

# Package ‘DoseFinding’

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**Type** Package

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**Maintainer** Bjoern Bornkamp <bbnkmp@mail.de>

**Description** The DoseFinding package provides functions for the design and analysis of dose-finding experiments (with focus on pharmaceutical Phase II clinical trials). It provides functions for: multiple contrast tests, fitting non-linear dose-response models (using Bayesian and non-Bayesian estimation), calculating optimal designs and an implementation of the MCPMod methodology (Pinheiro et al. (2014) <[doi:10.1002/sim.6052](https://doi.org/10.1002/sim.6052)>).

**VignetteBuilder** knitr

**License** GPL-3

**LazyLoad** yes

**NeedsCompilation** yes

**Author** Bjoern Bornkamp [aut, cre] (<<https://orcid.org/0000-0002-6294-8185>>),  
Jose Pinheiro [aut],  
Frank Bretz [aut],  
Ludger Sandig [aut]

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## R topics documented:

DoseFinding-package . . . . .	2
bFitMod . . . . .	4
biom . . . . .	8

defBnds . . . . .	8
DesignMCPModApp . . . . .	9
DR-Models . . . . .	10
fitMod . . . . .	14
glycobrom . . . . .	18
guesst . . . . .	20
IBScovars . . . . .	22
MCPMod . . . . .	23
MCTpval . . . . .	27
MCTtest . . . . .	28
migraine . . . . .	31
Mods . . . . .	31
mvtnorm.control . . . . .	35
neurodeg . . . . .	36
optContr . . . . .	37
optDesign . . . . .	40
planMod . . . . .	45
powMCT . . . . .	48
sampSize . . . . .	50
Target Doses . . . . .	53

<b>Index</b>	<b>56</b>
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DoseFinding-package     *Design and Analysis of dose-finding studies*

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## Description

The DoseFinding package provides functions for the design and analysis of dose-finding experiments (for example pharmaceutical Phase II clinical trials). It provides functions for: multiple contrast tests (`MCTtest`), fitting non-linear dose-response models (`fitMod`), a combination of testing and dose-response modelling (`MCPMod`), and calculating optimal designs (`optDesign`), both for normal and general response variable.

## Details

Package: DoseFinding  
 Type: Package  
 Version: 1.0-5  
 Date: 2023-06-27  
 License: GPL-3

The main functions are:

**MCTtest**: Implements a multiple contrast tests

**powMCT**: Power calculations for multiple contrast tests

**fitMod**: Fits non-linear dose-response models

**optDesign**: Calculates optimal designs for dose-response models

**MCPMod**: Performs MCPMod methodology  
**sampSize**: General function for sample size calculation

### Author(s)

Bjoern Bornkamp, Jose Pinheiro, Frank Bretz  
 Maintainer: Bjoern Bornkamp <bbnkmp@gmail.com>

### References

- Bornkamp, B., Bretz, F., Dette, H. and Pinheiro, J. C. (2011). Response-Adaptive Dose-Finding under model uncertainty, *Annals of Applied Statistics*, **5**, 1611–1631
- Bornkamp B., Pinheiro J. C., and Bretz, F. (2009). MCPMod: An R Package for the Design and Analysis of Dose-Finding Studies, *Journal of Statistical Software*, **29**(7), 1–23
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- O’Quigley, J., Iasonos, A. and Bornkamp, B. (2017) Handbook of methods for designing, monitoring, and analyzing dose-finding trials, CRC press, Part 3: Dose-Finding Studies in Phase II
- Pinheiro, J. C., Bornkamp, B., and Bretz, F. (2006). Design and analysis of dose finding studies combining multiple comparisons and modeling procedures, *Journal of Biopharmaceutical Statistics*, **16**, 639–656
- Pinheiro, J. C., Bornkamp, B., Glimm, E. and Bretz, F. (2014) Model-based dose finding under model uncertainty using general parametric models, *Statistics in Medicine*, **33**, 1646–1661
- Seber, G.A.F. and Wild, C.J. (2003). Nonlinear Regression, Wiley

### Examples

```
data(IBScovars)

## perform (model based) multiple contrast test
## define candidate dose-response shapes
models <- Mods(linear = NULL, emax = 0.2, quadratic = -0.17,
              doses = c(0, 1, 2, 3, 4))

## plot models
plot(models)
## perform multiple contrast test
test <- MCTtest(dose, resp, IBScovars, models=models,
               addCovars = ~ gender)

## fit non-linear emax dose-response model
fitemax <- fitMod(dose, resp, data=IBScovars, model="emax",
                 bnds = c(0.01,5))
## display fitted dose-effect curve
plot(fitemax, CI=TRUE, plotData="meansCI")
```

```
## Calculate optimal designs for target dose (TD) estimation
doses <- c(0, 10, 25, 50, 100, 150)
fmodels <- Mods(linear = NULL, emax = 25, exponential = 85,
               logistic = c(50, 10.8811),
               doses = doses, placEff=0, maxEff=0.4)
plot(fmodels, plotTD = TRUE, Delta = 0.2)
weights <- rep(1/4, 4)
desTD <- optDesign(fmodels, weights, Delta=0.2, designCrit="TD")
```

---

bFitMod

*Fit a dose-response model using Bayesian or bootstrap methods.*


---

### Description

For ‘type = "Bayes"’, MCMC sampling from the posterior distribution of the dose-response model is done. The function assumes a multivariate normal distribution for resp with covariance matrix S, and this is taken as likelihood function and combined with the prior distributions specified in prior to form the posterior distribution.

For ‘type = "bootstrap"’, a multivariate normal distribution for resp with covariance matrix S is assumed, and a large number of samples is drawn from this distribution. For each draw the fitMod function with ‘type = "general"’ is used to fit the draws from the multivariate normal distribution.

### Usage

```
bFitMod(dose, resp, model, S, placAdj = FALSE,
        type = c("Bayes", "bootstrap"),
        start = NULL, prior = NULL, nSim = 1000,
        MCMCcontrol = list(), control = NULL, bnds,
        addArgs = NULL)

## S3 method for class 'bFitMod'
coef(object, ...)

## S3 method for class 'bFitMod'
predict(object, predType = c("full-model", "effect-curve"),
        summaryFct = function(x) quantile(x, probs = c(0.025, 0.25, 0.5, 0.75, 0.975)),
        doseSeq = NULL, lenSeq = 101, ...)

## S3 method for class 'bFitMod'
plot(x, plotType = c("dr-curve", "effect-curve"),
     quant = c(0.025, 0.5, 0.975),
     plotData = c("means", "meansCI", "none"),
     level = 0.95, lenDose = 201, ...)
```

**Arguments**

dose	Numeric specifying the dose variable.
resp	Numeric specifying the response estimate corresponding to the doses in dose
S	Covariance matrix associated with the dose-response estimate specified via resp
model	Dose-response model to fit, possible models are "linlog", "linear", "quadratic", "emax", "exponential", "sigEmax", "betaMod" and "logistic", see <a href="#">drmodels</a> .
placAdj	Whether or not estimates in "placAdj" are placebo-adjusted (note that the linear in log and the logistic model cannot be fitted for placebo-adjusted data)
type	Character with allowed values "Bayes" and "bootstrap", Determining whether samples are drawn from the posterior, or the bootstrap distribution.
start	Optional starting values for the dose-response parameters in the MCMC algorithm.
prior	List containing the information regarding the prior distributions for 'type = "Bayes"'. The list needs to have as many entries as there are model parameters. The ordering of the list entries should be the same as in the arguments list of the model see (see <a href="#">drmodels</a> ). For example for the Emax model the first entry determines the prior for e0, the second to eMax and the third to ed50. For each list entry the user has the choice to choose from 4 possible distributions: <ul style="list-style-type: none"> <li>• norm: Vector of length 2 giving mean and standard deviation.</li> <li>• t: Vector of length 3 giving median, scale and degrees of freedom of the t-distribution.</li> <li>• lnorm: Vector of length 2 giving mean and standard deviation on log scale.</li> <li>• beta: Vector of length 4 giving lower and upper bound of the beta prior as well as the alpha and beta parameters of the beta distribution</li> </ul>
nSim	Desired number of samples to produce with the algorithm
MCMCcontrol	List of control parameters for the MCMC algorithm <ul style="list-style-type: none"> <li>• thin Thinning rate. Must be a positive integer.</li> <li>• w Numeric of same length as number of parameters in the model, specifies the width parameters of the slice sampler.</li> <li>• adapt Logical whether to adapt the w (width) parameter of the slice sampler in a short trial run. The widths are chosen as IQR/1.3 of the trial run.</li> </ul>
control	Same as the control argument in <a href="#">fitMod</a> .
bnds	Bounds for non-linear parameters, in case 'type = "bootstrap"'. If missing the the default bounds from <a href="#">defBnds</a> is used.
addArgs	List containing two entries named "scal" and "off" for the "betaMod" and "linlog" model. When addArgs is NULL the following defaults are used 'list(scal = 1.2*max(doses), off = 0.01*max(doses))'
x, object	A bFitMod object
predType, summaryFct, doseSeq, lenSeq	Arguments for the predict method. 'predType': predType determines whether predictions are returned for the dose-response curve or the effect curve (difference to placebo).

‘summaryFct’: If equal to NULL predictions are calculated for each sampled parameter value. Otherwise a summary function is applied to the dose-response predictions for each parameter value. The default is to calculate 0.025, 0.25, 0.5, 0.75, 0.975 quantiles of the predictions for each dose.

‘doseSeq’: Where to calculate predictions. If not specified predictions are calculated on a grid of length ‘lenSeq’ between minimum and maximum dose.

‘lenSeq’: Length of the default grid where to calculate predictions.

plotType, quant, plotData, level, lenDose

Arguments for plot method.

‘plotType’: Determining whether the dose-response curve or the effect curve should be plotted.

‘quant’: Vector of quantiles to display in plot

‘plotData’: Determines how the original data are plotted: Either as means or as means with CI or not. The level of the CI is determined by the argument ‘level’.

‘level’: Level for CI, when plotData is equal to ‘meansCI’.

‘lenDose’: Number of grid values to use for display.

... Additional arguments are ignored.

### Details

Componentwise univariate slice samplers are implemented (see Neal, 2003) to sample from the posterior distribution.

### Value

An object of class bFitMod, which is a list containing the matrix of posterior simulations plus some additional information on the fitted model.

### Author(s)

Bjoern Bornkamp

### References

Neal, R. M. (2003), Slice sampling, *Annals of Statistics*, 31, 705-767

### See Also

[fitMod](#)

### Examples

```
data(biom)
## produce first stage fit (using dose as factor)
anMod <- lm(resp~factor(dose)-1, data=biom)
drFit <- coef(anMod)
S <- vcov(anMod)
dose <- sort(unique(biom$dose))
```

```

## define prior list
## normal prior for E0 (mean=0 and sdev=10)
## normal prior for Emax (mean=0 and sdev=100)
## beta prior for ED50: bounds: [0,1.5] parameters shape1=0.45, shape2=1.7
prior <- list(norm = c(0, 10), norm = c(0,100), beta=c(0,1.5,0.45,1.7))
## now fit an emax model
gsample <- bFitMod(dose, drFit, S, model = "emax",
                  start = c(0, 1, 0.1), nSim = 1000, prior = prior)
## summary information
gsample
## samples are stored in
head(gsample$samples)
## predict 0.025, 0.25, 0.5, 0.75, 0.975 Quantile at 0, 0.5 and 1
predict(gsample, doseSeq = c(0, 0.5, 1))
## simple plot function
plot(gsample)

## now look at bootstrap distribution
gsample <- bFitMod(dose, drFit, S, model = "emax", type = "bootstrap",
                  nSim = 100, bnds = defBnds(1)$emax)
plot(gsample)

## now fit linear interpolation
prior <- list(norm = c(0,1000), norm = c(0,1000),
              norm = c(0,1000), norm = c(0,1000), norm = c(0,100))
gsample <- bFitMod(dose, drFit, S, model = "linInt",
                  start = rep(1,5), nSim = 1000, prior = prior)
gsample <- bFitMod(dose, drFit, S, model = "linInt", type = "bootstrap",
                  nSim = 100)

## data fitted on placebo adjusted scale
data(IBScovars)
anovaMod <- lm(resp~factor(dose)+gender, data=IBScovars)
drFit <- coef(anovaMod)[2:5] # placebo adjusted estimates at doses
vCov <- vcov(anovaMod)[2:5,2:5]
dose <- sort(unique(IBScovars$dose))[-1]
prior <- list(norm = c(0,100), beta=c(0,6,0.45,1.7))
## Bayes fit
gsample <- bFitMod(dose, drFit, vCov, model = "emax", placAdj=TRUE,
                  start = c(1, 0.1), nSim = 1000, prior = prior)
## bootstrap fit
gsample <- bFitMod(dose, drFit, vCov, model = "emax", placAdj=TRUE,
                  type = "bootstrap", start = c(1, 0.1),
                  nSim = 100, prior = prior, bnds = c(0.01,6))
## calculate target dose estimate
TD(gsample, Delta = 0.2)
## now fit linear interpolation
prior <- list(norm = c(0,1000), norm = c(0,1000), norm = c(0,1000), norm = c(0,100))
gsample <- bFitMod(dose, drFit, vCov, model = "linInt", placAdj=TRUE,
                  start = rep(1,4), nSim = 1000, prior = prior)
gsample <- bFitMod(dose, drFit, vCov, model = "linInt", type = "bootstrap",
                  placAdj = TRUE, nSim = 100)

```

---

biom	<i>Biometrics Dose Response data</i>
------	--------------------------------------

---

### Description

An example data set for dose response studies. This data set was used in Bretz et al. (2005) to illustrate the MCPMod methodology.

### Usage

```
data(biom)
```

### Format

A data frame with 100 observations on the following 2 variables.

resp a numeric vector containing the response values

dose a numeric vector containing the dose values

### Source

Bretz, F., Pinheiro, J. C., and Branson, M. (2005), Combining multiple comparisons and modeling techniques in dose-response studies, *Biometrics*, **61**, 738–748

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defBnds	<i>Calculates default bounds for non-linear parameters in dose-response models</i>
---------	--

---

### Description

Calculates reasonable bounds for non-linear parameters for the built-in non-linear regression model based on the dose range under investigation.

For the logistic model the first row corresponds to the ED50 parameter and the second row to the delta parameter. For the sigmoid Emax model the first row corresponds to the ED50 parameter and the second row to the h parameter, while for the beta model first and second row correspond to the delta1 and delta2 parameters. See [logistic](#), [sigEmax](#) and [betaMod](#) for details.

### Usage

```
defBnds(mD, emax = c(0.001, 1.5)*mD,
        exponential = c(0.1, 2)*mD,
        logistic = matrix(c(0.001, 0.01, 1.5, 1/2)*mD, 2),
        sigEmax = matrix(c(0.001*mD, 0.5, 1.5*mD, 10), 2),
        betaMod = matrix(c(0.05, 0.05, 4, 4), 2))
```



**Arguments**

mD                    Maximum dose in the study.  
emax, exponential, logistic, sigEmax, betaMod  
                         values for the nonlinear parameters for these model-functions

**Value**

List containing bounds for the model parameters.

**Author(s)**

Bjoern Bornkamp

**See Also**

[fitMod](#)

**Examples**

```
defBnds(mD = 1)  
defBnds(mD = 200)
```

---

DesignMCPModApp

*Start externally hosted DesignMCPMod Shiny App*

---

**Description**

This function starts the externally hosted DesignMCPMod Shiny App in a browser window. The app was developed by Sophie Sun [aut, cre], Danyi Xiong [aut], Bjoern Bornkamp [ctb], Frank Bretz [ctb], Ardlan Mirshani [ctb]. This app performs power and sample size calculations for a multiple contrast test for normal, binary and negative binomial outcomes. The app uses the DoseFinding package as calculation backend and the R code underlying the calculations in the app can be extracted from the app.

**Usage**

```
DesignMCPModApp()
```

**Description**

Dose-response model functions and gradients.

Below are the definitions of the model functions:

**E<sub>max</sub> model**

$$f(d, \theta) = E_0 + E_{max} \frac{d}{ED_{50} + d}$$

**Sigmoid E<sub>max</sub> Model**

$$f(d, \theta) = E_0 + E_{max} \frac{d^h}{ED_{50}^h + d^h}$$

**Exponential Model**

$$f(d, \theta) = E_0 + E_1(\exp(d/\delta) - 1)$$

**Beta model**

$$f(d, \theta) = E_0 + E_{max} B(\delta_1, \delta_2) (d/scal)^{\delta_1} (1 - d/scal)^{\delta_2}$$

here

$$B(\delta_1, \delta_2) = (\delta_1 + \delta_2)^{\delta_1 + \delta_2} / (\delta_1^{\delta_1} \delta_2^{\delta_2})$$

and *scal* is a fixed dose scaling parameter.

**Linear Model**

$$f(d, \theta) = E_0 + \delta d$$

**Linear in log Model**

$$f(d, \theta) = E_0 + \delta \log(d + off)$$

here *off* is a fixed offset parameter.

**Logistic Model**

$$f(d, \theta) = E_0 + E_{max} / \{1 + \exp [(ED_{50} - d) / \delta]\}$$

**Quadratic Model**

$$f(d, \theta) = E_0 + \beta_1 d + \beta_2 d^2$$

The standardized model equation for the quadratic model is  $d + \delta d^2$ , with  $\delta = \beta_2 / \beta_1$ .

**Linear Interpolation model**

The `linInt` model provides linear interpolation at the values defined by the nodes vector. In virtually all situations the nodes vector is equal to the doses used in the analysis. For example the `Mods` and the `fitMod` function automatically use the doses that are used in the context of the function call as nodes. The guesstimates specified in the `Mods` function need to be the treatment effects at the active doses standardized to the interval [0,1] (see the examples in the `Mods` function).

**Usage**

```

emax(dose, e0, eMax, ed50)
emaxGrad(dose, eMax, ed50, ...)

sigEmax(dose, e0, eMax, ed50, h)
sigEmaxGrad(dose, eMax, ed50, h, ...)

exponential(dose, e0, e1, delta)
exponentialGrad(dose, e1, delta, ...)

quadratic(dose, e0, b1, b2)
quadraticGrad(dose, ...)

betaMod(dose, e0, eMax, delta1, delta2, scal)
betaModGrad(dose, eMax, delta1, delta2, scal, ...)

linear(dose, e0, delta)
linearGrad(dose, ...)

linlog(dose, e0, delta, off = 1)
linlogGrad(dose, off, ...)

logistic(dose, e0, eMax, ed50, delta)
logisticGrad(dose, eMax, ed50, delta, ...)

linInt(dose, resp, nodes)
linIntGrad(dose, resp, nodes, ...)

```

**Arguments**

dose	Dose variable
e0	For most models placebo effect. For logistic model left-asymptote parameter, corresponding to a basal effect level (not the placebo effect)
eMax	Beta Model: Maximum effect within dose-range Emax, sigmoid Emax, logistic Model: Asymptotic maximum effect
ed50	Dose giving half of the asymptotic maximum effect
h	Hill parameter, determining the steepness of the model at the ED50
e1	Slope parameter for exponential model
delta	Exponential model: Parameter, controlling the convexity of the model. Linear and linlog model: Slope parameter Logistic model: Parameter controlling determining the steepness of the curve
delta1	delta1 parameter for beta model
delta2	delta2 parameter for beta model
b1	first parameter of quadratic model
b2	second parameter of quadratic model (controls, whether model is convex or concave)

resp	Response values at the nodes for the linInt model
off	Offset value to avoid problems with dose=0 (treated as a fixed value, not estimated)
scal	Scale parameter (treated as a fixed value, not estimated)
nodes	Interpolation nodes for the linear interpolation for the linInt model (treated as a fixed value, not estimated)
...	Just included for convenience in the gradient functions, so that for example <code>quadratic(dose, e0=0, b1=1, b2=3)</code> will not throw an error (although the gradient of the quadratic model is independent of e0, b1 and b2).

### Details

The **Emax model** is used to represent monotone, concave dose-response shapes. To distinguish it from the more general sigmoid emax model it is sometimes also called hyperbolic emax model.

The **sigmoid Emax** model is an extension of the (hyperbolic) Emax model by introducing an additional parameter  $h$ , that determines the steepness of the curve at the  $ed_{50}$  value. The sigmoid Emax model describes monotonic, sigmoid dose-response relationships. In the toxicology literature this model is also called four-parameter log-logistic (4pLL) model.

The **quadratic** model is intended to capture a possible non-monotonic dose-response relationship.

The **exponential model** is intended to capture a possible sub-linear or a convex dose-response relationship.

The **beta model** is intended to capture non-monotone dose-response relationships and is more flexible than the quadratic model. The kernel of the beta model function consists of the kernel of the density function of a beta distribution on the interval  $[0, scal]$ . The parameter `scal` is not estimated but needs to be set to a value larger than the maximum dose. It can be set in most functions ('fitMod', 'Mods') via the 'addArgs' argument, when omitted a value of  $1.2 * (\text{maximum dose})$  is used as default, where the maximum dose is inferred from other input to the respective function.

The **linear in log-dose** model is intended to capture concave shapes. The parameter `off` is not estimated in the code but set to a pre-specified value. It can be set in most functions ('fitMod', 'Mods') via the 'addArgs' argument, when omitted a value of  $0.01 * (\text{maximum dose})$  is used as default, where the maximum dose is inferred from other input to the respective function.

The **logistic model** is intended to capture general monotone, sigmoid dose-response relationships. The logistic model and the sigmoid Emax model are closely related: The sigmoid Emax model is a logistic model in  $\log(\text{dose})$ .

The **linInt model** provides linear interpolation of the means at the doses. This can be used as a "nonparametric" estimate of the dose-response curve, but is probably most interesting for specifying a "nonparametric" truth during planning and assess how well parametric models work under a nonparametric truth. For the function 'Mods' and 'fitMod' the interpolation 'nodes' are selected equal to the dose-levels specified.

### Value

Response value for model functions or matrix containing the gradient evaluations.

## References

MacDougall, J. (2006). Analysis of dose-response studies - Emax model, in N. Ting (ed.), *Dose Finding in Drug Development*, Springer, New York, pp. 127–145

Pinheiro, J. C., Bretz, F. and Branson, M. (2006). Analysis of dose-response studies - modeling approaches, in N. Ting (ed.). *Dose Finding in Drug Development*, Springer, New York, pp. 146–171

## See Also

[fitMod](#)

## Examples

```
## some quadratic example shapes
quadModList <- Mods(quadratic = c(-0.5, -0.75, -0.85, -1), doses = c(0,1))
plotMods(quadModList)

## some emax example shapes
emaxModList <- Mods(emax = c(0.02,0.1,0.5,1), doses = c(0,1))
plotMods(emaxModList)
## example for gradient
emaxGrad(dose = (0:4)/4, eMax = 1, ed50 = 0.5)

## some sigmoid emax example shapes
sigEmaxModList <- Mods(sigEmax = rbind(c(0.05,1), c(0.15,3), c(0.4,8),
                                       c(0.7,8)), doses = c(0,1))
plotMods(sigEmaxModList)
sigEmaxGrad(dose = (0:4)/4, eMax = 1, ed50 = 0.5, h = 8)

## some exponential example shapes
expoModList <- Mods(exponential = c(0.1,0.25,0.5,2), doses=c(0,1))
plotMods(expoModList)
exponentialGrad(dose = (0:4)/4, e1 = 1, delta = 2)

## some beta model example shapes
betaModList <- Mods(betaMod = rbind(c(1,1), c(1.5,0.75), c(0.8,2.5),
                                   c(0.4,0.9)), doses=c(0,1), addArgs=list(scal = 1.2))
plotMods(betaModList)
betaModGrad(dose = (0:4)/4, eMax = 1, delta1 = 1, delta2 = 1, scal = 5)

## some logistic model example shapes
logistModList <- Mods(logistic = rbind(c(0.5,0.05), c(0.5,0.15),
                                       c(0.2,0.05), c(0.2,0.15)), doses=c(0,1))
plotMods(logistModList)
logisticGrad(dose = (0:4)/4, eMax = 1, ed50 = 0.5, delta = 0.05)

## some linInt shapes
genModList <- Mods(linInt = rbind(c(0.5,1,1),
                                 c(0,1,1), c(0,0,1)), doses=c(0,0.5,1,1.5))
plotMods(genModList)
linIntGrad(dose = (0:4)/4, resp=c(0,0.5,1,1,1), nodes=(0:4)/4)
```

---

fitMod

*Fit non-linear dose-response model*


---

## Description

Fits a dose-response model. Built-in dose-response models are "linlog", "linear", "quadratic", "emax", "exponential", "sigEmax", "betaMod" and "logistic" (see [drmodels](#)).

When 'type = "normal"' ordinary least squares is used and additional additive covariates can be specified in 'addCovars'. The underlying assumption is hence normally distributed data and homoscedastic variance.

For 'type = "general"' a generalized least squares criterion is used

$$(f(dose, \theta) - resp)' S^{-1} (f(dose, \theta) - resp)$$

and an inverse weighting matrix is specified in 'S', 'type = "general"' is primarily of interest, when fitting a model to AN(C)OVA type estimates obtained in a first stage fit, then 'resp' contains the estimates and 'S' is the estimated covariance matrix for the estimates in 'resp'. Statistical inference (e.g. confidence intervals) rely on asymptotic normality of the first stage estimates, which makes this method of interest only for sufficiently large sample size for the first stage fit. A modified model-selection criterion can be applied to these model fits (see also Pinheiro et al. 2014 for details).

For details on the implemented numerical optimizer see the Details section below.

## Usage

```
fitMod(dose, resp, data = NULL, model, S = NULL, type = c("normal", "general"),
       addCovars = ~1, placAdj = FALSE, bnds, df = NULL,
       start = NULL, na.action = na.fail, control = NULL,
       addArgs = NULL)
```

```
## S3 method for class 'DRMod'
coef(object, sep = FALSE, ...)
```

```
## S3 method for class 'DRMod'
predict(object, predType = c("full-model", "ls-means", "effect-curve"),
        newdata = NULL, doseSeq = NULL, se.fit = FALSE, ...)
```

```
## S3 method for class 'DRMod'
vcov(object, ...)
```

```
## S3 method for class 'DRMod'
plot(x, CI = FALSE, level = 0.95,
     plotData = c("means", "meansCI", "raw", "none"),
     plotGrid = TRUE, colMn = 1, colFit = 1, ...)
```

```
## S3 method for class 'DRMod'
logLik(object, ...)
```

```
## S3 method for class 'DRMod'
AIC(object, ..., k = 2)
```

```
## S3 method for class 'DRMod'
gAIC(object, ..., k = 2)
```

## Arguments

dose, resp	Either vectors of equal length specifying dose and response values, or names of variables in the data frame specified in 'data'.
data	Data frame containing the variables referenced in dose and resp if 'data' is not specified it is assumed that 'dose' and 'resp' are variables referenced from data (and no vectors)
model	The dose-response model to be used for fitting the data. Built-in models are "linlog", "linear", "quadratic", "emax", "exponential", "sigEmax", "betaMod" and "logistic" (see <a href="#">drmodels</a> ).
S	The inverse weighting matrix used in case, when 'type = "general"', see Description. For later inference statements (vcov or predict methods) it is assumed this is the estimated covariance of the estimates in the first stage fit.
type	Determines whether inference is based on an ANCOVA model under a homoscedastic normality assumption (when 'type = "normal"'), or estimates at the doses and their covariance matrix and degrees of freedom are specified directly in 'resp', 'S' and 'df'. See also the Description above and Pinheiro et al. (2014).
addCovars	Formula specifying additional additive linear covariates (only for 'type = "normal"')
placAdj	Logical, if true, it is assumed that placebo-adjusted estimates are specified in 'resp' (only possible for 'type = "general"').
bnds	Bounds for non-linear parameters. If missing the the default bounds from <a href="#">defBnds</a> is used. When the dose-response model has only one non-linear parameter (for example Emax or exponential model), 'bnds' needs to be a vector containing upper and lower bound. For models with two non-linear parameters 'bnds' needs to be a matrix containing the bounds in the rows, see the Description section of <a href="#">defBnds</a> for details on the formatting of the bounds for the individual models.
df	Degrees of freedom to use in case of 'type = "general"'. If this argument is missing 'df = Inf' is used. For 'type = "normal"' this argument is ignored as the exact degrees of freedom can be deduced from the model.
start	Vector of starting values for the nonlinear parameters (ignored for linear models). When equal to NULL, a grid optimization is performed and the best value is used as starting value for the local optimizer.
na.action	A function which indicates what should happen when the data contain NAs.

control	<p>A list with entries: "nlminbcontrol", "optimizetol" and "gridSize".</p> <p>The entry nlminbcontrol needs to be a list and it is passed directly to control argument in the nlminb function, that is used internally for models with 2 nonlinear parameters.</p> <p>The entry optimizetol is passed directly to the tol argument of the optimize function, which is used for models with 1 nonlinear parameters.</p> <p>The entry gridSize needs to be a list with entries dim1 and dim2 giving the size of the grid for the gridsearch in 1d or 2d models.</p>
addArgs	<p>List containing two entries named "scal" and "off" for the "betaMod" and "linlog" model. When addArgs is NULL the following defaults is used 'list(scal = 1.2*max(doses), off = 0.01*max(doses))'.</p>
object, x	DRMod object
sep	Logical determining whether all coefficients should be returned in one numeric or separated in a list.
predType, newdata, doseSeq, se.fit	<p>predType determines whether predictions are returned for the full model (including potential covariates), the ls-means (SAS type) or the effect curve (difference to placebo).</p> <p>newdata gives the covariates to use in producing the predictions (for predType = "full-model"), if missing the covariates used for fitting are used.</p> <p>doseSeq dose-sequence on where to produce predictions (for predType = "effect-curve" and predType = "ls-means"). If missing the doses used for fitting are used.</p> <p>se.fit: logical determining, whether the standard error should be calculated.</p>
CI, level, plotData, plotGrid, colMn, colFit	<p>Arguments for plot method: 'CI' determines whether confidence intervals should be plotted. 'level' determines the level of the confidence intervals. 'plotData' determines how the data are plotted: Either as means or as means with CI, raw data or none. In case of 'type = "normal"' and covariates the ls-means are displayed, when 'type = "general"' the option "raw" is not available. 'colMn' and 'colFit' determine the colors of fitted model and the raw means.</p>
k	Penalty to use for model-selection criterion (AIC uses 2, BIC uses log(n)).
...	Additional arguments for plotting for the 'plot' method. For all other cases additional arguments are ignored.

## Details

Details on numerical optimizer for model-fitting:

For linear models fitting is done using numerical linear algebra based on the QR decomposition. For nonlinear models numerical optimization is performed only in the nonlinear parameters in the model and optimizing over the linear parameters in each iteration (similar as the Golub-Pereyra implemented in `nls`). For models with 1 nonlinear parameter the `optimize` function is used for 2 nonlinear parameters the `nlminb` function is used. The starting value is generated using a grid-search (with the grid size specified via `control$gridSize`), or can directly be handed over via `'start'`.



For details on the asymptotic approximation used for ‘type = “normal”’, see Seber and Wild (2003, chapter 5). For details on the asymptotic approximation used for ‘type = “general”’, and the gAIC, see Pinheiro et al. (2014).

### Value

An object of class DRMod. Essentially a list containing information about the fitted model coefficients, the residual sum of squares (or generalized residual sum of squares),

### Author(s)

Bjoern Bornkamp

### References

Pinheiro, J. C., Bornkamp, B., Glimm, E. and Bretz, F. (2014) Model-based dose finding under model uncertainty using general parametric models, *Statistics in Medicine*, **33**, 1646–1661

Seber, G.A.F. and Wild, C.J. (2003). *Nonlinear Regression*, Wiley.

### See Also

[defBnds](#), [drmodels](#)

### Examples

```
## Fit the emax model to the IBScovars data set
data(IBScovars)
fitemax <- fitMod(dose, resp, data=IBScovars, model="emax",
                 bnds = c(0.01, 4))

## methods for DRMod objects
summary(fitemax)
## extracting coefficients
coef(fitemax)
## (asymptotic) covariance matrix of estimates
vcov(fitemax)
## predicting
newdat <- data.frame(dose = c(0,0.5,1), gender=factor(1))
predict(fitemax, newdata=newdat, predType = "full-model", se.fit = TRUE)
## plotting
plot(fitemax, plotData = "meansCI", CI=TRUE)

## now include (additive) covariate gender
fitemax2 <- fitMod(dose, resp, data=IBScovars, model="emax",
                 addCovars = ~gender, bnds = c(0.01, 4))
vcov(fitemax2)
plot(fitemax2)
## fitted log-likelihood
logLik(fitemax2)
## extracting AIC (or BIC)
AIC(fitemax2)
```

```

## Illustrating the "general" approach for a binary regression
## produce first stage fit (using dose as factor)
data(migraine)
PFrate <- migraine$painfree/migraine$ntrt
doseVec <- migraine$dose
doseVecFac <- as.factor(migraine$dose)
## fit logistic regression with dose as factor
fitBin <- glm(PFrate~doseVecFac-1, family = binomial,
             weights = migraine$ntrt)
drEst <- coef(fitBin)
vCov <- vcov(fitBin)
## now fit an Emax model (on logit scale)
gfit <- fitMod(doseVec, drEst, S=vCov, model = "emax", bnds = c(0,100),
             type = "general")
## model fit on logit scale
plot(gfit, plotData = "meansCI", CI = TRUE)
## model on probability scale
logitPred <- predict(gfit, predType = "ls-means", doseSeq = 0:200,
                  se.fit=TRUE)
plot(0:200, 1/(1+exp(-logitPred$fit)), type = "l", ylim = c(0, 0.5),
     ylab = "Probability of being painfree", xlab = "Dose")
LB <- logitPred$fit-qnorm(0.975)*logitPred$se.fit
UB <- logitPred$fit+qnorm(0.975)*logitPred$se.fit
lines(0:200, 1/(1+exp(-LB)))
lines(0:200, 1/(1+exp(-UB)))

## now illustrate "general" approach for placebo-adjusted data (on
## IBScovars) note that the estimates are identical to fitemax2 above)
anovaMod <- lm(resp~factor(dose)+gender, data=IBScovars)
drFit <- coef(anovaMod)[2:5] # placebo adjusted estimates at doses
vCov <- vcov(anovaMod)[2:5,2:5]
dose <- sort(unique(IBScovars$dose))[-1]
## now fit an emax model to these estimates
gfit2 <- fitMod(dose, drFit, S=vCov, model = "emax", type = "general",
              placAdj = TRUE, bnds = c(0.01, 2))
## some outputs
summary(gfit2)
coef(gfit2)
vcov(gfit2)
predict(gfit2, se.fit = TRUE, doseSeq = c(1,2,3,4), predType = "effect-curve")
plot(gfit2, CI=TRUE, plotData = "meansCI")
gAIC(gfit2)

```

**Description**

Data from a clinical study evaluating Efficacy and Safety of Four Doses of Glycopyrronium Bromide in Patients With Stable Chronic Obstructive Pulmonary Disease (COPD). This data set was obtained from [clinicaltrials.gov](http://clinicaltrials.gov) (NCT00501852). The study design was a 4 period incomplete cross-over design. The primary endpoint is the trough forced expiratory volume in 1 second (FEV1) following 7 days of Treatment.

The data given here are summary estimates (least-square means) for each dose.

**Usage**

```
data(glycobrom)
```

**Format**

A data frame with 5 summary estimates (one per dose). Variables:

dose a numeric vector containing the dose values

fev1 a numeric vector containing the least square mean per dose

sdev a numeric vector containing the standard errors of the least square means per dose

n Number of participants analyzed per treatment group

**Source**

<http://clinicaltrials.gov/ct2/show/results/NCT00501852>

**Examples**

```
## simulate a full data set with given means and sdv (here we ignore
## the original study was a cross-over design, and simulate a parallel
## group design)
simData <- function(mn, sd, n, doses, fixed = TRUE){
  ## simulate data with means (mns) and standard deviations (sd), for
  ## fixed = TRUE, the data set will have observed means and standard
  ## deviations as given in mns and sd
  resp <- numeric(sum(n))
  uppind <- cumsum(n)
  lowind <- c(0,uppind)+1
  for(i in 1:length(n)){
    rv <- rnorm(n[i])
    if(fixed)
      rv <- scale(rv)
    resp[lowind[i]:uppind[i]] <- mn[i] + sd[i]*rv
  }
  data.frame(doses=rep(doses, n), resp=resp)
}
data(glycobrom)
fullDat <- simData(glycobrom$fev1, glycobrom$sdev, glycobrom$n,
                  glycobrom$dose)
```

---

 guesst

*Calculate guesstimates based on prior knowledge*


---

### Description

Calculates guesstimates for standardized model parameter(s) using the general approach described in Pinheiro et al. (2006).

### Usage

```
guesst(d, p, model = c("emax", "exponential", "logistic", "quadratic",
  "betaMod", "sigEmax"), less = TRUE, local = FALSE,
  dMax, Maxd, scal)
```

### Arguments

d	Vector containing dose value(s).
p	Vector of expected percentages of the maximum effect achieved at d.
model	Character string. Should be one of "emax", "exponential", "quadratic", "betaMod", "sigEmax", "logistic".
less	Logical, only needed in case of quadratic model. Determines if d is smaller ('less=TRUE') or larger ('less=FALSE') than dopt (see Pinheiro et al. (2006) for details).
local	Logical indicating whether local or asymptotic version of guesstimate should be derived (defaults to 'FALSE'). Only needed for emax, logistic and sigEmax model. When 'local=TRUE' the maximum dose must be provided via 'Maxd'.
dMax	Dose at which maximum effect occurs, only needed for the beta model
Maxd	Maximum dose to be administered in the trial
scal	Scale parameter, only needed for the beta model

### Details

Calculates guesstimates for the parameters  $\theta_2$  of the standardized model function based on the prior expected percentage of the maximum effect at certain dose levels. Note that this function should be used together with the [plot.Mods](#) function to ensure that the guesstimates are reflecting the prior beliefs.

For the logistic and sigmoid emax models at least two pairs (d,p) need to be specified.

For the beta model the dose at which the maximum effect occurs (dMax) has to be specified in addition to the (d,p) pair.

For the exponential model the maximum dose administered (Maxd) needs to be specified in addition to the (d,p) pair.

For the quadratic model one (d,p) pair is needed. It is advisable to specify the location of the maximum within the dose range with this pair.

For the emax, sigmoid Emax and logistic model one can choose between a local and an asymptotic version. In the local version one explicitly forces the standardized model function to pass through the specified points (d,p). For the asymptotic version it assumed that the standardized model function is equal to 1 at the largest dose (this is the approach described in Pinheiro et al. (2006)). If the local version is used, convergence problems with the underlying nonlinear optimization can occur.

### Value

Returns a numeric vector containing the guesstimates.

### References

Bornkamp B., Pinheiro J. C., and Bretz, F. (2009). MCPMod: An R Package for the Design and Analysis of Dose-Finding Studies, *Journal of Statistical Software*, **29**(7), 1–23

Pinheiro, J. C., Bretz, F., and Branson, M. (2006). Analysis of dose-response studies - modeling approaches, in N. Ting (ed.), *Dose Finding in Drug Development*, Springer, New York, pp. 146–171

### See Also

[emax](#), [logistic](#), [betaMod](#), [sigEmax](#), [quadratic](#), [exponential](#), [plot.Mods](#)

### Examples

```
## Emax model
## Expected percentage of maximum effect: 0.8 is associated with
## dose 0.3 (d,p)=(0.3, 0.8), dose range [0,1]
emx1 <- guesst(d=0.3, p=0.8, model="emax")
emax(0.3,0,1,emx1)
## local approach
emx2 <- guesst(d=0.3, p=0.8, model="emax", local = TRUE, Maxd = 1)
emax(0.3,0,1,emx2)/emax(1,0,1,emx2)
## plot models
models <- Mods(emax=c(emx1, emx2), doses=c(0,1))
plot(models)

## Logistic model
## Select two (d,p) pairs (0.2, 0.6) and (0.2, 0.95)
lgc1 <- guesst(d = c(0.2, 0.6), p = c(0.2, 0.95), "logistic")
logistic(c(0.2,0.6), 0, 1, lgc1[1], lgc1[2])
## local approach
lgc2 <- guesst(d = c(0.2, 0.6), p = c(0.2, 0.95), "logistic",
              local = TRUE, Maxd = 1)
r0 <- logistic(0, 0, 1, lgc2[1], lgc2[2])
r1 <- logistic(1, 0, 1, lgc2[1], lgc2[2])
(logistic(c(0.2,0.6), 0, 1, lgc2[1], lgc2[2])-r0)/(r1-r0)
## plot models
models <- Mods(logistic = rbind(lgc1, lgc2), doses=c(0,1))
plot(models)

## Beta Model
## Select one pair (d,p): (0.4,0.8)
```

```

## dose, where maximum occurs: 0.8
bta <- guesst(d=0.4, p=0.8, model="betaMod", dMax=0.8, scal=1.2, Maxd=1)
## plot
models <- Mods(betaMod = bta, doses=c(0,1), addArgs = list(scal = 1.2))
plot(models)

## Sigmoid Emax model
## Select two (d,p) pairs (0.2, 0.6) and (0.2, 0.95)
sgE1 <- guesst(d = c(0.2, 0.6), p = c(0.2, 0.95), "sigEmax")
sigEmax(c(0.2,0.6), 0, 1, sgE1[1], sgE1[2])
## local approach
sgE2 <- guesst(d = c(0.2, 0.6), p = c(0.2, 0.95), "sigEmax",
              local = TRUE, Maxd = 1)
sigEmax(c(0.2,0.6), 0, 1, sgE2[1], sgE2[2])/sigEmax(1, 0, 1, sgE2[1], sgE2[2])
models <- Mods(sigEmax = rbind(sgE1, sgE2), doses=c(0,1))
plot(models)

## Quadratic model
## For the quadratic model it is assumed that the maximum effect occurs at
## dose 0.7
quad <- guesst(d = 0.7, p = 1, "quadratic")
models <- Mods(quadratic = quad, doses=c(0,1))
plot(models)

## exponential model
## (d,p) = (0.8,0.5)
expo <- guesst(d = 0.8, p = 0.5, "exponential", Maxd=1)
models <- Mods(exponential = expo, doses=c(0,1))
plot(models)

```

---

IBScovars

*Irritable Bowel Syndrome Dose Response data with covariates*


---

## Description

A subset of the data used by (Biesheuvel and Hothorn, 2002). The data are part of a dose ranging trial on a compound for the treatment of the irritable bowel syndrome with four active treatment arms, corresponding to doses 1,2,3,4 and placebo. Note that the original dose levels have been blinded in this data set for confidentiality. The primary endpoint was a baseline adjusted abdominal pain score with larger values corresponding to a better treatment effect. In total 369 patients completed the study, with nearly balanced allocation across the doses.

## Usage

```
data(IBScovars)
```

## Format

A data frame with 369 observations on the following 2 variables.

gender a factor specifying the gender  
 dose a numeric vector  
 resp a numeric vector

### Source

Biesheuvel, E. and Hothorn, L. A. (2002). Many-to-one comparisons in stratified designs, *Biometrical Journal*, **44**, 101–116

---

MCPMod

---

*MCPMod - Multiple Comparisons and Modeling*


---

### Description

Tests for a dose-response effect using a model-based multiple contrast test (see [MCTtest](#)), selects one (or several) model(s) from the significant shapes, fits them using [fitMod](#). For details on the method see Bretz et al. (2005).

### Usage

```
MCPMod(dose, resp, data, models, S = NULL, type = c("normal", "general"),
  addCovars = ~1, placAdj = FALSE, selModel = c("AIC", "maxT", "aveAIC"),
  alpha = 0.025, df = NULL, critV = NULL, doseType = c("TD", "ED"),
  Delta, p, pVal = TRUE, alternative = c("one.sided", "two.sided"),
  na.action = na.fail, mvtcontrol = mvtnorm.control(),
  bnds, control = NULL)

## S3 method for class 'MCPMod'
predict(object,
  predType = c("full-model", "ls-means", "effect-curve"),
  newdata = NULL, doseSeq = NULL, se.fit = FALSE, ...)

## S3 method for class 'MCPMod'
plot(x, CI = FALSE, level = 0.95,
  plotData = c("means", "meansCI", "raw", "none"),
  plotGrid = TRUE, colMn = 1, colFit = 1, ...)
```

### Arguments

dose, resp	Either vectors of equal length specifying dose and response values, or names of variables in the data frame specified in 'data'.
data	Data frame containing the variables referenced in dose and resp if 'data' is not specified it is assumed that 'dose' and 'resp' are variables referenced from data (and no vectors)

models	An object of class <code>"Mods"</code> , see <a href="#">Mods</a> for details
S	The covariance matrix of <code>'resp'</code> when <code>'type = "general"</code> , see <a href="#">Description</a> .
type	Determines whether inference is based on an ANCOVA model under a homoscedastic normality assumption (when <code>'type = "normal"</code> ), or estimates at the doses and their covariance matrix and degrees of freedom are specified directly in <code>'resp'</code> , <code>'S'</code> and <code>'df'</code> . See also <a href="#">fitMod</a> and <a href="#">Pinheiro et al. (2014)</a> .
addCovars	Formula specifying additive linear covariates (for <code>'type = "normal"</code> )
placAdj	Logical, if true, it is assumed that placebo-adjusted estimates are specified in <code>'resp'</code> (only possible for <code>'type = "general"</code> ).
selModel	Optional character vector specifying the model selection criterion for dose estimation. Possible values are <ul style="list-style-type: none"> <li>• AIC: Selects model with smallest AIC (this is the default)</li> <li>• maxT: Selects the model corresponding to the largest t-statistic.</li> <li>• aveAIC: Uses a weighted average of the models corresponding to the significant contrasts. The model weights are chosen by the formula: <math>w_i = \exp(-0.5AIC_i) / \sum_i(\exp(-0.5AIC_i))</math> See <a href="#">Buckland et al. (1997)</a> for details.</li> </ul> For <code>'type = "general"</code> the "gAIC" is used.
alpha	Significance level for the multiple contrast test
df	Specify the degrees of freedom to use in case <code>'type = "general"</code> , for the call to <a href="#">MCTtest</a> and <a href="#">fitMod</a> . Infinite degrees of ( <code>'df=Inf'</code> ) correspond to the multivariate normal distribution. For <code>'type = "normal"</code> the degrees of freedom deduced from the AN(C)OVA fit are used and this argument is ignored.
critV	Supply a pre-calculated critical value. If this argument is NULL, no critical value will be calculated and the test decision is based on the p-values. If <code>'critV = TRUE'</code> the critical value will be calculated.
doseType, Delta, p	<code>'doseType'</code> determines the dose to estimate, ED or TD (see also <a href="#">Mods</a> ), and <code>'Delta'</code> and <code>'p'</code> need to be specified depending on whether TD or ED is to be estimated. See <a href="#">TD</a> and <a href="#">ED</a> for details.
pVal	Logical determining, whether p-values should be calculated.
alternative	Character determining the alternative for the multiple contrast trend test.
na.action	A function which indicates what should happen when the data contain NAs.
mvtcontrol	A list specifying additional control parameters for the <code>'qmvt'</code> and <code>'pmvt'</code> calls in the code, see also <a href="#">mvtnorm.control</a> for details.
bnds	Bounds for non-linear parameters. This needs to be a list with list entries corresponding to the selected bounds. The names of the list entries need to correspond to the model names. The <a href="#">defBnds</a> function provides the default selection.
control	Control list for the optimization. A list with entries: <code>"nlminbcontrol"</code> , <code>"optimizetol"</code> and <code>"gridSize"</code> . The entry <code>nlminbcontrol</code> needs to be a list and is passed directly to <code>control</code> argument in the <code>nlminb</code> function, that is used internally for models with 2 nonlinear parameters (e.g. sigmoid Emax or beta model).



The entry `optimizetol` is passed directly to the `tol` argument of the `optimize` function, which is used for models with 1 nonlinear parameters (e.g. Emax or exponential model).

The entry `gridSize` needs to be a list with entries `dim1` and `dim2` giving the size of the grid for the gridsearch in 1d or 2d models.

`object, x` MCPMod object  
`predType, newdata, doseSeq, se.fit, ...`  
`predType` determines whether predictions are returned for the full model (including potential covariates), the ls-means (SAS type) or the effect curve (difference to placebo).  
`newdata` gives the covariates to use in producing the predictions (for `'predType = "full-model"'`), if missing the covariates used for fitting are used.  
`doseSeq` dose-sequence on where to produce predictions (for `'predType = "effect-curve"'` and `'predType = "ls-means"'`). If missing the doses used for fitting are used.  
`se.fit`: logical determining, whether the standard error should be calculated.  
`...`: Additional arguments, for `plot.MCPMod` these are passed to `plot.DRMod`.  
`CI, level, plotData, plotGrid, colMn, colFit`  
Arguments for plot method: `'CI'` determines whether confidence intervals should be plotted. `'level'` determines the level of the confidence intervals. `'plotData'` determines how the data are plotted: Either as means or as means with CI, raw data or none. In case of `'type = "normal"'` and covariates the ls-means are displayed, when `'type = "general"'` the option "raw" is not available. `'colMn'` and `'colFit'` determine the colors of fitted model and the raw means.

## Value

An object of class `'MCPMod'`, which contains the fitted `'MCTtest'` object as well as the `'DRMod'` objects and additional information (model selection criteria, dose estimates, selected models).

## Author(s)

Bjoern Bornkamp

## References

- Bretz, F., Pinheiro, J. C., and Branson, M. (2005), Combining multiple comparisons and modeling techniques in dose-response studies, *Biometrics*, **61**, 738–748
- Pinheiro, J. C., Bornkamp, B., and Bretz, F. (2006). Design and analysis of dose finding studies combining multiple comparisons and modeling procedures, *Journal of Biopharmaceutical Statistics*, **16**, 639–656
- Pinheiro, J. C., Bretz, F., and Branson, M. (2006). Analysis of dose-response studies - modeling approaches, in N. Ting (ed.). *Dose Finding in Drug Development*, Springer, New York, pp. 146–171
- Pinheiro, J. C., Bornkamp, B., Glimm, E. and Bretz, F. (2014) Model-based dose finding under model uncertainty using general parametric models, *Statistics in Medicine*, **33**, 1646–1661
- Schorning, K., Bornkamp, B., Bretz, F., & Dette, H. (2016). Model selection versus model averaging in dose finding studies. *Statistics in Medicine*, **35**, 4021–4040

Xun, X. and Bretz, F. (2017) The MCP-Mod methodology: Practical Considerations and The DoseFinding R package, in O'Quigley, J., Iasonos, A. and Bornkamp, B. (eds) Handbook of methods for designing, monitoring, and analyzing dose-finding trials, CRC press

Buckland, S. T., Burnham, K. P. and Augustin, N. H. (1997). Model selection an integral part of inference, *Biometrics*, **53**, 603–618

Seber, G.A.F. and Wild, C.J. (2003). Nonlinear Regression, Wiley.

## See Also

[MCTtest](#), [fitMod](#), [drmodels](#)

## Examples

```
data(biom)
## first define candidate model set (only need "standardized" models)
models <- Mods(linear = NULL, emax=c(0.05,0.2), linInt=c(1, 1, 1, 1),
              doses=c(0,0.05,0.2,0.6,1))

plot(models)
## perform MCPMod procedure
MM <- MCPMod(dose, resp, biom, models, Delta=0.5)
## a number of things can be done with an MCPMod object
MM # print method provides basic information
summary(MM) # more information
## predict all significant dose-response models
predict(MM, se.fit=TRUE, doseSeq=c(0,0.2,0.4, 0.9, 1),
        predType="ls-means")
## display all model functions
plot(MM, plotData="meansCI", CI=TRUE)

## now perform model-averaging
MM2 <- MCPMod(dose, resp, biom, models, Delta=0.5, selModel = "aveAIC")
sq <- seq(0,1,length=11)
pred <- predict(MM, doseSeq=sq, predType="ls-means")
modWeights <- MM2$selMod
## model averaged predictions
pred <- do.call("cbind", pred)%*%modWeights
## model averaged dose-estimate
TDEst <- MM2$doseEst%*%modWeights

## now an example using a general fit and fitting based on placebo
## adjusted first-stage estimates
data(IBScovars)
## ANCOVA fit model including covariates
anovaMod <- lm(resp~factor(dose)+gender, data=IBScovars)
drFit <- coef(anovaMod)[2:5] # placebo adjusted estimates at doses
vCov <- vcov(anovaMod)[2:5,2:5]
dose <- sort(unique(IBScovars$dose))[-1] # no estimate for placebo
## candidate models
models <- Mods(emax = c(0.5, 1), betaMod=c(1,1), doses=c(0,4))
plot(models)
## hand over placebo-adjusted estimates drFit to MCPMod
MM3 <- MCPMod(dose, drFit, S=vCov, models = models, type = "general",
```

```

        placAdj = TRUE, Delta=0.2)
plot(MM3, plotData="meansCI")

## The first example, but with critical value handed over
## this is useful, e.g. in simulation studies
MM4 <- MCPMod(dose, resp, biom, models, Delta=0.5, critV = 2.31)

```

---

MCTpval

---

*Calculate multiplicity adjusted p-values for multiple contrast test*


---

## Description

Calculate multiplicity adjusted p-values for a maximum contrast test corresponding to a set of contrasts and given a set of observed test statistics. This function is exported as it may be a useful building block and used in more complex testing situations that are not covered by [MCTtest](#). Most users probably don't need to use this function.

## Usage

```

MCTpval(contMat, corMat, df, tStat,
        alternative = c("one.sided", "two.sided"),
        control = mvtnorm.control())

```

## Arguments

contMat	Contrast matrix to use. The individual contrasts should be saved in the columns of the matrix
corMat	correlation matrix of the contrasts
df	Degrees of freedom to assume in case 'S' (a general covariance matrix) is specified. When 'n' and 'sigma' are specified the ones from the corresponding ANOVA model are calculated.
tStat	Vector of contrast test statistics
alternative	Character determining the alternative for the multiple contrast trend test.
control	A list specifying additional control parameters for the 'qmvtnorm' and 'pmvtnorm' calls in the code, see also 'mvtnorm.control' for details.

## Value

Numeric containing the calculated p-values.

## Author(s)

Bjoern Bornkamp

## References

Pinheiro, J. C., Bornkamp, B., and Bretz, F. (2006). Design and analysis of dose finding studies combining multiple comparisons and modeling procedures, *Journal of Biopharmaceutical Statistics*, **16**, 639–656

## See Also

[MCTtest](#), [optContr](#)

## Examples

```
## need to add example
```

---

MCTtest	<i>Performs multiple contrast test</i>
---------	--

---

## Description

This function performs a multiple contrast test. The contrasts are either directly specified in ‘contMat’ or optimal contrasts derived from the ‘models’ argument. The directionality of the data (i.e. whether an increase or decrease in the response variable is beneficial is inferred from the ‘models’ object, see [Mods](#)).

For ‘type = "normal"’ an ANCOVA model based on a homoscedastic normality assumption (with additive covariates specified in ‘addCovars’) is fitted.

For ‘type = "general"’ it is assumed multivariate normally distributed estimates are specified in ‘resp’ with covariance given by ‘S’, and the contrast test statistic is calculated based on this assumption. Degrees of freedom specified in ‘df’.

## Usage

```
MCTtest(dose, resp, data = NULL, models, S = NULL, type = c("normal", "general"),
        addCovars = ~1, placAdj = FALSE, alpha = 0.025, df = NULL,
        critV = NULL, pVal = TRUE,
        alternative = c("one.sided", "two.sided"), na.action = na.fail,
        mvtcontrol = mvtnorm.control(), contMat = NULL)
```

## Arguments

dose, resp	Either vectors of equal length specifying dose and response values, or names of variables in the data frame specified in ‘data’.
data	Data frame containing the variables referenced in dose and resp if ‘data’ is not specified it is assumed that ‘dose’ and ‘resp’ are variables referenced from data (and no vectors)
models	An object of class ‘Mods’, see <a href="#">Mods</a> for details
S	The covariance matrix of ‘resp’ when ‘type = "general"’, see Description.

type	Determines whether inference is based on an ANCOVA model under a homoscedastic normality assumption (when ‘type = "normal"’), or estimates at the doses and their covariance matrix and degrees of freedom are specified directly in ‘resp’, ‘S’ and ‘df’. See also <a href="#">fitMod</a> and Pinheiro et al. (2014).
addCovars	Formula specifying additive linear covariates (for ‘type = "normal"’)
placAdj	Logical, if true, it is assumed that placebo-adjusted estimates are specified in ‘resp’ (only possible for ‘type = "general"’).
alpha	Significance level for the multiple contrast test
df	Specify the degrees of freedom to use in case ‘type = "general"’. If this argument is missing ‘df = Inf’ is used (which corresponds to the multivariate normal distribution). For type = "normal" the degrees of freedom deduced from the AN(C)OVA fit are used and this argument is ignored.
critV	Supply a pre-calculated critical value. If this argument is NULL, no critical value will be calculated and the test decision is based on the p-values. If ‘critV = TRUE’ the critical value will be calculated.
pVal	Logical determining, whether p-values should be calculated.
alternative	Character determining the alternative for the multiple contrast trend test.
na.action	A function which indicates what should happen when the data contain NAs.
mvtcontrol	A list specifying additional control parameters for the ‘qmvt’ and ‘pmvt’ calls in the code, see also <a href="#">mvtnorm.control</a> for details.
contMat	Contrast matrix to apply to the ANCOVA dose-response estimates. The contrasts need to be in the columns of the matrix (i.e. the column sums need to be 0).

### Details

Integrals over the multivariate t and multivariate normal distribution are calculated using the ‘mvtnorm’ package.

### Value

An object of class MCTtest, a list containing the output.

### Author(s)

Bjoern Bornkamp

### References

- Hothorn, T., Bretz, F., and Westfall, P. (2008). Simultaneous Inference in General Parametric Models, *Biometrical Journal*, **50**, 346–363
- Pinheiro, J. C., Bornkamp, B., Glimm, E. and Bretz, F. (2014) Model-based dose finding under model uncertainty using general parametric models, *Statistics in Medicine*, **33**, 1646–1661

### See Also

[powMCT](#), [optContr](#)

## Examples

```

## example without covariates
data(biom)
## define shapes for which to calculate optimal contrasts
modlist <- Mods(emax = 0.05, linear = NULL, logistic = c(0.5, 0.1),
               linInt = c(0, 1, 1, 1), doses = c(0, 0.05, 0.2, 0.6, 1))
m1 <- MCTtest(dose, resp, biom, models=modlist)
## now calculate critical value (but not p-values)
m2 <- MCTtest(dose, resp, biom, models=modlist, critV = TRUE, pVal = FALSE)
## now hand over critical value
m3 <- MCTtest(dose, resp, biom, models=modlist, critV = 2.24)

## example with covariates
data(IBScovars)
modlist <- Mods(emax = 0.05, linear = NULL, logistic = c(0.5, 0.1),
               linInt = c(0, 1, 1, 1), doses = c(0, 1, 2, 3, 4))
MCTtest(dose, resp, IBScovars, models = modlist, addCovars = ~gender)

## example using general approach (fitted on placebo-adjusted scale)
ancMod <- lm(resp~factor(dose)+gender, data=IBScovars)
## extract estimates and information to feed into MCTtest
drEst <- coef(ancMod)[2:5]
vc <- vcov(ancMod)[2:5, 2:5]
doses <- 1:4
MCTtest(doses, drEst, S = vc, models = modlist, placAdj = TRUE,
        type = "general", df = Inf)

## example with general alternatives handed over
data(biom)
## calculate contrast matrix for the step-contrasts
## represent them as linInt models
models <- Mods(linInt=rbind(c(1,1,1,1),
                           c(0,1,1,1),
                           c(0,0,1,1),
                           c(0,0,0,1)),
              doses=c(0,0.05,0.2,0.6,1))
plot(models)
## now calculate optimal contrasts for these means
## use weights from actual sample sizes
weights <- as.numeric(table(biom$dose))
contMat <- optContr(models, w = weights)
## plot contrasts
plot(contMat)
## perform multiple contrast test
MCTtest(dose, resp, data=biom, contMat = contMat)

## example for using the Dunnett contrasts
## Dunnett contrasts
doses <- sort(unique(biom$dose))
contMat <- rbind(-1, diag(4))
rownames(contMat) <- doses
colnames(contMat) <- paste("D", doses[-1], sep="")

```

```
MCTtest(dose, resp, data=biom, contMat = contMat)
```

---

migraine	<i>Migraine Dose Response data</i>
----------	------------------------------------

---

### Description

Data set obtained from clinicaltrials.gov (NCT00712725). This was randomized placebo controlled dose-response trial for treatment of acute migraine. The primary endpoint was "pain freedom at 2 hours postdose" (a binary measurement).

### Usage

```
data(migraine)
```

### Format

A data frame with 517 columns corresponding to the patients that completed the trial

dose a numeric vector containing the dose values

painfree number of treatment responders

ntrt number of subject per treatment group

### Source

<http://clinicaltrials.gov/ct2/show/results/NCT00712725>

---

Mods	<i>Define dose-response models</i>
------	------------------------------------

---

### Description

The Mods functions allows to define a set of dose-response models. The function is used as input object for a number of other different functions.

The dose-response models used in this package (see [drmodels](#) for details) are of form

$$f(d) = \theta_0 + \theta_1 f^0(d, \theta_2)$$

where the parameter  $\theta_2$  is the only non-linear parameter and can be one- or two-dimensional, depending on the used model.

One needs to hand over the effect at placebo and the maximum effect in the dose range, from which  $\theta_0, \theta_1$  are then back-calculated, the output object is of class "Mods". This object can form the input for other functions to extract the mean response ('getResp') or target doses (TD and ED) corresponding to the models. It is also needed as input to the functions [powMCT](#), [optDesign](#)

Some models, for example the beta model ('scal') and the linlog model ('off') have parameters that are not estimated from the data, they need to be specified via the 'addArgs' argument.

The default plot method for 'Mods' objects is based on a plot using the 'lattice' package for backward compatibility. The function 'plotMods' function implements a plot using the 'ggplot2' package.

NOTE: If a decreasing effect is beneficial for the considered response variable it needs to be specified here, either by using 'direction = "decreasing"' or by specifying a negative "maxEff" argument.

### Usage

```
Mods(..., doses, placEff = 0, maxEff,
      direction = c("increasing", "decreasing"), addArgs=NULL,
      fullMod = FALSE)
```

```
getResp(fmodels, doses)
```

```
## S3 method for class 'Mods'
plot(x, nPoints = 200, superpose = FALSE,
      xlab = "Dose", ylab = "Model means", modNams = NULL,
      plotTD = FALSE, Delta, ...)
```

```
plotMods(ModsObj, nPoints = 200, superpose = FALSE,
          xlab = "Dose", ylab = "Model means",
          modNams = NULL, trafo = function(x) x)
```

### Arguments

...	In function Mods: Dose-response model names with parameter values specifying the guesstimates for the $\theta_2$ parameters. See <a href="#">drmodels</a> for a complete list of dose-response models implemented. See below for an example specification.
	In function plot.Mods: Additional arguments to the 'xyplot' call.
doses	Dose levels to be used, this needs to include placebo.
addArgs	List containing two entries named "scal" and "off" for the "betaMod" and "linlog". When addArgs is NULL the following defaults are used 'list(scal = 1.2*max(doses), off = 0.01*max(doses), nodes = doses)'. 
fullMod	Logical determining, whether the model parameters specified in the Mods function (via the ... argument) should be interpreted as standardized or the full model parameters.
placEff, maxEff	Specify used placebo effect and the maximum effect over placebo. Either a numeric vector of the same size as the number of candidate models or of length one. When these parameters are not specified 'placEff = 0' is assumed, for 'maxEff



	= 1' is assumed, if 'direction = "increasing"' and 'maxEff = -1' is assumed, for 'direction = "decreasing"'.
direction	Character determining whether the beneficial direction is 'increasing' or 'decreasing' with increasing dose levels. This argument is ignored if 'maxEff' is specified.
fmodels	An object of class Mods
Delta	Delta: The target effect size use for the target dose (TD) (Delta should be > 0).
x	Object of class Mods with type Mods
nPoints	Number of points for plotting
superpose	Logical determining, whether model plots should be superposed
xlab, ylab	Label for y-axis and x-axis.
modNams	When 'modNams == NULL', the names for the panels are determined by the underlying model functions, otherwise the contents of 'modNams' are used.
plotTD	'plotTD' is a logical determining, whether the TD should be plotted. 'Delta' is the target effect to estimate for the TD.
ModsObj	For function 'plotMods' the 'ModsObj' should contain an object of class 'Mods'.
trafo	For function 'plotMods' there is the option to plot the candidate model set on a transformed scale (e.g. probability scale if the candidate models are formulated on log-odds scale). The default for 'trafo' is the identity function.

**Value**

Returns an object of class "Mods". The object contains the specified model parameter values and the derived linear parameters (based on "placEff" and "maxEff") in a list.

**Author(s)**

Bjoern Bornkamp

**References**

Pinheiro, J. C., Bornkamp, B., and Bretz, F. (2006). Design and analysis of dose finding studies combining multiple comparisons and modeling procedures, *Journal of Biopharmaceutical Statistics*, **16**, 639–656

**See Also**

[Mods](#), [drmodels](#), [optDesign](#), [powMCT](#)

**Examples**

```
## Example on how to specify candidate models

## Suppose one would like to use the following models with the specified
## guesstimates for theta2, in a situation where the doses to be used are
## 0, 0.05, 0.2, 0.6, 1

## Model          guesstimate(s) for theta2 parameter(s) (name)
```

```

## linear          -
## linear in log   -
## Emax            0.05 (ED50)
## Emax            0.3 (ED50)
## exponential     0.7 (delta)
## quadratic       -0.85 (delta)
## logistic        0.4 0.09 (ED50, delta)
## logistic        0.3 0.1 (ED50, delta)
## betaMod         0.3 1.3 (delta1, delta2)
## sigmoid Emax    0.5 2 (ED50, h)
## linInt          0.5 0.75 1 1 (perc of max-effect at doses)
## linInt          0.5 1 0.7 0.5 (perc of max-effect at doses)

## for the linInt model one specifies the effect over placebo for
## each active dose.
## The fixed "scal" parameter of the betaMod is set to 1.2
## The fixed "off" parameter of the linlog is set to 0.1
## These (standardized) candidate models can be specified as follows

models <- Mods(linear = NULL, linlog = NULL, emax = c(0.05, 0.3),
               exponential = 0.7, quadratic = -0.85,
               logistic = rbind(c(0.4, 0.09), c(0.3, 0.1)),
               betaMod = c(0.3, 1.3), sigEmax = c(0.5, 2),
               linInt = rbind(c(0.5, 0.75, 1, 1), c(0.5, 1, 0.7, 0.5)),
               doses = c(0, 0.05, 0.2, 0.6, 1),
               addArgs = list(scal=1.2, off=0.1))

## "models" now contains the candidate model set, as placEff, maxEff and
## direction were not specified a placebo effect of 0 and an effect of 1
## is assumed

## display of specified candidate set using default plot (based on lattice)
plot(models)
## display using ggplot2
plotMods(models)

## example for creating a candidate set with decreasing response
doses <- c(0, 10, 25, 50, 100, 150)
fmodels <- Mods(linear = NULL, emax = 25,
               logistic = c(50, 10.88111), exponential = 85,
               betaMod = rbind(c(0.33, 2.31), c(1.39, 1.39)),
               linInt = rbind(c(0, 1, 1, 1, 1),
                              c(0, 0, 1, 1, 0.8)),
               doses=doses, placEff = 0.5, maxEff = -0.4,
               addArgs=list(scal=200))

plot(fmodels)
plotMods(fmodels)
## some customizations (different model names, symbols, line-width)
plot(fmodels, lwd = 3, pch = 3, cex=1.2, col="red",
     modNams = paste("mod", 1:8, sep="-"))

## for a full-model object one can calculate the responses
## in a matrix
getResp(fmodels, doses=c(0, 20, 100, 150))

```

```

## calculate doses giving an improvement of 0.3 over placebo
TD(fmodels, Delta=0.3, direction = "decreasing")
## discrete version
TD(fmodels, Delta=0.3, TDtype = "discrete", doses=doses, direction = "decreasing")
## doses giving 50% of the maximum effect
ED(fmodels, p=0.5)
ED(fmodels, p=0.5, EDtype = "discrete", doses=doses)

plot(fmodels, plotTD = TRUE, Delta = 0.3)

## example for specifying all model parameters (fullMod=TRUE)
fmods <- Mods(emax = c(0, 1, 0.1), linear = cbind(c(-0.4,0), c(0.2,0.1)),
             sigEmax = c(0, 1.1, 0.5, 3),
             doses = 0:4, fullMod = TRUE)
getResp(fmods, doses=seq(0,4,length=11))
## calculate doses giving an improvement of 0.3 over placebo
TD(fmods, Delta=0.3)
## discrete version
TD(fmods, Delta=0.3, TDtype = "discrete", doses=0:4)
## doses giving 50% of the maximum effect
ED(fmods, p=0.5)
ED(fmods, p=0.5, EDtype = "discrete", doses=0:4)
plot(fmods)

```

---

mvtnorm.control

*Control options for pmvt and qmvt functions*


---

## Description

Returns a list (an object of class "GenzBretz") with control parameters for the 'pmvt' and 'qmvt' functions from the 'mvtnorm' package. Note that the DoseFinding package always uses "GenzBretz" algorithm. See the mvtnorm documentation for more information.

## Usage

```

mvtnorm.control(maxpts = 30000, abseps = 0.001, releps = 0,
               interval = NULL)

```

## Arguments

maxpts	Maximum number of function values as integer.
abseps	Absolute error tolerance as double.
releps	Relative error tolerance as double.
interval	Interval to be searched, when the quantile is calculated.

---

neurodeg	<i>Neurodegenerative disease simulated longitudinal dose-finding data set</i>
----------	---

---

## Description

This simulated data set is motivated by a real Phase 2 clinical study of a new drug for a neurodegenerative disease. The state of the disease is measured through a functional scale, with smaller values corresponding to more severe neurodeterioration. The goal of the drug is to reduce the rate of disease progression, which is measured by the linear slope of the functional scale over time.

The trial design includes placebo and four doses: 1, 3, 10, and 30 mg, with balanced allocation of 50 patients per arm. Patients are followed up for one year, with measurements of the functional scale being taken at baseline and then every three months.

The functional scale response is assumed to be normally distributed and, based on historical data, it is believed that the longitudinal progression of the functional scale over the one year of follow up can be modeled a simple linear trend. See the example below on how to analyse this type of data.

This data set was used in Pinheiro et al. (2014) to illustrate the generalized MCPMod methodology.

## Usage

```
data(neurodeg)
```

## Format

A data frame with 100 observations on the following 2 variables.

resp a numeric vector containing the response values

dose a numeric vector containing the dose values

id Patient ID

time time of measurement

## Source

Pinheiro, J. C., Bornkamp, B., Glimm, E. and Bretz, F. (2014) Model-based dose finding under model uncertainty using general parametric models, *Statistics in Medicine*, **33**, 1646–1661

## Examples

```
## Not run:
## reproduce analysis from Pinheiro et al. (2014)
data(neurodeg)
## first fit the linear mixed effect model
library(nlme)
fm <- lme(resp ~ as.factor(dose):time, neurodeg, ~time|id, method = "ML")
muH <- fixef(fm)[-1] # extract estimates
covH <- vcov(fm)[-1,-1]
```

```

## derive optimal contrasts for candidate shapes
doses <- c(0, 1, 3, 10, 30)
mod <- Mods(emax = 1.11, quadratic= -0.022, exponential = 8.867,
           linear = NULL, doses = doses) #
contMat <- optContr(mod, S=covH) # calculate optimal contrasts
## multiple contrast test
MCTtest(doses, muH, S=covH, type = "general", critV = TRUE,
        contMat=contMat)
## fit the emax model
fitMod(doses, muH, S=covH, model="emax", type = "general",
       bnds=c(0.1, 10))

## alternatively one can also fit the model using nlme
nlme(resp ~ b0 + (e0 + eM * dose/(ed50 + dose))*time, neurodeg,
     fixed = b0 + e0 + eM + ed50 ~ 1, random = b0 + e0 ~ 1 | id,
     start = c(200, -4.6, 1.6, 3.2))
## both approaches lead to rather similar results

## End(Not run)

```

---

optContr

*Calculate optimal contrasts*


---

## Description

This function calculates a contrast vectors that are optimal for detecting certain alternatives. The contrast is optimal in the sense of maximizing the non-centrality parameter of the underlying contrast test statistic:

$$\frac{c' \mu}{\sqrt{c' S c}}$$

Here  $\mu$  is the mean vector under the alternative and  $S$  the covariance matrix associated with the estimate of  $\mu$ . The optimal contrast is given by

$$c^{opt} \propto S^{-1} \left( \mu - \frac{\mu' S^{-1} \mathbf{1}}{\mathbf{1}' S^{-1} \mathbf{1}} \mathbf{1} \right),$$

see Pinheiro et al. (2014).

Note that the directionality (i.e. whether in "increase" in the response variable is beneficial or a "decrease", is inferred from the specified 'models' object, see [Mods](#) for details).

Constrained contrasts (type = "constrained") add the additional constraint in the optimization that the sign of the contrast coefficient for control and active treatments need to be different. The quadratic programming algorithm from the quadprog package is used to calculate the contrasts.

**Usage**

```
optContr(models, doses, w, S, placAdj = FALSE,
         type = c("unconstrained", "constrained"))

## S3 method for class 'optContr'
plot(x, superpose = TRUE, xlab = "Dose",
     ylab = NULL, plotType = c("contrasts", "means"), ...)

plotContr(optContrObj, xlab = "Dose",
          ylab = "Contrast coefficients")
```

**Arguments**

models	An object of class 'Mods' defining the dose-response shapes for which to calculate optimal contrasts.
doses	Optional argument. If this argument is missing the doses attribute in the 'Mods' object specified in 'models' is used.
w, S	Arguments determining the matrix S used in the formula for the optimal contrasts. Exactly one of 'w' and 'S' has to be specified. Note that 'w' and 'S' only have to be specified up to proportionality <ul style="list-style-type: none"> <li>• w Vector specifying weights for the different doses, in the formula for calculation of the optimal contrasts. Specifying a weights vector is equivalent to specifying <math>S = \text{diag}(1/w)</math> (e.g. in a homoscedastic case with unequal sample sizes, 'w' should be proportional to the group sample sizes).</li> <li>• S Directly specify a matrix proportional to the covariance matrix to use.</li> </ul>
placAdj	Logical determining, whether the contrasts should be applied to placebo-adjusted estimates. If yes the returned coefficients are no longer contrasts (i.e. do not sum to 0). However, the result of multiplying of this "contrast" matrix with the placebo adjusted estimates, will give the same results as multiplying the original contrast matrix to the unadjusted estimates.
type	For 'type = "constrained"' the contrast coefficients of the zero dose group are constrained to be different from the coefficients of the active treatment groups. So that a weighted sum of the active treatments is compared against the zero dose group. For an increasing trend the coefficient of the zero dose group is negative and all other coefficients have to be positive (for a decreasing trend the other way round).
x, superpose, xlab, ylab, plotType	Arguments for the plot method for optContr objects. plotType determines, whether the contrasts or the underlying (standardized) mean matrix should be plotted.
optContrObj	For function 'plotContr' the 'optContrObj' should contain an object of class 'optContr'.
...	Additional arguments for plot method

**Value**

Object of class 'optContr'. A list containing entries contMat and muMat (i.e. contrast, mean and correlation matrix).

**Author(s)**

Bjoern Bornkamp

**References**

Bretz, F., Pinheiro, J. C., and Branson, M. (2005), Combining multiple comparisons and modeling techniques in dose-response studies, *Biometrics*, **61**, 738–748

Pinheiro, J. C., Bornkamp, B., Glimm, E. and Bretz, F. (2014) Model-based dose finding under model uncertainty using general parametric models, *Statistics in Medicine*, **33**, 1646–1661

**See Also**

[MCTtest](#)

**Examples**

```
doses <- c(0,10,25,50,100,150)
models <- Mods(linear = NULL, emax = 25,
               logistic = c(50, 10.88111), exponential= 85,
               betaMod=rbind(c(0.33,2.31), c(1.39,1.39)),
               doses = doses, addArgs = list(scal = 200))
contMat <- optContr(models, w = rep(50,6))
plot(contMat)
plotContr(contMat) # display contrasts using ggplot2

## now we would like the "contrasts" for placebo adjusted estimates
dosPlac <- doses[-1]
## matrix proportional to cov-matrix of plac. adj. estimates for balanced data
S <- diag(5)+matrix(1, 5,5)
## note that we explicitly hand over the doses here
contMat0 <- optContr(models, doses=dosPlac, S = S, placAdj = TRUE)
## -> contMat0 is no longer a contrast matrix (columns do not sum to 0)
colSums(contMat0$contMat)
## calculate contrast matrix for unadjusted estimates from this matrix
## (should be same as above)
aux <- rbind(-colSums(contMat0$contMat), contMat0$contMat)
t(t(aux)/sqrt(colSums(aux^2))) ## compare to contMat$contMat

## now calculate constrained contrasts
optContr(models, w = rep(50,6), type = "constrained")
optContr(models, doses=dosPlac, S = S, placAdj = TRUE,
         type = "constrained")
```

optDesign

*Function to calculate optimal designs***Description**

Given a set of models (with full parameter values and model probabilities) the 'optDesign' function calculates the optimal design for estimating the dose-response model parameters (D-optimal) or the design for estimating the target dose (TD-optimal design) (see Dette, Bretz, Pepelyshev and Pinheiro (2008)), or a mixture of these two criteria. The design can be plotted (together with the candidate models) using 'plot.design'. 'calcCrit' calculates the design criterion for a discrete set of design(s). 'rndDesign' provides efficient rounding for the calculated continuous design to a finite sample size.

**Usage**

```
optDesign(models, probs, doses,
          designCrit = c("Dopt", "TD", "Dopt&TD", "userCrit"),
          Delta, standDopt = TRUE, weights,
          nold = rep(0, length(doses)), n,
          control=list(),
          optimizer = c("solnp", "Nelder-Mead", "nlminb", "exact"),
          lowbnd = rep(0, length(doses)), uppbnd = rep(1, length(doses)),
          userCrit, ...)

## S3 method for class 'DRdesign'
plot(x, models, lwdDes = 10, colDes = rgb(0,0,0,0.3), ...)

calcCrit(design, models, probs, doses,
         designCrit = c("Dopt", "TD", "Dopt&TD"),
         Delta, standDopt = TRUE, weights,
         nold = rep(0, length(doses)), n)

rndDesign(design, n, eps = 0.0001)
```

**Arguments**

models	An object of class 'c(Mods, fullMod)', see the <a href="#">Mods</a> function for details. When an TD optimal design should be calculated, the TD needs to exist for all models. If a D-optimal design should be calculated, you need at least as many doses as there are parameters in the specified models.
probs	Vector of model probabilities for the models specified in 'models', assumed in the same order as specified in models
doses	Optional argument. If this argument is missing the doses attribute in the 'c(Mods, fullMod)' object specified in 'models' is used.
designCrit	Determines which type of design to calculate. "TD&Dopt" uses both optimality criteria with equal weight.



Delta	Target effect needed for calculating "TD" and "TD&Dopt" type designs.
standDopt	Logical determining, whether the D-optimality criterion (specifically the log-determinant) should be standardized by the number of parameters in the model or not (only of interest if type = "Dopt" or type = "TD&Dopt"). This is of interest, when there is more than one model class in the candidate model set (traditionally standardization this is done in the optimal design literature).
weights	Vector of weights associated with the response at the doses. Needs to be of the same length as the 'doses'. This can be used to calculate designs for heteroscedastic or for generalized linear model situations.
nold, n	When calculating an optimal design at an interim analysis, 'nold' specifies the vector of sample sizes already allocated to the different doses, and 'n' gives sample size for the next cohort. For 'optimizer = "exact"' one always needs to specify the total sample size via 'n'.
control	List containing control parameters passed down to numerical optimization algorithms ( <code>optim</code> , <code>nlm</code> or <code>solnp</code> function).  For 'type = "exact"' this should be a list with possible entries 'maxvls1' and 'maxvls2', determining the maximum number of designs allowed for passing to the criterion function (default 'maxvls2=1e5') and for creating the initial unrestricted matrix of designs (default 'maxvls1=1e6'). In addition there can be an entry 'groupSize' in case the patients are allocated a minimum group size is required.
optimizer	Algorithm used for calculating the optimal design. Options "Nelder-Mead" and "nlminb" use the <code>optim</code> and <code>nlminb</code> function and use a trigonometric transformation to turn the constrained optimization problem into an unconstrained one (see Atkinson, Donev and Tobias, 2007, pages 130,131). Option "solnp" uses the <code>solnp</code> function from the <code>Rsolnp</code> package, which implements an optimizer for non-linear optimization under general constraints. Option "exact" tries all given combinations of 'n' patients to the given dose groups (subject to the bounds specified via 'lowbnd' and 'uppbnd') and reports the best design. When patients are only allowed to be allocated in groups of a certain 'groupSize', this can be adjusted via the control argument. 'n/groupSize' and 'length(doses)' should be rather small for this approach to be feasible. When the number of doses is small (<8) usually "Nelder-Mead" and "nlminb" are best suited ("nlminb" is usually a bit faster but less stable than "Nelder-Mead"). For a larger number of doses "solnp" is the most reliable option (but also slowest) ("Nelder-Mead" and "nlminb" often fail). When the sample size is small "exact" provides the optimal solution rather quickly.
lowbnd, uppbnd	Vectors of the same length as dose vector specifying upper and lower limits for the allocation weights. This option is only available when using the "solnp" and "exact" optimizers.
userCrit	User defined design criterion, should be a function that given a vector of allocation weights and the doses returns the criterion function. When specified 'models' does not need to be handed over.

The first argument of ‘userCrit’ should be the vector of design weights, while the second argument should be the ‘doses’ argument (see example below). Additional arguments to ‘userCrit’ can be passed via ...

... For function ‘optDesign’ these are additional arguments passed to ‘userCrit’.

For function ‘plot.design’ these are additional parameters passed to `plot.Mods`.

design	Argument for ‘rndDesign’ and ‘calcCrit’ functions: Numeric vector (or matrix) of allocation weights for the different doses. The rows of the matrices need to sum to 1. Alternatively also an object of class "DRdesign" can be used for ‘rndDesign’. Note that there should be at least as many design points available as there are parameters in the dose-response models selected in <code>models</code> (otherwise the code returns an NA).
eps	Argument for ‘rndDesign’ function: Value under which elements of <code>w</code> will be regarded as 0.
x	Object of class ‘DRdesign’ (for ‘plot.design’)
lwdDes, colDes	Line width and color of the lines plotted for the design (in ‘plot.design’)

## Details

Let  $M_m$  denote the Fisher information matrix under model  $m$  (up to proportionality).  $M_m$  is given by  $\sum a_i w_i g_i^T g_i$ , where  $a_i$  is the allocation weight to dose  $i$ ,  $w_i$  the weight for dose  $i$  specified via ‘weights’ and  $g_i$  the gradient vector of model  $m$  evaluated at dose  $i$ .

For ‘designCrit = "Dopt"' the code minimizes the design criterion

$$-\sum_m p_m / k_m \log(\det(M_m))$$

where  $p_m$  is the probability for model  $m$  and  $k_m$  is the number of parameters for model  $m$ . When ‘standDopt = FALSE’ the  $k_m$  are all assumed to be equal to one.

For ‘designCrit = "TD"' the code minimizes the design criterion

$$\sum_m p_m \log(v_m)$$

where  $p_m$  is the probability for model  $m$  and  $v_m$  is proportional to the asymptotic variance of the TD estimate and given by  $b'_m M_m^{-1} b_m$  (see Dette et al. (2008), p. 1227 for details).

For ‘designCrit = "Dopt&TD"' the code minimizes the design criterion

$$\sum_m p_m (-0.5 \log(\det(M_m)) / k_m + 0.5 \log(v_m))$$

Again, for ‘standDopt = FALSE’ the  $k_m$  are all assumed to be equal to one.

For details on the ‘rndDesign’ function, see Pukelsheim (1993), Chapter 12.

**Note**

In some cases (particularly when the number of doses is large, e.g. 7 or larger) it might be necessary to allow a larger number of iterations in the algorithm (via the argument 'control'), particularly for the Nelder-Mead algorithm. Alternatively one can use the solnp optimizer that is usually the most reliable, but not fastest option.

**Author(s)**

Bjoern Bornkamp

**References**

Atkinson, A.C., Donev, A.N. and Tobias, R.D. (2007). Optimum Experimental Designs, with SAS, Oxford University Press

Dette, H., Bretz, F., Pepelyshev, A. and Pinheiro, J. C. (2008). Optimal Designs for Dose Finding Studies, *Journal of the American Statistical Association*, **103**, 1225–1237

Pinheiro, J.C., Bornkamp, B. (2017) Designing Phase II Dose-Finding Studies: Sample Size, Doses and Dose Allocation Weights, in O'Quigley, J., Iasonos, A. and Bornkamp, B. (eds) Handbook of methods for designing, monitoring, and analyzing dose-finding trials, CRC press

Pukelsheim, F. (1993). Optimal Design of Experiments, Wiley

**See Also**

[Mods](#), [drmodels](#)

**Examples**

```
## calculate designs for Emax model
doses <- c(0, 10, 100)
emodel <- Mods(emax = 15, doses=doses, placEff = 0, maxEff = 1)
optDesign(emodel, probs = 1)
## TD-optimal design
optDesign(emodel, probs = 1, designCrit = "TD", Delta=0.5)
## 50-50 mixture of Dopt and TD
optDesign(emodel, probs = 1, designCrit = "Dopt&TD", Delta=0.5)
## use dose levels different from the ones specified in emodel object
des <- optDesign(emodel, probs = 1, doses = c(0, 5, 20, 100))
## plot models overlaid by design
plot(des, emodel)
## round des to a sample size of exactly 90 patients
rndDesign(des, n=90) ## using the round function would lead to 91 patients

## illustrating different optimizers (see Note above for more comparison)
optDesign(emodel, probs=1, optimizer="Nelder-Mead")
optDesign(emodel, probs=1, optimizer="nlminb")
## optimizer solnp (the default) can deal with lower and upper bounds:
optDesign(emodel, probs=1, designCrit = "TD", Delta=0.5,
          optimizer="solnp", lowbnd = rep(0.2,3))
## exact design using enumeration of all possibilities
optDesign(emodel, probs=1, optimizer="exact", n = 30)
```

```

## also allows to fix minimum groupSize
optDesign(emodel, probs=1, designCrit = "TD", Delta=0.5,
          optimizer="exact", n = 30, control = list(groupSize=5))

## optimal design at interim analysis
## assume there are already 10 patients on each dose and there are 30
## left to randomize, this calculates the optimal increment design
optDesign(emodel, 1, designCrit = "TD", Delta=0.5,
          nold = c(10, 10, 10), n=30)

## use a larger candidate model set
doses <- c(0, 10, 25, 50, 100, 150)
fmods <- Mods(linear = NULL, emax = 25, exponential = 85,
              linlog = NULL, logistic = c(50, 10.8811),
              doses = doses, addArgs=list(off=1),
              placEff=0, maxEff=0.4)
probs <- rep(1/5, 5) # assume uniform prior
desDopt <- optDesign(fmods, probs, optimizer = "nlnminb")
desTD <- optDesign(fmods, probs, designCrit = "TD", Delta = 0.2,
                  optimizer = "nlnminb")
desMix <- optDesign(fmods, probs, designCrit = "Dopt&TD", Delta = 0.2)
## plot design and truth
plot(desMix, fmods)

## illustrate calcCrit function
## calculate optimal design for beta model
doses <- c(0, 0.49, 25.2, 108.07, 150)
models <- Mods(betaMod = c(0.33, 2.31), doses=doses,
               addArgs=list(scal=200),
               placEff=0, maxEff=0.4)
probs <- 1
deswgts <- optDesign(models, probs, designCrit = "Dopt",
                    control=list(maxit=1000))
## now compare this design to equal allocations on
## 0, 10, 25, 50, 100, 150
doses2 <- c(0, 10, 25, 50, 100, 150)
design2 <- c(1/6, 1/6, 1/6, 1/6, 1/6, 1/6)
crit2 <- calcCrit(design2, models, probs, doses2, designCrit = "Dopt")
## ratio of determinants (returned criterion value is on log scale)
exp(deswgts$crit-crit2)

## example for calculating an optimal design for logistic regression
doses <- c(0, 0.35, 0.5, 0.65, 1)
fMod <- Mods(linear = NULL, doses=doses, placEff=-5, maxEff = 10)
## now calculate weights to use in the covariance matrix
mu <- as.numeric(getResp(fMod, doses=doses))
mu <- 1/(1+exp(-mu))
weights <- mu*(1-mu)
des <- optDesign(fMod, 1, doses, weights = weights)

## one can also specify a user defined criterion function
## here D-optimality for cubic polynomial

```

```

CubeCrit <- function(w, doses){
  X <- cbind(1, doses, doses^2, doses^3)
  CVinv <- crossprod(X*w)
  -log(det(CVinv))
}
optDesign(doses = c(0,0.05,0.2,0.6,1),
          designCrit = "userCrit", userCrit = CubeCrit,
          optimizer = "nlminb")

```

---

planMod

---

*Evaluate performance metrics for fitting dose-response models*


---

## Description

This function evaluates, the performance metrics for fitting dose-response models (using asymptotic approximations or simulations). Note that some metrics are available via the print method and others only via the summary method applied to planMod objects. The implemented metrics are

- Root of the mean-squared error to estimate the placebo-adjusted dose-response averaged over the used dose-levels, i.e. a rather discrete set (dRMSE). Available via the print method of planMod objects.
- Root of the mean-squared error to estimate the placebo-adjusted dose-response (cRMSE) averaged over fine (almost continuous) grid at 101 equally spaced values between placebo and the maximum dose. NOTE: Available via the summary method applied to planMod objects.
- Ratio of the placebo-adjusted mean-squared error (at the observed doses) of model-based vs ANOVA approach (Eff-vs-ANOVA). This can be interpreted on the sample size scale. NOTE: Available via the summary method applied to planMod objects.
- Power that the (unadjusted) one-sided ‘1-alpha’ confidence interval comparing the dose with maximum effect vs placebo is larger than ‘tau’. By default ‘alpha = 0.025’ and ‘tau = 0’ (Pow(maxDose)). Available via the print method of planMod objects.
- Probability that the EDp estimate is within the true [EDpLB, EDpUB] (by default ‘p=0.5’, ‘pLB=0.25’ and ‘pUB=0.75’). This metric gives an idea on the ability to characterize the increasing part of the dose-response curve (P(EDp)). Available via the print method of planMod objects.
- Length of the quantile range for a target dose (TD or EDp). This is calculated by taking the difference of the dUB and dLB quantile of the empirical distribution of the dose estimates. (lengthTDCI and lengthEDpCI). It is NOT calculated by calculating confidence interval lengths in each simulated data-set and taking the mean. NOTE: Available via the summary method of planMod objects.

A plot method exists to summarize dose-response and dose estimations graphically.

**Usage**

```

planMod(model, altModels, n, sigma, S, doses, asyApprox = TRUE,
        simulation = FALSE, alpha = 0.025, tau = 0, p = 0.5,
        pLB = 0.25, pUB = 0.75, nSim = 100, cores = 1,
        showSimProgress = TRUE, bnds, addArgs = NULL)

## S3 method for class 'planMod'
plot(x, type = c("dose-response", "ED", "TD"),
     p, Delta, placAdj = FALSE, xlab, ylab, ...)

## S3 method for class 'planMod'
summary(object, digits = 3, len = 101,
        Delta, p, dLB = 0.05, dUB = 0.95, ...)

```

**Arguments**

model	Character vector determining the dose-response model(s) to be used for fitting the data. When more than one dose-response model is provided the best fitting model is chosen using the AIC. Built-in models are "linlog", "linear", "quadratic", "emax", "exponential", "sigEmax", "betaMod" and "logistic" (see <a href="#">drmodels</a> ).
altModels	An object of class 'Mods', defining the true mean vectors under which operating characteristics should be calculated.
n, sigma, S	Either a vector 'n' and 'sigma' or 'S' need to be specified. When 'n' and 'sigma' are specified it is assumed computations are made for a normal homoscedastic ANOVA model with group sample sizes given by 'n' and residual standard deviation 'sigma', i.e. the covariance matrix used for the estimates is thus $\sigma^2 \text{diag}(1/n)$ and the degrees of freedom are calculated as $\text{sum}(n) - \text{nrow}(\text{contMat})$ . When a single number is specified for 'n' it is assumed this is the sample size per group and balanced allocations are used.  When 'S' is specified this will be used as covariance matrix for the estimates.
doses asyApprox, simulation	Doses to use  Logicals determining, whether asymptotic approximations or simulations should be calculated. If multiple models are specified in 'model' asymptotic approximations are not available.
alpha, tau	Significance level for the one-sided confidence interval for model-based contrast of best dose vs placebo. Tau is the threshold to compare the confidence interval limit to. CI(MaxDCont) gives the percentage that the bound of the confidence interval was larger than tau.
p, pLB, pUB	p determines the type of ED <sub>p</sub> to estimate. pLB and pUB define the bounds for the ED <sub>p</sub> estimate. The performance metric Pr(Id-ED) gives the percentage that the estimated ED <sub>p</sub> was within the true ED <sub>p</sub> LB and ED <sub>p</sub> UB.
nSim	Number of simulations

cores	Number of cores to use for simulations. By default 1 cores is used, note that cores > 1 will have no effect Windows, as the mclapply function is used internally.
showSimProgress	In case of simulations show the progress using a progress-bar.
bnds	Bounds for non-linear parameters. This needs to be a list with list entries corresponding to the selected bounds. The names of the list entries need to correspond to the model names. The <code>defBnds</code> function provides the default selection.
addArgs	See the corresponding argument in function <code>fitMod</code> . This argument is directly passed to <code>fitMod</code> .
x	An object of class <code>planMod</code>
type	Type of plot to produce
Delta	Additional arguments determining what dose estimate to plot, when 'type = "ED"' or 'type = "TD"'
placAdj	When 'type = "dose-response"', this determines whether dose-response estimates are shown on placebo-adjusted or original scale
xlab, ylab	Labels for the plot (ylab only applies for 'type = "dose-response"')
len	Number of equally spaced points to determine the mean-squared error on a grid (cRMSE).
dLB, dUB	Which quantiles to use for calculation of <code>lengthTDCI</code> and <code>lengthEDpCI</code> . By default <code>dLB = 0.05</code> and <code>dUB = 0.95</code> , so that this corresponds to a 90% interval.
object, digits	object: A <code>planMod</code> object. digits: Digits in summary output
...	Additional arguments (currently ignored)

**Author(s)**

Bjoern Bornkamp

**References**

TBD

**See Also**[fitMod](#)**Examples**

```
## Not run:
doses <- c(0,10,25,50,100,150)
fmodels <- Mods(linear = NULL, emax = 25,
               logistic = c(50, 10.88111), exponential= 85,
               betaMod=rbind(c(0.33,2.31),c(1.39,1.39)),
               doses = doses, addArgs=list(scal = 200),
               placEff = 0, maxEff = 0.4)

sigma <- 1
```

```

n <- rep(62, 6)*2

model <- "quadratic"
pObj <- planMod(model, fmodels, n, sigma, doses=doses,
               simulation = TRUE,
               alpha = 0.025, nSim = 200,
               p = 0.5, pLB = 0.25, pUB = 0.75)

print(pObj)
## to get additional metrics (e.g. Eff-vs-ANOVA, cRMSE, lengthTDCI, ...)
summary(pObj, p = 0.5, Delta = 0.3)
plot(pObj)
plot(pObj, type = "TD", Delta=0.3)
plot(pObj, type = "ED", p = 0.5)

## End(Not run)

```

---

powMCT

*Calculate power for multiple contrast test*

---

## Description

Calculate power for a multiple contrast test for a set of specified alternatives.

## Usage

```

powMCT(contMat, alpha = 0.025, altModels, n, sigma, S, placAdj=FALSE,
       alternative = c("one.sided", "two.sided"), df, critV,
       control = mvtnorm.control())

```

## Arguments

contMat	Contrast matrix to use. The individual contrasts should be saved in the columns of the matrix
alpha	Significance level to use
altModels	An object of class 'Mods', defining the mean vectors under which the power should be calculated
n, sigma, S	Either a vector 'n' and 'sigma' or 'S' need to be specified. When 'n' and 'sigma' are specified it is assumed computations are made for a normal homoscedastic ANOVA model with group sample sizes given by 'n' and residual standard deviation 'sigma', i.e. the covariance matrix used for the estimates is thus $\sigma^2 \text{diag}(1/n)$ and the degrees of freedom are calculated as $\text{sum}(n) - \text{nrow}(\text{contMat})$ . When a single number is specified for 'n' it is assumed this is the sample size per group and balanced allocations are used.

When 'S' is specified this will be used as covariance matrix for the estimates.



placAdj	Logical, if true, it is assumed that the standard deviation or variance matrix of the placebo-adjusted estimates are specified in 'sigma' or 'S', respectively. The contrast matrix has to be produced on placebo-adjusted scale, see <a href="#">optContr</a> , so that the coefficients are no longer contrasts (i.e. do not sum to 0).
alternative	Character determining the alternative for the multiple contrast trend test.
df	Degrees of freedom to assume in case 'S' (a general covariance matrix) is specified. When 'n' and 'sigma' are specified the ones from the corresponding ANOVA model are calculated.
critV	Critical value, if equal to 'TRUE' the critical value will be calculated. Otherwise one can directly specify the critical value here.
control	A list specifying additional control parameters for the 'qmvT' and 'pmvT' calls in the code, see also 'mvtnorm.control' for details.

### Value

Numeric containing the calculated power values

### Author(s)

Bjoern Bornkamp

### References

Pinheiro, J. C., Bornkamp, B., and Bretz, F. (2006). Design and analysis of dose finding studies combining multiple comparisons and modeling procedures, *Journal of Biopharmaceutical Statistics*, **16**, 639–656

### See Also

[powN](#), [sampSizeMCT](#), [MCTtest](#), [optContr](#), [Mods](#)

### Examples

```
## look at power under some dose-response alternatives
## first the candidate models used for the contrasts
doses <- c(0,10,25,50,100,150)
## define models to use as alternative
fmodels <- Mods(linear = NULL, emax = 25,
                logistic = c(50, 10.88111), exponential= 85,
                betaMod=rbind(c(0.33,2.31),c(1.39,1.39)),
                doses = doses, addArgs=list(scal = 200),
                placEff = 0, maxEff = 0.4)
## plot alternatives
plot(fmodels)
## power for to detect a trend
contMat <- optContr(fmodels, w = 1)
powMCT(contMat, altModels = fmodels, n = 50, alpha = 0.05, sigma = 1)

## Not run:
## power under the Dunnett test
```

```

## contrast matrix for Dunnett test with informative names
contMatD <- rbind(-1, diag(5))
rownames(contMatD) <- doses
colnames(contMatD) <- paste("D", doses[-1], sep="")
powMCT(contMatD, altModels = fmodels, n = 50, alpha = 0.05, sigma = 1)

## now investigate power of the contrasts in contMat under "general" alternatives
altFmods <- Mods(linInt = rbind(c(0, 1, 1, 1, 1),
                               c(0.5, 1, 1, 1, 0.5)),
                doses=doses, placEff=0, maxEff=0.5)
plot(altFmods)
powMCT(contMat, altModels = altFmods, n = 50, alpha = 0.05, sigma = 1)

## now the first example but assume information only on the
## placebo-adjusted scale
## for balanced allocations and 50 patients with sigma = 1 one obtains
## the following covariance matrix
S <- 1^2/50*diag(6)
## now calculate variance of placebo adjusted estimates
CC <- cbind(-1,diag(5))
V <- (CC)%*S%*t(CC)
linMat <- optContr(fmodels, doses = c(10,25,50,100,150),
                  S = V, placAdj = TRUE)
powMCT(linMat, altModels = fmodels, placAdj=TRUE,
        alpha = 0.05, S = V, df=6*50-6) # match df with the df above

## End(Not run)

```

---

sampSize

*Sample size calculations*


---

## Description

The 'sampSize' function implements a bisection search algorithm for sample size calculation. The user can hand over a general target function (via 'targFunc') that is then iterated so that a certain 'target' is achieved. The 'sampSizeMCT' is a convenience wrapper of 'sampSize' for multiple contrast tests using the power as target function.

The 'targN' functions calculates a general target function for different given sample sizes. The 'powN' function is a convenience wrapper of 'targN' for multiple contrast tests using the power as target function.

## Usage

```

sampSize(upperN, lowerN = floor(upperN/2), targFunc, target,
         tol = 0.001, alRatio, Ntype = c("arm", "total"),
         verbose = FALSE)

```

```

sampSizeMCT(upperN, lowerN = floor(upperN/2), ..., power, sumFct = mean,
            tol = 0.001, alRatio, Ntype = c("arm", "total"),

```

```

        verbose = FALSE)

targN(upperN, lowerN, step, targFunc, alRatio,
      Ntype = c("arm", "total"), sumFct = c("min", "mean", "max"))

powN(upperN, lowerN, step, ..., alRatio,
     Ntype = c("arm", "total"), sumFct = c("min", "mean", "max"))

## S3 method for class 'targN'
plot(x, superpose = TRUE, line.at = NULL,
     xlab = NULL, ylab = NULL, ...)

```

## Arguments

- upperN, lowerN** Upper and lower bound for the target sample size. `lowerN` defaults to `floor(upperN/2)`.
- step** Only needed for functions `'targN'` and `'powN'`. Stepsize for the sample size at which the target function is calculated. The steps are calculated via `seq(lowerN, upperN, by=step)`.
- targFunc, target**  
 The target function needs to take as an input the vector of sample sizes in the different dose groups. For `'sampSize'` it needs to return a univariate number. For function `'targN'` it should return a numerical vector.
- Example: `'targFunc'` could be a function that calculates the power of a test, and `'target'` the desired target power value. For function `'sampSize'` the bisection search iterates the sample size so that a specific target value is achieved (the implicit assumption is that `targFunc` is monotonically increasing in the sample size).
- Function `'targN'` simply calculates `'targFunc'` for a given set of sample sizes.
- tol** A positive numeric value specifying the tolerance level for the bisection search algorithm. Bisection is stopped if the `'targFunc'` value is within `'tol'` of `'target'`.
- alRatio** Vector describing the relative patient allocations to the dose groups up to proportionality, e.g. `'rep(1, length(doses))'` corresponds to balanced allocations.
- Ntype** One of "arm" or "total". Determines, whether the sample size in the smallest arm or the total sample size is iterated in bisection search algorithm.
- verbose** Logical value indicating if a trace of the iteration progress of the bisection search algorithm should be displayed.
- ...** Arguments directly passed to the [powMCT](#) function in the `'sampSizeMCT'` and `'powN'` function.
- The `'placAdj'` argument needs to be `'FALSE'` (which is the default value for this argument). If sample size calculations are desired for a placebo-adjusted formulation use `'sampSize'` or `'targN'` directly.
- In case `S` is specified, the specified matrix needs to be proportional to the (hypothetical) covariance matrix of one single observation. The covariance matrix

used for sample size calculation is  $1/N*S$ , where  $N$  is the total sample size. Hence 'Ntype == "total"' needs to be used if  $S$  is specified. When  $S$  is specified, automatically 'df = Inf' is assumed in the underlying 'powMCT' calls.

For a homoscedastic normally distributed response variable only 'sigma' needs to be specified, as the sample size 'n' is iterated in the different 'powMCT' calls.

power, sumFct    power is a numeric defining the desired summary power to achieve (in 'sampSizeMCT').  
 sumFct needs to be a function that combines the power values under the different alternatives into one value (in 'sampSizeMCT').

x, superpose, line.at, xlab, ylab  
 arguments for the plot method of 'targN' and 'powN', additional arguments are passed down to the low-level lattice plotting routines.

### Author(s)

Jose Pinheiro, Bjoern Bornkamp

### References

Pinheiro, J. C., Bornkamp, B., and Bretz, F. (2006). Design and analysis of dose finding studies combining multiple comparisons and modeling procedures, *Journal of Biopharmaceutical Statistics*, **16**, 639–656

Pinheiro, J.C., Bornkamp, B. (2017) Designing Phase II Dose-Finding Studies: Sample Size, Doses and Dose Allocation Weights, in O'Quigley, J., Iasonos, A. and Bornkamp, B. (eds) Handbook of methods for designing, monitoring, and analyzing dose-finding trials, CRC press

### See Also

[powMCT](#)

### Examples

```
## sampSize examples

## first define the target function
## first calculate the power to detect all of the models in the candidate set
fmodels <- Mods(linear = NULL, emax = c(25),
               logistic = c(50, 10.88111), exponential=c(85),
               betaMod=matrix(c(0.33,2.31,1.39,1.39), byrow=TRUE, nrow=2),
               doses = c(0,10,25,50,100,150), placEff=0, maxEff=0.4,
               addArgs = list(scal=200))

## contrast matrix to use
contMat <- optContr(fmodels, w=1)
## this function calculates the power under each model and then returns
## the average power under all models
tFunc <- function(n){
  powVals <- powMCT(contMat, altModels=fmodels, n=n, sigma = 1,
                   alpha=0.05)
  mean(powVals)
}
```

```

## assume we want to achieve 80% average power over the selected shapes
## and want to use a balanced allocations
## Not run:
sSize <- sampSize(upperN = 80, targFunc = tFunc, target=0.8,
                 alRatio = rep(1,6), verbose = TRUE)

sSize

## Now the same using the convenience sampSizeMCT function
sampSizeMCT(upperN=80, contMat = contMat, sigma = 1, altModels=fmodels,
            power = 0.8, alRatio = rep(1, 6), alpha = 0.05)
## Alternatively one can also specify an S matrix
## covariance matrix in one observation (6 total observation result in a
## variance of 1 in each group)
S <- 6*diag(6)
## this uses df = Inf, hence a slightly smaller sample size results
sampSizeMCT(upperN=500, contMat = contMat, S=S, altModels=fmodels,
            power = 0.8, alRatio = rep(1, 6), alpha = 0.05, Ntype = "total")

## targN examples
## first calculate the power to detect all of the models in the candidate set
fmodels <- Mods(linear = NULL, emax = c(25),
               logistic = c(50, 10.88111), exponential=c(85),
               betaMod=matrix(c(0.33,2.31,1.39,1.39), byrow=TRUE, nrow=2),
               doses = c(0,10,25,50,100,150), placEff=0, maxEff=0.4,
               addArgs = list(scal=200))
## corresponding contrast matrix
contMat <- optContr(fmodels, w=1)
## define target function
tFunc <- function(n){
  powMCT(contMat, altModels=fmodels, n=n, sigma = 1, alpha=0.05)
}
powVsN <- targN(upperN = 100, lowerN = 10, step = 10, tFunc,
               alRatio = rep(1, 6))
plot(powVsN)

## the same can be achieved using the convenience powN function
## without the need to specify a target function
powN(upperN = 100, lowerN=10, step = 10, contMat = contMat,
     sigma = 1, altModels = fmodels, alpha = 0.05, alRatio = rep(1, 6))

## End(Not run)

```

**Description**

The TD (target dose) is defined as the dose that achieves a target effect of Delta over placebo (if there are multiple such doses, the smallest is chosen):

$$TD_{\Delta} = \min\{x | f(x) > f(0) + \Delta\}$$

If a decreasing trend is beneficial the definition of the TD is

$$TD_{\Delta} = \min\{x | f(x) < f(0) - \Delta\}$$

When  $\Delta$  is the clinical relevance threshold, then the TD is similar to the usual definition of the minimum effective dose (MED).

The ED (effective dose) is defined as the dose that achieves a certain percentage  $p$  of the full effect size (within the observed dose-range!) over placebo (if there are multiple such doses, the smallest is chosen).

$$ED_p = \min\{x | f(x) > f(0) + p(f(dmax) - f(0))\}$$

Note that this definition of the ED $_p$  is different from traditional definition based on the Emax model, where the ED $_p$  is defined relative to the *asymptotic* maximum effect (rather than the maximum effect in the observed dose-range).

**Usage**

```
TD(object, Delta, TDtype = c("continuous", "discrete"),
  direction = c("increasing", "decreasing"), doses)
```

```
ED(object, p, EDtype = c("continuous", "discrete"), doses)
```

**Arguments**

<code>object</code>	An object of class <code>c(Mods, fullMod)</code> , <code>DRMod</code> or <code>bFitMod</code>
<code>Delta, p</code>	<code>Delta</code> : The target effect size use for the target dose (TD) (Delta should be > 0). <code>p</code> : The percentage of the dose to use for the effective dose.
<code>TDtype, EDtype</code>	character that determines, whether the dose should be treated as a continuous variable when calculating the TD/ED or whether the TD/ED should be calculated based on a grid of doses specified in ‘doses’
<code>direction</code>	Direction to be used in defining the TD. This depends on whether an increasing or decreasing of the response variable is beneficial.
<code>doses</code>	Dose levels to be used, this needs to include placebo, ‘TDtype’ or ‘EDtype’ are equal to “discrete”.

**Value**

Returns the dose estimate

**Author(s)**

Bjoern Bornkamp

**See Also**

[Mods](#), [fitMod](#), [bFitMod](#), [drmodels](#)

**Examples**

```
## example for creating a "full-model" candidate set placebo response
## and maxEff already fixed in Mods call
doses <- c(0, 10, 25, 50, 100, 150)
fmodels <- Mods(linear = NULL, emax = 25,
               logistic = c(50, 10.88111), exponential = 85,
               betaMod = rbind(c(0.33, 2.31), c(1.39, 1.39)),
               linInt = rbind(c(0, 1, 1, 1, 1),
                             c(0, 0, 1, 1, 0.8)),
               doses=doses, placEff = 0, maxEff = 0.4,
               addArgs=list(scal=200))

## calculate doses giving an improvement of 0.3 over placebo
TD(fmodels, Delta=0.3)
## discrete version
TD(fmodels, Delta=0.3, TDtype = "discrete", doses=doses)
## doses giving 50% of the maximum effect
ED(fmodels, p=0.5)
ED(fmodels, p=0.5, EDtype = "discrete", doses=doses)

plot(fmodels, plotTD = TRUE, Delta = 0.3)
```

# Index

- \* **datasets**
  - biom, 8
  - glycobrom, 18
  - IBScovars, 22
  - migraine, 31
  - neurodeg, 36
- \* **package**
  - DoseFinding-package, 2
- AIC.DRMod (fitMod), 14
- betaMod, 8, 21
- betaMod (DR-Models), 10
- betaModGrad (DR-Models), 10
- bFitMod, 4, 53, 55
- biom, 8
- calcCrit (optDesign), 40
- coef.bFitMod (bFitMod), 4
- coef.DRMod (fitMod), 14
- defBnds, 5, 8, 15, 17, 24, 47
- DesignMCPModApp, 9
- DoseFinding (DoseFinding-package), 2
- DoseFinding-package, 2
- DR-Models, 10
- drmodels, 5, 14, 15, 17, 26, 31–33, 43, 46, 55
- drmodels (DR-Models), 10
- ED, 24, 31
- ED (Target Doses), 53
- emax, 21
- emax (DR-Models), 10
- emaxGrad (DR-Models), 10
- exponential, 21
- exponential (DR-Models), 10
- exponentialGrad (DR-Models), 10
- fitMod, 5, 6, 9, 10, 13, 14, 23, 24, 26, 29, 47, 53, 55
- gAIC (fitMod), 14
- getResp (Mods), 31
- glycobrom, 18
- guesst, 20
- IBScovars, 22
- linear (DR-Models), 10
- linearGrad (DR-Models), 10
- linInt (DR-Models), 10
- linIntGrad (DR-Models), 10
- linlog (DR-Models), 10
- linlogGrad (DR-Models), 10
- logistic, 8, 21
- logistic (DR-Models), 10
- logisticGrad (DR-Models), 10
- logLik.DRMod (fitMod), 14
- MCPMod, 23
- MCTpval, 27
- MCTtest, 23, 24, 26–28, 28, 39, 49
- migraine, 31
- Mods, 10, 24, 28, 31, 33, 37, 40, 43, 49, 53, 55
- mvtnorm.control, 24, 29, 35
- neurodeg, 36
- nlminb, 16, 41
- nls, 16
- optContr, 28, 29, 37, 49
- optDesign, 31, 33, 40
- optim, 41
- optimize, 16
- planMod, 45
- plot.bFitMod (bFitMod), 4
- plot.DRdesign (optDesign), 40
- plot.DRMod (fitMod), 14
- plot.MCPMod (MCPMod), 23
- plot.Mods, 20, 21, 42
- plot.Mods (Mods), 31



plot.optContr (optContr), 37  
plot.planMod (planMod), 45  
plot.targN (sampSize), 50  
plotContr (optContr), 37  
plotMods (Mods), 31  
powMCT, 29, 31, 33, 48, 51, 52  
powN, 49  
powN (sampSize), 50  
predict.bFitMod (bFitMod), 4  
predict.DRMod (fitMod), 14  
predict.MCPMod (MCPMod), 23  
  
quadratic, 21  
quadratic (DR-Models), 10  
quadraticGrad (DR-Models), 10  
  
rndDesign (optDesign), 40  
  
sampSize, 50  
sampSizeMCT, 49  
sampSizeMCT (sampSize), 50  
sigEmax, 8, 21  
sigEmax (DR-Models), 10  
sigEmaxGrad (DR-Models), 10  
summary.planMod (planMod), 45  
  
Target Doses, 53  
targN (sampSize), 50  
TD, 24, 31  
TD (Target Doses), 53  
  
vcov.DRMod (fitMod), 14