

Package ‘ata’

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Title Automated Test Assembly

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Author Gulsah Gurkan [aut],
Michael Chajewski [aut, cre],
Sam Buttrey [cph]

Maintainer Michael Chajewski <mchajewski@hotmail.com>

Description Provides a collection of psychometric methods to process item metadata and use target assessment and measurement blueprint constraints to assemble a test form. Currently two automatic test assembly (ata) approaches are enabled. For example, the weighted (positive) deviations method, wdm(), proposed by Swanson and Stocking (1993) <[doi:10.1177/014662169301700205](https://doi.org/10.1177/014662169301700205)> was implemented in its full specification allowing for both item selection as well as test form refinement. The linear constraint programming approach, atalp(), uses the linear equation solver by Berkelaar et. al (2014) <<http://lpsolve.sourceforge.net/5.5/>> to enable a variety of approaches to select items.

Depends R (>= 3.0.0), lpSolve

Imports stats

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| | |
|-------|---|
| atalp | <i>Automated Test Assembly via Linear Constrained Programming</i> |
|-------|---|

Description

Ingests item metadata jointly with target test form constraints, and can be parameterized to uses either Boolean (0-1) Integer Linear Programming (ILP) or Mixed Integer Linear Programming (MILP) to construct a test form based on the desired objectives. When MILP is desired the selection of the objective function type should be changed.

Usage

```
atalp( ipool,
      id,
      constraints,
      refine = FALSE,
      permutate = FALSE,
      sorttimes = 999,
      tieselect = -1,
      type = "const",
      verbose = TRUE,
      aprioriadd = NA,
      posthocadd = NA )
```

Arguments

| | |
|-------------|--|
| ipool | Item by characteristic (property) metadata pool. |
| id | Name of unique item identifier. |
| constraints | Complex list object identifying the constraints to be applied in the ATA (see makeconstobj for guided process). |
| refine | Creates a final test form from permuted solutions, refined to attempt a deviation balance between the observed form and the constraints. Option only effective if permutate is TRUE and type = const in which the constraint weights have meaning; Default is FALSE. |

| | |
|------------|--|
| permutate | Requests the test form to be assembled by resorting (sorttimes) the metadata and selecting the most frequently occurring item combination satisfying the constraints. Relevant only for type = const; Default is FALSE. |
| sorttimes | Number of how often the original input metadata should be resorted. Only functional if permutate is TRUE and type = const; default 999, so that sorttimes + main analysis account for a total of 1,000 selection versions. |
| tieselect | How should tied items be resolved: -1 (default) - do not manipulate items (which allows for identically functioning items to be included), 1 - select the first item in the list of candidates (sensitive to data sorting); not applicable for situations with all categorical constraints only, 0 - randomly select candidate; not applicable for situations with all categorical constraints only. |
| type | Type of objective function: const - constraint based only (default), parmin - constraint + minimum non-categorical parameter combination, parmax - constraint + maximum non-categorical parameter combination. |
| verbose | Should progress be printed to the console? Default TRUE. |
| aprioriadd | Force item addition (via IDs) to test form before ATA, which affects item selection and constraint attainment success (currently not available). |
| posthocadd | Force item addition (via IDs) to test form after ATA, which affects final form specifications (currently not available). |

Value

A complex list object with test assembly specific estimates:

| | |
|---------------|---|
| objective | Constrained objective function value. |
| items_removed | Removed items from item pool when tieselect is not -1. |
| excluded | Items from pool excluded. |
| excluded_set | Item sets excluded. Only included if input constobj includes a set_id. |
| included | Items from pool included in new test form. |
| included_set | Item sets from pool included in new test form. Only included if input constobj includes a set_id. |
| final_ids | Final item ids in the test form. |
| final_setids | Final set ids in the test form. Only included if input constobj includes a set_id. |

Author(s)

Michael Chajewski (mchajewski@hotmail.com), Gulsah Gurkan (gurkangulsah@gmail.com)

References

- Chen, P. (2017). Should we stop developing heuristics and only rely on mixed integer programming solvers in automated test assembly? *Applied Psychological Measurement*, 41, 227-240.
- Diao, Q., & van der Linden, W. J. (2011). Automated test assembly using lp_Solve Version 5.5 in R. *Applied Psychological Measurement*, 35, 398-409.

Shao, C., Liu, S., Yang, H., & Tsai, T. (2019). Automated test assembly using SAS operations research software in a medical licensing examination. *Applied Psychological Measurement*, 00, 1-15.

van der Linden, W. J. (2005). A comparison of item-selection methods for adaptive tests with content constraints. *Journal of Educational Measurement*, 42, 283-302.

Examples

```
# Specifying constraints
constin <- list(
  nI = 5, # Number of items on the future test
  nC = 4, # Number of constraints to be satisfied
  nameC = c("Content_A", "Content_B", "p", "iSx"), # Name of constraint; must be numeric and must
  # reflect variable name in input
  lowerC = c(2, 3, 3.00, 0.50), # Lower bound total constraint value on ATA form
  upperC = c(2, 3, 3.50, 0.60), # Upper bound total constraint value on ATA form
  wC = c(1, 1, 1, 1), # Constraint weight used for weighted sum of
  # (positive) deviations St
  set_id = NA # Aggregation ID for units / sets
)

# Running atalp
testLP <- atalp(ipool = metadata_example,
  id = "Item",
  constraints = constin)

# Summary of results
summary(testLP)
```

makeconstobj

User-guided Function to Create a Constraints Input for ATA Form Creation

Description

Guides the user to create a complex list object identifying the constraints to be applied in automated test assembly functions from the *ata* package.

Usage

```
makeconstobj( ipool,
  id,
  empty = FALSE)
```

Arguments

| | |
|-------|--|
| ipool | Item by characteristic (or property) metadata. |
| id | Name (not actual codes) of unique item identifier (variable). |
| empty | Should the function return an empty list to be filled in manually. Default is FALSE. |

Value

A list object with "nC" "nameC" "lowerC" "upperC" "wC" "nI" "set_id"

Author(s)

Gulsah Gurkan (gurkangulsah@gmail.com), Michael Chajewski (mchajewski@hotmail.com)

References

Parshall, C. G., et al. (2002). Automated test assembly for online administration. In C. G. Parshall, J. A. Spray, J. C. Kalohn, & T. Davey, Practical considerations in computer based testing (pp.106-125). New York, NY: Springer-Verlag New York, Inc.

metadata_example

ATA Package Example Item Metadata

Description

Sample data based on data from Parshall et al. (2002) used for the demonstration of the Weighted (positive) Deviations Method (WDM).

Usage

metadata_example

Format

A data frame with 10 rows and 10 variables:

Item Unique item identifier, integer.

Content Content label, as factor identifying content "A" and "B".

Content_A Dummy code for content "A", 0 and 1 indicators.

Content_B Dummy code for content "B", 0 and 1 indicators.

p Item proportion correct responding, rounded decimal.

rpbis Item-total point biserial correlation, rounded decimal correlation in range -1.00 to 1.00.

iSx Item contribution to total composite standard deviation, double precision numeric.

Time Expected item response time, in minutes.

Parent0 Item set ID–initial, unique item set name.

Parent1 Item set ID–modified, unique item set name.

References

Parshall, C. G., et al. (2002). Automated test assembly for online administration. In C. G. Parshall, J. A. Spray, J. C. Kalohn, & T. Davey, Practical considerations in computer based testing (pp.106-125). New York, NY: Springer-Verlag New York, Inc.

metadata_large_example

ATA Package Large Example Item Metadata

Description

Sample data used to demonstrate automated test assembly.

Usage

metadata_large_example

Format

A data frame with 1096 rows and 44 variables:

Item Unique item identifier, alpha-numeric index code.

Content Content label, as factor identifying content "A" and "B".

Content_A Dummy code for content "A", 0 and 1 indicators.

Content_B Dummy code for content "B", 0 and 1 indicators.

Content_C Dummy code for content "C", 0 and 1 indicators.

Content_D Dummy code for content "D", 0 and 1 indicators.

Content_E Dummy code for content "E", 0 and 1 indicators.

Content_F Dummy code for content "F", 0 and 1 indicators.

Content_G Dummy code for content "G", 0 and 1 indicators.

Content_H Dummy code for content "H", 0 and 1 indicators.

Content_I Dummy code for content "I", 0 and 1 indicators.

Content_J Dummy code for content "J", 0 and 1 indicators.

Content_K Dummy code for content "K", 0 and 1 indicators.

Content_L Dummy code for content "L", 0 and 1 indicators.

Content_M Dummy code for content "M", 0 and 1 indicators.

Content_N Dummy code for content "N", 0 and 1 indicators.

Content_O Dummy code for content "O", 0 and 1 indicators.

Content_P Dummy code for content "P", 0 and 1 indicators.

Content_Q Dummy code for content "Q", 0 and 1 indicators.

Content_R Dummy code for content "R", 0 and 1 indicators.

- Content_S** Dummy code for content "S", 0 and 1 indicators.
- Content_T** Dummy code for content "T", 0 and 1 indicators.
- Content_U** Dummy code for content "U", 0 and 1 indicators.
- Content_V** Dummy code for content "V", 0 and 1 indicators.
- Content_W** Dummy code for content "W", 0 and 1 indicators.
- Content_X** Dummy code for content "X", 0 and 1 indicators.
- Content_Y** Dummy code for content "Y", 0 and 1 indicators.
- Content_Z** Dummy code for content "Z", 0 and 1 indicators.
- p** Item proportion correct responding.
- rpbis** Item-total point biserial correlation, rounded decimal correlation in range -1.00 to 1.00
- iSx** Item contribution to total composite standard deviation.
- Time** Observed median item response time, in seconds.
- Choices** Number of response choices in the multiple-choice question.
- Answer** Correct answer key. In the multiple-choice questions answer 1 = A, 2 = B, and so on.
- Skill** Formative insight skill classification.
- Skill_1** Formative skill insight dummy code for skill 1 (S1): Interpretive.
- Skill_2** Formative skill insight dummy code for skill 2 (S2): Factual.
- Skill_3** Formative skill insight dummy code for skill 3 (S3): Evaluative.
- IIF_m2** Item Response Theory (IRT) item information function value at a theta = -2.0.
- IIF_m1** Item Response Theory (IRT) item information function value at a theta = -1.0.
- IIF_0** Item Response Theory (IRT) item information function value at a theta = 0.0.
- IIF_1** Item Response Theory (IRT) item information function value at a theta = 1.0.
- IIF_2** Item Response Theory (IRT) item information function value at a theta = 2.0.
- Parent0** Passage based item set parent identification.

metadata_withreplic_example

ATA Package Example Item Metadata with Item Replications

Description

Sample data based on data from Parshall et al. (2002) used for the demonstration of the Weighted (positive) Deviations Method (WDM).

Usage

metadata_withreplic_example

Format

A data frame with 14 rows and 10 variables:

Item Unique item identifier, integer.

Item2 Unique item identifier, character letter.

Content Content label, as factor identifying content "A" and "B".

Content_A Dummy code for content "A", 0 and 1 indicators.

Content_B Dummy code for content "B", 0 and 1 indicators.

p Item proportion correct responding, rounded decimal.

rpbis Item-total point biserial correlation, rounded decimal correlation in range -1.00 to 1.00.

iSx Item contribution to total composite standard deviation, double precision numeric.

Time Expected item response time, in minutes.

Orig_Item Original item copy, corresponding "Item" column ID.

References

Parshall, C. G., et al. (2002). Automated test assembly for online administration. In C. G. Parshall, J. A. Spray, J. C. Kalohn, & T. Davey, Practical considerations in computer based testing (pp.106-125). New York, NY: Springer-Verlag New York, Inc.

plot.ata

Generic Plot Function for Class ata

Description

Default plotting function for output objects of class ata. The function detects the object's method and renders the appropriate visualizations.

Usage

```
\method{plot}{ata}(x,
  conditem=NA,
  useconst=TRUE,
  itemorder=NA,
  itemlab=NA,
  useitemlab=FALSE,
  together=FALSE,
  ...)
```

Arguments

| | |
|------------|---|
| x | An output object of class ata generated by either wdm() or atalp() from the ata package. |
| conditem | Provides a conditional or secondary item classification (i.e. content label). If provided, it must be given in the order of final_ids in the ata output object. |
| useconst | Indicator whether all constraints from the test assembly process should be visualized or whether only a selection is desired. If a selection is desired, the name of the constraint as given by the constobj should be provided. Default is TRUE. |
| itemorder | Identifies the item order with which to visualize constraints. If NA the observed order in the ata object will be used. If provided, the new order for the order of final_ids in the ata output object must be given. |
| itemlab | Identifies item labels. Default is NA. If NA, then the item ids in the final_ids vector of the ata output object will be used. If provided, ids must be given in the order of final_ids in the ata output object. |
| useitemlab | Identifies if items should be labeled. Default is FALSE. If FALSE then the item order in the final_ids vector of the ata output object will be used as labels. If TRUE, but itemlab is not provided, then the ids from the final_ids vector will be used. |
| together | Should progress plots be stacked together in one plot? Default is FALSE. Not advisable for situations with more than 5 constraints. |
| ... | Arguments to be passed to methods. |

Value

The function returns plots of the test form constraints and a cumulative additive constraint list for each constraint if assigned to an object.

| | |
|------------|---|
| plots | For each constraint in the test form two visualizations are considered: 1) A cumulative additive progressive plot showing the change in the constraint total value per selected item, and 2) a plot of the constraint item specific value for each selected item. |
| cumulative | If plot.ata is assigned to an object, the object will inherit a list of length equal to the number of constraints each element containing the cumulative constraint value after each selected item. |

Author(s)

Michael Chajewski (mchajewski@hotmail.com)

summary.ata

Generic Summary Function for Class ata

Description

Default summary function for output objects of class ata. The function provides a brief summary of the ATA form in text, and provides a binary table of constraint success.

Usage

```
\method{summary}{ata}(object, ...)
```

Arguments

| | |
|--------|--|
| object | An output object of class ata generated by either wdm() or atalp() from the package. |
| ... | Additional arguments affecting the summary produced. |

Value

The function returns a statement summarizing the evaluation of the assembled test form. Additionally, the function will return a pattern matrix for the test form constraints if assigned to an object.

| | |
|-----------|--|
| statement | A summary of items (and/or item sets) in the test form and the overview of constraint success. |
| pattern | A matrix of constraints by a classification if the additive constraints are below, at or above the constraint specific user provided bounds. This matrix, only returned if summary.ata is assigned to an object, will always demonstrate meeting all criteria for atalp test forms as all criteria have to be met to obtain a feasible solution. |

Author(s)

Gulsah Gurkan (gurkangulsah@gmail.com), Michael Chajewski (mchajewski@hotmail.com)

wdm

Automated Test Assembly via Weighted (positive) Deviations Method

Description

Ingests item metadata jointly with target test form constraints and uses the Weighted (positive) Deviations Method (WDM) to construct a test form based on the desired objectives.

Usage

```
wdm( ipool,
      id,
      constraints,
      first = NA,
      refine = TRUE,
      permutate = FALSE,
      tieselect = 1,
      verbose = TRUE,
      aprioriadd = NA,
      posthocadd = NA )
```

Arguments

| | |
|-------------|---|
| ipool | Item by characteristic (property) metadata pool. |
| id | Name of unique item identifier. |
| constraints | Complex list object identifying the constraints to be applied in the ATA (see <code>makeconstobj</code> for guided process). |
| first | How should item selection start: id of the item to be selected first from the pool, NA (default) - select randomly from the pool. |
| refine | Should the final test form be refined against the remaining item pool? Default is TRUE. |
| permutate | Assemble test forms starting with each item sequentially (as many forms as items in pool) and define final test form based on eligible constraint compliant solutions; Default is FALSE (currently not available). |
| tieselect | How should tied items be resolved: 1 (default) - select the first item in the list of candidates (sensitive to data sorting); not applicable for situations with all categorical constraints only, 0 - randomly select candidate; not applicable for situations with all categorical constraints only |
| verbose | Should progress of <code>wdm()</code> be printed to the console? Default = TRUE. |
| aprioriadd | Force item addition (via IDs) to test before ATA, which affects item selection and constraint attainment success (currently not available). |
| posthocadd | Force item addition (via IDs) to test after ATA, which affects final form specifications (currently not available). |

Value

A complex list object with test assembly specific estimates:

| | |
|------------|--|
| wde | Estimates of the computational steps deriving the positive weighted deviations and item selection. |
| evaluation | Final assembled test form additive properties across constraints. |
| considered | Estimates of the computational steps when <code>refine = TRUE</code> evaluating selected items and selecting replacements. |
| excluded | Items from pool excluded. |

| | |
|----------------|---|
| excluded_set | Item sets excluded. Only included if input constobj includes a set_id. |
| included | Items from pool included in new test form. |
| included_set | Item sets from pool included in new test form. Only included if input constobj includes a set_id. |
| initial_ids | Item sets from pool included in new test form. |
| initial_setids | Item sets from pool included in new test form. Only included if input constobj includes a set_id. |
| final_ids | Final item ids in the test form. |
| final_setids | Final set ids in the test form. Only included if input constobj includes a set_id. |

Author(s)

Gulsah Gurkan (gurkangulsah@gmail.com), Michael Chajewski (mchajewski@hotmail.com)

References

- Parshall, C. G., et al. (2002). Automated test assembly for online administration. In C. G. Parshall, J. A. Spray, J. C. Kalohn, & T. Davey, Practical considerations in computer based testing (pp.106-125). New York, NY: Springer-Verlag New York, Inc.
- Sanders, P. F., & Verschoor, A. J. (1998). Parallel test construction using classical item parameters. *Applied Psychological Measurement*, 22, 212-223.
- Swanson, L., & Stocking, M. L. (1993). A Model and heuristic for solving Very large item selection problems. *Applied Psychological Measurement*, 17, 151-166.

Examples

```
# Specifying constraints
constin <- list(
  nI = 5,                                # Number of items on the future test
  nC = 4,                                # Number of constraints to be satisfied
  nameC = c("Content_A", "Content_B", "p", "iSx"), # Name of constraint; must be numeric and must
  # reflect variable name in input
  lowerC = c(2, 3, 3.00, 0.50),          # Lower bound total constraint value on ATA form
  upperC = c(2, 3, 3.50, 0.60),          # Upper bound total constraint value on ATA form
  wC = c(1, 1, 1, 1),                    # Constraint weight used for weighted sum of
  # (positive) deviations St
  set_id = NA                             # Aggregation ID for units / sets
)

# Running WDM example from Parshall et al. (2002)
testWDM <- wdm( ipool = metadata_example,
  id = "Item",
  constraints = constin,
  first = 2)

# Summary of results
summary(testWDM)
```

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