Package ‘gaston’

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Description

Manipulation of genetic data (SNPs), computation of Genetic Relationship Matrix, Linkage Disequilibrium, etc. Efficient algorithms for Linear Mixed Model (AIREML, diagonalisation trick).

Introducing gaston

Gaston offers functions for efficient manipulation of large genotype (SNP) matrices, and state-of-the-art implementation of algorithms to fit Linear Mixed Models, that can be used to compute heritability estimates or to perform association tests.

Thanks to the packages Rcpp, RcppParallel, RcppEigen, gaston functions are mainly written in C++.

Many functions are multithreaded; the number of threads can be setted through RcppParallel function setThreadOptions. It is advised to try several values for the number of threads, as using too many threads might be counterproductive due to an important overhead.

Some functions have a verbose argument, which controls the function verbosity. To mute all functions at once you can use options(gaston.verbose = FALSE).

Genotype matrices

An S4 class for genotype matrices is defined, named bed.matrix. Each row corresponds to an individual, and each column to a SNP. They can be read from files using read.bed.matrix and saved using write.bed.matrix. The function read.vcf reads VCF files.

In first approach, a bed.matrix behaves as a "read-only" matrix containing only 0, 1, 2 and NAs, unless the genotypes are standardized (use standardize<). They are stored in a compact form, each genotype being coded on 2 bits (hence 4 genotypes per byte).

Bed.matrices can be converted to numerical matrices with as.matrix, and multiplied with numeric vectors or matrices with %*% (this feature can be used e.g. to simulate quantitative phenotypes, see a basic example in the example section of association.test).

It is possible to subset bed.matrices just as base matrices, writing e.g. x[1:100,] to extract the first 100 individuals, or x[1:100,1000:1999] for extract the SNPs 1000 to 1999 for these 100 individuals. The use of logical vectors for subsetting is allowed too. The functions select.inds and select.snps can also be used for subsetting with a nice syntax.

Some basic descriptive statistics can be added to a bed.matrix with set.stats (since gaston 1.4, this function is called by default by all functions that create a bed.matrix, unless options(gaston.auto.set.stats = FALSE) was set). Hardy-Weinberg Equilibrium can be tested for all SNPs with set.hwe.

Crossproducts of standardized matrices

If X is a standardized n × q genotype matrix, a Genetic Relationship Matrix (GRM) of the individuals can be computed as

\[ GRM = \frac{1}{q - 1} X X' \]
where \( q \) is the number of SNPs. This computation is done by the function GRM. The eigen decomposition of the GRM produces the Principal Components (PC) of the data set. If needed, the loadings corresponding to the PCs can be retrieved using bed.loadings.

Doing the above crossproduct in the reverse order produces a moment estimate of the Linkage Disequilibrium:

\[
LD = \frac{1}{n-1} X'X
\]

where \( n \) is the number of individuals. This computation is done by the function LD (usually, only parts of the whole LD matrix is computed). This method is also used by LD.thin to extract a set of SNPs in low linkage disequilibrium (it is often recommended to perform this operation before computing the GRM).

**Linear Mixed Models**

lmm.aireml is a function for linear mixed models parameter estimation and BLUP computations.

The model considered is of the form

\[
Y = X\beta + \omega_1 + \ldots + \omega_k + \varepsilon
\]

with \( \omega_i \sim N(0, \tau_i K_i) \) for \( i \in 1, \ldots, k \) and \( \varepsilon \sim N(0, \sigma^2 I_n) \).

Note that very often in genetics a mixed model is written as

\[
Y = X\beta + Zu + \varepsilon
\]

with \( Z \) a standardized genotype matrix, and \( u \sim N(0, \tau I_q) \). In that case, denoting \( \omega = Zu \), \( \omega \sim N(0, \tau ZZ' \) and letting \( K = ZZ' \) we get a mixed model of the previous form.

When \( k = 1 \) in the above general model (only one random term \( \omega \)), the likelihood can be computed very efficiently using the eigen decomposition of \( K = \text{var}(\omega) \). This "diagonalization trick" is used in lmm.diago.likelihood and lmm.diago, to compute the likelihood and for parameter estimation, respectively.

Two small functions complete this set of functions: lmm.simu, to simulate data under a linear mixed model, and random.pm, to generate random positive matrices. Both are used in examples and can be useful for data simulation.

**Author(s)**

Hervé Perdry and Claire Dandine-Roulland

Maintainer: Hervé Perdry
Description

These data have been extracted from the 1000 Genomes data. The data set contains the genotype matrix AGT.gen, the pedigree matrix AGT.fam and a matrix AGT.bim, corresponding to 503 individuals of European populations and 361 SNPs on chromosome 1, on a ~100kb segment containing the Angiotensinogen gene. There is also a factor AGT.pop, which gives the population from which each individual is drawn (CEU = Utah residents of Northern Western European ancestry, FIN = Finnish, GBR = England and Scotland, IBS = Iberian, TSI = Toscani).

Usage

data(AGT)

Format

There are three data objects in the dataset:

AGT.gen Genotype matrix
AGT.fam Data frame containing all variables corresponding to a .fam file
AGT.bim Data frame containing all variables corresponding to a .bim file
AGT.pop Factor giving the population from which each individual is drawn

Source

The data were obtained from the 1000 Genomes project (see https://www.internationalgenome.org/).

References


Examples

data(AGT)
x <- as.bed.matrix(AGT.gen, AGT.fam, AGT.bim)
x
as.bed.matrix  

Creation of a bed.matrix

Description

Creates a bed.matrix using a numeric matrix and two data frame for ped / snps slots

Usage

as.bed.matrix(x, fam, bim)

Arguments

x 
A numeric matrix

fam 
(Optional) A data frame (the contents of a .fam file)

bim 
(Optional) A data frame (the contents of a .bim file)

Details

The data frame fam should have columns named "famid", "id", "father", "mother", "sex" and "pheno". The data frame bim should have columns named "chr", "id", "dist", "pos", "A1" and "A2".

Value

A bed.matrix condensing all three arguments.

Author(s)

Hervé Perdry and Claire Dandine-Roulland

See Also

bed.matrix-class

Examples

data(AGT)
x <- as.bed.matrix(AGT.gen, AGT.fam, AGT.bim)
x
Description

Association tests between phenotype and SNPs.

Usage

association.test(x, Y = x@ped$pheno, X = matrix(1, nrow(x)),
    method = c("lm", "lmm"), response = c("quantitative", "binary"),
    test = c("score", "wald", "lrt"), K, eigenK, beg = 1,
    end = ncol(x), p = 0, tol = .Machine$double.eps^0.25, ...)

Arguments

x A bed.matrix
Y The phenotype vector. Default is the column (pheno) of x@ped
X A covariable matrix. The default is a column vector of ones, to include an
    intercept in the model
method Method to use: "lm" for (generalized) linear model, and "lmm" for (generalized)
    linear mixed model
response Is "Y" a quantitative or a binary phenotype?
.test Which test to use. For binary phenotypes, test = "score" is mandatory
K A Genetic Relationship Matrix (as produced by GRM), or a list of such matrices. For
    test = "wald" or "lrt".
eigenK Eigen decomposition of the Genetic Relationship Matrix (as produced by the
    function eigen). For test = "wald" or "lrt".
beg Index of the first SNP tested for association
end Index of the last SNP tested for association
p Number of Principal Components to include in the model with fixed effect (for
    test = "wald" or "lrt")
tol Parameter for the likelihood maximization (as in optimize)
... Additional parameters for lmm.aieml or logistic.mm.aieml (if test = "score").

Details

Tests the association between the phenotype and requested SNPs in x.

If method = "lm" and response = "quantitative" are used, a simple linear regression is per-
formed to test each SNP in the considered interval. Precisely, the following model is considered for
each SNP,

\[ Y = (X|PC)\alpha + G\beta + \varepsilon \]
with $\varepsilon \sim N(0, \sigma^2 I_n)$, $G$ the genotype vector of the SNP, $X$ the covariates matrix, and $PC$ the matrix of the first $p$ principal components. A Wald test is performed, independently of the value of test. If method = "lm" and response = "binary", a similar model is used for a logistic regression (Wald test). If method = "lmm" and response = "quantitative", the following model in considered for each SNP

$$Y = (X|PC)\alpha + G\beta + \omega + \varepsilon$$

with $\omega \sim N(0, \tau K)$ and $\varepsilon \sim N(0, \sigma^2 I_n)$. $G$ is the genotype vector of the SNP, $K$ is a Genetic Relationship Matrix (GRM) $X$ the covariates matrix, and $PC$ the matrix of the first $p$ principal components. If test = "score", all parameters are estimated with the same procedure as in lmm.aireml and the argument $K$ is used to specify the GRM matrix (or a list of GRM matrices for inclusion of several random effects in the model). If $p$ is positive, the parameter eigenK needs to be given as well. For Wald and LRT tests the procedure used is the same as in lmm.diago and eigenK is used to specify the GRM matrix.

If method = "lmm" and response = "binary", the following model in considered for each SNP

$$\text{logit}(P[Y = 1|X,G,\omega]) = X\alpha + G\beta + \omega$$

with $\omega \sim N(0, \tau K)$. $G$ is the genotype vector of the SNP, $K$ is a Genetic Relationship Matrix (GRM), $X$ the covariable matrix. A score test is performed, independently of the value of test. All parameters under null model are estimated with the same procedure as in logistic.mm.aireml. In case of convergence problems of the null problem, the user can try several starting values (in particular with parameter tau, trying e.g. tau = 0.1 or another value). It is possible to give a list of matrices in parameter $K$ for inclusion of several random effects in the model. If $p$ is positive, the paramater eigenK needs to be given as well.

Note: this function is not multithreaded. Wald test with Linear Mixed Models are computationally intensive, to run a GWAS with such tests consider using association.test.parallel in package gaston.utils (on github). Association tests with dosages can be done with association.test.dosage and association.test.dosage.parallel in the same package.

**Value**

A data frame, giving for each considered SNP, its position, id, alleles, and some of the following columns depending on the values of method and test:

- **score**: Score statistic for each SNP
- **h2**: Estimated value of $\frac{\tau}{1+\tau}$
- **beta**: Estimated value of $\beta$
- **sd**: Estimated standard deviation of the $\beta$ estimation
- **LRT**: Value of the Likelihood Ratio Test
- **p**: The corresponding p-value

**See Also**

qqplot.pvalues, manhattan, lmm.diago, lmm.aireml, logistic.mm.aireml, optimize
Examples

```r
# Load data
data(TTN)
x <- as.bed.matrix(TTN.gen, TTN.fam, TTN.bim)
standardize(x) <- "p"

# simulate quantitative phenotype with effect of SNP #631
set.seed(1)
y <- x %*% c(rep(0,630),0.5,rep(0,ncol(x)-631)) + rnorm(nrow(x))

# association test with linear model
test <- association.test(x, y, method="lm", response = "quanti")

# a p-values qq plot
qqplot.pvalues(test)

# a small Manhattan plot
# highlighting the link between p-values and LD with SNP #631
lds <- LD(x, 631, c(1,ncol(x)))
manhattan(test, col = rgb(lds,0,0), pch = 20)

# use y to simulate a binary phenotype
y1 <- as.numeric(y > mean(y))

# logistic regression
t_binary <- association.test(x, y1, method = "lm", response = "binary")
# another small Manhattan plot
manhattan(t_binary, col = rgb(lds,0,0), pch = 20)
```

---

**bed.loadings**

**SNP loadings**

---

**Description**

Compute the loadings corresponding to given PCs.

**Usage**

```r
bed.loadings(x, pc)
```

**Arguments**

- `x`: A `bed.matrix`
- `pc`: A matrix with Principal Components in columns

**Value**

A matrix with the corresponding loadings in columns.
Author(s)

Hervé Perdry and Claire Dandine-Roulland

Examples

# load chr2 data set (~10k SNPs in low LD)
\nlx <- read.bed.matrix( system.file("extdata", "chr2.bed", package="gaston") )

# Compute Genetic Relationship Matrix
\nstandardize(x) <- "p"
\nK <- GRM(x)

# Eigen decomposition
\neiK <- eigen(K)
\n# deal with small negative eigen values
\neiK$values[ eiK$values < 0 ] <- 0

# Note: the eigenvectors are normalized, to compute 'true' PCs
# multiply them by the square root of the associated eigenvalues
\nPC <- sweep(eiK$vectors, 2, sqrt(eiK$values), "*")

# Compute loadings for the 2 first PCs
# one can use PC[,1:2] instead of eiK$vectors[,1:2] as well
\nL <- bed.loadings(x, eiK$vectors[,1:2])
\ndim(L)
\nhead(L)

# the loadings are normalized
\ncolSums(L**2)

# Verify that these are loadings
\nhead( (x *%*% L) / sqrt(ncol(x)-1) )
\nhead( PC[,1:2] )

---

bed.matrix-class

Class "bed.matrix"

Description

S4 class for SNP genotype matrices

Objects from the Class

Objects can be created by calls of the form new("bed.matrix", ...).
Slots

ped: data frame containing information for each individual: famid = Family ID, id = Individual ID, father = Father ID, mother = Mother ID, sex = Sex and pheno = Phenotype. Can also contain individuals statistic, for example: N0, N1 and N2 = Number of genotypes equal to 0, 1 and 2 respectively, NAs = Number of missing genotypes, callrate = Individual callrate.

snps: data frame containing information for each SNP: chr = Chromosome, id = SNP ID, dist = Genetic Distance, pos = Physical position, A1 = Reference Allele, A2 = Alternative Allele. Can also contain SNPs statistic, for example: N0, N1 and N2 = Number of genotypes equal to 0, 1 and 2 respectively, NAs = Number of missing genotypes, callrate = SNP callrate, maf = Minor allele frequency), hz = heterozygosity

bed: externalptr (pointing to the genotype matrix).

p: vector or NULL for allelic frequencies (allèle A2).

mu: vector or NULL for genotype means (usually mu = 2*p).

sigma: vector or NULL for genotypic standard deviation

standardize_p: logical. If TRUE, the genotype matrix is standardized using means 2*p and genotypic standard deviation sqrt(2*p*(1-p))

standardize_mu_sigma: logical. If TRUE, the genotype matrix is standardize using means mu and genotypic standard deviation sigma.

For more details please check the vignette.

Methods

[ signature(x = "bed.matrix", i = "numeric" or "logical" or "missing", j = "numeric" or "logical" or "missing", drop = "missing"): Extract a sub-matrix (a new bed.matrix).

%*% signature(x = "bed.matrix", y = "matrix" or "vector"): Right matrix multiplication of the genotype matrix (possibly centered and reduced) with a matrix or a vector.

%*% signature(x = "matrix" or "vector", y = "bed.matrix"): Left matrix multiplication of the genotype matrix with a matrix or a vector.

as.matrix signature(x = "bed.matrix"): Convert a bed.matrix into a matrix. The resulting matrix can be huge, use this method only for a small bed.matrix!

standardize signature(x = "bed.matrix"): Get the standardize parameter of bed.matrix. Can be "none", "p" or "mu_sigma".

standardize<- signature(x = "bed.matrix"): Set the standardize parameter of a bed.matrix.

dim signature(x = "bed.matrix"): Get the number of individuals (rows) and the number of SNPs (columns).

head signature(x = "bed.matrix"): Print the head of the genotype matrix of a bed.matrix object.

mu signature(x = "bed.matrix"): Get the mu slot of a bed.matrix.
mu <- signature(x = "bed.matrix"):
   Set the mu slot of a bed.matrix.

p signature(x = "bed.matrix"):
   Get the p slot of a bed.matrix.

p <<- signature(x = "bed.matrix"):
   Set the p slot of a bed.matrix.

show signature(object = "bed.matrix"):
   Displays basic information about a bed.matrix.

sigma signature(x = "bed.matrix"):
   Get the sigma slot of a bed.matrix.

sigma <<- signature(x = "bed.matrix"):
   Set the sigma slot of a bed.matrix.

cbind signature(... = "bed.matrix"):
   Combine a sequence of bed.matrix by columns.

rbind signature(... = "bed.matrix"):
   Combine a sequence of bed.matrix by rows.

Author(s)

Hervé Perdry and Claire Dandine-Roulland

See Also

read.bed.matrix, write.bed.matrix, set.stats, select.snps, select.inds, GRM

Examples

showClass("bed.matrix")

# Conversion example
data(LCT)
x1 <- as(LCT.gen, "bed.matrix")
x1
head(x1@ped)
head(x1@snps)

# the function as.bed.matrix is an alternative
x2 <- as.bed.matrix(LCT.gen, LCT.fam, LCT.bim)
x2
head(x2@ped)
head(x2@snps)
Description

Compute the Dominance Matrix

Usage

```r
DM(x, which.snps, autosome.only = TRUE, chunk = 1L)
```

Arguments

- `x`: A `bed.matrix`
- `which.snps`: Logical vector, giving which SNPs to use in the computation. The default is to use all autosomal SNPs
- `autosome.only`: If TRUE, only autosomal SNPs will be considered.
- `chunk`: Parameter for the parallelization: how many SNPs are treated by each task

Details

The Dominance Matrix (DM) gives for each pair of individuals an estimation of their probability of sharing two alleles Identical By Descent.

It is computed by a moment estimator, \( \frac{1}{2} ZZ' \) with \( Z \) the matrix with entries \( \frac{p}{1-p}, -1, \frac{1-p}{p} \), according to the values 0, 1, 2 in the genotype matrix \( x \) (here \( p \) is the frequency of the alternate allele, and \( q \) is the number of SNPs \( \text{ncol}(x) \)).

Value

A symmetric square matrix of dimension equal to the number of individuals. Each entry can be interpreted as an estimated probability of sharing two alleles IBD — as it is a moment estimator, the value can (and will) fall outside of the range (0,1).

See Also

`GRM`, `reshape.GRM`

Examples

```r
# load chr2 data set (~10k SNPs in low LD)
x <- read.bed.matrix( system.file("extdata", "chr2.bed", package="gaston") )

# Compute Dominance Matrix
D <- DM(x)
dim(D)
```
**Description**

The SNPs in this data frame are as follows:

- **SNP 1.** Unduplicated SNP
- **SNPs 2a and 2b.** Two duplicated SNPs with identical alleles
- **SNPs 3a and 3b.** Two duplicated SNPs with swapped alleles
- **SNPs 4a and 4b.** Two duplicated SNPs with flipped reference strand
- **SNPs 5a and 5b.** Two duplicated SNPs with swapped alleles and flipped reference strand
- **SNPs 6a and 6b.** Two duplicated SNPs with incompatible alleles
- **SNPs 7a and 7b.** Two duplicated SNPs including one monomorphic SNP (one allele set to "0")
- **SNPs 8a, 8b and 8c.** Three duplicated SNPs
- **SNPs 9a, 9b and 9c.** Three duplicated SNPs with incompatible alleles

**Usage**

```r
data(dupli)
```

**Format**

There are three data objects in the dataset:

- **dupli.gen** Genotype matrix
- **dupli.ped** Data frame containing all variables corresponding to a `.fam` file
- **dupli.bim** Data frame containing all variables corresponding to a `.bim` file

**See Also**

`SNP.rm.duplicates`

**Examples**

```r
data(dupli)
x <- as.bed.matrix(dupli.gen, fam = dupli.ped, bim = dupli.bim)
```
**Description**

Compute the Genetic Relationship Matrix

**Usage**

```r
GRM(x, which.snps, autosome.only = TRUE, chunk = 1L)
```

**Arguments**

- `x`: A `bed.matrix`
- `which.snps`: Logical vector, giving which snps to use in the computation. The default is to use all autosomal SNPs
- `autosome.only`: If `TRUE`, only autosomal SNPs will be considered.
- `chunk`: Parameter for the parallelization: how many SNPs are treated by each task

**Details**

The Genetic Relationship Matrix (GRM) is computed by the formula $\frac{1}{q}XX'$, with $X$ the standardized genotype matrix and $q$ the number of SNPs ($\text{ncol}(x)$).

If `x` is not standardized before this computation, the function will use `standardize(x) <- "p"` by default.

**Value**

The GRM is a symmetric square matrix of dimension equal to the number of individuals. Each entry can be interpreted as an estimated kinship coefficient between individuals, although some authors might disagree. Note in particular that some entries will be negative.

**Author(s)**

Hervé Perdry and Claire Dandine-Roulland

**See Also**

- `DM`, `reshape.GRM`, `lmm aireml`, `lmm diago`, `standardize`, `bed.loadings`

**Examples**

```r
# load chr2 data set (~10k SNPs in low LD)
x <- read.bed.matrix(system.file("extdata", "chr2.bed", package="gaston") )

# Compute Genetic Relationship Matrix
K <- GRM(x)
dim(K)
```
is.autosome  

**Autosomes and X, Y, MT chromosomes**

**Description**

Test if a chromosome id corresponds to an autosome or to X, Y, MT chromosomes

**Usage**

```r
is.autosome(chr)
is.chr.x(chr)
is.chr.y(chr)
is.chr.mt(chr)
```

**Arguments**

- `chr`  
  A vector of chromosome ids

**Details**

These functions work by comparing the ids given in parameters with the options `gaston.autosomes`, `gaston.chr.x`, `gaston.chr.y`, `gaston.chr.mt`.

For example, `is.autosome(chr)` is a short cut for `chr %in% getOption("gaston.autosomes")`.

**Value**

A logical vector.

**Author(s)**

Hervé Perdry

---

**LCT**  

**LCT data set**

**Description**

These data have been extracted from the 1000 Genomes data. The data set contains the genotype matrix `LCT.gen`, the pedigree matrix `LCT.fam` and a matrix `LCT.bim`, corresponding to 503 individuals of European populations and 607 SNPs on chromosome 2, on a ~300kb segment containing the Lactase gene. There is also a factor `LCT.pop`, which gives the population from which each individual is drawn (CEU = Utah residents of Northern Western European ancestry, FIN = Finnish, GBR = England and Scotland, IBS = Iberian, TSI = Toscani).

Note that the SNP rs4988235 is associated with lactase persistence / lactose intolerance.
**LD**

**Usage**

```r
data(LCT)
```

**Format**

There are three data objects in the dataset:

- `LCT.gen` Genotype matrix
- `LCT.fam` Data frame containing all variables corresponding to a .fam file
- `LCT.bim` Data frame containing all variables corresponding to a .bim file
- `LCT.pop` Factor giving the population from which each individual is drawn

**Source**

The data were obtained from the 1000 Genomes project (see [https://www.internationalgenome.org/](https://www.internationalgenome.org/)).

**References**


**Examples**

```r
data(LCT)
x <- as.bed.matrix(LCT.gen, LCT.fam, LCT.bim)
x
which(x@snps$id == "rs4988235")
```

---

**LD**

*Linkage Disequilibrium*

**Description**

Compute Linkage Disequilibrium (LD) between given SNPs.

**Usage**

```r
LD(x, lim, lim2, measure = c("r2", "r", "D"), trim = TRUE)
```

**Arguments**

- `x` A `bed.matrix`
- `lim` Range of SNPs for which the LD is computed
- `lim2` (Optional) Second range of SNPs (see Details)
- `measure` The LD measure
- `trim` Logical. If TRUE, the values above 1 or below -1 are replaced by 1 and -1 respectively.
Details

If lim2 is missing, the LD is computed between all SNPs with indices between lim[1] and lim[2]; else, the LD is computed between the SNPs in the range given by lim and those in the range given by lim2.

Note that the LD estimates are moment estimates (which are less precise than Maximum Likelihood Estimates). If standardize(x) = "none", x will be standardized using x@mu and x@sigma. If standardize(x) = "p", the moment estimates can produce r values outside of the range [-1:1], hence the parameter trim. We recommend to set standardize(x) <- "mu" (trimming can still be necessary due to rounding errors).

Value

A matrix of LD values.

Author(s)

Hervé Perdry and Claire Dandine-Roulland

See Also

LD.thin, LD.plot

Examples

# Load data
data(AGT)
x <- as.bed.matrix(AGT.gen, AGT.fam, AGT.bim)

# Compute LD
ld.x <- LD(x, c(1,ncol(x)))

# Plot a tiny part of the LD matrix
LD.plot( ld.x[1:20,1:20], snp.positions = x@snp$pos[1:20] )

LD.clump

LD clumping

Description

Construct group of SNPs in LD with 'top associated SNPs'

Usage

LD.clump(x, p, r2.threshold, p.threshold, max.dist = 500e3)
**Arguments**

- **x**: A `bed.matrix`
- **p**: A vector of p-values, or a data frame including p-values, such as sent back by `association.test`
- **r2.threshold**: The maximum LD (measured by $r^2$) between SNPs in a group
- **p.threshold**: The threshold used to define associated SNPs
- **max.dist**: The maximum distance for which the LD is computed

**Details**

The p-values provided through argument p are assumed to correspond to the result of an association test with the SNPs of x.

The aim of the function is to construct cluster of SNPs in strong LD with associated SNPs. The algorithm first seeks the SNP with the lowest p-value (below `p.threshold`) : this SNP will be the 'index' of a cluster. The corresponding cluster is constructed by aggregating SNPs that are in LD (above `r2.threshold`) with the index. The cluster’s name is the position of the index SNP. The processus is repeated on the SNPs which are not yet attributed to a cluster, until there is no associated SNP (ie SNP with a p-value below `threshold`) left. The remaining SNPs are attributed to cluster 0.

The LD is computed only for SNP pairs for which distance is inferior to `max.dist`, expressed in number of bases: above this distance it is assumed to be null.

**Value**

If `p` was a data frame, then the function returns the same data frame with extra columns, `cluster` and `is.index`. If `p` was a vector of p-values, it returns a data frame with columns `chr`, `id`, `pos`, `p`, `cluster` and `is.index`.

**See Also**

`LD`, `LD.thin`

**Examples**

```r
# Construct a bed matrix
x <- as.bed.matrix(TTN.gen, TTN.fam, TTN.bim)
standardize(x) <- "p"

# simulate quantitative phenotype with effect of SNPs #108 and #631
beta <- numeric(ncol(x))
beta[c(108,631)] <- 0.5
set.seed(1)
y <- x %*% beta + rnorm(nrow(x))

# association test with linear model
test <- association.test(x, y, method="lm", response = "quanti")

# LD clumping
```
test <- LD.clump(x, test, r2.threshold = 0.25, p.threshold = 1e-8)

# use as.factor for a quick-and-dirty cluster colouring on the manhattan plot
manhattan(test, col = as.factor(test$cluster), pch = 20)

---

**LD.plot**

*Plot Linkage Disequilibrium*

**Description**

Pretty plot of a Linkage Disequilibrium (LD) matrix

**Usage**

```r
LD.plot(LD, snp.positions, max.dist = Inf, depth = nrow(LD),
        graphical.par = list(mar = c(0,0,0,0)), cex.ld, cex.snp,
        polygon.par = list(border = "white"),
        color.scheme = function(ld) rgb(1,1-abs(ld),1-abs(ld)),
        write.snp.id = TRUE, write.ld = function(ld) sprintf("%.2f", ld),
        draw.chr = TRUE, above.space = 1 + 2*write.snp.id + draw.chr,
        below.space = 1, pdf.file, finalize.pdf = TRUE)
```

**Arguments**

- **LD**: A symmetric LD matrix (such as produced by LD
- **snp.positions**: A vector of SNP positions
- **max.dist**: Maximal distance above which the LD is not plotted
- **depth**: Maximal number of neighbouring SNPs for which the LD is plotted
- **graphical.par**: A list of graphical parameters for function `par`
- **cex.ld**: The magnification to be used for LD values (if missing, an ad-hoc value is computed)
- **cex.snp**: The magnification to be used for SNPs ids (if missing, an ad-hoc value is computed)
- **polygon.par**: A list of parameters for function `polygon`
- **color.scheme**: A function to set the background color of a cell
- **write.snp.id**: Logical. If TRUE, SNP ids will be displayed above the plot
- **write.ld**: NULL, or a function which outputs the string used for displaying a LD value in a cell
- **draw.chr**: Logical. If TRUE, a chromosome with SNP positions is sketched above the plot
- **above.space**: Space above the plot (in user units = height of a cell)
- **below.space**: Space below the plot (in user units = height of a cell)
- **pdf.file**: The name of a pdf file in which to plot the LD matrix. If missing, current plot device will be used
- **finalize.pdf**: Logical. If TRUE, `dev.off()` will be called to finalize the pdf file
LD.thin

LD thinning

Description

Select SNPs in LD below a given threshold.

Usage

LD.thin(x, threshold, max.dist = 500e3, beg = 1, end = ncol(x),
which.snps, dist.unit = c("bases", "indices", "cM"),
extract = TRUE, keep = c("left", "right", "random"))
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**Arguments**

- **x**
  - A *bed.matrix*
- **threshold**
  - The maximum LD (measured by $r^2$) between SNPs
- **max.dist**
  - The maximum distance for which the LD is computed
- **beg**
  - The index of the first SNP to consider
- **end**
  - The index of the last SNP to consider
- **which.snps**
  - Logical vector, giving which SNPs are considered. The default is to use all SNPs
- **dist.unit**
  - Distance unit in **max.dist**
- **extract**
  - A logical indicating whether the function returns a *bed.matrix* (TRUE) or a logical vector indicating which SNPs are selected (FALSE)
- **keep**
  - Which SNP is selected in a pair with LD above **threshold**

**Details**

The SNPs to keep are selected by a greedy algorithm. The LD is computed only for SNP pairs for which distance is inferior to **max.dist**, expressed in number of bases if **dist.unit** = "bases", in number of SNPs if **dist.unit** = "indices", or in centiMorgan if **dist.unit** = "cM".

The argument **which.snps** allows to consider only a subset of SNPs.

The algorithm tries to keep the largest possible number of SNPs: it is not appropriate to select tag-SNPs.

**Value**

If **extract** = TRUE, a *bed.matrix* extracted from **x** with SNPs in pairwise LD below the given **threshold**. If **extract** = FALSE, a logical vector of length **end** - **beg** + 1, where TRUE indicates that the corresponding SNPs is selected.

**Author(s)**

Hervé Perdry and Claire Dandine-Roulland

**See Also**

*LD, set.dist*

**Examples**

```r
# Load data
data(TTN)
x <- as.bed.matrix(TTN.gen, TTN.fam, TTN.bim)

# Select SNPs in LD $r^2 < 0.4$, max.dist = 500 kb
y <- LD.thin(x, threshold = 0.4, max.dist = 500e3)
y

# Verifies that there is no SNP pair with LD $r^2 > 0.4$
# (note that the matrix ld.y has ones on the diagonal)
```
```r
ld.y <- LD(y, lim = c(1, ncol(y)))
sum(ld.y > 0.4)
```

---

**lik.contour**

*Contour plot for two parameters likelihood*

---

**Description**

Create a contour plot (superimposed with a heat map)

**Usage**

```r
lik.contour(x, y, z, levels = NULL, nlevels = 11, heat = TRUE, col.heat = NULL, ...)
```

**Arguments**

- `x, y, z`: As in `contour`
- `levels`: As in `contour`. If `NULL`, the function computes appropriate levels.
- `nlevels`: As in `contour`
- `heat`: If `TRUE`, a heat map is superimposed to the contour plot
- `col.heat`: Vector of heat colors
- `...`: Additional arguments to `image` and `contour`

**Details**

This function is a wrapper for `contour`, with a different method to compute a default value for `levels`. If `heat = TRUE`, a heatmap produced by `image` is added to the plot. See `contour` for details on parameters.

**Author(s)**

Hervé Perdry and Claire Dandine-Roulland

**See Also**

- `lmm.diago.likelihood`
- `contour`
- `image`

**Examples**

```r
data(AGT)
x <- as.bed.matrix(AGT.gen, AGT.fam, AGT.bim)

# Compute Genetic Relationship Matrix
K <- GRM(x)

# eigen decomposition of K
eiK <- eigen(K)
```
# simulate a phenotype
set.seed(1)
y <- 1 + lmm.simu(tau = 1, sigma2 = 2, eigenK = eiK)$y

# Likelihood
TAU <- seq(0.5,2.5,length=30)
S2 <- seq(1,3,length=30)
lik1 <- lmm.diago.likelihood(tau = TAU, s2 = S2, Y = y, eigenK = eiK)
lik.contour(TAU, S2, lik1, heat = TRUE, xlab = "tau", ylab = "sigma^2")

---

**lmm.aireml**

Linear mixed model fitting with AIREML

**Description**

Estimate the parameters of a linear mixed model, using Average Information Restricted Maximum Likelihood (AIREML) algorithm.

**Usage**

```r
lmm.aireml(Y, X = matrix(1, nrow = length(Y)), K,
EMsteps = 0L, EMsteps_fail = 1L, EM_alpha = 1,
min_tau, min_s2 = 1e-06, theta, constraint = TRUE, max_iter = 50L,
eps = 1e-05, verbose = getOption("gaston.verbose", TRUE),
contrast = FALSE, get.P = FALSE)
```

**Arguments**

- **Y**
  - Phenotype vector

- **X**
  - Covariable matrix. By default, a column of ones to include an intercept in the model

- **K**
  - A positive definite matrix or a list of such matrices

- **EMsteps**
  - Number of EM steps ran prior the AIREML

- **EMsteps_fail**
  - Number of EM steps performed when the AIREML algorithm fail to improve the likelihood value

- **EM_alpha**
  - Tweaking parameter for the EM (see Details)

- **min_tau**
  - Minimal value for model parameter \( \tau \) (if missing, will be set to \( 10^{-6} \))

- **min_s2**
  - Minimal value for model parameter \( \sigma^2 \)

- **theta**
  - (Optional) Optimization starting point \( \theta = c(\sigma^2, \tau) \)

- **constraint**
  - If TRUE, the model parameters respect the contraints given by min_tau and min_s2

- **max_iter**
  - Maximum number of iterations

- **eps**
  - The algorithm stops when the gradient norm is lower than this parameter
verbose If TRUE, display information on the algorithm progress
contrast If TRUE, use a contrast matrix to compute the Restricted Likelihood (usually slower)
get.P If TRUE, the function sends back the last matrix $P$ computed in the optimization process

Details

Estimate the parameters of the following linear mixed model, using AIREML algorithm:

$$Y = X\beta + \omega_1 + \ldots + \omega_k + \varepsilon$$

with $\omega_i \sim N(0, \tau_i K_i)$ for $i \in 1, \ldots, k$ and $\varepsilon \sim N(0, \sigma^2 I_n)$.

The variance matrices $K_1, \ldots, K_k$, are specified through the parameter K.

If EMsteps is positive, the function will use this number of EM steps to compute a better starting point for the AIREML algorithm. Setting EMsteps to a value higher than max_iter leads to an EM optimization. It can happen that after an AIREML step, the likelihood did not increase: if this happens, the functions falls back to EMsteps_fail EM steps. The parameter EM_alpha can be set to a value higher than 1 to attempt to accelerate EM convergence; this could also result in uncontrolled behaviour and should be used with care.

After convergence, the function also compute Best Linear Unbiased Predictors (BLUPs) for $\beta$ and $\omega$, and an estimation of the participation of the fixed effects to the variance of $Y$.

Value

A named list with members:

- `sigma2` Estimate of the model parameter $\sigma^2$
- `tau` Estimate(s) of the model parameter(s) $\tau_1, \ldots, \tau_k$
- `logL` Value of log-likelihood
- `logL0` Value of log-likelihood under the null model (without random effect)
- `niter` Number of iterations done
- `norm_grad` Last computed gradient’s norm
- `P` Last computed value of matrix $P$ (see reference)
- `Py` Last computed value of vector $Py$ (see reference)
- `BLUP_omega` BLUPs of random effects
- `BLUP_beta` BLUPs of fixed effects $\beta$
- `varbeta` Variance matrix for $\beta$ estimates
- `varXbeta` Participation of fixed effects to variance of $Y$

If `get.P = TRUE`, there is an additional member:

- `P` The last matrix $P$ computed in the AIREML step

Author(s)

Hervé Perdry and Claire Dandine-Roulland
References


See Also

lmm.diago, logistic.mm.aireml, lmm.simu

Examples

```r
# Load data
data(AGT)
x <- as.bed.matrix(AGT.gen, AGT.fam, AGT.bim)

# Compute Genetic Relationship Matrix
standardize(x) <- "p"
K <- GRM(x)

# Simulate a quantitative genotype under the LMM
set.seed(1)
y <- 1 + x %*% rnorm(ncol(x), sd = 1)/sqrt(ncol(x)) + rnorm(nrow(x), sd = sqrt(2))

# Estimates
estimates <- lmm.aireml(y, K = K, verbose = FALSE)
str(estimates)
```

#### lmm.diago

Linear mixed model fitting with the diagonalization trick

**Description**

Estimate the parameters of a linear mixed model, using the "diagonalization trick".

**Usage**

```r
lmm.diago(Y, X = matrix(1, nrow=length(Y)), eigenK, p = 0,
method = c("newton", "brent"), min_h2 = 0, max_h2 = 1,
verbose = getOption("gaston.verbose", TRUE),
tol = .Machine$double.eps^0.25)
```

**Arguments**

- **Y**: Phenotype vector
- **X**: Covariable matrix
- **eigenK**: Eigen decomposition of $K$ (a positive symmetric matrix)
- **p**: Number of Principal Components included in the mixed model with fixed effect
- **method**: Optimization method to use
**Details**

Estimate the parameters of the following linear mixed model, computing the restricted likelihood as in `lmm.diago.likelihood`, and using either a Newton algorithm, or Brent algorithm as in `optimize`:

\[ Y = (X|PC)\beta + \omega + \varepsilon \]

with \( \omega \sim N(0, \tau K) \) and \( \varepsilon \sim N(0, \sigma^2 I_n) \).

The matrix \( K \) is given through its eigen decomposition, as produced by `eigenK = eigen(K, symmetric = TRUE)`.

The matrix \((X|PC)\) is the concatenation of the covariable matrix \( X \) and of the first \( p \) eigenvectors of \( K \), included in the model with fixed effects.

**Value**

If the parameter \( p \) is a scalar, a list with following elements:

- `sigma2` Estimate of the model parameter \( \sigma^2 \)
- `tau` Estimate(s) of the model parameter(s) \( \tau_1, \ldots, \tau_k \)
- `Py` Last computed value of vector Py (see reference)
- `BLUP_omega` BLUPs of random effects
- `BLUP_beta` BLUPs of fixed effects \( \beta \) (only the components corresponding to \( X \))
- `Xbeta` Estimate of \((X|PC)\beta\)
- `varbeta` Variance matrix for \( \beta \) estimates (only the components corresponding to \( X \))
- `varXbeta` Participation of fixed effects to variance of \( Y \)
- `p` Number of Principal Components included in the linear mixed model with fixed effect

If the parameter \( p \) is a vector of length \( >1 \), a list of lists as described above, one for each value in \( p \).

**Author(s)**

Hervé Perdry and Claire Dandine-Roulland

**See Also**

`lmm.diago.likelihood`, `lmm.aireml`, `optimize`
Examples

# Load data
data(AGT)
x <- as.bed.matrix(AGT.gen, AGT.fam, AGT.bim)

# Compute Genetic Relationship Matrix
K <- GRM(x)

# eigen decomposition of K
eiK <- eigen(K)

# simulate a phenotype
set.seed(1)
y <- 1 + lmm.simu(tau = 1, sigma2 = 2, eigenK = eiK)$y

# Estimations
R <- lmm.diago(Y = y, eigenK = eiK, p = c(0,10))
str(R)

Description

Compute the Restricted or the Full Likelihood of a linear mixed model, using the "diagonalization trick".

Usage

lmm.diago.likelihood(tau, s2, h2, Y, X, eigenK, p = 0)
lmm.diago.profile.likelihood(tau, s2, h2, Y, X, eigenK, p = 0)

Arguments

tau  Value(s) of model parameter (see Details)
s2   Value(s) of model parameter (see Details)
h2   Value(s) of heritability (see Details)
Y    Phenotype vector
X    Covariable matrix
eigenK   Eigen decomposition of $K$ (a positive symmetric matrix)
p   Number of Principal Components included in the mixed model with fixed effect
Details

Theses function respectively compute the Restricted and the Profile Likelihood under the linear mixed model

\[ Y = (X'|PC)\beta + \omega + \varepsilon \]

with \( \omega \sim N(0, \tau K) \) and \( \varepsilon \sim N(0, \sigma^2 I_n) \).

The matrix \( K \) is given through its eigen decomposition, as produced by \( \text{eigenK} = \text{eigen}(K, \text{symmetric} = \text{TRUE}) \). The matrix \( (X'|PC) \) is the concatenation of the covariable matrix \( X \) and of the first \( p \) eigenvectors of \( K \), included in the model with fixed effects.

If both \( \tau \) and \( s^2 \) (for \( \sigma^2 \)) are provided, \( \text{lmm.diago.likelihood} \) computes the restricted likelihood for these values of the parameters; if these parameters are vectors of length \( > 1 \), then a matrix of likelihood values is computed.

The function \( \text{lmm.diago.profile.likelihood} \) computes the full likelihood, profiled for \( \beta \). That is, the value \( \beta \) which maximizes the full likelihood for the given values of \( \tau \) and \( \sigma^2 \) is computed, and then the full likelihood is computed.

If \( h^2 \) is provided, both functions compute \( \tau \) and \( \sigma^2 \) which maximizes the likelihood under the constraint \( \frac{\tau}{\tau + \sigma^2} = h^2 \), and output these values as well as the likelihood value at this point.

Value

If \( \tau \) and \( s^2 \) are provided, the corresponding likelihood values.

If \( \tau \) or \( s^2 \) are missing, and \( h^2 \) is provided, a named list with members

- \( \text{tau} \) Corresponding values of \( \tau \)
- \( \text{sigma2} \) Corresponding values of \( \sigma^2 \)
- \( \text{likelihood} \) Corresponding likelihood values

Author(s)

Hervé Perdry and Claire Dandine-Roulland

See Also

- \( \text{lmm.restricted.likelihood} \)
- \( \text{lmm.profile.restricted.likelihood} \)
- \( \text{lmm.diago} \)
- \( \text{lmm aireml} \)

Examples

# Load data
data(AGT)
x <- as.bed.matrix(AGT.gen, AGT.fam, AGT.bim)

# Compute Genetic Relationship Matrix
K <- GRM(x)

eiK <- eigen(K)

# eigen decomposition of K

eiK <- eigen(K)

# simulate a phenotype
```r
set.seed(1)
y <- 1 + lmm.simu(tau = 1, sigma2 = 2, eigenK = eiK)$y

# Likelihood
TAU <- seq(0.5,1.5,length=30)
S2 <- seq(1,3,length=30)
lik1 <- lmm.diago.likelihood(tau = TAU, s2 = S2, Y = y, eigenK = eiK)

H2 <- seq(0,1,length=51)
lik2 <- lmm.diago.likelihood(h2 = H2, Y = y, eigenK = eiK)

# Plotting
par(mfrow=c(1,2))
lik.contour(TAU, S2, lik1, heat = TRUE, xlab = "tau", ylab = "sigma^2")
lines(lik2$tau, lik2$sigma2)
plot(H2, exp(lik2$likelihood), type="l", xlab="h^2", ylab = "likelihood")
```

---

### lmm.restricted.likelihood

**Likelihood of a linear mixed model**

**Description**

Compute the Restricted or the Full Likelihood of a linear mixed model.

**Usage**

```r
lmm.restricted.likelihood(Y, X = matrix(1, nrow = length(Y)), K, tau, s2)
lmm.profile.restricted.likelihood(Y, X = matrix(1, nrow = length(Y)), K, h2)
```

**Arguments**

- **Y** Phenotype vector
- **X** Covariable matrix
- **K** A positive definite matrix or a list of such matrices
- **tau** Value(s) of parameter(s) $\tau$
- **s2** Value of parameter $\sigma^2$
- **h2** Value(s) of heritability

**Details**

Theses function respectively compute the Restricted and the Profile Likelihood under the linear mixed model

$$Y = X\beta + \omega_1 + \ldots + \omega_k + \varepsilon$$

with $\omega_i \sim N(0, \tau_i K_i)$ for $i \in 1,\ldots,k$ and $\varepsilon \sim N(0, \sigma^2 I_n)$. 
The variance matrices $K_1, ..., K_k$, are specified through the parameter $K$. The parameter $tau$ should be a vector of length $k$.

The function `lmm.restricted.likelihood` computes the restricted likelihood for the given values of $\tau$ and $\sigma^2$. Whenever $k = 1$, it is similar to `lmm.diago.likelihood(tau, s2, Y = Y, X = X, eigenK = eigen(K))` which should be preferred (with a preliminary computation of `eigen(K)`).

The function `lmm.profile.restricted.likelihood` computes a profile restricted likelihood: the values of $\tau$ and $\sigma^2$ which maximizes the likelihood are computed under the constraint $\frac{\tau}{\tau + \sigma^2} = h^2$, and the profiled likelihood value for these parameters is computed. Whenever $k = 1$, it is similar to `lmm.diago.likelihood(h2 = h2, Y = Y, X = X, eigenK = eigen(K))`.

### Value

The restricted likelihood value.

### Author(s)

Hervé Perdry and Claire Dandine-Roulland

### See Also

`lmm.diago.likelihood`, `lmm.diago`, `lmm.aireml`

### Examples

```r
# Load data
data(AGT)
x <- as.bed.matrix(AGT.gen, AGT.fam, AGT.bim)

# Compute Genetic Relationship Matrix and its eigen decomposition
K <- GRM(x)
eiK <- eigen(K)

# simulate a phenotype
set.seed(1)
y <- 1 + lmm.simu(tau = 1, sigma2 = 2, eigenK = eiK)$y

# compute restricted likelihood for tau = 0.2 and s2 = 0.8
lmm.restricted.likelihood(y, K=K, tau = 0.2, s2 = 0.8)

# compute profile restricted likelihood for h2 = 0.2
lmm.profile.restricted.likelihood(y, K=K, h2 = 0.2)

# identity with the values computed with the diagonalisation trick
lmm.diago.likelihood(tau = 0.2, s2 = 0.8, Y = y, eigenK = eiK)
lmm.diago.likelihood(h2 = 0.2, Y = y, eigenK = eiK)
```
Description

Simulate data under a linear mixed model, using the eigen decomposition of the variance matrix.

Usage

```r
lmm.simu(tau, sigma2, K, eigenK = eigen(K), X, beta)
```

Arguments

- `tau`: Model parameter
- `sigma2`: Model parameter
- `K`: (Optional) A positive symmetric matrix
- `eigenK`: Eigen decomposition of `K`
- `X`: Covariable matrix
- `beta`: Fixed effect vector of covariables

Details

The data are simulated under the following linear mixed model:

\[ Y = X\beta + \omega + \varepsilon \]

with \( \omega \sim N(0, \tau K) \) and \( \varepsilon \sim N(0, \sigma^2 I_n) \).

The simulation uses \( K \) only through its eigen decomposition; the parameter \( K \) is therefore optional.

Value

A named list with two members:

- `y`: Simulated value of \( Y \)
- `omega`: Simulated value of \( \omega \)

Author(s)

Hervé Perdry and Claire Dandine-Roulland

See Also

`random.pm`
Examples

```r
# generate a random positive matrix
set.seed(1)
R <- random.pm(503)

# simulate data with a "polygenic component"
y <- lmm.simu(0.3, 1, eigenK = R$eigen)
str(y)
```

---

**logistic.mm aireml**

*Logistic mixed model fitting with Penalized Quasi-Likelihood / AIREML*

---

**Description**

Estimate the parameters of a logistic linear mixed model using the Penalized Quasi-Likelihood with an AIREML step for the linear model.

**Usage**

```r
logistic.mm.aireml(Y, X = matrix(1, nrow = length(Y)), K,
                   min_tau, tau, beta, constraint = TRUE, max.iter = 50L, eps = 1e-5,
                   verbose = getOption("gaston.verbose", TRUE), get.P = FALSE, EM = FALSE)
```

**Arguments**

- **Y** Binary phenotype vector
- **X** Covariable matrix. By default, a column of ones to include an intercept in the model
- **K** A positive definite matrix or a list of such matrices
- **min_tau** Minimal value for model parameter \( \tau \) (if missing, will be set to \( 10^{-6} \))
- **tau** (Optional) Optimization starting point for variance component(s) \( \tau \)
- **beta** (Optional) Optimization starting point for fixed effect(s) \( \beta \)
- **constraint** If TRUE, the model parameters respect the constraints given by \( \text{min}_\text{tau} \)
- **max.iter** Maximum number of iterations
- **eps** The algorithm stops when the gradient norm is lower than this parameter
- **verbose** If TRUE, display information on the algorithm progress
- **get.P** If TRUE, the function sends back the last matrix \( P \) computed in the optimization process
- **EM** If TRUE, the AIREML step is replaced by an EM step
Details

Estimate the parameters of the following logistic mixed model:

$$\text{logit}(P|Y = 1|X, \omega_1, \ldots, \omega_k) = X\beta + \omega_1 + \ldots + \omega_k$$

with \(\omega_i \sim N(0, \tau_i K_i)\) for \(i \in 1, \ldots, k\).

The estimation is based on the Penalized Quasi-Likelihood with an AIREML step for the linear model (the algorithm is similar to the algorithm described in Chen et al 2016). If \(EM = \text{TRUE}\) the AIREML step is replaced by an EM step. In this case the convergence will be much slower, you’re advised to use a large value of \(\text{max.iter}\).

The variance matrices \(K_1, \ldots, K_k\), are specified through the parameter \(K\).

After convergence, the function also compute Best Linear Unbiased Predictors (BLUPs) for \(\beta\) and \(\omega\).

Value

A named list with members:

- \(tau\): Estimate(s) of the model parameter(s) \(\tau_1, \ldots, \tau_k\)
- \(niter\): Number of iterations done
- \(P\): Last computed value of matrix \(P\) (see reference)
- \(BLUP_\omega\): BLUPs of random effects
- \(BLUP_\beta\): BLUPs of fixed effects \(\beta\)
- \(var\beta\): Variance matrix for \(\beta\) estimates

If \(get.P = \text{TRUE}\), there is an additional member:

- \(P\): The last matrix \(P\) computed in the AIREML step

References


See Also

lmm.aireml, lmm.diago, lmm.simu

Examples

# Load data
data(AGT)
x <- as.bed.matrix(AGT.gen, AGT.fam, AGT.bim)

# Compute Genetic Relationship Matrix
standardize(x) <- "p"
K <- GRM(x)

# Simulate a quantitative genotype under the LMM
set.seed(1)
mu <- 1 + x %*% rnorm(ncol(x), sd = 2)/sqrt(ncol(x))
pi <- 1/(1+exp(-mu))
y <- 1*( runif(length(pi))<pi )

# Estimates
estimates <- logistic_mm aireml(y, K = K, verbose = FALSE)
str(estimates)

---

**manhattan**

**Manhattan plot**

### Description

Draws a Manhattan plot

### Usage

```r
manhattan(x, bty = "n", chrom.col = c("black", "gray50"), thinning = TRUE, ...)
```

### Arguments

- `x`: A data.frame with columns named `chr`, `pos` and `p`.
- `bty`: Type of box to draw about the plot. Default is to draw none.
- `thinning`: Logical. If TRUE, not all points are displayed.
- `chrom.col`: Alternating colors for chromosomes.
- `...`: Graphical parameters to be passed to `plot`.

### Details

If there is only one chromosome value in `x$chr`, the x-axis will be labeled with the SNP position. In the general case, the x-axis is labeled with the chromosome name and the color of the points alternates between the colors in `chrom.col`.

The default value `bty = "n"` should give the best result for GWAS Manhattan plots. See `par` for other possible values of `bty` and their meaning.

The thinning procedure suppress some points to avoid generating too heavy graphs. The user should check that setting `thinning = FALSE` does not change the final aspect of the plot.

### Value

An invisible copy of `x` is returned, in which a column `coord` has been added if there is more than one chromosome value in `x$chr`. This column contains the x-coordinates of each SNP on the plot, and should prove helpful to annotate it.
qqplot.pvalues

QQ plot of p-values

Description

Draws a QQ plot of p-values

Usage

qqplot.pvalues(p, col.abline = "red", CB = TRUE, col.CB = "gray80", CB.level = 0.95, thinning = TRUE, ...)

Arguments

p A vector of p-values, or a data.frame with a column named p
col.abline Color of the line of slope 1. Set to NA to suppress.
CB Logical. If TRUE, a confidence band is included in the plot.
col.CB The color of the confidence band.
CB.level The level of the confidence band.
thinning Logical. If TRUE, not all points are displayed.
... Graphical parameters to be passed to plot and points

Details

The QQ plot is on the $-\log_{10}$ scale, as is usual when reporting GWAS results.

The confidence band is not a global confidence region: it is the mere juxtaposition of confidence intervals for each quantile. Moreover it assumes independance of the p-values, an hypothesis which is false for the p-values resulting from an association test in presence of linkage disequilibrium. Therefore, the probability that some of the points lie outside of this band is greater than CB.level.

The thinning procedure suppress some points to avoid generating too heavy graphs. The user should check that setting thinning = FALSE does not change the final aspect of the QQ plot.

See Also

association.test, manhattan, qqplot.plot.default, points.default

Examples

# a vector of uniform p-values
p <- runif(1e6)
qqplot.pvalues(p)
# if we don't thin the points, using pch = "." is advised
qqplot.pvalues(p, pch = ".", cex = 2, thinning = FALSE)
Description

Generate a random definite positive matrix with specified dimension

Usage

random.pm(n, values)

Arguments

n       Dimension of matrix
values   (Optional) A numeric vector of dimension n : the eigenvalues of the matrix

Details

If values isn’t given, it is chosen (deterministically) so that the eigenvalues of the resulting matrix are similar to eigenvalues observed on Genetic Relationship Matrices.

The random matrix is generated as $U\text{diag}(values)U'$ with $U$ a random orthogonal matrix.

Value

A named list with members:

K       A n x n symmetric positive matrix
eigen   The eigen decomposition of K as eigen(K) would output it

See Also

lmm.simu, eigen

Examples

# generate a random positive matrix
set.seed(1)
R <- random.pm(500)
str(R)
read.bed.matrix

Description

Create a bed.matrix from a .bed file, and either a .rds file or a .bim and a .fam file.

Usage

read.bed.matrix(basename, bed = paste(basename, ".bed", sep=""),
               fam = paste(basename, ".fam", sep=""),
               bim = paste(basename, ".bim", sep=""),
               rds = paste(basename, ".rds", sep=""),
               verbose = getOption("gaston.verbose",TRUE))

Arguments

- basename: Basename of all files
- bed: Name of the .bed file
- fam: Name of the .fam file
- bim: Name of the .bim file
- rds: Name of the .rds file (ignored if NULL)
- verbose: If TRUE, display information on the function actions

Details

The .bed, .fam and .bim files follow the PLINK specifications (http://zzz.bwh.harvard.edu/plink/binary.shtml).

If a .rds file exists (created by write.bed.matrix), the .fam and .bim files will be ignored. To ignore an existing .rds file, set rds = NULL.

If the .bed file does not exist, and basename ends by ".bed", the function will try to generate a new basename by trimming the extension out. This allows to write read.bed.matrix("file.bed") instead of read.bed.matrix("file").

If the option gaston.auto.set.stats is set to TRUE (the default), the function set.stats will be called before returning the bed.matrix, unless a .rds file is present: in this case, the bed.matrix obtained is identical to the bed.matrix saved with write.bed.matrix.

Value

A bed.matrix

Author(s)

Hervé Perdry and Claire Dandine-Roulland
read.vcf  

See Also  
write.bed.matrix, set.stats

Examples  

# Read RDS and bed files  
x <- read.bed.matrix( system.file("extdata", "LCT.bed", package="gaston") )  
x

Description  
Create a bed.matrix from VCF files

Usage  
read.vcf(file, max.snps, get.info = FALSE, convert.chr = TRUE,  
verbose = getOption("gaston.verbose",TRUE))

Arguments  
file The name of the VCF file to read  
max.snps The maximal number of SNPs to read  
get.info If TRUE, the INFO field from the VCF file will integrated in @ped$info  
convert.chr If TRUE, chromosomes ids "X", "Y" and "MT" will be converted in their numeric equivalents  
verbose If TRUE, display information on the function progress

Details  
The vcf format is described in https://github.com/samtools/hts-specs

In addition to the usual data in the slot @snps, the bed.matrices produced by read.vcf have @snps$quality and @snps$filter columns corresponding to the QUAL and FILTER fields in the VCF file. If get.info = TRUE, an additionnal column @snps$info is added, corresponding to the INFO field.

The information about individuals in VCF files is incomplete: in the slot @ped, the columns @ped$famid and @ped$id will both contain the sample id; sex and phenotypes will be set to unknown.

The function currently assumes that the GT field is the first field in the genotypes format. If it is not the case, the variants are discarded.

Value  
A bed.matrix
Reshape a Genetic Relationship Matrix

Description

Reshapes a GRM into a data frame listing relationship of (possibly all) pairs of individuals. Options are provided to specify ranges of relationship values to include or exclude. This is useful in the Quality Control process.

Usage

```r
reshape.GRM(K, include = c(-Inf, +Inf), exclude)
```

Arguments

- `K`: A symmetric matrix (such as produced by `GRM`)
- `include`: Range of values to include (default is to include all values)
- `exclude`: Range of values to exclude (default is to exclude nothing)

Details

The relationship between individuals $i$ and $j$ is the coefficient $k_{ij}$ in the matrix $K$. The function lists all pairs $i, j$ with $i < j$ and $k_{ij}$ in the range defined by include and outside the range defined by exclude.

Value

A data frame with three columns named `i`, `j`, `k`.

Author(s)

Hervé Perdry and Claire Dandine-Roulland

See Also

`read.bed.matrix`
score.fixed.linear/score.fixed.logistic

See Also

GRM

Examples

# load chr2 data set (~10k SNPs in low LD)
x <- read.bed.matrix( system.file("extdata", "chr2.bed", package="gaston") )

# Compute Genetic Relationship Matrix
K <- GRM(x)

# List all pairs if individuals with a relationship above 0.07
pairs <- reshape.GRM(K, exclude = c(-Inf, 0.07))

# Exclude first individual from each such pair
x1 <- x[ -pairs$i, ]

score.fixed.linear/score.fixed.logistic

Score Test for Covariates with Fixed Effects in Linear or Logistic Mixed Model

Description

Score Test for association between covariates and phenotype.

Usage

score.fixed.linear(x, Y, X = matrix(1, length(Y)), K, ...)
score.fixed.logistic(x, Y, X = matrix(1, length(Y)), K, ...)

Arguments

x A matrix of covariates
Y The phenotype vector
X A covariable matrix. The default is a column vector of ones, to include an intercept in the model
K A positive definite matrix or a list of such matrices
... Optional arguments used to fit null model in lmm.aireml or logistic.mm.aireml function.
Details

The function `score.fixed.linear` considers the linear mixed model

\[ Y = X\alpha + x\beta + \omega_1 + \ldots + \omega_k + \varepsilon \]

whereas the `score.fixed.logistic` function considers the following logistic model

\[ \logit(P[Y = 1|X, x, \omega_1, \ldots, \omega_k]) = X\alpha + x\beta + \omega_1 + \ldots + \omega_k \]

with \( \omega_j \sim N(0, \tau_j K_j) \) where \( K_j \) are Genetic Relationship Matrix (GRM), \( \varepsilon \sim N(0, \sigma^2 I_n) \) and fixed effects \( \alpha \) and \( \beta \).

The two functions give score test for \( H_0 : \beta = 0 \) vs \( H_1 : \beta \neq 0 \). In this aim, all parameters under null model are estimated with `lmm aireml` or `logistic.mm aireml`.

Value

A named list of values:

- `score` Estimated score
- `p` The corresponding p-value
- `log.p` The logarithm of corresponding p-value

Author(s)

Hervé Perdry and Claire Dandine-Roulland

See Also

- `lmm aireml`, `logistic.mm aireml`

Examples

```r
# Load data
data(AGT)
x <- as.bed.matrix(AGT.gen, AGT.fam, AGT.bim)
standardize(x) <- "p"

# Calculate GRM et its eigen decomposition
k <- GRM(x)
eig <- eigen(k)
eig$values <- round(eig$values, 5)

# generate covariate matrix
set.seed(1)
X <- cbind( rbinom(nrow(x), 1, prob=1/2), rnorm(nrow(x)) )

# simulate quantitative phenotype with polygenic component and covariate effects
y <- X %*% c(-1,0.5) + lmm.simu(0.3,1,eigenK=eig)$y
t <- score.fixed.linear(X, y, K=k, verbose=FALSE)
```
# simulate binary phenotype with polygenic component and covariate effects
mu <- X %*% c(-1,0.5) + lmm.simu(1, 0, eigenK=eig)$y
pi <- 1/(1+exp(-mu))
y <- 1*( runif(length(pi))<pi )

tt <- score.fixed.logistic(X, y, K=k, verbose=FALSE)
str(tt)

score.variance.linear/score.variance.logistic

Variance Component Test in Linear or Logistic Mixed Model

Description
Test if a variance component is significantly different from 0 using score test in a Linear or Logistic Mixed Model.

Usage

score.variance.linear(K0, Y, X = matrix(1, length(Y)), K, acc_davies=1e-10, ...)
score.variance.logistic(K0, Y, X = matrix(1, length(Y)), K, acc_davies=1e-10, ...)

Arguments

K0       A positive definite matrix
Y        The phenotype vector
X        A covariate matrix. The default is a column vector of ones, to include an intercept in the model
K        A positive definite matrix or a list of such matrices
acc_davies  Accuracy in Davies method used to compute p-value
...      Optional arguments used to fit null model with lmm.aireml of logistic.mm.aireml function.

Details

In score.variance.linear, we consider the linear mixed model

\[ Y = X\alpha + \gamma + \omega_1 + \ldots + \omega_k + \varepsilon \]

or, in score.variance.logistic, we consider the following logistic model

\[ \text{logit}(P[Y = 1|X, \omega_1, \ldots, \omega_k]) = X\alpha + \gamma + \omega_1 + \ldots + \omega_k \]
with $\gamma \sim N(0, \kappa K_0)\gamma, \omega_j \sim N(0, \tau_j K_j), \varepsilon \sim N(0, \sigma^2 I_n)$. $K_0$ and $K_j$ are Genetic Relationship Matrix (GRM).

score.variance.linear and score.variance.logistic functions permit to test

$$H_0 : \kappa = 0 \text{ vs } H_1 : \kappa > 0$$

with, for linear mixed model, the score

$$Q = Y'P_0K_0P_0Y/2$$

or, for logistic mixed model, the score

$$Q = (Y - \pi_0)'K_0(Y - \pi_0)/2$$

where $P_0$ is the last matrix $P$ computed in the optimization process for null model and $\pi_0$ the vector of fitted values under null logistic model.

The associated p-value is computed with Davies method.

In this aim, all parameters under null model are estimated with lmm.aireml or logistic.mm.aireml. The p-value corresponding to the estimated score is computed using Davies method implemented in `CompQuadForm` R package.

Value

A named list of values:

- `score` Estimated score
- `p` The corresponding p-value

Author(s)

Hervé Perdry and Claire Dandine-Roulland

References


See Also

lmm.aireml, logistic.mm.aireml

Examples

```r
# Load data
data(AGT)
x <- as.bed.matrix(AGT.gen, AGT.fam, AGT.bim)
standardize(x) <- "p"

# Calculate GRM et its eigen decomposition
K0 <- GRM(x)
eig <- eigen(K0)
```
eig$values <- round(eig$values, 5)

# generate an other positive matrix (to play the role of the second GRM)
set.seed(1)
R <- random.pm(nrow(x))

# simulate quantitative phenotype with two polygenic components
y <- lmm.simu(0.1,1,eigenK=eig)$y + lmm.simu(0.2,0,eigenK=R$eigen)$y

t <- score.variance.linear(K0, y, K=R$K, verbose=FALSE)
str(t)

# simulate binary phenotype with two polygenic components
mu <- lmm.simu(0.1,0.5,eigenK=eig)$y + lmm.simu(0.2,0,eigenK=R$eigen)$y
pi <- 1/(1+exp(-mu))
y <- 1*(runif(length(pi))<pi)

tt <- score.variance.logistic(K0, y, K=R$K, verbose=FALSE)
str(tt)

select.inds

---

select.inds 

Subsetting from a bed.matrix

Description

Returns subset of individuals satisfying a condition.

Usage

select.inds(x, condition)

Arguments

x

A bed.matrix

c Condition used to select individuals

Details

The conditions can involve global variables and all variables defined in the data frame x@ped, in particular

- famid, id, father, mother, sex, pheno
- If basic stats have been computed (see set.stats), N0, N1, N2, NAs, callrate, etc.

If some condition evaluate to NA (e.g. sex == 1 when sex is undefined for some individuals), a warning is issued and the corresponding individuals are removed.
select.snps

Value

A bed.matrix similar to x, containing the selected individuals only

Author(s)

Hervé Perdry and Claire Dandine-Roulland

See Also

select.snps, set.stats

Examples

# Load data
data(LCT)
x <- as.bed.matrix(LCT.gen, LCT.fam, LCT.bim)

# Select individuals with a call rate > 95%
# and more than 5% of heterozygous genotypes
y <- select.inds(x, callrate > 0.95 & N1/(N0+N1+N2) > 0.05)
y

select.snps Subsetting from a bed.matrix

Description

Returns subset of SNPs satisfying a condition.

Usage

select.snps(x, condition)

Arguments

x A bed.matrix

condition Condition used to select SNPs

Details

The conditions can involve global variables and all variables defined in the data frame x@snps, in particular

• chr, id, dist, pos, A1, A2
• If basic stats have been computed (see set.stats), N0, N1, N2, NAs, callrate, maf, hz, etc.
• If Hardy-Weinberg Equilibrium test has been performed (see set.hwe), hwe.

If some condition evaluate to NA (e.g. maf > 0 when maf is undefined for some SNPs), a warning is issued and the corresponding SNPs are removed.
**set.dist**

*Return an updated bed.matrix with genetic distances in centimorgan computed from the variant positions.*

## Description

Returns an updated `bed.matrix` with genetic distances in centimorgan computed from the variant positions.

## Usage

```r
set.dist(x, map, verbose = getOption("gaston.verbose", TRUE))
```

## Arguments

- **x**: A `bed.matrix`
- **map**: The genetic map, given by a list of data frames (see Details)
- **verbose**: If TRUE, display information on the function actions

## Details

A map is a list of data frames, with names corresponding to chromosomes. Each of these data frames must have columns `pos` and `dist` corresponding to positions in bp and cM, respectively.

Such maps are too large to be included in a CRAN package. You can get two genetic maps for the Human Genome (build 36 and 37) in the package `HumanGeneticMap` on GitHub.

To install this package, run

```r
install.packages("HumanGeneticMap", repos="https://genostats.github.io/R/"")
```
You can then use this function with `set.dist(x, HumanGeneticMap::genetic.map.b36)` for example, for positions on the build 36. Use `map = HumanGeneticMap::genetic.map.b37)` for the build 37.

Value

A `bed.matrix` similar to `x`, with updated values in `x@snps$dist`.

**Description**

Returns an updated `bed.matrix` with a new variable for the genomic sex of each individual.

**Usage**

```r
set.genomic.sex(x, plot = FALSE, verbose = getOption("gaston.verbose",TRUE))
```

**Arguments**

- `x` A `bed.matrix`
- `plot` If `TRUE`, plots the variables used for the clustering
- `verbose` If `TRUE`, displays information on the function actions

**Details**

For each individual, the function uses the heterozygosity rate for SNPs on X chromosome, and the call rate for SNPs on the Y chromosomes (both statistics computed by `set.stats`), to cluster the individuals using `kmeans`.

If `plot = TRUE`, a plot is produced with the two variables used and the clusters determined by `kmeans`.

Value

A `bed.matrix` similar to `x`, with a new variable `x@ped$genomic.sex` containing the genomic sex for each individual.

**Author(s)**

Hervé Perdry

**See Also**

`set.stats`, `set.hwe`
set.hwe

Hardy-Weinberg Equilibrium

Description

Returns an updated bed.matrix with a new variable for the \( p\)-values of an Hardy-Weinberg Equilibrium test.

Usage

```
set.hwe(x, method = c("chisquare", "exact"),
       verbose = getOption("gaston.verbose", TRUE))
```

Arguments

- **x**: A bed.matrix
- **method**: The method to use, either "chisquare" or "exact"
- **verbose**: If TRUE, display information on the function actions

Details

Two tests of Hardy-Weinberg Equilibrium are proposed:

- if \( \text{method} = \text{"chisquare"} \), the good old Chi-square test
- if \( \text{method} = \text{"exact"} \), Haldane’s exact test (see Wigginton et al)

The function set.stats will be called first if necessary.

The \( p\)-value is set to 1.0 for SNPs on chromosomes Y and MT. For SNPs on chromosomes X, currently, the test is performed using only the genotypic counts of women.

Value

A bed.matrix similar to x, with a new variable \( x@\text{snps}\$hwe \) containing the \( p\)-values for each SNP.

Author(s)

Hervé Perdry and Claire Dandine-Roulland

References


See Also

set.stats, set.genomic.sex
Examples

# Load data
data(LCT)
x <- as.bed.matrix(LCT.gen, LCT.fam, LCT.bim)

# Compute Hardy-Weinberg p-values
x <- set.hwe(x)
head( x@snps[,c("id","hwe")])

set.stats

Basic statistics for a bed.matrix

Description

Return an updated bed.matrix with new variables for several basic statistics.

Usage

set.stats(x, set.p = TRUE, set.mu_sigma = TRUE, verbose = getOption("gaston.verbose",TRUE))
set.stats.snps(x, set.p = TRUE, set.mu_sigma = TRUE, verbose = getOption("gaston.verbose",TRUE))
set.stats.ped(x, verbose = getOption("gaston.verbose",TRUE))

Arguments

x A bed.matrix
set.p If TRUE, x@p is updated
set.mu_sigma If TRUE, x@mu and x@sigma are updated
verbose If TRUE, display information on the function actions

Details

set.stats is called by default by all functions that create a bed.matrix, unless the global option gaston.auto.set.stats is FALSE (cf example below).

set.stats and set.stats.ped update x@ped, adding the following variables:

- \(N_0\), \(N_1\), \(N_2\) and NAs give for each individual the number of autosomal SNPs with a genotype equal to 0, 1, 2 and missing, respectively
- \(N_0.x\), \(N_1.x\), \(N_2.x\) and NAs.x idem for chromosome X
- \(N_0.y\), \(N_1.y\), \(N_2.y\) and NAs.y idem for chromosome Y
- \(N_0.mt\), \(N_1.mt\), \(N_2.mt\) and NAs.mt idem for mitochondrial SNPs
- callrate, callrate.x, callrate.y, callrate.mt is the individual callrate for autosomal, X, Y, mitochondrial SNPs
set.stats

- hz, hz.x, hz.y, hz.mt is the individual heterozygosity for autosomal, X, Y, mitochondrial SNPs.

set.stats and set.stats.snps update x@snps, adding the following variables:

- N0, N1, N2 and NAs give for each SNP the number of individuals with a genotype equal to 0, 1, 2 and missing, respectively.
- N0.f, N1.f, N2.f and NAs.f give, only for SNPs on chromosome X, the number of female individuals with a genotype equal to 0, 1, 2 and missing, respectively.
- callrate is the SNP callrate (for Y linked SNPs, the callrate is computed using males only).
- maf is the Minor Allele Frequency.
- hz is the SNP heterozygosity (for X linked SNPs, the heterozygosity is computed using females only).

If set.p = TRUE, x@p is updated with the alternate allele frequency.

If set.mu_sigma = TRUE, x@mu is updated with the genotype mean (equal to 2*x@p) and x@sigma with the genotype standard deviation (should be approximately sqrt(2*x@p*(1-x@p)) under Hardy-Weinberg Equilibrium).

Value

A bed.matrix similar to x, with slots updated as described above.

Author(s)

Hervé Perdry and Claire Dandine-Roulland

See Also

set.hwe, set.genomic.sex

Examples

```r
# Disable auto set stats :
options(gaston.auto.set.stats = FALSE)

# Load data
data(TTN)
x <- as.bed.matrix(TTN.gen, TTN.fam, TTN.bim)
str(x@ped)
str(x@snps)

# Compute statistics
x <- set.stats(x)
str(x@ped)
str(x@snps)

# restore default behavior
options(gaston.auto.set.stats = TRUE)
```
SNP.duplicated

*Duplicated SNPs*

**Description**

Determines which SNPs are duplicates of previous SNPs and returns their indices.

**Usage**

```
SNP.duplicated(x, by = "chr:pos")
```

**Arguments**

- `x`: A bed.matrix or a data.frame
- `by`: The criterium used to determined if SNP is duplicated.

**Details**

When `x` is a bed.matrix, the data.frame `x@bed` will be used. The columns that will be taken in consideration are `id`, `chr`, `pos`, `A1`, and `A2`. Not all columns are mandatory, depending on the value of `by`.

The possible values for `by` are "chr:pos", "chr:pos:alleles", "id", "id:chr:pos" and "id:chr:pos:alleles". The default is `by = "chr:pos"`, which means that two SNPs are considered as duplicated if they have same `chr` and `pos` values.

Currently, when using a criterium involving alleles, this function does not consider the possibility of alleles swaps or reference strand flips.

**Value**

An integer vector of indices of SNPs which are duplicates of previously seen SNPs.

**See Also**

`SNP.match`

---

SNP.match

**SNP matching**

**Description**

Returns a vector of the positions of (first) SNP matching of its first argument in its second.

**Usage**

```
SNP.match(x, table, by = "chr:pos:alleles")
```
SNP.rm.duplicates

Arguments

x A bed.matrix or a data.frame
table A bed.matrix or a data.frame
by The criterium used to match SNPs

Details

When x is a bed.matrix, the data.frame x@bed will be used; the same holds for table. The columns that will be taken in consideration are id, chr, pos, A1, and A2. Not all columns are mandatory (see below).

The matching criterium is specified by parameter by. There are 5 possible criteria: (i) matching by chromosome and position with by = "chr:pos", (ii) matching by chromosome, position, and alleles with by = "chr:pos:alleles", (iii) matching by id with by = "id", (iv) matching by id, chromosome and position with by = "id:chr:pos", and (v) matching by id, chromosome, position and alleles with by = "id:chr:pos:alleles".

For each SNP in x, the function looks for the position of the first matching SNP in table. If alleles are included in the matching criterium (i.e., if allele columns A1 and A2 are present in x), the function also checks for SNP matching with swapped alleles (a SNP A/C would match a SNP C/A), or with reference strand flipped (i.e., a SNP A/C would match a SNP T/G) or both (a SNP A/C would match a SNP G/T).

This function should prove useful for data set merging.

Value

A named list with one or three members, depending on whether alleles are included in the matching criterium.

index An integer vector giving the position of first match in table, or NA if there is no match
swap A logical vector indicating whether the match is with swapped alleles
flip A logical vector indicating whether the match is with flipped strand

See Also

SNP.duplicated

SNP.rm.duplicates  Remove duplicated SNPs

Description

Remove duplicated SNPs, taking into account possible genotype mismatches

Usage

SNP.rm.duplicates(x, by = "chr:pos", na.keep = TRUE, incomp.rm = TRUE)
Arguments

- **x**: A bed.matrix
- **by**: The criterium used to determine duplicates
- **na.keep**: If TRUE, duplicated genotypes which are missing for at least one SNP are set to NA.
- **incomp.rm**: If TRUE, duplicated SNPs with allele incompatibility are removed.

Details

Positions of duplicated SNPs are determined using `SNP.duplicated` using parameter `by` (we recommend to use "chr:pos", the default).

Then the function considers the possibility of alleles swaps or reference strand flips. In case of allele incompatibility, the SNPs can be removed or not (according to `incomp.rm` parameter).

When alleles can be matched, only one of the two SNPs is conserved. If there are genotype incompatibilities between the duplicates for some individuals, these genotypes are set to NA. The parameter `na.keep` settles the case of genotypes missing in one of the SNPs.

Moreover the function takes special care of SNP with possible alleles "0". This case occurs for monomorphic SNPs, when data are read from a .ped file: for example, a whole column of A A’s will result in a SNP with alleles "A" and "0". If there’s a duplicate of the SNP with a few, says, A C’s in it, it will have alleles "A" and "C". In that case, `SNP.duplicated` with `by = "chr:pos:alleles"` will not consider these SNPs as duplicates.

Value

A bed.matrix without duplicated SNPs.

See Also

`SNP.match`, `SNP.duplicated`, `dupli`

Examples

```r
# Use example data of 10 individuals with 7 duplicated SNPs
data(dupli)
x <- as.bed.matrix(dupli.gen, fam = dupli.ped, bim = dupli.bim)

# There are any duplicated positions:
dupli.bim

x1 <- SNP.rm.duplicates(x)
# By default (na.keep = TRUE), as soon as the genotype is missing
# in one of the SNPs it is set to missing
# (here looking at duplicated SNPs 2a and 2b)
as.matrix(x[,2:3])
as.matrix(x1[,2])

# With na.keep = FALSE
x2 <- SNP.rm.duplicates(x, na.keep = FALSE)
```
```r
taxes(x2[,2])
# Let's examine SNP 3.a and 3.b (swapped alleles)
taxe(x[,4:5])
taxe(x1[,3])
taxe(x2[,3])
# and so on... (see also ?dupli)
```

Tests

Evaluation of a condition on SNPs or individuals in a `bed.matrix`

Description

Evaluate a condition and return logical vector or indices

Usage

```r
teste.snps(x, condition, na.to.false = TRUE)
teste inds(x, condition, na.to.false = TRUE)
which.e.snps(x, condition)
which.e inds(x, condition)
```

Arguments

- **x**: A `bed.matrix`
- **condition**: Condition used to select SNPs
- **na.to.false**: If TRUE, NAs are replaced by FALSE

Details

The conditions can involve global variables and all variables defined in the data frame `x@snps`, in particular for `test.e.snps` and `which.e.snps`

- `chr`, `id`, `dist`, `pos`, `A1`, `A2`
- If basic stats have been computed (see `set.stats`), `N0`, `N1`, `N2`, `NAs`, `callrate`, `maf`, `hz`, etc.
- If Hardy-Weinberg Equilibrium test has been performed (see `set.hwe`), `hwe`

and for `test.e.inds` and `which.e.inds`

- `famid`, `id`, `father`, `mother`, `sex`, `pheno`
- If basic stats have been computed (see `set.stats`), `N0`, `N1`, `N2`, `NAs`, `callrate`, etc.

Value

teste.snps and test.e.inds return a logical vector of length `ncol(x)` and `nrow(x)` respectively. `which.e.snps(x, condition)` is equivalent to `which(test.e.snps(x, condition))` and `which.e.inds(x, condition)` to `which(test.e.inds(x, condition))`. 
See Also

select.snps, select.inds, set.stats, set.hwe

Examples

```r
# Load data
data(LCT)
x <- as.bed.matrix(LCT.gen, LCT.fam, LCT.bim)

# SNPs and individuals with a callrate < 100%
w <- test.snps(x, callrate < 1)
table(w)
which.snps(x, callrate < 1)
which.inds(x, callrate < 1)
```

---

**TTN**

*TTN data set*

**Description**

These data have been extracted from the 1000 Genomes data. The data set contains the genotype matrix `TTN.gen`, the pedigree matrix `TTN.fam` and a matrix `TTN.bim`, corresponding to 503 individuals of European populations and 733 SNPs on chromosome 2, on a ~600kb segment containing the Titin gene. There is also a factor `TTN.pop`, which gives the population from which each individual is drawn (CEU = Utah residents of Northern Western European ancestry, FIN = Finnish, GBR = England and Scotland, IBS = Iberian, TSI = Toscani).

**Usage**

```r
data(TTN)
```

**Format**

There are three data objects in the dataset:

- `TTN.gen` Genotype matrix
- `TTN.fam` Data frame containing all variables corresponding to a .fam file
- `TTN.bim` Data frame containing all variables corresponding to a .bim file
- `TTN.pop` Factor giving the population from which each individual is drawn

**Source**

The data were obtained from the 1000 Genomes project (see [https://www.internationalgenome.org/](https://www.internationalgenome.org/)).

**References**

write.bed.matrix

Examples

data(TTN)
x <- as.bed.matrix(TTN.gen, TTN.fam, TTN.bim)
x

write.bed.matrix  Save a bed.matrix

Description

Save a bed.matrix in several files

Usage

write.bed.matrix(x, basename, bed = paste(basename, ".bed", sep=""),
                 fam = paste(basename, ".fam", sep=""),
                 bim = paste(basename, ".bim", sep=""),
                 rds = paste(basename, ".rds", sep=""))

Arguments

x  A bed.matrix
basename  Basename of all files
bed  Name of the .bed file
fam  Name of the .fam file
bim  Name of the .bim file
rds  Name of the .rds file

Details

If any of bed, fam, bim and rds is NULL, the corresponding file will not be written.

The .fam and .bim files are useful for reading files with other softwares. The .rds file can be read by read.bed.matrix.

The .bed, .fam and .bim files follow the PLINK specifications (http://zzz.bwh.harvard.edu/plink/binary.shtml).

Author(s)

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See Also

read.bed.matrix, saveRDS
Examples

# Load data
data(LCT)
x <- as.bed.matrix(LCT.gen, LCT.fam, LCT.bim)

# Write object in LCT.bed and LCT.RData
## Not run:
write.bed.matrix(x, "LCT")

## End(Not run)
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