Package ‘polyester’

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Title Simulate RNA-seq reads

Description This package can be used to simulate RNA-seq reads from differential expression experiments with replicates. The reads can then be aligned and used to perform comparisons of methods for differential expression.

VignetteBuilder knitr

Depends  R (>= 3.0.0)
Imports Biostrings (>= 2.32.0), IRanges, S4Vectors, logspline, limma, zlibbioc

Suggests knitr, ballgown, markdown

LazyLoad true

biocViews Sequencing, DifferentialExpression

RoxygenNote  7.1.1

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R topics documented:

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add_error

Description

simulate sequencing error by randomly changing the sequenced nucleotide on some of the reads

Usage

add_error(tFrags, error_rate = 0.005)


**add_gc_bias**

**Arguments**

- `tFrags` DNAStringSet representing sequencing reads
- `error_rate` error probability

**Value**

DNAStringSet equivalent to `tFrags` but with random sequencing errors inserted

**Examples**

```r
library(Biostrings)
data(srPhiX174)
set.seed(174)
srPhiX174_withError = add_error(srPhiX174)
#error was introduced in, e.g., position 10 of 2nd string in set.
```

**Description**

Given a matrix with rows corresponding to transcripts and sample-specific GC bias models, bias the count matrix using the bias model.

**Usage**

```r
add_gc_bias(readmat, gcbias, transcripts)
```

**Arguments**

- `readmat` matrix of counts, with rows corresponding to features (transcripts) and columns corresponding to replicates
- `gcbias` List of GC bias models to add to `readmat`. Must have length equal to the number of columns of `readmat`. List elements must either be integers 0 through 7, where 0 means no bias and 1-7 correspond to built-in GC bias models, or objects of class `loess` which can predict a deviation from overall mean count (on the log scale) given a GC percentage between 0 and 1.
- `transcripts` DNAStringSet object containing the sequences of the features (transcripts) corresponding to the rows of `readmat`. Length must be equal to the number of rows in `readmat`.

**Details**

Designed for internal use in `simulate_experiment` functions.

**Value**

matrix of the same size as `readmat`, but with counts for each replicate biased according to `gcbias`. 
Examples

```r
library(Biostrings)
fastapath = system.file("extdata", "chr22.fa", package="polyester")
numtx = count_transcripts(fastapath)
transcripts = readDNAStringSet(fastapath)

# create a count matrix:
readmat = matrix(20, ncol=10, nrow=numtx)
readmat[1:30, 1:5] = 40

# add biases randomly: use built-in bias models
set.seed(137)
biases = sample(0:7, 10, replace=TRUE)
readmat_biased = add_gc_bias(readmat, as.list(biases), transcripts)
```

---

**add_platform_error**  
*Simulate sequencing error using empirical error model*

**Description**

Given a sequencing platform and a set of sequencing reads, add sequencing errors to the reads given a known error profile from the platform.

**Usage**

```r
add_platform_error(tFrags, platform, paired, path = NULL)
```

**Arguments**

- **tFrags**: DNAStringSetList containing error-free sequencing reads. If simulating a paired-end experiment, mate-pairs should appear next to each other in tFrags.
- **platform**: Which sequencing platform should the error model be estimated from? Currently supports 'illumina4', 'illumina5', 'roche454', and 'custom'.
- **paired**: Does tFrags contain paired end reads, with mate pairs next to each other? (TRUE if yes.)
- **path**: if platform is 'custom', provide the path to the error model. After processing the error model with build_error_models.py, you will have either two files (ending in _mate1 and _mate2, if your model was for paired-end reads) or one file (ending in _single, if your model was for single-end reads). The path argument should be the path to the error model up to but not including _mate1/_mate2/_single.
Details

This function adds sequencing error to a set of reads based on the position in the read and the true nucleotide at that location. Position-specific probabilities of making each possible sequencing error (reading a T when it should have been A, reading a G when it should have been T, etc.) were calculated for each of three platforms using the empirical error models available with the GemSIM software (see references). Users can also estimate an error model from their own data using GemSIM and can use that error model with Polyester as described in the vignette. (You will need to run a Python script available at the Polyester GitHub repository to process the error model).

Value

DNAStringSet object that is the same as tFrags except but with sequencing error added.

References


See Also

add_error for uniform error

Examples

library(Biostrings)
# pretend the srPhiX174 DNAStringSet represents 35bp single-end
# sequencing reads:
data(srPhiX174)
set.seed(718)
data_with_errors = add_platform_error(srPhiX174, 'illumina4', paired=FALSE)

# the 17th read in this set has an error at position 20:
data_with_errors[17][[1]][20] # N
srPhiX174[17][[1]][20] # T

# 101 reads total have at least one sequencing error:
sum(data_with_errors != srPhiX174)

---

Model of positional bias that can arise when RNA-seq is performed using protocols relying on cDNA fragmentation.
Description

This positional bias model was estimated in Li and Jiang (2012). With cDNA fragmentation, reads are more likely to have come from the 3’ end of the transcript. The probabilities included in this dataset were estimated from Supplementary Figure S3 in Li and Jiang’s manuscript. Data points from the figure were inferred and exported as CSV files using WebPlotDigitizer. The CSV files and the code used to process them and create the datasets are available in the Polyester GitHub repository (https://github.com/alyssafrazee/polyester).

Format

data frame with 100 rows and 2 columns. Column 1 is position along a transcript (in percent), while Column 2 is the probability of getting a fragment at that position. Column 2 sums to 1.

References


count_transcripts

determine how many transcripts are annotated in a FASTA or GTF file

Description

determine how many transcripts are annotated in a FASTA or GTF file

Usage

count_transcripts(
  f,
  fasta = TRUE,
  identifier = "transcript_id",
  attrsep = "; "
)

Arguments

f character, path to a file in FASTA or GTF format
fasta TRUE if f is a fasta file; FALSE if f is a GTF file
identifier if f is a GTF file, how are transcripts identified in the attributes field (9th column) of the file? Default transcript_id.
attrsep if f is a GTF file, how are attributes separated in the attributes field (9th column) of the file? Default "; ". 
create_read_numbers

Value

Number of transcripts annotated in f

Examples

    fastapath = system.file("extdata", "chr22.fa", package="polyester")
    count_transcripts(fastapath) # 918

create_read_numbers Generate a simulated data set based on known model parameters

Description

Generate a simulated data set based on known model parameters

Usage

    create_read_numbers(
        mu,
        fit,
        p0,
        m = NULL,
        n = NULL,
        mod = NULL,
        beta = NULL,
        seed = NULL
    )

Arguments

mu Baseline mean expression for negative binomial model
fit Fitted relationship between log mean and log size
p0 A vector of the probabilities a count is zero
m Number of genes/transcripts to simulate (not necessary if mod, beta are specified)
n Number of samples to simulate (not necessary if mod, beta are specified)
mod Model matrix you would like to simulate from without an intercept
beta set of coefficients for the model matrix (must have same number of columns as mod)
seed optional seed to set (for reproducibility)

Value

counts Data matrix with counts for genes in rows and samples in columns
Author(s)

Jeff Leek

Examples

```r
library(ballgown)
data(bg)
countmat = fpkm_to_counts(bg, mean_rps=400000)
params = get_params(countmat)
Ntranscripts = 50
Nsamples = 10
custom_readmat = create_read_numbers(mu=params$mu, fit=params$fit,
p0=params$p0, m=Ntranscripts, n=Nsamples, seed=103)
```

empirical_density  

Estimated distribution of fragment lengths

Description

Empirical fragment length distribution was estimated using 7 randomly selected RNA-seq samples from the GEUVADIS dataset (‘t Hoen et al 2013). One sample was selected from each of the 7 laboratories that performed the sequencing. We used Picard’s “CollectInsertSizeMetrics” tool (http://broadinstitute.github.io/picard/), version 1.121, to estimate the fragment size distribution based on read alignments. Code we used to estimate this distribution is available at https://github.com/alyssafrazee/polyester/blob/master/make_fraglen_model.R.

Format

`logspline` object (created with `logspline`) specifying the empirical density of fragment lengths in the 7 GEUVADIS samples.

References


fpkm_to_counts  

Turn FPKMs from a ballgown object into estimated counts for transcripts

Description

Turn FPKMs from a ballgown object into estimated counts for transcripts
Usage

```r
defpkm_to_counts(
  bg = NULL,
  mat = NULL,
  tlengths = NULL,
  mean_rps = 1e+08,
  threshold = 0
)
```

Arguments

- **bg**: ballgown object created from real RNA-seq dataset
- **mat**: matrix of isoform-level FPKMs from which to derive counts. Rows should represent transcripts and columns should represent counts. Provide exactly one of bg or mat.
- **tlengths**: if using mat instead of bg, vector of transcript lengths. Entries correspond to the rows of mat. Lengths should only count the nucleotides within transcripts’ exons.
- **mean_rps**: This should be the number of reads per sample in total for use in backing out the FPKM calculations.
- **threshold**: only estimate parameters from transcripts with mean FPKM measurements at least as large as threshold.

Details

If transcripts/exons are represented by GRanges or GRangesList objects, the width function is really useful in calculating transcript lengths.

Value

A matrix of counts with the same number of rows and columns as the ballgown object

Author(s)

Jeff Leek

Examples

```r
library(ballgown)
data(bg)
countmat = fpmk_to_counts(bg, mean_rps=400000)
```
generate_fragments  

**generate a set of fragments from a set of transcripts**

### Description

Convert each sequence in a DNAStringSet to a "fragment" (subsequence)

### Usage

```r
generate_fragments(
  tObj,
  fraglen = 250,
  fragsd = 25,
  readlen = 100,
  distr = "normal",
  custdens = NULL,
  bias = "none",
  frag_GC_bias = "none"
)
```

### Arguments

- **tObj**  
  DNAStringSet of sequences from which fragments should be extracted

- **fraglen**  
  Mean fragment length, if drawing fragment lengths from a normal distribution.

- **fragsd**  
  Standard deviation of fragment lengths, if drawing lengths from a normal distribution. Note: fraglen and fragsd are ignored unless distr is 'normal'.

- **readlen**  
  Read length. Default 100. Used only to label read positions.

- **distr**  
  One of 'normal', 'empirical', or 'custom'. If 'normal', draw fragment lengths from a normal distribution with mean fraglen and standard deviation fragsd. If 'empirical', draw fragment lengths from a fragment length distribution estimated from a real data set. If 'custom', draw fragment lengths from a custom distribution, provided as the custdens argument, which should be a density fitted using `logspline`.

- **custdens**  
  If distr is 'custom', draw fragments from this density. Should be an object of class `logspline`.

- **bias**  
  One of 'none', 'rnaf', or 'cdnaf' (default 'none'). 'none' represents uniform fragment selection (every possible fragment in a transcript has equal probability of being in the experiment); 'rnaf' represents positional bias that arises in protocols using RNA fragmentation, and 'cdnaf' represents positional bias arising in protocols that use cDNA fragmentation (Li and Jiang 2012). Using the 'rnaf' model, coverage is higher in the middle of the transcript and lower at both ends, and in the 'cdnaf' model, coverage increases toward the 3' end of the transcript. The probability models used come from Supplementary Figure S3 of Li and Jiang (2012).

- **frag_GC_bias**  
  See explanation in `simulate_experiment`.


The empirical fragment length distribution was estimated using 7 randomly selected RNA-seq samples from the GEUVADIS dataset (‘t Hoen et al 2013), one sample from each laboratory that performed sequencing for that data set. We used Picard’s “CollectInsertSizeMetrics” (http://broadinstitute.github.io/picard/), version 1.121, to estimate the insert size distribution based on the read alignments.

DNAStringSet consisting of one randomly selected subsequence per element of t0bj.


library(Biostrings)
data(srPhiX174)

## get fragments with lengths drawn from normal distribution
set.seed(174)
srPhiX174_fragments = generate_fragments(srPhiX174, fraglen=15, fragsd=3, readlen=4)
srPhiX174_fragments

## get fragments with lengths drawn from an empirical distribution
empirical_frags = generate_fragments(srPhiX174, distr='empirical')
empirical_frags

## get fragments with lengths from a normal distribution, but include positional bias from cDNA fragmentation:
based_frags = generate_fragments(srPhiX174, bias='cdnaf')
based_frags

See Also

logspline
**getAttributeField**

extract a specific field of the "attributes" column of a data frame created from a GTF/GFF file

**Description**

extract a specific field of the "attributes" column of a data frame created from a GTF/GFF file

**Usage**

```
getAttributeField(x, field, attrsep = "; ")
```

**Arguments**

- `x` vector representing the "attributes" column of GTF/GFF file
- `field` name of the field you want to extract from the "attributes" column
- `attrsep` separator for the fields in the attributes column. Defaults to '; ', the separator for GTF files outputted by Cufflinks.

**Value**

vector of nucleotide positions included in the transcript

**Author(s)**

Wolfgang Huber, in the davidTiling package (LGPL license)

**See Also**


**Examples**

```
library(ballgown)
gtfPath = system.file('extdata', 'annot.gtf.gz', package='ballgown')
gffdata = gffRead(gtfPath)
gffdata$transcriptID = getAttributeField(gffdata$attributes, field = "transcript_id")
```
get_params

Estimate zero-inflated negative binomial parameters from a real dataset

Description

This function estimates the parameters of a zero inflated negative binomial distribution based on a real count data set based on the method of moments. The function also returns a spline fit of log mean to log size which can be used when generating new simulated data.

Usage

get_params(counts, threshold = NULL)

Arguments

counts
A matrix of counts. If you want to simulate from a ballgown object, see fpkm_to_counts

threshold
Only estimate parameters from transcripts with row means greater than threshold

Value

p0 A vector of probabilities that the count will be zero, one for each gene/transcript.
mu The estimated negative binomial mean by method of moments for the non-zero counts
size The estimated negative binomial size by method of moments for the non-zero counts
fit A fit relating log mean to log size for use in simulating new data.

Author(s)

Jeff Leek

Examples

library(ballgown)
data(bg)
countmat = fpkm_to_counts(bg, mean_rps=400000)
params = get_params(countmat)
get reads  get sequencing reads from fragments

Description

simulate the sequencing process by returning the sequence of one or both ends of provided fragments

Usage

get_reads(tFrags, readlen, paired = TRUE)

Arguments

tFrags  DNAStringSet representing fragments
readlen  Read length.
paired  If FALSE, return only the first readlen bases of each element of tFrags in the result; if TRUE, also return last readlen bases.

Value

DNAStringSet representing simulated RNA-seq reads

See Also

simulate_experiment, simulate_experiment_countmat

Examples

library(Biostrings)
data(srPhiX174)
set.seed(174)
srPhiX174_reads = get_reads(srPhiX174, readlen=15, paired=FALSE)
srPhiX174_reads
# set of single-end, 15bp reads, treating srPhiX174 as the fragments

Description

In the data frame gtf_dataframe, each row corresponds to an exon / coding sequence / start codon / stop codon, and the columns correspond to standard GTF columns denoting annotated genomic features. See http://www.ensembl.org/info/website/upload/gff.html.
loessfit1

**Format**

data frame, 9 columns, 17769 rows

**Source**

Illumina iGenomes, hg19, 6 March 2013 version: [http://ccb.jhu.edu/software/tophat/igenomes.shtml](http://ccb.jhu.edu/software/tophat/igenomes.shtml).

---

loessfit1  
*Empirical GC bias model, NA06985*

**Description**

Loess model for log counts measuring transcript expression as a function of the transcript’s GC content. The model was created using sample NA06985 in the Ballgown obtained at [http://files.figshare.com/1625419/fpkm.rda](http://files.figshare.com/1625419/fpkm.rda)

**Format**

Object of class `loess`

**Source**


**References**


---

loessfit2  
*Empirical GC bias model, NA12144*

**Description**

Loess model for log counts measuring transcript expression as a function of the transcript’s GC content. The model was created using sample NA12144 in the Ballgown obtained at [http://files.figshare.com/1625419/fpkm.rda](http://files.figshare.com/1625419/fpkm.rda)

**Format**

Object of class `loess`
Source


References


Description

Loess model for log counts measuring transcript expression as a function of the transcript’s GC content. The model was created using sample NA12776 in the Ballgown obtained at http://files.figshare.com/1625419/fpkm.rda

Format

Object of class loess

Source


References


**loessfit4**  
*Empirical GC bias model, NA18858*

**Description**
Loess model for log counts measuring transcript expression as a function of the transcript’s GC content. The model was created using sample NA18858 in the Ballgown obtained at [http://files.figshare.com/1625419/fpkm.rda](http://files.figshare.com/1625419/fpkm.rda)

**Format**
Object of class `loess`

**Source**

**References**

---

**loessfit5**  
*Empirical GC bias model, NA20542*

**Description**
Loess model for log counts measuring transcript expression as a function of the transcript’s GC content. The model was created using sample NA20542 in the Ballgown obtained at [http://files.figshare.com/1625419/fpkm.rda](http://files.figshare.com/1625419/fpkm.rda)

**Format**
Object of class `loess`

**Source**
References


Description

Loess model for log counts measuring transcript expression as a function of the transcript’s GC content. The model was created using sample NA20772 in the Ballgown obtained at http://files.figshare.com/1625419/fpkm.rda

Format

Object of class loess

Source


References


Description

Loess model for log counts measuring transcript expression as a function of the transcript’s GC content. The model was created using sample NA20815 in the Ballgown obtained at http://files.figshare.com/1625419/fpkm.rda

Format

Object of class loess
**Source**


**References**


---

**model1** *Empirical error model for Illumina Genome Analyzer IIx with Illumina Sequencing Kit v4 chemistry, read mate 1 of a pair*

**Description**

for each position in mate 1 of a paired-end read generated with the specified Illumina chemistry, this data frame contains the probability of not making a sequencing error, and of making each of the 4 possible types of sequencing errors. The reference base (truth) is in column 1, and the probabilities of sequencing that base given its read position (column 7) as each of the 5 possible bases (A, T, G, C, and N) is given in columns 2 through 6, respectively. So for example, at position 8 in mate 1 of a read where the true base is A, the probability of correctly calling that base an A is 0.9998, the probability of making an error by sequencing a T is 2.64e-05, the probability of making an error by sequencing a G is 1.58e-04, the probability of making an error by sequencing a C is 3.05e-05, and the probability of reading an ’N’ at position 8 is 0. This can be seen by looking at `model1[model1$pos == 8,]`. Note that position indexing is 1-based, though a 0 position is included as described in the GemSIM documentation.

**Format**

data frame named `model1`, 7 columns, 505 rows

**Source**

processed from the Illumina v4 error model that ships with GemSIM (see references)

**References**

**model2**

*Empirical error model for Illumina Genome Analyzer IIx with Illumina Sequencing Kit v4 chemistry, read mate 2 of a pair*

**Description**

For each position in mate 2 of a paired-end read generated with the specified Illumina chemistry, this data frame contains the probability of not making a sequencing error, and of making each of the 4 possible types of sequencing errors. The reference base (truth) is in column 1, and the probabilities of sequencing that base given its read position (column 7) as each of the 5 possible bases (A, T, G, C, and N) is given in columns 2 through 6, respectively. So for example, at position 8 in mate 1 of a read where the true base is A, the probability of correctly calling that base an A is 0.9995, the probability of making an error by sequencing a T is 0.00017, the probability of making an error by sequencing a G is 0.00023, the probability of making an error by sequencing a C is 6.02e-05, and the probability of reading an 'N' at position 8 is 1.15e-05. This can be seen by looking at `model2[model2$pos == 8,]`. Note that position indexing is 1-based, though a 0 position is included as described in the GemSIM documentation.

**Format**

Data frame named `model2`, 7 columns, 505 rows

**Source**

Processed from the Illumina v4 error model that ships with GemSIM (see references)

**References**


---

**model3**

*Empirical error model for Illumina Genome Analyzer IIx with Illumina Sequencing Kit v4 chemistry, single-end read*

**Description**

For each position in a single-end read generated with the specified Illumina chemistry, this data frame contains the probability of not making a sequencing error, and of making each of the 4 possible types of sequencing errors. The reference base (truth) is in column 1, and the probabilities of sequencing that base given its read position (column 7) as each of the 5 possible bases (A, T, G, C, and N) is given in columns 2 through 6, respectively. So for example, at position 8 in mate 1 of a read where the true base is A, the probability of correctly calling that base an A is 0.9998, the probability of making an error by sequencing a T is 2.95e-05, the probability of making an error by sequencing a G is 1.27e-04, the probability of making an error by sequencing a C is
1.85e-05, and the probability of reading an 'N' at position 8 is 0. This can be seen by looking at `model4[model4$pos == 8,]`. Note that position indexing is 1-based, though a 0 position is included as described in the GemSIM documentation.

**Format**

data frame named `model4`, 7 columns, 505 rows

**Source**

processed from the Illumina v5 error model that ships with GemSIM (see references)

**References**


---

**model4**

*Empirical error model for Illumina Genome Analyzer IIx with TrueSeq SBS Kit v5-GA chemistry, read mate 1 of a pair*

**Description**

for each position in mate 1 of a paired-end read generated with the specified Illumina chemistry, this data frame contains the probability of not making a sequencing error, and of making each of the 4 possible types of sequencing errors. The reference base (truth) is in column 1, and the probabilities of sequencing that base given its read position (column 7) as each of the 5 possible bases (A, T, G, C, and N) is given in columns 2 through 6, respectively. So for example, at position 8 in mate 1 of a read where the true base is A, the probability of correctly calling that base an A is 0.9998, the probability of making an error by sequencing a T is 4.00e-05, the probability of making an error by sequencing a G is 1.58e-04, the probability of making an error by sequencing a C is 1.46e-05, and the probability of reading an 'N' at position 8 is 0. This can be seen by looking at `model4[model4$pos == 8,]`. Note that position indexing is 1-based, though a 0 position is included as described in the GemSIM documentation.

**Format**

data frame named `model4`, 7 columns, 505 rows

**Source**

processed from the Illumina v5 error model that ships with GemSIM (see references)

**References**

Description

for each position in mate 2 of a paired-end read generated with the specified Illumina chemistry, this data frame contains the probability of not making a sequencing error, and of making each of the 4 possible types of sequencing errors. The reference base (truth) is in column 1, and the probabilities of sequencing that base given its read position (column 7) as each of the 5 possible bases (A, T, G, C, and N) is given in columns 2 through 6, respectively. So for example, at position 8 in mate 1 of a read where the true base is A, the probability of correctly calling that base an A is 0.9992, the probability of making an error by sequencing a T is 0.0002, the probability of making an error by sequencing a G is 0.0002, the probability of making an error by sequencing a C is 0.0001, and the probability of reading an 'N' at position 8 is 0.0002. This can be seen by looking at `model5[model5$pos == 8,]`. Note that position indexing is 1-based, though a 0 position is included as described in the GemSIM documentation.

Format

data frame named `model5`, 7 columns, 505 rows

Source

processed from the Illumina v5 error model that ships with GemSIM (see references)

References

1.27e-05, and the probability of reading an ‘N’ at position 8 is 0. This can be seen by looking at 
model6[model6$pos == 8,]. Note that position indexing is 1-based, though a 0 position is included 
as described in the GemSIM documentation.

**Format**

data frame named `model6`, 7 columns, 505 rows

**Source**

processed from the Illumina v5 error model that ships with GemSIM (see references)

**References**

next-generation sequencing data. BMC Genomics 13(1), 74.

---

**model7**

**Empirical error model Roche/454 FLX Titanium, single-end read**

**Description**

for each position in a single-end read generated with the specified chemistry, this data frame con-
tains the probability of not making a sequencing error, and of making each of the 4 possible types 
of sequencing errors. The reference base (truth) is in column 1, and the probabilities of sequencing 
that base given its read position (column 7) as each of the 5 possible bases (A, T, G, C, and N) is 
given in columns 2 through 6, respectively. So for example, at position 8 in mate 1 of a read where 
the true base is C, the probability of correctly calling that base a C is 0.9994, the probability of 
making an error by sequencing a T is 0.0002, the probability of making an error by sequencing a 
G is 0.0001, the probability of making an error by sequencing an A is 0.0002, and the probability 
of reading an ‘N’ at position 8 is 0. This can be seen by looking at 
model7[model7$pos == 8,]. Note that position indexing is 1-based, though a 0 position is included as described in the GemSIM documentation.

**Format**

data frame named `model7`, 7 columns, 505 rows

**Source**

processed from the Roche 454 error model that ships with GemSIM (see references)

**References**

next-generation sequencing data. BMC Genomics 13(1), 74.
**NB**  
*Draw nonzero negative binomial random numbers*

**Description**

Draw nonzero negative binomial random numbers

**Usage**

```r
NB(basemeans, size, seed = NULL)
```

**Arguments**

- `basemeans` vector of means, one per draw
- `size` vector of size parameters (controlling the mean/variance relationship); one per draw
- `seed` optional seed to set before drawing

**Value**

vector of negative binomial draws from specified distributions, where any zero draw is replaced with a 1. Length of return vector is equal to `length(basemeans)`.

**Examples**

```r
randomNBs = NB(c(100, 4, 29), size=c(50, 2, 4), seed=21)
randomNBs # 115, 5, 15
```

---

**polyester**  
*Polyester: simulating RNA-seq reads including differential expression*

**Description**

Polyester is an R package designed to simulate an RNA sequencing experiment. Given a set of annotated transcripts, polyester will simulate the steps of an RNA-seq experiment (fragmentation, reverse-complementing, and sequencing) and produce files containing simulated RNA-seq reads. Simulated reads can be analyzed using any of several downstream analysis tools.

**Details**

A single function call produces RNA-seq reads in FASTA format from a case/control experiment including biological replicates. Differential expression between cases and controls can be set by the user, facilitating comparisons of statistical differential expression methods for RNA-seq data. See detailed documentation for `simulate_experiment` and `simulate_experiment_countmat`.

See the vignette by typing `browseVignettes("polyester")` in the R prompt.
Author(s)
Alyssa Frazee, Andrew Jaffe, Rory Kirchner, Jeff Leek

References

reverse_complement
reverse-complement some fragments

Description
randomly reverse-complement half of the sequences in a DNAStringSet

Usage
reverse_complement(tObj, seed = NULL)

Arguments
tObj DNAStringSet representing sequences.
seed optional seed to set before randomly selecting the sequences to be reverse-complemented.

Value
DNAStringSet that is the same as tObj, but with about half the sequences reverse-complemented.

Examples
library(Biostrings)
data(srPhiX174)
srPhiX174_halfrc = reverse_complement(srPhiX174, seed=174)
Model of positional bias that can arise when RNA-seq is performed using protocols relying on RNA fragmentation.

**Description**

This positional bias model was estimated in Li and Jiang (2012). With RNA fragmentation, reads are more likely to have come from the middle of the transcript than either end. The probabilities included in this dataset were estimated from Supplementary Figure S3 in Li and Jiang’s manuscript. Data points from the figure were inferred and exported as CSV files using WebPlotDigitizer. The CSV files and the code used to process them and create the datasets are available in the Polyester GitHub repository (https://github.com/alyssafrazee/polyester).

**Format**

data frame with 100 rows and 2 columns. Column 1 is position along a transcript (in percent), while Column 2 is the probability of getting a fragment at that position. Column 2 sums to 1.

**References**


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**seq_gtf**

Get transcript sequences from GTF file and sequence info

**Description**

Given a GTF file (for transcript structure) and DNA sequences, return a DNAStringSet of transcript sequences

**Usage**

```r
seq_gtf(
  gtf, 
  seqs, 
  feature = "transcript", 
  exononly = TRUE, 
  idfield = "transcript_id", 
  attrsep = ";" 
)
```
simulate_experiment

simulate RNA-seq experiment using negative binomial model

Description

create FASTA files containing RNA-seq reads simulated from provided transcripts, with optional differential expression between two groups
simulate_experiment

Usage

simulate_experiment(
  fasta = NULL,
  gtf = NULL,
  seqpath = NULL,
  outdir = ".",
  num_reps = c(10, 10),
  reads_per_transcript = 300,
  size = NULL,
  fold_changes,
  paired = TRUE,
  reportCoverage = FALSE,
  ...
)

Arguments

fasta  path to FASTA file containing transcripts from which to simulate reads. See details.

htf  path to GTF file containing transcript structures from which reads should be simulated. See details.

seqpath  path to folder containing one FASTA file (.fa extension) for each chromosome in gtf. See details.

outdir  character, path to folder where simulated reads should be written, with *no* slash at the end. By default, reads are written to current working directory.

num_reps  How many biological replicates should be in each group? The length num_reps determines how many groups are in the experiment. For example, num_reps = c(5, 6, 5) specifies a 3-group experiment with 5 samples in group 1, 6 samples in group 2, and 5 samples in group 3. Defaults to a 2-group experiment with 10 reps per group (i.e., c(10, 10)).

reads_per_transcript  baseline mean number of reads to simulate from each transcript. Can be an integer, in which case this many reads are simulated from each transcript, or an integer vector whose length matches the number of transcripts in fasta. Default 300. You can also leave reads_per_transcript empty and set meanmodel=TRUE to draw baseline mean numbers from a model based on transcript length.

size  the negative binomial size parameter (see NegBinomial) for the number of reads drawn per transcript. It can be a matrix (where the user can specify the size parameter per transcript, per group), a vector (where the user can specify the size per transcript, perhaps relating to reads_per_transcript), or a single number, specifying the size for all transcripts and groups. If left NULL, defaults to reads_per_transcript * fold_changes / 3. Negative binomial variance is mean + mean^2 / size.

fold_changes  Matrix specifying multiplicative fold changes between groups. There is no default, so you must provide this argument. In real data sets, lowly-expressed transcripts often show high fold changes between groups, so this can be kept
in mind when setting fold_changes and reads_per_transcript. This argument must have the same number of columns as there are groups as specified by num_reps, and must have the same number of rows as there are transcripts in fasta. A fold change of X in matrix entry i,j means that for replicate j, the baseline mean number of reads (reads_per_transcript[i]) will be multiplied by X. Note that the multiplication happens before the negative binomial value (for the number of reads that “actually will” be drawn from transcript i, for replicate j) is drawn. This argument is ignored if length(num_reps) is 1 (meaning you only have 1 group in your simulation).

paired
If TRUE, paired-end reads are simulated; else single-end reads are simulated. Default TRUE

reportCoverage
whether to write out coverage information to sample_coverages.rda file in the outdir. defaults to FALSE

... any of several other arguments that can be used to add nuance to the simulation. See details.

Details

Reads can either be simulated from a FASTA file of transcripts (provided with the fasta argument) or from a GTF file plus DNA sequences (provided with the gtf and seqpath arguments). Simulating from a GTF file and DNA sequences may be a bit slower: it took about 6 minutes to parse the GTF/sequence files for chromosomes 1-22, X, and Y in hg19.

Several optional parameters can be passed to this function to adjust the simulation. The options are:

- readlen: read length. Default 100.
- lib_sizes: Library size factors for the biological replicates. lib_sizes should have length equal to the total number of replicates in the experiment, i.e., sum(num_reps). For each replicate, once the number of reads to simulate from each transcript for that replicate is known, all read numbers across all transcripts from that replicate are multiplied by the corresponding entry in lib_sizes.
- distr One of 'normal', 'empirical', or 'custom', which specifies the distribution from which to draw RNA fragment lengths. If 'normal', draw fragment lengths from a normal distribution. You can provide the mean of that normal distribution with fraglen (defaults to 250) and the standard deviation of that normal distribution with fragsd (defaults to 25). You can provide a single number for each, or a vector with length equal to the total number of samples. If 'empirical', draw fragment lengths from a fragment length distribution estimated from a real data set. If 'custom', draw fragment lengths from a custom distribution, which you can provide as the custdens argument. custdens should be a density fitted using logspline.
- error_model: The error model can be one of:
  - 'uniform': errors are distributed uniformly across reads. You can also provide an 'error_rate' parameter, giving the overall probability of making a sequencing error at any given nucleotide. This error rate defaults to 0.005.
  - 'illumina4' or 'illumina5': Empirical error models. See ?add_platform_error for more information.
  - 'custom': A custom error model you’ve estimated from an RNA-seq data set using GemErr. See ?add_platform_error for more info. You will need to provide both
model_path and model_prefix if using a custom error model. model_path is the output folder you provided to build_error_model.py. This path should contain either two files suffixed _mate1 and _mate2, or a file suffixed _single. model_prefix is the prefix argument you provided to build_error_model.py and is whatever comes before the _mate1/_mate2 or _single files in model_path.

• bias One of 'none', 'rnaf', or 'cdnaf'. 'none' represents uniform fragment selection (every possible fragment in a transcript has equal probability of being in the experiment); 'rnaf' represents positional bias that arises in protocols using RNA fragmentation, and 'cdnaf' represents positional bias arising in protocols that use cDNA fragmentation (Li and Jiang 2012). Using the 'rnaf' model, coverage is higher in the middle of the transcript and lower at both ends, and in the 'cdnaf' model, coverage increases toward the 3' end of the transcript. The probability models used come from Supplementary Figure S3 of Li and Jiang (2012). Defaults to 'none' if you don't provide this.

• gcbias list indicating which samples to add GC bias to, and from which models. Should be the same length as sum(num_reps); entries can be either numeric or of class loess. A numeric entry of 0 indicates no GC bias. Numeric entries 1 through 7 correspond to the 7 empirical GC models that ship with Polyester, estimated from GEUVADIS HapMap samples NA06985, NA12144, NA12776, NA18858, NA20542, NA20772, and NA20815, respectively. The code used to derive the empirical GC models is available at https://github.com/alyssafrazee/polyester/blob/master/make_gc_bias.R. A loess entry should be a loess prediction model that takes a GC content percent value (between 0 and 1) a transcript’s deviation from overall mean read count based on that GC value. Counts for each replicate will be adjusted based on the GC bias model specified for it. Numeric and loess entries can be mixed. By default, no bias is included.

• frag_GC_bias Either a matrix of dimensions 101 x sum(num_reps) or 'none'. The default is 'none'. If specified, the matrix contains the probabilities (a number in the range [0,1]) that a fragment will appear in the output given its GC content. The first row corresponds to a fragment with GC content of 0 percent, the second row 1 percent, the third row 2 percent, etc., and the last row 100 percent. The columns correspond to different probabilities for each sample. Internally, a coin flip (a Bernoulli trial) determines if each fragment is kept, depending on its GC content. Note that the final library size will depend on the elements of the matrix, and it might make sense to scale up the lib_size of the samples with low probabilities in the matrix in the range of the transcriptome GC content distribution. Note that the count_matrix written to outdir contains the counts before applying fragment GC bias.

• strand_specific defaults to FALSE, which means fragments are generated with equal probability from both strands of the transcript sequence. set to TRUE for strand-specific simulation (1st read forward strand, 2nd read reverse strand with respect to transcript sequence).

• meanmodel: set to TRUE if you’d like to set reads_per_transcripts as a function of transcript length. We fit a linear model regressing transcript abundance on transcript length, and setting meanmodel=TRUE means we will use transcript lengths to draw transcript abundance based on that linear model. You can see our modeling code at http://htmlpreview.github.io/?https://github.com/alyssafrazee/polyester_code/blob/master/length_simulation.html

• write_info: set to FALSE if you do not want files of simulation information written to disk. By default, transcript fold changes and expression status, replicate library sizes and group identifiers, and an R data object of the counts matrix (before application of fragment GC bias) are written to outdir.
simulate_experiment

- **seed**: specify a seed (e.g. `seed=142` or some other integer) to set before randomly drawing read numbers, for reproducibility.
- **transcriptid**: optional vector of transcript IDs to be written into `sim_info.txt` and used as transcript identifiers in the output fasta files. Defaults to `names(readDNAStringSet(fasta))`. This option is useful if default names are very long or contain special characters.
- **gzip**: pass `gzip=TRUE` to write gzipped fasta files as output (by default, fasta output files are not compressed when written to disk).
- **exononly**: (passed to `seq_gtf`) if `TRUE` (as it is by default), only create transcript sequences from the features labeled exon in `gtf`.
- **idfield**: (passed to `seq_gtf`) in the attributes column of `gtf`, what is the name of the field identifying transcripts? Should be character. Default "transcript_id".
- **attrsep**: (passed to `seq_gtf`) in the attributes column of `gtf`, how are attributes separated? Default ",", ".

**Value**

No return, but simulated reads and a simulation info file are written to `outdir`. Note that reads are written out transcript by transcript and so need to be shuffled if used as input to quantification algorithms such as eXpress or Salmon.

**References**


**Examples**

```r
## simulate a few reads from chromosome 22

fastapath = system.file("extdata", "chr22.fa", package="polyester")
numtx = count_transcripts(fastapath)
set.seed(4)
fold_change_values = sample(c(0.5, 1, 2), size=2*numtx,
    prob=c(0.05, 0.9, 0.05), replace=TRUE)
fold_changes = matrix(fold_change_values, nrow=numtx)
library(Biostrings)
# remove quotes from transcript IDs:
tNames = gsub("'", "", names(readDNAStringSet(fastapath)))

simulate_experiment(fastapath, reads_per_transcript=10,
    fold_changes=fold_changes, outdir='simulated_reads',
    transcriptid=tNames, seed=12)
```
**simulate_experiment_countmat**

*Simulate RNA-seq experiment*

**Description**
create FASTA files containing RNA-seq reads simulated from provided transcripts, with optional differential expression between two groups (designated via read count matrix)

**Usage**
```r
simulate_experiment_countmat(
  fasta = NULL,
  gtf = NULL,
  seqpath = NULL,
  readmat,
  outdir = ".",
  paired = TRUE,
  seed = NULL,
  ...
)
```

**Arguments**
- **fasta**: path to FASTA file containing transcripts from which to simulate reads. See details.
- **gtf**: path to GTF file or data frame containing transcript structures from which reads should be simulated. See details and `seq_gtf`.
- **seqpath**: path to folder containing one FASTA file (.fa extension) or DNAStringSet containing one entry for each chromosome in `gtf`. See details and `seq_gtf`.
- **readmat**: matrix with rows representing transcripts and columns representing samples. Entry i,j specifies how many reads to simulate from transcript i for sample j.
- **outdir**: character, path to folder where simulated reads should be written, without a slash at the end of the folder name. By default, reads written to the working directory.
- **paired**: If TRUE, paired-end reads are simulated; else single-end reads are simulated.
- **seed**: Optional seed to set before simulating reads, for reproducibility.
- **...**: Additional arguments to add nuance to the simulation, as described extensively in the details of `simulate_experiment`, or to pass to `seq_gtf`, if `gtf` is not NULL.

**Details**
Reads can either be simulated from a FASTA file of transcripts (provided with the `fasta` argument) or from a GTF file plus DNA sequences (provided with the `gtf` and `seqpath` arguments). Simulating from a GTF file and DNA sequences may be a bit slower: it took about 6 minutes to parse the GTF/sequence files for chromosomes 1-22, X, and Y in hg19.
Value

No return, but simulated reads are written to outdir.

References


Examples

```r
fastapath = system.file("extdata", "chr22.fa", package="polyester")
numtx = count_transcripts(fastapath)
readmat = matrix(20, ncol=10, nrow=numtx)
readmat[1:30, 1:5] = 40

simulate_experiment_countmat(fasta=fastapath,
   readmat=readmat, outdir='simulated_reads_2', seed=5)
```

---

**simulate_experiment_empirical**  
_Simulate RNA-seq experiment based on abundances from a data set_

Description

Create fasta files representing reads from a two-group experiment, where abundances and differential expression are estimated from a real data set

Usage

```r
simulate_experiment_empirical(
   bg = NULL,
   fpkmMat = NULL,
   mean_rps = 5e+06,
   grouplabels = NULL,
   decut = 1.5,
   outdir = ".",
   ...
)
```

Arguments

- **bg**: Ballgown object containing estimated transcript abundances in FPKM. Reads will be simulated for the same number of replicates that are in bg. Must provide exactly one of bg and fpkmMat.
- **fpkmMat**: transcript-by-sample matrix containing abundances (in FPKM) estimated from a real data set. MUST have row names identifying transcripts. The number of columns is the number of samples that will be simulated.
write_reads

mean_rps
Number of reads per sample to use in converting FPKM measurements to counts.
Should be somewhat close to the number of reads per sample in the experiment
that generated the estimated FPKMs. Defaults to 5 million (5e6).
grouplabels
vector indicating the group labels for each replicate in the experiment. Must be
convertible to a factor with exactly 2 levels.
decut
A transcript will be recorded as truly differentially expressed if its fold change
between the two groups is more extreme than decut, in either direction.
outdir
character, path to folder where simulated reads should be written, without a slash
at the end of the folder name. By default, reads written to the working directory.
... Additional arguments to pass to simulate_experiment_countmat

Value
No return, but reads are written to outdir.

Examples
## Not run:
library(ballgown)
data(bg)
bgs = subset(bg, "chr==22")

# load gtf file:
gtfpath = system.file('extdata', 'bg.gtf.gz', package='polyester')
gtf = subset(gffRead(gtfpath), seqname==22)

# load/download chromosome sequence (just for this example)
system('wget https://www.dropbox.com/s/04i6msi9vu2snif/chr22seq.rda')
load('chr22seq.rda')
names(chr22seq) = 22

# simulate reads based on this experiment's FPKMs
simulate_experiment_empirical(bg, grouplabels=pData(bg)$group, gtf=gtf,
   seqpath=chr22seq, mean_rps=5000, outdir='simulated_reads_3', seed=1247)

## End(Not run)

write_reads(write sequencing reads to disk)

Description
given a DNAStringSet representing simulated sequencing reads, write FASTA files to disk rep-resenting the simulated reads.

Usage
write_reads(reads, fname, readlen, paired = TRUE, gzip, offset = 1L)
write_reads

Arguments

reads  DNAStringSet representing sequencing reads
fname  file path/prefix specifying where sequencing reads should be written. Should not contain ".fasta" (this is appended automatically).
readlen  maximum length of the reads in reads.
paired  If TRUE, reads are assumed to be in pairs: i.e., read 1 and read 2 in reads are the left and right mate (respectively) of a read pair; same with read 3 and read 4, etc. The odd-numbered reads are written to fname_1.fasta and the even-numbered reads are written to fname_2.fasta. If FALSE, reads are assumed to be single-end and just one file, fname.fasta, is written.
gzip  If TRUE, gzip the output fasta files.
offset  An integer number greater or equal to 1 to start assigning read numbers at.

Details

The get_reads function returns a DNAStringSet object representing sequencing reads that can be directly passed to write_reads. If output other than that from get_reads is used and paired is TRUE, make sure reads is ordered properly (i.e., that mate pairs appear together and that the left mate appears first).

Value

No return, but FASTA file(s) containing the sequences in reads are written to fname.fasta (if paired is FALSE) or fname_1.fasta and fname_2.fasta if paired is TRUE.

See Also

get_reads

Examples

library(Biostrings)
data(srPhiX174) # pretend srPhiX174 represents a DNAStringSet of *reads*  
readlen = unique(width(srPhiX174)) #35  
write_reads(srPhiX174, fname='.srPhiX174', readlen=readlen, paired=FALSE, gzip=FALSE)

## If the file is too big, you can subset it and write it in chunks.  
## Here we split our 'reads' into two chunks and save them to the same file.  
write_reads(srPhiX174[1:100], fname='.srPhiX174-offset', readlen=readlen, paired=FALSE, gzip=FALSE, offset = 1L)  
write_reads(srPhiX174[101:length(srPhiX174)], fname='.srPhiX174-offset', readlen=readlen, paired=FALSE, gzip=FALSE, offset = 101L)

## We can verify that we get the same results  
srPhi <- readDNAStringSet('.srPhiX174.fasta')  
srPhiOffset <- readDNAStringSet('.srPhiX174-offset.fasta')  
identical(srPhi, srPhiOffset)
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