Package 'TestGardener'

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Title Optimal Analysis of Test and Rating Scale Data

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Depends R (>= 3.5), fda, ggplot2, rgl, knitr, rmarkdown

Description Develop, evaluate, and score multiple choice examinations, psychological scales, questionnaires, and similar types of data involving sequences of choices among one or more sets of answers. Using the package does not require any formal statistical knowledge beyond what would be provided by a first course in statistics in a social science department. There the user would encounter the concept of probability and how it is used to model data and make decisions, and would become familiar with basic mathematical and statistical notation. The essential aspects of each display were designed to be self-explanatory, although more statistically sophisticated users will also find information that they may find helpful. Most of the output is in graphical form. Two recent papers on the methodology are Ramsay, James; Li, Juan; Wiberg, Marie (2020) <doi:10.3390/psych2040026> and Ramsay, James; Wiberg, Marie; Li, Juan (2019) <doi:10.3102/1076998619885636>.

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R topics documented:

Analyze *Analyze test or rating scale data defined in* dataList.

Description

The test or rating scale data have already been processed by function make.dataList or or other code to produce the list object dataList. The user defines a list vector ParameterList which stores results from a set of cycles of estimating surprisal curves followed by estimating optimal score index values for each examinee or respondent. These score index values are within the interval [0,100]. The number of analysis cycles is the length of the parList list vector.

Usage

```
Analyze(theta, thetaQnt, dataList, ncycle=10, itdisp=FALSE)
```

Arguments

theta — A vector of N score index values for the examinees or respondents. These values are in the percent interval [0,100].

thetaQnt — A vector of length 2*nbin + 1 where nbin is the number of bins containing score index values. The vector begins with the lower boundary 0 and ends with the upper boundary 100. In between it alternates between the bin center value and the boundary separating the next bin.

dataList — A list that contains the objects needed to analyse the test or rating scale with the following fields:

U: A matrix of response data with N rows and n columns where N is the number of examinees or respondents and n is the number of items. Entries in the matrices are the indices of the options chosen. Column i of U is expected to contain only the integers 1,...,noption.

optList: A list vector containing the numerical score values assigned to the options for this question.

key: If the data are from a test of the multiple choices type where the right answer is scored 1 and the wrong answers 0, this is a numeric vector of length n containing the indices the right answers. Otherwise, it is NULL.

chartList: A list vector length n each member of which is a matrix of parameters values defining a set of M surprisal curves. The matrix has K rows and M - 1 columns where K is the number of basis functions defining the curves and M is the number curves.

WfdPar: An fdPar object for the defining the surprisal curves.

noption: A numeric vector of length n containing the numbers of options for each item.

nbin: The number of bins for binning the data.

scrrng: A vector of length 2 containing the limits of observed sum scores.

scrfine: A fine mesh of test score values for plotting.

scrvec: A vector of length N containing the examinee or respondent sum scores.

itemvec: A vector of length n containing the question or item sum scores.

percntrnk: A vector length N containing the sum score percentile ranks.

thetaQnt: A numeric vector of length 2*nbin + 1 containing the bin boundaries alternating with the bin centers. These are initially defined as seq(0,100,len=2*nbin+1).

Wdim: The total dimension of the surprisal scores.

PcntMarkers: The marker percentages for plotting: 5, 25, 50, 75 and 95.

`ncycle` The number of cycles executed by Analyze.

`itdisp` If TRUE, the progress of the iterations within each cycle for estimating theta are reported.

Details

The cycling process is described in detail in the references, and displayed in R code in the vignette `SweSATQuantitativeAnalysis`.

Value

The list vector `parList` where each member is a named list object containing the results of an analysis cycle. These results are:

theta: The optimal estimates of the score index values for the examinees/respondents. This is a vector of length `N`.

thetaQnt: A vector of length 2*nbin+1 containing bin boundaries alternating with bin edges.

WfdList: A list vector containing results from the estimation of surprisal curves. The list vector is of length `n`, the number of questions or items in the test of rating scale. For details concerning these results, see function `Wbinsmth()`.

logdensfd: A functional data object defining the estimate of the log of the probability density function for the distribution of the score index values.

C: The normalizing value for probability density functions. A density value is computed by dividing the exponential of the log density value by this constant.

densfine: The value of the probability density function over a fine mesh of 101 equally spaced score index values.

denscdf: The values over a fine mesh of the cumulative probability distribution function. These values start at 0 and end with 1 and are increasing. Ties are often found at the upper boundary, so that using these values for interpolation purposes may require using the vector `unique(denscdf)`.

binctr: A vector of length `nbin` containing the bin centers within the interval [0,100].

bdry: A vector of length `nbin+1` containing the bin boundaries.

freq: A vector of length `nbin` containing the number of score index values in the bins. An score index value is within a bin if it is less than or equal to the upper boundary and greater than the lower boundary. The first boundary also contains zero values.

Hval: A vector of length N containing the values of the negative log likelihood fitting criterion.

DHval: A vector of length N containing the values of the first derivative of the negative log likelihood fitting criterion.

D2Hval: A vector of length N containing the values of the second derivative of the negative log likelihood fitting criterion.

active: A vector of length N of the activity status of the values of theta. If convergence was not achieved, the value is TRUE, otherwise FALSE.

arclength: The length of the space curve defined by the surprisal curves.

alfine: A vector of length 101 of arclengths corresponding to equally spaced values of theta.

theta_al: A vector of length N of arclengths corresponding to estimated values of theta.

Author(s)

Juan Li and James Ramsay

References

Ramsay, J. O., Li J. and Wiberg, M. (2020) Full information optimal scoring. Journal of Educational and Behavioral Statistics, 45, 297-315.

Ramsay, J. O., Li J. and Wiberg, M. (2020) Better rating scale scores with information-based psychometrics. Psych, 2, 347-360.

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See Also

make.dataList,dataSimulation,Power.plot,scoreDensity,Sensitivity.plot,testscore,theta.distn,theta2a

Examples

```
#  Use of Analyze() presumes that make.data() has already been executed
#  Here we ask for only one iteration of Analyze, but a proper analysis
#  would involve 10 to 20 or so iterations.
#  Example 1:  Analysis of multiple choice test, 24 items, 1000 examinees
theta     <- Quant_dataList$percntrnk
thetaQnt  <- Quant_dataList$thetaQnt
chartList <- Quant_dataList$chartList
AnalyzeResult <- Analyze(theta, thetaQnt, Quant_dataList, ncycle=1)
#  extract the two objects returned by Analyze:
parList  <- AnalyzeResult$parList
meanHvec <- AnalyzeResult$meanHvec
#  The next step would be to select the cycle for which you wish to
#  display results.
#  Example 2:  analysis of rating scale, 13 items, 483 respondents
theta     <- SDS_dataList$percntrnk
thetaQnt  <- SDS_dataList$thetaQnt
chartList <- SDS_dataList$chartList
AnalyzeResult <- Analyze(theta, thetaQnt, SDS_dataList, ncycle=1)
#  extract the two objects returned by Analyze:
parList  <- AnalyzeResult$parList
meanHvec <- AnalyzeResult$meanHvec
#  The next step would be to select the cycle for which you wish to
#  display results.
```

ArcLength.plot *Plot arc length as a function of score index* theta.

Description

Arc length is the distance along the space curved traced out as score index theta increases from 0 to 100. It is measured in bits and is remains unchanged if the score index continuum is modified.

Usage

```
ArcLength.plot(arclength, alfine, titlestr=NULL)
```

Arguments

arclength	This is a positive real number indicating the total length of the space curve. It is expressed in terms of numbers of bits.
alfine	A vector of length 101 containing equally-spaced arc-length distances along the test information curve.
titlestr	A string for the title of the data.

Value

A gg or ggplot object defining the plot of arclength along the test information curve as a function of the score index theta. This is displayed by the print command. The plot is automatically displayed as a side value even if no return object is specified in the calling statement.

Author(s)

Juan Li and James Ramsay

References

Ramsay, J. O., Li J. and Wiberg, M. (2020) Full information optimal scoring. Journal of Educational and Behavioral Statistics, 45, 297-315.

Ramsay, J. O., Li J. and Wiberg, M. (2020) Better rating scale scores with information-based psychometrics. Psych, 2, 347-360.

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See Also

theta2arclen

Examples

```
#  Example 1.  Display the arc length curve for the
#  short SweSAT multiple choice test with 24 items and 1000 examinees
indfine       <- seq(0,100,len=101)
WfdList       <- Quant_parListi$WfdList
theta         <- Quant_parListi$theta
alfine        <- Quant_parListi$alfine
arclenList    <- theta2arclen(theta, WfdList, Quant_dataList$Wdim)
names(arclenList)
ArcLength.plot(arclenList$arclength, alfine)
#  Example 2.  Display the arc length curve for the
#  Symptom Distress Scale with 13 items and 473 respondents
#  Proceed as above changing "Quant" to "SDS".
```

---

dataSimulation *Evaluate index and score accuracy by conditional simulation.*

Description

The simulation is based on the assumption that the estimated surprisal curves can be taken as correct. Using these curves, a set of score index percentile values are fixed, and a sample of data matrices are generated using these fixed values. The data matrices are analyzed to estimate a sample of index or score values for each of these true values. Mean squared errors and biasses are then computed and displayed as curves.

Usage

```
dataSimulation(dataList, parList, nsample=1000)
```

Arguments

`dataList` A list that contains the objects needed to analyse the test or rating scale with the following fields:

U: A matrix of response data with N rows and n columns where N is the number of examinees or respondents and n is the number of items. Entries in the matrices are the indices of the options chosen. Column i of U is expected to contain only the integers 1,...,noption.

optList: A list vector containing the numerical score values assigned to the options for this question.

key: If the data are from a test of the multiple choices type where the right answer is scored 1 and the wrong answers 0, this is a numeric vector of length n containing the indices the right answers. Otherwise, it is NULL.

chartList: A list vector length n each member of which is a matrix of parameters values defining a set of M surprisal curves. The matrix has K rows and M - 1 columns where K is the number of basis functions defining the curves and M is the number curves.

WfdPar: An fdPar object for the defining the surprisal curves.

noption: A numeric vector of length n containing the numbers of options for each item.

nbin: The number of bins for binning the data.

scrrng: A vector of length 2 containing the limits of observed sum scores.

scrfine: A fine mesh of test score values for plotting.

scrvec: A vector of length N containing the examinee or respondent sum scores.

itemvec: A vector of length n containing the question or item sum scores.

percntrnk: A vector length N containing the sum score percentile ranks.

thetaQnt: A numeric vector of length 2*nbin + 1 containing the bin boundaries alternating with the bin centers. These are initially defined as seq(0,100,len=2*nbin+1).

Wdim: The total dimension of the surprisal scores.

PcntMarkers: The marker percentages for plotting: 5, 25, 50, 75 and 95.

`parList` A named list produced on a specific cycle of the analysis. It contains objects which are changed from cycle to cycle.

`nsample` A positive integer fixing the number of simulated samples.

Value

A named list containing these objects:

sumscr: A matrix with row dimension `ntheta`, the number of population score index values and column dimension `nsample`, the number of simulated samples.

theta: An `ntheta` by `nsample` of estimated score index values.

mu: An `ntheta` by `nsample` of estimated expected score values.

al: An `ntheta` by `nsample` of estimated test information curve values.

thepop: A vector of population score index values.

mupop: A vector of expected scores computed from the population score index values.

alpop: A vector of test information values computed from the population score index values.

n: The number of questions.

Qvec: The five marker percentile values.

Author(s)

Juan Li and James Ramsay

References

Ramsay, J. O., Li J. and Wiberg, M. (2020) Full information optimal scoring. Journal of Educational and Behavioral Statistics, 45, 297-315.

Ramsay, J. O., Li J. and Wiberg, M. (2020) Better rating scale scores with information-based psychometrics. Psych, 2, 347-360.

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See Also

`Usimulate`, `scorePerformance`, `dataSimulation.plot`

Examples

```
#  Use of dataSimulations() presumes that make.data() has already been executed
#  to set up the analysis, Analyze() has been run with the desired number of
#  iterations and its two objects extracted.
#  Example 1:  analysis of multiple choice test, 24 items, 1000 examinees
Quant_simulateResult <- dataSimulation(Quant_dataList, Quant_parListi, nsample=10)
#  Example 2:  analysis of 13-item Symptom Distress Scale with 473 respondents
SDS_simulateResult <- dataSimulation(SDS_dataList, SDS_parListi, nsample=10)
```

---

dataSimulation.plot *Plot root-mean-squared error and bias for* theta *and* mu(theta)

Description

This function is called after a call to function dataSimulation where a set of simulated data sets are analyzed. This function plots the performance of estimates of score index theta, expected score mu(theta), and the observed sum score.

Mean squared error for a function is a curve showing error variation in an estimated function. Root-mean-squared error converts this to a standard error curve just as a standard deviation does for the variance of a mean, and so provides a more visually direct sense of how well an estimated curve is defined by the data.

Mean squared error can be split into two orthogonal or independent components: (1) sampling variance showing variation around the mean estimate and (2) squared bias showing systematic variation around the true curve.

Usage

```
dataSimulation.plot(simList, Qvec, ttlsz=NULL, axisttl=NULL, axistxt=NULL, lgdlab=NULL)
```

Arguments

simList — A named list containing these objects:

sumscr: A matrix with row dimension ntheta, the number of population score index values and column dimension nsample, the number of simulated samples.

theta: An ntheta by nsample of estimated score index values.

mu: An ntheta by nsample of estimated expected score values.

al: An ntheta by nsample of estimated test information curve values.

thepop: A vector of population score index values.

mupop: A vector of expected scores computed from the population score index values.

alpop: A vector of test information values computed from the population score index values.

n: The number of questions.
Qvec: The five marker percentile values.

`Qvec`	Locations on the score index interval [0,100] of the five marker percentages.
`ttlsz`	Title font size.
`axisttl`	Axis title font size.
`axistxt`	Axis text(tick label) font size.
`lgdlab`	Legend label font size.

Value

Two ggplot objects are returned in a named list with these members:

thetaplot: A plot with two panels. The upper panel plots the root-mean-squared-error of estimation (RMSE) of the score index value `theta` as a solid line, and also plots the sampling error (square root of the sampling variance) as a red dashed line. The sampling error is necessarily smaller than the RMSE, but if it is only a small amount less, then the bias of the estimate is negligible. The lower plot shows the bias in the estimate as a function of `theta`.

muplot: A plot with two panels. The upper panel plots the root-mean-squared-error of estimation (RMSE) of the expected score value `mu(theta)` as a function of the score index value `theta` as a solid line, and also plots the RMSE of the observed sum score as a dashed blue line. The lower plot shows the bias in these estimate as a function of `theta`.

These plots are also displayed automatically as a side effect.

Author(s)

Juan Li and James Ramsay

References

Ramsay, J. O., Li J. and Wiberg, M. (2020) Full information optimal scoring. Journal of Educational and Behavioral Statistics, 45, 297-315.

Ramsay, J. O., Li J. and Wiberg, M. (2020) Better rating scale scores with information-based psychometrics. Psych, 2, 347-360.

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See Also

`Usimulate`,`scorePerformance`,`dataSimulation`

Examples

```
#  Use of dataSimulations() presumes that make.data() has already been executed
#  to set up the analysis, Analyze() has been run with the desired number of
#  iterations and its two objects extracted.
#  Example 1:  Ten simulations of multiple choice test, 24 items, 1000 examinees
Quant_simList <- dataSimulation(Quant_dataList, Quant_parListi, nsample=10)
```

```
dataSimulation.plot(Quant_simList, Quant_parListi$Qvec)
#  Example 2:  Ten simulations of 13-item Symptom Distress Scale with 473 respondents
SDS_simList <- dataSimulation(SDS_dataList, SDS_parListi, nsample=10)
dataSimulation.plot(SDS_simList, SDS_parListi$Qvec)
```

DHfun *Compute the first and second derivatives of the negative log likelihoods*

Description

DHfun computes the first and second derivatives of the negative log likelihoods for a set of examinees. Items can be either binary or multi-option. The analysis is within the closed interval [0,100].

Usage

```
DHfun(theta, WfdList, Umat)
```

Arguments

theta	Initial values for score indices in [0,n]/[0,100]. Vector of size N.
WfdList	A numbered list object produced by a TestGardener analysis of a test. Its length is equal to the number of items in the test or questions in the scale. Each member of WfdList is a named list containing information computed during the analysis. These named lists contain these objects: **Wfd:** A functional data object containing the M surprisal curves for a question. **M:** The number of options. **Pbin:** A matrix containing proportions at each bin. **Wbin:** A matrix containing surprisal values at each bin. **Pmatfine:** A matrix of probabilities over a fine mesh. **Wmatfine:** A matrix of surprisal values over a fine mesh. **DWmatfine:** A matrix of the values of the first derivative of surprisal curves over fine mesh. **D2Wmatfine:** A matrix of the values of the second derivative of surprisal curves over fine mesh. **chartList:** A list vector of length n. Each list contains the K by M-1 matrix of initial values for the surprisal curves for the corresponding item.
Umat	An N by n matrix of responses. If N = 1, it can be a vector of length n.

Value

A named list for results DH and D2H:

DH: First derivatives of the negative log likelihood values, vector of size N

D2H: Second derivatives of the negative log likelihood values, vector of size N

Author(s)

Juan Li and James Ramsay

References

Ramsay, J. O., Li J. and Wiberg, M. (2020) Full information optimal scoring. Journal of Educational and Behavioral Statistics, 45, 297-315.

Ramsay, J. O., Li J. and Wiberg, M. (2020) Better rating scale scores with information-based psychometrics. Psych, 2, 347-360.

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See Also

make.dataList,Hfun,Hfuns.plot

Examples

```
#  Example 1:
#  Compute the first and second derivative values of the objective function for
#  locating each examinee for the 24-item short form of the SweSAT quantitative
#  test on thepercentile score index continuum.
WfdList <- Quant_parListi$WfdList
theta   <- Quant_parListi$theta
U       <- Quant_dataList$U
DHfunResult <- DHfun(theta, WfdList, U)
DHval  <- DHfunResult$DH
D2Hval <- DHfunResult$D2H
print(paste("Mean               of objective gradient =",round(mean(DHval),4)))
print(paste("Standard deviation of objective gradient =",round(sqrt(var(DHval)),4)))
print(paste("Mean               of objective Hessian =",round(mean(D2Hval),4)))
print(paste("Standard deviation of objective Hessian =",round(sqrt(var(D2Hval)),6)))
#  Example 2:
#  Compute the first and second derivative values of the objective function for
#  locating each examinee for the 13-item Symptom Distress scale
#  on the percentile score index continuum.
#  Proceed as above changing "Quant" for "SDS".
```

Entropy.plot *Plot item entropy curves for selected items or questions.*

Description

Item the value of the entropy curve at a point `theta` is the expected value of the surprisal curve values. Entropy is a measure of the randomness of the surprisal value, which is maximized when all the surprisal curves have the same value and has a minimum of zero if all but a single curve has probability zero. This is unattainable in the calculation, but can be arbitrarily close to this state.

Usage

```
Entropy.plot(WfdList, Qvec, dataList, plotindex=1:n, height=1.0, value=0,
             saveplot=FALSE, ttlsz=NULL, axisttl=NULL, axistxt=NULL)
```

Arguments

WfdList	A numbered list object produced by a TestGardener analysis of a test. Its length is equal to the number of items in the test or questions in the scale. Each member of WfdList is a named list containing information computed during the analysis. These named lists contain these objects: **Wfd:** A functional data object containing the M surprisal curves for a question. **M:** The number of options. **Pbin:** A matrix containing proportions at each bin. **Wbin:** A matrix containing surprisal values at each bin. **Pmatfine:** A matrix of probabilities over a fine mesh. **Wmatfine:** A matrix of surprisal values over a fine mesh. **DWmatfine:** A matrix of the values of the first derivative of surprisal curves over fine mesh. **D2Wmatfine:** A matrix of the values of the second derivative of surprisal curves over fine mesh. **chartList:** A list vector of length n. Each list contains the K by M-1 matrix of initial values for the surprisal curves for the corresponding item.
Qvec	The five marker percentile values.
dataList	A list vector containing objects essential to an analysis.
plotindex	A set of integers specifying the numbers of the items or questions to be displayed.
height	A positive real number defining the upper limit on the ordinate for the plots.
value	Number required by ggplot2. Defaults to 0.
saveplot	A logical value indicating whether the plot should be saved to a pdf file.
ttlsz	Title font size.
axisttl	Axis title font size.
axistxt	Axis text(tick label) font size.

Details

An entropy curve for each question indexed in the index argument. A request for a keystroke is made for each question. The answer to question strongly defines the optimal position of an estimated score index value where the curve is high value. Values of entropy curves typically range over [0,1].

Value

The plots of the entropy curves specified in plotindex are produced as a side effect. If saveplot is TRUE, the plots of item entropy curves specified in plotindex are bundled into a single postscript or .pdf file and the file name is defined by paste(dataList$titlestr,i,'-entropy.pdf',sep=""). The file is then output as a returned value.

Author(s)

Juan Li and James Ramsay

References

Ramsay, J. O., Li J. and Wiberg, M. (2020) Full information optimal scoring. Journal of Educational and Behavioral Statistics, 45, 297-315.

Ramsay, J. O., Li J. and Wiberg, M. (2020) Better rating scale scores with information-based psychometrics. Psych, 2, 347-360.

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See Also

Sensitivity.plot, Power.plot, Item.plot, Hfuns.plot, Wbinsmth.plot

Examples

```
#  Example 1.  Display the item entropy curves for the
#  short SweSAT multiple choice test with 24 items and 1000 examinees
#  plot the entropy curve for the first item
WfdList <- Quant_parListi$WfdList
Qvec    <- Quant_parListi$Qvec
Entropy.plot(WfdList, Qvec, Quant_dataList, plotindex=1)
#  Example 2.  Display the item entropy curves for the
#  Symptom Distress Scale with 13 items and 473 respondents
#  Proceed as above changing "Quant" to "SDS".
```

`eval.surp` *Evaluate multinomial surprisal curves at a vector of score index values.*

Description

Surprisal is -log(probability) where the logarithm is equal to the length `M` of the multinomial observation vector. The surprisal curves for each question are estimated by fitting the surprisal values of binned data using curves whose values are within the M-1 dimensional surprisal subspace that is within the space of non-negative M-dimensional vectors. This function computes the values of the `M` surprisal curves at a vector of argument values.

Usage

```
eval.surp(evalarg, Wfdobj, nderiv=0)
```

Arguments

evalarg	Argument value array of length N, where N is the number of observed curve values for each curve. It is assumed that that these argument values are common to all observed curves. If this is not the case, you will need to run this function inside one or more loops, smoothing each curve separately.
Wfdobj	A functional data object that defines the surprisal curves.
nderiv	The order to derivative the curves to be evaluated. This must be 0, 1 or 2.

Value

A `length(argvals)` by `M` matrix of surprisal derivative values.

Author(s)

Juan Li and James Ramsay

References

Ramsay, J. O., Li J. and Wiberg, M. (2020) Full information optimal scoring. Journal of Educational and Behavioral Statistics, 45, 297-315.

Ramsay, J. O., Li J. and Wiberg, M. (2020) Better rating scale scores with information-based psychometrics. Psych, 2, 347-360.

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See Also

`smooth.surp`

Examples

```
#  see example for smooth.surp()
```

Hfun — *Compute the negative log likelihoods associated with a vector of score index values.*

Description

Hfun computes the negative log likelihoods for a set of examinees, each at a single value theta.

Usage

```
Hfun(theta, WfdList, Umat)
```

Arguments

theta	A vector of size N containing values for score indices in the interval [0,100].
WfdList	A numbered list object produced by a TestGardener analysis of a test. Its length is equal to the number of items in the test or questions in the scale. Each member of WfdList is a named list containing information computed during the analysis. These named lists contain these objects: **Wfd:** A functional data object containing the M surprisal curves for a question. **M:** The number of options. **Pbin:** A matrix containing proportions at each bin. **Wbin:** A matrix containing surprisal values at each bin. **Pmatfine:** A matrix of probabilities over a fine mesh. **Wmatfine:** A matrix of surprisal values over a fine mesh. **DWmatfine:** A matrix of the values of the first derivative of surprisal curves over fine mesh. **D2Wmatfine:** A matrix of the values of the second derivative of surprisal curves over fine mesh. **chartList:** A list vector of length n. Each list contains the K by M-1 matrix of initial values for the surprisal curves for the corresponding item.
Umat	An N by n matrix of responses or, for a single examinee, a vector of length n.

Value

Vector of length N of negative log likelihood values.

Author(s)

Juan Li and James Ramsay

References

Ramsay, J. O., Li J. and Wiberg, M. (2020) Full information optimal scoring. Journal of Educational and Behavioral Statistics, 45, 297-315.

Ramsay, J. O., Li J. and Wiberg, M. (2020) Better rating scale scores with information-based psychometrics. Psych, 2, 347-360.

http://www.testgardener.azurewebsites.net

See Also

make.dataList,Hfun,Hfuns.plot

Examples

```
#  Example 1:  Compute the values of the objective function for locating each
#  examinee or respondent for the 24-item short form of the SweSAT quantitative
# test on the percentile score index continuum [0,100].
WfdList <- Quant_parListi$WfdList
theta   <- Quant_parListi$theta
```

```
U       <- Quant_dataList$U
Hval    <- Hfun(theta, WfdList, U)
print(paste("Mean              of objective function =",round(mean(Hval),2)))
print(paste("Standard deviation of objective function =",round(sqrt(var(Hval)),2)))
#  Example 2:  Compute the values of the objective function for locating each
#  examinee or respondent for the 13-item Symptom Distress Scale
# on the percentile score index continuum [0,100].
#  Proceed as above changing "Quant" for "SDS".
```

`Hfuns.plot` *Plot a selection of fit criterion H functions and their first two derivatives.*

Description

These plots indicate whether an appropriate minimum of the fitting criterion was found. The value of theta should be at the function minimum, the first derivative be close to zero there, and the second derivative should be positive. If these conditions are not met, it may be worthwhile to use function `thetafun` initialized with an approximate minimum value of score index theta to re-estimate the value of theta.

Usage

```
Hfuns.plot(theta, WfdList, U, plotindex=1)
```

Arguments

`theta`	The entire vector of estimated values of theta.
`WfdList`	The list vector of length n containing the estimated surprisal curves.
`U`	The entire N by n matrix of choice indices.
`plotindex`	A subset of the integers `1:N`.

Details

The curves are displayed in three vertically organized panels along with values of theta and the values and first two derivative values of the fit criterion. If more than one index value is used, a press of the Enter or Return key moves to the next index value.

Value

A list vector is returned which is of the length of argument `plotindex`. Each member of the vector is a `gg` or `ggplot` object for the associated `plotindex` `value`. Each plot can be displayed using the `print` command. The plots of item power are produced as a side value even if no output object is specified in the call to the function.

Author(s)

Juan Li and James Ramsay

References

Ramsay, J. O., Li J. and Wiberg, M. (2020) Full information optimal scoring. Journal of Educational and Behavioral Statistics, 45, 297-315.

Ramsay, J. O., Li J. and Wiberg, M. (2020) Better rating scale scores with information-based psychometrics. Psych, 2, 347-360.

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See Also

thetafun, Hfun, DHfun

Examples

```
#  Example 1.  Display fit criterion values and derivatives for the
#  short SweSAT multiple choice test with 24 items and 1000 examinees
index <- 1
theta    <- Quant_parListi$theta
WfdList  <- Quant_parListi$WfdList
U        <- Quant_dataList$U
Hval     <-  Hfun(theta[index], WfdList, U[index,])
DHResult <- DHfun(theta[index], WfdList, U[index,])
DHval    <- DHResult$DH
D2Hval   <- DHResult$D2H
Hfuns.plot(theta, WfdList, U, plotindex=index)
#  Example 2.  Compute score index values theta for the
#  Symptom Distress Scale with 13 items and 473 respondents
#  Proceed as above changing "Quant" to "SDS".
```

Item.plot *Four plots for item assessment*

Description

Plots of probability curves, sensitivity curves, power curves and entropy curve for selected items.

Usage

```
Item.plot(WfdList, Qvec, dataList, plotindex=1:n, key=NULL,
          titlestr=NULL, saveplt=FALSE,
          ttlsz=NULL,axisttl=NULL,axistxt=NULL,lgdlab=NULL,
          width=c(-0.2,0.2), height=1)
```

Arguments

WfdList	List vector of length coden containing named list of objects specifying probability and surprisal curves.
Qvec	Score index values for current marker percentages.

dataList	Named list of objects required for analysis of data.
plotindex	Indices of item plots to be displayed.
key	Vector of length n of right answer option indices. Only required for multiple choice test data.
titlestr	String for title of data.
saveplt	Logical value. If TRUE, plots are saved in a pdf file.
ttlsz	Integer specifying font size for title.
axisttl	Axis title font size.
axistxt	Axis text(tick label) font size.
lgdlab	Legend label font size.
width	Vector of length 2 of ordinate axis limits.
height	Value for shifting marker value labels.

Details

The four panels in these plots provide graphical information about the performance of items as indicators of optimal score index values.

The probability curves are of probabilities of choice functions of score index.

The sensitivity curves are of the derivatives of surprisal curves, and their departure from 0 is a direct indication of the strength of the information about whether a specific score index value should be reduced or increased.

The power curve is the root-sum-square of the sensitivity curves, and indicate how much information at any score index value the item provides for indicating the value of the score index value.

The entropy curve displays the level of randomness in the surprisal curves at a score index value, which is maximized when all surprisal values are the same, and is minimized at zero when only one choice is non-zero. For multiple choice tests, the entropy curve should decrease from one on the right ot near zero on the left.

Value

The plots are a side effect. If saveplt=TRUE,a pdf file is returned containing all the plots for the selected items.

Author(s)

Juan Li and James Ramsay

References

Ramsay, J. O., Li J. and Wiberg, M. (2020) Full information optimal scoring. Journal of Educational and Behavioral Statistics, 45, 297-315.

Ramsay, J. O., Li J. and Wiberg, M. (2020) Better rating scale scores with information-based psychometrics. Psych, 2, 347-360.

http://www.testgardener.azurewebsites.net

See Also

Wbinsmth.plot, Sensitivity.plot, Power.plot, Entropy.plot

---

keyshsort *Option information for the short form of the SweSAT Quantitative test.*

Description

The file has two rows, each with 24 integers in string format. The first row contains the indices of the right answers among the options for the 24 questions. The second row contains the number of options for each question.

Usage

```
keyshort
```

Details

The code above inputs the contents of the file using the scan() function into a single character vector of length 48. The strings are converted to integers by the second command, and the integer vector is then reformatted into a 2 by 24 matrix. The subsequent analysis of these data is described in detail in the vignette SweSATQuanitativeShort.

---

make.dataList *Make a list object containing information required for analysis of choice data.*

Description

The returned named list object contains 11 named members, which are described in the value section below.

Usage

```
make.dataList(U, key, optList, scrrng=NULL, titlestr=NULL, nbin=nbinDefault(N),
              NumBasis=NumBasisDefault(N),
              jitterwrd=TRUE, PcntMarkers=c( 5, 25, 50, 75, 95))
```

Arguments

U	A matrix with rows corresponding to examinees or respondents, and columns to questions or items.
key	If the data are a multiple choice test with only weights 0 and 1, a vector of length n containing the indices of the right answers. Otherwise, NULL.
optList	A list vector of length number of questions. A member contains a vector of score values assigned to each answer or option by the test designer.
scrrng	A vector of length two containing the initial and final values for the interval over which test scores are to be plotted. Default is minimum and maximum sum score.
titlestr	A string to be used as a title in plots and other displays.
nbin	The number of bins for containing proportions of examinees choosing options. The default is computed by a function that uses the number of examinees.
NumBasis	The number of spline basis functions used to represent surprisal curves. The default is computed by a function that uses the number of examinees.
jitterwrd	A boolian constant: TRUE implies adding a small random value to each sum score value prior to computing percent rank values.
PcntMarkers	Used in plots of curves to display marker or reference percentage points for abscissa values in plots.

Details

The score range defined scrrng should contain all of the sum score values, but can go beyond them if desired. For example, it may be that no examinee gets a zero sum score, but for reporting and display purposes using zero as the lower limit seems desirable.

The number of bins is chosen so that a minimum of at least about 25 initial percentage ranks fall within a bin. For larger samples, the number per bin is also larger, making the proportions of choice more accurate. The number bins can be set by the user, or by a simple algorithm used to adjust the number of bins to the number N or examinees.

The number of spline basis functions used to represent a surprisal curve should be small for small sample sizes, but can be larger when larger samples are involved. A minimum of 7 and maximum of 24 basis functions is assigned by default. The number of basis function can be set by the user or otherwise by a simple algorithm used to adjust the number of bins to the number N of examinees.

Adding a small value to discrete values before computing ranks is considered a useful way of avoiding any biasses that might arise from the way the data are stored. The small values used leave the rounded jittered values fixed, but break up ties for sum scores.

It can be helpful to see in a plot where special marker percentages 5, 25, 50, 75 and 95 percent of the interval [0,100] are located. The median abscissa value is at 50 per cent for initial percent rank values, for example, but may not be located at the center of the interval after iterations of the analysis cycle.

Value

A named list with named members as follows:

U: A matrix of response data with N rows and n columns where N is the number of examinees or respondents and n is the number of items. Entries in the matrices are the indices of the options chosen. Column i of U is expected to contain only the integers `1,...,noption`.

optList: A list vector containing the numerical score values assigned to the options for this question.

key: If the data are from a test of the multiple choices type where the right answer is scored 1 and the wrong answers 0, this is a numeric vector of length n containing the indices the right answers. Otherwise, it is NULL.

chartList: A list vector length n each member of which is a matrix of parameters values defining a set of M surprisal curves. The matrix has K rows and M - 1 columns where K is the number of basis functions defining the curves and M is the number curves.

WfdPar: An fdPar object for the defining the surprisal curves.

noption: A numeric vector of length n containing the numbers of options for each item.

nbin: The number of bins for binning the data.

scrrng: A vector of length 2 containing the limits of observed sum scores.

scrfine: A fine mesh of test score values for plotting.

scrvec: A vector of length N containing the examinee or respondent sum scores.

itemvec: A vector of length n containing the question or item sum scores.

percntrnk: A vector length N containing the sum score percentile ranks.

thetaQnt: A numeric vector of length 2*nbin + 1 containing the bin boundaries alternating with the bin centers. These are initially defined as `seq(0,100,len=2*nbin+1)`.

Wdim: The total dimension of the surprisal scores.

PcntMarkers: The marker percentages for plotting: 5, 25, 50, 75 and 95.

Author(s)

Juan Li and James Ramsay

References

Ramsay, J. O., Li J. and Wiberg, M. (2020) Full information optimal scoring. Journal of Educational and Behavioral Statistics, 45, 297-315.

Ramsay, J. O., Li J. and Wiberg, M. (2020) Better rating scale scores with information-based psychometrics. Psych, 2, 347-360.

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See Also

Analyze

Examples

```
#  Example 1:  Input choice data and key for the short version of the
#  SweSAT quantitative multiple choice test with 24 items and 1000 examinees
#  input the choice data as 1000 strings of length 24
N <- dim(Quant_U)[1]
n <- dim(Quant_U)[2]
optList <- list()
for (item in 1:n){
  noptioni <- length(unique(Quant_U[,item]))
  scorei <- rep(0,noptioni)
  scorei[Quant_key[item]] <- 1
  optList[[item]] <- scorei
}
optList <- list(itemLab=NULL, optLab=NULL, optScr=optList)

#  Set up the dataList object containing the objects necessary
#  for further display and analyses
Quant_dataList <- make.dataList(Quant_U, Quant_key, optList)

#  Example 2:  Input choice data and key for the Symptom Distress Scale
#  with 13 items and 473 examinees.
#  input the choice data as 473 strings of length 13
N <- dim(SDS_U)[1]
n <- dim(SDS_U)[2]
# --------- Define the option score values for each item ---------
optList <- list()
for (item in 1:n){
  scorei <- c(0:4,0)
  optList[[item]]<- scorei
}
optList <- list(itemLab=NULL, optLab=NULL, optScr=optList)
#  largest observed sum score is 37
scrrng <- c(0,37)
dataList <- make.dataList(SDS_U, SDS_key, optList, scrrng)
```

`mu.plot` *Plot expected test score as a function of score index*

Description

The expected score `mu(theta)` is a function of the score index theta. A diagonal dashed line is displayed to show the linear relationship to the score range interval.

Usage

```
mu.plot(mufine, scrrng, titlestr)
```

Arguments

mufine	A mesh of 101 equally spaced values of mu as a function of theta.
scrrng	A vector of length 2 containing the score range.
titlestr	A string containing the title of the data.

Value

A gg or ggplot object defining the plot of the expected test score mu as a function of the score index theta. This is displayed by the print command. The plot is automatically displayed as a side value even if no return object is specified in the calling statement.

Author(s)

Juan Li and James Ramsay

References

Ramsay, J. O., Li J. and Wiberg, M. (2020) Full information optimal scoring. Journal of Educational and Behavioral Statistics, 45, 297-315.

Ramsay, J. O., Li J. and Wiberg, M. (2020) Better rating scale scores with information-based psychometrics. Psych, 2, 347-360.

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See Also

scoreDensity, testscore

Power.plot *Plot item power curves for selected items or questions.*

Description

Item surprisal power curves are the square root of the sum over options of the squared surprisal sensitivity curves.

Usage

```
Power.plot(WfdList, Qvec, dataList, plotindex=1:n, height=0.5, value=0,
           saveplot=FALSE, ttlsz=NULL, axisttl=NULL, axistxt=NULL)
```

Arguments

WfdList	A numbered list object produced by a TestGardener analysis of a test. Its length is equal to the number of items in the test or questions in the scale. Each member of WfdList is a named list containing information computed during the analysis. These named lists contain these objects: **Wfd:** A functional data object containing the M surprisal curves for a question. **M:** The number of options. **Pbin:** A matrix containing proportions at each bin. **Wbin:** A matrix containing surprisal values at each bin. **Pmatfine:** A matrix of probabilities over a fine mesh. **Wmatfine:** A matrix of surprisal values over a fine mesh. **DWmatfine:** A matrix of the values of the first derivative of surprisal curves over fine mesh. **D2Wmatfine:** A matrix of the values of the second derivative of surprisal curves over fine mesh. **chartList:** A list vector of length n. Each list contains the K by M-1 matrix of initial values for the surprisal curves for the corresponding item.
Qvec	The five marker percentile values.
dataList	A list vector containing objects essential to an analysis.
plotindex	A set of integers specifying the numbers of the items or questions to be displayed.
height	A positive real number defining the upper limit on the ordinate for the plots.
value	Number required by ggplot2. Defaults to 0.
saveplot	A logical value indicating whether the plot should be saved to a pdf file.
ttlsz	Title font size.
axisttl	Axis title font size.
axistxt	Axis text(tick label) font size.

Details

A surprisal power curve for each question indexed in the index argument. A request for a keystroke is made for each question. The answer to question strongly defines the optimal position of an estimated score index value where the curve is high value. Values of power curves typically range over [0,0.5].

Value

The plots of the power curves specified in plotindex are produced as a side effect. If saveplot is TRUE, the plots of item power curves specified in plotindex are bundled into a single postscript or .pdf file and the file name is defined by paste(dataList$titlestr,i,'-power.pdf',sep="").
The file is then output as a returned value.

Author(s)

Juan Li and James Ramsay

References

Ramsay, J. O., Li J. and Wiberg, M. (2020) Full information optimal scoring. Journal of Educational and Behavioral Statistics, 45, 297-315.

Ramsay, J. O., Li J. and Wiberg, M. (2020) Better rating scale scores with information-based psychometrics. Psych, 2, 347-360.

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See Also

Sensitivity.plot, Entropy.plot, Item.plot, Hfuns.plot, Wbinsmth.plot

Examples

```
#  Example 1.  Display the item power curves for the
#  short SweSAT multiple choice test with 24 items and 1000 examinees
#  plot the power curve for the first item
WfdList <- Quant_parListi$WfdList
Qvec    <- Quant_parListi$Qvec
Power.plot(WfdList, Qvec, Quant_dataList, plotindex=1)
#  Example 2.  Display the item power curves for the
#  Symptom Distress Scale with 13 items and 473 respondents
#  Proceed as above changing "Quant" to "SDS".
```

Quant_dataList *List of objects essential for an analysis of the abbreviated SweSAT Quantitative multiple choice test.*

Description

The data are for 1000 randomly selected examinees taking 24 math analysis multiple choice questions.

Usage

```
Quant_dataList
```

Format

A named list.

Details

A named list with 15 members. See below for a description of each member.

U: A matrix of response data with N rows and n columns where N is the number of examinees or respondents and n is the number of items. Entries in the matrices are the indices of the options chosen. Column i of U is expected to contain only the integers $1, \ldots, noption$.

optList: A list vector containing the numerical score values assigned to the options for this question.

key: If the data are from a test of the multiple choices type where the right answer is scored 1 and the wrong answers 0, this is a numeric vector of length n containing the indices the right answers. Otherwise, it is NULL.

chartList: A list vector length n each member of which is a matrix of parameters values defining a set of M surprisal curves. The matrix has K rows and M - 1 columns where K is the number of basis functions defining the curves and M is the number curves.

WfdPar: An fdPar object for the defining the surprisal curves.

noption: A numeric vector of length n containing the numbers of options for each item.

nbin: The number of bins for binning the data.

scrrng: A vector of length 2 containing the limits of observed sum scores.

scrfine: A fine mesh of test score values for plotting.

scrvec: A vector of length N containing the examinee or respondent sum scores.

itemvec: A vector of length n containing the question or item sum scores.

percntrnk: A vector length N containing the sum score percentile ranks.

thetaQnt: A numeric vector of length 2*nbin + 1 containing the bin boundaries alternating with the bin centers. These are initially defined as `seq(0,100,len=2*nbin+1)`.

Wdim: The total dimension of the surprisal scores.

PcntMarkers: The marker percentages for plotting: 5, 25, 50, 75 and 95.

titlestr: A string containing a title for the analysis.

`Quant_key` *Option information for the short form of the SweSAT Quantitative test.*

Description

A vector that contains the indices of the right answers among the options for the 24 questions

Usage

```
Quant_key
```

`Quant_parListi` *List vector containing results for an analysis of the abbreviated Swe-SAT Quantitative multiple choice test.*

Description

The data are for 1000 randomly selected examinees taking 24 math analysis multiple choice questions. The results are for each of 10 cycles of alternating between estimating surprisal curves and estimating percentile score index values.

Usage

```
Quant_parListi
```

Format

A named list.

Value

The object `SDS_dataList` is a list vector with length equal to the number of analysis cycles. Each member is a named list with these members:

theta: A vector of length N of estimated values of the percentile rank score index.

thetaQnt: A vector of length 2*nbin + 1 containing bin boundaries alternating with bin centres.

WfdList: A list vector of length equal to the number of questions. Each member contains the following eight results for the surprisal curves associated with a question:

- **Wfd:** A functional data object representing the M surprisal curves defined over the percentile rank range, where M is the number of options for that question.
- **M:** The number of option choices for the question.
- **type:** The type of question: 1 for multiple choice, 0 for rating scale.
- **Pbin:** A nbin by M matrix of proportions of examinees choosing each option for each bin,.
- **Wbin:** A nbin by M matrix of surprisal values of examinees choosing each option for each bin.
- **Pmatfine:** A nfine by M matrix of proportions over a fine mesh of proportions of examinees choosing each option.
- **Wmatfine:** A nfine by M matrix of surprisal values over a fine mesh of values of examinees choosing each option.
- **DWmatfine:** A nfine by M matrix of the first derivative of surprisal values over a fine mesh of values of examinees choosing each option. These are referred to as the sensitivity values.

logdensfd: A functional data object representing the logarithm of the density of the percentile rank score index values.

C: The norming constant: the density function is `exp(logdensfd)/C`.

densfine: A fine mesh of probability density values of the percentile rank score index.

denscdf: A fine mesh of cumulative probability distribution values used for interpolating values.

Qvec: The score index values associated with the five marker percentages 5, 25, 50, 75 and 95.

binctr: A vector of length nbin containing the centres of the bins.

bdry: A vector of length nbin+1 containing the boundaries of the bins.

freq: An nbin by M matrix of frequencies with which options are chosen.

Wmax: A maximum surprisal value used for plotting purposes.

Hval: The value of the fitting criterion `H` for a single examinee or respondent.

DHval: The value of the first derivative of the fitting criterion `H` for a single examinee or respondent.

D2Hval: The value of the second derivative of the fitting criterion `H` for a single examinee or respondent.

active: A logical vector of length N indicating which estimates of theta are converged (FALSE) or not converged (TRUE).

arclength: The length in bits of the test information curve.

alfine: A mesh of 101 equally spaced positions along the test information curve.

Qvec_al: The positions of the five marker percentages on the test information curve.

theta_al: A vector of length N containing the positions of each examinee or respondent on the test information curve.

`Quant_U` *Test data for 24 math calculation questions from the SweSAT Quantitative data.*

Description

These data are for a randomly selected subset of 1000 examinees.

Usage

```
Quant_U
```

Format

A matrix object with 1000 rows and 24 columns. The integers indicate which answer was chosen for each question by the examinee associated with the row.

scoreDensity *Compute and plot a score density histogram and and curve.*

Description

The tasks of function `theta.density()` and plotting the density are combined. The score density is plotted both as a histogram and as a smooth curve. All the score types may be plotted: sum scores, expected test scores, percentile score index values, and locations on the test information or scale curve. The plot is output as a ggplot2 plot object, which is actually plotted using the `print` command.

Usage

```
scoreDensity(scrvec, scrrng, ndensbasis=15, ttlstr=NULL, pltmax=0)
```

Arguments

`scrvec`	A vector of strictly increasing bin boundary values, with the first at the lowest plotting value and the last at the upper boundary. The number of bins in the histogram is one less than the number of bndry values.
`scrrng`	A vector of length 2 containing lower and upper boundaries on scores.
`ndensbasis`	The number of spline basis functions to be used to represent the smooth density curve.
`ttlstr`	A string object used as a title for the plot. Defaults to none.
`pltmax`	An upper limit on the vertical axis for plotting. Defaults to the maximum curve value.

Value

A ggplot2 plot object `dens.plot` that can be displayed using command `print(dens.plot)`.

Author(s)

Juan Li and James Ramsay

References

Ramsay, J. O., Li J. and Wiberg, M. (2020) Full information optimal scoring. Journal of Educational and Behavioral Statistics, 45, 297-315.

Ramsay, J. O., Li J. and Wiberg, M. (2020) Better rating scale scores with information-based psychometrics. Psych, 2, 347-360.

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See Also

`thetafun`, `theta2arclen`, `testscore`, `theta.distn`

Examples

```
#  Example 1.  Display probability density curves for the
#  short SweSAT multiple choice test with 24 items and 1000 examinees
WfdList <- Quant_parListi$WfdList
theta   <- Quant_parListi$theta
#  plot the density for the score indices within interval c(0,100)
theta.scrrng <- c(0,100)
theta_int <- theta[0 < theta & theta < 100]
scoreDensity(theta_int, theta.scrrng)
#  plot the density for the sum score
sumscr <- Quant_dataList$scrvec
scoreDensity(sumscr, c(0,24), ttlstr="Sum score")
#  plot the density for the expected score
mu <- testscore(theta, WfdList, Quant_dataList$optList)
mu.scrrng <- c(0,24)
scoreDensity(mu, mu.scrrng, ttlstr="Expected sum score")
#  plot the density for the arclength score
ArclenResult <- theta2arclen(theta, WfdList, Quant_dataList$Wdim)
theta_al     <- ArclenResult$theta_al
arclen.scrrng <- c(0,ArclenResult$arclength)
scoreDensity(theta_al, arclen.scrrng, ttlstr="Arc length score")
#  Example 2.  Display probbility density curves for the
# Symptom Distress Scale with 13 items and 473 respondents.
# Proceed as above changing "Quant" to "SDS"
```

`scorePerformance` *Calculate mean squared error and bias for a set of score index values from simulated data.*

Description

This function is used on `ConditionalSimulation` after the simulated data matrices have been analyzed. It prepares the objects necessary for the performance plots produced by functions `RMSEbias1.plot` and `RMSEbias2.plot`.

Usage

```
scorePerformance(dataList, simList)
```

Arguments

`dataList`	A list that contains the objects needed to analyse the test or rating scale with the following fields:

U: A matrix of response data with N rows and n columns where N is the number of examinees or respondents and n is the number of items. Entries in the matrices are the indices of the options chosen. Column i of U is expected to contain only the integers `1,...,noption`.

optList: A list vector containing the numerical score values assigned to the options for this question.

key: If the data are from a test of the multiple choices type where the right answer is scored 1 and the wrong answers 0, this is a numeric vector of length n containing the indices the right answers. Otherwise, it is NULL.

chartList: A list vector length n each member of which is a matrix of parameter values defining a set of M surprisal curves. The matrix has `K` rows and `M - 1` columns where `K` is the number of basis functions defining the curves and `M` is the number curves.

WfdPar: An fdPar object for the defining the surprisal curves.

noption: A numeric vector of length n containing the numbers of options for each item.

nbin: The number of bins for binning the data.

scrrng: A vector of length 2 containing the limits of observed sum scores.

scrfine: A fine mesh of test score values for plotting.

scrvec: A vector of length N containing the examinee or respondent sum scores.

itemvec: A vector of length n containing the question or item sum scores.

percntrnk: A vector length N containing the sum score percentile ranks.

thetaQnt: A numeric vector of length 2*nbin + 1 containing the bin boundaries alternating with the bin centers. These are initially defined as `seq(0,100,len=2*nbin+1)`.

Wdim: The total dimension of the surprisal scores.

PcntMarkers: The marker percentages for plotting: 5, 25, 50, 75 and 95.

`simList` A named list containing these objects:

sumscr: A matrix with row dimension `ntheta`, the number of population score index values and column dimension `nsample`, the number of simulated samples.

theta: An `ntheta` by `nsample` of estimated score index values.

mu: An `ntheta` by `nsample` of estimated expected score values.

al: An `ntheta` by `nsample` of estimated test information curve values.

thepop: A vector of population score index values.

mupop: A vector of expected scores computed from the population score index values.

alpop: A vector of test information values computed from the population score index values.

n: The number of questions.

Qvec: The five marker percentile values.

Value

A named list containing these objects:

sumscr: A matrix with row dimension `ntheta`, the number of population score index values and column dimension `nsample`, the number of simulated samples.

theta: An `ntheta` by `nsample` matrix of estimated score index values.

mu: An `ntheta` by `nsample` matrix of estimated expected score values.

al: An ntheta by nsample matrix of estimated test information curve values.

thepop: A vector of population score index values.

mupop: A vector of expected scores computed from the population score index values.

alpop: A vector of test information values computed from the population score index values.

n: The number of questions.

Qvec: The five marker percentile values.

References

Ramsay, J. O., Li J. and Wiberg, M. (2020) Full information optimal scoring. Journal of Educational and Behavioral Statistics, 45, 297-315.

Ramsay, J. O., Li J. and Wiberg, M. (2020) Better rating scale scores with information-based psychometrics. Psych, 2, 347-360.

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SDS *The Symptom Distress Scale data.*

Description

The SDS is a rating scale with 13 questions and scores 0, 1, 2, 3 and 4.

Usage

```
data("SDS")
```

Format

A text file with 473 rows, each containing a string of 13 characters.

SDS_dataList *List of objects essential for an analysis of the Symptom Distress Scale.*

Description

The data are for 473 respondents to the Symptom Distress Scale. Each question has rating scores 0, 1, 2, 3, and 4.

Usage

```
data("SDS_dataList")
```

Format

A named list.

Details

A named list with 15 members. See below for a description of each member.

U: An N by n matrix of integers indicating which option was chosen by one of N examinees for a question. The object should be in the matrix class and the contents should be integers. For any question the integers should be within the range 1 to the number of options.

optList: A list vector object of length equal to the number of questions. Each member of the list is a numeric vector of score values assigned to each option by the test designer. For multiple choice questions, these scores are usually 0 for wrong answers and 1 for the right answer. For rating scales they are often a sequence of signed integers indicating intensity of some experience.

WfdPar: A functional parameter object that is required to represent the surprisal curves. The number of basis functions should be small for smaller sizes and larger for large samples. For example, 7 for N <= 500, 11 for N in [500,2000], 24 for N >= 2000.

logdensfd: A functional data object used to represent the log density of the percentile score index values. The number of basis functions is often the same as used for the WfdPar object.

noption: An integer vector of length equal to the number of questions indicating the number of options for each question.

nbin: The number of bins used to contain the score index values. The number should ensure that each bin can hold at least 25 score values. For medium sized samples, 50 per bin is fine, and for large samples as many as are required to define the detail in the surprisal curves.

key: An integer vector of length equal to the number of questions and containing the right answer indices. This is not used for rating scales and can be NULL in that case.

scrrng: A vector of length 2 defining a range over which the sum and expected scores will be estimated.

scrvec: A vector of length N containing the sum scores for the examinees or respondents.

percntrnk: The percentile ranks for each of the examinees or respondents. This is the percentage of examinees with sum scores below that for an examinee. Ties are often broken by adding a small random quantity to each sum score before computing ranks.

scrfine: A fine mesh of score values used for plotting purposes, and running from scrrng[1] to scrrng[2]. Common number for mesh values are 51 or 101.

scrtype: If the question is of multiple choice, the value is 1, and if not, 0 .

indrng: Defines the range of the score index. Usually this is c(0,100).

indfine: A fine mesh of score index values used for plotting, and usually ranging from 0 to 100. The number of mesh values is commonly 51 or 101.

`SDS_key` *Key for Symptom Distress Scale.*

Description

NULL for scale data.

Usage

```
SDS_key
```

`SDS_parListi` *List of objects essential for an analysis of the Symptom Distress Scale.*

Description

The data are for 473 respondents to the Symptom Distress Scale. Each question has rating scores 0, 1, 2, 3, and 4.

Usage

```
SDS_parListi
```

Format

A named list.

Value

The object `SDS_dataList` is a list vector with length equal to the number of analysis cycles. Each member is a named list with these members:

theta: A vector of length N of estimated values of the percentile rank score index.

thetaQnt: A vector of length 2*nbin + 1 containing bin boundaries alternating with bin centres.

WfdList: A list vector of length equal to the number of questions. Each member contains the following eight results for the surprisal curves associated with a question:

- **Wfd:** A functional data object representing the M surprisal curves defined over the percentile rank range, where M is the number of options for that question.
- **M:** The number of option choices for the question.
- **type:** The type of question: 1 for multiple choice, 0 for rating scale.
- **Pbin:** A nbin by M matrix of proportions of examinees choosing each option for each bin,.
- **Wbin:** A nbin by M matrix of surprisal values of examinees choosing each option for each bin.
- **Pmatfine:** A nfine by M matrix of proportions over a fine mesh of proportions of examinees choosing each option.
- **Wmatfine:** A nfine by M matrix of surprisal values over a fine mesh of values of examinees choosing each option.
- **DWmatfine:** A nfine by M matrix of the first derivative of surprisal values over a fine mesh of values of examinees choosing each option. These are referred to as the sensitivity values.

logdensfd: A functional data object representing the logarithm of the density of the percentile rank score index values.

C: The norming constant: the density function is `exp(logdensfd)/C`.

densfine: A fine mesh of probability density values of the percentile rank score index.

denscdf: A fine mesh of cumulative probability distribution values used for interpolating values.

Qvec: The score index values associated with the five marker percentages 5, 25, 50, 75 and 95.

binctr: A vector of length nbin containing the centres of the bins.

bdry: A vector of length nbin+1 containing the boundaries of the bins.

freq: An nbin by M matrix of frequencies with which options are chosen.

Wmax: A maximum surprisal value used for plotting purposes.

Hval: The value of the fitting criterion H for a single examinee or respondent.

DHval: The value of the first derivative of the fitting criterion H for a single examinee or respondent.

D2Hval: The value of the second derivative of the fitting criterion H for a single examinee or respondent.

active: A logical vector of length N indicating which estimates of theta are converged (FALSE) or not converged (TRUE).

arclength: The length in bits of the test information curve.

alfine: A mesh of 101 equally spaced positions along the test information curve.

Qvec_al: The positions of the five marker percentages on the test information curve.

theta_al: A vector of length N containing the positions of each examinee or respondent on the test information curve.

SDS_U *Test data for Symptom Distress Scale.*

Description

The integers indicate which answer was chosen for each question by the examinee associated with the row.

Usage

```
SDS_U
```

Format

A vector object with 473 rows and 13 columns.

`Sensitivity.plot` *Plots all the sensitivity curves for selected items or questions.*

Description

A sensitivity curve for an option is the first derivative of the corresponding surprisal curve. Its values can be positive or negative, and the size of the departure from zero at any point on the curve is the amount information contributed by that curve to locating the value of an examinee or respondent on the score index continuum.

Usage

```
Sensitivity.plot(WfdList, Qvec, dataList, plotindex=1:n, key=NULL,
                 titlestr=NULL, saveplot=FALSE, width=c(-0.2,0.2),
                 ttlsz=NULL, axisttl=NULL, axistxt=NULL, lgdlab=NULL)
```

Arguments

`WfdList` A numbered list object produced by a TestGardener analysis of a test. Its length is equal to the number of items in the test or questions in the scale. Each member of `WfdList` is a named list containing information computed during the analysis. These named lists contain these objects:

Wfd: A functional data object containing the `M` surprisal curves for a question.

M: The number of options.

Pbin: A matrix containing proportions at each bin.

Wbin: A matrix containing surprisal values at each bin.

Pmatfine: A matrix of probabilities over a fine mesh.

Wmatfine: A matrix of surprisal values over a fine mesh.

DWmatfine: A matrix of the values of the first derivative of surprisal curves over fine mesh.

D2Wmatfine: A matrix of the values of the second derivative of surprisal curves over fine mesh.

chartList: A list vector of length `n`. Each list contains the `K` by `M-1` matrix of initial values for the surprisal curves for the corresponding item.

`Qvec` The values of the five marker percentiles.

`dataList` A list that contains the objects needed to analyse the test or rating scale with the following fields:

U: A matrix of response data with N rows and n columns where N is the number of examinees or respondents and n is the number of items. Entries in the matrices are the indices of the options chosen. Column i of U is expected to contain only the integers 1,...,noption.

optList: A list vector containing the numerical score values assigned to the options for this question.

key: If the data are from a test of the multiple choices type where the right answer is scored 1 and the wrong answers 0, this is a numeric vector of length n containing the indices the right answers. Otherwise, it is NULL.

chartList: A list vector length n each member of which is a matrix of parameters values defining a set of M surprisal curves. The matrix has K rows and M - 1 columns where K is the number of basis functions defining the curves and M is the number curves.

WfdPar: An fdPar object for the defining the surprisal curves.

noption: A numeric vector of length n containing the numbers of options for each item.

nbin: The number of bins for binning the data.

scrrng: A vector of length 2 containing the limits of observed sum scores.

scrfine: A fine mesh of test score values for plotting.

scrvec: A vector of length N containing the examinee or respondent sum scores.

itemvec: A vector of length n containing the question or item sum scores.

percntrnk: A vector length N containing the sum score percentile ranks.

thetaQnt: A numeric vector of length 2*nbin + 1 containing the bin boundaries alternating with the bin centers. These are initially defined as seq(0,100,len=2*nbin+1).

Wdim: The total dimension of the surprisal scores.

PcntMarkers: The marker percentages for plotting: 5, 25, 50, 75 and 95.

`plotindex` A set of integers specifying the numbers of the items or questions to be displayed.

`key` A integer vector of indices of right answers. If the data are rating scales, this can be NULL.

`titlestr` A title string for plots.

`saveplot` A logical value indicating whether the plot should be saved to a pdf file.

`width` A vector of length 2 defining the lower and upper limits on the ordinate for the plots.

`ttlsz` Title font size.

`axisttl` Axis title font size.

`axistxt` Axis text(tick label) font size.

`lgdlab` Legend label font size.

Details

Sensitivity curves for each question indexed in the `index` argument. A request for a keystroke is made for each question.

Value

A list vector is returned which is of the length of argument `plotindex`. Each member of the vector is a `gg` or `ggplot` object for the associated `plotindex` `value`. Each plot can be displayed using the `print` command. The plots of item power are produced as a side value even if no output object is specified in the call to the function.

Author(s)

Juan Li and James Ramsay

References

Ramsay, J. O., Li J. and Wiberg, M. (2020) Full information optimal scoring. Journal of Educational and Behavioral Statistics, 45, 297-315.

Ramsay, J. O., Li J. and Wiberg, M. (2020) Better rating scale scores with information-based psychometrics. Psych, 2, 347-360.

http://www.testgardener.azurewebsites.net

See Also

Power.plot, Entropy.plot, Item.plot, Wbinsmth.plot

Examples

```
#  Example 1.  Display the option sensitivity curves for the
#  short SweSAT multiple choice test with 24 items and 1000 examinees
WfdList <- Quant_parListi$WfdList
Qvec    <- Quant_parListi$Qvec
par(c(1,1))
Sensitivity.plot(WfdList, Qvec, Quant_dataList, plotindex=1)
#  Example 2.  Display the option sensitivity curves for the
#  Symptom Distress Scale with 13 items and 473 respondents
#  Proceed as above changing "Quant" to "SDS".
```

---

smooth.surp *Fit data with surprisal smoothing.*

Description

Surprisal is -log(probability) where the logarithm is to the base being the dimension Mof the multinomial observation vector. The surprisal curves for each question are estimated by fitting the surprisal values of binned data using curves whose values are within the M-1 dimensional surprisal subspace that is within the space of non-negative M-dimensional vectors.

Usage

```
smooth.surp(argvals, Wbin, Bmat0, WfdPar, wtvec=NULL, conv=1e-4,
            iterlim=50, dbglev=0)
```

Arguments

argvals	Argument value array of length N, where N is the number of observed curve values for each curve. It is assumed that that these argument values are common to all observed curves. If this is not the case, you will need to run this function inside one or more loops, smoothing each curve separately.
Wbin	A nbin by M_i matrix of surprisal values to be fit.
Bmat0	A Wnbasis by M_i -1 matrix containing starting values for the iterative optimization of the least squares fit of the surprisal curves to the surprisal data.
WfdPar	A functional parameter or fdPar object. This object contains the specifications for the functional data object to be estimated by smoothing the data. See comment lines in function fdPar for details. The functional data object WFD in WFDPAROBJ is used to initialize the optimization process. Its coefficient array contains the starting values for the iterative minimization of mean squared error.
wtvec	A vector of weights to be used in the smoothing.
conv	A convergence criterion.
iterlim	the maximum number of iterations allowed in the minimization of error sum of squares.
dbglev	Either 0, 1, or 2. This controls the amount information printed out on each iteration, with 0 implying no output, 1 intermediate output level, and 2 full output. If either level 1 or 2 is specified, it can be helpful to turn off the output buffering feature of S-PLUS.

Value

A named list with these members:

Wfdobj	a functional data object defining function $W(x)$ that that optimizes the fit to the data of the positive function that it defines.
Flist	a named list containing three results for the final converged solution: (1) **f**: the optimal function value being minimized, (2) **grad**: the gradient vector at the optimal solution, and (3) **norm**: the norm of the gradient vector at the optimal solution.
argvals, y	the corresponding input arguments

Author(s)

Juan Li and James Ramsay

References

Ramsay, J. O., Li J. and Wiberg, M. (2020) Full information optimal scoring. Journal of Educational and Behavioral Statistics, 45, 297-315.

Ramsay, J. O., Li J. and Wiberg, M. (2020) Better rating scale scores with information-based psychometrics. Psych, 2, 347-360.

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See Also

Wbinsmth

Examples

```
#  evaluation points
x = seq(-2,2,len=11)
#  evaluate a standard normal distribution function
p = pnorm(x)
#  combine with 1-p
mnormp = cbind(p,1-p)
#  convert to surprisal values
mnorms = -log2(mnormp)
#  plot the surprisal values
matplot(x, mnorms, type="l", lty=c(1,1), col=c(1,1),
        ylab="Surprisal (2-bits)")
# add some log-normal error
mnormdata = exp(log(mnorms) + rnorm(11)*0.1)
#  set up a b-spline basis object
nbasis = 7
sbasis = create.bspline.basis(c(-2,2),nbasis)
#  define an initial coefficient matrix
cmat = matrix(0,7,1)
#  set up a fdPar object for suprisal smoothing
sfd = fd(cmat, sbasis)
sfdPar = fdPar(sfd, Lfd=2, lambda=0)
#  smooth the noisy data
result = smooth.surp(x, mnormdata, cmat, sfdPar)
#  plot the data and the fits of the two surprisal curves
xfine = seq(-2,2,len=51)
sfine = eval.surp(xfine, result$Wfd)
matplot(xfine, sfine, type="l", lty=c(1,1), col=c(1,1))
points(x, mnormdata[,1])
points(x, mnormdata[,2])
#  convert the surprisal fit values to probabilities
pfine = 2^-sfine
#  check that they sum to one
apply(pfine,1,sum)
```

`testscore` *Compute the expected test score by substituting probability of choices for indicator variable 0-1 values. Binary items assumed coded as two choice items.*

Description

Compute the expected test score by substituting probability of choices for indicator variable 0-1 values. Binary items assumed coded as two choice items.

Usage

```
testscore(theta, WfdList, optList)
```

Arguments

theta	Initial values for score indices in the interval [0,100]. A vector of size N.
WfdList	A numbered list object produced by a TestGardener analysis of a test. Its length is equal to the number of items in the test or questions in the scale. Each member of WfdList is a named list containing information computed during the analysis. These named list in each member contains these objects: **Wfd:** A functional data object containing the M surprisal curves for a question. **M:** The number of options. **Pbin:** A matrix containing proportions at each bin. **Wbin:** A matrix containing surprisal values at each bin. **Pmatfine:** A matrix of probabilities over a fine mesh. **Wmatfine:** A matrix of surprisal values over a fine mesh. **DWmatfine:** A matrix of the values of the first derivative of surprisal curves over fine mesh. **D2Wmatfine:** A matrix of the values of the second derivative of surprisal curves over fine mesh. **chartList:** A list vector of length n. Each list contains the K by M-1 matrix of initial values for the surprisal curves for the corresponding item.
optList	A numbered list of length n. Each member contains the weights assigned to each option for that item or question.

Value

A vector of test score values.

Author(s)

Juan Li and James Ramsay

References

Ramsay, J. O., Li J. and Wiberg, M. (2020) Full information optimal scoring. Journal of Educational and Behavioral Statistics, 45, 297-315.

Ramsay, J. O., Li J. and Wiberg, M. (2020) Better rating scale scores with information-based psychometrics. Psych, 2, 347-360.

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See Also

scoreDensity

Examples

```
#  Example 1.  Compute expected sum score values for the
#  short SweSAT multiple choice test with 24 items and 1000 examinees
WfdList <- Quant_parListi$WfdList
theta   <- Quant_parListi$theta
mu      <- testscore(theta, WfdList, Quant_dataList$optList)
par(c(1,1))
hist(mu,11)
#  Example 2.  Compute expected sum score values for the
#  Symptom Distress Scale with 13 items and 473 respondents
#  Proceed as above changing "Quant" to "SDS".
```

---

theta.distn *Compute score density*

Description

Computes the log density `logdensfd`, the norming constant `C` and the values `denscdf` of the cumulative probability function over a set of score values. The score values may score index values, expected test score values, or locations on the test information or scale curve. The argument functional data object `logdensfd` should have a range that is appropriate for the score values being represented: For score indices, [0,100], for expected test scores, the range of observed or expected scores; and for test information curve locations in the interval [0,`arclength`].

Usage

```
theta.distn(thetadens, logdensbasis, nfine = 101)
```

Arguments

`thetadens`	A vector of score index, test score, or arc length values. In the score index case, these are usually only the values in the interior of the interval [0,100].
`logdensbasis`	A functional basis object for representing the log density function. The argument may also be a functional parameter object (`fdPar`) or a functional basis object (`Wbasis`).
`nfine`	The number of values in a fine grid, default as 101.

Value

A named list containing:

logdensfd: A functional data object (`fd`) representing the log of the probability function for input `theta`.

denscdf: A vector of the probability cumulative distribution function values over the fine mesh.

C: The normalization constant for computing the probability density function with the command `densityfd = exp(logdensfd)/C`.

densfine: The values of the probability density function over the fine mesh.

Author(s)

Juan Li and James Ramsay

References

Ramsay, J. O., Li J. and Wiberg, M. (2020) Full information optimal scoring. Journal of Educational and Behavioral Statistics, 45, 297-315.

Ramsay, J. O., Li J. and Wiberg, M. (2020) Better rating scale scores with information-based psychometrics. Psych, 2, 347-360.

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See Also

thetafun, theta2arclen, testscore, scoreDensity

Examples

```
#  Example 1.  Display the item power curves for the
#  short SweSAT multiple choice test with 24 items and 1000 examinees
#  Assemble information for estimating theta density
indfine   <- seq(0,100,len=101)
WfdList   <- Quant_parListi$WfdList
theta     <- Quant_parListi$theta
N         <- length(theta)
#  Define the density for only interior theta values
inside    <- theta > 0 & theta < 100
logdensbasis    <- Quant_parListi$logdensfd$basis
theta.distnList <- theta.distn(theta[inside], logdensbasis)
theta.densfine  <- theta.distnList$densfine
#  Add number of values at each boundary
thetazero <- length(theta[theta == 0])
thetacent <- length(theta[theta == 100])
#  Plot both the interior density and the boundary proportions
plot(indfine, theta.densfine, type="l", lwd=2, ylim=c(0,0.025),
     xlab="Percentile Index", ylab="Density")
lines(c(  0,100), c(1/100,1/100), lty=2)
lines(c(  0,  0), c(0,thetazero/N), lty=1, lwd=4)
lines(c(100,100), c(0,thetacent/N), lty=1, lwd=4)
#  Second task:  Plot the test score density
optList <- Quant_dataList$optList
mu      <- testscore(theta, WfdList, optList)
#  Define the functional data object for score distribution over [0,24]
logdensmubasis <- fda::create.bspline.basis(c(0,24), 11)
logdensmufd    <- fd(matrix(0,11,1), logdensmubasis)
mu.distnList   <- theta.distn(mu, logdensmubasis)
mu.densfine    <- mu.distnList$densfine
scrfine        <- Quant_dataList$scrfine
#  Plot the test score density
plot(scrfine, mu.densfine, type="l", lwd=2, ylim=c(0,0.15),
     xlab="Test Score", ylab="Expected Score Density")
```

theta2arclen *Compute arc length and positions along the test information or scale curve*

Description

The one-dimensional psychometric model defines a space curve within the vector space defined by the total collection of option surprisal curves. This curve is a valuable resource since positions along the curve are defined in bits and positions on the curve are subject to the same strict properties that apply to physical measurements.

Usage

```
theta2arclen(theta, WfdList, Wdim)
```

Arguments

theta	A vector of score index, test score, or arc length values, one for each examinee or respondent.
WfdList	A numbered list object produced by a TestGardener analysis of a test. Its length is equal to the number of items in the test or questions in the scale. Each member of WfdList is a named list containing information computed during the analysis. These named lists contain these objects: **Wfd:** A functional data object containing the M surprisal curves for a question. **M:** The number of options. **Pbin:** A matrix containing proportions at each bin. **Wbin:** A matrix containing surprisal values at each bin. **Pmatfine:** A matrix of probabilities over a fine mesh. **Wmatfine:** A matrix of surprisal values over a fine mesh. **DWmatfine:** A matrix of the values of the first derivative of surprisal curves over fine mesh. **D2Wmatfine:** A matrix of the values of the second derivative of surprisal curves over fine mesh. **chartList:** A list vector of length n. Each list contains the K by M-1 matrix of initial values for the surprisal curves for the corresponding item.
Wdim	The total number of options in the test or scale.

Value

A named list object containing these results of the analysis:

theta_al	A vector of positions on the test information or scale curve corresponding to the input score index values in argument theta.
arclength	The length of the test information or scale curve.
arclengthfine	Positions on the test information or scale curve corresponding to a fine mesh of score index values (typically 101 values between 0 and 100).
Qvec_al	Values in arc length of five marker percentages.

Author(s)

Juan Li and James Ramsay

References

Ramsay, J. O., Li J. and Wiberg, M. (2020) Full information optimal scoring. Journal of Educational and Behavioral Statistics, 45, 297-315.

Ramsay, J. O., Li J. and Wiberg, M. (2020) Better rating scale scores with information-based psychometrics. Psych, 2, 347-360.

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See Also

Wpca.plot

Examples

```
#  Example 1.  Display the arc length curve for the
#  short SweSAT multiple choice test with 24 items and 1000 examinees
indfine       <- seq(0,100,len=101)
WfdList       <- Quant_parListi$WfdList
theta         <- Quant_parListi$theta
arclenList    <- theta2arclen(theta, WfdList, Quant_dataList$Wdim)
names(arclenList)
ArcLength.plot(arclenList$arclength, arclenList$arclengthfine)
#  Example 2.  Display the arc length curve for the
#  Symptom Distress Scale with 13 items and 473 respondents
#  Proceed as above changing "Quant" to "SDS".
```

---

thetafun *Compute optimal scores*

Description

The percentile score index values are estimated for each person. The estimates minimize the negative log likelihoods, which are a type of surprisal. The main optimization method is a safe-guarded Newton-Raphson method.

For any iteration the method uses only those scores that are within the interior of the interval [0,100] or at a boundary with a first derivative that would take a step into the interior, and have second derivative values exceeding the value of argument `crit`. Consequently the number of values being optimized decrease on each iteration, and iterations cease when either all values meet the convergence criterion or are optimized on a boundary, or when the number of iterations reaches `itermax`. At that point, if there are any interior scores still associated with either non-positive second derivatives or values that exceed `crit`, the minimizing value along a fine mesh is used.

If `itdisp` is positive, the number of values to be estimated are printed for each iteration.

Usage

```
thetafun(theta, WfdList, dataList, itermax = 20, crit = 0.001,
         itdisp = FALSE)
```

Arguments

theta	A vector of size N containing initial values for score indices in the interval [0,100].
WfdList	A numbered list object produced by a TestGardener analysis of a test. Its length is equal to the number of items in the test or questions in the scale. Each member of WfdList is a named list containing information computed during the analysis. The named list in each member contains these objects: **Wfd:** A functional data object containing the M surprisal curves for a question. **M:** The number of options. **Pbin:** A matrix containing proportions at each bin. **Wbin:** A matrix containing surprisal values at each bin. **Pmatfine:** A matrix of probabilities over a fine mesh. **Wmatfine:** A matrix of surprisal values over a fine mesh. **DWmatfine:** A matrix of the values of the first derivative of surprisal curves over fine mesh. **D2Wmatfine:** A matrix of the values of the second derivative of surprisal curves over fine mesh. **chartList:** A list vector of length n. Each list contains the K by M-1 matrix of initial values for the surprisal curves for the corresponding item.
dataList	A list that contains the objects needed to analyse the test or rating scale with the following fields: **U:** A matrix of response data with N rows and n columns where N is the number of examinees or respondents and n is the number of items. Entries in the matrices are the indices of the options chosen. Column i of U is expected to contain only the integers 1,...,noption. **optList:** A list vector containing the numerical score values assigned to the options for this question. **key:** If the data are from a test of the multiple choices type where the right answer is scored 1 and the wrong answers 0, this is a numeric vector of length n containing the indices the right answers. Otherwise, it is NULL. **chartList:** A list vector length n each member of which is a matrix of parameters values defining a set of M surprisal curves. The matrix has K rows and M - 1 columns where K is the number of basis functions defining the curves and M is the number curves. **WfdPar:** An fdPar object for the defining the surprisal curves. **noption:** A numeric vector of length n containing the numbers of options for each item. **nbin:** The number of bins for binning the data. **scrrng:** A vector of length 2 containing the limits of observed sum scores. **scrfine:** A fine mesh of test score values for plotting.

scrvec: A vector of length N containing the examinee or respondent sum scores.

itemvec: A vector of length n containing the question or item sum scores.

percntrnk: A vector length N containing the sum score percentile ranks.

thetaQnt: A numeric vector of length 2*nbin + 1 containing the bin boundaries alternating with the bin centers. These are initially defined as seq(0,100,len=2*nbin+1).

Wdim: The total dimension of the surprisal scores.

PcntMarkers: The marker percentages for plotting: 5, 25, 50, 75 and 95.

`itermax` Maximum number of iterations for computing the optimal theta values. Default is 20.

`crit` Criterion for convergence of optimization. Default is 1e-8.

`itdisp` If TRUE, results are displayed for each iteration.

Value

A named list with these members:

theta_out: A vector of optimized score index value.

Hval: The negative log likelihood criterion.

DHval: The first derivative of the negative likelihood.

D2Hval: The second derivative of the negative likelihood.

iter: The number iterations used.

Author(s)

Juan Li and James Ramsay

References

Ramsay, J. O., Li J. and Wiberg, M. (2020) Full information optimal scoring. Journal of Educational and Behavioral Statistics, 45, 297-315.

Ramsay, J. O., Li J. and Wiberg, M. (2020) Better rating scale scores with information-based psychometrics. Psych, 2, 347-360.

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See Also

`theta.distn`, `Hfun`, `DHfun`, `theta2arclen`, `testscore`, `scoreDensity`

Examples

```
#  Example 1.  Compute score index values theta for the
#  short SweSAT multiple choice test with 24 items and 1000 examinees
theta_in  <- Quant_dataList$percntrnk
oldpar <- par(no.readonly = TRUE)
par(mfrow=c(2,1))
hist(theta_in,11)
```

```
WfdList   <- Quant_parListi$WfdList
thetafunResult <- thetafun(theta_in, WfdList, Quant_dataList)
theta_out      <- thetafunResult$theta_out
hist(theta_out,11)
par(oldpar)
#  Example 2.  Compute score index values theta for the
#  Symptom Distress Scale with 13 items and 473 respondents
#  Proceed as above changing "Quant" to "SDS".
```

`Ushort` *Test data for 24 math calculation questions from the SweSAT Quantitative data.*

Description

These data are for a randomly selected subset of 1000 examinees.

Usage

```
Ushort
```

Format

A .txt file with 1000 rows each containing 24 integers in string format. The integers indicate which answer was chosen for each question by the examinee associated with the row.

Details

The code above inputs the contents of the file using the scan() function into a single character vector of length 24,000. The strings are converted to integers by the third command, and the integer vector is then reformatted into a 1000 by 24 matrix containing choice indices. The subsequent analysis of these data is described in detail in the vignette `SweSATQuanitativeShort`.

`Usimulate` *Simulate a test or scale data matrix.*

Description

Used in `dataSimulation`, this function sets up an N by n matrix of index values that specify the index of the option chosen by an examinee or respondent for a specific question.

Usage

```
Usimulate(n, theta.pop, WfdList)
```

Arguments

n	The number questions in the examination or scale.
theta.pop	A vector containing population score index values at which data are to be simulated.
WfdList	A numbered list object produced by a TestGardener analysis of a test. Its length is equal to the number of items in the test or questions in the scale. Each member of WfdList is a named list containing information computed during the analysis. These named lists contain these objects:

Wfd: A functional data object containing the M surprisal curves for a question.

M: The number of options.

Pbin: A matrix containing proportions at each bin.

Wbin: A matrix containing surprisal values at each bin.

Pmatfine: A matrix of probabilities over a fine mesh.

Wmatfine: A matrix of surprisal values over a fine mesh.

DWmatfine: A matrix of the values of the first derivative of surprisal curves over fine mesh.

D2Wmatfine: A matrix of the values of the second derivative of surprisal curves over fine mesh.

chartList: A list vector of length n. Each list contains the K by M-1 matrix of initial values for the surprisal curves for the corresponding item.

Details

For each question and each examinee a vector of random multinomial integer values is generated using the probability transforms of the surprisal curves and the examinee's score index value.

Value

An N by n matrix of integer index values.

References

Ramsay, J. O., Li J. and Wiberg, M. (2020) Full information optimal scoring. Journal of Educational and Behavioral Statistics, 45, 297-315.

Ramsay, J. O., Li J. and Wiberg, M. (2020) Better rating scale scores with information-based psychometrics. Psych, 2, 347-360.

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Wbinsmth *Estimate the option probability and surprisal curves.*

Description

The function first bins the data in order to achieve rapid estimation of the option surprisal curves. The argument `thetaQnt` contains the sequence of bin boundaries separated by the bin centers, so that it is of length `2*nbin + 1` where `nbin` is the number of bins. These bin values are distributed over the percentile interval [0,100] so that the lowest boundary is 0 and highest 100. Prior to the call to `Wbinsmth` these boundaries are computed so that the numbers of values of `theta` falling in the bins are roughly equal. It is important that the number of bins be chosen so that the bins contain at least about 25 values.

After the values of `theta` are binned, the proportions that the bins are chosen for each question and each option are computed. Proportions of zero are given NA values.

The positive proportions are then converted to surprisal values where surprisal = -log_M (proportion) where log_M is the logarithm with base M, the number of options associated with a question. Bins with zero proportions are assigned a surprisal that is appropriately large in the sense of being in the range of the larger surprisal values associated with small but positive proportions.

The next step is to fit the surprisal values for each question by a functional data object that is smooth, passes as closely as possible to an option's surprisal values, and has values consistent with being a surprisal value. The function `smooth.surp()` is used for this purpose.

Finally the curves and other results for each question are saved in object `WfdList`, a list vector of length n, and the list vector is returned.

Usage

```
Wbinsmth(theta, dataList, thetaQnt=seq(0,100,len=2*nbin+1), chartList)
```

Arguments

`theta`	A vector of length N containing current values of score index percentile values.
`dataList`	A list that contains the objects needed to analyse the test or rating scale with the following fields:

U: A matrix of response data with N rows and n columns where N is the number of examinees or respondents and n is the number of items. Entries in the matrices are the indices of the options chosen. Column i of U is expected to contain only the integers `1,...,noption`.

optList: A list vector containing the numerical score values assigned to the options for this question.

key: If the data are from a test of the multiple choices type where the right answer is scored 1 and the wrong answers 0, this is a numeric vector of length n containing the indices the right answers. Otherwise, it is NULL.

chartList: A list vector length n each member of which is a matrix of parameters values defining a set of M surprisal curves. The matrix has K rows and M - 1 columns where K is the number of basis functions defining the curves and M is the number curves.

WfdPar: An fdPar object for the defining the surprisal curves.

noption: A numeric vector of length n containing the numbers of options for each item.

nbin: The number of bins for binning the data.

scrrng: A vector of length 2 containing the limits of observed sum scores.

scrfine: A fine mesh of test score values for plotting.

scrvec: A vector of length N containing the examinee or respondent sum scores.

itemvec: A vector of length n containing the question or item sum scores.

percntrnk: A vector length N containing the sum score percentile ranks.

thetaQnt: A numeric vector of length 2*nbin + 1 containing the bin boundaries alternating with the bin centers. These are initially defined as `seq(0,100,len=2*nbin+1)`.

Wdim: The total dimension of the surprisal scores.

PcntMarkers: The marker percentages for plotting: 5, 25, 50, 75 and 95.

`thetaQnt` A vector of length 2*n+1 containing the sequence of bin boundary and bin centre values.

`chartList` A list vector of length n containing for each item an K by M-1 dimension matrix to be used to initialize function smooth.surp(). K is the number of basis functions used defining a surprisal curve and M is the number of options.

Value

`WfdList` A numbered list object produced by a TestGardener analysis of a test. Its length is equal to the number of items in the test or questions in the scale. Each member of `WfdList` is a named list containing information computed during the analysis. These named lists contain these objects:

Wfd: A functional data object containing the `M` surprisal curves for a question.

M: The number of options.

Pbin: A matrix containing proportions at each bin.

Wbin: A matrix containing surprisal values at each bin.

Pmatfine: A matrix of probabilities over a fine mesh.

Wmatfine: A matrix of surprisal values over a fine mesh.

DWmatfine: A matrix of the values of the first derivative of surprisal curves over fine mesh.

D2Wmatfine: A matrix of the values of the second derivative of surprisal curves over fine mesh.

chartList: A list vector of length `n`. Each list contains the `K` by `M-1` matrix of initial values for the surprisal curves for the corresponding item.

Author(s)

Juan Li and James Ramsay

References

Ramsay, J. O., Li J. and Wiberg, M. (2020) Full information optimal scoring. Journal of Educational and Behavioral Statistics, 45, 297-315.

Ramsay, J. O., Li J. and Wiberg, M. (2020) Better rating scale scores with information-based psychometrics. Psych, 2, 347-360.

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See Also

Wbinsmth.plot, thetafun

Examples

```
#  Example 1.  Display the item probability and surprisal curves for the
#  short SweSAT multiple choice test with 24 items and 1000 examinees
#  estimate the initial surprisal curves
theta     <- Quant_dataList$percntrnk
chartList <- Quant_dataList$chartList
thetaQnt  <- Quant_parListi$thetaQnt
Qvec      <- Quant_parListi$Qvec
WfdResult_init <- Wbinsmth(theta, Quant_dataList, thetaQnt, chartList)
WfdList_init   <- WfdResult_init$WfdList
#  plot the curves for the first question
binctr <- Quant_parListi$binctr
Wbinsmth.plot(binctr, Qvec, WfdList_init, Quant_dataList, plotindex=1)
#  estimate the final surprisal curves
theta    <- Quant_parListi$theta
thetaQnt <- Quant_parListi$thetaQnt
Qvec     <- Quant_parListi$Qvec
WfdResult_final <- Wbinsmth(theta, Quant_dataList, thetaQnt, chartList)
WfdList_final   <- WfdResult_final$WfdList
#  plot the curves for the first question
Wbinsmth.plot(binctr, Qvec, WfdList_final, Quant_dataList, plotindex=1)
#  Example 2.  Display the item probability and surprisal curves for the
# Symptom Distress Scale with 13 items and 473 respondents.
# Proceed as above changing "Quant" to "SDS"
```

`Wbinsmth.plot` *Plot probability and surprisal curves for a selection of test or scale items.*

Description

Wbinsmth.plots plots each item in argument `plotindex` in turn after function`Wbinsmth()` has used spline smoothing to estimate item and option characteristic curves.

Usage

```
Wbinsmth.plot(binctr, Qvec, WfdList, dataList,
              twoplot=TRUE, ptsplot=TRUE, alltype=TRUE,
              landscape=FALSE, saveplot=FALSE, plotindex=1:n, Wrng=c(0,5),
              ttlsz=NULL, axisttl=NULL, axistxt=NULL, lgdlab=NULL)
```

Arguments

binctr	A vector of bin center values.
Qvec	A vector of five marker percentile values.
WfdList	A numbered list object produced by a TestGardener analysis of a test. Its length is equal to the number of items in the test or questions in the scale. Each member of WfdList is a named list containing information computed during the analysis. These named lists contain these objects: **Wfd:** A functional data object containing the M surprisal curves for a question. **M:** The number of options. **Pbin:** A matrix containing proportions at each bin. **Wbin:** A matrix containing surprisal values at each bin. **Pmatfine:** A matrix of probabilities over a fine mesh. **Wmatfine:** A matrix of surprisal values over a fine mesh. **DWmatfine:** A matrix of the values of the first derivative of surprisal curves over fine mesh. **D2Wmatfine:** A matrix of the values of the second derivative of surprisal curves over fine mesh. **chartList:** A list vector of length n. Each list contains the K by M-1 matrix of initial values for the surprisal curves for the corresponding item.
dataList	A list that contains the objects needed to analyse the test or rating scale with the following fields: **U:** A matrix of response data with N rows and n columns where N is the number of examinees or respondents and n is the number of items. Entries in the matrices are the indices of the options chosen. Column i of U is expected to contain only the integers 1,...,noption. **optList:** A list vector containing the numerical score values assigned to the options for this question. **key:** If the data are from a test of the multiple choices type where the right answer is scored 1 and the wrong answers 0, this is a numeric vector of length n containing the indices the right answers. Otherwise, it is NULL. **chartList:** A list vector length n each member of which is a matrix of parameters values defining a set of M surprisal curves. The matrix has K rows and M - 1 columns where K is the number of basis functions defining the curves and M is the number curves. **WfdPar:** An fdPar object for the defining the surprisal curves. **noption:** A numeric vector of length n containing the numbers of options for each item. **nbin:** The number of bins for binning the data.

scrrng: A vector of length 2 containing the limits of observed sum scores.
scrfine: A fine mesh of test score values for plotting.
scrvec: A vector of length N containing the examinee or respondent sum scores.
itemvec: A vector of length n containing the question or item sum scores.
percntrnk: A vector length N containing the sum score percentile ranks.
thetaQnt: A numeric vector of length 2*nbin + 1 containing the bin boundaries alternating with the bin centers. These are initially defined as `seq(0,100,len=2*nbin+1)`.
Wdim: The total dimension of the surprisal scores.
PcntMarkers: The marker percentages for plotting: 5, 25, 50, 75 and 95.

`twoplot`	logical, if true plot both P and W curves.
`ptsplot`	logical, if true plot observed proportions.
`alltype`	logical, if true, plot right and wrong P curves.
`landscape`	logical, if true plots are side by side.
`plotindex`	A vector of indices of items to be plotted.
`saveplot`	A logical value indicating whether the plot should be saved to a pdf file.
`Wrng`	A vector of length 2 specifying the range for plotting surprisal values.
`ttlsz`	Title font size.
`axisttl`	Axis title font size.
`axistxt`	Axis text(tick label) font size.
`lgdlab`	Legend label font size.

Value

A list vector is returned which is of the length of argument `plotindex`. Each member of the vector is a `gg` or `ggplot` object for the associated `plotindex` `value`. Each plot can be displayed using the `print` command. The plots of item power are produced as a side value even if no output object is specified in the call to the function.

Author(s)

Juan Li and James Ramsay

References

Ramsay, J. O., Li J. and Wiberg, M. (2020) Full information optimal scoring. Journal of Educational and Behavioral Statistics, 45, 297-315.

Ramsay, J. O., Li J. and Wiberg, M. (2020) Better rating scale scores with information-based psychometrics. Psych, 2, 347-360.

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See Also

`Sensitivity.plot`, `Power.plot`, `Entropy.plot`, `Item.plot`, `Wbinsmth`,

Examples

```
#  Example 1.  Display the item surprisal curves for the
#  short SweSAT multiple choice test with 24 items and 1000 examinees
WfdList  <- Quant_parListi$WfdList
Qvec     <- Quant_parListi$Qvec
binctr   <- Quant_parListi$binctr
titlestr <- NULL
#  plot the curves for the first question
Wbinsmth.plot(binctr, Qvec, WfdList, Quant_dataList, plotindex=1)
#  Example 2.  Display the item proability and surprisal curves for the
# Symptom Distress Scale with 13 items and 473 respondents.
# Proceed as above changing "Quant" to "SDS"
```

Wpca.plot *Plot the test information or scale curve in either two or three dimensions.*

Description

A test or scale analysis produces a space curve that varies with in the space of possible option curves of dimension `Wdim`. Fortunately, it is usual that most of the shape variation in the curve is within only two or three dimensions, and these can be fixed by using functional principal components analysis.

Usage

```
Wpca.plot(arclength, WfdList, Wdim, nharm=2, rotate=TRUE, dodge = 1.003,
titlestr = NULL)
```

Arguments

`arclength`	The total length of the test information or scale curve as computed by function `theta2arclen`.
`WfdList`	A numbered list object produced by a TestGardener analysis of a test. Its length is equal to the number of items in the test or questions in the scale. Each member of `WfdList` is a named list containing information computed during the analysis. These named lists contain these objects: **Wfd:** A functional data object containing the `M` surprisal curves for a question. **M:** The number of options. **Pbin:** A matrix containing proportions at each bin. **Wbin:** A matrix containing surprisal values at each bin. **Pmatfine:** A matrix of probabilities over a fine mesh. **Wmatfine:** A matrix of surprisal values over a fine mesh. **DWmatfine:** A matrix of the values of the first derivative of surprisal curves over fine mesh.

D2Wmatfine: A matrix of the values of the second derivative of surprisal curves over fine mesh.

chartList: A list vector of length n. Each list contains the K by M-1 matrix of initial values for the surprisal curves for the corresponding item.

Wdim	The total number of options in the test or scale.
nharm	The number of principal components of the test information or scale curve to be used to display the curve. Must be either 2 or 3.
rotate	If true, rotate principal components of the test information or scale curve to be used to display the curve to VARIMAX orientation.
dodge	A constant greater than 1 required by ggplot2. Defaults to 1.003.
titlestr	A string for the title of the plot. Defaults to NULL.

Value

A named list with these members:

pcaplot	If two dimensions or harmonics are specified, this is a gg or ggplot object that can be displayed using the print command. If three dimensions are specified, this is NULL.
harmvarmxfd	Functional data objects for the principal components of the curve shape.
varpropvarmx	Proportions of variance accounted for by the principal components

The principal components are VARIMAX rotated by default. The plot is displayed as a side value even if no output object is specified in the call to the function.

Author(s)

Juan Li and James Ramsay

References

Ramsay, J. O., Li J. and Wiberg, M. (2020) Full information optimal scoring. Journal of Educational and Behavioral Statistics, 45, 297-315.

Ramsay, J. O., Li J. and Wiberg, M. (2020) Better rating scale scores with information-based psychometrics. Psych, 2, 347-360.

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Examples

```
#  Example 1.  Display the test information curve for the
#  short SweSAT multiple choice test with 24 items and 1000 examinees
#  plot a two-dimension version of manifold curve
WfdList    <- Quant_parListi$WfdList
theta      <- Quant_parListi$theta
arclength  <- Quant_parListi$arclength
Wpca.plotResults <- Wpca.plot(arclength, WfdList, Quant_dataList$Wdim)
varprop <- Wpca.plotResults$varpropvarmx
print("Proportions of variance accounted for and their sum:")
```

```
print(round(c(varprop,sum(varprop)),3))
#  plot a three-dimension version of manifold curve
WfdList    <- Quant_parListi$WfdList
theta      <- Quant_parListi$theta
arclength  <- Quant_parListi$arclength
Wpca.plotResults <- Wpca.plot(arclength, WfdList, Quant_dataList$Wdim, nharm=3)
varprop <- Wpca.plotResults$varpropvarmx
print("Proportions of variance accounted for and their sum:")
print(round(c(varprop,sum(varprop)),3))
#  Example 2.  Display the test information curve for the
# Symptom Distress Scale with 13 items and 473 respondents.
# Proceed as above changing "Quant" to "SDS"
```

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