

Package ‘mlmpower’

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Type Package

Title Power Analysis and Data Simulation for Multilevel Models

Version 1.0.5

Description A declarative language for specifying multilevel models, solving for population parameters based on specified variance-explained effect size measures, generating data, and conducting power analyses to determine sample size recommendations. The specification allows for any number of within-cluster effects, between-cluster effects, covariate effects at either level, and random coefficients. Moreover, the models do not assume orthogonal effects, and predictors can correlate at either level and accommodate models with multiple interaction effects.

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BugReports <https://github.com/bkeller2/mlmpower/issues>

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analyze	<i>Analyzes a single mp_data using lme4::lmer</i>
---------	---

Description

Analyzes a single `mp_data` based on the data generating model.

Usage

```
analyze(data, alpha = 0.05, no_lrt = FALSE, ...)
```

Arguments

data	a mp_data .
alpha	the significance level to determine if an effect is statistically significant. If NULL then no nested model testing is conducted.
no_lrt	do not perform additional likelihood ratio tests. Setting to TRUE will speed up the analysis because the model is only fit once.
...	other arguments passed to <code>lme4::lmer()</code> .

Value

A [list](#) that with the following named elements:

- `estimates`: The estimates from fitting the model.
- `sig_test`: The logical if the estimates were statistically significant based on `alpha`.
- `parameters`: The [mp_parameters](#) extracted from data.

Examples

```
# Create Model
model <- (
  outcome('Y')
  + within_predictor('X')
  + effect_size(icc = 0.1)
)
# Set seed
set.seed(198723)
# Create data set and analyze
model |> generate(5, 50) |> analyze() -> results
```

```
as.data.frame.mp_power
```

Coerce a [mp_power](#) to a Data Frame

Description

Outputs [mp_power](#) as a data frame.

Usage

```
## S3 method for class 'mp_power'
as.data.frame(x, row.names = NULL, optional = FALSE, power = TRUE, ...)
```

Arguments

x	a <code>mp_power</code> .
row.names	passed to <code>base::as.data.frame</code>
optional	passed to <code>base::as.data.frame</code>
power	logical: do you want the power or the estimates
...	other arguments not used by this method.

Value

returns a data frame

Examples

```
# Create Model
model <- (
  outcome('Y')
  + within_predictor('X')
  + effect_size(icc = 0.1)
)
# Set seed
set.seed(19723)
# Create data set and analyze
# Note: Generally Use more than 50 replications
model |> power_analysis(50, 5, 50) -> powersim
# Obtain Results as a data frame
as.data.frame(powersim)
```

`as.list.mp_parameters` Convert `mp_parameters` to a `list`

Description

A wrapper to coerce `mp_parameters` to a `list`.

Usage

```
## S3 method for class 'mp_parameters'
as.list(x, ...)
```

Arguments

x	the <code>mp_parameters</code> to be coerced.
...	additional arguments passed to <code>as.list</code>

Value

a `list`

Examples

```
# Specify model
model <- (
  outcome('Y')
  + within_predictor('X')
  + effect_size(
    icc = c(0.1, 0.2),
    within = 0.3
  )
)
# Obtain parameters and convert to a list
model |> summary() |> as.list() -> param_list
```

correlations

Specify the Correlation Structure for the Model

Description

Creates a list of correlations to be added to a `mp_model`.

Usage

```
correlations(within, between, randeff)
```

Arguments

<code>within</code>	a single numeric value or <code>mp_corr_func</code> that specifies random correlations. Corresponds to the level-1 correlation among predictors.
<code>between</code>	a single numeric value or <code>mp_corr_func</code> that specifies random correlations. Corresponds to the level-2 correlation among predictors.
<code>randeff</code>	a single numeric value or <code>mp_corr_func</code> that specifies random correlations. Corresponds to the random effects correlation among predictors.

Details

The default values are `random(0.1, 0.3)`. Currently `randeff` are required to be zero if more than one random slope is in the model.

Value

A list that corresponds to each correlation value.

See Also

`random()` `fixed()`

Examples

```
(
  outcome('Y')
+ within_predictor('X')
+ effect_size(
  icc = c(0.1, 0.2),
  within = 0.3
)
# Defaults
+ correlations(
  within = random(0.1, 0.3),
  between = random(0.1, 0.3),
  randeff = random(0.1, 0.3)
)
)
```

effect_size

Specify the Effect Size for the Model

Description

Creates a list of effect sizes to be added to a [mp_model](#).

Returns suggested ICC's for cross-sectional studies (0.05, 0.15, and 0.25).

Returns suggested ICC ranges for longitudinal studies (0.40, 0.50, and 0.60).

Usage

```
effect_size(icc, within, between, random_slope, product)
```

```
cross_sectional()
```

```
longitudinal()
```

Arguments

icc	a numeric vector of global ICC values for mp_variable who are left unspecified. Values must be between 0 and 1.
within	a single numeric value that corresponds to the proportion of variance explained by the within variables.
between	a single numeric value that corresponds to the incremental proportion of variance explained by the between variables.
random_slope	a single numeric value that corresponds to the proportion of variance explained by the random slopes.
product	a single numeric value that corresponds to the proportion of variance explained by the product terms.

Value

A list that corresponds to each R2 value.

Examples

```
# Set ICCs
(
  outcome('Y')
  + within_predictor('X')
  + effect_size(
    icc = c(0.1, 0.2),
    within = 0.3
  )
)

# With cross-sectional ICC
(
  outcome('Y')
  + within_predictor('X')
  + effect_size(
    icc = cross_sectional,
    within = 0.3
  )
)

# With longitudinal ICC
(
  outcome('Y')
  + within_predictor('X')
  + effect_size(
    icc = longitudinal,
    within = 0.3
  )
)
```

generate

Generates Data Sets Based on a [mp_model](#)

Description

Generates data sets based on a [mp_model](#). These data sets will be returned as a [data.frame](#) and include the solved parameters as an attribute to the [data.frame](#).

Usage

```
generate(model, n_within, n_between, ndata = 1, mechanism = NULL)
```

Arguments

<code>model</code>	a mp_model .
<code>n_within</code>	a single positive integer of the desired within cluster observations.
<code>n_between</code>	a single positive integer of the desired between cluster observations.
<code>ndata</code>	a single positive integer of the number of desired data sets.
<code>mechanism</code>	a function for inducing missing data to the data set. If NULL it is ignored. See details below.

Details

Note that there must only be one global ICC in [mp_model](#).

Use the `mechanism` argument to specify missing data mechanisms. See [mechanisms](#) for predefined missing data mechanisms for the outcome and examples using them. When creating custom mechanisms care needs to be taken because it is considered for advanced usage. This argument expects a function with the [mp_data](#) as the input, and the function should return the modified [mp_data](#). Be careful when using this because it allows you to modify the population parameters, which will be incorrect. You should only induce missing data values on variables. Missing data on the predictors will cause listwise deletion to be used, but missing data on the outcome will be appropriate for MAR-based mechanisms. See examples below for an example that generates MCAR data on the outcome. See [parameters](#) to obtain the population parameters from each data set.

Value

For `ndata = 1` a single [data.frame](#) is returned. The first variable is the cluster identifier labeled `_id`. This object is also of class `mp_data` which means that it was generated based on a specified model. If multiple data sets are requested then they will be contained in a [list](#).

Examples

```
# Create Model
model <- (
  outcome('Y')
  + within_predictor('X')
  + effect_size(icc = 0.1)
)
# Set seed
set.seed(198723)
# Create data set
model |> generate(5, 50) -> mydata

# Induce missing data with custom function
model |> generate(50, 5, mechanism = MCAR(0.25)) -> mydata_mcar

# Induce missing data with custom function
model |> generate(50, 5, mechanism = \(data) {
  # `data` will be the `mp_data` used
  within(data, {
    # MCAR Process
    Y <- ifelse(runif(NROW(data)) < 0.5, Y, NA)
  })
})
```



```

    })
  }) -> mydata_mcar_custom

```

is_valid	<i>Check if a Model is Properly Specified</i>
----------	---

Description

This function is used to validate if a `mp_model` is correct. If the model is incorrect an appropriate error message describing while will be supplied

Usage

```
is_valid(x)
```

Arguments

x a `mp_model`

Value

Invisibly returns the original model.

Examples

```

# Create Model
model <- outcome('Y') + within_predictor('X')
# Throws error
tryCatch(
  is_valid(model),
  error = print
)
# Succeeds
is_valid(model + effect_size(icc = 0.1))

```

levels.mp_variable	<i>Obtain Level of Observation for a Variable</i>
--------------------	---

Description

Returns which level a variable is observed at in the multilevel model.

Usage

```

## S3 method for class 'mp_variable'
levels(x)

```

Arguments

x a `mp_variable`.

Value

Returns a single integer of the level of observation

Examples

```
# Returns 1
levels(
  within_predictor(
    'X',
    weight = 1,
    mean = 5,
    sd = 10,
    icc = 0.1
  )
)
```

 mechanisms

Helper functions for producing Missing Data Mechanisms

Description

Functions to generate data that always follows a specific mechanism in accordance to a single-level model.

Usage

```
# Generate MCAR data on outcome
MCAR(mis.rate)

# Generate MAR data on outcome due to `cause`
MAR(mis.rate, cause, r2, lower = TRUE)
```

Arguments

mis.rate	A proportion for the missing data rate at population level
cause	A character for a variable name that is the cause of missingness
r2	A proportion of variance explained by the cause in the missing data indicator's latent propensity
lower	A logical for the lower or upper tail being more likely to be missing

See Also

[power_analysis](#)

Examples

```
# Create Model
model <- (
  outcome('Y')
  + within_predictor('X')
  + effect_size(icc = 0.1)
)

# Induce MCAR data on outcome
set.seed(19723)
model |> power_analysis(50, 5, 50, mechanism = MCAR(0.25)) -> powersim_mcar

# Induce MAR data on outcome
set.seed(19723)
model |> power_analysis(
  50, 5, 50,
  mechanism = MAR(0.25, 'X', 0.6)
) -> powersim_mar
```

mlmpower

mlmpower *Modeling Framework*

Description

mlmpower constructs models by adding different features of the model using the plus sign (+). Every model requires an [outcome](#) and an ICC specified in [effect_size](#) to be valid.

```
model <- outcome('y') + effect_size(icc = 0.1)
```

Once a model is constructed, we can add additional features to build the model out more. For example, we may want to include a level-1 predictor that is centered within cluster.

```
model <- model + within_predictor('x', icc = 0.0)
```

The additions can be chained together to produce the entire model object. For example, the previous two code blocks can be combined into one.

```
model <- (
  outcome('y')
  + effect_size(icc = 0.1)
  + within_predictor('x', icc = 0.0)
)
```

Finally, we can also wrap multiple variables into a list and add that. This feature can be useful when programmatically generating a model.

```
model <- (  
  outcome('y')  
  + effect_size(icc = 0.1)  
  + lapply(1:10, \(i) within_predictor(paste0('x', i), icc = 0.0))  
)
```

For more detailed information see the help vignette by running the following:

```
vignette(package = 'mlmpower')
```

See Also

[Variables effect_size\(\)](#) [correlations\(\)](#) [random_slope\(\)](#) [product\(\)](#)

mp_corr_func

Functions for Generating Correlations

Description

Specify a random correlation that is uniform between lower and upper

Usage

```
random(lower, upper)
```

```
fixed(value)
```

Arguments

lower	the lower bound of the distribution.
upper	the upper bound of the distribution.
value	the fixed value for the correlation.

Value

A mp_corr_func that generates the desired correlation

See Also

[correlations\(\)](#)

Examples

```
# Create Model with random and fixed correlations
(
  outcome('Y')
  + within_predictor('X')
  + between_predictor('Z')
  + effect_size(icc = 0.1)
  # Defaults
  + correlations(
    within = random(0.1, 0.3),
    between = fixed(0.2)
  )
)
```

mp_parameters

mp_parameters *Object for mImpower*

Description

An S3 class that contains an `base::environment` with the following objects:

- `r2`: The population proportion of variance explained
- `phi_b`: The population predictor covariance matrix for between
- `phi_p`: The population within cluster covariance matrix for products
- `phi_w`: The population predictor covariance matrix for within
- `mean_Z`: The population mean for level-2 predictors
- `mean_X`: The population mean for level-1 predictors
- `var_e`: The population within residual variance
- `tau`: The population level-2 covariance matrix
- `gammas`: The regression coefficients
- `mean_Y`: The population mean of the outcome

See Also

[parameters](#)

parameters

Obtain [mp_parameters](#) from objects

Description

A generic function to obtain [mp_parameters](#) from defined models and data sets.

Usage

```
parameters(object)

## S3 method for class 'mp_model'
parameters(object)

## S3 method for class 'mp_data'
parameters(object)

## S3 method for class 'mp_power'
parameters(object)
```

Arguments

`object` an object which the [mp_parameters](#) are desired.

Details

Currently object can be:

- [mp_model](#)
- [mp_data](#)
- [mp_power](#)

If using on a [mp_model](#) and the model has random correlations then the average is used.

Value

A [mp_parameters](#) object

Examples

```
# Create Model
model <- (
  outcome('Y')
  + within_predictor('X')
  + effect_size(icc = 0.1)
)

# Create data set and obtain population parameters
```

```

model |> parameters()
# Set seed
set.seed(198723)
# Create data set and obtain population parameters
model |> generate(5, 50) |> parameters()
# Set seed
set.seed(198723)
# Create data set and obtain population parameters
model |> power_analysis(50, 5, 50) |> parameters()

```

power_analysis

Conduct a Power Analysis Based on [mp_model](#)

Description

This function will construct a multilevel power analysis via a Monte Carlo Simulation based on a constructed [mp_model](#).

Usage

```
power_analysis(model, replications, n_within, n_between, ...)
```

Arguments

model	a mp_model .
replications	a single positive integer of the number of replications per condition.
n_within	an integer vector of the desired within cluster observations.
n_between	an integer vector of the desired between cluster observations.
...	other arguments passed to analyze() .

Details

Specifying multiple `n_within` and `n_between` will produce a full factorial simulation design.

Specify a `mechanism` argument to pass down to the [generate](#) function. See the details of [generate](#) for more information about specifying missing data mechanisms. See [mechanisms](#) for predefined missing data mechanisms.

Specify an `analyze` argument to use custom analysis functions. These functions should map onto [analyze](#)'s structure, but can allow for things like specifying multiple imputations etc. This is considered an advance usage that requires extreme care and caution.

Value

A `mp_power` object that contains the results. See [print.mp_power](#) for more information. The object has the following slots:

- `sim`: The information about the simulation
- `power`: The power power results per condition.
- `estimates`: The simulation summaries of the parameter estimates per condition.
- `mean_parameters`: The average population parameter per condition.

See Also

[generate\(\)](#)
[mechanisms](#)

Examples

```
# Create Model
model <- (
  outcome('Y')
  + within_predictor('X')
  + effect_size(icc = 0.1)
)
# Set seed
set.seed(19723)
# Create data set and analyze
# Note: Generally Use more than 50 replications
model |> power_analysis(50, 5, 50)

# Induce missing data on outcome with built in mechanisms
set.seed(19723)
model |> power_analysis(50, 5, 50, mechanism = MCAR(0.25)) -> powersim_mcar
```

print.mp_correlations *Prints a mp_correlations*

Description

Prints a [mp_correlations](#) in a human readable format.

Usage

```
## S3 method for class 'mp_correlations'
print(x, ...)
```

Arguments

x a [mp_correlations](#).
... other arguments not used by this method.

Value

Invisibly returns the original variable.

Examples

```
model <- (  
  outcome('Y')  
  + within_predictor('X')  
  + effect_size(  
    icc = c(0.1, 0.2),  
    within = 0.3  
  )  
)  
# Print correlations only  
print(model$corrs)
```

print.mp_effsize	<i>Prints a mp_effsize</i>
------------------	----------------------------

Description

Prints a [mp_effsize](#) in a human readable format.

Usage

```
## S3 method for class 'mp_effsize'  
print(x, ...)
```

Arguments

x a [mp_effsize](#).
... other arguments not used by this method.

Value

Invisibly returns the original variable.

Examples

```
model <- (  
  outcome('Y')  
  + within_predictor('X')  
  + effect_size(  
    icc = c(0.1, 0.2),  
    within = 0.3  
  )  
)  
# Print effect size only  
print(model$effect_size)
```

print.mp_model *Prints a mp_model*

Description

Prints a [mp_variable](#) in a human readable format.

Usage

```
## S3 method for class 'mp_model'  
print(x, ...)
```

Arguments

x a [mp_model](#).
... other arguments not used by this method.

Value

Invisibly returns the original variable.

Examples

```
print(  
  outcome('Y')  
  + within_predictor('X')  
  + effect_size(icc = cross_sectional)  
)
```

print.mp_parameters *Prints a mp_parameters*

Description

Prints a [mp_parameters](#) in a human readable format.

Usage

```
## S3 method for class 'mp_parameters'  
print(x, ...)
```

Arguments

x a [mp_parameters](#).
... arguments passed to [print\(\)](#).

Value

Invisibly returns the original variable.

Examples

```
print(  
  summary(  
    outcome('Y')  
    + within_predictor('X')  
    + effect_size(icc = cross_sectional)  
  )  
)
```

`print.mp_power` *Prints a `mp_power`*

Description

Prints a `mp_power` in a human readable format.

Usage

```
## S3 method for class 'mp_power'  
print(x, ...)
```

Arguments

- `x` a `mp_power`.
- `...` other arguments not used by this method.

Value

Invisibly returns the original variable.

Examples

```
# Create Model  
model <- (  
  outcome('Y')  
  + within_predictor('X')  
  + effect_size(icc = 0.1)  
)  
# Set seed  
set.seed(19723)  
# Create data set and analyze  
# Note: Generally Use more than 50 replications  
model |> power_analysis(50, 5, 50) -> powersim  
# Print results  
print(powersim)
```

`print.mp_variable` *Prints a `mp_variable`*

Description

Prints a `mp_variable` in a human readable format.

Usage

```
## S3 method for class 'mp_variable'  
print(x, ...)
```

Arguments

`x` a `mp_variable`.
`...` other arguments not used by this method.

Value

Invisibly returns the original variable.

Examples

```
print(  
  within_predictor(  
    'X',  
    weight = 1,  
    mean = 5,  
    sd = 10,  
    icc = 0.1  
  )  
)
```

`product` *Create a Product Term in a Model*

Description

Creates a product term between two variables that can be added to a `mp_model`.

Usage

```
product(name1, name2, weight = 1)
```

Arguments

name1	a character string that references the first variable's name
name2	a character string that references the second variable's name
weight	a single numeric value specifying the variable's contribution to the variance explained metric. Weights are normalized across all variables of the same level.

Details

Currently the product term is only limited to cross-level interactions between a level-1 centered within cluster variable ($icc = 0$) and level-2 variable.

Value

A [mp_action](#) that can be added to a [mp_model](#).

Examples

```
# Create Model
model <- (
  outcome('Y')
  + within_predictor('X', icc = 0.0)
  + between_predictor('Z')
)
# Add random slope to the model
model + product('X', 'Z')
```

random_slope

Create a Random Slope in a Model

Description

Creates a random slope that can be added to a [mp_model](#).

Usage

```
random_slope(name, weight = 1)
```

Arguments

name	a character string that references a variable's name
weight	a single numeric value specifying the variable's contribution to the variance explained metric. Weights are normalized across all variables of the same level.

Value

A [mp_action](#) that can be added to a [mp_model](#).

Examples

```
# Create Model
model <- (
  outcome('Y')
  + within_predictor('X')
  + effect_size(
    icc = 0.1,
    within = 0.1,
    random_slope = 0.03
  )
)
# Add random slope to the model
model + random_slope('X')
```

subset.mp_model	Subset a mp_model by Global ICC
-----------------	---

Description

Subsets a [mp_model](#) with multiple ICC values specified in [effect_size](#) into a model with only the single ICC value.

Usage

```
## S3 method for class 'mp_model'
subset(x, icc, ...)
```

Arguments

x	a mp_model object
icc	a single numeric value to subset out of x
...	other arguments not used by this method.

Value

A new [mp_model](#) with only the subset ICC

Examples

```
# Create Model
model <- (
  outcome('Y')
  + within_predictor('X')
  + effect_size(icc = cross_sectional)
)
# Obtain Model with only 0.15 ICC
model |> subset(icc = 0.15)
```

summary.mp_model	<i>Obtain the Parameter Summaries for A mp_model</i>
------------------	--

Description

Provide the summarized parameter estimates for a [mp_model](#), including the variance explained break downs.

Usage

```
## S3 method for class 'mp_model'
summary(object, ...)
```

Arguments

object	a mp_model
...	other arguments not used by this method.

Value

A [mp_parameters](#) object that contains the population parameters based on the model. If random correlations are used the average correlation is used to compute the parameters. If multiple ICC's are specified then a named [base::list](#) is returned containing the parameter value for each ICC value.

Examples

```
summary(
  outcome('Y')
  + within_predictor('X')
  + effect_size(icc = cross_sectional)
)
```

summary.mp_power	<i>Summarizes a mp_power</i>
------------------	--

Description

Summarizes a [mp_power](#) in a human readable format. This is a simple wrapper for [print.mp_power](#).

Usage

```
## S3 method for class 'mp_power'
summary(object, ...)
```

Arguments

object a `mp_power`.
 ... other arguments not used by this method.

Value

Invisibly returns the original variable.

Examples

```
# Create Model
model <- (
  outcome('Y')
  + within_predictor('X')
  + effect_size(icc = 0.1)
)
# Set seed
set.seed(19723)
# Create data set and analyze
# Note: Generally Use more than 50 replications
model |> power_analysis(50, 5, 50) -> powersim
# Summarizes results
summary(powersim)
```

<code>to_formula</code>	<i>Convert <code>mp_data</code> to a <code>stats::formula</code> to be used for <code>lme4::lmer</code></i>
-------------------------	---

Description

Produces the formula including the centering functions based on a data set generated with `generate`.

Usage

```
to_formula(data, nested = FALSE)
```

Arguments

data the `mp_data` to be coerced.
 nested logical value, if true then produce the nested restricted model

Value

a `stats::formula`

Examples

```
# Specify model
model <- (
  outcome('Y')
  + within_predictor('X')
  + effect_size(
    icc = 0.2,
    within = 0.3
  )
)
# Set seed
set.seed(198723)
# Create formula based on data set
model |> generate(5, 50) |> to_formula()
```

Variables

*Functions for Creating Variables***Description**

These functions are the building blocks used to create the multilevel model and are used to specify the names, properties, and variable types.

Usage

```
outcome(name, mean = 10, sd = 5, icc = NULL)
```

```
within_predictor(name, weight = 1, mean = 0, sd = 1, icc = NULL)
```

```
within_time_predictor(name, values, weight = 1)
```

```
between_predictor(name, weight = 1, mean = 0, sd = 1)
```

```
between_binary_predictor(name, proportion = 0.5, weight = 1)
```

Arguments

name	a character string for the specific variable's name
mean	a single numeric value that specifies the variable's mean
sd	a single numeric value that specifies the variable's standard deviation
icc	a single numeric value between 0 and 1 that specifies the variable's intraclass correlation. If NULL then the global ICC specified in <code>effect_size()</code> is used instead.
weight	a single numeric value specifying the variable's contribution to the variance explained metric. Weights are normalized across all variables of the same level.
values	a numeric vector specifying the time scores that will be repeated within each cluster.

`proportion` a single numeric value between 0 and 1 that specifies the proportion of 1's at the population.

Details

Note that specifying an `icc = 0` in `within_predictor()` will result in a centered within cluster (CWC) predictor.

See vignettes for more details.

```
vignette(package = 'mlmpower')
```

Value

Returns a `mp_variable` object based on the variable's type.

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