

dispRity demo for palaeobiologists

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This demo aims to give quick overview of the dispRity package (v.0.1.2) for palaeobiology analysis. Please refer to GitHub page: github.com/TGuillermé/dispRity for other vignettes, namely the dispRity tutorial that explains the functions in more detail.

To keep it short, this package allows to easily perform **disparity-through-time** analysis. This type of analysis often starts by ordinating **morphometric** or **cladistic** data into a multidimensional object hereafter called the **morphospace**. One might then be interested how the occupancy of the morphospace changes through time by measuring a summary metric of this morphospace through time, called **disparity**. In the morphospace case, disparity might be seen as a value summarising the diversity of morphologies.

This demo showcases a typical disparity-through-time analyse: we are going to test whether the disparity changed through time in a subset of Eutheria since the last 100 million years.

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1 Before starting

1.1 Installing dispRity

You can install this package easily if you are using the latest version of R and devtools.

```
if(!require(devtools)) install.packages("devtools")
install_github("TGuillermé/dispRity", ref = "release")
library(dispRity)
```

1.2 The morphospace

In this example, we are going to use a subset of the data from Beck and Lee (2014) that contains an ordinated cladistic matrix and a phylogenetic tree containing both the same 50 taxa along side a table that contains some first and last occurrence data for several taxa. The ordinated matrix will represent our full morphospace, i.e. all the morphologies that ever existed through time (for this dataset).

```

## Loading demo and the package data
library(disprity)

## Loading required package: paleotree

## Setting the random seed for repeatability
set.seed(123)

## The morphospace:
data(BeckLee_mat50)
head(BeckLee_mat50[,1:5])

##           [,1]      [,2]      [,3]      [,4]      [,5]
## Cimolestes -0.5319679  0.1117759259  0.09865194 -0.1933148  0.2035833
## Maelestes  -0.4087147  0.0139690317  0.26268300  0.2297096  0.1310953
## Batodon     -0.6923194  0.3308625215 -0.10175223 -0.1899656  0.1003108
## Bulaklestes -0.6802291 -0.0134872777  0.11018009 -0.4103588  0.4326298
## Daulestes   -0.7386111  0.0009001369  0.12006449 -0.4978191  0.4741342
## Uchkudukodon -0.5105254 -0.2420633915  0.44170317 -0.1172972  0.3602273

dim(BeckLee_mat50)

## [1] 50 48

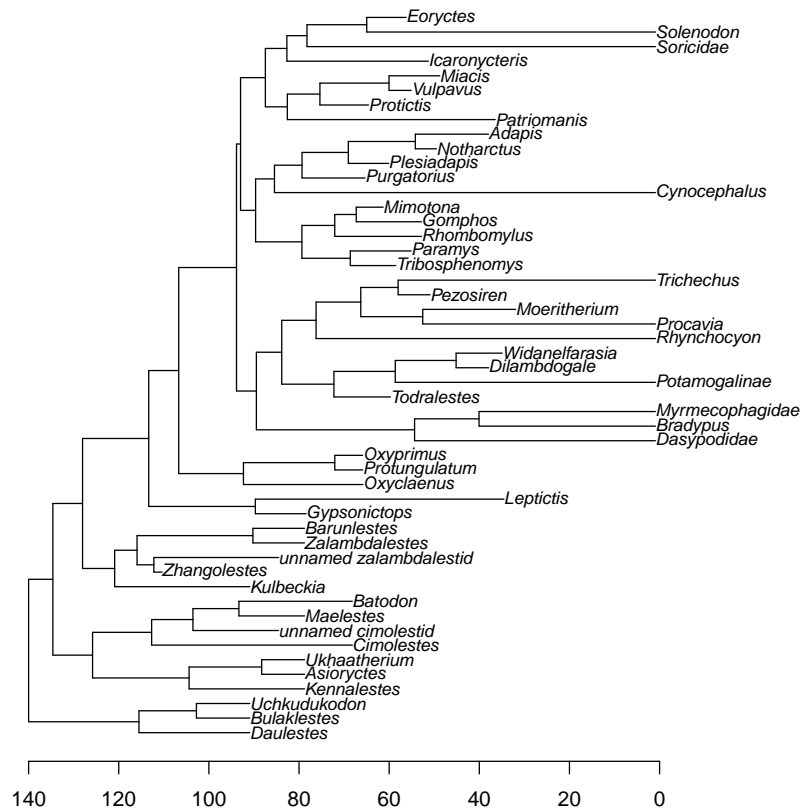
## The morphospace contains 50 taxa and has 48 dimensions (or axis)

## A list of first and last occurrences data for some fossils
data(BeckLee_ages)
head(BeckLee_ages)

##           FAD  LAD
## Adapis      37.2 36.8
## Asioryctes  83.6 72.1
## Leptictis   33.9 33.3
## Miacis      49.0 46.7
## Mimotona    61.6 59.2
## Notharctus  50.2 47.0

## And a phylogeny:
data(BeckLee_tree)
plot(BeckLee_tree, cex=0.8); axisPhylo(root=140)

```



Note that you can have an even nicer tree if you use the strap package:

```
if(!require(strap)) install.packages("strap")
geoscalePhylo(BeckLee_tree, cex.tip=0.8, cex.ts=0.6)
```

2 A disparity-through-time analysis

2.1 Splitting the morphospace through time

One of the crucial steps in disparity-through-time analysis is to split the full morphospace into smaller sub-samples that contain the total amount of morphologies at certain points in time (time-slicing) or during certain periods in time (time-binning). Basically, the full morphospace in the previous step represents the total amount of morphologies in all time and is likely to be greater than any sub-sample of the morphospace.

The `disparity` package provides a `time.series` function that allows to split the morphospace time slices (using `method = "continuous"`) or into time bins (using `method = "discrete"`). In this example, we are going to split the morphospace into 5 equal time bins of 20 million years long from 100 million years ago (Mya) to the present. Note that we will also provide to the function the table containing the first and last occurrences data for some fossils to take into account the fact that some fossils might span between our different time bins.

```
## Creating the vector of time bins ages
time_bins <- rev(seq(from=0, to=100, by=20))

## Splitting the morphospace using the time.series function
binned_morphospace <- time.series(data = BeckLee_mat50, tree = BeckLee_tree,
  method = "discrete", time = time_bins, inc.nodes = FALSE,
  FADLAD = BeckLee_ages)

## Some tips have no FAD/LAD and are assumed to be single points in time.
```

The warning message tells us that some taxa were considered as single points in time because we didn't provide temporal range information for all the taxa: they are therefore considered as unique time points without any occurrence range.

The output object is a `dispRity` object. For details about this object class, please refer to the `dispRity` manual. In brief, `dispRity` objects are lists of different elements (i.e. disparity results, morphospace sub-samples, etc...) that display only a summary of the object when calling the object for avoiding jamming the R console.

```
## The object class
class(binned_morphospace)

## [1] "dispRity"

## What's in the object (messy version for the console!)
str(binned_morphospace)

## List of 3
## $ data      :List of 5
## ..$ 100-80: num [1:8, 1:48] -0.739 -0.68 -0.511 -0.473 -0.459 ...
## .. ..- attr(*, "dimnames")=List of 2
## .. ..$ : chr [1:8] "Daulestes" "Bulaklestes" "Uchkudukodon" "Asioryctes" ...
## .. ..$ : NULL
## ..$ 80-60 : num [1:15, 1:48] -0.477 -0.473 -0.474 -0.532 -0.409 ...
## .. ..- attr(*, "dimnames")=List of 2
## .. ..$ : chr [1:15] "Kennalestes" "Asioryctes" "Ukhaatherium" "Cimolestes" ...
## .. ..$ : NULL
## ..$ 60-40 : num [1:13, 1:48] -0.165 0.254 0.622 0.753 0.671 ...
## .. ..- attr(*, "dimnames")=List of 2
## .. ..$ : chr [1:13] "Todralestes" "Pezosiren" "Tribosphenomys" "Paramys" ...
## .. ..$ : NULL
## ..$ 40-20 : num [1:6, 1:48] -0.121 -0.203 -0.158 0.696 0.355 ...
## .. ..- attr(*, "dimnames")=List of 2
## .. ..$ : chr [1:6] "Leptictis" "Dilambdogale" "Widanelfarasia" "Moeritherium" ...
## .. ..$ : NULL
## ..$ 20-0 : num [1:10, 1:48] 0.3079 0.6531 0.5089 -0.0419 0.235 ...
## .. ..- attr(*, "dimnames")=List of 2
## .. ..$ : chr [1:10] "Dasypodidae" "Bradypus" "Myrmecophagidae" "Potamogalinae" ...
## .. ..$ : NULL
## $ elements: chr [1:50] "Cimolestes" "Maelestes" "Batodon" "Bulaklestes" ...
## $ series : chr [1:6] "discrete" "100-80" "80-60" "60-40" ...
## - attr(*, "class")= chr "dispRity"

names(binned_morphospace)

## [1] "data"      "elements" "series"
```

```
## How it's printed by default
binned_morphospace

## 5 discrete series for 50 elements
## Series:
## 100-80, 80-60, 60-40, 40-20, 20-0.
```

Note that these objects will gradually contain more information when reaching the following steps in the disparity-through-time analysis.

2.2 Bootstrapping the data

Once we obtain our different subsamples, we can bootstrap and rarefy them (i.e. pseudo-replicating the data). The bootstrapping will allow to make each subsample more robust to outliers and the rarefaction will allow us to compare slices with the same number of taxa to get rid of eventual sampling problems (i.e. more taxa in one bin than the other). The `boot.matrix` function that allows to bootstrap the `disPRity` object and the rarefaction option within allows to rarefy it.

```
## Bootstrapping each sub-sample 100 times
boot_bin_morphospace <- boot.matrix(binned_morphospace, bootstraps = 100)

## Getting the minimum number of rows (=taxa) in the sub-samples
min(unlist(lapply(binned_morphospace$data, nrow)))

## [1] 6

## Bootstrapping each sub-sample 100 times and rarefying them
rare_bin_morphospace <- boot.matrix(binned_morphospace, bootstraps = 100,
  rarefaction = 6)

## Note that the output objects are both from the "disPRity" class ...
class(boot_bin_morphospace); class(rare_bin_morphospace)

## [1] "disPRity"
## [1] "disPRity"

## ... and display some more information on the previous step when printed:
boot_bin_morphospace

## Bootstrapped ordinated matrix with 50 elements
## Series:
## 100-80, 80-60, 60-40, 40-20, 20-0.
## Data was split using discrete method.
## Data was bootstrapped 100 times, using the full bootstrap method.

rare_bin_morphospace

## Bootstrapped ordinated matrix with 50 elements
## Series:
## 100-80, 80-60, 60-40, 40-20, 20-0.
## Data was split using discrete method.
## Data was bootstrapped 100 times, using the full bootstrap method.
## Data was rarefied with a maximum of 6 elements
```

2.3 Calculating disparity

We can now calculate the disparity within each sub-sample along side with some confidence intervals generated by the pseudo-replication step above (bootstraps/rarefaction). Disparity can be calculated in many ways and this package allows user to come up with their own disparity metrics. For more info, please refer to the `dispRity` manual and the metric vignette.

In this example, we are going to calculate the spread of the data in each sub-sample by calculating the disparity as the sum of the variance of each dimension of the morphospace in each sub-sample using the `dispRity` function. Thus, in this example, the disparity is defined by the multi-dimensional variance of each sub-sample (i.e. the spread of the taxa within the morphospace). Note that this metric comes with a caveat not solved here since it ignores the covariance among the dimensions of the morphospace.

```
## Disparity for the bootstrapped data
boot_disparity <- dispRity(boot_bin_morphospace, metric = c(sum, variances))

## Disparity for the rarefied data
rare_disparity <- dispRity(rare_bin_morphospace, metric = c(sum, variances))

## Again, these objects are both from the "dispRity" class and just display
## some information when called, note the results!
boot_disparity

## Disparity measurements across 5 series for 50 elements
## Series:
## 100-80, 80-60, 60-40, 40-20, 20-0.
## Disparity calculated as: c(sum, variances) for 48 dimensions.
## Data was split using discrete method.
## Data was bootstrapped 100 times, using the full bootstrap method.

rare_disparity

## Disparity measurements across 5 series for 50 elements
## Series:
## 100-80, 80-60, 60-40, 40-20, 20-0.
## Disparity calculated as: c(sum, variances) for 48 dimensions.
## Data was split using discrete method.
## Data was bootstrapped 100 times, using the full bootstrap method.
## Data was rarefied with a maximum of 6 elements

## To display the actual results we can use the summary function
summary(boot_disparity)

##   series  n observed  mean  2.5%   25%   75% 97.5%
## 1 100-80   8    1.675 1.460 1.087 1.389 1.568 1.648
## 2  80-60  15    1.782 1.678 1.538 1.631 1.728 1.792
## 3  60-40  13    1.913 1.773 1.607 1.734 1.826 1.886
## 4  40-20   6    2.022 1.673 1.212 1.537 1.822 1.942
## 5   20-0  10    1.971 1.773 1.598 1.716 1.842 1.890

summary(rare_disparity)

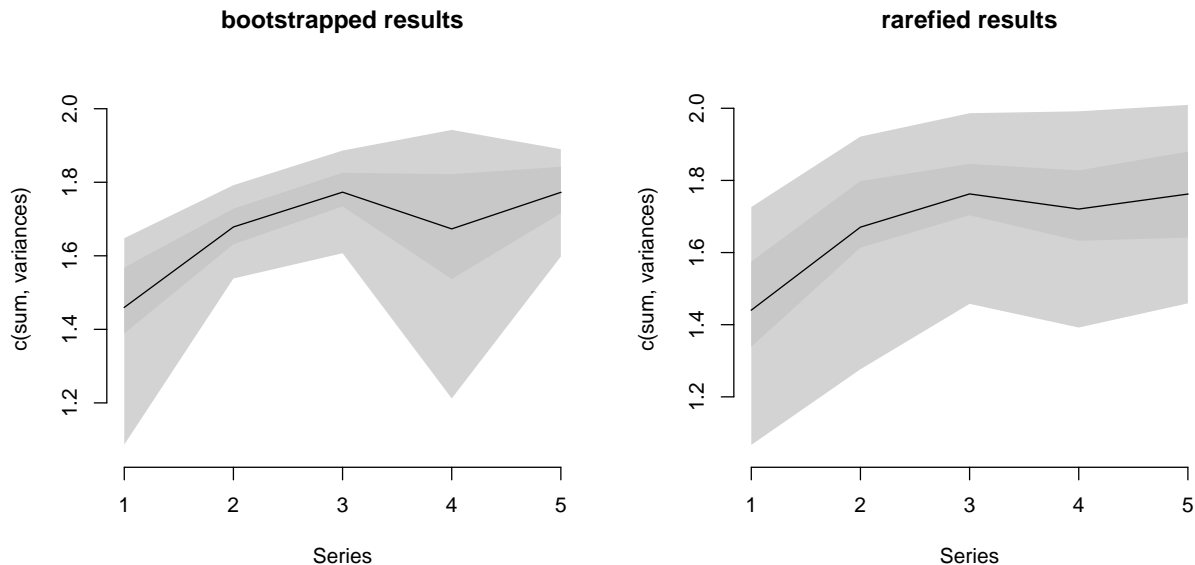
##   series n observed  mean  2.5%   25%   75% 97.5%
## 1 100-80  6      NA 1.440 1.067 1.339 1.575 1.726
## 2  80-60  6      NA 1.670 1.276 1.614 1.798 1.922
## 3  60-40  6      NA 1.763 1.458 1.704 1.846 1.986
## 4  40-20  6    2.02 1.721 1.392 1.633 1.828 1.992
## 5   20-0  6      NA 1.762 1.459 1.642 1.880 2.009
```

```
## See more options on the summary function:  
?summary.dispRity
```

2.4 Plotting the results

It is sometimes easier to visualise the results in a plot than in a table. For that we can use the plot function to plot the dispRity objects.

```
## Graphical options  
quartz(width = 10, height = 5) ; par(mfrow = (c(1,2)), bty = "n")  
  
## Plotting the bootstrapped and rarefied results  
plot(boot_disparity, type = "continuous", main = "bootstrapped results")  
plot(rare_disparity, type = "continuous", main = "rarefied results")  
  
## See more options on the plot function:  
?plot.dispRity
```



As we can see in this case, the rarefaction tends to increase the confidence intervals around the mean.

2.5 Testing differences

Finally, to draw some conclusions from these results, we need to apply some statistical testing. As stated before, we wanted to test whether the disparity changed through time in this dataset since the last 100 million years. To do so, we can apply some comparisons of the means between each time-bins in a sequential manner to see whether the disparity in bin X is equal to the disparity in bin Y which is in turn equal to the disparity in bin Z, etc. Because our data is temporally auto-correlated (i.e. what happens in bin Y depends on what happened in bin X) and was pseudo-replicated (i.e. each bootstrap draw creates non-independent sub-samples because they are all based on the same sub-sample), we are going to apply a non-parametric mean comparison: the `wilcox.test`. Also, we are going to apply a p-value correction to avoid type I error inflation due to performing multiple test for the same hypothesis (see `?p.adjust` for more details).

```
## testing the differences between bins in the bootstrapped dataset.
test.dispRity(boot_disparity, test = wilcox.test, comparison = "sequential",
  correction = "bonferroni")

##          W      p.value
## 100-80 - 80-60  471 7.427563e-28
## 80-60 - 60-40 1562 1.798899e-16
## 60-40 - 40-20 6250 9.061511e-03
## 40-20 - 20-0  3725 7.379715e-03

## testing the differences between bins in the rarefied dataset.
test.dispRity(rare_disparity, test = wilcox.test, comparison = "sequential",
  correction = "bonferroni")

##          W      p.value
## 100-80 - 80-60 1695 2.717026e-15
## 80-60 - 60-40 3424 4.733196e-04
## 60-40 - 40-20 5669 4.095267e-01
## 40-20 - 20-0  4254 2.740887e-01
```

Here our results show significant changes in disparity through time between all time bins during the last 100 million years. However, when looking at the rarefied results, there is no significant difference between the time bins in the Cenozoic (60-40, 40-20 and 20-0 Mya), suggesting that the differences detected in the first test might just be due to the differences in number of taxa sample (respectively 13, 6 and 10 in each time bin).

References

Beck, R. M. and M. S. Lee. 2014. Ancient dates or accelerated rates? Morphological clocks and the antiquity of placental mammals. *Proceedings of the Royal Society B: Biological Sciences* 281:1–10.