

Package ‘rsdv’

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Type Package

Title Synthetic Tabular Data Generation with Gaussian Copulas

Version 0.1.0

Description Generates synthetic tabular data from real datasets using Gaussian copula models, with parametric marginal selection for numerical columns and a cumulative-frequency embedding that brings categorical and boolean columns into the same joint copula. Includes a metadata system with column types and primary keys, declarative constraints enforced via rejection sampling, conditional sampling, and quality, validity and privacy reports modeled on those of the 'SDMetrics' library. Inspired by the Python 'SDV' (Synthetic Data Vault) library by 'DataCebo'; see Patki, Wedge and Veeramachaneni (2016) ``The Synthetic Data Vault" <doi:10.1109/DSAA.2016.49>.

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add_constraint	<i>Add a constraint to metadata</i>
----------------	-------------------------------------

Description

Add a constraint to metadata

Usage

```
add_constraint(meta, constraint)
```

Arguments

meta	An rsdv_metadata object.
constraint	A constraint object from <code>equality_constraint()</code> , <code>inequality_constraint()</code> , <code>fixed_combinations_constraint()</code> , or <code>custom_constraint()</code> .

Value

Updated rsdv_metadata (for piping).

Examples

```
meta <- metadata() |>
  set_column_type("low", "numerical") |>
  set_column_type("high", "numerical") |>
  add_constraint(inequality_constraint("low", "high", type = "lt"))
```

adult_income	<i>Adult Income dataset (500-row sample)</i>
--------------	--

Description

A 500-row random sample of the UCI Adult Income dataset, used in package examples and vignettes.

Usage

```
adult_income
```

Format

A tibble with 500 rows and 16 variables:

id Row identifier (integer)
age Age in years (integer)
workclass Employment type (character)
fnlwgt Final weight, a census sampling weight (integer)
education Highest level of education (character)
education_num Education encoded as an integer (integer)
marital_status Marital status (character)
occupation Occupation category (character)
relationship Relationship to householder (character)
race Race (character)
sex Sex (character)
capital_gain Capital gains (integer)
capital_loss Capital losses (integer)
hours_per_week Hours worked per week (integer)
native_country Country of origin (character)
income Income bracket: <=50K or >50K (character)

Source

<https://archive.ics.uci.edu/dataset/2/adult>

attribute_disclosure_risk

Attribute disclosure risk

Description

Estimates the fraction of synthetic rows where a sensitive column value can be correctly inferred from known columns via a k-NN lookup in the real training data.

Usage

```
attribute_disclosure_risk(real, synthetic, sensitive_col, known_cols, k = 1L)
```

Arguments

real, synthetic Data frames.
sensitive_col Name of the column to protect.
known_cols Character vector of columns assumed known to an adversary.
k Number of nearest neighbors used in inference.

Value

A scalar in [0, 1]; lower = more private.

Examples

```
real <- data.frame(age = sample(20:60, 50, replace = TRUE),
                  income = sample(c("low", "high"), 50, replace = TRUE),
                  stringsAsFactors = FALSE)
syn <- real[sample(50), ]
attribute_disclosure_risk(real, syn, sensitive_col = "income", known_cols = "age")
```

```
autoplot.rsdv_diagnostic_report
      Plot a diagnostic report
```

Description

Bar chart of per-column validity scores.

Usage

```
## S3 method for class 'rsdv_diagnostic_report'
autoplot(object, ...)
```

Arguments

object	An rsdv_diagnostic_report object.
...	Unused.

Value

A ggplot object.

Examples

```
meta <- metadata(adult_income)
syn <- gaussian_copula_synthesizer(meta) |> fit(adult_income)
synth <- sample(syn, n = 500)
ggplot2::autoplot(diagnostic_report(adult_income, synth, meta))
```

```
autoplot.rsdv_privacy_report
  Plot a privacy report
```

Description

Plots the NNDR score as a gauge-style bar.

Usage

```
## S3 method for class 'rsdv_privacy_report'
autoplot(object, ...)
```

Arguments

object	An rsdv_privacy_report object.
...	Unused.

Value

A ggplot object.

Examples

```
syn <- gaussian_copula_synthesizer(metadata(adult_income)) |> fit(adult_income)
synth <- sample(syn, n = 500)
pr <- privacy_report(adult_income, synth)
ggplot2::autoplot(pr)
```

```
autoplot.rsdv_quality_report
  Plot a quality report
```

Description

Produces a bar chart of per-column similarity scores, with a horizontal line at the overall score.

Usage

```
## S3 method for class 'rsdv_quality_report'
autoplot(object, ...)
```

Arguments

object	An rsdv_quality_report object.
...	Unused.

Value

A ggplot object.

Examples

```
syn <- gaussian_copula_synthesizer(metadata(adult_income)) |> fit(adult_income)
synth <- sample(syn, n = 500)
qr <- quality_report(adult_income, synth, metadata(adult_income))
ggplot2::autoplot(qr)
```

check_constraint	<i>Check a single constraint against each row of a data frame</i>
------------------	---

Description

Check a single constraint against each row of a data frame

Usage

```
check_constraint(data, constraint)
```

Arguments

data	A data frame.
constraint	An rsdv_constraint object.

Value

Logical vector of length nrow(data).

Examples

```
df <- data.frame(a = c(1, 2, 3), b = c(1, 2, 9))
check_constraint(df, equality_constraint("a", "b"))
```

check_constraints *Check all constraints in metadata against a data frame*

Description

Check all constraints in metadata against a data frame

Usage

```
check_constraints(data, meta)
```

Arguments

data	A data frame.
meta	An rsdv_metadata object.

Value

Logical vector of length `nrow(data)`. TRUE = row passes all constraints.

Examples

```
meta <- metadata() |>
  set_column_type("x", "numerical") |>
  add_constraint(custom_constraint(function(row) row$x > 0))
check_constraints(data.frame(x = c(1, -1, 2)), meta)
```

contingency_similarity
Contingency similarity between real and synthetic categorical column pairs

Description

For each pair of categorical columns, compares the joint (normalized contingency) distributions of real and synthetic data via total variation distance, scoring $1 - \text{TVD}$ (the `SDMetrics ContingencySimilarity` score). This is the categorical analogue of correlation similarity and captures categorical-vs-categorical dependence.

Usage

```
contingency_similarity(real, synthetic, meta)
```

Arguments

real	A data frame of real data.
synthetic	A data frame of synthetic data.
meta	An rsdv_metadata object.

Value

A list with pairs (a tibble of column_1, column_2, score) and score (the mean over pairs; 1 when there are fewer than two categorical columns).

Examples

```
meta <- metadata(adult_income)
syn  <- gaussian_copula_synthesizer(meta) |> fit(adult_income)
synth <- sample(syn, n = 500)
contingency_similarity(adult_income, synth, meta)
```

correlation_similarity

Correlation similarity between real and synthetic numerical column pairs

Description

For each pair of numerical columns, computes $1 - |\text{corr_real} - \text{corr_syn}| / 2$ (the SDMetrics CorrelationSimilarity score), where corr is the Pearson correlation. Returns one row per pair plus the mean.

Usage

```
correlation_similarity(real, synthetic, meta)
```

Arguments

real	A data frame of real data.
synthetic	A data frame of synthetic data.
meta	An rsdv_metadata object.

Value

A list with pairs (a tibble of column_1, column_2, score) and score (the mean over pairs; 1 when there are fewer than two numerical columns).

Examples

```
syn      <- gaussian_copula_synthesizer(metadata(adult_income)) |> fit(adult_income)
synth_data <- sample(syn, n = 500)
correlation_similarity(adult_income, synth_data, metadata(adult_income))
```

custom_constraint	<i>Constraint: arbitrary row-wise predicate</i>
-------------------	---

Description

Constraint: arbitrary row-wise predicate

Usage

```
custom_constraint(fn)
```

Arguments

fn A function $f(\text{row})$ accepting a one-row data frame, returning a single logical.

Value

An `rsdv_constraint` object.

Examples

```
custom_constraint(function(row) row$x > 0)
```

diagnostic_report	<i>Generate a diagnostic (validity) report for synthetic data</i>
-------------------	---

Description

Checks whether synthetic data is *structurally valid* against the real data and metadata — independent of how closely it matches the real distributions (that is the job of `quality_report()`). Mirrors the SDMetrics `DiagnosticReport` two-property hierarchy:

Usage

```
diagnostic_report(real, synthetic, metadata)
```

Arguments

real A data frame of real data.
synthetic A data frame of synthetic data.
metadata An `rsdv_metadata` object.

Details

- **Data Validity** — per-column checks:
 - numerical: boundary adherence (fraction of values within the real min/max range),
 - categorical: category adherence (fraction of values whose category was seen in the real data),
 - boolean: always valid,
 - primary key: key uniqueness (all values unique and non-missing).
- **Data Structure** — fraction of expected columns present in the synthetic data.

Missing (NA) values are excluded from adherence denominators, since missingness is modeled separately.

Value

An `rsdv_diagnostic_report` object.

Examples

```
meta <- metadata(adult_income)
syn  <- gaussian_copula_synthesizer(meta) |> fit(adult_income)
synth <- sample(syn, n = 500)
diagnostic_report(adult_income, synth, meta)
```

equality_constraint *Constraint: two columns must be equal row-wise*

Description

Constraint: two columns must be equal row-wise

Usage

```
equality_constraint(col_a, col_b)
```

Arguments

`col_a`, `col_b` Column names (character).

Value

An `rsdv_constraint` object.

Examples

```
equality_constraint("city", "city_copy")
```

fixed_combinations_constraint

Constraint: only observed column combinations are valid

Description

Constraint: only observed column combinations are valid

Usage

```
fixed_combinations_constraint(columns, reference_data)
```

Arguments

columns Character vector of column names.
reference_data Data frame containing the allowed combinations.

Value

An `rsdv_constraint` object.

Examples

```
ref <- data.frame(city = c("NY", "LA"), state = c("NY", "CA"),  
                  stringsAsFactors = FALSE)  
fixed_combinations_constraint(c("city", "state"), ref)
```

gaussian_copula_synthesizer

Create a Gaussian Copula synthesizer

Description

Fits a single Gaussian copula over **all** modeled columns. Numerical columns use a fitted parametric marginal (see `default_distribution`); categorical and boolean columns are embedded into the copula via their cumulative-frequency intervals, so cross-column dependence (numeric vs. categorical, categorical vs. categorical) is preserved.

Usage

```
gaussian_copula_synthesizer(  
  metadata,  
  enforce_min_max = TRUE,  
  numerical_distributions = list(),  
  default_distribution = "auto"  
)
```

Arguments

metadata	An rsdv_metadata object.
enforce_min_max	Logical. Clamp sampled numerical values to the observed range. Default TRUE.
numerical_distributions	Optional named character vector/list mapping numerical column names to a distribution in "norm", "beta", "gamma", "truncnorm", "uniform", or "auto".
default_distribution	Distribution used for numerical columns not named in numerical_distributions. "auto" (default) selects the best-fitting family per column by Kolmogorov-Smirnov distance.

Value

An unfitted gaussian_copula_synthesizer object.

Examples

```
meta <- metadata(adult_income) |>
  set_column_type("age", "numerical") |>
  set_column_type("occupation", "categorical")
syn <- gaussian_copula_synthesizer(meta, default_distribution = "auto")
syn <- fit(syn, adult_income)
```

inequality_constraint *Constraint: col_a must be less than / greater than col_b*

Description

Constraint: col_a must be less than / greater than col_b

Usage

```
inequality_constraint(col_a, col_b, type = c("lt", "lte", "gt", "gte"))
```

Arguments

col_a, col_b	Column names (character).
type	One of "lt", "lte", "gt", "gte".

Value

An rsdv_constraint object.

Examples

```
inequality_constraint("low", "high", type = "lt")
```

is_fitted	<i>Check whether a synthesizer has been fitted</i>
-----------	--

Description

Check whether a synthesizer has been fitted

Usage

```
is_fitted(x)
```

Arguments

x A synthesizer object.

Value

TRUE if `fit()` has been called; FALSE otherwise.

Examples

```
syn <- gaussian_copula_synthesizer(metadata())
is_fitted(syn) # FALSE before fitting
```

ks_similarity	<i>Kolmogorov-Smirnov similarity score per numerical column</i>
---------------	---

Description

Kolmogorov-Smirnov similarity score per numerical column

Usage

```
ks_similarity(real, synthetic, meta)
```

Arguments

real A data frame of real data.
synthetic A data frame of synthetic data.
meta An `rsdv_metadata` object.

Value

A tibble with columns `column` (chr) and `score` (dbl, 0–1, higher = better).

Examples

```
syn  <- gaussian_copula_synthesizer(metadata(adult_income)) |> fit(adult_income)
synth <- sample(syn, n = 500)
ks_similarity(adult_income, synth, metadata(adult_income))
```

load_metadata	<i>Load metadata from a JSON file</i>
---------------	---------------------------------------

Description

Load metadata from a JSON file

Usage

```
load_metadata(path)
```

Arguments

path Path to a JSON file produced by [save_metadata\(\)](#).

Value

An `rsdv_metadata` object.

Examples

```
meta <- metadata() |> set_column_type("age", "numerical")
tmp  <- tempfile(fileext = ".json")
save_metadata(meta, tmp)
load_metadata(tmp)
```

metadata	<i>Create a metadata object describing a dataset's column types</i>
----------	---

Description

Create a metadata object describing a dataset's column types

Usage

```
metadata(data = NULL)
```

Arguments

data Optional data frame. If supplied, column types are auto-detected. You can override them with [set_column_type\(\)](#).

Value

An rsvd_metadata object.

Examples

```
meta <- metadata(adult_income) |>
  set_column_type("age", "numerical") |>
  set_column_type("occupation", "categorical")
```

metadata_from_json *Deserialize metadata from a JSON string*

Description

Deserialize metadata from a JSON string

Usage

```
metadata_from_json(json)
```

Arguments

json A JSON character string produced by [metadata_to_json\(\)](#).

Value

An rsvd_metadata object.

Examples

```
json <- metadata_to_json(metadata()) |> set_column_type("age", "numerical")
metadata_from_json(json)
```

metadata_to_json *Serialize metadata to a JSON string*

Description

Serialize metadata to a JSON string

Usage

```
metadata_to_json(meta)
```

Arguments

meta An rsvd_metadata object.

Value

A JSON character string.

Examples

```
meta <- metadata() |> set_column_type("age", "numerical")
json <- metadata_to_json(meta)
meta2 <- metadata_from_json(json)
```

ml_efficacy	<i>ML efficacy: train-on-synthetic / test-on-real accuracy ratio (TSTR)</i>
-------------	---

Description

Trains an rpart decision tree on synthetic data and on a real training split, evaluates both on a real held-out test set, and returns the ratio TSTR / TRTR. A score near 1 means synthetic data is as informative as real data for this prediction task.

Usage

```
ml_efficacy(real, synthetic, meta, target_col, test_fraction = 0.2)
```

Arguments

real	A data frame of real data.
synthetic	A data frame of synthetic data.
meta	An rsvd_metadata object.
target_col	Name of a categorical column to use as the outcome.
test_fraction	Fraction of real to hold out as the test set.

Value

A list with elements tstr (accuracy), trtr (accuracy), and score (ratio, capped at 1).

Examples

```
meta <- metadata(adult_income)
syn <- gaussian_copula_synthesizer(meta) |> fit(adult_income)
synth_data <- sample(syn, n = 500)
ml_efficacy(adult_income, synth_data, meta, target_col = "income")
```

nndr	<i>Nearest-Neighbor Distance Ratio privacy score</i>
------	--

Description

For each synthetic row, computes the ratio of its distance to the nearest real row vs. its distance to the second-nearest real row. A high ratio (close to 1) means the synthetic row is not unusually close to any specific real row — low disclosure risk. Score = mean(ratio > 0.5).

Usage

```
nndr(real, synthetic)
```

Arguments

real, synthetic Data frames with only numerical columns.

Value

A scalar score in [0, 1]; higher = more private.

Examples

```
real <- data.frame(x = rnorm(50), y = rnorm(50))
syn <- data.frame(x = rnorm(50), y = rnorm(50))
nndr(real, syn)
```

print.rsdv_diagnostic_report	<i>Print method for rsdv_diagnostic_report</i>
------------------------------	--

Description

Print method for rsdv_diagnostic_report

Usage

```
## S3 method for class 'rsdv_diagnostic_report'
print(x, ...)
```

Arguments

x An rsdv_diagnostic_report object.
... Unused.

Value

x, invisibly.

```
print.rsdv_metadata    Print method for rsdv_metadata
```

Description

Print method for rsdv_metadata

Usage

```
## S3 method for class 'rsdv_metadata'  
print(x, ...)
```

Arguments

x	An rsdv_metadata object.
...	Unused.

Value

x, invisibly.

Examples

```
print(metadata())
```

```
print.rsdv_privacy_report  
    Print method for rsdv_privacy_report
```

Description

Print method for rsdv_privacy_report

Usage

```
## S3 method for class 'rsdv_privacy_report'  
print(x, ...)
```

Arguments

x	An rsdv_privacy_report object.
...	Unused.

Value

x, invisibly.

Examples

```
syn <- gaussian_copula_synthesizer(metadata(adult_income)) |> fit(adult_income)
synth <- sample(syn, n = 500)
pr <- privacy_report(adult_income, synth)
print(pr)
```

```
print.rsdv_quality_report
```

Print method for rsdv_quality_report

Description

Print method for rsdv_quality_report

Usage

```
## S3 method for class 'rsdv_quality_report'
print(x, ...)
```

Arguments

x	An rsdv_quality_report object.
...	Unused.

Value

x, invisibly.

```
privacy_report
```

Generate a privacy report comparing real and synthetic data

Description

Generate a privacy report comparing real and synthetic data

Usage

```
privacy_report(real, synthetic, sensitive_col = NULL, known_cols = NULL)
```

Arguments

real	A data frame of real data.
synthetic	A data frame of synthetic data.
sensitive_col	Optional. Column name for attribute disclosure risk.
known_cols	Optional. Column names known to an adversary (required if sensitive_col is supplied).

Value

An `rsdv_privacy_report` object.

Examples

```
syn <- gaussian_copula_synthesizer(metadata(adult_income)) |>
  fit(adult_income)
synth <- sample(syn, n = 500)
pr <- privacy_report(adult_income, synth)
print(pr)
```

quality_report	<i>Generate a quality report comparing real and synthetic data</i>
----------------	--

Description

Aggregates metrics into the two-property hierarchy used by `SDMetrics`:

Usage

```
quality_report(real, synthetic, metadata, target_col = NULL)
```

Arguments

<code>real</code>	A data frame of real data.
<code>synthetic</code>	A data frame of synthetic data.
<code>metadata</code>	An <code>rsdv_metadata</code> object.
<code>target_col</code>	Optional. Name of a categorical column for ML efficacy. Reported alongside the score but excluded from the overall.

Details

- **Column Shapes** — per-column marginal fidelity: KS similarity for numerical columns and TVD similarity for categorical columns.
- **Column Pair Trends** — pairwise dependence: correlation similarity for numerical pairs and contingency similarity for categorical pairs.

The overall score is the mean of the two property scores, so a table with many categorical columns and few numerical ones is not weighted by raw column counts. ML efficacy, when requested, is reported separately and does **not** enter the overall score (matching `SDMetrics`).

Value

An `rsdv_quality_report` object.

Examples

```
meta <- metadata(adult_income) |>
  set_column_type("age", "numerical") |>
  set_column_type("occupation", "categorical")
syn <- gaussian_copula_synthesizer(meta) |> fit(adult_income)
synth <- sample(syn, n = 500)
qr <- quality_report(adult_income, synth, meta)
print(qr)
```

sample

Sample synthetic rows from a fitted synthesizer

Description

Dispatches to the synthesizer-specific method when `x` is an `rsdv_synthesizer`. For plain R vectors, integers, or characters it falls back to `base::sample()`, preserving backward compatibility.

Usage

```
sample(x, n = NULL, ...)
```

Arguments

<code>x</code>	A fitted synthesizer object, or a vector for <code>base::sample()</code> compat.
<code>n</code>	Number of synthetic rows to generate (synthesizer path), or sample size (<code>base::sample</code> path).
<code>...</code>	Additional arguments passed to the method or to <code>base::sample()</code> .

Value

When `x` inherits from `rsdv_synthesizer`, a data frame of `n` synthetic rows whose columns match the metadata. When `x` is any other object, the value returned by `base::sample()` — typically a vector of the same type as `x` and length `n`.

Examples

```
# Falls back to base::sample for non-synthesizer objects:
sample(1:10, 3)
```

```
meta <- metadata(adult_income) |>
  set_column_type("age", "numerical") |>
  set_column_type("income", "categorical")
syn <- gaussian_copula_synthesizer(meta) |> fit(adult_income)
synth <- sample(syn, n = 100)
head(synth)
```

sample_conditions	<i>Sample synthetic rows that match fixed column values (conditional sampling)</i>
-------------------	--

Description

Generates rows in which one or more **categorical or boolean** columns are held to specified values, via rejection sampling against the fitted copula. This preserves the modeled dependence between the conditioned columns and the rest of the table (unlike overwriting values after the fact).

Usage

```
sample_conditions(x, conditions, max_tries = 100L)
```

Arguments

x	A fitted gaussian_copula_synthesizer.
conditions	A data frame whose columns are the variables to fix. Each row is one condition; an optional integer column .n gives how many rows to generate for that condition (default 1 per row).
max_tries	Maximum rejection-sampling rounds per condition.

Value

A data frame of synthetic rows satisfying the conditions.

Examples

```
meta <- metadata(adult_income)
syn <- gaussian_copula_synthesizer(meta) |> fit(adult_income)
sample_conditions(syn, data.frame(income = ">50K", .n = 20))
```

save_metadata	<i>Save metadata to a JSON file</i>
---------------	-------------------------------------

Description

Save metadata to a JSON file

Usage

```
save_metadata(meta, path)
```

Arguments

meta	An rsdv_metadata object.
path	File path to write to.

Value

Invisibly returns meta.

Examples

```
meta <- metadata() |> set_column_type("age", "numerical")
tmp <- tempfile(fileext = ".json")
save_metadata(meta, tmp)
meta2 <- load_metadata(tmp)
```

set_column_type	<i>Set the type of a column in metadata</i>
-----------------	---

Description

Set the type of a column in metadata

Usage

```
set_column_type(meta, column, type)
```

Arguments

meta	An rsdv_metadata object.
column	Column name (character).
type	One of "numerical", "categorical", "boolean", "datetime", "id".

Value

The updated rsdv_metadata object (for piping).

Examples

```
metadata() |> set_column_type("age", "numerical")
```

set_primary_key	<i>Set the primary key column of the metadata</i>
-----------------	---

Description

Set the primary key column of the metadata

Usage

```
set_primary_key(meta, column)
```

Arguments

meta	An rsdv_metadata object.
column	Name of the primary key column. Must already be registered via set_column_type() .

Value

The updated rsdv_metadata object (for piping).

Examples

```
meta <- metadata() |>
  set_column_type("id", "id") |>
  set_primary_key("id")
```

tv_dsimilarity	<i>Total variation distance similarity score per categorical column</i>
----------------	---

Description

Total variation distance similarity score per categorical column

Usage

```
tv_dsimilarity(real, synthetic, meta)
```

Arguments

real	A data frame of real data.
synthetic	A data frame of synthetic data.
meta	An rsdv_metadata object.

Value

A tibble with columns column (chr) and score (dbl, 0–1, higher = better).

Examples

```
syn  <- gaussian_copula_synthesizer(metadata(adult_income)) |> fit(adult_income)
synth <- sample(syn, n = 500)
tvd_similarity(adult_income, synth, metadata(adult_income))
```

`validate_data`*Validate that a data frame is compatible with metadata*

Description

Checks that all columns registered in meta are present in data.

Usage

```
validate_data(data, meta)
```

Arguments

<code>data</code>	A data frame.
<code>meta</code>	An <code>rsdv_metadata</code> object.

Value

Invisibly TRUE; throws an error if validation fails.

Examples

```
meta <- metadata() |> set_column_type("age", "numerical")
validate_data(data.frame(age = 1:5), meta)
```

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