Title  Surrogate Variable Analysis

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Description  The sva package contains functions for removing batch
effects and other unwanted variation in high-throughput
experiment. Specifically, the sva package contains functions
for the identifying and building surrogate variables for
high-dimensional data sets. Surrogate variables are covariates
constructed directly from high-dimensional data (like gene
expression/RNA sequencing/methylation/brain imaging data) that
can be used in subsequent analyses to adjust for unknown,
unmodeled, or latent sources of noise. The sva package can be
used to remove artifacts in three ways: (1) identifying and
estimating surrogate variables for unknown sources of variation
in high-throughput experiments (Leek and Storey 2007 PLoS
Genetics, 2008 PNAS), (2) directly removing known batch
effects using ComBat (Johnson et al. 2007 Biostatistics) and (3) removing
batch effects with known control probes (Leek 2014 biorXiv).
Removing batch effects and using surrogate variables in
differential expression analysis have been shown to reduce
dependence, stabilize error rate estimates, and improve
reproducibility, see (Leek and Storey 2007 PLoS Genetics, 2008
PNAS or Leek et al. 2011 Nat. Reviews Genetics).

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Depends  R (>= 3.2), mgcv, genefilter, BiocParallel

Imports  matrixStats, stats, graphics, utils, limma

Suggests  pamr, bladderbatch, BiocStyle, zebrafishRNASeq, testthat

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biocViews  Immunology, Microarray, StatisticalMethod,
            Preprocessing, MultipleComparison, Sequencing, RNASeq,
            BatchEffect, Normalization

RoxygenNote  6.0.1
ComBat

Adjust for batch effects using an empirical Bayes framework

ComBat allows users to adjust for batch effects in datasets where the batch covariate is known, using methodology described in Johnson et al. 2007. It uses either parametric or non-parametric empirical Bayes frameworks for adjusting data for batch effects. Users are returned an expression matrix that has been corrected for batch effects. The input data are assumed to be cleaned and normalized before batch effect removal.

Usage

ComBat(dat, batch, mod = NULL, par.prior = TRUE, prior.plots = FALSE, mean.only = FALSE, ref.batch = NULL, BPPARAM = bpparam("SerialParam"))

Arguments

dat Genomic measure matrix (dimensions probe x sample) - for example, expression matrix
batch Batch covariate (only one batch allowed)
mod Model matrix for outcome of interest and other covariates besides batch
empirical.controls

par.prior  (Optional) TRUE indicates parametric adjustments will be used, FALSE indicates non-parametric adjustments will be used
prior.plots (Optional) TRUE give prior plots with black as a kernel estimate of the empirical batch effect density and red as the parametric
mean.only  (Optional) FALSE if TRUE ComBat only corrects the mean of the batch effect (no scale adjustment)
ref.batch  (Optional) NULL If given, will use the selected batch as a reference for batch adjustment.
BPPARAM  (Optional) BiocParallelParam for parallel operation

Value
data A probe x sample genomic measure matrix, adjusted for batch effects.

Examples
library(bladderbatch)
data(bladderdata)
dat <- bladderEset[1:50,]

pheno = pData(dat)
edata = exprs(dat)
batch = pheno$batch
mod = model.matrix(~as.factor(cancer), data=pheno)

# parametric adjustment
combat_edata1 = ComBat(dat=edata, batch=batch, mod=NULL, par.prior=TRUE, prior.plots=FALSE)

# non-parametric adjustment, mean-only version
combat_edata2 = ComBat(dat=edata, batch=batch, mod=NULL, par.prior=FALSE, mean.only=TRUE)

# reference-batch version, with covariates
combat_edata3 = ComBat(dat=edata, batch=batch, mod=mod, par.prior=TRUE, ref.batch=3)

empirical.controls A function for estimating the probability that each gene is an empirical control

Description
This function uses the iteratively reweighted surrogate variable analysis approach to estimate the probability that each gene is an empirical control.

Usage
empirical.controls(dat, mod, mod0 = NULL, n.sv, B = 5, type = c("norm", "counts"))
Arguments

dat The transformed data matrix with the variables in rows and samples in columns
mod The model matrix being used to fit the data
mod0 The null model being compared when fitting the data
n.sv The number of surrogate variables to estimate
B The number of iterations of the irwsva algorithm to perform
type If type is norm then standard irwsva is applied, if type is counts, then the moderated log transform is applied first

Value

pcontrol A vector of probabilities that each gene is a control.

Examples

library(bladderbatch)
data(bladderdata)
dat <- bladderEset[1:5000,]

pheno = pData(dat)
edata = exprs(dat)
mod = model.matrix(~as.factor(cancer), data=pheno)

n.sv = num.sv(edata,mod,method="leek")
pcontrol <- empirical.controls(edata,mod,mod0=NULL,n.sv=n.sv,type="norm")

Description

This function does simple linear algebra to calculate f-statistics for each row of a data matrix comparing the nested models defined by the design matrices for the alternative (mod) and null (mod0) cases. The columns of mod0 must be a subset of the columns of mod.

Usage

f.pvalue(dat, mod, mod0)

Arguments

dat The transformed data matrix with the variables in rows and samples in columns
mod The model matrix being used to fit the data
mod0 The null model being compared when fitting the data

Value

p A vector of F-statistic p-values one for each row of dat.
Examples

```r
library(bladderbatch)
data(bladderdata)
dat <- bladderEset[1:50,]

pheno = pData(dat)
edata = exprs(dat)
mod = model.matrix(~as.factor(cancer), data=pheno)
mod0 = model.matrix(~1, data=pheno)

pValues = f.pvalue(edata, mod, mod0)
qValues = p.adjust(pValues, method="BH")
```

---

**fstats**  
A function for quickly calculating f statistics for use in sva

Description

This function does simple linear algebra to calculate f-statistics for each row of a data matrix comparing the nested models defined by the design matrices for the alternative (mod) and and null (mod0) cases. The columns of mod0 must be a subset of the columns of mod.

Usage

```r
fstats(dat, mod, mod0)
```

Arguments

- `dat`  
The transformed data matrix with the variables in rows and samples in columns
- `mod`  
The model matrix being used to fit the data
- `mod0`  
The null model being compared when fitting the data

Value

fstats A vector of F-statistics one for each row of dat.

Examples

```r
library(bladderbatch)
data(bladderdata)
dat <- bladderEset[1:50,]

pheno = pData(dat)
edata = exprs(dat)
mod = model.matrix(~as.factor(cancer), data=pheno)
mod0 = model.matrix(~1, data=pheno)

fs <- fstats(edata, mod, mod0)
```
**fsva**

A function for performing frozen surrogate variable analysis as proposed in Parker, Corrada Bravo and Leek 2013

**Description**

This function performs frozen surrogate variable analysis as described in Parker, Corrada Bravo and Leek 2013. The approach uses a training database to create surrogate variables which are then used to remove batch effects both from the training database and a new data set for prediction purposes. For inferential analysis see `sva`, `svaseq`, with low level functionality available through `irwsva.build` and `ssva`.

**Usage**

```r
fsva(dbdat, mod, sv, newdat = NULL, method = c("fast", "exact"))
```

**Arguments**

- `dbdat` A m genes by n arrays matrix of expression data from the database/training data
- `mod` The model matrix for the terms included in the analysis for the training data
- `sv` The surrogate variable object created by running `sva` on `dbdat` using `mod`.
- `newdat` (optional) A set of test samples to be adjusted using the training database
- `method` If method ="fast" then the SVD is calculated using an online approach, this may introduce slight bias. If method="exact" the exact SVD is calculated, but will be slower

**Value**

- `db` An adjusted version of the training database where the effect of batch/expression heterogeneity has been removed
- `new` An adjusted version of the new samples, adjusted one at a time using the `fsva` methodology.
- `newsv` Surrogate variables for the new samples

**Examples**

```r
library(bladderbatch)
library(pamr)
data(bladderdata)
dat <- bladderEset[1:50,
pheno = pData(dat)
edata = exprs(dat)

set.seed(1234)
trainIndicator = sample(1:57,size=30,replace=FALSE)
testIndicator = (1:57)[-trainIndicator]
trainData = edata[,trainIndicator]
testData = edata[,testIndicator]
trainPheno = pheno[trainIndicator,]
testPheno = pheno[testIndicator,]
```
mydata = list(x=trainData,y=trainPheno$cancer)
mytrain = pamr.train(mydata)
table(pamr.predict(mytrain,testData,threshold=2),testPheno$cancer)

trainMod = model.matrix(~cancer,data=trainPheno)
trainMod0 = model.matrix(~1,data=trainPheno)
trainSv = sva(trainData,trainMod,trainMod0)

fsvaobj = fsva(trainData,trainMod,trainSv,testData)
mydataSv = list(x=fsvaobj$db,y=trainPheno$cancer)
mytrainSv = pamr.train(mydataSv)
table(pamr.predict(mytrainSv,fsvaobj$new,threshold=1),testPheno$cancer)

---

**irwsva.build**  
*A function for estimating surrogate variables by estimating empirical control probes*

**Description**

This function is the implementation of the iteratively re-weighted least squares approach for estimating surrogate variables. As a by-product, this function produces estimates of the probability of being an empirical control. See the function `empirical.controls` for a direct estimate of the empirical controls.

**Usage**

`irwsva.build(dat, mod, mod0 = NULL, n.sv, B = 5)`

**Arguments**

- `dat` The transformed data matrix with the variables in rows and samples in columns
- `mod` The model matrix being used to fit the data
- `mod0` The null model being compared when fitting the data
- `n.sv` The number of surrogate variables to estimate
- `B` The number of iterations of the irwsva algorithm to perform

**Value**

- `sv` The estimated surrogate variables, one in each column
- `pprob.gam` A vector of the posterior probabilities each gene is affected by heterogeneity
- `pprob.b` A vector of the posterior probabilities each gene is affected by mod
- `n.sv` The number of significant surrogate variables
Examples

```r
library(bladderbatch)
data(bladderdata)
dat <- bladderEset[1:5000,]

pheno = pData(dat)
edata = exprs(dat)
mod = model.matrix(~as.factor(cancer), data=pheno)

n.sv = num.sv(edata,mod,method="leek")
res <- irwsva.build(edata, mod, mod0 = NULL,n.sv,B=5)
```

**num.sv**

A function for calculating the number of surrogate variables to estimate in a model

Description

This function estimates the number of surrogate variables that should be included in a differential expression model. The default approach is based on a permutation procedure originally proposed by Buja and Eyuboglu 1992. The function also provides an interface to the asymptotic approach proposed by Leek 2011 Biometrics.

Usage

```r
num.sv(dat, mod, method = c("be", "leek"), vfilter = NULL, B = 20,
      seed = NULL)
```

Arguments

- **dat**: The transformed data matrix with the variables in rows and samples in columns
- **mod**: The model matrix being used to fit the data
- **method**: One of "be" or "leek" as described in the details section
- **vfilter**: You may choose to filter to the vfilter most variable rows before performing the analysis
- **B**: The number of permutations to use if method = "be"
- **seed**: Set a seed when using the permutation approach

Value

- **n.sv**: The number of surrogate variables to use in the sva software

Examples

```r
library(bladderbatch)
data(bladderdata)
dat <- bladderEset[1:5000,]

pheno = pData(dat)
edata = exprs(dat)
```
mod = model.matrix(~as.factor(cancer), data=pheno)

n.sv = num.sv(edata,mod,method="leek")

psva  

A function for estimating surrogate variables with the two step approach of Leek and Storey 2007

Description

This function is the implementation of the two step approach for estimating surrogate variables proposed by Leek and Storey 2007 PLoS Genetics. This function is primarily included for backwards compatibility. Newer versions of the sva algorithm are available through sva, svaseq, with low level functionality available through irwsva.build and ssva.

Usage

psva(dat, batch, ...)

Arguments

dat The transformed data matrix with the variables in rows and samples in columns
batch A factor variable giving the known batch levels
... Other arguments to the sva function.

Value

psva.D Data with batch effect removed but biological heterogeneity preserved

Author(s)

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Examples

library(bladderbatch)
library(limma)
data(bladderdata)
dat <- bladderEset[1:50,]

pheno = pData(dat)
edata = exprs(dat)
batch = pheno$batch
batch.fac = as.factor(batch)

psva_data <- psva(edata,batch.fac)
qsva  

A function for computing quality surrogate variables (qSVs)

Description
This function computes quality surrogate variables (qSVs) from the library-size- and read-length-normalized degradation matrix for subsequent RNA quality correction.

Usage
qsva(degradationMatrix, mod = matrix(1, ncol = 1, nrow = ncol(degradationMatrix)))

Arguments
- degradationMatrix: the normalized degradation matrix, region by sample
- mod: (Optional) statistical model used in DE analysis

Value
the qSV adjustment variables

Examples
```
## Find files
bwPath <- system.file("extdata", "bwtool", package = "sva")

## Read the data
degCovAdj = read.degradation.matrix(
  covFiles = list.files(bwPath,full.names=TRUE),
  sampleNames = list.files(bwPath), readLength = 76,
  totalMapped = rep(100e6,5),type="bwtool")

## Input data
head(degCovAdj)

## Results
qsva(degCovAdj)
```

read.degradation.matrix

A function for reading in coverage data from degradation-susceptible regions

Description
This function reads in degradation regions to form a library-size- and read-length-normalized degradation matrix for subsequent RNA quality correction.
read.degradation.matrix

Usage

read.degradation.matrix(covFiles, sampleNames, totalMapped, readLength = 100, 
normFactor = 8e+07, type = c("bwtool", "region_matrix_single", 
"region_matrix_all"), BPPARAM = bpparam())

Arguments

covFiles coverage file(s) for degradation regions
sampleNames sample names; creates column names of degradation matrix
totalMapped how many reads per sample (library size normalization)
readLength read length in base pairs (read length normalization)
normFactor common library size to normalize to; 80M reads as default
type whether input are individual 'bwtool' output, 'region_matrix' run on individual 
samples, or 'region_matrix' run on all samples together
BPPARAM (Optional) BiocParallelParam for parallel operation

Value

the normalized degradation matrix, region by sample

Examples

# bwtool
bwPath = system.file("extdata", 'bwtool', package = 'sva')
degCovAdj = read.degradation.matrix(
covFiles = list.files(bwPath,full.names=TRUE),
sampleNames = list.files(bwPath), readLength = 76,
totalMapped = rep(100e6,5,type="bwtool")
head(degCovAdj))

# region_matrix: each sample
r1Path = system.file("extdata", 'region_matrix_one', package = 'sva')
degCovAdj1 = read.degradation.matrix(
covFiles = list.files(r1Path,full.names=TRUE),
sampleNames = list.files(r1Path), readLength = 76,
totalMapped = rep(100e6,5,type="region_matrix_single")
head(degCovAdj1))

r2Path = system.file("extdata", 'region_matrix_all', package = 'sva')
degCovAdj2 = read.degradation.matrix(
covFiles = list.files(r2Path,full.names=TRUE),
sampleNames = list.files(r1Path), readLength = 76,
totalMapped = rep(100e6,5,type="region_matrix_all")
head(degCovAdj2)
Description

This function implements a supervised surrogate variable analysis approach where genes/probes known to be affected by artifacts but not by the biological variables of interest are assumed to be known in advance. This supervised sva approach can be called through the `sva` and `svaseq` functions by specifying controls.

Usage

```r
ssva(dat, controls, n.sv)
```

Arguments

- **dat**: The transformed data matrix with the variables in rows and samples in columns
- **controls**: A vector of probabilities (between 0 and 1, inclusive) that each gene is a control. A value of 1 means the gene is certainly a control and a value of 0 means the gene is certainly not a control.
- **n.sv**: The number of surrogate variables to estimate

Value

- **sv**: The estimated surrogate variables, one in each column
- **pprob.gam**: A vector of the posterior probabilities each gene is affected by heterogeneity (exactly equal to controls for ssva)
- **pprob.b**: A vector of the posterior probabilities each gene is affected by mod (always null for ssva)
- **n.sv**: The number of significant surrogate variables

Examples

```r
library(bladderbatch)
data(bladderdata)
dat <- bladderEset[1:5000,]
pheno = pData(dat)
edata = exprs(dat)
mod = model.matrix(~as.factor(cancer), data=pheno)

n.sv = num.sv(edata,mod,method="leek")
set.seed(1234)
controls <- runif(nrow(edata))
ssva_res <- ssva(edata,controls,n.sv)
```
sva: a package for removing artifacts from microarray and sequencing data

Description

sva has functionality to estimate and remove artifacts from high dimensional data. The sva function can be used to estimate artifacts from microarray data. The svaseq function can be used to estimate artifacts from count-based RNA-sequencing (and other sequencing) data. The ComBat function can be used to remove known batch effects from microarray data. The fsva function can be used to remove batch effects for prediction problems.

This function is the implementation of the iteratively re-weighted least squares approach for estimating surrogate variables. As a by product, this function produces estimates of the probability of being an empirical control. See the function empirical.controls for a direct estimate of the empirical controls.

Usage

sva(dat, mod, mod0 = NULL, n.sv = NULL, controls = NULL, method = c("irw", "two-step", "supervised"), vfilter = NULL, B = 5, numSVmethod = "be")

Arguments

dat The transformed data matrix with the variables in rows and samples in columns
mod The model matrix being used to fit the data
mod0 The null model being compared when fitting the data
n.sv The number of surrogate variables to estimate
controls A vector of probabilities (between 0 and 1, inclusive) that each gene is a control. A value of 1 means the gene is certainly a control and a value of 0 means the gene is certainly not a control.
method For empirical estimation of control probes use "irw". If control probes are known use "supervised"
vfilter You may choose to filter to the vfilter most variable rows before performing the analysis. vfilter must be NULL if method is "supervised"
B The number of iterations of the irwsva algorithm to perform
numSVmethod If n.sv is NULL, sva will attempt to estimate the number of needed surrogate variables. This should not be adapted by the user unless they are an expert.

Details

A vignette is available by typing browseVignettes("sva") in the R prompt.

Value

sv The estimated surrogate variables, one in each column
pprob.gam: A vector of the posterior probabilities each gene is affected by heterogeneity
pprob.b A vector of the posterior probabilities each gene is affected by mod
n.sv The number of significant surrogate variables
sva.check

A function for post-hoc checking of an sva object to check for degenerate cases.

Description
This function is designed to check for degenerate cases in the sva fit and fix the sva object where possible.

Usage
sva.check(svaobj, dat, mod, mod0)
Arguments

svaobj  The transformed data matrix with the variables in rows and samples in columns
dat     The data set that was used to build the surrogate variables
mod     The model matrix being used to fit the data
mod0    The null model matrix being used to fit the data

data set that was used to build the surrogate variables
Details

empirical.controls for a direct estimate of the empirical controls.

Value

sv The estimated surrogate variables, one in each column
pprob.gam: A vector of the posterior probabilities each gene is affected by heterogeneity
pprob.b A vector of the posterior probabilities each gene is affected by mod
n.sv The number of significant surrogate variables

Examples

library(bladderbatch)
data(bladderdata)
#dat <- bladderEset
dat <- bladderEset[1:5000,]
pheno = pData(dat)
edata = exprs(dat)
mod = model.matrix(~as.factor(cancer), data=pheno)
mod0 = model.matrix(~1,data=pheno)
n.sv = num.sv(edata,mod,method="leek")
svobj = sva(edata,mod,mod0,n.sv=n.sv)
svacheckobj = sva.check(svobj,edata,mod,mod0)

svaseq A function for estimating surrogate variables for count based RNA-seq data.

Description

This function is the implementation of the iteratively re-weighted least squares approach for estimating surrogate variables. As a by product, this function produces estimates of the probability of being an empirical control. This function first applies a moderated log transform as described in Leek 2014 before calculating the surrogate variables. See the function empirical.controls for a direct estimate of the empirical controls.

Usage

svaseq(dat, mod, mod0 = NULL, n.sv = NULL, controls = NULL,
method = c("irw", "two-step", "supervised"), vfilter = NULL, B = 5,
numSVmethod = "be", constant = 1)
Arguments

dat The transformed data matrix with the variables in rows and samples in columns
mod The model matrix being used to fit the data
mod0 The null model being compared when fitting the data
n.sv The number of surrogate variables to estimate
controls A vector of probabilities (between 0 and 1, inclusive) that each gene is a control. A value of 1 means the gene is certainly a control and a value of 0 means the gene is certainly not a control.
method For empirical estimation of control probes use "irw". If control probes are known use "supervised"
vfilter You may choose to filter to the vfilter most variable rows before performing the analysis. vfilter must be NULL if method is "supervised"
B The number of iterations of the irwsva algorithm to perform
numSVmethod If n.sv is NULL, sva will attempt to estimate the number of needed surrogate variables. This should not be adapted by the user unless they are an expert.
constant The function takes log(dat + constant) before performing sva. By default constant = 1, all values of dat + constant should be positive.

Value

sv The estimated surrogate variables, one in each column
pprob.gam: A vector of the posterior probabilities each gene is affected by heterogeneity
pprob.b A vector of the posterior probabilities each gene is affected by mod
n.sv The number of significant surrogate variables

Examples

library(zebrafishRNASeq)
data(zfGenes)
filter = apply(zfGenes, 1, function(x) length(x[x>5])>=2)
filtered = zfGenes[filter,]
gen = rownames(filtered)[grep("ENS", rownames(filtered))]
controls = grepl("ERCC", rownames(filtered))
group = as.factor(rep("Ctl", "Trt"), each=3))
dat0 = as.matrix(filtered)
mod1 = model.matrix(~group)
mod0 = cbind(mod1[,1])
svseq = svaseq(dat0,mod1,mod0,n.sv=1)$sv
plot(svseq,pch=19,col="blue")
sva_network

A function to adjust gene expression data before network inference

Description

This function corrects a gene expression matrix prior to network inference by returning the residuals after regressing out the top principal components. The number of principal components to remove can be determined using a permutation-based approach using the "num.sv" function with method = "be"

Usage

sva_network(dat, n.pc)

Arguments

dat The raw gene expression data matrix (with variables in rows and samples in columns)
n.pc The number of principal components to remove

Value
dat.adjusted Cleaned gene expression data matrix with the top principal components removed

Examples

library(bladderbatch)
data(bladderdata)
dat <- bladderEset[1:5000,]

pheno = pData(dat)
edata = exprs(dat)
mod = model.matrix(~as.factor(cancer), data=pheno)

n.pc = num.sv(edata, mod, method="be")
dat.adjusted = sva_network(edata, n.pc)

---

twostepsva.build

A function for estimating surrogate variables with the two step approach of Leek and Storey 2007

Description

This function is the implementation of the two step approach for estimating surrogate variables proposed by Leek and Storey 2007 PLoS Genetics. This function is primarily included for backwards compatibility. Newer versions of the sva algorithm are available through sva, svaseq, with low level functionality available through irwsva.build and ssve.
Usage

\texttt{twostepsva.build(dat, mod, n.sv)}

Arguments

dat \hspace{1cm} \text{The transformed data matrix with the variables in rows and samples in columns}
dat \hspace{1cm} \text{The transformed data matrix with the variables in rows and samples in columns}
mod \hspace{1cm} \text{The model matrix being used to fit the data}
n.sv \hspace{1cm} \text{The number of surrogate variables to estimate}

Value

sv \hspace{1cm} \text{The estimated surrogate variables, one in each column}
pprob.gam \hspace{1cm} \text{A vector of the posterior probabilities each gene is affected by heterogeneity}
pprob.b \hspace{1cm} \text{A vector of the posterior probabilities each gene is affected by mod (this is always null for the two-step approach)}
n.sv \hspace{1cm} \text{The number of significant surrogate variables}

Examples

\texttt{library(bladderbatch)}
\texttt{library(limma)}
\texttt{data(bladderdata)}
\texttt{dat <- bladderEset}
\texttt{pheno = pData(dat)}
\texttt{edata = exprs(dat)}
\texttt{mod = model.matrix(~as.factor(cancer), data=pheno)}
\texttt{n.sv = num.sv(edata,mod,method="leek")}
\texttt{svatwostep <- twostepsva.build(edata,mod,n.sv)}
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