha < \pi$ and either $0 < \delta \leq 1$ or $\delta \geq 1$. With $\lambda = 2$, isotropy occurs when $\delta = 1$, and then the rotation angle α is irrelevant: correlation contours are circles, compared with ellipses in general. With $\lambda = 1$, correlation contours are diamonds.

- power models rely on the definition of distance for the associated term, for example,
 - the distance between time points in a one-dimensional longitudinal analysis,
 - the spatial distance between plot coordinates in a two-dimensional field trial analysis.

Information for determining distances is supplied by the *key* argument on the structure line.

- For one dimensional cases, *key* may be

- * the name of a data field containing the coordinate values when it relates to an R structure
 - * 0 in which case a vector of coordinates of length *order* must be supplied after all R and G structure lines.
 - * `fac(x)` when it relates to model term `fac(x)`.
- In two directions (`IEXP`, `IGAU`, `IEUC`, `AEXP`, `AGAU`, `MATn`) the *key* argument also depends on whether it relates to an R or G structure.
- * For an R structure, use the form `rrcc` where *rr* is the number of a data field containing the coordinates for the first dimension and *cc* is the number of a data field containing the coordinates for the second direction. For example, in the analysis of spatial data, if the *x* coordinate was in field 3 and the *y* coordinate was in field 4, the second argument would be 304.
 - * For a G structure relating to the model term `fac(x,y)`, use `fac(x,y)`. For example

```

:
y ~ mu ...!r fac(x,y) ...
:
fac(x,y) 1
fac(x,y) fac(x,y) IEUCV .7 1.3

```

- `FAk`, `FACV k` and `XFA k` are different parameterizations of the factor analytic model in which Σ is modelled as $\Sigma = \mathbf{\Gamma}\mathbf{\Gamma}' + \mathbf{\Psi}$ where $\mathbf{\Gamma}^{(\omega \times k)}$ is a matrix of loadings on the covariance scale and $\mathbf{\Psi}$ is a diagonal vector of specific variances. See Smith *et al.* (2001) and Thompson *et al.* (2003) for examples of factor analytic models in multi-environment trials. The general limitations are
 - that $\mathbf{\Psi}$ may not include zeros except in the `XFA k` formulation
 - constraints are required in $\mathbf{\Gamma}$ for $k > 1$ for identifiability. Typically, one zero is placed in the second column, two zeros in the third column, etc.
 - The total number of parameters fitted ($k\omega + \omega - k(k-1)/2$) may not exceed $\omega(\omega + 1)/2$.
- in `FA k` models the variance-covariance matrix $\Sigma^{(\omega \times \omega)}$ is modelled on the correlation scale as $\Sigma = \mathbf{D}\mathbf{C}\mathbf{D}$, where
 - $\mathbf{D}^{(\omega \times \omega)}$ is diagonal such that $\mathbf{D}\mathbf{D} = \text{diag}(\Sigma)$,
 - $\mathbf{C}^{(\omega \times \omega)}$ is a correlation matrix of the form $\mathbf{F}\mathbf{F}' + \mathbf{E}$ where $\mathbf{F}^{(\omega \times k)}$ is a matrix of loadings on the correlation scale and \mathbf{E} is diagonal and is defined by difference,
 - the parameters are specified in the order *loadings for each factor (F) followed by the variances* ($\text{diag}(\Sigma)$); when k is greater than 1, constraints on

the elements of \mathbf{F} are required, see Table 7.5,

- FACV k models (CV for *covariance*) are an alternative formulation of FA models in which Σ is modelled as $\Sigma = \mathbf{\Gamma}\mathbf{\Gamma}' + \mathbf{\Psi}$ where $\mathbf{\Gamma}^{(\omega \times k)}$ is a matrix of loadings on the covariance scale and $\mathbf{\Psi}$ is diagonal. The parameters in FACV
 - are specified in the order *loadings* ($\mathbf{\Gamma}$) *followed by variances* ($\mathbf{\Psi}$); when k is greater than 1, constraints on the elements of $\mathbf{\Gamma}$ are required, see Table 7.5,
 - are related to those in FA by $\mathbf{\Gamma} = \mathbf{D}\mathbf{F}$ and $\mathbf{\Psi} = \mathbf{D}\mathbf{E}\mathbf{D}$,
- difficult • XFA k (X for *extended*) is the third form of the factor analytic model and has the same parameterisation as for FACV, that is, $\Sigma = \mathbf{\Gamma}\mathbf{\Gamma}' + \mathbf{\Psi}$. However, XFA models
 - have parameters specified in the order *diag* ($\mathbf{\Psi}$) and *vec*($\mathbf{\Gamma}$); when k is greater than 1, constraints on the elements of $\mathbf{\Gamma}$ are required, see Table 7.5,
 - may not be used in R structures,
 - are used in G structures in combination with the `xfa(f, k)` model term,
 - return the factors as well as the effects.
 - permit some elements of $\mathbf{\Psi}$ to be fixed to zero,
 - are computationally faster than the FACV formulation for large problems when k is much smaller than ω ,

Special consideration is required when using the XFA k model. The SSP must be expanded to have room to hold the k factors. This is achieved by using the `xfa(f, k)` model term in place of f in the model. For example,

```
y ~ site !r geno.xfa(site,2)
0 0 1
geno.xfa(site,2) 2
geno
xfa(site,2) 0 XFA2
```

- difficult • the OWN variance structure is a facility whereby users may specify their own variance structure. This facility requires the user to supply a program MYOWNGDG that reads the current set of parameters, forms the \mathbf{G} matrix and a full set of derivative matrices, and writes these to disk. Before each iteration, ASReml writes the OWN parameters to a file, runs MYOWNGDG (which it presumes forms the \mathbf{G} and derivative matrix) and then reads the matrices back in. An example of MYOWNGDG.f90 is distributed with ASReml. It duplicates the AR1 and AR2 structures. The following job fits an AR2 structure using this program.

```
Example of using the OWN structure
rep
blcol
```

```

blow
variety 25
yield
barley.asd !skip 1 !OWN MYOWN.EXE
y ~ va
1 2
10 0 AR1 .1
15 0 OWN2 .2 .1 !TRR

```

The file written by ASReml has extension `.own` and looks like

```

      15      2      1
0.6025860D+000.1164403D+00
This file was written by asreml for reading by your
program MYOWNGDG
asreml writes this file, runs your program and then reads
shfown.gdg
which it presumes has the following format:
The first lines should agree with the top of this file
specifying the order of the matrices      ( 15)
           the number of variance parameters ( 2)
           and a control parameter you can specify ( 1).
These are written in (3I5) format. They are followed by
the list of variance parameters written in (6D13.7) format.
Follow this with      3 matrices written in (6D13.7) format.
These are to be each of 120 elements being lower triangle
row-wise of the G matrix and its derivatives with respect
to the parameters in turn.

```

This file contains details about what is expected in the file written by your program. The filename used has the same basename as the job you are running with extension `.own` for the file written by ASReml and `.gdg` for the file your program writes. The type of the parameters is set with the `!T` qualifier described below. The control parameter is set using the `!F` qualifier.

- `!F2` applies to OWN models. With OWN, the argument of `!F` is passed to the MYOWNGDG program as an argument the program can access. This is the mechanism that allows several OWN models to be fitted in a single run.
- `!Ts` is used to set the type of the parameters. It is primarily used in conjunction with the OWN structure as ASReml knows the type in other cases. The valid type codes are as follows:

code	description	action if !GP is set
V	variance	forced positive
G	variance ratio	forced positive
R	correlation	$-1 < r < 1$
C	covariance	
P	positive correlation	$0 < r < 1$
L	loading	

This coding also affects whether the parameter is scaled by σ^2 in the output.

7.6 Variance structure qualifiers

Table 7.4 describes the R and G structure line qualifiers.

Table 7.4: List of R and G structure qualifiers

<i>qualifier</i>	action
!=s	used to constrain parameters within variance structures, see Section 7.9.
!GP, !GU, !GF, !GZ	<p>modify the updating of the variance parameters. The exact action of these codes in setting bounds for parameters depends on the particular model.</p> <p>!GP (the default in most cases) attempts to keep the parameter in the theoretical parameter space and is activated when the update of a parameter would take it outside its space. For example, if an update would make a variance negative, the negative value is replaced by a small positive value. Under the !GP condition, repeated attempts to make a variance negative are detected and the value is then <i>fixed</i> at a small positive value. This is shown in the output in that the parameter will have the code B rather than P appended to the value in the variance component table.</p> <p>!GU (unrestricted) does not limit the updates to the parameter. This allows variance parameters to go negative and correlation parameters to exceed ± 1. Negative variance components may lead to problems; the mixed model coefficient matrix may become non-positive definite. In this case the sequence of REML log-likelihoods may be erratic and you may need to experiment with starting values.</p> <p>!GF fixes the parameter at its starting value</p> <p>!GZ only applies to FA and FACV models and fixes the corresponding parameter in to zero (0.00).</p>

List of R and G variance structure definition line qualifiers

<i>qualifier</i>	action
	<p>For multiple parameters, the form !GXXXX can be used to specify F, P, U or Z for the parameters individually. A shorthand notation allows a repeat count before a code letter. Thus !GPPPPPPPPPPPPPPZPPPZP could be written as !G14PZ3PZP.</p> <p>For a US model, !GP makes ASReml attempt to keep the matrix positive definite. After each AI update, it extracts the eigenvalues of the updated matrix. If any are negative or zero, the AI update is discarded and an EM update is performed. Notice that the EM update is applied to all of the variance parameters in the particular US model and cannot be applied to only a subset of them.</p>
!S2= <i>r</i>	sets the initial value of the error variance within the section to <i>r</i> : the !S2= qualifier may be used in R structure definitions to represent the residual variance associated with the particular section. There is always an error variance parameter associated with a section R structure. In multiple section analyses the !S2= qualifier is used on the first of the <i>c</i> lines for each section to set the initial error variance for that section. If this is not supplied, ASReml calculates an initial value that is half the simple variance of the data in the site. To fix the variance !S2= <i>r</i> is used.
!S2== <i>r</i>	is similar to !S2= except that the variance is fixed at <i>r</i> .
!S2==1	is used in the analysis of multiple section data and in multivariate analyses and when variance parameters are included in the R structure.

7.7 Rules for combining variance models

As noted in Section 2.1 under Combining variance models, variance structures are sometimes formed by combining variance models. For example, a two factor interaction may involve two variance models, one for each of the two factors in the interaction. Some of the rules for combining variance models differ for R structures and G structures.

A summary of the rules is as follows:

- when combining variance models in both R and G structures, the resulting direct product structure must match the ordered effects with the outer factor first, for example, the G structure in the example opposite is for `column.row` which tells ASReml that the direct product structure matches the effects ordered rows *within* columns. (The variance model can be written as $\sigma^2(I + \Sigma_C \otimes \lambda \Sigma_R)$.) This is why the G structure definition line for `column` is specified first,

```
NIN Alliance Trial 1989
  variety !A
  id
  :
  :
  row 22
  column 11
  nin89.asd !skip 1
  yield ~ mu variety !r repl,
  column.row
  0 0 1
  column.row 2
  column 0 AR1 0.4
  row 0 ARV1 0.3 0.1
```

- ASReml automatically includes and estimates an error variance parameter for each section of an R structure. The variance structures defined by the user should therefore normally be correlation matrices. A variance model can be specified but the `!S2==1` qualifier would then be required to fix the error variance at 1 and prevent ASReml trying to estimate two confounded parameters (error variance and the parameter corresponding to the variance model specified, see **3a** on page 111),
- ASReml does not have an implicit scale parameter for G structures that are defined explicitly. For this reason the model supplied when the G structure involves just one variance model must be a variance model; an initial value must be supplied for this associated scale parameter; this is discussed under *additional_initial_values* on page 119,
- when the G structure involves more than one variance model, one must be either a homogeneous or a heterogeneous variance model and the rest should be correlation models; if more than one are non-correlation models then the `!GF` qualifier should be used to avoid identifiability problems, that is, ASReml trying to estimate both parameters when they are confounded.

See Sections 2.1
and 7.5

7.8 G structures involving more than one random term

The usual case is that a variance structure applies to a particular term in the linear model and that there is no covariance between model terms. Sometimes it is appropriate to include a covariance. Then, it is essential that the model terms be listed together and that the variance structure defined for the first term be the structure required for both terms. When the terms are of different size, the terms must be linked together with the `!{` and `!}` qualifiers (Table 6.1). While ASReml

will check the overall size, it does not check that the order of effects matches the structure definition so the user must be careful to get this right. Check that the terms are conformable by considering the order of the fitted effects and ensuring the first term of the direct product corresponds to the outer factor in the nesting of the effects. Two examples are

Check the order

- **random regressions** where we want a covariance between intercept and slope

```

:
!r !{ animal animal.time !}
:
animal 2
2 0 US 3 -.5 2
animal

```

is equivalent (though not identical because of the scaling differences) to

```

:
!r pol(time,1).animal
:
pol(time,1).animal 2
pol(time,1) 0 US 1 -.1 .2
animal

```

- **maternal/direct genetic covariance**

```

lambid !P
sireid !P
damid !P
:
wwt ywt ~ Trait Trait.sex !r !{ Trait.lambid at(Trait,2).damid !}
:
Trait.lambid 2
3 0 US
1.3 # Var(wwt_D)
1.0 2.2 # Cov(wwt_D,ywt_D) Var(ywt_D)
-.1 -.2 0.8 # Cov(wwt_D,wwt_M) Cov(ywt_D,wwt_M) Var(wwt_M)
lambid 0 AINV # AINV explicitly requests to use A inverse

```

7.9 Constraining variance parameters

Parameter equality within and between variance structures

difficult

Equality of parameters in a variance model can be specified using the `!=s` qualifier where `s` is a string of letters and/or zeros (see Table 7.4). Positions in the string correspond to the parameters of the variance model:

- all parameters with the same letter in the structure are treated as the same parameter,
- 1-9 are different from a-z which are different from A-Z so that 61 equalities can be specified. 0 and . mean unconstrained. A colon generates a sequence viz. `a:e` is the same as `abcde`
- Putting % as the first character in `s` makes the interpretation of codes absolute (so that they apply across structures).
- Putting * as the first character in `s` indicates that numbers are repeat counts, A-Z are equality codes and only . is unconstrained. Thus `!=*.3A2.` is equivalent to `!=0AAA00` or `!=0aaa00`.

New

New

Examples are presented in Table 7.5.

Table 7.5: Examples of constraining variance parameters in ASReml

ASReml code	action
<code>!=ABACBAOCBA</code>	constrain all parameters corresponding to A to be equal, similarly for B and C. The 7th parameter would be left unconstrained. This sequence applied to an unstructured 4×4 matrix would make it banded, that is A B A C B A 0 C B A
<pre>site.gen 2 # G header line site 0 US .3 !=0A0AAO !GPUPUUP .1 .4 .1 .1 .3 gen</pre>	this example defines a structure for the genotype by site interaction effects in a MET in which the genotypes are independent random effects within sites but are correlated across sites with equal covariance.

Examples of constraining variance parameters in ASReml

ASReml code	action
<pre>site 0 FA2 !G4PZ3P4P !=0000000VVVV 4*.9 # initial values for 1st factor 0 3*.1 # initial values for 2nd factor # first fixed at 0 4*.2 # init values for site variances</pre>	a 2 factor Factor Analytic model for 4 sites with equal variance is specified using this syntax. The first loading in the second factor is constrained equal to 0 for identifiability. P places restrictions on the magnitude of the loadings and the variances to be positive.
<pre>xfa(site,2) 0 XFA2 !=VVVV0 !4P4PZ3P 4*.2 # initial specific variances 4*1.2 # initial loadings for 1st factor 0 3*.3 # initial loadings for 2nd factor</pre>	a 2 factor Factor analytic model in which the specific variances are all equal.

Constraints between and within variance models

difficult

More general relationships between variance parameters can be defined using the !VCC *c* qualifier placed on the data file definition line.

- !VCC *c* specifies that there are *c* constraint lines defining constraints to be applied,
- the constraint lines occur after the variance header line and any R and G structure lines, that is, there must be a variance header line,
- each constraint is specified in a separate line in the form

$$P_1 * V_1 \quad P_2 * V_2 \quad \dots$$

- P_i is the name of a random model term or the number of a parameter and V_i is a coefficient,
- P_1 is the primary parameter number,
- * indicates that the next values (V_i) is a weighting coefficient,
- if the coefficient is 1 you may omit the * 1,
- if the coefficient is -1 you may write $-P_i$ instead of $P_i * -1$,
- the meaning of the coefficients is as follows $P_2 = V_2 * P_1 / V_1$,
- typically $V_1 = 1$,
- a variance parameter may only be included in constraints once,

- the P_i terms refer to positions in the full variance parameter vector. This may change if the model is changed and is often difficult to determine as a number. If it refers to a parameter which is a single traditional variance component associated with a random term, the name of the random term may be given instead of the parameter number. The full parameter vector includes a term for each factor in the model and then a term for each parameter defined in the R and G structures. A list of P_i numbers and their initial values is returned in the `.res` file to help you to check the numbers. Alternatively, examine the `.asr` file from an initial run with `!VCC` included but no arguments supplied. The job will terminate but ASReml will provide the P_i values associated with each variance component. Otherwise the numbers are given in the `.res` file.

The following are examples:

ASReml code	action
<code>5 7 * .1</code>	parameter 7 is a tenth of parameter 5
<code>5 -7</code>	parameter 7 is the negative of parameter 5
<code>32 34 35 37 38 39</code>	for a (4×4) US matrix given by parameters 31 ... 40, the covariances are forced to be equal.
<code>units -uni(check)</code>	parameter associated with model term <code>uni(check)</code> has the same magnitude but opposite sign to the parameter associated with model term <code>units</code>

7.10 Model building using the `!CONTINUE` qualifier

difficult

In complex models, the Average Information algorithm can have difficulty maximising the REML log-likelihood when starting values are not reasonably close to the REML solution. ASReml has several internal strategies to cope with this problem but these are not always successful.

When the user needs to provide better starting values, one method is to fit a simpler variance model. For example, it can be difficult to guess reasonable starting values for an unstructured variance matrix. A first step might be to assume independence and just estimate the variances. If all the variances are not positive, there is little point proceeding to try and estimate the covariances.

The !CONTINUE qualifier instructs ASReml to retrieve variance parameters from the .rsv file if it exists rather than using the values in the .asr file. When reading the .rsv file, it will take results from some matrices as supplying starting values for other matrices. The transitions recognised are

```
DIAG to CORUH  
DIAG to FA1  
CORUH to FA1  
FA $i$  to FA $i+1$   
FA $i$  to CORGH  
FA $i$  to US  
CORGH to US
```

The use of the .rsv file with !CONTINUE in this way reduces the need for the user to type in the updated starting values.

The various models may be written in various !PART s of the job and controlled by the !DOPART qualifier. When used with the -r qualifier on the command line (see Chapter 12), the output from the various parts has the partnumber appended to the filename. In this case it would be necessary to copy the .rsv files with the new part number before running the next part to take advantage of this facility.

8

Command file: Multivariate analysis

Introduction

Repeated measures on rats

Wether trial data

Model specification

Variance structures

Specifying multivariate variance structures in ASReml

The output for a multivariate analysis

8.1 Introduction

Multivariate analysis is used here in the narrow sense of a multivariate mixed model. There are many other multivariate analysis techniques which are not covered by ASReml. Multivariate analysis is used when we are interested in estimating the correlations between distinct traits (for example, fleece weight and fibre diameter in sheep) and for repeated measures of a single trait.

Repeated measures on rats

Wolfinger (1996) summarises a range of variance structures that can be fitted to repeated measures data and demonstrates the models using five weights taken weekly on 27 rats subjected to 3 treatments. This command file demonstrates a multivariate analysis of the five repeated measures. Note that the two dimensional structure for common error meets the requirement of independent units and is correctly ordered traits with units.

```
Wolfinger rat data
treat !A
wt0 wt1 wt2 wt3 wt4
rat.dat
wt0 wt1 wt2 wt3 wt4 ~ Trait,
treat Trait.treat
1 2 0
27 0 ID #error variance
Trait 0 US
15 * 0
```

Wether trial data

Three key traits for the Australian wool industry are the weight of wool grown per year, the cleanness and the diameter of that wool. Much of the wool is produced from wethers and most major producers have traditionally used a particular strain or *bloodline*. To assess the importance of bloodline differences, many wether trials were conducted. One trial was conducted from 1984 to 1988 at Borenore near Orange. It involved 35 teams of wethers representing 27 bloodlines. The file `wether.dat` shown below contains greasy fleece weight (kg), yield (percentage of clean fleece weight to greasy fleece weight) and fibre diameter (microns). The code (`wether.as`) to the right performs a basic bivariate analysis of this data.

```
Orange Wether Trial 1984-8
SheepID !I
TRIAL
BloodLine !I
TEAM *
YEAR *
GFW YLD FDIAM
wether.dat !skip 1
GFW FDIAM ~ Trait Trait.YEAR,
!r Trait.TEAM Trait.SheepID
1 2 2
1485 0 ID
Trait 0 US .2 .2 .4
Trait.TEAM 2
Trait 0 US
0.4
0.3 1.3
TEAM 0 ID
Trait.SheepID 2
Trait 0 US
0.2 0.2 2
SheepID 0 ID
predict YEAR Trait
```

```

SheepID Site Bloodline Team Year GFW Yield FD
0101 3 21 1 1 5.6 74.3 18.5
0101 3 21 1 2 6.0 71.2 19.6
0101 3 21 1 3 8.0 75.7 21.5
0102 3 21 1 1 5.3 70.9 20.8
0102 3 21 1 2 5.7 66.1 20.9
0102 3 21 1 3 6.8 70.3 22.1
0103 3 21 1 1 5.0 80.7 18.9
0103 3 21 1 2 5.5 75.5 19.9
0103 3 21 1 3 7.0 76.6 21.9
:
:
4013 3 43 35 1 7.9 75.9 22.6
4013 3 43 35 2 7.8 70.3 23.9
4013 3 43 35 3 9.0 76.2 25.4
4014 3 43 35 1 8.3 66.5 22.2
4014 3 43 35 2 7.8 63.9 23.3
4014 3 43 35 3 9.9 69.8 25.5
4015 3 43 35 1 6.9 75.1 20.0
4015 3 43 35 2 7.6 71.2 20.3
4015 3 43 35 3 8.5 78.1 21.7

```

8.2 Model specification

The syntax for specifying a multivariate linear model in ASReml is

$$Y\text{-variates} \sim \text{fixed} [\text{!r random}] [\text{!f sparse_fixed}]$$

- *Y-variates* is a list of traits,
- *fixed*, *random* and *sparse_fixed* are as in the univariate case (see Chapter 6) but involve the special term **Trait** and interactions with **Trait**.

The design matrix for **Trait** has a level (column) for each trait.

- **Trait** by itself fits the mean for each variate,
- In an interaction **Trait.Fac** fits the factor **Fac** for each variate and **Trait.Cov** fits the covariate **Cov** for each variate.

ASReml internally rearranges the data so that n data records containing t traits each becomes n sets of t analysis records indexed by the internal factor **Trait** *i.e.* nt analysis records ordered **Trait** within data record. If the data is already in this long form, use the **!ASMV t** qualifier to indicate that a multivariate analysis is required.

8.3 Variance structures

Using the notation of Chapter 7, consider a multivariate analysis with t traits and n units in which the data are ordered *traits* within *units*. An algebraic expression for the variance matrix in this case is

$$\mathbf{I}_n \otimes \Sigma$$

where $\Sigma^{(t \times t)}$ is an unstructured variance matrix.

Specifying multivariate variance structures in ASReml

A more sophisticated error structure is required for multivariate analysis. For a standard multivariate analysis

- the error structure for the residual must be specified as two-dimensional with independent records and an unstructured variance matrix across traits; records may have observations missing in different patterns and these are handled internally during analysis,
- the R structure *must* be ordered traits within units, that is, the R structure definition line for units must be specified before the line for **Trait**,
- variance parameters are variances not variance ratios,
- the R structure definition line for units, that is, 1485 0 ID, could be replaced by 0 or 0 0 ID; this tells ASReml to fill in the number of units and is a useful option when the exact number of units in the data is not known to the user,
- the error variance matrix is specified by the model **Trait 0 US**
 - the initial values are for the lower triangle of the (symmetric) matrix specified row-wise,
 - finding reasonable initial values can be a problem. If initial values are written on the next line in the form $q * 0$ where q is $t(t+1)/2$ and t is the number of traits, ASReml will take half of the phenotypic variance matrix of the data as an initial value, see `.as` file in code box for example,

```
Orange Wether Trial 1984-8
SheepID !I
TRIAL
BloodLine !I
TEAM *
YEAR *
GFW YLD FDIAM
wether.dat !skip 1
GFW FDIAM ~ Trait Trait.YEAR,
!r Trait.TEAM Trait.SheepID
1 2 2
1485 0 ID
Trait 0 US
3*0
Trait.TEAM 2
Trait 0 US
3*0
TEAM 0 ID
Trait.SheepID 2
Trait 0 US
3*0
SheepID 0 ID
predict YEAR Trait
```

- the special qualifiers relating to multivariate analysis are !ASUV and !ASMV t , see Table 5.4 for detail
 - to use an error structure other than US for the residual stratum you must also specify !ASUV (see Table 5.4) and include mv in the model if there are missing values,
 - to perform a multivariate analysis when the data have already been expanded use !ASMV t (see Table 5.4)
 - t is the number of traits that ASReml should expect,
 - the data file must have t records for each multivariate record although some may be coded missing.

8.4 The output for a multivariate analysis

Below is the output returned in the .asr file for this analysis.

```
ASReml 1.63o [01 Jun 2005] Orange Wether Trial 1984-88
      Build: j [01 Jul 2005] 32 bit
13 Jul 2005 09:38:00.928 32.00 Mbyte Windows wether
Licensed to: Arthur Gilmour
*****
* SYNTAX change: A/B now means A A.B *
*
* Contact support@asreml.co.uk for licensing and support *
***** ARG *

Folder: C:\data\asr\UG2\manex
TAG !I
BloodLine !I
QUALIFIERS: !SKIP 1
Reading wether.dat FREE FORMAT skipping 1 lines

traits
Bivariate analysis of GFW and FDIAM
Using 1485 records of 1485 read
Model term          Size #miss #zero  MinNon0  Mean  MaxNon0
1 TAG                521    0    0        1  261.0956  521
2 TRIAL              0      0    0  3.000    3.000  3.000
3 BloodLine         27     0    0        1  13.4323  27
4 TEAM              35     0    0        1  18.0067  35
5 YEAR              3      0    0        1   2.0391   3
```

```

6 GFW          Variate      0    0  4.100    7.478    11.20
7 YLD          Variate      0    0  60.30    75.11    88.60
8 FDIAM        Variate      0    0  15.90    22.29    30.60
9 Trait                2
10 Trait.YEAR        6 9 Trait      : 2  5 YEAR          :  3
11 Trait.TEAM        70 9 Trait     : 2  4 TEAM          : 35
12 Trait.TAG         1042 9 Trait    : 2  1 TAG           : 521
1485 identity
  2 UnStructure    0.2000    0.2000    0.4000
2970 records assumed sorted  2 within  1485
  2 UnStructure    0.4000    0.3000    1.3000
35 identity
Structure for Trait.TEAM      has      70 levels defined
  2 UnStructure    0.2000    0.2000    2.0000
521 identity
Structure for Trait.TAG       has     1042 levels defined
Forming  1120 equations:  8 dense.
Initial updates will be shrunk by factor  0.316
Notice: Algebraic ANOVA Denominator DF calculation is not available
      Empirical derivatives will be used.
NOTICE:  2 singularities detected in design matrix.
convergence  1 LogL=-886.521    S2=  1.0000    2964 df
            2 LogL=-818.508    S2=  1.0000    2964 df
            3 LogL=-755.911    S2=  1.0000    2964 df
            4 LogL=-725.374    S2=  1.0000    2964 df
            5 LogL=-723.475    S2=  1.0000    2964 df
            6 LogL=-723.462    S2=  1.0000    2964 df
            7 LogL=-723.462    S2=  1.0000    2964 df
            8 LogL=-723.462    S2=  1.0000    2964 df

final
components  Source          Model  terms  Gamma  Component  Comp/SE  % C
Residual    UnStru  1  1  0.198351  0.198351  21.94  0 U
Residual    UnStru  2  1  0.128890  0.128890  12.40  0 U
Residual    UnStru  2  2  0.440601  0.440601  21.93  0 U
Trait.TEAM  UnStru  1  1  0.374493  0.374493  3.89  0 U
Trait.TEAM  UnStru  2  1  0.388740  0.388740  2.60  0 U
Trait.TEAM  UnStru  2  2  1.36533  1.36533  3.74  0 U
Trait.TAG   UnStru  1  1  0.257159  0.257159  12.09  0 U
Trait.TAG   UnStru  2  1  0.219557  0.219557  5.55  0 U
Trait.TAG   UnStru  2  2  1.92082  1.92082  14.35  0 U

```



```

Residual          Covariance/Variance/Correlation Matrix UnStructured
0.4360 is the    0.1984      0.4360
correlation      0.1289      0.4406
Trait.TEAM       Covariance/Variance/Correlation Matrix UnStructured
0.3745          0.5436
0.3887          1.365
Trait.TAG        Covariance/Variance/Correlation Matrix UnStructured
0.2572          0.3124
0.2196          1.921

```

Analysis of Variance	NumDF	DenDF	F_inc	Prob
9 Trait	2	33.0	5761.58	<.001
10 Trait.YEAR	4	1162.2	1094.90	<.001

Notice: The DenDF values are calculated ignoring fixed/boundary/singular variance parameters using empirical derivatives.

	Estimate	Standard Error	T-value	T-prev
10 Trait.YEAR				
2	-0.102262	0.290190E-01	-3.52	
3	1.06636	0.290831E-01	36.67	42.07
5	1.17407	0.433905E-01	27.06	
6	2.53439	0.434880E-01	58.28	32.85
9 Trait				
1	7.13717	0.107933	66.13	
2	21.0569	0.209095	100.71	78.16
11 Trait.TEAM				
				70 effects fitted
12 Trait.TAG				
				1042 effects fitted
SLOPES FOR LOG(ABS(RES)) on LOG(PV) for Section 1				
1.00	1.54			
10 possible outliers: see .res file				
Finished: 13 Jul 2005 09:38:05.725 LogL Converged				

9 Command file: Genetic analysis

Introduction

The command file

The pedigree file

Reading in the pedigree file

Genetic groups

GIV files

The example

Multivariate genetic analysis

9.1 Introduction

In an ‘animal model’ or ‘sire model’ genetic analysis we have data on a set of animals that are genetically linked via a pedigree. The genetic effects are therefore correlated and, assuming normal modes of inheritance, the correlation expected from additive genetic effects can be derived from the pedigree provided all the genetic links are in the pedigree. The additive genetic relationship matrix (sometimes called the numerator relationship matrix) can be calculated from the pedigree. It is actually the *inverse* relationship matrix that is formed by ASReml for analysis. Users new to this subject might find notes by Julius van der Werf helpful:

http://www-personal.une.edu.au/~jvanderw/Mixed_Models_for_Genetic_analysis.pdf

For the more general situation where the pedigree based inverse relationship matrix is not the appropriate/required matrix, the user can provide a particular general inverse variance (GIV) matrix explicitly in a `.giv` file.

In this chapter we consider data presented in Harvey (1977) using the command file `harvey.as`.

9.2 The command file

In ASReml the `!P` data field qualifier indicates that the corresponding data field has an associated pedigree. The file containing the pedigree (`harvey.ped` in the example) for `animal` is specified after all field definitions and before the datafile definition. See below for the first 20 lines of `harvey.ped` together with the corresponding lines of the data file `harvey.dat`. All individuals appearing in the data file must appear in the pedigree file. When all the pedigree information (individual, male_parent, female_parent) appears as the first three fields of the data file, the data file can double as the pedigree file. In this example the line `harvey.ped !ALPHA` could be replaced with `harvey.dat !ALPHA`. Typically additional individuals providing additional genetic links are present in the pedigree file.

```
Pedigree file example
animal !P
sire !A
dam
lines 2
damage
adailygain
harvey.ped !ALPHA
harvey.dat
adailygain mu lines, !r
animal 0.25
```

9.3 The pedigree file

The pedigree file is used to define the genetic relationships for fitting a genetic animal model and is required if the !P qualifier is associated with a data field. The pedigree file

- has three fields; the identities of an individual, its sire and its dam (or maternal grand sire if the !MGS qualifier, Table 9.1, is specified), in that order,
- is sorted so that the line giving the pedigree of an individual appears before any line where that individual appears as a parent,
- is read free format; it may be the same file as the data file if the data file is free format and has the necessary identities in the first three fields, see below,
- is specified on the line immediately preceding the data file line in the command file,
- use identity 0 or * for unknown parents.

harvey.ped

```
101 SIRE_1 0
102 SIRE_1 0
103 SIRE_1 0
104 SIRE_1 0
105 SIRE_1 0
106 SIRE_1 0
107 SIRE_1 0
108 SIRE_1 0
109 SIRE_2 0
110 SIRE_2 0
111 SIRE_2 0
112 SIRE_2 0
113 SIRE_2 0
114 SIRE_2 0
115 SIRE_2 0
116 SIRE_2 0
117 SIRE_3 0
118 SIRE_3 0
119 SIRE_3 0
120 SIRE_3 0
:
```

harvey.dat

```
101 SIRE_1 0 1 3 192 390 2241
102 SIRE_1 0 1 3 154 403 2651
103 SIRE_1 0 1 4 185 432 2411
104 SIRE_1 0 1 4 183 457 2251
105 SIRE_1 0 1 5 186 483 2581
106 SIRE_1 0 1 5 177 469 2671
107 SIRE_1 0 1 5 177 428 2711
108 SIRE_1 0 1 5 163 439 2471
109 SIRE_2 0 1 4 188 439 2292
110 SIRE_2 0 1 4 178 407 2262
111 SIRE_2 0 1 5 198 498 1972
112 SIRE_2 0 1 5 193 459 2142
113 SIRE_2 0 1 5 186 459 2442
114 SIRE_2 0 1 5 175 375 2522
115 SIRE_2 0 1 5 171 382 1722
116 SIRE_2 0 1 5 168 417 2752
117 SIRE_3 0 1 3 154 389 2383
118 SIRE_3 0 1 4 184 414 2463
119 SIRE_3 0 1 5 174 483 2293
120 SIRE_3 0 1 5 170 430 2303
:
```

9.4 Reading in the pedigree file

The syntax for specifying a pedigree file in the ASReml command file is

pedigree_file [*qualifiers*]

- the *qualifiers*¹ are listed in Table 9.1,
- the identities (individual, male_parent, female_parent) are merged into a single list and the inverse relationship is formed before the data file is read,
- when the data file is read, data fields with the !P qualifier are recoded according to the combined identity list,
- the inverse relationship matrix is automatically associated with factors coded from the pedigree file unless some other covariance structure is specified. The inverse relationship matrix is specified with the variance model name AINV,
- the inverse relationship matrix is written to `ainverse.bin`,
 - if `ainverse.bin` already exists ASReml assumes it was formed in a previous run and has the correct inverse
 - `ainverse.bin` is read, rather than the inverse being reformed (unless !MAKE is specified); this saves time when performing repeated analyses based on a particular pedigree,
 - delete `ainverse.bin` or specify !MAKE if the pedigree is changed between runs,
- identities are printed in the `.sln` file,
 - identities should be whole numbers less than 200,000,000 unless !ALPHA is specified,
 - pedigree lines for parents must precede their progeny,
 - unknown parents should be given the identity number 0,
 - if an individual appearing as a parent does not appear in the first column, it is assumed to have unknown parents, that is, parents with unknown parentage do not need their own line in the file,
 - identities may appear as both male and female parents, for example, in forestry.

¹A white paper downloadable from <http://www.vsnl.co.uk/resources/doc/> contains details of these options.

9.5 Genetic groups

If all individuals belong to one genetic group, then use 0 as the identity of the parents of base individuals. However, if base individuals belong to various genetic groups this is indicated by the `!GROUP` qualifier and the pedigree file must begin by identifying these groups. All base individuals should have group identifiers as parents. In this case the identity 0 will only appear on the group identity lines, as in the following example where three sire lines are fitted as genetic groups.

```
Genetic group example
animal !P
sire 9 !A
dam
lines 2
damage
adailygain
harveyg.ped !ALPHA !MAKE !GROUP 3
harvey.dat
adailygain ~ mu
!r animal 02.5 !GU
```

```
G1 0 0
G2 0 0
G3 0 0
SIRE_1 G1 G1
SIRE_2 G1 G1
SIRE_3 G1 G1
SIRE_4 G2 G2
SIRE_5 G2 G2
SIRE_6 G3 G3
SIRE_7 G3 G3
SIRE_8 G3 G3
SIRE_9 G3 G3
101 SIRE_1 G1
102 SIRE_1 G1
103 SIRE_1 G1
:
163 SIRE_9 G3
164 SIRE_9 G3
165 SIRE_9 G3
```

Important

It is usually appropriate to allocate a genetic group identifier where the parent is unknown.

Table 9.1: List of pedigree file qualifiers

<i>qualifier</i>	<i>description</i>
<code>!ALPHA</code>	indicates that the identities are alphanumeric with up to 20 characters; otherwise by default they are numeric whole numbers < 200,000,000.
<code>!DIAG</code>	causes the pedigree identifiers, the diagonal elements of the Inverse of the Relationship and the inbreeding coefficients for the individuals (calculated as the diagonal of $\mathbf{A} - \mathbf{I}$) to be written to <code>AINVERSE.DIA</code> .
<code>!GIV</code>	instructs ASReml to write out the A-inverse in the format of <code>.giv</code> files.

List of pedigree file qualifiers

<i>qualifier</i>	description
!GROUPS <i>g</i>	includes genetic groups in the pedigree. The first <i>g</i> lines of the pedigree identify genetic groups (with zero in both the sire and dam fields). All other lines must specify one of the genetic groups as sire or dam if the actual parent is unknown.
New !INBRED	generates pedigree for inbred lines. Each cross is assumed to be selfed several times to stabilize as an inbred line as is usual for cereals, before being evaluated or crossed with another line. Since inbreeding is usually associated with strong selection, it is not obvious that a pedigree assumption of covariance of 0.5 between parent and offspring actually holds. Do not use the !INBRED qualifier with the !MGS or !SELF qualifiers.
!MAKE	tells ASReml to make the A-inverse (rather than trying to retrieve it from the <code>ainverse.bin</code> file).
!MGS	indicates that the third identity is the sire of the dam rather than the dam.
!REPEAT	tells ASReml to ignore repeat occurrences of lines in the pedigree file. Warning Use of this option will avoid the check that animals occur in chronological order, but chronological order is still required.
New !SELF <i>s</i>	allows partial selfing when third field is unknown. It indicates that progeny from a cross where the second parent (<code>male_parent</code>) is unknown, is assumed to be from selfing with probability <i>s</i> and from outcrossing with probability $(1 - s)$. This is appropriate in some forestry tree breeding studies where seed collected from a tree may have been pollinated by the mother tree or pollinated by some other tree (Dutkowski and Gilmour, 2001). Do not use the !SELF qualifier with the !INBRED or !MGS qualifiers.
!SKIP <i>n</i>	allows you to skip <i>n</i> header lines at the top of the file.
New !SORT	causes ASReml to sort the pedigree into an acceptable order, that is parents before offspring, before forming the A-Inverse. The sorted pedigree is written to a file whose name has <code>.srt</code> appended to its name.

9.6 Reading a user defined inverse relationship matrix

New

Sometimes an inverse relationship matrix is required other than the one ASReml can produce from the pedigree file. We call this a GIV (G inverse) matrix. The user can prepare a `.giv` file containing this matrix and use it in the analysis. Alternatively, the user can prepare the relationship matrix in a `.grm` file and ASReml will invert it to form the GIV matrix. The syntax for specifying a G matrix file (say `name.grm`) or the G inverse file (say `name.giv`) is

`name.grm` [`!SKIP n`]

or

`name.giv` [`!SKIP n`]

- the named file must have a `.giv` or `.grm` extension,
- the G (inverse) files must be specified on the line(s) immediately prior to the data file line after any pedigree file,
- up to 98 G (inverse) matrices may be defined,
- the file must be free format with three numbers per line, namely

row column value

defining the lower triangle row-wise of the matrix,

- the file must be sorted *column* within *row*,
- every diagonal element must be represented; missing off-diagonal elements are assumed to be zero cells,
- the file is used by associating it with a factor in the model. The number and order of the rows must agree with the size and order of the associated factor,
- the `!SKIP n` qualifier tells ASReml to skip *n* header lines in the file.

```
1 1 1
2 2 1
3 3 1
4 4 1
5 5 1.066667
6 5 -0.266667
6 6 1.066667
7 7 1.066667
8 7 -0.266667
8 8 1.066667
9 9 1.066667
10 9 -0.266667
10 10 1.066667
11 11 1.066667
12 11 -0.266667
12 12 1.066667
```

The `.giv` file presented in the code box gives the following G inverse matrix

$$\begin{bmatrix} \mathbf{I}_4 & \mathbf{0} \\ \mathbf{0} & \mathbf{I}_4 \otimes \begin{bmatrix} 1.067 & -0.267 \\ -0.267 & 1.067 \end{bmatrix} \end{bmatrix}$$

The `.giv` file can be associated with a factor in two ways:

- the first is to declare a G structure for the model term and to refer to the `.giv` file with the corresponding identifier `GIV1`, `GIV2`, `GIV3`, \dots , ; for example,

```
animal 1                for a one-dimensional structure put the scale pa-
animal 0 GIV1 0.12      rameter (0.12 in this case) after the GIV $g$  identifier,
```

```
site.variety 2          for a two-dimensional structure.
```

```
site 0 CORUH 0.5
8*1.5
variety 0 GIV1
```

- the second is for one-dimensional structures; in this case the `.giv` structure can be directly associated with the term using the `giv(f, i)` model function which associates the i th `.giv` file with factor f , for example,

```
giv(animal,1) 0.12
```

is equivalent to the first of the preceding examples.

The example continued

Below is an extension of `harvey.as` to use `harvey.giv` which is partly shown to the right. This G inverse matrix is an identity matrix of order 74 scaled by 0.5, that is, $0.5\mathbf{I}_{74}$. This model is simply an example which is easy to verify. Note that `harvey.giv` is specified on the line immediately preceding `harvey.dat`.

Model term specification associating the `harvey.giv` structure to the coding of sire takes precedence over the relationship matrix structure implied by the `!P` qualifier for sire. In this case, the `!P` is being used to amalgamate animals and sires into a single list.

command file

```
GIV file example
animal !P
sire !P
dam
lines 2
damage
adailygain
harvey.ped !ALPHA
harvey.giv # giv structure file
harvey.dat
adailygain ~ mu line, !r giv(sire,1) .25
```

`.giv` file

```
01 01 .5
02 02 .5
03 03 .5
04 04 .5
05 05 .5
.
.
.
72 72 .5
73 73 .5
74 74 .5
```

10

Tabulation of the data and prediction from the model

Introduction

Tabulation

Prediction

Underlying principles

Syntax

Examples

10.1 Introduction

This chapter describes the `tabulate` directive and the `predict` directive introduced in Section 3.4 under Prediction.

Tabulation is the process of forming simple tables of averages and counts from the data. Such tables are useful for looking at the structure of the data and numbers of observations associated with factor combinations. Multiple `tabulate` directives may be specified in a job.

Prediction is the process of forming a linear function of the vector of fixed and random effects in the linear model to obtain an estimated or predicted value for a quantity of interest. It is primarily used for predicting tables of adjusted means. If a table is based on a subset of the explanatory variables then the other variables need to be accounted for. It is usual to form a predicted value either at specified values of the remaining variables, or averaging over them in some way.

10.2 Tabulation

A `tabulate` directive is provided to enable simple summaries of the data to be formed for the purpose of checking the structure of the data. The summaries are based on the same records as are used in the analysis of the model (i.e. leaving out records eliminated from the analysis because of missing values in variates and factors in the model). Multiple `tabulate` statements are permitted either immediately before or after the linear model. If a linear (mixed) model is not supplied, tabulation is based on all records.

New

The `tabulate` statement has the form

```
tabulate response_variables [!WT weight !COUNT !DECIMALS [d] !SD !RANGE
!STATS !FILTER filter !SELECT value] ~ factors
```

- `tabulate` is the directive name and must begin in column 1,
- *response_variables* is a list of variates for which means are required,
- `!WT weight` nominates a variable containing weights,
- `!COUNT` requests counts as well as means to be reported,
- `!DECIMALS [d]` ($1 \leq d \leq 7$) requests means be reported with *d* decimal places. If omitted, ASReML reports 5 significant digits; if specified without an argument, 2 decimal places are reported,

New

New

- !RANGE requests the minimum and maximum of each cell be reported,
- !SD requests the standard deviation within each cell be reported,
- !STATS is shorthand for !COUNT !SD !RANGE,
- !FILTER *filter* nominates a factor for selecting a portion of the data,
- !SELECT *value* indicates that only records with *value* in the *filter* column are to be included,
- \sim *factors* identifies the factors to be used for classifying the data. Only factors (not covariates) may be nominated and no more than six may be nominated.

ASReml prints the multiway table of means omitting empty cells to a file with extension `.tab`.

10.3 Prediction

Underlying principles

Our approach to prediction is a generalization of that of Lane and Nelder (1982) who consider fixed effects models. They form fitted values for all combinations of the explanatory variables in the model, then take marginal means across the explanatory variables not relevant to the current prediction. Our case is more general in that random effects can be fitted in our (mixed) models. A full description can be found in Gilmour *et al.* (2004) and Welham *et al.* (2004).

Random factor terms may contribute to predictions in several ways. They may be evaluated at values specified by the user, they may be averaged over, or they may be omitted from the fitted values used to form the prediction. Averaging over the set of random effects gives a prediction specific to the random effects observed. We call this a ‘conditional’ prediction. Omitting the term from the model produces a prediction at the population average (zero), that is, substituting the assumed population mean for an unknown random effect. We call this a ‘marginal’ prediction. Note that in any prediction, some terms may be evaluated as conditional and others at marginal values, depending on the aim of prediction.

For fixed factors there is no pre-defined population average, so there is no natural interpretation for a prediction derived by omitting a fixed term from the fitted values. Averages must therefore be taken over all the levels present to give a sample specific average, or prediction must be at specified levels.

For covariate terms (fixed or random) the associated effect represents the coefficient of a linear trend in the data with respect to the covariate values. These terms should be evaluated at a given value of the covariate, or averaged over several given values. Omission of a covariate from the predictive model is equivalent to predicting at a zero covariate value, which is often inappropriate.

Interaction terms constructed from factors generate an effect for each combination of the factor levels, and behave like single factor terms in prediction. Interactions constructed from covariates fit a linear trend for the product of the covariate values and behave like a single covariate term. An interaction of a factor and a covariate fits a linear trend for the covariate for each level of the factor. For both fixed and random terms, a value for the covariate must be given, but the factor may be evaluated at a given level, averaged over or (for random terms) omitted.

Before considering some examples in detail, it is useful to consider the conceptual steps involved in the prediction process. Given the explanatory variables used to define the linear (mixed) model, the four main steps are

- (a) Choose the explanatory variable(s) and their respective value(s) for which predictions are required; the variables involved will be referred to as the *classify* set and together define the multiway table to be predicted.
- (b) Determine which variables should be averaged over to form predictions. The values to be averaged over must also be defined for each variable; the variables involved will be referred to as the *averaging* set. The combination of the classify set with these averaging variables defines a multiway hyper-table. Note that variables evaluated at only one value, for example, a covariate at its mean value, can be formally introduced as part of the classifying or averaging set.
- (c) Determine which terms from the linear mixed model are to be used in forming predictions for each cell in the multiway hyper-table in order to give appropriate conditional or marginal prediction.
- (d) Choose the weights to be used when averaging cells in the hyper-table to produce the multiway table to be reported.

Note that after steps (a) and (b) there may be some explanatory variables in the fitted model that do not classify the hyper-table. These variables occur in terms that are ignored when forming the predicted values. It was concluded above that fixed terms could not sensibly be ignored in forming predictions, so that variables

should only be omitted from the hyper-table when they only appear in random terms. Whether terms derived from these variables should be used when forming predictions depends on the application and aim of prediction.

The main difference in this prediction process compared to that described by Lane and Nelder (1982) is the choice of whether to include or exclude model terms when forming predictions. In linear models, since all terms are fixed, terms not in the classify set must be in the averaging set.

Predict syntax

The first step is to specify the classify set of explanatory variables after the `predict` directive. The `predict` statement(s) may appear immediately after the model line (before or after any `tabulate` statements) or after the R and G structure lines. The syntax is

```
predict factors [qualifiers]
```

- `predict` must be the first element of the `predict` statement, commencing in column 1 in upper or lower case,
- `factors` is a list of the variables defining a multiway table to be predicted; each variable may be followed by a list of specific values to be predicted,
- the `qualifiers`, listed in Table 10.1, instruct ASReml to modify the predictions in some way,
- a `predict` statement may be continued on subsequent lines by terminating the current line with a comma,
- several `predict` statements may be specified.

```
NIN Alliance trial 1989
  variety !A
:
column 11
nin89.asd !skip 1
yield ~ mu variety !r repl
predict variety
0 0 1
repl 1
repl 0 IDV 0.1
```

ASReml parses the `predict` statement before fitting the model. If any syntax problems are encountered, these are reported in the `.pvs` file after which the statement is ignored: the job is completed as if the erroneous prediction statement did not exist. The predictions are formed as an extra process in the final iteration and are reported to the `.pvs` file. Consequently, aborting a run by creating the `ABORTASR.NOW` file (see page 65) will cause any `predict` statements to be ignored.

By default, factors are predicted at each level, simple covariates are predicted at their overall mean and covariates used as a basis for splines or orthogonal

polynomials are predicted at their design points. Covariates grouped into a single term (using **!G** qualifier page 49) are treated as covariates.

Model terms **mv** and **units** are always ignored.

Prediction at particular values of a covariate or particular levels of a factor is achieved by listing the values after the variate/factor name. Where there is a sequence of values, use the notation $a\ b\ \dots\ n$ to represent the sequence of values from a to n with step size $b - a$. The default stepsize is 1 (in which case b may be omitted). A colon (**:**) may replace the ellipsis (\dots). An increasing sequence is assumed. When giving particular values for factors, the default is to use the coded level ($1:n$) rather than the label (alphabetical or integer). To use the label, precede it with a quote (**"**).

The second step is to specify the averaging set. The default averaging set is those explanatory variables involved in fixed effect model terms that are not in the classifying set. By default variables that only define random model terms are ignored. The qualifier **!AVERAGE** allows these variables to be added to the default averaging set.

The third step is to select the linear model terms to use in prediction. The default is that all model terms based entirely on variables in the classifying and averaging sets are used. Two qualifiers allow this default to be modified by adding (**!USE**) or removing (**!IGNORE**) model terms. The qualifier **!ONLYUSE** explicitly specifies the model terms to use, ignoring all others. The qualifier **!EXCEPT** explicitly specifies the model terms not to use, including all others. These qualifiers may implicitly modify the averaging set by including variables defining terms in the predicted model not in the classify set. It is sometimes easier to specify the classify set and the model terms to use and allow **ASReml** to construct the averaging set.

The fourth step is to choose the weights to use when averaging over dimensions in the hyper-table. The default is to simply average over the specified levels but the qualifier **!AVERAGE factor weights** allows other weights to be specified.

For example,

```
yield ~ site variety !r site.variety at(site).block
predict variety
```

puts **variety** in the classify set, **site** in the averaging set and **block** in the ignore set. Consequently, **ASReml** forms the **site** \times **variety** hyper-table from model terms **site**, **variety** and **site.variety** but ignoring all terms in **at(site).block**,

and then forms averages across sites to produce variety predictions.

There are often situations in which the fixed effects design matrix X is not of full column rank. These can be classified according to the cause of aliasing.

1. linear dependencies among the model terms due to over-parameterisation of the model,
2. no data present for some factor combinations so that the corresponding effects cannot be estimated,
3. linear dependencies due to other, usually unexpected, structure in the data.

The first type of aliasing is imposed by the parameterisation chosen and can be determined from the model. The second type of aliasing can be detected when setting up the design matrix for parameter estimation (which may require revision of imposed constraints). The third type can then be detected during the absorption of the mixed model equations. Dependencies (aliasing) can be dealt with in several ways and ASReml checks that predictions are of estimable functions in the sense defined by Searle (1971, p160) and are invariant to the constraint method used.

prediction problems

ASReml doesn't print predictions of non-estimable functions unless the `!PRINTALL` qualifier is specified. However, using `!PRINTALL` is rarely a satisfactory solution. Failure to report predicted values normally means that the `predict` statement is averaging over some cells of the hyper-table that have no information and therefore cannot be averaged in a meaningful way. Appropriate use of the `!AVERAGE` and/or `!PRESENT` qualifiers will usually resolve the problem. The `!PRESENT` qualifier enables the construction of means by averaging only the estimable cells of the hyper-table. It is regularly used for nested factors, for example locations nested in regions.

Table 10.1 is a list of the prediction qualifiers with the following syntax:

- f is an explanatory variable which is a factor,
- t is a list of terms in the fitted model,
- v is a list of explanatory variables.

Table 10.1: List of prediction qualifiers

<i>qualifier</i>	action
Controlling formation of tables	
<code>!AVERAGE <i>f</i> [<i>weights</i>]</code>	is used to formally include a variable in the averaging set and to explicitly set the weights for averaging. Variables that only appear in random model terms are not included in the averaging set unless included with this qualifier. The default for <i>weights</i> is equal weights. <i>weights</i> can be expressed like <code>{3*1 0 2*1}/5</code> to represent the sequence 0.2 0.2 0.2 0 0.2 0.2. The string inside the curly brace is expanded first and the expression $n*v$ means n occurrences of v . A separate <code>!AVERAGE</code> qualifier is required for each variable requiring explicit weights or to be added to the default averaging set.
<code>!PARALLEL [<i>v</i>]</code>	without arguments means all classify variables are expanded in parallel. Otherwise list the variables from the classify set whose levels are to be taken in parallel.
New <code>!PRESENT <i>v</i></code>	is used when averaging is to be based only on cells with data. <i>v</i> is a list of variables and may include variables in the classify set. <i>v</i> may not include variables with an explicit <code>!AVERAGE</code> qualifier. The variable names in <i>v</i> may optionally be followed by a list of levels for inclusion if such a list has not been supplied in the specification of the classify set. ASReml works out what combinations are present from the design matrix. A second <code>!PRESENT</code> qualifier is allowed on a <code>predict</code> statement (but not with <code>!PRWTS</code>). This is needed when there are two nested factors such as sites within regions and genotype within family. The two lists must not overlap.
New <code>!PRWTS <i>v</i></code>	is used in conjunction with the first <code>!PRESENT</code> factors to specify the weights that ASReml will use for averaging that <code>!PRESENT</code> table. More details are given below.
Controlling inclusion of model terms	
<code>!EXCEPT <i>t</i></code>	causes the prediction to include all fitted model terms not in <i>t</i> .
<code>!IGNORE <i>t</i></code>	causes ASReml to set up a prediction model based on the default rules and then removes the terms in <i>t</i> . This might be used to omit the spline Lack of fit term (<code>!IGNORE fac(x)</code>) from predictions as in <pre>yield ~ mu x variety !r spl(x) fac(x) predict x !IGNORE fac(x)</pre> which would predict points on the spline curve averaging over variety .

List of prediction qualifiers

<i>qualifier</i>	action
!ONLYUSE <i>t</i>	causes the prediction to include only model terms in <i>t</i> . It can be used for example to form a table of slopes as in <pre>HI ~ mu X variety X.variety predict variety X 1 !onlyuse X X.variety</pre>
!USE <i>t</i>	causes ASReml to set up a prediction model based on the default rules and then adds the terms listed in <i>t</i> .
Printing	
New !DEC [<i>n</i>]	gives the user control of the number of decimal places reported in the table of predicted values where <i>n</i> is 0...9. The default is 4. G15.9 format is used if <i>n</i> exceeds 9. When !VVP or !SED are used, the values are displayed with 6 significant digits unless <i>n</i> is specified and even; then the values are displayed with 9 significant digits.
New !PLOT [<i>⊗</i>]	instructs ASReml to attempt a plot of the predicted values. This qualifier is only applicable in versions of ASReml linked with the Winteracter Graphics library. If there is no argument, ASReml produces a figure of the predicted values as best it can. The user can modify the appearance by typing <Esc> to expose a menu or with the plot arguments listed in Table 10.2.
!PRINTALL	instructs ASReml to print the predicted value, even if it is not of an estimable function. By default, ASReml only prints predictions that are of estimable functions.
!SED	requests all <i>standard errors of difference</i> be printed. Normally only an average value is printed.
!TDIFF	requests <i>t</i> -statistics be printed for all combinations of predicted values.
!TURNINGPOINTS <i>n</i>	requests ASReml to scan the predicted values from a fitted line for possible turning points and if found, report them and save them internally in a vector which can be accessed by subsequent parts of the same job using \$TP <i>n</i> . This was added to facilitate location of putative QTL.
New !TWOStageWEIGHTS	is intended for use with variety trials which will subsequently be combined in a meta analysis. It forms the variance matrix for the predictions, inverts it and writes the predicted variety means with the corresponding diagonal elements of this matrix to the .pvs file. These values are used in some variety testing programs in Australia for a subsequent second stage analysis across many trials. A data base is used to collect the results from the individual trials and write out the combined data set. The diagonal elements are used as weights in the combined analysis.

List of prediction qualifiers

<i>qualifier</i>	action
!VPV	requests that the variance matrix of predicted values be printed to the .pvs file.

PLOT graphic control qualifiers

This functionality was developed and this section was written by Damian Collins.

New

The !PLOT qualifier produces a graphic of the predictions. Where there is more than one prediction factor, a multi-panel 'trellis' arrangement may be used. Alternatively, one or more factors can be superimposed on the one panel. The data can be added to the plot to assist informal examination of the model fit.

With no plot options, ASReml chooses an arrangement for plotting the predictions by recognising any covariates and noting the size of factors. However, the user is able to customize how the predictions are plotted by either using options to the !PLOT qualifier or by using the graphical interface. The graphical interface is accessed by typing Esc when the figure is displayed.

The !PLOT qualifier has the following options:

Table 10.2: List of predict plot options

<i>option</i>	action
Lines and data	
<code>^addData</code>	superimposes the raw data.
<code>^addlabels <i>factors</i></code>	superimposes the raw data with the data points labelled using the given factors (which must not be prediction factors). This option may be useful to identify individual data points on the graph – for instance, potential outliers – or alternatively, to identify groups of data points (e.g. all data points in the same stratum).

List of predict plot options

<i>option</i>	action
<code>^addlines factors</code>	superimposes the raw data with the data points joined using the given factors which must not be prediction factors. This option may be useful for repeated measures data.
<code>^noSEs</code>	specifies that no error bars should be plotted (by default, they are plotted)
<code>^semult r</code>	specifies the multiplier of the SE used for creating error bars (default=1.0)
<code>^joinmeans</code>	specifies that the predicted values should be joined by lines (by default, they are only joined if the x-axis variable is numeric)
Predictions involving two or more factors	
	If these arguments are used, all prediction factors (except for those specified with only one prediction level) must be listed once and only once, otherwise these arguments are ignored.
<code>^xaxis factor</code>	specifies the prediction factor to be plotted on the x-axis
<code>^superimpose factors</code>	specifies the prediction factors to be superimposed on the one panel.
<code>^condition factors</code>	specifies the conditioning factors which define the panels. These should be listed in the order that they will be used.
Layout	
<code>^goto n</code>	specifies the page to start at, for multi-page predictions.
<code>^saveplot filename</code>	specifies the name of the file to save the plot to.
<code>^layout rows cols</code>	specifies the panel layout on each page
<code>^bycols</code>	specifies that the panels be arranged by columns (default is by rows)
<code>^blankpanels n</code>	specifies that each page contains n blank panels. This sub-option can only be used in combination with the layout sub-option.
<code>^extrablanks n</code> and <code>^extraspan p</code>	specifies that an additional n blank panels be used every p pages. These can only be used with the layout sub-option.
Improving the graphical appearance (and readability)	
<code>^labcharsize n</code>	specifies the relative size of the data points/labels (default=0.4)
<code>^panelcharsize n</code>	specifies the relative size of the labels used for the panels (default=1.0)
<code>^vertxlab</code>	specifies that vertical annotation be used on the x-axis (default is horizontal).

List of predict plot options

<i>option</i>	action
<code>^abbrdlab <i>n</i></code>	specifies that the labels used for the data be abbreviated to <i>n</i> characters.
<code>^abbrxlab <i>n</i></code>	specifies that the labels used for the x-axis annotation be abbreviated to <i>n</i> characters.
<code>^abbrslab <i>n</i></code>	specifies that the labels used for superimposed factors be abbreviated to <i>n</i> characters.

Complicated weighting

New

Generally, when forming a prediction table, it is necessary to average over (or ignore) some potential dimensions of the prediction table. By default, ASReml uses equal weights ($1/f$ for a factor with f levels). More complicated weighting is achieved by using the **!AVERAGE** qualifier to set specific (unequal) weights for each level of a factor. However, sometimes the weights to be used need to be defined with respect to two or more factors. The simplest case is when there are missing cells and weighting is equal for those cells in a multiway table that are present; achieved by using the **!PRESENT** qualifier. This is now further generalized by allowing the user to fill in the weights for use by the **!PRESENT** machinery via the **!PRWTS** qualifier.

Caution

The user specifies the factors in the table of weights with the **!PRESENT** statement and then gives the table of weights using the **!PRWTS** qualifier. There may only be one **!PRESENT** qualifier on the **predict** line when **!PRWTS** is specified. The order of factors in the tables of weights must correspond to the order in the **!PRESENT** list with later factors nested within preceding factors. Check the output to ensure that the values in the tables of weights are applied in the correct order. ASReml may transpose the table of weights to match the order it needs for processing.

Consider a rather complicated example from a rotation experiment conducted over several years. This particular analysis followed the analysis of the daily live weight gain per hectare of the sheep grazing the plots. There were periods when no sheep grazed. Different flocks grazed in the different years. Daily liveweight

gain was assessed between 5 and 8 times in the various years. To obtain a measure of total productivity in terms of sheep liveweight, we need to weight the daily per sheep figures by the number of sheep grazing days per month. To obtain treatment effects for each year, the experimenter used

```
predict year 1 crop 1 pasture lime !AVE month 56 55 56 53 57 63 6*0
predict year 2 crop 1 pasture lime !AVE month 36 0 0 53 23 24 54 54 43 35 0 0
predict year 3 crop 1 pasture lime !AVE month 70 0 21 17 0 0 0 70 0 0 53 0
predict year 4 crop 1 pasture lime !AVE month 53 56 22 92 19 44 0 0 36 0 0 49
predict year 5 crop 1 pasture lime !AVE month 0 22 0 53 70 22 0 51 16 51 0 0
```

but then wanted to average over years as well. Both of the following `predict` statements produce the required values.

```
predict crop 1 pasture lime !PRES year month !PRWTS { 56 55 56 53 57 63 0 0 0,
0 0 0 36 0 0 53 23 24 54 54 43 35 0 0 70 0 21 17 0 0 0 70 0 0 53 0 53,
56 22 92 19 44 0 0 36 0 0 49 0 22 0 53 70 22 0 51 16 51 0 0}/5
predict crop 1 pasture lime !PRES month year !PRWTS { 56 36 70 53 0,
55 0 0 56 22 56 0 21 22 0 53 53 17 92 53 57 23 0 19 70 63 24 0 44 22,
0 54 0 0 0 0 54 70 0 51 0 43 0 36 16 0 35 0 0 51 0 0 53 5*0 49 0}/5
```

We have presented both sets of `predict` statements to show how the weights were derived and presented. Notice that the order in `!PRESENT year month` implies that the weight coefficients are presented in standard order with the levels for months cycling within levels for years. There is a check which reports if non zero weights are associated with cells that have no data. The weights are reported in the `.pvs` file. `!PRESENT` counts are reported in the `.res` file.

Examples

Examples are as follows:

```
yield ~ mu variety !r repl
predict variety
```

is used to predict variety means in the NIN field trial analysis. Random `repl` is ignored in the prediction.

```
yield ~ mu x variety !r repl
predict variety
```

predicts variety means at the average of `x` ignoring random `repl`.

```
yield ~ mu x variety repl
predict variety x 2
```

forms the hyper-table based on `variety` and `repl` at the covariate value of 2 and

then averages across `repl` to produce variety predictions.

```
GFW Fdiam ~ Trait Trait.Year !r Trait.Team  
predict Trait Team
```

forms the hyper-table for each trait based on `Year` and `Team` with each linear combination in each cell of the hyper-table for each trait using `Team` and `Year` effects. `Team` predictions are produced by averaging over years.

```
yield ~ variety !r site.variety  
predict variety
```

will ignore the `site.variety` term in forming the predictions while

```
predict variety !AVERAGE site
```

forms the hyper-table based on `site` and `variety` with each linear combination in each cell using `variety` and `site.variety` effects and then forms averages across sites to produce variety predictions.

```
yield ~ site variety !r site.variety at(site).block  
predict variety
```

puts `variety` in the classify set, `site` in the averaging set and `block` in the ignore set. Consequently, it forms the `site`×`variety` hyper-table from model terms `site`, `variety` and `site.variety` but ignoring all terms in `at(site).block`, and then forms averages across sites to produce variety predictions.

11

Functions of variance components

Introduction

Syntax

Linear combinations of components

Heritability

Correlation

A more detailed example

11.1 Introduction

ASReml includes a post-analysis procedure to calculate functions of variance components.

Its intended use is when the variance components are either simple variances or are vari-

ances and covariances in an unstructured matrix. The functions covered are linear combinations of the variance components (for example, phenotypic variance), a ratio of two components (for example, heritabilities) and the correlation based on three components (for example, genetic correlation). The user must prepare a `.pin` file. A simple sample `.pin` file is shown in the ASReml code box above. The `.pin` file specifies the functions to be calculated. The user re-runs ASReml with the `-P` command line option specifying the `.pin` file as the input file. ASReml reads the model information from the `.asr` and `.vvp` files and calculates the requested functions. These are reported in the `.pvc` file.

```
F phenvar 1 + 2 # pheno var
F genvar 1 * 4 # geno var
H herit 4 3 # heritability
```

11.2 Syntax

Functions of the variance components are specified in the `.pin` file in lines of the form

letter label coefficients

- *letter* (either F, H or R) must occur in column 1
 - F is for linear combinations of variance components,
 - H is for forming the ratio of two components,
 - R is for forming the correlation based on three components,
- *label* names the result,
- *coefficients* is the list of coefficients for the linear function.

Linear combinations of components

First ASReml extracts the variance components from the `.asr` file and their variance matrix from the `.vvp` file. Each linear function formed by an F line is added to the list of components.

Thus, the number of coefficients increases by one each line. We seek to calculate $k + \mathbf{c}'\mathbf{v}$, $\text{cov}(\mathbf{c}'\mathbf{v}, \mathbf{v})$ and $\text{var}(\mathbf{c}'\mathbf{v})$ where \mathbf{v} is the vector of existing variance components, \mathbf{c} is the vector of coefficients for the linear function and k is an optional offset which is usually omitted but would be 1 to represent the

```
F phenvar 1 + 2 # pheno var
F genvar 1 * 4 # geno var
H herit 4 3 # heritability
```

residual variance in a probit analysis and 3.289 to represent the residual variance in a logit analysis. The general form of the directive is

```
F label a + b * cb + c + d + m * k
```

where a , b , c and d are subscripts to existing components v_a , v_b , v_c and v_d and c_b is a multiplier for v_b . m is a number bigger than the current length of v to flag the special case of adding the offset k . Where matrices are to be combined the form

```
F label a:b * k + c:d
```

can be used, as in the Coopworth data example, see page 300.

Assuming that the `.pin` file in the ASReml code box corresponds to a simple sire model and that variance component 1 is the sire variance and variance component 2 is the residual variance, then

```
F phenvar 1 + 2
```

gives a third component which is the sum of the variance components, that is, the phenotypic variance, and

```
F genvar 1 * 4
```

gives a fourth component which is the sire variance component multiplied by 4, that is, the genotypic variance.

Heritability

Heritabilities are requested by lines in the `.pin` file beginning with an H. The specific form of the directive in this case is

```
F phenvar 1 + 2 # pheno var
F genvar 1 * 4 # geno var
H herit 4 3 # heritability
```

```
H label n d
```

This calculates σ_n^2/σ_d^2 and $se[\sigma_n^2/\sigma_d^2]$ where n and d are integers pointing to components v_n and v_d that are to be used as the numerator and denominator respectively in the heritability calculation.

$$\text{Var}\left(\frac{\sigma_n^2}{\sigma_d^2}\right) = \left(\frac{\sigma_n^2}{\sigma_d^2}\right)^2 \left(\frac{\text{Var}(\sigma_n^2)}{\sigma_n^4} + \frac{\text{Var}(\sigma_d^2)}{\sigma_d^4} - \frac{2\text{Cov}(\sigma_n^2, \sigma_d^2)}{\sigma_n^2 \sigma_d^2} \right)$$

In the example

```
H herit 4 3
```

calculates the heritability by calculating component 4 (from second line of `.pin`)

/ component 3 (from first line of `.pin`), that is, genetic variance / phenotypic variance.

Correlation

Correlations are requested by lines in the `.pin` file beginning with an `R`. The specific form of the directive is

```
F phenvar 1:3 + 4:6
R phencorr 7 8 9
R gencorr 4:6
```

`R label a ab b`

This calculates the correlation $r = \sigma_{ab} / \sqrt{\sigma_a^2 \sigma_b^2}$ and the associated standard error. a , b and ab are integers indicating the position of the components to be used. Alternatively,

`R label a:n`

calculates the correlation $r = \sigma_{ab} / \sqrt{\sigma_a^2 \sigma_b^2}$ for all correlations in the lower triangular row-wise matrix represented by components a to n and the associated standard errors.

$$\begin{aligned} \text{var}(r) = r^2 & \left[\frac{\text{var}(\sigma_a^2)}{4\sigma_a^2} + \frac{\text{var}(\sigma_b^2)}{4\sigma_b^2} + \frac{\text{var}(\sigma_{ab})}{\sigma_{ab}^2} \right. \\ & \left. + \frac{2\text{cov}(\sigma_a^2)\sigma_b^2}{4\sigma_a^2\sigma_b^2} - \frac{2\text{cov}(\sigma_a^2)\sigma_{ab}}{2\sigma_a^2\sigma_{ab}} - \frac{2\text{cov}(\sigma_{ab})\sigma_b^2}{2\sigma_{ab}\sigma_b^2} \right] \end{aligned}$$

In the example

```
R phencorr 7 8 9
```

calculates the phenotypic covariance by calculating component 8 / $\sqrt{\text{component 7} \times \text{component 9}}$ where components 7, 8 and 9 are created with the first line of the `.pin` file, and

```
R gencorr 4:6
```

calculates the genotypic covariance by calculating component 5 / $\sqrt{\text{component 4} \times \text{component 6}}$ where components 4, 5 and 6 are variance components from the analysis.

A more detailed example

For convenience in preparing the `.pin` file, some users copy the variance component lines from the `.asr` file and insert them at the top of the `.pin` file, being careful to retain one leading space so that the lines will be just copied and otherwise ignored as the `.pin` file is processed.

The following sample `.pin` file is a little more complicated. It relates to the **bivariate sire model** in `bsiremod.asr` shown in the code box to the right.

The first six lines of the `.pin` file contain the variance component table on which the `.pin` file is based, copied from the `.asr` file for convenience in coding the rest of the file.

```
Bivariate sire model
sire !I
ywt fat
bsiremod.asr
ywt fat ~ Trait !r Trait.sire
1 2 1
0 # ASReml will count units
Trait 0 US
3*0
Trait.sire 2
Trait 0 US
3*0
sire
```

```
Residual          UnStruct      1  26.2197      26.2197      18.01  0 U
Residual          UnStruct      1   2.85090     2.85090     9.55  0 U
Residual          UnStruct      2   1.71556     1.71556    18.00  0 U
Tr.sire           UnStruct      1  16.5262     16.5262     2.69  0 U
Tr.sire           UnStruct      1   1.14422     1.14422     1.94  0 U
Tr.sire           UnStruct      2  0.132847    0.132847    1.88  0 U
F phenvar 1:3 + 4:6
F addvar 4:6 * 4
H heritA 10 7
H heritB 12 9
R phencorr 7 8 9
R gencor 4:6
```

Numbering the parameters reported in `bsiremod.asr` (and `bsiremod.vvp`)

- 1 error variance for `ywt`
- 2 error covariance for `ywt` and `fat`
- 3 error variance for `fat`
- 4 sire variance component for `ywt`
- 5 sire covariance for `ywt` and `fat`
- 6 sire variance for `fat`

then

```
F phenvar 1:3 + 4:6
```

creates new components $7 = 1+4$, $8 = 2+5$ and $9 = 3+6$,

```
F addvar 4:6 * 4
```

creates new components $10 = 4 \times 4$, $11 = 5 \times 4$ and $12 = 6 \times 4$,

```
H heritA 10 7
```

forms $10 / 7$ to give the heritability for `ywt`,

```
H heritB 12 9
```

forms $12 / 9$ to give the heritability for `fat`,

```
R phencorr 7 8 9
```

forms $8 / \sqrt{7 \times 9}$, that is, the phenotypic correlation between `ywt` and `fat`,

```
R gencorr 4:6
```

forms $5 / \sqrt{4 \times 6}$, that is, the genetic correlation between `ywt` and `fat`.

The result is:

`.pvc file`

```

7 phenvar 1      42.75      6.297
8 phenvar 2      3.995      0.6761
9 phenvar 3      1.848      0.1183
10 addvar 4      66.10      24.58
11 addvar 5      4.577      2.354
12 addvar 6      0.5314     0.2831
h2ywt          = addvar 10/phenvar 7=      1.5465  0.3574
h2fat          = addvar 12/phenvar 9=      0.2875  0.1430
phencorr       = phenvar /SQR[phenvar *phenvar ]= 0.4495  0.0483
gencor 2 1     = Tr.si 5/SQR[Tr.si 4*Tr.si 6]= 0.7722  0.1537

```

12 Command file: Running the job

Introduction

The command line

- Normal run
- Processing a .pin file
- Forming a job template

Command line options

- Prompt for arguments
- Output control command line options
 - Debug command line options
 - Graphics command line options
 - Job control command line options
 - Workspace command line options
 - Menu command line options
- Non-graphics command line options
- Examples

Advanced processing arguments

- Standard use of arguments
- Prompting for input
- Paths and Loops

12.1 Introduction

The command line, its options and arguments are discussed in this chapter. Command line options enable more workspace to be accessed to run the job, control some graphics output and control advanced processing options. Command line arguments are substituted into the job at run time.

As Windows likes to hide the command line, most command line options can be set on an optional initial line of the `.as` file we call *the top job control line* to distinguish it from the other job control lines discussed in Chapter 6. If the first line of the `.as` file contains a qualifier other than `!DOPATH`, it is interpreted as setting command line options and the *Title* is taken as the next line.

12.2 The command line

Normal run

The basic command to run ASReml is

```
[path] ASReml basename [.as[c]]
```

- *path* provides the path to the ASReml program (usually called `asrem1.exe` in a PC environment). In a UNIX environment, ASReml is usually run through a shell script called `ASReml`.

- if the ASReml program is in the search path then *path* is not required and the word `ASReml` will suffice; for example

```
ASReml nin89.as
```

will run the NIN analysis,

- if `asrem1.exe`(`ASReml`) is not in the search path then *path* is required, for example, if `asrem1.exe` is in the usual place then

```
c:\Program Files\ASReml2\bin\Asrem1 nin89.as
```

will run `nin89.as`,

- `ASReml` invokes the ASReml program,
- *basename* is the name of the `.as[c]` command file.

The basic command line can be extended with options and arguments to

```
[path] ASReml [options] basename [.as[c]] [arguments]
```

- *options* is a string preceded by a - (minus) sign. Its components control several operations (batch, graphic, workspace, ...) at run time; for example, the command line

```
ASReml -w128 rat.as
```

tells ASReml to run the job `rat.as` with workspace allocation of 128mb,

- *arguments* provide a mechanism (mostly for advanced users) to modify a job at run time; for example, the command line

```
ASReml rat.as alpha beta
```

tells ASReml to process the job in `rat.as` as if it read `alpha` wherever `$1` appears in the file `rat.as`, `beta` wherever `$2` appears and `0` wherever `$3` appears (see below).

Processing a .pin file

If the filename argument is a `.pin` file, (see Chapter 11), then ASReml processes it. If the pinfile basename differs from the basename of the output files it is processing, then the basename of the output files must be specified with the P option letter. Thus

```
ASReml border.pin
```

will perform the pinfile calculations defined in `border.pin` on the results in files `border.asr` and `border.vvp`.

```
ASReml -Pborderwwt border.pin
```

will perform the pinfile calculations defined in `border.pin` on the results in files `borderwwt.asr` and `borderwwt.vvp`.

Forming a job template from data file

The facility to generate a template `.as` file has been moved to the command line, and extended. Normally, the name of a `.as` command file is specified on the command line. If a `.as` file does not exist and a file with file extension `.asd`, `.csv`, `.dat`, `.gsh`, `.txt` or `.xls` is specified, ASReml assumes the data file has field labels in the first row and generates a `.as` file template. First, it seeks to convert the `.gsh` (Genstat) or `.xls` (Excel, see page 44) file to `.csv` format using the `ASRemload.dll` utility provided by VSN. In generating the `.as` template, ASReml

New

takes the first line of the `.csv` (or other) file as providing column headings, and generates field definition lines from them. If some labels have `!` appended, these are defined as factors, otherwise `ASReml` attempts to identify factors from the field contents. The template needs further editing before it is ready to run but does have the field names copied across.

12.3 Command line options

New

Command line options and arguments may be specified on the command line or on the top job control line. This is an optional first line of the `.as` file which sets command line options and arguments from within the job. If the first line of the `.as` file contains a qualifier other than `!DOPATH`, it is interpreted as setting command line options and the *Title* is taken as the next line.

The option string actually used by `ASReml` is the combination of what is on the command line and what is on the job control line, with options set in both places taking arguments from the command line. Arguments on the top job control line are ignored if there are arguments on the command line. This section defines the options. Arguments are discussed in detail in a following section.

Command line options are not case sensitive and are combined in a single string preceded by a `-` (minus) sign, for example `-LNW128`

The options can be set on the command line or on the first line of the job either as a concatenated string in the same format as for the command line, or as a list of qualifiers. For example, the command line

```
ASReml -h22r jobname 1 2 3           could be replaced with
ASReml jobname                       if the first line of jobname.as was either
!-h22r 1 2 3                          or
!HARDCOPY !EPS !RENAME !ARGS 1 2 3
```

Table 12.1 presents the command line options available in `ASReml` with brief descriptions. It also specifies the equivalent qualifier name used on the top job control line. Detailed descriptions follow.

Table 12.1: Command line options

<i>option</i>	qualifier	type	action
Frequently used command line options			
C	!CONTINUE	job control	continue iterations using previous estimates as initial values
F	!FINAL	job control	continue for one more iteration using previous estimates as initial values
L	!LOGFILE	screen output	copy screen output to <i>basename.as1</i>
N	!NOGRAPHS	graphics	suppress interactive graphics
Ww	!WORKSPACE <i>w</i>	workspace	set workspace size to <i>w</i> Mbyte
Other command line options			
	!ARGS <i>a</i>	job control	to set arguments (<i>a</i>) in job rather than on command line
A	!ASK	job control	prompt for options and arguments
B <i>b</i>	!BRIEF <i>b</i>	output control	reduce output to <i>.asr</i> file
D	!DEBUG	debug	invoke debug mode
E	!DEBUG 2	debug	invoke extended debug mode
G <i>g</i>	!GRAPHICS <i>g</i>	graphics	set interactive graphics device
H <i>g</i>	!HARDCOPY <i>g</i>	graphics	set interactive graphics device, graphics screens not displayed
I	!INTERACTIVE	graphics	display graphics screen
J	!JOIN	output control	concatenate !CYCLE output files
O	!ONERUN	job control	override rerunning requested by !RENAME
P	NA	post-processing	calculation of functions of variance components
Q	!QUIET	graphics	suppress screen output
R <i>r</i>	!RENAME	job control	repeat run for each argument renaming output filenames
S <i>s</i>	NA	workspace	set workspace size
Y <i>v</i>	!YVAR <i>v</i>	job control	over-ride <i>y</i> -variate specified in the command file with variate number <i>v</i>
Z	NA	license	reports current license details

Prompt for arguments (A)

A (!ASK) makes it easier to specify command line options in Windows Explorer. One of the options available when right clicking a .as file, invokes ASReml with this option. ASReml then prompts for the *options and arguments*, allowing these to be set interactively at run time. With !ASK on the top job control line, it is assumed that no other qualifiers are set on the line. For example, a response of

```
-h22r 1 2 3           would be equivalent to
ASReml -h22r basename 1 2 3
```

Output control (B, J)

New

B[b] (!BRIEF [b]) suppresses some of the information written to the .asr file. The data summary and regression coefficient estimates are suppressed by the options B, B1 or B2. This option should not be used for initial runs of a job before you have confirmed (by checking the data summary) that ASReml has read the data as you intended. Use B2 to also have the predicted values written to the .asr file instead of the .pvs file. Use B-1 to get BLUE estimates reported in .asr file.

New

J (!JOIN) is used in association with the !CYCLE qualifier to put the output from a set of runs into single files (see !CYCLE list !JOIN on page 186).

Debug command line options (D, E)

D and E (!DEBUG, !DEBUG 2) invoke debug mode and increase the information written to the screen or .as1 file. This information is not useful to most users. On Unix systems, if ASReml is crashing use the system `script` command to capture the screen output rather than using the L option, as the .as1 file is not properly closed after a crash.

Graphics command line options (G, H, I, N, Q)

Graphics are produced in the PC, Linux and SUN 32bit versions of ASReml using the Winteracter graphics library.

The I (!INTERACTIVE) option permits the variogram and residual graphics to be displayed. This is the default unless the L option is specified.

The N (!NOGRAPHICS) option prevents any graphics from being displayed. This is also the default when the L option is specified.

The Gg (!GRAPHICS g) option sets the file type for hard copy versions of the graphics. Hard copy is formed for all the graphics that are displayed.

New H[*g*] (!HARDCOPY *g*) replaces the G option when graphics are to be written to file but not displayed on the screen. The H may be followed by a format code e.g. H22 for .eps.

New Q (!QUIET) is used when running under the control of an editor such as ASReml-Wto suppress any POPUPs/ PAUSES from ASReml.

ASReml writes the graphics to files whose names are built up as *<basename> [<args>]<type> [<pass>] [<section>].<ext>* where square parentheses indicate elements that might be omitted, *<basename>* is the name portion of the .as file, *<args>* is any argument strings built into the output names by use of the !RENAME qualifier, *<type>* indicates the contents of the figure (as given in the following table), *<pass>* is inserted when the job is repeated (!RENAME or !CYCLE) to ensure filenames are unique across repeats, *<section>* is inserted to distinguish files produced from different sections of data (for example from multisite spatial analysis) and *<ext>* indicates the file graphics format.

<i><type></i>	file contents
R	marginal means of residuals from spatial analysis of a section
V	variogram of residuals from spatial analysis for a section
S	residuals in field plan for a section
H	histogram of residuals for a section
_RvE	residuals plotted against expected values
XYGi	figure produced by !X, !Y and !G qualifiers
PV_i	Predicted values plotted for PREDICT directive <i>i</i>

The graphics file format is specified by following the G or H option by a number *g*, or specifying the appropriate qualifier on the top job control line, as follows:

<i>g</i>	qualifier	description	<i><ext></i>
1	!HPGL	HP-GL	pgl
2	!PS	Postscript (default)	ps
6	!BMP	BMP	bmp
10	!WPM	Windows Print Manager	
11	!WMF	Windows Meta File	wmf
12	!HPGL 2	HP-GL2	hgl
22	!EPS	EncapsulatedPostScript	eps

Job control command line options (C, F, O, R)

C (!CONTINUE) indicates that the job is to continue iterating from the values in the `.rsv` file. This is equivalent to setting !CONTINUE on the datafile line, see Table 5.4 for details.

F (!FINAL) indicates that the job is to continue for one more iteration from the values in the `.rsv` file. This is useful when using `predict`, see Chapter 10.

New O (!ONERUN) is used with the R option to make ASReml perform a single analysis when the R option would otherwise attempt multiple analyses. The R option then builds some arguments into the output file name while other arguments are not. For example

```
ASReml -nor2 mabphen 2 TWT out(621) out(929)
```

results in one run with output files `mabphen2_TWT.*`.

New R[r] (!RENAME [r]) is used in conjunction with at least *r* argument(s) and does two things: it modifies the output filename to include the first *r* arguments so the output is identified by these arguments, and, if there are more than *r* arguments, the job is rerun moving the extra arguments up to position *r* (unless !ONERUN (O) is also set). If *r* is not specified, it is taken as 1.

For example

```
ASReml -r2 job wwt gfw fd fat
```

is equivalent to running three jobs:

```
ASReml -r2 job wwt gfw → jobwwt_gfw.asr
```

```
ASReml -r2 job wwt fd → jobwwt_fd.asr
```

```
ASReml -r2 job wwt fat → jobwwt_fat.asr
```

Yy (!YVAR *y*) overrides the value of *response*, the variate to be analysed (see Section 6.2) with the value *y*, where *y* is the *number* of the data field containing the trait to be analysed. This facilitates analysis of several traits under the same model. The value of *y* is appended to the *basename* so that output files are not overwritten when the next trait is analysed.

Workspace command line options (S, W)

The workspace requirements depend on problem size and may be quite large. An initial workspace allocation may be requested on the command line with the S or W options; if neither is specified, 32Mbyte (4 million double precision words) is allocated.

New

Wm (!WORKSPACE *m*) sets the initial size of the workspace in Mbytes. For example *W1600* requests 1600 Mbytes of workspace, the maximum typically available under Windows. *W2000* is the maximum available on 32bit Unix(Linux) systems. On 64bit systems, the argument, if less than 32, is taken as Gbyte.

Alternatively, *Ss* can be used to set the initial workspace allocation. *s* is a digit. The workspace allocated is $2^s \times 8$ Mbyte; *S3* is 64Mb, *S4* is 128Mb, *S5* is 256Mb, *S6* is 512Mb, *S7* is 1024Mb, *S8* is 2048Mb, *S9* is 4096Mb. This option was in Release 1.0; the more flexible option, *Wm*, has been introduced in Release 2.0. The *W* option is ignored if the *S* option is also specified.

Otherwise, additional workspace may be requested with the *Ss* or *Wm* options or the !WORKSPACE *m* qualifier on the top job control line if not specified on the control line. If your system cannot provide the requested workspace, the request will be diminished until it can be satisfied. On multi-user systems, do not unnecessarily request the maximum or other users may complain.

Having started with an initial allocation, if ASReml realises more space is required as it is running, it will attempt to restart the job with increased workspace. If the system has already allocated all available memory the job will stop.

Examples

ASReml code	action
<code>asrem1 -LW64 rat.as</code>	increase workspace to 64 Mbyte, send screen output to <code>rat.as1</code> and suppress interactive graphics
<code>asrem1 -IL rat.as</code>	send screen output to <code>rat.as1</code> but display interactive graphics
<code>asrem1 -N rat.as</code>	allow screen output but suppress interactive graphics
<code>asrem1 -ILW512 rat.as</code>	increase workspace to 512 Mbyte , send screen output to <code>rat.as1</code> but display interactive graphics
<code>asrem1 -rs3 coop wwt ywt</code>	runs <code>coop.as</code> twice writing results to <code>coopwwt.as</code> and <code>coopywt.as</code> using 64Mb workspace and substituting <code>wwt</code> and <code>ywt</code> for \$1 in the two runs.

12.4 Advanced processing arguments

Standard use of arguments

Command line arguments are intended to facilitate the running of a sequence of jobs that require small changes to the command file between runs. The output file name is modified by the use of this feature if the `-R` option is specified. This use is demonstrated in the Coopworth example of Section 15.10, see page 297.

Command line arguments are strings listed on the command line after *basename*, the command file name, or specified on the top job control line after the `!ARGS` qualifier. These strings are inserted into the command file at run time. When the input routine finds a `$n` in the command file it substitutes the *n*th argument (string). *n* may take the values 1..9 to indicate up to 9 strings after the command file name. If the argument has 1 character, a trailing blank is attached to the character and inserted into the command file. If no argument exists, a zero is inserted. For example,

```
asreml rat.as alpha beta
```

tells ASReml to process the job in `rat.as` as if it read `alpha` wherever `$1` appears in the command file, `beta` wherever `$2` appears and `0` wherever `$3` appears.

Table 12.2: The use of arguments in ASReml

in command file	on command line	becomes in ASReml run
<code>abc\$1def</code>	no argument	<code>abc0 def</code>
<code>abc\$1def</code>	with argument <code>X</code>	<code>abcX def</code>
<code>abc\$1def</code>	with argument <code>XY</code>	<code>abcXYdef</code>
<code>abc\$1def</code>	with argument <code>XYZ</code>	<code>abcXYZdef</code>
<code>abc\$1 def</code>	with argument <code>XX</code>	<code>abcXX def</code>
<code>abc\$1 def</code>	with argument <code>XXX</code>	<code>abcXXX def</code>
<code>abc\$1 def</code> (multiple spaces)	with argument <code>XXX</code>	<code>abcXXX def</code>

Prompting for input

Another way to gain some interactive control of a job in the PC environment is to insert `!?text` in the `.as` file where you want to specify the rest of the line at run time. ASReml prompts with *text* and waits for a response which is used to complete the line. The `!?` qualifier may be used anywhere in the job and the line is modified from that point.

Warning

Unfortunately the prompt may not appear on the top screen under some windows operating systems in which case it may not be obvious that ASReml is waiting for a keyboard response.

Paths and Loops

ASReml is designed to analyse just one model per run. However, the analysis of a data set typically requires many runs, fitting different models to different traits. It is often convenient to have all these runs coded into a single `.as` file and control the details from the command line (or top job control line) using arguments. The highlevel qualifiers `!CYCLE` and `DOPATH` enable multiple analyses to be defined and run in one execution of ASReml.

Table 12.3: High level qualifiers

qualifier	action
<code>!CYCLE <i>list</i> [!JOIN]</code>	<p>is a mechanism whereby ASReml can loop through a series of jobs. The <code>!CYCLE</code> qualifier must appear on its own line, starting in character 1. <i>em list</i> is a series of values which are substituted into the job wherever the <code>\$I</code> string appears. If <code>!JOIN</code> is not specified, the current value from <i>list</i> is built into the output filenames writing the output to separate files. If <code>!JOIN</code> is specified, the outputs are written to a single file.</p> <p>For example</p> <pre><code>!CYCLE 0.4 0.5 0.6 !JOIN 20 0 mat2 1.9 \$I !GPF</code></pre> <p>would result in three runs and the results would be appended to a single file.</p> <p>Warning: The <code>!CYCLE</code> mechanism does not work in combination with the <code>!RENAME</code> qualifier used with multiple command line arguments.</p>

New

High level qualifiers

qualifier	action
!DOPATH <i>n</i>	<p>The qualifiers !DOPART and !PART have been extended in release 2.0 and !DOPATH and !PATH are thought to be more appropriate names. Both spellings can be used interchangeably. !DOPATH allows several analyses to be coded and run sequentially without having to edit the .as file between runs. Which particular lines in the .as file are honoured is controlled by the argument <i>n</i> of the !DOPATH qualifier in conjunction with !PATH (or !PART) statements.</p> <p>The argument (<i>n</i>) is often given as \$1 indicating that the actual path to use is specified as the first argument on the command line (see Section 12.4). See Sections 15.7 and 15.10 for examples. The default value of <i>n</i> is 1.</p> <p>!DOPATH <i>n</i> can be located anywhere in the job but if placed on the top job control line, it cannot have the form !DOPATH \$1 unless the arguments are on the command line as the !DOPATH qualifier will be parsed before any job arguments on the same line are parsed.</p>
New	<p>The !PATH (or !PART) control statement may list multiple path numbers so that the following lines are honoured if any one of the listed path numbers is active. The !PATH qualifier must appear at the beginning of its own line after the !DOPATH qualifier. A sequence of path numbers can be written using <i>a : b</i> notation. For example</p>
!PATH <i>pathlist</i>	<pre>mydata.asd !DOPATH 4 !PATH 2 4 6:10</pre> <p>One situation where this might be useful is where it is necessary to run simpler models to get reasonable starting values for more complex variance models. The more complex models are specified in later parts and the !CONTINUE command is used to pick up the previous estimates.</p>

13

Description of output files

Introduction

An example

Key output files

The .asr file
The .sln file
The .yht file

Other ASReml output files

The .aov file
The .res file
The .vrb file
The .vvp file
The .rsv file
The .dpr file
The .pvc file
The .pvs file
The .tab file

ASReml output objects and where to find them

13.1 Introduction

With each ASReml run a number of output files are produced. ASReml generates the output files by appending various filename extensions to *basename*. A brief description of the filename extensions is presented in Table 13.1.

Table 13.1: Summary of ASReml output files

file	description
Key output files	
.asr	contains a summary of the data and analysis results.
.pvc	contains the report produced with the P option.
.pvs	contains predictions formed by the <code>predict</code> directive.
.res	contains information from using the <code>pol()</code> , <code>spl()</code> and <code>fac()</code> functions, the iteration sequence for the variance components and some statistics derived from the residuals.
.rsv	contains the final parameter values for reading back if the <code>!CONTINUE</code> qualifier is invoked, see Table 5.4.
.sln	contains the estimates of the fixed and random effects and their corresponding standard errors.
.tab	contains tables formed by the <code>tabulate</code> directive.
.yht	contains the predicted values, residuals and diagonal elements of the hat matrix for each data point.
Other output files	
.apj	is an ASReml project file created by ASReml-W.
.aov	contains details of the ANOVA calculations.
.asl	contains a progress log and error messages if the L command line option is specified.
.asp	contains transformed data, see <code>!PRINT</code> in Table 5.2.
.dbr/.dpr/.spr	contains the data and residuals in a binary form for further analysis (see <code>!RESIDUALS</code> , Table 5.5).
.veo	holds the equation order to speed up re-running big jobs when the model is unchanged. This binary file is of no use to the user.
.vrb	contains the estimates of the fixed effects and their variance.
.vvp	contains the approximate variances of the variance parameters. It is designed to be read back with the P option for calculating functions of the variance parameters.

An ASReml run generates many files and the `.sln` and `.yht` files, in particular, are often quite large and could fill up your disk space. You should therefore regularly tidy your working directories, maybe just keeping the `.as`, `.asr` and `.pvs` files.

13.2 An example

In this chapter the ASReml output files are discussed with reference to a two-dimensional separable autoregressive spatial analysis of the NIN field trial data, see model **3b** on page 111 of Chapter 7 for details. The ASReml command file for this analysis is presented to the right. Recall that this model specifies a separable autoregressive correlation structure for residual or plot errors that is the direct product of an autoregressive correlation matrix of order 22 for rows and an autoregressive correlation matrix of order 11 for columns. In this case 0.5 is the starting correlation for both columns and rows.

```
NIN Alliance Trial 1989
variety !A
id
raw
repl 4
nloc
yield
lat
long
row 22
column 11
nin89a.asd !skip 1 !DISPLAY 15

yield ~ mu variety !f mv
predict variety
1 2 0
row row AR1 0.5
column column AR1 0.5
```

13.3 Key output files

The key ASReml output files are the `.asr`, `.sln` and `.yht` files.

The `.asr` file

This file contains

- a general announcements box (outlined in asterisks) containing current messages,
- a summary of the data to validate the specification of the model,
- a summary of the fitting process to check convergence,
- a summary of the variance parameters:
 - The **Gamma** column reports the actual parameter fitted,
 - the **Component** column reports the gamma converted to a variance scale if appropriate,

- Comp/SE is the ratio of the component relative to the square root of the diagonal element of the inverse of the average information matrix [Warning](#) Comp/SE should not be used for formal testing,
 - The % shows the percentage change in the parameter at the last iteration,
 - use the .pin file described Chapter 11 to calculate meaningful functions of the variance components,
- an analysis of variance (ANOVA) table (Section 6.12). The table contains the numerator degrees of freedom for the terms and 'incremental' F-statistics for approximate testing of effects. It may also contain denominator degrees of freedom, a 'conditional' F-statistic and a significance probability.
 - estimated effects, their standard errors and *t* values for equations in the DENSE portion of the SSP matrix are reported if !BRIEF -1 is invoked; the T-prev column tests difference between successive coefficients in the same factor.

The following is a copy of nin89a.asr.

```

version & title  ASReml 1.63o [01 Jun 2005]  NIN alliance trial 1989
                  Build: j [01 Jul 2005]  128
date, workspace 14 Jul 2005 12:41:18.360  32.00 Mbyte Windows  nin89a
notices         Licensed to: Arthur Gilmour
                *****
                * SYNTAX change:  A/B now means  A A.B                *
                *                                                         *
                * Contact support@asreml.co.uk for licensing and support *
                ***** ARG *****

Folder: C:\data\asr\UG2\manex
      variety !A
QUALIFIERS: !SKIP 1                !DISPLAY 15
Reading nin89aug.asd  FREE FORMAT skipping  1 lines

Univariate analysis of yield
data summary  Using      242 records of      242 read
              Model term                Size #miss #zero  MinNon0  Mean      MaxNon0
              1 variety                   56    0    0        1    26.4545    56
              2 id                        0     0    0       1.000    26.45     56.00
              3 pid                       18    0    0      1101.    2628.     4156.
              4 raw                       18    0    0      21.00    510.5     840.0
              5 repl                       4     0    0        1     2.4132     4
              6 nloc                       0     0    0       4.000     4.000     4.000
              7 yield                      Variate 18    0    1.050    25.53     42.00
              8 lat                        0     0    0       4.300    25.80     47.30
              9 long                       0     0    0       1.200    13.80     26.40
             10 row                       22    0    0        1    11.5000     22
             11 column                    11    0    0        1     6.0000     11

```

```

12 mu 1
13 mv_estimates 18
22 AR=AutoReg 0.5000
11 AR=AutoReg 0.5000
Forming 75 equations: 57 dense.
Initial updates will be shrunk by factor 0.316
NOTICE: 1 singularities detected in design matrix.
iterations 1 LogL=-401.827 S2= 42.467 168 df 1.000 0.5000 0.5000
2 LogL=-400.780 S2= 43.301 168 df 1.000 0.5388 0.4876
3 LogL=-399.807 S2= 45.066 168 df 1.000 0.5895 0.4698
4 LogL=-399.353 S2= 47.745 168 df 1.000 0.6395 0.4489
5 LogL=-399.326 S2= 48.466 168 df 1.000 0.6514 0.4409
6 LogL=-399.324 S2= 48.649 168 df 1.000 0.6544 0.4384
7 LogL=-399.324 S2= 48.696 168 df 1.000 0.6552 0.4377
8 LogL=-399.324 S2= 48.708 168 df 1.000 0.6554 0.4375
Final parameter values 1.0000 0.65550 0.43748

parameter Source Model terms Gamma Component Comp/SE % C
estimates Variance 242 168 1.00000 48.7085 6.81 0 P
Residual AR=AutoR 22 0.655505 0.655505 11.63 0 U
Residual AR=AutoR 11 0.437483 0.437483 5.43 0 U

ANOVA Analysis of Variance NumDF DenDF F_inc Prob
12 mu 1 25.0 331.85 <.001
1 variety 55 110.8 2.22 <.001
Notice: The DenDF values are calculated ignoring fixed/boundary/singular
variance parameters using algebraic derivatives.
outliers! 13 mv_estimates 18 effects fitted
6 possible outliers: in section 1 (see .res file)
Finished: 14 Jul 2005 12:41:26.862 LogL Converged

```

Finally we display a portion of Regression Screen output. The qualifier was !SCREEN 3 !SMX 3.

```

Source Model terms Gamma Component Comp/SE % C
idsize 92 92 0.581102 0.136683 3.31 0 P
expt.idsize 828 828 0.121231 0.285153E-01 1.12 0 P
Variance 504 438 1.00000 0.235214 12.70 0 P

Analysis of Variance NumDF DenDF_con F_inc F_con M P_con
113 mu 1 72.4 65452.25 56223.68 . <.001
2 expt 6 37.5 5.27 0.64 A 0.695

4 type 4 63.8 22.95 3.01 A 0.024
114 expt.type 10 79.3 1.31 0.93 B 0.508
23 x20 1 55.1 4.33 2.37 B 0.130
24 x21 1 63.3 1.91 0.87 B 0.355
25 x23 1 68.3 23.93 0.11 B 0.745

26 x39 1 79.7 1.85 0.35 B 0.556
27 x48 1 69.9 1.58 2.08 B 0.154
28 x59 1 49.7 1.41 0.08 B 0.779

```

29	x60	1	59.6	1.46	0.42 B 0.518
30	x61	1	64.0	1.11	0.04 B 0.838
31	x62	1	61.8	2.18	0.09 B 0.770
32	x64	1	55.6	31.48	4.50 B 0.038
33	x65	1	57.8	4.72	6.12 B 0.016
34	x66	1	58.5	1.13	0.03 B 0.872
35	x70	1	59.3	1.71	1.40 B 0.242
36	x71	1	64.4	0.08	0.01 B 0.929
37	x73	1	59.0	1.79	3.01 B 0.088
38	x75	1	59.9	0.04	0.26 B 0.613
39	x91	1	63.8	1.44	1.44 B 0.234

Notice: The DenDF values are calculated ignoring fixed/boundary/singular variance parameters using empirical derivatives.

129 mv_estimates 9 effects fitted
 9 idsize 92 effects fitted (7 are zero)
 115 expt.idsize 828 effects fitted (672 are zero)
 127 at(expt,6).type.idsize.meth 9 effects fitted (+ 2199 singular)
 128 at(expt,7).type.idsize.meth 10 effects fitted (+ 2198 singular)

LINE	REGRESSION			RESIDUAL			ADJUSTED		FACTORS INCLUDED																		
	NO	DF	SUMSQUARES	DF	MEANSQU	R-SQUARED	R-SQUARED	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24	23			
1	3	0.1113D+02	452	0.2460	0.09098	0.08495	0.08495	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
2	3	0.1180D+02	452	0.2445	0.09648	0.09049	0.09049	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
3	3	0.1843D+01	452	0.2666	0.01507	0.00853	0.00853	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
4	3	0.1095D+02	452	0.2464	0.08957	0.08353	0.08353	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
5	3	0.1271D+02	452	0.2425	0.10390	0.09795	0.09795	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0		
6	3	0.9291D+01	452	0.2501	0.07594	0.06981	0.06981	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0		
7	3	0.9362D+01	452	0.2499	0.07652	0.07039	0.07039	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0		
8	3	0.1357D+02	452	0.2406	0.11091	0.10501	0.10501	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0		
9	3	0.9404D+01	452	0.2498	0.07687	0.07074	0.07074	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0		
10	3	0.1266D+02	452	0.2426	0.10350	0.09755	0.09755	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0		
11	3	0.1261D+02	452	0.2427	0.10313	0.09717	0.09717	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0		
12	3	0.9672D+01	452	0.2492	0.07906	0.07295	0.07295	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0		
13	3	0.9579D+01	452	0.2494	0.07830	0.07218	0.07218	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0		
14	3	0.9540D+01	452	0.2495	0.07797	0.07185	0.07185	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0		
15	3	0.1089D+02	452	0.2465	0.08907	0.08302	0.08302	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0		
16	3	0.2917D+01	452	0.2642	0.02384	0.01736	0.01736	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0		
17	3	0.2248D+01	452	0.2657	0.01838	0.01187	0.01187	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0		
18	3	0.1111D+02	452	0.2460	0.09088	0.08484	0.08484	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0		
19	3	0.1746D+01	452	0.2668	0.01427	0.00773	0.00773	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0		
20	3	0.1030D+02	452	0.2478	0.08423	0.07815	0.07815	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0		
21	3	0.1279D+02	452	0.2423	0.10454	0.09860	0.09860	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0		
22	3	0.8086D+01	452	0.2527	0.06609	0.05989	0.05989	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0		
23	3	0.7437D+01	452	0.2542	0.06079	0.05456	0.05456	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0		
24	3	0.1071D+02	452	0.2469	0.08755	0.08149	0.08149	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0		
25	3	0.1370D+02	452	0.2403	0.11200	0.10611	0.10611	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0		
26	3	0.1511D+02	452	0.2372	0.12351	0.11770	0.11770	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0		
27	3	0.1353D+02	452	0.2407	0.11064	0.10473	0.10473	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0		
...																											
680	3	0.1057D+02	452	0.2472	0.08641	0.08035	0.08035	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		

The .sln file

The .sln file contains estimates of the fixed and random effects with their standard errors in an array with four columns ordered as

factor_name level estimate standard_error

Note that the error presented for the estimate of a random effect is the square root of the prediction error variance. In a genetic context for example where a relationship matrix \mathbf{A} is involved, the accuracy is $\sqrt{(1 - \frac{s_i^2}{(1+f_i)\sigma_A^2})}$ where s_i is the standard error reported with the BLUP (u_i) for the i th individual, f_i is the inbreeding coefficient reported when !DIAG qualifier is given on a pedigree file line, $1 + f_i$ is the diagonal element of \mathbf{A} and σ_A^2 is the genetic variance. The .sln file can easily be read into a GENSTAT spreadsheet or an S-PLUS data frame. Below is a truncated copy of nin89a.sln. Note that

- the order of some terms may differ from the order in which those terms were specified in the model statement,
- the missing value estimates appear at the end of the file in this example.

variety estimates	variety	LANCER	0.000	0.000
	variety	BRULE	2.987	2.842
	variety	REDLAND	4.707	2.978
	variety	CODY	-0.3131	2.961
	variety	ARAPAHOE	2.954	2.727
	:			
	variety	NE87615	1.035	2.934
	variety	NE87619	5.939	2.850
	variety	NE87627	-4.376	2.998
intercept	mu	1	24.09	2.465
missing value	mv_estimates	1	21.91	6.729
estimates	mv_estimates	2	23.22	6.721
	mv_estimates	3	22.52	6.708
	mv_estimates	4	23.49	6.676
	mv_estimates	5	22.26	6.698
	mv_estimates	6	24.47	6.707
	mv_estimates	7	20.14	6.697
	mv_estimates	8	25.01	6.691
	mv_estimates	9	24.29	6.676
	mv_estimates	10	26.30	6.658
	mv_estimates	11	24.99	6.590
	mv_estimates	12	27.78	6.492
	:			

The .yht file

The .yht file contains the predicted values of the data in the original order (this is not changed by supplying row/column order in spatial analyses), the residuals and the diagonal elements of the hat matrix. Figure 13.1 shows the residuals plotted against the fitted values (**Yhat**) and a line printer version of this figure is written to the .res file. Where an observation is missing, the residual, missing values predicted value and **Hat** value are also declared missing. The missing value estimates with standard errors are reported in the .sln file.

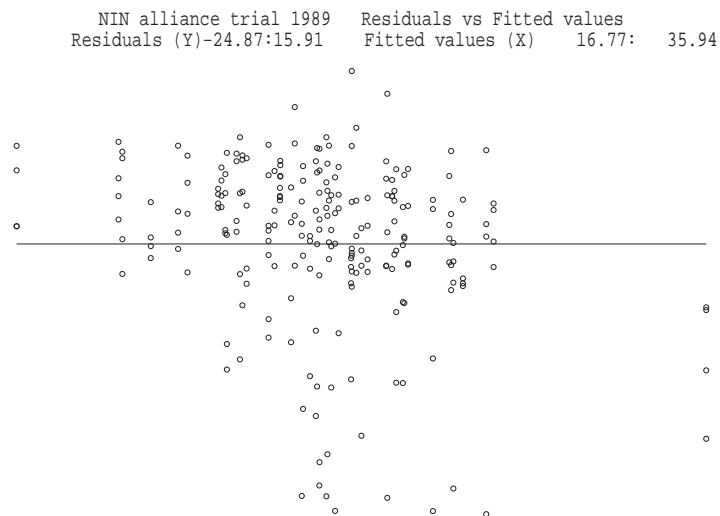


Figure 13.1 Residual versus Fitted values

This is the first 20 lines of `nin89a.yht`. Note that the values corresponding to the missing data (first 15 records) are all `-0.1000E-36` which is the internal value used for missing values.

Record	Yhat	Residual	Hat
1	-0.1000E-36	-0.1000E-36	-0.1000E-36
2	-0.1000E-36	-0.1000E-36	-0.1000E-36
3	-0.1000E-36	-0.1000E-36	-0.1000E-36
4	-0.1000E-36	-0.1000E-36	-0.1000E-36
5	-0.1000E-36	-0.1000E-36	-0.1000E-36
6	-0.1000E-36	-0.1000E-36	-0.1000E-36
7	-0.1000E-36	-0.1000E-36	-0.1000E-36
8	-0.1000E-36	-0.1000E-36	-0.1000E-36
9	-0.1000E-36	-0.1000E-36	-0.1000E-36
10	-0.1000E-36	-0.1000E-36	-0.1000E-36

11	-0.10000E-36	-0.1000E-36	-0.1000E-36
12	-0.10000E-36	-0.1000E-36	-0.1000E-36
13	-0.10000E-36	-0.1000E-36	-0.1000E-36
14	-0.10000E-36	-0.1000E-36	-0.1000E-36
15	-0.10000E-36	-0.1000E-36	-0.1000E-36
16	24.088	5.162	6.074
17	27.074	4.476	6.222
18	28.795	6.255	6.282
19	23.775	6.325	6.235
20	27.042	6.008	5.962
⋮			
240	24.695	1.855	6.114
241	25.452	0.1475	6.158
242	22.465	4.435	6.604

13.4 Other ASReml output files

The .aov file

This file reports details of the ANOVA calculations, particularly as relating to the conditional F-statistics (not computed in this run). In the following table relating to the incremental F-statistic, the columns are

- model term
- columns in design matrix
- numerator degrees of freedom
- simple F-statistic
- F-statistic scaled by λ
- λ as defined in Kenward & Roger.
- denominator degrees of freedom

mu	1	1	331.8483	331.8483	1.0000	25.0082
variety	56	55	2.2259	2.2259	0.9995	110.8419

A more useful example is obtained by adding a linear nitrogen contrast to the oats example (Section 15.2).

The basic design is six replicates of three whole plots to which `variety` was randomised, and four subplots which received 4 rates of nitrogen. A `!CONTRAST` qualifier defines the model term `linNitr` as the linear covariate representing nitrogen applied. Fitting this before the model term `nitrogen` means that this latter term represents lack of fit from a linear response.

The `!FCON` qualifier requests conditional F-statistics. As this is a small example, denominator degrees of freedom are reported by default. An extract from the `.asr` file is followed by the contents of the `.aov` file.

```
Split plot analysis - oat
blocks *
nitrogen !A
subplots
variety !A
wplots *
yield
oats.asd !skip 2
!CONTRAST linNitr nitrogen .6,
0.4 0.2 0.0
!FCON
yield ~ mu variety linNitr,
nitrogen variety.linNitr,
variety.nitrogen,
!r blocks blocks.wplots
```

Degrees of Freedom and Stratum Variances

5.00	3175.06	12.0	4.0	1.0
10.00	601.331	0.0	4.0	1.0
45.00	177.083	0.0	0.0	1.0

Source	Model	terms	Gamma	Component	Comp/SE	% C
blocks	6	6	1.21116	214.477	1.27	0 P
blocks.wplots	18	18	0.598937	106.062	1.56	0 P
Variance	72	60	1.00000	177.083	4.74	0 P

Analysis of Variance	NumDF	DenDF_con	F_inc	F_con	M	P_con
8 mu	1	6.0	245.14	138.14	.	<.001
4 variety	2	10.0	1.49	1.49	A	0.272
7 linNitr	1	45.0	110.32	110.32	a	<.001
2 nitrogen	2	45.0	1.37	1.37	A	0.265
9 variety.linNitr	2	45.0	0.48	0.48	b	0.625
10 variety.nitrogen	4	45.0	0.22	0.22	B	0.928

The analysis shows that there is a significant linear response to nitrogen level but the lack of fit term and the interactions with `variety` are not significant. In this example, the conditional F-statistic is the same as the incremental one because the contrast must appear before the lack-of-fit and the main effect before the interaction and otherwise it is a balanced analysis.

The first part of the `.aov` file, the `FMAP` table only appears if the job is run in `DEBUG` mode. There is a line for each model term showing the number

of non-singular effects in the terms before the current term is absorbed. For example, `variety.nitrogen` initially has 12 degrees of freedom (non-singular effects). `mu` takes 1, `variety` then takes 2, `linNitr` takes 1, `nitrogen` takes 2, `variety.linNitr` takes 2 and there are four degrees of freedom left. This information is used to make sure that the conditional F-statistic does not contradict marginality principles.

The next table indicates the details of the conditional F-statistic. The conditional F-statistic is based in the reduction in Sums of Squares from dropping the particular term (indicated by `*`) from the model also including the terms indicated by I, C and c.

The next two tables, based on incremental and conditional sums of squares report the model term, the number of effects in the term, the (numerator) degrees of freedom, the F-statistic, an adjusted F-statistic multiplied by a scaling constant reported in the next column and finally the computed denominator degrees of freedom. The scaling constant is discussed by Kenward and Roger (1997).

Table showing the reduction in the numerator degrees of freedom for each term as higher terms are absorbed.

Model Term	6	5	4	3	2	1
1 mu	12	3	4	1	3	1
2 variety	11	3	3	1	2	
3 LinNitr	9	3	3	1		
4 nitrogen	8	2	2			
5 variety.LinNitr	6	2				
6 variety.nitrogen	4					

Marginality pattern for F-con calculation

Model Term	DF	-- Model terms --					
		1	2	3	4	5	6
1 mu	1	*	.	C	.	C	.
2 variety	2	I	*	C	C	.	.
3 LinNitr	1	I	I	*	.	.	.
4 nitrogen	2	I	I	I	*	.	.
5 variety.LinNitr	2	I	I	I	I	*	.

6 variety.nitrogen 4 I I I I I *

F-inc tests the additional variation explained when the term (*) is added to a model consisting of the I terms.

F-con tests the additional variation explained when the term (*) is added to a model consisting of the I and C/c terms.

The . terms are ignored for both F-inc and F-con tests.

```

Incremental F statistics - calculation of Denominator degrees of freedom
Source          Size NumDF   F-value  Lambda*F   Lambda   DenDF
mu              1     1  245.1409  245.1409   1.0000    5.0000
variety         3     2   1.4853   1.4853    1.0000   10.0000
LinNitr         1     1  110.3232  110.3232   1.0000   45.0000
nitrogen        4     2   1.3669   1.3669    1.0000   45.0000
variety.LinNitr 3     2   0.4753   0.4753    1.0000   45.0000
variety.nitrogen 12    4   0.2166   0.2166    1.0000   45.0000

```

```

Conditional F statistics - calculation of Denominator degrees of freedom
Source          Size NumDF   F-value  Lambda*F   Lambda   DenDF
mu              1     1  327.5462  327.5462   1.0000    6.0475
variety         3     2   1.4853   1.4853    1.0000   10.0000
LinNitr         1     1  110.3232  110.3232   1.0000   45.0000
nitrogen        4     2   1.3669   1.3669    1.0000   45.0000
variety.LinNitr 3     2   0.4753   0.4753    1.0000   45.0000
variety.nitrogen 12    4   0.2166   0.2166    1.0000   45.0000

```

The .dpr file

The .dpr file contains the data and residuals from the analysis in double precision binary form. The file is produced when the !RES qualifier (Table 4.3) is invoked. The file could be renamed with filename extension .dbl and used for input to another run of ASReml. Alternatively, it could be used by another Fortran program or package. Factors will have level codes if they were coded using !A or !I. All the data from the run plus an extra column of residuals is in the file. Records omitted from the analysis are omitted from the file.

The .pvc file

The .pvc file contains functions of the variance components produced by running a .pin file on the results of an ASReml run as described in Chapter 11. The .pin and .pvc files for a half-sib analysis of the Coopworth data are presented in Section 15.10.

The .pvs file

The .pvs file contains the predicted values formed when a predict statement is included in the job. Below is an edited version of nin89a.pvs. See Section 3.6 for the .pvs file for the simple RCB analysis of the NIN data considered in that chapter.

title line

```
nin alliance trial
```

```
14 Jul 2005 12:41:18
```

```
nin89a
```

```

Ecode is E for Estimable, * for Not Estimable

Warning: mv_estimates          is ignored for prediction

----- 1 -----
Predicted values of yield

predicted variety means
variety      Predicted_Value Standard_Error Ecode
LANCER       24.0894      2.4645 E
BRULE        27.0728      2.4944 E
REDLAND      28.7954      2.5064 E
CODY         23.7728      2.4970 E
ARAPAHOE    27.0431      2.4417 E
NE83404     25.7197      2.4424 E
NE83406     25.3797      2.5028 E
NE83407     24.3982      2.6882 E
CENTURA    26.3532      2.4763 E
SCOUT66     29.1743      2.4361 E
:
NE87615     25.1238      2.4434 E
NE87619     30.0267      2.4666 E
NE87627     19.7126      2.4833 E
SED summary  SED: Overall Standard Error of Difference  2.925

```

The .res file

The .res file contains miscellaneous supplementary information including

- a list of unique values of x formed by using the `fac()` model term,
- a list of unique (x, y) combinations formed by using the `fac(x, y)` model term,
- legendre polynomials produced by `leg()` model term,
- orthogonal polynomials produced by `pol()` model term,
- the design matrix formed for the `spl()` model term,
- predicted values of the curvature component of cubic smoothing splines,
- the empirical variance-covariance matrix based on the BLUPs when a $\Sigma \otimes I$ or $I \otimes \Sigma$ structure is used; this may be used to obtain starting values for another run of ASReml,
- a table showing the variance components for each iteration,
- some statistics derived from the residuals from two-dimensional data (multivariate, repeated measures or spatial)

- the residuals from a spatial analysis will have the `units` part added to them (defined as the combined residual) unless the data records were sorted (within `ASReml`) in which case the `units` and the correlated residuals are in different orders (data file order and field order respectively),
- the residuals are printed in the `.yht` file but the statistics in the `.res` file are calculated from the combined residual,
- the `Covariance/Variance/Correlation` (C/V/C) matrix calculated directly from the residuals; it contains the covariance below the diagonals, the variances on the diagonal and the correlations above the diagonal:
The 'FITTED' matrix is the same as is reported in the `.asr` file and if the Logl has converged is the one you would report; the 'BLUPS' matrix is calculated from the BLUPS and is provided so it can be used as starting values when a simple initial model has been used and you are wanting to attempt to fit a full unstructured matrix; the rescaled has the variance from the FITTED and the covariance from the BLUPS and might be more suitable as an initial matrix if the variances have been estimated. The FITTED and RESCALED matrices should not be reported.
- relevant portions of the estimated variance matrix for each term for which an R structure or a G structure has been associated,
- a variogram and spatial correlations for spatial analysis; the spatial correlations are based on distance between data points (see Gilmour *et al.*, 1997),
- the slope of the $\log(\text{absolute residual})$ on $\log(\text{predicted value})$ for assessing possible mean-variance relationships and the location of large residuals. For example,

`SLOPES FOR LOG(ABS(RES)) ON LOG(PV) for section 1`

`0.99 2.01 4.34`

produced from a trivariate analysis reports the slopes. A slope of b suggests that y^{1-b} might have less mean variance relationship. If there is no mean variance relation, a slope of zero is expected. A slope of $\frac{1}{2}$ suggests a `SQRT` transformation might resolve the dependence; a slope of 1 means a `LOG` transformation might be appropriate. So, for the 3 traits, $\log(y_1)$, y_2^{-1} and y_3^{-3} are indicated. This diagnostic strategy works better when based on grouped data regressing $\log(\text{standard deviation})$ on $\log(\text{mean})$.

Also,

`STND RES 16 -2.35 6.58 5.64`

indicates that for the 16th data record, the residuals are -2.35, 6.58 and 5.64 times the respective standard deviations. The standard deviation used in this

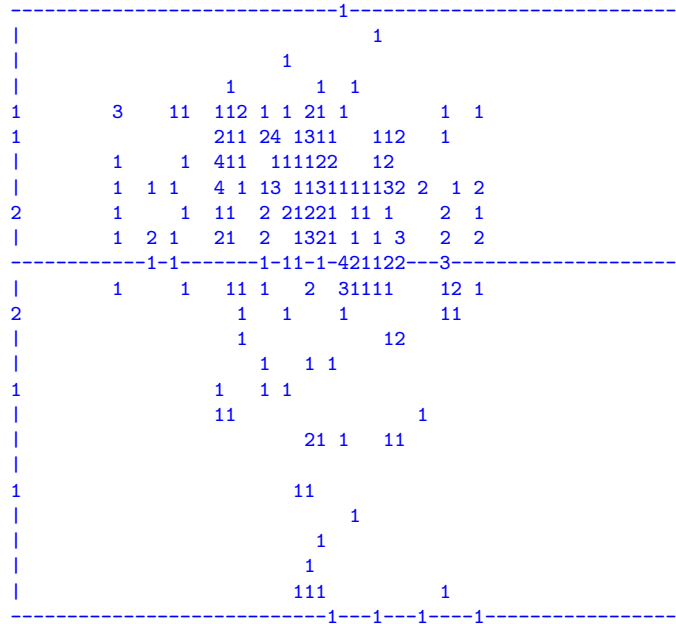
test is calculated directly from the residuals rather than from the analysis. They are intended to flag the records with large residuals rather than to precisely quantify their relative size. They are not studentised residuals and are generally not relevant when the user has fitted heterogeneous variances.

This is nin89a.res.

Convergence sequence of variance parameters

Iteration	1	2	3	4	5	6
LogL	-401.827	-400.780	-399.807	-399.353	-399.326	-399.324
Change %	59	80	83	21	5	1
Adjusted	0	0	0	0	0	0
StepSz	0.316	0.562	1.000	1.000	1.000	1.000
5	0.500000	0.538787	0.589519	0.639457	0.651397	0.654445
6	0.500000	0.487564	0.469768	0.448895	0.440861	0.438406

Plot of Residuals [-24.8730 15.9145] vs Fitted values [16.7724 35.9355] RvE



SLOPES FOR LOG(ABS(RES)) on LOG(PV) for Section 1
0.15

```

*
*
* ** **
* ** ** *
** ** ** ** *
*****
*****
* *
* ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** **
* ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** **
Min Mean Max -24.873 0.27954 15.915 omitting 18 zeros
    
```

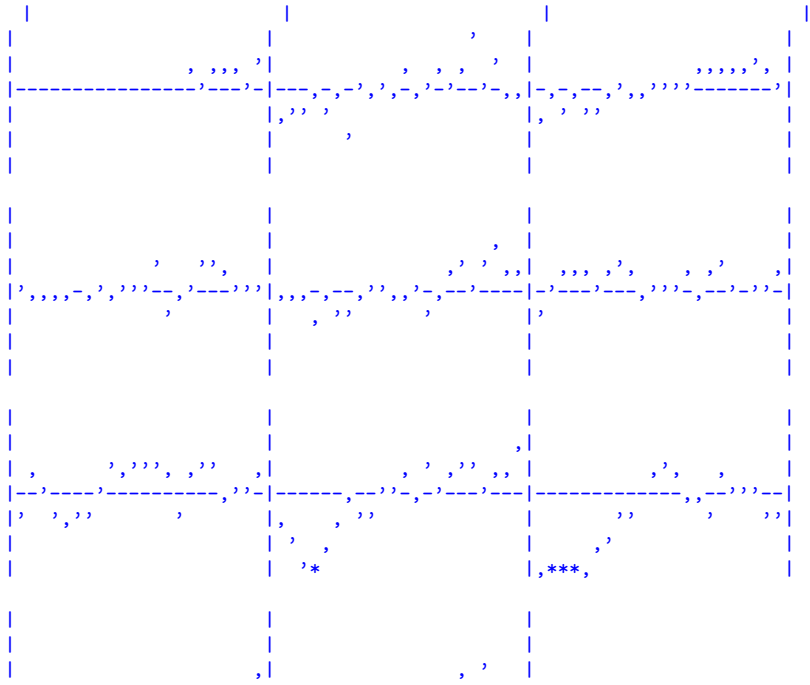


```

Spatial diagnostic statistics of Residuals      22  11
Residual Plot and Autocorrelations
<L0o- +xXH> [se 0.077]
|
|      +xxxxX|
|--- - 0+ x +x+x>X |
|o - -- +  +xxxx+X++|
|+      + + +x- +xxx+++|
|  o -- ++ +- xx+xHxx|
|+xxx+xXx +++x xX  ++x|
|++ o- +XxxXXx-xXX +++|
|ooL<0o --++x x+xXx+xH|
|<<<<00-- xX+  -x ++--|
|<0<<<<Loo -  -o-+-+ +|
|L<<<<0-OL-o  -++x x+ +|
1  0.28  0.38  0.50  0.65  0.77  1.00  0.77  0.65  0.50  0.38  0.28
2  0.17  0.27  0.39  0.51  0.56  0.64  0.56  0.50  0.40  0.32  0.26
3  0.05  0.11  0.19  0.28  0.35  0.42  0.40  0.35  0.30  0.24  0.19
    
```

```

Residuals [Percentage of sigma = 6.979 ]
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  74  64  90  91  86  65  141
-72 -29 -52 -20 -61 11 -132 26  0  63 15 99  9 37 84 48 110 228 49 131 -20  9
-87  1 -32 -14 -26 -30 -3 37 -6  4 23 32 44 46 109 97 83 67 68 141 69 40
44 11  0  3  6  0 21 41 -15 51 25 32 120 -33 10 58 117 113 109 63 57 25
18 18 -2 -84 -19 -51 -45 18 30 56 -9 -12 53 -41 7 99 123 47 119 181 101 104
-40 29 87 103 81 61 81 130 94 10 55 53 55 106 15 109 153 23  0 50 66 111
-29 75 43 -24 -90 -37 -23 64 130 84 122 129 126 90 -38 91 133 126 -16 57 30 70
-99 -114 -218 -332 -174 -77 -19 -38 -29 58 63 88  4 124 49 101 129 113 45 92 70 198
-257 -333 -352 -319 -253 -166 -152 -52 -28  0 97 135 67 16 -9 -36 96 24 62 48 -27 -29
-227 -167 -356 -335 -183 -179 -189 -118 -124 14 -52 19 -7 -56 -81 -33 63 -40 57 -15 24 73
-183 -277 -352 -323 -288 -151 -56 -130 -188 -29 -78  7 12 -30 39 57 89 -3 116 27  2  64
    
```



```

|-----',,---',-'|-----',,---',-'|
|',,,',,|',,,',,|
|',,,',,|',,,',,|
|',,,',,|',,,',,|
|',,,',,|',,,',,|
Residual [section 1, column 8 ( 11), row 4 ( 22)] is -3.32 SD
Residual [section 1, column 9 ( 11), row 2 ( 22)] is -3.33 SD
Residual [section 1, column 9 ( 11), row 3 ( 22)] is -3.52 SD
Residual [section 1, column 10 ( 11), row 3 ( 22)] is -3.56 SD
Residual [section 1, column 10 ( 11), row 4 ( 22)] is -3.35 SD
Residual [section 1, column 11 ( 11), row 3 ( 22)] is -3.52 SD
      6 possible outliers in section      1 : test value
      23.0311757288330

```

Figures 13.2 to 13.5 show the graphics derived from the residuals when the !DISPLAY 15 qualifier is specified and which are written to .eps files by running

```
ASReml -g22 nin89a.as
```

The graphs are a variogram of the residuals from the spatial analysis for site 1 (Figure 13.2), a plot of the residuals in field plan order (Figure 13.3), plots of the marginal means of the residuals (Figure 13.4) and a histogram of the residuals (Figure 13.5). The selection of which plots are displayed is controlled by the !DISPLAY qualifier (Table 5.4). By default, the variogram and field plan are displayed.

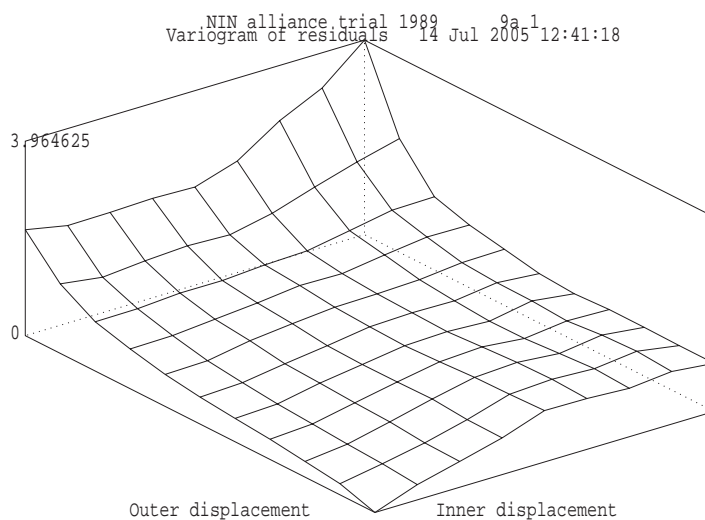


Figure 13.2 Variogram of residuals

The sample variogram is a plot of the semi-variances of differences of residuals at particular distances. The (0,0) position is zero because the difference is identically zero. ASReml displays the plot for distances 0, 1, 2, ..., 8, 9-10, 11-14, 15-20,

The plot of residuals in field plan order (Figure 13.3) contains in its top and right margins a diamond showing the minimum, mean and maximum residual for that row or column. Note that a gap identifies where the missing values occur.

The plot of marginal means of residuals shows residuals for each row/column as well as the trend in their means.

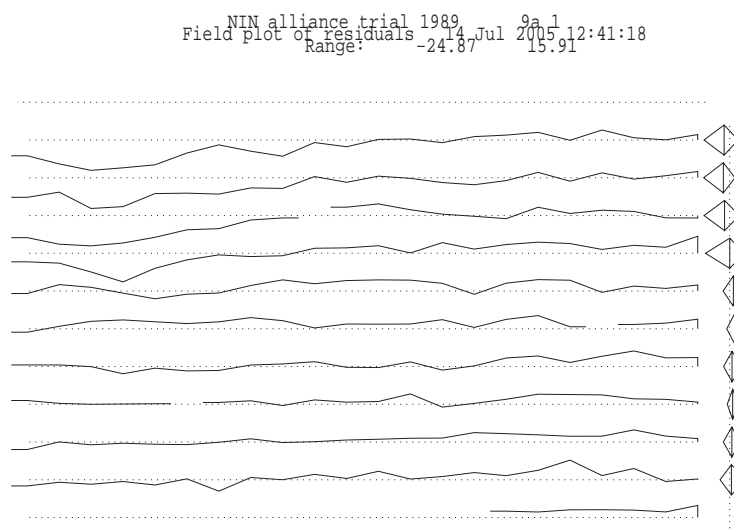


Figure 13.3 Plot of residuals in field plan order

The .rsv file

The .rsv file contains the variance parameters from the most recent iteration of a model. The primary use of the .rsv file is to supply the values for the !CONTINUE qualifier (see Table 5.4) and the C command line option (see Table 12.1). It contains sufficient information to match terms so that it can be used when the variance model has been changed. This is nin89a.rsv.

```
76 6 1690 120
  0.000000    0.000000    0.000000    1.000000    0.6555046    0.4374830
RSTRUCTURE          1  2
VARIANCE            1  1  0  1.00000
STRUCTURE           22  1  1  0.655505
```

NIN alliance trial 1989
Residuals V Row and Column position: 14 Jul 2005 12:41:18
Range: -24.87 15.91

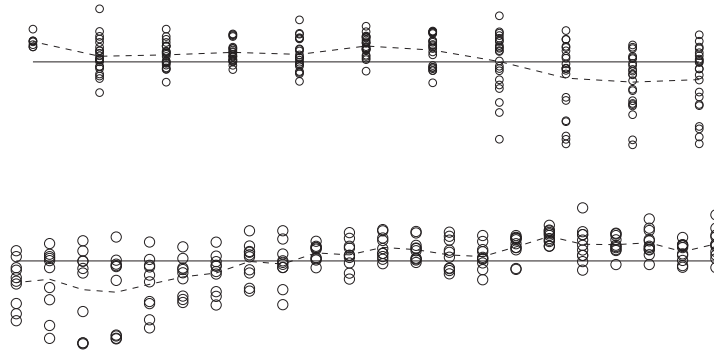


Figure 13.4 Plot of the marginal means of the residuals

NIN alliance trial 1989 vE A
Histogram of residuals 14 Jul 2005 12:41:18

Peak Count: 17
Range: -24.87 15.91

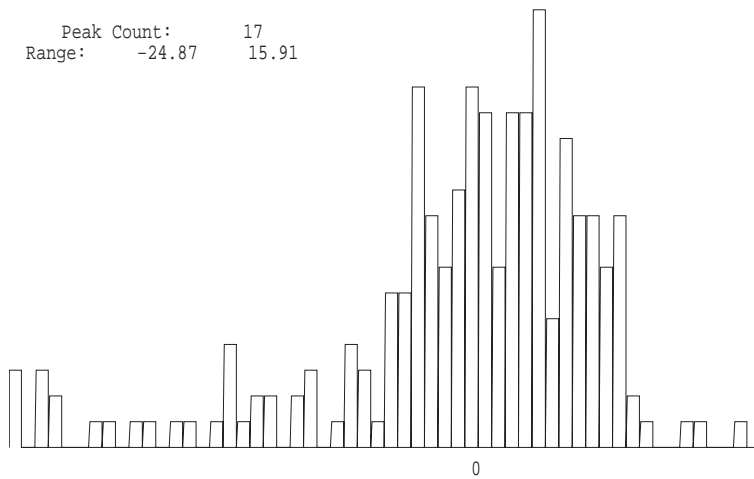


Figure 13.5 Histogram of residuals

```
STRUCTURE          11  1  1  0.437483
```

The .tab file

The .tab file contains the simple variety means and cell frequencies. Below is an edited version of nin89.tab.

```
nin alliance trial          10 Sep 2002 04:20:15
```

```
Simple tabulation of yield
```

```
variety
LANCER          28.56    4
BRULE           26.07    4
REDLAND        30.50    4
CODY           21.21    4
ARAPAHOE       29.44    4
NE83404        27.39    4
NE83406        24.28    4
NE83407        22.69    4
CENTURA       21.65    4
SCOUT66        27.52    4
COLT           27.00    4
:
NE87615        25.69    4
NE87619        31.26    4
NE87627        23.23    4
```

The .vrb file

The .vrb file contains the estimates of the effects together with their approximate prediction variance matrix corresponding to the dense portion. The file is formatted for reading back for post processing. The number of equations in the dense portion can be increased (to a maximum of 800) using the !DENSE option (Table 5.5) but not to include random effects. The matrix is lower triangular row-wise in the order that the parameters are printed in the .sln file. It can be thought of as a partitioned lower triangular matrix,

$$\begin{bmatrix} \sigma^2 & . \\ \tilde{\beta}_D & \sigma^2 C^{DD} \end{bmatrix}$$

where $\tilde{\beta}_D$ is the dense portion of β and C^{DD} is the dense portion of C^{-1} . This is the first 20 rows of `nin89a.vrb`. Note that the first element is the estimated error variance, that is, 48.6802, see the variance component estimates in the `.asr` output.

```

0.486802E + 02    0.000000E + 00    0.000000E + 00    0.298660E + 01    0.000000E + 00
0.807551E + 01    0.470711E + 01    0.000000E + 00    0.456648E + 01    0.886687E + 01
-0.313123E + 00    0.000000E + 00    0.410031E + 01    0.476546E + 01    0.876708E + 01
0.295404E + 01    0.000000E + 00    0.343331E + 01    0.389620E + 01    0.416124E + 01
0.743616E + 01    0.163302E + 01    0.000000E + 00    0.377176E + 01    0.428109E + 01
0.472519E + 01    0.402696E + 01    0.837281E + 01    0.129013E + 01    0.000000E + 00
0.330076E + 01    0.347471E + 01    0.357605E + 01    0.316915E + 01    0.412130E + 01
0.768275E + 01    0.310018E + 00    0.000000E + 00    0.376637E + 01    0.419780E + 01
0.395693E + 01    0.383429E + 01    0.458492E + 01    0.378585E + 01    0.985202E + 01
0.226478E + 01    0.000000E + 00    0.379286E + 01    0.442457E + 01    0.439485E + 01
0.402503E + 01    0.440539E + 01    0.362391E + 01    0.502071E + 01    0.901191E + 01
0.508553E + 01    0.000000E + 00    0.393626E + 01    0.430512E + 01    0.423753E + 01
0.428826E + 01    0.417864E + 01    0.363341E + 01    0.444776E + 01    0.527289E + 01
0.855241E + 01    0.243687E + 01    0.000000E + 00    0.351386E + 01    0.369983E + 01
0.384055E + 01    0.330171E + 01    0.362019E + 01    0.352370E + 01    0.359516E + 01
0.392097E + 01    0.406762E + 01    0.801579E + 01    0.475935E + 01    0.000000E + 00
...

```

The first 5 rows of the lower triangular matrix in this case are

$$\begin{bmatrix} 48.6802 & & & & \\ & 0 & 0 & & \\ & 2.98660 & 0 & 8.07551 & \\ & 4.70711 & 0 & 4.56648 & 8.86687 \\ -0.313123 & 0 & 4.10031 & 4.76546 & 8.76708 \\ & \vdots & \vdots & \vdots & \vdots & \ddots \end{bmatrix}$$

The `.vvp` file

The `.vvp` file contains the inverse of the average information matrix on the components scale. The file is formatted for reading back under the control of the `.pin` file described in Chapter 11. The matrix is lower triangular row-wise in the order the parameters are printed in the `.asr` file. This is `nin89a.vvp` with the parameter estimates in the order error variance, spatial row correlation, spatial column correlation.

```

Variance of Variance components      3
51.0852
0.217089      0.318058E-02
0.677748E-01 -0.201181E-02  0.649355E-02

```

13.5 ASReml output objects and where to find them

Table 13.2 presents a list of objects produced with each ASReml run and where to find them in the output files.

Table 13.2: ASReml output objects and where to find them

output object	found in	comment
analysis of variance table	.asr file	the analysis of variance table contains F-statistics for each term in the <i>fixed</i> part of the model. These provide for an incremental or optionally a conditional test of significance (see Section 6.12).
data summary	.asr file .ass file	includes the number of records read and retained for analysis, the minimum, mean, maximum, number of zeros, number of missing values per data field, factor/variante field distinction. An extended report of the data is written to the .ass file if the <code>!SUM</code> qualifier is specified. It includes cell counts for factors, histograms of variates and simple correlations among variates
eigen analysis	.res file .asl file	When ASReml reports a variance matrix to the .asr file, it also reports an eigen analysis of the matrix (eigen values and eigen vectors) to the .res file.
elapsed time	.asr file .asl file	this can be determined by comparing the start time with the finishing time. The execution times for parts of the Iteration process are written to the .asl file if the <code>!DEBUG !LOGFILE</code> command line qualifiers are invoked.
fixed and random effects	.sln file	if <code>!BRIEF -1</code> is invoked, the effects that were included in the dense portion of the solution are also printed in the .asr file with their standard error, a t-statistic for testing that effect and a t-statistic for testing it against the preceding effect in that factor.
heritability	.pvc file	placed in the .pvc file when postprocessing with a .pin file
histogram of residuals	.res file	and graphics file
intermediate results	.asl file	given if the <code>-DL</code> command line option is used.

Table of output objects and where to find them ASReml

output object	found in	comment
mean/variance relationship	.res file	for non-spatial analyses ASReml prints the slope of the regression of <code>log(abs(residual))</code> against <code>log(predicted value)</code> . This regression is expected to be near zero if the variance is independent of the mean. A power of the mean data transformation might be indicated otherwise. The suggested power is approximately $(1-b)$ where b is the slope. A slope of 1 suggests a <code>log</code> transformation. This is indicative only and should not be blindly applied. Weighted analysis or identifying the cause of the heterogeneity should also be considered. This statistic is not reliable in genetic animal models or when <code>units</code> is included in the linear model because then the predicted value includes some of the residual.
observed variance/covariance matrix formed from BLUPs and residuals	.res file	for an interaction fitted as random effects, when the first [outer] dimension is smaller than the inner dimension less 10, ASReml prints an observed variance matrix calculated from the BLUPs. The observed correlations are printed in the upper triangle. Since this matrix is not well scaled as an estimate of the underlying variance component matrix, a rescaled version is also printed, scaled according to the fitted variance parameters. The primary purpose for this output is to provide reasonable starting values for fitting more complex variance structure. The correlations may also be of interest. After a multivariate analysis, a similar matrix is also provided, calculated from the residuals.
phenotypic variance	.pvc file	placed in the <code>.pvc</code> file when postprocessing with a <code>.pin</code> file
plot of residuals against field position	graphics file	
possible outliers	.res file	these are residuals that are more than 3.5 standard deviations in magnitude
predicted (fitted) values at the data points	.yht file	these in the are printed in the second column
predicted values	.pvs file	given if a <code>predict</code> statement is supplied in the <code>.as</code> file.
REML log-likelihood	.asr file	the REML log-likelihood is given for each iteration. The REML log-likelihood should have converged

Table of output objects and where to find them ASReml

output object	found in	comment
residuals	.yht file	and in binary form in .dpr file; these are printed in column 3. Furthermore, for multivariate analyses the residuals will be in data order (traits within records). However, in a univariate analysis with missing values that are not fitted, there will be fewer residuals than data records - there will be no residual where the data was missing so this can make it difficult to line up the values unless you can manipulate them in another program (spreadsheet).
score	.asl file	given if the <code>-DL</code> command line option is used.
tables of means	.tab file .pvs file	simple averages of cross classified data are produced by the <code>tabulate</code> directive to the .tab file. Adjusted means predicted from the fitted model are written to the .pvs file by the <code>predict</code> directive.
variance of variance parameters	.vvp file	based on the inverse of the average information matrix
variance parameters	.asr file .res file	the values at each iteration are printed in the .res file. The final values are arranged in a table, printed with labels and converted if necessary to variances.
variogram	graphics file	

Introduction

Common problems

Things to check in the `.asr` file

An example

Error messages

Warning messages

14.1 Introduction

When ASReml finds an inconsistency it prints an error message to the screen (or the .asl file) and dumps the current information to the .asr file. Below is the screen output for a job that has been terminated due to an error. If a job has an error you should

- try and identify the problem from the error message in the **Fault:** line and the text of the **Last line read:** (this appears twice in the file to make it easier to find),
- check that all labels have been defined and are in the correct case,
- some errors arise from conflicting information; the error may point to something that appears valid but is inconsistent with something earlier in the file,
- reduce to a simpler model and gradually build up to the desired analysis - this should help to identify the exact location of the problem.

If the problem is not resolved from the above list, you may need to email Customer Support at support@asreml.co.uk. Please send the .as file, (a sample of) the data, the .asr file and the .asl file produced by running

```
asreml -dl basename.as
```

See Chapter 12 The `-dl` command line option invokes debug mode and sends all non-graphics screen output to the .asl file.

In this chapter we show some of the common typographical problems. Errors arising from attempts to fit an inappropriate model are often harder to resolve. Following is an example of output when the data file is not correctly named or is not present (ASReml tries to interpret the filename as a variable name when the file is not found).

```
ASReml 1.99a [01 Aug 2005]  nin alliance trial
      Build: c [26 Jul 2005]  32 bit
memory info 27 Jul 2005 15:41:25.267  64.00 Mbyte Windows  ninerr1
Licensed to: Arthur Gilmour
...
working  direc- Folder: C:\data\ex\manex
tory      Warning: FIELD DEFINITION lines should be INDENTED
          There is no file called nine.asd
          Invalid label for data field: 'nine.asd' contains a reserved character
```

```

                                or may get confused with a previous label or reserved word
Fault      12 FORMAT error reading data structures
Last line read was:  nine.asd !slip 1
Currently defined structures, COLS and LEVELS
  1 variety                1   56   0   0   0   0
  2 id                     1    1   0   0   0   0
  3 pid                    1    1   0   0   0   0
  4 raw                    1    1   0   0   0   0
  5 repl                   1    4   0   0   0   0
  6 nloc                   1    1   0   0   0   0
  7 yield                  1    1   0   0   0   0
  8 lat                    1    1   0   0   0   0
  9 long                   1    1   0   0   0   0
 10 row                    1   22   0   0   0   0
 11 column                 1   11   0   0   0   0
filename! 12 nine.asd      0    0   0   0   0   0
ninerr1 C:\data\ex\manex
      12 factors defined [max 500].
      0 variance parameters [max1500].  2 special structures
last line read Last line read was:  nine.asd !slip 1
      12  12  -1  0  8000
fault message Finished: 27 Jul 2005 15:41:26.379  FORMAT error reading data structures

```

14.2 Common problems

Common problems in coding ASReml are as follows:

- a variable name has been misspelt; variable names are case sensitive,
- a model term has been misspelt; model term functions and reserved words (`mu`, `Trait`, `mv`, `units`) are case sensitive,
- the data file name is misspelt or the wrong path has been given - enclose the pathname in quotes (') if it includes embedded blanks,
- a qualifier has been misspelt or is in the wrong place,
- there is an inconsistency between the variance header line and the structure definition lines presented,
- failure to use commas appropriately in model definition lines,
- there is an error in the R structure definition lines,

- there is an error in the G structure definition lines,
 - there is a factor name error,
 - there is a missing parameter,
 - there are too many/few initial values,
- there is an error in the predict statement,
- model term `mv` not included in the model when there are missing values in the data and the model fitted assumes all data is present.

The most common problem in running ASReml is that a variable label is misspelt.

14.3 Things to check in the .asr file

The information that ASReml dumps in the `.asr` file when an error is encountered is intended to give you some idea of the particular error:

- if there is no data summary ASReml has failed before or while reading the model line,
- if ASReml has completed one iteration the problem is probably associated with starting values of the variance parameters or the logic of the model rather than the syntax *per se*.

Part of the file `nin89.asr` presented in Chapter 13 is displayed below to indicate the lines of the `.asr` file that should be checked. You should check that

- sufficient workspace has been obtained,
- the records read/lines read/records used are correct,
- mean min max information is correct for each variable,
- the Loglikelihood has converged and the variance parameters are stable,
- ANOVA table has the expected degrees of freedom.

```

ASReml 1.63o [01 Jun 2005]  NIN alliance trial 1989
      Build: j [01 Jul 2005]  128
workspace 14 Jul 2005 12:41:18.360  32.00 Mbyte Windows  nin89a
Licensed to: Arthur Gilmour
...
working   direc- Folder: C:\data\asr\UG2\manex
tory
```

```

variety !A
QUALIFIERS: !SKIP 1          !DISPLAY 15
QUALIFIER: !DOPART 1 is active
Reading nin89aug.asd FREE FORMAT skipping 1 lines
    
```

records read
data summary

```

Univariate analysis of yield
Using 242 records of 242 read
Model term          Size #miss #zero  MinNon0  Mean  MaxNon0
1 variety           56    0    0      1    26.4545  56
2 id                0    0    0    1.000    26.45  56.00
3 pid              18    0    0   1101.    2628.  4156.
4 raw              18    0    0    21.00    510.5  840.0
5 repl             4    0    0      1    2.4132   4
6 nloc             0    0    0    4.000    4.000  4.000
7 yield            Variate  18    0    1.050    25.53  42.00
8 lat              0    0    0    4.300    25.80  47.30
9 long            0    0    0    1.200    13.80  26.40
10 row             22    0    0      1   11.5000  22
11 column          11    0    0      1    6.0000  11
12 mu              1
13 mv_estimates    18
    22 AR=AutoReg    0.5000
    11 AR=AutoReg    0.5000
    
```

check
convergence

```

Forming 75 equations: 57 dense.
Initial updates will be shrunk by factor 0.316
NOTICE: 1 singularities detected in design matrix.
1 LogL=-401.827 S2= 42.467 168 df 1.000 0.5000 0.5000
2 LogL=-400.780 S2= 43.301 168 df 1.000 0.5388 0.4876
3 LogL=-399.807 S2= 45.066 168 df 1.000 0.5895 0.4698
4 LogL=-399.353 S2= 47.745 168 df 1.000 0.6395 0.4489
5 LogL=-399.326 S2= 48.466 168 df 1.000 0.6514 0.4409
6 LogL=-399.324 S2= 48.649 168 df 1.000 0.6544 0.4384
7 LogL=-399.324 S2= 48.696 168 df 1.000 0.6552 0.4377
8 LogL=-399.324 S2= 48.708 168 df 1.000 0.6554 0.4375
    
```

```

Final parameter values          1.0000  0.65550  0.43748
    
```

parameter
estimates

```

Source          Model terms  Gamma  Component  Comp/SE  % C
Variance        242  168  1.00000    48.7085    6.81  0 P
Residual        AR=AutoR  22  0.655505  0.655505  11.63  0 U
    
```

```

Residual          AR=AutoR    11  0.437483    0.437483    5.43  0 U

ANOVA              Analysis of Variance          NumDF    DenDF    F_inc          Prob
    12 mu                    1      25.0   331.85         <.001
    1 variety                 55     110.8    2.22          <.001
Notice: The DenDF values are calculated ignoring fixed/boundary/singular
        variance parameters using algebraic derivatives.
    13 mv_estimates                    18 effects fitted
outliers?          6 possible outliers: in section 1 (see .res file)
Finished: 14 Jul 2005 12:41:26.862  LogL Converged

```

14.4 An example

See 2a in Section 7.3 This is the command file for a simple RCB analysis of the NIN variety trial data in the first part. However, this file contains eight common mistakes in coding ASReml. We also show two common mistakes associated with spatial analyses in the second part. The errors are highlighted and the numbers indicate the order in which they are detected. Each error is discussed with reference to the output written to the `.asr` file. A summary of the errors is as follows:

1. data file not found,
2. unrecognised qualifier,
3. incorrectly defined alphanumeric factor,
4. comma missing from first line of model,
5. misspelt variable label in linear model,
6. misspelt variable label in G structure header line,
7. wrong levels declared in G structure model line,

```

nin alliance trial
variety 56 # 3.
id
pid
raw
repl 4
nloc
yield
lat
long
row 22
column 11
nine.asd !slip 1 !dopart $1
# 1. & 2.
!part 1
yield~mu variety # 4.
!r Repl # 5.
0 0 1
Repl 1 # 6.
2 0 IDV 0.1 # 7.
!part 2
yield~mu variety # 9.
1 2
11 row AR1 .1 #10.
22 col AR1 .1
!part
predict voriety # 8.

```

8. misspelt variable label in predict statement.
9. mv omitted from spatial model
10. wrong levels declared in R structure model lines

1. Data file not found

Running this job produces the `.asr` file in Section 14.1. The first problem is that ASReml cannot find the data file `nine.asd` as indicated in the error message above the `Fault` line. ASReml reports the last line read before the job was terminated, an error message

```
nin alliance trial
:
nine.asd !slip 1
yield ~ mu variety
:
```

`FORMAT error reading data structures`

and other information obtained to that point. In this case the program only made it to the data file definition line in the command file. Since `nine.asd` commences in column 1, ASReml checks for a file of this name (in the working directory since no path is supplied). Since ASReml did not find the data file it tried to interpret the line as a variable definition but `.` is not permitted in a variable label. The problem is either that the filename is misspelt or a pathname is required. In this case the data file was given as `nine.asd` rather than `nin.asd`.

2. An unrecognised qualifier and 3. An incorrectly defined factor

After supplying the correct pathname and re-running the job, ASReml produces the warning message

```
WARNING: Unrecognised qualifier at character 9 !slip 1
```

followed by the fault message

```
ERROR Reading the data.
```

The warning does not cause the job to terminate immediately but arises because `!slip` is not a recognised data file line qualifier; the correct qualifier is `!skip`. The job terminates when reading the header line of the `nin.asd` file which is alphabetic when it is expecting numeric values. The following output displays the error message produced.

```
ASReml 1.99a [01 Aug 2005] nin alliance trial
      Build: c [26 Jul 2005] 32 bit
27 Jul 2005 15:41:38.987 64.00 Mbyte Windows ninerr2
```



```

Licensed to: Arthur Gilmour
...
Folder: C:\data\ex\manex
QUALIFIERS: !SLIP 1
Warning: Unrecognised qualifier at character 9 !SLIP 1
QUALIFIER: !DOPART 1 is active
Reading nin.asd FREE FORMAT skipping 0 lines

Univariate analysis of yield
error Error at field 1 [variety] of record 1 [line 1]
hint Since this is the first data record, you may need to skip some header lines
(see !SKIP) or append the !A qualifier to the definition of factor variety
Fault 0 Missing/faulty !SKIP or !A needed for variety
give away Last line read was: variety id pid raw rep nloc yield lat long row column
Currently defined structures, COLS and LEVELS
 1 variety 1 56 56 0 0 0
 2 id 1 1 1 0 1 0
 3 pid 1 1 1 0 2 0
 4 raw 1 1 1 0 3 0
 5 repl 1 4 4 0 4 0
 6 nloc 1 1 1 0 5 0
 7 yield 1 1 1 0 6 0
 8 lat 1 1 1 0 7 0
 9 long 1 1 1 0 8 0
10 row 1 22 22 0 9 0
11 column 1 11 11 0 10 0
12 mu 0 1 -8 0 -1 0
ninerr2 nin.asd
Model specification: TERM LEVELS GAMMAS
mu 0
variety 0
12 factors defined [max 500].
0 variance parameters [max1500]. 2 special structures
Last line read was: variety id pid raw rep nloc yield lat long row column
12 0 0 0 8000
Finished: 27 Jul 2005 15:41:40.068 Missing/faulty !SKIP or !A needed for variety

```

Fixing the error by changing !slip to !skip however still produces the fault message

Missing/faulty !SKIP or !A needed for variety.

The portion of output given below shows that ASReml has baulked at the name LANCER in the first field on the first data line. This alphabetic data field is not declared as alphabetic. The correct data field definition for variety is

variety !A

to indicate that variety is a character field.

hint

```
Folder: C:\asr\ex\manex
QUALIFIERS: !SKIP 1
Reading nin89.asd FREE FORMAT skipping      1 lines
Univariate analysis of yield
Field 1 [LANCER] of record      1 [line      1] is not valid.
Since this is the first data record, you may need to skip some header lines
(see !SKIP) or append the !A qualifier to the definition of factor variety
Fault      0 Missing/faulty !SKIP or !A needed for variety
Last line read was: LANCER 1 NA NA 1 4 NA 4.3 1.2 1 1
:
ninerr3 variety id      pid      raw      rep      nloc      yield      lat
Model specification: TERM LEVELS GAMMAS
mu                                  0      0.000
variety                             0      0.000
12 factors defined [max 500].
0 variance parameters [max 900]. 2 special structures
Last line read was: LANCER 1 NA NA 1 4 NA 4.3 1.2 1 1
12      0      0      0      8000
Finished: 28 Jul 2005 09:51:12.817 Missing/faulty !SKIP or !A needed for variety
```

4. A missing comma and 5. A misspelt factor name in linear model

The model has been written over two lines but ASReml does not realise this because the first line does not end with a comma. The missing comma causes the fault

R header SECTIONS DIMNS GSTRUCT

as ASReml tries to interpret the second line of the model (see Last line read) as the variance header line. The .asr file is displayed

```
nin alliance trial
variety !A
:
repl 4
:
nin89.asd !skip 1
yield ~ mu variety
!r Repl
:
```

below. Note that the data has now been successfully read as indicated by the data summary. You should always check the data summary to ensure that the correct number of records have been detected and the data values match the names appropriately.

```
ASReml 1.99a [01 Aug 2005]  nin alliance trial
      Build: d [27 Jul 2005]  32 bit
28 Jul 2005 09:53:15.553  64.00 Mbyte Windows  ninerr4
Licensed to: Arthur Gilmour
```

```
Folder: C:\data\ex\manex
      variety !A
QUALIFIERS: !SKIP 1
QUALIFIER: !DOPART  1 is active
Reading nin.asd  FREE FORMAT skipping  1 lines
```

Univariate analysis of yield

```
Using 224 records of 242 read
Model term          Size #miss #zero  MinNon0  Mean  MaxNon0
 1 variety          56    0    0    1    28.5000    56
 2 id                0    0    0  1.000    28.50    56.00
 3 pid              0    0    0 1101.    2628.    4156.
 4 raw              0    0    0  21.00    510.5    840.0
 5 repl             4    0    0    1    2.5000     4
 6 nloc             0    0    0  4.000    4.000    4.000
 7 yield            Variate  0    0  1.050    25.53    42.00
 8 lat              0    0    0  4.300    27.22    47.30
 9 long             0    0    0  1.200    14.08    26.40
10 row             22    0    0    1   11.7321    22
11 column          11    0    0    1    6.3304    11
12 mu              1
```

```
Fault 0 R header SECTIONS DIMNS GSTRUCT
```

```
Last line read was: !r Repl 0 0 0 0
ninerr4 variety id pid raw rep nloc yield lat
Model specification: TERM LEVELS GAMMAS
variety          56
mu                1
```

```
12 factors defined [max 500].
```

```
0 variance parameters [max1500]. 2 special structures
```

```
Final parameter values
```

```

Last line read was:   !r Repl 0 0 0 0
      12      0      242      224      8000
Finished: 28 Jul 2005 09:53:16.775   R header SECTIONS DIMNS GSTRUCT

```

Inserting a comma on the end of the first line of the model to give

```

yield ~ mu variety,
!r Repl

```

solves that problem but produces the error message

```
Error reading model factor list
```

because Repl should have been spelt repl. Portion of the output is displayed. Since the model line is parsed before the data is read, this run failed before reading the data.

```

ASReml 1.99a [01 Aug 2005]   nin alliance trial
      Build: d [27 Jul 2005]   32 bit
28 Jul 2005 10:06:48.042   64.00 Mbyte Windows   ninerr5
Licensed to: Arthur Gilmour

```

```
Folder: C:\data\ex\manex
```

```

variety !A
QUALIFIERS: !SKIP 1
QUALIFIER: !DOPART   1 is active
Reading nin.asd FREE FORMAT skipping   1 lines
Fault      0 Error reading model factor list
Last line read was:      Repl

```

```
Currently defined structures, COLS and LEVELS
```

1 variety	1	2	2	0	0	0
2 id	1	1	1	0	1	0
3 pid	1	1	1	0	2	0
4 raw	1	1	1	0	3	0
5 repl	1	4	4	0	4	0
6 nloc	1	1	1	0	5	0

```
:
```

```
Finished: 28 Jul 2005 10:06:49.173   Error reading model factor list
```

6. Misspelt factor name and 7. Wrong levels declaration in the G structure definition lines

The next fault ASReml detects is

G structure header: Factor, order

indicating that there is something wrong in the G structure definition lines. In this case the replicate term in the first G structure definition line has been spelt incorrectly. To correct this error replace `Repl` with `repl`.

```
nin alliance trial
:
nin89.asd !skip 1
yield ~ mu variety
!r Repl
0 0 1
Repl 1
2 0 IDV 0.1
```

```
ASReml 1.99a [01 Aug 2005] nin alliance trial
Build: c [26 Jul 2005] 32 bit
27 Jul 2005 15:41:52.606 64.00 Mbyte Windows ninerr6
Licensed to: Arthur Gilmour
```

```
Folder: C:\data\ex\manex
variety !A
QUALIFIERS: !SKIP 1
QUALIFIER: !DOPART 1 is active
Reading nin.asd FREE FORMAT skipping 1 lines
```

Univariate analysis of yield

```
Using 224 records of 242 read
```

Model term	Size	#miss	#zero	MinNon0	Mean	MaxNon0
1 variety	56	0	0	1	28.5000	56
2 id		0	0	1.000	28.50	56.00
3 pid		0	0	1101.	2628.	4156.
4 raw		0	0	21.00	510.5	840.0
5 repl	4	0	0	1	2.5000	4
6 nloc		0	0	4.000	4.000	4.000
7 yield	Variate	0	0	1.050	25.53	42.00
8 lat		0	0	4.300	27.22	47.30
9 long		0	0	1.200	14.08	26.40
10 row	22	0	0	1	11.7321	22
11 column	11	0	0	1	6.3304	11
12 mu	1					

Fault 1 G structure header: Factor, order

Last line read was: Repl 1 0 0 0 0

ninerr6 variety id pid raw rep nloc yield lat

```

Model specification:  TERM LEVELS GAMMAS
variety                56
mu                      1
repl                    4    0.100
SECTIONS    224        4        1
  TYPE        0        0        0
  STRUCT    224        0        0        0        0        0        0
  12 factors defined [max 500].
  4 variance parameters [max1500].  2 special structures
Final parameter values                0.10000    1.0000
Last line read was:  Repl 1 0 0 0 0
  12    1    242    224    8000
Finished: 27 Jul 2005 15:41:53.668  G structure header: Factor, order

```

Fixing the header line, we then get the error message

Structure / Factor mismatch

This arose because `repl` has 4 levels but we have only declared 2 in the G structure model line. The G structure should read

```

repl 1
4 0 IDV 0.1

```

The last lines of the output with this error are displayed below.

```

11 column                11    0    0    1    6.3304    11
12 mu                      1
  2 identity    0.1000
Structure for repl                has    2 levels defined
Fault    1 Structure / Factor mismatch
Last line read was:  2 0 IDV 0.1 0 0 0 0 0
ninerr7 variety id pid raw rep nloc yield lat
Model specification:  TERM LEVELS GAMMAS
variety                56
mu                      1
repl                    4    0.100
SECTIONS    224        4        1
  TYPE        0        0    1002
  STRUCT    224        0        0        0        0        0        0

```

```

                2      1      0      5      0      1      0
12 factors defined [max 500].
  5 variance parameters [max1500].  2 special structures
Final parameter values                0.10000    1.0000    0.10000

Last line read was:  2 0 IDV 0.1 0 0 0 0 0
12      1      242    224    8000
Finished: 27 Jul 2005 15:41:57.153    Structure / Factor mismatch

```

8. A misspelt factor name in the predict statement

The final error in the job is that a factor name is misspelt in the predict statement. This is a non-fatal error. The faulty statement is simply ignored by ASReml and no .pvs file is produced. To rectify this statement correct `voriety` to `variety`.
see Chapter 13

9. Forgetting `mv` in a spatial analysis

The first error message from running part 2 of the job is

```
R structures imply 0 + 242 records: only 224 exist
```

Checking the seventh line of the output below, we see that there were 242 records read but only 224 were retained for analysis. There are three reasons records are dropped.

1. the `!FILTER` qualifier has been specified,
2. the `!D` transformation qualifier has been specified and
3. there are missing values in the response variable and the user has not specified that they be estimated.

The last applies here so we must change the model line to read `yield ~ mu variety mv`.

```

Folder: C:\data\ex\manex
  variety !A
QUALIFIERS: !SKIP 1
QUALIFIER: !DOPART    2 is active
Reading nin.asd FREE FORMAT skipping    1 lines

Univariate analysis of yield
Using    224 records of    242 read
Model term                Size #miss #zero  MinNon0  Mean    MaxNon0
  1 variety                56     0     0       1    28.5000    56

```

```

:
11 column                11    0    0    1    6.3304        11
12 mu                    1
    11 AR=AutoReg        0.1000
    22 AR=AutoReg        0.1000
Maybe you need to include 'mv' in the model
Fault    1 R structures imply    0 +    242 records: only    224 e
Last line read was: 22 column AR1 0.1 0 0 0 0 0
ninerr9 variety id pid raw rep nloc yield lat
Model specification: TERM LEVELS GAMMAS
variety                                56
mu                                     1
SECTIONS    242      3      1
STRUCT      11      1      1      4      1      1      10
            22      1      1      5      1      1      11
    12 factors defined [max 500].
    5 variance parameters [max1500].    2 special structures
Final parameter values                0.0000    -.10000E-360.10000
0.10000
Last line read was: 22 column AR1 0.1 0 0 0 0 0
    12    1    242    224    8000
Finished: 27 Jul 2005 15:42:10.192 R structures imply 0+242 records: only 224 exist

```

10. Field layout error in a spatial analysis

The final common error we highlight is the misspecification of the field layout. In this case we have 'accidentally' switched the levels in rows and columns. However, ASReml can detect this error because we have also asked it to sort the data into field order. Had sorting not been requested, ASReml would not have been able to detect that the lines of the data file were not sorted into the appropriate field order and spatial analysis would be wrong.

```

:
Folder: C:\data\ex\manex
variety !A
QUALIFIERS: !SKIP 1
QUALIFIER: !DOPART    2 is active
Reading nin.asd FREE FORMAT skipping    1 lines

Univariate analysis of yield

```



```

Using      242 records of      242 read
Model term                Size #miss #zero  MinNon0  Mean  MaxNon0
  1 variety                 56    0    0      1  26.4545    56
:
10 row                     22    0    0      1  11.5000    22
11 column                  11    0    0      1   6.0000    11
12 mu                      1
13 mv_estimates           18
    11 AR=AutoReg    0.1000
    22 AR=AutoReg    0.1000
Warning: Spatial mapping information for side 1 of order  11
        ranges from      1.0 to      22.0
Warning: Spatial mapping information for side 2 of order  22
        ranges from      1.0 to      11.0
Fault      2 Sorting data into field order
Last line read was:  22 column AR1 0.1 0 0 0 0 0
ninerr10 variety id pid raw rep nloc yield lat
Model specification:  TERM LEVELS GAMMAS
variety                56
mu                    1
mv_estimates          18
SECTIONS      242      4      1
STRUCT        11      1      1      5      1      1      10
              22      1      1      6      1      1      11
    13 factors defined [max 500].
    6 variance parameters [max1500].  2 special structures
Final parameter values                0.0000  -.10000E-360.10000
0.10000
Last line read was:  22 column AR1 0.1 0 0 0 0 0
    13      2      242      242      8000
Finished: 27 Jul 2005 15:42:31.733  Sorting data into field order

```

14.5 Information, Warning and Error messages

ASReml prints information, warning and error messages in the `.asr` file. The major information messages are in Table 14.2. A list of warning messages together with the likely meaning(s) is presented in Table 14.1. Error messages with their probable cause(s) is presented in Table 14.3.

Table 14.1: Some information messages and comments

information message	comment
Logl converged	the REML log-likelihood changes between iterations were less than $0.002 * \text{iteration number}$ and variance parameter values appear stable.
BLUP run done	A full iteration has not been completed. See discussion of !BLUP.
JOB ABORTED by USER	See discussion of ABORTASR.NOW.
Logl converged, parameters not converged	the change in REML log-likelihood was small and convergence was assumed but the parameters are, in fact, still changing.
Logl not converged	the maximum number of iterations was reached before the REML log-likelihood converged. Examine the sequence of estimates in the <code>.res</code> file. You may need more iterations in which case restart with the !CONTINUE command line option (see Section 12.3 on job control). Otherwise restart with more appropriate initial variances. It may be necessary to simplify the model and estimate the dominant components before estimating other terms.
Warning: Only one iteration performed	Parameter values are not at the REML solution.
Parameters unchanged after one iteration.	Parameters appear to be at the REML solution in that the parameter values are stable.

Table 14.2: List of warning messages and likely meaning(s)

warning message	likely meaning
Warning: <i>e</i> missing values generated by !~ transformation	data values should be positive.
Warning: <i>i</i> singularities in AI matrix	usually means variance model is overparameterized.
Warning: <i>m</i> variance structures were modified	the structures are probably at the boundary of the parameter space.
Warning: <i>n</i> missing values were detected in the design	either use !MVINCLUDE or delete the records.
Warning: <i>n</i> negative weights	it is better to avoid negative weights unless you can check ASReml is doing the correct thing with them.
Warning: <i>r</i> records were read from multiple lines	check you have the intended number of fields per line.
WARNING <i>term</i> has more levels [##] than expected [##]:	You have probably mis-specified the number of levels in the factor or omitted the !I qualifier (see Section 5.4 on data field definition syntax). ASReml corrects the number of levels.
Warning: <i>term</i> in the predict !IGNORE list	the term did not appear in the model.
Warning: <i>term</i> in the predict !USE list	the term did not appear in the model.
Warning: <i>term</i> is ignored for prediction	terms like units and mv cannot be included in prediction.
Warning: Check if you need the !RECODE qualifier	!RECODE may be needed if the binary file was not prepared with ASReml.
Warning: Code B - fixed at a boundary (!GP)	suggest drop the term and refit the model.
Warning: Eigen analysis check of US matrix skipped	matrix is probably OK.
WARNING: Extra lines on the end of the input file ...:	this indicates that there are some lines on the end of the .as file that were not used. The first "extra" line is displayed. This is only a problem if you intended ASReml to read these lines.
Warning: Fewer levels found in <i>term</i>	ASReml increases to the correct value.
Warning: FIELD DEFINITION lines should be INDENTED	indent them to avert this message.

List of warning messages and likely meaning(s)

warning message	likely meaning
Warning: Fixed levels for factor	user nominated more levels than are permitted.
Warning: Initial gamma value is zero	constraint parameter is probably wrongly assigned.
Warning: Invalid argument.	fix the argument.
Warning: It is usual to include Trait	in multivariate analysis model.
Warning: LogL Converged; Parameters Not Converged	you may need more iterations.
Warning: LogL not converged	restart to do more iterations (see !CONTINUE).
Warning: Missing cells in table	missing cells are normally not reported.
Warning: More levels found in term	consider setting levels correctly.
Warning: PREDICT LINE IGNORED - TOO MANY	limit is 100.
Warning: PREDICT statement is being ignored	because it contains errors.
Warning: Second occurrence of term dropped	if you really want to fit this term twice, create a copy with another name.
Warning: Spatial mapping information for side	gives details so you can check ASReml is doing what you intend.
Warning: Standard errors	that is, these standard errors are approximate.
Warning: SYNTAX CHANGE: text may be invalid	use the correct syntax.
Warning: The !A qualifier ignored when reading BINARY data	the !A fields will be treated as factors but are not encoded.
Warning: The !SPLINE qualifier has been redefined.	use correct syntax.
Warning: The !X !Y !G qualifiers are ignored. There is no data to plot	revise the qualifier arguments.
Warning: The estimation was ABORTED	do not accept the estimates printed.
Warning: The labels for predictions are erroneous	the labels for predicted terms are probably out of kilter. Try a simpler predict statement. If the problem persists, send for help.

List of warning messages and likely meaning(s)

warning message	likely meaning
Warning: This US structure is not positive definite	check the initial values.
Warning: Unrecognised qualifier at character	the qualifier either is misspelt or is in the wrong place.
Warning: US matrix was not positive definite: MODIFIED	the initial values were modified.
Warning: User specified spline points	the points have been rescaled to suit the data values.
Warning: Variance parameters were modified by BENDING	ASReml may not have converged to the best estimate.
WARNING Likelihood decreased. Check gammas and singularities.:	a common reason is that some constraints have restricted the gammas. Add the !GU qualifier to any factor definition whose gamma value is approaching zero (or the correlation is approaching (-)1. Alternatively, more singularities may have been detected. You should identify where the singularities are expected and modify the data so that they are omitted or consistently detected. One possibility is to centre and scale covariates involved in interactions so that their standard deviation is close to 1.

Table 14.3: Alphabetical list of error messages and probable cause(s)/remedies

error message	probable cause/remedy
!PRINT: Cannot open output file	Check filename.
AINV/GIV matrix undefined or wrong size	Check the size of the factor associated with the AINV/GIV structure.
ASReml command file is EMPTY:	The job file should be in ASCII format.
ASReml failed in ...	Try running the job with increased workspace, or using a simpler model. Otherwise send the job to VSN (mailto:support@asreml.co.uk) for investigation.

Alphabetical list of error messages and probable cause(s)/remedies

error message	probable cause/remedy
Continue from .rsv file	Try running without the !CONTINUE qualifier.
Convergence failed	<p>the program did not proceed to convergence because the REML log-likelihood was fluctuating wildly. One possible reason is that some singular terms in the model are not being detected consistently. Otherwise, the updated G structures are not positive definite. There are some things to try:</p> <ul style="list-style-type: none"> - define US structures as positive definite by using !GP, - supply better starting values, - fix parameters that you are confident of while getting better estimates for others (that is, fix variances when estimating covariances), - fit a simpler model, - reorganise the model to reduce covariance terms (for example, use CORUH instead of US.)
Correlation structure is not positive definite	It is best to start with a positive definite correlation structure. Maybe use a structured correlation matrix.
Define structure for ...	A variance structure should be specified for this term.
Error in !CONTRAST label factor values	The error could be in the variable(factor) name or in the number of values or the list of values.
Error in !SUBSET label factor values	The error could be in the variable(factor) name or in the number of values or the list of values.
Error in R structure: model checks	the error model is not correctly specified.
Error opening file	the file did not exist or was of the wrong file type (binary = unformatted, sequential).
Error reading <i>something</i>	There are several messages of this form where <i>something</i> is what ASReml is attempting to read. Either there is an error telling ASReml to read <i>something</i> when it does not need to, or there is an error in the way <i>something</i> is specified.

Alphabetical list of error messages and probable cause(s)/remedies

error message	probable cause/remedy
Error reading the data:	the data file could not be interpreted: alphanumeric fields need the !A qualifier.
Error reading the DATA FILENAME line	data file name may be wrong
Error reading the model factor list	the model specification line is in error: a variable is probably misnamed.
Error setting constraints (!VCC) on variance components	The !VCC constraints are specified last of all and require knowing the position of each parameter in the parameter vector.
Error setting dependent variable	the specified dependent variable name is not recognised.
Error setting MBF design matrix: !MBF mbf(x,k) filename	It is likely that the covariate values do not match the values supplied in the file. The values in the file should be in sorted order.
Error structures are wrong size:	the declared size of the error structures does not match the actual number of data records.
Error when reading knot point values	There is some problem on the !SPLINE line. It could be a wrong variable name or the wrong number of knot points. Knot points should be in increasing order.
Failed forming R/G scores...?	Try increasing workspace.
Failed ordering Level labels	The problem may be due to the use of the !SORT qualifier.
Failed to parse R/G structure line	May be an unrecognised factor/model-term name or variance structure name or wrong count of initial values, possible on an earlier line. May be insufficient lines in the job.
Failed to read R/G structure line	
Failed to process MYOWNGDG files	Check your MYOWNGDG program and the .gdg file.
Failed when sorting pedigree ...	Maybe increase !WORKSPACE.
Failed when processing pedigree file ...	
Failed while ordering equations.	Try increasing the workspace or simplifying the model.

Alphabetical list of error messages and probable cause(s)/remedies

error message	probable cause/remedy
FORMAT error reading factor Definitions:	Likely causes are <ul style="list-style-type: none"> - bad syntax or invalid characters in the variable labels; variable labels must not include any of these symbols; !|-+(:#\$ and ., - the data file name is misspelt, - there are too many variables declared or there is no valid <i>value</i> supplied with an arithmetic transformation option.
G-structure header: Factor order:	there is a problem reading G structure header line. The line must contain the name of a term in the linear model spelt exactly as it appears in the model
G structure: ORDER 0 MODEL GAMMAS:	a G structure line cannot be interpreted.
G structure size does not match	The size of the structure defined does not agree with the model term that it is associated with.
Gamma Constraint READ error	Check the syntax.
Getting Pedigree:	an error occurred processing the pedigree. The pedigree file must be ascii, free format with ANIMAL, SIRE and DAM as the first three fields.
GLM Bounds failure	ASReml failed to calculate the GLM working variables or weights. Check the data.
Increase declared levels for factor ...	Either the field has alphanumeric values but has not been declared using the !A qualifier, or there is not enough space to hold the levels of the factor. To 'increase the levels', insert the expected number of levels after the !A or !I qualifier in the field definition.
Increase workspace ...	Use !WORKSPACE <i>s</i> to increase the workspace available to ASReml . If the data set is not extremely big, check the data summary.
Insufficient data read from file	Maybe the response variable is all missing.
Insufficient points for :	there must be at least 3 distinct data values for a spline term

Alphabetical list of error messages and probable cause(s)/remedies

error message	probable cause/remedy
Insufficient workspace.	If ASReml has not obtained the maximum available workspace, then use !WORKSPACE to increase it. The problem could be with the way the model is specified. Try fitting a simpler model or using a reduced data set to discover where the workspace is being used.
invalid analysis trait number	The response variable nominated by the !YVAR command line qualifier is not in the data.
Invalid binary data Invalid Binomial Variable	The data values are out of the expected range for binary/binomial data.
Invalid definition of factor ...	there is a problem with forming one of the <i>generated</i> factors. The most probable cause is that an interaction cannot be formed.
Invalid error structure for Multivariate Analysis	You must either use the US error structure or use the !ASUV qualifier (and maybe include mv in the model).
Invalid factor definition:	a term in the model has no levels
Invalid factor in model:	a term in the <i>model specification</i> is not among the terms that have been defined. Check the spelling.
Invalid model factor ... :	there is a problem with the named variable.
Invalid SOURCE in R structure definition	The second field in the R structure line does not refer to a variate in the data.
Invalid weight/filter column number:	the weight and filter columns must be data fields. Check the data summary.
Iteration aborted because of singularities	See the discussion of !AISINGULARITIES.
Iteration failed	Maybe increase workspace or restructure/simplify the model.
Maximum number of special structures exceeded	special structures are weights, the Ainverse and GIV structures. The limit is 98 and so no more than 96 GIV structures can be defined.
Maximum number of variance parameters exceeded	The limit is 1500. It may be possible to restructure the job so the limit is not exceeded, assuming that the actual number of parameters to be estimated is less.

Alphabetical list of error messages and probable cause(s)/remedies

error message	probable cause/remedy
Missing/faulty !SKIP or !A needed for ...	ASReml failed to read the first data record. Maybe it is a heading line which should be skipped by using the !SKIP qualifier, or maybe the field is an alphanumeric field but has not been declared so with the !A qualifier.
Missing values in design variables/factors	You need to identify which design terms contain missing values and decide whether delete the records containing the missing values in these variables or, if it is reasonable, to treat the missing values as zero by using !MVINCLUDE.
Missing Value Miscount forming design	More missing values in the response were found than expected.
Missing values not allowed here:	missing observations have been dropped so that multivariate structure is messed up.
Multiple trait mapping problem	Maybe a trait name is repeated.
Negative Sum of Squares:	This is typically caused by negative variance parameters; try changing the starting values or using the !STEP option. If the problem occurs after several iterations it is likely that the variance components are very small. Try simplifying the model. In multivariate analyses it arises if the error variance is (becomes) negative definite. Try specifying !GP on the structure line for the error variance.
NFACT out of range:	too many terms are being defined.
No .giv file for	Fix the argument to giv().
No residual variation:	after fitting the model, the residual variation is essentially zero, that is, the model fully explains the data. If this is intended, use the !BLUP 1 qualifier so that you can see the estimates. Otherwise check that the dependent values are what you intend and then identify which variables explain it. Again, the !BLUP 1 qualifier might help.
Out of ...	A program limit has been breached. Try simplifying the model.
Out of memory ...	use -WORKSPACE option to increase the workspace allocation. It may be possible to revise the models to increase sparsity.

Alphabetical list of error messages and probable cause(s)/remedies

error message	probable cause/remedy
Out of memory: forming design:	factors are probably not declared properly. Check the number of levels. Possibly use the <code>-WORKSPACE</code> command line option.
Overflow structure table:	occurs when space allocated for the structure table is exceeded. There is room for three structures for each model term for which G structures are explicitly declared. The error might occur when <code>ASReml</code> needs to construct rows of the table for structured terms when the user has not formally declared the structures. Increasing g on the variance header line for the number of G structures (see page 117) will increase the space allocated for the table. You will need to add extra explicit declarations also.
Pedigree coding errors:	check the pedigree file and see any messages in the output. Check that identifiers and pedigrees are in chronological order.
Pedigree factor has wrong size:	the A-inverse factors are not the same size as the A-inverse. Delete the <code>ainverse.bin</code> file and rerun the job.
Pedigree too big:	program will need to be recompiled if file is correct.
POWER model setup error	Check the details for the distance based variance structure.
POWER Model: Unique points disagree with size	Check the distances specified for the distance based variance structure.
PROGRAM failed in ...	Try increasing workspace. Otherwise send problem to VSN.
PROGRAMMING error:	Try increasing the memory, simplifying the model and changing starting values for the gammas. If this fails send the problem to the VSN (mailto:support@asrem1.co.uk) for investigation.
reading !SELF option	Check the argument.

Alphabetical list of error messages and probable cause(s)/remedies

error message	probable cause/remedy
Reading distances for POWER structure	POWER structures are the spatial variance models which require a list of distances. Distances should be in increasing order. If the distances are not obtained from variables, the 'SORT' field is zero and the distances are presented after all the R and G structures are defined.
Reading factor names:	something is wrong in the terms definitions. It could also be that the data file is misnamed.
reading Overdispersion factor	Check the argument.
READING OWN structures ...	There is probably a problem with the output from MYOWNGDG. Check the files, including the time stamps to check the .gdg file is being formed properly.
Reading the data:	if you read less data than you expect, there are two likely explanations. First, the data file has less fields than implied by the data structure definitions (you will probably read half the expected number). Second, there is an alphanumeric field where a numeric field is expected.
Reading Update step size:	check the !STEP qualifier argument.
Residual Variance is Zero:	either all data is deleted or the model fully fits the data.
R header SECTIONS DIMNS GSTRUCT R structure header SITE DIM GSTRUCT Variance header: SEC DIM GSTRUCT	error with the variance header line. Often, some other error has meant that the wrong line is being interpreted as the variance header line. Commonly, the model is written over several lines but the incomplete lines do not all end with a comma.
R structure error ORDER SORTCOL MODEL GAMMAS:	an error reading the error model.
R structures are larger than number of records	Maybe you need to include mv in the model to stop ASReml discarding records with missing values in the response variable.
REQUIRE !ASUV qualifier for this R structure REQUIRE I x E R structure	Without the ASUV qualifier, the multivariate error variance MUST be specified as US.

Alphabetical list of error messages and probable cause(s)/remedies

error message	probable cause/remedy
Scratch:	Apparently ASReml could not open a scratch file to hold the transformed data. On unix, check the temp directory //tmp for old large scratch files.
Segmentation fault:	this is a Unix memory error. The first thing to try is to increase the memory workspace using the !WORKSPACE (see Section 12.3 on memory) command line option. Otherwise you may need to send your data and the .as files to Customer Support for debugging.
Singularity appeared in AI matrix Singularity in Average Information Matrix	See the discussion on !AISINGULARITIES
Sorting data by !Section !Row ... Sorting the data into field order	the field order coding in the spatial error model does not generate a complete grid with one observation in each cell; missing values may be deleted: they should be fitted. Also may be due to incorrect specification of number of rows or columns.
STOP SCRATCH FILE DATA STORAGE ERROR:	ASReml attempts to hold the data on a scratch file. Check that the disk partition where the scratch files might be written is not too full; use the !NOSCRATCH qualifier to avoid these scratch files.
Structure/ Factor mismatch:	the declared size of a variance structure does not match the size of the model term that it is associated with.
Too many alphanumeric factor level labels:	if the factor level labels are actually all integers, use the !I option instead. Otherwise, you will have to convert a factor with alphanumeric labels to numeric sequential codes external to ASReml so that an !A option can be avoided.
Too many factors with !A or !I; max 100	The data file may need to be rewritten with some factors recoded as sequential integers.
Too many [max 20] dependent variables	This is an internal limit. Reduce the number of response variables.

Alphabetical list of error messages and probable cause(s)/remedies

error message	probable cause/remedy
Unable to invert R or G [US?] matrix:	this message occurs when there is an error forming the inverse of a variance structure. The probable cause is a non positive definite (initial) variance structure (US, CHOL and ANTE models). It may also occur if an <i>identity by unstructured</i> (ID⊗US) error variance model is not specified in a multivariate analysis (including !ASMV), see Chapter 8. If the failure is on the first iteration, the problem is with the starting values. If on a subsequent iteration, the updates have caused the problem. You could try reducing the updates by using the !STEP qualifier. Otherwise, you could try fitting an alternative parameterisation. The CORGH model may be more stable than the US model.
Unable to invert R or G [CORR?] matrix:	generally refers to a problem setting up the mixed model equations. Most commonly, it is caused by a non positive definite matrix.
Variance structure is not positive definite	Use better initial values or a structured variance matrix that is positive definite.
XFA model not permitted in R structures XFA may not be used as an R structure	You may use FA or FACV. The R structure must be positive definite.

Introduction

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15.1 Introduction

In this chapter we present the analysis of a variety of examples. The primary aim is to illustrate the capabilities of ASReml in the context of analysing real data sets. We also discuss the output produced by ASReml and indicate when problems may occur. Statistical concepts and issues are discussed as necessary but we stress that the analyses are illustrative, not prescriptive.

15.2 Split plot design - Oats

The first example involves the analysis of a split plot design originally presented by Yates (1935). The experiment was conducted to assess the effects on yield of three oat varieties (Golden Rain, Marvellous and Victory) with four levels of nitrogen application (0, 0.2, 0.4 and 0.6 cwt/acre). The field layout consisted of six blocks (labelled I, II, III, IV, V and VI) with three whole-plots per block, each split into four sub-plots. The three varieties were randomly allocated to the three whole-plots while the four levels of nitrogen application were randomly assigned to the four sub-plots within each whole-plot. The data is presented in Table 15.1.

Table 15.1 A split-plot field trial of oat varieties and nitrogen application

block	variety	nitrogen			
		0.0cwt	0.2cwt	0.4cwt	0.6cwt
I	Victory	111	130	157	174
	GoldenRain	117	114	161	141
	Marvellous	105	140	118	156
II	Victory	61	91	97	100
	GoldenRain	70	108	126	149
	Marvelous	96	124	121	144
III	Victory	68	64	112	86
	GoldenRain	60	102	89	96
	Marvellous	89	129	132	124
IV	Victory	74	89	81	122
	GoldenRain	64	103	132	133
	Marvelous	70	89	104	117
V	Victory	62	90	100	116
	GoldenRain	80	82	94	126
	Marvellous	63	70	109	99
VI	Victory	53	74	118	113
	GoldenRain	89	82	86	104
	Marvellous	97	99	119	121

A standard analysis of these data recognises the two basic elements inherent in the experiment. These two aspects are firstly the stratification of the experiment units, that is the blocks, whole-plots and sub-plots, and secondly, the treatment

structure that is superimposed on the experimental material. The latter is of prime interest, in the presence of stratification. Thus the aim of the analysis is to examine the importance of the treatment effects while accounting for the stratification and restricted randomisation of the treatments to the experimental units. The ASReml input file is presented below.

```
split plot example
blocks 6 # Coded 1...6 in first data field of oats.asd
nitrogen !A 4 # Coded alphabetically
subplots * # Coded 1...4
variety !A 3 # Coded alphabetically
wplots * # Coded 1...3
yield
oats.asd !SKIP 2

yield ~ mu variety nitrogen variety.nitrogen !r blocks blocks.wplots
predict nitrogen # Print table of predicted nitrogen means
predict variety
predict variety nitrogen !SED
```

The data fields were `blocks`, `wplots`, `subplots`, `variety`, `nitrogen` and `yield`. The first five variables are factors that describe the stratification or experiment design and treatments. The standard split plot analysis is achieved by fitting the model terms `blocks` and `blocks.wplots` as random effects. The `blocks.wplots.subplots` term is not listed in the model because this interaction corresponds to the experimental units and is automatically included as the residual term. The fixed effects include the main effects of both `variety` and `nitrogen` and their interaction. The tables of predicted means and associated standard errors of differences (SEDs) have been requested. These are reported in the `.pvs` file. Abbreviated output is shown below.

Approximate stratum variance decomposition						
Stratum	Degrees-Freedom	Variance	Component	Coefficients		
blocks	5.00	3175.06	12.0	4.0	1.0	
blocks.wplots	10.00	601.331	0.0	4.0	1.0	
Residual Variance	45.00	177.083	0.0	0.0	1.0	

Source	Model	terms	Gamma	Component	Comp/SE	% C
blocks	6	6	1.21116	214.477	1.27	0 P
blocks.wplots	18	18	0.598937	106.062	1.56	0 P
Variance	72	60	1.00000	177.083	4.74	0 P

Analysis of Variance	NumDF	DenDF	F_inc	Prob
7 mu	1	5.0	245.14	<.001
4 variety	2	10.0	1.49	0.272
2 nitrogen	3	45.0	37.69	<.001
8 variety.nitrogen	6	45.0	0.30	0.932

For simple variance component models such as the above, the default parameterisation for the variance component parameters is as the ratio to the residual variance. Thus `ASReml` prints the variance component ratio and variance component for each term in the random model in the columns labelled `Gamma` and `Component` respectively.

The analysis of variance (ANOVA) is printed below this summary. The usual decomposition has three strata, with treatment effects separating into different strata as a consequence of the balanced design and the allocation of `variety` to whole-plots. In this balanced case, it is straightforward to derive the ANOVA estimates of the stratum variances from the REML estimates of the variance components. That is

$$\begin{aligned} \text{blocks stratum variance} &= 12\tilde{\sigma}_b^2 + 4\tilde{\sigma}_w^2 + \tilde{\sigma}^2 = 3175.06 \\ \text{blocks.wplots stratum variance} &= 4\tilde{\sigma}_w^2 + \tilde{\sigma}^2 = 601.331 \\ \text{residual stratum variance} &= \tilde{\sigma}^2 = 177.083 \end{aligned}$$

where $\tilde{\sigma}_b^2$ is the *blocks* variance component, $\tilde{\sigma}_w^2$ is the *blocks.wplots* component and $\tilde{\sigma}^2$ is the *residual* variance.

The default output for testing fixed effects used by `ASReml` is a table of so-called incremental F-statistics. These F-statistics are described in Section 6.12. The statistics are simply the appropriate Wald test statistics divided by the number of estimable effects for that term. In this example there are four terms included in the summary. The overall mean (denoted by `mu`) is of no interest for these data. The tests are sequential, that is the effect of each term is assessed by the change in sums of squares achieved by adding the term to the current model, defined by the model which includes those terms appearing above the current term given the variance parameters. For example, the test of `nitrogen` is calculated from the change in sums of squares for the two models `mu variety nitrogen` and `mu variety`. No refitting occurs, that is the variance parameters are held constant at the REML estimates obtained from the currently specified fixed model.

The incremental Wald statistics have an asymptotic χ^2 distribution, with degrees of freedom (df) given by the number of estimable effects (the number in the `DF` column). In this example, the incremental F-statistics are numerically the same as the ANOVA F-statistics, and `ASReml` has calculated the appropriate denominator df for testing fixed effects. This is a simple problem for balanced designs, such as the split plot design, but it is not straightforward to determine the relevant denominator df in unbalanced designs, such as the rat data set described in the next section.

Tables of predicted means are presented for the nitrogen, variety, and variety by nitrogen tables in the .pvs file. The qualifier !SED has been used on the third predict statement and so the matrix of SEDs for the variety by nitrogen table is printed. For the first two predictions, the average SED is calculated from the average variance of differences. Note also that the order of the predictions (e.g. 0.6_cwt, 0.4_cwt 0.2_cwt 0_cwt for nitrogen) is simply the order those treatment labels were discovered in the data file.

Split plot analysis - oat Variety.Nitrogen 28 Jul 2005 19:28:02

Ecode is E for Estimable, * for Not Estimable

```
----- 1 -----
Predicted values of yield
variety      is averaged over fixed levels
blocks       is ignored in the prediction (except where specifically included
wplots       is ignored in the prediction (except where specifically included

nitrogen      Predicted_Value Standard_Error Ecode
0.6_cwt       123.3889          7.1747 E
0.4_cwt       114.2222          7.1747 E
0.2_cwt       98.8889           7.1747 E
0_cwt         79.3889           7.1747 E
SED: Overall Standard Error of Difference  4.436
```

```
----- 2 -----
Predicted values of yield
nitrogen      is averaged over fixed levels
blocks       is ignored in the prediction (except where specifically included
wplots       is ignored in the prediction (except where specifically included

variety      Predicted_Value Standard_Error Ecode
Marvellous   109.7917          7.7975 E
Victory      97.6250           7.7975 E
Golden_rain  104.5000          7.7975 E
SED: Overall Standard Error of Difference  7.079
```

```
----- 3 -----
Predicted values of yield
blocks       is ignored in the prediction (except where specifically included
wplots       is ignored in the prediction (except where specifically included

nitrogen      variety      Predicted_Value Standard_Error Ecode
0.6_cwt       Marvellous   126.8333          9.1070 E
0.6_cwt       Victory      118.5000          9.1070 E
0.6_cwt       Golden_rain  124.8333          9.1070 E
0.4_cwt       Marvellous   117.1667          9.1070 E
0.4_cwt       Victory      110.8333          9.1070 E
0.4_cwt       Golden_rain  114.6667          9.1070 E
```

0.2_cwt	Marvellous	108.5000	9.1070 E
0.2_cwt	Victory	89.6667	9.1070 E
0.2_cwt	Golden_rain	98.5000	9.1070 E
0_cwt	Marvellous	86.6667	9.1070 E
0_cwt	Victory	71.5000	9.1070 E
0_cwt	Golden_rain	80.0000	9.1070 E

Predicted values with SED(PV)

126.833				
118.500	9.71503			
124.833	9.71503	9.71503		
117.167	7.68295	9.71503	9.71503	
110.833	9.71503	7.68295	9.71503	9.71503
114.667	9.71503	9.71503	7.68295	9.71503
9.71503				
108.500	7.68295	9.71503	9.71503	7.68295
9.71503	9.71503			
89.6667	9.71503	7.68295	9.71503	9.71503
7.68295	9.71503	9.71503		
98.5000	9.71503	9.71503	7.68295	9.71503
9.71503	7.68295	9.71503	9.71503	
86.6667	7.68295	9.71503	9.71503	7.68295
9.71503	9.71503	7.68295	9.71503	9.71503
71.5000	9.71503	7.68295	9.71503	9.71503
7.68295	9.71503	9.71503	7.68295	9.71503
9.71503				
80.0000	9.71503	9.71503	7.68295	9.71503
9.71503	7.68295	9.71503	9.71503	7.68295
9.71503	9.71503			

SED: Standard Error of Difference: Min 7.6830 Mean 9.1608 Max 9.7150

15.3 Unbalanced nested design - Rats

The second example we consider is a data set which illustrates some further aspects of testing fixed effects in linear mixed models. This example differs from the split plot example, as it is unbalanced and so more care is required in assessing the significance of fixed effects.

The experiment was reported by Dempster *et al.* (1984) and was designed to compare the effect of three doses of an experimental compound (control, low and high) on the maternal performance of rats. Thirty female rats (**dams**) were randomly split into three groups of 10 and each group randomly assigned to the three different doses. All pups in each litter were weighed. The litters differed in total size and in the numbers of males and females. Thus the additional covariate, **littersize** was included in the analysis. The differential effect of the compound

on male and female pups was also of interest. Three litters had to be dropped from experiment, which meant that one dose had only 7 dams. The analysis must account for the presence of between dam variation, but must also recognise the stratification of the experimental units (pups within litters) and that doses and littersize belong to the dam stratum. Table 15.2 presents an indicative AOV decomposition for this experiment.

Table 15.2 Rat data: AOV decomposition

stratum	decomposition	type	df or ne
constant dams	1	F	1
	dose	F	2
	littersize	F	1
	dam	R	27
dams.pups	sex	F	1
	dose.sex	F	2
	error	R	

The dose and littersize effects are tested against the residual dam variation, while the remaining effects are tested against the residual within litter variation. The ASReml input to achieve this analysis is presented below.

```
Rats example
dose 3 !A
sex 2 !A
littersize
dam 27
pup 18
weight
rats.asd !DOPATH 1 # Change DOPATH argument to select each PATH
!PATH 1
weight ~ mu littersize dose sex dose.sex !r dam
!PATH 2
weight ~ mu out(66) littersize dose sex dose.sex !r dam
!PATH 3
weight ~ mu littersize dose sex !r dam
!PATH 4
weight ~ mu littersize dose sex
```

The input file contains an example of the use of the !DOPATH qualifier. Its argument specifies which part to execute. We will discuss the models in the two parts. It also includes the !FCON qualifier to request conditional F-statistics. Abbreviated output from part 1 is presented below.

```

1 LogL= 74.2174      S2= 0.19670      315 df    0.1000      1.000
2 LogL= 79.1579      S2= 0.18751      315 df    0.1488      1.000
3 LogL= 83.9408      S2= 0.17755      315 df    0.2446      1.000
4 LogL= 86.8093      S2= 0.16903      315 df    0.4254      1.000
5 LogL= 87.2249      S2= 0.16594      315 df    0.5521      1.000
6 LogL= 87.2398      S2= 0.16532      315 df    0.5854      1.000
7 LogL= 87.2398      S2= 0.16530      315 df    0.5867      1.000
8 LogL= 87.2398      S2= 0.16530      315 df    0.5867      1.000
Final parameter values                0.58667      1.0000

          Approximate stratum variance decomposition
Stratum   Degrees-Freedom   Variance   Component Coefficients
dam                22.56    1.27762      11.5    1.0
Residual Variance  292.44    0.165300     0.0    1.0

Source                Model terms      Gamma      Component   Comp/SE   % C
dam                    27      27  0.586674      0.969770E-01  2.92  0 P
Variance                322     315  1.00000      0.165300      12.09  0 P

Analysis of Variance                NumDF      DenDF_con F_inc      F_con M   P_con
7 mu                                1          32.0  9049.48  1099.20 b <.001

3 littersize                        1          31.5   27.99   46.25 B <.001
1 dose                               2          23.9   12.15   11.51 A <.001
2 sex                                1          299.8   57.96   57.96 A <.001
8 dose.sex                           2          302.1    0.40    0.40 B 0.673
Notice: The DenDF values are calculated ignoring fixed/boundary/singular
        variance parameters using algebraic derivatives.
4 dam                                27 effects fitted
SLOPES FOR LOG(ABS(RES)) on LOG(PV) for Section 1
2.27
3 possible outliers: see .res file

```

The iterative sequence has converged and the variance component parameter for **dam** hasn't changed for the last three iterations. The incremental Wald tests indicate that the interaction between **dose** and **sex** is not significant. The **F_con** column helps us to assess the significance of the other terms in the model. It confirms **littersize** is significant after the other terms, that **dose** is significant when adjusted for **littersize** and **sex** but ignoring **dose.sex**, and that **sex** is significant when adjusted for **littersize** and **dose** but ignoring **dose.sex**. These tests respect marginality to the **dose.sex** interaction.

We also note the comment 3 possible outliers: see `.res` file. Checking the `.res` file, we discover unit 66 has a standardised residual of -8.80 (see Figure 15.1). The weight of this female rat, within litter 9 is only 3.68, compared to weights of 7.26 and 6.58 for two other female sibling pups. This weight appears erroneous, but without knowledge of the actual experiment we retain the observation in the following. However, part 2 shows one way of 'dropping' unit 66 by fitting an effect for it with `out(66)`.

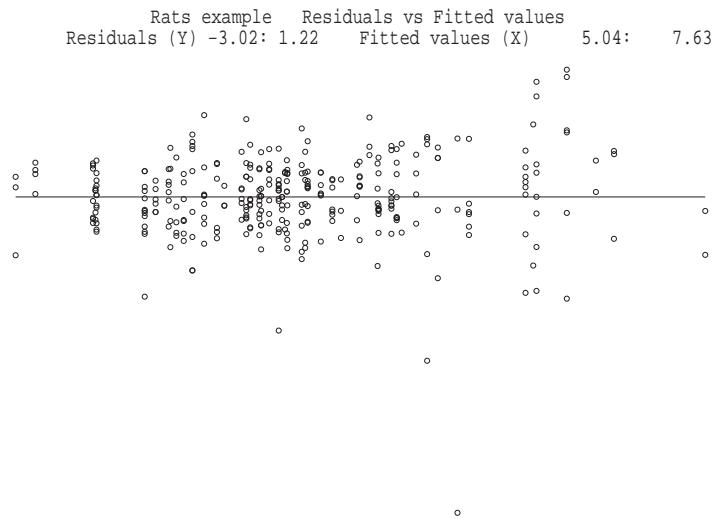


Figure 15.1 Residual plot for the rat data

We refit the model without the `dose.sex` term. Note that the variance parameters are re-estimated, though there is little change from the previous analysis.

Source	Model	terms	Gamma	Component	Comp/SE	% C
dam	27	27	0.595157	0.979179E-01	2.93	0 P
Variance	322	317	1.00000	0.164524	12.13	0 P

Analysis of Variance			NumDF	DenDF_con	F_inc	F_con	M	P_con
7	mu		1	32.0	8981.48	1093.05	.	<.001
3	littersize		1	31.4	27.85	46.43	A	<.001
1	dose		2	24.0	12.05	11.42	A	<.001
2	sex		1	301.7	58.27	58.27	A	<.001

Part 4 shows what happens if we (wrongly) drop `dam` from this model. Even if a random term is not 'significant', it should not be dropped from the model if it represents a strata of the design as in this case.

Source	Model	terms	Gamma	Component	Comp/SE	% C
Variance	322	317	1.00000	0.253182	12.59	0 P

Analysis of Variance	NumDF	DenDF_con	F_inc	F_con	M	P_con
7 mu	1	317.0	47077.31	3309.42	.	<.001
3 littersize	1	317.0	68.48	146.50	A	<.001
1 dose	2	317.0	60.99	58.43	A	<.001
2 sex	1	317.0	24.52	24.52	A	<.001

15.4 Source of variability in unbalanced data - Volts

In this example we illustrate an analysis of unbalanced data in which the main aim is to determine the sources of variation rather than assess the significance of imposed treatments. The data are taken from Cox and Snell (1981) and involve an experiment to examine the variability in the production of car voltage regulators. Standard production of regulators involves two steps. Regulators are taken from the production line to a setting station and adjusted to operate within a specified voltage range. From the setting station the regulator is then passed to a testing station where it is tested and returned if outside the required range.

The voltage of 64 regulators was set at 10 setting stations (`setstat`); between 4 and 8 regulators were set at each station. The regulators were each tested at four testing stations (`teststat`). The ASReml input file is presented below.

```
Voltage data
teststat 4 # 4 testing stations tested each regulator
setstat !A # 10 setting stations each set 4-8 regulators
regulatr 8 # regulators numbered within setting stations
voltage
voltage.asd !skip 1
voltage ~ mu !r setstat setstat.regulatr teststat setstat.teststat
0 0 0
```

The factor `regulatr` numbers the regulators within each setting station. Thus the term `setstat.regulatr` allows for differential effects of each regulator, while the other terms examine the effects of the setting and testing stations and possible interaction. The abbreviated output is given below

```
LogL= 188.604      S2= 0.67074E-01      255 df
LogL= 199.530      S2= 0.59303E-01      255 df
```



```

LogL= 203.007      S2= 0.52814E-01      255 df
LogL= 203.240      S2= 0.51278E-01      255 df
LogL= 203.242      S2= 0.51141E-01      255 df
LogL= 203.242      S2= 0.51140E-01      255 df

Source           Model  terms      Gamma      Component    Comp/SE    % C
setstat          10    10  0.233418    0.119371E-01  1.35    0 P
setstat.regulatr 80    64  0.601817    0.307771E-01  3.64    0 P
teststat         4     4  0.642752E-01 0.328706E-02  0.98    0 P
setstat.teststat 40    40  0.100000E-08 0.511404E-10  0.00    0 B
Variance         256   255  1.00000     0.511404E-01  9.72    0 P
Warning: Code B - fixed at a boundary (!GP)      F - fixed by user
? - liable to change from P to B      P - positive definite
C - Constrained by user (!VCC)        U - unbounded
S - Singular Information matrix

```

The convergence criteria has been satisfied after six iterations. A warning message is printed below the summary of the variance components because the variance component for the `setstat.teststat` term has been fixed near the boundary. The default constraint for variance components (!GP) is to ensure that the REML estimate remains positive. Under this constraint, if an update for any variance component results in a negative value then ASReml sets that variance component to a small positive value. If this occurs in subsequent iterations the parameter is fixed to a small positive value and the code B replaces P in the C column of the summary table. The default constraint can be overridden using the !GU qualifier, but it is not generally recommended for standard analyses.

Figure 15.2 presents the residual plot which indicates two unusual data values. These values are successive observations, namely observation 210 and 211, being testing stations 2 and 3 for setting station 9(*J*), regulator 2. These observations will not be dropped from the following analyses for consistency with other analyses conducted by Cox and Snell (1981) and in the GENSTAT manual.

The REML log-likelihood from the model without the `setstat.teststat` term was 203.242, the same as the REML log-likelihood for the previous model. Table 15.3 presents a summary of the REML log-likelihood ratio for the remaining terms in the model. The summary of the ASReml output for the current model is given below. The column labelled `Comp/SE` is printed by ASReml to give a guide as to the significance of the variance component for each term in the model. The statistic is simply the REML estimate of the variance component divided by the square root of the diagonal element (for each component) of the inverse of the average information matrix. The diagonal elements of the expected (not the average) information matrix are the asymptotic variances of the REML estimates

ltage example 5-3-6 from the GENSTAT REML manual Residuals vs Fitted valu
 Residuals (Y) -1.08: 1.45 Fitted values (X) 15.56: 16.81

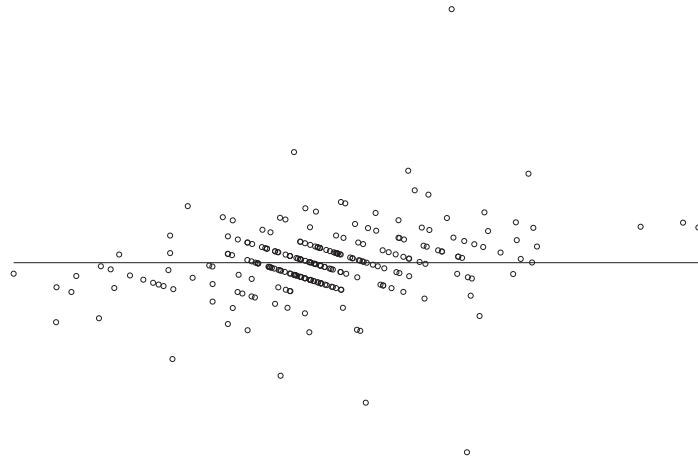


Figure 15.2 Residual plot for the voltage data

of the variance parameters. These **Comp/SE** statistics cannot be used to test the null hypothesis that the variance component is zero. If we had used this crude measure then the conclusions would have been inconsistent with the conclusions obtained from the REML log-likelihood ratio (see Table 15.3).

Source	Model	terms	Gamma	Component	Comp/SE	% C
setstat	10	10	0.233417	0.119370E-01	1.35	0 P
setstat.regulatr	80	64	0.601817	0.307771E-01	3.64	0 P
teststat	4	4	0.642752E-01	0.328705E-02	0.98	0 P
Variance	256	255	1.00000	0.511402E-01	9.72	0 P

Table 15.3: REML log-likelihood ratio for the variance components in the voltage data

terms	REML log-likelihood	$-2 \times$ difference	P-value
– setstat	200.31	5.864	.0077
– setstat.regulatr	184.15	38.19	.0000
– teststat	199.71	7.064	.0039

15.5 Balanced repeated measures - Height

The data for this example is taken from the GENSTAT manual. It consists of a total of 5 measurements of height (cm) taken on 14 plants. The 14 plants were either diseased or healthy and were arranged in a glasshouse in a completely random design. The heights were measured 1, 3, 5, 7 and 10 weeks after the plants were placed in the glasshouse. There were 7 plants in each treatment. The data are depicted in Figure 15.3 obtained by qualifier line

```
!Y y1 !G tmt !JOIN
```

in the following multivariate ASReml job.

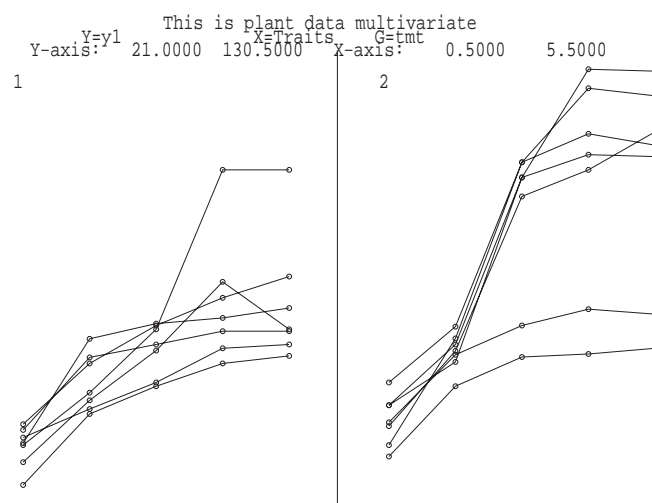


Figure 15.3 Trellis plot of the height for each of 14 plants

In the following we illustrate how various repeated measures analyses can be conducted in ASReml. For these analyses it is convenient to arrange the data in a multivariate form, with 7 fields representing the plant number, treatment identification and the 5 heights. The ASReml input file, up to the specification of the *R* structure is

```
This is plant data multivariate
tmt !A # Diseased Healthy
plant 14
y1 y3 y5 y7 y10
grass.asd !skip 1 !ASUV
```

The focus is modelling of the error variance for the data. Specifically we fit the multivariate regression model given by

$$\mathbf{Y} = \mathbf{D}\mathbf{T} + \mathbf{E} \quad (15.1)$$

where $\mathbf{Y}^{14 \times 5}$ is the matrix of heights, $\mathbf{D}^{14 \times 2}$ is the design matrix, $\mathbf{T}^{2 \times 5}$ is the matrix of fixed effects and $\mathbf{E}^{14 \times 5}$ is the matrix of errors. The heights taken on the same plants will be correlated and so we assume that

$$\text{var}(\text{vec}(\mathbf{E})) = \mathbf{I}_{14} \otimes \boldsymbol{\Sigma} \quad (15.2)$$

where $\boldsymbol{\Sigma}^{5 \times 5}$ is a symmetric positive definite matrix.

The variance models used for $\boldsymbol{\Sigma}$ are given in Table 15.4. These represent some commonly used models for the analysis of repeated measures data (see Wolfinger, 1986). The variance models are fitted by changing the last four lines of the input file. The sequence of commands for the first model fitted is

```
y1 y3 y5 y7 y10 ~ Trait tmt Tr.tmt !r units
1 2 0
14
Trait
```

Table 15.4 Summary of variance models fitted to the plant data

model	number of parameters	REML log-likelihood	BIC
Uniform	2	-196.88	401.95
Power	2	-182.98	374.15
Heterogeneous Power	6	-171.50	367.57
Antedependence (order 1)	9	-160.37	357.51
Unstructured	15	-158.04	377.50

The split plot in time model can be fitted in two ways, either by fitting a `units` term plus an independent residual as above, or by specifying a `CORU` variance model for the R -structure as follows

```
y1 y3 y5 y7 y10 ~ Trait tmt Tr.tmt
1 2 0
14
Trait 0 CORU .5
```

The two forms for Σ are given by

$$\begin{aligned}\Sigma &= \sigma_1^2 \mathbf{J} + \sigma_2^2 \mathbf{I}, & \text{units} \\ \Sigma &= \sigma_e^2 \mathbf{I} + \sigma_e^2 \rho (\mathbf{J} - \mathbf{I}), & \text{CORU}\end{aligned}\quad (15.3)$$

It follows that

$$\begin{aligned}\sigma_e^2 &= \sigma_1^2 + \sigma_2^2 \\ \rho &= \frac{\sigma_1^2}{\sigma_1^2 + \sigma_2^2}\end{aligned}\quad (15.4)$$

Portions of the two outputs are given below. The REML log-likelihoods for the two models are the same and it is easy to verify that the REML estimates of the variance parameters satisfy (15.4), viz. $\sigma_e^2 = 286.310 \approx 159.858 + 126.528 = 286.386$; $159.858/286.386 = 0.558191$.

```
#
# !r units
#
LogL=-204.593      S2= 224.61          60 df   0.1000      1.000
LogL=-201.233      S2= 186.52          60 df   0.2339      1.000
LogL=-198.453      S2= 155.09          60 df   0.4870      1.000
LogL=-197.041      S2= 133.85          60 df   0.9339      1.000
LogL=-196.881      S2= 127.56          60 df   1.204       1.000
LogL=-196.877      S2= 126.53          60 df   1.261       1.000
Final parameter values                1.2634      1.0000

Source          Model terms      Gamma      Component      Comp/SE      % C
units           14      14      1.26342      159.858      2.11      0 P
Variance        70      60      1.00000      126.528      4.90      0 P
#
# CORU
#
LogL=-196.975      S2= 264.10          60 df   1.000       0.5000
LogL=-196.924      S2= 270.14          60 df   1.000       0.5178
LogL=-196.886      S2= 278.58          60 df   1.000       0.5400
LogL=-196.877      S2= 286.23          60 df   1.000       0.5580
LogL=-196.877      S2= 286.31          60 df   1.000       0.5582
Final parameter values                1.0000      0.55819

Source          Model terms      Gamma      Component      Comp/SE      % C
Variance        70      60      1.00000      286.310      3.65      0 P
Residual        CORRelat      5      0.558191      0.558191      4.28      0 U
```

A more realistic model for repeated measures data would allow the correlations to decrease as the lag increases such as occurs with the first order autoregressive model. However, since the heights are not measured at equally spaced time points we use the EXP model. The correlation function is given by

$$\rho(u) = \phi^u$$

where u is the time lag in weeks. The coding for this is

```

y1 y3 y5 y7 y10 ~ Trait tmt Tr.tmt
1 2 0          # One error structure in two dimensions
14            # Outer dimension: 14 plants
Tr 0 EXP .5
1 3 5 7 10    # Time coordinates

```

A portion of the output is

```

LogL=-183.734      S2= 435.58          60 df    1.000    0.9500
LogL=-183.255      S2= 370.40          60 df    1.000    0.9388
LogL=-183.010      S2= 321.50          60 df    1.000    0.9260
LogL=-182.980      S2= 298.84          60 df    1.000    0.9179
LogL=-182.979      S2= 302.02          60 df    1.000    0.9192
Final parameter values                                1.0000    0.91897

```

Source	Model	terms	Gamma	Component	Comp/SE	% C
Variance	70	60	1.00000	302.021	3.11	0 P
Residual	POW-EXP	5	0.918971	0.918971	29.53	0 U

When fitting power models be careful to ensure the scale of the defining variate, here *time*, does not result in an estimate of ϕ too close to 1. For example, use of days in this example would result in an estimate for ϕ of about .993.

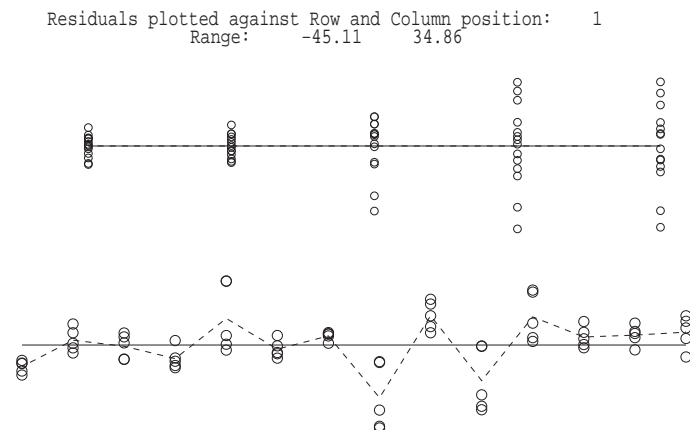


Figure 15.4 Residual plots for the EXP variance model for the plant data

The residual plot from this analysis is presented in Figure 15.4. This suggests increasing variance over time. This can be modelled by using the EXPH model,

which models Σ by

$$\Sigma = D^{0.5}CD^{0.5}$$

where D is a diagonal matrix of variances and C is a correlation matrix with elements given by $c_{ij} = \phi^{|t_i - t_j|}$. The coding for this is

```
y1 y3 y5 y7 y10 ~ Trait tmt Tr.tmt
1 2 0
14 !S2==1
Tr 0 EXPH .5 100 200 300 300 300
1 3 5 7 10
```

Note that it is necessary to fix the scale parameter to 1 (!S2==1) to ensure that the elements of D are identifiable. Abbreviated output from this analysis is

```
1 LogL=-195.598      S2=  1.0000      60 df      :  1 components constrained
2 LogL=-179.036      S2=  1.0000      60 df
3 LogL=-175.483      S2=  1.0000      60 df
4 LogL=-173.128      S2=  1.0000      60 df
5 LogL=-171.980      S2=  1.0000      60 df
6 LogL=-171.615      S2=  1.0000      60 df
7 LogL=-171.527      S2=  1.0000      60 df
8 LogL=-171.504      S2=  1.0000      60 df
9 LogL=-171.498      S2=  1.0000      60 df
10 LogL=-171.496     S2=  1.0000      60 df
```

Source	Model	terms	Gamma	Component	Comp/SE	% C
Residual	POW-EXP	5	0.906917	0.906917	21.89	0 U
Residual	POW-EXP	5	60.9599	60.9599	2.12	0 U
Residual	POW-EXP	5	72.9904	72.9904	1.99	0 U
Residual	POW-EXP	5	309.259	309.259	2.22	0 U
Residual	POW-EXP	5	436.380	436.380	2.52	0 U
Residual	POW-EXP	5	382.369	382.369	2.74	0 U

Covariance/Variance/Correlation Matrix POWER

61.11	0.8227	0.6769	0.5569	0.4156
54.88	72.80	0.8227	0.6769	0.5051
93.12	123.5	309.7	0.8227	0.6140
91.02	120.7	302.7	437.1	0.7462
63.57	84.34	211.4	305.3	382.9

Analysis of Variance	DF	F_inc
8 Trait	5	127.95
1 tmt	1	0.00
9 Tr.tmt	4	4.75

The last two models we fit are the antedependence model of order 1 and the unstructured model. These require, as starting values the lower triangle of the full variance matrix. We use the REML estimate of Σ from the heterogeneous

power model shown in the previous output. The antedependence model models Σ by the inverse cholesky decomposition

$$\Sigma^{-1} = UDU'$$

where D is a diagonal matrix and U is a unit upper triangular matrix. For an antedependence model of order q , then $u_{ij} = 0$ for $j > i + q - 1$. The antedependence model of order 1 has 9 parameters for these data, 5 in D and 4 in U . The input is given by

```
y1 y3 y5 y7 y10 ~ Trait tmt Tr.tmt
1 2 0
14 !S2==1
Tr 0 ANTE
  60.16
  54.65      73.65
  91.50      123.3      306.4
  89.17      120.2      298.6      431.8
  62.21      83.85      208.3      301.2      379.8
```

The abbreviated output file is

```
1 LogL=-171.501      S2=  1.0000      60 df
2 LogL=-170.097      S2=  1.0000      60 df
3 LogL=-166.085      S2=  1.0000      60 df
4 LogL=-161.335      S2=  1.0000      60 df
5 LogL=-160.407      S2=  1.0000      60 df
6 LogL=-160.370      S2=  1.0000      60 df
7 LogL=-160.369      S2=  1.0000      60 df

Source      Model terms      Gamma      Component      Comp/SE      % C
Residual ANTE=UDU      1  0.268657E-01  0.268657E-01  2.44  0 U
Residual ANTE=UDU      1 -0.628413      -0.628413      -2.55  0 U
Residual ANTE=UDU      2  0.372801E-01  0.372801E-01  2.41  0 U
Residual ANTE=UDU      2 -1.49108      -1.49108      -2.54  0 U
Residual ANTE=UDU      3  0.599632E-02  0.599632E-02  2.43  0 U
Residual ANTE=UDU      3 -1.28041      -1.28041      -6.19  0 U
Residual ANTE=UDU      4  0.789713E-02  0.789713E-02  2.44  0 U
Residual ANTE=UDU      4 -0.967815      -0.967815      -15.40  0 U
Residual ANTE=UDU      5  0.390635E-01  0.390635E-01  2.45  0 U
Covariance/Variance/Correlation Matrix ANTE=UDU'
  37.20      0.5946      0.3549      0.3114      0.3040
  23.38      41.55      0.5968      0.5237      0.5112
  34.83      61.89      258.9      0.8775      0.8565
  44.58      79.22      331.4      550.8      0.9761
  43.14      76.67      320.7      533.0      541.4

Analysis of Variance      DF      F_inc
  8 Trait      5      188.84
```



```

1 tmt 1 4.14
9 Tr.tmt 4 3.91

```

The iterative sequence converged and the antedependence parameter estimates are printed columnwise by time, the column of U and the element of D . I.e.

$$D = \text{diag} \begin{bmatrix} 0.0269 \\ 0.0373 \\ 0.0060 \\ 0.0079 \\ 0.0391 \end{bmatrix}, U = \begin{bmatrix} 1 & -0.6284 & 0 & 0 & 0 \\ 0 & 1 & -1.4911 & 0 & 0 \\ 0 & 0 & 1 & -1.2804 & 0 \\ 0 & 0 & 0 & 1 & -0.9678 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}.$$

Finally the input and output files for the unstructured model are presented below. The REML estimate of Σ from the ANTE model is used to provide starting values.

```

#####
#input
#####
y1 y3 y5 y7 y10 ~ Trait tmt Tr.tmt
1 2 0
14 !S2==1
Tr 0 US
  37.20
  23.38    41.55
  34.83    61.89    258.9
  44.58    79.22    331.4    550.8
  43.14    76.67    320.7    533.0    541.4
#####
# output
#####
1 LogL=-160.368    S2= 1.0000    60 df
2 LogL=-159.027    S2= 1.0000    60 df
3 LogL=-158.247    S2= 1.0000    60 df
4 LogL=-158.040    S2= 1.0000    60 df
5 LogL=-158.036    S2= 1.0000    60 df

Source    Model    terms    Gamma    Component    Comp/SE    % C
Residual US=UnStr    1    37.2262    37.2262    2.45    0 U
Residual US=UnStr    1    23.3935    23.3935    1.77    0 U
Residual US=UnStr    2    41.5195    41.5195    2.45    0 U
Residual US=UnStr    1    51.6524    51.6524    1.61    0 U
Residual US=UnStr    2    61.9169    61.9169    1.78    0 U
Residual US=UnStr    3    259.121    259.121    2.45    0 U
Residual US=UnStr    1    70.8113    70.8113    1.54    0 U

```

```

Residual US=UnStr      2  57.6146      57.6146      1.23  0 U
Residual US=UnStr      3  331.807      331.807      2.29  0 U
Residual US=UnStr      4  551.507      551.507      2.45  0 U
Residual US=UnStr      1  73.7857      73.7857      1.60  0 U
Residual US=UnStr      2  62.5691      62.5691      1.33  0 U
Residual US=UnStr      3  330.851      330.851      2.29  0 U
Residual US=UnStr      4  533.756      533.756      2.42  0 U
Residual US=UnStr      5  542.175      542.175      2.45  0 U
Covariance/Variance/Correlation Matrix US=UnStructu
 37.23    0.5950    0.5259    0.4942    0.5194
 23.39    41.52    0.5969    0.3807    0.4170
 51.65    61.92    259.1     0.8777    0.8827
 70.81    57.61    331.8     551.5     0.9761
 73.79    62.57    330.9     533.8     542.2

```

The antedependence model of order 1 is clearly more parsimonious than the unstructured model. Table 15.5 presents the incremental Wald tests for each of the variance models. There is a surprising level of discrepancy between models for the Wald tests. The main effect of treatment is significant for the uniform, power and antedependence models.

Table 15.5: Summary of Wald test for fixed effects for variance models fitted to the plant data

model	treatment (df=1)	treatment.time (df=4)
Uniform	9.41	5.10
Power	6.86	6.13
Heterogeneous power	0.00	4.81
Antedependence (order 1)	4.14	3.96
Unstructured	1.71	4.46

15.6 Spatial analysis of a field experiment - Barley

In this section we illustrate the ASReml syntax for performing spatial and incomplete block analysis of a field experiment. There has been a large amount of interest in developing techniques for the analysis of spatial data both in the context of field experiments and geostatistical data (see for example, Cullis and Gleeson, 1991; Cressie, 1991; Gilmour *et al.*, 1997). This example illustrates the analysis of 'so-called' regular spatial data, in which the data is observed on a lattice or regular grid. This is typical of most small plot designed field experiments. Spatial data is often irregularly spaced, either by design or because of the observational nature of the study. The techniques we present in the following can be extended for the analysis of irregularly spaced spatial data, though, larger spatial data sets may be computationally challenging, depending on the degree of irregularity or models fitted.

The data we consider is taken from Gilmour *et al.* (1995) and involves a field experiment designed to compare the performance of 25 varieties of barley. The experiment was conducted at Slate Hall Farm, UK in 1976, and was designed as a balanced lattice square with replicates laid out as shown in Table 15.6. The data fields were `Rep`, `RowBlk`, `ColBlk`, `row`, `column` and `yield`. Lattice row and column numbering is typically within replicates and so the terms specified in the linear model to account for the lattice row and lattice column effects would be `Rep.latticerow` `Rep.latticecolumn`. However, in this example lattice rows and columns are both numbered from 1 to 30 across replicates (see Table 15.6). The terms in the linear model are therefore simply `RowBlk` `ColBlk`. Additional fields `row` and `column` indicate the spatial layout of the plots.

The ASReml input file is presented below. Three models have been fitted to these data. The lattice analysis is included for comparison in `PATH 3`. In `PATH 1` we use the separable first order autoregressive model to model the variance structure of the plot errors. Gilmour *et al.* (1997) suggest this is often a useful model to commence the spatial modelling process. The form of the variance matrix for the plot errors (R structure) is given by

$$\sigma^2 \Sigma = \sigma^2 (\Sigma_c \otimes \Sigma_r) \quad (15.5)$$

where Σ_c and Σ_r are 15×15 and 10×10 matrix functions of the column (ϕ_c) and row (ϕ_r) autoregressive parameters respectively.

Gilmour *et al.* (1997) recommend revision of the current spatial model based on the use of diagnostics such as the sample variogram of the residuals (from

the current model). This diagnostic and a summary of row and column residual trends are produced by default with graphical versions of ASReml when a spatial model has been fitted to the errors. It can be suppressed, by the use of the `-n` option on the command line. We have produced the following plots by use of the `-g22` option.

Table 15.6 Field layout of Slate Hall Farm experiment

Column - Replicate levels															
Row	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	1	1	1	1	2	2	2	2	2	3	3	3	3	3
2	1	1	1	1	1	2	2	2	2	2	3	3	3	3	3
3	1	1	1	1	1	2	2	2	2	2	3	3	3	3	3
4	1	1	1	1	1	2	2	2	2	2	3	3	3	3	3
5	1	1	1	1	1	2	2	2	2	2	3	3	3	3	3
6	4	4	4	4	4	5	5	5	5	5	6	6	6	6	6
7	4	4	4	4	4	5	5	5	5	5	6	6	6	6	6
8	4	4	4	4	4	5	5	5	5	5	6	6	6	6	6
9	4	4	4	4	4	5	5	5	5	5	6	6	6	6	6
10	4	4	4	4	4	5	5	5	5	5	6	6	6	6	6
Column - Rowblk levels															
Row	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	1	1	1	1	11	11	11	11	11	21	21	21	21	21
2	2	2	2	2	2	12	12	12	12	12	22	22	22	22	22
3	3	3	3	3	3	13	13	13	13	13	23	23	23	23	23
4	4	4	4	4	4	14	14	14	14	14	24	24	24	24	24
5	5	5	5	5	5	15	15	15	15	15	25	25	25	25	25
6	6	6	6	6	6	16	16	16	16	16	26	26	26	26	26
7	7	7	7	7	7	17	17	17	17	17	27	27	27	27	27
8	8	8	8	8	8	18	18	18	18	18	28	28	28	28	28
9	9	9	9	9	9	19	19	19	19	19	29	29	29	29	29
10	10	10	10	10	10	20	20	20	20	20	30	30	30	30	30
Column - Colblk levels															
Row	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
3	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
4	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
5	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
6	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
7	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
8	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
9	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
10	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

Slate Hall example

```

Rep 6      # Six replicates of 5x5 plots in 2x3 arrangement
RowBlk 30 # Rows within replicates numbered across replicates
ColBlk 30 # Columns within replicates numbered across replicates
row 10    # Field row
column 15 # Field column

```

```

    variety 25
    yield
barley.asd !skip 1 !DOPATH 1
!PATH 1 # AR1 x AR1
y ~ mu var
predict var
1 2
15 column AR1 0.1 # Second field is specified so ASReml can sort
10 row AR1 0.1 # records properly into field order

!PATH 2 # AR1 x AR1 + units
y ~ mu var !r units
predict var
1 2
15 column AR1 0.1
10 row AR1 0.1

!PATH 3 # incomplete blocks
y ~ mu var !r Rep Rowblk Colblk
predict var

```

Abbreviated ASReml output file is presented below. The iterative sequence has converged to column and row correlation parameters of (.68377,.45859) respectively. The plot size and orientation is not known and so it is not possible to ascertain whether these values are spatially sensible. It is generally found that the closer the plot centroids, the higher the spatial correlation. This is not always the case and if the highest between plot correlation relates to the larger spatial distance then this may suggest the presence of extraneous variation (see Gilmour *et al.*, 1997), for example. Figure 15.5 presents a plot of the sample variogram of the residuals from this model. The plot appears in reasonable agreement with the model.

The next model includes a measurement error or nugget effect component. That is the variance model for the plot errors is now given by

$$\sigma^2 \Sigma = \sigma^2 (\Sigma_c \otimes \Sigma_r) + \psi \mathbf{I}_{150} \quad (15.6)$$

where ψ is the ratio of nugget variance to error variance (σ^2). The abbreviated output for this model is given below. There is a significant improvement in the REML log-likelihood with the inclusion of the nugget effect (see Table 15.7).

```

# AR1 x AR1
#
    1 LogL=-739.681      S2= 36034.      125 df      1.000      0.1000      0.1000

```

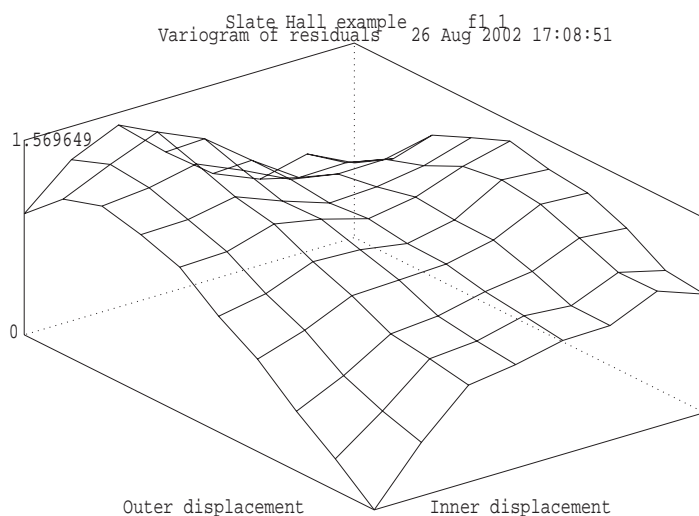


Figure 15.5: Sample variogram of the residuals from the $AR1 \times AR1$ model for the Slate Hall data

2	LogL=-714.340	S2= 28109.	125 df	1.000	0.4049	0.1870
3	LogL=-703.338	S2= 29914.	125 df	1.000	0.5737	0.3122
4	LogL=-700.371	S2= 37464.	125 df	1.000	0.6789	0.4320
5	LogL=-700.324	S2= 38602.	125 df	1.000	0.6838	0.4542
6	LogL=-700.322	S2= 38735.	125 df	1.000	0.6838	0.4579
7	LogL=-700.322	S2= 38754.	125 df	1.000	0.6838	0.4585
8	LogL=-700.322	S2= 38757.	125 df	1.000	0.6838	0.4586
Final parameter values				1.0000	0.68377	0.45861

Source	Model terms	Gamma	Component	Comp/SE	% C
Variance	150 125	1.00000	38756.6	5.00	0 P
Residual	AR=AutoR 15	0.683767	0.683767	10.80	0 U
Residual	AR=AutoR 10	0.458607	0.458607	5.55	0 U

Analysis of Variance	NumDF	DenDF	F_inc	Prob
8 mu	1	12.8	850.88	<.001
6 variety	24	80.0	13.04	<.001

# AR1 x AR1 + units					
1	LogL=-740.735	S2= 33225.	125 df	:	2 components constrained
2	LogL=-723.595	S2= 11661.	125 df	:	1 components constrained
3	LogL=-698.498	S2= 46239.	125 df		
4	LogL=-696.847	S2= 44725.	125 df		
5	LogL=-696.823	S2= 45563.	125 df		

```

6 LogL=-696.823      S2= 45753.      125 df
7 LogL=-696.823      S2= 45796.      125 df

Source              Model  terms      Gamma      Component  Comp/SE  % C
units              150   150  0.106154    4861.48    2.72    0 P
Variance           150   125   1.00000    45796.3    2.74    0 P
Residual           AR=AutoR  15  0.843795    0.843795   12.33   0 U
Residual           AR=AutoR  10  0.682686    0.682686    6.68   0 U

Analysis of Variance          NumDF  DenDF  F_inc          Prob
8 mu                          1      3.5   259.81         <.001
6 variety                      24     75.7   10.21         <.001

```

The lattice analysis (with recovery of between block information) is presented below. This variance model is not competitive with the preceding spatial models. The models can be formally compared using the BIC values for example.

```

# IB analysis
1 LogL=-734.184      S2= 26778.      125 df
2 LogL=-720.060      S2= 16591.      125 df
3 LogL=-711.119      S2= 11173.      125 df
4 LogL=-707.937      S2= 8562.4      125 df
5 LogL=-707.786      S2= 8091.2      125 df
6 LogL=-707.786      S2= 8061.8      125 df
7 LogL=-707.786      S2= 8061.8      125 df

Source              Model  terms      Gamma      Component  Comp/SE  % C
Rep                 6      6   0.528714    4262.39    0.62    0 P
RowBlk              30     30   1.93444    15595.1    3.06    0 P
ColBlk              30     30   1.83725    14811.6    3.04    0 P
Variance            150    125   1.00000    8061.81    6.01    0 P

Analysis of Variance          NumDF  DenDF  F_inc          Prob
8 mu                          1      5.0  1216.29         <.001
6 variety                      24     79.3   8.84         <.001

```

Finally, we present portions of the `.pvs` files to illustrate the prediction facility of `ASReml`. The first five and last three variety means are presented for illustration. The overall SED printed is the square root of the average variance of difference between the variety means. The two spatial analyses have a range of SEDs which are available if the `!SED` qualifier is used. All variety comparisons have the same SED from the third analysis as the design is a balanced lattice square. The F-statistic statistics for the spatial models are greater than for the lattice analysis. We note the F-statistic for the `AR1×AR1 + units` model is smaller than the F-statistic for the `AR1×AR1`.

```

Predicted values of yield
#AR1 x AR1
  variety      Predicted_Value Standard_Error Ecode
  1.0000          1257.9763         64.6146 E
  2.0000          1501.4483         64.9783 E
  3.0000          1404.9874         64.6260 E
  4.0000          1412.5674         64.9027 E
  5.0000          1514.4764         65.5889 E
  .
 23.0000          1311.4888         64.0767 E
 24.0000          1586.7840         64.7043 E
 25.0000          1592.0204         63.5939 E
SED: Overall Standard Error of Difference   59.05

#AR1 x AR1 + units
  variety      Predicted_Value Standard_Error Ecode
  1.0000          1245.5843         97.8591 E
  2.0000          1516.2331         97.8473 E
  3.0000          1403.9863         98.2398 E
  4.0000          1404.9202         97.9875 E
  5.0000          1471.6197         98.3607 E
  .
 23.0000          1316.8726         98.0402 E
 24.0000          1557.5278         98.1272 E
 25.0000          1573.8920         97.9803 E
SED: Overall Standard Error of Difference   60.51

# IB
Rep      is ignored in the prediction
RowBlk   is ignored in the prediction
ColBlk   is ignored in the prediction

  variety      Predicted_Value Standard_Error Ecode
  1.0000          1283.5870         60.1994 E
  2.0000          1549.0133         60.1994 E
  3.0000          1420.9307         60.1994 E
  4.0000          1451.8554         60.1994 E
  5.0000          1533.2749         60.1994 E
  .
 23.0000          1329.1088         60.1994 E
 24.0000          1546.4699         60.1994 E
 25.0000          1630.6285         60.1994 E
SED: Overall Standard Error of Difference   62.02

```

Notice the differences in SE and SED associated with the various models. Choosing a model on the basis of smallest SE or SED is not recommended because the model is not necessarily fitting the variability present in the data.

Table 15.7 Summary of models for the Slate Hall data

model	REML log-likelihood	number of parameters	F-statistic	SED
AR1×AR1	-700.32	3	13.04	59.0
AR1×AR1 + units	-696.82	4	10.22	60.5
IB	-707.79	4	8.84	62.0

15.7 Unreplicated early generation variety trial - Wheat

To further illustrate the approaches presented in the previous section, we consider an unreplicated field experiment conducted at Tullibigeal situated in southwestern NSW. The trial was an S1 (early stage) wheat variety evaluation trial and consisted of 525 test lines which were randomly assigned to plots in a 67 by 10 array. There was a check plot variety every 6 plots within each column. That is the check variety was sown on rows 1,7,13,...,67 of each column. This variety was numbered 526. A further 6 replicated commercially available varieties (numbered 527 to 532) were also randomly assigned to plots with between 3 to 5 plots of each. The aim of these trials is to identify and retain the top, say 20% of lines for further testing. Cullis *et al.* (1989) considered the analysis of early generation variety trials, and presented a one-dimensional spatial analysis which was an extension of the approach developed by Gleeson and Cullis (1987). The test line effects are assumed random, while the check variety effects are considered fixed. This may not be sensible or justifiable for most trials and can lead to inconsistent comparisons between check varieties and test lines. Given the large amount of replication afforded to check varieties there will be very little shrinkage irrespective of the realised heritability.

We consider an initial analysis with spatial correlation in one direction and fitting the variety effects (check, replicated and unreplicated lines) as random. We present three further spatial models for comparison. The ASReml input file is

```
Tullibigeal trial
  linenum
  yield
  weed
  column 10
  row 67
  variety 532 # testlines 1:525, check lines 526:532
```

```

wheat.asd !skip 1 !DOPATH 1
!PATH 1 # AR1 x I
y ~ mu weed mv !r variety
1 2
67 row AR1 0.1
10 column I 0

!PATH 2 # AR1 x AR1
y ~ mu weed mv !r variety
1 2
67 row AR1 0.1
10 column AR1 0.1

!PATH 3 # AR1 x AR1 + column trend
y ~ mu weed pol(column,-1) mv !r variety
1 2
67 row AR1 0.1
10 column AR1 0.1

!PATH 4 # AR1 x AR1 + Nugget + column trend
y ~ mu weed pol(column,-1) mv !r variety units
1 2
67 row AR1 0.1
10 column AR1 0.1
predict var

```

The data fields represent the factors `variety`, `row` and `column`, a covariate `weed` and the plot yield (`yield`). There are three paths in the `ASReml` file. We begin with the one-dimensional spatial model, which assumes the variance model for the plot effects within columns is described by a first order autoregressive process. The abbreviated output file is

1	LogL=-4280.75	S2= 0.12850E+06	666 df	0.1000	1.000	0.1000
2	LogL=-4268.57	S2= 0.12138E+06	666 df	0.1516	1.000	0.1798
3	LogL=-4255.89	S2= 0.10968E+06	666 df	0.2977	1.000	0.2980
4	LogL=-4243.76	S2= 88033.	666 df	0.7398	1.000	0.4939
5	LogL=-4240.59	S2= 84420.	666 df	0.9125	1.000	0.6016
6	LogL=-4240.01	S2= 85617.	666 df	0.9344	1.000	0.6428
7	LogL=-4239.91	S2= 86032.	666 df	0.9474	1.000	0.6596
8	LogL=-4239.88	S2= 86189.	666 df	0.9540	1.000	0.6668
9	LogL=-4239.88	S2= 86253.	666 df	0.9571	1.000	0.6700
10	LogL=-4239.88	S2= 86280.	666 df	0.9585	1.000	0.6714
Final parameter values				0.95918	1.0000	0.67205
Source	Model	terms	Gamma	Component	Comp/SE	% C
variety	532	532	0.959184	82758.6	8.98	0 P
Variance	670	666	1.00000	86280.2	9.12	0 P
Residual	AR=AutoR	67	0.672052	0.672052	16.04	1 U

Analysis of Variance	NumDF	DenDF	F_inc	Prob
7 mu	1	83.6	9799.18	<.001
3 weed	1	477.0	109.33	<.001

The iterative sequence converged, the REML estimate of the autoregressive parameter indicating substantial within column heterogeneity.

The abbreviated output from the two-dimensional AR1×AR1 spatial model is

1	LogL=-4277.99	S2= 0.12850E+06	666	df
2	LogL=-4266.13	S2= 0.12097E+06	666	df
3	LogL=-4253.05	S2= 0.10777E+06	666	df
4	LogL=-4238.72	S2= 83156.	666	df
5	LogL=-4234.53	S2= 79868.	666	df
6	LogL=-4233.78	S2= 82024.	666	df
7	LogL=-4233.67	S2= 82725.	666	df
8	LogL=-4233.65	S2= 82975.	666	df
9	LogL=-4233.65	S2= 83065.	666	df
10	LogL=-4233.65	S2= 83100.	666	df

Source	Model	terms	Gamma	Component	Comp/SE	% C
variety	532	532	1.06038	88117.5	9.92	0 P
Variance	670	666	1.00000	83100.1	8.90	0 P
Residual	AR=AutoR	67	0.685387	0.685387	16.65	0 U
Residual	AR=AutoR	10	0.285909	0.285909	3.87	0 U

Analysis of Variance	NumDF	DenDF	F_inc	Prob
7 mu	1	41.7	6248.65	<.001
3 weed	1	491.2	85.84	<.001

The change in REML log-likelihood is significant ($\chi_1^2 = 12.46, p < .001$) with the inclusion of the autoregressive parameter for columns. Figure 15.6 presents the sample variogram of the residuals for the AR1×AR1 model. There is an indication that a linear drift from column 1 to column 10 is present. We include a linear regression coefficient `pol(column,-1)` in the model to account for this. Note we use the '-1' option in the `pol` term to exclude the overall constant in the regression, as it is already fitted. The linear regression of column number on yield is significant ($t = -2.96$). The sample variogram (Figure 15.7) is more satisfactory, though interpretation of variograms is often difficult, particularly for unreplicated trials. This is an issue for further research. The abbreviated output for this model and the final model in which a nugget effect has been included is

```
#AR1xAR1 + pol(column,-1)
1 LogL=-4270.99    S2= 0.12730E+06    665 df
2 LogL=-4258.95    S2= 0.11961E+06    665 df
```

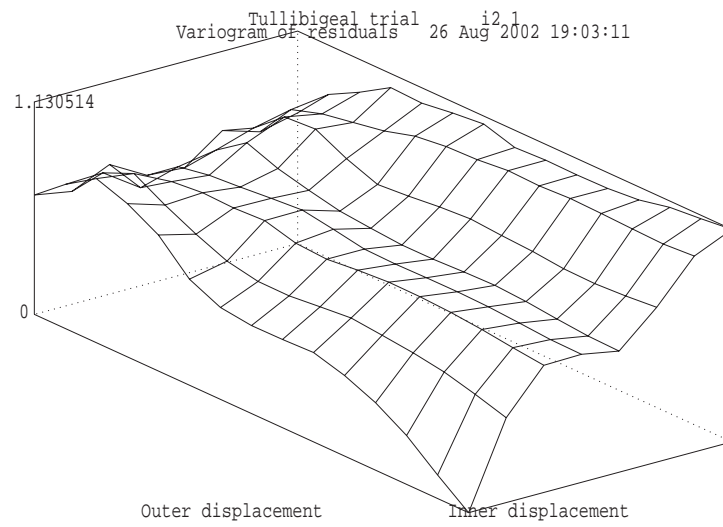


Figure 15.6: Sample variogram of the residuals from the $AR1 \times AR1$ model for the Tullibigeal data

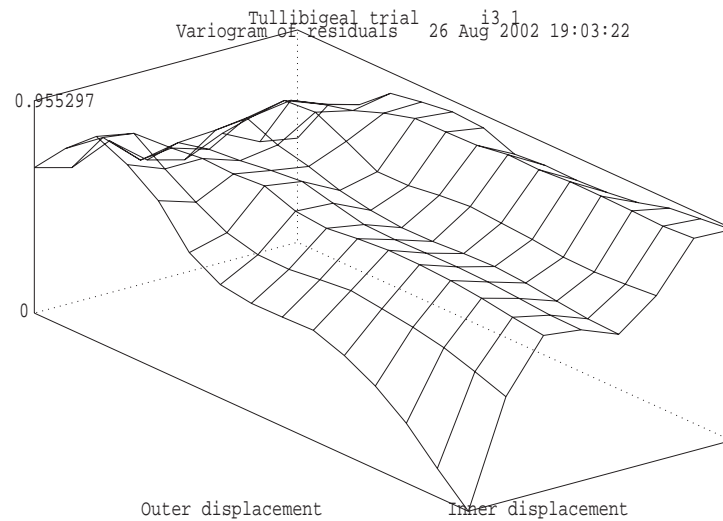


Figure 15.7: Sample variogram of the residuals from the $AR1 \times AR1 + \text{pol}(\text{column}, -1)$ model for the Tullibigeal data

```

3 LogL=-4245.27      S2= 0.10545E+06      665 df
4 LogL=-4229.50      S2= 78387.              665 df
5 LogL=-4226.02      S2= 75375.              665 df
6 LogL=-4225.64      S2= 77373.              665 df
7 LogL=-4225.60      S2= 77710.              665 df
8 LogL=-4225.60      S2= 77786.              665 df
9 LogL=-4225.60      S2= 77806.              665 df

Source              Model terms      Gamma      Component      Comp/SE      % C
variety              532      532      1.14370      88986.3      9.91      0 P
Variance              670      665      1.00000      77806.0      8.79      0 P
Residual              AR=AutoR      67      0.671436      0.671436      15.66      0 U
Residual              AR=AutoR      10      0.266088      0.266088      3.53      0 U

Analysis of Variance              NumDF      DenDF      F_inc              Prob
7 mu              1              42.5      7073.70              <.001
3 weed              1              457.4      91.91              <.001
8 pol(column,-1)      1              50.8      8.73              0.005

#
#AR1xAR1 + units + pol(column,-1)
#
1 LogL=-4272.74      S2= 0.11683E+06      665 df      :      1 components constrained
2 LogL=-4266.07      S2= 50207.              665 df      :      1 components constrained
3 LogL=-4228.96      S2= 76724.              665 df
4 LogL=-4220.63      S2= 55858.              665 df
5 LogL=-4220.19      S2= 54431.              665 df
6 LogL=-4220.18      S2= 54732.              665 df
7 LogL=-4220.18      S2= 54717.              665 df
8 LogL=-4220.18      S2= 54715.              665 df

Source              Model terms      Gamma      Component      Comp/SE      % C
variety              532      532      1.34824      73769.0      7.08      0 P
units              670      670      0.556400      30443.6      3.77      0 P
Variance              670      665      1.00000      54715.2      5.15      0 P
Residual              AR=AutoR      67      0.837503      0.837503      18.67      0 U
Residual              AR=AutoR      10      0.375382      0.375382      3.26      0 U

Analysis of Variance              NumDF      DenDF      F_inc              Prob
7 mu              1              13.6      4241.53              <.001
3 weed              1              469.0      86.39              <.001
8 pol(column,-1)      1              18.5      4.84              0.040

```

The increase in REML log-likelihood is significant. The predicted means for the varieties can be produced and printed in the .pvs file as

```

Warning: mv_estimates      is ignored for prediction
Warning: units              is ignored for prediction

```

```

----- 1 -----

```

```

column          evaluated at      5.5000
weed            is evaluated at average value of      0.4597
Predicted values of yield

variety          Predicted_Value Standard_Error Ecode
  1.0000          2917.1782      179.2881 E
  2.0000          2957.7405      178.7688 E
  3.0000          2872.7615      176.9880 E
  4.0000          2986.4725      178.7424 E
.
522.0000         2784.7683      179.1541 E
523.0000         2904.9421      179.5383 E
524.0000         2740.0330      178.8465 E
525.0000         2669.9565      179.2444 E
526.0000         2385.9806       44.2159 E
527.0000         2697.0670      133.4406 E
528.0000         2727.0324      112.2650 E
529.0000         2699.8243      103.9062 E
530.0000         3010.3907      112.3080 E
531.0000         3020.0720      112.2553 E
532.0000         3067.4479      112.6645 E
SED: Overall Standard Error of Difference   245.8

```

Note that the (replicated) check lines have lower SE than the (unreplicated) test lines. There will also be large differences in SEDs. Rather than obtaining the large table of all SEDs, you could do the prediction in parts

```
predict var 1:525 column 5.5
```

```
predict var 526:532 column 5.5 !SED
```

to examine the matrix of pairwise prediction errors of variety differences.

15.8 Paired Case-Control study - Rice

This data is concerned with an experiment conducted to investigate the tolerance of rice varieties to attack by the larvae of bloodworms. The data have been kindly provided by Dr. Mark Stevens, Yanco Agricultural Institute. A full description of the experiment is given by Stevens *et al.* (1999). Bloodworms are a significant pest of rice in the Murray and Murrumbidgee irrigation areas where they can cause poor establishment and substantial yield loss.

The experiment commenced with the transplanting of rice seedlings into trays. Each tray contained 32 seedlings and the trays were paired so that a control tray (no bloodworms) and a treated tray (bloodworms added) were grown in a controlled environment room for the duration of the experiment. At the end

of this time rice plants were carefully extracted, the root system washed and root area determined for the tray using an image analysis system described by Stevens *et al.* (1999). Two pairs of trays, each pair corresponding to a different variety, were included in each run. A new batch of bloodworm larvae was used for each run. A total of 44 varieties was investigated with three replicates of each. Unfortunately the variety concurrence within runs was less than optimal. Eight varieties occurred with only one other variety, 22 with two other varieties and the remaining 14 with three different varieties.

In the next three sections we present an exhaustive analysis of these data using equivalent univariate and multivariate techniques. It is convenient to use two data files one for each approach. The univariate data file consists of factors `pair`, `run`, `variety`, `tmt`, `unit` and variate `rootwt`. The factor `unit` labels the individual trays, `pair` labels pairs of trays (to which varieties are allocated) and `tmt` is the two level bloodworm treatment factor (control/treated). The multivariate data file consists of factors `variety` and `run` and variates for root weight of both the control and exposed treatments (labelled `yc` and `ye` respectively).

Preliminary analyses indicated variance heterogeneity so that subsequent analyses were conducted on the square root scale. Figure 15.8 presents a plot of the treated and the control root area (on the square root scale) for each variety. There is a strong dependence between the treated and control root area, which is not surprising. The aim of the experiment was to determine the tolerance of varieties to bloodworms and thence identify the most tolerant varieties. The definition of tolerance should allow for the fact that varieties differ in their inherent seedling vigour (Figure 15.8). The original approach of the scientist was to regress the treated root area against the control root area and define the index of vigour as the residual from this regression. This approach is clearly inefficient since there is error in both variables. We seek to determine an index of tolerance from the joint analysis of treated and control root area.

Standard analysis

The allocation of bloodworm treatments within varieties and varieties within runs defines a nested block structure of the form

```
run/variety/tmt = run + run.variety + run.variety.tmt
                ( = run + pair + pair.tmt )
                ( = run + run.variety + units )
```

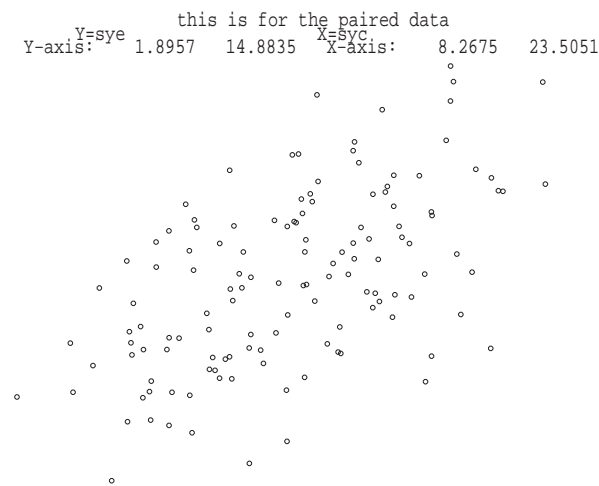


Figure 15.8: Rice bloodworm data: Plot of square root of root weight for treated versus control

There is an additional blocking term, however, due to the fact that the bloodworms within a run are derived from the same batch of larvae whereas between runs the bloodworms come from different sources. This defines a block structure of the form

```
run/tmt/variety = run + run.tmt + run.tmt.variety
                ( = run + run.tmt + pair.tmt )
```

Combining the two provides the full block structure for the design, namely

```
run + run.variety + run.tmt + run.tmt.variety
= run + run.variety + run.tmt + units
= run + pair + run.tmt + pair.tmt
```

In line with the aims of the experiment the treatment structure comprises variety and treatment main effects and treatment by variety interactions. In the traditional approach the terms in the block structure are regarded as random and the treatment terms as fixed. The choice of treatment terms as fixed or random depends largely on the aims of the experiment. The aim of this example is to select the "best" varieties. The definition of best is somewhat more complex since it does not involve the single trait $\text{sqrt}(\text{rootwt})$ but rather two traits,

namely $\text{sqrt}(\text{rootwt})$ in the presence/absence of bloodworms. Thus to minimise selection bias the variety main effects and thence the `tmt.variety` interactions are taken as random. The main effect of treatment is fitted as fixed to allow for the likely scenario that rather than a single population of treatment by variety effects there are in fact two populations (control and treated) with a different mean for each. There is evidence of this prior to analysis with the large difference in mean $\text{sqrt}(\text{rootwt})$ for the two groups (14.93 and 8.23 for control and treated respectively). The inclusion of `tmt` as a fixed effect ensures that BLUPs of `tmt.variety` effects are shrunk to the correct mean (treatment means rather than an overall mean).

The model for the data is given by

$$\mathbf{y} = \mathbf{X}\boldsymbol{\tau} + \mathbf{Z}_1\mathbf{u}_1 + \mathbf{Z}_2\mathbf{u}_2 + \mathbf{Z}_3\mathbf{u}_3 + \mathbf{Z}_4\mathbf{u}_4 + \mathbf{Z}_5\mathbf{u}_5 + \mathbf{e} \quad (15.7)$$

where \mathbf{y} is a vector of length $n = 264$ containing the $\text{sqrt}(\text{rootwt})$ values, $\boldsymbol{\tau}$ corresponds to a constant term and the fixed treatment contrast and $\mathbf{u}_1 \dots \mathbf{u}_5$ correspond to random variety, treatment by variety, run, treatment by run and variety by run effects. The random effects and error are assumed to be independent Gaussian variables with zero means and variance structures $\text{var}(\mathbf{u}_i) = \sigma_i^2 \mathbf{I}_{b_i}$ (where b_i is the length of \mathbf{u}_i , $i = 1 \dots 5$) and $\text{var}(\mathbf{e}) = \sigma^2 \mathbf{I}_n$.

The ASReml code for this analysis is

```
Bloodworm data Dr M Stevens
pair 132
rootwt
run 66
tmt 2 !A
id
variety 44 !A
rice.asd !skip 1 !DOPATH 1
!PATH 1
sqrt(rootwt) ~ mu tmt !r variety variety.tmt run pair run.tmt
0 0 0
!PATH 2
sqrt(rootwt) ~ mu tmt !r variety tmt.variety run pair tmt.run,
uni(tmt,2)
0 0 2
tmt.variety 2
2 0 DIAG .1 .1 !GU
44 0 0
tmt.run 2
2 0 DIAG .1 .1 !GU
66 0 0
```

Table 15.8: Estimated variance components from univariate analyses of bloodworm data. (a) Model with homogeneous variance for all terms and (b) Model with heterogeneous variance for interactions involving tmt

source	(a)	(b)	
		control	treated
variety	2.378	2.334	
tmt.variety	0.492	1.505	-0.372
run	0.321	0.319	
tmt.run	1.748	1.388	2.223
variety.run (pair)	0.976	0.987	
tmt.pair	1.315	1.156	1.359
REML log-likelihood	-345.256	-343.22	

The two paths in the input file define the two univariate analyses we will conduct. We consider the results from the analysis defined in `PATH 1` first. A portion of the output file is

```

5 LogL=-345.306      S2=  1.3216      262 df
6 LogL=-345.267      S2=  1.3155      262 df
7 LogL=-345.264      S2=  1.3149      262 df
8 LogL=-345.263      S2=  1.3149      262 df

Source              Model  terms   Gamma   Component  Comp/SE  % C
variety              44    44     1.80947  2.37920    3.01    0 P
run                  66    66     0.244243 0.321144   0.59    0 P
variety.tmt         88    88     0.374220 0.492047   1.78    0 P
pair                 132   132    0.742328 0.976057   2.51    0 P
run.tmt             132   132    1.32973  1.74841    3.65    0 P
Variance            264   262    1.00000  1.31486    4.42    0 P

Analysis of Variance      NumDF  DenDF   F_inc      Prob
7 mu                      1      53.5  1484.27    <.001
4 tmt                      1      60.4   469.36    <.001

```

The estimated variance components from this analysis are given in column (a) of table 15.8. The variance component for the `variety` main effects is large. There is evidence of `tmt.variety` interactions so we may expect some discrimination between varieties in terms of tolerance to bloodworms.

Given the large difference ($p < 0.001$) between `tmt` means we may wish to allow for heterogeneity of variance associated with `tmt`. Thus we fit a separate `variety` variance for each level of `tmt` so that instead of assuming $\text{var}(\mathbf{u}_2) = \sigma_2^2 \mathbf{I}_{88}$ we assume

$$\text{var}(\mathbf{u}_2) = \begin{bmatrix} \sigma_{2c}^2 & 0 \\ 0 & \sigma_{2t}^2 \end{bmatrix} \otimes \mathbf{I}_{44}$$

where σ_{2c}^2 and σ_{2t}^2 are the `tmt.variety` interaction variances for control and treated respectively. This model can be achieved using a diagonal variance structure for the treatment part of the interaction. We also fit a separate `run` variance for each level of `tmt` and heterogeneity at the residual level, by including the `uni(tmt,2)` term. We have chosen level 2 of `tmt` as we expect more variation for the exposed treatment and thus the extra variance component for this term should be positive. Had we mistakenly specified level 1 then `ASReml` would have estimated a negative component by setting the `!GU` option for this term. The portion of the `ASReml` output for this analysis is

```

6 LogL=-343.428      S2=  1.1498      262 df      :   1 components constrained
7 LogL=-343.234      S2=  1.1531      262 df
8 LogL=-343.228      S2=  1.1572      262 df
9 LogL=-343.228      S2=  1.1563      262 df

Source              Model  terms   Gamma      Component    Comp/SE    % C
variety              44    44      2.01903     2.33451      3.01      0 P
run                  66    66      0.276045    0.319178     0.59      0 P
pair                 132   132     0.853941    0.987372     2.59      0 P
uni(tmt,2)           264   264     0.176158    0.203684     0.32      0 P
Variance              264   262     1.00000     1.15625      2.77      0 P
tmt.variety          DIAGonal  1     1.30142     1.50477      2.26      0 U
tmt.variety          DIAGonal  2    -0.321901   -0.372199    -0.82      0 U
tmt.run              DIAGonal  1     1.20098     1.38864      2.18      0 U
tmt.run              DIAGonal  2     1.92457     2.22530      3.07      0 U

Analysis of Variance              NumDF   DenDF   F_inc              Prob
7 mu                              1       56.5   1276.73             <.001
4 tmt                              1       60.6   448.83              <.001

```

The estimated variance components from this analysis are given in column (b) of table 15.8. There is no significant variance heterogeneity at the residual or `tmt.run` level. This indicates that the square root transformation of the data has successfully stabilised the error variance. There is, however, significant variance heterogeneity for `tmt.variety` interactions with the variance being much greater for the control group. This reflects the fact that in the absence of bloodworms the potential maximum root area is greater. Note that the `tmt.variety` interaction variance for the treated group is negative. The negative component is meaningful

(and in fact necessary and obtained by use of the !GU option) in this context since it should be considered as part of the variance structure for the combined variety main effects and treatment by variety interactions. That is,

$$\text{var}(\mathbf{1}_2 \otimes \mathbf{u}_1 + \mathbf{u}_2) = \begin{bmatrix} \sigma_1^2 + \sigma_{2c}^2 & \sigma_1^2 \\ \sigma_1^2 & \sigma_1^2 + \sigma_{2t}^2 \end{bmatrix} \otimes \mathbf{I}_{44} \quad (15.8)$$

Using the estimates from table 15.8 this structure is estimated as

$$\begin{bmatrix} 3.84 & 2.33 \\ 2.33 & 1.96 \end{bmatrix} \otimes \mathbf{I}_{44}$$

Thus the variance of the variety effects in the control group (also known as the genetic variance for this group) is 3.84. The genetic variance for the treated group is much lower (1.96). The genetic correlation is $2.33/\sqrt{3.84 * 1.96} = 0.85$ which is strong, supporting earlier indications of the dependence between the treated and control root area (Figure 15.8).

A multivariate approach

In this simple case in which the variance heterogeneity is associated with the two level factor `tmt`, the analysis is equivalent to a bivariate analysis in which the two traits correspond to the two levels of `tmt`, namely `sqrt(rootwt)` for control and treated. The model for each trait is given by

$$\mathbf{y}_j = \mathbf{X}\boldsymbol{\tau}_j + \mathbf{Z}_v\mathbf{u}_{v_j} + \mathbf{Z}_r\mathbf{u}_{r_j} + \mathbf{e}_j \quad (j = c, t) \quad (15.9)$$

where \mathbf{y}_j is a vector of length $n = 132$ containing the sqrtroot values for variate j ($j = c$ for control and $j = t$ for treated), $\boldsymbol{\tau}_j$ corresponds to a constant term and \mathbf{u}_{v_j} and \mathbf{u}_{r_j} correspond to random variety and run effects. The design matrices are the same for both traits. The random effects and error are assumed to be independent Gaussian variables with zero means and variance structures $\text{var}(\mathbf{u}_{v_j}) = \sigma_{v_j}^2 \mathbf{I}_{44}$, $\text{var}(\mathbf{u}_{r_j}) = \sigma_{r_j}^2 \mathbf{I}_{66}$ and $\text{var}(\mathbf{e}_j) = \sigma_j^2 \mathbf{I}_{132}$. The bivariate model can be written as a direct extension of (15.9), namely

$$\mathbf{y} = (\mathbf{I}_2 \otimes \mathbf{X})\boldsymbol{\tau} + (\mathbf{I}_2 \otimes \mathbf{Z}_v)\mathbf{u}_v + (\mathbf{I}_2 \otimes \mathbf{Z}_r)\mathbf{u}_r + \mathbf{e}^* \quad (15.10)$$

where $\mathbf{y} = (\mathbf{y}'_c, \mathbf{y}'_t)'$, $\mathbf{u}_v = (\mathbf{u}'_{vc}, \mathbf{u}'_{vt})'$, $\mathbf{u}_r = (\mathbf{u}'_{rc}, \mathbf{u}'_{rt})'$ and $\mathbf{e}^* = (\mathbf{e}'_c, \mathbf{e}'_t)'$.

There is an equivalence between the effects in this bivariate model and the univariate model of (15.7). The variety effects for each trait (\mathbf{u}_v in the bivariate model) are partitioned in (15.7) into variety main effects and `tmt.variety` interactions so that $\mathbf{u}_v = \mathbf{1}_2 \otimes \mathbf{u}_1 + \mathbf{u}_2$. There is a similar partitioning for the run effects and the errors (see table 15.9).

Table 15.9 Equivalence of random effects in bivariate and univariate analyses

effects	bivariate (model 15.10)	univariate (model 15.7)
trait.variety	\mathbf{u}_v	$\mathbf{1}_2 \otimes \mathbf{u}_1 + \mathbf{u}_2$
trait.run	\mathbf{u}_r	$\mathbf{1}_2 \otimes \mathbf{u}_3 + \mathbf{u}_4$
trait.pair	\mathbf{e}^*	$\mathbf{1}_2 \otimes \mathbf{u}_5 + \mathbf{e}$

In addition to the assumptions in the models for individual traits (15.9) the bivariate analysis involves the assumptions $\text{cov}(\mathbf{u}_{vc}) \mathbf{u}'_{vt} = \sigma_{vct} \mathbf{I}_{44}$, $\text{cov}(\mathbf{u}_{rc}) \mathbf{u}'_{rt} = \sigma_{rct} \mathbf{I}_{66}$ and $\text{cov}(\mathbf{e}_c) \mathbf{e}'_t = \sigma_{ct} \mathbf{I}_{132}$. Thus random effects and errors are correlated between traits. So, for example, the variance matrix for the variety effects for each trait is given by

$$\text{var}(\mathbf{u}_v) = \begin{bmatrix} \sigma_{vc}^2 & \sigma_{vct} \\ \sigma_{vct} & \sigma_{vt}^2 \end{bmatrix} \otimes \mathbf{I}_{44}$$

This unstructured form for `trait.variety` in the bivariate analysis is equivalent to the `variety` main effect plus heterogeneous `tmt.variety` interaction variance structure (15.8) in the univariate analysis. Similarly the unstructured form for `trait.run` is equivalent to the `run` main effect plus heterogeneous `tmt.run` interaction variance structure. The unstructured form for the errors (`trait.pair`) in the bivariate analysis is equivalent to the `pair` plus heterogeneous error (`tmt.pair`) variance in the univariate analysis. This bivariate analysis is achieved in ASReml as follows, noting that the `tmt` factor here is equivalent to traits.

```
this is for the paired data
id
pair 132
run 66
variety 44 !A
yc ye
ricem.asd !skip 1 !X syc !Y sye
sqrt(yc) sqrt(ye) ~ Trait !r Tr.variety Tr.run
1 2 2
132 !S2==1
Tr 0 US 2.21 1.1 2.427
Tr.variety 2
2 0 US 1.401 1 1.477
44 0 0
```

```

Tr.run 2
2 0 US .79 .5 2.887
66 0 0
predict variety

```

A portion of the output from this analysis is

```

7 LogL=-343.220      S2=  1.0000      262 df
8 LogL=-343.220      S2=  1.0000      262 df

Source              Model  terms      Gamma      Component    Comp/SE    % C
Residual            UnStruct  1  2.14373    2.14373      4.44    0 U
Residual            UnStruct  1  0.987401   0.987401     2.59    0 U
Residual            UnStruct  2  2.34751    2.34751      4.62    0 U
Tr.variety          UnStruct  1  3.83959    3.83959      3.47    0 U
Tr.variety          UnStruct  1  2.33394    2.33394      3.01    0 U
Tr.variety          UnStruct  2  1.96173    1.96173      2.69    0 U
Tr.run              UnStruct  1  1.70788    1.70788      2.62    0 U
Tr.run              UnStruct  1  0.319145   0.319145     0.59    0 U
Tr.run              UnStruct  2  2.54326    2.54326      3.20    0 U
Covariance/Variance/Correlation Matrix UnStructured
 2.144      0.4402
0.9874      2.348
Covariance/Variance/Correlation Matrix UnStructured
 3.840      0.8504
 2.334      1.962
Covariance/Variance/Correlation Matrix UnStructured
 1.708      0.1531
0.3191      2.543

```

The resultant REML log-likelihood is identical to that of the heterogeneous univariate analysis (column (b) of table 15.8). The estimated variance parameters are given in Table 15.10.

Table 15.10: Estimated variance parameters from bivariate analysis of bloodworm data

source	control variance	treated variance	covariance
us(trait).variety	3.84	1.96	2.33
us(trait).run	1.71	2.54	0.32
us(trait).pair	2.14	2.35	0.99

The predicted variety means in the .pvs file are used in the following section on interpretation of results. A portion of the file is presented below. There is a wide range in SED reflecting the imbalance of the variety concurrence within runs.

```

Assuming Power transformation was (Y+ 0.000)^ 0.500
run          is ignored in the prediction (except where specifically included

Trait      variety      Power_value  Stand_Error  Ecode  Retrtransformed  approx_SE
sqrt(yc)   AliCombo      14.9532     0.9181 E    223.5982  27.4571
sqrt(ye)   AliCombo      7.9941     0.7993 E    63.9054  12.7790
sqrt(yc)   Bluebelle     13.1033     0.9310 E    171.6969  24.3980
sqrt(ye)   Bluebelle     6.6299     0.8062 E    43.9559  10.6901
sqrt(yc)   C22           16.6679     0.9181 E    277.8192  30.6057
sqrt(ye)   C22           8.9543     0.7993 E    80.1798  14.3140
.
sqrt(yc)   YRK1         15.1859     0.9549 E    230.6103  29.0012
sqrt(ye)   YRK1         8.3356     0.8190 E    69.4817  13.6534
sqrt(yc)   YRK3         13.3057     0.9549 E    177.0428  25.4106
sqrt(ye)   YRK3         8.1133     0.8190 E    65.8264  13.2894
SED: Overall Standard Error of Difference  1.215

```

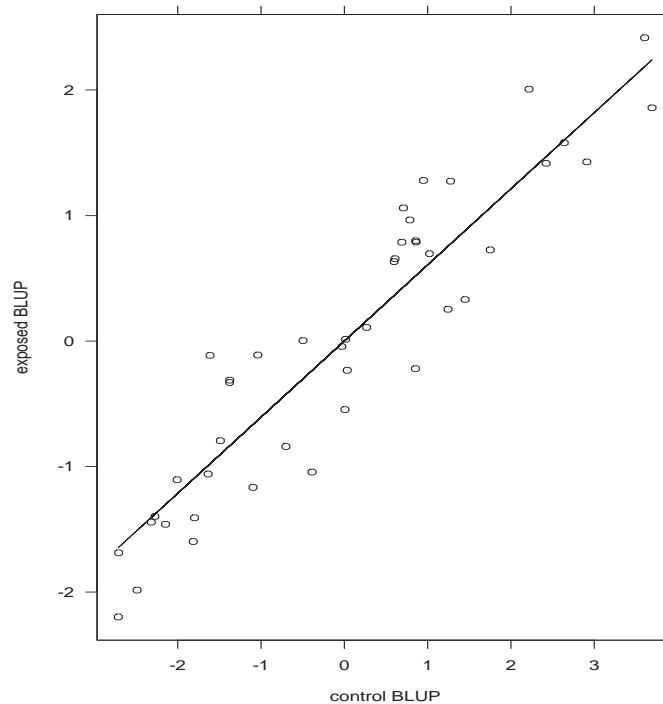


Figure 15.9 BLUPs for treated for each variety plotted against BLUPs for control

Interpretation of results

Recall that the researcher is interested in varietal tolerance to bloodworms. This could be defined in various ways. One option is to consider the regression implicit in the variance structure for the trait by variety effects. The variance structure can arise from a regression of treated variety effects on control effects, namely

$$\mathbf{u}_{vt} = \beta \mathbf{u}_{vc} + \boldsymbol{\epsilon}$$

where the slope $\beta = \sigma_{v_{ct}} / \sigma_{v_c}^2$. Tolerance can be defined in terms of the deviations from regression, $\boldsymbol{\epsilon}$. Varieties with large positive deviations have greatest tolerance to bloodworms. Note that this is similar to the researcher's original intentions except that the regression has been conducted at the genotypic rather than the phenotypic level. In Figure 15.9 the BLUPs for treated have been plotted against the BLUPs for control for each variety and the fitted regression line (slope = 0.61) has been drawn. Varieties with large positive deviations from the regression line include YRK3, Calrose, HR19 and WC1403.

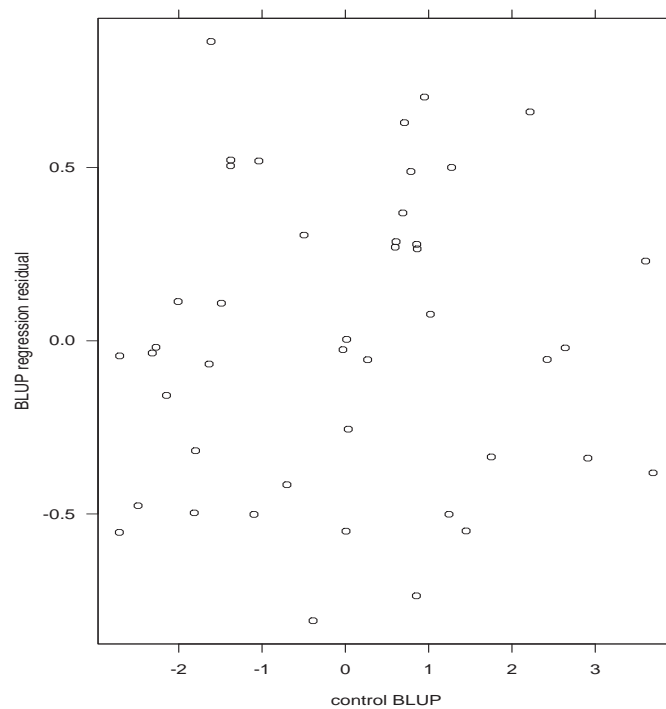


Figure 15.10: Estimated deviations from regression of treated on control for each variety plotted against estimate for control

An alternative definition of tolerance is the simple difference between treated and control BLUPs for each variety, namely $\delta = \mathbf{u}_{v_c} - \mathbf{u}_{v_t}$. Unless $\beta = 1$ the two measures ϵ and δ have very different interpretations. The key difference is that ϵ is a measure which is *independent* of inherent vigour whereas δ is not. To see this consider

$$\begin{aligned} \text{cov}(\epsilon) \mathbf{u}'_{v_c} &= \text{cov}(\mathbf{u}_{v_t} - \beta \mathbf{u}_{v_c}) \mathbf{u}'_{v_c} \\ &= \left(\sigma_{v_{ct}} - \frac{\sigma_{v_{ct}}}{\sigma_{v_c}^2} \sigma_{v_c}^2 \right) \mathbf{I}_{44} \\ &= \mathbf{0} \end{aligned}$$

whereas

$$\begin{aligned} \text{cov}(\delta) \mathbf{u}'_{v_c} &= \text{cov}(\mathbf{u}_{v_c} - \mathbf{u}_{v_t}) \mathbf{u}'_{v_c} \\ &= \left(\sigma_{v_c}^2 - \sigma_{v_{ct}} \right) \mathbf{I}_{44} \end{aligned}$$

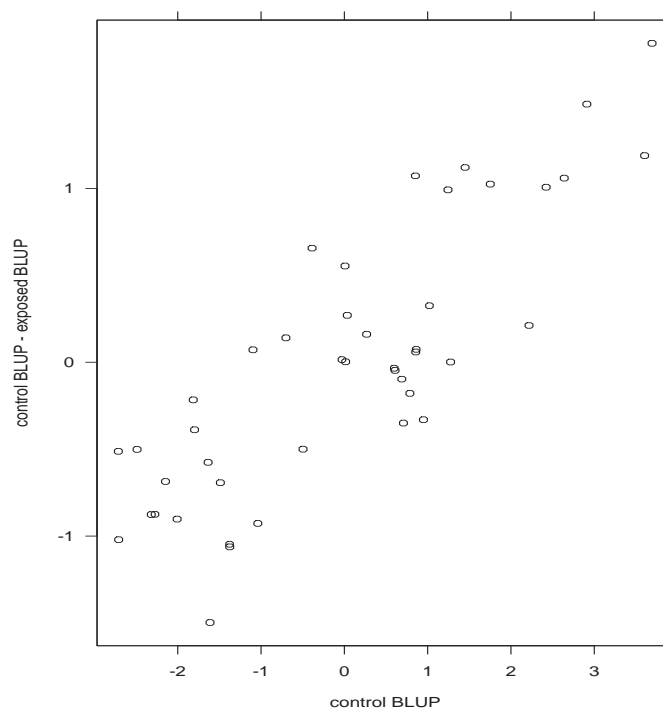


Figure 15.11: Estimated difference between control and treated for each variety plotted against estimate for control

The independence of ϵ and \mathbf{u}_{v_c} and dependence between δ and \mathbf{u}_{v_c} is clearly illustrated in Figures 15.10 and 15.11. In this example the two measures have provided very different rankings of the varieties. The choice of tolerance measure depends on the aim of the experiment. In this experiment the aim was to identify tolerance which is independent of inherent vigour so the deviations from regression measure is preferred.

15.9 Balanced longitudinal data - Random coefficients and cubic smoothing splines - Oranges

We now illustrate the use of random coefficients and cubic smoothing splines for the analysis of balanced longitudinal data. The implementation of cubic smoothing splines in ASReml was originally based on the mixed model formulation presented by Verbyla *et al.* (1999). More recently the technology has been enhanced so that the user can specify knot points; in the original approach the knot points were taken to be the ordered set of unique values of the explanatory variable. The specification of knot points is particularly useful if the number of unique values in the explanatory variable is large, or if units are measured at different times.

The data we use was originally reported by Draper and Smith (1998, ex24N, p559) and has recently been reanalysed by Pinheiro and Bates (2000, p338). The data are displayed in Figure 15.12 and are the trunk circumferences (in millimetres) of each of 5 trees taken at 7 times. All trees were measured at the same time so that the data are balanced. The aim of the study is unclear, though, both previous analyses involved modelling the overall ‘growth’ curve, accounting for the obvious variation in both level and shape between trees. Pinheiro and Bates (2000) used a nonlinear mixed effects modelling approach, in which they modelled the growth curves by a three parameter logistic function of age, given by

$$y = \frac{\phi_1}{1 + \exp[-(x - \phi_2)/\phi_3]} \quad (15.11)$$

where y is the trunk circumference, x is the tree age in days since December 31 1968, ϕ_1 is the asymptotic height, ϕ_2 is the inflection point or the time at which the tree reaches $0.5\phi_1$, ϕ_3 is the time elapsed between trees reaching half and about $3/4$ of ϕ_1 .

The datafile consists of 5 columns viz, **Tree**, a factor with 5 levels, **age**, tree age in days since 31st December 1968, **circ** the trunk circumference and **season**. The last column **season** was added after noting that tree age spans several years and if



Figure 15.12 Trellis plot of trunk circumference for each tree

converted to day of year, measurements were taken in either **Spring** (April/May) or **Autumn** (September/October).

First we demonstrate the fitting of a cubic spline in **ASReml** by restricting the dataset to tree 1 only. The model includes the intercept and linear regression of trunk circumference on *age* and an additional random term `spl(age,7)` which instructs **ASReml** to include a random term with a special design matrix with $7 - 2 = 5$ columns which relate to the vector, δ whose elements $\delta_i, i = 2, \dots, 6$ are the second differentials of the cubic spline at the knot points. The second differentials of a natural cubic spline are zero at the first and last knot points (Green and Silverman, 1994). The **ASReml** job is

```
this is the orange data, for tree 1
seq      # record number is not used
Tree 5
age      # 118  484  664 1004 1231 1372 1582
circ
season !L Spring Autumn
orange.asd !skip 1 !filter 2 !select 1
!SPLINE spl(age,7) 118  484  664 1004 1231 1372 1582
!PVAL age 150 200:1500
circ ~ mu age !r spl(age,7)
predict age
```

Note that the data for tree 1 has been selected by use of the `!filter` and `!select` qualifiers. Also note the use of `!PVAL` so that the spline curve is properly predicted at the additional nominated points. These additional data points are required for ASReml to form the design matrix to properly interpolate the cubic smoothing spline between knot points in the prediction process. Since the spline knot points are specifically nominated in the `!SPLINE` line, these extra points have no effect on the analysis run time. The `!SPLINE` line does not modify the analysis in this example since it simply nominates the 7 ages in the data file. The same analysis would result if the `!SPLINE` line was omitted and `spl(age,7)` in the model was replaced with `spl(age)`. An extract of the output file is

```

1 LogL=-20.9043      S2= 48.470           5 df   0.1000      1.000
2 LogL=-20.9017      S2= 49.022           5 df   0.9266E-01  1.000
3 LogL=-20.8999      S2= 49.774           5 df   0.8356E-01  1.000
4 LogL=-20.8996      S2= 50.148           5 df   0.7937E-01  1.000
5 LogL=-20.8996      S2= 50.213           5 df   0.7866E-01  1.000
Final parameter values                0.78798E-01 1.0000

          Approximate stratum variance decomposition
Stratum   Degrees-Freedom   Variance   Component Coefficients
spl(age,7)      1.49    97.4813      12.0    1.0
Residual Variance  3.51    50.1888      0.0    1.0

Source              Model terms      Gamma      Component      Comp/SE      % C
spl(age,7)           5      5  0.787457E-01   3.95215      0.40   0 P
Variance             7      5  1.00000      50.1888      1.33   0 P

Analysis of Variance              NumDF      DenDF      F_inc              Prob
7 mu                               1          3.5   1382.80             <.001
3 age                              1          3.5   217.60              <.001
Notice: The DenDF values are calculated ignoring fixed/boundary/singular
variance parameters using algebraic derivatives.

              Estimate      Standard Error      T-value      T-prev
3 age
1  0.814772E-01   0.552336E-02      14.75
7 mu
1  24.4378        5.75429           4.25
6 spl(age,7)                5 effects fitted
Finished: 19 Aug 2005 10:08:11.980  LogL Converged

```

The REML estimate of the smoothing constant indicates that there is some non-linearity. The fitted cubic smoothing spline is presented in Figure 15.13. The fitted values were obtained from the `.pvs` file. The four points below the line were the spring measurements.

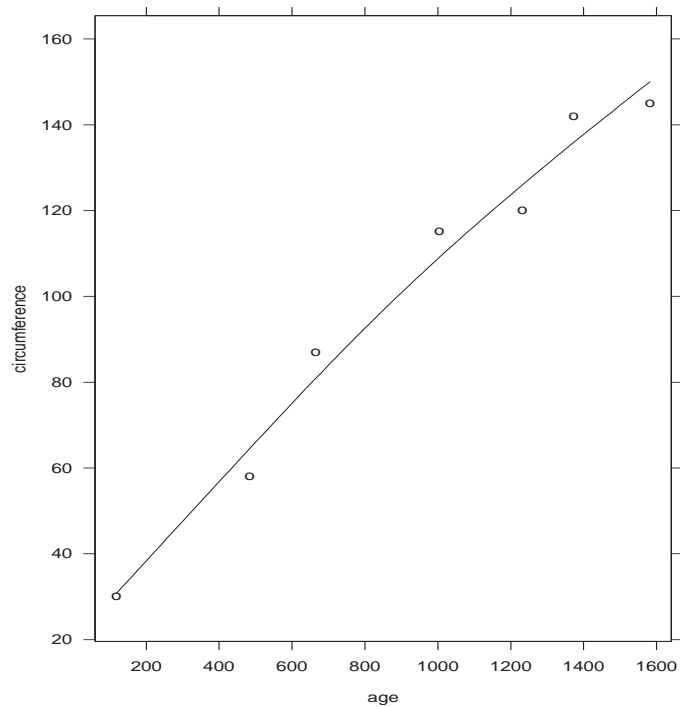


Figure 15.13 Fitted cubic smoothing spline for tree 1

We now consider the analysis of the full dataset. Following Verbyla *et al.* (1999) we consider the analysis of variance decomposition (see Table 15.11) which models the overall and individual curves.

An overall spline is fitted as well as tree deviation splines. We note however, that the intercept and slope for the tree deviation splines are assumed to be random effects. This is consistent with Verbyla *et al.* (1999). In this sense the tree deviation splines play a role in modelling the conditional curves for each tree and variance modelling. The intercept and slope for each tree are included as random coefficients (denoted by RC in Table 15.11). Thus, if $\mathbf{U}^{5 \times 2}$ is the matrix of intercepts (column 1) and slopes (column 2) for each tree, then we assume that

$$\text{var}(\text{vec}(\mathbf{U})) = \boldsymbol{\Sigma} \otimes \mathbf{I}_5$$

where $\boldsymbol{\Sigma}$ is a 2×2 symmetric positive definite matrix. Non smooth variation can be modelled at the overall mean (across trees) level and this is achieved in ASReml by inclusion of `fac(age)` as a random term.

Table 15.11 Orange data: AOV decomposition

stratum	decomposition	type	df or ne
constant	1	F	1
age	age	F	1
	spl(age,7)	R	5
	fac(age)	R	7
tree	tree	RC	5
age.tree	x.tree	RC	5
	spl(age,7).tree	R	25
error		R	

An extract of the ASReml input file is

```

circ ~ mu age !r Tree 4.6 Tree.age .000094 spl(age,7) .1,
spl(age,7).Tree 2.3 fac(age) 13.9
0 0 1
Tree 2
2 0 US 4.6 .00001 .000094
5 0 0
predict age Tree !IGNORE fac(age)

```

We stress the importance of model building in these settings, where we generally commence with relatively simple variance models and update to more complex variance models if appropriate. Table 15.12 presents the sequence of fitted models we have used. Note that the REML log-likelihoods for models 1 and 2 are comparable and likewise for models 3 to 6. The REML log-likelihoods are not comparable between these groups due to the inclusion of the fixed `season` term in the second set of models.

We begin by modelling the variance matrix for the intercept and slope for each tree, Σ , as a diagonal matrix as there is no point including a covariance component between the intercept and slope if the variance component(s) for one (or both) is zero. Model 1 also does not include a non-smooth component at the overall level (that is, `fac(age)`). Abbreviated output is shown below.

Table 15.12 Sequence of models fitted to the Orange data

term	model					
	1	2	3	4	5	6
tree	y	y	y	y	y	y
age.tree	y	y	y	y	y	y
(covariance)	n	n	n	n	n	y
spl(age,7)	y	y	y	y	n	y
tree.spl(age,7)	y	y	y	n	y	y
fac(age)	n	y	y	n	n	n
season	n	n	y	y	y	y
REML log-likelihood	-97.78	-94.07	-87.95	-91.22	-90.18	-87.43

```

12 LogL=-97.7788      S2=  6.3550          33 df

Source              Model  terms      Gamma      Component    Comp/SE    % C
Tree                5      5      4.79025     30.4420     1.24      0 P
Tree.age            5      5      0.939436E-04  0.597011E-03  1.41      0 P
spl(age,7)          5      5      100.513     638.759     1.55      0 P
spl(age,7).Tree     25     25      1.11728     7.10033     1.44      0 P
Variance            35     33      1.00000     6.35500     1.74      0 P

Analysis of Variance      NumDF   DenDF   F_inc      Prob
  7 mu                    1       4.0     47.04     0.002
  3 age                    1       4.0     95.00     <.001

```

A quick look suggests this is fine until we look at the predicted curves in Figure 15.14. The fit is unacceptable because the spline has picked up too much curvature, and suggests that there may be systematic non-smooth variation at the overall level. This can be formally examined by including the `fac(age)` term as a random effect. This increased the log-likelihood 3.71 ($P < 0.05$) with the `spl(age,7)` smoothing constants heading to the boundary. There is a possible explanation in the `season` factor. When this is added (Model 3) it has an F ratio of 107.5 ($P < 0.01$) while the `fac(age)` term goes to the boundary. Notice that the inclusion of the fixed term `season` in models 3 to 6 means that comparisons with models 1 and 2 on the basis of the log-likelihood are not valid. The spring

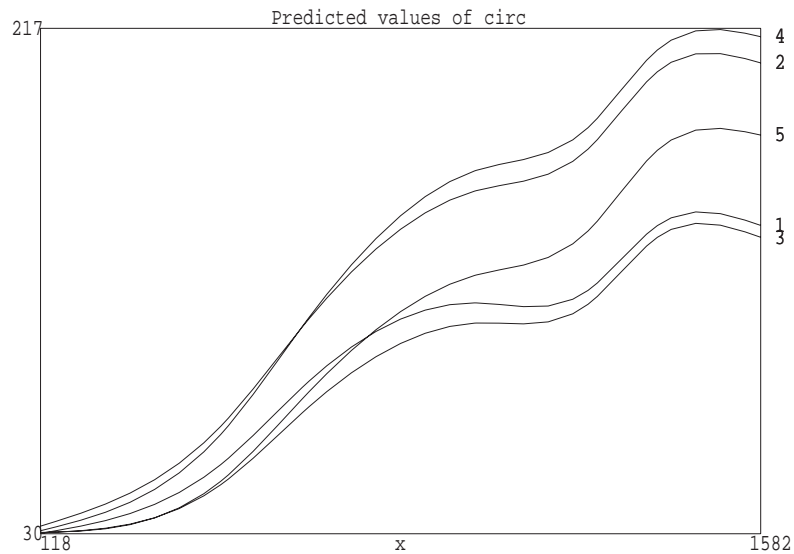


Figure 15.14 Plot of fitted cubic smoothing spline for model 1

measurements are lower than the autumn measurements so growth is slower in winter. Models 4 and 5 successively examined each term, indicating that both smoothing constants are significant ($P < 0.05$). Lastly we add the covariance parameter between the intercept and slope for each tree in model 6. This ensures that the covariance model will be translation invariant. A portion of the output file for model 6 is

```

      8 LogL=-87.4291      S2=  5.6303      32 df

Source           Model  terms      Gamma      Component      Comp/SE      % C
spl(age,7)             5      5      2.17239      12.2311         1.09      0 P
spl(age,7).Tree       25     25      1.38565       7.80160         1.47      0 P
Variance              35     32      1.00000       5.63028         1.72      0 P
Tree                  UnStru   1      1      5.62219       31.6545         1.26      0 U
Tree                  UnStru   2      1     -0.124202E-01  -0.699290E-01    -0.85      0 U
Tree                  UnStru   2      2      0.108377E-03   0.610192E-03     1.40      0 U
Covariance/Variance/Correlation Matrix UnStructured
  31.65      -0.5032
-0.6993E-01  0.6102E-03

Analysis of Variance           NumDF      DenDF      F_inc           Prob
  7 mu                          1          4.0      169.87          <.001
  3 age                          1          4.0       92.78          <.001
  5 Season                       1          8.9      108.60          <.001

```

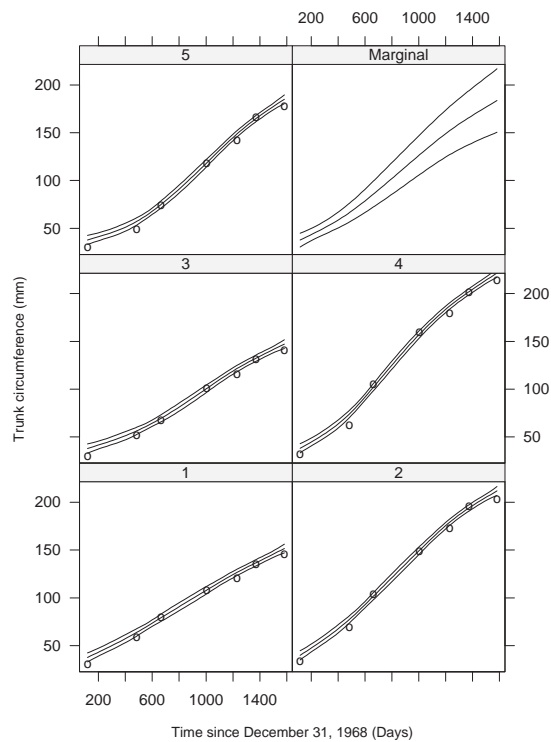



Figure 15.15: Trellis plot of trunk circumference for each tree at sample dates (adjusted for *season* effects), with fitted profiles across time and confidence intervals

Figure 15.15 presents the predicted growth over time for individual trees and a marginal prediction for trees with approximate confidence intervals ($2\pm\times$ standard error of prediction). Within this figure, the data is adjusted to remove the estimated seasonal effect. The conclusions from this analysis are quite different from those obtained by the nonlinear mixed effects analysis. The individual curves for each tree are not convincingly modelled by a logistic function. Figure 15.16 presents a plot of the residuals from the nonlinear model fitted on p340 of Pinheiro and Bates (2000). The distinct pattern in the residuals, which is the same for all trees is taken up in our analysis by the *season* term.

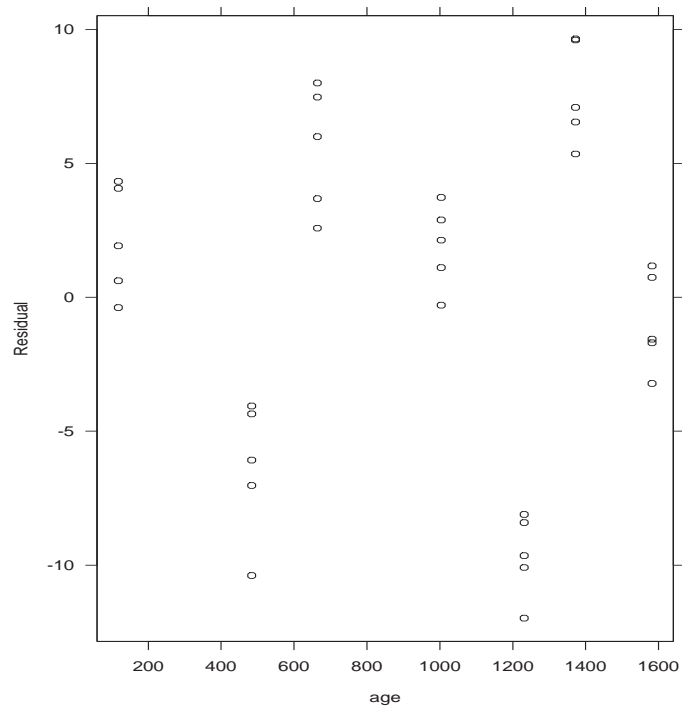


Figure 15.16 Plot of the residuals from the nonlinear model of Pinheiro and Bates

15.10 Multivariate animal genetics data - Sheep

The analysis of incomplete or unbalanced multivariate data often presents computational difficulties. These difficulties are exacerbated by either the number of random effects in the linear mixed model, the number of traits, the complexity of the variance models being fitted to the random effects or the size of the problem. In this section we illustrate two approaches to the analysis of a complex set of incomplete multivariate data.

Much of the difficulty in conducting such analyses in ASReml centres on obtaining good starting values. Derivative based algorithms such as the AI algorithm can be unreliable when fitting complex variance structures unless good starting values are available. Poor starting values may result in divergence of the algorithm or slow convergence. A particular problem with fitting unstructured variance models is keeping the estimated variance matrix positive definite. These are not simple issues and in the following we present a pragmatic approach to them.

The data are taken from a large genetic study on Coopworth lambs. A total of 5 traits, namely weaning weight (**wwt**), yearling weight (**ywt**), greasy fleece weight (**gfw**), fibre diameter (**fdm**) and ultrasound fat depth at the C site (**fat**) were measured on 7043 lambs. The lambs were the progeny of 92 sires and 3561 dams, produced from 4871 litters over 49 flock-year combinations. Not all traits were measured on each group. No pedigree data was available for either sires or dams.

The aim of the analysis is to estimate heritability (h^2) of each trait and to estimate the genetic correlations between the five traits. We will present two approaches, a half-sib analysis and an analysis based on the use of an animal model, which directly defines the genetic covariance between the progeny and sires and dams.

The data fields included factors defining sire, dam and lamb (**tag**), covariates such as **age**, the age of the lamb at a set time, **brr** the birth rearing rank (1 = born single raised single, 2 = born twin raised single, 3 = born twin raised twin and 4 = other), **sex** (M, F) and **grp** a factor indicating the flock-year combination.

Half-sib analysis

In the half-sib analysis we include terms for the random effects of **sires**, **dams** and **litters**. In univariate analyses the variance component for **sires** is denoted by $\sigma_s^2 = \frac{1}{4}\sigma_A^2$ where σ_A^2 is the additive genetic variance, the variance component for **dams** is denoted by $\sigma_d^2 = \frac{1}{4}\sigma_A^2 + \sigma_m^2$ where σ_m^2 is the maternal variance component and the variance component for **litters** is denoted by σ_l^2 and represents variation attributable to the particular mating.

For a multivariate analysis these variance components for **sires**, **dams** and **litters** are, in theory replaced by unstructured matrices, one for each term. Additionally we assume the residuals for each trait may be correlated. Thus for this example we would like to fit a total of 4 unstructured variance models. For such a situation, it is sensible to commence the modelling process with a series of univariate analyses. These give starting values for the diagonals of the variance matrices, but also indicate what variance components are estimable. The ASReml job for the univariate analyses is

Multivariate Sire & Dam model

```
tag
sire  92 !I
dam  3561 !I
grp   49
sex
brr   4
litter 4871
```

Table 15.13: REML estimates of a subset of the variance parameters for each trait for the genetic example, expressed as a ratio to their asymptotic s.e.

term	wwt	ywt	gfw	fdm	fat
sire	3.68	3.57	3.95	1.92	1.92
dam	6.25	4.93	2.78	0.37	0.05
litter	8.79	0.99	2.23	1.91	0.00
age.grp	2.29	1.39	0.31	1.15	1.74
sex.grp	2.90	3.43	3.70	-	1.83

Table 15.14 Wald tests of the fixed effects for each trait for the genetic example

term	wwt	ywt	gfw	fdm	fat
age	331.3	67.1	52.4	2.6	7.5
brr	554.6	73.4	14.9	0.3	13.9
sex	196.1	123.3	0.2	2.9	0.6
age.sex	10.3	1.7	1.9	-	5.0

```

age      wwt  !M0 ywt  !M0  # !M0 recodes zeros as missing values
gfw     !M0 fdm  !M0 fat  !M0
coop.fmt
wwt ~ mu age brr sex age.sex !r sire dam lit age.grp sex.grp !f grp

```

Tables 15.13 and 15.14 present the summary of these analyses. Fibre diameter was measured on only 2 female lambs and so interactions with `sex` were not fitted. The dam variance component was quite small for both fibre diameter and fat. The REML estimate of the variance component associated with litters was effectively zero for fat.

Thus in the multivariate analysis we consider fitting the following models to the sire, dam and litter effects,

$$\text{var}(\mathbf{u}_s) = \boldsymbol{\Sigma}_s \otimes \mathbf{I}_{92}$$

$$\begin{aligned}\text{var}(\mathbf{u}_d) &= \boldsymbol{\Sigma}_d \otimes \mathbf{I}_{3561} \\ \text{var}(\mathbf{u}_l) &= \boldsymbol{\Sigma}_l \otimes \mathbf{I}_{4891}\end{aligned}$$

where $\boldsymbol{\Sigma}_s^{5 \times 5}$, $\boldsymbol{\Sigma}_d^{3 \times 3}$ and $\boldsymbol{\Sigma}_l^{4 \times 4}$ are positive definite symmetric matrices corresponding to the between traits variance matrices for sires, dams and litters respectively. The variance matrix for dams does not involve fibre diameter and fat depth, while the variance matrix for litters does not involve fat depth. The effects in each of the above vectors are ordered levels within traits. Lastly we assume that the residual variance matrix is given by

$$\boldsymbol{\Sigma}_e \otimes \mathbf{I}_{7043}$$

Table 15.15 presents the sequence variance models fitted to each of the four random terms `sire`, `dam`, `litter` and `error` in the ASReml job

Multivariate Sire & Dam model

```

tag
sire 92 !I
dam 3561 !I
grp 49
sex
brr 4
litter 4871
age wwt !m0 ywt !m0 # !M0 identifies missing values
gfw !m0 fdm !m0 fat !m0
coop.fmt !DOPATH $1 !CONTINUE !MAXIT 20
!PATH 3
!EXTRA 4
!PATH
wwt ywt gfw fdm fat ~ Trait Tr.age Tr.brr Tr.sex Tr.age.sex,
!r Tr.sire,
!{ at(Tr,1).dam at(Tr,2).dam at(Tr,3).dam !},
!{ at(Tr,1).lit at(Tr,2).lit at(Tr,3).lit at(Tr,4).lit !},
at(Trait,1).age.grp .0024,
at(Trait,2).age.grp .0019,
at(Trait,4).age.grp .0020,
at(Trait,5).age.grp .00026,
at(Trait,1).sex.grp .93,
at(Trait,2).sex.grp 16.0,
at(Trait,3).sex.grp .28,
at(Trait,5).sex.grp 1.18,
!f Tr.grp

1 2 3 #1 R structure with 2 dimensions and 3 G structures

0 0 0 #Independent across animals

Tr 0 US #General structure across traits

```

```

15*0.                #Asreml will estimate some starting values

Tr.sire 2            #Sire effects.

!PATH 1              #Initial analysis ignoring genetic correlations
Tr 0 DIAG            #Specified diagonal variance structure
0.608 1.298 0.015 0.197 0.035      #Initial sire variances

!PATH 2              #Factor Analytic model
Tr 0 FA1 !GP
    0.5 0.5 -.01 -.01 0.1          #Correlation factors
0.608 1.298 0.015 0.197 0.035      #Variances

!PATH 3              #Unstructured variance model
Tr 0 US
0.6199              #Lower triangle row-wise
    0.6939          1.602
    0.003219 0.007424 0.01509
-0.02532 -0.05840 -0.0002709 0.1807
    0.06013 0.1387      0.0006433 -0.005061 0.03487
!PATH
sire

#Maternal structure covers the 3 model terms
#          at(Tr,1).dam at(Tr,2).dam at(Tr,3).dam

at(Tr,1).dam 2      # Maternal effects.
!PATH 1
3 0 CORGH !GU      # Equivalent to Unstructured
.9
.1 .1
2.2 4.14 0.018
!PATH 2
3 0 CORGH !GU
.9
.1 .1
2.2 4.14 0.018
!PATH 3
3 0 US !GU
.9
.1 .1
2.2 4.14 0.018
!PATH
dam

#Litter structure covers the 4 model terms at(Tr,1).lit at(Tr,2).lit
#at(Tr,3).lit at(Tr,4).lit

at(Tr,1).lit 2     # Litter effects.
!PATH 1
4 0 DIAG           # Diagonal structure

```

```

3.74 0.97 0.019 0.941
!PATH 2
4 0 FA1 !GP                # Factor Analytic 1
.5 .5 .01 .1
4.95 4.63 0.037 0.941
!PATH 3
4 0 US                      # Unstructured
5.073
  3.545      3.914
0.1274      0.08909 0.02865
0.07277 0.05090 0.001829 1.019

!PATH
lit

```

Table 15.15: Variance models fitted for each part of the ASReml job in the analysis of the genetic example

term	matrix	!PATH 1	!PATH 2	!PATH 3
sire	Σ_s	DIAG	FA1	US
dam	Σ_d	CORGH	CORGH	US
litter	Σ_l	DIAG	FA1	US
error	Σ_e	US	US	US

In !PATH 1, the error variance model is taken to be unstructured, but the starting values are set to zero. This instructs ASReml to obtain starting values from the sample covariance matrix of the data. For incomplete data the matrix so obtained may not, in general be positive definite. Care should be taken when using this option for incomplete multivariate data. The command to run !PATH 1 is

```
asreml -nrw64 mt 1
```

The Loglikelihood from this run is $-20000 - 1444.93$. When the job runs, the message

```
Non positive definite G matrix: 0 singularities 1 negative pivots;
order 3
```

appears to the screen. This refers to the 3×3 dam matrix which is estimated as

```
Covariance/Variance/Correlation Matrix CORRelation
2.573      1.025      0.6568
3.024      3.382      0.7830
0.1526     0.2086     0.2098E-01
```

Note the correlation between `wwt` and `ywt` is estimated at 1.025.

The results from this analysis can be automatically used by ASReml for the next part, if the `.rsv` is copied prior to running the next part. That is, we add the `!PATH 2` coding to the job, copy `mt1.rsv` to `mt2.rsv` so that when we run `!PATH 2` it starts from where `!PATH 1` finished, and run the job using

```
asreml -cnrw64 mt 2
```

The Loglikelihood from this run is $-20000 - 1427.37$.

Finally, we use the `!PATH 3` coding to obtain the final analysis, copy `mt2.rsv` to `mt3.rsv` and run the final stage starting from the stage 2 results. Note that we are using the automatic updating associated with `!CONTINUE`. A portion of the final output file is

```
Notice: LogL values are reported relative to a base of      -20000.00
NOTICE:      76 singularities detected in design matrix.
 1 LogL=-1427.37      S2=  1.0000      35006 df : 2 components constrained
 2 LogL=-1424.58      S2=  1.0000      35006 df
 3 LogL=-1421.07      S2=  1.0000      35006 df : 1 components constrained
 4 LogL=-1420.11      S2=  1.0000      35006 df
 5 LogL=-1419.93      S2=  1.0000      35006 df
 6 LogL=-1419.92      S2=  1.0000      35006 df
 7 LogL=-1419.92      S2=  1.0000      35006 df
 8 LogL=-1419.92      S2=  1.0000      35006 df
 9 LogL=-1419.92      S2=  1.0000      35006 df
10 LogL=-1419.92      S2=  1.0000      35006 df
11 LogL=-1419.92      S2=  1.0000      35006 df

Source              Model  terms      Gamma      Component      Comp/SE      % C
at(Trait,1).age.grp  49    49  0.135360E-02  0.135360E-02  2.03  0 P
at(Trait,2).age.grp  49    49  0.101561E-02  0.101561E-02  1.24  0 P
at(Trait,4).age.grp  49    49  0.176505E-02  0.176505E-02  1.13  0 P
at(Trait,5).age.grp  49    49  0.209279E-03  0.209279E-03  1.68  0 P
at(Trait,1).sex.grp  49    49  0.919610      0.919610      2.89  0 P
at(Trait,2).sex.grp  49    49  15.3912      15.3912      3.50  0 P
at(Trait,3).sex.grp  49    49  0.279496      0.279496      3.71  0 P
at(Trait,5).sex.grp  49    49  1.44032      1.44032      1.80  0 P
Residual            UnStru  1    1  9.46220      9.46220      33.30  0 U
:                   :                   :                   :                   :
```



```

Covariance/Variance/Correlation Matrix UnStructured Residual
 9.462    0.5691    0.2356    0.1640    0.2183
 7.332    17.54     0.4241    0.2494    0.4639
 0.2728   0.6686     0.1417    0.3994    0.1679
 0.9625   1.994      0.2870    3.642     0.4875E-01
 0.8336   2.412      0.7846E-01 0.1155    1.541
Covariance/Variance/Correlation Matrix UnStructured Tr.sire
 0.5941   0.7044     0.2966    0.2032    0.2703
 0.6745   1.544      0.1364E-01-0.1224    0.5726
 0.2800E-01 0.2076E-02 0.1500E-01 0.1121    -0.4818E-02
 0.6238E-01-0.6056E-01 0.5469E-02 0.1586    -0.6331
 0.3789E-01 0.1294     -0.1073E-03-0.4586E-01 0.3308E-01
Covariance/Variance/Correlation Matrix UnStructured at(Tr,1).dam
 2.161    1.010     0.7663
 2.196    2.186     0.8301
 0.1577   0.1718     0.1959E-01
Covariance/Variance/Correlation Matrix UnStructured at(Tr,1).lit
 3.547    0.5065    -0.1099    -0.4096E-01
 1.555    2.657     0.1740    -0.5150
-0.2787E-01 0.3821E-01 0.1815E-01-0.3282
-0.7312E-01-0.7957    -0.4191E-01 0.8984

Analysis of Variance          NumDF          F_inc
15 Tr.age                    5              98.95
16 Tr.brr                    15             116.72
17 Tr.sex                    5              59.78
19 Tr.age.sex                 4              4.90

```

In the `.res` file is reported an eigen analysis of these four variance structures.

```

Eigen Analysis of UnStructured matrix for Residual
Eigen values  22.458    5.210    3.395    1.160    0.103
Percentage   69.474   16.118   10.502    3.588    0.318
 1          0.4970   -0.8663   0.0141    0.0470    0.0027
 2          0.8509    0.4765  -0.1316   -0.1746   -0.0327
 3          0.0335    0.0230   0.0585   -0.0048    0.9974
 4          0.1168    0.0871   0.9843    0.0769   -0.0633
 5          0.1187    0.1196  -0.1010    0.9805    0.0039

Eigen Analysis of UnStructured matrix for Tr.sire
Eigen values  1.904    0.304    0.114    0.013    0.010
Percentage   81.199   12.963    4.859    0.535    0.444
 1          0.4578    0.7476   0.4695   -0.1052    0.0087
 2          0.8860   -0.3646  -0.2766    0.0248   -0.0700
 3          0.0077    0.0798   0.0826    0.9438   -0.3098
 4         -0.0163    0.5260  -0.8015    0.1116    0.2612
 5          0.0710   -0.1587    0.2320    0.2918    0.9115

Eigen Analysis of UnStructured matrix for at(Tr,1).dam

```

```

Eigen values      4.382      0.010      -0.025
Percentage        100.352      0.225      -0.577
  1                0.7041     -0.2321     0.6711
  2                0.7081     0.1585     -0.6881
  3                0.0533     0.9597     0.2760

Eigen Analysis of UnStructured matrix for at(Tr,1).lit
Eigen values      4.795      1.827      0.482      0.016
Percentage        67.345     25.664      6.769      0.221
  1                0.7752     0.5928     0.2178     0.0133
  2                0.6159     -0.6328    -0.4691    -0.0106
  3                0.0016     -0.0340     0.0255     0.9991
  4               -0.1403     0.4969    -0.8555     0.0390

```

The REML estimates of all the variance matrices except for the dam components are positive definite. Heritabilities for each trait can be calculated using the `.pin` file facility of ASReml. The heritability is given by

$$h^2 = \frac{\sigma_A^2}{\sigma_P^2}$$

where σ_P^2 is the phenotypic variance and is given by

$$\sigma_P^2 = \sigma_s^2 + \sigma_d^2 + \sigma_l^2 + \sigma_e^2$$

recalling that

$$\sigma_s^2 = \frac{1}{4}\sigma_A^2$$

$$\sigma_d^2 = \frac{1}{4}\sigma_A^2 + \sigma_m^2$$

In the half-sib analysis we only use the estimate of additive genetic variance from the sire variance component. The ASReml `.pin` file is presented below along with the output from the following command

```
asreml -p mt3
```

```

F phenWYG 9:14 + 24:29 + 39:44 + 45:50 # defines 55:60
F phenD 15:18 + 30:33 + 51:54 # defines 61:64
F phenF 19:23 + 34:38 # defines 65:69
F Direct 24:38 * 4. # defines 70:84
F Maternal 39:44 - 24:29 # defines 85:90
H WWTh2 70 55
H YWTh2 72 57
H GFWh2 75 60
H FDMh2 79 64
H FATH2 84 69
R GenCor 24:38
R MatCor 85:90

```

55 phenWYG 9	15.76	0.3130		
56 phenWYG 10	11.76	0.3749		
57 phenWYG 11	23.92	0.6313		
.
70 Direct 24	2.376	0.6458		
71 Direct 25	2.698	0.8487		
72 Direct 26	6.174	1.585		
73 Direct 27	0.1120	0.7330E-01		
.
85 Maternal 39	1.567	0.3788		
86 Maternal 40	1.521	0.4368		
87 Maternal 41	0.6419	0.7797		
.
WTh2	= Direct 2	70/phenWYG	55=	0.1507 0.0396
YTh2	= Direct 2	72/phenWYG	57=	0.2581 0.0624
GFWh2	= Direct 2	75/phenWYG	60=	0.3084 0.0716
FDMh2	= Direct 3	79/phenD 18	64=	0.1350 0.0717
FATH2	= Direct 3	84/phenF 23	69=	0.0841 0.0402
GenCor 2 1	= Tr.si 25/SQR	[Tr.si 24*Tr.si 26]=		0.7044 0.1025
GenCor 3 1	= Tr.si 27/SQR	[Tr.si 24*Tr.si 29]=		0.2966 0.1720
GenCor 3 2	= Tr.si 28/SQR	[Tr.si 26*Tr.si 29]=		0.0136 0.1810
GenCor 4 1	= Tr.si 30/SQR	[Tr.si 24*Tr.si 33]=		0.2028 0.3513
GenCor 4 2	= Tr.si 31/SQR	[Tr.si 26*Tr.si 33]=		-0.1227 0.3247
GenCor 4 3	= Tr.si 32/SQR	[Tr.si 29*Tr.si 33]=		0.1115 0.3868
GenCor 5 1	= Tr.si 34/SQR	[Tr.si 24*Tr.si 38]=		0.2703 0.2724
GenCor 5 2	= Tr.si 35/SQR	[Tr.si 26*Tr.si 38]=		0.5726 0.2022
GenCor 5 3	= Tr.si 36/SQR	[Tr.si 29*Tr.si 38]=		-0.0048 0.2653
GenCor 5 4	= Tr.si 37/SQR	[Tr.si 33*Tr.si 38]=		-0.6333 0.3775
MatCor 2 1	= Mater 86/SQR	[Mater 85*Mater 87]=		1.5168 0.7131
MatCor 3 1	= Mater 88/SQR	[Mater 85*Mater 90]=		1.5285 1.1561
MatCor 3 2	= Mater 89/SQR	[Mater 87*Mater 90]=		3.1251 2.7985

Animal model

In this section we will illustrate the use of `.ped` files to define the genetic pedigree structure between animals. This is an alternate method of estimating additive genetic variance for these data. The variance matrix of the animals (sires, dams and lambs) for which we only have data on lambs is given by

$$\text{var}(\mathbf{u}_A) = \boldsymbol{\Sigma}_A \otimes \mathbf{A}^{-1}$$

where \mathbf{A}^{-1} is the inverse of the genetic relationship matrix. There are a total of $10696 = 92 + 3561 + 7043$ animals in the pedigree. The ASReml input file is presented below. Note that this model is not equivalent to the sire/dam/litter model with respect to the animal/litter components for gfw, fd and fat.

```
Multivariate Animal model
tag !P
sire
dam !P
grp 49
sex
brr 4
litter 4871
age wwt !m0 ywt !m0 # !M0 identifies missing values
gfw !m0 fdm !m0 fat !m0
coop.fmt # read pedigree from first three fields
coop.fmt !DOPATH $1 !CONTINUE !MAXIT 20 !STEP 0.01
# $1 allows selection of PATH as a command line argument
!PATH 3
!EXTRA 4 # Force 4 more iterations after convergence criterion met
!PATH
wwt ywt gfw fdm fat ~ Trait Tr.age Tr.brr Tr.sex Tr.age.sex,
!r Tr.tag ,
at(Tr,1).dam, at(Tr,2).dam, -at(Tr,3).dam .003,
at(Tr,1).lit, at(Tr,2).lit, at(Tr,3).lit, at(Tr,4).lit,
at(Trait,1).age.grp .0024,
at(Trait,2).age.grp .0019,
at(Trait,4).age.grp .0020,
at(Trait,5).age.grp .00026,
at(Trait,1).sex.grp .93,
at(Trait,2).sex.grp 16.0,
at(Trait,3).sex.grp .28,
at(Trait,5).sex.grp 1.18,
!f Tr.grp

1 2 3 # One multivariate R structure, 3 G structures

0 0 0 # No structure across lamb records
# First zero lets ASReml count the number of records
Tr 0 US #General structure across traits
7.66
```

```

5.33 13
.18 .66 .10
.78 2.1 .27 3.2
.73 2.02 .08 .20 1.44

Tr.tag 2                # Direct animal effects.

!PATH 2
Tr 0 FA1 !GP
    0.5 0.5 -.01 -.01 0.1
2.4 5.2 0.06 .8 .14

!PATH 3
Tr 0 US
2.4800
    2.8 6.4
0.0128 0.03 0.06
-.1 -.22 -.0011 0.72
    0.24 0.55      0.0026 -0.0202 0.14
!PATH
tag

at(Tr,1).dam 2          # Maternal effects.
!PATH 2
2 0 CORGH !GFU
.99
1.6 2.54
!PATH 3
2 0 US !GU
1.1 .58 .31
!PATH
dam

at(Tr,1).lit 2          # Litter effects.
!PATH 2
4 0 FA1 !GP            # Factor Analytic
.5 .5 .01 .1 .01
4.95 4.63 0.037 0.941 0.102
!PATH 3
4 0 US                # Unstructured
5.073
    3.545      3.914
    0.1274     0.08909 0.02865
    0.07277 0.05090 0.001829 1.019

!PATH
lit

```

The term `Tr.tag` now replaces the `sire` (and part of `dam`) terms in the half-sib analysis. This analysis uses information from both sires and dams to estimate

additive genetic variance. The dam variance component in this analysis only estimates the maternal variance component. It is only significant for the weaning and yearling weights. The litter variation remains unchanged. The ASReml input file again consists of several parts, which progressively build up to fitting unstructured variance models to `Tr.tag`, `Tr.dam`, `Tr.litter` and error. A portion of the output file is

```

tag !P
dam !P
age      wwt  !m0 ywt  !m0
gfw  !m0 fdm  !m0 fat  !m0
A-inverse retrieved from ainverse.bin
PEDIGREE [pcoop.fmt ] has 10696 identities, 29474 Non zero elements
QUALIFIERS: !CONTINUE !MAXIT 20 !STEP 0.01
QUALIFIERS: !EXTRA 4
QUALIFIER: !DOPATH 3 is active
Reading pcoop.fmt FREE FORMAT skipping 0 lines

Multivariate analysis of wwt          ywt          gfw          fdm

Multivariate analysis of fat
Using 7043 records of 7043 read
Model term          Size #miss #zero  MinNon0  Mean  MaxNon0
1 tag                !P 10696  0  0  3.000  5380.  0.1070E+05
2 sire                !P 10696  0  0  1.000  48.06  92.00
3 dam                !P 10696  0  0  1.000  5197.  0.1070E+05
:
Forming 95033 equations: 40 dense.
Initial updates will be shrunk by factor 0.010
Restarting iteration from previous solution
Notice: LogL values are reported relative to a base of -20000.00
NOTICE: 76 singularities detected in design matrix.
1 LogL=-1437.10 S2= 1.0000 35006 df : 2 components constrained
2 LogL=-1436.87 S2= 1.0000 35006 df : 3 components constrained
3 LogL=-1434.97 S2= 1.0000 35006 df : 2 components constrained
4 LogL=-1430.73 S2= 1.0000 35006 df : 2 components constrained
5 LogL=-1424.71 S2= 1.0000 35006 df : 1 components constrained
6 LogL=-1417.98 S2= 1.0000 35006 df : 1 components constrained
7 LogL=-1417.77 S2= 1.0000 35006 df : 1 components constrained
8 LogL=-1417.62 S2= 1.0000 35006 df : 1 components constrained
9 LogL=-1417.28 S2= 1.0000 35006 df
10 LogL=-1417.23 S2= 1.0000 35006 df
:
16 LogL=-1417.23 S2= 1.0000 35006 df

Source          Model terms  Gamma  Component  Comp/SE  % C
at(Trait,1).age.grp  49 49 0.132682E-02 0.132682E-02 2.02 0 P
at(Trait,2).age.grp  49 49 0.908220E-03 0.908220E-03 1.15 0 P
at(Trait,4).age.grp  49 49 0.175614E-02 0.175614E-02 1.13 0 P
at(Trait,5).age.grp  49 49 0.223617E-03 0.223617E-03 1.73 0 P

```

```

at(Trait,1).sex.grp      49      49  0.902586      0.902586      2.88  0 P
at(Trait,2).sex.grp      49      49  15.3623      15.3623      3.50  0 P
at(Trait,3).sex.grp      49      49  0.280673     0.280673     3.71  0 P
at(Trait,5).sex.grp      49      49  1.42136      1.42136      1.80  0 P
Residual                 UnStru   1   1   7.47555      7.47555     13.86  0 U
:
Covariance/Variance/Correlation Matrix UnStructured Residual
  7.476    0.4918    0.1339    0.1875    0.1333
  4.768    12.57     0.4381    0.3425    0.3938
  0.1189    0.5049    0.1056    0.4864    0.1298
  0.9377    2.221     0.2891    3.345     0.1171
  0.4208    1.612     0.4869E-01 0.2473    1.333

Covariance/Variance/Correlation Matrix UnStructured Tr.tag
  3.898    0.8164    0.5763    0.3899E-01 0.6148
  4.877    9.154     0.3689   -0.1849    0.7217
  0.3029    0.2971    0.7085E-01-0.2415E-01 0.3041
  0.6021E-01-0.4375   -0.5027E-02 0.6117   -0.4672
  0.6154    1.107     0.4104E-01-0.1853    0.2570

Covariance/Variance/Correlation Matrix UnStructured at(Tr,1).dam
  0.9988    0.7024
  0.5881   -0.7018

Covariance/Variance/Correlation Matrix UnStructured at(Tr,1).lit
  3.714    0.5511    0.1635   -0.6157E-01
  2.019    3.614     0.5176   -0.4380
  0.4506E-01 0.1407    0.2045E-01-0.3338
-0.1021   -0.7166   -0.4108E-01 0.7407

Analysis of Variance          NumDF          F_inc
15 Tr.age                    5              99.16
16 Tr.brr                     15             116.52
17 Tr.sex                      5              59.94
19 Tr.age.sex                  4              5.10

```

There is no guarantee that unstructured variance component matrices will be positive definite unless !GP qualifier is set. This example highlights this issue. We used the !GU qualifier on the maternal component to obtain the matrix

$$\begin{bmatrix} 0.9988 & 0.5881 \\ 0.5881 & -0.7018 \end{bmatrix}.$$

ASReml reports the correlation as 0.7024 which it obtains by ignoring the sign in -0.7018. This is the maternal component for ywt. Since it is entirely reasonable to expect maternal influences on growth to have dissipated at 12 months of age, it would be reasonable to refit the model omitting at(Tr,2).dam and changing the dimension of the G structure.

Bibliography

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