TreeCmp 2.0: a comparison of trees in polynomial time – manual

# Introduction

A phylogenetic tree represents a historical evolutionary relationship between different species or organisms. There are various methods for reconstructing phylogenetic trees. Applying those techniques usually results in different trees for the same input data. An important problem is to determine how distant from each other two trees reconstructed in such a way are. Comparing phylogenetic trees is also useful in mining phylogenetic information databases. The TreeCmp application was designed to compute distances between arbitrary (not necessary binary) phylogenetic trees. TreeCmp 2.0 is a command line application based on which two Spring framework-based applications were created: hosted web-based and stand-alone web-based, both called Visual TreeCmp and are available as part of the same package. The package offers various metrics for rooted and unrooted phylogenies, purely topological as well as weighted metrics (i.e. taking into account numerical lengths/weights of edges in the form of non-negative real numbers). All distances are implemented using polynomial time algorithms and all of them fulfill classic mathematical metric space axioms.

# Input data format

The TreeCmp software was designed to support BEAST (<http://beast.bio.ed.ac.uk/>) and MrBayes (<http://mrbayes.csit.fsu.edu/>) data files, where phylogenetic trees are stored in the NEWICK format. Note that plain text files containing only trees in this format are supported as well. The input file can contain any number of trees separated by a semicolon.

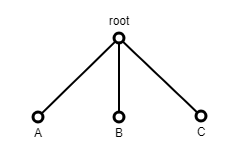
Example:

(((((((((1,2),3),4),5),6),7),8),9),10);

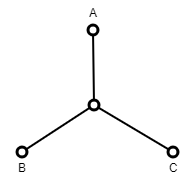
((((((((2,3),4),5),6),7),8),9),(1,10));

Before performing calculations, the validity of entered data is checked. In the case of any incompatibilities with the NEWICK/NEXUS format, the execution of the program will be terminated and an error message will be displayed. If only metrics not including edge weights are used in the calculations (unweighted metrics), the existing weights will not be interpreted. If at least one metric includes weights, positive weights must be assigned to all edges in the trees, otherwise the calculations will be terminated and an error message will be displayed. These restrictions can be relaxed by using the -W parameter, which enables applying zero weights, and if there is no weight, zero value will be assigned to the edge as default.

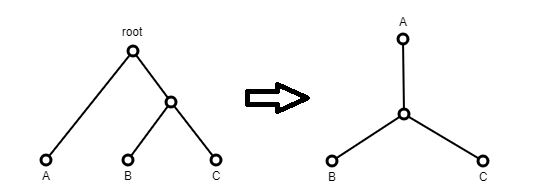
Newick trees are interpreted as rooted, even if there is a multifurcation at the base. The unrooted metrics modify each tree by removing the root indication, and if a node of degree 2 is left behind it is also suppressed. For example, if an unrooted binary tree in the NEWICK format: (A, B, C) is entered in the metric dedicated for a rooted tree, it will be interpreted as a rooted, non-binary tree consisting of a 3-degree root and 3 descendant vertices A, B and C.



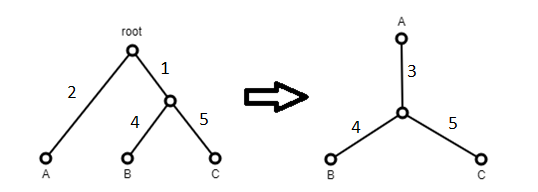
In the case when a rooted binary tree is entered to the metric dedicated for an unrooted tree, the root will be treated as an internal vertex or will be automatically suppressed if its degree equals 2. For example, if a rooted binary tree in the NEWICK format (A, B, C) is entered in the metric for a unrooted tree, then the root will be treated as an internal vertex and the tree will be interpreted as an unrooted, binary tree.



However, after entering the rooted tree (A, (B, C)) to the metric dedicated for unrooted trees, the root will be suppressed as in the figure below.



In the case with a weighted tree (a tree with weights on the edge) the sum of edge weights incident to the removed root vertex has been assigned to the newly created edge as in the figure below.



Summing up, Newick trees are interpreted as rooted, even if there is a multifurcation at the base. The unrooted metrics modify each tree by removing the root indication, and if a node of degree 2 is left behind, it is also suppressed.

# Running TreeCmp

The TreeCmp application is distributed as a zip archive. In order to unpack the file use any software supporting zip compression, for example a free software 7-zip (<http://www.7-zip.org/>) can be used. Running the TreeCmp application requires at least 1.6 version of Java VM.

## Directory structure

|  |  |  |
| --- | --- | --- |
| **Description** | | |
| bin |  | contains main jar file: **TreeCmp.jar** and lib folder with necessary open source libraries. |
| config |  | contains xml configuration file |
| data |  | contains text files with pre-computed data (average value and other statistics) for all 18 metrics under the two models of generation of random binary trees: the Yule model and the uniform model. |
| examples |  | contains subdirectories with examples |
|  | align | contains an example of creating alignments |
|  | beast | contains an example input file created using BEAST |
|  | mr\_bayes | contains an example input file created using MrBayes |
|  | plain | contains an example input file with plain trees |
|  | plain2 | contains an example input file with plain trees |
|  | prune | contains an example of comparing trees with different sets of taxa |
|  | ref\_tree | contains an example of comparing reference trees to a set of trees |
|  | scaled | contains an example with reporting scaled values of chosen metrics |
| src |  | contains source code of this application |

## Command line syntax

Usage:

java -jar TreeCmp.jar -w <size>|-s|-m|-r <refTreeFile> –d <metrics> -i <inputfile> -o <outputfile> [-N] [-P] [-I] [-W] [-A|-O]

See section 4 for details regarding an output file format for a particular combination of the options.

**Mandatory switches:**

* The comparison mode options (only one option should be specified):
  + –s – an overlapping pair comparison mode; every two neighboring trees in the input file are compared,
  + -w <size> – a window comparison mode; every two trees within a window with a specified size are compared – the average distance and the standard deviation go to the output file,
  + –m – a matrix comparison mode; every two trees in the input file are compared.
  + -r <refTreeFile> – a reference trees to all trees mode. Each tree in the input file is compared to all reference trees.

Details of the computation flow in each of these cases are explained in the pictures below.



*Tree*

*1*

*Tree*

*2*

*…*

*…*

*Tree*

*n*

*-*

*1*

*Tree*

*n*

Reference trees

to

all input trees mode (

-

r )

Input

Output

Reference tree 1

…

Reference tree

m

…

n

rows

n rows

* The metric option (-d). At least one and at most 18 metrics can be specified. Metrics should be separated by spaces.

Metrics for rooted trees:

* + tt – the Triples metric (Crichlow et al. 1996),
  + rc – the Robinson-Foulds metric based on clusters (Robinson and Foulds 1981),
  + mp – the Matching Pair metric (Bogdanowicz and Giaro 2014),
  + ns – the Nodal Splitted metric with L2 norm (Cardona et al. 2010),
  + mc – the Matching Cluster metric (Bogdanowicz et al. 2012),
  + mt – the Rooted Maximum Agreement Subtree distance (Farach and Thorup 1994),
  + co – the Cophenetic metric with L2 norm (Cardona, Mir, Rosselló, Rotger and Sánchez 2013),
  + rcw – the Robinson-Foulds weighted metric based on clusters (Robinson and Foulds 1979),
  + nsw – the Nodal Splitted weighted metric with L2 norm (Cardona et al. 2010),
  + gdr – the Geodesic (BHV) rooted distance for weighted trees (Owen, Provan 2009),
  + cow – the Cophenetic weighted metric with L2 norm (Cardona, Mir, Rosselló, Rotger and Sánchez 2013).

Metrics for unrooted trees:

* + qt – the Quartet distance (Estabrook 1985),
  + pd – the Path difference distance (Steel and Penny 1993),
  + rf – the Robinson-Foulds distance (Robinson and Foulds 1981),
  + ms – the Matching Split distance (Bogdanowicz and Giaro 2012),
  + um – the Unrooted Maximum Agreement Subtree distance (Farach and Thorup 1994),
  + rfw – the Robinson-Foulds weighted distance (Robinson and Foulds 1979),
  + gdu – the Geodesic (BHV) unrooted distance for weighted trees (Owen, Provan 2009).

Example: -d ms rf

* IO options (both options should be specified):
* -i <inputfile> – inputs data file with trees in the NEWICK format,
* -o <outputfile> – outputs data file with the results of computations.

**Optional switches:**

* General options:
  + –N – reports normalized distances δ*m* for a particular metric (works only for unweighted metrics) *m* (Bogdanowicz et al. 2012; based on an average value from pre-computed data). This functionality is available for trees with the number of leaves between 4 and 1000. Note that a normalized tree similarity for a particular metric *m* (*NTSm*) can be expressed by a normalized distance as follows: *NTSm*. = 1 - δ*m* (Bogdanowicz et al. 2012).
  + –P – prunes compared trees if needed. This option is designed to allow comparing trees with different (partially overlapping) sets of taxa. After using this option three additional columns appear in the output file (see section 4 for details).
  + –I – includes a summary section in the output file.
  + –W – weights of zero value are allowed. If there is no weight, its default value will be set to zero.
* Matching metric specific options (only one option should be specified).
  + –A – Generates alignment files – this option should be used together with the selection of the MS or MC metrics. As a result additional files containing aligned splits or clusters are generated:
    - [output\_file\_name].out.aln\_MS.txt,
    - [output\_file\_name].out.aln\_MC.txt,

where [output\_file\_name] is the file name specified after -o option.

* + -O – uses special implementations of MS/MC metrics optimized for similar trees.

# Output data format

Output files created by the application regardless of the chosen mode have a similar structure. Output files are tab separated text files (TSV), which means that they can be easily read by various data analysis software (e.g. MS Excel, R, OpenOffice.org). For direct saving in CSV or Microsoft Excel format see subsection 6.5. An output file consists of two sections. The first section contains values of distances in selected metrics formatted in rows. The second (optional) section contains summary data computed on the basis of all rows that appears in the first section.

## Basic output file structure

The base output file format for options -s, -m, and -w

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **No** | **Tree1** | **Tree2** | **MetricName\_1** | **MetricName\_2** | **…** | **MetricName\_n** |
| Comparison number | Tree1 number | Tree2 number | Distance value | Distance value | … | Distance value |

The base output file format for option -r,

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **No** | **RefTree** | **Tree** | **MetricName\_1** | **MetricName\_2** | **…** | **MetricName\_n** |
| Comparison number | Reference tree number | Tree number | Distance value | Distance value | … | Distance value |

Tree, tree1, tree2 numbers in the output file correspond to the number of the tree in the input file.

The following table contains a mapping between available metrics and column names in the output file that are related to them.

|  |  |  |
| --- | --- | --- |
| **Metric name in the output file** | **Full metric name** | **TreeCmp command line parameter** |
| Triples | Triples metric | tt |
| RFCluster(0.5) | Robinson-Foulds metric based on clusters | rc |
| MatchingPair | Matching Pair metric | mp |
| NodalSplitted | Nodal Splitted metric with L2 norm | ns |
| MatchingCluster | Matching Cluster metric | mc |
| MAST | Rooted Maximum Agreement Subtree distance | mt |
| CopheneticL2 | Cophenetic Metric with L2 norm | co |
| RFClusterWeighted(0.5) | Weighted Robinson-Foulds metric based on clusters | rcw |
| NodalSplittedWeighted | Weighted Nodal Splitted metric with L2 norm | nsw |
| GeoRooted | Weighted Geodesic (BHV) Rooted metric | gdr |
| CopheneticL2Weighted | Weighted Cophenetic Metric with L2 norm | cow |
| Quartet | Quartet distance | qt |
| PathDiffernce | Path difference distance | pd |
| RF(0.5) | Robinson-Foulds distance | rf |
| MatchingSplit | Matching Split distance | ms |
| UMAST | Unrooted Maximum Agreement Subtree distance | um |
| RFWeighted(0.5) | Weighted Robinsin Foulds distance | rfw |
| GeoUnrooted | Weighted Geodesic (BHV) Unrooted distance | gdu |

## Additional columns (-P and -N options)

After using switch -P the following three columns appear additionally in the output file.

|  |  |  |
| --- | --- | --- |
| **Tree1\_taxa** | **Tree2\_taxa (or RefTree\_taxa)** | **Common\_taxa** |
| Number of taxa in the first tree | Number of taxa in the second (or reference) tree | Number of taxa in common |

After using switch -N the following two columns per each chosen metric appear additionally in the output file. These columns contain the value of the distance in a particular metric divided by its empirical average value. If the number of common leaves in the compared trees is out of supported range (which is from 4 to 1000) or a metric for weighted trees is selected, then “N/A” value is inserted.

|  |  |
| --- | --- |
| **MetricName\_toYuleAvg** | **MetricName\_toUnifAvg** |
| (Distance value)/(Empirical average value in the Yule model) | (Distance value)/(Empirical average value in the uniform model) |

For details regarding generating phylogenetic trees under the Yule and uniform models see (McKenzie and Steel 2000; Semple and Steel 2003).

## Summary section format (-I option)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Name** | **Avg** | **Std** | **Min** | **Max** | **Count** |
| Metric name 1 | Average value | Standard deviation value | Minimal value | Maximal value | Number of analyzed values |
| Metric name 2 | … | … | … | … | … |
| … | … | … | … | … | … |
| Metric name n | … | … | … | … | … |

# Useful Java VM parameters

In the case of a large trees analysis the following exceptions might occur:

1. Exception in thread "main" java.lang.OutOfMemoryError: Java heap space

To solve the problem increase Java heap space memory limit using JVM option –Xmx

Example:

java –Xmx700m –jar TreeCmp.jar <further options>

1. Exception in thread "main" java.lang.StackOverflowError at pal.io.FormattedInput.skipWhiteSpace(FormattedInput.java:111)

at pal.io.FormattedInput.readNextChar(FormattedInput.java:131)

at pal.tree.ReadTree.readNH(ReadTree.java:81)

…..

at pal.tree.ReadTree.readNH(ReadTree.java:89)

To solve the problem increase Java thread stack size limit using JVM option –Xss

Example:

java –Xss1m –jar TreeCmp.jar <further options>

These options can be used in conjunction.

# Examples

## Running application to compare trees using MS

Input file: \examples\beast\testBSP.newick

Invocation:

java -jar TreeCmp.jar -w 2 -d ms -i testBSP.newick -o testBSP.newick\_w\_2.out -I

Console output:

TreeCmp version 1.0-b291

Active options:

Type of the analysis: window comparison mode (-w) with window size: 2

Metrics:

1. MatchingSplit (ms)

Input file: testBSP.newick

Output file: testBSP.newick\_w\_2.out

Additional options:

I - Include summary section in the output file.

-----

2011-08-27 16:03:17: Start of scanning input file: testBSP.newick

2011-08-27 16:03:17: End of scanning input file: testBSP.newick

2011-08-27 16:03:17: 11 valid trees found in file: testBSP.newick

2011-08-27 16:03:17: Start of calculation...please wait...

2011-08-27 16:03:17: 0.00% completed...

2011-08-27 16:03:17: 20.00% completed...

2011-08-27 16:03:17: 40.00% completed...

2011-08-27 16:03:17: 60.00% completed...

2011-08-27 16:03:17: 80.00% completed...

2011-08-27 16:03:17: 100.00% completed.

2011-08-27 16:03:17: End of calculation.

2011-08-27 16:03:17: Total calculation time: 62 ms.

Output file testBSP.newick\_w\_2.out:

No Tree1 Tree2 MatchingSplit

1 1 2 58.0000

2 3 4 24.0000

3 5 6 10.0000

4 7 8 13.0000

5 9 10 14.0000

---------

Summary:

Name Avg Std Min Max Count

MatchingSplit 23.8 17.73583942191629 10.0 58.0 5

## Computing normalized distances

Reporting unweighted distances divided by pre-computed empirical average values for random trees (generated according to Yule and uniform models, -N option) can help in an interpretation of the similarity level of analyzed trees in a chosen metric. This functionality is available for trees with a number of leaves between 4 and 1000 by using –N option. In the following example, the distance in the MS metric of each tree from a given set to the reference tree is computed. Analyzed trees have 15 leaves.

Input files: \examples\sclaed\ref\_tree.trees

\examples\sclaed\test\_set.trees

Invocation:

java -jar TreeCmp.jar -r ref\_tree.trees -d ms -i test\_set.trees -o test\_set.trees.r.out –N

Output file test\_set.trees.r.out:

No RefTree Tree MatchingSplit MatchingSplit\_toYuleAvg MatchingSplit\_toUnifAvg

1 1 1 43.0000 1.0742 0.9663

2 1 2 43.0000 1.0742 0.9663

3 1 3 41.0000 1.0242 0.9214

4 1 4 40.0000 0.9992 0.8989

5 1 5 43.0000 1.0742 0.9663

6 1 6 41.0000 1.0242 0.9214

7 1 7 43.0000 1.0742 0.9663

8 1 8 41.0000 1.0242 0.9214

9 1 9 39.0000 0.9742 0.8764

10 1 10 40.0000 0.9992 0.8989

11 1 11 0.0000 0.0000 0.0000

12 1 12 6.0000 0.1499 0.1348

Basic interpretation:

* The tree number 11 has the same topology as the reference tree.
* The tree number 12 is very similar to the reference tree in comparison with the similarity of two randomly chosen 15-leaves trees (the normalized distance is about 0.15 and 0.13 depending on the random model).
* Trees with numbers 1 to 10 are approximately as similar to the reference tree as random trees to each other (the normalized distance is close to 1).

In ordered to perform a more advanced similarity analysis, e.g. involving a different model of generation of random trees, the user may need to use TreeCmp twice:

* to compute distances between the custom set of random trees generated by other software, e.g. Evolver application from PAML package (<http://abacus.gene.ucl.ac.uk/software/paml.html>) to obtain the empirical average distance in a particular metric or its distribution,
* to compute the distance between analyzed trees.

## Generating new data for computing normalized distances

If the number of compared trees’ leaves is greater than 1000, it is possible to generate manually a set of random trees and calculate statistics for them. To generate a set of trees we can use PRTGen program – a phylogenetic random trees generator. Let's assume that we want to generate 2000 rooted trees on 1001 leaves using a uniform model and save them to the file: trees.newick. Let's use the command:

PRTGen –n 1001 –e 2000 –r –f trees.newick

Then, using TreeCmp, we calculate the value of the selected metric (for instance MC) between each subsequent pair of trees. We will get 1000 values:

java –jar TreeCmp.jar -w 2 -d MC -i trees.newick -o results.out

Based on these results, we can calculate desired values: (average, standard deviation, minimum, maximum, and subsequent quantiles: 0.02, 0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.95, 0.97), e.g. in RStudio:

filename<-"<path\_to\_file>\results.out"

m<-read.table(filename,header = TRUE,sep = "\t")

v<-m[,4]

q\_seq<-c(0.02,0.05,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,0.95,0.97)

q<-quantile(v,q\_seq,type=1,name=FALSE)

row<-c(1001,mean(v),sd(v),min(v),max(v),q)

outfile<-"<path\_to\_file>\row.out"

write(row,file=outfile,append=TRUE,ncolumns=length(row),sep="\t")

The line obtained in row.out file should be pasted into the appropriate file in the data folder. In that case it will be: unif\_MC.txt. Now Treecmp is ready for computing normalized MC distances for rooted trees on 1001 leaves based on a uniform model.

## Finding the most similar trees in the input file

The most convenient comparison mode for such a purpose is a matrix mode (-m). In the following example, the Matching Split distance is used.

Input file: \examples\plain2\plain2.trees

(a,(b,c),(d,e));

(a,b,(c,(d,e)));

(((a,b),c),d,e);

(a,(b,(c,d)),e);

Invocation:

java -jar TreeCmp.jar -m -d ms -i plain2.trees -o plain2.trees.m.out

Output file plain2.trees.m.out:

The most similar trees

No Tree1 Tree2 MatchingSplit

1 1 2 2.0000

2 1 3 2.0000

3 1 4 3.0000

4 2 3 0.0000

5 2 4 3.0000

6 3 4 3.0000

Trees number 2, i.e.: (a,b,(c,(d,e))) and 3, i.e.:(((a,b),c),d,e) in the input file are the most similar. In fact, they have the same topology (trees are assumed to be unrooted as metric for unrooted trees is used) because their distance is 0.

## Exporting data to other applications: MS Excel, R

To save a file in MS Excel format, just use the .xlsx extension in the output data file name (option: -o <outputfile>.xlsx). Similarly, to save a file in CSV format, use the .csv extension in the output data file name (option: -o <outputfile>.csv).

In order to pass data to R (<http://www.r-project.org/>) it is convenient to have the TreeCmp output file in a simple tabular form (therefore, it is recommended to avoid -I option, because it results in generating the summary section which disturbs the tabular order). Such files can be easily read by R environment by using for example the read.table function as follows:

treeCmpData<-read.table("C:\\Program Files\\TreeCmp\\examples\\plain\\plain.trees.m.out", header = TRUE, sep = "\t")

In the example, the file to be read “plain.trees.m.out” is placed in “C:\Program Files\TreeCmp\examples\plain” folder.

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