

# Package ‘caMST’

June 25, 2022

**Type** Package

**Title** Mixed Computerized Adaptive Multistage Testing

**Version** 0.1.6

**Date** 2022-06-24

**Description** Provides functions to more easily analyze computerized adaptive tests. Currently, functions for computerized adaptive tests (CAT), computer adaptive multistage tests (CMT), and mixed computer adaptive multistage tests (McaMST) utilizing CAT item-level adaptation for the initial stage and traditional MST module-level adaptation for the subsequent stages have been created, and a variation of Hybrid computer adaptive MST is planned as well. For an in-depth look at CAT and MST, see Weiss & Kingsbury (1984) <[doi:10.1111/j.1745-3984.1984.tb01040.x](https://doi.org/10.1111/j.1745-3984.1984.tb01040.x)> and Luecht & Nungester (2000) <[doi:10.1007/0-306-47531-6\\_6](https://doi.org/10.1007/0-306-47531-6_6)> respectively.

**License** LGPL (>= 2.0, < 3) | Mozilla Public License

**Encoding** UTF-8

**LazyData** true

**Depends** R (>= 3.5.0)

**Imports** catR, mstR, diagram, methods

**Suggests** testthat, knitr, rmarkdown

**RoxygenNote** 7.2.0

**NeedsCompilation** no

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**Repository** CRAN

**Date/Publication** 2022-06-24 22:40:12 UTC

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.onAttach	<i>Package Attach Hook Function</i>
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---

### Description

Hook triggered when package attached.

### Usage

```
.onAttach(lib, pkg)
```

### Arguments

lib	a character string giving the library directory where the package defining the namespace was found
pkg	a character string giving the name of the package

### Details

Idea taken from <https://github.com/ntguardian/MCHT/blob/master/R/StartupMessage.R>

### Examples

```
caMST:::onAttach(.libPaths()[1], "caMST")
```

---

caMST	caMST <i>package</i>
-------	----------------------

---

**Description**

Computer Adaptive Mutistage Test Analysis

**Details**

See the README on [GitHub](#) for more information.

---

caMSTStartup	<i>Create Package Startup Message</i>
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---

**Description**

Makes package startup message.

**Usage**

```
caMSTStartup()
```

**Details**

Idea taken from <https://github.com/ntguardian/MCHT/blob/master/R/StartupMessage.R>

**Examples**

```
caMST:::caMSTStartup()
```

---

CAT-class	<i>An S4 class for computerized adaptive tests</i>
-----------	--

---

**Description**

An S4 class for computerized adaptive tests

**Value**

An S4 object of class 'CAT'.

**Slots**

`function.call` The original function call.

`final.theta.estimate` Numeric vector of theta estimates calculated by the provided ‘method’.

`eap.theta` Numeric vector of theta estimates calculated by ‘catR::eapEst’.

`final.theta.Baker` Numeric vector of theta estimates calculated by the internal ‘iterative.theta.estimate’ function.

`final.theta.SEM` Numeric vector of SEM estimates calculated by the internal ‘iterative.theta.estimate’ function.

`final.items.seen` Character matrix of the final items seen by each individual.

`final.responses` Numeric matrix of the response patterns observed.

`runtime` A ‘difftime’ object of the total run time of the function.

---

 cat\_items

*Example items for the CAT stage of an example adaptive test.*


---

**Description**

A data frame formatted in the style required by **mstR** for item data. Represents items to be used in an item-level adaptation portion of a computerized adaptive test.

**Usage**

```
cat_items
```

**Format**

A data frame with 564 rows (items) and 6 columns (item parameters):

**a** item discrimination

**b** item difficulty

**c** item guessing

**u** item carelessness

**content\_ID** what content area the item comes from

**stage** which stage the item belongs to

---

computerized\_adaptive\_test  
*Computerized Adaptive Test*

---

## Description

Computerized Adaptive Test

## Usage

```
computerized_adaptive_test(
  cat_item_bank,
  response_matrix,
  initial_theta = 0,
  model = NULL,
  randomesque = 1,
  maxItems = 50,
  method = "BM",
  nextItemControl = list(criterion = "MFI", method = method, priorDist = "norm",
    priorPar = c(0, 1), D = 1, range = c(-4, 4), parInt = c(-4, 4, 33), infoType =
    "Fisher", random.seed = NULL, rule = "precision", thr = 0.3, SETH = NULL, AP = 1,
    nAvailable = NULL, cbControl = NULL, cbGroup = NULL),
  ...
)
```

## Arguments

<code>cat_item_bank</code>	A data frame with the items on the rows and their item parameters on the columns. These should be in the <b>catR</b> package format for item banks.
<code>response_matrix</code>	A matrix of the person responses, with individuals as rows and items as columns.
<code>initial_theta</code>	The initial theta estimate for all individuals. Default is 0.
<code>model</code>	Either NULL (default) for dichotomous models or a character value indicating the polytomous model used. See the <b>mstR</b> package for more details.
<code>randomesque</code>	An integer value that indicates the number of items from which the selection rule should choose from randomly for administration. See the help documentation for <code>catR::nextItem</code> for more details.
<code>maxItems</code>	An integer value indicating the maximum number of items to administer, regardless of other stopping rules.
<code>method</code>	A character value indicating method for the provisional theta estimate. Defaults to "BM" (Bayes Modal). See the <b>catR</b> package for more details.
<code>nextItemControl</code>	A list of control values passed to <code>catR::nextItem</code> . See that function for more details.
<code>...</code>	Further arguments to be passed to internal functions. Currently unimplemented.

**Value**

An S4 object of class 'CAT' with the following slots:

<code>function.call</code>	The function and arguments called to create this object.
<code>final.theta.estimate</code>	A numeric vector of the final theta estimates using the method provided in <code>function.call</code> .
<code>eap.theta</code>	A numeric vector of the final theta estimates using the expected a posteriori (EAP) theta estimate from <code>catR::eapEst</code> .
<code>final.theta.Baker</code>	A numeric vector of the final theta estimates using an iterative maximum likelihood estimation procedure as described in chapter 5 of Baker (2001).
<code>final.theta.SEM</code>	A numeric vector of the final standard error of measurement (SEM) estimates using an iterative maximum likelihood estimation procedure as described in chapter 5 of Baker (2001)[ <a href="http://echo.edres.org:8080/irt/baker/final.pdf">http://echo.edres.org:8080/irt/baker/final.pdf</a> ].
<code>final.items.seen</code>	A matrix of the final items seen by each individual using the supplied item names. NA values indicate that an individual wasn't given any items to answer after the last specified item in their row.
<code>final.responses</code>	A matrix of the responses to the items seen in <code>final.items.seen</code> . NA values indicate that the individual didn't answer the question in the supplied response file or wasn't given any more items to answer.
<code>runtime</code>	A <code>difftime</code> object recording how long the function took to complete.

**References**

Baker, F. B. (2001). The basics of item response theory. For full text: <http://echo.edres.org:8080/irt/baker/final.pdf>.

**See Also**

[`mixed_adaptive_test`] for a multistage test with a routing module using item-level adaptation.

**Examples**

```
data(example_thetas) # 5 simulated abilities
data(example_responses) # 5 simulated responses
data(cat_items) # using just the CAT routing stage items
catResults <- computerized_adaptive_test(cat_item_bank = cat_items,
response_matrix = example_responses, randomesque = 1, maxItems = 3,
nextItemControl = list(criterion = "MFI",
priorDist = "norm", priorPar = c(0, 1), D = 1, range = c(-4, 4),
parInt = c(-4, 4, 33), infoType = "Fisher", randomesque = 1, random.seed = NULL,
rule = "precision", thr = .3, nAvailable = NULL,
cbControl = NULL, cbGroup = NULL))
```

---

example_module_items	<i>Example "item-to-module" map matrix, showcasing how the items and modules are related.</i>
----------------------	---

---

**Description**

A matrix with items on the rows and modules on the columns, where 0 indicates the item and module are unrelated and 1 indicates that the item is a part of that module. Used in combination with a transition matrix to describe a multistage adaptive test.

**Usage**

```
example_module_items
```

**Format**

An object of class `matrix` (inherits from `array`) with 42 rows and 7 columns.

---

example_responses	<i>Responses to all of the example items by the five individuals represented in the "example_thetas" data.</i>
-------------------	--

---

**Description**

A data frame with individuals on the rows and items on the columns. The values of the data frame are the response patterns of the individuals to all of the items in the example item files.

**Usage**

```
example_responses
```

**Format**

An object of class `data.frame` with 5 rows and 600 columns.

---

example_thetas	<i>Theta values used in the examples.</i>
----------------	---

---

**Description**

A numeric vector with five simulated theta values.

**Usage**

```
example_thetas
```

**Format**

An object of class `numeric` of length 5.

---

example_transition_matrix	<i>Example transition matrix showing how individuals traverse the multistage test.</i>
---------------------------	--

---

**Description**

A matrix with modules on the rows and columns. A 0 indicates that an individual cannot move from the row module to the column module, while a 1 indicates that an individual who has completed the row module can potentially transition into the column module.

**Usage**

```
example_transition_matrix
```

**Format**

An object of class `matrix` (inherits from `array`) with 7 rows and 7 columns.



---

MAT-class	<i>An S4 method for mixed adaptive tests.</i>
-----------	---

---

**Description**

An S4 method for mixed adaptive tests.

**Value**

An S4 object of class 'MAT'.

**Slots**

`function.call` The original function call.

`final.theta.estimate` Numeric vector of theta estimates calculated by the provided 'method'.

`eap.theta` Numeric vector of theta estimates calculated by 'catR::eapEst'.

`final.theta.Baker` Numeric vector of theta estimates calculated by the internal 'iterative.theta.estimate' function.

`final.theta.SEM` Numeric vector of SEM estimates calculated by the internal 'iterative.theta.estimate' function.

`final.items.seen` Character matrix of the final items seen by each individual.

`modules.seen` Numeric matrix of the modules seen by each individual.

`final.responses` Numeric matrix of the response patterns observed.

`transition.matrix` Numeric matrix; the transition matrix entered into the function.

`n.stages` Numeric; the number of stages specified.

`runtime` A 'difftime' object of the total run time of the function.

---

<code>mixed_adaptive_test</code>	<i>Mixed Computerized Adaptive Multistage Test</i>
----------------------------------	--

---

**Description**

Mixed Computerized Adaptive Multistage Test

**Usage**

```

mixed_adaptive_test(
  response_matrix,
  cat_item_bank,
  initial_theta = 0,
  method = "BM",
  item_method = "MFI",
  cat_length,
  nAvailable_cat = NULL,
  cbControl = NULL,
  cbGroup = NULL,
  randomesque = 1,
  mst_item_bank,
  modules,
  transition_matrix,
  n_stages,
  module_select = "MFI"
)

```

**Arguments**

response_matrix	A matrix of the person responses, with individuals as rows and items as columns.
cat_item_bank	A data frame with the first stage items on the rows and their item parameters on the columns. These should be in the <b>mstR</b> package format for item banks.
initial_theta	The initial theta estimate for all individuals.
method	A character value indicating method for the provisional theta estimate. Defaults to "BM" (Bayes Modal). See the <b>catR</b> and <b>mstR</b> packages for more details.
item_method	A character value indicating the method for the item-level selection in the first stage. Defaults to "MFI" (Maximum Fisher Information). See the <b>catR</b> and <b>mstR</b> packages for more details.
cat_length	A numeric value indicating the number of items in the first stage.
nAvailable_cat	Defaults to 'NULL'. See the <b>catR</b> package for more information on how to use this option.
cbControl	A list of the appropriate format used to control for content balancing in the first stage. See the Details in the nextItem function in <b>catR</b> .
cbGroup	A factor vector of the appropriate format used to control for content balancing in the first stage. See the Details in the nextItem function in <b>catR</b> .
randomesque	An integer indicating the number of items from which to select the next item to administer in the first stage. Default value is 1.
mst_item_bank	A data frame with the second stage and beyond items on the rows and their item parameters on the columns. These should be in the <b>mstR</b> package format for item banks.
modules	A matrix describing the relationship between the items and the modules they belong to. See <b>Details</b> .

transition_matrix	A matrix describing how individuals can transition from one stage to the next.
n_stages	A numerical value indicating the number of stages in the test.
module_select	A character value indicating the information method used to select modules at transition stages. One of "MFI" (default), "MLWMI", "MPWMI", "MKL", "MKLP", "random". See the <b>mstR</b> for more details.

## Details

To be filled in later.

## Value

A list of all individuals with the following elements: the vector of final theta estimates based on "method", the vector of final theta estimates based on EAP, the vector of final theta estimates based on the iterative estimate from Baker 2004, a matrix of the final items taken, a matrix of the modules seen, and a matrix of the final responses.

An S4 object of class 'MST' with the following slots:

function.call	The function and arguments called to create this object.
final.theta.estimate	A numeric vector of the final theta estimates using the method provided in function.call.
eap.theta	A numeric vector of the final theta estimates using the expected a posteriori (EAP) theta estimate from catR::eapEst.
final.theta.Baker	A numeric vector of the final theta estimates using an iterative maximum likelihood estimation procedure as described in chapter 5 of Baker (2001).
final.theta.SEM	A numeric vector of the final standard error of measurement (SEM) estimates using an iterative maximum likelihood estimation procedure as described in chapter 5 of Baker (2001).
final.items.seen	A matrix of the final items seen by each individual using the supplied item names. 'NA' values indicate that an individual wasn't given any items to answer after the last specified item in their row.
final.responses	A matrix of the responses to the items seen in final.items.seen. NA values indicate that the individual didn't answer the question in the supplied response file or wasn't given any more items to answer.
transition.matrix	The transition_matrix originally supplied to the function.
n.stages	The n_stages originally supplied to the function.
runtime	A difftime object recording how long the function took to complete.

## References

Baker (2001). <http://echo.edres.org:8080/irt/baker/final.pdf>

**See Also**

[`multistage_test`] for a standard multistage test, [`computerized_adaptive_test`] for a standard computerized adaptive test.

**Examples**

```
# using simulated test data
data(example_thetas) # 5 simulated abilities
data(example_responses) # 5 simulated response vectors
# the transition matrix for an 18 item 1-3-3 balanced design
data(example_transition_matrix)
# the items designated for use in the routing module with item-level
# adaptation
data(cat_items)
# the items designated for use in the second and third modules with
# module-level adaptation
data(mst_items)
# the matrix specifying how the item data frame relates to the modules
data(example_module_items)

# run the Mca-MST model
results <- mixed_adaptive_test(response_matrix = example_responses[1:2,],
                              cat_item_bank = cat_items, initial_theta = 0,
                              method = "EAP", item_method = "MFI",
                              cat_length = 6, cbControl = NULL, cbGroup = NULL,
                              randomesque = 1, mst_item_bank = mst_items,
                              modules = example_module_items,
                              transition_matrix = example_transition_matrix,
                              n_stages = 3)
```

---

MST-class

*An S4 method for multistage adaptive tests.*


---

**Description**

An S4 method for multistage adaptive tests.

**Value**

An S4 object of class ‘MST’.

**Slots**

`function.call` The original function call.

`final.theta.estimate` Numeric vector of theta estimates calculated by the provided ‘method’.

`eap.theta` Numeric vector of theta estimates calculated by `'catR::eapEst'`.  
`final.theta.Baker` Numeric vector of theta estimates calculated by the internal `'iterative.theta.estimate'` function.  
`final.theta.SEM` Numeric vector of SEM estimates calculated by the internal `'iterative.theta.estimate'` function.  
`final.items.seen` Character matrix of the final items seen by each individual.  
`modules.seen` Numeric matrix of the modules seen by each individual.  
`final.responses` Numeric matrix of the response patterns observed.  
`transition.matrix` Numeric matrix; the transition matrix entered into the function.  
`n.stages` Numeric; the number of stages specified.  
`nc.list` A list of the number correct scoring logic and method, if applicable. Defaults to `'NULL'`.  
`runtime` A `'difftime'` object of the total run time of the function.

---

 mst\_items

*Example items for the MST stages of an example adaptive test.*


---

## Description

A data frame formatted in the style required by **mstR** for item data. Represents items to be used in module-level adaptation portions of a computerized adaptive test.

## Usage

```
mst_items
```

## Format

A data frame with 564 rows (items) and 6 columns (item parameters):

**a** item discrimination

**b** item difficulty

**c** item guessing

**u** item carelessness

**content\_ID** what content area the item comes from

**stage** which stage the item belongs to

---

mst_only_items	<i>The matrix of items used in the "multistage_test" example.</i>
----------------	---

---

### Description

A data frame formatted in the style required by **mstR** for item data. Represents items to be used in an item-level adaptation portion of a computerized adaptive test.

### Usage

```
mst_only_items
```

### Format

A data frame with 564 rows (items) and 6 columns (item parameters):

- a** item discrimination
- b** item difficulty
- c** item guessing
- u** item carelessness
- content\_ID** what content area the item comes from

---

mst_only_matrix	<i>Example "item-to-module" map matrix for the "multistage_test" example.</i>
-----------------	---

---

### Description

A matrix with items on the rows and modules on the columns, where 0 indicates the item and module are unrelated and 1 indicates that the item is a part of that module. Used in combination with a transition matrix to describe a multistage adaptive test.

### Usage

```
mst_only_matrix
```

### Format

An object of class `matrix` (inherits from `array`) with 42 rows and 7 columns.

---

multistage\_test      *Computer Adaptive Multistage Test*

---

## Description

Computer Adaptive Multistage Test

## Usage

```
multistage_test(
  mst_item_bank,
  modules,
  transition_matrix,
  method = "BM",
  response_matrix,
  initial_theta = 0,
  model = NULL,
  n_stages = 3,
  test_length = 18,
  module_select = "MFI",
  nc_list = NULL,
  verbose = FALSE
)
```

## Arguments

mst_item_bank	A data frame with the items on the rows and their item parameters on the columns. These should be in the <b>mstR</b> package format for item banks.
modules	A matrix describing the relationship between the items and the modules they belong to. See <b>Details</b> .
transition_matrix	A matrix describing how individuals can transition from one stage to the next.
method	A character value indicating method for the provisional theta estimate. Defaults to "BM" (Bayes Modal). See the <b>mstR</b> package for more details.
response_matrix	A matrix of the person responses, with individuals as rows and items as columns.
initial_theta	The initial theta estimate for all individuals. Default is 0.
model	Either NULL (default) for dichotomous models or a character value indicating the polytomous model used. See the <b>mstR</b> package for more details.
n_stages	A numeric value indicating the number of stages in the test.
test_length	A numeric value indicating the total number of items each individual answers.
module_select	A character value indicating the information method used to select modules at transition stages. One of "MFI" (default), "MLWMI", "MPWMI", "MKL", "MKLP", "random". See the <b>mstR</b> for more details.

nc_list	This parameter controls whether or not to use number correct ("NC") scoring to select modules. Defaults to 'NULL', using module information. Otherwise, this should be a list where the elements of the list correspond to each module which routes to other modules by number correct. If no 'method' argument is provided in this list, or if an invalid entry is given, the method will default to 'cumulative_sum', meaning the values provided are a running tally of the number of items correctly answered on the test. If 'method' is set to 'module_sum', then the sum of the number correct within the current module will be used to select the next module. See 'details' for more information.
verbose	A 'TRUE' or 'FALSE' (default) switch for printing the current subject being tested in the console.

### Details

When using (cumulative) number correct module selection, the input list should contain one element for each module that needs to route to other modules. For example, in a 1-3-3 design the first module can route to any module in the second stage, so the first element of 'nc\_list' would be a numeric vector with three values indicating the *maximum* number of correct items needed in order to be routed to the second, third, or fourth module respectively. When the design is not crossed (e.g., a person routed to the easy module in the second stage *cannot* be routed to the hard module in the third stage), '-Inf' and 'Inf' need to be used within 'nc\_list' to indicate this. Continuing the example, let's assume the 1-3-3 design is not crossed and will be balanced so that each stage has the same number of items (10 each) for a total of 30 items administered. The 'nc\_list' object could be specified like so: nc\_list = list(module1 = c(4, 5, 7), module2 = c(8, 14, Inf), module3 = c(8, 14, 20), module4 = c(-Inf, 14, 20), method = "cumulative\_sum").

As it is the most common method of number correct scoring, "cumulative\_sum" is the default. Any value included in the 'method' argument of 'nc\_list' that does `_not_equal` "module\_sum" will cause the default "cumulative\_sum" to be used. `_This is intentional and will not be changed unless I am given a good argument to change it_.`

### Value

A list of all individuals with the following elements: the vector of final theta estimates based on "method", the vector of final theta estimates based on EAP, the vector of final theta estimates based on the iterative estimate from Baker 2004, a matrix of the final items taken, a matrix of the modules seen, and a matrix of the final responses.

An S4 object of class 'MST' with the following slots:

function.call	The function and arguments called to create this object.
final.theta.estimate	A numeric vector of the final theta estimates using the method provided in function.call.
eap.theta	A numeric vector of the final theta estimates using the expected a posteriori (EAP) theta estimate from catR: :eapEst.
final.theta.Baker	A numeric vector of the final theta estimates using an iterative maximum likelihood estimation procedure as described in chapter 5 of Baker (2001).



<code>final.theta.SEM</code>	A numeric vector of the final standard error of measurement (SEM) estimates using the <code>catR::semTheta</code> function.
<code>final.items.seen</code>	A matrix of the final items seen by each individual using the supplied item names. 'NA' values indicate that an individual wasn't given any items to answer after the last specified item in their row.
<code>final.responses</code>	A matrix of the responses to the items seen in <code>final.items.seen</code> . NA values indicate that the individual didn't answer the question in the supplied response file or wasn't given any more items to answer.
<code>transition.matrix</code>	The <code>transition_matrix</code> originally supplied to the function.
<code>n.stages</code>	The <code>n_stages</code> originally supplied to the function.
<code>nc.list</code>	The <code>nc_list</code> originally supplied to the function.
<code>runtime</code>	A <code>difftime</code> object recording how long the function took to complete.

## References

Baker (2001). <http://echo.edres.org:8080/irt/baker/final.pdf>

## See Also

[`mixed_adaptive_test`] for a multistage test with a routing module using item-level adaptation.

## Examples

```
# using simulated test data
data(example_thetas) # 5 simulated abilities
data(example_responses) # 5 simulated response vectors
# the transition matrix for an 18 item 1-3-3 design
data(example_transition_matrix)
# the MST item bank
data(mst_only_items)
# the MST module matrix
data(example_module_items)
# run the MST model
results <- multistage_test(mst_item_bank = mst_only_items,
  modules = example_module_items, transition_matrix = example_transition_matrix,
  method = "BM", response_matrix = example_responses, initial_theta = 0,
  model = NULL, n_stages = 3, test_length = 18)

# using number correct scoring for the same data
# create nc_list as explained in 'details'
nc_list = list(module1 = c(4, 5, 7),
  module2 = c(8, 14, Inf),
  module3 = c(8, 14, 18),
  module4 = c(-Inf, 14, 18),
  method = 3) # the method here will default to "cumulative_sum" as described in 'details'
```

```
# this is the ONLY difference currently! Everything else remains the same
# run the example
nc.results <- multistage_test(mst_item_bank = mst_only_items,
  modules = example_module_items, transition_matrix = example_transition_matrix,
  method = "BM", response_matrix = example_responses, initial_theta = 0,
  model = NULL, n_stages = 3, test_length = 18, nc_list = nc_list)
```

---

transition\_matrix\_plot

*Transition Matrix Plot*

---

### Description

Given a transition matrix and the number of modules at each stage, produces a plot that demonstrates the potential paths through a (mixed) multistage test.

### Usage

```
transition_matrix_plot(object = NULL, n_stages = NULL)
```

### Arguments

object	Either an S4 object of class <code>"MST"</code> or class <code>"MAT"</code> , or a matrix describing how individuals can transition from one stage to the next. If an S4 object is provided, the <code>'transition.matrix'</code> slot is used to create the plot.
n_stages	A numeric value indicating how many stages are used in the (mixed) multistage test. If an S4 object is provided, this value is taken from the object and the input value is ignored.

### Value

A plot using the current graphic device.

### Examples

```
# Create a plot for a multistage test with a 1-3-3 design
data('example_transition_matrix')
transition_matrix_plot(example_transition_matrix, n_stages = 3)

## Not run:
# Save the plot as a png file.
png("Example 1-3-3 Transition Matrix Plot.png")
transition_matrix_plot(example_transition_matrix, n_stages = 3)
title("Transition Matrix for a 1-3-3 Design MST")
dev.off()

# Use the `results` object from the `mixed_adaptive_test()` example to create
# a transition matrix plot and save as a .pdf file.
pdf("MAT Transition Matrix.pdf")
```

```
transition_matrix_plot(results)
title("Transition Matrix from the mixed_adaptive_test Example")
dev.off()

## End(Not run)
```

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