Package 'fungible'

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Title Psychometric Functions from the Waller Lab

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Imports crayon (>= 1.4.1), clue, CVXR, DEoptim, GA (>= 3.2.1), GPArotation, lattice, MASS, MBESS (>= 4.8.0), MCMCpack, methods, mvtnorm, nleqslv, pbmcapply, Rcsdp, RSpectra, sem (>= 3.1-11), utils, graphics, grDevices

Description Computes fungible coefficients and Monte Carlo data. Underlying theory for these functions is described in the following publications:
Waller, N. (2008). Fungible Weights in Multiple Regression. Psychometrika, 73(4), 691-703, <DOI:10.1007/s11336-008-9066-z>.
Waller, N. & Jones, J. (2009). Locating the Extrema of Fungible Regression Weights. Psychometrika, 74(4), 589-602, <DOI:10.1007/s11336-008-9087-7>.
Waller, N. G. (2016). Fungible Correlation Matrices:
A Method for Generating Nonsingular, Singular, and Improper Correlation Matrices for Monte Carlo Research. Multivariate Behavioral Research, 51(4), 554-568.
Jones, J. A. & Waller, N. G. (2015). The normal-theory and asymptotic distribution-free (ADF) covariance matrix of standardized regression coefficients: theoretical extensions and finite sample behavior. Psychometrika, 80, 365-378, <DOI:10.1007/s11336-013-9380-y>.
Waller, N. G. (2018). Direct Schmid-Leiman transformations and rank-deficient loadings matrices. Psychometrika, 83, 858-870. <DOI:10.1007/s11336-017-9599-0>.

License GPL (>= 2)

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ACL *Adjective Checklist Data.*

Description

Adjective checklist data from the California Twin Registry.

Usage

```
data(ACL)
```

Format

Adjective Checklist data from the California Twin Registry (see Waller, Bouchard, Lykken, Tellegen, A., & Blacker, 1993). **ACL** variables:

1. id
2. sex
3. age
4. items 1 ... 300

Details

This is a de-identified subset of the ACL data from the California Twin Registry (data collected by Waller in the 1990s). This data set of 257 cases includes complete (i.e., no missing data) ACL item responses from a random member of each twin pair. The item response vectors are independent.

References

Gough, H. G. & Heilbrun, A. B. (1980). The Adjective Checklist Manual: 1980 Edition. Consulting Psychologists Press.

Waller, N. G., Bouchard, T. J., Lykken, D. T., Tellegen, A., and Blacker, D. (1993). Creativity, heritability, familiarity: Which word does not belong?. Psychological Inquiry, 4(3), 235–237.

Examples

```
## Not run:

 data(ACL)

# Factor analyze a random subset of ACL items
# for illustrative purposes

set.seed(1)
RandomItems <- sample(1:300,
                      50,
                      replace = FALSE)

ACL50 <- ACL[, RandomItems + 3]

tetR_ACL50 <- tetcor(x = ACL50)$r

fout <- faMain(R     = tetR_ACL50,
               numFactors    = 5,
               facMethod     = "fals",
               rotate        = "oblimin",
               bootstrapSE   = FALSE,
        rotateControl = list(
```

```
                numberStarts = 100,
                standardize  = "none"),
                Seed = 123)

summary(fout, itemSort = TRUE)

## End(Not run)
```

---

adfCor *Asymptotic Distribution-Free Covariance Matrix of Correlations*

Description

Function for computing an asymptotic distribution-free covariance matrix of correlations.

Usage

```
adfCor(X, y = NULL)
```

Arguments

X	Data matrix.
y	Optional vector of criterion scores.

Value

adfCorMat	Asymptotic distribution-free estimate of the covariance matrix of correlations.

Author(s)

Jeff Jones and Niels Waller

References

Browne, M. W. (1984). Asymptotically distribution-free methods for the analysis of covariance structures. *British Journal of Mathematical and Statistical Psychology, 37*, 62–83.

Steiger, J. H. and Hakstian, A. R. (1982). The asymptotic distribution of elements of a correlation matrix: Theory and application. *British Journal of Mathematical and Statistical Psychology, 35*, 208–215.

Examples

```
## Generate non-normal data using monte1
set.seed(123)
## we will simulate data for 1000 subjects
N <- 1000

## R = the desired population correlation matrix among predictors
```

```
R <- matrix(c(1, .5, .5, 1), 2, 2)

## Consider a regression model with coefficient of determination (Rsq):
Rsq <- .50

## and vector of standardized regression coefficients
Beta <- sqrt(Rsq/t(sqrt(c(.5, .5))) %*% R %*% sqrt(c(.5, .5))) * sqrt(c(.5, .5))

## generate non-normal data for the predictors (X)
## x1 has expected skew = 1 and kurtosis = 3
## x2 has expected skew = 2 and kurtosis = 5
X <- monte1(seed = 123, nvar = 2, nsub = N, cormat = R, skewvec = c(1, 2),
            kurtvec = c(3, 5))$data

## generate criterion scores
y <- X %*% Beta + sqrt(1-Rsq)*rnorm(N)

## Create ADF Covariance Matrix of Correlations
adfCor(X, y)

#>              12           13           23
#> 12 0.0012078454 0.0005331086 0.0004821594
#> 13 0.0005331086 0.0004980130 0.0002712080
#> 23 0.0004821594 0.0002712080 0.0005415301
```

---

adfCov *Asymptotic Distribution-Free Covariance Matrix of Covariances*

Description

Function for computing an asymptotic distribution-free covariance matrix of covariances.

Usage

```
adfCov(X, y = NULL)
```

Arguments

X	Data matrix.
y	Optional vector of criterion scores.

Value

adfCovMat	Asymptotic distribution-free estimate of the covariance matrix of covariances

Author(s)

Jeff Jones and Niels Waller

References

Browne, M. W. (1984). Asymptotically distribution-free methods for the analysis of covariance structures. *British Journal of Mathematical and Statistical Psychology, 37,* 62–83.

Examples

```
## Generate non-normal data using monte1
set.seed(123)

## we will simulate data for 1000 subjects
N <- 1000

## R = the desired population correlation matrix among predictors
R <- matrix(c(1, .5, .5, 1), 2, 2)

## Consider a regression model with coefficient of determination (Rsq):
Rsq <- .50

## and vector of standardized regression coefficients
Beta <- sqrt(Rsq/t(sqrt(c(.5, .5))) %*% R %*% sqrt(c(.5, .5))) * sqrt(c(.5, .5))

## generate non-normal data for the predictors (X)
## x1 has expected skew = 1 and kurtosis = 3
## x2 has expected skew = 2 and kurtosis = 5
X <- monte1(seed = 123, nvar = 2, nsub = N, cormat = R, skewvec = c(1, 2),
           kurtvec = c(3, 5))$data

## generate criterion scores
y <- X %*% Beta + sqrt(1-Rsq)*rnorm(N)

## Create ADF Covariance Matrix of Covariances
adfCov(X, y)

#>          11       12       13       22       23       33
#> 11 3.438760 2.317159 2.269080 2.442003 1.962584 1.688631
#> 12 2.317159 3.171722 2.278212 3.349173 2.692097 2.028701
#> 13 2.269080 2.278212 2.303659 2.395033 2.149316 2.106310
#> 22 2.442003 3.349173 2.395033 6.275088 4.086652 2.687647
#> 23 1.962584 2.692097 2.149316 4.086652 3.287088 2.501094
#> 33 1.688631 2.028701 2.106310 2.687647 2.501094 2.818664
```

---

alphaR *Generate random R matrices with a known coefficient alpha*

Description

alphaR can generate a list of fungible correlation matrices with a user-defined (standardized) coefficient α.

Usage

```
alphaR(alpha, k, Nmats, SEED)
```

Arguments

alpha	(numeric) A desired coefficient α within the range $\alpha \in (-\infty, 1]$.
k	(integer). The order of each R (correlation) matrix.
Nmats	(integer) The number of fungible R matrices with a known α. Default (Nmats = 5).
SEED	(numeric) The initial seed for the random number generator. If SEED is not supplied then the program will generate (and return) a randomly generated seed.

Value

- **alpha** The desired (standardized) coefficient α.
- **R** The initial correlation matrix with a desired coefficient α.
- **Rlist** A list with Nmats fungible correlation matrices with a desired coefficient α.
- **SEED** The initial value for the random number generator.

Author(s)

Niels G. Waller

References

Waller, N. & Revelle, W. (2023). What are the mathematical bounds for coefficient α? *Psychological Methods*. doi.org/10.1037/met0000583

Examples

```
## Function to compute standardized alpha
Alphaz <- function(Rxx){
  k <- ncol(Rxx)
  k/(k-1) * (1 - (k/sum(Rxx)) )
}# END Alphaz

## Example 1
## Generate 25 6 x 6 R matrices with a standardized alpha of .85
alpha =  .85
k = 6
Nmats =  25
SEED = 1

out = alphaR(alpha, k , Nmats, SEED)
Alphaz(out$Rlist[[1]])

## Example 2
## Generate 25 6 x 6 R matrices with a standardized alpha of -5
alpha =  -5
```

```
k = 6
Nmats =  25
SEED = 1

out = alphaR(alpha, k , Nmats, SEED)
Alphaz(out$Rlist[[5]])
```

AmzBoxes *Length, width, and height measurements for 98 Amazon shipping boxes*

Description

Length, width, and height measurements for 98 Amazon shipping boxes

Usage

```
data(AmzBoxes)
```

Format

A data set of measurements for 98 Amazon shipping boxes. These data were downloaded from the BoxDimensions website: (https://www.boxdimensions.com/). The data set includes five variables:

- Amazon Box Size
- Length (inches)
- Width (inches)
- Height (inches)
- Volume (inches)

Examples

```
data(AmzBoxes)

hist(AmzBoxes$`Length (inches)`,
     main = "Histogram of Box Lengths",
     xlab = "Length",
     col = "blue")
```

BadRBY *Improper correlation matrix reported by Bentler and Yuan*

Description

Example improper R matrix reported by Bentler and Yuan (2011)

Format

A 12 by 12 non-positive definite correlation matrix.

Source

Bentler, P. M. & Yuan, K. H. (2011). Positive definiteness via off-diagonal scaling of a symmetric indefinite matrix. Psychometrika, 76(1), 119–123.

Examples

```
data(BadRBY)
```

BadRJN *Improper R matrix reported by Joseph and Newman*

Description

Example NPD improper correlation matrix reported by Joseph and Newman

Format

A 14 by 14 non-positive definite correlation matrix.

Source

Joseph, D. L. & Newman, D. A. (2010). Emotional intelligence: an integrative meta-analysis and cascading model. Journal of Applied Psychology, 95(1), 54–78.

Examples

```
data(BadRJN)
```

BadRKtB — *Improper R matrix reported by Knol and ten Berge*

Description

Example improper R matrix reported by Knol and ten Berge

Format

A 6 by 6 non-positive definite correlation matrix.

Source

Knol, D. L. and Ten Berge, J. M. F. (1989). Least-squares approximation of an improper correlation matrix by a proper one. Psychometrika, 54(1), 53-61.

Examples

```
data(BadRKtB)
```

BadRLG — *Improper R matrix reported by Lurie and Goldberg*

Description

Example improper R matrix reported by Lurie and Goldberg

Format

A 3 by 3 non-positive definite correlation matrix.

Source

Lurie, P. M. & Goldberg, M. S. (1998). An approximate method for sampling correlated random variables from partially-specified distributions. Management Science, 44(2), 203–218.

Examples

```
data(BadRLG)
```

BadRRM *Improper R matrix reported by Rousseeuw and Molenberghs*

Description

Example improper R matrix reported by Rousseeuw and Molenberghs

Format

A 3 by 3 non-positive definite correlation matrix.

Source

Rousseeuw, P. J. & Molenberghs, G. (1993). Transformation of non positive semidefinite correlation matrices. Communications in Statistics–Theory and Methods, 22(4), 965–984.

Examples

```
data(BadRRM)
```

BiFAD *Bifactor Analysis via Direct Schmid-Leiman (DSL) Transformations*

Description

This function estimates the (rank-deficient) Direct Schmid-Leiman (DSL) bifactor solution as well as the (full-rank) Direct Bifactor (DBF) solution.

Usage

```
BiFAD(
  R,
  B = NULL,
  numFactors = NULL,
  facMethod = "fals",
  rotate = "oblimin",
  salient = 0.25,
  rotateControl = NULL,
  faControl = NULL
)
```

Arguments

R	(Matrix) A correlation matrix.
B	(Matrix) Bifactor target matrix. If B is NULL the program will create an empirically defined target matrix.
numFactors	(Numeric) The number of group factors to estimate.
facMethod	(Character) The method used for factor extraction (faX). The supported options are "fals" for unweighted least squares, "faml" for maximum likelihood, "fapa" for iterated principal axis factoring, "faregLS" for regularized least squares, "faregML" for regularized maximum likelihood, and "pca" for principal components analysis. The default method is "fals". • **"fals"**: Factors are extracted using the unweighted least squares estimation procedure using the fals function. • **"faml"**: Factors are extracted using the maximum likelihood estimation procedure using the factanal function. • **"fapa"**: Factors are extracted using the iterated principal axis factoring estimation procedure using the fapa function. • **"faregLS"**: Factors are extracted using regularized least squares factor analysis using the fareg function. • **"faregML"**: Factors are extracted using regularized maximum likelihood factor using the fareg function. • **"pca"**: Principal components are extracted.
rotate	(Character) Designate which rotation algorithm to apply. See the faMain function for more details about possible rotations. An oblimin rotation is the default.
salient	(Numeric) Threshold value for creating an empirical target matrix.
rotateControl	(List) A list of control values to pass to the factor rotation algorithms. • **numberStarts**: (Numeric) The number of random (orthogonal) starting configurations for the chosen rotation method (e.g., oblimin). The first rotation will always commence from the unrotated factors orientation. Defaults to numberStarts = 10. • **gamma**: (Numeric) This is a tuning parameter (between 0 and 1, inclusive) for an oblimin rotation. See the **GPArotation** library's oblimin documentation for more details. Defaults to gamma = 0 (i.e., a quartimin rotation). • **delta**: (Numeric) This is a tuning parameter for the geomin rotation. It adds a small number (default = .01) to the squared factor loadings before computing the geometric means in the discrepancy function. • **kappa**: (Numeric) The main parameterization of the Crawford-Ferguson (CF) rotations (i.e., "cfT" and "cfQ" for orthogonal and oblique CF rotation, respectively). Defaults to kappa = 0. • **k**: (Numeric) A specific parameter of the simplimax rotation. Defaults to k = the number of observed variables. • **standardize**: (Character) The standardization routine used on the unrotated factor structure. The three options are "none", "Kaiser", and "CM". Defaults to standardize = "none". – **"none"**: No standardization is applied to the unrotated factor structure.

  - **"Kaiser"**: Use a factor structure matrix that has been normed by Kaiser's method (i.e., normalize all rows to have a unit length).
  - **"CM"**: Use a factor structure matrix that has been normed by the Cureton-Mulaik method.
- **epsilon**: (Numeric) The rotational convergence criterion to use. Defaults to epsilon = 1e-5.
- **power**: (Numeric) Raise factor loadings the the n-th power in the `promaxQ` rotation. Defaults to power = 4.
- **maxItr**: (Numeric) The maximum number of iterations for the rotation algorithm. Defaults to maxItr = 15000.

`faControl` (List) A list of optional parameters passed to the factor extraction (`faX`) function.

- **treatHeywood**: (Logical) In `fals`, if treatHeywood is true, a penalized least squares function is used to bound the communality estimates below 1.0. Defaults to treatHeywood = TRUE.
- **nStart**: (Numeric) The number of starting values to be tried in `faml`. Defaults to nStart = 10.
- **start**: (Matrix) NULL or a matrix of starting values, each column giving an initial set of uniquenesses. Defaults to start = NULL.
- **maxCommunality**: (Numeric) In `faml`, set the maximum communality value for the estimated solution. Defaults to maxCommunality = .995.
- **epsilon**: (Numeric) In `fapa`, the numeric threshold designating when the algorithm has converged. Defaults to epsilon = 1e-4.
- **communality**: (Character) The method used to estimate the initial communality values in `fapa`. Defaults to communality = 'SMC'.
  - **"SMC"**: Initial communalities are estimated by taking the squared multiple correlations of each indicator after regressing the indicator on the remaining variables.
  - **"maxr"**: Initial communalities equal the largest (absolute value) correlation in each column of the correlation matrix.
  - **"unity"**: Initial communalities equal 1.0 for all variables.
- **maxItr**: (Numeric) In `fapa`, the maximum number of iterations to reach convergence. Defaults to maxItr = 15,000.

Value

The following output are returned in addition to the estimated Direct Schmid-Leiman bifactor solution.

- **B**: (Matrix) The target matrix used for the Procrustes rotation.
- **BstarSL**: (Matrix) The resulting (rank-deficient) matrix of Direct Schmid-Leiman factor loadings.
- **BstarFR**: (Matrix) The resulting (full-rank) matrix of Direct Bifactor factor loadings.
- **rmsrSL**: (Scalar) The root mean squared residual (rmsr) between the known B matrix and the estimated (rank-deficient) Direct Schmid-Leiman rotation. If the B target matrix is empirically generated, this value is NULL.

- **rmsrFR**: (Scalar) The root mean squared residual (rmsr) between the known B matrix and the estimated (full-rank) Direct Bifactor rotation. If the B target matrix is empirically generated, this value is NULL.

Author(s)

- Niels G. Waller (nwaller@umn.edu)

References

- Giordano, C. & Waller, N. G. (under review). Recovering bifactor models: A comparison of seven methods.
- Mansolf, M., & Reise, S. P. (2016). Exploratory bifactor analysis: The Schmid-Leiman orthogonalization and Jennrich-Bentler analytic rotations. *Multivariate Behavioral Research, 51*(5), 698-717.
- Waller, N. G. (2018). Direct Schmid Leiman transformations and rank deficient loadings matrices. *Psychometrika, 83*, 858-870.

See Also

Other Factor Analysis Routines: Box26, GenerateBoxData(), Ledermann(), SLi(), SchmidLeiman(), faAlign(), faEKC(), faIB(), faLocalMin(), faMB(), faMain(), faScores(), faSort(), faStandardize(), faX(), fals(), fapa(), fareg(), fsIndeterminacy(), orderFactors(), print.faMB(), print.faMain(), promaxQ(), summary.faMB(), summary.faMain()

Examples

```
cat("\nExample 1:\nEmpirical Target Matrix:\n")
# Mansolf and Reise Table 2 Example
Btrue <- matrix(c(.48, .40,  0,   0,   0,
                  .51, .35,  0,   0,   0,
                  .67, .62,  0,   0,   0,
                  .34, .55,  0,   0,   0,
                  .44,  0, .45,   0,   0,
                  .40,  0, .48,   0,   0,
                  .32,  0, .70,   0,   0,
                  .45,  0, .54,   0,   0,
                  .55,  0,   0, .43,   0,
                  .33,  0,   0, .33,   0,
                  .52,  0,   0, .51,   0,
                  .35,  0,   0, .69,   0,
                  .32,  0,   0,   0, .65,
                  .66,  0,   0,   0, .51,
                  .68,  0,   0,   0, .39,
                  .32,  0,   0,   0, .56), 16, 5, byrow=TRUE)

Rex1 <- Btrue %*% t(Btrue)
diag(Rex1) <- 1

out.ex1 <- BiFAD(R          = Rex1,
                 B          = NULL,
```

```
                  numFactors = 4,
                  facMethod  = "fals",
                  rotate     = "oblimin",
                  salient    = .25)

cat("\nRank Deficient Bifactor Solution:\n")
print( round(out.ex1$BstarSL, 2) )

cat("\nFull Rank Bifactor Solution:\n")
print( round(out.ex1$BstarFR, 2) )

cat("\nExample 2:\nUser Defined Target Matrix:\n")

Bpattern <- matrix(c( 1,  1,  0,   0,   0,
                      1,  1,  0,   0,   0,
                      1,  1,  0,   0,   0,
                      1,  1,  0,   0,   0,
                      1,  0,  1,   0,   0,
                      1,  0,  1,   0,   0,
                      1,  0,  1,   0,   0,
                      1,  0,  1,   0,   0,
                      1,  0,   0,  1,   0,
                      1,  0,   0,  1,   0,
                      1,  0,   0,  1,   0,
                      1,  0,   0,  1,   0,
                      1,  0,   0,   0,  1,
                      1,  0,   0,   0,  1,
                      1,  0,   0,   0,  1,
                      1,  0,   0,   0,  1), 16, 5, byrow=TRUE)

out.ex2 <- BiFAD(R          = Rex1,
                 B          = Bpattern,
                 numFactors = NULL,
                 facMethod  = "fals",
                 rotate     = "oblimin",
                 salient    = .25)

cat("\nRank Deficient Bifactor Solution:\n")
print( round(out.ex2$BstarSL, 2) )

cat("\nFull Rank Bifactor Solution:\n")
print( round(out.ex2$BstarFR, 2) )
```

---

bigen *Generate Correlated Binary Data*

Description

Function for generating binary data with population thresholds.

Usage

```
bigen(data, n, thresholds = NULL, Smooth = FALSE, seed = NULL)
```

Arguments

data	Either a matrix of binary (0/1) indicators or a correlation matrix.
n	The desired sample size of the simulated data.
thresholds	If data is a correlation matrix, thresholds must be a vector of threshold cut points.
Smooth	(logical) Smooth = TRUE will smooth the tetrachoric correltion matrix.
seed	Default = FALSE. Optional seed for random number generator.

Value

data	Simulated binary data
r	Input or calculated (tetrachoric) correlation matrix

Author(s)

Niels G Waller

Examples

```
## Example: generating binary data to match
## an existing binary data matrix
##
## Generate correlated scores using factor
## analysis model
## X <- Z *L' + U*D
## Z is a vector of factor scores
## L is a factor loading matrix
## U is a matrix of unique factor scores
## D is a scaling matrix for U

N <- 5000

# Generate data from a single factor model
# factor patter matrix
L <- matrix( rep(.707, 5), nrow = 5, ncol = 1)

# common factor scores
Z <- as.matrix(rnorm(N))

# unique factor scores
U <- matrix(rnorm(N *5), nrow = N, ncol = 5)
D <- diag(as.vector(sqrt(1 - L^2)))

# observed scores
X <- Z %*% t(L) + U %*% D

cat("\nCorrelation of continuous scores\n")
```

```
print(round(cor(X),3))

# desired difficulties (i.e., means) of
# the dichotomized scores
difficulties <- c(.2, .3, .4, .5, .6)

# cut the observed scores at these thresholds
# to approximate the above difficulties
thresholds <- qnorm(difficulties)

Binary <- matrix(0, N, ncol(X))
for(i in 1:ncol(X)){
  Binary[X[,i] <= thresholds[i],i] <- 1
}

cat("\nCorrelation of Binary scores\n")
print(round(cor(Binary), 3))

## Now use 'bigen' to generate binary data matrix with
## same correlations as in Binary

z <- bigen(data = Binary, n = N)

cat("\n\nnames in returned object\n")
print(names(z))

cat("\nCorrelation of Simulated binary scores\n")
print(round(cor(z$data), 3))


cat("Observed thresholds of simulated data:\n")
cat(apply(z$data, 2, mean))
```

`Boruch70` *Multi-Trait Multi-Method correlation matrix reported by Boruch, Larkin, Wolins, and MacKinney (1970)*

Description

The original study assessed supervisors on seven dimensions (i.e., 7 variables) from two sources (i.e., their least effective and most effective subordinate).

Usage

```
data(Boruch70)
```

Format

A 14 by 14 correlation matrix with dimension names

Details

The sample size is $n = 111$.

The following variables were assessed: **Variables**:

1. Consideration
2. Structure
3. Satisfaction with the supervisor
4. Job satisfaction
5. General effectiveness
6. Human relations skill
7. Leadership

The test structure is as follows: **Test Structure**:

- Test One: variables 1 through 7
- Test Two: variables 8 through 14

Source

Boruch, R. F., Larkin, J. D., Wolins, L., and MacKinney, A. C. (1970). Alternative methods of analysis: Multitrait multimethod data. *Educational and Psychological Measurement, 30*, 833-853.

Examples

```
## Load Boruch et al.'s dataset
data(Boruch70)

Example4Output <- faMB(R             = Boruch70,
                       n             = 111,
                       NB            = 2,
                       NVB           = c(7,7),
                       numFactors    = 2,
                       rotate        = "oblimin",
                       rotateControl = list(standardize  = "Kaiser",
                                            numberStarts = 100))

summary(Example4Output, digits = 3)
```

Box20 *Length, width, and height measurements for Thurstone's 20 boxes*

Description

Length, width, and height measurements for Thurstone's 20 hypothetical boxes

Usage

```
data(Box20)
```

Format

A data set of measurements for Thurstone's 20 hypothetical boxes. The data set includes three variables:

- **x** Box length
- **y** Box width
- **z** Box height

Examples

```
data(Box20)

hist(Box20$x,
     main = "Histogram of Box Lengths",
     xlab = "Length",
     col = "blue")

# To create the raw data for Thurstone's 20 hypothetical
# box attributes:
data(Box20)
 ThurstoneBox20 <- GenerateBoxData(XYZ = Box20,
                                   BoxStudy = 20,
                                   Reliability = 1,
                                   ModApproxErrVar = 0)$BoxData

RThurstoneBox20 <- cor(ThurstoneBox20)

# Smooth matrix to calculate factor indeterminacy values
RsmThurstoneBox20 <- smoothBY(RThurstoneBox20)$RBY

fout <- faMain(R = RsmThurstoneBox20,
               numFactors = 3,
               rotate = "varimax",
               facMethod = "faregLS",
               rotateControl = list(numberStarts = 100,
                                    maxItr =15000))
summary(fout, digits=3)

# Note that given the small ratio of subjects to variables,
# it is not possible to generate data for this example with model error
# (unless SampleSize is increased).
```

Box26 *R matrix for Thurstone's 26 hypothetical box attributes.*

Description

Correlation matrix for Thurstone's 26 hypothetical box attributes.

Usage

```
data(Box26)
```

Format

Correlation matrix for Thurstone's 26 hypothetical box attributes. The so-called Thurstone invariant box problem contains measurements on the following 26 functions of length, width, and height. **Box26** variables:

1. x
2. y
3. z
4. xy
5. xz
6. yz
7. x^2 * y
8. x * y^2
9. x^2 * z
10. x * z^ 2
11. y^2 * z
12. y * z^2
13. x/y
14. y/x
15. x/z
16. z/x
17. y/z
18. z/y
19. 2x + 2y
20. 2x + 2z
21. 2y + 2z
22. sqrt(x^2 + y^2)
23. sqrt(x^2 + z^2)

24. sqrt(y^2 + z^2)
25. xyz
26. sqrt(x^2 + y^2 + z^2)

- **x** Box length
- **y** Box width
- **z** Box height

Details

Two data sets have been described in the literature as Thurstone's Box Data (or Thurstone's Box Problem). The first consists of 20 measurements on a set of 20 hypothetical boxes (i.e., Thurstone made up the data). Those data are available in **Box20**. The second data set, which is described in this help file, was collected by Thurstone to provide an illustration of the invariance of simple structure factor loadings. In his classic textbook on multiple factor analysis (Thurstone, 1947), Thurstone states that "[m]easurements of a random collection of thirty boxes were actually made in the Psychometric Laboratory and recorded for this numerical example. The three dimensions, x, y, and z, were recorded for each box. A list of 26 arbitrary score functions was then prepared" (p. 369). The raw data for this example were not published. Rather, Thurstone reported a correlation matrix for the 26 score functions (Thurstone, 1947, p. 370). Note that, presumably due to rounding error in the reported correlations, the correlation matrix for this example is non positive definite.

References

Thurstone, L. L. (1947). Multiple factor analysis. Chicago: University of Chicago Press.

See Also

Box20, AmzBoxes

Other Factor Analysis Routines: BiFAD(), GenerateBoxData(), Ledermann(), SLi(), SchmidLeiman(), faAlign(), faEKC(), faIB(), faLocalMin(), faMB(), faMain(), faScores(), faSort(), faStandardize(), faX(), fals(), fapa(), fareg(), fsIndeterminacy(), orderFactors(), print.faMB(), print.faMain(), promaxQ(), summary.faMB(), summary.faMain()

Examples

```
data(Box26)
fout <- faMain(R     = Box26,
               numFactors    = 3,
               facMethod     = "faregLS",
               rotate        = "varimax",
               bootstrapSE   = FALSE,
        rotateControl = list(
               numberStarts = 100,
               standardize  = "none"),
               Seed = 123)

summary(fout)
```

```
# We now choose Cureton-Mulaik row standardization to reveal
# the underlying factor structure.

fout <- faMain(R     = Box26,
               numFactors    = 3,
               facMethod     = "faregLS",
               rotate        = "varimax",
               bootstrapSE   = FALSE,
        rotateControl = list(
               numberStarts = 100,
               standardize  = "CM"),
               Seed = 123)

summary(fout)
```

---

cb *Cudeck & Browne (1992) model error method*

Description

Generate a population correlation matrix using the model described in Cudeck and Browne (1992). This function uses the implementation of the Cudeck and Browne method from Ken Kelley's MBESS package.

Usage

```
cb(mod, target_rmsea)
```

Arguments

mod	A 'fungible::simFA()' model object.
target_rmsea	(scalar) Target RMSEA value.

References

Cudeck, R., & Browne, M. W. (1992). Constructing a covariance matrix that yields a specified minimizer and a specified minimum discrepancy function value. *Psychometrika*, *57*(3), 357–369. <https://doi.org/10/cq6ckd>

Kelley, K. (2017). MBESS (Version 4.0.0 and higher) [computer software and manual]. Accessible from http://cran.r-project.org.

cfi — *Calculate CFI for two correlation matrices*

Description

Given two correlation matrices of the same dimension, calculate the CFI value value using the independence model as the null model.

Usage

```
cfi(Sigma, Omega)
```

Arguments

Sigma	(matrix) Population correlation or covariance matrix (with model error).
Omega	(matrix) Model-implied population correlation or covariance matrix.

Examples

```
library(fungible)

mod <- fungible::simFA(Model = list(NFac = 3),
                       Seed = 42)
set.seed(42)
Omega <- mod$Rpop
Sigma <- noisemaker(
  mod = mod,
  method = "CB",
  target_rmsea = 0.05
)$Sigma
cfi(Sigma, Omega)
```

CompleteRcvx — *Complete a Partially Specified Correlation Matrix by Convex Optimization*

Description

This function completes a partially specified correlation matrix by the method of convex optimization. The completed matrix will maximize the log(det(R)) over the space of PSD R matrices.

Usage

```
CompleteRcvx(Rna, Check_Convexity = TRUE, PRINT = TRUE)
```

Arguments

Rna	(matrix) An n x n incomplete correlation matrix. Missing entries must be specified by NA values.
Check_Convexity	(logical) If Check_Convexity= FALSE the program will not check the convexity of the objective function. Since the convexity of the R completion problem is known to be true, setting this argument to FALSE can decrease computation time.
PRINT	(logical) If PRINT = TRUE then the program will print the convergence status of the final solution.

Value

The CompleteCvxR function returns the following objects.

- **R** (matrix) A PSD completed correlation matrix.
- **converged**: (Logical) a logical that indicates the convergence status of the optimization.
- **max_delta** The maximum absolute difference between the known elements in the partially specified R matrix and the estimated matrix.
- **convergence_status** (list) A list containing additional information about the convergence status of the solution.

Author(s)

Niels G. Waller

References

Georgescu, D. I., Higham, N. J., and Peters, G. W. (2018). Explicit solutions to correlation matrix completion problems, with an application to risk management and insurance. Royal Society Open Science, 5(3), 172348.

Olvera Astivia, O. L. (2021). A Note on the general solution to completing partially specified correlation matrices. Measurement: Interdisciplinary Research and Perspectives, 19(2), 115–123.

Examples

```
## Not run:
  Rmiss <- matrix(
    c( 1,  .25, .6,  .55, .65,  0,  .4,   .6,  .2,  .3,
       .25, 1,    0,   0,   0,   0,  NA,   NA,  NA,  NA,
       .6,  0,   1,   .75, .75,  0,  NA,   NA,  NA,  NA,
       .55, 0,   .75, 1,   .5,   0,  NA,   NA,  NA,  NA,
       .65, 0,   .75,  .5, 1,    0,  NA,   NA,  NA,  NA,
       0,  0,    0,   0,   0,  1,   NA,   NA,  NA,  NA,
       .4, NA,   NA,  NA,  NA,  NA, 1,   .25, .25,  .5,
       .6, NA,   NA,  NA,  NA,  NA, .25,  1,  .25,  0,
       .2, NA,   NA,  NA,  NA,  NA, .25,  .25, 1,   0,
       .3, NA,   NA,  NA,  NA,  NA, .5,    0,   0,  1), 10,10)
```

```
  out <- CompleteRcvx(Rna = Rmiss,
                      Check_Convexity = FALSE,
                      PRINT = FALSE)

  round(out$R, 3)

## End(Not run)
```

CompleteRdev *Complete a Partially Specified Correlation Matrix by the Method of Differential Evolution*

Description

This function completes a partially specified correlation matrix by the method of differential evolution.

Usage

```
CompleteRdev(
  Rna,
  NMatrices = 1,
  MaxDet = FALSE,
  MaxIter = 200,
  delta = 1e-08,
  PRINT = FALSE,
  Seed = NULL
)
```

Arguments

Rna	(matrix) An n x n incomplete correlation matrix. Missing entries must be specified by NA values.
NMatrices	(integer) CompleteRDEV will complete NMatrices correlation matrices.
MaxDet	(logical) If MaxDet = TRUE then the correlation matrix will be completed with entries that maximize the determinant of R.
MaxIter	(integer) The maximum number of iterations (i.e., generations) allowed. Default MaxIter = 200.
delta	(numeric > 0) A number that controls the convergence accuracy of the differential evolution algorithm. Default delta = 1E-8.
PRINT	(logical) When PRINT = TRUE the algorithm convergence status is printed. Default PRINT = FALSE.
Seed	(integer) Initial random number seed. Default (Seed = NULL).

Value

`CompleteRdev` returns the following objects:

- **R** (matrix) A PSD completed correlation matrix.
- **converged**: (logical) a logical that indicates the convergence status of the optimizaton.
- **iter** (integer) The number of cycles needed to reach converged solution.

Author(s)

Niels G. Waller

References

Ardia, D., Boudt, K., Carl, P., Mullen, K.M., Peterson, B.G. (2011) Differential Evolution with DEoptim. An Application to Non-Convex Portfolio Optimization. URL The R Journal, 3(1), 27-34. URL https://journal.r-project.org/archive/2011-1/RJournal_2011-1_Ardia~et~al.pdf.

Georgescu, D. I., Higham, N. J., and Peters, G. W. (2018). Explicit solutions to correlation matrix completion problems, with an application to risk management and insurance. Royal Society Open Science, 5(3), 172348.

Mauro, R. (1990). Understanding L.O.V.E. (left out variables error): a method for estimating the effects of omitted variables. Psychological Bulletin, 108(2), 314-329.

Mishra, S. K. (2007). Completing correlation matrices of arbitrary order by differential evolution method of global optimization: a Fortran program. Available at SSRN 968373.

Mullen, K.M, Ardia, D., Gil, D., Windover, D., Cline, J. (2011). DEoptim: An R Package for Global Optimization by Differential Evolution. Journal of Statistical Software, 40(6), 1-26. URL http://www.jstatsoft.org/v40/i06/.

Price, K.V., Storn, R.M., Lampinen J.A. (2005) Differential Evolution - A Practical Approach to Global Optimization. Berlin Heidelberg: Springer-Verlag. ISBN 3540209506.

Zhang, J. and Sanderson, A. (2009) Adaptive Differential Evolution Springer-Verlag. ISBN 978-3-642-01526-7

Examples

```
## Example 1: Generate random 4 x 4 Correlation matrices.
  Rmiss <- matrix(NA, nrow = 4, ncol = 4)
  diag(Rmiss) <- 1

  out <- CompleteRdev(Rna = Rmiss,
                      NMatrices = 4,
                      PRINT = TRUE,
                      Seed = 1)

  print( round( out$R[[1]] , 3) )

## Not run:
# Example 2: Complete a partially specified R matrix.
# Example from Georgescu, D. I., Higham, N. J., and
#              Peters, G. W.  (2018).
```

```
Rmiss <- matrix(
     c( 1,  .25, .6,  .55, .65,  0,  .4,   .6,  .2,  .3,
       .25, 1,    0,   0,   0,   0,  NA,   NA,  NA,  NA,
       .6,  0,   1,   .75, .75,  0,  NA,   NA,  NA,  NA,
       .55, 0,   .75, 1,   .5,   0,  NA,   NA,  NA,  NA,
       .65, 0,   .75,  .5, 1,    0,  NA,   NA,  NA,  NA,
        0,  0,    0,   0,   0,  1,   NA,   NA,  NA,  NA,
        .4, NA,   NA,  NA,  NA,  NA, 1,   .25, .25,  .5,
        .6, NA,   NA,  NA,  NA,  NA, .25,  1,  .25,  0,
        .2, NA,   NA,  NA,  NA,  NA, .25,  .25, 1,   0,
        .3, NA,   NA,  NA,  NA,  NA, .5,    0,   0,  1), 10,10)

# Complete Rmiss with values that maximize
# the matrix determinant (this is the MLE solution)
 set.seed(123)
 out <- CompleteRdev(Rna = Rmiss,
                     MaxDet = TRUE,
                     MaxIter = 1000,
                     delta = 1E-8,
                     PRINT = FALSE)

cat("\nConverged = ", out$converged,"\n")
print( round(out$R, 3))
print( det(out$R))
print( eigen(out$R)$values, digits = 5)

## End(Not run)
```

`CompleteRmap` *Complete a Partially Specified Correlation Matrix by the Method of Alternating Projections*

Description

This function completes a (possibly) partially specified correlation matrix by a modified alternating projections algorithm.

Usage

```
CompleteRmap(
  Rna,
  NMatrices = 1,
  RBounds = FALSE,
  LB = -1,
  UB = 1,
  delta = 1e-16,
  MinLambda = 0,
```

```
  MaxIter = 1000,
  detSort = FALSE,
  Parallel = FALSE,
  ProgressBar = FALSE,
  PrintLevel = 0,
  Digits = 3,
  Seed = NULL
)
```

Arguments

Rna	(matrix) An n x n incomplete correlation matrix. Missing entries must be specified by NA values. If all off diagonal values are NA then the function will generate a random correlation matrix.
NMatrices	(integer) CompleteRmap will complete NMatrices correlation matrices.
RBounds	(logical) If RBounds = TRUE then the function will attempt to produce a matrix on the surface of the associated elliptope (i.e., the space of all possible PSD R matrices of a given dimension). When RBounds = FALSE, during each cycle of the alternating projections algorithm all negative eigenvalues of the provisional R matrix are replaced by (sorted) uniform random numbers between the smallest positive eigenvalue and zero (inclusive) of the indefinite matrix. Default RBounds = FALSE.
LB	(numeric) The lower bound for the random number generator when generating initial estimates for the missing elements of a partially specified correlation matrix.
UB	(numeric) The upper bound for the random number generator when generating initial estimates for the missing elements of a partially specified correlation matrix. Start values (for missing correlations) are sampled from a uniform distribution with bounds [LB, UB].
delta	(numeric) A small number that controls the precision of the estimated solution. Default delta = 1E-16.
MinLambda	(numeric) A small value greater than or equal to 0 used to replace negative eigenvalues during the modified alternating projections algorithm.
MaxIter	(integer) The maximum number of cycles of the alternating projections algorithm. Default MaxIter = 1000.
detSort	(logical). If detSort = TRUE then all results will be sorted according to the sizes of the matrix determinants (det(Ri)). Default detSort = FALSE
Parallel	(logical). If Parallel = TRUE parallel processing will be used to generate the completed correlation matrices. Default: Parallel = FALSE.
ProgressBar	(logical). If Parallel = TRUE and ProgressBar = TRUE a progress bar will be printed to screen. Default ProgressBar = FALSE.
PrintLevel	(integer) The PrintLevel argument can take one of three values: • 0 No output will be printed. Default (PrintLevel = 0). • 1 Print Delta and the minimum eigenvalue of the currently completed correlation matrix.

- 2 Print convergence history.

Digits	(integer) Controls the number of printed significant digits if PrintLevel = 2.
Seed	(integer) Initial random number seed. If reproducible results are desired then it is necessary to specify ProgressBar = FALSE. Default Seed = NULL.

Value

- **CALL** The function call.
- **NMatrices** The number of completed R matrices.
- **Rna** The input partially specified R matrix.
- **Ri** A list of the completed R matrices.
- **RiEigs** A list of eigenvalues for each Ri.
- **RiDet** A list of the determinants for each Ri.
- **converged** The convergence status (TRUE/FALSE) for each Ri.

Author(s)

Niels G. Waller

References

Higham, N. J. (2002). Computing the nearest correlation matrix: A problem from finance. IMA Journal of Numerical Analysis, 22(3), 329–343.

Waller, N. G. (2020). Generating correlation matrices with specified eigenvalues using the method of alternating projections. The American Statistician, 74(1), 21-28.

Examples

```
## Not run:
Rna4 <- matrix(c( 1,  NA,  .29, .18,
                  NA, 1,   .11, .24,
                 .29, .11, 1,   .06,
                 .18, .24, .06, 1), 4, 4)

Out4  <- CompleteRmap(Rna = Rna4,
                      NMatrices = 5,
                      RBounds = FALSE,
                      LB = -1,
                      UB = 1,
                      delta = 1e-16,
                      MinLambda = 0,
                      MaxIter = 5000,
                      detSort = FALSE,
                      ProgressBar = TRUE,
                      Parallel = TRUE,
                      PrintLevel = 1,
                      Digits = 3,
                      Seed = 1)
```

```
summary(Out4,
        PrintLevel = 2,
        Digits = 5)

## End(Not run)
```

`corDensity` *Generate the marginal density of a correlation from a uniformly sampled R matrix.*

Description

Generate the marginal density of a correlation from a uniformly sampled R matrix.

Usage

```
corDensity(NVar)
```

Arguments

`NVar`	(integer) The order of the correlation matrix.

Value

`corDensity` returns the following objects:

- **r** (numeric) A sequence of numbers from -1, to 1 in .001 increments.
- **rDensity** (numeric) The density of `r`.

Author(s)

Niels G. Waller

References

Hürlimann, W. (2012). Positive semi-definite correlation matrices: Recursive algorithmic generation and volume measure. Pure Mathematical Science, 1(3), 137–149.

Joe, H. (2006). Generating random correlation matrices based on partial correlations. Journal of Multivariate Analysis, 97(10), 2177–2189.

Examples

```
out <- corDensity(NVar = 5)

plot(out$r, out$rDensity,
     typ = "l",
     xlab = "r",
     ylab = "Density of r",
     main = "")
```

corSample *Sample Correlation Matrices from a Population Correlation Matrix*

Description

Sample correlation (covariance) matrices from a population correlation matrix (see Browne, 1968; Kshirsagar, 1959)

Usage

```
corSample(R, n)
```

Arguments

R	A population correlation matrix.
n	Sample correlation (covariance) matrices will be generated assuming a sample size of n.

Value

cor.sample	Sample correlation matrix.
cov.sample	Sample covariance matrix.

Author(s)

Niels Waller

References

Browne, M. (1968). A comparison of factor analytic techniques. *Psychometrika, 33(3)*, 267-334.

Kshirsagar, A. (1959). Bartlett decomposition and Wishart distribution. *The Annals of Mathematical Statistics, 30(1)*, 239-241.

Examples

```
R <- matrix(c(1, .5, .5, 1), 2, 2)
# generate a sample correlation from pop R with n = 25
out <- corSample(R, n = 25)
out$cor.sample
out$cov.sample
```

corSmooth *Smooth a Non PD Correlation Matrix*

Description

A function for smoothing a non-positive definite correlation matrix by the method of Knol and Berger (1991).

Usage

```
corSmooth(R, eps = 1e+08 * .Machine$double.eps)
```

Arguments

R	A non-positive definite correlation matrix.
eps	Small positive number to control the size of the non-scaled smallest eigenvalue of the smoothed R matrix. Default = 1E8 * .Machine$double.eps

Value

Rsmoothed	A Smoothed (positive definite) correlation matrix.

Author(s)

Niels Waller

References

Knol, D. L., and Berger, M. P. F., (1991). Empirical comparison between factor analysis and multi-dimensional item response models.*Multivariate Behavioral Research, 26*, 457-477.

Examples

```
## choose eigenvalues such that R is NPD
l <- c(3.0749126,  0.9328397,  0.5523868,  0.4408609, -0.0010000)

## Generate NPD R
R <- genCorr(eigenval = l, seed = 123)
print(eigen(R)$values)

#> [1]  3.0749126  0.9328397  0.5523868  0.4408609 -0.0010000

## Smooth R
Rsm<-corSmooth(R, eps = 1E8 * .Machine$double.eps)
print(eigen(Rsm)$values)

#> [1] 3.074184e+00 9.326669e-01 5.523345e-01 4.408146e-01 2.219607e-08
```

cosMat *Compute the cosine(s) between either 2 matrices or 2 vectors.*

Description

This function will compute the cosines (i.e., the angle) between two vectors or matrices. When applied to matrices, it will compare the two matrices one vector (i.e., column) at a time. For instance, the cosine (angle) between factor 1 in matrix A and factor 1 in matrix B.

Usage

```
cosMat(A, B, align = FALSE, digits = NULL)
```

Arguments

A	(Matrix, Vector) Either a matrix or vector.
B	(Matrix, Vector) Either a matrix or vector (must be of the same dimensions as A).
align	(Logical) Whether to run a factor alignment before computing the cosine.
digits	(Numeric) The number of digits to round the output to.

Details

- **Chance Congruence**: Factor cosines were originally described by Burt (1948) and later popularized by Tucker (1951). Several authors have noted the tendency for two factors to have spuriously large factor cosines. Paunonen (1997) provides a good overview and describes how factor cosines between two vectors of random numbers can appear to be congruent.
- **Effect Size Benchmarks**: When computing congruence coefficients (cosines) in factor analytic studies, it can be useful to know what constitutes large versus small congruence. Lorenzo-Seva and ten Berge (2006) currently provide the most popular (i.e., most frequently cited) recommended benchmarks for congruence. "A value in the range .85-.94 means that the two factors compared display *fair* similarity. This result should prevent congruence below .85 from being interpreted as indicative of any factor similarity at all. A value higher than .95 means that the two factors or components compared can be considered equal. That is what we have called a *good* similarity in our study" (Lorenzo-Seva & ten Berge, 2006, p. 61, emphasis theirs).

Value

A vector of cosines will be returned. When comparing two vectors, only one cosine can be computed. When comparing matrices, one cosine is computed per column.

- **cosine**: (Matrix) A matrix of cosines between the two inputs.
- **A**: (Matrix) The A input matrix.
- **B**: (Matrix) The B input matrix.
- **align**: (Logical) Whether Matrix B was aligned to A.

Author(s)

- Casey Giordano (Giord023@umn.edu)
- Niels G. Waller (nwaller@umn.edu)

References

Burt, C. (1948). The factorial study of temperament traits. *British Journal of Psychology, Statistical Section, 1*, 178-203.

Lorenzo-Seva, U., & ten Berge, J. M. F. (2006). Tuckers Congruence Coefficient as a meaningful index of factor similarity. *Methodology, 2*(2), 57-64.

Paunonen, S. V. (1997). On chance and factor congruence following orthogonal Procrustes rotation. *Educational and Psychological Measurement*, 57, 33-59.

Tucker, L. R. (1951). *A method for synthesis of factor analysis studies* (Personnel Research Section Report No. 984). Washington, DC: Department of the Army.

Examples

```
## Cosine between two vectors
A <- rnorm(5)
B <- rnorm(5)

cosMat(A, B)

## Cosine between the columns of two matrices
A <- matrix(rnorm(5 * 5), 5, 5)
B <- matrix(rnorm(5 * 5), 5, 5)

cosMat(A, B)
```

---

d2r *Convert Degrees to Radians*

Description

A simple function to convert degrees to radians

Usage

```
d2r(deg)
```

Arguments

deg	Angle in degrees.

Value

Angle in radians.

Examples

```
d2r(90)
```

---

eap *Compute eap trait estimates for FMP and FUP models*

Description

Compute eap trait estimates for items fit by filtered monotonic polynomial IRT models.

Usage

```
eap(data, bParams, NQuad = 21, priorVar = 2, mintheta = -4, maxtheta = 4)
```

Arguments

data	N(subjects)-by-p(items) matrix of 0/1 item response data.
bParams	A p-by-9 matrix of FMP or FUP item parameters and model designations. Columns 1 - 8 hold the (possibly zero valued) polynomial coefficients; column 9 holds the value of k.
NQuad	Number of quadrature points used to calculate the eap estimates.
priorVar	Variance of the normal prior for the eap estimates. The prior mean equals 0.
mintheta, maxtheta	NQuad quadrature points will be evenly spaced between mintheta and maxtheta

Value

eap trait estimates.

Author(s)

Niels Waller

Examples

```
## this example demonstrates how to calculate
## eap trait estimates for a scale composed of items
## that have been fit to FMP models of different
## degree

NSubjects <- 2000

## Assume that
## items 1 - 5 fit a k=0 model,
```

```
## items 6 - 10 fit a k=1 model, and
## items 11 - 15 fit a k=2 model.


 itmParameters <- matrix(c(
  #  b0    b1     b2    b3    b4  b5, b6, b7,  k
  -1.05, 1.63,  0.00, 0.00, 0.00,  0,     0,  0,   0, #1
  -1.97, 1.75,  0.00, 0.00, 0.00,  0,     0,  0,   0, #2
  -1.77, 1.82,  0.00, 0.00, 0.00,  0,     0,  0,   0, #3
  -4.76, 2.67,  0.00, 0.00, 0.00,  0,     0,  0,   0, #4
  -2.15, 1.93,  0.00, 0.00, 0.00,  0,     0,  0,   0, #5
  -1.25, 1.17, -0.25, 0.12, 0.00,  0,     0,  0,   1, #6
   1.65, 0.01,  0.02, 0.03, 0.00,  0,     0,  0,   1, #7
  -2.99, 1.64,  0.17, 0.03, 0.00,  0,     0,  0,   1, #8
  -3.22, 2.40, -0.12, 0.10, 0.00,  0,     0,  0,   1, #9
  -0.75, 1.09, -0.39, 0.31, 0.00,  0,     0,  0,   1, #10
  -1.21, 9.07,  1.20,-0.01,-0.01,  0.01,  0,  0,   2, #11
  -1.92, 1.55, -0.17, 0.50,-0.01,  0.01,  0,  0,   2, #12
  -1.76, 1.29, -0.13, 1.60,-0.01,  0.01,  0,  0,   2, #13
  -2.32, 1.40,  0.55, 0.05,-0.01,  0.01,  0,  0,   2, #14
  -1.24, 2.48, -0.65, 0.60,-0.01,  0.01,  0,  0,   2),#15
  15, 9, byrow=TRUE)

# generate data using the above item parameters
ex1.data<-genFMPData(NSubj = NSubjects, bParams = itmParameters,
                     seed = 345)$data


## calculate eap estimates for mixed models
thetaEAP<-eap(data = ex1.data, bParams = itmParameters,
                   NQuad = 25, priorVar = 2,
                   mintheta = -4, maxtheta = 4)

## compare eap estimates with initial theta surrogates

if(FALSE){     #set to TRUE to see plot

  thetaInit <- svdNorm(ex1.data)
  plot(thetaInit,thetaEAP, xlim = c(-3.5,3.5),
                         ylim = c(-3.5,3.5),
                         xlab = "Initial theta surrogates",
                         ylab = "EAP trait estimates (Mixed models)")
}
```

---

eigGen *Generate eigenvalues for R matrices with underlying component structure*

Description

Generate eigenvalues for R matrices with underlying component structure

Usage

```
eigGen(nDimensions = 15, nMajorFactors = 5, PrcntMajor = 0.8, threshold = 0.5)
```

Arguments

nDimensions	Total number of dimensions (variables).
nMajorFactors	Number of major factors.
PrcntMajor	Percentage of variance accounted for by major factors.
threshold	Minimm difference in eigenvalues between the last major factor and the first minor factor.

Value

A vector of eigenvalues that satisfies the above criteria.

Author(s)

Niels Waller

Examples

```
## Example
set.seed(323)
nDim <- 25   # number of dimensions
nMaj <- 5    # number of major components
pmaj <- 0.70 # percentage of variance accounted for
             # by major components
thresh <- 1  # eigenvalue difference between last major component
             # and first minor component

L <- eigGen(nDimensions = nDim, nMajorFactors = nMaj,
            PrcntMajor = pmaj, threshold = thresh)

maxy <- max(L+1)

plotTitle <- paste("  n Dimensions = ", nDim,
                   ",  n Major Factors = ", nMaj,
          "\n % Variance Major Factors = ", pmaj*100,
   "%", sep = "")

plot(1:length(L), L,
     type = "b",
     main = plotTitle,
     ylim = c(0, maxy),
     xlab = "Dimensions",
   ylab = "Eigenvalues",
   cex.main = .9)
```

enhancement *Find OLS Regression Coefficients that Exhibit Enhancement*

Description

Find OLS regression coefficients that exhibit a specified degree of enhancement.

Usage

```
enhancement(R, br, rr)
```

Arguments

R	Predictor correlation matrix.
br	Model R-squared = b' r. That is, br is the model coefficient of determination: b'Rb= Rsq = br
rr	Sum of squared predictor-criterion correlations (rxy). That is, rr = r'r = Sum(rxy^2)

Value

b	Vector of standardized regression coefficients.
r	Vector of predictor-criterion correlations.

Author(s)

Niels Waller

References

Waller, N. G. (2011). The geometry of enhancement in multiple regression. *Psychometrika, 76*, 634–649.

Examples

```
## Example: For a given predictor correlation  matrix (R) generate
## regression coefficient vectors that produce enhancement (br - rr > 0)

## Predictor correlation matrix
R <- matrix(c( 1,  .5, .25,
              .5, 1,   .30,
              .25, .30, 1), 3, 3)

## Model coefficient of determination
Rsq <- .60

output<-enhancement(R, br = Rsq, rr =.40)

r <- output$r
```

```
b <- output$b

##Standardized regression coefficients
print(t(b))

##Predictor-criterion correlations
print(t(r))

##Coefficient of determinations (b'r)
print(t(b) %*% r)

##Sum of squared correlations (r'r)
print(t(r) %*% r)
```

---

erf *Utility fnc to compute the components for an empirical response function*

Description

Utility function to compute empirical response functions.

Usage

```
erf(theta, data, whichItem, min = -3, max = 3, Ncuts = 12)
```

Arguments

theta	Vector of estimated latent trait scores.
data	A matrix of binary item responses.
whichItem	Data for an erf will be generated for whichItem.
min	Default = -3. Minimum value of theta.
max	Default = 3. Maximum value of theta.
Ncuts	Number of score groups for erf.

Value

probs	A vector (of length Ncuts) of bin response probabilities for the empirical response function.
centers	A vector of bin centers.
Ni	Bin sample sizes.
se.p	Standard errors of the estimated bin response probabilities.

Author(s)

Niels Waller

Examples

```
NSubj <- 2000

#generate sample k=1 FMP  data
b <- matrix(c(
    #b0    b1     b2    b3      b4   b5 b6 b7  k
  1.675, 1.974, -0.068, 0.053,  0,  0,  0,  0, 1,
  1.550, 1.805, -0.230, 0.032,  0,  0,  0,  0, 1,
  1.282, 1.063, -0.103, 0.003,  0,  0,  0,  0, 1,
  0.704, 1.376, -0.107, 0.040,  0,  0,  0,  0, 1,
  1.417, 1.413,  0.021, 0.000,  0,  0,  0,  0, 1,
 -0.008, 1.349, -0.195, 0.144,  0,  0,  0,  0, 1,
  0.512, 1.538, -0.089, 0.082,  0,  0,  0,  0, 1,
  0.122, 0.601, -0.082, 0.119,  0,  0,  0,  0, 1,
  1.801, 1.211,  0.015, 0.000,  0,  0,  0,  0, 1,
 -0.207, 1.191,  0.066, 0.033,  0,  0,  0,  0, 1,
 -0.215, 1.291, -0.087, 0.029,  0,  0,  0,  0, 1,
  0.259, 0.875,  0.177, 0.072,  0,  0,  0,  0, 1,
 -0.423, 0.942,  0.064, 0.094,  0,  0,  0,  0, 1,
  0.113, 0.795,  0.124, 0.110,  0,  0,  0,  0, 1,
  1.030, 1.525,  0.200, 0.076,  0,  0,  0,  0, 1,
  0.140, 1.209,  0.082, 0.148,  0,  0,  0,  0, 1,
  0.429, 1.480, -0.008, 0.061,  0,  0,  0,  0, 1,
  0.089, 0.785, -0.065, 0.018,  0,  0,  0,  0, 1,
 -0.516, 1.013,  0.016, 0.023,  0,  0,  0,  0, 1,
  0.143, 1.315, -0.011, 0.136,  0,  0,  0,  0, 1,
  0.347, 0.733, -0.121, 0.041,  0,  0,  0,  0, 1,
 -0.074, 0.869,  0.013, 0.026,  0,  0,  0,  0, 1,
  0.630, 1.484, -0.001, 0.000,  0,  0,  0,  0, 1),
  nrow=23, ncol=9, byrow=TRUE)

theta <- rnorm(NSubj)
data<-genFMPData(NSubj = NSubj, bParam = b, theta = theta, seed = 345)$data

erfItem1 <- erf(theta, data, whichItem = 1, min = -3, max = 3, Ncuts = 12)

plot( erfItem1$centers, erfItem1$probs, type="b",
      main="Empirical Response Function",
      xlab = expression(theta),
      ylab="Probability",
      cex.lab=1.5)
```

`faAlign` *Align the columns of two factor loading matrices*

Description

Align factor loading matrices across solutions using the Hungarian algorithm to locate optimal matches. faAlign will match the factors of F2 (the input matrix) to those in F1 (the target matrix) to

minimize a least squares discrepancy function or to maximize factor congruence coefficients (i.e., vector cosines).

Usage

```
faAlign(F1, F2, Phi2 = NULL, MatchMethod = "LS")
```

Arguments

F1	target Factor Loadings Matrix.
F2	input Factor Loadings Matrix. F2 will be aligned with the target matrix, F1.
Phi2	optional factor correlation matrix for F2 (default = NULL).
MatchMethod	"LS" (Least Squares) or "CC" (congruence coefficients).

Value

F2	re-ordered and reflected loadings of F2.
Phi2	reordered and reflected factor correlations.
FactorMap	a 2 x k matrix (where k is the number of columns of F1) structured such that row 1: the original column order of F2; row 2: the sorted column order of F2.
UniqueMatch	(logical) indicates whether a unique match was found.
MatchMethod	"LS" (least squares) or "CC" (congruence coefficients, i.e., cosines).
CC	Congruence coefficients for the matched factors.
LS	Root-mean-squared-deviations (least squares criterion) for the matched factors.
Dsgn	The Diagonal Sign Matrix that reflects the matched factors to have positive salient loadings.

Note

The Hungarian algorithm is implemented with the clue (Cluster Ensembles, Hornik, 2005) package. See Hornik K (2005). A CLUE for CLUster Ensembles. *Journal of Statistical Software, 14*(12). doi: 10.18637/jss.v014.i12 (URL: http://doi.org/10.18637/jss.v014.i12).

Author(s)

Niels Waller

References

Kuhn, H. W. (1955). The Hungarian Method for the assignment problem. *Naval Research Logistics Quarterly, 2*, 83-97.

Kuhn, H. W. (1956). Variants of the Hungarian method for assignment problems. *Naval Research Logistics Quarterly, 3*, 253-258.

Papadimitriou, C. & Steiglitz, K. (1982). Combinatorial Optimization: Algorithms and Complexity. Englewood Cliffs: Prentice Hall.

See Also

Other Factor Analysis Routines: BiFAD(), Box26, GenerateBoxData(), Ledermann(), SLi(), SchmidLeiman(), faEKC(), faIB(), faLocalMin(), faMB(), faMain(), faScores(), faSort(), faStandardize(), faX(), fals(), fapa(), fareg(), fsIndeterminacy(), orderFactors(), print.faMB(), print.faMain(), promaxQ(), summary.faMB(), summary.faMain()

Examples

```
# This example demonstrates the computation of
# non-parametric bootstrap confidence intervals
# for rotated factor loadings.


library(GPArotation)

data(HS9Var)

HS9 <- HS9Var[HS9Var$school == "Grant-White",7:15]

# Compute an R matrix for the HSVar9 Mental Abilities Data
R.HS9 <- cor(HS9)

varnames <- c( "vis.per", "cubes",
            "lozenges", "paragraph.comp",
            "sentence.comp","word.mean",
            "speed.add", "speed.count.dots",
            "speed.discr")



# Extract and rotate a 3-factor solution
# via unweighted least squares factor extraction
# and oblimin rotation.

NFac <- 3
NVar <- 9
B <- 200      # Number of boostrap samples
NSubj <- nrow(HS9)

# Unrotated 3 factor uls solution
 F3.uls <- fals(R = R.HS9, nfactors = NFac)

# Rotate via oblimin
 F3.rot <- oblimin(F3.uls$loadings,
                     gam = 0,
                     normalize = FALSE)

 F3.loadings <- F3.rot$loadings
 F3.phi <- F3.rot$Phi

 # Reflect factors so that salient loadings are positive
 Dsgn <- diag(sign(colSums(F3.loadings^3)))
```

```
F3.loadings <- F3.loadings %*% Dsgn
F3.phi <- Dsgn %*% F3.phi %*% Dsgn

rownames(F3.loadings) <- varnames
colnames(F3.loadings) <- paste0("f", 1:3)
colnames(F3.phi) <- rownames(F3.phi) <- paste0("f", 1:3)

cat("\nOblimin rotated factor loadings for 9 Mental Abilities Variables")
print( round(F3.loadings, 2))

cat("\nFactor correlation matrix")
print( round( F3.phi, 2))

 # Declare variables to hold bootstrap output
 Flist <- Philist <- as.list(rep(0, B))
 UniqueMatchVec <- rep(0, B)
 rows <- 1:NSubj

 # Analyze bootstrap samples and record results
 for(i in 1:B){
   cat("\nWorking on sample ", i)
   set.seed(i)

   # Create bootstrap sanples
   bsRows <- sample(rows, NSubj, replace= TRUE)
   Fuls <- fals(R = cor(HS9[bsRows, ]), nfactors = NFac)
   # rotated loadings
   Fboot <- oblimin(Fuls$loadings,
                            gam = 0,
                            normalize = FALSE)


   out <- faAlign(F1 = F3.loadings,
                  F2 = Fboot$loadings,
                  MatchMethod = "LS")

   Flist[[i]] <- out$F2 # aligned version of Fboot$loadings
   UniqueMatchVec[i] <- out$UniqueMatch
 }

 cat("\nNumber of Unique Matches: ",
     100*round(mean(UniqueMatchVec),2),"%\n")


 #  Make a 3D array from list of matrices
 arr <- array( unlist(Flist) , c(NVar, NFac, B) )

 #  Get quantiles of factor elements over third dimension (samples)
 F95 <- apply( arr , 1:2 , quantile, .975 )
 F05 <- apply( arr , 1:2 , quantile, .025 )
 Fse <- apply( arr , 1:2, sd  )

 cat("\nUpper Bound 95% CI\n")
```

```
print( round(F95,3))
cat("\n\nLower Bound 95% CI\n")
print( round(F05,3))

# plot distribution of bootstrap estimates
# for example element
hist(arr[5,1,], xlim=c(.4,1),
     main = "Bootstrap Distribution for F[5,1]",
     xlab = "F[5,1]")

print(round (F3.loadings, 2))
cat("\nStandard Errors")
print( round( Fse, 2))
```

---

faBounds *Bounds on the Correlation Between an External Variable and a Common Factor*

Description

This function computes the bounds on the correlation between an external variable and a common factor.

Usage

```
faBounds(Lambda, RX, rXY, alphaY = 1)
```

Arguments

Lambda	(matrix) A p x 1 matrix of factor loadings.
RX	(matrix) A p x p matrix of correlations for the factor indicators.
rXY	(vector) A p x 1 vector of correlations between the factor indicators (X) and the external variable (Y).
alphaY	(scalar) The reliability of Y. Default alphaY = 1.

Value

faBounds returns the following objects:

- **Lambda** (matrix) A p x 1 vector of factor loadings.
- **RX** (matrix) The indicator correlation matrix.
- **rXY**: (vector) The correlations between the factor indicators (X) and the external variable (Y).
- **alphaY** (integer) The reliability of the external variable.
- **bounds** (vector) A 2 x 1 vector that includes the lower and upper bounds for the correlation between an external variable and a common factor.

- **rUiY** (vector) Correlations between the unique factors and the external variable for the lower bound estimate.
- **rUjY** (vector) Correlations between the unique factors and the external variable for the upper bound estimate.

Author(s)

Niels G. Waller

References

Steiger, J. H. (1979). The relationship between external variables and common factors. Psychometrika, 44, 93-97.

Waller, N. G. (under review). New results on the relationship between an external variable and a common factor.

Examples

```
## Example
## We wish to compute the bounds between the Speed factor from the
## Holzinger (H) and Swineford data and a hypothetical external
## variable, Y.

## RH = R matrix for *H*olzinger Swineford data
RH <-
 matrix(c( 1.00,   0,    0,     0,     0,     0,
           .73, 1.00,    0,     0,     0,     0,
           .70,  .72,  1.00,    0,     0,     0,
           .17,  .10,   .12,  1.00,    0,     0,
           .11,  .14,   .15,   .49,  1.00,    0,
           .21,  .23,   .21,   .34,   .45,  1.00), 6, 6)

RH <- RH + t(RH) - diag(6)
RX <- RH[4:6, 4:6]

## S-C = Straight-curved
 colnames(RX) <- rownames(RX) <-
        c("Addition", "Counting dots", "S-C capitals")
print( RX, digits = 2 )

## Extract 1 MLE factor
fout <- faMain(R = RX,
               numFactors = 1,
               facMethod = "faml",
               rotate="none")

## Lambda = factor loadings matrix
Lambda <- fout$loadings
print( Lambda, digits = 3 )

## rXY = correlations between the factor indicators (X) and
```

```
## the external variable (Y)

 rXY = c(.1, .2, .3)

 # Assume that the reliability of Y = .75

 faBounds(Lambda, RX, rXY, alphaY = .75)
```

---

faEKC *Calculate Reference Eigenvalues for the Empirical Kaiser Criterion*

Description

Calculate Reference Eigenvalues for the Empirical Kaiser Criterion

Usage

```
faEKC(R = NULL, NSubj = NULL, Plot = FALSE)
```

Arguments

R	Input correlation matrix.
NSubj	Number of subjects (observations) used to create R.
Plot	(logical). If Plot = TRUE the function will plot the observed and reference eigenvalues of R.

Value

- ljEKC,
- ljEKC1,
- dimensions The estimated number of common factors.

Author(s)

Niels Waller

References

Braeken, J. & Van Assen, M. A. (2017). An empirical Kaiser criterion. *Psychological Methods, 22*(3), 450-466.

See Also

Other Factor Analysis Routines: BiFAD(), Box26, GenerateBoxData(), Ledermann(), SLi(), SchmidLeiman(), faAlign(), faIB(), faLocalMin(), faMB(), faMain(), faScores(), faSort(), faStandardize(), faX(), fals(), fapa(), fareg(), fsIndeterminacy(), orderFactors(), print.faMB(), print.faMain(), promaxQ(), summary.faMB(), summary.faMain()

Examples

```
data(AmzBoxes)
AmzBox20<- GenerateBoxData(XYZ = AmzBoxes[,2:4],
                           BoxStudy = 20)$BoxData
RAmzBox20 <- cor(AmzBox20)
EKCout  <- faEKC(R = RAmzBox20,
                 NSubj = 98,
                 Plot = TRUE)
```

`faIB` *Inter-Battery Factor Analysis by the Method of Maximum Likelihood*

Description

This function conducts maximum likelihood inter-battery factor analysis using procedures described by Browne (1979). The unrotated solution can be rotated (using the **GPArotation** package) from a user-specified number of random (orthogonal) starting configurations. Based on the resulting complexity function value, the function determines the number of local minima and, among these local solutions, will find the "global minimum" (i.e., the minimized complexity value from the finite number of solutions). See Details below for an elaboration on the global minimum. This function can also return bootstrap standard errors of the factor solution.

Usage

```
faIB(
  X = NULL,
  R = NULL,
  n = NULL,
  NVarX = 4,
  numFactors = 2,
  itemSort = FALSE,
  rotate = "oblimin",
  bootstrapSE = FALSE,
  numBoot = 1000,
  CILevel = 0.95,
  rotateControl = NULL,
  Seed = 1
)
```

Arguments

`X`	(Matrix) A raw data matrix (or data frame) structured in a subject (row) by variable (column) format. Defaults to `X = NULL`.
`R`	(Matrix) A correlation matrix. Defaults to `R = NULL`.

`n` (Numeric) Sample size associated with either the raw data (X) or the correlation matrix (R). Defaults to `n = NULL`.

`NVarX` (Integer) Given batteries X and Y, `NVarX` denotes the number of variables in battery X.

`numFactors` (Numeric) The number of factors to extract for subsequent rotation. Defaults to `numFactors = NULL`.

`itemSort` (Logical) if `itemSort = TRUE` the factor loadings will be sorted within batteries.

`rotate` (Character) Designate which rotation algorithm to apply. The following are available rotation options: "oblimin", "quartimin", "oblimax", "entropy", "quartimax", "varimax", "simplimax", "bentlerT", "bentlerQ", "tandemI", "tandemII", "geominT", "geominQ", "cfT", "cfQ", "infomaxT", "infomaxQ", "mccammon", "bifactorT", "bifactorQ", and "none". Defaults to rotate = "oblimin". See **GPArotation** package for more details. Note that rotations ending in "T" and "Q" represent orthogonal and oblique rotations, respectively.

`bootstrapSE` (Logical) Computes bootstrap standard errors. All bootstrap samples are aligned to the global minimum solution. Defaults to bootstrapSE = FALSE (no standard errors).

`numBoot` (Numeric) The number bootstraps. Defaults to numBoot = 1000.

`CILevel` (Numeric) The confidence level (between 0 and 1) of the bootstrap confidence interval. Defaults to CILevel = .95.

`rotateControl` (List) A list of control values to pass to the factor rotation algorithms.

- **numberStarts**: (Numeric) The number of random (orthogonal) starting configurations for the chosen rotation method (e.g., oblimin). The first rotation will always commence from the unrotated factors orientation. Defaults to numberStarts = 10.
- **gamma**: (Numeric) This is a tuning parameter (between 0 and 1, inclusive) for an oblimin rotation. See the **GPArotation** library's oblimin documentation for more details. Defaults to gamma = 0 (i.e., a quartimin rotation).
- **delta**: (Numeric) This is a tuning parameter for the geomin rotation. It adds a small number (default = .01) to the squared factor loadings before computing the geometric means in the discrepancy function.
- **kappa**: (Numeric) The main parameterization of the Crawford-Ferguson (CF) rotations (i.e., "cfT" and "cfQ" for orthogonal and oblique CF rotation, respectively). Defaults to kappa = 0.
- **k**: (Numeric) A specific parameter of the simplimax rotation. Defaults to k = the number of observed variables.
- **standardize**: (Character) The standardization routine used on the unrotated factor structure. The three options are "none", "Kaiser", and "CM". Defaults to standardize = "none".
  - **"none"**: No standardization is applied to the unrotated factor structure.
  - **"Kaiser"**: Use a factor structure matrix that has been normed by Kaiser's method (i.e., normalize all rows to have a unit length).
  - **"CM"**: Use a factor structure matrix that has been normed by the Cureton-Mulaik method.

- **epsilon**: (Numeric) The rotational convergence criterion to use. Defaults to epsilon = 1e-5.
- **power**: (Numeric) Raise factor loadings the the n-th power in the promaxQ rotation. Defaults to power = 4.
- **maxItr**: (Numeric) The maximum number of iterations for the rotation algorithm. Defaults to maxItr = 15000.

Seed (Integer) Starting seed for the random number generator.

Details

- **Global Minimum**: This function uses several random starting configurations for factor rotations in an attempt to find the global minimum solution. However, this function is not guaranteed to find the global minimum. Furthermore, the global minimum solution need not be more psychologically interpretable than any of the local solutions (cf. Rozeboom, 1992). As is recommended, our function returns all local solutions so users can make their own judgements.
- **Finding clusters of local minima**: We find local-solution sets by sorting the rounded rotation complexity values (to the number of digits specified in the epsilon argument of the rotateControl list) into sets with equivalent values. For example, by default epsilon = 1e-5. and thus will only evaluate the complexity values to five significant digits. Any differences beyond that value will not effect the final sorting.

Value

The faIB function will produce abundant output in addition to the rotated inter-battery factor pattern and factor correlation matrices.

- **loadings**: (Matrix) The rotated inter-battery factor solution with the lowest evaluated discrepancy function. This solution has the lowest discrepancy function *of the examined random starting configurations*. It is not guaranteed to find the "true" global minimum. Note that multiple (or even all) local solutions can have the same discrepancy functions.
- **Phi**: (Matrix) The factor correlations of the rotated factor solution with the lowest evaluated discrepancy function (see Details).
- **fit**: (Vector) A vector containing the following fit statistics:
  - **chiSq**: Chi-square goodness of fit value (see Browne, 1979, for details). Note that we apply Lawley's (1959) correction when computing the chi-square value.
  - **DF**: Degrees of freedom for the estimated model.
  - **p-value**: P-value associated with the above chi-square statistic.
  - **MAD**: Mean absolute difference between the model-implied and the sample across-battery correlation matrices. A lower value indicates better fit.
  - **AIC**: Akaike's Information Criterion where a lower value indicates better fit.
  - **BIC**: Bayesian Information Criterion where a lower value indicates better fit.
- **R**: (Matrix) Returns the (possibly sorted) correlation matrix, useful when raw data are supplied. If itemSort = TRUE then the returned matrix is sorted to be consistent with the factor loading matrix.
- **Rhat**: (Matrix) The (possibly sorted) reproduced correlation matrix.If itemSort = TRUE then the returned matrix is sorted to be consistent with the factor loading matrix.

- **Resid**: (Matrix) A (possibly sorted) residual matrix (R - Rhat) for the between battery correlations.
- **facIndeterminacy**: (Vector) A vector (with length equal to the number of factors) containing Guttman's (1955) index of factor indeterminacy for each factor.
- **localSolutions**: (List) A list containing all local solutions in ascending order of their factor loadings, rotation complexity values (i.e., the first solution is the "global" minimum). Each solution returns the
  - **loadings**: (Matrix) the factor loadings,
  - **Phi**: (Matrix) factor correlations,
  - **RotationComplexityValue**: (Numeric) the complexity value of the rotation algorithm,
  - **facIndeterminacy**: (Vector) A vector of factor indeterminacy indices for each common factor, and
  - **RotationConverged**: (Logical) convergence status of the rotation algorithm.
- **numLocalSets** (Numeric) How many sets of local solutions with the same discrepancy value were obtained.
- **localSolutionSets**: (List) A list containing the sets of unique local minima solutions. There is one list element for every unique local solution that includes (a) the factor loadings matrix, (b) the factor correlation matrix (if estimated), and (c) the discrepancy value of the rotation algorithm.
- **rotate** (Character) The chosen rotation algorithm.
- **rotateControl**: (List) A list of the control parameters passed to the rotation algorithm.
- **unSpunSolution**: (List) A list of output parameters (e.g., loadings, Phi, etc) from the rotated solution that was obtained by rotating directly from the unrotated (i.e., unspun) common factor orientation.
- **Call**: (call) A copy of the function call.

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See Also

Other Factor Analysis Routines: BiFAD(), Box26, GenerateBoxData(), Ledermann(), SLi(), SchmidLeiman(), faAlign(), faEKC(), faLocalMin(), faMB(), faMain(), faScores(), faSort(), faStandardize(), faX(), fals(), fapa(), fareg(), fsIndeterminacy(), orderFactors(), print.faMB(), print.faMain(), promaxQ(), summary.faMB(), summary.faMain()

Examples

```
# Example 1:
# Example from: Browne, M. W.  (1979).
#
# Data originally reported in:
# Thurstone, L. L. & Thurstone, T. G. (1941). Factorial studies
# of intelligence. Psychometric Monograph (2), Chicago: Univ.
# Chicago Press.

R.XY <- matrix(c(
 1.00, .554, .227, .189, .461, .506, .408, .280, .241,
 .554, 1.00, .296, .219, .479, .530, .425, .311, .311,
 .227, .296, 1.00, .769, .237, .243, .304, .718, .730,
 .189, .219, .769, 1.00, .212, .226, .291, .681, .661,
 .461, .479, .237, .212, 1.00, .520, .514, .313, .245,
 .506, .530, .243, .226, .520, 1.00, .473, .348, .290,
 .408, .425, .304, .291, .514, .473, 1.00, .374, .306,
 .280, .311, .718, .681, .313, .348, .374, 1.00, .672,
 .241, .311, .730, .661, .245, .290, .306, .672, 1.00), 9, 9)


dimnames(R.XY) <- list(c( paste0("X", 1:4),
                          paste0("Y", 1:5)),
                       c( paste0("X", 1:4),
                          paste0("Y", 1:5)))

    out <- faIB(R = R.XY,
                n = 710,
                NVarX = 4,
                numFactors = 2,
                itemSort = FALSE,
                rotate = "oblimin",
                rotateControl = list(standardize  = "Kaiser",
                                     numberStarts = 10),
                Seed = 1)
```

```
# Compare with Browne 1979 Table 2.
print(round(out$loadings, 2))
cat("\n\n")
print(round(out$Phi,2))
cat("\n\n MAD = ", round(out$fit["MAD"], 2),"\n\n")
print( round(out$facIndeterminacy,2) )


# Example 2:
## Correlation values taken from Boruch et al.(1970) Table 2 (p. 838)
## See also, Cudeck (1982) Table 1 (p. 59)
corValues <- c(
  1.0,
  .11,  1.0,
  .61,  .47, 1.0,
  .42, -.02, .18,  1.0,
  .75,  .33, .58,  .44, 1.0,
  .82,  .01, .52,  .33, .68,  1.0,
  .77,  .32, .64,  .37, .80,  .65, 1.0,
  .15, -.02, .04,  .08, .12,  .11, .13, 1.0,
  -.04,  .22, .26, -.06, .07, -.10, .07, .09,  1.0,
  .13,  .21, .23,  .05, .07,  .06, .12, .64,  .40, 1.0,
  .01,  .04, .01,  .16, .05,  .07, .05, .41, -.10, .29, 1.0,
  .27,  .13, .18,  .17, .27,  .27, .27, .68,  .18, .47, .33, 1.0,
  .24,  .02, .12,  .12, .16,  .23, .18, .82,  .08, .55, .35, .76, 1.0,
  .20,  .18, .16,  .17, .22,  .11, .29, .69,  .20, .54, .34, .68, .68, 1.0)

## Generate empty correlation matrix
BoruchCorr <- matrix(0, nrow = 14, ncol = 14)

## Add upper-triangle correlations
BoruchCorr[upper.tri(BoruchCorr, diag = TRUE)] <- corValues
BoruchCorr <- BoruchCorr + t(BoruchCorr) - diag(14)

## Add variable names to the correlation matrix
varNames <- c("Consideration", "Structure", "Sup.Satisfaction",
"Job.Satisfaction", "Gen.Effectiveness", "Hum.Relations", "Leadership")

## Distinguish between rater X and rater Y
varNames <- paste0(c(rep("X.", 7), rep("Y.", 7)), varNames)

## Add row/col names to correlation matrix
dimnames(BoruchCorr) <- list(varNames, varNames)

## Estimate a model with one, two, and three factors
for (jFactors in 1:3) {
  tempOutput <- faIB(R          = BoruchCorr,
                     n          = 111,
                     NVarX      = 7,
                     numFactors = jFactors,
                     rotate     = "oblimin",
                     rotateControl = list(standardize  = "Kaiser",
```

```
                                          numberStarts = 100))

  cat("\nNumber of inter-battery factors:", jFactors,"\n")
  print( round(tempOutput$fit,2) )
} # END for (jFactors in 1:3)

## Compare output with Cudeck (1982) Table 2 (p. 60)
BoruchOutput <-
  faIB(R             = BoruchCorr,
       n             = 111,
       NVarX         = 7,
       numFactors    = 2,
       rotate        = "oblimin",
       rotateControl = list(standardize = "Kaiser"))

## Print the inter-battery factor loadings
print(round(BoruchOutput$loadings, 3))
print(round(BoruchOutput$Phi, 3))
```

`faLocalMin` *Investigate local minima in faMain objects*

Description

Compute pairwise root mean squared deviations (RMSD) among rotated factor patterns in an `faMain` object. Prior to computing the RMSD values, each pair of solutions is aligned to the first member of the pair. Alignment is accomplished using the Hungarian algorithm as described in `faAlign`.

Usage

```
faLocalMin(fout, Set = 1, HPthreshold = 0.1, digits = 5, PrintLevel = 1)
```

Arguments

`fout`	(Object from class `faMain`).
`Set`	(Integer) The index of the solution set (i.e., the collection of rotated factor patterns with a common complexity value) from an `faMain` object.
`HPthreshold`	(Scalar) A number between [0, 1] that defines the hyperplane threshold. Factor pattern elements below `HPthreshold` in absolute value are counted in the hyperplane count.
`digits`	(Integer) Specifies the number of significant digits in the printed output. Default `digits` = 5.
`PrintLevel`	(Integer) Determines the level of printed output. PrintLevel = • **0**: No output is printed. • **1**: Print output for the six most discrepant pairs of rotated factor patterns. • **2**: Print output for all pairs of rotated factor patterns.

Details

Compute pairwise RMSD values among rotated factor patterns from an `faMain` object.

Value

`faLocalMin` function will produce the following output.

- **rmsdTable**: (Matrix) A table of `RMSD` values for each pair of rotated factor patterns in solution set `Set`.
- **Set**: (Integer) The index of the user-specified solution set.
- **complexity.val** (Numeric): The common complexity value for all members in the user-specified solution set.
- **HPcount**: (Integer) The hyperplane count for each factor pattern in the solution set.

Author(s)

Niels Waller

See Also

Other Factor Analysis Routines: `BiFAD()`, `Box26`, `GenerateBoxData()`, `Ledermann()`, `SLi()`, `SchmidLeiman()`, `faAlign()`, `faEKC()`, `faIB()`, `faMB()`, `faMain()`, `faScores()`, `faSort()`, `faStandardize()`, `faX()`, `fals()`, `fapa()`, `fareg()`, `fsIndeterminacy()`, `orderFactors()`, `print.faMB()`, `print.faMain()`, `promaxQ()`, `summary.faMB()`, `summary.faMain()`

Examples

```
## Not run:
  ## Generate Population Model and Monte Carlo Samples ####
  sout <- simFA(Model = list(NFac = 5,
                             NItemPerFac = 5,
                              Model = "orthogonal"),
                Loadings = list(FacLoadDist = "fixed",
                                FacLoadRange = .8),
                MonteCarlo = list(NSamples = 100,
                                  SampleSize = 500),
                Seed = 655342)

  ## Population EFA loadings
  (True_A <- sout$loadings)

  ## Population Phi matrix
  sout$Phi

  ## Compute EFA on Sample 67 ####
  fout <- faMain (R = sout$Monte$MCData[[67]],
                  numFactors = 5,
                  targetMatrix = sout$loadings,
                  facMethod = "fals",
                  rotate= "cfT",
```

```
                rotateControl = list(numberStarts = 50,
                                     standardize="CM",
                                     kappa = 1/25),
                Seed=3366805)

  ## Summarize output from faMain
  summary(fout, Set = 1, DiagnosticsLevel = 2, digits=4)

  ## Investigate Local Solutions
  LMout <- faLocalMin(fout,
                   Set = 1,
                   HPthreshold = .15,
                   digits= 5,
                   PrintLevel = 1)

  ## Print hyperplane count for each factor pattern
  ## in the solution set
  LMout$HPcount

## End(Not run)
```

`fals` *Unweighted least squares factor analysis*

Description

Unweighted least squares factor analysis

Usage

```
fals(R, nfactors, TreatHeywood = TRUE)
```

Arguments

`R`	Input correlation matrix.
`nfactors`	Number of factors to extract.
`TreatHeywood`	If TreatHeywood = TRUE then a penalized least squares function is used to bound the commonality estimates below 1.0. Default(TreatHeywood = TRUE).

Value

`loadings`	Unrotated factor loadings. If a Heywood case is present in the initial solution then the model is re-estimated via non-iterated principal axes with max(rij^2) as fixed communaility (h2) estimates.
`h2`	Vector of final commonality estimates.
`uniqueness`	Vector of factor uniquenesses, i.e. (1 - h2).
`Heywood`	(logical) TRUE if a Heywood case was produced in the LS solution.

TreatHeywood	(logical) Value of the TreatHeywood argument.
converged	(logical) TRUE if all values of the gradient are sufficiently close to zero.
MaxAbsGrad	The maximum absolute value of the gradient at the solution.
f.value	The discrepancy value associated with the final solution.

Author(s)

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See Also

Other Factor Analysis Routines: BiFAD(), Box26, GenerateBoxData(), Ledermann(), SLi(), SchmidLeiman(), faAlign(), faEKC(), faIB(), faLocalMin(), faMB(), faMain(), faScores(), faSort(), faStandardize(), faX(), fapa(), fareg(), fsIndeterminacy(), orderFactors(), print.faMB(), print.faMain(), promaxQ(), summary.faMB(), summary.faMain()

Examples

```
Rbig <- fungible::rcor(120)
out1 <- fals(R = Rbig,
             nfactors = 2,
             TreatHeywood = TRUE)
```

---

faMain *Automatic Factor Rotation from Random Configurations with Bootstrap Standard Errors*

Description

This function conducts factor rotations (using the **GPArotation** package) from a user-specified number of random (orthogonal) starting configurations. Based on the resulting complexity function value, the function determines the number of local minima and, among these local solutions, will find the "global minimum" (i.e., the minimized complexity value from the finite number of solutions). See Details below for an elaboration on the global minimum. This function can also return bootstrap standard errors of the factor solution.

Usage

```
faMain(
  X = NULL,
  R = NULL,
  n = NULL,
  numFactors = NULL,
  facMethod = "fals",
  urLoadings = NULL,
```

```
  rotate = "oblimin",
  targetMatrix = NULL,
  bootstrapSE = FALSE,
  numBoot = 1000,
  CILevel = 0.95,
  Seed = 1,
  digits = NULL,
  faControl = NULL,
  rotateControl = NULL,
  ...
)
```

Arguments

X	(Matrix) A raw data matrix (or data frame).
R	(Matrix) A correlation matrix.
n	(Numeric) Sample size associated with the correlation matrix. Defaults to n = NULL.
numFactors	(Numeric) The number of factors to extract for subsequent rotation.
facMethod	(Character) The method used for factor extraction (faX). The supported options are "fals" for unweighted least squares, "faml" for maximum likelihood, "fapa" for iterated principal axis factoring, "faregLS" for regularized least squares, "faregML" for regularized maximum likelihood, and "pca" for principal components analysis. The default method is "fals". • **"fals"**: Factors are extracted using the unweighted least squares estimation procedure using the fals function. • **"faml"**: Factors are extracted using the maximum likelihood estimation procedure using the factanal function. • **"fapa"**: Factors are extracted using the iterated principal axis factoring estimation procedure using the fapa function. • **"faregLS"**: Factors are extracted using regularized least squares factor analysis using the fareg function. • **"faregML"**: Factors are extracted using regularized maximum likelihood factor using the fareg function. • **"pca"**: Principal components are extracted.
urLoadings	(Matrix) An unrotated factor-structure matrix to be rotated.
rotate	(Character) Designate which rotation algorithm to apply. The following are available rotation options: "oblimin", "quartimin", "targetT", "targetQ", "obliMax", "entropy", "quartimax", "varimax", "simplimax", "bentlerT", "bentlerQ", "tandemI", "tandemII", "geominT", "geominQ", "cfT", "cfQ", "infomaxT", "infomaxQ", "mccammon", "bifactorT", "bifactorQ", and "none". Defaults to rotate = "oblimin". See **GPArotation** package for more details. Note that rotations ending in "T" and "Q" represent orthogonal and oblique rotations, respectively.
targetMatrix	(Matrix) This argument serves two functions. First, if a user has requested either a "targetT" or "targetQ' rotation, then the target matrix is used to conduct a fully or partially specified target rotation. In the latter case, freely estimated factor

loadings are designated by "NA" values and rotation will be conducted using Browne's (1972a, 1972b, 2001) method for a partially-specified target rotation. Second, if any other rotation option is chosen then all rotated loadings matrices (and assorted output) will be aligned (but not rotated) with the target solution.

`bootstrapSE` (Logical) Computes bootstrap standard errors. All bootstrap samples are aligned to the global minimum solution. Defaults to bootstrapSE = FALSE (no standard errors).

`numBoot` (Numeric) The number bootstraps. Defaults to numBoot = 1000.

`CILevel` (Numeric) The confidence level (between 0 and 1) of the bootstrap confidence interval. Defaults to CILevel = .95.

`Seed` (Numeric) Starting seed for reproducible bootstrap results and factor rotations. Defaults to Seed = 1.

`digits` (Numeric) Rounds the values to the specified number of decimal places. Defaults to digits = NULL (no rounding).

`faControl` (List) A list of optional parameters passed to the factor extraction (`faX`) function.

- **treatHeywood**: (Logical) In `fals`, if treatHeywood is true, a penalized least squares function is used to bound the communality estimates below 1.0. Defaults to treatHeywood = TRUE.
- **nStart**: (Numeric) The number of starting values to be tried in `faml`. Defaults to nStart = 10.
- **start**: (Matrix) NULL or a matrix of starting values, each column giving an initial set of uniquenesses. Defaults to start = NULL.
- **maxCommunality**: (Numeric) In `faml`, set the maximum communality value for the estimated solution. Defaults to maxCommunality = .995.
- **epsilon**: (Numeric) In `fapa`, the numeric threshold designating when the algorithm has converged. Defaults to epsilon = 1e-4.
- **communality**: (Character) The method used to estimate the initial communality values in `fapa`. Defaults to communality = 'SMC'.
  - **"SMC"**: Initial communalities are estimated by taking the squared multiple correlations of each indicator after regressing the indicator on the remaining variables.
  - **"maxr"**: Initial communalities equal the largest (absolute value) correlation in each column of the correlation matrix.
  - **"unity"**: Initial communalities equal 1.0 for all variables.
- **maxItr**: (Numeric) In `fapa`, the maximum number of iterations to reach convergence. Defaults to maxItr = 15,000.

`rotateControl` (List) A list of control values to pass to the factor rotation algorithms.

- **numberStarts**: (Numeric) The number of random (orthogonal) starting configurations for the chosen rotation method (e.g., oblimin). The first rotation will always commence from the unrotated factors orientation. Defaults to numberStarts = 10.
- **gamma**: (Numeric) This is a tuning parameter (between 0 and 1, inclusive) for an oblimin rotation. See the **GPArotation** library's oblimin documentation for more details. Defaults to gamma = 0 (i.e., a quartimin rotation).

- **delta**: (Numeric) This is a tuning parameter for the geomin rotation. It adds a small number (default = .01) to the squared factor loadings before computing the geometric means in the discrepancy function.
- **kappa**: (Numeric) The main parameterization of the Crawford-Ferguson (CF) rotations (i.e., "cfT" and "cfQ" for orthogonal and oblique CF rotation, respectively). Defaults to kappa = 0.
- **k**: (Numeric) A specific parameter of the simplimax rotation. Defaults to k = the number of observed variables.
- **standardize**: (Character) The standardization routine used on the unrotated factor structure. The three options are "none", "Kaiser", and "CM". Defaults to standardize = "none".
  - **"none"**: No standardization is applied to the unrotated factor structure.
  - **"Kaiser"**: Use a factor structure matrix that has been normed by Kaiser's method (i.e., normalize all rows to have a unit length).
  - **"CM"**: Use a factor structure matrix that has been normed by the Cureton-Mulaik method.
- **epsilon**: (Numeric) The rotational convergence criterion to use. Defaults to epsilon = 1e-5.
- **power**: (Numeric) Raise factor loadings the the n-th power in the `promaxQ` rotation. Defaults to power = 4.
- **maxItr**: (Numeric) The maximum number of iterations for the rotation algorithm. Defaults to maxItr = 15000.

... Values to be passed to the `cor` function.

- **use**: (Character) A character string giving a method for computing correlations in the presence of missing values: "everything" (the default), "all.obs", "complete.obs", "na.or.complete", or "pairwise.complete.obs".
- **method**: (Character) A character string indicating which correlation coefficient is to be computed: "pearson" (the default), "kendall", or "spearman".
- **na.rm**: (Logical) Should missing values be removed (TRUE) or not (FALSE)?

Details

- **Global Minimum**: This function uses several random starting configurations for factor rotations in an attempt to find the global minimum solution. However, this function is not guaranteed to find the global minimum. Furthermore, the global minimum solution need not be more psychologically interpretable than any of the local solutions (cf. Rozeboom, 1992). As is recommended, our function returns all local solutions so users can make their own judgements.
- **Finding clusters of local minima**: We find local-solution sets by sorting the rounded rotation complexity values (to the number of digits specified in the `epsilon` argument of the `rotateControl` list) into sets with equivalent values. For example, by default `epsilon = 1e-5.` will only evaluate the complexity values to five significant digits. Any differences beyond that value will not effect the final sorting.

Value

The `faMain` function will produce a lot of output in addition to the rotated factor pattern matrix and the factor correlations.

- **R**: (Matrix) Returns the correlation matrix, useful when raw data are supplied.
- **loadings**: (Matrix) The rotated factor solution with the lowest evaluated discrepancy function. This solution has the lowest discrepancy function *of the examined random starting configurations*. It is not guaranteed to find the "true" global minimum. Note that multiple (or even all) local solutions can have the same discrepancy functions.
- **Phi**: (Matrix) The factor correlations of the rotated factor solution with the lowest evaluated discrepancy function (see Details).
- **facIndeterminacy**: (Vector) A vector (with length equal to the number of factors) containing Guttman's (1955) index of factor indeterminacy for each factor.
- **h2**: (Vector) The vector of final communality estimates.
- **loadingsSE**: (Matrix) The matrix of factor-loading standard errors across the bootstrapped factor solutions. Each matrix element is the standard deviation of all bootstrapped factor loadings for that element position.
- **CILevel** (Numeric) The user-defined confidence level (between 0 and 1) of the bootstrap confidence interval. Defaults to CILevel = .95.
- **loadingsCIupper**: (Matrix) Contains the upper confidence interval of the bootstrapped factor loadings matrix. The confidence interval width is specified by the user.
- **loadingsCIlower**: (Matrix) Contains the lower confidence interval of the bootstrapped factor loadings matrix. The confidence interval width is specified by the user.
- **PhiSE**: (Matrix) The matrix of factor correlation standard errors across the bootstrapped factor solutions. Each matrix element is the standard deviation of all bootstrapped factor correlations for that element position.
- **PhiCIupper**: (Matrix) Contains the upper confidence interval of the bootstrapped factor correlation matrix. The confidence interval width is specified by the user.
- **PhiCIlower**: (Matrix) Contains the lower confidence interval of the bootstrapped factor correlation matrix. The confidence interval width is specified by the user.
- **facIndeterminacySE**: (Matrix) A row vector containing the standard errors of Guttman's (1955) factor indeterminacy indices across the bootstrap factor solutions.
- **localSolutions**: (List) A list containing all local solutions in ascending order of their factor loadings, rotation complexity values (i.e., the first solution is the "global" minimum). Each solution returns the
  - **loadings**: (Matrix) the factor loadings,
  - **Phi**: (Matrix) factor correlations,
  - **RotationComplexityValue**: (Numeric) the complexity value of the rotation algorithm,
  - **facIndeterminacy**: (Vector) A vector of factor indeterminacy indices for each common factor, and
  - **RotationConverged**: (Logical) convergence status of the rotation algorithm.
- **numLocalSets** (Numeric) How many sets of local solutions with the same discrepancy value were obtained.
- **localSolutionSets**: (List) A list containing the sets of unique local minima solutions. There is one list element for every unique local solution that includes (a) the factor loadings matrix, (b) the factor correlation matrix (if estimated), and (c) the discrepancy value of the rotation algorithm.

- **loadingsArray**: (Array) Contains an array of all bootstrapped factor loadings. The dimensions are factor indicators, factors, and the number of bootstrapped samples (representing the row, column, and depth, respectively).
- **PhiArray**: (Array) Contains an array of all bootstrapped factor correlations. The dimension are the number of factors, the number of factors, and the number of bootstrapped samples (representing the row, column, and depth, respectively).
- **facIndeterminacyArray**: (Array) Contains an array of all bootstrap factor indeterminacy indices. The dimensions are 1, the number of factors, and the number of bootstrap samples (representing the row, column, and depth order, respectively).
- **faControl**: (List) A list of the control parameters passed to the factor extraction (faX) function.
- **faFit**: (List) A list of additional output from the factor extraction routines.
  - **facMethod**: (Character) The factor extraction routine.
  - **df**: (Numeric) Degrees of Freedom from the maximum likelihood factor extraction routine.
  - **n**: (Numeric) Sample size associated with the correlation matrix.
  - **objectiveFunc**: (Numeric) The evaluated objective function for the maximum likelihood factor extraction routine.
  - **RMSEA**: (Numeric) Root mean squared error of approximation from Steiger & Lind (1980). Note that bias correction is computed if the sample size is provided.
  - **testStat**: (Numeric) The significance test statistic for the maximum likelihood procedure. Cannot be computed unless a sample size is provided.
  - **pValue**: (Numeric) The p value associated with the significance test statistic for the maximum likelihood procedure. Cannot be computed unless a sample size is provided.
  - **gradient**: (Matrix) The solution gradient for the least squares factor extraction routine.
  - **maxAbsGradient**: (Numeric) The maximum absolute value of the gradient at the least squares solution.
  - **Heywood**: (Logical) TRUE if a Heywood case was produced.
  - **convergedX**: (Logical) TRUE if the factor **extraction** routine converged.
  - **convergedR**: (Logical) TRUE if the factor **rotation** routine converged (for the local solution with the minimum discrepancy value).
- **rotateControl**: (List) A list of the control parameters passed to the rotation algorithm.
- **unSpunSolution**: (List) A list of output parameters (e.g., loadings, Phi, etc) from the rotated solution that was obtained by rotating directly from the unrotated (i.e., unspun) common factor orientation.
- **targetMatrix** (Matrix) The input target matrix if supplied by the user.
- **Call**: (call) A copy of the function call.

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See Also

Other Factor Analysis Routines: `BiFAD()`, `Box26`, `GenerateBoxData()`, `Ledermann()`, `SLi()`, `SchmidLeiman()`, `faAlign()`, `faEKC()`, `faIB()`, `faLocalMin()`, `faMB()`, `faScores()`, `faSort()`, `faStandardize()`, `faX()`, `fals()`, `fapa()`, `fareg()`, `fsIndeterminacy()`, `orderFactors()`, `print.faMB()`, `print.faMain()`, `promaxQ()`, `summary.faMB()`, `summary.faMain()`

Examples

```
## Example 1

## Generate an oblique factor model
lambda <- matrix(c(.41, .00, .00,
                   .45, .00, .00,
                   .53, .00, .00,
                   .00, .66, .00,
                   .00, .38, .00,
                   .00, .66, .00,
                   .00, .00, .68,
                   .00, .00, .56,
                   .00, .00, .55),
                 nrow = 9, ncol = 3, byrow = TRUE)

## Generate factor correlation matrix
Phi <- matrix(.50, nrow = 3, ncol = 3)
diag(Phi) <- 1
```

```
## Model-implied correlation matrix
R <- lambda %*% Phi %*% t(lambda)
diag(R) <- 1

## Load the MASS package to create multivariate normal data
library(MASS)

## Generate raw data to perfectly reproduce R
X <- mvrnorm(Sigma = R, mu = rep(0, nrow(R)), empirical = TRUE, n = 300)

## Not run:
## Execute 50 promax rotations from a least squares factor extraction
## Compute 100 bootstrap samples to compute standard errors and
## 80 percent confidence intervals
Out1 <- faMain(X             = X,
               numFactors    = 3,
               facMethod     = "fals",
               rotate        = "promaxQ",
               bootstrapSE   = TRUE,
               numBoot       = 100,
               CILevel       = .80,
               faControl     = list(treatHeywood = TRUE),
               rotateControl = list(numberStarts = 2,
                                    power        = 4,
                                    standardize  = "Kaiser"),
               digits        = 2)
Out1[c("loadings", "Phi")]

## End(Not run)

## Example 2

## Load Thurstone's (in)famous box data
data(Thurstone, package = "GPArotation")

## Execute 5 oblimin rotations with Cureton-Mulaik standardization
Out2 <- faMain(urLoadings    = box26,
               rotate        = "oblimin",
               bootstrapSE   = FALSE,
               rotateControl = list(numberStarts = 5,
                                    standardize  = "CM",
                                    gamma        = 0,
                                    epsilon      = 1e-6),
               digits        = 2)

Out2[c("loadings", "Phi")]

## Example 3

## Factor matrix from Browne 1972
lambda <- matrix(c(.664,  .322, -.075,
                   .688,  .248,  .192,
```

```
                    .492,  .304,  .224,
                    .837, -.291,  .037,
                    .705, -.314,  .155,
                    .820, -.377, -.104,
                    .661,  .397,  .077,
                    .457,  .294, -.488,
                    .765,  .428,  .009),
                  nrow = 9, ncol = 3, byrow = TRUE)

## Create partially-specified target matrix
Targ <- matrix(c(NA, 0,  NA,
                 NA, 0,  0,
                 NA, 0,  0,
                 NA, NA, NA,
                 NA, NA, 0,
                 NA, NA, NA,
                 .7, NA, NA,
                 0,  NA, NA,
                 .7, NA, NA),
               nrow = 9, ncol = 3, byrow = TRUE)

## Perform target rotation
Out3 <- faMain(urLoadings   = lambda,
               rotate       = "targetT",
               targetMatrix = Targ,
               digits       = 3)$loadings
Out3
```

---

faMAP *Velicer's minimum partial correlation method for determining the number of major components for a principal components analysis or a factor analysis*

Description

Uses Velicer's MAP (i.e., matrix of partial correlations) procedure to determine the number of components from a matrix of partial correlations.

Usage

```
faMAP(R, max.fac = 8, Print = TRUE, Plot = TRUE, ...)
```

Arguments

R	input data in the form of a correlation matrix.
max.fac	maximum number of dimensions to extract.
Print	(logical) Print = TRUE will print complete results.
Plot	(logical) Plot = TRUE will plot the MAP values.
...	Arguments to be passed to the plot functions (see par).

Value

MAP	Minimum partial correlations
MAP4	Minimum partial correlations
fm	average of the squared partial correlations after the first m components are partialed out.
fm4	see Velicer, Eaton, & Fava, 2000.
PlotAvgSq	A saved object of the original MAP plot (based on the average squared partial r's.)
PlotAvg4th	A saved object of the revised MAP plot (based on the average 4th power of the partial r's.)

Author(s)

Niels Waller

References

Velicer, W. (1976). Determining the number of components from the matrix of partial correlations. Psychometrika, 41(3):321–327.

Velicer,W. F., Eaton, C. A. , & Fava, J. L. (2000). Construct explication through factor or component analysis: A review and evaluation of alternative procedures for determining the number of factors or components. In R. D. Goffin & E. Helmes (Eds.). Problems and Solutions in Human Assessment: Honoring Douglas N. Jackson at Seventy (pp. 41-71. Boston, MA: Kluwer Academic.

Examples

```
# Harman's data (1967, p 80)
# R = matrix(c(
# 1.000,  .846,  .805,  .859,  .473,  .398,  .301,  .382,
#  .846, 1.000,  .881,  .826,  .376,  .326,  .277,  .415,
#  .805,  .881, 1.000,  .801,  .380,  .319,  .237,  .345,
#  .859,  .826,  .801, 1.000,  .436,  .329,  .327,  .365,
#  .473,  .376,  .380,  .436, 1.000,  .762,  .730,  .629,
#  .398,  .326,  .319,  .329,  .762, 1.000,  .583,  .577,
#  .301,  .277,  .237,  .327,  .730,  .583, 1.000,  .539,
#  .382,  .415,  .345,  .365,  .629,  .577,  .539, 1.000), 8,8)

  F <- matrix(c(  .4,  .1,  .0,
                  .5,  .0,  .1,
                  .6,  .03, .1,
                  .4, -.2,  .0,
                   0,  .6,  .1,
                  .1,  .7,  .2,
                  .3,  .7,  .1,
                   0,  .4,  .1,
                   0,   0,  .5,
                  .1, -.2,  .6,
                  .1,  .2,  .7,
                 -.2,  .1,  .7),12,3)
```

```
R <- F %*% t(F)
diag(R) <- 1

 faMAP(R, max.fac = 8, Print = TRUE, Plot = TRUE)
```

---

faMB *Multiple Battery Factor Analysis by Maximum Likelihood Methods*

Description

faMB estimates multiple battery factor analysis using maximum likelihood estimation procedures described by Browne (1979, 1980). Unrotated multiple battery solutions are rotated (using the **GPArotation** package) from a user-specified number of of random (orthogonal) starting configurations. Based on procedures analogous to those in the faMain function, rotation complexity values of all solutions are ordered to determine the number of local solutions and the "global" minimum solution (i.e., the minimized rotation complexity value from the finite number of solutions).

Usage

```
faMB(
  X = NULL,
  R = NULL,
  n = NULL,
  NB = NULL,
  NVB = NULL,
  numFactors = NULL,
  epsilon = 1e-06,
  rotate = "oblimin",
  rotateControl = NULL,
  PrintLevel = 0,
  Seed = 1
)
```

Arguments

X	(Matrix) A raw data matrix (or data frame) structured in a subject (row) by variable (column) format. Defaults to X = NULL.
R	(Matrix) A correlation matrix. Defaults to R = NULL.
n	(Numeric) Sample size associated with either the raw data (X) or the correlation matrix (R). Defaults to n = NULL.
NB	(Numeric) The number of batteries to analyze. In interbattery factor analysis NB = 2.
NVB	(Vector) The number of variables in each battery. For example, analyzing three batteries including seven, four, and five variables (respectively) would be specified as NVB = c(7, 4, 5).

`numFactors` (Numeric) The number of factors to extract for subsequent rotation. Defaults to `numFactors = NULL`.

`epsilon` (Numeric) The convergence threshold for the Gauss-Seidel iterator when analyzing three or more batteries. Defaults to `epsilon = 1e-06`.

`rotate` (Character) Designate which rotation algorithm to apply. The following are available rotation options: "oblimin", "quartimin", "oblimax", "entropy", "quartimax", "varimax", "simplimax", "bentlerT", "bentlerQ", "tandemI", "tandemII", "geominT", "geominQ", "cfT", "cfQ", "infomaxT", "infomaxQ", "mccammon", "bifactorT", "bifactorQ", and "none". Defaults to rotate = "oblimin". See **GPArotation** package for more details. Note that rotations ending in "T" and "Q" represent orthogonal and oblique rotations, respectively.

`rotateControl` (List) A list of control values to pass to the factor rotation algorithms.

- **numberStarts**: (Numeric) The number of random (orthogonal) starting configurations for the chosen rotation method (e.g., oblimin). The first rotation will always commence from the unrotated factors orientation. Defaults to numberStarts = 10.
- **gamma**: (Numeric) This is a tuning parameter (between 0 and 1, inclusive) for an oblimin rotation. See the **GPArotation** library's oblimin documentation for more details. Defaults to gamma = 0 (i.e., a quartimin rotation).
- **delta**: (Numeric) This is a tuning parameter for the geomin rotation. It adds a small number (default = .01) to the squared factor loadings before computing the geometric means in the discrepancy function.
- **kappa**: (Numeric) The main parameterization of the Crawford-Ferguson (CF) rotations (i.e., "cfT" and "cfQ" for orthogonal and oblique CF rotation, respectively). Defaults to kappa = 0.
- **k**: (Numeric) A specific parameter of the simplimax rotation. Defaults to k = the number of observed variables.
- **standardize**: (Character) The standardization routine used on the unrotated factor structure. The three options are "none", "Kaiser", and "CM". Defaults to standardize = "none".
  - **"none"**: No standardization is applied to the unrotated factor structure.
  - **"Kaiser"**: Use a factor structure matrix that has been normed by Kaiser's method (i.e., normalize all rows to have a unit length).
  - **"CM"**: Use a factor structure matrix that has been normed by the Cureton-Mulaik method.
- **epsilon**: (Numeric) The rotational convergence criterion to use. Defaults to epsilon = 1e-5.
- **power**: (Numeric) Raise factor loadings the the n-th power in the `promaxQ` rotation. Defaults to power = 4.
- **maxItr**: (Numeric) The maximum number of iterations for the rotation algorithm. Defaults to maxItr = 15000.

`PrintLevel` (Numeric) When a value greater than zero is specified, `PrintLevel` prints the maximum change in communality estimates for each iteration of the Gauss-Seidel function. Note that Gauss-Seidel iteration is only called when three or more batteries are analyzed. Defaults to `PrintLevel = 0`.

`Seed` (Integer) Starting seed for the random number generator. Defaults to `Seed = 1`.

Value

The `faMB` function will produce abundant output in addition to the rotated multiple battery factor pattern and factor correlation matrices.

- **loadings**: (Matrix) The (possibly) rotated multiple battery factor solution with the lowest evaluated complexity value *of the examined random starting configurations*. It is not guaranteed to find the "true" global minimum. Note that multiple (or even all) local solutions can have the same discrepancy functions.
- **Phi**: (Matrix) The factor correlations of the rotated factor solution with the lowest evaluated discrepancy function (see Details).
- **fit**: (Vector) A vector containing the following fit statistics:
  - **ChiSq**: Chi-square goodness of fit value. Note that, as recommended by Browne (1979), we apply Lawley's (1959) correction when computing the chi-square value when `NB = 2`.
  - **DF**: Degrees of freedom for the estimated model.
  - **pvalue**: P-value associated with the above chi-square statistic.
  - **AIC**: Akaike's Information Criterion where a lower value indicates better fit.
  - **BIC**: Bayesian Information Criterion where a lower value indicates better fit.
  - **RMSEA**: Root mean squared error of approximation (Steiger & Lind, 1980).
- **R**: (Matrix) The *sample* correlation matrix, useful when raw data are supplied.
- **Rhat**: (Matrix) The *reproduced* correlation matrix with communalities on the diagonal.
- **Resid**: (Matrix) A residual matrix (R - Rhat).
- **facIndeterminacy**: (Vector) A vector (with length equal to the number of factors) containing Guttman's (1955) index of factor indeterminacy for each factor.
- **localSolutions**: (List) A list (of length equal to the `numberStarts` argument within `rotateControl`) containing all local solutions in ascending order of their rotation complexity values (i.e., the first solution is the "global" minimum). Each solution returns the following:
  - **loadings**: (Matrix) the factor loadings,
  - **Phi**: (Matrix) factor correlations,
  - **RotationComplexityValue**: (Numeric) the complexity value of the rotation algorithm,
  - **facIndeterminacy**: (Vector) A vector of factor indeterminacy indices for each common factor, and
  - **RotationConverged**: (Logical) convergence status of the rotation algorithm.
- **numLocalSets**: (Numeric) An integer indicating how many sets of local solutions with the same discrepancy value were obtained.
- **localSolutionSets**: (List) A list (of length equal to the `numLocalSets`) that contains all local solutions with the same rotation complexity value. Note that it is not guarenteed that all solutions with the same complexity values have equivalent factor loading patterns.
- **rotate**: (Character) The chosen rotation algorithm.
- **rotateControl**: (List) A list of the control parameters passed to the rotation algorithm.
- **unSpunSolution**: (List) A list of output parameters (e.g., loadings, Phi, etc) from the rotated solution that was obtained by rotating directly from the unspun (i.e., not multiplied by a random orthogonal transformation matrix) common factor orientation.
- **Call**: (call) A copy of the function call.

Author(s)

- Niels G. Waller (nwaller@umn.edu)
- Casey Giordano (Giord023@umn.edu)

References

Boruch, R. F., Larkin, J. D., Wolins, L., & MacKinney, A. C. (1970). Alternative methods of analysis: Multitrait-multimethod data. *Educational and Psychological Measurement, 30*(4), 833–853. https://doi.org/10.1177/001316447003000405 5

Browne, M. W. (1979). The maximum-likelihood solution in inter-battery factor analysis. *British Journal of Mathematical and Statistical Psychology, 32*(1), 75-86.

Browne, M. W. (1980). Factor analysis of multiple batteries by maximum likelihood. *British Journal of Mathematical and Statistical Psychology, 33*(2), 184-199.

Browne, M. W. (2001). An overview of analytic rotation in exploratory factor analysis. *Multivariate Behavioral Research, 36*(1), 111-150.

Browne, M. and Cudeck, R. (1992). Alternative ways of assessing model fit. *Sociological Methods and Research, 21(2)*, 230-258.

Burnham, K. P. & Anderson, D. R. (2004). Multimodel inference: Understanding AIC and BIC in model selection. *Sociological methods and research, 33*, 261-304.

Cudeck, R. (1982). Methods for estimating between-battery factors, *Multivariate Behavioral Research, 17*(1), 47-68. 10.1207/s15327906mbr1701_3

Cureton, E. E., & Mulaik, S. A. (1975). The weighted varimax rotation and the promax rotation. *Psychometrika, 40*(2), 183-195.

Guttman, L. (1955). The determinacy of factor score matrices with implications for five other basic problems of common factor theory. *British Journal of Statistical Psychology, 8*(2), 65-81.

Steiger, J. & Lind, J. (1980). Statistically based tests for the number of common factors. In *Annual meeting of the Psychometric Society, Iowa City, IA, volume 758*.

Tucker, L. R. (1958). An inter-battery method of factor analysis. *Psychometrika, 23*(2), 111-136.

See Also

Other Factor Analysis Routines: `BiFAD()`, `Box26`, `GenerateBoxData()`, `Ledermann()`, `SLi()`, `SchmidLeiman()`, `faAlign()`, `faEKC()`, `faIB()`, `faLocalMin()`, `faMain()`, `faScores()`, `faSort()`, `faStandardize()`, `faX()`, `fals()`, `fapa()`, `fareg()`, `fsIndeterminacy()`, `orderFactors()`, `print.faMB()`, `print.faMain()`, `promaxQ()`, `summary.faMB()`, `summary.faMain()`

Examples

```
# These examples reproduce published multiple battery analyses.

# ----EXAMPLE 1: Browne, M. W. (1979)----
#
# Data originally reported in:
# Thurstone, L. L. & Thurstone, T. G. (1941). Factorial studies
# of intelligence. Psychometric Monograph (2), Chicago: Univ.
# Chicago Press.
```

```
## Load Thurstone & Thurstone's data used by Browne (1979)
data(Thurstone41)

Example1Output <-  faMB(R             = Thurstone41,
                        n             = 710,
                        NB            = 2,
                        NVB           = c(4,5),
                        numFactors    = 2,
                        rotate        = "oblimin",
                        rotateControl = list(standardize = "Kaiser"))

summary(Example1Output, PrintLevel = 2)

# ----EXAMPLE 2: Browne, M. W. (1980)----
# Data originally reported in:
# Jackson, D. N. & Singer, J. E. (1967). Judgments, items and
# personality. Journal of Experimental Research in Personality, 20, 70-79.

## Load Jackson and Singer's dataset
data(Jackson67)



Example2Output <-  faMB(R             = Jackson67,
                        n             = 480,
                        NB            = 5,
                        NVB           = rep(4,5),
                        numFactors    = 4,
                        rotate        = "varimax",
                        rotateControl = list(standardize = "Kaiser"),
                        PrintLevel    = 1)

summary(Example2Output)



# ----EXAMPLE 3: Cudeck (1982)----
# Data originally reported by:
# Malmi, R. A., Underwood, B. J., & Carroll, J. B. (1979).
# The interrelationships among some associative learning tasks.
# Bulletin of the Psychonomic Society, 13(3), 121-123. DOI: 10.3758/BF03335032

## Load Malmi et al.'s dataset
data(Malmi79)

Example3Output <- faMB(R             = Malmi79,
                       n             = 97,
                       NB            = 3,
                       NVB           = c(3, 3, 6),
                       numFactors    = 2,
                       rotate        = "oblimin",
                       rotateControl = list(standardize = "Kaiser"))
```

```
summary(Example3Output)



# ----Example 4: Cudeck (1982)----
# Data originally reported by:
# Boruch, R. F., Larkin, J. D., Wolins, L. and MacKinney, A. C. (1970).
#  Alternative methods of analysis: Multitrait-multimethod data. Educational
#  and Psychological Measurement, 30,833-853.

## Load Boruch et al.'s dataset
data(Boruch70)

Example4Output <- faMB(R             = Boruch70,
                       n             = 111,
                       NB            = 2,
                       NVB           = c(7,7),
                       numFactors    = 2,
                       rotate        = "oblimin",
                       rotateControl = list(standardize  = "Kaiser",
                                            numberStarts = 100))

summary(Example4Output, digits = 3)
```

`fapa` *Iterated Principal Axis Factor Analysis (fapa)*

Description

This function applies the iterated principal axis factoring method to extract an unrotated factor structure matrix.

Usage

```
fapa(
  R,
  numFactors = NULL,
  epsilon = 1e-04,
  communality = "SMC",
  maxItr = 15000
)
```

Arguments

`R`	(Matrix) A correlation matrix to be analyzed.
`numFactors`	(Numeric) The number of factors to extract.

`epsilon` (Numeric) A numeric threshold to designate whether the function has converged. The default value is 1e-4.

`communality` (Character) The routine requires an initial estimate of the communality values. There are three options (see below) with "SMC" (i.e., squared multiple correlation) being the default.

- **"SMC"**: Initial communalities are estimated by taking the squared multiple correlations of each indicator after regressing the indicator on the remaining variables. The following equation is employed to find the squared multiple correlation: $1 - 1/diag(R^{-}1)$.
- **"maxr"**: Initial communalities equal the largest (absolute value) correlation in each column of the correlation matrix.
- **"unity"**: Initial communalities equal 1.0 for all variables.

`maxItr` (Numeric) The maximum number of iterations to reach convergence. The default is 15,000.

Details

- **Initial communality estimate**: The choice of the initial communality estimate can impact the resulting principal axis factor solution.
  - **Impact on the Estimated Factor Structure**: According to Widaman and Herringer (1985), the initial communality estimate does not have much bearing on the resulting solution *when a stringent convergence criterion is used*. In their analyses, a convergence criterion of .001 (i.e., slightly less stringent than the default of 1e-4) is sufficiently stringent to produce virtually identical communality estimates irrespective of the initial estimate used. Based on their findings, it is not recommended to use a convergence criterion lower than 1e-3.
  - **Impact on the Iteration Procedure**: The initial communality estimates have little impact on the *final factor structure* but they can impact the iterated procedure. It is possible that poor communality estimates produce a non-positive definite correlation matrix (i.e., eigenvalues <= 0) whereas different communality estimates result in a converged solution. If the fapa procedure fails to converge due to a non-positive definite matrix, try using different communality estimates before changing the convergence criterion.

Value

The main output is the matrix of unrotated factor loadings.

- **loadings**: (Matrix) A matrix of unrotated factor loadings extracted via iterated principal axis factoring.
- **h2**: (Vector) A vector containing the resulting communality values.
- **iterations**: (Numeric) The number of iterations required to converge.
- **converged**: (Logical) TRUE if the iterative procedure converged.
- **faControl**: (List) A list of the control parameters used to generate the factor structure.
  - **epsilon**: (Numeric) The convergence criterion used for evaluating each iteration.
  - **communality**: (Character) The method for estimating the initial communality values.
  - **maxItr**: (Numeric) The maximum number of allowed iterations to reach convergence.

Author(s)

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- Niels G. Waller (nwaller@umn.edu)

References

Widaman, K. F., & Herringer, L. G. (1985). Iterative least squares estimates of communality: Initial estimate need not affect stabilized value. *Psychometrika, 50*(4), 469-477.

See Also

Other Factor Analysis Routines: BiFAD(), Box26, GenerateBoxData(), Ledermann(), SLi(), SchmidLeiman(), faAlign(), faEKC(), faIB(), faLocalMin(), faMB(), faMain(), faScores(), faSort(), faStandardize(), faX(), fals(), fareg(), fsIndeterminacy(), orderFactors(), print.faMB(), print.faMain(), promaxQ(), summary.faMB(), summary.faMain()

Examples

```
## Generate an example factor structure matrix
lambda <- matrix(c(.62, .00, .00,
                   .54, .00, .00,
                   .41, .00, .00,
                   .00, .31, .00,
                   .00, .58, .00,
                   .00, .62, .00,
                   .00, .00, .38,
                   .00, .00, .43,
                   .00, .00, .37),
                 nrow = 9, ncol = 3, byrow = TRUE)

## Find the model implied correlation matrix
R <- lambda %*% t(lambda)
diag(R) <- 1

## Extract factors using the fapa function
Out1 <- fapa(R           = R,
             numFactors  = 3,
             communality = "SMC")

## Call fapa through the factExtract function
Out2 <- faX(R          = R,
            numFactors = 3,
            facMethod  = "fapa",
            faControl  = list(communality = "maxr",
                              epsilon     = 1e-4))

## Check for equivalence of the two results
all.equal(Out1$loadings, Out2$loadings)
```

`fareg` *Regularized Factor Analysis*

Description

This function applies the regularized factoring method to extract an unrotated factor structure matrix.

Usage

```
fareg(R, numFactors = 1, facMethod = "rls")
```

Arguments

`R`	(Matrix) A correlation matrix to be analyzed.
`numFactors`	(Integer) The number of factors to extract. Default: numFactors = 1.
`facMethod`	(Character) "rls" for regularized least squares estimation or "rml" for regularized maximum likelihood estimation. Default: facMethod = "rls".

Value

The main output is the matrix of unrotated factor loadings.

- **loadings**: (Matrix) A matrix of unrotated factor loadings.
- **h2**: (Vector) A vector of estimated communality values.
- **L**: (Numeric) Value of the estimated penality parameter.
- **Heywood** (Logical) TRUE if a Heywood case is detected (this should never happen).

Author(s)

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References

Jung, S. & Takane, Y. (2008). Regularized common factor analysis. New trends in psychometrics, 141-149.

See Also

Other Factor Analysis Routines: `BiFAD()`, `Box26`, `GenerateBoxData()`, `Ledermann()`, `SLi()`, `SchmidLeiman()`, `faAlign()`, `faEKC()`, `faIB()`, `faLocalMin()`, `faMB()`, `faMain()`, `faScores()`, `faSort()`, `faStandardize()`, `faX()`, `fals()`, `fapa()`, `fsIndeterminacy()`, `orderFactors()`, `print.faMB()`, `print.faMain()`, `promaxQ()`, `summary.faMB()`, `summary.faMain()`

Examples

```
data("HW")

# load first HW data set

RHW <- cor(x = HW$HW6)

# Compute principal axis factor analysis
fapaOut <- faMain(R = RHW,
                  numFactors = 3,
                  facMethod = "fapa",
                  rotate = "oblimin",
                  faControl = list(treatHeywood = FALSE))


fapaOut$faFit$Heywood
round(fapaOut$h2, 2)

 # Conduct a regularized factor analysis
regOut <- fareg(R = RHW,
                numFactors = 3,
                facMethod = "rls")
regOut$L
regOut$Heywood


# rotate regularized loadings and align with
# population structure
regOutRot <- faMain(urLoadings = regOut$loadings,
                    rotate = "oblimin")

# ALign
FHW  <- faAlign(HW$popLoadings, fapaOut$loadings)$F2
Freg <- faAlign(HW$popLoadings, regOutRot$loadings)$F2

AllSolutions <- round(cbind(HW$popLoadings, Freg, FHW),2)
colnames(AllSolutions) <- c("F1", "F2", "F3", "Fr1", "Fr2", "Fr3",
                            "Fhw1", "Fhw2", "Fhw3")
AllSolutions


rmsdHW <- rmsd(HW$popLoadings, FHW,
               IncludeDiag = FALSE,
               Symmetric = FALSE)

rmsdReg <- rmsd(HW$popLoadings, Freg,
                IncludeDiag = FALSE,
                Symmetric = FALSE)

cat("\nrmsd HW =  ", round(rmsdHW,3),
    "\nrmsd reg = ", round(rmsdReg,3))
```

faScores *Factor Scores*

Description

This function computes factor scores by various methods. The function will acceptan an object of class faMain or, alternatively, user-input factor pattern (i.e., Loadings) and factor correlation (Phi) matrices.

Usage

```
faScores(
  X = NULL,
  faMainObject = NULL,
  Loadings = NULL,
  Phi = NULL,
  Method = "Thurstone"
)
```

Arguments

X	(Matrix) An N x variables data matrix. If X is a matrix of raw scores then faScores will convert the data to z scores.
faMainObject	(Object of class **faMain**) The returned object from a call to **faMain**. Default = NULL
Loadings	(Matrix) A factor pattern matrix. Default = NULL.
Phi	(Matrix) A factor correlation matrix. Default = NULL. If a factor pattern is entered via the **Loadings** argument but **Phi = NULL** the program will set Phi to an identity matrix.
Method	(Character) Factor scoring method. Defaults to the Thurstone or regression based method. Available options include: • **Thurstone** Generates regression based factor score estimates. • **Bartlett** Generates Bartlett method factor score estimates. • **tenBerge** Generates factor score estimates with correlations identical to that found in **Phi**. • **Anderson** The Anderson Rubin method. Generates uncorrelated factor score estimates. This method is only appropriate for orthogonal factor models. • **Harman** Generates estimated factor scores by Harman's idealized variables method. • **PCA** Returns unrotated principal component scores.

Details

faScores can be used to calculate estimated factor scores by various methods. In general, to calculate score estimates, users must input a data matrix **X** and either (a) an object of class **faMain** or (b) a factor loadings matrix, **Loadings** and an optional (for oblique models) factor correlation matrix **Phi**. The one exception to this rule concerns scores for the principal components model. To calculate unrotated PCA scores (i.e., when **Method = "PCA"**) users need only enter a data matrix, **X**.

Value

- **fscores** A matrix om common factor score estimates.
- **Method** The method used to create the factor score estimates.
- **W** The factor scoring coefficient matrix.
- **Z** A matrix of standardized data used to create the estimated factor scores.

Author(s)

Niels Waller

References

- Bartlett, M. S. (1937). The statistical conception of mental factors.British Journal of Psychology, 28,97-104.
- Grice, J. (2001). Computing and evaluating factor scores. Psychological Methods, 6(4), 430-450.
- Harman, H. H. (1976). Modern factor analysis. University of Chicago press.
- McDonald, R. P. and Burr, E. J. (1967). A Comparison of Four Methods of Constructing Factor Scores. Psychometrika, 32, 381-401.
- Ten Berge, J. M. F., Krijnen, W. P., Wansbeek, T., and Shapiro, A. (1999). Some new results on correlation-preserving factor scores prediction methods. Linear Algebra and its Applications, 289(1-3), 311-318.
- Tucker, L. (1971). Relations of factor score estimates to their use. Psychometrika, 36, 427-436.

See Also

Other Factor Analysis Routines: `BiFAD()`, `Box26`, `GenerateBoxData()`, `Ledermann()`, `SLi()`, `SchmidLeiman()`, `faAlign()`, `faEKC()`, `faIB()`, `faLocalMin()`, `faMB()`, `faMain()`, `faSort()`, `faStandardize()`, `faX()`, `fals()`, `fapa()`, `fareg()`, `fsIndeterminacy()`, `orderFactors()`, `print.faMB()`, `print.faMain()`, `promaxQ()`, `summary.faMB()`, `summary.faMain()`

Examples

```
lambda.Pop <- matrix(c(.41, .00, .00,
                       .45, .00, .00,
                       .53, .00, .00,
                       .00, .66, .00,
```

```
                      .00, .38, .00,
                      .00, .66, .00,
                      .00, .00, .68,
                      .00, .00, .56,
                      .00, .00, .55),
                      nrow = 9, ncol = 3, byrow = TRUE)
 NVar <- nrow(lambda.Pop)
 NFac <- 3

## Factor correlation matrix
Phi.Pop <- matrix(.50, nrow = 3, ncol = 3)
diag(Phi.Pop) <- 1

#Model-implied correlation matrix
R <- lambda.Pop %*% Phi.Pop %*% t(lambda.Pop)
diag(R) <- 1


#Generate population data to perfectly reproduce pop R
Out <- simFA( Model = list(Model = "oblique"),
              Loadings = list(FacPattern = lambda.Pop),
              Phi = list(PhiType = "user",
                         UserPhi = Phi.Pop),
              FactorScores = list(FS = TRUE,
                                  CFSeed = 1,
                                  SFSeed = 2,
                                  EFSeed = 3,
                                  Population = TRUE,
                                  NFacScores = 100),
              Seed = 1)

PopFactorScores <- Out$Scores$FactorScores
X <- PopObservedScores <- Out$Scores$ObservedScores


fout <- faMain(X             = X,
               numFactors    = 3,
               facMethod     = "fals",
               rotate        = "oblimin")


print( round(fout$loadings, 2) )
print( round(fout$Phi,2) )

fload <- fout$loadings
Phi <- fout$Phi

  fsOut <- faScores(X = X,
                    faMainObject = fout,
                    Method = "Thurstone")

  fscores <- fsOut$fscores
```

```
 print( round(cor(fscores), 2 ))
 print(round(Phi,2))

CommonFS <- PopFactorScores[,1:NFac]
SpecificFS <-PopFactorScores[ ,(NFac+1):(NFac+NVar)]
ErrorFS <-   PopFactorScores[ , (NFac + NVar + 1):(NFac + 2*NVar) ]

print( cor(fscores, CommonFS) )
```

---

faSort *Sort a factor loadings matrix*

Description

faSort takes an unsorted factor pattern or structure matrix and returns a sorted matrix with (possibly) reflected columns. Sorting is done such that variables that load on a common factor are grouped together for ease of interpretation.

Usage

```
faSort(fmat, phi = NULL, BiFactor = FALSE, salient = 0.25, reflect = TRUE)
```

Arguments

fmat	factor loadings (pattern or structure) matrix.
phi	factor correlation matrix. Default = NULL. If reflect = TRUE then phi will be corrected to match the new factor orientations.
BiFactor	(logical) Is the solution a bifactor model?
salient	factor markers with loadings >= abs(salient) will be saved in the markers list. Note that a variable can be a marker of more than one factor.
reflect	(logical) if reflect = TRUE then the factors will be reflected such that salient loadings are mostly positive. Default Reflect = TRUE.

Value

loadings	sorted factor loadings matrix.
phi	reflected factor correlation matrix when phi is given as an argument.
markers	A list of factor specific markers with loadings >= abs(salient). Markers are sorted by the absolute value of the salient factor loadings.
sortOrder	sorted row numbers.
SEmat	The SEmat is a so-called Start-End matrix that lists the first (start) and last (end) row for each factor in the sorted pattern matrix.

Author(s)

Niels Waller

See Also

fals

Other Factor Analysis Routines: BiFAD(), Box26, GenerateBoxData(), Ledermann(), SLi(), SchmidLeiman(), faAlign(), faEKC(), faIB(), faLocalMin(), faMB(), faMain(), faScores(), faStandardize(), faX(), fals(), fapa(), fareg(), fsIndeterminacy(), orderFactors(), print.faMB(), print.faMain(), promaxQ(), summary.faMB(), summary.faMain()

Examples

```
set.seed(123)
F <- matrix( c( .5,  0,
                .6,  0,
                 0, .6,
                .6,  0,
                 0, .5,
                .7,  0,
                 0, .7,
                 0, .6), nrow = 8, ncol = 2, byrow=TRUE)

Rex1 <- F %*% t(F); diag(Rex1) <- 1

Items <- c("1. I am often tense.\n",
           "2. I feel anxious much of the time.\n",
           "3. I am a naturally curious individual.\n",
           "4. I have many fears.\n",
           "5. I read many books each year.\n",
           "6. My hands perspire easily.\n",
           "7. I have many interests.\n",
           "8. I enjoy learning new words.\n")

exampleOut <- fals(R = Rex1, nfactors = 2)

# Varimax rotation
Fload <- varimax(exampleOut$loadings)$loadings[]

# Add some row labels
rownames(Fload) <- paste0("V", 1:nrow(Fload))

cat("\nUnsorted fator loadings\n")
print(round( Fload, 2) )

# Sort items and reflect factors
out1 <- faSort(fmat = Fload,
               salient = .25,
               reflect = TRUE)

FloadSorted <- out1$loadings

cat("\nSorted fator loadings\n")
print(round( FloadSorted, 2) )
```

```
# Print sorted items
cat("\n Items sorted by Factor\n")
cat("\n",Items[out1$sortOrder])
```

---

faStandardize *Standardize the Unrotated Factor Loadings*

Description

This function standardizes the unrotated factor loadings using two methods: Kaiser's normalization and Cureton-Mulaik standardization.

Usage

```
faStandardize(method, lambda)
```

Arguments

method	(Character) The method used for standardization. There are three option: "none", "Kaiser", and "CM". • **"none"**: No standardization is conducted on the unrotated factor loadings matrix • **"Kaiser"**: The rows of the unrotated factor loadings matrix are rescaled to have unit-lengths. • **"CM"**: Apply the Cureton-Mulaik standardization to the unrotated factor loadings matrix.
lambda	(Matrix) The unrotated factor loadings matrix (or data frame).

Value

The resulting output can be used to standardize the factor loadings as well as providing the inverse matrix used to unstandardize the factor loadings after rotating the factor solution.

- **Dv**: (Matrix) A diagonal weight matrix used to standardize the unrotated factor loadings. Pre-multiplying the loadings matrix by the diagonal weight matrix (i.e., Dv
- **DvInv**: (Matrix) The inverse of the diagonal weight matrix used to standardize. To unstandardize the ultimate rotated solution, pre-multiply the rotated factor loadings by the inverse of Dv (i.e., DvInv
- **lambda**: (Matrix) The standardized, unrotated factor loadings matrix.
- **unstndLambda**: (Matrix) The original, unstandardized, unrotated factor loadings matrix. (DvInv

References

Browne, M. W. (2001). An overview of analytic rotation in exploratory factor analysis. *Multivariate Behavioral Research, 36*(1), 111-150.

Cureton, E. E., & Mulaik, S. A. (1975). The weighted varimax rotation and the promax rotation. *Psychometrika, 40*(2), 183-195.

See Also

Other Factor Analysis Routines: BiFAD(), Box26, GenerateBoxData(), Ledermann(), SLi(), SchmidLeiman(), faAlign(), faEKC(), faIB(), faLocalMin(), faMB(), faMain(), faScores(), faSort(), faX(), fals(), fapa(), fareg(), fsIndeterminacy(), orderFactors(), print.faMB(), print.faMain(), promaxQ(), summary.faMB(), summary.faMain()

---

faX *Factor Extraction (faX) Routines*

Description

This function can be used to extract an unrotated factor structure matrix using the following algorithms: (a) unweighted least squares ("fals"); (b) maximum likelihood ("faml"); (c) iterated principal axis factoring ("fapa"); and (d) principal components analysis ("pca").

Usage

```
faX(R, n = NULL, numFactors = NULL, facMethod = "fals", faControl = NULL)
```

Arguments

R	(Matrix) A correlation matrix used for factor extraction.
n	(Numeric) Sample size associated with the correlation matrix. Defaults to n = NULL.
numFactors	(Numeric) The number of factors to extract for subsequent rotation.
facMethod	(Character) The method used for factor extraction. The supported options are "fals" for unweighted least squares, "faml" for maximum likelihood, "fapa" for iterated principal axis factoring, and "pca" for principal components analysis. The default method is "fals". • **"fals"**: Factors are extracted using the unweighted least squares estimation procedure using the fals function. • **"faml"**: Factors are extracted using the maximum likelihood estimation procedure using the factanal function. • **"faregLS"**: Factors are extracted using regularized least squares factor analysis using the fareg function. • **"faregML"**: Factors are extracted using regularized maximum likelihood factor using the fareg function. • **"fapa"**: Factors are extracted using the iterated principal axis factoring estimation procedure using the fapa function. • **"pca"**: Principal components are extracted.
faControl	(List) A list of optional parameters passed to the factor extraction (faX) function. • **treatHeywood**: (Logical) In fals, if treatHeywood is true, a penalized least squares function is used to bound the communality estimates below 1.0. Defaults to treatHeywood = TRUE.

- **nStart**: (Numeric) The number of starting values to be tried in `faml`. Defaults to nStart = 10.
- **start**: (Matrix) NULL or a matrix of starting values, each column giving an initial set of uniquenesses. Defaults to start = NULL.
- **maxCommunality**: (Numeric) In `faml`, set the maximum communality value for the estimated solution. Defaults to maxCommunality = .995.
- **epsilon**: (Numeric) In `fapa`, the numeric threshold designating when the algorithm has converged. Defaults to epsilon = 1e-4.
- **communality**: (Character) The method used to estimate the initial communality values in `fapa`. Defaults to communality = 'SMC'.
  - **"SMC"**: Initial communalities are estimated by taking the squared multiple correlations of each indicator after regressing the indicator on the remaining variables.
  - **"maxr"**: Initial communalities equal the largest (absolute value) correlation in each column of the correlation matrix.
  - **"unity"**: Initial communalities equal 1.0 for all variables.
- **maxItr**: (Numeric) In `fapa`, the maximum number of iterations to reach convergence. Defaults to maxItr = 15,000.

Details

- **Initial communality estimate**: According to Widaman and Herringer (1985), the initial communality estimate does not have much bearing on the resulting solution *when the a stringent convergence criterion is used*. In their analyses, a convergence criterion of .001 (i.e., slightly less stringent than the default of 1e-4) is sufficiently stringent to produce virtually identical communality estimates irrespective of the initial estimate used. It should be noted that all four methods for estimating the initial communality in Widaman and Herringer (1985) are the exact same used in this function. Based on their findings, it is not recommended to use a convergence criterion lower than 1e-3.

Value

This function returns a list of output relating to the extracted factor loadings.

- **loadings**: (Matrix) An unrotated factor structure matrix.
- **h2**: (Vector) Vector of final communality estimates.
- **faFit**: (List) A list of additional factor extraction output.
  - **facMethod**: (Character) The factor extraction routine.
  - **df**: (Numeric) Degrees of Freedom from the maximum likelihood factor extraction routine.
  - **n**: (Numeric) Sample size associated with the correlation matrix.
  - **objectiveFunc**: (Numeric) The evaluated objective function for the maximum likelihood factor extraction routine.
  - **RMSEA**: (Numeric) Root mean squared error of approximation from Steiger & Lind (1980). Note that bias correction is computed if the sample size is provided.
  - **testStat**: (Numeric) The significance test statistic for the maximum likelihood procedure. Cannot be computed unless a sample size is provided.

- **pValue**: (Numeric) The p value associated with the significance test statistic for the maximum likelihood procedure. Cannot be computed unless a sample size is provided.
- **gradient**: (Matrix) The solution gradient for the least squares factor extraction routine.
- **maxAbsGradient**: (Numeric) The maximum absolute value of the gradient at the least squares solution.
- **Heywood**: (Logical) TRUE if a Heywood case was produced.
- **converged**: (Logical) TRUE if the least squares or principal axis factor extraction routine converged.

Author(s)

- Casey Giordano (Giord023@umn.edu)
- Niels G. Waller (nwaller@umn.edu)

References

Jung, S. & Takane, Y. (2008). Regularized common factor analysis. New trends in psychometrics, 141-149.

Steiger, J. H., & Lind, J. (1980). Paper presented at the annual meeting of the Psychometric Society. *Statistically-based tests for the number of common factors.*

Widaman, K. F., & Herringer, L. G. (1985). Iterative least squares estimates of communality: Initial estimate need not affect stabilized value. *Psychometrika, 50*(4), 469-477.

See Also

Other Factor Analysis Routines: `BiFAD()`, `Box26`, `GenerateBoxData()`, `Ledermann()`, `SLi()`, `SchmidLeiman()`, `faAlign()`, `faEKC()`, `faIB()`, `faLocalMin()`, `faMB()`, `faMain()`, `faScores()`, `faSort()`, `faStandardize()`, `fals()`, `fapa()`, `fareg()`, `fsIndeterminacy()`, `orderFactors()`, `print.faMB()`, `print.faMain()`, `promaxQ()`, `summary.faMB()`, `summary.faMain()`

Examples

```
## Generate an example factor structure matrix
lambda <- matrix(c(.62, .00, .00,
                   .54, .00, .00,
                   .41, .00, .00,
                   .00, .31, .00,
                   .00, .58, .00,
                   .00, .62, .00,
                   .00, .00, .38,
                   .00, .00, .43,
                   .00, .00, .37),
                 nrow = 9, ncol = 3, byrow = TRUE)

## Find the model implied correlation matrix
R <- lambda %*% t(lambda)
diag(R) <- 1

## Extract (principal axis) factors using the factExtract function
```

```
Out1 <- faX(R          = R,
            numFactors = 3,
            facMethod  = "fapa",
            faControl  = list(communality = "maxr",
                              epsilon     = 1e-4))

## Extract (least squares) factors using the factExtract function
Out2 <- faX(R          = R,
            numFactors = 3,
            facMethod  = "fals",
            faControl  = list(treatHeywood = TRUE))
```

FMP *Estimate the coefficients of a filtered monotonic polynomial IRT model*

Description

Estimate the coefficients of a filtered monotonic polynomial IRT model.

Usage

```
FMP(data, thetaInit, item, startvals, k = 0, eps = 1e-06)
```

Arguments

data	N(subjects)-by-p(items) matrix of 0/1 item response data.
thetaInit	Initial theta (θ) surrogates (e.g., calculated by svdNorm).
item	Item number for coefficient estimation.
startvals	Start values for function minimization. Start values are in the gamma metric (see Liang & Browne, 2015)
k	Order of monotonic polynomial = 2k+1 (see Liang & Browne, 2015). k can equal 0, 1, 2, or 3.
eps	Step size for gradient approximation, default = 1e-6. If a convergence failure occurs during function optimization reducing the value of eps will often produce a converged solution.

Details

As described by Liang and Browne (2015), the filtered polynomial model (FMP) is a quasi-parametric IRT model in which the IRF is a composition of a logistic function and a polynomial function, $m(\theta)$, of degree 2k + 1. When k = 0, $m(\theta) = b_0 + b_1\theta$ (the slope intercept form of the 2PL). When k = 1, 2k + 1 equals 3 resulting in $m(\theta) = b_0 + b_1\theta + b_2\theta^2 + b_3\theta^3$. Acceptable values of k = 0,1,2,3. According to Liang and Browne, the "FMP IRF may be used to approximate any IRF with a continuous derivative arbitrarily closely by increasing the number of parameters in the monotonic polynomial" (2015, p. 2) The FMP model assumes that the IRF is monotonically increasing, bounded by 0 and 1, and everywhere differentiable with respect to theta (the latent trait).

Value

b	Vector of polynomial coefficients.
gamma	Polynomial coefficients in gamma metric (see Liang & Browne, 2015).
FHAT	Function value at convergence.
counts	Number of function evaluations during minimization (see optim documentation for further details).
AIC	Pseudo scaled Akaike Information Criterion (AIC). Candidate models that produce the smallest AIC suggest the optimal number of parameters given the sample size. Scaling is accomplished by dividing the non-scaled AIC by sample size.
BIC	Pseudo scaled Bayesian Information Criterion (BIC). Candidate models that produce the smallest BIC suggest the optimal number of parameters given the sample size. Scaling is accomplished by dividing the non-scaled BIC by sample size.
convergence	Convergence = 0 indicates that the optimization algorithm converged; convergence=1 indicates that the optimization failed to converge.

Author(s)

Niels Waller

References

Liang, L. & Browne, M. W. (2015). A quasi-parametric method for fitting flexible item response functions. *Journal of Educational and Behavioral Statistics, 40*, 5–34.

Examples

```
## Not run:
## In this example we will generate 2000 item response vectors
## for a k = 1 order filtered polynomial model and then recover
## the estimated item parameters with the FMP function.

k <- 1  # order of polynomial

NSubjects <- 2000


## generate a sample of 2000 item response vectors
## for a k = 1 FMP model using the following
## coefficients
b <- matrix(c(
   #b0     b1      b2     b3   b4  b5  b6  b7  k
  1.675, 1.974, -0.068, 0.053,  0,  0,  0,  0, 1,
  1.550, 1.805, -0.230, 0.032,  0,  0,  0,  0, 1,
  1.282, 1.063, -0.103, 0.003,  0,  0,  0,  0, 1,
  0.704, 1.376, -0.107, 0.040,  0,  0,  0,  0, 1,
```

```
  1.417, 1.413,  0.021, 0.000,  0,  0,  0,  0, 1,
 -0.008, 1.349, -0.195, 0.144,  0,  0,  0,  0, 1,
  0.512, 1.538, -0.089, 0.082,  0,  0,  0,  0, 1,
  0.122, 0.601, -0.082, 0.119,  0,  0,  0,  0, 1,
  1.801, 1.211,  0.015, 0.000,  0,  0,  0,  0, 1,
 -0.207, 1.191,  0.066, 0.033,  0,  0,  0,  0, 1,
 -0.215, 1.291, -0.087, 0.029,  0,  0,  0,  0, 1,
  0.259, 0.875,  0.177, 0.072,  0,  0,  0,  0, 1,
 -0.423, 0.942,  0.064, 0.094,  0,  0,  0,  0, 1,
  0.113, 0.795,  0.124, 0.110,  0,  0,  0,  0, 1,
  1.030, 1.525,  0.200, 0.076,  0,  0,  0,  0, 1,
  0.140, 1.209,  0.082, 0.148,  0,  0,  0,  0, 1,
  0.429, 1.480, -0.008, 0.061,  0,  0,  0,  0, 1,
  0.089, 0.785, -0.065, 0.018,  0,  0,  0,  0, 1,
 -0.516, 1.013,  0.016, 0.023,  0,  0,  0,  0, 1,
  0.143, 1.315, -0.011, 0.136,  0,  0,  0,  0, 1,
  0.347, 0.733, -0.121, 0.041,  0,  0,  0,  0, 1,
 -0.074, 0.869,  0.013, 0.026,  0,  0,  0,  0, 1,
  0.630, 1.484, -0.001, 0.000,  0,  0,  0,  0, 1),
  nrow=23, ncol=9, byrow=TRUE)

ex1.data<-genFMPData(NSubj = NSubjects, bParams = b, seed = 345)$data

## number of items in the data matrix
NItems <- ncol(ex1.data)

# compute (initial) surrogate theta values from
# the normed left singular vector of the centered
# data matrix
thetaInit <- svdNorm(ex1.data)


## earlier we defined k = 1
  if(k == 0) {
            startVals <- c(1.5, 1.5)
            bmat <- matrix(0, NItems, 6)
        colnames(bmat) <- c(paste("b", 0:1, sep = ""),"FHAT", "AIC", "BIC", "convergence")
  }
  if(k == 1) {
           startVals <- c(1.5, 1.5, .10, .10)
           bmat <- matrix(0, NItems, 8)
        colnames(bmat) <- c(paste("b", 0:3, sep = ""),"FHAT", "AIC", "BIC", "convergence")
  }
  if(k == 2) {
           startVals <- c(1.5, 1.5, .10, .10, .10, .10)
           bmat <- matrix(0, NItems, 10)
        colnames(bmat) <- c(paste("b", 0:5, sep = ""),"FHAT", "AIC", "BIC", "convergence")
  }
  if(k == 3) {
           startVals <- c(1.5, 1.5, .10, .10, .10, .10, .10, .10)
           bmat <- matrix(0, NItems, 12)
        colnames(bmat) <- c(paste("b", 0:7, sep = ""),"FHAT", "AIC", "BIC", "convergence")
  }
```

```
# estimate item parameters and fit statistics
  for(i in 1:NItems){
    out <- FMP(data = ex1.data, thetaInit, item = i, startvals = startVals, k = k)
    Nb <- length(out$b)
    bmat[i,1:Nb] <- out$b
    bmat[i,Nb+1] <- out$FHAT
    bmat[i,Nb+2] <- out$AIC
    bmat[i,Nb+3] <- out$BIC
    bmat[i,Nb+4] <- out$convergence
  }

# print output
print(bmat)

## End(Not run)
```

FMPMonotonicityCheck *Utility function for checking FMP monotonicity*

Description

Utility function for checking whether candidate FMP coefficients yield a monotonically increasing polynomial.

Usage

```
FMPMonotonicityCheck(b, lower = -20, upper = 20, PLOT = FALSE)
```

Arguments

b	A vector of 8 polynomial coefficients (b) for $m(\theta) = b_0 + b_1\theta + b_2\theta^2 + b_3\theta^3 + b_4\theta^4 + b_5\theta^5 + b_6\theta^6 + b_7\theta^7$.
lower, upper	θ bounds for monotonicity check.
PLOT	Logical (default = FALSE). If PLOT = TRUE the function will plot the original polynomial function for θ between lower and upper.

Value

increasing	Logical indicating whether function is monotonically increasing.
minDeriv	Minimum value of the derivative for the polynomial.
minTheta	Value of θ at derivative minimum.

Author(s)

Niels Waller

Examples

```
## A set of candidate coefficients for an FMP model.
## These coefficients fail the test and thus
## should not be used with genFMPdata to generate
## item response data that are consistent with an
## FMP model.
 b <- c(1.21, 1.87, -1.02, 0.18, 0.18, 0, 0, 0)
 FMPMonotonicityCheck(b)
```

`fsIndeterminacy` *Understanding Factor Score Indeterminacy with Finite Dimensional Vector Spaces*

Description

This function illustrates the algebra of factor score indeterminacy using concepts from finite dimensional vector spaces. Given any factor loading matrix, factor correlation matrix, and desired sample size, the program will compute a matrix of observed scores and multiple sets of factors scores. Each set of (m common and p unique) factors scores will fit the model perfectly.

Usage

```
fsIndeterminacy(
  Lambda = NULL,
  Phi = NULL,
  N = NULL,
  X = NULL,
  SeedX = NULL,
  SeedBasis = NULL,
  SeedW = NULL,
  SeedT = 1,
  DoFCorrection = TRUE,
  Print = "short",
  Digits = 3,
  Example = FALSE
)
```

Arguments

`Lambda`	(Matrix) A p x m matrix of factor loadings.
`Phi`	(Matrix) An m x m factor correlation matrix.
`N`	(Integer) The desired sample size.
`X`	(Matrix) an optional N x p matrix of observed scores. Note that the observed scores are expected to fit the factor model (as they will if they are generated from simFA and Population = TRUE is specified). Default (`X = NULL`).

SeedX	(Integer) Starting seed for generating the matrix of observed scores, X.
SeedBasis	(Integer) Starting seed for generating a basis for all scores.
SeedW	(Integer) Starting seed for generating a weight matrix that is used to construct those parts of the factor scores that lie outside of span(X).
SeedT	(Integer) Starting seed for generating a rotation matrix that creates a new set of factor scores from an existing set of scores such that the new set also perfectly fits the factor model.
DoFCorrection	(Logical) Degrees of freedom correction. If DoFCorrection = TRUE then var(x) = 1/(N-1) * t(x) %*% x; else var(x) = 1/N * t(x) %*% x. Default (DoFCorrection = TRUE).
Print	(Character) If Print = "none" no summary information will be printed. If Print = "short" then basic output for evaluating the factor scores will be printed. If Print = "long" extended output will be printed. Default (Print = "short").
Digits	(Integer) Sets the number of significant digits to print when printing is requested.
Example	(Logical) If Example = TRUE the program will execute the orthogonal two factor model described in Waller (2021).

Value

- **"Sigma"**: The p x p model implied covariance matrix.
- **"X"**: An N x p data matrix for the observed variables.
- **"Fhat"**: An N x (m + p) matrix of regression factor score estimates.
- **"Fi"**: A possible set of common and unique factor scores.
- **"Fj"**: The set of factor scores that are minimally correlated with Fi.
- **"Fk"**: Another set of common and unique factor scores. Note that in a 1-factor model, Fk = Fi.
- **"Fl"**: The set of factor scores that are minimally correlated with Fk. Note that in a 1-factor model, Fj = Fl.
- **"Ei"**: Residual scores for Fi.
- **"Ej"**: Residual scores for Fj.
- **"Ek"**: Residual scores for Fk.
- **"El"**: Residual scores for Fl.
- **"L"**: The factor loading super matrix.
- **"C"**: The factor correlation super matrix.
- **"V"**: A (non unique) basis for R^N.
- **"W"**: Weight matrix for generating Zi.
- **"Tmat"**: The orthogonal transformation matrix used to construct Fk from Fi .
- **"B**: The matrix that takes Ei to Ek (Ek = Ei B).
- **"Bstar"** In an orthogonal factor model, Bstar takes Fi to Fk (Fk = Fi Bstar). In an oblique model the program returns Bstar=NULL.
- **"P"**: The matrix that imposes the proper covariance structure on Ei.

- **"SeedX"**: Starting seed for X.
- **"SeedBasis"**: Starting seed for the basis.
- **"SeedW"**: Starting seed for weight matrix W.
- **"SeedT"**: Starting seed for rotation matrix T.
- **"Guttman"**: Guttman indeterminacy measures for the common and unique factors.
- **"CovFhat"**: Covariance matrix of estimated factor scores.

Author(s)

Niels G. Waller (nwaller@umn.edu)

References

Guttman, L. (1955). The determinacy of factor score matrices with applications for five other problems of common factor theory. *British Journal of Statistical Psychology, 8*, 65-82.

Ledermann, W. (1938). The orthogonal transformation of a factorial matrix into itself. *Psychometrika, 3*, 181-187.

Schönemann, P. H. (1971). The minimum average correlation between equivalent sets of uncorrelated factors. *Psychometrika, 36*, 21-30.

Steiger, J. H. and Schonemann, P. H. (1978). In Shye, S. (Ed.), *A history of factor indeterminacy* (pp. 136–178). San Francisco: Jossey-Bass.

Waller, N. G. (2021) Understanding factor indeterminacy through the lens of finite dimensional vector spaces. Manuscript under review.

See Also

Other Factor Analysis Routines: `BiFAD()`, `Box26`, `GenerateBoxData()`, `Ledermann()`, `SLi()`, `SchmidLeiman()`, `faAlign()`, `faEKC()`, `faIB()`, `faLocalMin()`, `faMB()`, `faMain()`, `faScores()`, `faSort()`, `faStandardize()`, `faX()`, `fals()`, `fapa()`, `fareg()`, `orderFactors()`, `print.faMB()`, `print.faMain()`, `promaxQ()`, `summary.faMB()`, `summary.faMain()`

Examples

```
# ---- Example 1: ----
# To run the example in Waller (2021) enter:
out1 <- fsIndeterminacy(Example = TRUE)

# ---- Example 1: Extended Version: ----

N <- 10 # number of observations
# Generate Lambda: common factor loadings
#          Phi: Common factor correlation matrix

Lambda <- matrix(c(.8,  0,
                   .7,  0,
                   .6,  0,
                    0, .5,
                    0, .4,
```

```
                    0, .3), 6, 2, byrow=TRUE)

out1  <- fsIndeterminacy(Lambda,
                         Phi = NULL,    # orthogonal model
                         SeedX = 1,     # Seed for X
                         SeedBasis = 2, # Seed for Basis
                         SeedW = 3,     # Seed for Weight matrix
                         SeedT = 5,     # Seed for Transformation matrix
                         N = 10,        # Number of subjects
                         Print = "long",
                         Digits = 3)

# Four sets of factor scores
  Fi <- out1$Fi
  Fj <- out1$Fj
  Fk <- out1$Fk
  Fl <- out1$Fl

# Estimated Factor scores
  Fhat <- out1$Fhat

# B wipes out Fhat (in an orthogonal model)
  B <- out1$B
  round( cbind(Fhat[1:5,1:2], (Fhat %*% B)[1:5,1:2]), 3)

# B takes Ei -> Ek
  Ei <- out1$Ei
  Ek <- out1$Ek
  Ek - (Ei %*% B)

# The Transformation Approach
# Bstar takes Fi --> Fk
  Bstar <- out1$Bstar
  round( Fk - Fi %*% Bstar, 3)

# Bstar L' = L'
  L <- out1$L
  round( L %*% t(Bstar), 3)[,1:2]


# ---- Example 3 ----
# We choose a different seed for T

out2  <- fsIndeterminacy(Lambda ,
                        Phi = NULL,
                        X = NULL,
                        SeedX = 1,     # Seed for X
                        SeedBasis = 2, #  Seed for Basis
                        SeedW = 3,     #  Seed for Weight matrix
                        SeedT = 4,     # Seed for Transformation matrix
                        N,
                        Print = "long",
                        Digits = 3,
```

```
                        Example = FALSE)
 Fi <- out2$Fi
 Fj <- out2$Fj
 Fk <- out2$Fk
 Fl <- out2$Fl
 X  <- out2$X

# Notice that all sets of factor scores are model consistent
 round( t( solve(t(Fi) %*% Fi) %*% t(Fi) %*% X) ,3)
 round( t( solve(t(Fj) %*% Fj) %*% t(Fj) %*% X) ,3)
 round( t( solve(t(Fk) %*% Fk) %*% t(Fk) %*% X) ,3)
 round( t( solve(t(Fl) %*% Fl) %*% t(Fl) %*% X) ,3)

# Guttman's Indeterminacy Index
round( (1/N * t(Fi) %*% Fj)[1:2,1:2], 3)
```

`fungible` *Generate Fungible Regression Weights*

Description

Generate fungible weights for OLS Regression Models.

Usage

```
fungible(R.X, rxy, r.yhata.yhatb, sets, print = TRUE)
```

Arguments

`R.X`	p x p Predictor correlation matrix.
`rxy`	p x 1 Vector of predictor-criterion correlations.
`r.yhata.yhatb`	Correlation between least squares (yhatb) and alternate-weight (yhata) composites.
`sets`	Number of returned sets of fungible weights.
`print`	Logical, if TRUE then print 5-point summaries of alternative weights.

Value

`a`	Number of sets x p matrix of fungible weights.
`k`	Number of sets x p matrix of k weights.
`b`	p x 1 vector of LS weights.
`u`	p x 1 vector of u weights.
`r.yhata.yhatb`	Correlation between yhata and yhatb.
`r.y.yhatb`	Correlation between y and yhatb.
`cov.a`	Expected covariance matrix for a.
`cor.a`	Expected correlation matrix for a.

Author(s)

Niels Waller

References

Waller, N. (2008). Fungible weights in multiple regression. *Psychometrika, 73*, 69–703.

Examples

```
## Predictor correlation matrix
R.X <- matrix(c(1.00,   .56,  .77,
                .56,  1.00,  .73,
                .77,   .73, 1.00), 3, 3)

## vector of predictor-criterion correlations
rxy <- c(.39, .34, .38)


## OLS standardized regression coefficients
b <- solve(R.X) %*% rxy

## Coefficient of determination (Rsq)
OLSRSQ <- t(b) %*% R.X %*% b

## theta controls the correlation between
## yhatb: predicted criterion scores using OLS coefficients
## yhata: predicted criterion scores using alternate weights
theta <- .01

## desired correlation between yhata and yhatb
r.yhata.yhatb <- sqrt( 1 - (theta)/OLSRSQ)

## number of returned sets of fungible weight vectors
Nsets <- 50

output <- fungible(R.X, rxy, r.yhata.yhatb, sets = Nsets, print = TRUE)
```

---

fungibleExtrema *Locate Extrema of Fungible Regression Weights*

Description

Locate extrema of fungible regression weights.

Usage

```
fungibleExtrema(
  R.X,
  rxy,
  r.yhata.yhatb,
  Nstarts = 100,
  MaxMin = "Max",
  Seed = NULL,
  maxGrad = 1e-05,
  PrintLevel = 1
)
```

Arguments

R.X	p x p Predictor variable correlation matrix.
rxy	p x 1 Vector of predictor-criterion correlations.
r.yhata.yhatb	Correlation between least squares (yhatb) and alternate-weight (yhata) composites.
Nstarts	Maximum number of (max) minimizations from random starting configurations.
MaxMin	Character: "Max" = maximize cos(a,b); "Min" = minimize cos(a,b).
Seed	Starting seed for the random number generator. If Seed = NULL then the program will sample a random integer in the (0, 100,000) interval. Default (Seed = NULL).
maxGrad	The optimization routine will end when the maximimum of the (absolute value of the) function gradient falls below the value specified in maxGrad. Default (maxGrad = 1E-05).
PrintLevel	(integer). If PrintLevel = 1 then the program will print additional output during function convergence. Default (PrintLevel = 1).

Value

cos.ab	cosine between OLS and alternate weights.
a	extrema of fungible weights.
k	k weights.
z	z weights: a normalized random vector.
b	OLS weights.
u	p x 1 vector of u weights.
r.yhata.yhatb	Correlation between yhata and yhatb.
r.y.yhatb	Correlation between y and yhatb.
gradient	Gradient of converged solution.

Author(s)

Niels Waller and Jeff Jones

References

Koopman, R. F. (1988). On the sensitivity of a composite to its weights. *Psychometrika, 53(4)*, 547–552.

Waller, N. & Jones, J. (2009). Locating the extrema of fungible regression weights in multiple regression. *Psychometrika, 74*, 589–602.

Examples

```
## Not run:
## Example
## This is Koopman's Table 2 Example


R.X <- matrix(c(1.00,  .69,  .49,  .39,
                .69, 1.00,  .38,  .19,
                .49,  .38, 1.00,  .27,
                .39,  .19,  .27, 1.00),4,4)


b <- c(.39, .22, .02, .43)
rxy <- R.X %*% b

OLSRSQ <- t(b) %*% R.X %*% b

theta <- .02
r.yhata.yhatb <- sqrt( 1 - (theta)/OLSRSQ)

Converged = FALSE
SEED = 1234
MaxTries = 100
iter = 1

while( iter <= MaxTries){
   SEED <- SEED + 1

   cat("\nCurrent Seed = ", SEED, "\n")
   output <- fungibleExtrema(R.X, rxy,
                             r.yhata.yhatb,
                             Nstarts = 5,
                             MaxMin = "Min",
                             Seed = SEED,
                             maxGrad = 1E-05,
                             PrintLevel = 1)

   Converged <- output$converged
   if(Converged) break
   iter = iter + 1
}

print( output )
```

```
## Scale to replicate Koopman
a <- output$a
a.old <- a
aRa <- t(a) %*% R.X %*% a

## Scale a such that a' R a = .68659
## vc = variance of composite
vc <- aRa
## sf = scale factor
sf <- .68659/vc
a <- as.numeric(sqrt(sf)) * a
cat("\nKoopman Scaling\n")
print(round(a,2))

## End(Not run)
```

`fungibleL` *Generate Fungible Logistic Regression Weights*

Description

Generate fungible weights for Logistic Regression Models.

Usage

```
fungibleL(
  X,
  y,
  Nsets = 1000,
  method = "LLM",
  RsqDelta = NULL,
  rLaLb = NULL,
  s = 0.3,
  Print = TRUE
)
```

Arguments

`X`	An n by nvar matrix of predictor scores without the leading column of ones.
`y`	An n by 1 vector of dichotomous criterion scores.
`Nsets`	The desired number of fungible coefficient vectors.
`method`	Character: "LLM" = Log-Likelihood method. "EM" = Ellipsoid Method. Default: method = "LLM".
`RsqDelta`	The desired decrement in the pseudo-R-squared - used when method = "LLM".
`rLaLb`	The desired correlation between the logits - used when method = "EM".
`s`	Scale factor for random deviates. s controls the range of random start values for the optimization routine. Recommended 0 <= s < 1. Default: s = 0.3.
`Print`	Boolean (TRUE/FALSE) for printing output summary.

Details

fungibleL provides two methods for evaluating parameter sensitivity in logistic regression models by computing fungible logistic regression weights. For for additional information on the underlying theory of these methods see Jones and Waller (in press).

Value

`model`	A glm model object.
`call`	The function call to glm().
`ftable`	A data frame with the mle estimates and the minimum and maximum fungible coefficients.
`lnLML`	The maximum likelihood log likelihood value.
`lnLf`	The decremented, fungible log likelihood value.
`pseudoRsq`	The pseudo R-squared.
`fungibleRsq`	The fungible pseudo R-squared.
`fungiblea`	The Nsets by Nvar + 1 matrix of fungible (alternate) coefficients.
`rLaLb`	The correlation between the logits.
`maxPosCoefChange`	The maximum positive change in a single coefficient holding all other coefficients constant.
`maxNegCoefChange`	The maximum negative change in a single coefficient holding all other coefficients constant.

Author(s)

Jeff Jones and Niels Waller

References

Jones, J. A. & Waller, N. G. (in press). Fungible weights in logistic regression. *Psychological Methods*.

Examples

```
# Example: Low Birth Weight Data from Hosmer Jr, D. W. & Lemeshow, S.(2000).
# low : low birth rate (0 >= 2500 grams, 1 < 2500 grams)
# race: 1 = white, 2 = black, 3 = other
# ftv : number of physician visits during the first trimester

library(MASS)
attach(birthwt)

race <- factor(race, labels = c("white", "black", "other"))
predictors <- cbind(lwt, model.matrix(~ race)[, -1])

# compute mle estimates
```

```
BWght.out <- glm(low ~ lwt + race, family = "binomial")

# compute fungible coefficients
fungible.LLM <- fungibleL(X = predictors, y = low, method = "LLM",
                          Nsets = 10, RsqDelta = .005, s = .3)

# Compare with Table 2.3 (page 38) Hosmer Jr, D. W. & Lemeshow, S.(2000).
# Applied logistic regression.  New York, Wiley.

print(summary(BWght.out))
print(fungible.LLM$call)
print(fungible.LLM$ftable)
cat("\nMLE log likelihod       = ", fungible.LLM$lnLML,
    "\nfungible log likelihood = ", fungible.LLM$lnLf)
cat("\nPseudo Rsq              = ", round(fungible.LLM$pseudoRsq, 3))
cat("\nfungible Pseudo Rsq     = ", round(fungible.LLM$fungibleRsq, 3))


fungible.EM <- fungibleL(X = predictors, y = low, method = "EM" ,
                         Nsets = 10, rLaLb = 0.99)

print(fungible.EM$call)
print(fungible.EM$ftable)

cat("\nrLaLb = ", round(fungible.EM$rLaLb, 3))
```

`fungibleR` *Generate Fungible Correlation Matrices*

Description

Generate fungible correlation matrices. For a given vector of standardized regression coefficients, Beta, and a user-define R-squared value, Rsq, find predictor correlation matrices, R, such that Beta' R Beta = Rsq. The size of the smallest eigenvalue (Lp) of R can be defined.

Usage

```
fungibleR(R, Beta, Lp = 0, eps = 1e-08, Print.Warnings = TRUE)
```

Arguments

`R`	A p x p predictor correlation matrix.
`Beta`	A p x 1 vector of standardized regression coefficients.
`Lp`	Controls the size of the smallest eigenvalue of RstarLp.
`eps`	Convergence criterion.
`Print.Warnings`	Logical, default = TRUE. When TRUE, convergence failures are printed.

Value

R	Any input correlation matrix that satisfies Beta' R Beta = Rsq.
Beta	Input vector of std reg coefficients.
Rstar	A random fungible correlation matrix.
RstarLp	A fungible correlation matrix with a fixed minimum eigenvalue (RstarLp can be PD, PSD, or ID).
s	Scaling constant for Rstar.
sLp	Scaling constant for RstarLp.
Delta	Vector in the null space of vecp(Beta Beta').
Q	Left null space of Beta.
FrobNorm	Frobenius norm ||R - Rstar||_F.
FrobNormLp	Frobenius norm ||R - RstarLp||_F given random Delta.
converged	An integer code. 0 indicates successful completion.

Author(s)

Niels Waller

References

Waller, N. (2016). Fungible Correlation Matrices: A method for generating nonsingular, singular, and improper correlation matrices for Monte Carlo research. Multivariate Behavioral Research.

Examples

```
library(fungible)

## ===== Example 1 =====
## Generate 5 random PD fungible R matrices
## that are consistent with a user-defined predictive
## structure: B' Rxx B = .30

set.seed(246)
## Create a 5 x 5 correlation matrix, R,  with all r_ij = .25
R.ex1 <- matrix(.25, 5, 5)
diag(R.ex1) <- 1

## create a 5 x 1 vector of standardized regression coefficients,
## Beta.ex1
Beta.ex1 <- c(-.4, -.2, 0, .2, .4)
cat("\nModel Rsq = ",  t(Beta.ex1) %*% R.ex1 %*% Beta.ex1)

## Generate fungible correlation matrices, Rstar, with smallest
## eigenvalues > 0.

Rstar.list <- list(rep(99,5))
```

```
i <- 0
while(i <= 5){
  out <- fungibleR(R = R.ex1, Beta = Beta.ex1, Lp = 1e-8, eps = 1e-8,
                   Print.Warnings = TRUE)
  if(out$converged==0){
    i <- i + 1
    Rstar.list[[i]] <- out$Rstar
  }
}

## Check Results
cat("\n *** Check Results ***")
for(i in 1:5){
  cat("\n\n\n++++++++++++++++++++++++++++++++++++++++++++++++++")
  cat("\nRstar", i,"\n")
  print(round(Rstar.list[[i]], 2),)
  cat("\neigenvalues of Rstar", i,"\n")
  print(eigen(Rstar.list[[i]])$values)
  cat("\nBeta' Rstar",i, "Beta = ",
      t(Beta.ex1) %*% Rstar.list[[i]] %*% Beta.ex1)
}



## ===== Example 2 =====
## Generate a PD fungible R matrix with a fixed smallest
## eigenvalue (Lp).

## Create a 5 x 5 correlation matrix, R,  with all r_ij = .5
R <- matrix(.5, 5, 5)
diag(R) <- 1

## create a 5 x 1 vector of standardized regression coefficients, Beta,
## such that Beta_i = .1 for all i
Beta <- rep(.1, 5)

## Generate fungible correlation matrices (a) Rstar and (b) RstarLp.
## Set Lp = 0.12345678 so that the smallest eigenvalue (Lp) of RstarLp
## = 0.12345678
out <- fungibleR(R, Beta, Lp = 0.12345678, eps = 1e-10, Print.Warnings = TRUE)

## print R
cat("\nR: a user-specified seed matrix")
print(round(out$R,3))

## Rstar
cat("\nRstar: A random fungible correlation matrix for R")
print(round(out$Rstar,3))

cat("\nCoefficient of determination when using R\n")
print(  t(Beta) %*% R %*% Beta )

cat("\nCoefficient of determination when using Rstar\n")
```

```
print( t(Beta) %*% out$Rstar %*% Beta)

## Eigenvalues of  R
cat("\nEigenvalues of R\n")
print(round(eigen(out$R)$values, 9))

## Eigenvalues of  Rstar
cat("\nEigenvalues of Rstar\n")
print(round(eigen(out$Rstar)$values, 9))

## What is the Frobenius norm (Euclidean distance) between
## R and Rstar
cat("\nFrobenious norm ||R - Rstar||\n")
print( out$FrobNorm)

## RstarLp is a random fungible correlation matrix with
## a fixed smallest eigenvalue of 0.12345678
cat("\nRstarLp: a random fungible correlation matrix with a user-defined
smallest eigenvalue\n")
print(round(out$RstarLp, 3))

## Eigenvalues of RstarLp
cat("\nEigenvalues of RstarLp")
print(eigen(out$RstarLp)$values, digits = 9)

cat("\nCoefficient of determination when using RstarLp\n")
print( t(Beta) %*% out$RstarLp %*% Beta)

## Check function convergence
if(out$converged) print("Falied to converge")


## ===== Example 3 =====
## This examples demonstrates how fungibleR  can be used
## to generate improper correlation matrices (i.e., pseudo
## correlation matrices with negative eigenvalues).
library(fungible)

## We desire an improper correlation matrix that
## is close to a user-supplied seed matrix.  Create an
## interesting seed matrix that reflects a Big Five
## factor structure.

set.seed(123)
minCrossLoading <- -.2
maxCrossLoading <-  .2
F1 <- c(rep(.6,5),runif(20,minCrossLoading, maxCrossLoading))
F2 <- c(runif(5,minCrossLoading, maxCrossLoading), rep(.6,5),
      runif(15,minCrossLoading, maxCrossLoading))
F3 <- c(runif(10,minCrossLoading,maxCrossLoading), rep(.6,5),
      runif(10,minCrossLoading,maxCrossLoading) )
F4 <- c(runif(15,minCrossLoading,maxCrossLoading), rep(.6,5),
      runif(5,minCrossLoading,maxCrossLoading))
```

```
F5 <- c(runif(20,minCrossLoading,maxCrossLoading), rep(.6,5))
FacMat <- cbind(F1,F2,F3,F4,F5)
R.bfi <- FacMat %*% t(FacMat)
diag(R.bfi) <- 1

## Set Beta to a null vector to inform fungibleR that we are
## not interested in placing constraints on the predictive structure
## of the fungible R matrices.
Beta <- rep(0, 25)


## We seek a NPD fungible R matrix that is close to the bfi seed matrix.
## To find a suitable matrix we generate a large number (e.g., 50000)
## fungible R matrices. For illustration purposes I will set Nmatrices
## to a smaller number: 10.
Nmatrices<-10

## Initialize a list to contain the Nmatrices fungible R objects
RstarLp.list <- as.list( rep(0, Nmatrices ) )
## Initialize a vector for the Nmatrices Frobeius norms ||R - RstarLp||
FrobLp.vec <- rep(0, Nmatrices)


## Constraint the smallest eigenvalue of RStarLp by setting
## Lp = -.1 (or any suitably chosen user-defined value).

## Generate Nmatrices fungibleR matrices and identify the NPD correlation
## matrix that is "closest" (has the smallest Frobenious norm) to the bfi
## seed matrix.
BestR.i <- 0
BestFrob <- 99
i <- 0

set.seed(1)
while(i < Nmatrices){
  out<-fungibleR(R = R.bfi, Beta, Lp = -.1, eps=1e-10)
  ## retain solution if algorithm converged
  if(out$converged == 0)
  {
    i<- i + 1
  ## print progress
    cat("\nGenerating matrix ", i, " Current minimum ||R - RstarLp|| = ",BestFrob)
    tmp <- FrobLp.vec[i] <- out$FrobNormLp #Frobenious Norm ||R - RstarLp||
    RstarLp.list[[i]]<-out$RstarLp
    if( tmp < BestFrob )
    {
      BestR.i <- i     # matrix with lowest ||R - RstarLp||
      BestFrob <- tmp  # value of lowest ||R - RstarLp||
    }
  }
}
```

```
# CloseR is an improper correlation matrix that is close to the seed matrix.
CloseR<-RstarLp.list[[BestR.i]]

plot(1:25, eigen(R.bfi)$values,
     type = "b",
     lwd = 2,
     main = "Scree Plots for R and RstarLp",
     cex.main = 1.5,
     ylim = c(-.2,6),
     ylab = "Eigenvalues",
     xlab = "Dimensions")
points(1:25,eigen(CloseR)$values,
       type = "b",
       lty = 2,
       lwd = 2,
       col = "red")
   abline(h = 0, col = "grey")
legend(legend=c(expression(paste(lambda[i]~" of R",sep = "")),
                expression(paste(lambda[i]~" of RstarLp",sep = ""))),
       lty=c(1,2),
       x = 17,y = 5.75,
       cex = 1.5,
       col=c("black","red"),
       text.width = 5.5,
       lwd = 2)
```

FUP *Estimate the coefficients of a filtered unconstrained polynomial IRT model*

Description

Estimate the coefficients of a filtered unconstrained polynomial IRT model.

Usage

```
FUP(data, thetaInit, item, startvals, k = 0)
```

Arguments

data	N(subjects)-by-p(items) matrix of 0/1 item response data.
thetaInit	Initial theta surrogates (e.g., calculated by svdNorm).
item	item number for coefficient estimation.
startvals	start values for function minimization.
k	order of monotonic polynomial = 2k+1 (see Liang & Browne, 2015).

Value

b	Vector of polynomial coefficients.
FHAT	Function value at convergence.
counts	Number of function evaluations during minimization (see optim documentation for further details).
AIC	Pseudo scaled Akaike Information Criterion (AIC). Candidate models that produce the smallest AIC suggest the optimal number of parameters given the sample size. Scaling is accomplished by dividing the non-scaled AIC by sample size.
BIC	Pseudo scaled Bayesian Information Criterion (BIC). Candidate models that produce the smallest BIC suggest the optimal number of parameters given the sample size. Scaling is accomplished by dividing the non-scaled BIC by sample size.
convergence	Convergence = 0 indicates that the optimization algorithm converged; convergence=1 indicates that the optimization failed to converge.
	.

Author(s)

Niels Waller

References

Liang, L. & Browne, M. W. (2015). A quasi-parametric method for fitting flexible item response functions. *Journal of Educational and Behavioral Statistics, 40*, 5–34.

Examples

```
## Not run:
NSubjects <- 2000


## generate sample k=1 FMP data
b <- matrix(c(
    #b0    b1     b2    b3      b4   b5 b6 b7  k
  1.675, 1.974, -0.068, 0.053,  0,  0,  0,  0, 1,
  1.550, 1.805, -0.230, 0.032,  0,  0,  0,  0, 1,
  1.282, 1.063, -0.103, 0.003,  0,  0,  0,  0, 1,
  0.704, 1.376, -0.107, 0.040,  0,  0,  0,  0, 1,
  1.417, 1.413,  0.021, 0.000,  0,  0,  0,  0, 1,
 -0.008, 1.349, -0.195, 0.144,  0,  0,  0,  0, 1,
  0.512, 1.538, -0.089, 0.082,  0,  0,  0,  0, 1,
  0.122, 0.601, -0.082, 0.119,  0,  0,  0,  0, 1,
  1.801, 1.211,  0.015, 0.000,  0,  0,  0,  0, 1,
 -0.207, 1.191,  0.066, 0.033,  0,  0,  0,  0, 1,
 -0.215, 1.291, -0.087, 0.029,  0,  0,  0,  0, 1,
  0.259, 0.875,  0.177, 0.072,  0,  0,  0,  0, 1,
 -0.423, 0.942,  0.064, 0.094,  0,  0,  0,  0, 1,
  0.113, 0.795,  0.124, 0.110,  0,  0,  0,  0, 1,
```

```
  1.030, 1.525,  0.200, 0.076,  0,  0,  0,  0, 1,
  0.140, 1.209,  0.082, 0.148,  0,  0,  0,  0, 1,
  0.429, 1.480, -0.008, 0.061,  0,  0,  0,  0, 1,
  0.089, 0.785, -0.065, 0.018,  0,  0,  0,  0, 1,
 -0.516, 1.013,  0.016, 0.023,  0,  0,  0,  0, 1,
  0.143, 1.315, -0.011, 0.136,  0,  0,  0,  0, 1,
  0.347, 0.733, -0.121, 0.041,  0,  0,  0,  0, 1,
 -0.074, 0.869,  0.013, 0.026,  0,  0,  0,  0, 1,
  0.630, 1.484, -0.001, 0.000,  0,  0,  0,  0, 1),
  nrow=23, ncol=9, byrow=TRUE)

# generate data using the above item parameters
ex1.data<-genFMPData(NSubj = NSubjects, bParams = b, seed = 345)$data

NItems <- ncol(ex1.data)

# compute (initial) surrogate theta values from
# the normed left singular vector of the centered
# data matrix
thetaInit <- svdNorm(ex1.data)

# Choose model
k <- 1  # order of polynomial = 2k+1

# Initialize matrices to hold output
if(k == 0) {
  startVals <- c(1.5, 1.5)
  bmat <- matrix(0,NItems,6)
  colnames(bmat) <- c(paste("b", 0:1, sep = ""),"FHAT", "AIC", "BIC", "convergence")
}

if(k == 1) {
  startVals <- c(1.5, 1.5, .10, .10)
  bmat <- matrix(0,NItems,8)
  colnames(bmat) <- c(paste("b", 0:3, sep = ""),"FHAT", "AIC", "BIC", "convergence")
}

if(k == 2) {
  startVals <- c(1.5, 1.5, .10, .10, .10, .10)
  bmat <- matrix(0,NItems,10)
  colnames(bmat) <- c(paste("b", 0:5, sep = ""),"FHAT", "AIC", "BIC", "convergence")
}

if(k == 3) {
  startVals <- c(1.5, 1.5, .10, .10, .10, .10, .10, .10)
  bmat <- matrix(0,NItems,12)
  colnames(bmat) <- c(paste("b", 0:7, sep = ""),"FHAT", "AIC", "BIC", "convergence")
}


# estimate item parameters and fit statistics
for(i in 1:NItems){
  out<-FUP(data = ex1.data,thetaInit = thetaInit, item = i, startvals = startVals, k = k)
```

```
  Nb <- length(out$b)
  bmat[i,1:Nb] <- out$b
  bmat[i,Nb+1] <- out$FHAT
  bmat[i,Nb+2] <- out$AIC
  bmat[i,Nb+3] <- out$BIC
  bmat[i,Nb+4] <- out$convergence
}

# print results
print(bmat)

## End(Not run)
```

---

gen4PMData *Generate item response data for 1, 2, 3, or 4-parameter IRT models*

Description

Generate item response data for or 1, 2, 3 or 4-parameter IRT Models.

Usage

```
gen4PMData(
  NSubj = NULL,
  abcdParams,
  D = 1.702,
  seed = NULL,
  theta = NULL,
  thetaMN = 0,
  thetaVar = 1
)
```

Arguments

NSubj	the desired number of subject response vectors.
abcdParams	a p(items)-by-4 matrix of IRT item parameters: a = discrimination, b = difficulty, c = lower asymptote, and d = upper asymptote.
D	Scaling constant to place the IRF on the normal ogive or logistic metric. Default = 1.702 (normal ogive metric)
seed	Optional seed for the random number generator.
theta	Optional vector of latent trait scores. If theta = NULL (the default value) then gen4PMData will simulate theta from a normal distribution.
thetaMN	Mean of simulated theta distribution. Default = 0.
thetaVar	Variance of simulated theta distribution. Default = 1

Value

data	N(subject)-by-p(items) matrix of item response data.
theta	Latent trait scores.
seed	Value of the random number seed.

Author(s)

Niels Waller

Examples

```
## Generate simulated 4PM data for 2,000 subjects
# 4PM Item parameters from MMPI-A CYN scale

Params<-matrix(c(1.41, -0.79, .01, .98, #1
                 1.19, -0.81, .02, .96, #2
                 0.79, -1.11, .05, .94, #3
                 0.94, -0.53, .02, .93, #4
                 0.90, -1.02, .04, .95, #5
                 1.00, -0.21, .02, .84, #6
                 1.05, -0.27, .02, .97, #7
                 0.90, -0.75, .04, .73, #8
                 0.80, -1.42, .06, .98, #9
                 0.71,  0.13, .05, .94, #10
                 1.01, -0.14, .02, .81, #11
                 0.63,  0.18, .18, .97, #12
                 0.68,  0.18, .02, .87, #13
                 0.60, -0.14, .09, .96, #14
                 0.85, -0.71, .04, .99, #15
                 0.83, -0.07, .05, .97, #16
                 0.86, -0.36, .03, .95, #17
                 0.66, -0.64, .04, .77, #18
                 0.60,  0.52, .04, .94, #19
                 0.90, -0.06, .02, .96, #20
                 0.62, -0.47, .05, .86, #21
                 0.57,  0.13, .06, .93, #22
                 0.77, -0.43, .04, .97),23,4, byrow=TRUE)

 data <- gen4PMData(NSubj=2000, abcdParams = Params, D = 1.702,
                    seed = 123, thetaMN = 0, thetaVar = 1)$data

 cat("\nClassical item difficulties for simulated data")
 print( round( apply(data,2,mean),2) )
```

genCorr *Generate Correlation Matrices with User-Defined Eigenvalues*

Description

Uses the Marsaglia and Olkin (1984) algorithm to generate correlation matrices with user-defined eigenvalues.

Usage

```
genCorr(eigenval, seed = "rand")
```

Arguments

eigenval	A vector of eigenvalues that must sum to the order of the desired correlation matrix. For example: if you want a correlation matrix of order 4, then you need 4 eigenvalues that sum to 4. A warning message will display if sum(eigenval) != length(eigenval)
seed	Either a user supplied seed for the random number generator or 'rand' for a function generated seed. Default seed='rand'.

Value

Returns a correlation matrix with the eigen-stucture specified by eigenval.

Author(s)

Jeff Jones

References

Jones, J. A. (2010). GenCorr: An R routine to generate correlation matrices from a user-defined eigenvalue structure. *Applied Psychological Measurement, 34*, 68-69.

Marsaglia, G., & Olkin, I. (1984). Generating correlation matrices. *SIAM J. Sci. and Stat. Comput., 5*, 470-475.

Examples

```
## Example
## Generate a correlation matrix with user-specified eigenvalues
set.seed(123)
R <- genCorr(c(2.5, 1, 1, .3, .2))

print(round(R, 2))

#>       [,1]  [,2]  [,3]  [,4]  [,5]
#> [1,]  1.00  0.08 -0.07 -0.07  0.00
```

```
#> [2,]  0.08  1.00  0.00 -0.60  0.53
#> [3,] -0.07  0.00  1.00  0.51 -0.45
#> [4,] -0.07 -0.60  0.51  1.00 -0.75
#> [5,]  0.00  0.53 -0.45 -0.75  1.00

print(eigen(R)$values)

#[1] 2.5 1.0 1.0 0.3 0.2
```

`GenerateBoxData` *Generate Thurstone's Box Data From length, width, and height box measurements*

Description

Generate data for Thurstone's 20 variable and 26 variable Box Study From length, width, and height box measurements.

Usage

```
GenerateBoxData(
  XYZ,
  BoxStudy = 20,
  Reliability = 0.75,
  ModApproxErrVar = 0.1,
  SampleSize = NULL,
  NMinorFac = 50,
  epsTKL = 0.2,
  Seed = 1,
  SeedErrorFactors = 2,
  SeedMinorFactors = 3,
  PRINT = FALSE,
  LB = FALSE,
  LBVal = 1,
  Constant = 0
)
```

Arguments

`XYZ`	(Matrix) Length, width, and height measurements for N boxes. The Amazon Box data can be accessed by calling `data(AmxBoxes)`. The Thurstone Box data (20 hypothetical boxes) can be accessed by calling `data(Thurstone20Boxes)`.
`BoxStudy`	(Integer) If BoxStudy = 20 then data will be generated for Thurstone's classic 20 variable box problem. If BoxStudy = 26 then data will be generated for Thurstone's 26 variable box problem. Default: `BoxStudy = 20`.

`Reliability` (Scalar [0, 1]) The common reliability value for each measured variable. Default: Reliability = .75.

`ModApproxErrVar` (Scalar [0, 1]) The proportion of reliable variance (for each variable) that is due to all minor common factors. Thus, if `x` (i.e., error free length) has variance `var(x)` and `ModApproxErrVar = .10`, then `var(e.ma)/var(x + e.ma) = .10`.

`SampleSize` (Integer) Specifies the number of boxes to be sampled from the population. If `SampleSize = NULL` then measurements will be generated for the original input box sizes.

`NMinorFac` (Integer) The number of minor factors to use while generating model approximation error. Default: `NMinorFac = 50`.

`epsTKL` (Numeric [0, 1]) A parameter of the Tucker, Koopman, and Linn (1969) algorithm that controls the spread of the influence of the minor factors. Default: `epsTKL = .20`.

`Seed` (Integer) Starting seed for box sampling.

`SeedErrorFactors` (Integer) Starting seed for the error-factor scores.

`SeedMinorFactors` (Integer) Starting seed for the minor common-factor scores.

`PRINT` (Logical) If PRINT = TRUE then the computed reliabilites will be printed. Default: `PRINT = FALSE`. Setting `PRINT` to TRUE can be useful when `LB = TRUE`.

`LB` (lower bound; logical) If LB = TRUE then minimum box measurements will be set to LBVal (inches) if they fall below 0 after adding measurement error. If LB = FALSE then negative attribute values will not be modified. This argument has no effect on data that include model approximation error.

`LBVal` (Numeric) If `LB = TRUE` then values in `BoxDataE` will be bounded from below at `LBVal`. This can be used to avoid negative or very small box measurements.

`Constant` (Numeric) Optional value to add to all box measurements. Default: `Constant = 0`.

Details

This function can be used with the Amazon boxes dataset (`data(AmzBoxes)`) or with any collection of user-supplied scores on three variables. The Amazon Boxes data were downloaded from the `BoxDimensions` website: (https://www.boxdimensions.com/). These data contain length (x), width (y), and height (z) measurements for 98 Amazon shipping boxes. In his classical monograph on Multiple Factor Analysis (Thurstone, 1947) Thurstone describes two data sets (one that he created from fictitious data and a second data set that he created from actual box measurements) that were used to illustrate topics in factor analysis. The first (fictitious) data set is known as the Thurstone Box problem (see Kaiser and Horst, 1975). To create his data for the Box problem, Thurstone constructed 20 nonlinear combinations of fictitious length, width, and height measurements. **Box20** variables:

1. x^2
2. y^2

3. z^2
4. xy
5. xz
6. yz
7. sqrt(x^2 + y^2)
8. sqrt(x^2 + z^2)
9. sqrt(y^2 + z^2)
10. 2x + 2y
11. 2x + 2z
12. 2y + 2z
13. log(x)
14. log(y)
15. log(z)
16. xyz
17. sqrt(x^2 + y^2 + z^2)
18. exp(x)
19. exp(y)
20. exp(z)

The second Thurstone Box problem contains measurements on the following 26 functions of length, width, and height. **Box26** variables:

1. x
2. y
3. z
4. xy
5. xz
6. yz
7. x^2 * y
8. x * y^2
9. x^2 * z
10. x * z^ 2
11. y^2 * z
12. y * z^2
13. x/y
14. y/x
15. x/z
16. z/x
17. y/z

18. z/y
19. 2x + 2y
20. 2x + 2z
21. 2y + 2z
22. sqrt(x^2 + y^2)
23. sqrt(x^2 + z^2)
24. sqrt(y^2 + z^2)
25. xyz
26. sqrt(x^2 + y^2 + z^2)

Note that when generating unreliable data (i.e., variables with reliability values less than 1) and/or data with model error, **SampleSize** must be greater than **NMinorFac**.

Value

- **XYZ** The length (x), width (y), and height (z) measurements for the sampled boxes. If `SampleSize = NULL` then `XYZ` contains the x, y, z values for the original 98 boxes.
- **BoxData** Error free box measurements.
- **BoxDataE** Box data with added measurement error.
- **BoxDataEME** Box data with added (reliable) model approximation and (unreliable) measurement error.
- **Rel.E** Classical reliabilities for the scores in `BoxDataE`.
- **Rel.EME** Classical reliabilities for the scores in `BoxDataEME`.
- **NMinorFac** Number of minor common factors used to generate `BoxDataEME`.
- **epsTKL** Minor factor spread parameter for the Tucker, Koopman, Linn algorithm.
- **SeedErrorFactors** Starting seed for the error-factor scores.
- **SeedMinorFactors** Starting seed for the minor common-factor scores.

Author(s)

Niels G. Waller (nwaller@umn.edu)

References

Cureton, E. E. & Mulaik, S. A. (1975). The weighted varimax rotation and the promax rotation. Psychometrika, 40(2), 183-195. Kaiser, H. F. and Horst, P. (1975). A score matrix for Thurstone's box problem. Multivariate Behavioral Research, 10(1), 17-26.

Thurstone, L. L. (1947). Multiple Factor Analysis. Chicago: University of Chicago Press.

Tucker, L. R., Koopman, R. F., and Linn, R. L. (1969). Evaluation of factor analytic research procedures by means of simulated correlation matrices. *Psychometrika, 34*(4), 421-459.

See Also

Other Factor Analysis Routines: BiFAD(), Box26, Ledermann(), SLi(), SchmidLeiman(), faAlign(), faEKC(), faIB(), faLocalMin(), faMB(), faMain(), faScores(), faSort(), faStandardize(), faX(), fals(), fapa(), fareg(), fsIndeterminacy(), orderFactors(), print.faMB(), print.faMain(), promaxQ(), summary.faMB(), summary.faMain()

Examples

```
data(AmzBoxes)
BoxList <- GenerateBoxData (XYZ = AmzBoxes[,2:4],
                            BoxStudy = 20,
                            Reliability = .75,
                            ModApproxErrVar = .10,
                            SampleSize = 300,
                            NMinorFac = 50,
                            epsTKL = .20,
                            Seed = 1,
                            SeedErrorFactors = 1,
                            SeedMinorFactors = 2,
                            PRINT = FALSE,
                            LB = FALSE,
                            LBVal = 1,
                            Constant = 0)

 BoxData <- BoxList$BoxData

 RBoxes <- cor(BoxData)
 fout <- faMain(R = RBoxes,
               numFactors = 3,
               facMethod = "fals",
               rotate = "geominQ",
               rotateControl = list(numberStarts = 100,
                                    standardize = "CM"))

summary(fout)
```

---

genFMPData — *Generate item response data for a filtered monotonic polynomial IRT model*

Description

Generate item response data for the filtered polynomial IRT model.

Usage

```
genFMPData(NSubj, bParams, theta = NULL, thetaMN = 0, thetaVar = 1, seed)
```

Arguments

NSubj	the desired number of subject response vectors.
bParams	a p(items)-by-9 matrix of polynomial coefficients and model designations. Columns 1 - 8 hold the polynomial coefficients; column 9 holds the value of k.
theta	A user-supplied vector of latent trait scores. Default theta = NULL.
thetaMN	If theta = NULL genFMPdata will simulate random normal deviates from a population with mean thetaMN and variance thetaVar.
thetaVar	If theta = NULL genFMPData will simulate random normal deviates from a population with mean thetaMN and variance thetaVar.
seed	initial seed for the random number generator.

Value

theta	theta values used for data generation
data	N(subject)-by-p(items) matrix of item response data.
seed	Value of the random number seed.

Author(s)

Niels Waller

Examples

```
# The following code illustrates data generation for
# an FMP of order 3 (i.e., 2k+1)

# data will be generated for 2000 examinees
NSubjects <- 2000


## Example item paramters, k=1 FMP
b <- matrix(c(
    #b0    b1     b2    b3      b4   b5 b6 b7  k
  1.675, 1.974, -0.068, 0.053,  0,  0,  0,  0, 1,
  1.550, 1.805, -0.230, 0.032,  0,  0,  0,  0, 1,
  1.282, 1.063, -0.103, 0.003,  0,  0,  0,  0, 1,
  0.704, 1.376, -0.107, 0.040,  0,  0,  0,  0, 1,
  1.417, 1.413,  0.021, 0.000,  0,  0,  0,  0, 1,
 -0.008, 1.349, -0.195, 0.144,  0,  0,  0,  0, 1,
  0.512, 1.538, -0.089, 0.082,  0,  0,  0,  0, 1,
  0.122, 0.601, -0.082, 0.119,  0,  0,  0,  0, 1,
  1.801, 1.211,  0.015, 0.000,  0,  0,  0,  0, 1,
 -0.207, 1.191,  0.066, 0.033,  0,  0,  0,  0, 1,
 -0.215, 1.291, -0.087, 0.029,  0,  0,  0,  0, 1,
  0.259, 0.875,  0.177, 0.072,  0,  0,  0,  0, 1,
 -0.423, 0.942,  0.064, 0.094,  0,  0,  0,  0, 1,
  0.113, 0.795,  0.124, 0.110,  0,  0,  0,  0, 1,
  1.030, 1.525,  0.200, 0.076,  0,  0,  0,  0, 1,
```

```
  0.140, 1.209,  0.082, 0.148,  0,  0,  0,  0, 1,
  0.429, 1.480, -0.008, 0.061,  0,  0,  0,  0, 1,
  0.089, 0.785, -0.065, 0.018,  0,  0,  0,  0, 1,
 -0.516, 1.013,  0.016, 0.023,  0,  0,  0,  0, 1,
  0.143, 1.315, -0.011, 0.136,  0,  0,  0,  0, 1,
  0.347, 0.733, -0.121, 0.041,  0,  0,  0,  0, 1,
 -0.074, 0.869,  0.013, 0.026,  0,  0,  0,  0, 1,
  0.630, 1.484, -0.001, 0.000,  0,  0,  0,  0, 1),
  nrow=23, ncol=9, byrow=TRUE)

# generate data using the above item paramters
data<-genFMPData(NSubj = NSubjects, bParams=b, seed=345)$data
```

---

genPhi *Create a random Phi matrix with maximum factor correlation*

Description

Create a random Phi matrix with maximum factor correlation.

Usage

```
genPhi(NFac, EigenValPower = 6, MaxAbsPhi = 0.5)
```

Arguments

NFac	Number of factors.
EigenValPower	(Scalar > 1) A scalar than controls the positive skewness of the distribution of eigenvalues of Phi.
MaxAbsPhi	(Scaler in [0,1]) The maximum off diagonal of Phi (the factor correlation matrix).

Value

A factor correlation matrix. Note that the returned matrix is not guaranteed to be positive definite. However, a PD check is performed in simFA so that simFA always produces a PD Phi matrix.

Author(s)

Niels Waller

Examples

```
NFac <- 5
par(mfrow=c(2,2))
  for(i in 1:4){
     R <- genPhi(NFac,
                 EigenValPower = 6,
                 MaxAbsPhi = 0.5)

    L <- eigen(R)$values
    plot(1:NFac, L,
        type="b",
        ylab = "Eigenvalues of Phi",
        xlab = "Dimensions",
        ylim=c(0,L[1]+.5))
  }
```

`get_wb_mod` *Find an 'lm' model to use with the Wu & Browne (2015) model error method*

Description

The Wu & Browne (2015) model error method takes advantage of the relationship between v and RMSEA:

Usage

```
get_wb_mod(mod, n = 50, values = 10, lower = 0.01, upper = 0.095)
```

Arguments

`mod`	A 'fungible::simFA()' model object.
`n`	The number of times to evaluate 'wb()' at each point.
`values`	The number of target RMSEA values to evaluate between 0.02 and 0.1.
`lower`	(scalar) The smallest target RMSEA value to use.
`upper`	(scalar) The largest target RMSEA value to use.

Details

$$v = RMSEA^2 + o(RMSEA^2).$$

As RMSEA increases, the approximation $v = RMSEA^2$ becomes worse. This function generates population correlation matrices with model error for multiple target RMSEA values and then regresses the target RMSEA values on the median observed RMSEA values for each target. The fitted model can then be used to predict a 'target_rmsea' value that will give solutions with RMSEA values that are close to the desired value.

Value

('lm' object) An 'lm' object to use with the wb function to obtain population correlation matrices with model error that have RMSEA values closer to the target RMSEA values. The 'lm' object will predict a 'target_rmsea' value that will give solutions with (median) RMSEA values close to the desired RMSEA value.

Examples

```
mod <- fungible::simFA(Seed = 42)
set.seed(42)
wb_mod <- get_wb_mod(mod)
noisemaker(mod, method = "WB", target_rmsea = 0.05, wb_mod = wb_mod)
```

HS9Var *9 Variables from the Holzinger and Swineford (1939) Dataset*

Description

Mental abilities data on seventh- and eighth-grade children from the classic Holzinger and Swineford (1939) dataset.

Format

A data frame with 301 observations on the following 15 variables.

id subject identifier

sex gender

ageyr age, year part

agemo age, month part

school school name (Pasteur or Grant-White)

grade grade

x1 Visual perception

x2 Cubes

x3 Lozenges

x4 Paragraph comprehension

x5 Sentence completion

x6 Word meaning

x7 Speeded addition

x8 Speeded counting of dots

x9 Speeded discrimination straight and curved capitals

Source

These data were retrieved from the lavaan package. The complete data for all 26 tests are available in the MBESS package.

References

Holzinger, K., and Swineford, F. (1939). A study in factor analysis: The stability of a bifactor solution. Supplementary Educational Monograph, no. 48. Chicago: University of Chicago Press.

Joreskog, K. G. (1969). A general approach to confirmatory maximum likelihood factor analysis. *Psychometrika, 34*, 183-202.

Examples

```
data(HS9Var)
head(HS9Var)
```

HW *Six data sets that yield a Heywood case*

Description

Six data sets that yield a Heywood case in a 3-factor model.

Usage

```
data(HW)
```

Format

Each data set is a matrix with 150 rows and 12 variables:

Each data set (HW1, HW2, ... HW6) represents a hypothetical sample of 150 subjects from a population 3-factor model. The population factor loadings are given in `HW$popLoadings`.

Examples

```
data(HW)

# Compute a principal axis factor analysis
# on the first data set
RHW <- cor(HW$HW1)
fapaOut <- faMain(R = RHW,
                  numFactors = 3,
                  facMethod = "fapa",
                  rotate = "oblimin",
                  faControl = list(treatHeywood = FALSE))
```

```
fapaOut$faFit$Heywood
round(fapaOut$h2, 2)
```

`irf` *Plot item response functions for polynomial IRT models.*

Description

Plot model-implied (and possibly empirical) item response function for polynomial IRT models.

Usage

```
irf(
  data,
  bParams,
  item,
  plotERF = TRUE,
  thetaEAP = NULL,
  minCut = -3,
  maxCut = 3,
  NCuts = 9
)
```

Arguments

`data`	N(subjects)-by-p(items) matrix of 0/1 item response data.
`bParams`	p(items)-by-9 matrix. The first 8 columns of the matrix should contain the FMP or FUP polynomial coefficients for the p items. The 9th column contains the value of k for each item (where the item specific order of the polynomial is 2k+1).
`item`	The IRF for `item` will be plotted.
`plotERF`	A logical that determines whether to plot discrete values of the empirical response function.
`thetaEAP`	If `plotERF=TRUE`, the user must supply previously calculated eap trait estimates to `thetaEAP`.
`minCut, maxCut`	If `plotERF=TRUE`, the program will (attempt to) plot `NCuts` points of the empirical response function between trait values of `minCut` and `maxCut` Default minCut = -3. Default maxCut = 3.
`NCuts`	Desired number of bins for the empirical response function.

Author(s)

Niels Waller

Examples

```
NSubjects <- 2000
NItems <- 15

itmParameters <- matrix(c(
 #  b0    b1     b2    b3    b4  b5,    b6,  b7,  k
 -1.05, 1.63,  0.00, 0.00, 0.00,  0,     0,  0,   0, #1
 -1.97, 1.75,  0.00, 0.00, 0.00,  0,     0,  0,   0, #2
 -1.77, 1.82,  0.00, 0.00, 0.00,  0,     0,  0,   0, #3
 -4.76, 2.67,  0.00, 0.00, 0.00,  0,     0,  0,   0, #4
 -2.15, 1.93,  0.00, 0.00, 0.00,  0,     0,  0,   0, #5
 -1.25, 1.17, -0.25, 0.12, 0.00,  0,     0,  0,   1, #6
  1.65, 0.01,  0.02, 0.03, 0.00,  0,     0,  0,   1, #7
 -2.99, 1.64,  0.17, 0.03, 0.00,  0,     0,  0,   1, #8
 -3.22, 2.40, -0.12, 0.10, 0.00,  0,     0,  0,   1, #9
 -0.75, 1.09, -0.39, 0.31, 0.00,  0,     0,  0,   1, #10
 -1.21, 9.07,  1.20,-0.01,-0.01,  0.01,  0,  0,   2, #11
 -1.92, 1.55, -0.17, 0.50,-0.01,  0.01,  0,  0,   2, #12
 -1.76, 1.29, -0.13, 1.60,-0.01,  0.01,  0,  0,   2, #13
 -2.32, 1.40,  0.55, 0.05,-0.01,  0.01,  0,  0,   2, #14
 -1.24, 2.48, -0.65, 0.60,-0.01,  0.01,  0,  0,   2),#15
 15, 9, byrow=TRUE)


ex1.data<-genFMPData(NSubj = NSubjects, bParams = itmParameters,
                     seed = 345)$data

## compute initial theta surrogates
thetaInit <- svdNorm(ex1.data)

## For convenience we assume that the item parameter
## estimates equal their population values.  In practice,
## item parameters would be estimated at this step.
itmEstimates <- itmParameters

## calculate eap estimates for mixed models
thetaEAP <- eap(data = ex1.data, bParams = itmEstimates, NQuad = 21,
                priorVar = 2,
                mintheta = -4, maxtheta = 4)

## plot irf and erf for item 1
irf(data = ex1.data, bParams = itmEstimates,
    item = 1,
    plotERF = TRUE,
    thetaEAP)

## plot irf and erf for item 12
irf(data = ex1.data, bParams = itmEstimates,
    item = 12,
    plotERF = TRUE,
    thetaEAP)
```

`itemDescriptives` *Compute basic descriptives for binary-item analysis*

Description

Compute basic descriptives for binary item analysis

Usage

```
itemDescriptives(X, digits = 3)
```

Arguments

`X`	a matrix of binary (0/1) item responses.
`digits`	number of digits to print.

Value

`alpha`	Coefficient alpha for the total scale.
`means`	item means.
`standard deviations`	item standard deviations.
`pt. biserial correlations`	corrected item-total point biserial correlations.
`biserial correlations`	corrected item-total point biserial correlations.
`corrected.alpha`	corrected (leave item out) alpha coefficients.

Author(s)

Niels Waller

Examples

```
## Example 1: generating binary data to match
## an existing binary data matrix
##
## Generate correlated scores using factor
## analysis model
## X <- Z *L' + U*D
## Z is a vector of factor scores
## L is a factor loading matrix
## U is a matrix of unique factor scores
## D is a scaling matrix for U
```

```
Nsubj <- 2000
L <- matrix( rep(.707,5), nrow = 5, ncol = 1)
Z <-as.matrix(rnorm(Nsubj))
U <-matrix(rnorm(Nsubj * 5),nrow = Nsubj, ncol = 5)
tmp <-  sqrt(1 - L^2)
D<-matrix(0, 5, 5)
diag(D) <- tmp
X <- Z %*% t(L) + U%*%D

cat("\nCorrelation of continuous scores\n")
print(round(cor(X),3))

thresholds <- c(.2,.3,.4,.5,.6)

Binary<-matrix(0,Nsubj,5)
for(i in 1:5){
  Binary[X[,i]<=thresholds[i],i]<-1
}

cat("\nCorrelation of Binary scores\n")
print(round(cor(Binary),3))

## Now use 'bigen' to generate binary data matrix with
## same correlations as in Binary

z <- bigen(data = Binary, n = 5000)

cat("\n\nnames in returned object\n")
print(names(z))

cat("\nCorrelation of Simulated binary scores\n")
print(round( cor(z$data), 3))


cat("Observed thresholds of simulated data:\n")
cat( apply(z$data, 2, mean) )

itemDescriptives(z$data)
```

Jackson67 *Multi-Trait Multi-Method correlation matrix reported by Jackson and Singer (1967)*

Description

The original study assessed four personality traits (i.e., femininity, anxiety, somatic complaints, and socially-deviant attitudes) from five judgemental perspectives (i.e., ratings about (a) desirability in self, (b) desirability in others, (c) what others find desirable, (d) frequency, and (e) harmfulness). The harmfulness variable was reverse coded.

The sample size is $n = 480$.

The following four variables were assessed (abbreviations in parentheses): **Variables**:

1. Femininity (Fem)
2. Anxiety (Anx)
3. Somatic Complaints (SomatComplaint)
4. Socially-Deviant Attitudes (SDAttitude)

Usage

```
data(Jackson67)
```

Format

A 20 by 20 correlation matrix with dimension names

Details

The above variables were assessed from the following methodological judgement perspectives (abbreviations in parentheses): **Test Structure**:

- Desirability in the Self (DiS)
- Desirability in Others (DiO)
- What Others Find Desirable (WOFD)
- Frequency (Freq)
- Harmfulness (Harm)

Source

Jackson, D. N., & Singer, J. E. (1967). Judgments, items, and personality. *Journal of Experimental Research in Personality, 2*(1), 70-79.

Examples

```
## Load Jackson and Singer's dataset
data(Jackson67)



Example2Output <-  faMB(R             = Jackson67,
                        n             = 480,
                        NB            = 5,
                        NVB           = rep(4,5),
                        numFactors    = 4,
                        rotate        = "varimax",
                        rotateControl = list(standardize = "Kaiser"),
                        PrintLevel    = 1)

summary(Example2Output)
```

kurt *Calculate Univariate Kurtosis for a Vector or Matrix*

Description

Calculate univariate kurtosis for a vector or matrix (algorithm G2 in Joanes & Gill, 1998). Note that, as defined in this function, the expected kurtosis of a normally distributed variable is 0 (i.e., not 3).

Usage

```
kurt(x)
```

Arguments

x	Either a vector or matrix of numeric values.

Value

Kurtosis for each column in x.

Author(s)

Niels Waller

References

Joanes, D. N. & Gill, C. A. (1998). Comparing measures of sample skewness and kurtosis. *The Statistician, 47*, 183-189.

See Also

skew

Examples

```
x <- matrix(rnorm(1000), 100, 10)
print(kurt(x))
```

`Ledermann` *Ledermann's inequality for factor solution identification*

Description

Ledermann's (1937) inequality to determine either (a) how many factor indicators are needed to uniquely estimate a user-specified number of factors or (b) how many factors can be uniquely estimated from a user-specified number of factor indicators. See the **Details** section for more information

Usage

```
Ledermann(numFactors = NULL, numVariables = NULL)
```

Arguments

`numFactors`	(Numeric) Determine the number of variables needed to uniquely estimate the [user-specifed] number of factors. Defaults to `numFactors = NULL`.
`numVariables`	(Numeric) Determine the number of factors that can be uniquely estimated from the [user-specifed] number of variables Defaults to `numVariables = NULL`.

Details

The user will specified either (a) `numFactors` or (b) `numVariables`. When one value is specified, the obtained estimate for the other may be a non-whole number. If estimating the number of required variables, the obtained estimate is rounded up (using `ceiling`). If estimating the number of factors, the obtained estimate is rounded down (using `floor`). For example, if `numFactors = 2`, roughly 4.56 variables are required for an identified solution. However, the function returns an estimate of 5.

For the relevant equations, see Thurstone (1947, p. 293) Equations 10 and 11.

Value

- **numFactors** (Numeric) Given the inputs, the number of factors to be estimated from the `numVariables` number of factor indicators.
- **numVariables** (Numeric) Given the inputs, the number of variables needed to estimate `numFactorso`.

Author(s)

Casey Giordano

References

Ledermann, W. (1937). On the rank of the reduced correlational matrix in multiple-factor analysis. *Psychometrika, 2*(2), 85-93.

Thurstone, L. L. (1947). Multiple-factor analysis; a development and expansion of The Vectors of Mind.

See Also

Other Factor Analysis Routines: BiFAD(), Box26, GenerateBoxData(), SLi(), SchmidLeiman(), faAlign(), faEKC(), faIB(), faLocalMin(), faMB(), faMain(), faScores(), faSort(), faStandardize(), faX(), fals(), fapa(), fareg(), fsIndeterminacy(), orderFactors(), print.faMB(), print.faMain(), promaxQ(), summary.faMB(), summary.faMain()

Examples

```
## To estimate 3 factors, how many variables are needed?
Ledermann(numFactors   = 3,
          numVariables = NULL)

## Provided 10 variables are collected, how many factors
  ## can be estimated?
Ledermann(numFactors   = NULL,
          numVariables = 10)
```

Malmi79 *Multi-Trait Multi-Method correlation matrix reported by Malmi, Underwood, and Carroll (1979).*

Description

The original study assessed six variables across three separate assessment methods. Note that only the last method included six variables whereas the other two methods included three variables.

Usage

```
data(Malmi79)
```

Format

A 12 by 12 correlation matrix with dimension names

Details

The sample size is $n = 97$.

The following variables were assessed (abbreviations in parentheses): **Variables**:

1. Words (Words)
2. Triads (Triads)
3. Sentences (Sentences)
4. 12 stimuli with 2 responses each (12s.2r)
5. 4 stimuli with 6 responses each (4s.6r)
6. 2 stimuli with 12 responses each (2s.12r)

The above variables were assessed from the following three assessment methods (abbreviations in parentheses): **Test Structure**:

- **Free Recall** (FR)
  - Words
  - Triads
  - Sentences
- **Serial List** (SL)
  - Words
  - Triads
  - Sentences
- **Paired Association** (PA)
  - Words
  - Triads
  - Sentences
  - 12 stimuli with 4 responses
  - 4 stimuli with 6 responses
  - 2 stimuli with 12 responses

Source

Malmi, R. A., Underwood, 3. J. & Carroll, J. B. The interrelationships among some associative learning tasks. *Bulletin of the Psychrmomic Society, 13*(3), 121-123. https://doi.org/10.3758/BF03335032

Examples

```
## Load Malmi et al.'s dataset
data(Malmi79)

Example3Output <- faMB(R            = Malmi79,
                       n            = 97,
                       NB           = 3,
                       NVB          = c(3, 3, 6),
                       numFactors   = 2,
                       rotate       = "oblimin",
                       rotateControl = list(standardize = "Kaiser"))

summary(Example3Output)
```

monte *Simulate Clustered Data with User-Defined Properties*

Description

Function for simulating clustered data with user defined characteristics such as: within cluster indicator correlations, within cluster indicator skewness values, within cluster indicator kurtosis values, and cluster separations as indexed by each variable (indicator validities).

Usage

```
monte(
  seed = 123,
  nvar = 4,
  nclus = 3,
  clus.size = c(50, 50, 50),
  eta2 = c(0.619, 0.401, 0.941, 0.929),
  cor.list = NULL,
  random.cor = FALSE,
  skew.list = NULL,
  kurt.list = NULL,
  secor = NULL,
  compactness = NULL,
  sortMeans = TRUE
)
```

Arguments

seed	Required: An integer to be used as the random number seed.
nvar	Required: Number of variables to simulate.
nclus	Required: Number of clusters to simulate. *Note* that number of clusters must be equal to or greater than 2.
clus.size	Required: Number of objects in each cluster.
eta2	Required: A vector of indicator validities that range from 0 to 1. Higher numbers produce clusters with greater separation on that indicator.
cor.list	Optional: A list of correlation matrices. There should be one correlation matrix for each cluster. The first correlation matrix will represent the indicator correlations within cluster 1. The second correlation matrix will represent the indicator correlations for cluster 2. Etc.
random.cor	Optional: Set to TRUE to generate a common within cluster correlation matrix.
skew.list	Optional: A list of within cluster indicator skewness values.
kurt.list	Optional: A list of within cluster indicator kurtosis values.
secor	Optional: If 'random.cor = TRUE' then 'secor' determines the standard error of the simulated within group correlation matrices.

compactness	Optional: A vector of cluster compactness parameters. The meaning of this option is explained Waller et al. (1999). Basically, 'compactness' allows users some control over cluster overlap without changing indicator validities. See the example below for an illustration.
sortMeans	Optional: A logical that determines whether the latent means will be sorted by taxon. Default = TRUE

Value

data	The simulated data. The 1st column of 'data' denotes cluster membership.
lmn	The cluster indicator means.
fl	The factor loading matrix as described in Waller, et al. 1999.
fs	The unique values of the linearized factor scores.
call	The call.
nclus	Number of clusters.
nvar	Number of variables.
cor.list	The input within cluster correlation matrices.
skew.list	The input within cluster indicator skewness values.
kurt.list	The input within cluster indicator kurtosis values.
clus.size	The number of observations in each cluster.
eta2	Vector of indicator validities.
seed	The random number seed.

Author(s)

Niels Waller

References

Fleishman, A. I (1978). A method for simulating non-normal distributions. *Psychometrika, 43*, 521-532.

Olvera Astivia, O. L. & Zumbo, B. D. (2018). On the solution multiplicity of the Fleishman method and its impact in simulation studies. *British Journal of Mathematical and Statistical Psychology, 71* (3), 437-458.

Vale, D. C., & Maurelli, V. A. (1983). Simulating multivariate nonnormal distributions. *Psychometrika, 48*, 465-471.

Waller, N. G., Underhill, J. M., & Kaiser, H. A. (1999). A method for generating simulated plasmodes and artificial test clusters with user-defined shape, size, and orientation. *Multivariate Behavioral Research, 34*, 123-142.

Examples

```
## Example 1
## Simulating Fisher's Iris data
# The original data were reported in:
# Fisher, R. A. (1936) The use of multiple measurements in taxonomic
#     problems. Annals of Eugenics, 7, Part II, 179-188.
#
# This example includes 3 clusters. Each cluster represents
# an Iris species: Setosa, Versicolor, and Virginica.
# On each species, four variables were measured: Sepal Length,
# Sepal Width, Petal Length, and Petal Width.
#
# The within species (cluster) correlations of the flower
# indicators are as follows:
#
# Iris Type 1:
#      [,1]  [,2]  [,3]  [,4]
# [1,] 1.000 0.743 0.267 0.178
# [2,] 0.743 1.000 0.278 0.233
# [3,] 0.267 0.278 1.000 0.332
# [4,] 0.178 0.233 0.332 1.000
#
# Iris Type 2
#      [,1]  [,2]  [,3]  [,4]
# [1,] 1.000 0.526 0.754 0.546
# [2,] 0.526 1.000 0.561 0.664
# [3,] 0.754 0.561 1.000 0.787
# [4,] 0.546 0.664 0.787 1.000
#
# Iris Type 3
#      [,1]  [,2]  [,3]  [,4]
# [1,] 1.000 0.457 0.864 0.281
# [2,] 0.457 1.000 0.401 0.538
# [3,] 0.864 0.401 1.000 0.322
# [4,] 0.281 0.538 0.322 1.000
#
# 'monte' expects a list of correlation matrices
#

#create a list of within species correlations
data(iris)
cormat <- cm <- lapply(split(iris[,1:4], iris[,5]), cor)

# create a list of within species indicator
# skewness and kurtosis
 sk.lst <- list(c(0.120,  0.041,  0.106,  1.254),
                c(0.105, -0.363, -0.607, -0.031),
                c(0.118,  0.366,  0.549, -0.129) )


 kt.lst <- list(c(-0.253, 0.955,  1.022,  1.719),
                c(-0.533,-0.366,  0.048, -0.410),
```

```
                c( 0.033, 0.706, -0.154, -0.602) )


#Generate a new sample of iris data
my.iris <- monte(seed=123, nvar = 4, nclus = 3, cor.list = cormat,
                clus.size = c(50, 50, 50),
                eta2=c(0.619, 0.401, 0.941, 0.929),
                random.cor = FALSE,
                skew.list = sk.lst,
                kurt.list = kt.lst,
                secor = .3, compactness=c(1, 1, 1),
                sortMeans = TRUE)


summary(my.iris)
plot(my.iris)

# Now generate a new data set with the sample indicator validities
# as before but with different cluster compactness values.

my.iris2<-monte(seed = 123, nvar = 4, nclus = 3,
               cor.list = cormat, clus.size = c(50, 50, 50),
               eta2 = c(0.619, 0.401, 0.941, 0.929), random.cor = FALSE,
               skew.list = sk.lst ,kurt.list = kt.lst,
               secor = .3,
               compactness=c(2, .5, .5),
               sortMeans = TRUE)


summary(my.iris2)

# Notice that cluster 1 has been blow up whereas clusters 2 and 3 have been shrunk.
plot(my.iris2)


### Now compare your original results with the actual
## Fisher iris data
library(lattice)
data(iris)
super.sym <- trellis.par.get("superpose.symbol")
splom(~iris[1:4], groups = Species, data = iris,
      #panel = panel.superpose,
      key = list(title = "Three Varieties of Iris",
                 columns = 3,
                 points = list(pch = super.sym$pch[1:3],
                 col = super.sym$col[1:3]),
                 text = list(c("Setosa", "Versicolor", "Virginica"))))


############### EXAMPLE 2 ###################################

## Example 2
## Simulating data for Taxometric
```

```
## Monte Carlo Studies.
##
## In this four part example we will
## generate two group mixtures
## (Complement and Taxon groups)
## under four conditions.
##
## In all conditions
## base rate (BR) = .20
## 3 indicators
## indicator validities = .50
## (This means that 50 percent of the total
## variance is due to the mixture.)
##
##
## Condition 1:
## All variables have a slight degree
## of skewness (.10) and kurtosis (.10).
## Within group correlations = 0.00.
##
##
##
## Condition 2:
## In this conditon we generate data in which the
## complement and taxon distributions differ in shape.
## In the complement group all indicators have
## skewness values of 1.75 and kurtosis values of 3.75.
## In the taxon group all indicators have skewness values
## of .50 and kurtosis values of 0.
## As in the previous condition, all within group
## correlations (nuisance covariance) are 0.00.
##
##
## Conditon 3:
## In this condition we retain all previous
## characteristics except that the within group
## indicator correlations now equal .80
## (they can differ between groups).
##
##
## Conditon 4:
## In this final condition we retain
## all previous data characteristics except that
## the variances of the indicators in the complement
## class are now 5 times the indicator variances
## in the taxon class (while maintaining indicator skewness,
## kurtosis, correlations, etc.).


##-----------------------------


library(lattice)
```

```
############################
##      Condition 1
############################
in.nvar <- 3  ##Number of variables
in.nclus <-2  ##Number of taxa
in.seed <- 123
BR <- .20     ## Base rate of higher taxon

## Within taxon indicator skew and kurtosis
in.skew.list <- list(c(.1, .1, .1),c(.1, .1, .1))
in.kurt.list <- list(c(.1, .1, .1),c(.1, .1, .1))

## Indicator validities
in.eta2 <- c(.50, .50, .50)

## Groups sizes for Population
BigN <- 100000
in.clus.size <- c(BigN*(1-BR), BR * BigN)

## Generate Population of scores with "monte"
sample.data <- monte(seed = in.seed,
                nvar=in.nvar,
                nclus = in.nclus,
                clus.size = in.clus.size,
                eta2 = in.eta2,
                skew.list = in.skew.list,
                kurt.list = in.kurt.list)


output <- summary(sample.data)

z <- data.frame(sample.data$data[sample(1:BigN, 600, replace=FALSE),])
z[,2:4] <- scale(z[,2:4])
names(z) <- c("id","v1","v2","v3")

#trellis.device()
trellis.par.set( col.whitebg() )
print(
 cloud(v3 ~ v1 * v2,
       groups = as.factor(id),data=z,
       subpanel = panel.superpose,
       zlim=c(-4, 4),
       xlim=c(-4, 4),
       ylim=c(-4, 4),
       main="",
       screen = list(z = 20, x = -70)),
   position=c(.1, .5, .5, 1), more = TRUE)



############################
```

```
##      Condition 2
############################

## Within taxon indicator skew and kurtosis
in.skew.list <- list(c(1.75, 1.75, 1.75),c(.50, .50, .50))
in.kurt.list <- list(c(3.75, 3.75, 3.75),c(0, 0, 0))

## Generate Population of scores with "monte"
sample.data <- monte(seed = in.seed,
               nvar = in.nvar,
               nclus = in.nclus,
               clus.size = in.clus.size,
               eta2 = in.eta2,
               skew.list = in.skew.list,
               kurt.list = in.kurt.list)


output <- summary(sample.data)

z <- data.frame(sample.data$data[sample(1:BigN, 600, replace=FALSE),])
z[,2:4] <- scale(z[, 2:4])
names(z) <-c("id", "v1","v2", "v3")

print(
 cloud(v3 ~ v1 * v2,
       groups = as.factor(id), data = z,
       subpanel = panel.superpose,
       zlim = c(-4, 4),
       xlim = c(-4, 4),
       ylim = c(-4, 4),
       main="",
       screen = list(z = 20, x = -70)),
       position = c(.5, .5, 1, 1), more = TRUE)


############################
##      Condition 3
############################

## Set within group correlations to .80
cormat <- matrix(.80, 3, 3)
diag(cormat) <- rep(1, 3)
in.cor.list <- list(cormat, cormat)

## Generate Population of scores with "monte"
sample.data <- monte(seed = in.seed,
               nvar = in.nvar,
               nclus = in.nclus,
               clus.size = in.clus.size,
               eta2 = in.eta2,
               skew.list = in.skew.list,
               kurt.list = in.kurt.list,
               cor.list = in.cor.list)
```

```
output <- summary(sample.data)

z <- data.frame(sample.data$data[sample(1:BigN, 600,
               replace = FALSE), ])
z[,2:4] <- scale(z[, 2:4])
names(z) <- c("id", "v1", "v2", "v3")

##trellis.device()
##trellis.par.set( col.whitebg() )
print(
  cloud(v3 ~ v1 * v2,
       groups = as.factor(id),data=z,
       subpanel = panel.superpose,
       zlim = c(-4, 4),
       xlim = c(-4, 4),
       ylim = c(-4, 4),
       main="",
       screen = list(z = 20, x = -70)),
position = c(.1, .0, .5, .5), more = TRUE)


############################
##      Condition 4
############################

## Change compactness so that variance of
## complement indicators is 5 times
## greater than variance of taxon indicators

 v <-  ( 2 * sqrt(5))/(1 + sqrt(5))
 in.compactness <- c(v, 2-v)

## Generate Population of scores with "monte"
sample.data <- monte(seed = in.seed,
               nvar = in.nvar,
               nclus = in.nclus,
               clus.size = in.clus.size,
               eta2 = in.eta2,
               skew.list = in.skew.list,
               kurt.list = in.kurt.list,
               cor.list = in.cor.list,
               compactness = in.compactness)

output <- summary(sample.data)

z <- data.frame(sample.data$data[sample(1:BigN, 600, replace = FALSE), ])
z[, 2:4] <- scale(z[, 2:4])
names(z) <- c("id", "v1", "v2", "v3")
print(
  cloud(v3 ~ v1 * v2,
       groups = as.factor(id),data=z,
       subpanel = panel.superpose,
```

```
        zlim = c(-4, 4),
        xlim = c(-4, 4),
        ylim = c(-4, 4),
        main="",
        screen = list(z = 20, x = -70)),
 position = c(.5, .0, 1, .5), more = TRUE)
```

---

monte1 *Simulate Multivariate Non-normal Data by Vale & Maurelli (1983) Method*

Description

Function for simulating multivariate nonnormal data by the methods described by Fleishman (1978) and Vale & Maurelli (1983).

Usage

```
monte1(seed, nvar, nsub, cormat, skewvec, kurtvec)
```

Arguments

seed	An integer to be used as the random number seed.
nvar	Number of variables to simulate.
nsub	Number of simulated subjects (response vectors).
cormat	The desired correlation matrix.
skewvec	A vector of indicator skewness values.
kurtvec	A vector of indicator kurtosis values.

Value

data	The simulated data.
call	The call.
nsub	Number of subjects.
nvar	Number of variables.
cormat	The desired correlation matrix.
skewvec	The desired indicator skewness values.
kurtvec	The desired indicator kurtosis values.
seed	The random number seed.

Author(s)

Niels Waller

References

Fleishman, A. I (1978). A method for simulating non-normal distributions. *Psychometrika, 43*, 521-532.

Olvera Astivia, O. L. & Zumbo, B. D. (2018). On the solution multiplicity of the Fleishman method and its impact in simulation studies. *British Journal of Mathematical and Statistical Psychology, 71* (3), 437-458.

Vale, D. C., & Maurelli, V. A. (1983). Simulating multivariate nonnormal distributions. *Psychometrika, 48*, 465-471.

See Also

monte, summary.monte, summary.monte1

Examples

```
## Generate dimensional data for 4 variables.
## All correlations = .60; all variable
## skewness = 1.75;
## all variable kurtosis = 3.75

cormat <- matrix(.60,4,4)
diag(cormat) <- 1

nontaxon.dat <- monte1(seed = 123, nsub = 100000, nvar = 4, skewvec = rep(1.75, 4),
               kurtvec = rep(3.75, 4), cormat = cormat)

print(cor(nontaxon.dat$data), digits = 3)
print(apply(nontaxon.dat$data, 2, skew), digits = 3)
print(apply(nontaxon.dat$data, 2, kurt), digits = 3)
```

---

noisemaker *Simulate a population correlation matrix with model error*

Description

This tool lets the user generate a population correlation matrix with model error using one of three methods: (1) the Tucker, Koopman, and Linn (TKL; 1969) method, (2) the Cudeck and Browne (CB; 1992) method, or (3) the Wu and Browne (WB; 2015) method. If the CB or WB methods are used, the user can specify the desired RMSEA value. If the TKL method is used, an optimization procedure finds a solution that produces RMSEA and/or CFI values that are close to the user-specified values.

Usage

```
noisemaker(
  mod,
  method = c("TKL", "CB", "WB"),
  target_rmsea = 0.05,
  target_cfi = NULL,
  tkl_ctrl = list(),
  wb_mod = NULL
)
```

Arguments

mod	A simFA model object.
method	(character) Model error method to use ("TKL", "CB", or "WB").
target_rmsea	(scalar) Target RMSEA value.
target_cfi	(scalar) Target CFI value.
tkl_ctrl	(list) A control list containing the following TKL-specific arguments. See the tkl help file for more details.
wb_mod	('lm' object) An optional lm object used to find a target RMSEA value that results in solutions with RMSEA values close to the desired value. Note that if no 'wb_mod' is provided, a model will be estimated at run time. If many population correlation matrices are going to be simulated using the same model, it will be considerably faster to estimate 'wb_mod' ahead of time. See also get_wb_mod.

Value

A list containing Σ, RMSEA and CFI values, and the TKL parameters (if applicable).

Examples

```
mod <- fungible::simFA(Seed = 42)

set.seed(42)
# Simulate a population correlation matrix using the TKL method with target
# RMSEA and CFI values specified.
noisemaker(mod, method = "TKL",
           target_rmsea = 0.05,
           target_cfi = 0.95,
           tkl_ctrl = list(optim_type = "optim"))

# Simulate a population correlation matrix using the CB method with target
# RMSEA value specified.
noisemaker(mod, method = "CB",
           target_rmsea = 0.05)

# Simulation a population correlation matrix using the WB method with target
# RMSEA value specified.
noisemaker(mod,
```

```
            method = "WB",
            target_rmsea = 0.05)
```

`normalCor` *Compute Normal-Theory Covariances for Correlations*

Description

Compute normal-theory covariances for correlations

Usage

```
normalCor(R, Nobs)
```

Arguments

`R`	a p x p matrix of correlations.
`Nobs`	Number of observations.

Value

A normal-theory covariance matrix of correlations.

Author(s)

Jeff Jones and Niels Waller

References

Nel, D.G. (1985). A matrix derivation of the asymptotic covariance matrix of sample correlation coefficients. *Linear algebra and its applications, 67*, 137–145.

See Also

`adfCor`

Examples

```
data(Harman23.cor)
normalCor(Harman23.cor$cov, Nobs = 305)
```

normF *Compute the Frobenius norm of a matrix*

Description

A function to compute the Frobenius norm of a matrix

Usage

```
normF(X)
```

Arguments

X	A matrix.

Value

The Frobenius norm of X.

Author(s)

Niels Waller

Examples

```
data(BadRLG)
out <- smoothLG(R = BadRLG, Penalty = 50000)
cat("\nGradient at solution:", out$gr,"\n")
cat("\nNearest Correlation Matrix\n")
print( round(out$RLG,8) )
cat("\nFrobenius norm of (NPD - PSD) matrix\n")
print(normF(BadRLG - out$RLG ))
```

obj_func *Objective function for optimizing RMSEA and CFI*

Description

This is the objective function that is minimized by the tkl function.

Usage

```
obj_func(
  par = c(v, eps),
  Rpop,
  W,
  p,
  u,
  df,
  target_rmsea,
  target_cfi,
  weights = c(1, 1),
  WmaxLoading = NULL,
  NWmaxLoading = 2,
  penalty = 0,
  return_values = FALSE
)
```

Arguments

par	(vector) Values of model error variance (ν_e) and epsilon (ϵ).
Rpop	(matrix) The model-implied correlation matrix.
W	(matrix) Matrix of provisional minor common factor loadings with unit column variances.
p	(scalar) Number of variables.
u	(vector) Major common factor variances.
df	(scalar) Model degrees of freedom.
target_rmsea	(scalar) Target RMSEA value.
target_cfi	(scalar) Target CFI value.
weights	(vector) Vector of length two indicating how much weight to give RMSEA and CFI, e.g., 'c(1,1)' (default) gives equal weight to both indices; 'c(1,0)' ignores the CFI value.
WmaxLoading	(scalar) Threshold value for 'NWmaxLoading'.
NWmaxLoading	(scalar) Maximum number of absolute loadings $\geq$ 'WmaxLoading' in any column of 'W'.
penalty	(scalar) Large (positive) penalty value to apply if the NWmaxLoading condition is violated.
return_values	(boolean) If 'TRUE', return the objective function value along with 'Rpop', 'RpopME', 'W', 'RMSEA', 'CFI', 'v', and 'eps' values. If 'FALSE', return only the objective function value.

`Omega` *Compute Omega hierarchical*

Description

This function computes McDonald's Omega hierarchical to determine the proportions of variance (for a given test) associated with the latent factors and with the general factor.

Usage

```
Omega(lambda, genFac = 1, digits = NULL)
```

Arguments

`lambda`	(Matrix) A factor pattern matrix to be analyzed.
`genFac`	(Scalar, Vector) Which column(s) contains the general factor(s). The default value is the first column.
`digits`	(Scalar) The number of digits to round all output to.

Details

- **Omega Hierarchical**: For a reader-friendly description (with some examples), see the Rodriguez et al., (2016) *Psychological Methods* article. Most of the relevant equations and descriptions are found on page 141.

Value

- **omegaTotal**: (Scalar) The total reliability of the latent, common factors for the given test.
- **omegaGeneral**: (Scalar) The proportion of total variance that is accounted for by the general factor(s).

Author(s)

- Casey Giordano (Giord023@umn.edu)
- Niels G. Waller (nwaller@umn.edu)

References

McDonald, R. P. (1999). *Test theory: A unified approach*. Mahwah, NJ:Erlbaum.

Rodriguez, A., Reise, S. P., & Haviland, M. G. (2016). Evaluating bifactor models: Calculating and interpreting statistical indices. *Psychological Methods, 21*(2), 137.

Zinbarg, R.E., Revelle, W., Yovel, I., & Li. W. (2005). Cronbach's Alpha, Revelle's Beta, McDonald's Omega: Their relations with each and two alternative conceptualizations of reliability. *Psychometrika.* 70, 123-133. https://personality-project.org/revelle/publications/zinbarg.revelle.pmet.05.pdf

Examples

```
## Create a bifactor structure
bifactor <- matrix(c(.21, .49, .00, .00,
                     .12, .28, .00, .00,
                     .17, .38, .00, .00,
                     .23, .00, .34, .00,
                     .34, .00, .52, .00,
                     .22, .00, .34, .00,
                     .41, .00, .00, .42,
                     .46, .00, .00, .47,
                     .48, .00, .00, .49),
                   nrow = 9, ncol = 4, byrow = TRUE)

## Compute Omega
Out1 <- Omega(lambda = bifactor)
```

---

orderFactors *Order factor-loadings matrix by the sum of squared factor loadings*

Description

Order the columns of a factor loadings matrix in descending order based on the sum of squared factor loadings.

Usage

```
orderFactors(Lambda, PhiMat, salient = 0.29, reflect = TRUE)
```

Arguments

`Lambda`	(Matrix) Factor loadings matrix to be reordered.
`PhiMat`	(Matrix, NULL) Factor correlation matrix to be reordered.
`salient`	(Numeric) Indicators with loadings < `salient` will be suppressed when computing the factor sum of squares values. Defaults to salient = .29.
`reflect`	(Logical) If true, negatively-keyed factors will be reflected. Defaults to reflect = TRUE.

Value

Returns the sorted factor loading and factor correlation matrices.

- **Lambda**: (Matrix) The sorted factor loadings matrix.
- **Phi**: (Matrix) The sorted factor correlation matrix.

See Also

Other Factor Analysis Routines: BiFAD(), Box26, GenerateBoxData(), Ledermann(), SLi(), SchmidLeiman(), faAlign(), faEKC(), faIB(), faLocalMin(), faMB(), faMain(), faScores(), faSort(), faStandardize(), faX(), fals(), fapa(), fareg(), fsIndeterminacy(), print.faMB(), print.faMain(), promaxQ(), summary.faMB(), summary.faMain()

Examples

```
## Not run:
Loadings <-
  matrix(c(.49, .41, .00, .00,
           .73, .45, .00, .00,
           .47, .53, .00, .00,
           .54, .00, .66, .00,
           .60, .00, .38, .00,
           .55, .00, .66, .00,
           .39, .00, .00, .68,
           .71, .00, .00, .56,
           .63, .00, .00, .55),
         nrow = 9, ncol = 4, byrow = TRUE)

fungible::orderFactors(Lambda = Loadings,
                       PhiMat = NULL)$Lambda

## End(Not run)
```

---

plot.monte *Plot Method for Class Monte*

Description

plot method for class "monte"

Usage

```
## S3 method for class 'monte'
plot(x, ...)
```

Arguments

x	An object of class 'monte', usually, a result of a call to monte.
...	Optional arguments passed to plotting function.

Value

The function plot.monte creates a scatter plot of matrices plot (a splom plot). Cluster membership is denoted by different colors in the plot.

Examples

```
#plot(monte.object)
```

`print.faMain` *Print Method for an Object of Class faMain*

Description

Print Method for an Object of Class faMain

Usage

```
## S3 method for class 'faMain'
print(x, ..., digits = 2, Set = 1, itemSort = FALSE)
```

Arguments

`x`	(Object of class **faMain**) The returned object from a call to **faMain**.
`...`	Additional arguments affecting the summary produced.
`digits`	(Integer) Print output with user-specified number of significant digits. Default `digits = 2`.
`Set`	• integer (Integer) Summarize the solution from the specified solution set. • 'UnSpun' (Character) Summarize the solution from the rotated output that was produced by rotating from the unrotated (i.e., unspun) factor orientation.
`itemSort`	(Logical) If TRUE, sort the order of the observed variables to produce a "staircase"-like pattern. In bifactor models (i.e., bifactorT and bifactorQ) item sorting is determined by the magnitudes of the group factor loadings. Defaults to `itemSort = FALSE`.

See Also

Other Factor Analysis Routines: `BiFAD()`, `Box26`, `GenerateBoxData()`, `Ledermann()`, `SLi()`, `SchmidLeiman()`, `faAlign()`, `faEKC()`, `faIB()`, `faLocalMin()`, `faMB()`, `faMain()`, `faScores()`, `faSort()`, `faStandardize()`, `faX()`, `fals()`, `fapa()`, `fareg()`, `fsIndeterminacy()`, `orderFactors()`, `print.faMB()`, `promaxQ()`, `summary.faMB()`, `summary.faMain()`

print.faMB *Print Method for an Object of Class faMB*

Description

Print Method for an Object of Class faMB

Usage

```
## S3 method for class 'faMB'
print(x, ..., digits = 2, Set = 1, itemSort = FALSE)
```

Arguments

x	(Object of class **faMB**) The returned object from a call to **faMB**.
...	Additional arguments affecting the summary produced.
digits	(Integer) Print output with user-specified number of significant digits. Default digits = 2.
Set	• integer (Integer) Summarize the solution from the specified solution set. • 'UnSpun' (Character) Summarize the solution from the rotated output that was produced by rotating from the unrotated (i.e., unspun) factor orientation.
itemSort	(Logical) If TRUE, sort the order of the observed variables to produce a "staircase"-like pattern. Defaults to itemSort = FALSE.

See Also

Other Factor Analysis Routines: BiFAD(), Box26, GenerateBoxData(), Ledermann(), SLi(), SchmidLeiman(), faAlign(), faEKC(), faIB(), faLocalMin(), faMB(), faMain(), faScores(), faSort(), faStandardize(), faX(), fals(), fapa(), fareg(), fsIndeterminacy(), orderFactors(), print.faMain(), promaxQ(), summary.faMB(), summary.faMain()

promaxQ *Conduct an Oblique Promax Rotation*

Description

This function is an extension of the promax function. This function will extract the unrotated factor loadings (with three algorithm options, see faX) if they are not provided. The factor intercorrelations (Phi) are also computed within this function.

Usage

```
promaxQ(
  R = NULL,
  urLoadings = NULL,
  facMethod = "fals",
  numFactors = NULL,
  power = 4,
  standardize = "Kaiser",
  epsilon = 1e-04,
  maxItr = 15000,
  faControl = NULL
)
```

Arguments

R	(Matrix) A correlation matrix.
urLoadings	(Matrix) An unrotated factor-structure matrix to be rotated.
facMethod	(Character) The method used for factor extraction (faX). The supported options are "fals" for unweighted least squares, "faml" for maximum likelihood, "fapa" for iterated principal axis factoring, "faregLS" for regularized least squares, "faregML" for regularized maximum likelihood, and "pca" for principal components analysis. The default method is "fals". • **"fals"**: Factors are extracted using the unweighted least squares estimation procedure using the fals function. • **"faml"**: Factors are extracted using the maximum likelihood estimation procedure using the factanal function. • **"fapa"**: Factors are extracted using the iterated principal axis factoring estimation procedure using the fapa function. • **"faregLS"**: Factors are extracted using regularized least squares factor analysis using the fareg function. • **"faregML"**: Factors are extracted using regularized maximum likelihood factor using the fareg function. • **"pca"**: Principal components are extracted.
numFactors	(Scalar) The number of factors to extract if the lambda matrix is not provided.
power	(Scalar) The power with which to raise factor loadings for minimizing trivial loadings. The default value is 4.
standardize	(Character) Which standardization routine is applied to the unrotated factor structure. The three options are "none", "Kaiser", and "CM". The default option is "Kaiser" as is recommended by Kaiser and others. See faStandardize for more details. • **"none"**: Do *not* rotate the normalized factor structure matrix. • **"Kaiser"**: Use a factor structure matrix that has been normed by Kaiser's method (i.e., normalize all rows to have a unit length). • **"CM"**: Use a factor structure matrix that has been normed by the Cureton-Mulaik method.

`epsilon` (Scalar) The convergence criterion used for evaluating the varimax rotation. The default value is 1e-4 (i.e., .0001).

`maxItr` (Scalar) The maximum number of iterations allowed for computing the varimax rotation. The default value is 15,000 iterations.

`faControl` (List) A list of optional parameters passed to the factor extraction (`faX`) function.

- **treatHeywood**: (Logical) In `fals`, if treatHeywood is true, a penalized least squares function is used to bound the communality estimates below 1.0. Defaults to treatHeywood = TRUE.
- **nStart**: (Numeric) The number of starting values to be tried in `faml`. Defaults to nStart = 10.
- **start**: (Matrix) NULL or a matrix of starting values, each column giving an initial set of uniquenesses. Defaults to start = NULL.
- **maxCommunality**: (Numeric) In `faml`, set the maximum communality value for the estimated solution. Defaults to maxCommunality = .995.
- **epsilon**: (Numeric) In `fapa`, the numeric threshold designating when the algorithm has converged. Defaults to epsilon = 1e-4.
- **communality**: (Character) The method used to estimate the initial communality values in `fapa`. Defaults to communality = 'SMC'.
  - **"SMC"**: Initial communalities are estimated by taking the squared multiple correlations of each indicator after regressing the indicator on the remaining variables.
  - **"maxr"**: Initial communalities equal the largest (absolute value) correlation in each column of the correlation matrix.
  - **"unity"**: Initial communalities equal 1.0 for all variables.
- **maxItr**: (Numeric) In `fapa`, the maximum number of iterations to reach convergence. Defaults to maxItr = 15,000.

Details

- **Varimax Standardization**: When conducting the varimax rotation, it is recommended to standardize the factor loadings using Kaiser's normalization (i.e., rescaling the factor indicators [rows] so that the vectors have unit length). The standardization/normalization occurs by pre-multiplying the unrotated factor structure, **A**, by the inverse of **H**, where **H**^2 is a diagonal matrix with the communality estimates on the diagonal. A varimax rotation is then applied to the normalized, unrotated factor structure. Then, the varimax-rotated factor structure is rescaled to its original metric by pre-multiplying the varimax factor structure by **H**. For details, see Mulaik (2009).
- **Oblique Procrustes Rotation of the Varimax Solution**: According to Hendrickson & White (1964), an unrestricted (i.e., oblique) Procrustes rotation is applied to the orthogonal varimax solution. Specifically, a target matrix is generated by raising the varimax factor loadings to the user-specified power (typically, power = 4) (must retain the signs of the original factor loadings). This should quickly diminish trivial factor loadings while retaining larger factor loadings. The Procrustes rotation takes the varimax solution and rotates it toward the promax-generated target matrix. For a modern description of this approach, see Mulaik (2009, ch. 12, p. 342-343).

- **Choice of a Power**: Changing the power in which varimax factor loadings are raised will change the target matrix in the oblique Procrustes rotation. After raising factor loadings to some power, there will be a larger discrepancy between high and low loadings than before (e.g., squaring factor loadings of .6 and .7 yields loadings of .36 and .49 and cubing yields loadings of .216 and .343). Furthermore, increasing the power will increase the number of near-zero loadings, resulting in larger factor intercorrelations. Many (cf. Gorsuch, 1983; Hendrickson & White, 1964; Mulaik, 2009) advocate for raising varimax loadings to the fourth power (the default) but some (e.g., Gorsuch) advocate for trying power = 2 and power = 6 to see if there is an improvement in the simple structure without overly inflating factor correlations.

Value

A list of the following elements are produced:

- **loadings**: (Matrix) The oblique, promax-rotated, factor-pattern matrix.
- **vmaxLoadings**: (Matrix) The orthogonal, varimax-rotated, factor-structure matrix used as the input matrix for the promax rotation.
- **rotMatrix**: (Matrix) The (rescaled) transformation matrix used in an attempt to minimize the Euclidean distance between the varimax loadings and the generated promax target matrix (cf. Hendrickson & White, 1964; Mulaik, 2009, p. 342-343, eqn. 12.44).
- **Phi**: (Matrix) The factor correlation matrix associated with the promax solution. Phi is found by taking the inverse of the inner product of the (rescaled) rotation matrix (rotMatrix) with itself (i.e., $solve(T'T)$, where T is the (rescaled) rotation matrix).
- **vmaxDiscrepancy**: (Scalar) The value of the minimized varimax discrepancy function. promax does not have a rotational criterion but the varimax rotation does.
- **convergence**: (Logical) Whether the varimax rotation congerged.
- **Table**: (Matrix) The table returned from `GPForth` from the `GPArotation` package.
- **rotateControl**: (List) A list containing (a) the power parameter used, (b) whether the varimax rotation used Kaiser normalization, (c) the varimax epsilon convergence criterion, and (d) the maximum number of iterations specified.
  - **power**: The power in which the varimax-rotated factor loadings are raised.
  - **standardize**: Which standardization routine was used.
  - **epsilon**: The convergence criterion set for the varimax rotation.
  - **maxItr**: The maximum number of iterations allowed for reaching convergence in the varimax rotation.

Author(s)

- Casey Giordano (Giord023@umn.edu)
- Niels G. Waller (nwaller@umn.edu)

References

Gorsuch, R. L. (1983). *Factor Analysis*, 2nd. Hillsdale, NJ: LEA.

Hendrickson, A. E., & White, P. O. (1964). Promax: A quick method for rotation to oblique simple structure. *British Journal of Statistical Psychology, 17*(1), 65-70.

Mulaik, S. A. (2009). *Foundations of Factor Analysis*. Chapman and Hall/CRC.

See Also

Other Factor Analysis Routines: BiFAD(), Box26, GenerateBoxData(), Ledermann(), SLi(), SchmidLeiman(), faAlign(), faEKC(), faIB(), faLocalMin(), faMB(), faMain(), faScores(), faSort(), faStandardize(), faX(), fals(), fapa(), fareg(), fsIndeterminacy(), orderFactors(), print.faMB(), print.faMain(), summary.faMB(), summary.faMain()

Examples

```
## Generate an orthgonal factor model
lambda <- matrix(c(.41, .00, .00,
                   .45, .00, .00,
                   .53, .00, .00,
                   .00, .66, .00,
                   .00, .38, .00,
                   .00, .66, .00,
                   .00, .00, .68,
                   .00, .00, .56,
                   .00, .00, .55),
                 nrow = 9, ncol = 3, byrow = TRUE)

## Model-implied correlation (covariance) matrix
R <- lambda %*% t(lambda)

## Unit diagonal elements
diag(R) <- 1

## Start from just a correlation matrix
Out1 <- promaxQ(R           = R,
                facMethod   = "fals",
                numFactors  = 3,
                power       = 4,
                standardize = "Kaiser")$loadings

## Iterate the promaxQ rotation using the rotate function
Out2 <- faMain(R             = R,
               facMethod     = "fals",
               numFactors    = 3,
               rotate        = "promaxQ",
               rotateControl = list(power       = 4,
                                    standardize = "Kaiser"))$loadings

## Align the factors to have the same orientation
Out1 <- faAlign(F1 = Out2,
                F2 = Out1)$F2

## Show the equivalence of factor solutions from promaxQ and rotate
all.equal(Out1, Out2, check.attributes = FALSE)
```

r2d *Convert Radians to Degrees*

Description

Convert radian measure to degrees.

Usage

```
r2d(radian)
```

Arguments

radian	Radian measure of an angle.

Value

Degree measure of an angle.

Examples

```
r2d(.5*pi)
```

rarc *Rotate Points on the Surface on an N-Dimensional Ellipsoid*

Description

Rotate between two points on the surface on an n-dimensional ellipsoid. The hyper-ellipsoid is composed of all points, B, such that B' Rxx B = Rsq. Vector B contains standardized regression coefficients.

Usage

```
rarc(Rxx, Rsq, b1, b2, Npoints)
```

Arguments

Rxx	Predictor correlation matrix.
Rsq	Model coefficient of determination.
b1	First point on ellipsoid. If b1 and b2 are scalars then choose scaled eigenvectors v[b1] and v[b2] as the start and end vectors.
b2	Second point on ellipsoid. If b1 and b2 are scalars then choose scaled eigenvectors v[b1] and v[b2] as the start and end vectors.
Npoints	Generate "Npoints" +1 OLS coefficient vectors between b1 and b2.

Value

b	N+1 sets of OLS coefficient vectors between b1 and b2.

Author(s)

Niels Waller and Jeff Jones.

References

Waller, N. G. & Jones, J. A. (2011). Investigating the performance of alternate regression weights by studying all possible criteria in regression models with a fixed set of predictors. *Psychometrika, 76*, 410-439.

Examples

```
## Example
## GRE/GPA Data
##-------------------##
R <- Rxx <- matrix(c(1.00, .56, .77,
                     .56, 1.00, .73,
                     .77, .73, 1.00), 3, 3)

## GPA validity correlations
rxy <- c(.39, .34, .38)
b <- solve(Rxx) %*% rxy

Rsq <- t(b) %*% Rxx %*% b
N <- 200

b <- rarc(Rxx = R, Rsq, b1 = 1, b2 = 3, Npoints = N)

## compute validity vectors
r <- Rxx %*% b
N <- N + 1
Rsq.r <- Rsq.unit <- rep(0, N)

for(i in 1:N){
## eval performance of unit weights
  Rsq.unit[i] <- (t(sign(r[,i])) %*% r[,i])^2 /
             (t(sign(r[,i])) %*% R %*% sign(r[,i]))

## eval performance of correlation weights
  Rsq.r[i] <- (t(r[,i]) %*% r[,i])^2 /(t(r[,i]) %*% R %*% r[,i])
}

cat("\nAverage relative performance of unit weights across elliptical arc:",
      round(mean(Rsq.unit)/Rsq,3) )
cat("\n\nAverage relative performance of r weights across elliptical arc:",
      round(mean(Rsq.r)/Rsq,3) )
```

```
plot(seq(0, 90, length = N), Rsq.r, typ = "l",
          ylim = c(0, .20),
          xlim = c(0, 95),
          lwd = 3,
          ylab = expression(R^2),
          xlab = expression(paste("Degrees from ",b[1]," in the direction of ",b[2])),
          cex.lab = 1.25, lab = c(10, 5, 5))
 points(seq(0, 90, length = N), Rsq.unit,
          type = "l",
          lty = 2, lwd = 3)
 legend(x = 0,y = .12,
        legend = c("r weights", "unit weights"),
        lty = c(1, 2),
        lwd = c(4, 3),
        cex = 1.5)
```

`Ravgr` *Generate a random R matrix with an average rij*

Description

Ravgr(Rseed, NVar = NULL, u = NULL, rdist = "U", alpha = 4, beta = 2, SEED = NULL)

Usage

```
Ravgr(
  Rseed,
  NVar = NULL,
  u = NULL,
  rdist = "U",
  alpha = 4,
  beta = 2,
  SEED = NULL
)
```

Arguments

`Rseed`	(matrix or scalar) This argument can take one of two alternative inputs. The first input is an $n \times n$ **R** matrix with a known, average rij. The second type of input is a scalar $\bar{r}_{ij}$.
`NVar`	(integer) If `Rseed` is a scalar then the user must specify `NVar`, the number of variables in the desired **R** matrix. Default(`NVar = NULL`).
`u`	(scalar). A scalar $\in [0, 1]$. Higher values of u will produce **R** matrices with more variable off-diagonal elements.

rdist	(character). A character that controls the variance of the off diagonal elements of the generated **R**. If u = NULL and rdist="U" then the **R** matrices are uniformly sampled from the space of all $n \times n$ **R** matrices with a fixed average rij. If u = NULL and rdist = "B" then the **R** matrices are selected as a function of the alpha and beta arguments of a Beta distribution. Default rdist= "U". See Waller (2024) for details.
alpha	(numeric) The shape1 parameter of a beta distribution.
beta	(numeric) The shape2 parameter of a beta distribution.
SEED	(numeric) The initial seed for the random number generator. If SEED is not supplied then the program will generate (and return) a randomly generated seed.

Value

- **R** A random **R** matrix with a known, average off-diagonal element rij.
- **Rseed** The input **R** matrix or scalar with the desired average rij.
- **u** A random number $\in [0, 1]$.
- **s** Scaling factor for hollow matrix H.
- **H** A hollow matrix used to create a fungible **R** matrix.
- **alpha** First argument of the beta distribution. If rdist= "U" then alpha = NULL.
- **beta** Second argument of the beta distribution. If rdist= "U" then beta = NULL.
- **SEED** The initial value for the random number generator.

Author(s)

Niels G. Waller

References

Waller, N. G. (2024). Generating correlation matrices with a user-defined average correlation. Manuscript under review.

Examples

```
# Example 1
 R <- matrix(.35, 6, 6)
 diag(R) <- 1

 Rout <- Ravgr(Rseed = R,
              rdist = "U", SEED = 123)$R

 Rout |> round(3)
 mean( Rout[upper.tri(Rout, diag = FALSE)] )

 # Example 2
 Rout <- Ravgr(Rseed = .35, NVar = 6,
              rdist = "U", SEED = 123)$R
```

```
Rout |> round(3)
mean( Rout[upper.tri(Rout, diag = FALSE)] )

# Example 3
# Generate an R matrix with a larger var(rij)
Rout <- Ravgr(Rseed = .35,
              NVar = 6,
              rdist = "B",
              alpha = 7,
              beta = 2)$R

Rout |> round(3)
mean( Rout[upper.tri(Rout, diag = FALSE)] )

# Example 4: Demonstrate the function of u
sdR <- function(R){
  sd(R[lower.tri(R, diag = FALSE)])
}

Rout <- Ravgr(Rseed = .35,
              NVar = 6,
              u = 0,
              SEED = 123)
sdR(Rout$R)

Rout <- Ravgr(Rseed = .35,
              NVar = 6,
              u = .5,
              SEED = 123)
sdR(Rout$R)

Rout <- Ravgr(Rseed = .35,
              NVar = 6,
              u = 1,
              SEED = 123)
sdR(Rout$R)
```

Rbounds *Generate random R matrices with user-defined bounds on the correlation coefficients via differential evolution (DE).*

Description

Rbounds can generate uniformly sampled correlation matrices with user-defined bounds on the correlation coefficients via differential evolution (DE). Unconstrained R matrices (i.e., with no constraints placed on the r_{ij}) computed from 12 or fewer variables can be generated relatively quickly on a personal computer. Larger matrices may require very long execution times. Rbounds can generate larger matrices when the correlations are tightly bounded (e.g., $0 < r_{ij} < .5$ for all $i \neq j$). To generate uniformly sampled R matrices, users should leave NPopFactor and crAdaption at their default values.

Usage

```
Rbounds(
  Nvar = 3,
  NMatrices = 1,
  Minr = -1,
  Maxr = 1,
  MinEig = 0,
  MaxIter = 200,
  NPopFactor = 10,
  crAdaption = 0,
  delta = 1e-08,
  PRINT = FALSE,
  Seed = NULL
)
```

Arguments

Nvar	(integer) The order of the generated correlation matrices.
NMatrices	(integer) Generate NMatrices correlation matrices.
Minr	(numeric > -1 and < Maxr) The lower bound for all r_{ij} in the generated R matrices. Default Minr = -1.
Maxr	(numeric > Minr and <= 1). The upper bound for all r_{ij} in the generated R matrices. Default Maxr = 1.
MinEig	(numeric). Minimum size of the last eigenvalue of R. Default MinEig = 0. By setting MinEig to a value slightly greater than 0 (e.g., 1E-3), all generated matrices will be positive definite.
MaxIter	(integer) The maximum number of iterations (i.e., generations) for the DE optimizer. Default MaxIter = 200.
NPopFactor	(numeric > 0). If R is an $n \times n$ matrix, then each generation will contain NPopFactor $\times n(n-1)/2$ members. Default NPOP = 10.
crAdaption	(numeric (0,1]). Controls the speed of the crossover adaption. This parameter is called 'c' in the DEoptim.control help page. Default crAdaption = 0.
delta	(numeric > 0) A number that controls the convergence. See the DEoptim.control accuracy of the differential evolution algorithm. Default delta = 1E-8.
PRINT	(logical) When PRINT = TRUE the algorithm convergence status is printed. Default PRINT = FALSE.
Seed	(integer) Initial random number seed. Default (Seed = NULL).

Value

Rbounds returns the following objects:

- **R** (matrix) A list of generated correlation matrices.
- **converged**: (logical) a logical that indicates the convergence status of the optimization for each matrix.
- **iter** (integer) The number of cycles needed to reach a converged solution for each matrix.

Author(s)

Niels G. Waller

References

Ardia, D., Boudt, K., Carl, P., Mullen, K.M., Peterson, B.G. (2011) Differential Evolution with DEoptim. An Application to Non-Convex Portfolio Optimization. URL The R Journal, 3(1), 27-34. URL https://journal.r-project.org/archive/2011-1/RJournal_2011-1_Ardia~et~al.pdf.

Georgescu, D. I., Higham, N. J., and Peters, G. W. (2018). Explicit solutions to correlation matrix completion problems, with an application to risk management and insurance. Royal Society Open Science, 5(3), 172348.

Mishra, S. K. (2007). Completing correlation matrices of arbitrary order by differential evolution method of global optimization: a Fortran program. Available at SSRN 968373.

Mullen, K.M, Ardia, D., Gil, D., Windover, D., Cline, J. (2011). DEoptim: An R Package for Global Optimization by Differential Evolution. *Journal of Statistical Software, 40*, 1-26. URL http://www.jstatsoft.org/v40/i06/.

Price, K.V., Storn, R.M., Lampinen J.A. (2005) *Differential Evolution - A Practical Approach to Global Optimization*. Berlin Heidelberg: Springer-Verlag. ISBN 3540209506.

Zhang, J. and Sanderson, A. (2009) *Adaptive Differential Evolution*. Springer-Verlag. ISBN 978-3-642-01526-7

Examples

```
## Example 1: Generate random 4 x 4 Correlation matrices with all rij >= 0.

  out <- Rbounds(Nvar = 4,
              NMatrices = 4,
              Minr = 0,
              Maxr = 1,
              PRINT = TRUE,
              Seed = 1)

  # Check convergence status of matrices
  print( table(out$converged) )

  print( round( out$R[[1]] , 3) )
```

---

rcone *Generate a Cone of Regression Coefficient Vectors*

Description

Compute a cone of regression vectors with a constant R-squared around a target vector.

Usage

```
rcone(R, Rsq, b, axis1, axis2, deg, Npoints = 360)
```

Arguments

R	Predictor correlation matrix.
Rsq	Coefficient of determination.
b	Target vector of OLS regression coefficients.
axis1	1st axis of rotation plane.
axis2	2nd axis of rotation plane.
deg	All vectors b.i will be 'deg' degrees from b.
Npoints	Number of rotation vectors, default = 360.

Value

b.i	Npoints values of b.i

Author(s)

Niels Waller and Jeff Jones

References

Waller, N. G. & Jones, J. A. (2011). Investigating the performance of alternate regression weights by studying all possible criteria in regression models with a fixed set of predictors. *Psychometrika, 76*, 410-439.

Examples

```
R <- matrix(.5, 4, 4)
diag(R) <- 1

Npoints <- 1000
Rsq <- .40
NumDeg <- 20
V <- eigen(R)$vectors

## create b parallel to v[,3]
## rotate in the 2 - 4 plane
b <- V[,3]
bsq <- t(b) %*% R %*% b
b <- b * sqrt(Rsq/bsq)
b.i <- rcone(R, Rsq,b, V[,2], V[,4], deg = NumDeg, Npoints)

t(b.i[,1]) %*% R %*% b.i[,1]
t(b.i[,25]) %*% R %*% b.i[,25]
```

rcor *Generate Random PSD Correlation Matrices*

Description

Generate random PSD correlation matrices.

Usage

```
rcor(Nvar)
```

Arguments

Nvar	An integer that determines the order of the random correlation matrix.

Details

rcor generates random PSD correlation matrices by (1) generating Nvar squared random normal deviates, (2) scaling the deviates to sum to Nvar, and then (3) placing the scaled values into a diagonal matrix L. Next, (4) an Nvar x Nvar orthogonal matrix, Q, is created by performing a QR decomposition of a matrix, M, that contains random normal deviates. (5) A PSD covariance matrix, C, is created from Q L Q^T and then (6) scaled to a correlation metric.

Value

A random correlation matrix.

Author(s)

Niels Waller

See Also

genCorr

Examples

```
R <- rcor(4)
print( R )
```

`rellipsoid` *Generate Uniformly Spaced OLS Regression Coefficients that Yield a User-Supplied R-Squared Value*

Description

Given predictor matrix R, generate OLS regression coefficients that yield a user-supplied R-Squared value. These regression coefficient vectors will be uniformly spaced on the surface of a (hyper) ellipsoid.

Usage

```
rellipsoid(R, Rsq, Npoints)
```

Arguments

`R`	A p x p predictor correlation matrix.
`Rsq`	A user-supplied R-squared value.
`Npoints`	Desired number of generated regression vectors.

Value

`b`	A p x Npoints matrix of regression coefficients

Author(s)

Niels Waller and Jeff Jones.

References

Waller, N. G. and Jones, J. A. (2011). Investigating the performance of alternate regression weights by studying all possible criteria in regression models with a fixed set of predictors. *Psychometrika, 76*, 410-439.

Examples

```
## generate uniformly distributed regression vectors
## on the surface of a 14-dimensional ellipsoid
N <- 10000
Rsq <- .21

# Correlations from page 224 WAIS-III manual
# The Psychological Corporation (1997).
wais3 <- matrix(
 c(1, .76, .58, .43, .75, .75, .42, .54, .41, .57, .64, .54, .50, .53,
 .76,   1, .57, .36, .69, .71, .45, .52, .36, .63, .68, .51, .47, .54,
 .58, .57,   1, .45, .65, .60, .47, .48, .43, .59, .60, .49, .56, .47,
 .43, .36, .45,   1, .37, .40, .60, .30, .32, .34, .35, .28, .35, .29,
```

```
 .75, .69, .65, .37,   1, .70, .44, .54, .34, .59, .62, .54, .45, .50,
 .75, .71, .60, .40, .70,   1, .42, .51, .44, .53, .60, .50, .52, .44,
 .42, .45, .47, .60, .44, .42,   1, .46, .49, .47, .43, .27, .50, .42,
 .54, .52, .48, .30, .54, .51, .46,   1, .45, .50, .58, .55, .53, .56,
 .41, .36, .43, .32, .34, .44, .49, .45,   1, .47, .49, .41, .70, .38,
 .57, .63, .59, .34, .59, .53, .47, .50, .47,   1, .63, .62, .58, .66,
 .64, .68, .60, .35, .62, .60, .43, .58, .49, .63,   1, .59, .50, .59,
 .54, .51, .49, .28, .54, .50, .27, .55, .41, .62, .59,   1, .48, .53,
 .50, .47, .56, .35, .45, .52, .50, .53, .70, .58, .50, .48,   1, .51,
 .53, .54, .47, .29, .50, .44, .42, .56, .38, .66, .59, .53, .51,   1),
 nrow = 14, ncol = 14)

R <- wais3[1:6,1:6]
b <- rellipsoid(R, Rsq, Npoints = N)
b <- b$b
#
plot(b[1,],b[2,])
```

`restScore` *Plot an ERF using rest scores*

Description

Plot an empirical response function using rest scores.

Usage

```
restScore(data, item, NCuts = 10)
```

Arguments

`data`	N(subjects)-by-p(items) matrix of 0/1 item response data.
`item`	Generate a rest score plot for item `item`.
`NCuts`	Divide the rest scores into `NCuts` bins of equal width.

Value

A restscore plot with 95% confidence interval bars for the conditional probability estimates.

`item`	The item number.
`bins`	A vector of bin limits and bin sample sizes.
`binProb`	A vector of bin conditional probabilities.

Author(s)

Niels Waller

Examples

```
NSubj <- 2000

#generate sample k=1 FMP  data
b <- matrix(c(
    #b0    b1     b2    b3      b4   b5 b6 b7  k
  1.675, 1.974, -0.068, 0.053,  0,  0,  0,  0, 1,
  1.550, 1.805, -0.230, 0.032,  0,  0,  0,  0, 1,
  1.282, 1.063, -0.103, 0.003,  0,  0,  0,  0, 1,
  0.704, 1.376, -0.107, 0.040,  0,  0,  0,  0, 1,
  1.417, 1.413,  0.021, 0.000,  0,  0,  0,  0, 1,
 -0.008, 1.349, -0.195, 0.144,  0,  0,  0,  0, 1,
  0.512, 1.538, -0.089, 0.082,  0,  0,  0,  0, 1,
  0.122, 0.601, -0.082, 0.119,  0,  0,  0,  0, 1,
  1.801, 1.211,  0.015, 0.000,  0,  0,  0,  0, 1,
 -0.207, 1.191,  0.066, 0.033,  0,  0,  0,  0, 1,
 -0.215, 1.291, -0.087, 0.029,  0,  0,  0,  0, 1,
  0.259, 0.875,  0.177, 0.072,  0,  0,  0,  0, 1,
 -0.423, 0.942,  0.064, 0.094,  0,  0,  0,  0, 1,
  0.113, 0.795,  0.124, 0.110,  0,  0,  0,  0, 1,
  1.030, 1.525,  0.200, 0.076,  0,  0,  0,  0, 1,
  0.140, 1.209,  0.082, 0.148,  0,  0,  0,  0, 1,
  0.429, 1.480, -0.008, 0.061,  0,  0,  0,  0, 1,
  0.089, 0.785, -0.065, 0.018,  0,  0,  0,  0, 1,
 -0.516, 1.013,  0.016, 0.023,  0,  0,  0,  0, 1,
  0.143, 1.315, -0.011, 0.136,  0,  0,  0,  0, 1,
  0.347, 0.733, -0.121, 0.041,  0,  0,  0,  0, 1,
 -0.074, 0.869,  0.013, 0.026,  0,  0,  0,  0, 1,
  0.630, 1.484, -0.001, 0.000,  0,  0,  0,  0, 1),
  nrow=23, ncol=9, byrow=TRUE)

data<-genFMPData(NSubj = NSubj, bParam = b, seed = 345)$data

## generate a rest score plot for item 12.
## the grey horizontal lines in the plot
## respresent pseudo asymptotes that
## are significantly different from the
## (0,1) boundaries
restScore(data, item = 12, NCuts = 9)
```

RGen *Generate random R matrices with various user-defined properties via differential evolution (DE).*

Description

Generate random R matrices with various user-defined properties via differential evolution (DE).

Usage

```
RGen(
  Nvar = 3,
  NMatrices = 1,
  Minr = -1,
  Maxr = 1,
  MinEig = 0,
  MaxIter = 200,
  delta = 1e-08,
  PRINT = FALSE,
  Seed = NULL
)
```

Arguments

Nvar	(integer) The order of the generated correlation matrices.
NMatrices	(integer) Generate NMatrices correlation matrices.
Minr	(numeric > -1 and < Maxr) The minimum rij in the generated R matrices. Default Minr = -1.
Maxr	(numeric > Minr and <= 1). The maximum rij in the generated R matrices. Default Maxr = 1.
MinEig	(numeric). Minimum size of the last eigenvalue of R. Default MinEig = 0. By setting MinEig to a value slightly greater than 0 (e.g., 1E-3), all generated matrices will be positive definite.
MaxIter	(integer) The maximum number of iterations (i.e., generations) for the DE optimizer. Default MaxIter = 200.
delta	(numeric > 0) A number that controls the convergence accuracy of the differential evolution algorithm. Default delta = 1E-8.
PRINT	(logical) When PRINT = TRUE the algorithm convergence status is printed. Default PRINT = FALSE.
Seed	(integer) Initial random number seed. Default (Seed = NULL).

Value

RGen returns the following objects:

- **R** (matrix) A list of generated correlation matrices.
- **converged**: (logical) a logical that indicates the convergence status of the optimization for each matrix.
- **iter** (integer) The number of cycles needed to reach a converged solution for each matrix.

Author(s)

Niels G. Waller

References

Ardia, D., Boudt, K., Carl, P., Mullen, K.M., Peterson, B.G. (2011) Differential Evolution with DEoptim. An Application to Non-Convex Portfolio Optimization. URL The R Journal, 3(1), 27-34. URL https://journal.r-project.org/archive/2011-1/RJournal_2011-1_Ardia~et~al.pdf.

Georgescu, D. I., Higham, N. J., and Peters, G. W. (2018). Explicit solutions to correlation matrix completion problems, with an application to risk management and insurance. Royal Society Open Science, 5(3), 172348.

Mishra, S. K. (2007). Completing correlation matrices of arbitrary order by differential evolution method of global optimization: a Fortran program. Available at SSRN 968373.

Mullen, K.M, Ardia, D., Gil, D., Windover, D., Cline, J. (2011). DEoptim: An R Package for Global Optimization by Differential Evolution. Journal of Statistical Software, 40(6), 1-26. URL http://www.jstatsoft.org/v40/i06/.

Price, K.V., Storn, R.M., Lampinen J.A. (2005) Differential Evolution - A Practical Approach to Global Optimization. Berlin Heidelberg: Springer-Verlag. ISBN 3540209506.

Zhang, J. and Sanderson, A. (2009) Adaptive Differential Evolution Springer-Verlag. ISBN 978-3-642-01526-7

Examples

```
## Example 1: Generate random 4 x 4 Correlation matrices.

  out <- RGen(Nvar = 4,
              NMatrices = 4,
              PRINT = TRUE,
              Seed = 1)

  # Check convergence status of all matrices
  print( table(out$converged) )

  print( round( out$R[[1]] , 3) )
```

---

rGivens *Generate Correlation Matrices with Specified Eigenvalues*

Description

rGivens generates correlation matrices with user-specified eigenvalues via a series of Givens rotations by methods described in Bendel & Mickey (1978) and Davis & Higham (2000).

Usage

```
rGivens(eigs, Seed = NULL)
```

Arguments

eigs	A vector of eigenvalues that must sum to the order of the desired correlation matrix. A fatal error will occur if sum(eigs) != length(eigs).
Seed	Either a user supplied seed for the random number generator or 'NULL' for a function generated seed. Default Seed = 'NULL'.

Value

R	A correlation matrix with desired spectrum.
Frob	The Frobenius norm of the difference between the initial and final matrices with the desired spectrum.
convergence	(Logical) TRUE if rGivens converged to a feasible solution, otherwise FALSE.

References

Bendel, R. B. & Mickey, M. R. (1978). Population correlation matrices for sampling experiments, Commun. Statist. Simulation Comput., B7, pp. 163-182.

Davies, P. I, & Higham,N. J. (2000). Numerically stable generation of correlation matrices and their factors, BIT, 40 (2000), pp. 640-651.

Examples

```
## Example
## Generate a correlation matrix with user-specified eigenvalues

out <- rGivens(c(2.5, 1, 1, .3, .2), Seed = 123)

#> eigen(out$R)$values
#[1] 2.5 1.0 1.0 0.3 0.2

print(out)
#$R
#           [,1]       [,2]        [,3]        [,4]       [,5]
#[1,]  1.0000000 -0.1104098 -0.24512327  0.46497370  0.2392817
#[2,] -0.1104098  1.0000000  0.33564370 -0.46640155 -0.7645915
#[3,] -0.2451233  0.3356437  1.00000000 -0.02935466 -0.2024926
#[4,]  0.4649737 -0.4664016 -0.02935466  1.00000000  0.6225880
#[5,]  0.2392817 -0.7645915 -0.20249261  0.62258797  1.0000000
#
#$Frob
#[1] 2.691613
#
##$S0
#           [,1]        [,2]        [,3]        [,4]        [,5]
#[1,]  1.0349665  0.22537748 -0.46827121 -0.10448336 -0.24730565
#[2,]  0.2253775  0.31833805 -0.23208078  0.06591368 -0.14504161
#[3,] -0.4682712 -0.23208078  2.28911499  0.05430754  0.06964858
#[4,] -0.1044834  0.06591368  0.05430754  0.94884439 -0.14439623
#[5,] -0.2473056 -0.14504161  0.06964858 -0.14439623  0.40873606
```

```
#
#$convergence
#[1] TRUE
```

---

rMAP *Generate Correlation Matrices with Specified Eigenvalues*

Description

rMAP uses the method of alternating projections (MAP) to generate correlation matrices with specified eigenvalues.

Usage

```
rMAP(eigenval, eps = 1e-12, maxits = 5000, Seed = NULL)
```

Arguments

eigenval	A vector of eigenvalues that must sum to the order of the desired correlation matrix. A fatal error will occur if sum(eigenval) != length(eigenval).
eps	Convergence criterion. Default = 1e-12.
maxits	Maximm number of iterations of MAP.
Seed	Either a user supplied seed for the random number generator or 'NULL' for a function generated seed. Default Seed = 'NULL'.

Value

R	A correlation matrix with the desired spectrum.
evals	Eigenvalues of the returned matrix, R.
convergence	(Logical) TRUE if MAP converged to a feasible solution, otherwise FALSE.

Author(s)

Niels Waller

References

Waller, N. G. (2016). Generating correlation matrices with specified eigenvalues using the method of alternating projections.

Examples

```
## Example
## Generate a correlation matrix with user-specified eigenvalues

R <- rMAP(c(2.5, 1, 1, .3, .2), Seed = 123)$R
print(R, 2)

#       [,1]    [,2]   [,3]    [,4]   [,5]
#[1,]  1.000  0.5355 -0.746 -0.0688 -0.545
#[2,]  0.535  1.0000 -0.671 -0.0016 -0.056
#[3,] -0.746 -0.6711  1.000  0.0608  0.298
#[4,] -0.069 -0.0016  0.061  1.0000  0.002
#[5,] -0.545 -0.0564  0.298  0.0020  1.000


eigen(R)$values
#[1] 2.5 1.0 1.0 0.3 0.2
```

---

rmsd *Root Mean Squared Deviation of (A - B)*

Description

Calculates the root mean squared deviation of matrices A and B. If these matrices are symmetric (Symmetric = TRUE) then the calculation is based on the upper triangles of each matrix. When the matrices are symmetric, the diagonal of each matrix can be included or excluded from the calculation (IncludeDiag = FALSE)

Usage

```
rmsd(A, B, Symmetric = TRUE, IncludeDiag = FALSE)
```

Arguments

A	A possibly non square matrix.
B	A matrix of the same dimensions as matrix A.
Symmetric	Logical indicating whether A and B are symmetric matrices. (Default: Symmetric = TRUE)
IncludeDiag	Logical indicating whether to include the diagonals in the calculation. (Default: IncludeDiag = FALSE).

Value

Returns the root mean squared deviation of (A - B).

Author(s)

Niels Waller

Examples

```
A <- matrix(rnorm(9), nrow = 3)
B <- matrix(rnorm(9), nrow = 3)

( rmsd(A, B, Symmetric = FALSE, IncludeDiag = TRUE) )
```

---

rmsea *Calculate RMSEA between two correlation matrices*

Description

Given two correlation matrices of the same dimension, calculate the RMSEA value using the degrees of freedom for the exploratory factor analysis model (see details).

Usage

```
rmsea(Sigma, Omega, k)
```

Arguments

Sigma	(matrix) Population correlation or covariance matrix (with model error).
Omega	(matrix) Model-implied population correlation or covariance matrix.
k	(scalar) Number of major common factors.

Details

Note that this function uses the degrees of freedom for an exploratory factor analysis model:

$$df = p(p-1)/2 - (pk) + k(k-1)/2,$$

where p is the number of items and k is the number of major factors.

Examples

```
mod <- fungible::simFA(Model = list(NFac = 3),
                       Seed = 42)
set.seed(42)
Omega <- mod$Rpop
Sigma <- noisemaker(
  mod = mod,
  method = "CB",
  target_rmsea = 0.05
)$Sigma
rmsea(Sigma, Omega, k = 3)
```

RnpdMAP *Generate Random NPD R matrices from a user-supplied population R*

Description

Generate a list of Random NPD (pseudo) R matrices with a user-defined fixed minimum eigenvalue from a user-supplied population R using the method of alternating projections.

Usage

```
RnpdMAP(
  Rpop,
  Lp = NULL,
  NNegEigs = 1,
  NSmoothPosEigs = 4,
  NSubjects = NULL,
  NSamples = 0,
  MaxIts = 15000,
  PRINT = FALSE,
  Seed = NULL
)
```

Arguments

Rpop	input (PD or PSD) p x p Population correlation matrix.
Lp	desired minimum eigenvalue in the NPD matrices.
NNegEigs	number of eigenvalues < 0 in Rnpd.
NSmoothPosEigs	number of eigenvalues > 0 to smooth: the smallest NSmoothPosEigs > 0 will be smoothed toward 0.
NSubjects	sample size (required when NSamples > 0) parameter used to generate sample correlation matrices. Default = NULL.
NSamples	generate NSamples sample R matrices. If NSamples = 0 the program will attempt to find Rnpd such that ||Rpop - Rnpd||_2 is minimized.
MaxIts	maximum number of projection iterations.
PRINT	(logical) If TRUE the program will print the iteration history for Lp. Default = NULL.
Seed	Optional seed for random number generation.

Value

Rpop	population (PD) correlation matrix.
R	sample correlation matrix.
Rnpd	NPD improper (pseudo) correlation matrix.
Lp	desired value of minimum eigenvalue.

minEig	observed value of minimum eigenvalue of Rnpd.
convergence	0 = converged; 1 = not converged in MaxIts iterations of the alternating projections algorithm.
feasible	logical) TRUE if max(abs(r_ij)) <= 1. If FALSE then one or more values in Rnpd > 1 in absolute value.
Seed	saved seed for random number generator.
prbs1	vector probabilities used to generate eigenvalues < 0.
prbs2	vector of probabilities used to smooth the smallest NSmoothPosEigs towards zero.

Author(s)

Niels G. Waller

Examples

```
library(MASS)

Nvar = 20
Nfac = 4
NSubj = 2000
Seed = 123

set.seed(Seed)

## Generate a vector of classical item difficulties
p <- runif(Nvar)

cat("\nClassical Item Difficulties:\n")

print(rbind(1:Nvar,round(p,2)) )

summary(p)


## Convert item difficulties to quantiles
b <- qnorm(p)


## fnc to compute root mean squared standard deviation
RMSD <- function(A, B){
  sqrt(mean( ( A[lower.tri(A, diag = FALSE)] - B[lower.tri(B, diag = FALSE)] )^2))
}


## Generate vector of eigenvalues with clear factor structure
  L <- eigGen(nDimensions = Nvar,
              nMajorFactors = Nfac,
              PrcntMajor = .60,
              threshold  = .50)
```

```
## Generate a population R matrix with the eigenvalues in L
  Rpop <- rGivens(eigs = L)$R

## Generate continuous data that will reproduce Rpop (exactly)
  X <- mvrnorm(n = NSubj, mu = rep(0, Nvar),
               Sigma = Rpop, empirical = TRUE)

while( any(colSums(X) == 0) ){
  warning("One or more variables have zero variance. Generating a new data set.")
   X <- mvrnorm(n = NSubj, mu = rep(0, Nvar),
               Sigma = Rpop, empirical = TRUE)
 }

## Cut X at thresholds given in b to produce binary data U
  U <- matrix(0, nrow(X), ncol(X))
  for(j in 1:Nvar){
    U[X[,j] <= b[j],j] <- 1
  }

## Compute tetrachoric correlations
  Rtet <- tetcor(U, Smooth = FALSE, PRINT = TRUE)$r
  # Calculate eigenvalues of tetrachoric R matrix
  Ltet <- eigen(Rtet)$values

  if(Ltet[Nvar] >= 0) stop("Rtet is P(S)D")

## Simulate NPD R matrix with minimum eigenvalue equal to
  # min(Ltet)
  out <- RnpdMAP(Rpop,
               Lp = Ltet[Nvar],
               NNegEigs = Nvar/5,
               NSmoothPosEigs = Nvar/5,
               NSubjects = 150,
               NSamples = 1,
               MaxIts = 15000,
               PRINT = FALSE,
               Seed = Seed)

## RLp is a NPD pseudo R matrix with min eigenvalue = min(Ltet)
  RLp <- out[[1]]$Rnpd

## Calculate eigenvalues of simulated NPD R matrix (Rnpd)
  Lnpd <- eigen(RLp, only.values = TRUE)$values

## Scree plots for observed and simulated NPD R matrices.
  ytop <- max(c(L,Lnpd,Ltet))
  pointSize = .8
  plot(1:Nvar, L, typ = "b", col = "darkgrey", lwd=3,
       lty=1,
       main =
       "Eigenvalues of Rpop, Tet R, and Sim Tet R:
```

```
      \nSimulated vs Observed npd Tetrachoric R Matrices",
      ylim = c(-1, ytop),
      xlab = "Dimensions",
      ylab = "Eigenvalues",
      cex = pointSize,cex.main = 1.2)
  points(1:Nvar, Lnpd, typ="b",
         col = "red", lwd = 3, lty=2, cex=pointSize)
  points(1:Nvar, Ltet, typ="b",
         col = "darkgreen", lwd = 3, lty = 3, cex= pointSize)

  legend("topright",
         legend = c("eigs Rpop", "eigs Sim Rnpd", "eigs Emp Rnpd"),
         col = c("darkgrey", "red","darkgreen"),
         lty = c(1,2,3),
         lwd = c(4,4,4), cex = 1.5)

  abline(h = 0, col = "grey", lty = 2, lwd = 4)

  cat("\nRMSD(Rpop, Rtet) = ", round(rmsd(Rpop, Rtet), 3))
  cat("\nRMSD(Rpop, RLp) = ",  round(rmsd(Rpop, RLp),  3))
```

---

rPCA *Generate a Correlation Matrix from a Truncated PCA Loadings Matrix.*

Description

This function generates a random (or possibly unique) correlation matrix (R) from an unrotated or orthogonally rotated PCA loadings matrix via a modified alternating projections algorithm.

Usage

```
rPCA(
  F,
  epsMax = 1e-18,
  maxit = 2000,
  Seed = NULL,
  InitP2 = 2,
  Eigs = NULL,
  PrintLevel = 1
)
```

Arguments

F	(Matrix) A p (variables) by k (components) PCA loadings matrix. F can equal either an unrotated or an orthogonally rotated loadings matrix.
epsMax	(Scalar) A small number used to evaluate function convergence. Default (epsMax = 1E-18).

`maxit` (Integer) An integer that specifies the maximum number of iterations of the modified alternating projections algorithm (APA).

`Seed` (Integer) A user-defined starting seed for the random number generator. If Seed = NULL then rPCA will generate a random starting seed. Setting Seed to a positive integer will generate reproducible results. Default (Seed = NULL)

`InitP2` (Integer) The method used to initiate the remaining columns of the truncated principal components solution. If `InitP2 = 1` then the starting P2 will be a random semi-orthogonal matrix. If If `InitP2 = 2` then the starting P2 will be a semi-orthogonal matrix that is in the left null space of P1. Default (`InitP2 = 2`). Of the two options, `InitP2 = 2` generally converges to a single feasible solution in less time. `InitP2 = 1` can be used to generate different solutions from different starting seeds.

`Eigs` (Vector) Under some conditions, `rPCA` can generate (or reproduce) a unique correlation matrix with known (i.e., user-specified) eigenvalues from a truncated PC loadings matrix, `F`, even when the rank of `F` is less than p (the number of observed variables). `Eigs` is an optional p-length vector of eigenvalues for `R`. Default (`Eigs = NULL`).

`PrintLevel` (Integer) If PrintLevel = 0 no output will be printed (choose this option for Monte Carlo simulations). If PrintLevel = 1 the program will print the APA convergence status and the number of iterations used to achieve convergence. If PrintLevel = 2 then rPCA will print the iteration convergence history of the modified APA algorithm. Default (PrintLevel = 1).

Value

- **R** (Matrix) A p by p correlation matrix that generates the desired PCA loadings.
- **Tmat** (Matrix) A k by k orthogonal rotation matrix that will rotate the unrotated PCA loadings matrix, P1, to F (if F is an orthogonally rotated loadings matrix).
- **P1** (Matrix) The p by k unrotated PCA loadings matrix that is associated with F.
- **Fhat** (Matrix) The p by k estimated (and possibly rotated) PCA loadings matrix from the simulated matrix R.
- **error** (Logical) A logical that indicates whether F is a legitimate PCA loadings matrix.
- **Lambda** (Vector) The sorted eigenvalues of R.
- **iterHx** (Vector) Criterion (i.e., fit) values for for each iteration of the modified APA algorithm.
- **converged** (Logical) A logical that signifies function convergence.
- **Seed** (Integer) Either a user-defined or function generated starting seed for the random number generator.

Author(s)

Niels G. Waller (nwaller@umn.edu)

References

Escalante, R. and Raydan, M. (2011). Alternating projection methods. Society for Industrial and Applied Mathematics.

ten Berge, J. M. and Kiers, H. A. (1999). Retrieving the correlation matrix from a truncated PCA solution: The inverse principal component problem. Psychometrika, 64(3), 317–324.

Examples

```
# External PCA function ---
# used to check results

PCA <- function(R, k = NULL){
  if(is.null(k)) k <- ncol(R)
  VLV <- eigen(R)
 V <- VLV$vectors
 L <- VLV$values


 if( k > 1){
   P <-  V[, 1:k] %*% diag(L[1:k]^.5)
 }
 else{
   P <- as.matrix(V[, 1], drop=False) * L[1]^.5
 }
  Psign <- sign(apply(P, 2, sum))
  if(k > 1) Psign = diag(Psign)
  P <- P %*%  Psign
 P
}#END PCA


## Generate Desired Population rotated PCA loadings matrix
## Example = 1
 k = 2
 F <- matrix(0, 8, 2)
 F[1:4, 1] <- seq(.75, .72, length= 4)
 F[5:8, 2] <- seq(.65, .62, length= 4)
 F[1,2] <- .1234
 F[8,1] <- .4321
 colnames(F) <-   paste0("F", 1:k)
 (F)

 ## Run Example 1
 pout <- rPCA(F,
              maxit = 5000,
              Seed = 1,
              epsMax = 1E-18,
              PrintLevel = 1)
pout$converged
eigen(pout$R)$values
if(pout$error == FALSE & pout$converged){
```

```
   Fhat <- pout$Fhat
   cat("\nPCA Loadings\n")
   ( round( cbind(F,Fhat ), 5) )
 }

 ## Example = 2
 ## Single component example from Widaman 2018

 k = 1
 F <- matrix(rep(c(.8,.6, .4), each = 3 ), nrow = 9, ncol = 1)
 colnames(F) <-   paste0("F", 1:k)
 (F)

 ## Run Example 2
 pout <- rPCA(F,
              maxit = 5000,
              Seed = 1,
              epsMax = 1E-18,
              PrintLevel = 1)
 pout$converged
 pout$Fhat
 eigen(pout$R)$values
if(pout$error == FALSE & pout$converged){
   Fhat <- pout$Fhat
   cat("\nPCA Loadings\n")
   ( round( cbind(F,Fhat ), 5) )
 }

## Example 3 ----
## 2 Component example from Goldberg and Velicer (2006).
 k = 2
 F = matrix(c( .18, .75,
               .65, .19,
               .12, .69,
               .74, .06,
               .19, .80,
               .80, .14,
              -.05, .65,
               .71, .02), 8, 2, byrow=TRUE)
 colnames(F) <-   paste0("F", 1:k)
 (F)

## Run Example 3
pout <- rPCA(F,
            maxit = 5000,
            Seed = 1,
            epsMax = 1E-18,
            PrintLevel = 1)
pout$converged

eigen(pout$R)$values

if(pout$error == FALSE & pout$converged){
```

```
  Fhat <- pout$Fhat
  cat("\nPCA Loadings\n")
  ( round( cbind(F,Fhat ), 5) )
#
#
## Example 4
#
SEED = 4321
set.seed(SEED)
k= 3
## Generate eigenvalues for example R matrix
L7 <- eigGen(nDimensions = 7,
             nMaj = 3,
             PrcntMajor = .85,
             threshold = .8)

## Scree Plot
plot(1:7, L7,
    type = "b",
    ylim = c(0,4),
    main = "Scree Plot for R",
    ylab = "Eigenvalues",
    xlab = "Dimensions")

## Generate R
R <- rGivens(eigs=L7, Seed = SEED)$R
print( R, digits = 4)

#Extract loadings for 3 principal components
F <- PCA(R, k = k)

# rotate loadings with varimax to examine underlying structure
print( round(varimax(F)$loadings[], 3) )

## run rPCA with user-defined eigenvalues
rout <- rPCA(F,
             epsMax = 1e-20,
             maxit = 25000,
             Seed = SEED,
             InitP2 = 1,
             Eigs = L7,
             PrintLevel = 1)

## Compute PCA on generated R

Fhat <- PCA(rout$R, k = 3)
#
## align factors
Fhat <- fungible::faAlign(F, Fhat)$F2

## Compare solutions
print( round( cbind(F, Fhat), 5) )
```

```
## Compare Eigenvalues
print( cbind(L7, eigen(rout$R)$values ), digits=8)
#
## Compare R matrices: 8 digit accuracy
print( round(R - rout$R, 8) )

}
```

SchmidLeiman *Schmid-Leiman Orthogonalization to a (Rank-Deficient) Bifactor Structure*

Description

The Schmid-Leiman (SL) procedure orthogonalizes a higher-order factor structure into a rank-deficient bifactor structure. The Schmid-Leiman method is a generalization of Thomson's orthogonalization routine.

Usage

```
SchmidLeiman(
  R,
  numFactors,
  facMethod = "fals",
  rotate = "oblimin",
  rescaleH2 = 0.98,
  faControl = NULL,
  rotateControl = NULL
)
```

Arguments

R	(Matrix) A correlation matrix.
numFactors	(Vector) The number of latent factors at each level of analysis. For example, c(3, 1) estimates three latent factors in the first-order common factor model and one latent factor in the second-order common factor model (i.e., 3 group factors and 1 general factor). This function can orthogonalize up to (and including) a three-order factor solution.
facMethod	(Character) The method used for factor extraction (faX). The supported options are "fals" for unweighted least squares, "faml" for maximum likelihood, "fapa" for iterated principal axis factoring, "faregLS" for regularized least squares, "faregML" for regularized maximum likelihood, and "pca" for principal components analysis. The default method is "fals". • **"fals"**: Factors are extracted using the unweighted least squares estimation procedure using the fals function. • **"faml"**: Factors are extracted using the maximum likelihood estimation procedure using the factanal function.

- **"fapa"**: Factors are extracted using the iterated principal axis factoring estimation procedure using the fapa function.
- **"faregLS"**: Factors are extracted using regularized least squares factor analysis using the fareg function.
- **"faregML"**: Factors are extracted using regularized maximum likelihood factor using the fareg function.
- **"pca"**: Principal components are extracted.

rotate (Character) Designate which rotation algorithm to apply. See the faMain function for more details about possible rotations. Defaults to rotate = "oblimin".

rescaleH2 (Numeric) If a Heywood case is detected at any level of the higher-order factor analyses, rescale the communality value to continue with the matrix algebra. When a Heywood case occurs, the uniquenesses (i.e., specific-factor variances) will be negative and the SL orthogonalization of the group factors is no longer correct.

faControl (List) A list of optional parameters passed to the factor extraction (faX) function.

- **treatHeywood**: (Logical) In fals, if treatHeywood is true, a penalized least squares function is used to bound the communality estimates below 1.0. Defaults to treatHeywood = TRUE.
- **nStart**: (Numeric) The number of starting values to be tried in faml. Defaults to nStart = 10.
- **start**: (Matrix) NULL or a matrix of starting values, each column giving an initial set of uniquenesses. Defaults to start = NULL.
- **maxCommunality**: (Numeric) In faml, set the maximum communality value for the estimated solution. Defaults to maxCommunality = .995.
- **epsilon**: (Numeric) In fapa, the numeric threshold designating when the algorithm has converged. Defaults to epsilon = 1e-4.
- **communality**: (Character) The method used to estimate the initial communality values in fapa. Defaults to communality = 'SMC'.
  - **"SMC"**: Initial communalities are estimated by taking the squared multiple correlations of each indicator after regressing the indicator on the remaining variables.
  - **"maxr"**: Initial communalities equal the largest (absolute value) correlation in each column of the correlation matrix.
  - **"unity"**: Initial communalities equal 1.0 for all variables.
- **maxItr**: (Numeric) In fapa, the maximum number of iterations to reach convergence. Defaults to maxItr = 15,000.

rotateControl (List) A list of control values to pass to the factor rotation algorithms.

- **numberStarts**: (Numeric) The number of random (orthogonal) starting configurations for the chosen rotation method (e.g., oblimin). The first rotation will always commence from the unrotated factors orientation. Defaults to numberStarts = 10.
- **gamma**: (Numeric) This is a tuning parameter (between 0 and 1, inclusive) for an oblimin rotation. See the **GPArotation** library's oblimin documentation for more details. Defaults to gamma = 0 (i.e., a quartimin rotation).

- **delta**: (Numeric) This is a tuning parameter for the geomin rotation. It adds a small number (default = .01) to the squared factor loadings before computing the geometric means in the discrepancy function.
- **kappa**: (Numeric) The main parameterization of the Crawford-Ferguson (CF) rotations (i.e., "cfT" and "cfQ" for orthogonal and oblique CF rotation, respectively). Defaults to kappa = 0.
- **k**: (Numeric) A specific parameter of the simplimax rotation. Defaults to k = the number of observed variables.
- **standardize**: (Character) The standardization routine used on the unrotated factor structure. The three options are "none", "Kaiser", and "CM". Defaults to standardize = "none".
  - **"none"**: No standardization is applied to the unrotated factor structure.
  - **"Kaiser"**: Use a factor structure matrix that has been normed by Kaiser's method (i.e., normalize all rows to have a unit length).
  - **"CM"**: Use a factor structure matrix that has been normed by the Cureton-Mulaik method.
- **epsilon**: (Numeric) The rotational convergence criterion to use. Defaults to epsilon = 1e-5.
- **power**: (Numeric) Raise factor loadings the the n-th power in the promaxQ rotation. Defaults to power = 4.
- **maxItr**: (Numeric) The maximum number of iterations for the rotation algorithm. Defaults to maxItr = 15000.

Details

The obtained Schmid-Leiman (SL) factor structure matrix is rescaled if its communalities differ from those of the original first-order solution (due to the presence of one or more Heywood cases in a solution of any order). Rescaling will produce SL communalities that match those of the original first-order solution.

Value

- **L1**: (Matrix) The first-order (oblique) factor pattern matrix.
- **L2**: (Matrix) The second-order (oblique) factor pattern matrix.
- **L3**: (Matrix, NULL) The third-order (oblique) factor pattern matrix (if applicable).
- **Phi1**: (Matrix) The first-order factor correlation matrix.
- **Phi2**: (Matrix) The second-order factor correlation matrix.
- **Phi3**: (Matrix, NULL) The third-order factor pattern matrix (if applicable).
- **U1**: (Matrix) The square root of the first-order factor uniquenesses (i.e., factor standard deviations).
- **U2**: (Matrix) The square root of the second-order factor uniquenesses (i.e., factor standard deviations).
- **U3**: (Matrix, NULL) The square root of the third-order factor uniquenesses (i.e., factor standard deviations) (if applicable).
- **B**: (Matrix) The resulting Schmid-Leiman transformation.

- **rotateControl**: (List) A list of the control parameters passed to the faMain function.
- **faControl**: (List) A list of optional parameters passed to the factor extraction (faX) function.
- **HeywoodFlag**(Integer) An integer indicating whether one or more Heywood cases were encountered during estimation.

Author(s)

- Casey Giordano (Giord023@umn.edu)
- Niels G. Waller (nwaller@umn.edu)

References

Abad, F. J., Garcia-Garzon, E., Garrido, L. E., & Barrada, J. R. (2017). Iteration of partially specified target matrices: application to the bi-factor case. *Multivariate Behavioral Research, 52*(4), 416-429.

Giordano, C. & Waller, N. G. (under review). Recovering bifactor models: A comparison of seven methods.

Schmid, J., & Leiman, J. M. (1957). The development of hierarchical factor solutions. *Psychometrika, 22*(1), 53-61.

See Also

Other Factor Analysis Routines: BiFAD(), Box26, GenerateBoxData(), Ledermann(), SLi(), faAlign(), faEKC(), faIB(), faLocalMin(), faMB(), faMain(), faScores(), faSort(), faStandardize(), faX(), fals(), fapa(), fareg(), fsIndeterminacy(), orderFactors(), print.faMB(), print.faMain(), promaxQ(), summary.faMB(), summary.faMain()

Examples

```
## Dataset used in Schmid & Leiman (1957) rounded to 2 decimal places
SLdata <-
  matrix(c(1.0, .72, .31, .27, .10, .05, .13, .04, .29, .16, .06, .08,
           .72, 1.0, .35, .30, .11, .06, .15, .04, .33, .18, .07, .08,
           .31, .35, 1.0, .42, .08, .04, .10, .03, .22, .12, .05, .06,
           .27, .30, .42, 1.0, .06, .03, .08, .02, .19, .11, .04, .05,
           .10, .11, .08, .06, 1.0, .32, .13, .04, .11, .06, .02, .03,
           .05, .06, .04, .03, .32, 1.0, .07, .02, .05, .03, .01, .01,
           .13, .15, .10, .08, .13, .07, 1.0, .14, .14, .08, .03, .04,
           .04, .04, .03, .02, .04, .02, .14, 1.0, .04, .02, .01, .01,
           .29, .33, .22, .19, .11, .05, .14, .04, 1.0, .45, .15, .17,
           .16, .18, .12, .11, .06, .03, .08, .02, .45, 1.0, .08, .09,
           .06, .07, .05, .04, .02, .01, .03, .01, .15, .08, 1.0, .42,
           .08, .08, .06, .05, .03, .01, .04, .01, .17, .09, .42, 1.0),
         nrow = 12, ncol = 12, byrow = TRUE)

Out1 <- SchmidLeiman(R          = SLdata,
                     numFactors = c(6, 3, 1))$B

## An orthogonalization of a two-order structure
bifactor <- matrix(c(.46, .57, .00, .00,
```

```
                      .48, .61, .00, .00,
                      .61, .58, .00, .00,
                      .46, .00, .55, .00,
                      .51, .00, .62, .00,
                      .46, .00, .55, .00,
                      .47, .00, .00, .48,
                      .50, .00, .00, .50,
                      .49, .00, .00, .49),
                    nrow = 9, ncol = 4, byrow = TRUE)

## Model-implied correlation (covariance) matrix
R <- bifactor %*% t(bifactor)

## Unit diagonal elements
diag(R) <- 1

Out2 <- SchmidLeiman(R          = R,
                     numFactors = c(3, 1),
                     rotate     = "oblimin")$B
```

---

seBeta *Standard Errors and CIs for Standardized Regression Coefficients*

Description

Computes Normal Theory and ADF Standard Errors and CIs for Standardized Regression Coefficients

Usage

```
seBeta(
  X = NULL,
  y = NULL,
  cov.x = NULL,
  cov.xy = NULL,
  var.y = NULL,
  Nobs = NULL,
  alpha = 0.05,
  estimator = "ADF",
  digits = 3
)
```

Arguments

X	Matrix of predictor scores.
y	Vector of criterion scores.
cov.x	Covariance or correlation matrix of predictors.

cov.xy	Vector of covariances or correlations between predictors and criterion.
var.y	Criterion variance.
Nobs	Number of observations.
alpha	Desired Type I error rate; default = .05.
estimator	'ADF' or 'Normal' confidence intervals - requires raw X and raw y; default = 'ADF'.
digits	Number of significant digits to print; default = 3.

Value

cov.Beta	Normal theory or ADF covariance matrix of standardized regression coefficients.
se.Beta	standard errors for standardized regression coefficients.
alpha	desired Type-I error rate.
CI.Beta	Normal theory or ADF (1-alpha)% confidence intervals for standardized regression coefficients.
estimator	estimator = "ADF" or "Normal".

Author(s)

Jeff Jones and Niels Waller

References

Jones, J. A, and Waller, N. G. (2015). The Normal-Theory and Asymptotic Distribution-Free (ADF) covariance matrix of standardized regression coefficients: Theoretical extensions and finite sample behavior. *Psychometrika, 80*, 365-378.

Examples

```
library(MASS)

set.seed(123)

R <- matrix(.5, 3, 3)
diag(R) <- 1
X <- mvrnorm(n = 200, mu = rep(0, 3), Sigma = R, empirical = TRUE)
Beta <- c(.2, .3, .4)
y <- X%*% Beta + .64 * scale(rnorm(200))
seBeta(X, y, Nobs = 200, alpha = .05, estimator = 'ADF')

# 95% CIs for Standardized Regression Coefficients:
#
#        lbound estimate ubound
# beta_1  0.104    0.223  0.341
# beta_2  0.245    0.359  0.473
# beta_3  0.245    0.360  0.476
```

`seBetaCor` *Standard Errors and CIs for Standardized Regression Coefficients from Correlations*

Description

Computes Normal Theory and ADF Standard Errors and CIs for Standardized Regression Coefficients from Correlations

Usage

```
seBetaCor(R, rxy, Nobs, alpha = 0.05, digits = 3, covmat = "normal")
```

Arguments

`R`	A p x p predictor correlation matrix.
`rxy`	A p x 1 vector of predictor-criterion correlations
`Nobs`	Number of observations.
`alpha`	Desired Type I error rate; default = .05.
`digits`	Number of significant digits to print; default = 3.
`covmat`	String = 'normal' (the default) or a (p+1)p/2 x (p+1)p/2 covariance matrix of correlations. The default option computes an asymptotic covariance matrix under the assumption of multivariate normal data. Users can supply a covariance matrix under asymptotic distribution free (ADF) or elliptical distributions when available.

Value

`cov.Beta`	Covariance matrix of standardized regression coefficients.
`se.Beta`	Vector of standard errors for the standardized regression coefficients.
`alpha`	Type-I error rate.
`CI.Beta`	(1-alpha)% confidence intervals for standardized regression coefficients.

Author(s)

Jeff Jones and Niels Waller

References

Jones, J. A, and Waller, N. G. (2013). The Normal-Theory and asymptotic distribution-free (ADF) covariance matrix of standardized regression coefficients: Theoretical extensions and finite sample behavior.Technical Report (052913)[TR052913]

Nel, D.A.G. (1985). A matrix derivation of the asymptotic covariance matrix of sample correlation coefficients. *Linear Algebra and its Applications, 67*, 137-145.

Yuan, K. and Chan, W. (2011). Biases and standard errors of standardized regression coefficients. *Psychometrika*, 76(4), 670–690.

Examples

```
R <- matrix(c(1.0000, 0.3511, 0.3661,
          0.3511, 1.0000, 0.4359,
          0.3661, 0.4359, 1.0000), 3, 3)

rxy <- c(0.5820, 0.6997, 0.7621)
Nobs <- 46
out <- seBetaCor(R = R, rxy = rxy, Nobs = Nobs)

# 95% CIs for Standardized Regression Coefficients:
#
#        lbound estimate ubound
# beta_1  0.107    0.263  0.419
# beta_2  0.231    0.391  0.552
# beta_3  0.337    0.495  0.653
```

`seBetaFixed` *Covariance Matrix and Standard Errors for Standardized Regression Coefficients for Fixed Predictors*

Description

Computes Normal Theory Covariance Matrix and Standard Errors for Standardized Regression Coefficients for Fixed Predictors

Usage

```
seBetaFixed(
  X = NULL,
  y = NULL,
  cov.x = NULL,
  cov.xy = NULL,
  var.y = NULL,
  var.error = NULL,
  Nobs = NULL
)
```

Arguments

`X`	Matrix of predictor scores.
`y`	Vector of criterion scores.
`cov.x`	Covariance or correlation matrix of predictors.
`cov.xy`	Vector of covariances or correlations between predictors and criterion.
`var.y`	Criterion variance.
`var.error`	Optional argument to supply the error variance: var(y - yhat).
`Nobs`	Number of observations.

Value

cov.Beta	Normal theory covariance matrix of standardized regression coefficients for fixed predictors.
se.Beta	Standard errors for standardized regression coefficients for fixed predictors.

Author(s)

Jeff Jones and Niels Waller

References

Yuan, K. & Chan, W. (2011). Biases and standard errors of standardized regression coefficients. *Psychometrika, 76(4)*, 670-690.

See Also

seBeta

Examples

```
## We will generate some data and pretend that the Predictors are being held fixed

library(MASS)
R <- matrix(.5, 3, 3); diag(R) <- 1
Beta <- c(.2, .3, .4)

rm(list = ".Random.seed", envir = globalenv()); set.seed(123)
X <- mvrnorm(n = 200, mu = rep(0, 3), Sigma = R, empirical = TRUE)
y <- X %*% Beta + .64*scale(rnorm(200))

seBetaFixed(X, y)

# $covBeta
#              b1           b2           b3
# b1  0.003275127 -0.001235665 -0.001274303
# b2 -0.001235665  0.003037100 -0.001491736
# b3 -0.001274303 -0.001491736  0.002830157
#
# $seBeta
#         b1         b2         b3
# 0.05722872 0.05510989 0.05319922

## you can also supply covariances instead of raw data

seBetaFixed(cov.x = cov(X), cov.xy = cov(X, y), var.y = var(y), Nobs = 200)

# $covBeta
#              b1           b2           b3
# b1  0.003275127 -0.001235665 -0.001274303
# b2 -0.001235665  0.003037100 -0.001491736
# b3 -0.001274303 -0.001491736  0.002830157
```

```
#
# $seBeta
#         b1         b2         b3
# 0.05722872 0.05510989 0.05319922
```

`semify` *Generate an sem model from a simFA model object*

Description

Generate an sem model from a simFA model object

Usage

```
semify(mod)
```

Arguments

`mod`	A 'fungible::simFA()' model object.

Examples

```
ex_mod <- fungible::simFA(Seed = 42)
semify(mod = ex_mod)
```

`simFA` *Generate Factor Analysis Models and Data Sets for Simulation Studies*

Description

A function to simulate factor loadings matrices and Monte Carlo data sets for common factor models, bifactor models, and IRT models.

Usage

```
simFA(
  Model = list(),
  Loadings = list(),
  CrossLoadings = list(),
  Phi = list(),
  ModelError = list(),
  Bifactor = list(),
  MonteCarlo = list(),
  FactorScores = list(),
```

```
  Missing = list(),
  Control = list(),
  Seed = NULL
)
```

Arguments

`Model` (list)

- `NFac` (scalar) Number of common or group factors; defaults to `NFac = 3`.
- `NItemPerFac`
  - (scalar) All factors have the same number of primary loadings.
  - (vector) A vector of length `NFac` specifying the number of primary loadings for each factor; defaults to `NItemPerFac = 3`.
- `Model` (character) `"orthogonal"` or `"oblique"`; defaults to `Model = "orthogonal"`.

`Loadings` (list)

- `FacPattern` (`NULL` or matrix).
  - `FacPattern = M` where `M` is a user-defined factor pattern matrix.
  - `FacPattern = NULL`; `simFA` will generate a factor pattern based on the arguments specified under other keywords (e.g., `Model`, `CrossLoadings`, etc.); defaults to `FacPattern = NULL`.
- `FacLoadDist` (character) Specifies the sampling distribution for the common factor loadings. Possible values are `"runif"`, `"rnorm"`, `"sequential"`, and `"fixed"`; defaults to `FacLoadDist = "runif"`.
- `FacLoadRange` (vector of length `NFac`, 2, or 1); defaults to `FacLoadRange = c(.3, .7)`.
  - If `FacLoadDist = "runif"` the vector defines the bounds of the uniform distribution;
  - If `FacLoadDist = "rnorm"` the vector defines the mean and standard deviation of the normal distribution from which loadings are sampled.
  - If `FacLoadDist = "sequential"` the vector specifies the lower and upper bound of the loadings sequence.
  - If `FacLoadDist = "fixed"` and `FacLoadRange` is a vector of length 1 then all common loadings will equal the constant specified in `FacLoadRange`. If `FacLoadDist = "fixed"` and `FacLoadRange` is a vector of length `NFac` then each factor will have fixed loadings as specified by the associated element in `FacLoadRange`.
- `h2` (vector) An optional vector of communalities used to constrain the population communalities to user-defined values; defaults to `h2 = NULL`.

`CrossLoadings` (list)

- `ProbCrossLoad` (scalar) A value in the (0,1) interval that determines the probability that a cross loading will be present in elements of the loadings matrix that do not have salient (primary) factor loadings. If set to `ProbCrossLoad = 1`, a single cross loading will be added to each factor; defaults to `ProbCrossLoad = 0`.
- `CrossLoadRange` (vector of length 2) Controls size of the cross loadings; defaults to `CrossLoadRange = c(.20, .25)`.

- CrossLoadPositions (matrix) Specifies the row and column positions of (optional) cross loadings; defaults to CrossLoadPositions = NULL.
- CrossLoadValues (vector) If CrossLoadPositions is specified then CrossLoadValues is a vector of user-supplied cross-loadings; defaults to CrossLoadValues = NULL.
- CrudFactor (scalar) Controls the size of tertiary factor loadings. If CrudFactor != 0 then elements of the loadings matrix with neither primary nor secondary (i.e., cross) loadings will be sampled from a \[-(CrudFactor), (CrudFactor)\] uniform distribution; defaults to CrudFactor = 0.

Phi (list)

- MaxAbsPhi (scalar) Upper (absolute) bound on factor correlations; defaults to MaxAbsPhi = .5.
- EigenValPower (scalar) Controls the skewness of the eigenvalues of Phi. Larger values of EigenValPower result in a Phi spectrum that is more right-skewed (and thus closer to a unidimensional model); defaults to EigenValPower = 2.
- PhiType (character); defaults to PhiType = "free".
  - If PhiType = "free" factor correlations will be randomly generated under the constraints of MaxAbsPhi and EigenValPower.
  - If PhiType = "fixed" all factor correlations will equal the value specified in MaxAbsPhi. A fatal error will be produced if Phi is not positive semidefinite.
  - If PhiType = "user" the factor correlations are defined by the matrix specified in UserPhi (see below).
- UserPhi (matrix) A positive semidefinite (PSD) matrix of user-defined factor correlations; defaults to UserPhi = NULL.

ModelError (list)

- ModelError (logical) If ModelError = TRUE model error will be introduced into the factor pattern via the method described by Tucker, Koopman, and Linn (TKL, 1969); defaults to ModelError = FALSE.
- W (matrix) An optional user-supplied factor loading matrix for the NMinorFac minor common factors; defaults to W = NULL.
- NMinorFac (scalar) Number of minor factors in the TKL model; defaults to NMinorFac = 150.
- ModelErrorType (character) If ModelErrorType = "U" then ModelErrorVar is the proportion of uniqueness variance that is due to model error. If ModelErrorType = "V" then ModelErrorVar is the proportion of total variance that is due to model error; defaults to ModelErrorType = "U".
- ModelErrorVar (scalar \[0,1\]) The proportion of uniqueness (U) or total (V) variance that is due to model error; defaults to ModelErrorVar = .10.
- epsTKL (scalar \[0,1\]) Controls the size of the factor loadings in successive minor factors; defaults to epsTKL = .20.
- Wattempts (scalar > 0) Maximum number of tries when attempting to generate a suitable W matrix. Default = 10000.
- WmaxLoading (scalar > 0) Threshold value for NWmaxLoading. Default WmaxLoading = .30.

- NWmaxLoading (scalar >= 0) Maximum number of absolute loadings >= WmaxLoading in any column of W (matrix of model approximation error factor loadings). Default NWmaxLoading = 2. Under the defaults, no column of W will have 3 or more loadings > |.30|.
- PrintW (Boolean) If PrintW = TRUE then simFA will print the attempt history when searching for a suitable W matrix given the constraints defined in WmaxLoading and NWmaxLoading. Default PrintW = FALSE.
- RSpecific (matrix) Optional correlation matrix for specific factors; defaults to RSpecific = NULL.

Bifactor (list)

- Bifactor (logical) If Bifactor = TRUE parameters for the bifactor model will be generated; defaults to Bifactor = FALSE.
- Hierarchical (logical) If Hierarchical = TRUE then a hierarchical Schmid Leiman (1957) bifactor model will be generated; defaults to Hierarchical = FALSE.
- F1FactorDist (character) Specifies the sampling distribution for the general factor loadings. Possible values are "runif", "rnorm", "sequential", and "fixed"; defaults to F1FactorDist = "sequential".
- F1FactorRange (vector of length 1 or 2) Controls the sizes of the general factor loadings in non-hierarchical bifactor models; defaults to F1FactorRange = c(.4, .7).
  - If F1FactorDist = "runif", the vector of length 2 defines the bounds of the uniform distribution, c(lower, upper);
  - If F1FactorDist = "rnorm", the vector defines the mean and standard deviation of the normal distribution from which loadings are sampled, c(MN, SD).
  - If F1FactorDist = "sequential", the vector specifies the lower and upper bound of the loadings sequence, c(lower, upper).

MonteCarlo (list)

- NSamples (integer) Defines number of Monte Carlo Samples; defaults to NSamples = 0.
- SampleSize (integer) Sample size for each Monte Carlo sample; defaults to SampleSize = 250.
- Raw (logical) If Raw = TRUE, simulated data sets will contain raw data. If Raw = FALSE, simulated data sets will contain correlation matrices; defaults to Raw = FALSE.
- Thresholds (list) List elements contain thresholds for each item. Thresholds are required when generating Likert variables.

FactorScores (list)

- FS (logical) If FS = TRUE (true) factor scores will be simulated; defaults to FS = FALSE.
- CFSeed (integer) Optional starting seed for the common factor scores; defaults to CFSeed = NULL in which case a random seed is used.
- MCFSeed (integer) Optional starting seed for the minor common factor scores; defaults to MCFSeed = NULL.

- SFSeed (integer) Optional starting seed for the specific factor scores; defaults to SFSeed = NULL in which case a random seed is used.
- EFSeed (integer) Optional starting seed for the error factor scores; defaults to EFSeed = NULL in which case a random seed is used. Note that CFSeed, MCFSeed, SFSeed, and EFSeed must be different numbers (a fatal error is produced when two or more seeds are specified as equal).
- VarRel (vector) A vector of manifest variable reliabilities. The specific factor variance for variable i will equal $VarRel[i] - h^2[i]$ (the manifest variable reliability minus its commonality). By default, $VarRel = h^2$ (resulting in uniformly zero specific factor variances).
- Population (logical) If Population = TRUE, factor scores will fit the correlational constraints of the factor model exactly (e.g., the common factors will be orthogonal to the unique factors); defaults to Population = FALSE.
- NFacScores (scalar) Sample size for the factor scores; defaults to NFacScores = 250.
- Thresholds (list) A list of quantiles used to polychotomize the observed data that will be generated from the factor scores.

Missing (list)

- Missing (logical) If Missing = TRUE all data sets will contain missing values; defaults to Missing = FALSE.
- Mechanism (character) Specifies the missing data mechanism. Currently, the program only supports missing completely at random (MCAR): Missing = "MCAR".
- MSProb (scalar or vector of length NVar) Specifies the probability of missingness for each variable; defaults to MSprob = 0.

Control (list)

- IRT (logical) If IRT = TRUE then user-supplied thresholds will be interpreted as item intercepts; defaults to IRT = FALSE.
- Dparam (scalar). If Dparam = 1 then item intercepts should be scaled in the logistic metric. If Dparam = 1.702 then intercepts should be scaled in the probit metric.
- Maxh2 (scalar) Rows of the loadings matrix will be rescaled to have a maximum communality of Maxh2; defaults to Maxh2 = .98.
- Reflect (logical) If Reflect = TRUE loadings on the common factors will be randomly reflected; defaults to Reflect = FALSE.

Seed (integer) Starting seed for the random number generator; defaults to Seed = NULL. When no seed is specified by the user, the program will generate a random seed.

Details

For a complete description of simFA's capabilities, users are encouraged to consult the simFABook at http://users.cla.umn.edu/~nwaller/simFA/simFABook.pdf.

simFA is a program for exploring factor analysis models via simulation studies. After calling simFA all relevant output can be saved for further processing by calling one or more of the following object names.

Value

- loadings A common factor or bifactor loadings matrix.
- Phi A factor correlation matrix.
- urloadings The unrotated loadings matrix.
- h2 A vector of item communalities.
- h2PopME A vector item communalities that may include model approximation error.
- Rpop The model-implied population correlation matrix.
- RpopME The model-implied population correlation matrix with model error.
- W The factor loadings for the minor factors (when ModelError = TRUE). Default = NULL.
- Xm That part of the observed scores that is due to the minor common factors.
- SFSvars Variances of the Specific Factors in the metric of the observed scores.
- ModelErrorFitStats A list of model fit indices (for the underlying equations, see: Bentler, 1990; Hu & Bentler, 1999; Marsh, Hau, & Grayson, 2005; Steiger, 2016):
  - SRMR_theta Standardized Root Mean Square Residual based on the model that is implied by the error free major factors only (underlying Rpop),
  - SRMR_thetahat Standardized Root Mean Square Residual based on an exploratory factor analysis of the population correlation matrix, RpopME,
  - CRMR_theta Correlation Root Mean Square Residual based on the model that is implied by the error free major factors only (underlying Rpop),
  - CRMR_thetahat Correlation Root Mean Square Residual based on an exploratory factor analysis of the population correlation matrix, RpopME,
  - RMSEA_theta Root Mean Square Error of Approximation (Steiger, 2016) based on the model that is implied by the error free major factors only (underlying Rpop),
  - RMSEA_thetahat Root Mean Square Error of Approximation (Steiger, 2016) based on an exploratory factor analysis of the population correlation matrix, RpopME,
  - CFI_theta Comparative Fit Index (Bentler, 1990) based on the model that is implied by the error free major factors only (underlying Rpop),
  - CFI_thetahat Comparative Fit Index (Bentler, 1990) based on an exploratory factor analysis of the population correlation matrix, RpopME.
  - Fm MLE fit function for population target model.
  - Fb MLE fit function for population baseline model.
  - DFm Degrees of freedom for population target model.
- CovMatrices A list containing:
  - CovMajor The model implied covariances from the major factors.
  - CovMinor The model implied covariances from the minor factors.
  - CovUnique The model implied variances from the uniqueness factors.
- Bifactor A list containing:
  - loadingsHier Factor loadings of the 1st order solution of a hierarchical bifactor model.
  - PhiHier Factor correlations of the 1st order solution of a hierarchical bifactor model.
- Scores A list containing:
  - FactorScores Factor scores for the common and uniqueness factors.

  - FacInd Factor indeterminacy indices for the error free population model.
  - FacIndME Factor score indeterminacy indices for the population model with model error.
  - ObservedScores A matrix of model implied ObservedScores. If Thresholds were supplied under Keyword FactorScores, ObservedScores will be transformed into Likert scores.
- Monte A list containing output from the Monte Carlo simulations if generated.
- IRT Factor loadings expressed in the normal ogive IRT metric. If Thresholds were given then IRT difficulty values will also be returned.
- Seed The initial seed for the random number generator.
- call A copy of the function call.
- cn A list of all active and nonactive function arguments.

Author(s)

Niels G. Waller with contributions by Hoang V. Nguyen

References

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Hu, L.-T. & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. Structural Equation Modeling: A Multidisciplinary Journal, 6(1), 1–55.

Marsh, H. W., Hau, K.-T., & Grayson, D. (2005). Goodness of fit in structural equation models. In A. Maydeu-Olivares & J. J. McArdle (Eds.), Multivariate applications book series. Contemporary psychometrics: A festschrift for Roderick P. McDonald (p. 275–340). Lawrence Erlbaum Associates Publishers.

Schmid, J. and Leiman, J. M. (1957). The development of hierarchical factor solutions. Psychometrika, 22(1), 53–61.

Steiger, J. H. (2016). Notes on the Steiger–Lind (1980) handout. Structural Equation Modeling: A Multidisciplinary Journal, 23:6, 777-781.

Tucker, L. R., Koopman, R. F., and Linn, R. L. (1969). Evaluation of factor analytic research procedures by means of simulated correlation matrices. Psychometrika, 34(4), 421–459.

Examples

```
## Not run:
#  Ex 1. Three Factor Simple Structure Model with Cross loadings and
#  Ideal Non salient Loadings
   out <-  simFA(Seed = 1)
   print( round( out$loadings, 2 ) )

# Ex 2. Non Hierarchical bifactor model 3 group factors
# with constant loadings on the general factor
   out <- simFA(Bifactor = list(Bifactor = TRUE,
                                Hierarchical = FALSE,
                                F1FactorRange = c(.4, .4),
```

```
                                F1FactorDist = "runif"),
                Seed = 1)
    print( round( out$loadings, 2 ) )

    # Ex 3.  Model Fit Statistics for Population Data with
    # Model Approximation Error. Three Factor model.
        out <- simFA(Loadings = list(FacLoadDist = "fixed",
                                     FacLoadRange = .5),
                     ModelError = list(ModelError = TRUE,
                                       NMinorFac = 150,
                                       ModelErrorType = "V",
                                       ModelErrorVar = .1,
                                       Wattempts = 10000,
                                       epsTKL = .2),
                     Seed = 1)

        print( out$loadings )
        print( out$ModelErrorFitStats[seq(2,8,2)] )

## End(**Not run**)
```

---

skew *Calculate Univariate Skewness for a Vector or Matrix*

Description

Calculate univariate skewness for vector or matrix (algorithm G1 in Joanes & Gill, 1998).

Usage

```
skew(x)
```

Arguments

x	Either a vector or matrix of numeric values.

Value

Skewness for each column in x.

Author(s)

Niels Waller

References

Joanes, D. N. & Gill, C. A. (1998). Comparing measures of sample skewness and kurtosis. *The Statistician, 47*, 183-189.

See Also

kurt

Examples

```
x <- matrix(rnorm(1000), 100, 10)
skew(x)
```

SLi *Conduct a Schmid-Leiman Iterated (SLi) Target Rotation*

Description

Compute an iterated Schmid-Leiman target rotation (SLi). This algorithm applies Browne's partially-specified Procrustes target rotation to obtain a full-rank bifactor solution from a rank-deficient (Direct) Schmid-Leiman procedure. Note that the target matrix is automatically generated based on the salient argument. Note also that the algorithm will converge when the partially-specified target pattern in the n-th iteration is equivalent to the partially-specified target pattern in the (n-1)th iteration.

Usage

```
SLi(
  R,
  SL = NULL,
  rotate = "geominQ",
  numFactors = NULL,
  facMethod = "fals",
  salient = 0.2,
  urLoadings = NULL,
  freelyEstG = TRUE,
  gFac = 1,
  maxSLiItr = 20,
  rotateControl = NULL,
  faControl = NULL
)
```

Arguments

R	(Matrix) A correlation matrix
SL	(Matrix, NULL) A (rank-deficient) Schmid-Leiman (SL) bifactor solution (e.g., from a Schmid-Leiman or Direct Schmid-Leiman rotation). If NULL, the function will estimate the SL solution using the SchmidLeiman function.
rotate	(Character) Designate which rotation algorithm to apply. See the faMain function for more details about possible rotations. A geomin rotation is the default.

`numFactors` (Vector) The number of latent factors at each level of analysis. For example, c(3, 1) estimates three latent factors in the first-order common factor model and one latent factor in the second-order common factor model (i.e., 3 group factors and 1 general factor).

`facMethod` (Character) The method used for factor extraction (`faX`). The supported options are "fals" for unweighted least squares, "faml" for maximum likelihood, "fapa" for iterated principal axis factoring, "faregLS" for regularized least squares, "faregML" for regularized maximum likelihood, and "pca" for principal components analysis. The default method is "fals".

- **"fals"**: Factors are extracted using the unweighted least squares estimation procedure using the `fals` function.
- **"faml"**: Factors are extracted using the maximum likelihood estimation procedure using the `factanal` function.
- **"fapa"**: Factors are extracted using the iterated principal axis factoring estimation procedure using the `fapa` function.
- **"faregLS"**: Factors are extracted using regularized least squares factor analysis using the `fareg` function.
- **"faregML"**: Factors are extracted using regularized maximum likelihood factor using the `fareg` function.
- **"pca"**: Principal components are extracted.

`salient` (Numeric) A threshold parameter used to dichotomize factor loadings to create the target matrix. The default value is .20 (in absolute value) which is based on the Abad et al., 2017 application of this method.

`urLoadings` (Matrix, NULL) A full-rank matrix of unrotated factor loadings to be rotated using the (automatically generated) target matrix. If specified as NULL, a full-rank matrix of factor loadings will be extracted using the `faX` function. An unweighted least squares ("fals") procedure is the default.

`freelyEstG` (Logical) Specify whether the general factor loadings are freely estimated (in the partially-specified target matrix). If set to FALSE, only general factor loadings above the salient threshold will be estimated in the partially-specified target rotation.

`gFac` (Numeric, Vector) The position of the general factor(s) to be estimated. Solutions with multiple general factors may be estimated. Must either (a) freely estimate all loadings on the general factors or (b) only freely estimate general factor loadings that are above the salient threshold. The default column position is 1.

`maxSLiItr` (Numeric) The maximum number of iterations for the SLi procedure. Typically, 10 iterations is usually sufficient to converge (cf. Abad et al., 2017). The default is 20 iterations.

`rotateControl` (List) A list of control values to pass to the factor rotation algorithms.

- **numberStarts**: (Numeric) The number of random (orthogonal) starting configurations for the chosen rotation method (e.g., oblimin). The first rotation will always commence from the unrotated factors orientation. Defaults to numberStarts = 10.

- **gamma**: (Numeric) This is a tuning parameter (between 0 and 1, inclusive) for an oblimin rotation. See the **GPArotation** library's oblimin documentation for more details. Defaults to gamma = 0 (i.e., a quartimin rotation).
- **delta**: (Numeric) This is a tuning parameter for the geomin rotation. It adds a small number (default = .01) to the squared factor loadings before computing the geometric means in the discrepancy function.
- **kappa**: (Numeric) The main parameterization of the Crawford-Ferguson (CF) rotations (i.e., "cfT" and "cfQ" for orthogonal and oblique CF rotation, respectively). Defaults to kappa = 0.
- **k**: (Numeric) A specific parameter of the simplimax rotation. Defaults to k = the number of observed variables.
- **standardize**: (Character) The standardization routine used on the unrotated factor structure. The three options are "none", "Kaiser", and "CM". Defaults to standardize = "none".
  - **"none"**: No standardization is applied to the unrotated factor structure.
  - **"Kaiser"**: Use a factor structure matrix that has been normed by Kaiser's method (i.e., normalize all rows to have a unit length).
  - **"CM"**: Use a factor structure matrix that has been normed by the Cureton-Mulaik method.
- **epsilon**: (Numeric) The rotational convergence criterion to use. Defaults to epsilon = 1e-5.
- **power**: (Numeric) Raise factor loadings the the n-th power in the `promaxQ` rotation. Defaults to power = 4.
- **maxItr**: (Numeric) The maximum number of iterations for the rotation algorithm. Defaults to maxItr = 15000.

`faControl` (List) A list of optional parameters passed to the factor extraction (`faX`) function.

- **treatHeywood**: (Logical) In `fals`, if treatHeywood is true, a penalized least squares function is used to bound the communality estimates below 1.0. Defaults to treatHeywood = TRUE.
- **nStart**: (Numeric) The number of starting values to be tried in `faml`. Defaults to nStart = 10.
- **start**: (Matrix) NULL or a matrix of starting values, each column giving an initial set of uniquenesses. Defaults to start = NULL.
- **maxCommunality**: (Numeric) In `faml`, set the maximum communality value for the estimated solution. Defaults to maxCommunality = .995.
- **epsilon**: (Numeric) In `fapa`, the numeric threshold designating when the algorithm has converged. Defaults to epsilon = 1e-4.
- **communality**: (Character) The method used to estimate the initial communality values in `fapa`. Defaults to communality = 'SMC'.
  - **"SMC"**: Initial communalities are estimated by taking the squared multiple correlations of each indicator after regressing the indicator on the remaining variables.
  - **"maxr"**: Initial communalities equal the largest (absolute value) correlation in each column of the correlation matrix.
  - **"unity"**: Initial communalities equal 1.0 for all variables.

- **maxItr**: (Numeric) In `fapa`, the maximum number of iterations to reach convergence. Defaults to maxItr = 15,000.

Value

This function iterates the Schmid-Leiman target rotation and returns several relevant output.

- **loadings**: (Matrix) The bifactor solution obtain from the SLi procedure.
- **iterations**: (Numeric) The number of iterations required for convergence
- **rotateControl**: (List) A list of the control parameters passed to the `faMain` function.
- **faControl**: (List) A list of optional parameters passed to the factor extraction (`faX`) function.

Author(s)

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- Niels G. Waller (nwaller@umn.edu)

References

Abad, F. J., Garcia-Garzon, E., Garrido, L. E., & Barrada, J. R. (2017). Iteration of partially specified target matrices: Application to the bi-factor case. *Multivariate Behavioral Research, 52*(4), 416-429.

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Reise, S. P., Moore, T. M., & Haviland, M. G. (2010). Bifactor models and rotations: Exploring the extent to which multidimensional data yield univocal scale scores. *Journal of Personality Assessment, 92*(6), 544-559.

Schmid, J., & Leiman, J. M. (1957). The development of hierarchical factor solutions. *Psychometrika, 22*(1), 53-61.

See Also

Other Factor Analysis Routines: `BiFAD()`, `Box26`, `GenerateBoxData()`, `Ledermann()`, `SchmidLeiman()`, `faAlign()`, `faEKC()`, `faIB()`, `faLocalMin()`, `faMB()`, `faMain()`, `faScores()`, `faSort()`, `faStandardize()`, `faX()`, `fals()`, `fapa()`, `fareg()`, `fsIndeterminacy()`, `orderFactors()`, `print.faMB()`, `print.faMain()`, `promaxQ()`, `summary.faMB()`, `summary.faMain()`

Examples

```
## Generate a bifactor model
bifactor <- matrix(c(.35, .61, .00, .00,
                     .35, .61, .00, .00,
                     .35, .61, .00, .00,
                     .35, .00, .61, .00,
                     .35, .00, .61, .00,
```

```
                      .35, .00, .61, .00,
                      .35, .00, .00, .61,
                      .35, .00, .00, .61,
                      .35, .00, .00, .61),
                    nrow = 9, ncol = 4, byrow = TRUE)

## Model-implied correlation (covariance) matrix
R <- bifactor %*% t(bifactor)

## Unit diagonal elements
diag(R) <- 1

Out1 <- SLi(R          = R,
            numFactors = c(3, 1))
```

---

smoothAPA *Smooth a NPD R matrix to PD using the Alternating Projection Algorithm*

Description

Smooth a Non positive defnite (NPD) correlation matrix to PD using the Alternating Projection Algorithm with Dykstra's correction via Theory described in Higham 2002.

Usage

```
smoothAPA(R, delta = 1e-06, fixR = NULL, Wghts = NULL, maxTries = 1000)
```

Arguments

R	A p x p indefinite matrix.
delta	Desired value of the smallest eigenvalue of smoothed matrix, RAPA. (Default = 1e-06).
fixR	User-supplied integer list that instructs the program to constrain elements in RAPA to equal corresponding elements in R. For example if fixR = c(1,2) then smoothed matrix, RAPA[1:2,1:2] = R[1:2,1:2]. Default (fixR = NULL).
Wghts	A p-length vector of weights for differential variable weighting. Default (Wghts = NULL).
maxTries	Maximum number of iterations in the alternating projections algorithm. Default (maxTries = 1000).

Value

RAPA	A smoothed matrix.
delta	User-supplied delta value.
Wghts	User-supplied weight vector.

fixR	User-supplied integer list that instructs the program to constrain elements in RAPA to equal corresponding elements in R.
convergence	A value of 0 indicates that the algorithm located a feasible solution. A value of 1 indicates that no feasible solution was located within maxTries.

Author(s)

Niels Waller

Examples

```
data(BadRKtB)

#####################################################################
##  Replicate analyses in Table 2 of Knol and ten Berge (1989).
#####################################################################

## n1 = 0,1
out<-smoothAPA(R = BadRKtB, delta = .0, fixR = NULL, Wghts = NULL, maxTries=1e06)
S <- out$RAPA
round(S - BadRKtB,3)
normF(S - BadRKtB)
eigen(S)$val

## n1 = 2
out<-smoothAPA(R = BadRKtB, fixR =c(1,2), delta=.0, Wghts = NULL, maxTries=1e06)
S <- out$RAPA
round(S - BadRKtB,3)
normF(S - BadRKtB)
eigen(S)$val

## n1 = 4
out<-smoothAPA(R = BadRKtB, fixR = 1:4, delta=.0, Wghts = NULL, maxTries=1e06)
S <- out$RAPA
round(S - BadRKtB,3)
normF(S - BadRKtB)
eigen(S)$val

## n1 = 5
out<-smoothAPA(R = BadRKtB, fixR = 1:5, delta=0, Wghts = NULL, maxTries=1e06)
S <- out$RAPA
round(S - BadRKtB,3)
normF(S - BadRKtB)
eigen(S)$val

#####################################################################
##  Replicate analyses in Table 3 of Knol and ten Berge (1989).
#####################################################################

## n1 = 0,1
out<-smoothAPA(R = BadRKtB, delta = .05, fixR = NULL, Wghts = NULL, maxTries=1e06)
S <- out$RAPA
```

```
round(S - BadRKtB,3)
normF(S - BadRKtB)
eigen(S)$val

## n1 = 2
out<-smoothAPA(R = BadRKtB, fixR =c(1,2), delta=.05, Wghts = NULL, maxTries=1e06)
S <- out$RAPA
round(S - BadRKtB,3)
normF(S - BadRKtB)
eigen(S)$val

## n1 = 4
out<-smoothAPA(R = BadRKtB, fixR = 1:4, delta=.05, Wghts = NULL, maxTries=1e06)
S <- out$RAPA
round(S - BadRKtB,3)
normF(S - BadRKtB)
eigen(S)$val

## n1 = 5
out<-smoothAPA(R = BadRKtB, fixR = 1:5, delta=.05, Wghts = NULL, maxTries=1e06)
S <- out$RAPA
round(S - BadRKtB,3)
normF(S - BadRKtB)
eigen(S)$val

#####################################################################
## This example illustrates differential variable weighting.
##
## Imagine a scenerio in which variables 1 & 2 were collected with
## 5 times more subjects than variables 4 - 6 then . . .
#####################################################################
## n1 = 2
out<-smoothAPA(R = BadRKtB, delta=.0, fixR = NULL, Wghts = c(5, 5, rep(1,4)), maxTries=1e5)
S <- out$RAPA
round(S - BadRKtB,3)
normF(S - BadRKtB)
eigen(S)$val
```

---

smoothBY *Smooth an NPD R matrix to PD using the Bentler Yuan 2011 method*

Description

Smooth a NPD correlation matrix to PD using the Bentler and Yuan method.

Usage

```
smoothBY(R, const = 0.98, eps = 0.001)
```

Arguments

R	Indefinite Matrix.
const	const is a user-defined parameter that is defined as k in Bentler and Yuan (2011). If 0 < const < 1, then const is treated as a fixed value. If const = 1 then the program will attempt to find the highest value of const such that R is positive (semi) definite.
eps	If const = 1 then the program will iteratively reduce const by eps until either (a) the program converges or (b) const < = 0.

Value

RBY	smoothed correlation matrix.
constant	The final value of const.
convergence	(Logical) a value of TRUE indicates that the function converged.
outStatus	Convergence state for Rcsdp::csdp function.

0:

Success. Problem solved to full accuracy

1:

Success. Problem is primal infeasible

2:

Success. Problem is dual infeasible

3:

Partial Success. Solution found but full accuracy was not achieved

4:

Failure. Maximum number of iterations reached

5:

Failure. Stuck at edge of primal feasibility

6:

Failure. Stuch at edge of dual infeasibility

7:

Failure. Lack of progress

8:

Failure. X or Z (or Newton system O) is singular

9:

Failure. Detected NaN or Inf values

glb	Greatest lower bound reliability estimates.
eps	Default value (eps = 1E-03) or user-supplied value of eps.

Author(s)

Code modified from that reported in Debelak, R. & Tran, U. S. (2011).

References

Bentler, P. M. & Yuan, K. H. (2011). Positive definiteness via off-diagonal scaling of a symmetric indefinite matrix. *Psychometrika, 76*(1), 119–123.

Debelak, R. & Tran, U. S. (2013). Principal component analysis of smoothed tetrachoric correlation matrices as a measure of dimensionality. *Educational and Psychological Measurement, 73*(1), 63–77.

Examples

```
data(BadRBY)

out<-smoothBY(R = BadRBY, const = .98)
cat("\nSmoothed Correlation Matrix\n")
print( round(out$RBY,8) )
cat("\nEigenvalues of smoothed matrix\n")
print( eigen(out$RBY)$val  )
```

---

smoothKB *Smooth a Non PD Correlation Matrix using the Knol-Berger algorithm*

Description

A function for smoothing a non-positive definite correlation matrix by the method of Knol and Berger (1991).

Usage

```
smoothKB(R, eps = 1e+08 * .Machine$double.eps)
```

Arguments

R	A non-positive definite correlation matrix.
eps	Small positive number to control the size of the non-scaled smallest eigenvalue of the smoothed R matrix. Default = 1E8 * .Machine$double.eps

Value

RKB	A Smoothed (positive definite) correlation matrix.
eps	Small positive number to control the size of the non-scaled smallest eigenvalue of the smoothed R matrix.

Author(s)

Niels Waller

References

Knol, D. L., & Berger, M. P. F., (1991). Empirical comparison between factor analysis and multidimensional item response models.*Multivariate Behavioral Research, 26*, 457-477.

Examples

```
data(BadRLG)

## RKB = smoothed R
RKB<-smoothKB(R=BadRLG, eps = 1E8 * .Machine$double.eps)$RKB
print(eigen(RKB)$values)
```

---

smoothLG *Smooth NPD to Nearest PSD or PD Matrix*

Description

Smoothing an indefinite matrix to a PSD matrix via theory described by Lurie and Goldberg

Usage

```
smoothLG(
  R,
  start.val = NULL,
  Wghts = NULL,
  PD = FALSE,
  Penalty = 50000,
  eps = 1e-07
)
```

Arguments

R	Indefinite Matrix.
start.val	Optional vector of start values for Cholesky factor of S.
Wghts	An optional matrix of weights such that the objective function minimizes wij(rij - sij)^2, where wij is Wghts[i,j].
PD	Logical (default = FALSE). If PD = TRUE then the objective function will smooth the least squares solution to insure Positive Definitness.
Penalty	A scalar weight to scale the Lagrangian multiplier. Default = 50000.
eps	A small value to add to zero eigenvalues if smoothed matrix must be PD. Default = 1e-07.

Value

RLG	Lurie Goldberg smoothed matrix.
RKB	Knol and Berger smoothed matrix.
convergence	0 = converged solution, 1 = convergence failure.
start.val	Vector of start.values.
gr	Analytic gradient at solution.
Penalty	Scalar used to scale the Lagrange multiplier.
PD	User-supplied value of PD.
Wghts	Weights used to scale the squared euclidean distances.
eps	Value added to zero eigenvalue to produce PD matrix.

Author(s)

Niels Waller

Examples

```
data(BadRLG)

out<-smoothLG(R = BadRLG, Penalty = 50000)
cat("\nGradient at solution:", out$gr,"\n")
cat("\nNearest Correlation Matrix\n")
print( round(out$RLG,8) )

################################
##  Rousseeuw Molenbergh example
data(BadRRM)

out <- smoothLG(R = BadRRM, PD=TRUE)
cat("\nGradient at solution:", out$gr,"\n")
cat("\nNearest Correlation Matrix\n")
print( round(out$RLG,8) )

## Weights for the weighted solution
```

```
W <- matrix(c(1,  1, .5,
              1,  1,  1,
              .5,  1,  1), nrow = 3, ncol = 3)
tmp <- smoothLG(R = BadRRM,  PD = TRUE, eps=.001)
cat("\nGradient at solution:", out$gr,"\n")
cat("\nNearest Correlation Matrix\n")
print( round(out$RLG,8) )
print( eigen(out$RLG)$val )

## Rousseeuw Molenbergh
## non symmetric matrix
T <- matrix(c(.8, -.9, -.9,
            -1.2,  1.1, .3,
             -.8, .4, .9),  nrow = 3, ncol = 3,byrow=TRUE)
out <- smoothLG(R = T,  PD = FALSE, eps=.001)

cat("\nGradient at solution:", out$gr,"\n")
cat("\nNearest Correlation Matrix\n")
print( round(out$RLG,8) )
```

`summary.faMain` *Summary Method for an Object of Class faMain*

Description

This function summarizes results from a call to **faMain**.

Usage

```
## S3 method for class 'faMain'
summary(
  object,
  digits = 2,
  Set = 1,
  HPthreshold = 0.05,
  PrintLevel = 1,
  DiagnosticsLevel = 1,
  itemSort = FALSE,
  ...
)
```

Arguments

`object`	(Object of class `faMain`) The returned object from a call to **faMain**.
`digits`	(Integer) Print output with user-specified number of significant digits. Default `digits = 2`.
`Set`	The argument `Set` can be specified as either an integer value (i.e., 1 through the number of unique solution sets) or a character value (i.e., 'UnSpun').

- **Integer** Summarize the solution from the specified solution set. If `Set = 1`, the "global minimum" solution is reported. See `faMain` for more details about finding the "global" and local minima.
- **'UnSpun'** Summarize the solution from the rotated output that was produced by rotating from the unrotated (i.e., unspun) factor orientation. All other solutions are rotated from a randomly 'spun' rotation (i.e., by orientating the unrotated factor solution via a random orthonormal matrix) .

`HPthreshold` (Numeric) User-defined threshold for declaring that the absolute value of a factor pattern coefficient is in a hyperplane. The hyperplane count is the number of near-zero (as defined by HPthreshold; see Cattell, 1978, p. 105) elements in the factor pattern matrix. Default `HPthreshold = .05`.

`PrintLevel` (Integer) Controls the level of printing. If `PrintLevel = 0` then no output is printed. If `PrintLevel = 1` then the standard output will be printed. If `PrintLevel = 2` more extensive output (e.g., the Factor Structure Matrix) will be printed. Default `PrintLevel = 1`.

`DiagnosticsLevel` (Integer) Controls the amount of diagnostics information that is computed on the rotation local minima. If `DiagnosticsLevel = 1` then only the number of local solution sets will be reported. If `DiagnosticsLevel = 2` then the program will determine whether all solutions within a solution set are identicial. Default `DiagnosticsLevel = 1`.

`itemSort` (Logical) If TRUE, sort the order of the observed variables to produce a "staircase"-like pattern. Note that this argument cannot handle bifactor models at this time. Defaults to `itemSort` = FALSE.

`...` Additional arguments affecting the summary produced.

Details

summary.faMain provides various criteria for judging the adequacy of the rotated factor solution(s). After reporting the number of solution sets. (i.e., rotated solutions with the same complexity value) the following measures of factor adequacy are reported for each solution set:

- **Complexity Value**: The rotation complexity value (see `faMain` for details).
- **Hyperplane Count**: The number of near-zero loadings (defined by **HPthreshold**) for all factor patterns in a solution set (if **MaxWithinSetRMSD > 0** then Hyperplane Count refers to the first factor pattern in the solution set).
- **% Cases (x 100) in Set**: The percentage of factor patterns in each solution set.
- **RMSD**: The root mean squared deviation between the first factor pattern in each solution set with the first factor pattern in the solution set specified by the **Set** parameter. By default, **Set = 1**.
- **MaxWithinSetRMSD**: The maximum root mean squared deviation between all within set solutions and the first element in the solution set. When **MaxWithinSetRMSD > 0** then the solution set contains non-identical rotated factor patterns with identical complexity values.
- **Converged**: A Logical (TRUE/FALSE) that indicates whether the first solution in a solution set has a TRUE convergence status.

Note that the printed factor pattern is not sorted even if **itemSort** is requested in faMain.

Value

- `loadings` (Matrix) Factor loadings for the solution associated with the minimum (maximum) rotation complexity value (default) or the user-chosen solution.
- `Phi` (Matrix) Factor correlation matrix for the solution associated with the minimum (maximum) rotation complexity value (default) or the user-chosen solution.
- `FS` (Matrix) Factor structure matrix for the solution associated with the minimum (maximum) rotation complexity value (default) or the user-chosen solution.
- `Set` (Integer) The returned Set number.
- `h2` (Matrix) Communalities for the returned factor solution. If `Boostrap = TRUE` then `h2` also returns the bootstrap standard errors and associated confidence bounds from the bootstrap distribution.
- facIndeterminacy (Vector) Factor Indeterminacy values (correlations between the factors and factor scores). If `Boostrap = TRUE` then `facIndeterminacy` also returns the bootstrap standard errors and associated confidence bounds from the boostrap distribution.
- `SetComplexityValues` (Vector) Rotation complexity value for each solution set.
- `HP_counts` (Vector) Hyperplane count for each solution set.
- `MaxWithinSetRMSD` (Vector) If `DiagnosticsLevel = 2` the the program will compute within set RMSD values. These values represent the root mean squared deviations of each within set solution with the first solution in a set. If the `MaxWithinSetRMSD = 0` for a set, then all within set solutions are identical. If `MaxWithinSetRMSD > 0` then at least one solution differs from the remaining solutions within a set (i.e., two solutions with different factor loadings produced identical complexity values).
- `RMSD` (Numeric) The root mean squared deviation between the observed and model-implied correlation matrix.
- `RMSAD` (Numeric) The root mean squared absolute deviation between the observed and model-implied correlation matrix.
- `NumberLocalSolutions` (Integer) The number of local solution sets.
- `LocalSolutions` (List) A list of local solutions (factor loadings, factor correlations, etc).
- `rotate` Designates which rotation method was applied.
- `itemOrder` The item order of the (possibly) sorted factor loadings.

Author(s)

- Niels G. Waller (nwaller@umn.edu)
- Casey Giordano (Giord023@umn.edu)

References

Cattell, R. (1978). The scientific use of factor analysis in behavioral and life sciences. New York, New York, Plenum.

See Also

Other Factor Analysis Routines: BiFAD(), Box26, GenerateBoxData(), Ledermann(), SLi(), SchmidLeiman(), faAlign(), faEKC(), faIB(), faLocalMin(), faMB(), faMain(), faScores(), faSort(), faStandardize(), faX(), fals(), fapa(), fareg(), fsIndeterminacy(), orderFactors(), print.faMB(), print.faMain(), promaxQ(), summary.faMB()

Examples

```
## Load Thurstone's Box data from the fungible library
library(fungible)
data(Box26)

## Create a matrix from Thurstone's solution
## Used as a target matrix to sort columns of the estimated solution
ThurstoneSolution <- matrix(c(   .95,  .01,  .01,
                                 .02,  .92,  .01,
                                 .02,  .05,  .91,
                                 .59,  .64, -.03,
                                 .60,  .00,  .62,
                                -.04,  .60,  .58,
                                 .81,  .38,  .01,
                                 .35,  .79,  .01,
                                 .79, -.01,  .41,
                                 .40, -.02,  .79,
                                -.04,  .74,  .40,
                                -.02,  .41,  .74,
                                 .74, -.77,  .06,
                                -.74,  .77, -.06,
                                 .74,  .02, -.73,
                                -.74, -.02,  .73,
                                -.07,  .80, -.76,
                                 .07, -.80,  .76,
                                 .51,  .70, -.03,
                                 .56, -.04,  .69,
                                -.02,  .60,  .58,
                                 .50,  .69, -.03,
                                 .52, -.01,  .68,
                                -.01,  .60,  .55,
                                 .43,  .46,  .45,
                                 .31,  .51,  .46), nrow = 26, ncol = 3,
                                                          byrow=TRUE)
## Example 1: Multiple solution sets.
## Ignore warnings about non-positive definite sample correlation matrix
suppressWarnings(
  fout <- faMain(R             = Box26,
                 numFactors    = 3,
                 facMethod     = 'faregLS',
                 rotate        = 'infomaxQ',
                 targetMatrix  = ThurstoneSolution,
                 rotateControl =
                   list(numberStarts = 25, ## increase in real problem
                        standardize  = 'none'),
```

```
                Seed          = 123)
)

## Summarize the factor analytic output
summary(object           = fout,
        digits           = 2,
        Set              = 2,
        HPthreshold      = .10,
        PrintLevel       = 1,
        DiagnosticsLevel = 2)


## Example 2: Bootstrap Illustration
## Step 1: In an initial analysis, confirm that all rotations converge
  ## to a single minimum complexity value.
## Step 2: If Step 1 is satisfied then generate bootstrap samples.

## Load Amazon box data
data("AmzBoxes")

## Convert box dimensions into Thurstone's indicators
BoxData <-
  GenerateBoxData(AmzBoxes[, 2:4],          ## Select columns 2, 3, & 4
                  BoxStudy         = 26,    ## 26 indicators
                  Reliability      = 0.75,  ## Add unreliability
                  SampleSize       = 200,   ## Add sampling error
                  ModApproxErrVar  = 0.1,   ## Add model approx error
                  NMinorFac        = 50,    ## Number of minor factors
                  epsTKL           = 0.2,   ## Spread of minor factor influence
                  SeedErrorFactors = 1,     ## Reproducible starting seed
                  SeedMinorFactors = 2,     ## Reproducible starting seed
                  PRINT            = FALSE, ## Suppress some output
                  LB               = FALSE, ## Do not set lower-bounds
                  LBVal            = 1,     ## Lower bound value (ignored)
                  Constant         = 0)     ## Do not add constant to data

## Analyze new box data with added measurement error
fout <- faMain(X             = BoxData$BoxDataE,
               numFactors    = 3,
               facMethod     = 'fapa',
               rotate        = 'infomaxQ',
               targetMatrix  = ThurstoneSolution,
               bootstrapSE   = FALSE,
               rotateControl =
                 list(numberStarts = 25, ## increase in real problem
                      standardize  = 'CM'),
               Seed          = 1)

## Summarize factor analytic output
sout <- summary(object     = fout,
                Set        = 1,
                PrintLevel = 1)
```

```
## Generate bootstrap samples
fout <- faMain(X             = BoxData$BoxDataE,
               numFactors    = 3,
               facMethod     = 'fapa',
               rotate        = 'infomaxQ',
               targetMatrix  = ThurstoneSolution,
               bootstrapSE   = TRUE,
               numBoot       = 25,   ## increase in real problem
               rotateControl =
                 list(numberStarts = 1,
                      standardize  = 'CM'),
               Seed          = 1)

## Summarize factor analytic output with bootstraps
sout <- summary(object     = fout,
                Set        = 1,
                PrintLevel = 2)

 ## To print a specific solution without computing diagnostics and
   ## summary information, use the print function.

   print(fout,
         Set = 1)
```

---

summary.faMB *Summary Method for an Object of Class faMB*

Description

This function summarizes results from a call to **faMB**.

Usage

```
## S3 method for class 'faMB'
summary(
  object,
  digits = 2,
  Set = 1,
  HPthreshold = 0.05,
  PrintLevel = 1,
  DiagnosticsLevel = 1,
  ...
)
```

Arguments

object	(Object of class faMB) The returned object from a call to **faMB**.

`digits` (Integer) Print output with user-specified number of significant digits. Default `digits = 2`.

`Set` The argument `Set` can be specified as either an integer value (i.e., 1 through the number of unique solution sets) or a character value (i.e., 'UnSpun').

- **Integer** Summarize the solution from the specified solution set. If `Set = 1`, the "global minimum" solution is reported. See `faMain` for more details about finding the "global" and local minima.
- **'UnSpun'** Summarize the solution from the rotated output that was produced by rotating from the unrotated (i.e., unspun) factor orientation. All other solutions are rotated from a randomly 'spun' rotation (i.e., by orientating the unrotated factor solution via a random orthonormal matrix) .

`HPthreshold` (Numeric) User-defined threshold for declaring that the absolute value of a factor pattern coefficient is in a hyperplane. The hyperplane count is the number of near-zero (as defined by HPthreshold; see Cattell, 1978, p. 105) elements in the factor pattern matrix. Default `HPthreshold = .05`.

`PrintLevel` (Integer) Controls the level of printing. If `PrintLevel = 0` then no output is printed. If `PrintLevel = 1` then the standard output will be printed. If `PrintLevel = 2` more extensive output (e.g., the Factor Structure Matrix, the Residuals Matrix [i.e., Observed - fitted R]) will be printed. Default `PrintLevel = 1`.

`DiagnosticsLevel` (Integer) Controls the amount of diagnostics information that is computed on the rotation local minima. If `DiagnosticsLevel = 1` then only the number of local solution sets will be reported. If `DiagnosticsLevel = 2` then the program will determine whether all solutions within a solution set are identicial. Default `DiagnosticsLevel = 1`.

`...` Additional arguments affecting the summary produced.

Details

summary.faMB provides various criteria for judging the adequacy of the rotated factor solution(s). After reporting the number of solution sets. (i.e., rotated solutions with the same complexity value) the following measures of factor adequacy are reported for each solution set:

- **Complexity Value**: The rotation complexity value (see `faMain` for details).
- **Hyperplane Count**: The number of near-zero loadings (defined by **HPthreshold**) for all factor patterns in a solution set (if **MaxWithinSetRMSD > 0** then Hyperplane Count refers to the first factor pattern in the solution set).
- **% Cases (x 100) in Set**: The percentage of factor patterns in each solution set.
- **RMSD**: The root mean squared deviation between the first factor pattern in each solution set with the first factor pattern in the solution set specified by the **Set** parameter. By default, **Set = 1**.
- **MaxWithinSetRMSD**: The maximum root mean squared deviation between all within set solutions and the first element in the solution set. When **MaxWithinSetRMSD > 0** then the solution set contains non-identical rotated factor patterns with identical complexity values.
- **Converged**: A Logical (TRUE/FALSE) that indicates whether all within set rotations converged.

Value

- `loadings` (Matrix) Factor loadings for the solution associated with the minimum (maximum) rotation complexity value (default) or the user-chosen solution.
- `Phi` (Matrix) Factor correlation matrix for the solution associated with the minimum (maximum) rotation complexity value (default) or the user-chosen solution.
- `FS` (Matrix) Factor structure matrix for the solution associated with the minimum (maximum) rotation complexity value (default) or the user-chosen solution.
- `Set` (Integer) The returned Set number.
- `facIndeterminacy` (Matrix) Factor Indeterminacy values.
- `SetComplexityValues` (vector) Rotation complexity value for each solution set.
- `HP_counts` (vector) Hyperplane count for each solution set.
- `MaxWithinSetRMSD` (vector) If `DiagnosticsLevel = 2` the the program will compute within set RMSD values. These values represent the root mean squared deviations of each within set solution with the first solution in a set. If the `MaxWithinSetRMSD = 0` for a set, then all within set solutions are identical. If `MaxWithinSetRMSD > 0` then at least one solution differs from the remaining solutions within a set (i.e., two solutions with different factor loadings produced identical complexity values).
- `ChiSq` (Numeric) Chi-square goodness of fit value. As recommended by Browne (1979), we apply Lawley's (1959) correction when computing the chi-square value when `NB = 2`.
- `DF` (Numeric) Degrees of freedom for the estimated model.
- `pvalue` (Numeric) P-value associated with the above chi-square statistic.
- `AIC` (Numeric) Akaike's Information Criterion where a lower value indicates better fit.
- `BIC` (Numeric) Bayesian Information Criterion where a lower value indicates better fit.
- `RMSEA` (Numeric) The root mean squared error of approximation (Steiger & Lind, 1980).
- `Resid` (Matrix) The residuals matrix (R - Rhat).
- `NumberLocalSolutions` (Integer) The number of local solution sets.
- `LocalSolutions` (List) A list of local solutions (factor loadings, factor correlations, etc).
- `rotate` Designates which rotation method was applied.

Author(s)

- Niels G. Waller (nwaller@umn.edu)
- Casey Giordano (Giord023@umn.edu)

References

Cattell, R. (1978). The scientific use of factor analysis in behavioral and life sciences. New York, New York, Plenum.

See Also

Other Factor Analysis Routines: `BiFAD()`, `Box26`, `GenerateBoxData()`, `Ledermann()`, `SLi()`, `SchmidLeiman()`, `faAlign()`, `faEKC()`, `faIB()`, `faLocalMin()`, `faMB()`, `faMain()`, `faScores()`, `faSort()`, `faStandardize()`, `faX()`, `fals()`, `fapa()`, `fareg()`, `fsIndeterminacy()`, `orderFactors()`, `print.faMB()`, `print.faMain()`, `promaxQ()`, `summary.faMain()`

Examples

```
# These examples reproduce published multiple battery analyses.

# ----EXAMPLE 1: Browne, M. W. (1979)----
#
# Data originally reported in:
# Thurstone, L. L. & Thurstone, T. G. (1941). Factorial studies
# of intelligence. Psychometric Monograph (2), Chicago: Univ.
# Chicago Press.

## Load Thurstone & Thurstone's data used by Browne (1979)
data(Thurstone41)

Example1Output <-  faMB(R             = Thurstone41,
                        n             = 710,
                        NB            = 2,
                        NVB           = c(4,5),
                        numFactors    = 2,
                        rotate        = "oblimin",
                        rotateControl = list(standardize = "Kaiser"))

## Call the summary function
summary(Example1Output)

# ----EXAMPLE 2: Browne, M. W. (1980)----
# Data originally reported in:
# Jackson, D. N. & Singer, J. E. (1967). Judgments, items and
# personality. Journal of Experimental Research in Personality, 20, 70-79.

## Load Jackson and Singer's dataset
data(Jackson67)

Example2Output <-  faMB(R             = Jackson67,
                        n             = 480,
                        NB            = 5,
                        NVB           = rep(4,5),
                        numFactors    = 4,
                        rotate        = "varimax",
                        rotateControl = list(standardize = "Kaiser"),
                        PrintLevel    = 1)

## Call the summary function
summary(object     = Example2Output,
        Set        = 1,
        PrintLevel = 1)

# ----EXAMPLE 3: Cudeck (1982)----
# Data originally reported by:
# Malmi, R. A., Underwood, B. J., & Carroll, J. B. (1979).
# The interrelationships among some associative learning tasks.
# Bulletin of the Psychonomic Society, 13(3), 121-123. DOI: 10.3758/BF03335032
```

```
## Load Malmi et al.'s dataset
data(Malmi79)

Example3Output <- faMB(R             = Malmi79,
                       n             = 97,
                       NB            = 3,
                       NVB           = c(3, 3, 6),
                       numFactors    = 2,
                       rotate        = "oblimin",
                       rotateControl = list(standardize = "Kaiser"))

## Call the summary function
summary(object     = Example3Output,
        Set        = 1,
        PrintLevel = 2)

# ----Example 4: Cudeck (1982)----
# Data originally reported by:
# Boruch, R. F., Larkin, J. D., Wolins, L. and MacKinney, A. C. (1970).
#  Alternative methods of analysis: Multitrait-multimethod data. Educational
#  and Psychological Measurement, 30,833-853.

## Load Boruch et al.'s dataset
data(Boruch70)

Example4Output <- faMB(R             = Boruch70,
                       n             = 111,
                       NB            = 2,
                       NVB           = c(7,7),
                       numFactors    = 2,
                       rotate        = "oblimin",
                       rotateControl = list(standardize  = "Kaiser",
                                            numberStarts = 100))

## Call the summary function
summary(Example4Output)
```

---

summary.monte *Summary Method for an Object of Class Monte*

Description

summary method for class “monte"

Usage

```
## S3 method for class 'monte'
summary(
  object,
```

```
  digits = 3,
  compute.validities = FALSE,
  Total.stats = TRUE,
  ...
)
```

Arguments

`object`	An object of class `monte`, usually, a result of a call to `monte`.
`digits`	Number of digits to print. Default = 3.
`compute.validities`	Logical: If TRUE then the program will calculate the indicator validities (eta^2) for the generated data.
`Total.stats`	Logical: If TRUE then the program will return the following statistics for the total sample: (1) indicator correlation matrix, (2) indicator skewness, (3) indicator kurtosis.
`...`	Optional arguments.

Value

Various descriptive statistics will be computed within groups including"

clus.size Number of objects within each group.

centroids Group centroids.

var.matrix Within group variances.

cor.list Expected within group correlations.

obs.cor Observed within group correlations.

skew.list Expected within group indicator skewness values.

obs.skew Observed within group indicator skewness values.

kurt.list Expected within group indicator kurtosis values.

obs.kurt Observed within group indicator kurtosis values.

validities Observed indicator validities.

Total.cor Total sample correlation matrix.

Total.skew Total sample indicator skewness.

Total.kurt Total sample indicator kurtosis.

Examples

```
## set up a 'monte' run for the Fisher iris data

sk.lst <- list(c(0.120,  0.041,  0.106,  1.254),                    #
               c(0.105, -0.363, -0.607, -0.031),
               c(0.118,  0.366,  0.549, -0.129) )
```

```
kt.lst <- list(c(-0.253, 0.955,  1.022,  1.719),
               c(-0.533,-0.366,  0.048, -0.410),
               c( 0.033, 0.706, -0.154, -0.602))

cormat <- lapply(split(iris[,1:4],iris[,5]), cor)

my.iris <- monte(seed = 123, nvar = 4, nclus = 3, cor.list = cormat,
              clus.size = c(50, 50, 50),
                eta2 = c(0.619, 0.401, 0.941, 0.929),
                random.cor = FALSE,
                skew.list = sk.lst, kurt.list = kt.lst,
                secor = .3,
                compactness = c(1, 1, 1),
                sortMeans = TRUE)
summary(my.iris)
```

`summary.monte1` *Summary Method for an Object of Class Monte1*

Description

summary method for class "monte1"

Usage

```
## S3 method for class 'monte1'
summary(object, digits = 3, ...)
```

Arguments

`object`	An object of class `monte1`, usually, a result of a call to `monte1`.
`digits`	Number of significant digits to print in final results.
`...`	Additional argument affecting the summary produced.

Value

Various descriptive statistics will be computed including

1. Expected correlation matrix.
2. Observed correlation matrix.
3. Expected indicator skewness values.
4. Observed indicator skewness values.
5. Expected indicator kurtosis values.
6. Observed indicator kurtosis values.

Examples

```
## Generate dimensional data for 4 variables.
## All correlations = .60; all variable
## skewness = 1.75;
## all variable kurtosis = 3.75

cormat <- matrix(.60, 4, 4)
diag(cormat) <- 1

nontaxon.dat <- monte1(seed = 123, nsub = 100000, nvar = 4, skewvec = rep(1.75, 4),
                kurtvec = rep(3.75, 4), cormat = cormat)

summary(nontaxon.dat)
```

---

svdNorm *Compute theta surrogates via normalized SVD scores*

Description

Compute theta surrogates by calculating the normalized left singular vector of a (mean-centered) data matrix.

Usage

```
svdNorm(data)
```

Arguments

data	N(subjects)-by-p(items) matrix of 0/1 item response data.

Value

the normalized left singular vector of the mean centered data matrix.
svdNorm will center the data automatically.

Author(s)

Niels Waller

Examples

```
NSubj <- 2000

## example item parameters for sample data: k=1 FMP
b <- matrix(c(
    #b0    b1     b2    b3      b4   b5 b6 b7  k
  1.675, 1.974, -0.068, 0.053,  0,  0,  0,  0, 1,
  1.550, 1.805, -0.230, 0.032,  0,  0,  0,  0, 1,
```

```
  1.282, 1.063, -0.103, 0.003,  0,  0,  0,  0, 1,
  0.704, 1.376, -0.107, 0.040,  0,  0,  0,  0, 1,
  1.417, 1.413,  0.021, 0.000,  0,  0,  0,  0, 1,
 -0.008, 1.349, -0.195, 0.144,  0,  0,  0,  0, 1,
  0.512, 1.538, -0.089, 0.082,  0,  0,  0,  0, 1,
  0.122, 0.601, -0.082, 0.119,  0,  0,  0,  0, 1,
  1.801, 1.211,  0.015, 0.000,  0,  0,  0,  0, 1,
 -0.207, 1.191,  0.066, 0.033,  0,  0,  0,  0, 1,
 -0.215, 1.291, -0.087, 0.029,  0,  0,  0,  0, 1,
  0.259, 0.875,  0.177, 0.072,  0,  0,  0,  0, 1,
 -0.423, 0.942,  0.064, 0.094,  0,  0,  0,  0, 1,
  0.113, 0.795,  0.124, 0.110,  0,  0,  0,  0, 1,
  1.030, 1.525,  0.200, 0.076,  0,  0,  0,  0, 1,
  0.140, 1.209,  0.082, 0.148,  0,  0,  0,  0, 1,
  0.429, 1.480, -0.008, 0.061,  0,  0,  0,  0, 1,
  0.089, 0.785, -0.065, 0.018,  0,  0,  0,  0, 1,
 -0.516, 1.013,  0.016, 0.023,  0,  0,  0,  0, 1,
  0.143, 1.315, -0.011, 0.136,  0,  0,  0,  0, 1,
  0.347, 0.733, -0.121, 0.041,  0,  0,  0,  0, 1,
 -0.074, 0.869,  0.013, 0.026,  0,  0,  0,  0, 1,
  0.630, 1.484, -0.001, 0.000,  0,  0,  0,  0, 1),
  nrow=23, ncol=9, byrow=TRUE)

# generate data using the above item paramters
data<-genFMPData(NSubj=NSubj, bParam=b, seed=345)$data

# compute (initial) surrogate theta values from
# the normed left singular vector of the centered
# data matrix
thetaInit<-svdNorm(data)
```

`TaylorRussell` *A generalized (multiple predictor) Taylor-Russell function.*

Description

Generalized Taylor-Russell Function for Multiple Predictors

Usage

```
TaylorRussell(SR = NULL, BR = NULL, R = NULL, PrintLevel = 0, Digits = 3)
```

Arguments

SR	(vector) A vector of Selection Ratios for N selection tests.
BR	(scalar) The Base Rate of criterion performance.
R	(matrix) An (N + 1) x (N + 1) correlation matrix in which the predictor/criterion correlations are in column N + 1 of R.

PrintLevel	(integer). If PrintLevel = 0 then no output is printed to screen. If PrintLevel > 0 then output is printed to screen. Defaults to PrintLevel = 0.
Digits	(integer) The number of significant digits in the printed output.

Value

The following output variables are returned.

- **BR**: (scalar) The Base Rate of criterion performance.
- **SR**: (vector) The user-defined vector of predictor Selection Ratios.
- **R**: (matrix) The input correlation matrix.
- **TP**: (scalar) The percentage of True Positives.
- **FP**: (scalar) The percentage of False Positives.
- **TN**: (scalar) The percentage of True Negatives.
- **FN**: (scalar) The percentage of False Negatives.
- **Accepted**: The percentage of selected individuals (i.e., TP + FP).
- **PPV**: The Positive Predictive Value. This is the probability that a selected individual is a True Positive.
- **Sensitivity**: The test battery Sensitivity rate. This is the probability that a person who is acceptable on the criterion is called acceptable by the test battery.
- **Specificity**: The test battery Specificity rate. This is the probability that a person who falls below the criterion threshold is deemed unacceptable by the test battery.

Author(s)

- Niels G. Waller (nwaller@umn.edu)

References

- Taylor, H. C. & Russell, J. (1939). The relationship of validity coefficients to the practical effectiveness of tests in selection: Discussion and tables. Journal of Applied Psychology, 23(5), 565–578.
- Thomas, J. G., Owen, D., & Gunst, R. (1977). Improving the use of educational tests as selection tools. Journal of Educational Statistics, 2(1), 55–77.

Examples

```
# Example 1
# Reproduce Table 3 (p. 574) of Taylor and Russell

r <- seq(0, 1, by = .05)
sr <- c(.05, seq(.10, .90, by = .10), .95)
num.r <- length(r)
num.sr <- length(sr)

old <- options(width = 132)
```

```
Table3 <- matrix(0, num.r, num.sr)
for(i in 1 : num.r){
   for(j in 1:num.sr){

     Table3[i,j] <-  TaylorRussell(
                       SR = sr[j],
                       BR = .20,
                       R = matrix(c(1, r[i], r[i], 1), 2, 2),
                       PrintLevel = 0,
                       Digits = 3)$PPV

  }# END over j
}# END over i

rownames(Table3) <- r
colnames(Table3) <- sr
Table3 |> round(2)

# Example 2
# Thomas, Owen, & Gunst (1977) -- Example 1: Criterion = GPA

R <- matrix(c(1, .5, .7,
              .5, 1, .7,
             .7, .7, 1), 3, 3)

 # See Table 6: Target Acceptance = 20%
 out.20 <- TaylorRussell(
 SR = c(.354, .354),  # the marginal probabilities
 BR = .60,
 R = R,
 PrintLevel = 1)

# See Table 6:  Target Acceptance = 50%
out.50 <- TaylorRussell(
 SR = c(.653, .653),   # the marginal probabilities
 BR = .60,
 R = R,
 PrintLevel = 1)

 options(old)
```

---

tetcor *Compute ML Tetrachoric Correlations*

Description

Compute ML tetrachoric correlations with optional bias correction and smoothing.

Usage

```
tetcor(
  X,
  y = NULL,
  BiasCorrect = TRUE,
  stderror = FALSE,
  Smooth = TRUE,
  max.iter = 5000,
  PRINT = TRUE
)
```

Arguments

X	Either a matrix or vector of (0/1) binary data.
y	An optional(if X is a matrix) vector of (0/1) binary data.
BiasCorrect	A logical that determines whether bias correction (Brown & Benedetti, 1977) is performed. Default = TRUE.
stderror	A logical that determines whether standard errors are calulated. Default = FALSE.
Smooth	A logical which determines whether the tetrachoric correlation matrix should be smoothed. A smoothed matrix is always positive definite.
max.iter	Maximum number of iterations. Default = 50.
PRINT	A logical that determines whether to print progress updates during calculations. Default = TRUE

Value

If stderror = FALSE, tetcor returns a matrix of tetrachoric correlations. If stderror = TRUE then tetcor returns a list the first component of which is a matrix of tetrachoric correlations and the second component is a matrix of standard errors (see Hamdan, 1970).

r	The tetrachoric correlation matrix
.	
se	A matrix of standard errors.
convergence	(logical) The convergence status of the algorithm. A value of TRUE denotes that the algorithm converged. A value of FALSE denotes that the algorithm did not converge and the returned correlations are Pearson product moments.
Warnings	A list of warnings.

Author(s)

Niels Waller

References

Brown, M. B. & Benedetti, J. K. (1977). On the mean and variance of the tetrachoric correlation coefficient. *Psychometrika, 42*, 347–355.

Divgi, D. R. (1979) Calculation of the tetrachoric correlation coefficient. *Psychometrika, 44*, 169-172.

Hamdan, M. A. (1970). The equivalence of tetrachoric and maximum likelihood estimates of rho in 2 by 2 tables. *Biometrika, 57*, 212-215.

Examples

```
## generate bivariate normal data
library(MASS)
set.seed(123)
rho <- .85
xy <- mvrnorm(100000, mu = c(0,0), Sigma = matrix(c(1, rho, rho, 1), ncol = 2))

# dichotomize at difficulty values
p1 <- .7
p2 <- .1
xy[,1] <- xy[,1] < qnorm(p1)
xy[,2] <- xy[,2] < qnorm(p2)

print( apply(xy,2,mean), digits = 2)
#[1] 0.700 0.099

tetcor(X = xy, BiasCorrect = TRUE,
       stderror = TRUE, Smooth = TRUE, max.iter = 5000)

# $r
# [,1]      [,2]
# [1,] 1.0000000 0.8552535
# [2,] 0.8552535 1.0000000
#
# $se
# [,1]           [,2]
# [1,] NA         0.01458171
# [2,] 0.01458171 NA
#
# $Warnings
# list()
```

`tetcorQuasi` *Correlation between a Naturally and an Artificially Dichotomized Variable*

Description

A function to compute Ulrich and Wirtz's correlation of a naturally and an artificially dichotomized variable.

Usage

```
tetcorQuasi(x, y = NULL)
```

Arguments

x	An N x 2 matrix or an N x 1 vector of binary responses coded 0/1.
y	An optional (if x is a vector) vector of 0/1 responses.

Value

A quasi tetrachoric correlation

...

Author(s)

Niels Waller

References

Ulrich, R. & Wirtz, M. (2004). On the correlation of a naturally and an artificially dichotomized variable. *British Journal of Mathematical and Statistical Psychology, 57*, 235-252.

Examples

```
set.seed(321)
Nsubj <- 5000

## Generate mvn data with rxy = .5
R <- matrix(c(1, .5, .5, 1), 2, 2)
X <- MASS::mvrnorm(n = Nsubj, mu = c(0, 0), Sigma = R, empirical = TRUE)

## dichotomize data
thresholds <- qnorm(c(.2, .3))
binaryData <- matrix(0, Nsubj, 2)

for(i in 1:2){
  binaryData[X[,i] <= thresholds[i],i] <- 1
}

## calculate Pearson correlation
cat("\nPearson r: ", round(cor(X)[1,2], 2))

## calculate Pearson Phi correlation
cat("\nPhi r: ", round(cor(binaryData)[1,2], 2))

## calculate tetrachoric correlation
```

```
cat("\nTetrachoric r: ", round(tetcor(binaryData)$r[1,2], 2))

## calculate Quasi-tetrachoric correlation
cat("\nQuasi-tetrachoric r: ", round(tetcorQuasi(binaryData), 2))
```

Thurstone41 *Multi-Trait Multi-Method correlation matrix reported by Thurstone and Thurstone (1941).*

Description

The original study assessed a total of 63 variables. However, we report the 9 variables, across 2 tests, used to reproduce the multiple battery factor analyses of Browne (1979).

Usage

```
data(Thurstone41)
```

Format

A 9 by 9 correlation matrix with dimension names

Details

The sample size is $n = 710$.

The following variables were assessed (abbreviations in parentheses): **Variables**:

- **Test #1** (X)
  - Prefixes (Prefix)
  - Suffixes (Suffix)
  - Sentences (Sentences)
  - Chicago Reading Test: Vocabulary (Vocab)
  - Chicago Reading Test: Sentences (Sentence)
- **Test #2** (Y)
  - First and Last Letters (FLLetters)
  - First Letters (Letters)
  - Four-Letter Words (Words)
  - Completion (Completion)
  - Same and Opposite (SameOpposite)

Source

Thurstone, L. L. and Thurstone, T. G. (1941). Factorial studies of intelligence. *Psychometric Monographs, 2*. Chicago: University Chicago Press.

Examples

```
## Load Thurstone & Thurstone's data used by Browne (1979)
data(Thurstone41)
Example1Output <-  faMB(R             = Thurstone41,
                        n             = 710,
                        NB            = 2,
                        NVB           = c(4,5),
                        numFactors    = 2,
                        rotate        = "oblimin",
                        rotateControl = list(standardize = "Kaiser"))

summary(Example1Output, PrintLevel = 2)
```

`ThurstoneBox20` *Factor Pattern and Factor Correlations for Thurstone's 20 hypothetical box attributes.*

Description

Factor Pattern and Factor Correlations for Thurstone's 20 hypothetical box attributes.

Usage

```
data(ThurstoneBox20)
```

Format

This is a list containing the `Loadings` (original factor pattern) and `Phi` matrix (factor correlation matrix) from Thurstone's 20 Box problem (Thurstone, 1940, p. 227). The original 20-variable Box problem contains measurements on the following score functions of box length (x), width (y), and height (z). **Box20** variables:

1. x^2
2. y^2
3. z^2
4. xy
5. xz
6. yz
7. sqrt(x^2 + y^2)
8. sqrt(x^2 + z^2)
9. sqrt(y^2 + z^2)
10. 2x + 2y
11. 2x + 2z
12. 2y + 2z

13. log(x)
14. log(y)
15. log(z)
16. xyz
17. sqrt(x^2 + y^2 + z^2)
18. exp(x)
19. exp(y)
20. exp(z)

Details

Two data sets have been described in the literature as Thurstone's Box Data (or Thurstone's Box Problem). The first consists of 20 measurements on a set of 20 hypothetical boxes (i.e., Thurstone made up the data). Those data are available in **Box20**.

References

Thurstone, L. L. (1940). Current issues in factor analysis. Psychological Bulletin, 37(4), 189. Thurstone, L. L. (1947). Multiple factor analysis. Chicago: University of Chicago Press.

See Also

AmzBoxes, Box20, Box26, GenerateBoxData

Examples

```
data(ThurstoneBox20)
ThurstoneBox20
```

ThurstoneBox26 *Factor Pattern Matrix for Thurstone's 26 box attributes.*

Description

Factor Pattern Matrix for Thurstone's 26 box attributes.

Usage

```
data(ThurstoneBox26)
```

Format

The original factor pattern (3 graphically rotated centroid factors) from Thurstone's 26 hypothetical box data as reported by Thurstone (1947, p. 371). The so-called Thurstone invariant box problem contains measurements on the following 26 functions of length (x), width (y), and height (z). **Box26** variables:

1. x
2. y
3. z
4. xy
5. xz
6. yz
7. x^2 * y
8. x * y^2
9. x^2 * z
10. x * z^ 2
11. y^2 * z
12. y * z^2
13. x/y
14. y/x
15. x/z
16. z/x
17. y/z
18. z/y
19. 2x + 2y
20. 2x + 2z
21. 2y + 2z
22. sqrt(x^2 + y^2)
23. sqrt(x^2 + z^2)
24. sqrt(y^2 + z^2)
25. xyz
26. sqrt(x^2 + y^2 + z^2)

Details

Two data sets have been described in the literature as Thurstone's Box Data (or Thurstone's Box Problem). The first consists of 20 measurements on a set of 20 hypothetical boxes (i.e., Thurstone made up the data). Those data are available in **Box20**. The second data set was collected by Thurstone to provide an illustration of the invariance of simple structure factor loadings. In his classic textbook on multiple factor analysis (Thurstone, 1947), Thurstone states that "[m]easurements of a random collection of thirty boxes were actually made in the Psychometric Laboratory and recorded

for this numerical example. The three dimensions, x, y, and z, were recorded for each box. A list of 26 arbitrary score functions was then prepared" (p. 369). The raw data for this example were not published. Rather, Thurstone reported a correlation matrix for the 26 score functions (Thurstone, 1947, p. 370). Note that, presumably due to rounding error in the reported correlations, the correlation matrix for this example is non positive definite. This file includes the rotated centroid solution that is reported in his book (Thurstone, 1947, p. 371).

References

Thurstone, L. L. (1947). Multiple factor analysis. Chicago: University of Chicago Press.

See Also

Box20, AmzBoxes

Examples

```
data(ThurstoneBox26)
ThurstoneBox26
```

---

tkl *Optimize TKL parameters to find a solution with target RMSEA and CFI values*

Description

Find the optimal W matrix such that the RMSEA and CFI values are as close as possible to the user-specified target values.

Usage

```
tkl(mod, target_rmsea = NULL, target_cfi = NULL, tkl_ctrl = list())
```

Arguments

mod	A simFA model object.
target_rmsea	(scalar) Target RMSEA value.
target_cfi	(scalar) Target CFI value.
tkl_ctrl	(list) A control list containing the following TKL-specific arguments:

- weights (vector) Vector of length two indicating how much weight to give RMSEA and CFI, e.g., `c(1,1)` (default) gives equal weight to both indices; `c(1,0)` ignores the CFI value.
- v_start (scalar) Starting value to use for ν, the proportion of uniqueness variance reallocated to the minor common factors. Note that only `v` as a proportion of the unique (not total) variance is supported in this function.
- eps_start (scalar) Starting value to use for ϵ, which controls how common variance is distributed among the minor common factors.

- v_start (vector) A vector of length two specifying the lowest and highest acceptable values of ν.
- eps_start (vector) A vector of length two specifying the lowest and highest acceptable values of ϵ.
- NMinorFac (scalar) Number of minor common factors.
- WmaxLoading (scalar) Threshold value for `NWmaxLoading`.
- NWmaxLoading (scalar) Maximum number of absolute loadings $\geq$ `WmaxLoading` in any column of W.
- penalty (scalar) Penalty applied to objective function if the `NmaxLoading` condition isn't satisfied.
- optim_type (character) Which optimization function to use, `optim` or `ga`? `optim` is faster, but might not converge in some cases. If `optim` doesn't converge, `ga` will be used as a fallback option.
- max_tries (numeric) How many times to restart optimization with new start parameter values if optimization doesn't converge?
- factr (numeric) controls the convergence of the "L-BFGS-B" method. Convergence occurs when the reduction in the objective is within this factor of the machine tolerance. Default is 1e7, that is a tolerance of about 1e-8. (when using `optim`).
- maxit (number) Maximum number of iterations to use (when using `optim`).
- ncores (boolean/scalar) Controls whether `ga` optimization is done in parallel. If `TRUE`, uses the maximum available number of processor cores. If `FALSE`, does not use parallel processing. If an integer is provided, that's how many processor cores will be used (if available).

Details

This function attempts to find optimal values of the TKL parameters ν and ϵ such that the resulting correlation matrix with model error (Σ) has population RMSEA and/or CFI values that are close to the user-specified values. It is important to note that solutions are not guaranteed to produce RMSEA and CFI values that are reasonably close to the target values; in fact, some combinations of RMSEA and CFI will be difficult or impossible to obtain for certain models (see Lai & Green, 2016). It can be particularly difficult to find good solutions when additional restrictions are placed on the minor factor loadings (i.e., using the `WmaxLoading` and `NWmaxLoading` arguments).

Optimization is fastest when the `optim_type = optim` optimization method is chosen. This indicates that optimization should be done using the `L-BFGS-B` algorithm implemented in the `optim` function. However, this method can sometimes fail to find a solution. In that case, I recommend setting `optim_type = ga`, which indicates that a genetic algorithm (implemented in `ga`) will be used. This method takes longer than `optim` but is more likely to find a solution.

References

Tucker, L. R., Koopman, R. F., & Linn, R. L. (1969). Evaluation of factor analytic research procedures by means of simulated correlation matrices. *Psychometrika*, *34*(4), 421–459.

TR *Estimate the parameters of the Taylor-Russell function.*

Description

A Taylor-Russell function can be computed with any three of the following four variables: the Base Rate (BR); the Selection Ratio (SR); the Criterion Validity (CV) and the Positive Predictive Value (PPV). The `TR()` function will compute a Taylor Russell function when given any three of these parameters and estimate the remaining parameter.

Usage

```
TR(BR = NULL, SR = NULL, CV = NULL, PPV = NULL, PrintLevel = 1, Digits = 3)
```

Arguments

`BR`	(numeric): The Base Rate of successful criterion performance (i.e., within the target population, the proportion of individuals who can successfully execute the job demands).
`SR`	(numeric): The Selection Ratio. A real number between 0 and 1 that denotes the test selection ratio (i.e., the proportion of hired candidates from the target population).
`CV`	(numeric) The correlation (Criterion Validity) between the selection test and a measure of job performance.
`PPV`	(numeric): The Positive Predicted Value. The PPV denotes the probability that a hired candidate has the necessary skills to succeed on the job.
`PrintLevel`	(integer): If `PrintLevel = 0` then no output will be printed to screen. If `PrintLevel = 1` then a brief summary of output is printed to screen. Default `PrintLevel = 1`.
`Digits`	(integer) Controls the number of significant digits in the printed output.

Details

When any three of the main program arguments (BR, SR, CV, PPV) are specified (with the remaining argument given a NULL value), `TR()` will calculate the model-implied value for the remaining variable. It will also compute the test Sensitivity (defined as the probability that a qualified individual will be hired) and test Specificity (defined as the probability that an unqualified individual will not be hired), the True Positive rate, the False Positive rate, the True Negative rate, and the False Negative rate.

Value

- **BR** The base rate.
- **SR** The selection ratio.
- **CV** The criterion validity.

- **PPV** The positive predictive value.
- **Sensitivity** The test sensitivity rate.
- **Specificity** The test specificity rate.
- **TP** The selection True Positive rate.
- **FP** The selection False Positive rate.
- **TN** The selection True Negative rate.
- **FN** The selection False Negative rate.

Author(s)

- Niels G. Waller (nwaller@umn.edu)

References

- Taylor, H. C. & Russell, J. (1939). The relationship of validity coefficients to the practical effectiveness of tests in selection: Discussion and tables. *Journal of Applied Psychology, 23*, 565–578.

Examples

```
## Example 1:
       TR(BR = .3,
          SR = NULL,
          CV = .3,
          PPV = .5,
          PrintLevel = 1,
          Digits = 3)

## Example 2:

       TR(BR = NULL,
          SR = .1012,
          CV = .3,
          PPV = .5,
          PrintLevel = 1,
          Digits = 3)

## Example 3: A really bad test!
 # If the BR > PPV then the actual test
 # validity is zero. Thus, do not use the test!

       TR(BR = .50,
          SR = NULL,
          CV = .3,
          PPV = .25,
          PrintLevel = 1,
          Digits = 3)
```

vcos *Compute the Cosine Between Two Vectors*

Description

Compute the cosine between two vectors.

Usage

```
vcos(x, y)
```

Arguments

x	A p x 1 vector.
y	A p x 1 vector.

Value

`Cosine between x and y`

Examples

```
x <- rnorm(5)
y <- rnorm(5)
vcos(x, y)
```

vnorm *Norm a Vector to Unit Length*

Description

Norm a vector to unit length.

Usage

```
vnorm(x)
```

Arguments

x	An n by 1 vector.

Value

the scaled (i.e., unit length) input vector

Author(s)

Niels Waller

Examples

```
x <- rnorm(5)
v <- vnorm(x)
print(v)
```

`VolElliptope` *Compute the volume of the elliptope of possible correlation matrices of a given dimension.*

Description

Compute the volume of the elliptope of possible correlation matrices of a given dimension.

Usage

```
VolElliptope(NVar)
```

Arguments

`NVar`	(integer) The size of each correlation matrix in the elliptope. For instance, if we are interested in the volume of the space of all possible 5 x 5 correlation matrices then `NVar = 5`.

Value

`VolElliptope` returns the following objects:

- **VolElliptope** (numeric) The volume of the elliptope.
- **VolCube**: (numeric) The volume of the embedding hyper-cube.
- **PrcntCube** (numeric) The percent of the hyper-cube that is occupied by the elliptope. `PrcntCube = 100 x VolElliptope/VolCube`.

Author(s)

Niels G. Waller

References

Joe, H. (2006). Generating random correlation matrices based on partial correlations. *Journal of Multivariate Analysis*, *97* (10), 2177–2189.

Hürlimann, W. (2012). Positive semi-definite correlation matrices: Recursive algorithmic generation and volume measure. *Pure Mathematical Science, 1* (3), 137–149.

Examples

```
# Compute the volume of a 5 x 5 correlation matrix.

VolElliptope(NVar = 5)
```

---

wb *Wu & Browne model error method*

Description

Generate a population correlation matrix using the model described in Wu and Browne (2015).

Usage

```
wb(mod, target_rmsea, wb_mod = NULL, adjust_target = TRUE)
```

Arguments

mod	A 'fungible::simFA()' model object.
target_rmsea	(scalar) Target RMSEA value.
wb_mod	('lm' object) An optional 'lm' object used to find a target RMSEA value that results in solutions with RMSEA values close to the desired value. Note that if no 'wb_mod' is provided, a model will be estimated at run time. If many population correlation matrices are going to be simulated using the same model, it will be considerably faster to estimate 'wb_mod' ahead of time. See also 'get_wb_mod()'.
adjust_target	(TRUE; logical) Should the target_rmsea value be adjusted to ensure that solutions have RMSEA values that are close to the provided target RMSEA value? Defaults to TRUE and should stay there unless you have a compelling reason to change it.

Details

The Wu and Browne method generates a correlation matrix with model error (Σ) using

$$(\Sigma|\Omega)\ IW(m, m\Omega),$$

where $m = 1/\epsilon^2$ is a precision parameter related to RMSEA (ϵ) and $IW(m, m\Omega)$ denotes an inverse Wishart distribution. Note that *there is no guarantee that the RMSEA will be very close to the target RMSEA*, particularly when the target RMSEA value is large. Based on experience, the method tends to give solutions with RMSEA values that are larger than the target RMSEA values. Therefore, it might be worth using a target RMSEA value that is somewhat lower than what is actually needed. Alternatively, the get_wb_mod function can be used to estimate a coefficient to shrink the target RMSEA value by an appropriate amount so that the solution RMSEA values are close to the (nominal) target values.

Author(s)

Justin Kracht <krach018@umn.edu>

References

Wu, H., & Browne, M. W. (2015). Quantifying adventitious error in a covariance structure as a random effect. *Psychometrika*, *80*(3), 571–600. <https://doi.org/10/gjrkc4>

Examples

```
# Specify a default model using simFA()
mod <- fungible::simFA(Seed = 42)

set.seed(42)
wb(mod, target_rmsea = 0.05)
```

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