Package: volesti (via r-universe)

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Type Package

License LGPL-3

Title Volume Approximation and Sampling of Convex Polytopes

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Description Provides an R interface for 'volesti' C++ package. 'volesti' computes estimations of volume of polytopes given by (i) a set of points, (ii) linear inequalities or (iii) Minkowski sum of segments (a.k.a. zonotopes). There are three algorithms for volume estimation as well as algorithms for sampling, rounding and rotating polytopes. Moreover, 'volesti' provides algorithms for estimating copulas useful in computational finance. Methods implemented in 'volesti' are described in A. Chalkis and V. Fisikopoulos (2022) <doi:10.32614/RJ-2021-077> and references therein.

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`compute_indicators` *Compute an indicator for each time period that describes the state of a market.*

Description

Given a matrix that contains row-wise the assets' returns and a sliding window `win_length`, this function computes an approximation of the joint distribution (copula, e.g. see https://en.wikipedia.org/wiki/Copula_(probability_theory)) between portfolios' return and volatility in each time period defined by `win_len`. For each copula it computes an indicator: If the indicator is large it corresponds to a crisis period and if it is small it corresponds to a normal period. In particular, the periods over which the indicator is greater than 1 for more than 60 consecutive sliding windows are warnings and for more than 100 are crisis. The sliding window is shifted by one day.

Usage

```
compute_indicators(
  returns,
 parameters = list(win_length = 60, m = 100, n = 5e+05, nwarning = 60, ncrisis = 100)
)
```

Arguments

returns	A d-dimensional vector that describes the direction of the first family of parallel hyperplanes.
parameters	A list to set a parameterization.

win_length The length of the sliding window. The default value is 60.

m The number of slices for the copula. The default value is 100.

n The number of points to sample. The default value is $5 \cdot 10^5$.

nwarning The number of consecutive indicators larger than 1 required to declare a warning period. The default value is 60.

ncrisis The number of consecutive indicators larger than 1 required to declare a crisis period. The default value is 100.

seed A fixed seed for the number generator.

Value

A list that contains the indicators and the corresponding vector that label each time period with respect to the market state: a) normal, b) crisis, c) warning.

References

L. Cales, A. Chalkis, I.Z. Emiris, V. Fisikopoulos, "Practical volume computation of structured convex bodies, and an application to modeling portfolio dependencies and financial crises," Proc. of Symposium on Computational Geometry, Budapest, Hungary, *2018.*

Examples

```
# simple example on random asset returns
asset_returns = replicate(10, rnorm(14))
market_states_and_indicators = compute_indicators(asset_returns,
   parameters = list("win_length" = 10, "m" = 10, "n" = 10000, "nwarning" = 2, "ncrisis" = 3))
```

`copula` *Construct a copula using uniform sampling from the unit simplex*

Description

Given two families of parallel hyperplanes or a family of parallel hyperplanes and a family of concentric ellispoids centered at the origin intersecting the canonical simplex, this function uniformly samples from the canonical simplex and construct an approximation of the bivariate probability distribution, called copula (see https://en.wikipedia.org/wiki/Copula_(probability_theory)). At least two families of hyperplanes or one family of hyperplanes and one family of ellipsoids have to be given as input.

Usage

```
copula(r1, r2 = NULL, sigma = NULL, m = NULL, n = NULL, seed = NULL)
```

Arguments

r1	The d-dimensional normal vector of the first family of parallel hyperplanes.
r2	Optional. The d-dimensional normal vector of the second family of parallel hyperplanes.
sigma	Optional. The $d \times d$ symmetric positive semidefine matrix that describes the family of concentric ellipsoids centered at the origin.
m	The number of the slices for the copula. The default value is 100.
n	The number of points to sample. The default value is $5 \cdot 10^5$.
seed	Optional. A fixed seed for the number generator.

Value

A $m \times m$ numerical matrix that corresponds to a copula.

References

L. Cales, A. Chalkis, I.Z. Emiris, V. Fisikopoulos, "Practical volume computation of structured convex bodies, and an application to modeling portfolio dependencies and financial crises," Proc. of Symposium on Computational Geometry, Budapest, Hungary, *2018.*

Examples

```
# compute a copula for two random families of parallel hyperplanes
h1 = runif(n = 10, min = 1, max = 1000)
h1 = h1 / 1000
h2=runif(n = 10, min = 1, max = 1000)
h2 = h2 / 1000
cop = copula(r1 = h1, r2 = h2, m = 10, n = 100000)

# compute a copula for a family of parallel hyperplanes and a family of conentric ellipsoids
h = runif(n = 10, min = 1, max = 1000)
h = h / 1000
E = replicate(10, rnorm(20))
E = cov(E)
cop = copula(r1 = h, sigma = E, m = 10, n = 100000)
```

`direct_sampling` *Sample perfect uniformly distributed points from well known convex bodies: (a) the unit simplex, (b) the canonical simplex, (c) the boundary of a hypersphere or (d) the interior of a hypersphere.*

Description

The d-dimensional unit simplex is the set of points $\vec{x} \in \mathsf{R}^d$, s.t.: $\sum_i x_i \leq 1$, $x_i \geq 0$. The d-dimensional canonical simplex is the set of points $\vec{x} \in \mathsf{R}^d$, s.t.: $\sum_i x_i = 1$, $x_i \geq 0$.

Usage

```
direct_sampling(body, n)
```

Arguments

`body`	A list to request exact uniform sampling from special well known convex bodies through the following input parameters:
	`type` A string that declares the type of the body for the exact sampling: a) `'unit_simplex'` for the unit simplex, b) `'canonical_simplex'` for the canonical simplex, c) `'hypersphere'` for the boundary of a hypersphere centered at the origin, d) `'ball'` for the interior of a hypersphere centered at the origin.
	`dimension` An integer that declares the dimension when exact sampling is enabled for a simplex or a hypersphere.
	`radius` The radius of the d-dimensional hypersphere. The default value is 1.
	`seed` A fixed seed for the number generator.
`n`	The number of points that the function is going to sample.

Value

A $d \times n$ matrix that contains, column-wise, the sampled points from the convex polytope P.

References

R.Y. Rubinstein and B. Melamed, "Modern simulation and modeling" Wiley Series in Probability and Statistics, *1998.*

A Smith, Noah and W Tromble, Roy, "Sampling Uniformly from the Unit Simplex," Center for Language and Speech Processing Johns Hopkins University, *2004.*

Examples

```
# 100 uniform points from the 2-d unit ball
points = direct_sampling(n = 100, body = list("type" = "ball", "dimension" = 2))
```

exact_vol *Compute the exact volume of (a) a zonotope (b) an arbitrary simplex in V-representation or (c) if the volume is known and declared by the input object.*

Description

Given a zonotope (as an object of class Zonotope), this function computes the sum of the absolute values of the determinants of all the $d \times d$ submatrices of the $m \times d$ matrix G that contains row-wise the m d-dimensional segments that define the zonotope. For an arbitrary simplex that is given in V-representation this function computes the absolute value of the determinant formed by the simplex's points assuming it is shifted to the origin.

Usage

```
exact_vol(P)
```

Arguments

P	A polytope

Value

The exact volume of the input polytope, for zonotopes, simplices in V-representation and polytopes with known exact volume

References

E. Gover and N. Krikorian, "Determinants and the Volumes of Parallelotopes and Zonotopes," Linear Algebra and its Applications, 433(1), 28 - 40, *2010.*

Examples

```
# compute the exact volume of a 5-dimensional zonotope defined by the Minkowski sum of 10 segments
Z = gen_rand_zonotope(2, 5)
vol = exact_vol(Z)

# compute the exact volume of a 2-d arbitrary simplex
V = matrix(c(2,3,-1,7,0,0),ncol = 2, nrow = 3, byrow = TRUE)
P = Vpolytope(V = V)
vol = exact_vol(P)


# compute the exact volume the 10-dimensional cross polytope
P = gen_cross(10,'V')
vol = exact_vol(P)
```

`frustum_of_simplex` *Compute the percentage of the volume of the simplex that is contained in the intersection of a half-space and the simplex.*

Description

A half-space H is given as a pair of a vector $a \in R^d$ and a scalar $z0 \in R$ s.t.: $a^T x \leq z0$. This function calls the Ali's version of the Varsi formula to compute a frustum of the simplex.

Usage

```
frustum_of_simplex(a, z0)
```

Arguments

`a`	A d-dimensional vector that defines the direction of the hyperplane.
`z0`	The scalar that defines the half-space.

Value

The percentage of the volume of the simplex that is contained in the intersection of a given half-space and the simplex.

References

Varsi, Giulio, "The multidimensional content of the frustum of the simplex," Pacific J. Math. 46, no. 1, 303–314, *1973.*

Ali, Mir M., "Content of the frustum of a simplex," Pacific J. Math. 48, no. 2, 313–322, *1973.*

Examples

```
# compute the frustum of H: -x1+x2<=0
a=c(-1,1)
z0=0
frustum = frustum_of_simplex(a, z0)
```

`gen_cross` *Generator function for cross polytopes*

Description

This function generates the d-dimensional cross polytope in H- or V-representation.

Usage

```
gen_cross(dimension, representation = "H")
```

Arguments

`dimension`	The dimension of the cross polytope.
`representation`	A string to declare the representation. It has to be `'H'` for H-representation or `'V'` for V-representation. Default valus is 'H'.

Value

A polytope class representing a cross polytope in H- or V-representation.

Examples

```
# generate a 10-dimensional cross polytope in H-representation
P = gen_cross(5, 'H')

# generate a 15-dimension cross polytope in V-representation
P = gen_cross(15, 'V')
```

---

gen_cube *Generator function for hypercubes*

Description

This function generates the d-dimensional unit hypercube $[-1, 1]^d$ in H- or V-representation.

Usage

```
gen_cube(dimension, representation = "H")
```

Arguments

`dimension`	The dimension of the hypercube
`representation`	A string to declare the representation. It has to be `'H'` for H-representation or `'V'` for V-representation. Default valus is 'H'.

Value

A polytope class representing the unit d-dimensional hypercube in H- or V-representation.

Examples

```
# generate a 10-dimensional hypercube in H-representation
P = gen_cube(10, 'H')

# generate a 15-dimension hypercube in V-representation
P = gen_cube(5, 'V')
```

gen_prod_simplex *Generator function for product of simplices*

Description

This function generates a $2d$-dimensional polytope that is defined as the product of two d-dimensional unit simplices in H-representation.

Usage

```
gen_prod_simplex(dimension)
```

Arguments

dimension	The dimension of the simplices.

Value

A polytope class representing the product of the two d-dimensional unit simplices in H-representation.

Examples

```
# generate a product of two 5-dimensional simplices.
P = gen_prod_simplex(5)
```

gen_rand_hpoly *Generator function for random H-polytopes*

Description

This function generates a d-dimensional polytope in H-representation with m facets. We pick m random hyperplanes tangent on the d-dimensional unit hypersphere as facets.

Usage

```
gen_rand_hpoly(dimension, nfacets, generator = list(constants = "sphere"))
```

Arguments

dimension	The dimension of the convex polytope.
nfacets	The number of the facets.
generator	A list that could contain two elements.
	constants To declare how to set the constants b_i for each facets: (i) 'sphere', each hyperplane is tangent to the hypersphere of radius 10, (ii) 'uniform' for each b_i the generator picks a uniform number from $(0, 1)$. The defalut value is 'sphere'.
	seed Optional. A fixed seed for the number generator.

Value

A polytope class representing a H-polytope.

Examples

```
# generate a 10-dimensional polytope with 50 facets
P = gen_rand_hpoly(10, 50)
```

`gen_rand_vpoly` *Generator function for random V-polytopes*

Description

This function generates a d-dimensional polytope in V-representation with m vertices. We pick m random points from the boundary of the d-dimensional unit hypersphere as vertices.

Usage

```
gen_rand_vpoly(dimension, nvertices, generator = list(body = "sphere"))
```

Arguments

`dimension`	The dimension of the convex polytope.
`nvertices`	The number of the vertices.
`generator`	A list that could contain two elements.
	body the body that the generator samples uniformly the vertices from: (i) 'cube' or (ii) 'sphere', the default value is 'sphere'.
	seed Optional. A fixed seed for the number generator.

Value

A polytope class representing a V-polytope.

Examples

```
# generate a 10-dimensional polytope defined as the convex hull of 25 random vertices
P = gen_rand_vpoly(10, 25)
```

gen_rand_zonotope *Generator function for zonotopes*

Description

This function generates a random d-dimensional zonotope defined by the Minkowski sum of m d-dimensional segments. The function considers m random directions in R^d. There are three strategies to pick the length of each segment: a) it is uniformly sampled from $[0, 100]$, b) it is random from $\mathcal{N}(50, (50/3)^2)$ truncated to $[0, 100]$, c) it is random from $Exp(1/30)$ truncated to $[0, 100]$.

Usage

```
gen_rand_zonotope(
  dimension,
  nsegments,
  generator = list(distribution = "uniform")
)
```

Arguments

dimension	The dimension of the zonotope.
nsegments	The number of segments that generate the zonotope.
generator	A list that could contain two elements.

distribution The distribution to pick the length of each segment from $[0, 100]$: (i) 'uniform', (ii) 'gaussian' or (iii) 'exponential', the default value is 'uniform.

seed Optional. A fixed seed for the number generator.

Value

A polytope class representing a zonotope.

Examples

```
# generate a 10-dimensional zonotope defined by the Minkowski sum of 20 segments
P = gen_rand_zonotope(10, 20)
```

gen_simplex *Generator function for simplices*

Description

This function generates the d-dimensional unit simplex in H- or V-representation.

Usage

```
gen_simplex(dimension, representation = "H")
```

Arguments

dimension	The dimension of the unit simplex.
representation	A string to declare the representation. It has to be 'H' for H-representation or 'V' for V-representation. Default valus is 'H'.

Value

A polytope class representing the d-dimensional unit simplex in H- or V-representation.

Examples

```
# generate a 10-dimensional simplex in H-representation
PolyList = gen_simplex(10, 'H')

# generate a 20-dimensional simplex in V-representation
P = gen_simplex(20, 'V')
```

gen_skinny_cube *Generator function for skinny hypercubes*

Description

This function generates a d-dimensional skinny hypercube $[-1, 1]^{d-1} \times [-100, 100]$.

Usage

```
gen_skinny_cube(dimension)
```

Arguments

dimension	The dimension of the skinny hypercube.

Value

A polytope class representing the d-dimensional skinny hypercube in H-representation.

Examples

```
# generate a 10-dimensional skinny hypercube.
P = gen_skinny_cube(10)
```

Hpolytope-class *An R class to represent an H-polytope*

Description

An H-polytope is a convex polytope defined by a set of linear inequalities or equivalently a d-dimensional H-polytope with m facets is defined by a $m \times d$ matrix A and a m-dimensional vector b, s.t.: $Ax \leq b$.

Details

A An $m \times d$ numerical matrix.

b An m-dimensional vector b.

volume The volume of the polytope if it is known, NaN otherwise by default.

type A character with default value 'Hpolytope', to declare the representation of the polytope.

Examples

```
A = matrix(c(-1,0,0,-1,1,1), ncol=2, nrow=3, byrow=TRUE)
b = c(0,0,1)
P = Hpolytope(A = A, b = b)
```

---

inner_ball *Compute an inscribed ball of a convex polytope*

Description

For a H-polytope described by a $m \times d$ matrix A and a m-dimensional vector b, s.t.: $P = \{x \mid Ax \leq b\}$, this function computes the largest inscribed ball (Chebychev ball) by solving the corresponding linear program. For both zonotopes and V-polytopes the function computes the minimum r s.t.: $re_i \in P$ for all $i = 1, \ldots, d$. Then the ball centered at the origin with radius $r/\sqrt{d}$ is an inscribed ball.

Usage

```
inner_ball(P)
```

Arguments

P	A convex polytope. It is an object from class (a) Hpolytope or (b) Vpolytope or (c) Zonotope or (d) VpolytopeIntersection.

Value

A $(d+1)$-dimensional vector that describes the inscribed ball. The first d coordinates corresponds to the center of the ball and the last one to the radius.

Examples

```
# compute the Chebychev ball of the 2d unit simplex
P = gen_simplex(2,'H')
ball_vec = inner_ball(P)

# compute an inscribed ball of the 3-dimensional unit cube in V-representation
P = gen_cube(3, 'V')
ball_vec = inner_ball(P)
```

---

read_sdpa_format_file *Read a SDPA format file*

Description

Read a SDPA format file and return a spectrahedron (an object of class Spectrahedron) which is defined by the linear matrix inequality in the input file, and the objective function.

Usage

```
read_sdpa_format_file(path)
```

Arguments

path	Name of the input file

Value

A list with two named items: an item "matrices" which is an object of class Spectrahedron and an vector "objFunction"

Examples

```
path = system.file('extdata', package = 'volesti')
l = read_sdpa_format_file(paste0(path,'/sdpa_n2m3.txt'))
Spectrahedron = l$spectrahedron
objFunction = l$objFunction
```

`rotate_polytope` *Apply a random rotation to a convex polytope (H-polytope, V-polytope, zonotope or intersection of two V-polytopes)*

Description

Given a convex H- or V- polytope or a zonotope or an intersection of two V-polytopes as input, this function applies (a) a random rotation or (b) a given rotation by an input matrix T.

Usage

```
rotate_polytope(P, rotation = list())
```

Arguments

`P`	A convex polytope. It is an object from class (a) Hpolytope, (b) Vpolytope, (c) Zonotope, (d) intersection of two V-polytopes.
`rotation`	A list that contains (a) the rotation matrix T and (b) the 'seed' to set a spesific seed for the number generator.

Details

Let P be the given polytope and Q the rotated one and T be the matrix of the linear transformation.

- If P is in H-representation and A is the matrix that contains the normal vectors of the facets of Q then AT contains the normal vactors of the facets of P.
- If P is in V-representation and V is the matrix that contains column-wise the vertices of Q then T^TV contains the vertices of P.
- If P is a zonotope and G is the matrix that contains column-wise the generators of Q then T^TG contains the generators of P.
- If M is a matrix that contains column-wise points in Q then T^TM contains points in P.

Value

A list that contains the rotated polytope and the matrix T of the linear transformation.

Examples

```
# rotate a H-polytope (2d unit simplex)
P = gen_simplex(2, 'H')
poly_matrix_list = rotate_polytope(P)

# rotate a V-polytope (3d cube)
P = gen_cube(3, 'V')
poly_matrix_list = rotate_polytope(P)

# rotate a 5-dimensional zonotope defined by the Minkowski sum of 15 segments
Z = gen_rand_zonotope(3, 6)
poly_matrix_list = rotate_polytope(Z)
```

round_polytope *Apply rounding to a convex polytope (H-polytope, V-polytope or a zonotope)*

Description

Given a convex H or V polytope or a zonotope as input this function brings the polytope in rounded position based on minimum volume enclosing ellipsoid of a pointset.

Usage

```
round_polytope(P, settings = list())
```

Arguments

P	A convex polytope. It is an object from class (a) Hpolytope or (b) Vpolytope or (c) Zonotope.
settings	Optional. A list to parameterize the method by the random walk.
	random_walk The random walk to sample uniformly distributed points: (a) 'CDHR' for Coordinate Directions Hit-and-Run, (b) 'RDHR' for Random Directions Hit-and-Run or (c) 'BiW' for Billiard walk. The default random walk is 'CDHR' for H-polytopes and 'BiW' for the rest of the representations.
	walk_length The walk length of the random walk. The default value is $10 + 10d$ for 'CDHR' or 'RDHR' and 2 for 'BiW'.
	seed Optional. A fixed seed for the number generator.

Value

A list with 4 elements: (a) a polytope of the same class as the input polytope class and (b) the element "T" which is the matrix of the inverse linear transformation that is applied on the input polytope, (c) the element "shift" which is the opposite vector of that which has shifted the input polytope, (d) the element "round_value" which is the determinant of the square matrix of the linear transformation that is applied on the input polytope.

References

I.Z.Emiris and V. Fisikopoulos, "Practical polytope volume approximation," ACM Trans. Math. Soft., *2018.*,

Michael J. Todd and E. Alper Yildirim, "On Khachiyan's Algorithm for the Computation of Minimum Volume Enclosing Ellipsoids," Discrete Applied Mathematics, *2007.*

Examples

```
# rotate a H-polytope (2d unit simplex)
A = matrix(c(-1,0,0,-1,1,1), ncol=2, nrow=3, byrow=TRUE)
b = c(0,0,1)
P = Hpolytope(A = A, b = b)
listHpoly = round_polytope(P)

# rotate a V-polytope (3d unit cube) using Random Directions HnR with step equal to 50
P = gen_cube(3, 'V')
ListVpoly = round_polytope(P)

# round a 2-dimensional zonotope defined by 6 generators using ball walk
Z = gen_rand_zonotope(2,6)
ListZono = round_polytope(Z)
```

---

sample_points *Sample uniformly or normally distributed points from a convex Polytope (H-polytope, V-polytope, zonotope or intersection of two V-polytopes).*

Description

Sample n points with uniform or multidimensional spherical gaussian -with a mode at any point- as the target distribution.

Usage

```
sample_points(P, n, random_walk = NULL, distribution = NULL)
```

Arguments

P	A convex polytope. It is an object from class (a) Hpolytope or (b) Vpolytope or (c) Zonotope or (d) VpolytopeIntersection.
n	The number of points that the function is going to sample from the convex polytope.
random_walk	Optional. A list that declares the random walk and some related parameters as follows:

`walk` A string to declare the random walk: i) `'CDHR'` for Coordinate Directions Hit-and-Run, ii) `'RDHR'` for Random Directions Hit-and-Run, iii) `'BaW'` for Ball Walk, iv) `'BiW'` for Billiard walk, v) `'BCDHR'` boundary sampling by keeping the extreme points of CDHR or vi) `'BRDHR'` boundary sampling by keeping the extreme points of RDHR. The default walk is `'BiW'` for the uniform distribution or `'CDHR'` for the Gaussian distribution.

`walk_length` The number of the steps per generated point for the random walk. The default value is 1.

`nburns` The number of points to burn before start sampling.

`starting_point` A d-dimensional numerical vector that declares a starting point in the interior of the polytope for the random walk. The default choice is the center of the ball as that one computed by the function `inner_ball()`.

`BaW_rad` The radius for the ball walk.

`L` The maximum length of the billiard trajectory.

`seed` A fixed seed for the number generator.

`distribution` Optional. A list that declares the target density and some related parameters as follows:

`density` A string: (a) `'uniform'` for the uniform distribution or b) `'gaussian'` for the multidimensional spherical distribution. The default target distribution is uniform.

`variance` The variance of the multidimensional spherical gaussian. The default value is 1.

`mode` A d-dimensional numerical vector that declares the mode of the Gaussian distribution. The default choice is the center of the as that one computed by the function `inner_ball()`.

Value

A $d \times n$ matrix that contains, column-wise, the sampled points from the convex polytope P.

Examples

```
# uniform distribution from the 3d unit cube in H-representation using ball walk
P = gen_cube(3, 'H')
points = sample_points(P, n = 100, random_walk = list("walk" = "BaW", "walk_length" = 5))

# gaussian distribution from the 2d unit simplex in H-representation with variance = 2
A = matrix(c(-1,0,0,-1,1,1), ncol=2, nrow=3, byrow=TRUE)
b = c(0,0,1)
P = Hpolytope(A = A, b = b)
points = sample_points(P, n = 100, distribution = list("density" = "gaussian", "variance" = 2))

# uniform points from the boundary of a 2-dimensional random H-polytope
P = gen_rand_hpoly(2,20)
points = sample_points(P, n = 100, random_walk = list("walk" = "BRDHR"))
```

Spectrahedron-class *An R class to represent a Spectrahedron*

Description

A spectrahedron is a convex body defined by a linear matrix inequality of the form $A_0 + x_1 A_1 + ... + x_n A_n \preceq 0$. The matrices A_i are symmetric $m \times m$ real matrices and $\preceq 0$ denoted negative semidefiniteness.

Details

matrices A List that contains the matrices $A_0, A_1, ..., A_n$.

Examples

```
A0 = matrix(c(-1,0,0,0,-2,1,0,1,-2), nrow=3, ncol=3, byrow = TRUE)
A1 = matrix(c(-1,0,0,0,0,1,0,1,0), nrow=3, ncol=3, byrow = TRUE)
A2 = matrix(c(0,0,-1,0,0,0,-1,0,0), nrow=3, ncol=3, byrow = TRUE)
lmi = list(A0, A1, A2)
S = Spectrahedron(matrices = lmi);
```

---

volume *The main function for volume approximation of a convex Polytope (H-polytope, V-polytope, zonotope or intersection of two V-polytopes)*

Description

For the volume approximation can be used three algorithms. Either CoolingBodies (CB) or SequenceOfBalls (SOB) or CoolingGaussian (CG). An H-polytope with m facets is described by a $m \times d$ matrix A and a m-dimensional vector b, s.t.: $P = \{x \mid Ax \leq b\}$. A V-polytope is defined as the convex hull of m d-dimensional points which correspond to the vertices of P. A zonotope is desrcibed by the Minkowski sum of m d-dimensional segments.

Usage

```
volume(P, settings = NULL, rounding = FALSE)
```

Arguments

`P`	A convex polytope. It is an object from class a) Hpolytope or b) Vpolytope or c) Zonotope or d) VpolytopeIntersection.
`settings`	Optional. A list that declares which algorithm, random walk and values of parameters to use, as follows:

`algorithm` A string to set the algorithm to use: a) `'CB'` for CB algorithm, b) `'SoB'` for SOB algorithm or b) `'CG'` for CG algorithm. The defalut algorithm is `'CB'`.

`error` A numeric value to set the upper bound for the approximation error. The default value is 1 for SOB algorithm and 0.1 otherwise.

`random_walk` A string that declares the random walk method: a) `'CDHR'` for Coordinate Directions Hit-and-Run, b) `'RDHR'` for Random Directions Hit-and-Run, c) `'BaW'` for Ball Walk, or `'BiW'` for Billiard walk. For CB and SOB algorithms the default walk is `'CDHR'` for H-polytopes and `'BiW'` for the other representations. For CG algorithm the default walk is `'CDHR'` for H-polytopes and `'RDHR'` for the other representations.

`walk_length` An integer to set the number of the steps for the random walk. The default value is $\lfloor 10 + d/10 \rfloor$ for `'SOB'` and 1 otherwise.

`win_len` The length of the sliding window for CB or CG algorithm. The default value is $400 + 3d^2$ for CB or $500 + 4d^2$ for CG.

`hpoly` A boolean parameter to use H-polytopes in MMC of CB algorithm when the input polytope is a zonotope. The default value is `TRUE` when the order of the zonotope is < 5, otherwise it is `FALSE`.

`seed` A fixed seed for the number generator.

`rounding` A boolean parameter for rounding. The default value is `FALSE`.

Value

The approximation of the volume of a convex polytope.

References

I.Z.Emiris and V. Fisikopoulos, "Practical polytope volume approximation," ACM Trans. Math. Soft., *2018.*,

A. Chalkis and I.Z.Emiris and V. Fisikopoulos, "Practical Volume Estimation by a New Annealing Schedule for Cooling Convex Bodies," CoRR, abs/1905.05494, *2019.*,

B. Cousins and S. Vempala, "A practical volume algorithm," Springer-Verlag Berlin Heidelberg and The Mathematical Programming Society, *2015.*

Examples

```
# calling SOB algorithm for a H-polytope (3d unit simplex)
HP = gen_cube(3,'H')
vol = volume(HP)

# calling CG algorithm for a V-polytope (2d simplex)
VP = gen_simplex(2,'V')
vol = volume(VP, settings = list("algorithm" = "CG"))

# calling CG algorithm for a 2-dimensional zonotope defined as the Minkowski sum of 4 segments
Z = gen_rand_zonotope(2, 4)
vol = volume(Z, settings = list("random_walk" = "RDHR", "walk_length" = 2))
```

Vpolytope-class *An R class to represent a V-polytope*

Description

A V-polytope is a convex polytope defined by the set of its vertices.

Details

V An $m \times d$ numerical matrix that contains the vertices row-wise.

volume The volume of the polytope if it is known, NaN otherwise by default.

type A character with default value 'Vpolytope', to declare the representation of the polytope.

Examples

```
V = matrix(c(2,3,-1,7,0,0),ncol = 2, nrow = 3, byrow = TRUE)
P = Vpolytope(V = V)
```

VpolytopeIntersection-class

An R class to represent the intersection of two V-polytopes

Description

An intersection of two V-polytopes is defined by the intersection of the two coresponding convex hulls.

Details

V1 An $m \times d$ numerical matrix that contains the vertices of the first V-polytope (row-wise).

V2 An $q \times d$ numerical matrix that contains the vertices of the second V-polytope (row-wise).

volume The volume of the polytope if it is known, NaN otherwise by default.

type A character with default value 'VpolytopeIntersection', to declare the representation of the polytope.

Examples

```
P1 = gen_simplex(2,'V')
P2 = gen_cross(2,'V')
P = VpolytopeIntersection(V1 = P1@V, V2 = P2@V)
```

---

write_sdpa_format_file

Write a SDPA format file

Description

Outputs a spectrahedron (the matrices defining a linear matrix inequality) and a vector (the objective function) to a SDPA format file.

Usage

```
write_sdpa_format_file(spectrahedron, objective_function, output_file)
```

Arguments

spectrahedron	A spectrahedron in n dimensions; must be an object of class Spectrahedron
objective_function	A numerical vector of length n
output_file	Name of the output file

Examples

```
A0 = matrix(c(-1,0,0,0,-2,1,0,1,-2), nrow=3, ncol=3, byrow = TRUE)
A1 = matrix(c(-1,0,0,0,0,1,0,1,0), nrow=3, ncol=3, byrow = TRUE)
A2 = matrix(c(0,0,-1,0,0,0,-1,0,0), nrow=3, ncol=3, byrow = TRUE)
lmi = list(A0, A1, A2)
S = Spectrahedron(matrices = lmi)
objFunction = c(1,1)
write_sdpa_format_file(S, objFunction, "output.txt")
```

Zonotope-class *An R class to represent a Zonotope*

Description

A zonotope is a convex polytope defined by the Minkowski sum of m d-dimensional segments.

Details

G An $m \times d$ numerical matrix that contains the segments (or generators) row-wise

volume The volume of the polytope if it is known, NaN otherwise by default.

type A character with default value 'Zonotope', to declare the representation of the polytope.

Examples

```
G = matrix(c(2,3,-1,7,0,0),ncol = 2, nrow = 3, byrow = TRUE)
P = Zonotope(G = G)
```

`zonotope_approximation` *A function to over-approximate a zonotope with PCA method and to evaluate the approximation by computing a ratio of fitness.*

Description

For the evaluation of the PCA method the exact volume of the approximation body is computed and the volume of the input zonotope is computed by CoolingBodies algorithm. The ratio of fitness is $R = vol(P)/vol(P_{red})$, where P_{red} is the approximate polytope.

Usage

```
zonotope_approximation(
  Z,
  fit_ratio = FALSE,
  settings = list(error = 0.1, walk_length = 1, win_len = 250, hpoly = FALSE)
)
```

Arguments

`Z`	A zonotope.
`fit_ratio`	Optional. A boolean parameter to request the computation of the ratio of fitness.
`settings`	Optional. A list that declares the values of the parameters of CB algorithm as follows:
	`error` A numeric value to set the upper bound for the approximation error. The default value is 0.1.
	`walk_length` An integer to set the number of the steps for the random walk. The default value is 1.
	`win_len` The length of the sliding window for CB algorithm. The default value is 250.
	`hpoly` A boolean parameter to use H-polytopes in MMC of CB algorithm. The default value is `TRUE` when the order of the zonotope is < 5, otherwise it is `FALSE`.
	`seed` Optional. A fixed seed for the number generator.

Value

A list that contains the approximation body in H-representation and the ratio of fitness

References

A.K. Kopetzki and B. Schurmann and M. Althoff, "Methods for Order Reduction of Zonotopes," IEEE Conference on Decision and Control, *2017.*

Examples

```
# over-approximate a 2-dimensional zonotope with 10 generators and compute the ratio of fitness
Z = gen_rand_zonotope(2, 8)
retList = zonotope_approximation(Z = Z)
```

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