

# Package ‘cauphy’

October 1, 2024

**Version** 1.0.3

**Title** Trait Evolution on Phylogenies Using the Cauchy Process

**Description** The Cauchy Process can model pulsed continuous trait evolution on phylogenies. The likelihood is tractable, and is used for parameter inference and ancestral trait reconstruction.

See Bastide and Didier (2023) <[doi:10.1093/sysbio/syad053](https://doi.org/10.1093/sysbio/syad053)>.

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|           |                                    |
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| ancestral | <i>Posterior density of a node</i> |
|-----------|------------------------------------|

---

### Description

Compute the posterior density of a node value under a fitted Cauchy process on a phylogenetic tree.

### Usage

```
ancestral(x, ...)
```

```
## S3 method for class 'cauphylm'
```

```
ancestral(x, node, values, n_values = 100, n_cores = 1, ...)
```

```
## S3 method for class 'cauphyfit'
```

```
ancestral(x, node, values, n_values = 100, n_cores = 1, ...)
```

### Arguments

|        |  |
|--------|--|
| x      | an object of class <code>fitCauchy</code> or <code>cauphylm</code> .   |
| ...    | other arguments to be passed to the method.  |
| node   | the vector of nodes for which to compute the posterior density. If not specified, the reconstruction is done on all the nodes.   |
| values | the vector of values where the density should be computed. If not specified, the reconstruction is done for a grid of <code>n_values</code> values between $1.5 * \min(x\$y)$ and $1.5 * \max(x\$y)$ . |

|          |  |
|----------|--|
| n_values | the number of point for the grid of values. Default to 100. Ignored if values is provided. |
| n_cores  | number of cores for the parallelization. Default to 1.                                     |

### Details

This function assumes a Cauchy Process on the tree with fitted parameters (see [fitCauchy](#)), and computes the posterior ancestral density of internal nodes, conditionally on the vector of tip values. It computes the posterior density on all the points in values, that should be refined enough to get a good idea of the density curve.

### Value

an object of S3 class `ancestralCauchy`, which is a matrix of posterior values, with nodes in rows and values in columns.

### Methods (by class)

- `ancestral(cauphylm)`: [cauphylm](#) object
- `ancestral(cauphyfit)`: [fitCauchy](#) object

### References

Bastide, P. and Didier, G. 2023. The Cauchy Process on Phylogenies: a Tractable Model for Pulsed Evolution. *Systematic Biology*. doi:10.1093/sysbio/syad053.

### See Also

[fitCauchy](#), [cauphylm](#), [plot.ancestralCauchy](#), [plot\\_asr](#), [increment](#), [hdi.ancestralCauchy](#)

### Examples

```
set.seed(1289)
# Simulate tree and data
phy <- ape::rphylo(10, 0.1, 0)
dat <- rTraitCauchy(n = 1, phy = phy, model = "cauchy",
                  parameters = list(root.value = 10, disp = 0.1))
# Fit the data
fit <- fitCauchy(phy, dat, model = "cauchy", method = "reml")
# Reconstruct the ancestral nodes
anc <- ancestral(fit)
plot_asr(fit, anc = anc, offset = 3)
plot(anc, type = "l", node = c(11, 17))
# Refine grid for node 12 and 17
anc2 <- ancestral(fit, node = c(12, 17), n_values = 1000)
plot(anc2, type = "l")
# Find HDI
library(HDIInterval)
hdi_anc <- hdi(anc2)
hdi_anc
```

```
plot(anc2, interval = hdi_anc, type = "l")
```

---

cauphylm

*Phylogenetic Regression using a Cauchy Process*


---

## Description

Perform a phylogenetic regression using the Cauchy Process, by numerical optimization.

## Usage

```
cauphylm(
  formula,
  data = list(),
  phy,
  model = c("cauchy", "lambda"),
  lower.bound = list(displacement = 0, lambda = 0),
  upper.bound = list(displacement = Inf, lambda = NULL),
  starting.value = list(displacement = NULL, lambda = NULL),
  hessian = FALSE
)
```

## Arguments

|                |   |
|----------------|---|
| formula        | a model formula.  |
| data           | a data frame containing variables in the model. If not found in data, the variables are taken from current environment.   |
| phy            | a phylogenetic tree of class <a href="#">phylo</a> .  |
| model          | a model for the trait evolution. One of "cauchy" or "lambda" (see Details).   |
| lower.bound    | named list with lower bound values for the parameters. See Details for the default values.                                |
| upper.bound    | named list with upper bound values for the parameters. See Details for the default values.                                |
| starting.value | named list initial values for the parameters. See Details for the default values.   |
| hessian        | if TRUE, then the numerical hessian is computed, for confidence interval computations. See <a href="#">compute_vcov</a> . |

## Details

This function fits a Cauchy Process on the phylogeny, using maximum likelihood and the "fixed.root" method (see [fitCauchy](#)). It further assumes that the root value  $x_0$  is a linear combination of the covariables in formula. The corresponding regression model is:

$$Y = X\beta + E,$$

with:

$Y$  the vector of traits at the tips of the tree;  
 $X$  the regression matrix of covariables in formula;  
 $\beta$  the vector of coefficients;  
 $E$  a centered error vector that is Cauchy distributed, and can be seen as the result of a Cauchy process starting at 0 at the root, and with a dispersion `disp` (see [fitCauchy](#)).

Unless specified by the user, the initial values for the parameters are taken according to the following heuristics:

`coefficients`:  $\beta$  are obtained from a robust regression using [lmrob.S](#);  
`disp`: is initialized from the trait centered and normalized by tip heights, with one of the following statistics, taken from Rousseeuw & Croux 1993:  
`IQR`: half of the inter-quartile range (see [IQR](#));  
`MAD`: median absolute deviation with constant equal to 1 (see [mad](#));  
`Sn`: Sn statistics with constant 0.7071 (see [Sn](#));  
`Qn`: Qn statistics with constant 1.2071 (see [Qn](#)).

Unless specified by the user, `disp` is taken positive unbounded.

The function uses [nloptr](#) for the numerical optimization of the (restricted) likelihood, computed with function [logDensityTipsCauchy](#). It uses algorithms [BOBYQA](#) and [MLSL\\_LDS](#) for local and global optimization.

If `model="lambda"`, the CP is fit on a tree with branch lengths re-scaled using the Pagel's lambda transform (see [transf.branch.lengths](#)), and the lambda value is estimated using numerical optimization. The default initial value for the lambda parameter is computed using adequate robust moments. The default maximum value is computed using `phytools:::maxLambda`, and is the ratio between the maximum height of a tip node over the maximum height of an internal node. This can be larger than 1. The default minimum value is 0.

## Value

|                            |  |
|----------------------------|--|
| <code>coefficients</code>  | the named vector of estimated coefficients.                                |
| <code>disp</code>          | the maximum likelihood estimate of the dispersion parameter.               |
| <code>logLik</code>        | the maximum of the log likelihood.   |
| <code>p</code>             | the number of all parameters of the model.                                 |
| <code>aic</code>           | AIC value of the model.  |
| <code>fitted.values</code> | fitted values  |
| <code>residuals</code>     | raw residuals  |
| <code>y</code>             | response   |
| <code>X</code>             | design matrix  |
| <code>n</code>             | number of observations (tips in the tree)                                  |
| <code>d</code>             | number of dependent variables  |
| <code>formula</code>       | the model formula  |
| <code>call</code>          | the original call to the function  |
| <code>model</code>         | the phylogenetic model for the covariance                                  |
| <code>phy</code>           | the phylogenetic tree  |
| <code>lambda</code>        | the ml estimate of the lambda parameter (for <code>model="lambda"</code> ) |

## References

- Bastide, P. and Didier, G. 2023. The Cauchy Process on Phylogenies: a Tractable Model for Pulsed Evolution. *Systematic Biology*. doi:10.1093/sysbio/syad053.
- Rothenberg T. J., Fisher F. M., Tilanus C. B. 1964. A Note on Estimation from a Cauchy Sample. *Journal of the American Statistical Association*. 59:460–463.
- Rousseeuw P.J., Croux C. 1993. Alternatives to the Median Absolute Deviation. *Journal of the American Statistical Association*. 88:1273–1283.

## See Also

[fitCauchy](#), [confint.cauphylm](#), [ancestral](#), [increment](#), [logDensityTipsCauchy](#), [phylolm](#)

## Examples

```
# Simulate tree and data
set.seed(1289)
phy <- ape::rphylo(20, 0.1, 0)
error <- rTraitCauchy(n = 1, phy = phy, model = "cauchy",
                     parameters = list(root.value = 0, disp = 0.1))
x1 <- ape::rTraitCont(phy, model = "BM", sigma = 0.1, root.value = 0)
trait <- 3 + 2*x1 + error
# Fit the data
fit <- cauphylm(trait ~ x1, phy = phy)
fit
# Approximate confidence intervals
confint(fit)
```

---

compute\_vcov

*Compute Approximated Variance Covariance Matrix*

---

## Description

Find the approximated variance covariance matrix of the parameters.

## Usage

```
compute_vcov(obj)
```

## Arguments

obj                    a fitted object, either with [fitCauchy](#) or [cauphylm](#).

**Details**

This function computes the numerical Hessian of the likelihood at the optimal value using function [hessian](#), and then uses its inverse to approximate the variance covariance matrix. It can be used to compute confidence intervals with functions [confint.cauphym](#) or [confint.cauphyfit](#).

[confint.cauphym](#) and [confint.cauphyfit](#) internally call `compute_vcov`, but do not save the result. This function can be used to save the vcov matrix.

**Value**

The same object, with added vcov entry.

**See Also**

[fitCauchy](#), [cauphym](#), [confint.cauphym](#), [confint.cauphyfit](#), [vcov.cauphym](#), [vcov.cauphyfit](#)

**Examples**

```
# Simulate tree and data
set.seed(1289)
phy <- ape::rphylo(20, 0.1, 0)
dat <- rTraitCauchy(n = 1, phy = phy, model = "cauchy",
                  parameters = list(root.value = 10, disp = 0.1))
# Fit the data, without computing the Hessian at the estimated parameters.
fit <- fitCauchy(phy, dat, model = "cauchy", method = "reml", hessian = FALSE)
# Precompute the vcov matrix
fit <- compute_vcov(fit)
# Approximate confidence intervals
confint(fit)
```

---

fitCauchy

*Model fitting for a Cauchy Process*


---

**Description**

Fit the Cauchy process on a phylogeny, using numerical optimization.

**Usage**

```
fitCauchy(
  phy,
  trait,
  model = c("cauchy", "lambda"),
  method = c("reml", "random.root", "fixed.root"),
  starting.value = list(x0 = NULL, disp = NULL, lambda = NULL),
  lower.bound = list(disp = 0, lambda = 0),
  upper.bound = list(disp = Inf, lambda = NULL),
  root.edge = 100,
```

```

    hessian = FALSE,
    optim = c("local", "global"),
    method.init.disp = c("Qn", "Sn", "MAD", "IQR")
)

```

### Arguments

|                  |  |
|------------------|--|
| phy              | a phylogenetic tree of class <a href="#">phylo</a> .   |
| trait            | named vector of traits at the tips.  |
| model            | a model for the trait evolution. One of "cauchy" or "lambda" (see Details).  |
| method           | the method used to fit the process. One of <code>reml</code> (the default), <code>fixed.root</code> or <code>random.root</code> . See Details.   |
| starting.value   | starting value for the parameters of the Cauchy. This should be a named list, with <code>x0</code> and <code>disp</code> the root starting value and the dispersion parameter. The default initial values are computed from standard statistics used on (independent) Cauchy variables, see Details. |
| lower.bound      | named list with lower bound values for the parameters. See Details for the default values.   |
| upper.bound      | named list with upper bound values for the parameters. See Details for the default values.   |
| root.edge        | multiplicative factor for the root dispersion, equal to the length of the root edge. Ignored if <code>method!=random.root</code> .   |
| hessian          | if TRUE, then the numerical hessian is computed, for confidence interval computations. See <a href="#">compute_vcov</a> .  |
| optim            | if "local", only a local optimization around the initial parameter values is performed (the default). If "global", a global maximization is attempted using the "MLSL" approach (see <a href="#">nloptr</a> ).   |
| method.init.disp | the initialization method for the dispersion. One of "Qn", "Sn", "MAD", "IQR". Default to the "Qn" statistics. See Details.  |

### Details

For the default `model="cauchy"`, the parameters of the Cauchy Process (CP) are `disp`, the dispersion of the process, and `x0`, the starting value of the process at the root (for `method="fixed.root"`).

The model assumes that each increment of the trait  $X$  on a branch going from node  $k$  to  $l$  follows a Cauchy distribution, with a dispersion proportional to the length  $t_l$  of the branch:

$$X_l - X_k \sim \mathcal{C}(0, \text{disp} \times t_l).$$

Unless specified by the user, the initial values for the parameters are taken according to the following heuristics:

`x0`: is the trimmed mean of the trait, keeping only 24% of the observations, as advocated in Rothenberg et al. 1964 (for `method="fixed.root"`);



`disp`: is initialized from the trait centered and normalized by tip heights, with one of the following statistics, taken from Rousseeuw & Croux 1993:

`IQR`: half of the inter-quartile range (see [IQR](#));

`MAD`: median absolute deviation with constant equal to 1 (see [mad](#));

`Sn`: Sn statistics with constant 0.7071 (see [Sn](#));

`Qn`: (default) Qn statistics with constant 1.2071 (see [Qn](#)).

Unless specified by the user, `x0` is taken to be unbounded, `disp` positive unbounded.

The method argument specifies the method used for the fit:

`method="reml"`: the dispersion parameter is fitted using the REML criterion, obtained by re-rooting the tree to one of the tips. See [logDensityTipsCauchy](#) for the default choice of the re-rooting tip;

`method="random.root"`: the root value is assumed to be a random Cauchy variable, centered at `x0=0`, and with a dispersion `disp_root = disp * root.edge`;

`method="fixed.root"`: the model is fitted conditionally on the root value `x0`, i.e. with a model where the root value is fixed and inferred from the data.

In the first two cases, the optimization is done on the dispersion only, while in the last case the optimization is on the root value and the dispersion.

The function uses `nloptr` for the numerical optimization of the (restricted) likelihood, computed with function [logDensityTipsCauchy](#). It uses algorithms `BOBYQA` and `MLSL_LDS` for local and global optimization.

If `model="lambda"`, the CP is fit on a tree with branch lengths re-scaled using the Pagel's lambda transform (see [transf.branch.lengths](#)), and the lambda value is estimated using numerical optimization. The default initial value for the lambda parameter is computed using adequate robust moments. The default maximum value is computed using `phytools:::maxLambda`, and is the ratio between the maximum height of a tip node over the maximum height of an internal node. This can be larger than 1. The default minimum value is 0.

## Value

An object of S3 class `cauphyfit`, with fields:

|                     |  |
|---------------------|--|
| <code>x0</code>     | the fitted starting value (for <code>method="fixed.root"</code> )                  |
| <code>disp</code>   | the ml or reml estimate of the dispersion parameter                                |
| <code>lambda</code> | the ml or reml estimate of the lambda parameter (for <code>model="lambda"</code> ) |
| <code>logLik</code> | the maximum of the log (restricted) likelihood                                     |
| <code>p</code>      | the number of parameters of the model  |
| <code>aic</code>    | the AIC value of the model   |
| <code>trait</code>  | the named vector of traits at the tips used in the fit                             |
| <code>y</code>      | the named vector of traits at the tips used in the fit                             |
| <code>n</code>      | the number of tips in the tree   |
| <code>d</code>      | the number of dependent variables  |
| <code>call</code>   | the original call of the function  |

|               |  |
|---------------|--|
| model         | the phylogenetic model (one of "cauchy" or "lambda")         |
| phy           | the phylogenetic tree  |
| method        | the method used (one of "reml", "fixed.root", "random.root") |
| random.root   | TRUE if method="random.root"                                 |
| reml          | TRUE if method="reml"  |
| root_tip_reml | name of the tip used to reroot the tree (for method="reml")  |

## References

- Bastide, P. and Didier, G. 2023. The Cauchy Process on Phylogenies: a Tractable Model for Pulsed Evolution. *Systematic Biology*. doi:10.1093/sysbio/syad053.
- Rothenberg T. J., Fisher F. M., Tilanus C. B. 1964. A Note on Estimation from a Cauchy Sample. *Journal of the American Statistical Association*. 59:460–463.
- Rousseeuw P.J., Croux C. 1993. Alternatives to the Median Absolute Deviation. *Journal of the American Statistical Association*. 88:1273–1283.

## See Also

[confint.cauchyfit](#), [profile.cauchyfit](#), [ancestral](#), [increment](#), [logDensityTipsCauchy](#), [cauphylm](#), [fitContinuous](#)

## Examples

```
# Simulate tree and data
set.seed(1289)
phy <- ape::rphylo(20, 0.1, 0)
dat <- rTraitCauchy(n = 1, phy = phy, model = "cauchy",
                   parameters = list(root.value = 10, disp = 0.1))

# Fit the data
fit <- fitCauchy(phy, dat, model = "cauchy", method = "reml")
fit

# Approximate confidence intervals
confint(fit)

# Profile likelihood
pl <- profile(fit)
plot(pl)
```

---

`hdi.ancestralCauchy`     *Highest (Posterior) Density Interval*

---

## Description

This function takes an object of class `ancestralCauchy`, result of function [ancestral](#) or [increment](#), and find the Highest (Posterior) Density Interval of reconstructed states for given nodes. It relies on function [hdi](#) from package [HDInterval](#).

**Usage**

```
## S3 method for class 'ancestralCauchy'
hdi(object, credMass = 0.95, allowSplit = TRUE, node, ...)
```

**Arguments**

|            |   |
|------------|---|
| object     | an object of class <code>ancestralCauchy</code> , result of function <code>ancestral</code> or <code>increment</code> .                                       |
| credMass   | a scalar between 0 and 1 specifying the mass within the credible interval.  |
| allowSplit | if FALSE and the proper HDI is discontinuous, a single credible interval is returned, but this is not HDI. See <code>hdi</code> for details. Default to TRUE. |
| node       | the vector of nodes where to plot the ancestral reconstruction. Can be missing, in which case all the nodes reconstructed in the <code>ancestralCauchy</code> |
| ...        | further arguments to be passed to <code>plot</code> .   |

**Details**

The function relies on the density method of the `hdi` function. Package `HDInterval` must be loaded in the workspace for this function to work. See documentation of this functions for more details on the definition and computation of the HDI.

The density is obtained on the grid of values defined by the `ancestralCauchy` object, which defaults to 100 values. See details in the documentation of the `ancestral` and `increment` functions.

NOTE: if the grid of values is too coarse (if it has too few values), then the result can be a poor approximation. Please make sure to use an appropriate grid in the reconstruction to get meaningful results (see example).

**Value**

A named list. Each item of the list is named after a node, and contains the HDI interval of the node, in the same format as in `hdi`: a vector of length 2 or a 2-row matrix with the lower and upper limits of the HDI, with an attribute `credMass`. If `allowSplit=TRUE`, the matrix has a row for each component of a discontinuous HDI and columns for begin and end. It has an additional attribute "height" giving the probability density at the limits of the HDI.

**See Also**

`plot.ancestralCauchy`, `ancestral`, `increment`, `fitCauchy`

**Examples**

```
# Lizard dataset
data(lizards)
attach(lizards)
# Fit CP
fit_CP <- fitCauchy(phy, svl, model = "cauchy", method = "reml")
# Reconstruct increments for some branches
inc <- increment(fit_CP, node = c(142, 151), n_cores = 1)
# HDI
library(HDInterval)
```

```

inc_int <- hdi(inc)
plot(inc, intervals = inc_int, type = "l")
# HDI of edge ending at node 142 is unimodal
inc_int[["142"]]
# HDI of edge ending at node 151 is bimodal
inc_int[["151"]]
# If the grid is coarse, the result is meaningless
inc <- increment(fit_CP, node = c(151), n_cores = 1, n_values = 10)
inc_int <- hdi(inc)
plot(inc, intervals = inc_int, type = "l")

```

---

increment

*Posterior density of an increment*


---

### Description

Compute the posterior density of a branch increment under a fitted Cauchy process on a phylogenetic tree.

### Usage

```

increment(x, ...)

## S3 method for class 'cauphylm'
increment(x, node, values, n_values = 100, n_cores = 1, ...)

## S3 method for class 'cauphyfit'
increment(x, node, values, n_values = 100, n_cores = 1, ...)

```

### Arguments

|          |  |
|----------|--|
| x        | an object of class <code>fitCauchy</code> or <code>cauphylm</code> .   |
| ...      | other arguments to be passed to the method.  |
| node     | vector of nodes ending the branches for which to compute the posterior density of the increment. If not specified, the reconstruction is done on all the possible edges.   |
| values   | the vector of values where the density should be computed. If not specified, the reconstruction is done for a grid of <code>n_values</code> values between $-1.5 * \text{maxdiff}$ and $1.5 * \text{maxdiff}$ , where <code>maxdiff</code> is the difference between the larger and smaller tip value. |
| n_values | the number of point for the grid of values. Default to 100. Ignored if <code>values</code> is provided.  |
| n_cores  | number of cores for the parallelization. Default to 1.   |

## Details

This function assumes a Cauchy Process on the tree with fitted parameters (see [fitCauchy](#)), and computes the posterior ancestral density of trait increments at branches (ie, the difference between the traits value at the end and beginning of the branch), conditionally on the vector of tip values.

It computes the posterior density on all the points in values, that should be refined enough to get a good idea of the density curve.

## Value

an object of S3 class `ancestralCauchy`, which is a matrix of posterior increment values, with nodes in rows and values in columns.

## Methods (by class)

- `increment(cauphylm)`: [cauphylm](#) object
- `increment(cauphyfit)`: [fitCauchy](#) object

## References

Bastide, P. and Didier, G. 2023. The Cauchy Process on Phylogenies: a Tractable Model for Pulsed Evolution. *Systematic Biology*. doi:10.1093/sysbio/syad053.

## See Also

[fitCauchy](#), [cauphylm](#), [plot.ancestralCauchy](#), [plot\\_asr](#), [ancestral](#), [hdi.ancestralCauchy](#)

## Examples

```
set.seed(1289)
# Simulate tree and data
phy <- ape::rphylo(10, 0.1, 0)
dat <- rTraitCauchy(n = 1, phy = phy, model = "cauchy",
                    parameters = list(root.value = 10, disp = 0.1))

# Fit the data
fit <- fitCauchy(phy, dat, model = "cauchy", method = "reml")
# Reconstruct the ancestral increments
inc <- increment(fit)
plot_asr(fit, inc = inc, offset = 3)
plot(inc, node = c(3, 8), type = "l")
# Refine grid for edges ending at tips 3 and 8
inc2 <- increment(fit, node = c(3, 8), values = seq(-3, 3, 0.01))
plot(inc2, type = "l")
# Find HDI
library(HDIInterval)
hdi_inc <- hdi(inc2)
hdi_inc
plot(inc2, interval = hdi_inc, type = "l")
```

---

lizards

*Greater Antillean Anolis lizard dataset*

---

### Description

A dataset containing the dated phylogeny and the log snout-to-vent length for Greater Antillean Anolis lizard species, taken from Mahler et al. 2013.

### Usage

lizards

### Format

A data frame with 53940 rows and 10 variables:

**phy** Bayesian maximum clade credibility chronogram for Greater Antillean Anolis from Mahler et al. 2013

**svl** Natural log-transformed species average snout-to-vent length

**ecomorph** Ecomorph assignments for each of the species

### Source

[doi:10.5061/dryad.9g182](https://doi.org/10.5061/dryad.9g182)

### References

Mahler, D. Luke; Ingram, Travis; Revell, Liam J.; Losos, Jonathan B. (2013), Data from: Exceptional convergence on the macroevolutionary landscape in island lizard radiations, Dryad, Dataset, <https://doi.org/10.5061/dryad.9g182>

---

logDensityTipsCauchy *Log Density of a Cauchy Process*

---

### Description

Compute the log density of the vector of trait at the tips of the phylogenetic tree, assuming a Cauchy process.

**Usage**

```
logDensityTipsCauchy(
  tree,
  tipTrait,
  root.value = NULL,
  disp,
  method = c("reml", "random.root", "fixed.root"),
  rootTip = NULL,
  do_checks = TRUE
)
```

**Arguments**

|            |  |
|------------|--|
| tree       | a phylogenetic tree of class <a href="#">phylo</a> .   |
| tipTrait   | a names vector of tip trait values, with names matching the tree labels.   |
| root.value | the root starting value of the process.  |
| disp       | the dispersion value.  |
| method     | the method used to compute the likelihood. One of <code>reml</code> (the default), <code>fixed.root</code> or <code>random.root</code> . See <a href="#">Details</a> .   |
| rootTip    | the tip used to re-root the tree, when the REML method is used. If <code>NULL</code> , the tip with the smallest distance to all the others is used (see <a href="#">Details</a> ). Ignored in <code>method != "reml"</code> . |
| do_checks  | if <code>FALSE</code> , the entry parameters are not checked for consistency. This can be useful when doing multiple calls to the function, as in numerical optimization. Default to <code>TRUE</code> .                       |

**Details**

The parameters of the Cauchy Process (CP) are `disp`, the dispersion of the process, and `root.value`, the starting value of the process at the root (for `method="fixed.root"`).

The model assumes that each increment of the trait  $X$  on a branch going from node  $k$  to  $l$  follows a Cauchy distribution, with a dispersion proportional to the length  $t_l$  of the branch:

$$X_l - X_k \sim \mathcal{C}(0, \text{disp} \times t_l).$$

The `method` argument specifies the type of likelihood that is computed:

`method="reml"`: the dispersion parameter is fitted using the REML criterion, obtained by re-rooting the tree to one of the tips. The default tip used to reroot the tree is: `rootTip = which.min(colSums(cophenetic.phylo(tree)))`. Any tip can be used, but this default empirically proved to be the most robust numerically;

`method="random.root"`: the root value is assumed to be a random Cauchy variable, centered at `root.value=0`, and with a dispersion `disp_root = disp * root.edge`;

`method="fixed.root"`: the model is fitted conditionally on the root value `root.value`, i.e. with a model where the root value is fixed and inferred from the data.

**Value**

the log density value.

**See Also**

[fitCauchy](#)

**Examples**

```
phy <- ape::rphylo(5, 0.1, 0)
dat <- rTraitCauchy(n = 1, phy = phy, model = "cauchy", parameters = list(root.value = 0, disp = 1))
logDensityTipsCauchy(phy, dat, 0, 1, method = "fixed.root")
```

---

plot.ancestralCauchy *Plot for class ancestralCauchy*

---

**Description**

This function takes an object of class `ancestralCauchy`, result of function [ancestral](#) or [increment](#), and plots the reconstructed states for given nodes.

**Usage**

```
## S3 method for class 'ancestralCauchy'
plot(x, node, n_col, intervals = NULL, ...)
```

**Arguments**

|                        |   |
|------------------------|---|
| <code>x</code>         | an object of class <code>ancestralCauchy</code> , result of function <a href="#">ancestral</a> or <a href="#">increment</a> .   |
| <code>node</code>      | the vector of nodes where to plot the ancestral reconstruction. Can be missing, in which case all the nodes reconstructed in the <code>ancestralCauchy</code> object are plotted. |
| <code>n_col</code>     | the number of columns on which to display the plot. Can be missing, in which case a default number is used.   |
| <code>intervals</code> | a list of HDI intervals produced by function <a href="#">hdi.ancestralCauchy</a> . If the HDI of a plotted node is in the list, then it is plotted by the function.               |
| <code>...</code>       | further arguments to be passed to <a href="#">plot</a> .  |

**Value**

None.

**See Also**

[plot\\_asr](#), [ancestral](#), [increment](#), [fitCauchy](#)



## Examples

```
set.seed(1289)
# Simulate tree and data
phy <- ape::rphylo(10, 0.1, 0)
dat <- rTraitCauchy(n = 1, phy = phy, model = "cauchy",
                   parameters = list(root.value = 10, disp = 0.1))
# Fit the data
fit <- fitCauchy(phy, dat, model = "cauchy", method = "reml")
# Reconstruct the ancestral values
inc <- increment(fit, node = c(3, 8), values = seq(-3, 3, 0.01))
plot(inc, type = "l")
anc <- ancestral(fit, node = c(12, 17), n_values = 1000)
plot(anc, type = "l")
```

---

plot.profile.cauchyfit

*Plot for class profile.cauchyfit*

---

## Description

This function takes an object of class `profile.cauchyfit`, and plots the profile likelihood for each parameter.

## Usage

```
## S3 method for class 'profile.cauchyfit'
plot(x, n_col, ...)
```

## Arguments

|                    |  |
|--------------------|--|
| <code>x</code>     | an object of class <code>profile.cauchyfit</code>                      |
| <code>n_col</code> | the number of columns on which to display the plot. Can be left blank. |
| <code>...</code>   | further arguments to be passed to <code>plot</code> .                  |

## Value

None.

## See Also

`profile.cauchyfit`, `fitCauchy`.

**Examples**

```

phy <- ape::rphylo(5, 0.1, 0)
dat <- rTraitCauchy(n = 1, phy = phy, model = "cauchy", parameters = list(root.value = 0, disp = 1))
fit <- fitCauchy(phy, dat, model = "cauchy", method = "fixed.root")
pr <- profile(fit)
plot(pr)

```

---

plot\_asr

*Plot Ancestral States Reconstructions*


---

**Description**

Plot the ancestral states reconstructions from a fitted Cauchy model.

**Usage**

```

plot_asr(
  x,
  anc = NULL,
  inc = NULL,
  common_colorscale = FALSE,
  x.legend = "topleft",
  y.legend = NULL,
  adj = c(0.5, 0.5),
  piecol = NULL,
  width.node = NULL,
  height.node = NULL,
  width.edge = NULL,
  height.edge = NULL,
  style = "bars",
  offset = 1,
  scaling = 1,
  x.lim = NULL,
  x.intersp = NULL,
  ...
)

```

**Arguments**

|                   |   |
|-------------------|---|
| x                 | a <code>cauphylm</code> or <code>fitCauchy</code> object.   |
| anc               | (optional) an object of class <code>ancestralCauchy</code> , obtained with <code>ancestral</code> .                       |
| inc               | (optional) an object of class <code>ancestralCauchy</code> , obtained with <code>increment</code> .                       |
| common_colorscale | If both plotted, should the ancestral states and the increment be represented by the same color scale ? Default to FALSE. |

|  |   |
|--|---|
| x.legend, y.legend                               | the x and y co-ordinates to be used to position the legend. They can be specified by keyword or in any way which is accepted by <a href="#">legend</a> .  |
| adj  | one or two numeric values specifying the horizontal and vertical, respectively, justification of the text or symbols. By default, the text is centered horizontally and vertically. If a single value is given, this alters only the horizontal position of the text. |
| piecol   | a list of colours (given as a character vector) to be used by thermo or pie; if left NULL, a series of colours given by the function rainbow is used.   |
| width.node, height.node, width.edge, height.edge | parameters controlling the aspect of thermometers for the nodes and the edges; by default, their width and height are determined automatically.   |
| style  | a character string specifying the type of graphics; can be abbreviated (see details).   |
| offset   | offset of the tip labels (can be negative).   |
| scaling  | the scaling factor to apply to the data.  |
| x.lim  | a numeric vector of length one or two giving the limit(s) of the x-axis. If NULL, this is computed with respect to various parameters such as the string lengths of the labels and the branch lengths. If a single value is given, this is taken as the upper limit.  |
| x.intersp  | character interspacing factor for horizontal (x) spacing between symbol and legend text (see <a href="#">legend</a> ).  |
| ...  | other parameters to be passed on to <a href="#">plot.phylo</a> or <a href="#">phydataplot</a> .   |

### Details

The main plot is done with [plot.phylo](#), the node annotation use [nodelabels](#), and the tip data plot use [phydataplot](#). Please refer to these functions for the details of the parameters.

The width of each color in the thermo plots approximately represents the weight of each node of the distribution, that is estimated by numerically integrating the density function around each mode. Function [findpeaks](#) is first used to find the modes and estimate their starting and ending points. Then function [trapz](#) estimates the integral of the density around the mode.

For an exact representation of a node posterior density, please plot it separately, using function [plot.ancestralCauchy](#).

### Value

None.

### See Also

[cauphylm](#), [fitCauchy](#), [ancestral](#), [increment](#), [plot.phylo](#), [phydataplot](#), [nodelabels](#)

**Examples**

```

set.seed(1289)
# Simulate tree and data
phy <- ape::rphylo(10, 0.1, 0)
dat <- rTraitCauchy(n = 1, phy = phy, model = "cauchy",
                  parameters = list(root.value = 10, disp = 0.1))
# Fit the data
fit <- fitCauchy(phy, dat, model = "cauchy", method = "reml")
# Reconstruct the ancestral states and increments
inc <- increment(fit, n_values = 100)
anc <- ancestral(fit, n_values = 100)
plot_asr(fit, inc = inc, anc = anc, offset = 3,
        width.node = 0.8, height.node = 0.5,
        width.edge = 1.5, height.edge = 0.2,
        x.legend = "topright")

```

---

posteriorDensityAncestral

*Posterior density of a node*

---

**Description**

Compute the posterior density of a set of node values under a Cauchy process on a phylogenetic tree.

**Usage**

```

posteriorDensityAncestral(
  node,
  vals,
  tree,
  tipTrait,
  root.value = NULL,
  disp,
  method = c("reml", "random.root", "fixed.root")
)

```

**Arguments**

|            |  |
|------------|--|
| node       | the node for which to compute the posterior density.                     |
| vals       | the table of values where the density should be computed.                |
| tree       | a phylogenetic tree of class <code>phylo</code> .                        |
| tipTrait   | a names vector of tip trait values, with names matching the tree labels. |
| root.value | the root starting value of the process.                                  |

|        |   |
|--------|---|
| disp   | the dispersion value.   |
| method | the method used to compute the likelihood. One of <code>rem1</code> (the default), <code>fixed.root</code> or <code>random.root</code> . See Details. |

### Details

This function is internally called by [ancestral](#), which is the preferred way of doing ancestral reconstruction on a fitted object.

### Value

the posterior density value.

### See Also

[ancestral](#), [fitCauchy](#)

### Examples

```
phy <- ape::rphylo(5, 0.1, 0)
dat <- rTraitCauchy(n = 1, phy = phy, model = "cauchy", parameters = list(root.value = 0, disp = 1))
posteriorDensityAncestral(7, 0.1, phy, dat, disp = 1)
```

---

posteriorDensityIncrement

*Posterior density of an increment*

---

### Description

Compute the posterior density of a set of branch increments under a Cauchy process on a phylogenetic tree.

### Usage

```
posteriorDensityIncrement(
  node,
  vals,
  tree,
  tipTrait,
  root.value = NULL,
  disp,
  method = c("rem1", "random.root", "fixed.root")
)
```

**Arguments**

|            |  |
|------------|--|
| node       | the node ending the branch for which to compute the posterior density of the increment.  |
| vals       | the table of values where the density should be computed.  |
| tree       | a phylogenetic tree of class <a href="#">phylo</a> .   |
| tipTrait   | a names vector of tip trait values, with names matching the tree labels.   |
| root.value | the root starting value of the process.  |
| disp       | the dispersion value.  |
| method     | the method used to compute the likelihood. One of <code>reml</code> (the default), <code>fixed.root</code> or <code>random.root</code> . See <a href="#">Details</a> . |

**Details**

This function is internally called by [increment](#), which is the preferred way of doing ancestral reconstruction on a fitted object.

**Value**

the posterior density value.

**See Also**

[increment](#), [fitCauchy](#)

**Examples**

```
set.seed(1289)
phy <- ape::rphylo(5, 0.1, 0)
dat <- rTraitCauchy(n = 1, phy = phy, model = "cauchy", parameters = list(root.value = 0, disp = 1))
posteriorDensityIncrement(2, 0.1, phy, dat, disp = 1)
```

---

print.cauphyfit

*Generic Methods for S3 class cauphyfit.*

---

**Description**

Generic Methods for S3 class cauphyfit.

**Usage**

```
## S3 method for class 'cauphyfit'
print(x, digits = max(3, getOption("digits") - 3), ...)

## S3 method for class 'cauphyfit'
vcov(object, ...)

## S3 method for class 'cauphyfit'
logLik(object, ...)

## S3 method for class 'logLik.cauphyfit'
AIC(object, k = 2, ...)

## S3 method for class 'cauphyfit'
AIC(object, k = 2, ...)

## S3 method for class 'cauphyfit'
confint(object, parm, level = 0.95, ...)

## S3 method for class 'cauphyfit'
coef(object, ...)
```

**Arguments**

|        |   |
|--------|---|
| x      | an object of class "phylolm".   |
| digits | number of digits to show in summary method.   |
| ...    | further arguments to methods.   |
| object | an object of class cauphyfit.   |
| k      | numeric, the penalty per parameter to be used; the default k = 2 is the classical AIC.  |
| parm   | a specification of which parameters are to be given confidence intervals, either a vector of numbers or a vector of names. If missing, all parameters are considered. |
| level  | the confidence level required.  |

**Value**

Same value as the associated methods from the stats package:

[vcov](#) an estimated covariance matrix, see [compute\\_vcov](#);

[logLik](#) an object of class [logLik](#);

[AIC](#) a numeric value;

[confint](#) a matrix (or vector) with columns giving lower and upper confidence limits for each parameter;

[coef](#) coefficients extracted from the model;

**See Also**

[fitCauchy](#), [vcov](#), [logLik](#) [AIC](#), [confint](#), [coef](#), [predict](#), [predict.phylolm](#)

**Examples**

```
# Simulate tree and data
set.seed(1289)
phy <- ape::rphylo(20, 0.1, 0)
dat <- rTraitCauchy(n = 1, phy = phy, model = "cauchy",
                  parameters = list(root.value = 10, disp = 0.1))

# Fit the data
fit <- fitCauchy(phy, dat, model = "cauchy", method = "reml")
fit
# vcov matrix
vcov(fit)
# Approximate confidence intervals
confint(fit)
# log likelihood of the fitted object
logLik(fit)
# AIC of the fitted object
AIC(fit)
# coefficients
coef(fit)
```

---

print.cauphylm

*Generic Methods for S3 class cauphylm.*

---

**Description**

Generic Methods for S3 class cauphylm.

**Usage**

```
## S3 method for class 'cauphylm'
print(x, digits = max(3, getOption("digits") - 3), ...)

## S3 method for class 'cauphylm'
vcov(object, ...)

## S3 method for class 'cauphylm'
logLik(object, ...)

## S3 method for class 'logLik.cauphylm'
AIC(object, k = 2, ...)

## S3 method for class 'cauphylm'
AIC(object, k = 2, ...)
```



```
## S3 method for class 'cauphylm'
predict(object, newdata = NULL, se.fit = FALSE, ...)

## S3 method for class 'cauphylm'
confint(object, parm, level = 0.95, ...)

## S3 method for class 'cauphylm'
coef(object, ...)
```

### Arguments

|         |  |
|---------|--|
| x       | an object of class "phylolm".  |
| digits  | number of digits to show in summary method.  |
| ...     | further arguments to methods.  |
| object  | an object of class cauphylm.   |
| k       | numeric, the penalty per parameter to be used; the default k = 2 is the classical AIC.   |
| newdata | an optional data frame to provide the predictor values at which predictions should be made. If omitted, the fitted values are used. Currently, predictions are made for new species whose placement in the tree is unknown. Only their covariate information is used. The prediction for the trend model is not currently implemented. |
| se.fit  | A switch indicating if standard errors are required.   |
| parm    | a specification of which parameters are to be given confidence intervals, either a vector of numbers or a vector of names. If missing, all parameters are considered.  |
| level   | the confidence level required.   |

### Value

Same value as the associated methods from the stats package:

[vcov](#) an estimated covariance matrix, see [compute\\_vcov](#);

[logLik](#) an object of class [logLik](#);

[AIC](#) a numeric value;

[confint](#) a matrix (or vector) with columns giving lower and upper confidence limits for each parameter;

[coef](#) coefficients extracted from the model;

[predict](#) a vector of predicted values.

### See Also

[cauphylm](#), [vcov](#), [logLik](#) [AIC](#), [confint](#), [coef](#), [predict](#), [predict.phylolm](#)

**Examples**

```

# Simulate tree and data
set.seed(1289)
phy <- ape::rphylo(20, 0.1, 0)
error <- rTraitCauchy(n = 1, phy = phy, model = "cauchy",
                     parameters = list(root.value = 0, disp = 0.1))
x1 <- ape::rTraitCont(phy, model = "BM", sigma = 0.1, root.value = 0)
trait <- 3 + 2*x1 + error
# Fit the data
fit <- cauphylm(trait ~ x1, phy = phy)
fit
# vcov matrix
vcov(fit)
# Approximate confidence intervals
confint(fit)
# log likelihood of the fitted object
logLik(fit)
# AIC of the fitted object
AIC(fit)
# predicted values
predict(fit)
# coefficients
coef(fit)

```

---

profile.cauphyfit      *Method for Profiling cauphyfit Objects*

---

**Description**

Investigates the profile log-likelihood function for a fitted model of class cauphyfit.

**Usage**

```

## S3 method for class 'cauphyfit'
profile(fitted, which = 1:npar, level = 0.8, npoints = 100, ...)

```

**Arguments**

|         |   |
|---------|---|
| fitted  | the cauphyfit fitted model object.  |
| which   | the original model parameters which should be profiled. This can be a numeric or character vector. By default, all parameters are profiled. |
| level   | highest confidence level for parameters intervals, computed using the approximated Hessian (see <a href="#">compute_vcov</a> ).             |
| npoints | number of points to profile the likelihood for each parameter.  |
| ...     | further arguments passed to or from other methods.  |

**Details**

This function computes a confidence interval for the parameters using `confint.cauchyfit`, and then computes the likelihood function on a grid with `npoints` values evenly spaced between the bounds of the interval, for each parameter one by one, all other parameters being fixed.

**Value**

An object of class `profile.cauchyfit`, which is a list with an element for each parameter being profiled. The elements are data-frames with two variables:

`par.vals`: a matrix of parameter values for each fitted model.

`profLogLik`: the profile log likelihood.

**See Also**

[fitCauchy](#), [plot.profile.cauchyfit](#), [profile](#).

**Examples**

```
phy <- ape::rphylo(5, 0.1, 0)
dat <- rTraitCauchy(n = 1, phy = phy, model = "cauchy", parameters = list(root.value = 0, disp = 1))
fit <- fitCauchy(phy, dat, model = "cauchy", method = "reml")
pr <- profile(fit)
plot(pr)
```

---

rTraitCauchy

*Cauchy Trait Simulation*


---

**Description**

Simulate a continuous trait using the Cauchy Process

**Usage**

```
rTraitCauchy(
  n = 1,
  phy,
  model = c("cauchy", "lambda", "kappa", "delta"),
  parameters = NULL
)
```

**Arguments**

|                         |  |
|-------------------------|--|
| <code>n</code>          | number of independent replicates   |
| <code>phy</code>        | a phylogeny in <a href="#">ape phylo</a> format.   |
| <code>model</code>      | a phylogenetic model. Default is "cauchy", for the Cauchy process. Alternative are "lambda", "kappa", and "delta". |
| <code>parameters</code> | list of parameters for the model (see Details).  |

**Details**

The default choice of parameters is as follow:

```
model = cauchy root.value = 0, disp = 1
model = lambda root.value = 0, disp = 1, lambda = 1
model = kappa root.value = 0, disp = 1, kappa = 1
model = delta root.value = 0, disp = 1, delta = 1
```

**Value**

If  $n=1$ , a numeric vector with names from the tip labels in the tree. For more than 1 replicate, a matrix with the tip labels as row names, and one column per replicate.

**See Also**

[rTrait](#), [rTraitCont](#)

**Examples**

```
set.seed(1289)
phy <- ape::rphylo(40, 0.01, 0)
# One trait
y <- rTraitCauchy(n = 1, phy = phy, model = "cauchy",
                 parameters = list(root.value = 0, disp = 0.1))
y
plot(phy, x.lim = c(0, 750))
phydataplot(y, phy, offset = 150)
# Many trait
y <- rTraitCauchy(n = 10, phy = phy, model = "cauchy",
                 parameters = list(root.value = 0, disp = 0.1))
head(y)
```

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