

# Package ‘caRamel’

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**Title** Automatic Calibration by Evolutionary Multi Objective Algorithm

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**Author** Nicolas Le Moine [aut],  
Celine Monteil [aut],  
Frederic Hendrickx [ctb],  
Fabrice Zaoui [aut, cre]

**Maintainer** Fabrice Zaoui <fabrice.zaoui@edf.fr>

**Depends** geometry, parallel

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**Description** Multi-objective optimizer initially developed for the calibration of hydrological models. The algorithm is a hybrid of the MEAS algorithm (Efstratiadis and Koutsoyianis (2005) <doi:10.13140/RG.2.2.32963.81446>) by using the directional search method based on the simplexes of the objective space and the epsilon-NGSA-II algorithm with the method of classification of the parameter vectors archiving management by epsilon-dominance (Reed and Devireddy <doi:10.1142/9789812567796\_0004>).

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**URL** <https://github.com/fzao/caRamel>

**BugReports** <https://github.com/fzao/caRamel/issues>

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caRamel-package	<i>caRamel optimizer</i>
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## Description

Automatic Calibration by Evolutionary Multi Objective Algorithm

## Details

*caRamel* is a package for multi-objective optimization of complex environmental models.

The algorithm is a hybrid of the *MEAS* algorithm (Efstratiadis and Koutsoyiannis, 2005) by using the directional search method based on the simplexes of the objective space and the *epsilon-NGSA-II* algorithm with the method of classification of the parameter vectors archiving management by epsilon-dominance (Reed and Devireddy, 2004).

The main function of the package is *caRamel()*.

This function uses all the other functions of the package.

An example of an hydrological optimization is available on the following presentation: [useR! 2019](#)

## Author(s)

Fabrice Zaoui, Nicolas Le Moine, Celine Monteil (EDF R&D - LNHE)

## References

Efstratiadis, A. and Koutsoyiannis, D. (2005) *The multi-objective evolutionary annealing-simplex method and its application in calibration hydrological models*, in EGU General Assembly 2005, Geophysical Research Abstracts, Vol. 7, Vienna, 04593, European Geophysical Union. doi:10.13140/RG.2.2.32963.81446.

Le Moine, N. (2009) *Description d'un algorithme génétique multi-objectif pour la calibration d'un modèle pluie-débit* (in French). Post-Doctoral Status Rep. 2, UPMC/EDF, 13 pp.

Reed, P. and Devireddy, D. (2004) *Groundwater monitoring design: a case study combining epsilon-dominance archiving and automatic parameterization for the NSGA-II*, in Coello-Coello C, editor. Applications of multi-objective evolutionary algorithms, Advances in natural computation series, vol. 1, pp. 79-100, World Scientific, New York. doi:10.1142/9789812567796\_0004.

---

boxes

*Box numbering for each points individual of the population*

---

## Description

This function returns a box number for each points individual of the population

## Usage

```
boxes(points, prec)
```

## Arguments

points : matrix of the objectives  
prec : (double, length = nobj) desired accuracy for the objectives (edges of the boxes)

## Value

vector of numbers for the boxes. boxes[i] gives the number of the box containing points[i].

## Author(s)

Fabrice Zaoui

## Examples

```
# Definition of the parameters
points <- matrix(rexp(200), 100, 2)
prec <- c(1.e-3, 1.e-3)
# Call the function
res <- boxes(points, prec)
```

---

 caRamel

---

 MAIN FUNCTION: multi-objective optimizer
 

---

### Description

Multi-objective optimizer. It requires to define a multi-objective function (func) to calibrate the model and bounds on the parameters to optimize.

### Usage

```
caRamel(
  nobj,
  nvar,
  minmax,
  bounds,
  func,
  popsize,
  archsize,
  maxrun,
  prec,
  repart_gene = c(5, 5, 5, 5),
  gpp = NULL,
  blocks = NULL,
  pop = NULL,
  funcinit = NULL,
  objnames = NULL,
  listsave = NULL,
  write_gen = FALSE,
  carallel = 1,
  numcores = NULL,
  graph = TRUE,
  sensitivity = FALSE,
  verbose = TRUE,
  worklist = NULL
)
```

### Arguments

nobj	: (integer, length = 1) the number of objectives to optimize (nobj >= 2)
nvar	: (integer, length = 1) the number of variables
minmax	: (logical, length = nobj) the objective is either a minimization (FALSE value) or a maximization (TRUE value)
bounds	: (matrix, nrow = nvar, ncol = 2) lower and upper bounds for the variables
func	: (function) the objective function to optimize. Input argument is the number of parameter set (integer) in the x matrix. The function has to return a vector of at least 'nobj' values (Objectives 1 to nobj are used for optimization, values after nobj are recorded for information.).

popsize	: (integer, length = 1) the population size for the genetic algorithm
archsize	: (integer, length = 1) the size of the Pareto front
maxrun	: (integer, length = 1) the max. number of simulations allowed
prec	: (double, length = nobj) the desired accuracy for the optimization of the objectives
repart_gene	: (integer, length = 4) optional, number of new parameter sets for each rule and per generation
gpp	: (integer, length = 1) optional, calling frequency for the rule "Fireworks"
blocks	(optional): groups for parameters
pop	: (matrix, nrow = nset, ncol = nvar or nvar+nobj ) optional, initial population (used to restart an optimization)
funcinit	(function, optional): the initialization function applied on each node of cluster when parallel computation. The arguments are cl and numcores
objnames	(optional): names of the objectives
listsave	(optional): names of the listing files. Default: None (no output). If exists, fields to be defined: "pmt" (file of parameters on the Pareto Front), "obj" (file of corresponding objective values), "evol" (evolution of maximum objectives by generation). Optional field: "totalpop" (total population and corresponding objectives, useful to restart a computation)
write_gen	: (logical, length = 1) optional, if TRUE, save files 'pmt' and 'obj' at each generation (FALSE by default)
carallel	: (integer, length = 1) optional, do parallel computations? (0: sequential, 1:parallel (default) , 2:user-defined choice)
numcores	: (integer, length = 1) optional, the number of cores for the parallel computations (all cores by default)
graph	: (logical, length = 1) optional, plot graphical output at each generation (TRUE by default)
sensitivity	: (logical, length = 1) optional, compute the first order derivatives of the pareto front (FALSE by default)
verbose	: (logical, length = 1) optional, verbosity mode (TRUE by default)
worklist	: optional values to be transmitted to the user's function (not used)

## Details

The optimizer was originally written for Scilab by Nicolas Le Moine. The algorithm is a hybrid of the MEAS algorithm (Efstratiadis and Koutsoyiannis (2005) <doi:10.13140/RG.2.2.32963.81446>) by using the directional search method based on the simplexes of the objective space and the epsilon-NGSA-II algorithm with the method of classification of the parameter vectors archiving management by epsilon-dominance (Reed and Devireddy <doi:10.1142/9789812567796\_0004>). Reference : "Multi-objective calibration by combination of stochastic and gradient-like parameter generation rules – the caRamel algorithm" Celine Monteil (EDF), Fabrice Zaoui (EDF), Nicolas Le Moine (UPMC) and Frederic Hendrickx (EDF) June 2020 Hydrology and Earth System Sciences 24(6):3189-3209 DOI: 10.5194/hess-24-3189-2020 Documentation : "Principe de l'optimiseur CaRAMEL et illustration au travers d'exemples de parametres dans le cadre de la modelisation hydrologique conceptuelle" Frederic Hendrickx (EDF) and Nicolas Le Moine (UPMC) Report EDF H-P73-2014-09038-FR

**Value**

List of seven elements:

**success** return value (logical, length = 1) : TRUE if successful

**parameters** Pareto front (matrix, nrow = archsize, ncol = nvar)

**objectives** objectives of the Pareto front (matrix, nrow = archsize, ncol = nobj+nadditional)

**derivatives** list of the Jacobian matrices of the Pareto front if the sensitivity parameter is TRUE or NA otherwise

**save\_crit** evolution of the optimal objectives

**total\_pop** total population (matrix, nrow = popsize+archsize, ncol = nvar+nobj+nadditional)

**gpp** the calling period for the third generation rule (independent sampling with a priori parameters variance)

**Author(s)**

Fabrice Zaoui - Celine Monteil

**Examples**

```
# Definition of the test function
viennet <- function(i) {
  val1 <- 0.5*(x[i,1]*x[i,1]+x[i,2]*x[i,2])+sin(x[i,1]*x[i,1]+x[i,2]*x[i,2])
  val2 <- 15+(x[i,1]-x[i,2]+1)*(x[i,1]-x[i,2]+1)/27+(3*x[i,1]-2*x[i,2]+4)*(3*x[i,1]-2*x[i,2]+4)/8
  val3 <- 1/(x[i,1]*x[i,1]+x[i,2]*x[i,2]+1) -1.1*exp(-(x[i,1]*x[i,1]+x[i,2]*x[i,2]))
  return(c(val1,val2,val3))
}
# Number of objectives
nobj <- 3
# Number of variables
nvar <- 2
# All the objectives are to be minimized
minmax <- c(FALSE, FALSE, FALSE)
# Define the bound constraints
bounds <- matrix(data = 1, nrow = nvar, ncol = 2)
bounds[, 1] <- -3 * bounds[, 1]
bounds[, 2] <- 3 * bounds[, 2]

# Caramel optimization
results <-
  caRamel(nobj = nobj,
          nvar = nvar,
          minmax = minmax,
          bounds = bounds,
          func = viennet,
          popsize = 100,
          archsize = 100,
          maxrun = 500,
          prec = matrix(1.e-3, nrow = 1, ncol = nobj),
          carallel = 0)
```

---

Cextrap	<i>Extrapolation along orthogonal directions to the Pareto front in the space of the objectives</i>
---------	---

---

### Description

gives n new candidates by extrapolation along orthogonal directions to the Pareto front in the space of the objectives

### Usage

```
Cextrap(param, crit, directions, longu, n)
```

### Arguments

param : matrix [ NPoints , NPar ] of already evaluated parameters  
crit : matrix [ Npoints , NObj ] of associated criteria  
directions : matrix [ NDir, 2 ] the starting and ending points of the candidate vectors  
longu : matrix [ NDir , 1 ] giving the length of each segment thus defined in the OBJ space (measure of the probability of exploring this direction)  
n : number of new vectors to generate

### Value

xnew : matrix [ n , NPar ] of new vectors  
pcrit : matrix [ n , NObj ] estimated positions of new sets in the goal space

### Author(s)

Fabrice Zaoui

### Examples

```
# Definition of the parameters
param <- matrix(rexp(100), 100, 1)
crit <- matrix(rexp(200), 100, 2)
directions <- matrix(c(1,3,2,7,13,40), nrow = 3, ncol = 2)
longu <- runif(3)
n <- 5
# Call the function
res <- Cextrap(param, crit, directions, longu, n)
```

---

Cinterp

*Interpolation in simplexes of the objective space*

---

### Description

proposes n new candidates by interpolation in simplexes of the objective space

### Usage

```
Cinterp(param, crit, simplices, volume, n)
```

### Arguments

param : matrix [ NPoints , NPar ] of already evaluated parameters  
crit : matrix [ Npoints , NObj ] of associated criteria  
simplices : matrix [ NSimp , NObj+1 ] containing all or part of the triangulation of the space of the objectives  
volume : matrix [ NSimp , 1 ] giving the volume of each simplex (measure of the probability of interpolating in this simplex)  
n : number of new vectors to generate

### Value

xnew : matrix [ n , NPar ] of new vectors  
pcrit : matrix [ n , NObj ] estimated positions of new sets in the goal space

### Author(s)

Fabrice Zaoui

### Examples

```
# Definition of the parameters
param <- matrix(rexp(100), 100, 1)
crit <- matrix(rexp(200), 100, 2)
simplices <- matrix(c(15,2,1,15,22,1,18,15,2,17,13,14), nrow = 4, ncol = 3)
volume <- runif(4)
n <- 5
# Call the function
res <- Cinterp(param, crit, simplices, volume, n)
```



---

Crecombination	<i>Recombination of the sets of parameters</i>
----------------	--

---

**Description**

performs a recombination of the sets of parameters

**Usage**

```
Crecombination(param, blocks, n)
```

**Arguments**

param : matrix [ . , NPar ] of the population of parameters  
blocks : list of integer vectors: list of variable blocks for recombination  
n : number of new vectors to generate

**Value**

xnew : matrix [ n , NPar ] of new vectors

**Author(s)**

Fabrice Zaoui

**Examples**

```
# Definition of the parameters  
param <- matrix(rexp(15), 15, 1)  
blocks <- NULL  
n <- 5  
# Call the function  
res <- Crecombination(param, blocks, n)
```

---

Cusecovar	<i>New parameter vectors generation respecting a covariance structure</i>
-----------	---

---

**Description**

proposes new parameter vectors respecting a covariance structure

**Usage**

```
Cusecovar(xref, amplif, n)
```

**Arguments**

xref : matrix [ . , NPar ] of the reference population whose covariance structure is to be used  
 amplif : amplification factor of the standard deviation on each parameter  
 n : number of new vectors to generate

**Value**

xnew : matrix [ n , NPar ] of new vectors

**Author(s)**

Fabrice Zaoui

**Examples**

```
# Definition of the parameters
xref <- matrix(rexp(35), 35, 1)
amplif <- 2.
n <- 5
# Call the function
res <- Cusecovar(xref, amplif, n)
```

---

 decrease\_pop

*Decreasing of the population of parameters sets*


---

**Description**

decreases the population of parameters sets

**Usage**

```
decrease_pop(matobj, minmax, prec, archsize, popsize)
```

**Arguments**

matobj : matrix of objectives, dimension (ngames, nobj)  
 minmax : vector of booleans, of dimension nobj: TRUE if maximization of the objective, FALSE otherwise  
 prec : nobj dimension vector: accuracy  
 archsize : integer: archive size  
 popsize : integer: population size

**Value**

A list containing two elements:

**ind\_arch** indices of individuals in the updated Pareto front

**ind\_pop** indices of individuals in the updated population

**Author(s)**

Fabrice Zaoui

**Examples**

```
# Definition of the parameters
matobj <- matrix(rexp(200), 100, 2)
prec <- c(1.e-3, 1.e-3)
archsize <- 100
minmax <- c(FALSE, FALSE)
popsize <- 100
# Call the function
res <- decrease_pop(matobj, minmax, prec, archsize, popsize)
```

---

Dimprove

*Determination of directions for improvement*

---

**Description**

determines directions for improvement

**Usage**

```
Dimprove(o_splx, f_splx)
```

**Arguments**

**o\_splx** : matrix of objectives of simplexes (nrow = npoints, ncol = nobj)

**f\_splx** : vector (npoints) of associated Pareto numbers (1 = dominated)

**Value**

list of elements "oriedge": oriented edges and "ledge": length

**Author(s)**

Fabrice Zaoui

**Examples**

```
# Definition of the parameters
o_splx <- matrix(rexp(6), 3, 2)
f_splx <- c(1,1,1)
# Call the function
res <- Dimprove(o_splx, f_splx)
```

---

dominate

*Successive Pareto fronts of a population*

---

**Description**

calculates the successive Pareto fronts of a population (classification "onion peel"), when objectives need to be maximized.

**Usage**

```
dominate(matobj)
```

**Arguments**

matobj : matrix [ NInd , NObj ] of objectives

**Value**

f : vector of dimension NInd of dominances

**Author(s)**

Fabrice Zaoui

**Examples**

```
# Definition of the parameters
matobj <- matrix(runif(200), 100, 2)
# Call the function
pareto_rank <- dominate(matobj)
```

---

dominated	<i>Rows domination of a matrix by a vector</i>
-----------	--

---

**Description**

indicates which rows of the matrix Y are dominated by the vector (row) x

**Usage**

```
dominated(x, Y)
```

**Arguments**

x : row vecteur  
Y : matrix

**Value**

D : vector of booleans

**Author(s)**

Fabrice Zaoui

**Examples**

```
# Definition of the parameters  
Y <- matrix(rexp(200), 100, 2)  
x <- Y[1,]  
# Call the function  
res <- dominated(x, Y)
```

---

downsize	<i>Downsizing of a population to only one individual per box up to a given accuracy</i>
----------	---

---

**Description**

reduces the number of individuals in a population to only one individual per box up to a given accuracy

**Usage**

```
downsize(points, Fo, prec)
```

**Arguments**

points : matrix of objectives  
Fo : rank on the front of each point (1: dominates on the Pareto)  
prec : (double, length = nobj) desired accuracy for sorting objectives

**Value**

vector indices

**Author(s)**

Fabrice Zaoui

**Examples**

```
# Definition of the parameters
points <- matrix(rexp(200), 100, 2)
prec <- c(1.e-3, 1.e-3)
Fo <- sample(1:100, 100)
# Call the function
res <- downsize(points, Fo, prec)
```

---

matvcov

*Calculation of the variances-covariances matrix on the reference population*

---

**Description**

calculates the variances-covariances matrix on the reference population

**Usage**

```
matvcov(x, g)
```

**Arguments**

x : population  
g : center of reference population (in the parameter space)

**Value**

rr : variances-covariances matrix on the reference population

**Author(s)**

Fabrice Zaoui

**Examples**

```
# Definition of the parameters
x <- matrix(rexp(30), 30, 1)
g <- mean(x)
# Call the function
res <- matvcov(x, g)
```

---

newXval	<i>Generation of a new population of parameter sets following the five rules of caRamel</i>
---------	---

---

**Description**

generates a new population of parameter sets following the five rules of caRamel

**Usage**

```
newXval(param, crit, isperf, sp, bounds, repart_gene, blocks, fireworks)
```

**Arguments**

param	: matrix [ Nvec , NPar ] of parameters of the current population
crit	: matrix [ Nvec , NObj ] of associated criteria
isperf	: vector of Booleans of length NObj, TRUE if maximization of the objective, FALSE otherwise
sp	: variance a priori of the parameters
bounds	: lower and upper bounds of parameters [ NPar , 2 ]
repart_gene	: matrix of length 4 giving the number of games to be generated with each rule: 1 Interpolation in the simplexes of the front, 2 Extrapolation according to the directions of the edges "orthogonal" to the front, 3 Random draws with prescribed variance-covariance matrix, 4 Recombination by functional blocks
blocks	: list of integer vectors containing function blocks of parameters
fireworks	: boolean, TRUE if one tests a random variation on each parameter and each maximum of O.F.

**Value**

xnew : matrix of new vectors [ sum(Repart\_Gene) + eventually (nobj+1)\*nvar if fireworks , NPar ]  
 project\_crit: assumed position of the new vectors in the criteria space: [ sum(Repart\_Gene)+ eventually (nobj+1)\*nvar if fireworks , NObj ];

**Author(s)**

Fabrice Zaoui

**Examples**

```

# Definition of the parameters
param <- matrix(rexp(100), 100, 1)
crit <- matrix(rexp(200), 100, 2)
isperf <- c(FALSE, FALSE)
bounds <- matrix(data = 1, nrow = 1, ncol = 2)
bounds[, 1] <- -5 * bounds[, 1]
bounds[, 2] <- 10 * bounds[, 2]
sp <- (bounds[, 2] - bounds[, 1]) / (2 * sqrt(3))
repart_gene <- c(5, 5, 5, 5)
fireworks <- TRUE
blocks <- NULL
# Call the function
res <- newXval(param, crit, isperf, sp, bounds, repart_gene, blocks, fireworks)

```

---

pareto

*Indicates which rows are Pareto*


---

**Description**

indicates which rows of the X criterion matrix are Pareto, when objectives need to be maximized

**Usage**

```
pareto(X)
```

**Arguments**

X : matrix of objectives [NInd \* NObj]

**Value**

Ft : vector [NInd], TRUE when the set is on the Pareto front.

**Author(s)**

Fabrice Zaoui

**Examples**

```

# Definition of the parameters
X <- matrix(runif(200), 100, 2)
# Call the function
is_pareto <- pareto(X)

```



---

plot_caramel	<i>Plotting of caRamel results</i>
--------------	------------------------------------

---

## Description

Plot graphs of the Pareto front and a graph of optimization evolution

## Usage

```
plot_caramel(caramel_results, nobj = NULL, objnames = NULL)
```

## Arguments

`caramel_results` : list resulting from the `caRamel()` function, with fields `$objectives` and `$save_crit`

`nobj` : number of objectives (optional)

`objnames` : vector of objectives names (optional)

## Examples

```
# Definition of the test function
viennet <- function(i) {
  val1 <- 0.5*(x[i,1]*x[i,1]+x[i,2]*x[i,2])+sin(x[i,1]*x[i,1]+x[i,2]*x[i,2])
  val2 <- 15+(x[i,1]-x[i,2]+1)*(x[i,1]-x[i,2]+1)/27+(3*x[i,1]-2*x[i,2]+4)*(3*x[i,1]-2*x[i,2]+4)/8
  val3 <- 1/(x[i,1]*x[i,1]+x[i,2]*x[i,2]+1) -1.1*exp(-(x[i,1]*x[i,1]+x[i,2]*x[i,2]))
  return(c(val1,val2,val3))
}
nobj <- 3 # Number of objectives
nvar <- 2 # Number of variables
minmax <- c(FALSE, FALSE, FALSE) # All the objectives are to be minimized
bounds <- matrix(data = 1, nrow = nvar, ncol = 2) # Define the bound constraints
bounds[, 1] <- -3 * bounds[, 1]
bounds[, 2] <- 3 * bounds[, 2]

# Caramel optimization
results <- caRamel(nobj, nvar, minmax, bounds, viennet, popsize = 100, archsize = 100,
  maxrun = 500, prec = matrix(1.e-3, nrow = 1, ncol = nobj), carallel = FALSE)

# Plot of results
plot_caramel(results)
```

---

plot_pareto	<i>Plotting of a population of objectives and Pareto front</i>
-------------	--

---

**Description**

Plots graphs the population regarding each couple of objectives and emphasizes the Pareto front

**Usage**

```
plot_pareto(MatObj, nobj = NULL, objnames = NULL, maximized = NULL)
```

**Arguments**

MatObj	: matrix of the objectives [NInd, nobj]
nobj	: number of objectives (optional)
objnames	: vector, length nobj, of names of the objectives (optional)
maximized	: vector of logical, length nobj, TRUE if objective need to be maximized, FALSE if minimized

**Author(s)**

Celine Monteil

**Examples**

```
# Definition of the population
Pop <- matrix(runif(300), 100, 3)

# Definition of objectives to maximize (Obj1, Obj2) and to minimize (Obj3)
maximized <- c(TRUE, TRUE, FALSE)

# Call the function
plot_pareto(MatObj = Pop, maximized = maximized)
```

---

plot_population	<i>Plotting of a population of objectives</i>
-----------------	---

---

**Description**

Plot graphs the population regarding each couple of objectives

**Usage**

```
plot_population(
  MatObj,
  nobj,
  ngen = NULL,
  nrun = NULL,
  objnames = NULL,
  MatEvol = NULL,
  popsize = 0
)
```

**Arguments**

MatObj : matrix of the objectives [NInd, nobj]  
 nobj : number of objectives  
 ngen : number of generations (optional)  
 nrun : number of model evaluations (optional)  
 objnames : vector of objectives names (optional)  
 MatEvol : matrix of the evolution of the optimal objectives (optional)  
 popsize : integer, size of the initial population (optional)

**Author(s)**

Celine Monteil

**Examples**

```
# Definition of the population
Pop <- matrix(runif(300), 100, 3)
# Call the function
plot_population(MatObj = Pop, nobj = 3, objnames = c("Obj1", "Obj2", "Obj3"))
```

---

rselect

*Selection of n points*


---

**Description**

performs a selection of n points in facp

**Usage**

```
rselect(n, facp)
```

**Arguments**

n : number of points to select  
facp : vector of initial points

**Value**

ix : ranks of selected points (vector of dimension n)

**Author(s)**

Fabrice Zaoui

**Examples**

```
# Definition of the parameters
n <- 5
facp <- runif(30)
# Call the function
res <- rselect(n, facp)
```

---

val2rank

*Converting the values of a vector into their rank*

---

**Description**

converts the values of a vector into their rank

**Usage**

```
val2rank(X, opt)
```

**Arguments**

X : vector to treat  
opt : integer which gives the rule to follow in case of tied ranks (repeated values): if opt = 1, one returns the average rank, if opt = 2, one returns the corresponding rank in the series of the unique values, if opt = 3, return the max rank

**Value**

R : rank vector

**Author(s)**

Fabrice Zaoui

**Examples**

```
# Definition of the parameters
X <- matrix(rexp(100), 100, 1)
opt <- 3
# Call the function
res <- val2rank(X, opt)
```

---

vol\_splx

*Volume of a simplex*

---

**Description**

calculates the volume of a simplex

**Usage**

```
vol_splx(S)
```

**Arguments**

S : matrix (d+1) rows \* d columns containing the coordinates in d-dim of d + 1 vertices of a simplex

**Value**

V : simplex volume

**Author(s)**

Fabrice Zaoui

**Examples**

```
# Definition of the parameters
S <- matrix(rexp(6), 3, 2)
# Call the function
res <- vol_splx(S)
```

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