

# Package ‘MOODE’

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**Type** Package

**Title** Multi-Objective Optimal Design of Experiments

**Version** 1.1.0

**Description** Provides functionality to generate compound optimal designs for targeting the multiple experimental objectives directly, ensuring that the full set of research questions is answered as economically as possible. Designs can be found using point or coordinate exchange algorithms combining estimation, inference and lack-of-fit criteria that account for model inadequacy. Details and examples are given by Koutra et al. (2024) <[doi:10.48550/arXiv.2412.17158](https://doi.org/10.48550/arXiv.2412.17158)>.

**License** GPL (>= 3)

**URL** <https://github.com/vkstats/MOODE>

**BugReports** <https://github.com/vkstats/MOODE/issues>

**Depends** R (>= 4.1.0)

**Imports** cli, far, progressr, Rdpack, rlang

**Suggests** doFuture, foreach

**RdMacros** Rdpack

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**RoxygenNote** 7.3.2

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candidate_set_full	<i>Forms the full candidate set of treatments for all polynomial terms</i>
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### Description

This function forms the full extended candidate set with all polynomial terms, with labels, not orthonormalised.

### Usage

```
candidate_set_full(cand.trt, K)
```

### Arguments

cand.trt	Candidate set of treatments, the first column contains treatment labels. Usually obtained as output from the <a href="#">candidate_trt_set</a> function.
K	Number of factors.

### Value

The full extended candidate set: the column of treatment labels, then named columns with polynomial terms up to the 4th order. For example, "x12" stands for  $x_1^2$ , and "x1x2" stands for  $x_1x_2$ , and "x23x4" for  $x_2^3x_4$ .

### Examples

```
# Full extended candidate set for two 3-level factors

K<-2; Levels <- rep(list(1:3),K);
candidate_set_full(candidate_trt_set(Levels, K), K)
```

---

candidate\_set\_orth      *Forms the orthonormalised full candidate set*

---

### Description

This function forms the full extended orthonormalised candidate set of primary and potential terms, with an intercept column and labels.

### Usage

```
candidate_set_orth(cand.full, primary.terms, potential.terms)
```

### Arguments

`cand.full`      Candidate set containing terms up to 4th order, with labels in the first column.  
`primary.terms`    Character vector identifying primary model terms.  
`potential.terms`    Character vector identifying potential model terms.

### Value

The orthonormalised full candidate set containing primary and potential terms, with labels.

### Examples

```
# Full extended orthonormalised candidate set for two 4-level factors,
# full quadratic polynomial model as primary model and all three-order terms as potential.

K<-2; Levels <- rep(list(1:4),K)
cand.trt <- candidate_trt_set(Levels, K)
cand.full <- candidate_set_full(cand.trt, K)
prime.terms <- colnames(cand.full)[2:7]
poten.terms <- colnames(cand.full)[8:11]
Parameters <- c(1, rep(1,K), rep(1,K), K*(K-1)/2)
candidate_set_orth(cand.full, prime.terms, poten.terms)
```

---

candidate\_trt\_set      *Forms the labelled candidate set of treatments*

---

### Description

This function forms the candidate set of treatments from the factors' levels, adds labels, with optional spherical transformation of the coordinates.

### Usage

```
candidate_trt_set(Levels, K, Hypercube = TRUE)
```

**Arguments**

Levels	Levels of each factor.
K	Number of factors.
Hypercube	Indicates if the experimental region is a hypercube ('TRUE') or spherical ('FALSE').

**Value**

Matrix of candidate set of treatments, with treatment labels contained in the first column.

**Examples**

```
# Candidate treatment set for five 3-level factors

K<-5; Levels <- rep(list(1:3),K);
candidate_trt_set(Levels, K)
```

---

criteria.GD	<i>Calculates the values of the Generalised Ds-criterion and its components</i>
-------------	---

---

**Description**

This function evaluates the Generalised Ds-criterion (Goos et al. 2005) for given primary and potential model matrices.

**Usage**

```
criteria.GD(X1, X2, search.object, eps = 1e-23)
```

**Arguments**

X1	The primary model matrix, with the first column containing the labels of treatments, and the second – the intercept term.
X2	The matrix of potential terms, with the first column containing the labels of treatments.
search.object	Object of class <code>mood()</code> specifying experiment parameters.
eps	Computational tolerance, the default value is $10^{-23}$

**Value**

A list of values: indicator of whether the evaluation was successful ("eval"), Ds-criterion value – intercept excluded ("Ds"), Lack-of-fit criterion value ("LoF"), the bias component value ("bias"), the number of pure error degrees of freedom ("df") and the value of the compound criterion ("compound").

## References

Goos P, Kobilinsky A, O'Brien TE, Vandebroek M (2005). "Model-Robust and Model-Sensitive Designs." *Computational Statistics and Data Analysis*, **49**, 201-216.

## Examples

```
#Experiment: one 5-level factor, primary model -- full quadratic, one potential (cubic) term
# setting up the example
ex.mood <- mood(K = 1, Levels = 5, Nruns = 7, criterion.choice = "GDP",
               kappa = list(kappa.Ds = 1./3, kappa.LoF = 1./3, kappa.bias = 1./3),
               model_terms = list(primary.model = "second_order", potential.model = "cubic_terms"))
# Generating candidate set: orthonormalised
K <- ex.mood$K
Levels <- ex.mood$Levels
cand.not.orth <- candidate_set_full(candidate_trt_set(Levels, K), K)
cand.full.orth <- candidate_set_orth(cand.not.orth, ex.mood$primary.terms, ex.mood$potential.terms)
# Choosing a design
index <- c(rep(1, 2), 3, 4, rep(5, 3))
X.primary <- cand.full.orth[index, c(1, match(ex.mood$primary.terms, colnames(cand.full.orth)))]
X.potential <- cand.full.orth[index,
                              (c(1, match(ex.mood$potential.terms, colnames(cand.full.orth)))]
# Evaluating a compound GD-criterion
criteria.GD(X1 = X.primary, X2 = X.potential, ex.mood)
# Output: eval = 1, Ds = 0.7334291, LoF = 0.7212544, bias = 1.473138, df = 3, compound = 0.9202307
```

---

criteria.GDP	<i>Calculates the values of the Generalised DPs-criterion and its components</i>
--------------	--

---

## Description

This function evaluates the Generalised DPs-criterion for given primary and potential model matrices. Components: Ds-, DPs-, LoF(DP)- and Bias(D)-optimality.

## Usage

```
criteria.GDP(X1, X2, search.object, eps = 10^-23)
```

## Arguments

X1	The primary model matrix, with the first column containing the labels of treatments, and the second – the intercept term.
X2	The matrix of potential terms, with the first column containing the labels of treatments.
search.object	Object of class <code>mood()</code> specifying experiment parameters.
eps	Computational tolerance, the default value is $10^{-23}$

**Value**

A list of values: indicator of whether the evaluation was successful ("eval"), Ds-criterion value – intercept excluded ("Ds"), DPs-criterion value – intercept excluded ("DPs"), Lack-of-fit(DP) criterion value ("LoF"), the bias component value ("bias"), the number of pure error degrees of freedom ("df") and the value of the compound criterion ("compound").

**Examples**

```
# Experiment: one 5-level factor, primary model -- full quadratic, X^3 and X^4 potential terms.
ex.mood <- mood(K = 1, Levels = 5, Nruns = 8, criterion.choice = "GDP",
               kappa = list(kappa.Ds = .25, kappa.LoF = .25, kappa.bias = .25, kappa.DP = .25),
               model_terms = list(primary.model = "second_order", potential_terms = "x14"))
# Generating candidate sets: primary and full orthonormalised ones
K <- ex.mood$K
Levels <- ex.mood$Levels
cand.not.orth <- candidate_set_full(candidate_trt_set(Levels, K), K)
cand.full.orth <- candidate_set_orth(cand.not.orth, ex.mood$primary.terms, ex.mood$potential.terms)
# Choosing a design
index <- c(rep(1,2),3,rep(4,2),rep(5,3))
X.primary <- cand.full.orth[index, c(1, match(ex.mood$primary.terms, colnames(cand.full.orth)))]
X.potential <- cand.full.orth[index,
(c(1, match(ex.mood$potential.terms, colnames(cand.full.orth)))]
# Evaluating a compound GDP-criterion
criteria.GDP(X1 = X.primary, X2 = X.potential, ex.mood)

# Output: eval = 1, Ds = 0.6884783, DP = 4.4538023, LoF = 3.895182,
# bias = 1.03807, df = 4, compound = 2.465318
```

---

criteria.GL

*Calculates the values of the Generalised L-criterion and its components*

---

**Description**

This function evaluates the Generalised L-criterion (Goos et al. 2005) for given primary and potential model matrices.

**Usage**

```
criteria.GL(X1, X2, search.object, eps = 10^-23)
```

**Arguments**

X1	The primary model matrix, with the first column containing the labels of treatments, and the second – the intercept term.
X2	The matrix of potential terms, with the first column containing the labels of treatments.
search.object	Object of class <code>mood()</code> specifying experiment parameters.
eps	Computational tolerance, the default value is $10^{-23}$

**Value**

A list of values: indicator of whether the evaluation was successful ("eval"), Ls-criterion value – intercept excluded ("Ls"), Lack-of-fit criterion value ("LoF"), the bias component value ("bias"), the number of pure error degrees of freedom ("df") and the value of the compound criterion ("compound").

**References**

Goos P, Kobilinsky A, O'Brien TE, Vandebroek M (2005). "Model-Robust and Model-Sensitive Designs." *Computational Statistics and Data Analysis*, **49**, 201-216.

**Examples**

```
#Experiment: one 5-level factor, primary model -- full quadratic, one potential (cubic) term
# setting up the example
ex.mood <- mood(K = 1, Levels = 5, Nruns = 7, criterion.choice = "GL",
               kappa = list(kappa.L = 1./3, kappa.LoF = 1./3, kappa.bias = 1./3),
               model_terms = list(primary.model = "second_order", potential.model = "cubic_terms"))
# Generating candidate set: orthonormalised
K <- ex.mood$K
Levels <- ex.mood$Levels
cand.not.orth <- candidate_set_full(candidate_trt_set(Levels, K), K)
cand.full.orth <- candidate_set_orth(cand.not.orth, ex.mood$primary.terms, ex.mood$potential.terms)
# Choosing a design
index <- c(rep(1, 2), 3, 4, rep(5, 3))
X.primary <- cand.full.orth[index, c(1, match(ex.mood$primary.terms, colnames(cand.full.orth)))]
X.potential <- cand.full.orth[index,
(c(1, match(ex.mood$potential.terms, colnames(cand.full.orth)))]
# Evaluating a compound GD-criterion
criteria.GLP(X1 = X.primary, X2 = X.potential, ex.mood)
# Output: eval = 1, L = 0.3118626, LoF = 0.7212544, bias = 1.473138, df = 3, compound = 0.6919878
```

---

criteria.GLP

*Calculates the values of the Generalised LP-criterion and its components*

---

**Description**

This function evaluates the Generalised LP-criterion for given primary and potential model matrices. Components: L-, LP-, LoF(LP)- and Bias(L)-optimality.

**Usage**

```
criteria.GLP(X1, X2, search.object, eps = 1e-23)
```

**Arguments**

X1	The primary model matrix, with the first column containing the labels of treatments, and the second – the intercept term.
X2	The matrix of potential terms, with the first column containing the labels of treatments.
search.object	Object of class <code>mood()</code> specifying experiment parameters.
eps	Computational tolerance, the default value is $10^{-23}$

**Value**

A list of values: indicator of whether the evaluation was successful ("eval"), Ls-criterion value – intercept excluded ("L"), LP-criterion value – intercept excluded ("LP"), Lack-of-fit(LP) criterion value ("LoF"), the bias component value ("bias"), the number of pure error degrees of freedom ("df") and the value of the compound criterion ("compound").

**Examples**

```
#' # Experiment: one 5-level factor, primary model -- full quadratic, X^3 and X^4 potential terms.
ex.mood <- mood(K = 1, Levels = 5, Nruns = 8, criterion.choice = "GLP",
               kappa = list(kappa.L = .25, kappa.LoF = .25, kappa.bias = .25, kappa.LP = .25),
               model_terms = list(primary.model = "second_order", potential.terms = "x14"))
# Generating candidate sets: primary and full orthonormalised ones
K <- ex.mood$K
Levels <- ex.mood$Levels
cand.not.orth <- candidate_set_full(candidate_trt_set(Levels, K), K)
cand.full.orth <- candidate_set_orth(cand.not.orth, ex.mood$primary.terms, ex.mood$potential.terms)
# Choosing a design
index <- c(rep(1,2),3,rep(4,2),rep(5,3))
X.primary <- cand.full.orth[index, c(1, match(ex.mood$primary.terms, colnames(cand.full.orth)))]
X.potential <- cand.full.orth[index,
(c(1, match(ex.mood$potential.terms, colnames(cand.full.orth)))]
# Evaluating a compound GDP-criterion
criteria.GLP(X1 = X.primary, X2 = X.potential, ex.mood)
# Output: eval = 1, L = 0.2952603, LP = 4.584705, LoF = 3.895182,
# bias = 1.03807, df = 4, compound = 1.529564
```

---

criteria.mseD

*Calculates the values of the MSE DPs-criterion and its components*

---

**Description**

This function evaluates the MSE DPs-criterion for given primary and potential model matrices. Candidate full model matrices do not have to be orthonormalised. Components: DPs-, LoF(DP)- and MSE(D)-optimality.



**Usage**

```
criteria.mseD(X1, X2, search.object, eps = 1e-23)
```

**Arguments**

X1	The primary model matrix, with the first column containing the labels of treatments, and the second – the intercept term.
X2	The matrix of potential terms, with the first column containing the labels of treatments.
search.object	Object of class <code>mood()</code> specifying experiment parameters.
eps	Computational tolerance, the default value is $10^{-23}$

**Value**

A list of values: indicator of whether the evaluation was successful ("eval"), DPs-criterion value – intercept excluded ("DP"), Lack-of-fit(DP) criterion value ("LoF"), the MSE(D) component value ("mse"), the number of pure error degrees of freedom ("df") and the value of the compound criterion ("compound").

**Examples**

```
# Experiment: one 5-level factor, primary model -- full quadratic, X^3 and X^4 potential terms.
set.seed(20210930)
ex.mood <- mood(K = 1, Levels = 5, Nruns = 8, criterion.choice = "MSE.D",
               kappa = list(kappa.DP = 1./3, kappa.LoF = 1./3, kappa.mse = 1./3),
               control = list(Biter = 1000),
               model_terms = list(primary.model = "second_order", potential.terms = "x14"))
# Generating candidate sets: primary and full orthonormalised ones
K <- ex.mood$K
Levels <- ex.mood$Levels
cand.not.orth <- candidate_set_full(candidate_trt_set(Levels, K), K)
cand.full.orth <- candidate_set_orth(cand.not.orth, ex.mood$primary.terms, ex.mood$potential.terms)
# Choosing a design
index <- c(rep(1,2),3,rep(4,2),rep(5,3))
X.primary <- cand.full.orth[index, c(1, match(ex.mood$primary.terms, colnames(cand.full.orth)))]
X.potential <- cand.full.orth[index,
(c(1, match(ex.mood$potential.terms, colnames(cand.full.orth)))]
# Evaluating a compound GDP-criterion
criteria.mseD(X.primary, X.potential, ex.mood)
# Output: eval = 1, DP = 4.538023, LoF = 3.895182, mse = 0.6986903, df = 4, compound = 2.310728
```

---

```
criteria.mseL
```

*Calculates the values of the MSE LP-criterion and its components*

---

**Description**

This function evaluates the MSE LP-criterion for given primary and potential model matrices. Candidate full model matrices do not have to be orthonormalised. Components: LP-, LoF(LP)- and MSE(L)-optimality.

**Usage**

```
criteria.msel(X1, X2, search.object, eps = 10^-23)
```

**Arguments**

X1	The primary model matrix, with the first column containing the labels of treatments, and the second – the intercept term.
X2	The matrix of potential terms, with the first column containing the labels of treatments.
search.object	Object of class <code>mood()</code> specifying experiment parameters.
eps	Computational tolerance, the default value is $10^{-23}$

**Value**

A list of values: indicator of whether the evaluation was successful ("eval"), LP-criterion value – intercept excluded ("LP"), Lack-of-fit(LP) criterion value ("LoF"), the MSE(L) component value ("mse"), the number of pure error degrees of freedom ("df") and the value of the compound criterion ("compound").

**Examples**

```
## Experiment: one 5-level factor, primary model -- full quadratic, X^3 and X^4 potential terms.
ex.mood <- mood(K = 1, Levels = 5, Nruns = 8, criterion.choice = "MSE.L",
               kappa = list(kappa.LP = 1./3, kappa.LoF = 1./3, kappa.mse = 1./3),
               model_terms = list(primary.model = "second_order", potential.terms = "x14"))
# Generating candidate sets: primary and full orthonormalised ones
K <- ex.mood$K
Levels <- ex.mood$Levels
cand.not.orth <- candidate_set_full(candidate_trt_set(Levels, K), K)
cand.full.orth <- candidate_set_orth(cand.not.orth, ex.mood$primary.terms, ex.mood$potential.terms)
# Choosing a design
index <- c(rep(1,2),3,rep(4,2),rep(5,3))
X.primary <- cand.full.orth[index, c(1, match(ex.mood$primary.terms, colnames(cand.full.orth)))]
X.potential <- cand.full.orth[index,
(c(1, match(ex.mood$potential.terms, colnames(cand.full.orth)))]
# Evaluating a compound GDP-criterion
criteria.msel(X.primary, X.potential, ex.mood)
# Output: eval = 1, LP = 4.584705, LoF = 3.895182, mse = 0.3926842, df = 4, compound = 1.914084
```

---

```
criteria.mseP
```

*Calculates the values of the MSE DPs-criterion using the point prior for the MSE(D)-component estimation*

---

**Description**

This function evaluates the MSE DPs-criterion for given primary and potential model matrices, using point MSE(D)-component estimation. Candidate full model matrices do not have to be orthonormalised. Components: DPs-, LoF(DP)- and MSE(D)-optimality.

**Usage**

```
criteria.mseP(X1, X2, search.object, eps = 10^-23)
```

**Arguments**

X1	The primary model matrix, with the first column containing the labels of treatments, and the second – the intercept term.
X2	The matrix of potential terms, with the first column containing the labels of treatments.
search.object	Object of class <code>mood()</code> specifying experiment parameters.
eps	Computational tolerance, the default value is $10^{-23}$

**Value**

A list of values: indicator of whether the evaluation was successful ("eval"), DPs-criterion value – intercept excluded ("DP"), Lack-of-fit(DP) criterion value ("LoF"), the MSE(D) component value ("mse"), the number of pure error degrees of freedom ("df") and the value of the compound criterion ("compound").

**Examples**

```
# Experiment: one 5-level factor, primary model -- full quadratic, X^3 and X^4 potential terms.
ex.mood <- mood(K = 1, Levels = 5, Nruns = 8, criterion.choice = "MSE.P",
               kappa = list(kappa.DP = 1./3, kappa.LoF = 1./3, kappa.mse = 1./3),
               model_terms = list(primary.model = "second_order", potential.terms = "x14"))
# Generating candidate sets: primary and full orthonormalised
K <- ex.mood$K
Levels <- ex.mood$Levels
cand.not.orth <- candidate_set_full(candidate_trt_set(Levels, K), K)
cand.full.orth <- candidate_set_orth(cand.not.orth, ex.mood$primary.terms, ex.mood$potential.terms)
# Choosing a design
index <- c(rep(1,2),3,rep(4,2),rep(5,3))
X.primary <- cand.full.orth[index, c(1, match(ex.mood$primary.terms, colnames(cand.full.orth)))]
X.potential <- cand.full.orth[index,
(c(1, match(ex.mood$potential.terms, colnames(cand.full.orth)))]
# Evaluating a compound GDP-criterion
criteria.mseP(X.primary, X.potential, ex.mood)
# Output: eval = 1, DP = 4.538023, LoF = 3.895182, mse = 0.6992699, df = 4, compound = 2.312135
```

---

criteria.values.G      *Evaluating individual criteria of the designs, from the Generalized compound criteria (Goos et al. 2005; Egorova,~O. 2017)*

---

**Description**

Calculating values of determinant- and trace-based components of Generalized D-, DP-, L- and LP-criteria for an output of a search object, with model and control parameters set in a mood object.

**Usage**

```
criteria.values.G(search.obj, mood.obj, eps = 10^-23)
```

**Arguments**

search.obj	Output of the 'Search' function
mood.obj	Output of the 'mood' function
eps	Computational tolerance, default $10^{-20}$

**Value**

List of the calculated values:

- df pure error degrees of freedom
- Ds Ds-criterion value, intercept excluded
- DP DPs-criterion value, intercept excluded
- LoFD LoF(D)-criterion value from the GD-criterion
- LoFDP LoF(DP)-criterion value from the GDP-criterion
- biasD bias(D)-criterion value from the GD-criterion
- Ls Ls-criterion value, intercept excluded
- LP LPs-criterion value, intercept excluded
- LoFL LoF(L)-criterion value from the GL-criterion
- LoFLP LoF(LP)-criterion value from the GLP-criterion
- biasL bias(L)-criterion value from the GL-criterion

**References**

Egorova,~O. (2017). *Optimal Design of Experiments for Multiple Objectives*. Ph.D. thesis, University of Southampton.

Goos P, Kobilinsky A, O'Brien TE, Vandebroek M (2005). "Model-Robust and Model-Sensitive Designs." *Computational Statistics and Data Analysis*, **49**, 201-216.

---

criteria.values.mse     *Evaluating individual criteria of the designs*

---

**Description**

Calculating values of determinant- and trace-based components of MSE(D)- and MSE(L)- criteria for an output of a search object, with model and control parameters set in a mood object.

**Usage**

```
criteria.values.mse(search.obj, mood.obj, eps = 10^-20, Biter = 1000)
```

**Arguments**

search.obj	Output of the ‘Search’ function
mood.obj	Output of the ‘mood’ function
eps	Computational tolerance, default $10^{-20}$
Biter	MC sample size for evaluating the mse(D)-component

**Value**

List of the calculated values:

- df pure error degrees of freedom
- Ds Ds-criterion value, intercept excluded
- DP DPs-criterion value, intercept excluded
- LoFDP LoF(DP)-criterion value
- mseD mse(D)-criterion value, obtained via MC sampling
- mseP mse(D)-criterion value, obtained using point prior
- L L-criterion value, intercept excluded
- LP LP-criterion value, intercept excluded
- LoFLP LoF(LP)-criterion value
- mseL mse(L)-criterion value

---

mood	<i>Setting up the parameters of a factorial experiment to search for multi-objective optimal completely randomised design.</i>
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---

**Description**

Creates an object containing the parameters of the experiment, compound optimality criterion with the weights and parameters of the search.

**Usage**

```
mood(
  K,
  Levels,
  Nruns,
  criterion.choice = c("GD", "GL", "GDP", "GLP", "MSE.D", "MSE.L", "MSE.P"),
  kappa = list(),
  control = list(),
  prob = list(),
  model_terms = list(primary.model = "first_order")
)
```

**Arguments**

K	Number of factors.
Levels	Either (a) a common number of levels for each factor or (b) a list of length K of the vectors containing levels of each factor.
Nruns	Number of runs of the experiment.
criterion.choice	Compound criterion to be used for the optimal design search or evaluation. Possible values are: <ul style="list-style-type: none"> <li>• GL, GD for Generalised D- and L-optimality (Goos et al. 2005)</li> <li>• GDP and GLP for Generalised DP- and LP-optimality (Gilmour and Trinca 2012)</li> <li>• MSE.D, MSE.L and MSE.P for compound criteria with MSE-component: determinant-based, trace-based and determinant-based but with point estimates for the MSE(D)-component</li> </ul>
kappa	List specifying the weights used in the compound criterion. Each named entry must be between 0 and 1. <ul style="list-style-type: none"> <li>• kappa.Ds Weight of the Ds-criterion (default = 1 if criterion.choice = GD)</li> <li>• kappa.DP Weight of the DP-criterion (default = 1 if criterion.choice = GDP)</li> <li>• kappa.L Weight of the L-criterion (default = 1 if criterion.choice = GL)</li> <li>• kappa.LP Weight of the LP-criterion (default = 1 if criterion.choice = GLP)</li> <li>• kappa.LoF Weight of the lack-of-fit criterion</li> <li>• kappa.bias Weight of the bias criterion</li> <li>• kappa.mse Weight of the MSE criterion (default = 1 if 'criterion.choice = MSE.*')</li> </ul>
control	Named list specifying control parameters for the design search. <ul style="list-style-type: none"> <li>• Nstarts The number of randomly generated start designs of the search algorithm (default = 10).</li> <li>• Cubic Indicator of whether the experimental region is cubic (TRUE, default) or spherical (FALSE).</li> <li>• tau2 The variance scaling parameter for the prior distribution of the potential terms (default = 1).</li> <li>• Biter Number of samples for evaluating the MSE determinant-based component criterion (default = 50).</li> <li>• MC Indicator of whether to apply a multiple comparison (Bonferroni) correction for trace-based criteria (TRUE, default) or not (FALSE).</li> <li>• orth Indicator of whether to orthonormalise the potential and primary terms (TRUE, default) or not (FALSE).</li> </ul>
prob	Named list specifying confidence levels for DP- (prob.DP), LP- (prob.LP) and Lack-of-fit (prob.LoF) criteria (pre-Bonferroni correction). All default to 0.95.
model_terms	A list specifying the primary (fitted) and potential (biased) models with the following named elements (see Details).

- `primary.model` The order of the fitted polynomial model. Alternatively polynomial terms can be directly specified through the `primary.terms` parameter.
- `potential.model` The order of the potential/extra polynomial terms. Alternatively can be specified through the `potential.terms` parameter.
- `primary.terms` Alternative specification of the primary model via character vector of the names of the primary terms.
- `potential.terms` Alternative specification of the potential model via character vector of the names of the potential terms.

## Details

The function provides different ways of specifying the levels of the factors and the models. Although some default options are provided for, e.g., `criterion.choice` and `kappa.*` values, specification of these input parameters should be carefully chosen to reflect the aims of the experiment and available prior information.

Specifying the factors and levels

If all K factors have the same number of levels, `Levels` parameter is used to input that number. Otherwise, `Levels` is set to be a list of vectors containing the values of the factors, e.g. `list(1:3, 1:2, 1:4)` for 3 factors with equally spaced 3, 2 and 4 levels respectively.

Specifying the fitted model and the potential terms

There are two ways to describe the primary and potential sets of model terms via the `model_terms` list. Named elements `primary.model` and `potential.model` can be used to specify the fitted model and the potential terms via a string form. They are used to generate the sets of `primary.terms` and `potential.terms` which alternatively can be input directly. Possible values of `primary.model` are:

- `main_effects` – main effects for all the factors (default for all criteria)
- `first_order` – main effects and linear interactions
- `second_order` – full second order polynomial
- `third_order` – full second order polynomial model and all interactions of degree 3
- `cubic` – third order polynomial model with cubic terms

The intercept is always included as a primary term.

Possible elements of the `potential.model` vector argument:

- `linear_interactions` – linear interactions among the factors (default for MSE criteria)
- `quadratic_terms` – quadratic terms for all the factors
- `third_order_terms` – all interactions of degree 3: linear-by-linear-by-linear and quadratic-by-linear terms
- `cubic_terms` – cubic terms for all the factors
- `fourth_order_terms` – all interactions of degree 4, similar to `third_order_terms`

`primary.terms` and `potential.terms` arguments are used to specify the fitted model and the potential terms explicitly – up to the total power of 4.

- Single factor powers, are coded as a string starting with "x" and followed by the index of the factor and the power: "x32". For example,  $x_3^2$  is coded as "x32"; "x22" stands for  $x_2^2$ , and "x4" stands for the linear term  $x_4$ .
- Interaction of factors' powers are coded by merging the individual factors' powers, ordered by the factors' indexes. For example,  $x_2^2 \times x_1$  is coded as "x1x22",  $x_3x_12x_4$  – as "x12x3x4".

## Value

Object of class mood specifying parameters of the experiment, compound criterion of choice, and primary and potential model terms.

- K Number of factors.
- Klev Number of levels of each factor, if all factors have the same number of levels.
- Levels List of length K of the vectors containing values of the factors.
- Nruns Number of runs of the experiment.
- criterion.choice Compound criterion to be used for the optimal design search or evaluation.
- Nstarts The number of randomly generated start designs of the search algorithm.
- Biter Number of samples for evaluating the MSE determinant-based component criterion.
- tau2 The variance scaling parameter for the prior distribution of the potential terms.
- tau The square root of tau2
- Cubic Whether the experimental region is cubic (TRUE) or spherical (FALSE).
- MC Indicator of the multiple comparison (Bonferroni) correction for trace-based criteria.
- prob.DP, prob.LP, prob.LoF, prob.LoFL Confidence levels for the DP-, LP-, lack of fit determinant- and trace-based criteria.
- alpha.DP, alpha.LP, alpha.LoF, alpha.LoFL Significance levels for the DP-, LP-, lack of fit determinant- and trace-based criteria.
- orth Whether the candidate sets are orthonormalised (TRUE) or not (FALSE).
- Z0 Z0 matrix.
- W Weight matrix for Ls criterion.
- primary.terms Fitted (primary) model terms.
- potential.terms Potential terms.
- P The number of terms in the fitted model (including intercept).
- Q The number of potential terms.
- kappa.Ds, kappa.DP, kappa.L, kappa.LP, kappa.LoF, kappa.bias, kappa.mse Compound criterion weights.
- warning.msg Warning messages.

## References

Gilmour SG, Trinca LA (2012). "Optimum Design of Experiments for Statistical Inference (with discussion)." *Journal of the Royal Statistical Society C*, **61**, 345-401.

Goos P, Kobilinsky A, O'Brien TE, Vandebroek M (2005). "Model-Robust and Model-Sensitive Designs." *Computational Statistics and Data Analysis*, **49**, 201-216.



**Examples**

```
example1 <- mood(K = 5, Levels = 3, Nruns = 40, criterion.choice = "GDP",
kappa = list(kappa.Ds = 1./3, kappa.DP = 1./3, kappa.LoF = 1./3),
control = list(Nstarts = 50, tau2 = 0.1),
model_terms = list(primary.model = "second_order",
potential.terms = c("x12x2", "x22x3", "x32x4", "x42x5")))
example1
```

```
example2 <- mood(K = 3, Nruns = 12, Levels = list(1:3, 1:2, 1:2), criterion.choice = "MSE.L",
kappa = list(kappa.LP = 1./2, kappa.LoF = 1./4, kappa.mse = 1./4),
control = list(Nstarts = 50, tau2 = 1),
model_terms = list(primary.terms = "first_order",
potential.terms = c("x12", "x12x2", "x12x3")))
example2
```

---

Search	<i>Searching for a multi-objective optimal completely randomised design.</i>
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**Description**

Performing search for a (nearly) optimum factorial design, optimising with respect to a specified compound criterion.

**Usage**

```
Search(
  mood.object,
  algorithm = c("ptex", "coordex"),
  parallel = FALSE,
  verbose = TRUE
)
```

**Arguments**

mood.object	Object of class mood, generated by mood function, containing the parameters of the experiment, the compound criterion and search parameters
algorithm	Parameter specifying the search algorithm. If ptex (default for $K \leq 4$ ), the point-exchange algorithm is used, and if coordex (default for $K > 4$ ), the coordinate-exchange.
parallel	If TRUE use the doFuture package to run independent iterations of the algorithm in parallel using foreach. Requires doFuture library to be installed and a Future plan to be specified. See examples.
verbose	If TRUE, progress messages through the search iterations are shown.

## Details

Search takes the mood object as an input with all the parameters of the experiment. Runs a point-exchange or a coordinate-exchange algorithm, returns design and model matrices, computation time and criteria values. See (Koutra et al. 2024) for examples of using `parallel = TRUE`.

## Value

Updated object of class mood containing the outputs generated by the search:

- `X.design` Design matrix.
- `df` The number of pure error degrees of freedom.
- `X1` Primary model matrix for the found (nearly-) optimum design.
- `X2` Model matrix of potential terms for the found (nearly-) optimum design.
- `compound.value` The compound criterion value of the (nearly-) optimum design.
- `criteria.values` Component criteria values of the (nearly-) optimum design.
- `path` The "path" of compound criterion values of the optimum designs obtained after for each random start.
- `time` Computation time.
- `algorithm` Point exchange or coordinate exchange used to find the design?
- `parallel` Were different runs of the algorithm performed across different CPU cores (TRUE/FALSE)

## References

Koutra V, Egorova O, Gilmour SG, Trinca LA (2024). "MOODE: An R Package for Multi-Objective Optimal Design of Experiments." arXiv:2412.17158, <https://arxiv.org/abs/2412.17158>.

## See Also

[mood](#)

## Examples

```
example1 <- mood(K = 2, Levels = 3, Nruns = 10, criterion.choice = "GDP",
               kappa = list(kappa.Ds = 1./3, kappa.DP = 1./3, kappa.LoF = 1./3),
               control = list(tau2 = 0.1),
               model_terms = list(primary.model = "first_order",
                                potential.terms = c("x12", "x22", "x1x2")))
# Using point exchange
Search_point <- Search(example1, algorithm = 'ptex')
Search_point
# Using coordinate exchange (the default for K>4)
Search_coord <- Search(example1)
Search_coord
```

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