Employing `asremlPlus`, in conjunction with `asreml`, to calculate and use information criteria

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This vignette illustrates the facilities in `asremlPlus` (Brien, 2021), in conjunction with `asreml` (Butler et al., 2020), for calculating and using information. Here, `asremlPlus` and `asreml` are packages for the R Statistical Computing environment (R Core Team, 2021).

It is divided into the following main sections:

1. Set up the maximal model for this experiment
2. Obtaining information criteria for separate models
3. Obtaining information criteria for a prescribed sequence of model changes
4. Using information criteria to decide model changes

1. Set up the maximal model for this experiment

```
library(knitr)
opts_chunk$set("tidy" = FALSE, comment = NA)
suppressMessages(library(asreml, quietly=TRUE))
```

```
## Online License checked out Mon Dec  6 12:35:24 2021
```

```
packageVersion("asreml")
```

```
## [1] '4.1.0.154'
```

```
suppressMessages(library(asremlPlus))
packageVersion("asremlPlus")
```

```
## [1] '4.3.31'
```

```
options(width = 100)
```

Get data available in asremlPlus

The data are from a 1976 spring wheat experiment and are taken from Gilmour et al. (1995). An analysis is presented in the `asreml` manual by Butler et al. (2020, Section 7.6), although they suggest that it is a barley experiment.

```
data(Wheat.dat)
```

Fit the maximal model

In the following a model is fitted that has the terms that would be included for a balanced lattice. In addition, a term WithinColPairs has been included to allow for extraneous variation arising between pairs of adjacent lanes. Also, separable ar1 residual autocorrelation has been included. This model represents the maximal anticipated model,

```
max.asr <- asreml(yield ~ WithinColPairs + Variety,
                  random = ~ Rep/(Row + Column) + units,
                  residual = ~ ar1(Row):ar1(Column),
                  data=Wheat.dat)
```

```
Online License checked out Mon Dec  6 12:35:25 2021
Model fitted using the gamma parameterization.
ASReml 4.1.0 Mon Dec  6 12:35:25 2021
          LogLik        Sigma2    DF      wall       cpu
  1      -724.121     23034.14   124 12:35:25       0.0
  2      -717.415      9206.93   124 12:35:25       0.0 (2 restrained)
  3      -694.875     26492.99   124 12:35:25       0.0 (2 restrained)
  4      -694.160     33101.80   124 12:35:25       0.0 (1 restrained)
  5      -692.002     36912.26   124 12:35:25       0.0 (1 restrained)
  6      -691.789     46701.51   124 12:35:25       0.0 (2 restrained)
  7      -691.834     46208.51   124 12:35:25       0.0 (1 restrained)
  8      -691.775     47698.26   124 12:35:25       0.0
  9      -691.771     47041.85   124 12:35:25       0.0
```

```
Warning in asreml(yield ~ WithinColPairs + Variety, random = ~Rep/(Row + : Some components changed
by more than 1% on the last iteration.
```

The warning from `asreml` is probably due to a bound term.

Initialize a testing sequence by loading the current fit into an asrtests object

```
max.asrt <- as.asrtests(max.asr, NULL, NULL)
```

Check for and remove any boundary terms

```
max.asrt <- rmboundary(max.asrt)
summary(max.asrt$asreml.obj)$varcomp
```

```
                          component      std.error      z.ratio bound %ch
Rep:Row                4.293282e+03 3.199458e+03   1.3418779     P 0.0
Rep:Column             1.575689e+02 1.480357e+03   0.1064398     P 0.7
units                  5.742689e+03 1.652457e+03   3.4752438     P 0.0
Row:Column!R           4.706787e+04 2.515832e+04   1.8708669     P 0.0
Row:Column!Row!cor     7.920301e-01 1.014691e-01   7.8056280     U 0.0
Row:Column!Column!cor  8.799559e-01 7.370402e-02  11.9390486     U 0.0
```

```
print(max.asrt, which = "testsummary")
```

Sequence of model investigations

(If a row has NA for p but not denDF, DF and denDF relate to fixed and variance parameter numbers)

```
  terms DF denDF  p AIC BIC   action
1   Rep  1    NA NA  NA  NA Boundary
```

Rep has been removed because it has been constrained to zero. Following the recommendation of Littel et al. (2006, p. 150), the bound on all variance components is set to unconstrained (U) using `setvariances.asreml` so as to avoid bias in the estimate of the residual variance. Alternatively, one could move Rep to the fixed model.

Unbind Rep, Row and Column components and reload into an asrtests object

```
max.asr <- setvarianceterms(max.asr$call,
                            terms = c("Rep", "Rep:Row", "Rep:Column"),
                            bounds = "U")
```

```
Model fitted using the gamma parameterization.
ASReml 4.1.0 Mon Dec  6 12:35:25 2021
          LogLik        Sigma2   DF      wall    cpu
  1      -724.121      23034.14  124 12:35:25    0.0
  2      -717.415       9206.93  124 12:35:25    0.0 (2 restrained)
  3      -694.875      26492.99  124 12:35:25    0.0 (2 restrained)
  4      -693.974      33129.65  124 12:35:25    0.0 (1 restrained)
  5      -692.886      39662.12  124 12:35:25    0.0
  6      -691.428      53103.83  124 12:35:25    0.0
  7      -691.239      48092.17  124 12:35:26    0.0
  8      -691.181      47278.94  124 12:35:26    0.0
  9      -691.171      46850.98  124 12:35:26    0.0
 10      -691.170      46690.46  124 12:35:26    0.0
```

Warning in asreml(fixed = yield ~ WithinColPairs + Variety, random = ~Rep/(Row + : Some components changed by more than 1% on the last iteration.

```
max.asrt <- as.asrtests(max.asr, NULL, NULL)
max.asrt <- rmboundary(max.asrt)
summary(max.asrt$asreml.obj)$varcomp
```

```
                         component     std.error    z.ratio bound %ch
Rep                   -2462.3785855 1.191435e+03  -2.066734     U 0.2
Rep:Row                5012.4021412 3.396848e+03   1.475604     U 0.1
Rep:Column              920.5936388 1.704008e+03   0.540252     U 1.1
units                  5964.9099373 1.608792e+03   3.707695     P 0.1
Row:Column!R          46690.4620349 2.731906e+04   1.709080     P 0.0
Row:Column!Row!cor        0.8152180 9.988929e-02   8.161216     U 0.1
Row:Column!Column!cor     0.8857252 7.487875e-02  11.828793     U 0.0
```

```
print(max.asrt, which = "testsummary")
```

Sequence of model investigations

(If a row has NA for p but not denDF, DF and denDF relate to fixed and variance parameter numbers)

```
[1] terms  DF    denDF  p    AIC    BIC    action
<0 rows> (or 0-length row.names)
```

Now the Rep component estimate is negative.

The `test.summary` output shows that no changes have been made to the model loaded using `as.asrtests`. The pseudo-anova table shows that Varieties are highly significant ($p < 0.001$)

2. Obtaining information criteria for separate models

The method `infoCriteria` has two methods for calculating information criteria. One, `infoCriteria.asreml`, is a method for `asreml` objects and the other, `infoCriteria.list`, if for 'list`objects, the components of the`list`being`asreml' objects.

Single models

Firstly, `infoCriteria` is called with the default `IClikelihood`, which is `REML`. Then it is called with `IClikelihood` set to `full` (Verbyla, 2019).

```
infoCriteria(max.asr)
```

```
  fixedDF varDF NBound     AIC      BIC  loglik
1       0     7      0 1396.34 1416.082 -691.17
```

```
infoCriteria(max.asr, IClikelihood = "full")
```

```
Model fitted using the gamma parameterization.
ASReml 4.1.0 Mon Dec  6 12:35:26 2021
          LogLik        Sigma2    DF    wall    cpu
 1      -691.170      46641.98   124 12:35:26   0.0


Warning in asreml(fixed = yield ~ WithinColPairs + Variety, random = ~Rep/(Row + : Log-likelihood
not converged


  fixedDF varDF NBound      AIC      BIC   loglik
1      26     7      0 1647.193 1746.544 -790.5967
```

A list of models

Now, a second model, from which the `withinColPairs` term has been omitted, is fitted; to be consistent, the variance components are unconstrained using `setvariances.asreml`. Then the `asreml` objects for this model and the maximal model are combined into a `list` and a `data.frame` produced that includes their information criteria.

```
m1.asr <- asreml(yield ~ Variety,
                 random = ~ Rep/(Row + Column) + units,
                 residual = ~ ar1(Row):ar1(Column),
                 data=Wheat.dat)
```

```
Model fitted using the gamma parameterization.
ASReml 4.1.0 Mon Dec  6 12:35:26 2021
          LogLik        Sigma2    DF     wall    cpu
  1      -727.774      22898.99   125 12:35:26    0.0
  2      -721.097       9190.30   125 12:35:26    0.0 (2 restrained)
  3      -698.313      26671.76   125 12:35:26    0.0 (2 restrained)
  4      -697.517      32677.28   125 12:35:26    0.0 (1 restrained)
  5      -695.419      36662.27   125 12:35:26    0.0 (1 restrained)
  6      -695.208      46263.96   125 12:35:26    0.0 (2 restrained)
  7      -695.198      46156.63   125 12:35:26    0.0
  8      -695.191      46630.21   125 12:35:26    0.0
```

Warning in asreml(yield ~ Variety, random = ~Rep/(Row + Column) + units, : Some components changed by more than 1% on the last iteration.

```
m1.asr <- setvarianceterms(m1.asr$call,
                           terms = c("Rep", "Rep:Row", "Rep:Column"),
                           bounds = "U")
```

```
Model fitted using the gamma parameterization.
ASReml 4.1.0 Mon Dec  6 12:35:26 2021
          LogLik        Sigma2    DF     wall    cpu
  1      -727.774      22898.99   125 12:35:26    0.0
  2      -721.097       9190.30   125 12:35:26    0.0 (2 restrained)
  3      -698.313      26671.76   125 12:35:26    0.0 (2 restrained)
  4      -697.333      32689.33   125 12:35:26    0.0 (1 restrained)
  5      -697.016      39975.97   125 12:35:26    0.0
  6      -695.070      54825.30   125 12:35:26    0.0
  7      -694.757      47637.20   125 12:35:26    0.0
  8      -694.644      46775.41   125 12:35:26    0.0
  9      -694.618      46175.06   125 12:35:26    0.0
 10      -694.615      45940.69   125 12:35:26    0.0
```

Warning in asreml(fixed = yield ~ Variety, random = ~Rep/(Row + Column) + : Some components changed by more than 1% on the last iteration.

```
mods <- list(max = max.asr, m1 = m1.asr)
ic <- infoCriteria(mods, IClikelihood = "full")
print(ic)
```

```
     fixedDF varDF NBound       AIC       BIC     loglik
max       26     7      0  1647.193  1746.544  -790.5967
m1        25     7      0  1645.326  1741.666  -790.6629
```

3. Obtaining information criteria for a prescribed sequence of model changes

The use of `changeTerms.asrtests` is demonstrated for a sequence of models, starting with the maximal model.

Drop the term for within Column pairs (a post hoc factor)

```
current.asrt <- as.asrtests(max.asrt$asreml.obj, NULL, NULL,
                            label = "Maximal model", IClikelihood = "full")
```

```
Warning in asreml(fixed = yield ~ WithinColPairs + Variety, random = ~Rep/(Row + : Log-likelihood
not converged
```

```
current.asrt <- changeTerms(current.asrt, dropFixed = "WithinColPairs",
                            label = "Drop withinColPairs", IClikelihood = "full")
```

```
Warning in asreml(fixed = yield ~ Variety, random = ~Rep + units + Rep:Row + : Some components
changed by more than 1% on the last iteration.
```

```
print(current.asrt, which = "testsummary", omit.columns = "p")
```

```
####  Sequence of model investigations

(If a row has NA for p but not denDF, DF and denDF relate to fixed and variance parameter numbers)

              terms DF denDF      AIC      BIC         action
1       Maximal model 26      7 1647.193 1746.544 Starting model
2 Drop withinColPairs 25      7 1645.326 1741.666  Changed fixed
```

So the same values of the information criteria have been obtained as when `infoCriteria.list` was used on a `list` containing the `asreml` objects for the two models. The differences is that here there is ultimately only one fitted model, the model stored in the `asreml` object in the `asrtests` object named `current.asrt`: this is the model with `withinColPairs` omitted.

Note this use of the `omit.columns` argument from `print.test.summary` to omit the irrelevant column `p` from the `test.summary`.

Drop nugget term

```
current.asrt <- changeTerms(current.asrt, dropRandom = "units",
                            label = "Drop units", IClikelihood = "full")
```

```
Warning in asreml(fixed = yield ~ Variety, random = ~Rep + Rep:Row + Rep:Column, : Some components
changed by more than 1% on the last iteration.
```

Check Row autocorrelation

```
current.asrt <- changeTerms(current.asrt, newResidual = "Row:ar1(Column)",
                            label="Row autocorrelation", IClikelihood = "full")
print(current.asrt, which = "testsummary", omit.columns = "p")
```

```
####  Sequence of model investigations

(If a row has NA for p but not denDF, DF and denDF relate to fixed and variance parameter numbers)

                  terms DF denDF      AIC      BIC          action
1         Maximal model 26     7 1647.193 1746.544    Starting model
2 Drop withinColPairs 25     7 1645.326 1741.666     Changed fixed
3            Drop units 25     6 1650.126 1743.456    Changed random
4 Row autocorrelation 25     5 1660.882 1751.201 Changed residual
```

4. Using information criteria to decide model changes

This sections illustrates the use of `changeModelOnIC.asrtests` to decide between consecutive models in a sequence of models. The default information criterion to use for this is the `AIC`. However, `which.IC` can be used to specify the use of the `BIC` or `both`. Here we use the `AIC` and the `full` likelihood.

Check the term for within Column pairs (a post hoc factor)

As before, we start with the maximal model, in which the variance components have been unconstrained and look to decide whether of not to drop the `withinColPairs` term.

```
current.asrt <- as.asrtests(max.asrt$asreml.obj, NULL, NULL,
                            label = "Maximal model", IClikelihood = "full")
```

```
Warning in asreml(fixed = yield ~ WithinColPairs + Variety, random = ~Rep/(Row + : Log-likelihood
not converged
```

```
current.asrt <- iterate(current.asrt)
current.asrt <- changeModelOnIC(current.asrt, dropFixed = "WithinColPairs",
                                label = "withinColPairs",
                                IClikelihood = "full", which.IC = "AIC",
                                allow.unconverged = FALSE)
```

```
Warning in asreml(fixed = yield ~ Variety, random = ~Rep + units + Rep:Row + : Some components
changed by more than 1% on the last iteration.
```

```
print(current.asrt, which = "testsummary", omit.columns = "p")
```

```
####  Sequence of model investigations
```

```
(If a row has NA for p but not denDF, DF and denDF relate to fixed and variance parameter numbers)

            terms DF denDF        AIC        BIC      action
1  Maximal model 26     7 1647.193455 1746.544420 Starting model
2 withinColPairs -1     0   -1.867556   -4.878191      Swapped
```

Given the warning about a lack of convergence, we use `iterate.asrtests` to perform additional iterations of the fitting process. It seems that it was successful.

It can be seen from the `test.summary` that the term has been swapped out and this has the effect of reducing the number of fixed parameters by one and makes no change to the variance parameters.

Check the nugget term

```
current.asrt <- changeModelOnIC(current.asrt, dropRandom = "units",
                                label = "units", IClikelihood = "full",
                                allow.unconverged = FALSE)
```

```
Warning in asreml(fixed = yield ~ Variety, random = ~Rep + Rep:Row + Rep:Column, : Some components
changed by more than 1% on the last iteration.
```

Check Row autocorrelation

```
current.asrt <- changeModelOnIC(current.asrt, newResidual = "Row:ar1(Column)",
                                label="Row autocorrelation", IClikelihood = "full",
                                allow.unconverged = FALSE)
```

```
Warning in asreml(fixed = yield ~ Variety, random = ~Rep + units + Rep:Row + : Log-likelihood not
converged
```

```
Warning in asreml(fixed = yield ~ Variety, random = ~Rep + units + Rep:Row + : Some components
changed by more than 1% on the last iteration.
```

```
Warning in newfit.asreml(asreml.obj, fixed. = fix.form, random. = ran.form, :
```

```
Warning in asreml(fixed = yield ~ Variety, random = ~Rep + units + Rep:Row + : Some components
changed by more than 1% on the last iteration.
```

```
Warning in asreml(fixed = yield ~ Variety, random = ~Rep + units + Rep:Row + : Some components
changed by more than 1% on the last iteration.
```

Check Column autocorrelation (depends on whether Row autocorrelation retained)

```
{
  last.action <- current.asrt$test.summary$action[current.asrt$test.summary$terms ==
                                                   "Row autocorrelation"]
  if (grepl("Unswapped", last.action, fixed = TRUE) |
      grepl("Unchanged", last.action, fixed = TRUE))
    current.asrt <- changeModelOnIC(current.asrt, newResidual = "ar1(Row):Column",
                                    label="Col autocorrelation", IClikelihood = "full",
                                    allow.unconverged = FALSE)
  else
    current.asrt <- testresidual(current.asrt, newResidual = "Row:Column",
                                 label="Col autocorrelation", IClikelihood = "full",
                                 allow.unconverged = FALSE)
}
```

Warning in infoCriteria.asreml(asreml.obj, IClikelihood = ic.lik, bound.exclusions = bound.exclusions):
 Row:Column!Row!cor

Warning in infoCriteria.asreml(new.asrtests.obj$asreml.obj, IClikelihood = ic.lik, : The following bound
 Row:Column!Row!cor

Output the results

```
print(current.asrt, which = "test", omit.columns = "p")
```


```
####   Sequence of model investigations

(If a row has NA for p but not denDF, DF and denDF relate to fixed and variance parameter numbers)

                terms DF denDF           AIC          BIC                         action
1       Maximal model 26     7 1647.193455 1746.544420                  Starting model
2      withinColPairs -1     0   -1.867556   -4.878191                         Swapped
3               units  0    -1    4.801145    1.790510                       Unswapped
4 Row autocorrelation  0    -1   17.819174   14.808538 Unchanged - new unconverged
5 Col autocorrelation  0    -2   19.479776   13.458506                       Unswapped
```

```
summary(current.asrt$asreml.obj)$varcomp
```


```
                         component     std.error     z.ratio bound %ch
Rep                  -2391.9489939 1.194581e+03 -2.0023338     U 0.4
Rep:Row               5035.5311054 3.406006e+03  1.4784269     U 0.3
Rep:Column             761.9535622 1.612103e+03  0.4726458     U 1.2
units                 5933.2133794 1.610805e+03  3.6833848     P 0.1
Row:Column!R         45970.8383027 2.635124e+04  1.7445415     P 0.0
Row:Column!Row!cor       0.8101615 9.995498e-02  8.1052641     U 0.1
Row:Column!Column!cor    0.8846970 7.503039e-02 11.7911827     U 0.0
```

The `test.summary` shows us that the model without the autocorrelation failed to converge and so no change
was made to the model. It, and the messages from checking the Column autocorrelation, also show us that

the omission of the Column autocorrelation resulted in the Row autocorrelation becoming bound. That is, dropping the Column autocorrelation resulted in the dropping of two variance parameters

The function `printFormulae.asreml` is used to display the fitted model.

```
printFormulae(current.asrt$asreml.obj)
```

```
#### Formulae from asreml object

fixed: yield ~ Variety
random: ~ Rep + units + Rep:Row + Rep:Column
residual: ~ ar1(Row):ar1(Column)
```

References

Brien, C. J. (2021) `asremlPlus`: *Augments ASReml-R in fitting mixed models and packages generally in exploring prediction differences.* Version 4.3-31. https://cran.r-project.org/package=asremlPlus/ or http://chris.brien.name/rpackages/.

Butler, D. G., Cullis, B. R., Gilmour, A. R., Gogel, B. J. and Thompson, R. (2020). *ASReml-R Reference Manual Version 4.1.0.130.* VSN International Ltd, https://https://asreml.kb.vsni.co.uk/.

Gilmour, A. R., Thompson, R., & Cullis, B. R. (1995). Average Information REML: An Efficient Algorithm for Variance Parameter Estimation in Linear Mixed Models. *Biometrics*, **51**, 1440–1450.

Littell, R. C., Milliken, G. A., Stroup, W. W., Wolfinger, R. D., & Schabenberger, O. (2006). *SAS for Mixed Models* (2nd ed.). Cary, N.C.: SAS Press.

R Core Team (2021) `R`: *A language and environment for statistical computing.* Vienna, Austria: R Foundation for Statistical Computing. https://www.r-project.org/.

Verbyla, A. P. (2019). A note on model selection using information criteria for general linear models estimated using REML. *Australian & New Zealand Journal of Statistics*, **61**, 39-50. https://doi.org/10.1111/anzs.12254/.