

# Package ‘VAExprs’

October 16, 2023

**Type** Package

**Title** Generating Samples of Gene Expression Data with Variational Autoencoders

**Description** A fundamental problem in biomedical research is the low number of observations, mostly due to a lack of available biosamples, prohibitive costs, or ethical reasons. By augmenting a few real observations with artificially generated samples, their analysis could lead to more robust and higher reproducible. One possible solution to the problem is the use of generative models, which are statistical models of data that attempt to capture the entire probability distribution from the observations. Using the variational autoencoder (VAE), a well-known deep generative model, this package is aimed to generate samples with gene expression data, especially for single-cell RNA-seq data. Furthermore, the VAE can use conditioning to produce specific cell types or subpopulations. The conditional VAE (CVAE) allows us to create targeted samples rather than completely random ones.

**Version** 1.6.0

**Date** 2022-05-16

**LazyData** TRUE

**Depends** keras, mclust

**Imports** SingleCellExperiment, SummarizedExperiment, tensorflow, scater, CatEncoders, DeepPINCS, purrr, DiagrammeR, stats

**Suggests** SC3, knitr, testthat, reticulate, rmarkdown

**License** Artistic-2.0

**biocViews** Software, GeneExpression, SingleCell

**NeedsCompilation** no

**VignetteBuilder** knitr

**git\_url** <https://git.bioconductor.org/packages/VAExprs>

**git\_branch** RELEASE\_3\_17

**git\_last\_commit** 50d5ca2

**git\_last\_commit\_date** 2023-04-25

**Date/Publication** 2023-10-15

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fit_vae	<i>Variational autoencoder model fitting</i>
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### Description

A fundamental problem in biomedical research is the low number of observations available. Augmenting a few real observations with generated in silico samples could lead to more robust analysis. Here, the variational autoencoder (VAE) is used for the realistic generation of single-cell RNA-seq data. Also, the conditional variational autoencoder (CVAE) can be used if labels of samples are available. This function allows us to fit variational autoencoders with the standard Gaussian prior to expression data. It is assumed that there will likely be no clusters in the latent space representation of variational autoencoders.

### Usage

```
fit_vae(object = NULL,
        x_train = NULL,
        x_val = NULL,
        y_train = NULL,
        y_val = NULL,
        encoder_layers,
        decoder_layers,
        latent_dim = 2,
        regularization = 1,
        epochs,
        batch_size,
        preprocessing = list(
          x_train = NULL,
          x_val = NULL,
          y_train = NULL,
          y_val = NULL,
          minmax = NULL,
          lenc = NULL),
        use_generator = FALSE,
        optimizer = "adam",
        validation_split = 0, ...)
```

**Arguments**

object	SummarizedExperiment object
x_train	expression data for train, where each row is a cell and each column is a gene
x_val	expression data for validation, where each row is a cell and each column is a gene
y_train	labels for train
y_val	labels for validation
encoder_layers	list of layers for encoder
decoder_layers	list of layers for decoder
latent_dim	dimension of latent vector (default: 2)
regularization	regularization parameter, which is nonnegative (default: 1)
epochs	number of epochs
batch_size	batch size
preprocessing	list of preprocessed results, they are set to NULL as default <ul style="list-style-type: none"> <li>• x_train : expression data for train</li> <li>• x_val : expression data for validation</li> <li>• y_train : labels for train</li> <li>• y_val : labels for validation</li> <li>• minmax : result of min-max normalization</li> <li>• lenc : encoded labels</li> </ul>
use_generator	use data generator if TRUE (default: FALSE)
optimizer	name of optimizer (default: adam)
validation_split	proportion of validation data, it is ignored when there is a validation set (default: 0)
...	additional parameters for the "fit" or "fit_generator"

**Value**

model	trained VAE model
encoder	trained encoder model
decoder	trained decoder model
preprocessing	preprocessed results

**Author(s)**

Dongmin Jung

**References**

Marouf, M., Machart, P., Bansal, V., Kilian, C., Magruder, D. S., Krebs, C. F., & Bonn, S. (2020). Realistic in silico generation and augmentation of single-cell RNA-seq data using generative adversarial networks. *Nature communications*, 11(1), 1-12.

**See Also**

SummarizedExperiment::assay, SummarizedExperiment::colData, scater::logNormCounts, keras::fit, keras::fit\_generator, keras::compile, CatEncoders::LabelEncoder.fit, CatEncoders::transform, DeepPINCS::multiple\_sampling\_generator

**Examples**

```

if (keras::is_keras_available() & reticulate::py_available()) {
  ### simulate differentially expressed genes
  set.seed(1)
  g <- 3
  n <- 100
  m <- 1000
  mu <- 5
  sigma <- 5
  mat <- matrix(rnorm(n*m*g, mu, sigma), m, n*g)
  rownames(mat) <- paste0("gene", seq_len(m))
  colnames(mat) <- paste0("cell", seq_len(n*g))
  group <- factor(sapply(seq_len(g), function(x) {
    rep(paste0("group", x), n)
  })))
  names(group) <- colnames(mat)
  mu_upreg <- 6
  sigma_upreg <- 10
  deg <- 100
  for (i in seq_len(g)) {
    mat[(deg*(i-1) + 1):(deg*i), group == paste0("group", i)] <-
      mat[1:deg, group==paste0("group", i)] + rnorm(deg, mu_upreg, sigma_upreg)
  }
  # positive expression only
  mat[mat < 0] <- 0
  x_train <- as.matrix(t(mat))

  ### model
  batch_size <- 32
  original_dim <- 1000
  intermediate_dim <- 512
  epochs <- 2
  # VAE
  vae_result <- fit_vae(x_train = x_train,
    encoder_layers = list(layer_input(shape = c(original_dim)),
      layer_dense(units = intermediate_dim,
        activation = "relu")),
    decoder_layers = list(layer_dense(units = intermediate_dim,
      activation = "relu"),
      layer_dense(units = original_dim,
        activation = "sigmoid")),
    epochs = epochs, batch_size = batch_size,
    validation_split = 0.5,
    use_generator = FALSE,
    callbacks = keras::callback_early_stopping(

```

```

        monitor = "val_loss",
        patience = 10,
        restore_best_weights = TRUE))

### from preprocessing
vae_result_preprocessing <- fit_vae(preprocessing = vae_result$preprocessing,
    encoder_layers = list(layer_input(shape = c(original_dim)),
        layer_dense(units = intermediate_dim,
            activation = "relu")),
    decoder_layers = list(layer_dense(units = intermediate_dim,
        activation = "relu"),
        layer_dense(units = original_dim,
            activation = "sigmoid")),
    epochs = epochs, batch_size = batch_size,
    validation_split = 0.5,
    use_generator = FALSE,
    callbacks = keras::callback_early_stopping(
        monitor = "val_loss",
        patience = 10,
        restore_best_weights = TRUE))
}

```

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gen\_exprs

*Generate samples with expression data*


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## Description

This function generate expression data by drawing samples from the latent vectors following the standard multivariate Gaussian distribution (the standard multivariate normal distribution) for convenience. However, this assumption for the prior may not be appropriate because there may be underlying distinctions between groups of samples. Any density function can be modeled by the Gaussian mixture model. Here, by using the library "mclust", the finite Gaussian mixture is applied for such sampling. Note that the Gaussian mixture model is not used for fitting in the function "fit\_vae".

## Usage

```
gen_exprs(x, num_samples,
          batch_size, use_generator = FALSE)
```

## Arguments

x	result of the function "fit_vae"
num_samples	number of samples to be generated
batch_size	batch size
use_generator	use data generator if TRUE (default: FALSE)

**Value**

x_gen	generated expression data, where each row is a cell and each column is a gene
y_gen	generated labels
x_train	real expression data, where each row is a cell and each column is a gene
y_train	real labels
latent_vector	latent vector from real expression data

**Author(s)**

Dongmin Jung

**See Also**

mclust::mclustBIC, mclust::mclustModel, mclust::sim, DeepPINCS::multiple\_sampling\_generator, CatEncoders::inverse.transform

**Examples**

```
if (keras::is_keras_available() & reticulate::py_available()) {
  ### simulate differentially expressed genes
  set.seed(1)
  g <- 3
  n <- 100
  m <- 1000
  mu <- 5
  sigma <- 5
  mat <- matrix(rnorm(n*m*g, mu, sigma), m, n*g)
  rownames(mat) <- paste0("gene", seq_len(m))
  colnames(mat) <- paste0("cell", seq_len(n*g))
  group <- factor(sapply(seq_len(g), function(x) {
    rep(paste0("group", x), n)
  })))
  names(group) <- colnames(mat)
  mu_upreg <- 6
  sigma_upreg <- 10
  deg <- 100
  for (i in seq_len(g)) {
    mat[(deg*(i-1) + 1):(deg*i), group == paste0("group", i)] <-
      mat[1:deg, group==paste0("group", i)] + rnorm(deg, mu_upreg, sigma_upreg)
  }
  # positive expression only
  mat[mat < 0] <- 0
  x_train <- as.matrix(t(mat))

  ### model
  batch_size <- 32
  original_dim <- 1000
  intermediate_dim <- 512
  epochs <- 2
}
```

```

# VAE
vae_result <- fit_vae(x_train = x_train,
                    encoder_layers = list(layer_input(shape = c(original_dim)),
                                         layer_dense(units = intermediate_dim,
                                                      activation = "relu")),
                    decoder_layers = list(layer_dense(units = intermediate_dim,
                                                      activation = "relu"),
                                         layer_dense(units = original_dim,
                                                      activation = "sigmoid")),
                    epochs = epochs, batch_size = batch_size,
                    validation_split = 0.5,
                    use_generator = FALSE,
                    callbacks = keras::callback_early_stopping(
                      monitor = "val_loss",
                      patience = 10,
                      restore_best_weights = TRUE))

# plot
plot_vae(vae_result$model)

### generate samples
set.seed(1)
gen_sample_result <- gen_exprs(vae_result, num_samples = 100)
}

```

---

plot\_aug

*Visualization for augmented data*


---

## Description

For augmented data, we can create plots for specific types of dimension reduction.

## Usage

```
plot_aug(x, plot_fun, ...)
```

## Arguments

x	result of the function "gen_exprs"
plot_fun	"PCA", "MDS", "TSNE", "UMAP", "NMF", or "DiffusionMap"
...	additional parameters for the reduced dimension plots such as "scatter::runPCA"

## Value

plot for augmented data

## Author(s)

Dongmin Jung

**See Also**

SingleCellExperiment::SingleCellExperiment, scater::logNormCounts, scater::runPCA, scater::runMDS, scater::runTSNE, scater::runUMAP, scater::runNMF, scater::runDiffusionMap, scater::plotPCA, scater::plotMDS, scater::plotTSNE, scater::plotUMAP, scater::plotNMF, scater::plotDiffusionMap

**Examples**

```
if (keras::is_keras_available() & reticulate::py_available()) {
  ### simulate differentially expressed genes
  set.seed(1)
  g <- 3
  n <- 100
  m <- 1000
  mu <- 5
  sigma <- 5
  mat <- matrix(rnorm(n*m*g, mu, sigma), m, n*g)
  rownames(mat) <- paste0("gene", seq_len(m))
  colnames(mat) <- paste0("cell", seq_len(n*g))
  group <- factor(sapply(seq_len(g), function(x) {
    rep(paste0("group", x), n)
  })))
  names(group) <- colnames(mat)
  mu_upreg <- 6
  sigma_upreg <- 10
  deg <- 100
  for (i in seq_len(g)) {
    mat[(deg*(i-1) + 1):(deg*i), group == paste0("group", i)] <-
      mat[1:deg, group==paste0("group", i)] + rnorm(deg, mu_upreg, sigma_upreg)
  }
  # positive expression only
  mat[mat < 0] <- 0
  x_train <- as.matrix(t(mat))

  ### model
  batch_size <- 32
  original_dim <- 1000
  intermediate_dim <- 512
  epochs <- 2
  # VAE
  vae_result <- fit_vae(x_train = x_train,
    encoder_layers = list(layer_input(shape = c(original_dim)),
      layer_dense(units = intermediate_dim,
        activation = "relu")),
    decoder_layers = list(layer_dense(units = intermediate_dim,
      activation = "relu"),
      layer_dense(units = original_dim,
        activation = "sigmoid")),
    epochs = epochs, batch_size = batch_size,
    validation_split = 0.5,
    use_generator = FALSE,
    callbacks = keras::callback_early_stopping(
```



```

        monitor = "val_loss",
        patience = 10,
        restore_best_weights = TRUE))
# plot
plot_vae(vae_result$model)

### generate samples
set.seed(1)
gen_sample_result <- gen_exprs(vae_result, num_samples = 100)
# plot
plot_aug(gen_sample_result, "PCA")
}

```

---

plot\_vae

*Visualization for the variational autoencoder*


---

## Description

You can create a plot of the VAE model. This plot can help you check that the model is connected the way you intended. The node colors indicate the components of the VAE.

## Usage

```

plot_vae(x, node_color = list(encoder_col = "tomato",
                              mean_vector_col = "orange",
                              stddev_vector_col = "lavender",
                              latent_vector_col = "lightblue",
                              decoder_col = "palegreen",
                              condition_col = "gray"))

```

## Arguments

x	VAE model
node_color	node colors for encoder(default: tomato), mean vector(default: orange), standard deviation vector(default: lavender), latent_vector(default: lightblue), decoder(default: palegreen), and condition(default: gray)

## Value

plot for the model architecture

## Author(s)

Dongmin Jung

## See Also

purrr::map, purrr::map\_chr, purrr::pluck, purrr::imap\_dfr, DiagrammeR::grViz

**Examples**

```

if (keras::is_keras_available() & reticulate::py_available()) {
  ### simulate differentially expressed genes
  set.seed(1)
  g <- 3
  n <- 100
  m <- 1000
  mu <- 5
  sigma <- 5
  mat <- matrix(rnorm(n*m*g, mu, sigma), m, n*g)
  rownames(mat) <- paste0("gene", seq_len(m))
  colnames(mat) <- paste0("cell", seq_len(n*g))
  group <- factor(sapply(seq_len(g), function(x) {
    rep(paste0("group", x), n)
  })))
  names(group) <- colnames(mat)
  mu_upreg <- 6
  sigma_upreg <- 10
  deg <- 100
  for (i in seq_len(g)) {
    mat[(deg*(i-1) + 1):(deg*i), group == paste0("group", i)] <-
      mat[1:deg, group==paste0("group", i)] + rnorm(deg, mu_upreg, sigma_upreg)
  }
  # positive expression only
  mat[mat < 0] <- 0
  x_train <- as.matrix(t(mat))

  ### model
  batch_size <- 32
  original_dim <- 1000
  intermediate_dim <- 512
  epochs <- 2
  # VAE
  vae_result <- fit_vae(x_train = x_train,
    encoder_layers = list(layer_input(shape = c(original_dim)),
      layer_dense(units = intermediate_dim,
        activation = "relu")),
    decoder_layers = list(layer_dense(units = intermediate_dim,
      activation = "relu"),
      layer_dense(units = original_dim,
        activation = "sigmoid")),
    epochs = epochs, batch_size = batch_size,
    validation_split = 0.5,
    use_generator = FALSE,
    callbacks = keras::callback_early_stopping(
      monitor = "val_loss",
      patience = 10,
      restore_best_weights = TRUE))

  # plot
  plot_vae(vae_result$model)
}

```

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