

# Package ‘TreeDist’

January 31, 2021

**Type** Package

**Title** Distances Between Phylogenetic Trees

**Version** 2.0.3

**License** GPL (>= 3)

**Description** Implements measures of tree similarity, including information-based generalized Robinson-Foulds distances (Phylogenetic Information Distance, Clustering Information Distance, Matching Split Information Distance; Smith, 2020) <doi:10.1093/bioinformatics/btaa614>; Jaccard-Robinson-Foulds distances (Bocker et al. 2013) <doi:10.1007/978-3-642-40453-5\_13>, including the Nye et al. (2006) metric <doi:10.1093/bioinformatics/bti720>; the Matching Split Distance (Bogdanowicz & Giaro 2012) <doi:10.1109/TCBB.2011.48>; Maximum Agreement Subtree distances; the Kendall-Colijn (2016) distance <doi:10.1093/molbev/msw124>, and the Nearest Neighbour Interchange (NNI) distance, approximated per Li et al. (1996) <doi:10.1007/3-540-61332-3\_168>. Includes tools for visualizing the landscape of a tree space, and for calculating the median of a set of trees under any distance metric.

**Copyright** Incorporates Jonker-Volgenant Linear Assignment Problem implementation by Roy Jonker, modified by Yong Yang after Yi Cao.

**URL** <https://ms609.github.io/TreeDist/>,  
<https://github.com/ms609/TreeDist/>

**BugReports** <https://github.com/ms609/TreeDist/issues/>

**Additional\_repositories** <https://ms609.github.io/packages/>

**Depends** R (>= 3.4.0), stats

**Imports** ape (>= 5.0), colorspace, memoise, phangorn (>= 2.2.1), Rdpack, shiny, shinyjs, TreeTools (> 1.3.1)

**Suggests** bookdown, cluster, kdensity, knitr, MASS, protoclust, Quartet, readxl, rmarkdown, Rcpp, rgl, testthat, Ternary (>= 1.1.2), TreeDistData (> 0.1.0), TreeSearch, vdiff, viridisLite

**LinkingTo** Rcpp, TreeTools  
**RdMacros** Rdpack  
**VignetteBuilder** knitr  
**SystemRequirements** C++14  
**LazyData** true  
**ByteCompile** true  
**Encoding** UTF-8  
**Language** en-GB  
**X-schema.org-keywords** phylogenetics, tree-distance  
**RoxygenNote** 7.1.1  
**NeedsCompilation** yes  
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**Repository** CRAN  
**Date/Publication** 2021-01-31 05:40:08 UTC

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AllSplitPairings	<i>Variation of information for all split pairings</i>
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---

### Description

Calculate the variation of clustering information (Meila 2007) for each possible pairing of non-trivial splits on  $n$  leaves, tabulating the number of pairings with each similarity.

### Usage

AllSplitPairings( $n$ )

### Arguments

$n$  Integer specifying the number of leaves in a tree.

### Value

AllSplitPairings() returns a named vector. The name of each element corresponds to a certain variation of information, in bits; the value of each element specifies the number of pairings of non-trivial splits that give rise to that variation of information. Split AB|CD is treated as distinct from CD|AB. If pairing AB|CD=CD|AB is considered equivalent to CD|AB=CD|AB (etc), then values should be divided by four.

### Author(s)

Martin R. Smith ([martin.smith@durham.ac.uk](mailto:martin.smith@durham.ac.uk))

### References

Meila M (2007). “Comparing clusterings—an information based distance.” *Journal of Multivariate Analysis*, **98**(5), 873–895. doi: [10.1016/j.jmva.2006.11.013](https://doi.org/10.1016/j.jmva.2006.11.013), <https://doi.org/10.1016/j.jmva.2006.11.013>.

Smith MR (2020). “Information theoretic Generalized Robinson-Foulds metrics for comparing phylogenetic trees.” *Bioinformatics*, **36**(20), 5007–5013. doi: [10.1093/bioinformatics/btaa614](https://doi.org/10.1093/bioinformatics/btaa614), <https://doi.org/10.1093/bioinformatics/btaa614>.

**Examples**

```
AllSplitPairings(6)
# Treat equivalent splits as identical by dividing by four:
AllSplitPairings(6) / 4L
```

---

```
as.matrix.ClusterTable
```

*S3 methods for ClusterTable objects*

---

**Description**

S3 methods for ClusterTable objects

**Usage**

```
## S3 method for class 'ClusterTable'
as.matrix(x, ...)

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

## S3 method for class 'ClusterTable'
summary(object, ...)
```

**Arguments**

`x`, `object`      Object of class ClusterTable.  
`...`              Additional arguments for consistency with S3 methods.

**Author(s)**

**Martin R. Smith** ([martin.smith@durham.ac.uk](mailto:martin.smith@durham.ac.uk))

---

```
ClusteringEntropy
```

*Clustering entropy of all splits within a tree*

---

**Description**

Sum the entropy (`ClusteringEntropy()`) or information content (`ClusteringInfo()`) across each split within a phylogenetic tree, treating each split as dividing the leaves of the tree into two clusters (*sensu* Meila 2007; Vinh *et al.* 2010).

**Usage**

```

ClusteringEntropy(x)

ClusteringInfo(x)

## S3 method for class 'phylo'
ClusteringEntropy(x)

## S3 method for class 'list'
ClusteringEntropy(x)

## S3 method for class 'multiPhylo'
ClusteringEntropy(x)

## S3 method for class 'Splits'
ClusteringEntropy(x)

## S3 method for class 'phylo'
ClusteringInfo(x)

## S3 method for class 'list'
ClusteringInfo(x)

## S3 method for class 'multiPhylo'
ClusteringInfo(x)

## S3 method for class 'Splits'
ClusteringInfo(x)

```

**Arguments**

x                    A tree of class phylo, a list of trees, or a multiPhylo object.

**Details**

Clustering entropy addresses the question "how much information is contained in the splits within a tree". Its approach is complementary to the phylogenetic information content, used in [SplitwiseInfo\(\)](#). In essence, it asks, given a split that subdivides the leaves of a tree into two partitions, how easy it is to predict which partition a randomly drawn leaf belongs to.

Formally, the entropy of a split  $S$  that divides  $n$  leaves into two partitions of sizes  $a$  and  $b$  is given by  $H(S) = - a/n \log a/n - b/n \log b/n$ .

Base 2 logarithms are conventionally used, such that entropy is measured in bits. Entropy denotes the number of bits that are necessary to encode the outcome of a random variable: here, the random variable is "what partition does a randomly selected leaf belong to".

An even split has an entropy of 1 bit: there is no better way of encoding an outcome than using one bit to specify which of the two partitions the randomly selected leaf belongs to.

An uneven split has a lower entropy: membership of the larger partition is common, and thus less surprising; it can be signified using fewer bits in an optimal compression system.

If this sounds confusing, let's consider creating a code to transmit the cluster label of two randomly selected leaves. One straightforward option would be to use

- 00 = 'Both leaves belong to partition A'
- 11 = 'Both leaves belong to partition B'
- 01 = 'First leaf in A, second in B'
- 10 = 'First leaf in B, second in A'

This code uses two bits to transmit the partition labels of two leaves. If partitions A and B are equiprobable, this is the optimal code; our entropy – the average information content required per leaf – is 1 bit.

Alternatively, we could use the (suboptimal) code

- 0 = 'Both leaves belong to partition A'
- 111 = 'Both leaves belong to partition B'
- 101 = 'First leaf in A, second in B'
- 110 = 'First leaf in B, second in A'

If A is much larger than B, then most pairs of leaves will require just a single bit (code 0). The additional bits when 1+ leaf belongs to B may be required sufficiently rarely that the average message requires fewer than two bits for two leaves, so the entropy is less than 1 bit. (The optimal coding strategy will depend on the exact sizes of A and B.)

As entropy measures the bits required to transmit the cluster label of each leaf (Vinh *et al.* 2010: p. 2840), the information content of a split is its entropy multiplied by the number of leaves.

### Value

Returns the sum of the entropies or (clustering) information content, in bits, of each split in *x*.

### Author(s)

Martin R. Smith ([martin.smith@durham.ac.uk](mailto:martin.smith@durham.ac.uk))

### References

- Meila M (2007). "Comparing clusterings—an information based distance." *Journal of Multivariate Analysis*, **98**(5), 873–895. doi: [10.1016/j.jmva.2006.11.013](https://doi.org/10.1016/j.jmva.2006.11.013), <https://doi.org/10.1016/j.jmva.2006.11.013>.
- Vinh NX, Epps J, Bailey J (2010). "Information theoretic measures for clusterings comparison: variants, properties, normalization and correction for chance." *Journal of Machine Learning Research*, **11**, 2837–2854. doi: [10.1145/1553374.1553511](https://doi.org/10.1145/1553374.1553511), <https://doi.org/10.1145/1553374.1553511>.

### See Also

Other information functions: [SplitEntropy\(\)](#), [SplitSharedInformation\(\)](#), [SplitwiseInfo\(\)](#)

**Examples**

```
# Clustering entropy of an even split = 1 bit
ClusteringEntropy(TreeTools::as.Splits(c(rep(TRUE, 4), rep(FALSE, 4))))

# Clustering entropy of an uneven split < 1 bit
ClusteringEntropy(TreeTools::as.Splits(c(rep(TRUE, 2), rep(FALSE, 6))))

tree1 <- TreeTools::BalancedTree(8)
tree2 <- TreeTools::PectinateTree(8)

ClusteringInfo(tree1)
ClusteringEntropy(tree1)
ClusteringInfo(list(one = tree1, two = tree2))

ClusteringInfo(tree1) + ClusteringInfo(tree2)
ClusteringEntropy(tree1) + ClusteringEntropy(tree2)
ClusteringInfoDistance(tree1, tree2)
MutualClusteringInfo(tree1, tree2)
```

---

ClusterTable

---

*Convert phylogenetic tree to ClusterTable*


---

**Description**

as.ClusterTable() converts a phylogenetic tree to a ClusterTable object, which is an internal representation of its splits suitable for rapid tree distance calculation (per Day, 1985).

**Usage**

```
as.ClusterTable(x, tipLabels = NULL, ...)

## S3 method for class 'phylo'
as.ClusterTable(x, tipLabels = NULL, ...)

## S3 method for class 'list'
as.ClusterTable(x, tipLabels = NULL, ...)

## S3 method for class 'multiPhylo'
as.ClusterTable(x, tipLabels = NULL, ...)
```

**Arguments**

x	Object to convert into ClusterTable: perhaps a tree of class <a href="#">phylo</a> .
tipLabels	Character vector specifying sequence in which to order tip labels.
...	Presently unused.

## Details

Each row of a cluster table relates to a clade on a tree rooted on tip 1. Tips are numbered according to the order in which they are visited in preorder: i.e., if plotted using `plot(x)`, from the top of the page downwards. A clade containing the tips 2 .. 5 would be denoted by the entry 2, 5, in either row 2 or row 5 of the cluster table.

## Value

`as.ClusterTable()` returns an object of class `ClusterTable`.

## Author(s)

Martin R. Smith ([martin.smith@durham.ac.uk](mailto:martin.smith@durham.ac.uk))

## References

Day WHE (1985). "Optimal algorithms for comparing trees with labeled leaves." *Journal of Classification*, 2(1), 7–28. doi: [10.1007/BF01908061](https://doi.org/10.1007/BF01908061), <https://doi.org/10.1007/BF01908061>.

## See Also

[S3 methods](#) for `ClusterTable` objects.

## Examples

```
tree1 <- ape::read.tree(text = "(A, (B, (C, (D, E))))");
tree2 <- ape::read.tree(text = "(A, (B, (D, (C, E))))");
ct1 <- as.ClusterTable(tree1)
summary(ct1)
as.matrix(ct1)

# Tip label order must match ct1 to allow comparison
ct2 <- as.ClusterTable(tree2, tipLabels = LETTERS[1:5])
```

---

CompareAll

*Distances between each pair of trees*

---

## Description

Calculate the distance between each tree in a list, and each other tree in the same list.

## Usage

```
CompareAll(x, Func, FUN.VALUE = Func(x[[1]], x[[1]], ...), ...)
```

**Arguments**

x	List of trees, in the format expected by Func().
Func	distance function returning distance between two trees, e.g. <code>path.dist()</code> .
FUN.VALUE	Format of output of Func(), to be passed to <code>vapply()</code> . If unspecified, calculated by running <code>Func(x[[1]], x[[1]])</code> .
...	Additional parameters to pass to Func().

**Details**

`CompareAll()` is not limited to tree comparisons: Func can be any symmetric function.

**Value**

`CompareAll()` returns a distance matrix of class `dist` detailing the distance between each pair of trees. Identical trees are assumed to have zero distance.

**Author(s)**

[Martin R. Smith \(martin.smith@durham.ac.uk\)](mailto:martin.smith@durham.ac.uk)

**Examples**

```
# Generate a list of trees to compare
library('TreeTools', quietly = TRUE, warn.conflicts = FALSE)
trees <- list(bal1 = BalancedTree(1:8),
             pec1 = PectinateTree(1:8),
             pec2 = PectinateTree(c(4:1, 5:8)))

# Compare each tree with each other tree
CompareAll(trees, NNIDist)

# Providing FUN.VALUE yields a modest speed gain:
dist <- CompareAll(trees, NNIDist, FUN.VALUE = integer(7))

# View distances as a matrix
as.matrix(dist$lower)
```

---

Entropy

*Entropy in bits*

---

**Description**

Calculate the entropy of a vector of probabilities, in bits. Probabilities should sum to one. Probabilities equalling zero will be ignored.

**Usage**

```
Entropy(...)
```

**Arguments**

... Numerics or numeric vector specifying probabilities of outcomes.

**Value**

Entropy() returns the entropy of the specified probabilities, in bits.

**Author(s)**

Martin R. Smith ([martin.smith@durham.ac.uk](mailto:martin.smith@durham.ac.uk))

**Examples**

```
Entropy(1/2, 0, 1/2) # = 1
Entropy(rep(1/4, 4)) # = 2
```

---

JaccardRobinsonFoulds *Jaccard–Robinson–Foulds metric*

---

**Description**

Calculate the **Jaccard–Robinson–Foulds metric** (Böcker *et al.* 2013), a **Generalized Robinson–Foulds metric**.

**Usage**

```
JaccardRobinsonFoulds(
  tree1,
  tree2 = NULL,
  k = 1L,
  allowConflict = TRUE,
  similarity = FALSE,
  normalize = FALSE,
  reportMatching = FALSE
)

JaccardSplitSimilarity(
  splits1,
  splits2,
  nTip = attr(splits1, "nTip"),
  k = 1L,
  allowConflict = TRUE,
  reportMatching = FALSE
)
```

**Arguments**

tree1	Trees of class <code>phylo</code> , with leaves labelled identically, or lists of such trees to undergo pairwise comparison. Where implemented, <code>tree2 = NULL</code> will compute distances between each pair of trees in the list <code>tree1</code> using a fast algorithm based on Day (1985).
tree2	Trees of class <code>phylo</code> , with leaves labelled identically, or lists of such trees to undergo pairwise comparison. Where implemented, <code>tree2 = NULL</code> will compute distances between each pair of trees in the list <code>tree1</code> using a fast algorithm based on Day (1985).
k	An arbitrary exponent to which to raise the Jaccard index. Integer values greater than one are anticipated by Böcker <i>et al.</i> The Nye <i>et al.</i> metric uses $k = 1$ . As $k$ increases towards infinity, the metric converges to the Robinson–Foulds metric.
allowConflict	Logical specifying whether to allow conflicting splits to be paired. If <code>FALSE</code> , such pairings will be allocated a similarity score of zero.
similarity	Logical specifying whether to report the result as a tree similarity, rather than a difference.
normalize	If a numeric value is provided, this will be used as a maximum value against which to rescale results. If <code>TRUE</code> , results will be rescaled against a maximum value calculated from the specified tree sizes and topology, as specified in the 'Normalization' section below. If <code>FALSE</code> , results will not be rescaled.
reportMatching	Logical specifying whether to return the clade matchings as an attribute of the score.
splits1	Logical matrices where each row corresponds to a leaf, either listed in the same order or bearing identical names (in any sequence), and each column corresponds to a split, such that each leaf is identified as a member of the ingroup ( <code>TRUE</code> ) or outgroup ( <code>FALSE</code> ) of the respective split.
splits2	Logical matrices where each row corresponds to a leaf, either listed in the same order or bearing identical names (in any sequence), and each column corresponds to a split, such that each leaf is identified as a member of the ingroup ( <code>TRUE</code> ) or outgroup ( <code>FALSE</code> ) of the respective split.
nTip	(Optional) Integer specifying the number of leaves in each split.

**Details**

In short, the Jaccard–Robinson–Foulds metric is a generalized Robinson–Foulds metric: it finds the optimal matching that pairs each split in one tree with a similar split in the second. Matchings are scored according to the size of the largest split that is consistent with both of them, normalized against the Jaccard index, and raised to an arbitrary exponent. A more detailed explanation is provided in the [vignettes](#).

By default, conflicting splits may be paired.

Note that the settings `k = 1`, `allowConflict = TRUE`, `similarity = TRUE` give the similarity metric of Nye *et al.* (2006); a slightly faster implementation of this metric is available as `NyeSimilarity()`.

The examples section below details how to visualize matchings with non-default parameter values.

**Value**

JaccardRobinsonFoulds() returns an array of numerics providing the distances between each pair of trees in tree1 and tree2, or splits1 and splits2.

**Normalization**

If normalize = TRUE, then results will be rescaled from zero to one by dividing by the maximum possible value for trees of the given topologies, which is equal to the sum of the number of splits in each tree. You may wish to normalize instead against the maximum number of splits present in a pair of trees with  $n$  leaves, by specifying normalize =  $n - 3$ .

**Author(s)**

Martin R. Smith ([martin.smith@durham.ac.uk](mailto:martin.smith@durham.ac.uk))

**References**

- Nye TMW, Li P, Gilks WR (2006). “A novel algorithm and web-based tool for comparing two alternative phylogenetic trees.” *Bioinformatics*, **22**(1), 117–119. doi: [10.1093/bioinformatics/bti720](https://doi.org/10.1093/bioinformatics/bti720), <https://doi.org/10.1093/bioinformatics/bti720>.
- Bächler S, Canzar S, Klau GW (2013). “The generalized Robinson-Foulds metric.” In Darling A, Stoye J (eds.), *Algorithms in Bioinformatics. WABI 2013. Lecture Notes in Computer Science, vol 8126*, 156–169. Springer, Berlin, Heidelberg. doi: [10.1007/9783642404535\\_13](https://doi.org/10.1007/9783642404535_13), [https://doi.org/10.1007/978-3-642-40453-5\\_13](https://doi.org/10.1007/978-3-642-40453-5_13).

**See Also**

Other tree distances: [KendallColijn\(\)](#), [MASTSize\(\)](#), [MatchingSplitDistance\(\)](#), [NNIDist\(\)](#), [NyeSimilarity\(\)](#), [PathDist\(\)](#), [Robinson-Foulds](#), [SPRDist\(\)](#), [TreeDistance\(\)](#)

**Examples**

```
set.seed(2)
tree1 <- ape::rtree(10)
tree2 <- ape::rtree(10)
JaccardRobinsonFoulds(tree1, tree2, k = 2, allowConflict = FALSE)
JaccardRobinsonFoulds(tree1, tree2, k = 2, allowConflict = TRUE)

JRF2 <- function (tree1, tree2, ...)
  JaccardRobinsonFoulds(tree1, tree2, k = 2, allowConflict = FALSE, ...)

VisualizeMatching(JRF2, tree1, tree2, matchZeros = FALSE)
```

---

KendallColijn	<i>Kendall-Colijn distance</i>
---------------	--------------------------------

---

**Description**

Calculate the Kendall-Colijn tree distance, a measure related to the path difference.

**Usage**

```
KendallColijn(tree1, tree2 = tree1)
```

```
KCVector(tree)
```

**Arguments**

tree1, tree2	Trees of class <code>phylo</code> , with leaves labelled identically, or lists of such trees to undergo pairwise comparison. Where implemented, <code>tree2 = NULL</code> will compute distances between each pair of trees in the list <code>tree1</code> using a fast algorithm based on Day (1985).
tree	A tree of class <code>phylo</code> .

**Details**

The Kendall-Colijn distance works by measuring, for each pair of leaves, the distance from the most recent common ancestor of those leaves and the root node. For a given tree, this produces a vector of values recording the distance-from-the-root of each most recent common ancestor of each pair of leaves.

Two trees are compared by taking the Euclidian distance between the respective vectors. This is calculated by taking the square root of the sum of the squares of the differences between the vectors.

This metric emphasizes the position of the root; the path difference instead measures the distance of the last common ancestor of each pair of leaves from the leaves themselves, i.e. the length of the path from one leaf to another.

**Value**

`KendallColijn()` returns an array of numerics providing the distances between each pair of trees in `tree1` and `tree2`, or `splits1` and `splits2`.

**Functions**

- `KCVector`: Creates a vector that characterises a rooted tree, as described in Kendall & Colijn (2016).

**Author(s)**

Martin R. Smith ([martin.smith@durham.ac.uk](mailto:martin.smith@durham.ac.uk))

## References

Kendall M, Colijn C (2016). “Mapping phylogenetic trees to reveal distinct patterns of evolution.” *Molecular Biology and Evolution*, **33**(10), 2735–2743. doi: [10.1093/molbev/msw124](https://doi.org/10.1093/molbev/msw124), <https://doi.org/10.1093/molbev/msw124>.

## See Also

`treospace::treeDist` is a more sophisticated, if more cumbersome, implementation that supports  $\lambda > 0$ , i.e. use of edge lengths in tree comparison.

Other tree distances: `JaccardRobinsonFoulds()`, `MASTSize()`, `MatchingSplitDistance()`, `NNIDist()`, `NyeSimilarity()`, `PathDist()`, `Robinson-Foulds`, `SPRDist()`, `TreeDistance()`

## Examples

```
KendallColijn(TreeTools::BalancedTree(8), TreeTools::PectinateTree(8))

set.seed(0)
KendallColijn(TreeTools::BalancedTree(8), lapply(rep(8, 3), ape::rtree))
KendallColijn(lapply(rep(8, 4), ape::rtree))
```

---

LAPJV

*Solve linear assignment problem using LAPJV*


---

## Description

Use the algorithm of Jonker & Volgenant (1987) to solve the **Linear Sum Assignment Problem**.

## Usage

```
LAPJV(x)
```

## Arguments

`x`                      Square matrix of costs.

## Details

The Linear Assignment Problem seeks to match each row of a matrix with a column, such that the cost of the matching is minimized.

The Jonker & Volgenant approach is a faster alternative to the Hungarian algorithm (Munkres 1957), which is implemented in `clue::solve_LSAP()`.

Note: the JV algorithm expects integers. In order to apply the function to a non-integer  $n$ , as in the tree distance calculations in this package, each  $n$  is multiplied by the largest available integer before applying the JV algorithm. If two values of  $n$  exhibit a trivial difference – e.g. due to floating point errors – then this can lead to interminable run times. (If numbers of the magnitude of billions differ only in their last significant digit, then the JV algorithm may undergo billions of iterations.) To avoid this, integers over  $2^{22}$  that differ by a value of 8 or less are treated as equal.

NB. At present, only square matrices are supported; if you need support for non-square matrices, drop a note at [issue #25](#) and I'll prioritize development.

### Value

A list with two entries: `score`, the score of the optimal matching; and `matching`, the columns matched to each row of the matrix in turn.

### Author(s)

**C++ code** by Roy Jonker, MagicLogic Optimization Inc. [roy\\_jonker@magiclogic.com](mailto:roy_jonker@magiclogic.com), with contributions from Yong Yang [yongyanglink@gmail.com](mailto:yongyanglink@gmail.com), after Yi Cao

### References

Jonker R, Volgenant A (1987). "A shortest augmenting path algorithm for dense and sparse linear assignment problems." *Computing*, **38**, 325–340. doi: [10.1007/BF02278710](https://doi.org/10.1007/BF02278710), <https://doi.org/10.1007/BF02278710>.

Munkres J (1957). "Algorithms for the assignment and transportation problems." *Journal of the Society for Industrial and Applied Mathematics*, **5**(1), 32–38. doi: [10.1137/0105003](https://doi.org/10.1137/0105003), <https://doi.org/10.1137/0105003>.

### Examples

```
problem <- matrix(c(7, 9, 8, 9,
                   2, 8, 5, 7,
                   1, 6, 6, 9,
                   3, 6, 2, 2), 4, 4, byrow=TRUE)

LAPJV(problem)
```

---

MASTSize	<i>Maximum Agreement Subtree size</i>
----------	---------------------------------------

---

### Description

Calculate the size or phylogenetic information content (Steel & Penny 2006) of the maximum agreement subtree between two phylogenetic trees, i.e. the largest tree that can be obtained from both `tree1` and `tree2` by deleting, but not rearranging, leaves, using the algorithm of Valiente (2009).

### Usage

```
MASTSize(tree1, tree2 = tree1, rooted = TRUE)

MASTInfo(tree1, tree2 = tree1, rooted = TRUE)
```

**Arguments**

tree1, tree2      Trees of class phylo, or lists of such trees to undergo pairwise comparison.  
 rooted            Logical specifying whether to treat the trees as rooted.

**Details**

Implemented for trees with up to 4096 tips. Contact the maintainer if you need to process larger trees.

**Value**

MASTSize() returns an integer specifying the number of leaves in the maximum agreement subtree.  
 MASTInfo() returns a vector or matrix listing the phylogenetic information content, in bits, of the maximum agreement subtree.

**Author(s)**

**Martin R. Smith** ([martin.smith@durham.ac.uk](mailto:martin.smith@durham.ac.uk))

**References**

Steel MA, Penny D (2006). “Maximum parsimony and the phylogenetic information in multistate characters.” In Albert VA (ed.), *Parsimony, Phylogeny, and Genomics*, 163–178. Oxford University Press, Oxford.

Valiente G (2009). *Combinatorial Pattern Matching Algorithms in Computational Biology using Perl and R*, CRC Mathematical and Computing Biology Series. CRC Press, Boca Raton.

**See Also**

[phangorn::mast\(\)](#), a slower implementation that also lists the leaves contained within the subtree.  
 Other tree distances: [JaccardRobinsonFoulds\(\)](#), [KendallColijn\(\)](#), [MatchingSplitDistance\(\)](#), [NNIDist\(\)](#), [NyeSimilarity\(\)](#), [PathDist\(\)](#), [Robinson-Foulds](#), [SPRDist\(\)](#), [TreeDistance\(\)](#)

**Examples**

```
# for as.phylo, BalancedTree, PectinateTree:
library('TreeTools', quietly = TRUE, warn.conflicts = FALSE)

MASTSize(PectinateTree(8), BalancedTree(8))
MASTInfo(PectinateTree(8), BalancedTree(8))

MASTSize(BalancedTree(7), as.phylo(0:3, 7))
MASTSize(as.phylo(0:3, 7), PectinateTree(7))

MASTInfo(BalancedTree(7), as.phylo(0:3, 7))
MASTInfo(as.phylo(0:3, 7), PectinateTree(7))

MASTSize(list(Bal = BalancedTree(7), Pec = PectinateTree(7)),
          as.phylo(0:3, 7))
```

```

MASTInfo(list(Bal = BalancedTree(7), Pec = PectinateTree(7)),
          as.phylo(0:3, 7))

CompareAll(as.phylo(0:4, 8), MASTSize)
CompareAll(as.phylo(0:4, 8), MASTInfo)

```

---

## MatchingSplitDistance *Matching Split Distance*

---

### Description

Calculate the **Matching Split Distance** (Bogdanowicz and Giaro 2012; Lin *et al.* 2012) for unrooted binary trees.

### Usage

```

MatchingSplitDistance(
  tree1,
  tree2 = NULL,
  normalize = FALSE,
  reportMatching = FALSE
)

MatchingSplitDistanceSplits(
  splits1,
  splits2,
  nTip = attr(splits1, "nTip"),
  normalize = TRUE,
  reportMatching = FALSE
)

```

### Arguments

tree1	Trees of class phylo, with leaves labelled identically, or lists of such trees to undergo pairwise comparison. Where implemented, tree2 = NULL will compute distances between each pair of trees in the list tree1 using a fast algorithm based on Day (1985).
tree2	Trees of class phylo, with leaves labelled identically, or lists of such trees to undergo pairwise comparison. Where implemented, tree2 = NULL will compute distances between each pair of trees in the list tree1 using a fast algorithm based on Day (1985).
normalize	If a numeric value is provided, this will be used as a maximum value against which to rescale results. If TRUE, results will be rescaled against a maximum value calculated from the specified tree sizes and topology, as specified in the 'Normalization' section below. If FALSE, results will not be rescaled.
reportMatching	Logical specifying whether to return the clade matchings as an attribute of the score.

splits1	Logical matrices where each row corresponds to a leaf, either listed in the same order or bearing identical names (in any sequence), and each column corresponds to a split, such that each leaf is identified as a member of the ingroup (TRUE) or outgroup (FALSE) of the respective split.
splits2	Logical matrices where each row corresponds to a leaf, either listed in the same order or bearing identical names (in any sequence), and each column corresponds to a split, such that each leaf is identified as a member of the ingroup (TRUE) or outgroup (FALSE) of the respective split.
nTip	(Optional) Integer specifying the number of leaves in each split.

**Value**

MatchingSplitDistance() returns an array of numerics providing the distances between each pair of trees in tree1 and tree2, or splits1 and splits2.

**Normalization**

A normalization value or function must be provided in order to return a normalized value. If you are aware of a generalised formula, please let me know by [creating a GitHub issue](#) so that it can be implemented.

**Author(s)**

Martin R. Smith ([martin.smith@durham.ac.uk](mailto:martin.smith@durham.ac.uk))

**References**

- Bogdanowicz D, Giaro K (2012). “Matching split distance for unrooted binary phylogenetic trees.” *IEEE/ACM Transactions on Computational Biology and Bioinformatics*, **9**(1), 150–160. doi: [10.1109/TCBB.2011.48](https://doi.org/10.1109/TCBB.2011.48), <https://doi.org/10.1109/TCBB.2011.48>.
- Lin Y, Rajan V, Moret BME (2012). “A metric for phylogenetic trees based on matching.” *IEEE/ACM Transactions on Computational Biology and Bioinformatics*, **4**(9), 1014–1022. doi: [10.1109/TCBB.2011.157](https://doi.org/10.1109/TCBB.2011.157), <https://doi.org/10.1109/TCBB.2011.157>.

**See Also**

Other tree distances: [JaccardRobinsonFoulds\(\)](#), [KendallColijn\(\)](#), [MASTSize\(\)](#), [NNIDist\(\)](#), [NyeSimilarity\(\)](#), [PathDist\(\)](#), [Robinson-Foulds](#), [SPRDist\(\)](#), [TreeDistance\(\)](#)

**Examples**

```
MatchingSplitDistance(lapply(rep(8, 5), ape::rtree), normalize = 16)
```

```
MatchingSplitDistance(TreeTools::BalancedTree(6),
  TreeTools::PectinateTree(6),
  reportMatching = TRUE)
```

```
VisualizeMatching(MatchingSplitDistance, TreeTools::BalancedTree(6),
  TreeTools::PectinateTree(6))
```

---

median.multiPhylo      *Median of a set of trees*

---

### Description

Calculate the single binary tree that represents the geometric median – an 'average' – of a forest of tree topologies.

### Usage

```
## S3 method for class 'multiPhylo'
median(
  x,
  na.rm = FALSE,
  Distance = ClusteringInfoDistance,
  index = FALSE,
  breakTies = TRUE,
  ...
)
```

### Arguments

x	Object of class multiPhylo containing phylogenetic trees.
na.rm, ...	Unused; included for consistency with default function..
Distance	Function to calculate distances between each pair of trees in x.
index	Logical: if TRUE, return the index of the median tree(s); if FALSE, return the tree itself.
breakTies	Logical: if TRUE, return a single tree with the minimum score; if FALSE, return all tied trees.

### Details

The geometric median is the tree that exhibits the shortest average distance from each other tree topology in the set. It represents an 'average' of a set of trees, though note that an unsampled tree may be closer to the geometric 'centre of gravity' of the input set – such a tree would not be considered.

The result will depend on the metric chosen to calculate distances between tree topologies. In the absence of a natural metric of tree topologies, the default choice is [ClusteringInfoDistance\(\)](#) – which discards branch length information. If specifying a different function, be sure that it returns a difference, rather than a similarity.

### Value

median() returns an object of class phylo corresponding to the geometric median of a set of trees: that is, the tree whose average distance from all other trees in the set is lowest. If multiple trees tie in their average distance, the first will be returned, unless breakTies = FALSE, in which case an object of class multiPhylo containing all such trees will be returned.

**Author(s)**

[Martin R. Smith \(martin.smith@durham.ac.uk\)](mailto:martin.smith@durham.ac.uk)

**See Also**

Consensus methods: [ape::consensus\(\)](#), [TreeTools::ConsensusWithout\(\)](#)

Other tree space functions: [ProjectionQuality\(\)](#), [Project\(\)](#), [SpectralClustering\(\)](#)

**Examples**

```
library('TreeTools', quietly = TRUE, warn.conflicts = FALSE)
tenTrees <- as.phylo(1:10, nTip = 8)

# Default settings:
median(tenTrees)

# Robinson-Foulds distances include ties:
median(tenTrees, Distance = RobinsonFoulds, breakTies = FALSE)

# Be sure to use a distance function, rather than a similarity:
NyeDistance <- function (...) NyeSimilarity(..., similarity = FALSE)
median(tenTrees, Distance = NyeDistance)

# To analyse a list of trees that is not of class multiPhylo:
treeList <- lapply(1:10, as.phylo, nTip = 8)
class(treeList)
median(structure(treeList, class = 'multiPhylo'))
```

---

MeilaVariationOfInformation

*Use variation of clustering information to compare pairs of splits*

---

**Description**

Compare a pair of splits viewed as clusterings of taxa, using the variation of clustering information proposed by Meila (2007).

**Usage**

```
MeilaVariationOfInformation(split1, split2)
```

```
MeilaMutualInformation(split1, split2)
```

**Arguments**

`split1`, `split2` Logical vectors listing leaves in a consistent order, identifying each leaf as a member of the ingroup (TRUE) or outgroup (FALSE) of the split in question.

**Details**

This is equivalent to the mutual clustering information (Vinh *et al.* 2010). For the total information content, multiply the VoI by the number of leaves.

**Value**

MeilaVariationOfInformation() returns the variation of (clustering) information, measured in bits.

MeilaMutualInformation() returns the mutual information, measured in bits.

**Author(s)**

Martin R. Smith ([martin.smith@durham.ac.uk](mailto:martin.smith@durham.ac.uk))

**References**

Meila M (2007). “Comparing clusterings—an information based distance.” *Journal of Multivariate Analysis*, **98**(5), 873–895. doi: [10.1016/j.jmva.2006.11.013](https://doi.org/10.1016/j.jmva.2006.11.013), <https://doi.org/10.1016/j.jmva.2006.11.013>.

Vinh NX, Epps J, Bailey J (2010). “Information theoretic measures for clusterings comparison: variants, properties, normalization and correction for chance.” *Journal of Machine Learning Research*, **11**, 2837–2854. doi: [10.1145/1553374.1553511](https://doi.org/10.1145/1553374.1553511), <https://doi.org/10.1145/1553374.1553511>.

**Examples**

```
# Maximum variation = information content of each split separately
A <- TRUE
B <- FALSE
MeilaVariationOfInformation(c(A, A, A, B, B, B), c(A, A, A, A, A, A))
Entropy(c(3, 3) / 6) + Entropy(c(0, 6) / 6)

# Minimum variation = 0
MeilaVariationOfInformation(c(A, A, A, B, B, B), c(A, A, A, B, B, B))

# Not always possible for two evenly-sized splits to reach maximum
# variation of information
Entropy(c(3, 3) / 6) * 2 # = 2
MeilaVariationOfInformation(c(A, A, A, B, B, B), c(A, B, A, B, A, B)) # < 2

# Phylogenetically uninformative groupings contain splitting information
Entropy(c(1, 5) / 6)
MeilaVariationOfInformation(c(B, A, A, A, A, A), c(A, A, A, A, A, B))
```

---

 NNIDist

*Approximate Nearest Neighbour Interchange distance*


---

### Description

Use the approach of Li *et al.* (1996) to approximate the Nearest Neighbour Interchange distance (Robinson, 1971) between phylogenetic trees.

### Usage

```
NNIDist(tree1, tree2 = tree1)
```

```
NNIDiameter(tree)
```

### Arguments

tree1, tree2	Single trees of class <code>phylo</code> to undergo comparison.
tree	Object of supported class representing a tree or list of trees, or an integer specifying the number of leaves in a tree/trees.

### Details

In brief, this approximation algorithm works by identifying edges in one tree that do not match edges in the second. Each of these edges must undergo at least one NNI operation in order to reconcile the trees. Edges that match in both trees need never undergo an NNI operation, and divide each tree into smaller regions. By 'cutting' matched edges into two, a tree can be divided into a number of regions that solely comprise unmatched edges.

These regions can be viewed as separate trees that need to be reconciled. One way to reconcile these trees is to conduct a series of NNI operations that reduce a tree to a pectinate (caterpillar) tree, then to conduct an analogue of the mergesort algorithm. This takes at most  $n \log n + O(n)$  NNI operations, and provides a loose upper bound on the NNI score. The maximum number of moves for an  $n$ -leaf tree ([OEIS A182136](#)) can be calculated exactly for small trees (Fack *et al.* 2002); this provides a tighter upper bound, but is unavailable for  $n > 12$ . `NNIDiameter()` reports the limits on this bound.

Leaves:	1	2	3	4	5	6	7	8	9	10	11	12	13
Diameter:	0	0	0	1	3	5	7	10	12	15	18	21	?

### Value

`NNIDist()` returns, for each pair of trees, a named vector containing three integers:

- `lower` is a lower bound on the NNI distance, and corresponds to the RF distance between the trees.
- `tight_upper` is an upper bound on the distance, based on calculated maximum diameters for trees with  $< 13$  leaves. `NA` is returned if trees are too different to employ this approach.

- loose\_upper is a looser upper bound on the distance, using  $n \log n + O(n)$ .

NNIDiameter() returns a matrix specifying (bounds on) the diameter of the NNI distance metric on the specified tree(s). Columns correspond to:

- liMin:

$$n - 3$$

, a lower bound on the diameter (Li *et al.* 1996);

- fackMin: Lower bound on diameter following Fack *et al.* (2002), i.e.

$$\log 2N!/4$$

;

- min: The larger of liMin and fackMin;
- exact: The exact value of the diameter, where  $n < 13$ ;
- liMax: Upper bound on diameter following Li *et al.* (1996), i.e.

$$n \log 2n + O(n)$$

;

- fackMax: Upper bound on diameter following Fack *et al.* (2002), i.e. (

$$N - 2$$

) ceiling(

$$\log 2n$$

)

- N;

- max: The smaller of liMax and fackMax;

where  $n$  is the number of leaves, and  $N$  the number of internal nodes, i.e.

$$n - 2$$

#### Author(s)

Martin R. Smith ([martin.smith@durham.ac.uk](mailto:martin.smith@durham.ac.uk))

#### References

Fack V, Lievens S, Van der Jeugt J (2002). "On the diameter of the rotation graph of binary coupling trees." *Discrete Mathematics*, **245**(1-3), 1–18. doi: [10.1016/S0012-365X\(01\)00418-6](https://doi.org/10.1016/S0012-365X(01)00418-6), [https://doi.org/10.1016/S0012-365X\(01\)00418-6](https://doi.org/10.1016/S0012-365X(01)00418-6).

Li M, Tromp J, Zhang L (1996). "Some notes on the nearest neighbour interchange distance." In Goos G, Hartmanis J, Leeuwen J, Cai J, Wong CK (eds.), *Computing and Combinatorics*, volume 1090, 343–351. Springer, Berlin, Heidelberg. ISBN 978-3-540-61332-9 978-3-540-68461-9, doi: [10.1007/3540613323\\_168](https://doi.org/10.1007/3540613323_168), [https://doi.org/10.1007/3-540-61332-3\\_168](https://doi.org/10.1007/3-540-61332-3_168).

Robinson DF (1971). "Comparison of labeled trees with valency three." *Journal of Combinatorial Theory, Series B*, **11**(2), 105–119. doi: [10.1016/0095-8956\(71\)900207](https://doi.org/10.1016/0095-8956(71)900207), [https://doi.org/10.1016/0095-8956\(71\)90020-7](https://doi.org/10.1016/0095-8956(71)90020-7).

**See Also**

Other tree distances: [JaccardRobinsonFoulds\(\)](#), [KendallColijn\(\)](#), [MASTSize\(\)](#), [MatchingSplitDistance\(\)](#), [NyeSimilarity\(\)](#), [PathDist\(\)](#), [Robinson-Foulds](#), [SPRDist\(\)](#), [TreeDistance\(\)](#)

**Examples**

```
library('TreeTools', quietly = TRUE, warn.conflicts = FALSE)

NNIDist(BalancedTree(7), PectinateTree(7))

NNIDist(BalancedTree(7), as.phylo(0:2, 7))
NNIDist(as.phylo(0:2, 7), PectinateTree(7))

NNIDist(list(bal = BalancedTree(7), pec = PectinateTree(7)),
        as.phylo(0:2, 7))

CompareAll(as.phylo(30:33, 8), NNIDist)
```

---

NyeSimilarity

*Nye et al. (2006) tree comparison*


---

**Description**

`NyeSimilarity()` and `NyeSplitSimilarity()` implement the **Generalized Robinson–Foulds** tree comparison metric of Nye *et al.* (2006). In short, this finds the optimal matching that pairs each branch from one tree with a branch in the second, where matchings are scored according to the size of the largest split that is consistent with both of them, normalized against the Jaccard index. A more detailed account is available in the [vignettes](#).

**Usage**

```
NyeSimilarity(
  tree1,
  tree2 = NULL,
  similarity = TRUE,
  normalize = FALSE,
  normalizeMax = !is.logical(normalize),
  reportMatching = FALSE,
  diag = TRUE
)

NyeSplitSimilarity(
  splits1,
  splits2,
  nTip = attr(splits1, "nTip"),
  reportMatching = FALSE
)
```

**Arguments**

tree1	Trees of class <code>phylo</code> , with leaves labelled identically, or lists of such trees to undergo pairwise comparison. Where implemented, <code>tree2 = NULL</code> will compute distances between each pair of trees in the list <code>tree1</code> using a fast algorithm based on Day (1985).
tree2	Trees of class <code>phylo</code> , with leaves labelled identically, or lists of such trees to undergo pairwise comparison. Where implemented, <code>tree2 = NULL</code> will compute distances between each pair of trees in the list <code>tree1</code> using a fast algorithm based on Day (1985).
similarity	Logical specifying whether to report the result as a tree similarity, rather than a difference.
normalize	If a numeric value is provided, this will be used as a maximum value against which to rescale results. If <code>TRUE</code> , results will be rescaled against a maximum value calculated from the specified tree sizes and topology, as specified in the 'Normalization' section below. If <code>FALSE</code> , results will not be rescaled.
normalizeMax	When calculating similarity, normalize against the maximum number of splits that could have been present ( <code>TRUE</code> ), or the number of splits that were actually observed ( <code>FALSE</code> )? Defaults to the number of splits in the better-resolved tree; set <code>normalize = pmin.int</code> to use the number of splits in the less resolved tree.
reportMatching	Logical specifying whether to return the clade matchings as an attribute of the score.
diag	Logical specifying whether to return similarities along the diagonal, i.e. of each tree with itself. Applies only if <code>tree2</code> is a list identical to <code>tree1</code> , or <code>NULL</code> .
splits1	Logical matrices where each row corresponds to a leaf, either listed in the same order or bearing identical names (in any sequence), and each column corresponds to a split, such that each leaf is identified as a member of the ingroup ( <code>TRUE</code> ) or outgroup ( <code>FALSE</code> ) of the respective split.
splits2	Logical matrices where each row corresponds to a leaf, either listed in the same order or bearing identical names (in any sequence), and each column corresponds to a split, such that each leaf is identified as a member of the ingroup ( <code>TRUE</code> ) or outgroup ( <code>FALSE</code> ) of the respective split.
nTip	(Optional) Integer specifying the number of leaves in each split.

**Details**

The measure is defined as a similarity score. If `similarity = FALSE`, the similarity score will be converted into a distance by doubling it and subtracting it from the number of splits present in both trees. This ensures consistency with `JaccardRobinsonFoulds`.

Note that `NyeSimilarity(tree1, tree2)` is equivalent to, but slightly faster than, `JaccardRobinsonFoulds(tree1, tree2, k = 1, allowConflict = TRUE)`.

**Value**

`NyeSimilarity()` returns an array of numerics providing the distances between each pair of trees in `tree1` and `tree2`, or `splits1` and `splits2`.

### Normalization

If `normalize = TRUE` and `similarity = TRUE`, then results will be rescaled from zero to one by dividing by the mean number of splits in the two trees being compared.

You may wish to normalize instead against the number of splits present in the smaller tree, which represents the maximum value possible for a pair of trees with the specified topologies (`normalize = pmin.int`); the number of splits in the most resolved tree (`normalize = pmax.int`); or the maximum value possible for any pair of trees with  $n$  leaves,  $n - 3$  (`normalize = TreeTools::NTip(tree1) - 3L`).

If `normalize = TRUE` and `similarity = FALSE`, then results will be rescaled from zero to one by dividing by the total number of splits in the pair of trees being considered.

### Author(s)

Martin R. Smith ([martin.smith@durham.ac.uk](mailto:martin.smith@durham.ac.uk))

### References

Nye TMW, Li P, Gilks WR (2006). "A novel algorithm and web-based tool for comparing two alternative phylogenetic trees." *Bioinformatics*, **22**(1), 117–119. doi: [10.1093/bioinformatics/bti720](https://doi.org/10.1093/bioinformatics/bti720), <https://doi.org/10.1093/bioinformatics/bti720>.

### See Also

Other tree distances: [JaccardRobinsonFoulds\(\)](#), [KendallColijn\(\)](#), [MASTSize\(\)](#), [MatchingSplitDistance\(\)](#), [NNIDist\(\)](#), [PathDist\(\)](#), [Robinson-Foulds](#), [SPRDist\(\)](#), [TreeDistance\(\)](#)

### Examples

```
library('TreeTools')
NyeSimilarity(BalancedTree(8), PectinateTree(8))
VisualizeMatching(NyeSimilarity, BalancedTree(8), PectinateTree(8))
NyeSimilarity(as.phylo(0:5, nTip = 8), PectinateTree(8))
NyeSimilarity(as.phylo(0:5, nTip = 8), similarity = FALSE)
```

---

PathDist

*Path distance*

---

### Description

Calculate the path distance between trees.

### Usage

```
PathDist(tree1, tree2 = NULL)
```

## Arguments

tree1, tree2      Trees of class `phylo`, with leaves labelled identically, or lists of such trees to undergo pairwise comparison. Where implemented, `tree2 = NULL` will compute distances between each pair of trees in the list `tree1` using a fast algorithm based on Day (1985).

## Details

This function is a wrapper for the function `path.dist()` in the `phangorn` package. It pre-processes trees to ensure that their internal representation does not cause the `path.dist()` function to crash R.

The path distance is also termed the cladistic difference or topological distance.

Use of the path distance is discouraged as it emphasizes shallow relationships at the expense of deeper (and arguably more fundamental) relationships (Farris, 1973).

## Value

`PathDist()` returns a vector or distance matrix of distances between trees.

## Author(s)

Martin R. Smith ([martin.smith@durham.ac.uk](mailto:martin.smith@durham.ac.uk))

## References

Farris JS (1973). "On comparing the shapes of taxonomic trees." *Systematic Zoology*, **22**(1), 50–54. doi: [10.2307/2412378](https://doi.org/10.2307/2412378), <https://doi.org/10.2307/2412378>.

## See Also

Other tree distances: `JaccardRobinsonFoulds()`, `KendallColijn()`, `MASTSize()`, `MatchingSplitDistance()`, `NNIDist()`, `NyeSimilarity()`, `Robinson-Foulds`, `SPRDist()`, `TreeDistance()`

## Examples

```
library('TreeTools')

PathDist(BalancedTree(7), PectinateTree(7))

PathDist(BalancedTree(7), as.phylo(0:2, 7))
PathDist(as.phylo(0:2, 7), PectinateTree(7))

PathDist(list(bal = BalancedTree(7), pec = PectinateTree(7)),
          as.phylo(0:2, 7))

CompareAll(as.phylo(30:33, 8), PathDist)
```

---

Project	<i>Graphical user interface for projecting distances and analysing tree space</i>
---------	---

---

## Description

Project() launches a 'Shiny' application for the visualization and evaluation of tree spaces.

## Usage

Project()

## Input tab

The input tab allows for the upload of sets of phylogenetic trees from file. Trees at the start or end of a file can be excluded, and the number of trees can be brought down to a manageable number by uniformly subsampling every `_n_th` tree. Samples of c. 100 trees can be analysed in seconds; analysis of larger samples will take longer, particularly with slower methods (e.g. quartet distances; Kruskal-1 MDS; large minimum spanning trees).

Different batches can be plotted with different colours / symbols.

If each tree is associated with a property – for example, the data or method used to generate it, or its stratigraphic congruence – a list of properties for each tree, with one entry per line/row, can be uploaded along with the trees. Points in tree space can then be styled according to the corresponding property.

If trees are subsampled (using the 'Sample every' slider), then the values in the tree properties file can also be subsampled accordingly. Unfortunately there is not yet support for multiple point property files; one file will be applied to all trees, in the sequence that they were added to memory.

## Analysis tab

Select from a suite of distance methods: clustering information and phylogenetic information are quick and satisfactory; quartet is slow but gives slightly better projections; path is very fast but may not reflect evolutionary signal very well; and Robinson–Foulds should probably never be used for analysis; it is included for comparison purposes.

Principle components projections should suffice for most purposes; Sammon and Kruskal projections are slower and seldom differ by much, in character or quality, but may emphasize outliers more.

Partitioning around medoids or minimax-linkage hierarchical clustering will typically find a close-to-optimal clustering where one exists; select additional methods for a more exhaustive search. To avoid redundant calculation, clusterings are only updated when 'recalculate clustering' is clicked, or the 'maximum cluster number' slider is modified; clustering solutions using more than this many clusters are not considered. Clusterings with silhouette coefficients  $< 0.25$  are unlikely to represent genuine structure and are not reported or depicted.

### Display tab

Up to 15 dimensions can be depicted; the quality of a projection – that is, the faithfulness of projected distances to true tree-to-tree distances – is quantified by the product of the Trustworthiness and Continuity metrics, which should exceed 0.9 (at least).

An interactive 3D plot can be explored by dragging the mouse and scrolling, but do be careful to check that three dimensions are enough to depict your data accurately.

The minimum spanning tree is the shortest possible line selecting the chosen subsample of trees; if it takes a convoluted zig-zagging route, then the projection is doing a poor job of reflecting true tree to tree distances.

Convex hulls are the smallest polygons enclosing all points in each cluster; they are handy for spotting clusters, but their area does not correspond to a genuine quantity, so should not be interpreted.

Tree numbers correspond to the sequence of trees in their original input file, before subsampling.

Each tree is denoted by a point, whose symbol can be styled according to cluster membership or according to the file that contains the tree, with each click of 'Add to existing' on the input tab constituting a new batch with a new symbol.

Points can be coloured according to a category – the cluster or batch to which they belong, or custom data provided in the Point Property File on the input tab – or continuously, either by the sequence in which they were added to memory, or according to custom data.

### Exporting tree spaces

A projection can be saved to PDF or as a PNG bitmap at the size selected.

### References

A list of references employed when constructing the tree space is populated according to the methods used; it would be appropriate to cite and briefly discuss these studies in any publication using figures generated using this application. The application itself can be cited using Smith (2020, 2021) below.

### Author(s)

Martin R. Smith ([martin.smith@durham.ac.uk](mailto:martin.smith@durham.ac.uk))

### References

Smith MR (2020). “Information theoretic Generalized Robinson-Foulds metrics for comparing phylogenetic trees.” *Bioinformatics*, **36**(20), 5007–5013. doi: [10.1093/bioinformatics/btaa614](https://doi.org/10.1093/bioinformatics/btaa614), <https://doi.org/10.1093/bioinformatics/btaa614>.

Smith MR (2021). “The importance of methodology when analysing landscapes of phylogenetic trees.” *Forthcoming*.

### See Also

Full detail of tree space analysis in R is provided in the accompanying [vignette](#).

Other tree space functions: [ProjectionQuality\(\)](#), [SpectralClustering\(\)](#), [median.multiPhylo\(\)](#)

---

ProjectionQuality      *Quality of projected distances*

---

### Description

ProjectionQuality() calculates the trustworthiness and continuity of projected distances (Venna & Kaski 2001; Kaski *et al.* 2003). Trustworthiness measures, on a scale from 0–1, the degree to which points that are nearby in a projection are truly close neighbours; continuity, the extent to which points that are truly nearby retain their close spatial proximity in a projection.

### Usage

```
ProjectionQuality(original, projected, neighbours = 10L)
```

### Arguments

original, projected      Square matrix or dist object containing original / projected pairwise distances.  
neighbours      Number of nearest neighbours to use in calculation.

### Value

ProjectionQuality() returns a named vector of length four, containing the entries: Trustworthiness, Continuity, TxC (the product of these values), and sqrtTxC (its square root).

### Author(s)

Wrapper for functions from Charlotte Soneson’s **dreval**, <https://github.com/csoneson/dreval/blob/master/R/trustworthiness.R>

### References

Venna J, Kaski S (2001). “Neighborhood preservation in nonlinear projection methods: an experimental study.” In Dorffner G, Bischof H, Hornik K (eds.), *Artificial Neural Networks — ICANN 2001*, Lecture Notes in Computer Science, 485–491. doi: [10.1007/3540446680\\_68](https://doi.org/10.1007/3540446680_68), [https://doi.org/10.1007/3-540-44668-0\\_68](https://doi.org/10.1007/3-540-44668-0_68).

Kaski S, Nikkila J, Oja M, Venna J, Toronen P, Castren E (2003). “Trustworthiness and metrics in visualizing similarity of gene expression.” *BMC Bioinformatics*, **4**, 48. doi: [10.1186/1471-2105-4-48](https://doi.org/10.1186/1471-2105-4-48), <https://doi.org/10.1186/1471-2105-4-48>.

### See Also

Other tree space functions: [Project\(\)](#), [SpectralClustering\(\)](#), [median.multiPhylo\(\)](#)

**Examples**

```
library('TreeTools', quietly = TRUE, warn.conflict = FALSE)
trees <- as.phylo(0:10, nTip = 8)
distances <- ClusteringInfoDistance(trees)
projection <- cmdscale(distances)
ProjectionQuality(distances, dist(projection), 4)
```

---

Robinson-Foulds	<i>Robinson-Foulds distances, with adjustments for phylogenetic information content</i>
-----------------	---

---

**Description**

Calculate the Robinson-Foulds distance, or the equivalent similarity measure, with options to (i) annotate matched splits; (ii) weight splits according to their phylogenetic information content (Smith 2020).

**Usage**

```
InfoRobinsonFoulds(  
  tree1,  
  tree2 = NULL,  
  similarity = FALSE,  
  normalize = FALSE,  
  reportMatching = FALSE  
)  
  
InfoRobinsonFouldsSplits(  
  splits1,  
  splits2,  
  nTip = attr(splits1, "nTip"),  
  reportMatching = FALSE  
)  
  
RobinsonFoulds(  
  tree1,  
  tree2 = NULL,  
  similarity = FALSE,  
  normalize = FALSE,  
  reportMatching = FALSE  
)  
  
RobinsonFouldsMatching(  
  tree1,  
  tree2,  
  similarity = FALSE,  
  normalize = FALSE,
```

```

    ...
)

RobinsonFouldsSplits(
  splits1,
  splits2,
  nTip = attr(splits1, "nTip"),
  reportMatching = FALSE
)

```

### Arguments

<code>tree1</code>	Trees of class <code>phylo</code> , with leaves labelled identically, or lists of such trees to undergo pairwise comparison. Where implemented, <code>tree2 = NULL</code> will compute distances between each pair of trees in the list <code>tree1</code> using a fast algorithm based on Day (1985).
<code>tree2</code>	Trees of class <code>phylo</code> , with leaves labelled identically, or lists of such trees to undergo pairwise comparison. Where implemented, <code>tree2 = NULL</code> will compute distances between each pair of trees in the list <code>tree1</code> using a fast algorithm based on Day (1985).
<code>similarity</code>	Logical specifying whether to report the result as a tree similarity, rather than a difference.
<code>normalize</code>	If a numeric value is provided, this will be used as a maximum value against which to rescale results. If <code>TRUE</code> , results will be rescaled against a maximum value calculated from the specified tree sizes and topology, as specified in the 'Normalization' section below. If <code>FALSE</code> , results will not be rescaled.
<code>reportMatching</code>	Logical specifying whether to return the clade matchings as an attribute of the score.
<code>splits1</code>	Logical matrices where each row corresponds to a leaf, either listed in the same order or bearing identical names (in any sequence), and each column corresponds to a split, such that each leaf is identified as a member of the ingroup ( <code>TRUE</code> ) or outgroup ( <code>FALSE</code> ) of the respective split.
<code>splits2</code>	Logical matrices where each row corresponds to a leaf, either listed in the same order or bearing identical names (in any sequence), and each column corresponds to a split, such that each leaf is identified as a member of the ingroup ( <code>TRUE</code> ) or outgroup ( <code>FALSE</code> ) of the respective split.
<code>nTip</code>	(Optional) Integer specifying the number of leaves in each split.
<code>...</code>	Not used.

### Details

Note that if `reportMatching = TRUE`, the `pairScores` attribute returns a logical matrix specifying whether each pair of splits is identical.

`InfoRobinsonFoulds()` calculates the tree similarity or distance by summing the phylogenetic information content of all splits that are (or are not) identical in both trees. Consequently, splits that are more likely to be identical by chance alone make a smaller contribution to overall tree distance, because their similarity is less remarkable.

Rapid comparison between multiple pairs of trees employs the Day (1985) linear-time algorithm.

### Value

RobinsonFoulds() and InfoRobinsonFoulds() return an array of numerics providing the distances between each pair of trees in tree1 and tree2, or splits1 and splits2.

### Functions

- RobinsonFouldsMatching: Matched splits, intended for use with `VisualizeMatching()`.

### Normalization

- RobinsonFoulds() is normalized against the total number of splits that are present.
- InfoRobinsonFoulds() is normalized against the sum of the phylogenetic information of all splits in both trees, treated independently.

### Author(s)

Martin R. Smith ([martin.smith@durham.ac.uk](mailto:martin.smith@durham.ac.uk))

### References

- Robinson DF, Foulds LR (1981). “Comparison of phylogenetic trees.” *Mathematical Biosciences*, **53**(1-2), 131–147. doi: [10.1016/00255564\(81\)900432](https://doi.org/10.1016/00255564(81)900432), [https://doi.org/10.1016/0025-5564\(81\)90043-2](https://doi.org/10.1016/0025-5564(81)90043-2).
- Day WHE (1985). “Optimal algorithms for comparing trees with labeled leaves.” *Journal of Classification*, **2**(1), 7–28. doi: [10.1007/BF01908061](https://doi.org/10.1007/BF01908061), <https://doi.org/10.1007/BF01908061>.
- Steel MA, Penny D (2006). “Maximum parsimony and the phylogenetic information in multistate characters.” In Albert VA (ed.), *Parsimony, Phylogeny, and Genomics*, 163–178. Oxford University Press, Oxford.
- Smith MR (2020). “Information theoretic Generalized Robinson-Foulds metrics for comparing phylogenetic trees.” *Bioinformatics*, **36**(20), 5007–5013. doi: [10.1093/bioinformatics/btaa614](https://doi.org/10.1093/bioinformatics/btaa614), <https://doi.org/10.1093/bioinformatics/btaa614>.

### See Also

Display paired splits: `VisualizeMatching()`

Other tree distances: `JaccardRobinsonFoulds()`, `KendallColijn()`, `MASTSize()`, `MatchingSplitDistance()`, `NNIDist()`, `NyeSimilarity()`, `PathDist()`, `SPRDist()`, `TreeDistance()`

### Examples

```
# For BalancedTree, PectinateTree, as.phylo:
library('TreeTools', quietly = TRUE, warn.conflicts = FALSE)
balanced7 <- BalancedTree(7)
pectinate7 <- PectinateTree(7)
RobinsonFoulds(balanced7, pectinate7)
RobinsonFoulds(balanced7, pectinate7, normalize = TRUE)
```

```
VisualizeMatching(RobinsonFouldsMatching, balanced7, pectinate7)
InfoRobinsonFoulds(balanced7, pectinate7)
VisualizeMatching(InfoRobinsonFoulds, balanced7, pectinate7)
```

---

SpectralClustering      *Spectral clustering*

---

### Description

Spectral clustering

### Usage

```
SpectralClustering(D, nn = 10, nEig = 2)
```

### Arguments

D	Square matrix or dist object containing Euclidean distances between data points.
nn	Integer specifying number of nearest neighbours to consider
nEig	Integer specifying number of eigenvectors to retain.

### Author(s)

Adapted by MRS from script by [Nura Kawa](#)

### See Also

Other tree space functions: [ProjectionQuality\(\)](#), [Project\(\)](#), [median.multiPhylo\(\)](#)

### Examples

```
library('TreeTools', quietly = TRUE, warn.conflict = FALSE)
trees <- as.phylo(0:10, nTip = 8)
distances <- ClusteringInfoDistance(trees)
SpectralClustering(distances)
```

---

`SplitEntropy`*Entropy of two splits*

---

**Description**

Calculate the entropy, joint entropy, entropy distance and information content of two splits, treating each split as a division of  $n$  leaves into two groups. Further details are available in a [vignette](#), MacKay (2003) and Meila (2007).

**Usage**

```
SplitEntropy(split1, split2 = split1)
```

**Arguments**

`split1`, `split2` Logical vectors listing leaves in a consistent order, identifying each leaf as a member of the ingroup (TRUE) or outgroup (FALSE) of the split in question.

**Value**

A numeric vector listing, in bits:

- H1 The entropy of split 1;
- H2 The entropy of split 2;
- H12 The joint entropy of both splits;
- I The mutual information of the splits;
- Hd The entropy distance (variation of information) of the splits.

**Author(s)**

Martin R. Smith ([martin.smith@durham.ac.uk](mailto:martin.smith@durham.ac.uk))

**References**

MacKay DJC (2003). *Information Theory, Inference, and Learning Algorithms*. Cambridge University Press, Cambridge. <https://www.inference.org.uk/itprnn/book.pdf>.

Meila M (2007). “Comparing clusterings—an information based distance.” *Journal of Multivariate Analysis*, **98**(5), 873–895. doi: [10.1016/j.jmva.2006.11.013](https://doi.org/10.1016/j.jmva.2006.11.013), <https://doi.org/10.1016/j.jmva.2006.11.013>.

**See Also**

Other information functions: [ClusteringEntropy\(\)](#), [SplitSharedInformation\(\)](#), [SplitwiseInfo\(\)](#)

**Examples**

```
A <- TRUE
B <- FALSE
SplitEntropy(c(A, A, A, B, B, B), c(A, A, B, B, B, B))
```

---

SplitsCompatible	<i>Are splits compatible?</i>
------------------	-------------------------------

---

**Description**

Determine whether splits are compatible (concave); i.e. they can both occur on a single tree.

**Usage**

```
SplitsCompatible(split1, split2)
```

**Arguments**

`split1`, `split2` Logical vectors listing leaves in a consistent order, identifying each leaf as a member of the ingroup (TRUE) or outgroup (FALSE) of the split in question.

**Value**

`SplitsCompatible()` returns a logical specifying whether the splits provided are compatible with one another.

**Author(s)**

**Martin R. Smith** ([martin.smith@durham.ac.uk](mailto:martin.smith@durham.ac.uk))

**Examples**

```
A <- TRUE
B <- FALSE
SplitsCompatible(c(A, A, A, B, B, B),
                 c(A, A, B, B, B, B))
SplitsCompatible(c(A, A, A, B, B, B),
                 c(A, A, B, B, B, A))
```

---

SplitSharedInformation

*Shared information content of two splits*


---

### Description

Calculate the phylogenetic information shared, or not shared, between two splits. See the [accompanying vignette](#) for definitions.

### Usage

```
SplitSharedInformation(n, A1, A2 = A1)
```

```
SplitDifferentInformation(n, A1, A2 = A1)
```

```
TreesConsistentWithTwoSplits(n, A1, A2 = A1)
```

```
LnTreesConsistentWithTwoSplits(n, A1, A2 = A1)
```

### Arguments

n	Integer specifying the number of leaves
A1, A2	Integers specifying the number of taxa in <i>A1</i> and <i>A2</i> , once the splits have been arranged such that <i>A1</i> fully overlaps with <i>A2</i> .

### Details

Split *S1* divides *n* leaves into two splits, *A1* and *B1*. Split *S2* divides the same leaves into the splits *A2* and *B2*.

Splits must be named such that *A1* fully overlaps with *A2*: that is to say, all taxa in *A1* are also in *A2*, or *vice versa*. Thus, all taxa in the smaller of *A1* and *A2* also occur in the larger.

### Value

TreesConsistentWithTwoSplits() returns the number of unrooted bifurcating trees consistent with two splits.

SplitSharedInformation() returns the phylogenetic information that two splits have in common, in bits.

SplitDifferentInformation() returns the amount of phylogenetic information distinct to one of the two splits, in bits.

### Functions

- SplitDifferentInformation: Different information between two splits.
- TreesConsistentWithTwoSplits: Number of trees consistent with two splits.
- LnTreesConsistentWithTwoSplits: Natural logarithm of TreesConsistentWithTwoSplits.

**Author(s)**

Martin R. Smith ([martin.smith@durham.ac.uk](mailto:martin.smith@durham.ac.uk))

**References**

Meila M (2007). “Comparing clusterings—an information based distance.” *Journal of Multivariate Analysis*, **98**(5), 873–895. doi: [10.1016/j.jmva.2006.11.013](https://doi.org/10.1016/j.jmva.2006.11.013), <https://doi.org/10.1016/j.jmva.2006.11.013>.

**See Also**

Other information functions: [ClusteringEntropy\(\)](#), [SplitEntropy\(\)](#), [SplitwiseInfo\(\)](#)

**Examples**

```
# Eight leaves, labelled A to H.
# Split 1: ABCD|EFGH
# Split 2: ABC|DEFGH
# Let A1 = ABCD (four taxa), and A2 = ABC (three taxa).
# A1 and A2 overlap (both contain ABC).

TreesConsistentWithTwoSplits(n = 8, A1 = 4, A2 = 3)
SplitSharedInformation(n = 8, A1 = 4, A2 = 3)
SplitDifferentInformation(n = 8, A1 = 4, A2 = 3)

# If splits are identical, then their shared information is the same
# as the information of either split:
SplitSharedInformation(n = 8, A1 = 3, A2 = 3)
TreeTools::SplitInformation(3, 5)
```

---

SplitwiseInfo

*Information content of splits within a tree*

---

**Description**

Sum the phylogenetic information content for all splits within a phylogenetic tree. This value will be greater than the total information content of the tree where a tree contains multiple splits, as these splits will contain mutual information.

**Usage**

```
SplitwiseInfo(x)
```

**Arguments**

x                    A tree of class phylo, a list of trees, or a multiPhylo object.

**Author(s)**

Martin R. Smith ([martin.smith@durham.ac.uk](mailto:martin.smith@durham.ac.uk))

**See Also**

An introduction to the phylogenetic information content of a split is given in [SplitInformation\(\)](#) and in a [package vignette](#).

Other information functions: [ClusteringEntropy\(\)](#), [SplitEntropy\(\)](#), [SplitSharedInformation\(\)](#)

**Examples**

```
SplitwiseInfo(TreeTools::PectinateTree(8))
```

---

 SPRDist

*Approximate Subtree Prune and Regraft distance*


---

**Description**

Approximate the Subtree Prune and Regraft (SPR) distance.

**Usage**

```
SPRDist(tree1, tree2 = NULL, symmetric = TRUE)
```

**Arguments**

tree1, tree2	Trees of class <code>phylo</code> , with leaves labelled identically, or lists of such trees to undergo pairwise comparison. Where implemented, <code>tree2 = NULL</code> will compute distances between each pair of trees in the list <code>tree1</code> using a fast algorithm based on Day (1985).
symmetric	Logical specifying whether to produce a better heuristic by calculating the minimum of <code>SPRDist(t1, t2)</code> and <code>SPRDist(t2, t1)</code> , which are not guaranteed to be equal due to the heuristic nature of the approximation (see <a href="#">phangorn#97</a> ). Set to <code>FALSE</code> for the faster approximation, as implemented in 'phangorn'.

**Details**

`SPRDist()` is a wrapper for the function `SPR.dist()` in the `phangorn` package. It pre-processes trees to ensure that their internal representation does not cause the `SPR.dist()` function to crash R, and allows an improved (but slower) symmetric heuristic.

A memory leak is present in `phangorn` v2.5.5. To avoid a drain on system resources, install the latest version of `phangorn` with `devtools::install_github('KlausVigo/phangorn')`.

**Value**

`SPRDist()` returns a vector or distance matrix of distances between trees.

**Author(s)**

Martin R. Smith ([martin.smith@durham.ac.uk](mailto:martin.smith@durham.ac.uk))

**See Also**

Other tree distances: [JaccardRobinsonFoulds\(\)](#), [KendallColijn\(\)](#), [MASTSize\(\)](#), [MatchingSplitDistance\(\)](#), [NNIDist\(\)](#), [NyeSimilarity\(\)](#), [PathDist\(\)](#), [Robinson-Foulds](#), [TreeDistance\(\)](#)

**Examples**

```
library('TreeTools', quietly = TRUE, warn.conflicts = FALSE)

SPRDist(BalancedTree(7), PectinateTree(7))

SPRDist(BalancedTree(7), as.phylo(0:2, 7))
SPRDist(as.phylo(0:2, 7), PectinateTree(7))

SPRDist(list(bal = BalancedTree(7), pec = PectinateTree(7)),
         as.phylo(0:2, 7))

CompareAll(as.phylo(30:33, 8), SPRDist)
```

---

TreeDistance

*Information-based generalized Robinson–Foulds distances*

---

**Description**

Calculate tree similarity and distance measures based on the amount of phylogenetic or clustering information that two trees hold in common, as proposed in Smith (2020).

**Usage**

```
TreeDistance(tree1, tree2 = tree1)
```

```
SharedPhylogeneticInfo(
  tree1,
  tree2 = NULL,
  normalize = FALSE,
  reportMatching = FALSE,
  diag = TRUE
)
```

```
DifferentPhylogeneticInfo(
  tree1,
  tree2 = NULL,
  normalize = FALSE,
  reportMatching = FALSE
)
```

```
PhylogeneticInfoDistance(  
  tree1,  
  tree2 = NULL,  
  normalize = FALSE,  
  reportMatching = FALSE  
)  
  
ClusteringInfoDistance(  
  tree1,  
  tree2 = NULL,  
  normalize = FALSE,  
  reportMatching = FALSE  
)  
  
ExpectedVariation(tree1, tree2, samples = 10000)  
  
MutualClusteringInfo(  
  tree1,  
  tree2 = NULL,  
  normalize = FALSE,  
  reportMatching = FALSE,  
  diag = TRUE  
)  
  
SharedPhylogeneticInfoSplits(  
  splits1,  
  splits2,  
  nTip = attr(splits1, "nTip"),  
  reportMatching = FALSE  
)  
  
MutualClusteringInfoSplits(  
  splits1,  
  splits2,  
  nTip = attr(splits1, "nTip"),  
  reportMatching = FALSE  
)  
  
MatchingSplitInfo(  
  tree1,  
  tree2 = NULL,  
  normalize = FALSE,  
  reportMatching = FALSE,  
  diag = TRUE  
)  
  
MatchingSplitInfoDistance(  

```

```

    tree1,
    tree2 = NULL,
    normalize = FALSE,
    reportMatching = FALSE
)

MatchingSplitInfoSplits(
  splits1,
  splits2,
  nTip = attr(splits1, "nTip"),
  reportMatching = FALSE
)

```

### Arguments

tree1, tree2	Trees of class phylo, with leaves labelled identically, or lists of such trees to undergo pairwise comparison. Where implemented, tree2 = NULL will compute distances between each pair of trees in the list tree1 using a fast algorithm based on Day (1985).
normalize	If a numeric value is provided, this will be used as a maximum value against which to rescale results. If TRUE, results will be rescaled against a maximum value calculated from the specified tree sizes and topology, as specified in the 'Normalization' section below. If FALSE, results will not be rescaled.
reportMatching	Logical specifying whether to return the clade matchings as an attribute of the score.
diag	Logical specifying whether to return similarities along the diagonal, i.e. of each tree with itself. Applies only if tree2 is a list identical to tree1, or NULL.
samples	Integer specifying how many samplings to obtain; accuracy of estimate increases with $\sqrt{\text{samples}}$ .
splits1, splits2	Logical matrices where each row corresponds to a leaf, either listed in the same order or bearing identical names (in any sequence), and each column corresponds to a split, such that each leaf is identified as a member of the ingroup (TRUE) or outgroup (FALSE) of the respective split.
nTip	(Optional) Integer specifying the number of leaves in each split.

### Details

**Generalized Robinson–Foulds distances** calculate tree similarity by finding an optimal matching that the similarity between a split on one tree and its pair on a second, considering all possible ways to pair splits between trees (including leaving a split unpaired).

The methods implemented here use the concepts of **entropy and information** (MacKay 2003) to assign a similarity score between each pair of splits.

The returned tree similarity measures state the amount of information, in bits, that the splits in two trees hold in common when they are optimally matched, following Smith (2020). The complementary tree distance measures state how much information is different in the splits of two trees, under an optimal matching.

**Value**

If `reportMatching = FALSE`, the functions return a numeric vector specifying the requested similarities or differences.

If `reportMatching = TRUE`, the functions additionally return an integer vector listing the index of the split in `tree2` that is matched with each split in `tree1` in the optimal matching. Unmatched splits are denoted NA. Use `VisualizeMatching()` to plot the optimal matching.

**Concepts of information**

The phylogenetic (Shannon) information content and entropy of a split are defined in [a separate vignette](#).

Using the mutual (clustering) information (Meila 2007, Vinh *et al.* 2010) of two splits to quantify their similarity gives rise to the Mutual Clustering Information measure (`MutualClusteringInfo()`, `MutualClusteringInfoSplits()`); the entropy distance gives the Clustering Information Distance (`ClusteringInfoDistance()`). This approach is optimal in many regards, and is implemented with normalization in the convenience function `TreeDistance()`.

Using the amount of phylogenetic information common to two splits to measure their similarity gives rise to the Shared Phylogenetic Information similarity measure (`SharedPhylogeneticInfo()`, `SharedPhylogeneticInfoSplits()`). The amount of information distinct to each of a pair of splits provides the complementary Different Phylogenetic Information distance metric (`DifferentPhylogeneticInfo()`).

The Matching Split Information measure (`MatchingSplitInfo()`, `MatchingSplitInfoSplits()`) defines the similarity between a pair of splits as the phylogenetic information content of the most informative split that is consistent with both input splits; `MatchingSplitInfoDistance()` is the corresponding measure of tree difference. ([More information here.](#))

**Conversion to distances:**

To convert similarity measures to distances, it is necessary to subtract the similarity score from a maximum value. In order to generate distance *metrics*, these functions subtract the similarity twice from the total information content (SPI, MSI) or entropy (MCI) of all the splits in both trees (Smith 2020).

**Normalization:**

If `normalize = TRUE`, then results will be rescaled such that distance ranges from zero to (in principle) one. The maximum **distance** is the sum of the information content or entropy of each split in each tree; the maximum **similarity** is half this value. (See Vinh *et al.* (2010, table 3) and Smith (2020) for alternative normalization possibilities.)

Note that a distance value of one (= similarity of zero) will seldom be achieved, as even the most different trees exhibit some similarity. It may thus be helpful to rescale the normalized value such that the *expected* distance between a random pair of trees equals one. This can be calculated with `ExpectedVariation()`; or see package `'TreeDistData'` for a compilation of expected values under different metrics for trees with up to 200 leaves.

Alternatively, to scale against the information content or entropy of all splits in the most or least informative tree, use `normalize = pmax` or `pmin` respectively. To calculate the relative similarity against a reference tree that is known to be 'correct', use `normalize = SplitwiseInfo(trueTree)` (SPI, MSI) or `ClusteringEntropy(trueTree)` (MCI).

## Troubleshooting

Trees being compared must have identical tips. (If you have a use case for comparing trees with non-identical tips, do file a [GitHub issue](#) or drop the maintainer an e-mail.)

To determine which tips do not occur in both trees, try:

```
library('TreeTools')
setdiff(TipLabels(tree1), TipLabels(tree2)) # In tree1 but not tree2
setdiff(TipLabels(tree2), TipLabels(tree1)) # In tree2 but not tree1
```

## Author(s)

Martin R. Smith ([martin.smith@durham.ac.uk](mailto:martin.smith@durham.ac.uk))

## References

- Day WHE (1985). “Optimal algorithms for comparing trees with labeled leaves.” *Journal of Classification*, **2**(1), 7–28. doi: [10.1007/BF01908061](https://doi.org/10.1007/BF01908061), <https://doi.org/10.1007/BF01908061>.
- MacKay DJC (2003). *Information Theory, Inference, and Learning Algorithms*. Cambridge University Press, Cambridge. <https://www.inference.org.uk/itprnn/book.pdf>.
- Meila M (2007). “Comparing clusterings—an information based distance.” *Journal of Multivariate Analysis*, **98**(5), 873–895. doi: [10.1016/j.jmva.2006.11.013](https://doi.org/10.1016/j.jmva.2006.11.013), <https://doi.org/10.1016/j.jmva.2006.11.013>.
- Smith MR (2020). “Information theoretic Generalized Robinson-Foulds metrics for comparing phylogenetic trees.” *Bioinformatics*, **36**(20), 5007–5013. doi: [10.1093/bioinformatics/btaa614](https://doi.org/10.1093/bioinformatics/btaa614), <https://doi.org/10.1093/bioinformatics/btaa614>.
- Vinh NX, Epps J, Bailey J (2010). “Information theoretic measures for clusterings comparison: variants, properties, normalization and correction for chance.” *Journal of Machine Learning Research*, **11**, 2837–2854. doi: [10.1145/1553374.1553511](https://doi.org/10.1145/1553374.1553511), <https://doi.org/10.1145/1553374.1553511>.

## See Also

Other tree distances: [JaccardRobinsonFoulds\(\)](#), [KendallColijn\(\)](#), [MASTSize\(\)](#), [MatchingSplitDistance\(\)](#), [NNIDist\(\)](#), [NyeSimilarity\(\)](#), [PathDist\(\)](#), [Robinson-Foulds](#), [SPRDist\(\)](#)

## Examples

```
tree1 <- ape::read.tree(text='(((a, b), c), d), (e, (f, (g, h)))));')
tree2 <- ape::read.tree(text='(((a, b), (c, d)), ((e, f), (g, h)))));')
tree3 <- ape::read.tree(text='(((h, b), c), d), (e, (f, (g, a)))));')

# Best possible score is obtained by matching a tree with itself
DifferentPhylogeneticInfo(tree1, tree1) # 0, by definition
SharedPhylogeneticInfo(tree1, tree1)
SplitwiseInfo(tree1) # Maximum shared phylogenetic information

# Best possible score is a function of tree shape; the splits within
```

```

# balanced trees are more independent and thus contain less information
SplitwiseInfo(tree2)

# How similar are two trees?
SharedPhylogeneticInfo(tree1, tree2) # Amount of phylogenetic information in common
attr(SharedPhylogeneticInfo(tree1, tree2, reportMatching = TRUE), 'matching')
VisualizeMatching(SharedPhylogeneticInfo, tree1, tree2) # Which clades are matched?

DifferentPhylogeneticInfo(tree1, tree2) # Distance measure
DifferentPhylogeneticInfo(tree2, tree1) # The metric is symmetric

# Are they more similar than two trees of this shape would be by chance?
ExpectedVariation(tree1, tree2, sample=12)['DifferentPhylogeneticInfo', 'Estimate']

# Every split in tree1 conflicts with every split in tree3
# Pairs of conflicting splits contain clustering, but not phylogenetic,
# information
SharedPhylogeneticInfo(tree1, tree3) # = 0
MutualClusteringInfo(tree1, tree3) # > 0

# Converting trees to Splits objects can speed up multiple comparisons
splits1 <- TreeTools::as.Splits(tree1)
splits2 <- TreeTools::as.Splits(tree2)

SharedPhylogeneticInfoSplits(splits1, splits2)
MatchingSplitInfoSplits(splits1, splits2)
MutualClusteringInfoSplits(splits1, splits2)

```

---

VisualizeMatching

*Visualise a matching*


---

## Description

Depict the splits that are matched between two trees using a specified **Generalized Robinson–Foulds** similarity measure.

## Usage

```

VisualizeMatching(
  Func,
  tree1,
  tree2,
  setPar = TRUE,
  precision = 3L,
  Plot = plot.phylo,
  matchZeros = TRUE,
  plainEdges = FALSE,
  edge.width = 1,
  edge.color = "black",

```

```
    ...
  )
```

### Arguments

Func	Function used to construct tree similarity.
tree1, tree2	Trees of class <code>phylo</code> , with identical leaf labels.
setPar	Logical specifying whether graphical parameters should be set to display trees side by side.
precision	Integer specifying number of significant figures to display when reporting matching scores.
Plot	Function to use to plot trees.
matchZeros	Logical specifying whether to pair splits with zero similarity (TRUE), or leave them unpaired (FALSE).
plainEdges	Logical specifying whether to plot edges with a uniform width and colour (TRUE), or whether to draw edge widths according to the similarity of the associated splits (FALSE).
edge.width, edge.color, ...	Additional parameters to send to <code>Plot()</code> .

### Details

Note that when visualizing a Robinson–Foulds distance (using `Func = RobinsonFouldsMatching`), matched splits are assigned a *similarity* score of 1, which is deducted from the total number of splits to calculate the Robinson–Foulds *distance*. Unmatched splits thus contribute one to total tree distance.

### Author(s)

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### Examples

```
tree1 <- TreeTools::BalancedTree(6)
tree2 <- TreeTools::PectinateTree(6)
```

```
VisualizeMatching(RobinsonFouldsMatching, tree1, tree2)
VisualizeMatching(SharedPhylogeneticInfo, tree1, tree2, matchZeros = FALSE)
```

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