

Package ‘EFAutilities’

September 19, 2020

Type Package

Title Utility Functions for Exploratory Factor Analysis

Version 2.1.1

Date 2020-08-23

Author Guangjian Zhang, Ge Jiang, Minami Hattori, Lauren Trichtinger

Maintainer Guangjian Zhang <gzhang3@nd.edu>

Depends R (>= 2.10)

Description A number of utility function for exploratory factor analysis are included in this package. In particular, it computes standard errors for parameter estimates and factor correlations under a variety of conditions.

License GPL-2

LazyLoad yes

Imports GPArotation, plyr, graphics, stats, utils, MASS, mvtnorm

RoxygenNote 7.1.1

NeedsCompilation yes

Repository CRAN

Date/Publication 2020-09-19 19:20:03 UTC

Suggests knitr, rmarkdown

VignetteBuilder knitr

Encoding UTF-8

R topics documented:

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Align.Matrix

*Factor Alignment***Description**

The function is to align a factor solution according to an order matrix. The output matrix is a $(p+m+1)$ by m matrix, where the first p rows are factor loadings of the best match, the next m rows are factor correlations of the best match, and the last row contains the sums of squared deviations for the best match and the second best match. The difference between the best match and the second best match could be considered as a confidence on the success of the aligning procedure (a computationally more efficient method exists for some conditions; whenever this occurs we only report that of the best match).

Usage

```
Align.Matrix(Order.Matrix, Input.Matrix, Weight.Matrix=NULL)
```

Arguments

Order.Matrix	A p by m matrix: p is the number of manifest variables and m is the number of latent factors
Input.Matrix	A $(p+m)$ by m matrix, the first p rows are factor loadings, the last m rows are factor correlations
Weight.Matrix	A p by m matrix that assigns weight to the order matrix: NULL (default)

Details

Align.Matrix is an R function to reflect and interchange columns of Input.Matrix to match those of Order.Matrix. Because it considers all possible permutations of columns of Input.Matrix, the best match in terms of the smallest sum of squared deviations between these two matrices can always be found. It may be slow if there are too many factors.

Author(s)

Guangjian Zhang

Examples

```
#Order Matrix
A <- matrix(c(0.8,0.7,0,0,0,0.8,0.7),nrow=4,ncol=2)

#Input.Matrix
B <-matrix(c(0,0,-0.8,-0.7,1,-0.2,0.8,0.7,0,0,-0.2,1),nrow=6,ncol=2)

Align.Matrix(Order.Matrix=A, Input.Matrix=B)
```

BFI228

Ordinal Data of the Big Five Inventory (BFI)

Description

The BFI228 is part of the study on personality and relationship satisfaction (Luo, 2005). The participants were 228 undergraduate students at a large public university in the US. The data were participants' self ratings on the 44 items of the Big Five Inventory (John, Donahue, & Kentle, 1991). These items are Likert variables: disagree strongly (1), disagree a little (2), neither agree nor disagree (3), agree a little (4), and agree strongly (5).

Usage

```
data(BFI228)
```

Format

The format is a n by p matrix of ordinal variables, where n is the number of participants (228) and p is the number of manifest variables (44).

Details

The variables were ordered such that indicators of the same factor are grouped together. Note that reverse-coded items are denoted by '_R'.

V01 to V08 are variables for the factor extraversion: talkative, reserved_R, fullenergy, enthusiastic, quiet_R, assertive, shy_R, and outgoing.

V09 to V17 are variables for the factor agreeableness: findfault_R, helpful, quarrels_R, forgiving, trusting, cold_R, considerate, rude_R, and cooperative.

V18 to V26 are variables for the factor conscientiousness are: thorough, careless_R, reliable, disorganized_R, lazy_R, persevere, efficient, plans, and distracted_R.

V27 to V34 are variables for the factor neuroticism: blue, relaxed_R, tense, worries, emostable_R, moody, calm_R, and nervous.

V35 to V44 are variables for the factor openness: ideas, curious, ingenious, imagination, inventive, artistic, routine_R, reflect, nonartistic, and sophisticated.

References

John, O. P., Donahue, E. M., & Kentle, R. L. (1991). The Big Five Inventory versions 4a and 54. Berkeley, CA: University of California, Berkeley, Institute of Personality and Social Research.

Luo, S. (2005): unpublished study on personality traits and relationship satisfaction.

CPAI537

Composite Scores of the Chinese Personality Assessment Inventory (CPAI)

Description

CPAI537 is part of a big survey study on marital satisfaction (Luo et al., 2008). The participants were 537 urban Chinese couples in the first year of their marriage. Included here are 28 composite scores of the CPAI (Cheung et al., 1996) for the 537 wives.

Usage

```
data(CPAI537)
```

Format

The format is a n by p matrix, where n is the number of participants (537) and p is the number of manifest variables (28).

Details

The column names stand for the following variable names:

Nov - Novelty
 Div - Diversity
 Dit - Diverse thinking
 LEA - Leadership
 L_A - Logical orientation vs affective orientation
 AES - Aesthetics
 E_I - Extroversion-Introversion
 ENT - Enterprise
 RES - Responsibility
 EMO - Emotionality
 I_S - Inferiority vs. self-acceptance
 PRA - Practical mindedness
 O_P - Optimistic vs. pessimistic
 MET - Meticulousness
 FAC - Face
 I_E - Internal control vs. external control
 FAM - Family orientation
 DEF - Defensiveness
 G_M - Graciousness vs. meanness
 INT - Interpersonal tolerance
 S_S - Self orientation vs. social orientation
 V_S - Veraciousness vs. slickness
 T_M - Traditionalism vs. modernity
 REN - Relationship orientation
 SOC - Social sensitivity

DIS - Discipline
 HAR - Harmony
 T_E - Thrift vs. extravagance

References

- Cheung, F. M., Leung, K., Fan, R., Song, W., Zhang, J., & Zhang, J. (1996). Development of the Chinese Personality Assessment Inventory (CPAI). *Journal of Cross-Cultural Psychology*, 27, 181-199.
- Luo, S., Chen, H., Yue, G., Zhang, G., Zhaoyang, R., & Xu, D. (2008). Predicting marital satisfaction from self, partner, and couple characteristics: Is it me, you, or us? *Journal of Personality*, 76, 1231-1266.

 efa

Exploratory Factor Analysis

Description

Performs exploratory factor analysis under a variety of conditions. In particular, it provides standard errors for rotated factor loadings and factor correlations for normal variables, nonnormal continuous variables, and Likert scale variables with and without model error.

Usage

```
efa(x=NULL, factors=NULL, covmat=NULL, acm=NULL, n.obs=NULL, dist='normal',
fm='ols', mtest = TRUE, rtype='oblique', rotation='CF-varimax', normalize=FALSE,
maxit=1000, geomin.delta=NULL, MTarget=NULL, MWeight=NULL, PhiWeight = NULL,
PhiTarget = NULL, useorder=FALSE, se='sandwich', LConfid=c(0.95,0.90),
CItpe='pse', Ib=2000, mnames=NULL, fnames=NULL, merror='YES', wxt2 = 1e0)
```

Arguments

x	The raw data: an n-by-p matrix where n is number of participants and p is the number of manifest variables.
factors	The number of factors m: specified by the researcher; the default one is the Kaiser rule which is the number of eigenvalues of covmat larger than one.
covmat	A p-by-p manifest variable correlation matrix.
acm	A p(p-1)/2 by p(p-1)/2 asymptotic covariance matrix of correlations: specified by the researcher.
n.obs	The number of participants used in calculating the correlation matrix. This is not required when the raw data (x) is provided.
dist	Manifest variable distributions: 'normal'(default), 'continuous', 'ordinal' and 'ts'. 'normal' stands for normal distribution. 'continuous' stands for nonnormal continuous distributions. 'ordinal' stands for Likert scale variable. 'ts' stands for distributions for time-series data.

fm	Factor extraction methods: 'ols' (default) and 'ml'
mtest	Whether the test statistic is computed: TRUE (default) and FALSE
rtype	Factor rotation types: 'oblique' (default) and 'orthogonal'. Factors are correlated in 'oblique' rotation, and they are uncorrelated in 'orthogonal' rotation.
rotation	Factor rotation criteria: 'CF-varimax' (default), 'CF-quartimax', 'CF-equamax', 'CF-facparsim', 'CF-parsimax', 'target', and 'geomin'. These rotation criteria can be used in both orthogonal and oblique rotation. In addition, a fifth rotation criterion 'xtarget' (extended target) rotation is available for oblique rotation. The extended target rotation allows targets to be specified on both factor loadings and factor correlations.
normalize	Row standardization in factor rotation: FALSE (default) and TRUE (Kaiser standardization).
maxit	Maximum number of iterations in factor rotation: 1000 (default)
geomin.delta	The controlling parameter in Geomin rotation, 0.01 as the default value.
MTarget	The p-by-m target matrix for the factor loading matrix in target rotation and xtarget rotation.
MWeight	The p-by-m weight matrix for the factor loading matrix in target rotation and xtarget rotation. Optional
PhiWeight	The m-by-m target matrix for the factor correlation matrix in xtarget rotation. Optional
PhiTarget	The m-by-m weight matrix for the factor correlation matrix in xtarget rotation
useorder	Whether an order matrix is used for factor alignment: FALSE (default) and TRUE
se	Methods for estimating standard errors for rotated factor loadings and factor correlations, 'information', 'sandwich', 'bootstrap', and 'jackknife'. For normal variables and ml estimation, the default method is 'information'. For all other situations, the default method is 'sandwich'. In addition, the 'bootstrap' and 'jackknife' methods require raw data.
LConfid	Confidence levels for model parameters (factor loadings and factor correlations) and RMSEA, respectively: c(.95, .90) as default.
CItype	Type of confidence intervals: 'pse' (default) or 'percentile'. CIs with 'pse' are based on point and standard error estimates; CIs with 'percentile' are based on bootstrap percentiles.
Ib	The number of bootstrap samples when se='bootstrap': 2000 (default)
mnames	Names of p manifest variables: Null (default)
fnames	Names of m factors: Null (default)
merror	Model error: 'YES' (default) or 'NO'. In general, we expect our model is a parsimonious representation to the complex real world. Thus, some amount of model error is unavoidable. When merror = 'NO', the efa model is assumed to fit perfectly in the population.
wxt2	The relative weight for factor correlations in 'xtarget' (extended target) rotation: 1 (default)

Details

The function `efa` conducts exploratory factor analysis (EFA) (Gorsuch, 1983) in a variety of conditions. Data can be normal variables, non-normal continuous variables, and Likert variables. Our implementation of EFA includes three major steps: factor extraction, factor rotation, and estimating standard errors for rotated factor loadings and factor correlations.

Factors can be extracted using two methods: maximum likelihood estimation (`ml`) and ordinary least squares (`ols`). These factor loading matrices are referred to as unrotated factor loading matrices. The `ml` unrotated factor loading matrix is obtained using `factanal`. The `ols` unrotated factor loading matrix is obtained using `optim` where the residual sum of squares is minimized. The starting values for communalities are squared multiple correlations (SMCs). The test statistic and model fit measures are provided.

Seven rotation criteria (`CF-varimax`, `CF-quartimax`, `'CF-equamax'`, `'CF-facparsim'`, `'CF-parsimax'`, `geomin`, and `target`) are available for both orthogonal rotation and oblique rotation (Browne, 2001). Additionally, a new rotation criteria, `xtarget`, can be specified for oblique rotation. The factor rotation methods are achieved by calling functions in the package `GPArotation`. `CF-varimax`, `CF-quartimax`, `CF-equamax`, `CF-facparsim`, and `CF-parsimax` are members of the Crawford-Ferguson family (Crawford, & Ferguson, 1970) whose kappa is $1/p$, 0 , $m/2p$, 1 , and $(m-1)/(p+m-2)$ respectively where p is the number of manifest variables and m is the number of factors. `CF-varimax` and `CF-quartimax` are equivalent to `varimax` and `quartimax` rotation in orthogonal rotation. The equivalence does not carry over to oblique rotation, however. Although `varimax` and `quartimax` often fail to give satisfactory results in oblique rotation, `CF-varimax` and `CF-quartimax` do give satisfactory results in many oblique rotation applications. `CF-quartimax` rotation is equivalent to direct oblimin rotation for oblique rotation. The target matrix in target rotation can either be a fully specified matrix or a partially specified matrix. Target rotation can be considered as a procedure which is located between EFA and CFA. In CFA, if a factor loading is specified to be zero, its value is fixed to be zero; in target rotation, if a factor loading is specified to be zero, it is made to zero as close as possible. In `xtarget` rotation, target values can be specified on both factor loadings and factor correlations.

Confidence intervals for rotated factor loadings and correlation matrices are constructed using point estimates and their standard error estimates. Standard errors for rotated factor loadings and factor correlations are computed using a sandwich method (Ogasawara, 1998; Yuan, Marshall, & Bentler, 2002), which generalizes the augmented information method (Jennrich, 1974). The sandwich standard error are consistent estimates even when the data distribution is non-normal and model error exists in the population. Sandwich standard error estimates require a consistent estimate of the asymptotic covariance matrix of manifest variable correlations. Such estimates are described in Browne & Shapiro (1986) for non-normal continuous variables and in Yuan & Schuster (2013) for Likert variables. Estimation of the asymptotic covariance matrix of polychoric correlations is slow if the EFA model involves a large number of Likert variables.

When manifest variables are normally distributed (`dist = 'normal'`) and model error does not exist (`merror = 'NO'`), the sandwich standard errors are equivalent to the usual standard error estimates, which come from the inverse of the information matrix. The information standard error estimates in EFA is available `CEFA` (Browne, Cudeck, Tateneni, & Mels, 2010) and `SAS Proc Factor`. `Mplus` (Muthen & Muthen, 2015) also implemented a version of sandwich standard errors for EFA, which are robust against non-normal distribution but not model error. Sandwich standard errors computed in `efa` tend to be larger than those computed in `Mplus`. Sandwich standard errors for non-normal distributions and with model error are equivalent to the infinitesimal jackknife standard errors described in Zhang, Preacher, & Jennrich (2012). Two computationally intensive standard

error methods (`se='bootstrap'` and `se='jackknife'`) are also implemented. More details on standard error estimation methods in EFA are documented in Zhang (2014).

Value

An object of class `efa`, which includes:

<code>details</code>	summary information about the analysis such as number of manifest variables, number of factors, sample size, factor extraction method, factor rotation method, target values for target rotation and <code>xtarget</code> rotation, and levels for confidence intervals.
<code>unrotated</code>	the unrotated factor loading matrix
<code>fdiscrepancy</code>	discrepancy function value used in factor extraction
<code>convergence</code>	whether the factor extraction stage converged successfully, successful convergence indicated by 0
<code>heywood</code>	the number of heywood cases
<code>R0</code>	the sample correlation matrix
<code>Phat</code>	the model implied correlation matrix
<code>Residual</code>	the residual correlation matrix
<code>rotated</code>	the rotated factor loadings
<code>Phi</code>	the rotated factor correlations
<code>rotatedse</code>	the standard errors for rotated factor loadings
<code>Phise</code>	the standard errors for rotated factor correlations
<code>ModelF</code>	the test statistic and measures of model fit
<code>rotatedlow</code>	the lower bound of confidence levels for factor loadings
<code>rotatedupper</code>	the upper bound of confidence levels for factor loadings
<code>Philow</code>	the lower bound of confidence levels for factor correlations
<code>Phiupper</code>	the lower bound of confidence levels for factor correlations

Author(s)

Guangjian Zhang, Ge Jiang, Minami Hattori, and Lauren Trichtinger

References

- Browne, M. W. (2001). An overview of analytic rotation in exploratory factor analysis. *Multivariate Behavioral Research*, 36, 111-150.
- Browne, M. W., Cudeck, R., Tateneni, K., & Mels, G. (2010). CEFA 3.04: Comprehensive Exploratory Factor Analysis. Retrieved from <http://faculty.psy.ohio-state.edu/browne/>.
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Jennrich, R. I. (1974). Simplified formula for standard errors in maximum-likelihood factor analysis. *British Journal of Mathematical and Statistical Psychology*, 27, 122-131.

Jennrich, R. I. (2002). A simple general method for oblique rotation. *Psychometrika*, 67, 7-19.

Muthen, L. K., & Muthen, B. O. (1998-2015). *Mplus user's guide* (7th ed.). Los Angeles, CA: Muthen & Muthen.

Ogasawara, H. (1998). Standard errors of several indices for unrotated and rotated factors. *Economic Review*, Otaru University of Commerce, 49(1), 21-69.

Yuan, K., Marshall, L. L., & Bentler, P. M. (2002). A unified approach to exploratory factor analysis with missing data, nonnormal data, and in the presence of outliers. *Psychometrika*, 67, 95-122.

Yuan, K.-H., & Schuster, C. (2013). Overview of statistical estimation methods. In T. D. Little (Ed.), *The Oxford handbook of quantitative methods* (pp. 361-387). New York, NY: Oxford University Press.

Zhang, G. (2014). Estimating standard errors in exploratory factor analysis. *Multivariate Behavioral Research*, 49, 339-353.

Zhang, G., Preacher, K. J., & Jennrich, R. I. (2012). The infinitesimal jackknife with exploratory factor analysis. *Psychometrika*, 77, 634-648.

Examples

#Examples using the data sets included in the packages:

```
data("CPAI537") # Chinese personality assessment inventory (N = 537)
```

```
#1a) normal, ml, oblique, CF-varimax, information, merror='NO'
```

```
#res1 <- efa(x=CPAI537,factors=4, fm='ml')
```

```
#res1
```

```
#1b) confidence intervals: normal, ml, oblique, CF-varimax, information, merror='NO'
```

```
#res1$rotatedlow # lower bound for 95 percent confidence intervals for factor loadings
```

```
#res1$rotatedupper # upper bound for 95 percent confidence intervals for factor loadings
```

```
#res1$Philow # lower bound for 95 percent confidence intervals for factor correlations
```

```
#res1$Phiupper # upper bound for 95 percent confidence intervals for factor correlations
```

```
#2) continuous, ml, oblique, CF-quartimax, sandwich, merror='YES'
```

```
#efa(x=CPAI537, factors=4, dist='continuous',fm='ml',rotation='CF-quartimax', merror='YES')
```

```
#3) continuous, ml, oblique, CF-equamax, sandwich, merror='YES'
```

```
#efa(x = CPAI537, factors = 4, dist = 'continuous',
```

```
#fm = 'ml', rotation = 'CF-equamax', merror = 'YES')
```

```
#4) continuous, ml, oblique, CF-facparism, sandwich, merror='YES'
```

```
#efa(x = CPAI537, factors = 4, fm = 'ml',
```

```
#dist = 'continuous', rotation = 'CF-facparsim', merror='YES')
```

```

#5)continuous, ml, orthogonal, CF-parsimax, sandwich, merror='YES'
#efa(x = CPAI537, factors = 4, fm = 'ml', rtype = 'orthogonal',
#dist = 'continuous', rotation = 'CF-parsimax', merror = 'YES')

#6) continuous, ols, orthogonal, geomin, sandwich, merror='Yes'
#efa(x=CPAI537, factors=4, dist='continuous',
#rtype= 'orthogonal',rotation='geomin', merror='YES')

#7) ordinal, ols, oblique, CF-varimax, sandwich, merror='Yes'
#data("BFI228")      # Big-five inventory (N = 228)
# For ordinal data, estimating SE with the sandwich method
# can take time with a dataset with 44 variables
#reduced2 <- BFI228[,1:17] # extracting 17 variables corresponding to the first 2 factors
#efa(x=reduced2, factors=2, dist='ordinal', merror='YES')

#8) continuous, ml, oblique, Cf-varimax, jackknife
#efa(x=CPAI537,factors=4, dist='continuous',fm='ml', merror='YES', se= 'jackknife')

#9) extracting the test statistic
#res2 <-efa(x=CPAI537,factors=4)
#res2
#res2$ModelF$f.stat

#10) extended target rotation, ml
# # The data come from Engle et al. (1999) on memory and intelligence.
# datcor <- matrix(c(1.00, 0.51, 0.47, 0.35, 0.37, 0.38, 0.28, 0.34,
#                   0.51, 1.00, 0.32, 0.35, 0.35, 0.31, 0.24, 0.28,
#                   0.47, 0.32, 1.00, 0.43, 0.31, 0.31, 0.29, 0.32,
#                   0.35, 0.35, 0.43, 1.00, 0.54, 0.44, 0.19, 0.27,
#                   0.37, 0.35, 0.31, 0.54, 1.00, 0.59, 0.05, 0.19,
#                   0.38, 0.31, 0.31, 0.44, 0.59, 1.00, 0.20, 0.21,
#                   0.28, 0.24, 0.29, 0.19, 0.05, 0.20, 1.00, 0.68,
#                   0.34, 0.28, 0.32, 0.27, 0.19, 0.21, 0.68, 1.00),
#                   ncol = 8)
#
# # Prepare target and weight matrices for lambda -----
# MTarget1 <- matrix(c(9, 0, 0,
#                     9, 0, 0,
#                     9, 0, 0, # 0 corresponds to targets
#                     0, 9, 0,
#                     0, 9, 0,
#                     0, 9, 0,
#                     0, 0, 9,
#                     0, 0, 9), ncol = 3, byrow = TRUE)
# MWeight1 <- matrix(0, ncol = 3, nrow = 8)
# MWeight1[MTarget1 == 0] <- 1 # 1 corresponds to targets
#
# # Prepare target and weight matrices for phi -----
# PhiTarget1 <- matrix(c(1, 9, 9,
#                       9, 1, 0,
#                       9, 0, 1), ncol = 3)
# PhiWeight1 <- matrix(0, ncol = 3, nrow = 3)
# PhiWeight1[PhiTarget1 == 0] <- 1

```

```
#
# # Conduct extended target rotation -----
# mod.xtarget <- efa(covmat = datcor, factors = 3, n.obs = 133,
#                   rotation = 'xtarget', fm = 'ml', useorder = T,
#                   MTarget = MTarget1, MWeight = MWeight1,
#                   PhiTarget = PhiTarget1, PhiWeight = PhiWeight1)
# mod.xtarget
#
```

efaMR

Exploratory Factor Analysis with Multiple Rotations

Description

The function compares EFA solutions from multiple random starts or from multiple rotation criteria.

Usage

```
efaMR(x=NULL, factors=NULL, covmat=NULL, n.obs=NULL,
      dist='normal', fm='ols', rtype='oblique', rotation = 'CF-varimax',
      input.A=NULL, additionalRC = NULL,
      nstart = 100, compare = 'First', plot = T, cex = .5,
      normalize = FALSE, geom.in.delta = .01,
      MTarget = NULL, MWeight = NULL, PhiTarget = NULL, PhiWeight = NULL,
      useorder = FALSE, mnames = NULL, fnames = NULL, wxt2 = 1)
```

Arguments

x	The raw data: an n-by-p matrix where n is number of participants and p is the number of manifest variables.
factors	The number of factors m: specified by a researcher; the default one is the Kaiser rule which is the number of eigenvalues of covmat larger than one.
covmat	A p-by-p manifest variable correlation matrix.
n.obs	The number of participants used in calculating the correlation matrix. This is not required when the raw data (x) is provided.
dist	Manifest variable distributions: 'normal'(default), 'continuous', 'ordinal' and 'ts'. 'normal' stands for normal distribution. 'continuous' stands for nonnormal continuous distributions. 'ordinal' stands for Likert scale variable. "ts" stands for distributions for time-series data.
fm	Factor extraction methods: 'ols' (default) and 'ml'
rtype	Factor rotation types: 'oblique' (default) and 'orthogonal'. Factors are correlated in 'oblique' rotation, and they are uncorrelated in 'orthogonal' rotation.

rotation	Factor rotation criteria: 'CF-varimax' (default), 'CF-quartimax', 'CF-equamax', 'CF-facparsim', 'CF-parsimax', 'target', and 'geomin'. These rotation criteria can be used in both orthogonal and oblique rotation. In addition, a fifth rotation criterion 'xtarget' (extended target) rotation is available for oblique rotation. The extended target rotation allows targets to be specified on both factor loadings and factor correlations.
input.A	A p-by-m unrotated factor loading matrix. It can replace x or covmat as input arguments. Only factor rotation will be conducted; factor extraction will not be conducted.
additionalRC	A string of factor extraction methods against which the main rotation is compared. Required only when nstart = 1. See details.
nstart	The number random orthogonal starts used, with 100 as the default value. With nstart = 1, only one random start is used. See details.
compare	'First' (default) or 'All': The global solution is compared against all local solutions with 'First'; All solutions are compared with each other with 'All'.
plot	Whether a bar graph that shows the number and frequencies of local solutions or not: TRUE (default) and FALSE.
cex	A tuning parameter if the plot is produced: .5 (default)
normalize	Row standardization in factor rotation: FALSE (default) and TRUE (Kaiser standardization).
geomin.delta	The controlling parameter in Geomin rotation, 0.01 as the default value.
Mtarget	The p-by-m target matrix for the factor loading matrix in target rotation or xtarget rotation.
MWeight	The p-by-m weight matrix for the factor loading matrix in target rotation or xtarget rotation.
PhiTarget	The m-by-m target matrix for the factor correlation matrix in xtarget rotation.
PhiWeight	The m-by-m weight matrix for the factor correlation matrix in xtarget rotation.
useorder	Whether an order matrix is used for factor alignment: FALSE (default) and TRUE
mnames	Names of p manifest variables: Null (default)
fnames	Names of m factors: Null (default)
wxt2	The relative weight for factor correlations in 'xtarget' (extended target) rotation: 1 (default)

Details

efaMR performs EFA with multiple rotation using random starts.

Geomin rotation, in particular, is known to produce multiple local solutions; the use of random starts is advised (Hattori, Zhang, & Preacher, 2018).

The p-by-m unrotated factor loading matrix is post-multiplied by an m-by-m random orthogonal matrices before rotation.

The number of random starts can be specified with the default value of nstart = 100. Bar plot that represents frequencies of each solution is provided. If multiple solutions are found, they are compared with each other using congruence coefficient.

If `nstart = 1`, no random start is used. The solution is compared against solutions using additional rotation criterion provided by `additionalRC`.

For example, with `rotation = geomin`, `additionalRC = c('CF-varimax', 'CF-quartimax')`, the `geomin` solution is compared against those with `CF-varimax` and `CF-quartimax`.

Estimation of standard errors and construction of confidence intervals are disabled with the function `efaMR()`. They are available with a function `efa()`.

Author(s)

Minami Hattori, Guangjian Zhang

References

Hattori, M., Zhang, G., & Preacher, K. J. (2017). Multiple local solutions and geomin rotation. *Multivariate Behavioral Research*, 720–731. doi: 10.1080/00273171.2017.1361312

Examples

```
#data("CPAI537")    # Chinese personality assessment inventory (N = 537)

# # Example 1: Oblique geomin rotation with 10 random starts
# res1 <- efaMR(CPAI537, factors = 5, fm = 'ml',
#              rtype = 'oblique', rotation = 'geomin',
#              geomin.delta = .01, nstart = 10)
# res1
# summary(res1)
# res1$MultipleSolutions
# res1$Comparisons

# In practice, we recommend nstart = 100 or more (Hattori, Zhang, & Preacher, 2018).

# Example 2: Oblique geomin rotation (no random starts)
#              compared against CF-varimax and CF-quartimax rotation solutions
# res2 <- efaMR(CPAI537, factors = 5, fm = 'ml',
#              rtype = 'oblique', rotation = 'geomin',
#              additionalRC = c('CF-varimax', 'CF-quartimax'),
#              geomin.delta = .01, nstart = 1)
# res2$MultipleSolutions
# res2$Comparisons

# Example 3: Obtaining multiple solutions from the unrotated factor loading matrix as input
# res3 <- efa(CPAI537, factors = 5, fm = 'ml',
#            rtype = 'oblique', rotation = 'geomin')
# set.seed(2017)
# res3MR <- efaMR(input.A = res3$unrotated, rtype = 'oblique',
#                rotation = 'geomin', geomin.delta = .01)
# res3MR$MultipleSolutions
# res3MR$Comparisons
```

Description

This function fits saturated Structural equation models (SSEM) under a variety of conditions. SSEM re-parameterizes the obliquely rotated factor correlation matrix such that factors can be either endogenous or exogenous. In comparison, all factors are exogenous in exploratory factor analysis. Manifest variables can be normal variables, nonnormal variables, nonnormal continuous variable, Likert scale variables and time series. It also provides standard errors and confidence intervals for rotated factor loadings and structural parameters.

Usage

```
ssem(x=NULL, factors=NULL, exfactors=1, covmat=NULL,
acm=NULL, n.obs=NULL, dist='normal', fm='ml', mtest = TRUE,
rotation='semtarget', normalize=FALSE, maxit=1000, geomin.delta=NULL,
MTarget=NULL, MWeight=NULL, BGWeight = NULL, BGTarget = NULL,
PhiWeight = NULL, PhiTarget = NULL, useorder=TRUE, se='sandwich',
LConfid=c(0.95,0.90), CItype='pse', Ib=2000, mnames=NULL, fnames=NULL,
merror='YES', wxt2 = 1e0)
```

Arguments

x	The raw data: an n-by-p matrix where n is number of participants and p is the number of manifest variables.
factors	The number of factors m: specified by a researcher; the default one is the Kaiser rule which is the number of eigenvalues of covmat larger than one.
exfactors	The number of exogenous factors: 1 (default)
covmat	A p-by-p manifest variable correlation matrix.
acm	A $p(p-1)/2$ by $p(p-1)/2$ asymptotic covariance matrix of correlations: specified by the researcher.
n.obs	The number of participants used in calculating the correlation matrix. This is not required when the raw data (x) is provided.
dist	Manifest variable distributions: 'normal'(default), 'continuous', 'ordinal' and 'ts'. 'normal' stands for normal distribution. 'continuous' stands for nonnormal continuous distributions. 'ordinal' stands for Likert scale variable. 'ts' stands for distributions for time-series data.
fm	Factor extraction methods: 'ml' (default) and 'ols'
mtest	Whether the test statistic is computed: TRUE (default) and FALSE
rotation	Factor rotation criteria: 'semtarget' (default), 'CF-varimax', 'CF-quartimax', 'CF-equamax', 'CF-parsimax', 'CF-facparsim', 'target', and 'geomin'. These rotation criteria can be used in both orthogonal and oblique rotation. In addition, a fifth rotation criterion 'xtarget' (extended target) rotation is available for oblique rotation. The ssem target rotation allows targets to be specified on both factor loadings and factor structural parameters.

normalize	Row standardization in factor rotation: FALSE (default) and TRUE (Kaiser standardization).
maxit	Maximum number of iterations in factor rotation: 1000 (default)
geomin.delta	The controlling parameter in Geomin rotation, 0.01 as the default value.
MTarget	The p-by-m target matrix for the factor loading matrix in target rotation and semtarget rotation.
MWeight	The p-by-m weight matrix for the factor loading matrix in target rotation and semtarget rotation. Optional
BGWeight	The m1-by-m weight matrix for the [Beta Gamma] matrix in semtarget rotation (see details) Optional
BGTarget	The m1-by-m target matrix for the [Beta Gamma] matrix in semtarget rotation where m1 is the number of endogenous factors (see details)
PhiWeight	The m2-by-m2 target matrix for the exogenous factor correlation matrix in semtarget rotation. Optional
PhiTarget	The m2-by-m2 weight matrix for the exogenous factor correlation matrix in semtarget rotation
useorder	Whether an order matrix is used for factor alignment: TRUE (default) and FALSE
se	Methods for estimating standard errors for rotated factor loadings and factor correlations, 'sandwich' (default), 'information', 'bootstrap', and 'jackknife'. The 'bootstrap' and 'jackknife' methods require raw data.
LConfid	Confidence levels for model parameters (rotated factor loadings and structural parameters) and RMSEA, respectively: c(.95, .90) as default.
CItyp	Type of confidence intervals: 'pse' (default) or 'percentile'. CIs with 'pse' are based on point and standard error estimates; CIs with 'percentile' are based on bootstrap percentiles.
Ib	The Number of bootstrap samples when se='bootstrap': 2000 (default)
mnames	Names of p manifest variables: Null (default)
fnames	Names of m factors: Null (default)
merror	Model error: 'YES' (default) or 'NO'. In general, we expect our model is a parsimonious representation to the complex real world. Thus, some amount of model error is unavoidable. When merror = 'NO', the ssem model is assumed to fit perfectly in the population.
wxt2	The relative weight for structural parameters in 'semtarget' rotation: 1 (default)

Details

The function `ssem` conducts saturated structural equation modeling (ssem) in a variety of conditions. Data can be normal variables, non-normal continuous variables, and Likert variables. Our implementation of SSEM includes three major steps: factor extraction, factor rotation, and estimating standard errors for rotated factor loadings and factor correlations.

Factors can be extracted using two methods: maximum likelihood estimation (ml) and ordinary least squares (ols). These factor loading matrices are referred to as unrotated factor loading matrices. The ml unrotated factor loading matrix is obtained using `factanal`. The ols unrotated factor

loading matrix is obtained using `optim` where the residual sum of squares is minimized. The starting values for communalities are squared multiple correlations (SMCs). The test statistic and model fit measures are provided.

Eight rotation criteria (`semtarget`, `CF-varimax`, `CF-quartimax`, `CF-equamax`, `CF-parsimax`, `CF-facparsim`, `target`, and `geomin`) are available for oblique rotation (Browne, 2001). Additionally, a new rotation criteria, `ssemtarget`, can be specified for oblique rotation. The factor rotation methods are achieved by calling functions in the package `GPArotation`. `CF-varimax`, `CF-quartimax`, `CF-equamax`, `CF-parsimax`, and `CF-facparsim` are members of the Crawford-Ferguson family (Crawford, & Ferguson, 1970) whose $\kappa = 1/p$ and $\kappa = 0$, respectively. The target matrix in target rotation can either be a fully specified matrix or a partially specified matrix. Target rotation can be considered as a procedure which is located between EFA and CFA. In CFA, if a factor loading is specified to be zero, its value is fixed to be zero; if target rotation, if a factor loading is specified to be zero, it is made to zero as close as possible. In `xtarget` rotation, target values can be specified on both factor loadings and factor correlations. In `ssemtarget`, target values can be specified for the [Beta | Gamma] matrix where Beta is the regression weights of the endogenous factors on itself and the Gamma is the regression weights of the endogenous factors on the exogenous factors.

Confidence intervals for rotated factor loadings and correlation matrices are constructed using point estimates and their standard error estimates. Standard errors for rotated factor loadings and factor correlations are computed using a sandwich method (Ogasawara, 1998; Yuan, Marshall, & Bentler, 2002), which generalizes the augmented information method (Jennrich, 1974). The sandwich standard error are consistent estimates even when the data distribution is non-normal and model error exists in the population. Sandwich standard error estimates require a consistent estimate of the asymptotic covariance matrix of manifest variable correlations. Such estimates are described in Browne & Shapiro (1986) for non-normal continuous variables and in Yuan & Schuster (2013) for Likert variables. Estimation of the asymptotic covariance matrix of polychoric correlations is slow if the EFA model involves a large number of Likert variables.

When manifest variables are normally distributed (`dist = 'normal'`) and model error does not exist (`merror = 'NO'`), the sandwich standard errors are equivalent to the usual standard error estimates, which come from the inverse of the information matrix. The information standard error estimates in EFA is available `CEFA` (Browne, Cudeck, Tateneni, & Mels, 2010) and `SAS Proc Factor`. `Mplus` (Muthen & Muthen, 2015) also implemented a version of sandwich standard errors for EFA, which are robust against non-normal distribution but not model error. Sandwich standard errors computed in `efa` tend to be larger than those computed in `Mplus`. Sandwich standard errors for non-normal distributions and with model error are equivalent to the infinitesimal jackknife standard errors described in Zhang, Preacher, & Jennrich (2012). Two computationally intensive standard error methods (`se='bootstrap'` and `se='jackknife'`) are also implemented. More details on standard error estimation methods in EFA are documented in Zhang (2014).

Value

An object of class `ssem`, which includes:

<code>details</code>	summary information about the analysis such as number of manifest variables, number of factors, number of endogenous factors, number of exogenous factors, sample size, distribution, factor extraction method, factor rotation method, target values for target rotation, <code>xtarget</code> rotation and <code>ssemtarget</code> rotation, and levels for confidence intervals.
<code>unrotated</code>	the unrotated factor loading matrix

fdiscrepancy	discrepancy function value used in factor extraction
convergence	whether the factor extraction stage converged successfully, successful convergence indicated by 0
heywood	the number of heywood cases
nq	the number of effective parameters
compsi	contains eigenvalues, SMCs, communalities, and unique variances
R0	the sample correlation matrix
Phat	the model implied correlation matrix
Residual	the residual correlation matrix
rotated	the rotated factor loadings
Phi	the rotated factor correlations
BG	the [Beta Gamma] latent regression coefficients
psi	the endogenous residuals
Phi.xi	the exogenous correlation
rotatedse	the standard errors for rotated factor loadings
Phise	the standard errors for rotated factor correlations
BGse	the standard errors for the [Beta Gamma] latent regression coefficients
psise	the standard errors for the endogenous residuals
Phi.xise	the standard errors for the exogenous correlation
ModelF	the test statistic and measures of model fit
rotatedlow	the lower bound of confidence levels for factor loadings
rotatedupper	the upper bound of confidence levels for factor loadings
Philow	the lower bound of confidence levels for factor correlations
Phiupper	the lower bound of confidence levels for factor correlations
BGlower	the lower bound of the [Beta Gamma] latent regression coefficients
BGupper	the upper bound of the [Beta Gamma] latent regression coefficients
psilower	the lower bound of the endogenous residuals
psiupper	the upper bound of the endogenous residuals
Phixilower	the lower bound of the exogenous correlation
Phixiupper	the upper bound of the exogenous correlation

Author(s)

Guangjian Zhang, Minami Hattori, and Lauren Trichtinger

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Examples

```
#cormat <- matrix(c(1, .865, .733, .511, .412, .647, -.462, -.533, -.544,
#                   .865, 1, .741, .485, .366, .595, -.406, -.474, -.505,
#                   .733, .741, 1, .316, .268, .497, -.303, -.372, -.44,
#                   .511, .485, .316, 1, .721, .731, -.521, -.531, -.621,
#                   .412, .366, .268, .721, 1, .599, -.455, -.425, -.455,
#                   .647, .595, .497, .731, .599, 1, -.417, -.47, -.521,
#                   -.462, -.406, -.303, -.521, -.455, -.417, 1, .747, .727,
#                   -.533, -.474, -.372, -.531, -.425, -.47, .747, 1, .772,
#                   -.544, -.505, -.44, -.621, -.455, -.521, .727, .772, 1),
#                 ncol = 9)
```

```
#p <- 9      # a number of manifest variables
```

```

#m <- 3      # a total number of factors

#m1 <- 2     # a number of endogenous variables
#N <- 138    # a sample size

#mvnames <- c("H1_likelihood", "H2_certainty", "H3_amount", "S1_sympathy",
#            "S2_pity", "S3_concern", "C1_controllable", "C2_responsible", "C3_fault")

#fnames <- c('H', 'S', 'C')
# Step 2: Preparing target and weight matrices =====
# a 9 x 3 matrix for lambda; p = 9, m = 3

#MT <- matrix(0, p, m, dimnames = list(mvnames, fnames))

#MT[c(1:3,6),1] <- 9

#MT[4:6,2] <- 9

#MT[7:9,3] <- 9

#MW <- matrix(0, p, m, dimnames = list(mvnames, fnames))

#MW[MT == 0] <- 1

# a 2 x 3 matrix for [B|G]; m1 = 2, m = 3

# m1 = 2
#BGT <- matrix(0, m1, m, dimnames = list(fnames[1:m1], fnames))

#BGT[1,2] <- 9

#BGT[2,3] <- 9

#BGT[1,3] <- 9

#BGW <- matrix(0, m1, m, dimnames = list(fnames[1:m1], fnames))

#BGW[BGT == 0] <- 1

#BGW[,1] <- 0

#BGW[2,2] <- 0
# a 1 x 1 matrix for Phi.xi; m - m1 = 1 (only one exogenous factor)

#PhiT <- matrix(0, m - m1, m - m1)

#PhiW <- matrix(0, m - m1, m - m1)
#SSEMres <- ssem(covmat = cormat, factors = m, exfactors = m - m1,
#               dist = 'normal', n.obs = N, fm = 'm1', rotation = 'semtarget',
#               maxit = 10000,
#               MTarget = MT, MWeight = MW, BGTarget = BGT, BGWeight = BGW,
#               PhiTarget = PhiT, PhiWeight = PhiW, useorder = TRUE, se = 'information',

```

```
#          mnames = mvnames, fnames = fnames)  
#
```

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