

Package ‘vines’

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Type Package

Title Multivariate Dependence Modeling with Vines

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Description Vines are graphical models for pair-copula constructions that represent high-dimensional distributions as a factorization of bivariate copulas and marginal density functions. This package contains S4 classes for vines (C-vines and D-vines) and methods for inference, goodness-of-fit tests, density/distribution function evaluation, and simulation.

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URL <https://github.com/ygf/vines>

Depends methods, copula

Imports ADGofTest, cubature, TSP

Collate h.R hinverse.R Vine.R show.R dimnames.R vineParameters.R
vineIter.R vineFit.R vineFitML.R vinePIT.R vineGoF.R vineOrder.R dvine.R pvine.R rvine.R

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CVine-class	<i>Class for C-vines</i>
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Description

Extends the [RVine](#) class to represent C-vines.

Slots

See [RVine](#) for information about the inherited slots.

Methods

`show` signature(object = "CVine"): Print a textual representation of the C-vine.

See Also

[Vine](#), [RVine](#), [DVine](#).

 DVine-class

Class for D-vines

Description

Extends the [RVine](#) class to represent D-vines.

Slots

See [RVine](#) for information about the inherited slots.

Methods

`show signature(object = "DVine")`: Print a textual representation of the D-vine.

See Also

[Vine](#), [RVine](#), [CVine](#).

 h-methods

Methods for the h-functions

Description

The h function represents the conditional distribution function of a bivariate copula and it should be defined for every copula used in a pair-copula construction. It is defined as the partial derivative of the distribution function of the copula w.r.t. the second argument $h(x, v) = F(x|v) = \partial C(x, v) / \partial v$.

Usage

`h(copula, x, v)`

Arguments

<code>copula</code>	A bivariate copula object.
<code>x</code>	Numeric vector with values in $[0, 1]$.
<code>v</code>	Numeric vector with values in $[0, 1]$.

Methods

signature(copula = "copula") Default definition of the h function for a bivariate copula. This method is used if no particular definition is given for a copula. The partial derivative is calculated numerically using the `numericDeriv` function.

signature(copula = "indepCopula") The h function of the independence copula.

$$h(x, v) = x$$

signature(copula = "normalCopula") The h function of the normal copula.

$$h(x, v; \rho) = \Phi \left(\frac{\Phi^{-1}(x) - \rho \Phi^{-1}(v)}{\sqrt{1 - \rho^2}} \right)$$

signature(copula = "tCopula") The h function of the t copula.

$$h(x, v; \rho, \nu) = t_{\nu+1} \left(\frac{t_{\nu}^{-1}(x) - \rho t_{\nu}^{-1}(v)}{\sqrt{\frac{(\nu + (t_{\nu}^{-1}(v))^2)(1 - \rho^2)}{\nu+1}}} \right)$$

signature(copula = "claytonCopula") The h function of the Clayton copula.

$$h(x, v; \theta) = v^{-\theta-1} (x^{-\theta} + v^{-\theta} - 1)^{-1-1/\theta}$$

signature(copula = "gumbelCopula") The h function of the Gumbel copula.

$$h(x, v; \theta) = C(x, v; \theta) \frac{1}{v} (-\log v)^{\theta-1} ((-\log x)^{\theta} + (-\log v)^{\theta})^{1/\theta-1}$$

signature(copula = "fgmCopula") The h function of the Farlie-Gumbel-Morgenstern copula.

$$h(x, v; \theta) = (1 + \theta (-1 + 2v) (-1 + x)) x$$

signature(copula = "frankCopula") The h function of the Frank copula.

$$h(x, v; \theta) = \frac{e^{-\theta v}}{\frac{1-e^{-\theta}}{1-e^{-\theta x}} + e^{-\theta v} - 1}$$

signature(copula = "galambosCopula") The h function of the Galambos copula.

$$h(x, v; \theta) = \frac{C(x, v; \theta)}{v} \left(1 - \left[1 + \left(\frac{-\log v}{-\log x} \right)^{\theta} \right]^{-1-1/\theta} \right)$$

References

- Aas, K. and Czado, C. and Frigessi, A. and Bakken, H. (2009) Pair-copula constructions of multiple dependence. *Insurance: Mathematics and Economics* **44**, 182–198.
- Schirmacher, D. and Schirmacher, E. (2008) Multivariate dependence modeling using pair-copulas. *Enterprise Risk Management Symposium, Chicago*.

Description

The h^{-1} function represents the inverse of the h function with respect to its first argument. It should be defined for every copula used in a pair-copula construction (or it will be evaluated numerically).

Usage

```
hinverse(copula, u, v)
```

Arguments

copula	A bivariate copula object.
u	Numeric vector with values in $[0, 1]$.
v	Numeric vector with values in $[0, 1]$.

Methods

signature(copula = "copula") Default definition of the h^{-1} function for a bivariate copula.

This method is used if no particular definition is given for a copula. The inverse is calculated numerically using the [uniroot](#) function.

signature(copula = "indepCopula") The h^{-1} function of the Independence copula.

$$h^{-1}(u, v) = u$$

signature(copula = "normalCopula") The h^{-1} function of the normal copula.

$$h^{-1}(u, v; \rho) = \Phi \left(\Phi^{-1}(u) \sqrt{1 - \rho^2} + \rho \Phi^{-1}(v) \right)$$

signature(copula = "tCopula") The h^{-1} function of the t copula.

$$h^{-1}(u, v; \rho, \nu) = t_{\nu} \left(t_{\nu+1}^{-1}(u) \sqrt{\frac{(\nu + (t_{\nu}^{-1}(v))^2)(1 - \rho^2)}{\nu + 1}} + \rho t_{\nu}^{-1}(v) \right)$$

signature(copula = "claytonCopula") The h^{-1} function of the Clayton copula.

$$h^{-1}(u, v; \theta) = \left((u v^{\theta+1})^{-\frac{\theta}{\theta+1}} + 1 - v^{-\theta} \right)^{-1/\theta}$$

signature(copula = "frankCopula") The h^{-1} function of the Frank copula.

$$h^{-1}(u, v; \theta) = -\log \left(1 - \frac{1 - e^{-\theta}}{(u^{-1} - 1)e^{-\theta v} + 1} \right) / \theta$$

References

- Aas, K. and Czado, C. and Frigessi, A. and Bakken, H. (2009) Pair-copula constructions of multiple dependence. *Insurance: Mathematics and Economics* **44**, 182–198.
- Schirmacher, D. and Schirmacher, E. (2008) Multivariate dependence modeling using pair-copulas. *Enterprise Risk Management Symposium, Chicago*.

RVine-class	<i>Class for Regular Vines</i>
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Description

Extends the [Vine](#) class to represent regular vines.

Slots

See [Vine](#) for information about the inherited slots.

See Also

[Vine](#), [CVine](#), [DVine](#).

Vine	<i>Create Vine Objects</i>
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Description

Functions to create [Vine](#) objects.

Usage

```
Vine(type, dimension = 2, trees = dimension - 1,
      copulas = matrix(list(indepCopula()),
                        dimension - 1, dimension - 1))
CVine(dimension = 2, trees = dimension - 1,
      copulas = matrix(list(indepCopula()),
                        dimension - 1, dimension - 1))
DVine(dimension = 2, trees = dimension - 1,
      copulas = matrix(list(indepCopula()),
                        dimension - 1, dimension - 1))
```

Arguments

type	Type of vine. Supported values: "CVine" and "DVine".
dimension	See the documentation of the Vine slot.
trees	See the documentation of the Vine slot.
copulas	See the documentation of the Vine slot.

See Also

[Vine](#), [CVine](#), [DVine](#).

Examples

```
dimension <- 3
copulas <- matrix(list(normalCopula(0.5),
                      claytonCopula(2.75),
                      tCopula(0.75, df = 2),
                      NULL),
                 ncol = dimension - 1,
                 nrow = dimension - 1,
                 byrow = TRUE)

Vine("DVine", dimension = dimension, trees = dimension - 1,
     copulas = copulas)
DVine(dimension = dimension, trees = dimension - 1,
     copulas = copulas)
```

Vine-class

Base Vine Class

Description

Base class of all classes that implement vine models in the package. It is a virtual class, no objects may be created from it.

Slots

type: Object of class "character". Descriptive name of the type of vine: Canonical vine or D-vine.

dimension: Object of class "numeric". Dimension of the vine.

dimensionNames: Object of class "character". Names of the variables of the vine. It is either an empty character vector or a vector with one element for each variable of the vine.

copulas: Object of class "matrix". It contains the [copula](#) objects for each copula in the pair-copula decomposition. The indexes of the matrix follow the notation used for the subscripts of Θ in (Aas et al., 2009).

trees: Object of class "numeric". Number of dependence trees of the vine. It should be an integer between 0 and `dimension - 1`, including both endpoints. Functions acting on vines assume that copulas in arcs of all trees greater than `trees` are independence copulas.

Methods

show signature(object = "Vine"): Print a textual representation of the vine.

dimnames signature(x = "Vine"): Retrieve the names of the variables of the vine.

dimnames<- signature(x = "Vine"): Set the names of the variables of the vine.

References

Aas, K. and Czado, C. and Frigessi, A. and Bakken, H. (2009) Pair-copula constructions of multiple dependence. *Insurance: Mathematics and Economics* **44**, 182–198.

See Also

[RVine](#), [CVine](#), [DVine](#).

Vine-distribution *Vine Distribution Functions*

Description

Density evaluation, distribution function evaluation, and random number generation.

Usage

```
dvine(vine, u)
pvine(vine, u)
rvine(vine, n)
```

Arguments

<code>vine</code>	A Vine object.
<code>u</code>	Vector of the same dimension of the vine or a matrix with one column for each variable of the vine.
<code>n</code>	Number of observations.

Details

The implementation of the `dvine` function for [CVine](#) and [DVine](#) objects is based on the Algorithms 3 and 4 of (Aas et al. 2009), respectively.

The `pvine` function is evaluated through the numerical integration of the density function (using the [cubature](#) package). This is a computationally demanding procedure, even for small dimensions.

The implementation of the `rvine` function for [CVine](#) and [DVine](#) objects is based on the Algorithms 1 and 2 of (Aas et al. 2009), respectively.

Value

`dnorm` returns a vector with the evaluation of the density. `pnorm` returns a vector with the evaluation of the distribution function. `rvine` returns a matrix with one column for each variable of the vine and one row for each observation.

References

- Aas, K. and Czado, C. and Frigessi, A. and Bakken, H. (2009) Pair-copula constructions of multiple dependence. *Insurance: Mathematics and Economics* **44**, 182–198.
- Bedford, T. and Cooke, R. M. (2001) Monte Carlo simulation of vine dependent random variables for applications in uncertainty analysis. In *2001 Proceedings of ESREL2001, Turin, Italy*.
- Bedford, T. and Cooke, R. M. (2001) Probability density decomposition for conditionally dependent random variables modeled by vines. *Annals of Mathematics and Artificial Intelligence* **32**, 245–268.
- Kurowicka, D. and Cooke, R. M. (2005) Sampling algorithms for generating joint uniform distributions using the vine-copula method. In *3rd IASC World Conference on Computational Statistics & Data Analysis, Limassol, Cyprus*.

Examples

```
dimension <- 3
copulas <- matrix(list(normalCopula(0.5),
                      claytonCopula(2.75),
                      tCopula(0.75, df = 2),
                      NULL),
                 ncol = dimension - 1,
                 nrow = dimension - 1)
vine <- DVine(dimension = dimension, trees = dimension - 1,
             copulas = copulas)
dimnames(vine) <- c("A", "B", "C")

data <- rvine(vine, 1)
dvine(vine, data)
pvine(vine, data)
```

vineFit

Vine Inference

Description

Estimate a vine model from multivariate data in the unit hypercube. Data can be pseudo-observations constructed from empirical or parametric marginal cumulative distribution functions.

Usage

```
vineFit(type, data, method = "ml", ...)
```

Arguments

type	Type of vine. Supported values: "CVine" and "DVine".
data	Data matrix of pseudo-observations.
method	Inference method. Supported values: "ml" (Maximum Likelihood).
...	Additional arguments for the inference method.

Details

The "ml" (Maximum Likelihood) method starts with the sequential estimation procedure described in (Aas et al., 2009) and then executes a numerical maximization of the full log-likelihood of the vine. The sequential procedure is used to determine the family and the initial values of the parameters of each bivariate copula in the decomposition. Additional arguments for this method are:

`selectCopula` Function provided by the user to select the copulas in the pair-copula construction. This function should return a `copula` object and expect the following arguments.

`vine` Vine object being constructed.

`j`, `i` Indexes of the copula under selection in the matrix of the copulas slot of the vine.

`x`, `y` Bivariate sample.

The default value is function `(vine, j, i, x, y) indepCopula()` that assigns the independence copula to all the arcs of the vine.

`trees` Maximum number of dependence trees of the vine. Independence copulas will be used in all the arcs of the following trees. The final number of dependence trees could be smaller because of the use of a truncation method. The default value is `ncol(data) - 1`.

`truncMethod` Method used to automatically truncate the vine if enough dependence is captured in a given number of trees. Supported methods are "AIC" and "BIC". See (Brechmann, 2010; Brechmann et al., 2010) for information about these methods. The default value is "" that means no truncation.

`optimMethod` `optim` method used in the optimization of the log-likelihood function. If "" is specified the optimization is disabled and the vine calculated using the sequential estimation procedure is returned. The default value is "Nelder-Mead".

`optimControl` List of control parameters for `optim`. The default value is `list()`.

Value

A `vineFit` object or a subclass with specific information about inference method used. The `vine` slot of this object contains the fitted `Vine` object.

References

Aas, K. and Czado, C. and Frigessi, A. and Bakken, H. (2009) Pair-copula constructions of multiple dependence. *Insurance: Mathematics and Economics* **44**, 182–198.

Brechmann, E. C. (2010) Truncated and simplified regular vines and their applications. Diploma thesis. *Technische Universitaet Muenchen*.

Brechmann, E. C. and Czado, C. and Aas, K. (2010) Truncated regular vines in high dimensions with application to financial data. *Norwegian Computing Center, NR*. Note SAMBA/60/10.

See Also

[CVine](#), [DVine](#), [vineFit](#), [vineFitML](#).

Examples

```
data <- matrix(runif(5 * 100), ncol = 5, nrow = 100)
colnames(data) <- c("A", "B", "C", "D", "E")

selectCopula <- function (vine, j, i, x, y) {
  data <- cbind(x, y)
  fit <- fitCopula(normalCopula(), data, method = "itau")
  fit@copula
}
fit <- vineFit("DVine", data, method = "ml",
              selectCopula = selectCopula,
              optimMethod = "")

show(fit)
show(fit@vine)
```

vineFit-class

Class for the Results of Vine Inference

Description

Base class of all classes providing information about vine inference. Objects of this class (or subclasses) are created by calling the `vineFit` function.

Slots

`vine`: Object of class `Vine`. Fitted vine.

`observations`: Object of class `numeric`. Number of observations in the sample.

`method`: Object of class `character`. Inference method.

Methods

`show` signature(`object` = "vineFit"): Print the result of the vine inference.

See Also

`vineFit`, `vineFitML`.

vineFitML-class	<i>Class for the Results of Vine Inference by Maximum Likelihood</i>
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Description

Extends the [vineFit](#) class to include information about the Maximum Likelihood inference.

Slots

See [vineFit](#) for information about inherited slots.

optimMethod: Object of class character. [optim](#) method.

optimConv: Object of class numeric. [optim](#) convergence code (0 indicates successful completion).

startParams: Object of class numeric. Vector with the parameters of the copulas in the pair-copula construction calculated using the sequential estimation procedure.

finalParams: Object of class numeric. Vector with the parameters of the copulas in the pair-copula construction after the maximization of the log-likelihood.

Methods

show signature(object = "vineFitML"): Print information about the fitted vine.

See Also

[vineFit](#), [vineFit](#), [vineParameters](#).

vineGoF	<i>Vine Goodness-of-fit Tests</i>
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Description

Goodness-of-fit tests to verify whether the dependence structure of a sample is appropriately modeled by vine model.

Usage

```
vineGoF(vine, data, method = "PIT", ...)
```

Arguments

vine A [Vine](#) object.

data Data matrix of pseudo-observations.

method Goodness-of-fit method. Supported values: "PIT" (Probability Integral Transform).

... Additional arguments for the goodness-of-fit method.

Details

The "PIT" (Probability Integral Transform) method uses the `vinePIT` function to transform the data into variables which are independent and Uniform(0,1) and then use a hypothesis test to verify whether the resulting variables are independent and Uniform(0,1). The additional parameter `statistic` specifies the test to be applied for this purpose.

`statistic` Statistic used to verify if the transformed variables are independent and Uniform(0,1). The default value is "Breyman" and supported methods are:

"Breyman" Test proposed in the Section 7.1 of (Aas et al., 2009). See (Breyman et al., 2003) for more information.

Value

A `vineGoF` or a subclass with specific information about the goodness-of-fit method used. The `statistic` slot of this object contains the value of the statistic and `pvalue` the p-value.

References

Aas, K. and Czado, C. and Frigessi, A. and Bakken, H. (2009) Pair-copula constructions of multiple dependence. *Insurance: Mathematics and Economics* **44**, 182–198.

Breyman, W. and Dias, A. and Embrechts, P. (2003) Dependence structures for multivariate high-frequency data in finance. *Quantitative Finance* **1**, 1–14.

See Also

`vineGoF`, `vinePIT`.

Examples

```
copula <- normalCopula(c(-0.25, -0.21, 0.34, 0.51, -0.07, -0.18),
                      dispstr = "un", dim = 4)
data <- rCopula(100, copula)

selectCopula <- function (vine, j, i, x, y) {
  data <- cbind(x, y)
  fit <- fitCopula(normalCopula(), data, method = "itau")
  fit@copula
}
normalCVine <- vineFit("CVine", data, method = "ml",
                      selectCopula = selectCopula,
                      optimMethod = "")@vine
normalDVine <- vineFit("DVine", data, method = "ml",
                      selectCopula = selectCopula,
                      optimMethod = "")@vine

show(normalCVine)
show(normalDVine)

normalCVineGof <- vineGoF(normalCVine, data, method = "PIT",
                          statistic = "Breyman")
normalDVineGof <- vineGoF(normalDVine, data, method = "PIT",
```

```

                                statistic = "Breyman")
show(normalCVineGof)
show(normalDVineGof)

```

vineGoF-class

Class for the Results of Vine Goodness-of-fit Tests

Description

Base class of all classes containing information about vine goodness-of-fit tests. Objects of this class (or subclasses) are created by calling the [vineGoF](#) function.

Slots

method: Object of class character. Goodness-of-fit method.
 statistic: Object of class numeric. Value of the test statistic.
 pvalue: Object of class numeric. P-value.

Methods

show signature(object = "vineGoF"): Print the result of the goodness-of-fit test.

See Also

[vineGoF](#).

vineLogLik

Vine Log-likelihood Evaluation

Description

Evaluate the log-likelihood of a [Vine](#).

Usage

```
vineLogLik(vine, data)
```

Arguments

vine A [Vine](#) object.
 data Data matrix of pseudo-observations.

Examples

```

dimension <- 3
copulas <- matrix(list(normalCopula(0.5),
                      claytonCopula(2.75),
                      NULL, NULL),
                  ncol = dimension - 1,
                  nrow = dimension - 1,
                  byrow = TRUE)
vine <- DVine(dimension = dimension, trees = 1,
             copulas = copulas)

data <- matrix(runif(dimension * 100),
              ncol = dimension, nrow = 100)

vineLogLik(vine, data)

```

vineOrder *Select an Order of the Variables*

Description

Select an order of the variables. The order of the variables determines the bivariate dependencies that will be explicitly modeled in the first tree of the vine.

Usage

```
vineOrder(type, data, method = "greedy", ...)
```

Arguments

type	Type of vine. Supported values: "CVine" and "DVine".
data	Data matrix of pseudo-observations.
method	Ordering method. Supported values: "random", "greedy".
...	Additional arguments for the order method.

Details

In D-vines, the order of the variables determines the structure of all the trees of the vine. This is not the case for C-vines where the root node of each tree can be selected.

The "random" method returns a random permutation of the variables.

The "greedy" method returns an order of the variables that intends to capture as much dependence as possible in the first tree of the vine. The method finds the order of the variables that defines a tree that maximizes a given dependence measure used as edge weights. For C-vines, it is determined iteratively checking each variable as root node. For D-vines, it is equivalent to solve the traveling salesman problem (TSP), see (Brechmann, 2010) for details. The TSP is solved using the cheapest insertion algorithm implemented by the `solve_TSP` function of the **TSP** package. The following are additional parameters for this method.

according Dependence measure. The default value is "kendall" and supported values are:

- "kendall" Absolute value of Kendall's τ .
- "spearman" Absolute value of Spearman's ρ .
- "pearson" Absolute value of Pearson's product moment correlation coefficient.
- "df" Smaller degrees of freedom of a bivariate t copula.

Value

A vector with the ordered indexes of the variables. This vector should be used to reorder the variables of the data matrix.

References

Brechmann, E. C. (2010) Truncated and simplified regular vines and their applications. Diploma thesis. *Technische Universitaet Muenchen*.

Examples

```
data <- matrix(runif(5 * 100), ncol = 5, nrow = 500)

vineOrder("CVine", data, method = "random")
vineOrder("DVine", data, method = "greedy",
          according = "spearman")
```

vineParameters

Parameters of a Vine

Description

Retrieve or set the parameters of a [Vine](#).

Usage

```
vineParameters(vine)
vineParameters(vine) <- value
```

Arguments

- vine A [Vine](#) object.
- value Vector with the parameters of the copulas in the pair-copula construction. This vector is the result of the concatenation of the parameters slots of the [copula](#) objects in the copulas slot of the [Vine](#) object (by rows).

Examples

```

dimension <- 5
copulas <- matrix(c(list(tCopula(-0.25, df = 2),
                        tCopula(-0.5, df = 4),
                        tCopula(0.25, df = 6),
                        tCopula(0.5, df = 8)),
                  rep(list(NULL), 12)),
                 ncol = dimension - 1,
                 nrow = dimension - 1,
                 byrow = TRUE)
vine <- DVine(dimension = dimension, trees = 1,
             copulas = copulas)
dimnames(vine) <- c("A", "B", "C", "D", "E")

vineParameters(vine)
show(vine)

vineParameters(vine) <- c(-0.25, 3, -0.5, 5, 0.25, 7, 0.5, 9)

vineParameters(vine)
show(vine)

```

vinePIT-methods

*Vine Probability Integral Transform Methods***Description**

Probability integral transform (PIT) of (Rosenblatt, 1952) for vine models. The PIT converts a set of dependent variables into a new set of variables which are independent and uniformly distributed in $(0, 1)$ under the hypothesis that the data follows a given multivariate distribution.

Usage

```
vinePIT(vine, u)
```

Arguments

vine	A Vine object.
u	Vector with one component for each variable of the vine or a matrix with one column for each variable of the vine.

Value

A matrix with one column for each variable of the vine and one row for each observation.

Methods

`signature(vine = "CVine")` PIT algorithm for [CVine](#) objects based on the Algorithm 5 of (Aas et al., 2009).

`signature(vine = "DVine")` PIT algorithm for [DVine](#) objects based on the Algorithm 6 of (Aas et al., 2009).

References

Aas, K. and Czado, C. and Frigessi, A. and Bakken, H. (2009) Pair-copula constructions of multiple dependence. *Insurance: Mathematics and Economics* **44**, 182–198.

Rosenblatt, M. (1952) Remarks on multivariate transformation. *Annals of Mathematical Statistics* **23**, 1052–1057.

See Also

[vinePIT](#).

Examples

```
dimension <- 3
copulas <- matrix(list(normalCopula(0.5),
                      claytonCopula(2.75),
                      NULL, NULL),
                 ncol = dimension - 1,
                 nrow = dimension - 1,
                 byrow = TRUE)
vine <- CVine(dimension = dimension, trees = 1,
             copulas = copulas)

data <- matrix(runif(dimension * 100),
              ncol = dimension, nrow = 100)

vinePIT(vine, data)
```

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