Package 'ARTool'

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Title Aligned Rank Transform

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Description The Aligned Rank Transform for nonparametric factorial ANOVAs as described by J. O. Wobbrock, L. Findlater, D. Gergle, & J. J. Higgins, ``The Aligned Rank Transform for nonparametric factorial analyses using only ANOVA procedures", CHI 2011 <DOI:10.1145/1978942.1978963>.

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License GPL (>= 2)

BugReports https://github.com/mjskay/ARTool/issues/new

URL https://github.com/mjskay/ARTool

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R topics documented:

`anova.art` *Aligned Rank Transform Analysis of Variance*

Description

Conduct analyses of variance on aligned rank transformed data.

Usage

```
## S3 method for class 'art'
anova(object, response = c("art", "aligned"), type = c("III",
  "II", "I", 3, 2, 1), factor.contrasts = "contr.sum", test = c("F",
  "Chisq"), all.rows = FALSE, ...)

## S3 method for class 'anova.art'
print(x, verbose = FALSE, digits = 5, ...)
```

Arguments

`object`	An object of class `art`.
`response`	Which response to run the ANOVA on: the aligned responses (`"aligned"`) or the aligned and ranked responses (`"art"`). This argument is passed to `artlm`. See 'Details'.
`type`	Type of ANOVAs to conduct. If `type` is `1` or `"I"`, then conducts Type I ANOVAs using `anova`. Otherwise, conducts Type II or Type III ANOVAs using `Anova`. The default is Type III *if* the underlying model supports it. Models fit with `Error` terms are fit using `aov`, which only supports Type I ANOVAs.
`factor.contrasts`	The name of the contrast-generating function to be applied by default to fixed effect factors. See the first element of `options("contrasts")`. The default is to use `"contr.sum"`, i.e. sum-to-zero contrasts, which is appropriate for Type III ANOVAs (also the default). This argument is passed to `artlm`.
`test`	Test statistic to use. Default `"F"`. Note that some models and ANOVA types may not support `"Chisq"`.
`all.rows`	Show all rows of the resulting ANOVA tables? By default (`FALSE`), shows only the rows that are relevant depending on the type of `response`.
`...`	Additional arguments passed to `Anova` or `anova` by `anova.art` or to `print` by `print.anova.art`.

x	An object of class art.
verbose	When TRUE, sums of squares and residual sum of squares in addition to degrees of freedom are printed in some ANOVA types (e.g. repeated measures ANOVAs). Default FALSE, for brevity.
digits	Digits of output in printed table; see print.

Details

This function runs several ANOVAs: one for each fixed effect term in the model object. In each ANOVA, the independent variables are the same, but the response is aligned by a different fixed effect term (if response is "aligned") or aligned and ranked by that fixed effect term (if response is "art"). These models are generated using artlm.

From each model, only the relevant output rows are kept (unless all.rows is TRUE, in which case all rows are kept).

When response is "art" (the default), only one row is kept from each ANOVA: the row corresponding to fixed effect term the response was aligned and ranked by. These results represent nonparametric tests of significance for the effect of each term on the original response variable.

When response is "aligned", all rows *except* the row corresponding to the fixed effect term the response was aligned by are kept. If the ART procedure is appropriate for this data, these tests should have all effects "stripped out", and have an F value of ~0. If that is not the case, another analysis should be considered. This diagnostic is tested by summary.art and a warning generated if the F values are not all approximately 0.

Value

An object of class "anova", which usually is printed.

Author(s)

Matthew Kay

References

Wobbrock, J. O., Findlater, L., Gergle, D., and Higgins, J. J. (2011). The Aligned Rank Transform for nonparametric factorial analyses using only ANOVA procedures. *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI '11)*. Vancouver, British Columbia (May 7-12, 2011). New York: ACM Press, pp. 143-146.

See Also

See art for an example. See also summary.art, artlm.

art *Aligned Rank Transform*

Description

Apply the aligned rank transform to a factorial model (with optional grouping terms). Usually done in preparation for a nonparametric analyses of variance on models with numeric or ordinal responses, which can be done by following up with `anova.art`.

Usage

```
art(formula, data,
  rank.comparison.digits = -floor(log10(.Machine$double.eps^0.5)),
  check.errors.are.factors = TRUE)
```

Arguments

`formula`	A factorial formula with optional grouping terms or error terms (but not both). Should be a formula with a single response variable (left-hand side) and one or more terms with all interactions on the right-hand side, e.g. `y ~ x` or `y ~ a*b*c` or `y ~ a + b + b:c`. If you want to run a mixed effects ANOVA on the transformed data using `lmer`, you can include grouping terms, as in `y ~ a*b*c + (1|d)`. If you want to run a repeated measures ANOVA using `aov`, you can include error terms, as in `y ~ a*b*c + Error(d)`. See 'Details'.
`data`	An optional data frame containing the variables in the model.
`rank.comparison.digits`	The number of digits to round aligned responses to before ranking (to ensure ties are computed consistently). See the `digits` argument of `round`. The default value is based on the default `tolerance` used for fuzzy comparison in `all.equal`.
`check.errors.are.factors`	Should we check to ensure `Error()` terms are all factors? A common mistake involves coding a categorical variable as numeric and passing it to `Error()`, yielding incorrect results from `aov`. Disabling this check is not recommended unless you know what you are doing; the most common uses of `Error()` (e.g. in repeated measures designs) involve categorical variables (factors).

Details

The aligned rank transform allows a nonparametric analysis of variance to be conducted on factorial models with fixed and random effects (or repeated measures) and numeric or ordinal responses. This is done by first aligning and ranking the fixed effects using this function, then conducting an analysis of variance on linear models built from the transformed data using `anova.art` (see 'Examples'). The model specified using this function *must* include all interactions of fixed effects.

The `formula` should contain a single response variable (left-hand side) that can be numeric, an ordered factor, or logical. The right-hand side of the formula should contain one or more fixed effect

factors, zero or more grouping terms, and zero or more error terms. Error terms and grouping terms cannot be used simultaneously. All possible interactions of the fixed effect terms must be included. For example, `y ~ x` and `y ~ a*b*c` and `y ~ a + b + b:c` are legal, but `y ~ a + b` is not, as it omits the interaction `a:b`. Grouping terms are specified as in `lmer`, e.g. `y ~ a*b*c + (1|d)` includes the random intercept term `(1|d)`. Error terms are specified as in `aov`, e.g. `y ~ a*b*c + Error(d)`. Grouping terms and error terms are not involved in the transformation, but are included in the model when ANOVAs are conducted, see `anova.art`.

For details on the transformation itself, see Wobbrock *et al.* (2011) or the ARTool website: http://depts.washington.edu/aimgroup/proj/art/.

Value

An object of class `"art"`:

`call`	The call used to generate the transformed data.
`formula`	The formula used to generate the transformed data.
`cell.means`	A data frame of cell means for each fixed term and interaction on the right-hand side of formula.
`estimated.effects`	A data frame of estimated effects for each fixed term and interaction on the right-hand side of formula.
`residuals`	A vector of residuals (response - cell mean of highest-order interaction).
`aligned`	A data frame of aligned responses for each fixed term and interaction on the right-hand side of formula.
`aligned.ranks`	A data frame of aligned and ranked responses for each fixed term and interaction on the right-hand side of formula.
`data`	The input data frame
`n.grouping.terms`	The number of grouping variables in the input formula.

For a complete description of cell means, estimated effects, aligned ranks, etc., in the above output, see Wobbrock *et al.* (2011).

Author(s)

Matthew Kay

References

Wobbrock, J. O., Findlater, L., Gergle, D., and Higgins, J. J. *ARTool*. http://depts.washington.edu/aimgroup/proj/art/.

Wobbrock, J. O., Findlater, L., Gergle, D., and Higgins, J. J. (2011). The Aligned Rank Transform for nonparametric factorial analyses using only ANOVA procedures. *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI '11)*. Vancouver, British Columbia (May 7-12, 2011). New York: ACM Press, pp. 143-146.

See Also

summary.art, anova.art, artlm.

Examples

```
## Not run:
data(Higgins1990Table5, package="ARTool")

## perform aligned rank transform
m <- art(DryMatter ~ Moisture*Fertilizer + (1|Tray), data=Higgins1990Table5)

## see summary data to ensure aligned rank transform is appropriate for this data
summary(m)
## looks good (aligned effects sum to 0 and F values on aligned responses
## not of interest are all ~0)

## we can always look at the anova of aligned data if we want more detail
## to assess the appropriateness of ART.  F values in this anova should all
## be approx 0.
anova(m, response="aligned")

## then we can run an anova on the ART responses (equivalent to anova(m, response="art"))
anova(m)

## if we want post-hoc tests, artlm(m, term) returns the linear model for the
## given term
## which we can then examine using our preferred method (emmeans, glht, etc)
## e.g., pairwise contrasts on Moisture:
library(emmeans)
emmeans(artlm(m, "Moisture"), pairwise ~ Moisture)

## pairwise contrasts on Fertilizer:
emmeans(artlm(m, "Fertilizer"), pairwise ~ Fertilizer)

## N.B. The above types of contrasts ARE NOT valid for interactions.
## Instead, use testInteractions from the phia package. For example:
library(phia)
testInteractions(artlm(m, "Moisture:Fertilizer"), pairwise=c("Moisture", "Fertilizer"))
## For a more in-depth explanation and example, see this vignette:
vignette("art-contrasts")


## End(Not run)
```

---

artlm *Per-Term Linear Model from Aligned Rank Transformed Data*

Description

Build a linear model for ART data with response aligned or aligned and ranked by the specified term from the model.

Usage

```
artlm(m, term, response = c("art", "aligned"),
  factor.contrasts = "contr.sum", ...)
```

Arguments

`m`	An object of class `art`.
`term`	An object of type `"character"` indicating the effect term in the transformed data in `m` to use as the aligned or art response.
`response`	Which response to use: the aligned response (`"aligned"`) or the aligned and ranked (`"art"`) response.
`factor.contrasts`	The name of the contrast-generating function to be applied by default to fixed effect factors. Sets the the first element of `options("contrasts")` for the duration of this function. The default is to use `"contr.sum"`, i.e. sum-to-zero contrasts, which is appropriate for Type III ANOVAs (the default ANOVA type for `anova.art`).
`...`	Additional arguments passed to `lm` or `lmer`.

Details

This function is used primarily for post-hoc tests. To run an ANOVA, it does not need to be called directly; instead, use `anova.art`, which calls this function as needed.

Value

An object of class `lm` if `formula(m)` does not contain grouping or error terms, an object of class `merMod` (i.e. a model fit by `lmer`) if it contains grouping terms, or an object of class `aovlist` (i.e. a model fit by `aov`) if it contains error terms.

Author(s)

Matthew Kay

See Also

See `art` for an example. See also `anova.art`, which makes use of this function.

Higgins1990Table1 *Synthetic 3x3 Factorial Randomized Experiment*

Description

Synthetic data from a balanced 3x3 factorial experiment with main effects, no interaction, and independent and identically distributed (i.i.d.) Normal errors.

Format

A data frame with 36 observations on the following 4 variables.

Subject a factor with levels `"s1"` .. `"s36"`

Row a factor with levels `"r1"` .. `"r3"`

Column a factor with levels `"c1"` .. `"c3"`

Response a numeric vector

Source

Higgins, J. J., Blair, R. C. and Tashtoush, S. (1990). The aligned rank transform procedure. *Proceedings of the Conference on Applied Statistics in Agriculture*. Manhattan, Kansas: Kansas State University, pp. 185-195.

See Also

`art`, `anova.art`.

Examples

```
data(Higgins1990Table1)

## run aligned-rank transform and ANOVA on the data
## Note: because there is only one observation per Subject
## in this dataset, we do not need to include Subject as
## a grouping term in this formula. Indeed, if we did,
## lmer would complain when we attempt the ANOVA.
m <- art(Response ~ Row*Column, data=Higgins1990Table1)
anova(m)
```

Higgins1990Table5 *Split-plot Experiment Examining Effect of Moisture and Fertilizer on Dry Matter in Peat Pots*

Description

This dataset comes from a split-plot experiment examining `Trays` of 4 peat pots each. `Moisture` was varied between `Trays` (i.e. it was the whole-plot treatment) and `Fertilizer` was varied within `Trays` (i.e. it was the sub-plot treatment). The outcome measure was `DryMatter`.

Format

A data frame with 48 observations on the following 4 variables.

Tray a factor with levels `"t1"` .. `"t12"`

Moisture a factor with levels `"m1"` .. `"m4"`

Fertilizer a factor with levels `"f1"` .. `"f4"`

DryMatter a numeric vector

Details

This dataset, originally from Milliken & Johnson (1984), is reproduced here from Higgins *et al.* (1990).

Source

Milliken, G.A., Johnson, D.E. (1984). *Analysis of Messy Data Vol I: Designed Experiments*. Van Nostrand Reinhold Company, New York.

References

Higgins, J. J., Blair, R. C. and Tashtoush, S. (1990). The aligned rank transform procedure. *Proceedings of the Conference on Applied Statistics in Agriculture*. Manhattan, Kansas: Kansas State University, pp. 185-195.

See Also

See `art` for a more complete example. See also `anova.art`.

Examples

```
data(Higgins1990Table5)

## run aligned-rank transform and ANOVA on the data
m <- art(DryMatter ~ Moisture*Fertilizer + (1|Tray), data=Higgins1990Table5)
anova(m)
```

HigginsABC *Synthetic 2x2x2 Mixed Design Experiment*

Description

Synthetic data from an experiment with two between-Subjects factors (A and B) having two levels each and one within-Subjects factor (C) with two levels.

Format

A data frame with 16 observations on the following 5 variables.

Subject a factor with levels "s1" .. "s8"

A a factor with levels "a1" "a2"

B a factor with levels "b1" "b2"

C a factor with levels "c1" "c2"

Y a numeric vector

Source

Wobbrock, J. O., Findlater, L., Gergle, D., and Higgins, J. J. *ARTool*. http://depts.washington.edu/aimgroup/proj/art/.

See Also

art, anova.art.

Examples

```
## Not run:
data(HigginsABC, HigginsABC.art, package="ARTool")

## run aligned-rank transform and ANOVA on the data
m <- art(Y ~ A*B*C + Error(Subject), data=HigginsABC)
anova(m)

## End(Not run)
```

InteractionTestData *Synthetic Data Used in the Contrast Test Vignette*

Description

See (`vignette("art-contrasts")` for a description of this data.

See Also

`art`, `anova.art`.

Examples

```
## Not run:
## see this vignette
vignette("art-contrasts")

## End(Not run)
```

summary.art *Aligned Rank Transform Summary*

Description

Summary and diagnostics for aligned rank transformed data

Usage

```
## S3 method for class 'art'
summary(object, ...)
```

Arguments

`object`	An object of class `art`.
`...`	Potentially further arguments passed from other methods.

Details

This function gives diagnostic output to help evaluate whether the ART procedure is appropriate for an analysis. It tests that column sums of aligned responses are ~0 and that F values of ANOVAs on aligned responses not of interest are ~0. For more details on these diagnostics see Wobbrock *et al.* (2011).

Value

An object of class `"summary.art"`, which usually is printed.

Author(s)

Matthew Kay

References

Wobbrock, J. O., Findlater, L., Gergle, D., and Higgins, J. J. (2011). The Aligned Rank Transform for nonparametric factorial analyses using only ANOVA procedures. *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI '11)*. Vancouver, British Columbia (May 7-12, 2011). New York: ACM Press, pp. 143-146.

See Also

See `art` for an example. See also `anova.art`.

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